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Regional Aspects of Climate-Terrestrial-Hydrologic Interactions in Non-boreal Eastern Europe

Edited by
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Regional Aspects of Climate-Terrestrial-Hydrologic Interactions in Non-boreal Eastern Europe

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Series C: Environmental Security

Regional Aspects of Climate-Terrestrial-Hydrologic Interactions in Non-boreal Eastern Europe

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Preface

Regional Science Team Meeting "Regional aspects of climate–terrestrial–hydrologic interactions in non-boreal Eastern Europe" devoted to the southwestern areas of the NEESPI domain was held at Odessa, Ukraine, 23–28 August 2008. The Workshop earning the status of the ***NATO Advanced Research Workshop***. It was organized under the auspices of the Northern Eurasia Earth Science Partnership Initiative (NEESPI) with sponsorship from NATO Partnership for Peace Programme and International START Secretariat, and several Ukrainian, Russian, and U.S. Universities and Agencies. Odessa Environmental and Polytechnic Universities served as a host of the Meeting. The goal of the Meeting was to promote and coordinate research related to temperate Eastern Europe by bringing together an international group of researchers from diverse backgrounds, ranging from physical climate to ecosystem and human dimension fields. The Meeting brought together 47 participants from Ukraine, European Union, U.S., Russia, and Georgia.

In their presentations at the Workshop, the Participants summarized the current status of changes across the non-boreal Eastern Europe, set up major research priorities in this part of the NEESPI domain, identified the ongoing regional modeling efforts, outlined missing links and deficiencies in data and process knowledge, and developed a set of recommendations that will further advance the Initiative toward its objectives. Taking into account coherence of projections of warmer and drier climatic conditions for the region associated with "global warming", special attention was paid to regional scale hydrometeorological modeling and its linkage with optimal land use and early mitigation measures to prepare for future changes. In these regards, a rigorous fulfillment of national reforestation plans was suggested. These plans exist in each nation of the region but their priority should be raised. Among recommendations, the workshop stresses the need for much better environmental data exchange and integration among the countries within the region and investments in regional-scale hydrometeorological modeling to better understand ongoing environmental processes in the region.

Several publications based on the Meeting discussions are currently in preparation and/or submitted to refereed journals. However, a broader impact of this NATO Advanced Research Workshop will be seen for years to come. A significant number of graduate students and early career scientists from Odessa institutions attended the Workshop as listeners to acquire top notch experience. The Workshop presentations and Statement have been made publicly available through the NEESPI web site (http://neespi.org/meetings/Odessa_2008_presentations.html). To further extent the outreach of the Workshop, a work was started to prepare monograph "Earth Systems Change over Temperate Eastern Europe" and this ***NATO Advanced Research Workshop Proceedings*** has been compiled. It includes extended abstracts of 28 selected presentations at the Workshop.

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The Northern Eurasia Earth Science Partnership Initiative: An Introduction

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Abstract. Northern Eurasia, the largest landmass in the northern extratropics, accounts for ~20% of the global land area. Yet little is known about how the biogeochemical cycles, energy and water cycles, and human activities specific to this carbon-rich, cold region interact with global climate. A major concern is that changes in the distribution of land-based life, as well as its interactions with the environment, may lead to a self-reinforcing cycle of accelerated regional and global warming. With this as its motivation, the Northern Eurasian Earth Science Partnership Initiative (NEESPI) was formed in 2004 to better understand and quantify feedbacks between Northern Eurasian and global climates.

Keywords: northern Eurasian studies, NEESPI, climate and environmental changes

The Northern Eurasian Earth Science Partnership Initiative (NEESPI), whose domain of approximately 28.6 x 10^6 km^2 (Fig. 1) accounts for roughly 60% of the terrestrial land area north of 40° N, was formed to better understand the nature of global climate feedbacks to land processes and anthropogenic activities in the region. The ecosystems within this vast region vary substantially, from tundra in the North to semi-arid grassland and deserts in the South. Northern Eurasia has land cover unique to cold regions, including around 70% of the Earth's boreal forest and greater than two thirds of the Earth's permafrost.

The region is undergoing rapid changes resulting both from a warming climate and socio-economic changes. Lugina et al. (2007) reported that surface air temperature averaged over northern Eurasia increased by 1.4 K across Northern Eurasia – almost double the average for the global land areas – over the past 127

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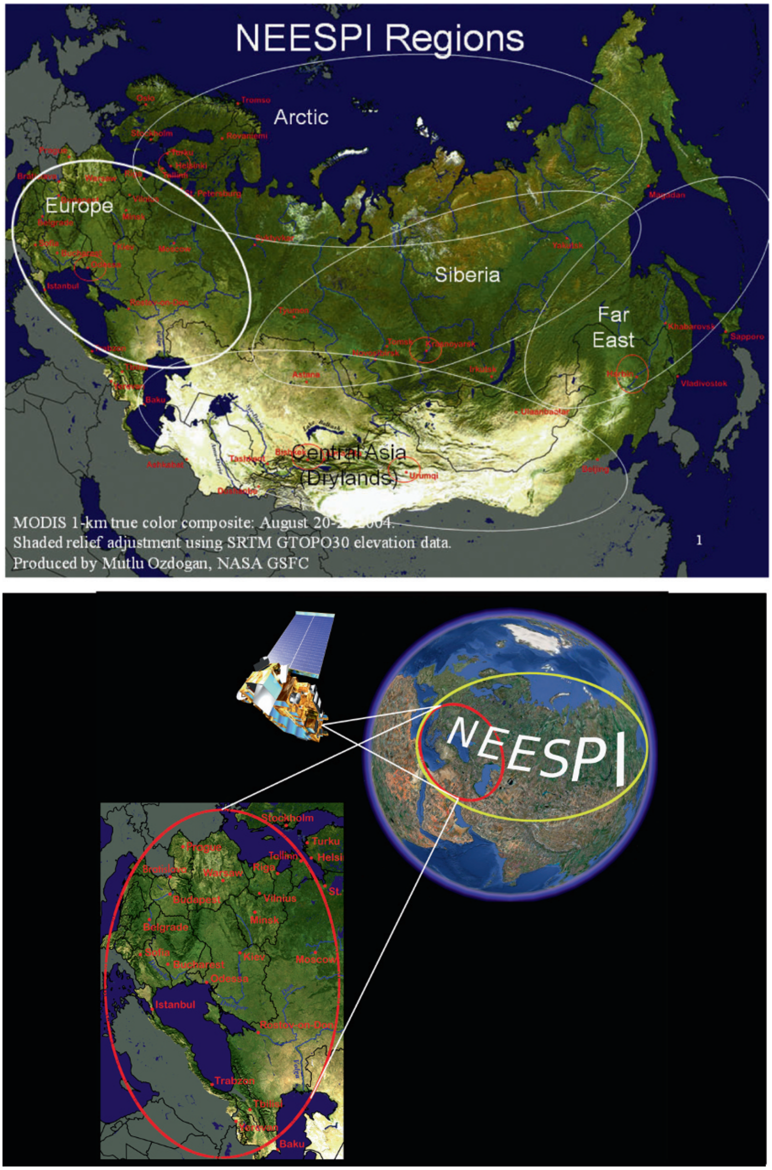

Fig. 1. (*Top*) NEESPI Study Area is loosely defined as the region lying between 15° E Longitude in the west, the Pacific Coast in the east, 40° N Latitude in the south, and the Arctic Ocean coastal zone in the north. Locations of past (Harbin, Urumqi, Helsinki, and Odessa) and projected (Krasnoyarsk and Bishkek) regional NEESPI focus research meetings are marked by red circles. (*Bottom*) Region (non-boreal Eastern Europe) that was a focus of this NATO Advanced Research Workshop.

years (Fig. 2). Given the large area of the region, these changes can have global influence as a result of associated changes in atmospheric circulation and through biogeophysical and biogeochemical feedbacks. In particular, interactions of the climate of Northern Eurasia with the global system have tremendous implications for global carbon management because more than half of all terrestrial carbon is stored in the boreal forest and tundra zones (mostly in soil), and two thirds of these zones fall within Northern Eurasia. Unfortunately, little is known about how this cold, carbon-rich region functions and the specifics of its interactions with the global system. In response to this deficiency of knowledge, NEESPI was formed in 2004 to better understand and quantify climate feedbacks within and beyond Northern Eurasia. NEESPI views the global Earth system as functioning through the interaction of biogeochemical, energy, and water cycles, and human activity (Groisman and Bartalev 2007). Biogeochemical cycles impact atmospheric and oceanic composition, soil formation, and biome evolution. Energy and water cycle processes define the Earth climate system as we know it. Human activity, beginning with the establishment of agriculture, forest harvest and mineral extraction, and continuing through industrial development, originally impacted regional environments and now alters the global climate system. NEESPI prioritizes scientific research that addresses processes with direct feedback to the global system and those of greatest importance to society in three main areas: terrestrial biogeochemical cycles, energy and water cycles, and societal–environment interactions.

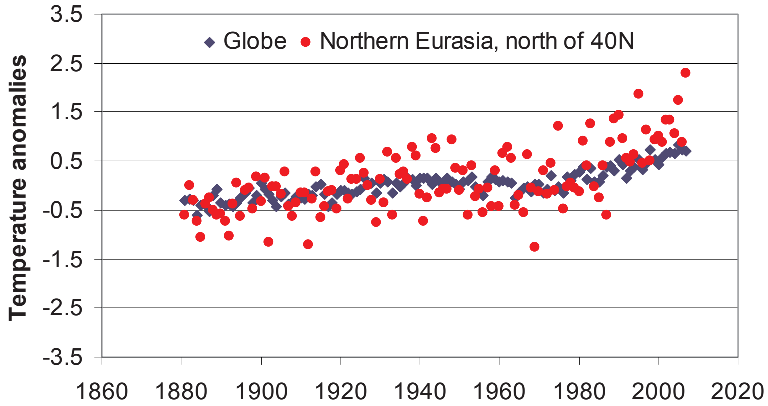

Fig. 2. Mean annual surface air temperature anomalies during the past 127 years over Northern Eurasia (linear trend 1.4 K per 127 years) compared to near-global changes within zone 60° S–90° N (linear trend 0.84 K per 127 years) (Archive of Lugina et al. 2007).

To date, the NEESPI has brought together more than 125 individually funded projects in the United States, Russia, China, European Union countries, Japan, and Canada. More than 25 of them include and/or are dedicated to studies in non-boreal Eastern Europe. On an intergovernmental level, the NEESPI research foci on regional modeling and studies of climate impacts and adaptation capacity were included in a Memorandum of Understanding for Collaboration in the Fields of Meteorology, Hydrology, and Oceanography between the U.S. NOAA and the Russian Federal Service for Hydrometeorology and Environmental Monitoring. NEESPI has been also recognized by major International Earth Science Programs and Projects: the Earth System Science Partnership Program (ESSP), through its Global Water System Project, Global Land Project, and Global Carbon Project, by the ESSP-parent International Geosphere–Biosphere Programme and the World Climate Research Programme's Global Energy and Water Cycle Experiment and Climate and Cryosphere Projects.

The first group of NEESPI projects has mostly focused on assembling regional data bases (e.g., Leptoukh et al. 2007; NCDC 2008), on organizing improved environmental monitoring of the region (e.g., Loboda et al. 2007; Romanovsky et al. 2007, 2008), and studies of individual environmental processes (e.g., Khan et al. 2007; Smith et al. 2007). This has been a necessary step to address challenges that emerged in the region with rapidly and simultaneously changing climate, environment, and societal systems. Some of these efforts have not yet been completed we already see a general picture of changes taking place within the NEESPI domain (Groisman et al. 2009; de Beurs and Henebry 2008; Bulygina et al. 2007; Lammers et al. 2007). A clear understanding of the gaps in our knowledge of environmental changes in the NEESPI domain and consequent systematic addressing/resolving them were one of the intangible major achievements of the first stage of NEESPI. The NEESPI projects have since begun to consolidate spatially extensive projections of the consequences of regional-scale processes such as wildfires (Soja et al. 2007; McRae et al. 2006), soil carbon storage (Ojima and Chuluun 2008), forest dynamics (Shugart et al. 2006), permafrost change (Romanovsky et al. 2007, 2008) and methane generation (Bohn et al. 2007) into a regional ecosystem understanding. At the same time, intense field campaigns using fine-scale measurements of material and energy fluxes (e.g., Elansky et al. 2007; Georgiadi and Zolotokrylin 2007; Houghton et al. 2007; Kurbatova et al. 2008; Peregon et al. 2008; Shakhova et al. 2007; Walter et al. 2006) have begun providing locations and tools for testing these regional projections.

Early NEESPI findings have been used by IPCC Working Groups 1 and 2 in preparation of the Fourth Assessment IPCC Report (2007) and by the Russian Federal Service for Hydrometeorology and Environmental Monitoring in preparation of the First Assessment Report on Climate Changes and their Impacts over the Territory of Russian Federation. More recently, the NEESPI research focus has begun to shift towards modeling and its ability to project the future state of climate, environment, and societies in the NEESPI domain (e.g., Aizen et al. 2007; Bohn et al. 2007; Goetz et al. 2007; Romanovsky et al. 2008; Shkolnik et al. 2008; Stendel et al. 2007; Vygodskaya et al. 2007). This new focus requires a higher level of integration than in previous NEESPI studies. In a modeling context, it is not sufficient to describe a given environmental or societal process. This process should be linked to other processes in order to assess its actual role in the Earth system. Thus, modeling becomes an engine of integration of diverse regional studies critical for understanding not only the functioning of the region's biogeochemical, energy, and water cycles, but also the role of humans in a rapidly changing, and vitally important, region.

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Section 1
Observations Issues in the Non-boreal Eastern Europe

The NASA NEESPI Data Portal to Support Studies of Climate and Environmental Changes in Non-boreal Europe

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Abstract. Goddard Interactive Online Visualization ANd aNalysis Infrastructure (Giovanni) data portal is ready to support NEESPI studies in Northern Eurasia with high quality remote sensing information.

Keywords: remote sensing, online visualization, data analysis, fire, NDVI

Introduction

NASA NEESPI (Northern Eurasia Earth Science Partnership Initiative) data portal is a NASA funded project that focuses on collecting satellite remote sensing data, providing tools, information, and services in support of NEESPI scientific objectives (Leptoukh et al. 2007). The data can be accessed online through anonymous ftp, through an advanced data searching and ordering system – Mirador that uses keywords to find data quickly in a Google-like interface, and through the Goddard Interactive Online Visualization ANd aNalysis Infrastructure (Giovanni). The portal provides preprocessed data from different satellite sensors and numerical models to the same spatial and temporal resolution and the same projection so that the

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data can be used easily to perform inter-comparison or relationship studies. It provides parameter and spatially subsetted data for regional studies too.

Studies of regional carbon, hydrology, aerosols in non-boreal Europe and their interactions with global climate are very challenging research topics. The NASA NEESPI data portal makes many satellite data available for such studies, including information on land cover types, fire, vegetation index, aerosols, land surface temperature, soil moisture, precipitation, snow/ice, and other parameters. This paper will introduce the features and products available in the system, focusing on the online data tool, Giovanni NEESPI. An example that explores different data through Giovanni NEESPI in temperate region of non-boreal Europe is presented.

Features of Giovanni NEESPI

Giovanni is developed by the NASA Goddard Earth Sciences Data and Information Services Center (GES DISC). It provides a simple and intuitive way to visualize, analyze, and access vast amounts of Earth science data without having to download the data (Acker and Leptoukh 2007; Berrick et al. 2009). The system consists of the following components: the easy use Web interfaces, back-end data processing software, image renders, and an instance generator. The instance generator can create customized Giovanni instances based on scientific needs by selecting desired analysis functions and parameters of one or more satellite instruments or numerical models from Giovanni database. Giovanni has been used widely to explore data and conduct initial studies, for example, dust and aerosol (Ramachandran and Cherian 2008); ocean color (Shen et al. 2008); and precipitation (Huffman, et al. 2007). Giovanni NEESPI is a customized Giovanni that integrates atmospheric, land surface and cryospheric products from a number of sensors within the boundaries of Northern Eurasia in support of the NEESPI project. This instance allows for visualization of parameters through plot functions including latitude-longitude area maps, animations, time-series, and cross-sections (Latitude/Longitude–Time and Height–Latitude/Longitude). It enables comparisons or relationship studies between parameters through functions, such as scatter plots, correlation coefficient maps, difference, and overlays. Other features of Giovanni NEESPI include: downloading original full spatial coverage or intermediate subsetted data for a region of interest in different formats, such as ASCII, hdf, or netCDF; provide products lineage which presents brief descriptions of how images and data were created; and provides images with KMZ format that can be viewed through Google Earth. In addition, Giovanni NEESPI can be accessed in a machine-to-machine way via WMS and WCS protocols. It can act as Web Mapping Service (WMS) or Web Coverage Service (WCS), thus allowing any GIS clients to add layers or get subsetted data from Giovanni. Finally, the system can act as a client by getting remotely located data via WCS or WMS.

Products in Giovanni NEESPI

Two Giovanni NEESPI instances are in operation. The first instance includes monthly products from MODIS Terra, MODIS Aqua, AMSR-E, AIRS and NESDIS/IMS. The parameters in the monthly instance have been grouped into three groups: atmosphere, land surface and cryosphere. Another operational instance is for daily products. It contains mostly atmospheric parameters from MODIS Terra, MODIS Aqua, and a few land surface parameters from AIRS. Both operational instances contain products of 1^o x 1^o horizontal resolution. We are working on higher resolution daily or 8-day products to better support regional-scale studies. Table 1.1 lists parameters, instrument name, temporal coverage and status of products in Giovanni-NEESPI.

Table 1.1. Parameters in Giovanni-NEESPI system.

Group	Parameter name	Sensor name	Available since	Status	
				Monthly	Daily
	Aerosol optical depth at 0.55 μm	MODIS-Terra	2000.02	OPS	OPS
		MODIS-Aqua	2002.07		
	Atmospheric water vapor (QA-weighted)	MODIS-Terra.	2000.02	OPS	OPS
Atmosphere		MODIS-Aqua	2002.07		
	Aerosol small mode fraction	MODIS-Terra,	2000.02	OPS	OPS
		MODIS-Aqua	2002.07		
	Cloud fraction (day and night)	MODIS-Terra,	2000.02	OPS	OPS
		MODIS-Aqua	2002.07		
	Cloud fraction (day only)	MODIS-Terra,	2000.02	OPS	OPS
		MODIS-Aqua	2002.07		
	Cloud fraction (night only)	MODIS-Terra,	2000.02	OPS	OPS
		MODIS-Aqua	2002.07		
	Cloud optical depth – total (QA-w)	MODIS-Terra,	2000.02	OPS	OPS
		MODIS-Aqua	2002.07		
	Cloud optical depth – ice (QA-w)	MODIS-Terra,	2000.02	OPS	OPS
		MODIS-Aqua	2002.07		
	Cloud optical depth – liquid (QA-w)	MODIS-Terra,	2000.02	OPS	OPS
		MODIS-Aqua	2002.07		
	Cloud effective radius – total (QA-W)	MODIS-Terra,	2000.02	OPS	OPS
		MODIS-Aqua	2002.07		
	Cloud effective radius – ice (QA-W)	MODIS-Terra,	2000.02	OPS	OPS
		MODIS-Aqua	2002.07		
	Cloud effective radius – liquid (QA-W)	MODIS-Terra,	2000.02	OPS	OPS
		MODIS-Aqua	2002.07		

	Cloud top pressure (day and night)	MODIS-Terra, MODIS-Aqua	2000.02 2002.07	OPS	OPS
	Cloud top pressure (day only)	MODIS-Terra, MODIS-Aqua	2000.02 2002.07	OPS	OPS
	Cloud top pressure (night only)	MODIS-Terra, MODIS-Aqua	2000.02 2002.07	OPS	OPS
	Cloud top temperature (day and night)	MODIS-Terra, MODIS-Aqua	2000.02 2002.07	OPS	OPS
	Cloud top temperature (day only)	MODIS-Terra, MODIS-Aqua	2000.02 2002.07	OPS	OPS
	Cloud top temperature (night only)	MODIS-Terra, MODIS-Aqua	2000.02 2002.07	OPS	OPS
	Column amount ozone	Aura OMI	2004.08	NA	OPS
	GPCP precipitation	GPCP Derived	1979.01	OPS	WK
	Cloud and overpass corrected fire pixel count	MODIS-Terra MODIS-Aqua	2000.11 2002.07	OPS	WK
Land surface	Overpass corrected fire pixel count	MODIS-Terra MODIS-Aqua	2000.11 2002.07	OPS	WK
	Mean cloud fraction over land for fire detection	MODIS-Terra MODIS-Aqua	2000.11 2002.07	OPS	WK
	Mean fire radiative power	MODIS-Terra MODIS-Aqua	2000.11 2002.07	OPS	WK
	Enhanced vegetation index (EVI)	MODIS-Terra MODIS-Aqua	2000.02 2002.07	OPS	WK
	Normalized difference vegetation index (NDVI)	MODIS-Terra MODIS-Aqua	2000.02 2002.07	OPS	WK
	Land surface temperature (daytime)	MODIS-Terra	2000.03	OPS	WK
	The same, but nighttime	MODIS-Terra	2000.03	OPS	WK
	Surface air temperature	AIRS	2002.08	OPS	OPS
	Surface skin temperature	AIRS	2002.08	OPS	OPS
	Land cover type	MODIS Terra	2001.01	TS	NA
Cryosphere	Ice occurrence frequency	NESDIS/IMS	2000.01	OPS	WK
	Snow occurrence frequency	NESDIS/IMS	2000.01	OPS	WK

Note: OPS = operational, TS = in test, WK = working on, NA = no data

Sample Application: Variations of Fire in Temperate Europe

As an example application of Giovanni NEESPI, we have studied interannual variations of fire occurrence in the temperate regions of non-boreal Europe. At 1° resolution, land cover of temperate Europe is dominated by three major classes:

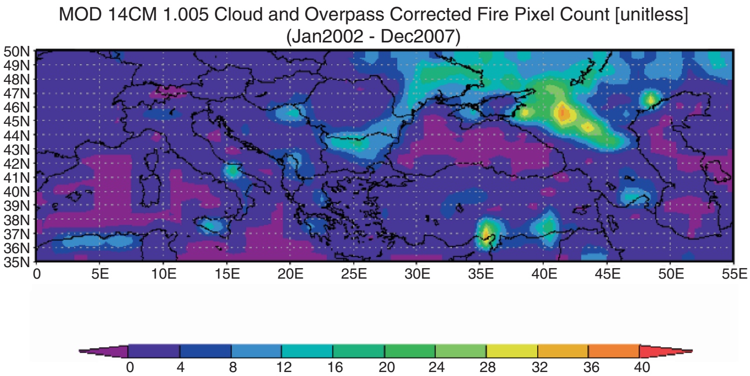

Fig. 1.1. Fire pixel count observed from MODIS Terra over temperate Europe. The data were averaged from January 2002 to December 2007.

croplands, mixed forest, and grasslands. The official statistics on wildland fire occurrence in Europe (excluding Russian Federation, Armenia, and Georgia) show that over the last decade on the average 75% of all burned areas in Europe were found in Spain, Portugal, Italy, and Greece positioned in southern subtropical Europe (UNECE Timber Committee and the FAO European Forestry Commission: http://www.unece.org/trade/timber/ff-stats.html). Satellite observations show that in temperate Europe fires or hot spots occur mainly in croplands (Fig. 1.1). Using Giovanni NEESPI, we have studied the variations of fire frequency observed in this region from satellites. Figure 1.2 shows monthly time series of fire pixel counts from MODIS Terra and MODIS Aqua over the cropland regions. Fire occurrence has clear seasonal variations in this region. It features two fire peaks: one in spring (March and April) and another in late summer (July and August). The spring peak is generally weaker than the one in late summer. Previous studies (Korontzi et al. 2006) have indicated that agricultural fires are common in this region. These fires are frequently set as a crop residue management application which allows for inexpensive and quick stubble removal while adding nutrients to the soil and killing weeds and pests at the same time. Despite the official ban on agricultural burning in many countries of Western Europe (Jenkins et al. 1992) a considerable number of fires are observed in cropland areas there. Agricultural use of fire is even more prominent in Eastern Europe where cropland fires presented ~86% of all detected fire activity in Ukraine during 2001–2003 (Korontzi et al. 2006).

Fire occurrence in late summer of year 2003 was noticeably lower as compared to other years during 2001–2007. Considering that fires in this region are associated with crop growth, we investigated the precipitation and vegetation index in this region through Giovanni NEESPI. The precipitation was derived from the NASA

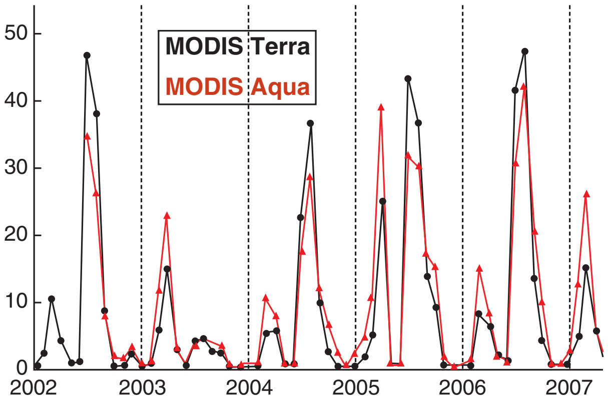

Fig. 1.2. Monthly time series of cloud and overpass corrected fire pixel count over cropland regions of temperate Europe (25° E–45° E, 42° E–50° E). The black curve is from MODIS Terra and the red curve is from MODIS Aqua.

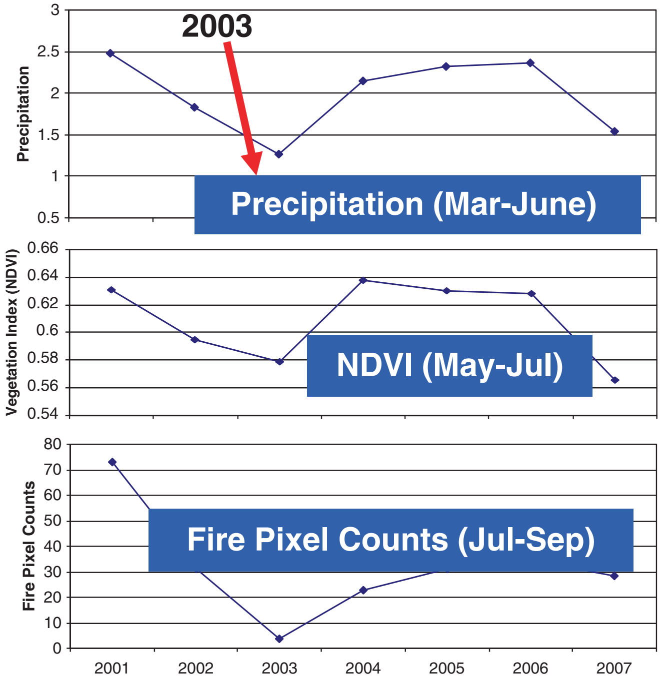

Fig. 1.3. Interannual variations of fires in July–September and its relationship with NDVI in May–July and precipitation in March–June.

GPCP monthly product. The vegetation index was derived from MODIS Terra and MODIS Aqua normalized difference vegetation index (NDVI). We found that the late summer fire in temperate cropland region has a strong relationship with spring precipitation and NDVI in early summer (Fig. 1.3). The amount of precipitation in spring 2003 was noticeably smaller compared to other years which may have caused the stunted crop growth in this region. The latter is indicated by the lower NDVI values in May through July. The weaker growing season resulted in a reduced production of winter wheat in Ukraine from ~3 mt/ha in 2001 and 2002 to 1.5 mt/ha in 2003 with a subsequent increase in yields up to ~3 mt/ha in 2004 (USDA/FAS/PSD 2008). However, a similar drop in spring precipitation and subsequent lower NDVI values observed in 2007, has not led to decrease in the fire activity during that year. Our analysis of additional parameters available in Giovanni NEESPI shows that it might have been linked to unusually high land surface temperature observed during July–September of 2007 (Fig. 1.4).

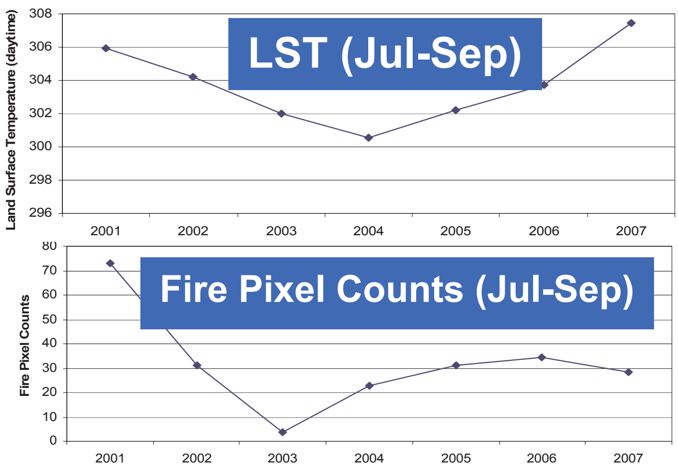

Fig. 1.4. Interannual variations of fires in July–September and its relationship with land surface temperature in same time period.

Summary

This paper presents a quick summary of the NASA NEESPI data portal and the Giovanni NEESPI system. The study of variability of fire occurrence in temperate Europe demonstrates that Giovanni NEESPI is a convenient, simple, and useful tool for exploring satellite remote sensed data aimed at developing an understanding of continental- and regional-scale relationships between various parameters and processes. More products including modeled and long term *in situ* data and more visualization functions will be added into the data portal to better support climate studies. We are working on a prototype to allow the portal to access data dynamically from other center through WMS and WCS, such as regional high resolution data. This will make the portal a virtual universal data center that allows scientists to access data from a single point.

Acknowledgements. The project is supported by NASA through ROSES 2005 NNH05ZDA001N-ACCESS. The authors wish to express great appreciation for the technical support of the Giovanni software development and S4PA data ingest working groups at NASA GES-DISC.

Relevant URL: The NASA NEESPI Data Center: http://neespi.gsfc.nasa.gov/, Giovanni: http://giovanni.gsfc.nasa.gov

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Baseline Climatological Data Sets for Eastern Europe Area

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Abstract. Availability, formats, and peculiarity of observation routines of major in situ meteorological variables in the former USSR and, thereafter, in the Russian Federation are described.

Keywords: Russia, in situ observations, temperature, precipitation, snow

Introduction

The reliability of data on regional climate changes is determined, in many respects, by the quality of instrumental observations used to analyze the state of the climate system. In the Russian Federation, the responsibility for hydrometeorological data collection, archiving and dissemination is placed upon the All-Russian Research Institute of Hydrometeorological Information that also acts as a World Data Centre-B for Meteorology (RIHMI-WDC). The Institute is situated in Obninsk, 100 km away from Moscow.

Description of the Data Sets

Observational data are accumulated in the Unified State Fund of Environmental Data (State Fund). These data are the main source of information in analyzing regional climate variability. It should be noted that special demands are made on climate data and other State Fund data to serve as an original data source to create climate data sets. Specifically, climate data are to be created as time series as long as possible. These are not to have gaps and erroneous values and are to be complemented with additional information on the station history, station displacements and changes in observation procedures and instruments. Thus the preparation of climate data bases by using State Fund observational data is the challenge that requires significant financial and production resources. At present, 1,642

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meteorological stations are located in the territory of Russia (Fig. 2.1), with 602 of these being in European Russia.

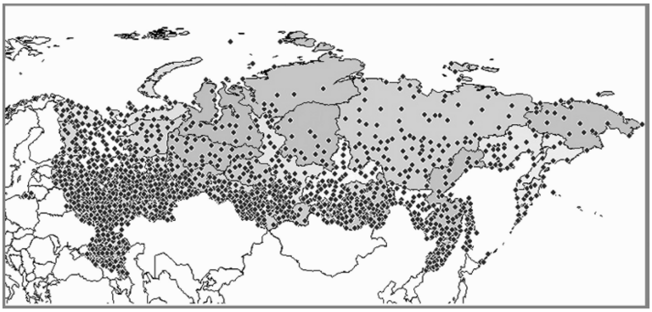

Fig. 2.1. Meteorological stations over the territory of Russia.

These stations are included in the Regional Reference Network and the National Network of Meteorological Stations. Making these data available for the international data exchange, including the Global Climate Observing System (GCOS) and the Global Telecommunication System (GTS), is regulated by the rules that are valid over the territory of the Russian Federation. As few as 59 meteorological stations of European Russia are included in GCOS (Fig. 2.2).

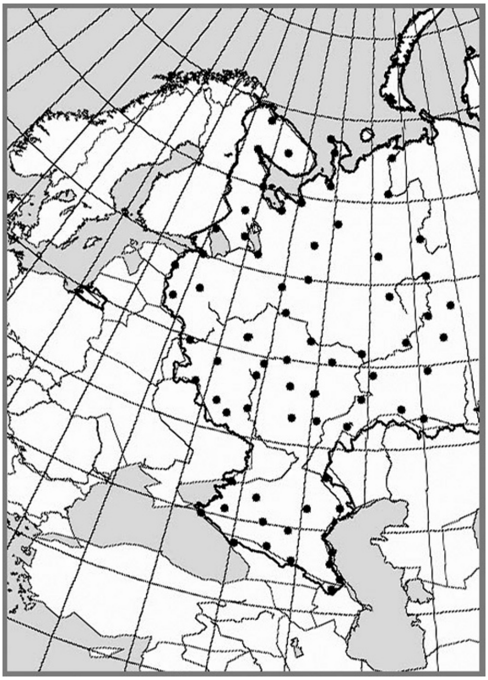

Fig. 2.2. GCOS meteorological stations over European Russia.

A substantial increase in the number of stations took place in 1936 and 1959, when meteorological stations that made observations under the programs of different organizations were included in the single network of the USSR stations with the common observation program.

Unfortunately, since 1990, the number of meteorological stations has decreased by about 200, largely in remote and hard-to-reach places. Measures are now being taken to increase the number of operating stations. The length of observation series for European stations is different (Fig. 2.3).

By now, RIHMI-WDC has prepared several climate data sets which are used as a basis in analyzing climate changes in Northern Eurasia, including Eastern

Europe. These data sets are constantly worked with. Much attention is given to detecting errors and their correction, so as to derive homogeneous data sets. Sometimes it is reasonable to create specialized data sets that are convenient for the solution of the definite problem. These data sets normally prove to be useful and they are placed on the website and distributed free of charge.

One of the most required data sets contains data on daily (mean, maximum and minimum) air temperatures and daily precipitation totals for 223 stations of the former USSR. The first version of this data set containing data for the period from the onset of observations up to 1983 is prepared by RIHMI-WDC in cooperation with the Carbon Dioxide Information Analysis Center (CDIAC, Oak-Ridge National Laboratory) (Razuvaev et al. 1993). This version was distributed through FTP CDIAC at no cost. A large number of responses and wishes to continue work on the data set were received. At present, RIHMI-WDC has prepared a new version of this data set that was revised and updated with data up to 2006. This version of the data set with complementary information on station displacements is placed on the RIHMI-WDC website (http://www.meteo.ru/climate/sp_clim.php) and is distributed free of charge. In 2009, it will also be placed on the CDIAC website.

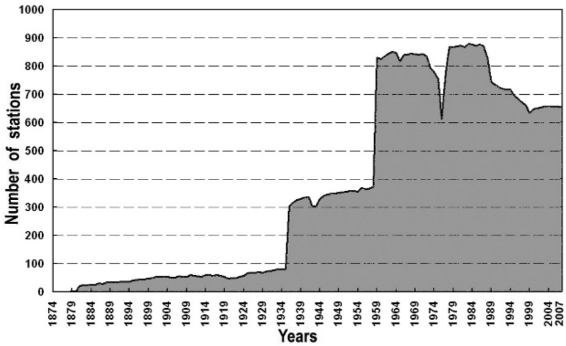

Fig. 2.3. European meteorological stations of Russia.

Air temperature is the most important climatic element. The analysis of air temperature time series allows major information about climate change to be obtained. In this connection RIHMI-WDC prepared mean monthly air temperature series from 476 evenly distributed Russian meteorological stations (Fig. 2.4.) for the period from the onset of observations up to 2006. This data set is placed on the RIHMI-WDC website (http://www.meteo.ru/climate/sp_clim.php); it is distributed at no cost and widely used by different research groups involved in climate monitoring and climate variability studies.

During 10 years RIHMI-WDC and NCDC (Ashville, USA) were engaged in creating the base data set of daily precipitation from the Russian meteorological stations included in the list of stations for the international data exchange (more than 1,000 stations). At present, the first version of the data set containing data from the onset of observations up to 2005 has been prepared. Due to the fact that in the period to 1966, procedures of precipitation observations over the USSR territory often changed; different versions taking into account these changes were included in the data set. The data set is placed on the NCDC website and is available on request (td-9813). Once the subsequent modifications of the data set are ready, this will be reported on the NCDC and RIHMI-WDC websites.

Fig. 2.4. Four hundred and seventy-six meteorological stations over the territory of Russia.

3-HOURLY DATA SET

Air temperature
Water vapour pressure
Dew-point temperature
Relative humidity
Sea level pressure
Station level pressure
Air pressure tendency
Visibility
Total cloud amount
Lower cloud amount
Cloud genera
Height of cloud base
Wind speed
Wind direction
Precipitation
Present weather
Past weather
Surface temperature
Ground state
Atmospheric phenomena

DAILY DATA SET

Mean daily air temperature
Maximum air temperature
Minimum air temperature
Daily precipitation
Snow depth
Snow coverage
Characteristics of site
Minimum of relative humidity
Minimum of surface temperature
Wind speed maximum
Atmospheric phenomena
Atmospheric phenomena duration
Daily total and low cloud amount
Sunshine duration

Fig. 2.5. List of meteorological elements observed at the first order stations in Russia.

One of the most important climatic elements over the Russian territory is snow cover. In Russia, much attention was traditionally given to studying the state of snow cover and its changes under the influence of different factors. However, the lack of computer-readable complete data sets was a serious constraint. The first versions of daily and decade snow data sets from some of the Russian stations were prepared within the bilateral Russia-USA data exchange cooperation and were placed on the NSIDC website (Boulder, USA). At present, RIHMI-WDC, with the assistance of INTAS (INTAS-SCCONE project No : 01-0077), has prepared a full version of daily snow data sets from 223 meteorological stations of the former USSR for the period from the onset of observations up to 2007. The data set is placed on the RIHMI-WDC website (http://www.meteo.ru/climate/sp_clim.php) and is distributed at no cost.

Original meteorological data sets archived in the State Fund contain information about nearly all climatic elements that are defined by GCOS as the major elements in studying climate change. Specifically, Fig. 2.5 shows the list of meteorological elements included in the original data set of daily observations.

Based on these data sets, it is possible to create specialized one-element data sets (for example, visibility and air humidity) that are widely used in solving many scientific and applied problems.

Years	Times\day
1891 - 1935	Three (7, 13, 21 Local Time)
1936 - 1965	Four (1, 7, 13, 19 LT)
1966 - 1992	Eight (3, 6, 9... Moscow Time)
1993 - now	Eight (3, 6, 9... Greenwich Time)

Fig. 2.6. Historical changes of time of meteorological observations in Russia.

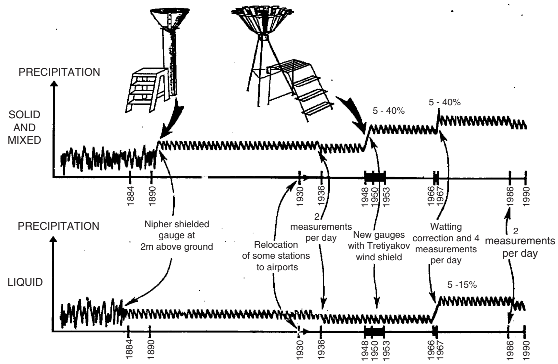

Fig. 2.7. A depiction of the systematic changes in the precipitation network over the USSR. Characteristic ranges of the changes are provided where possible (Groisman et al. 1991).

Important components of the entire complex of base data sets are the metadata sets that contain essential information about changes in observation procedures, station displacements, etc., which is required to exclude data inhomogeneity. Specifically, to prepare homogeneous air temperature data sets, additional information is required concerning observation hours that changed several times from the onset of observations up to the present (Fig. 2.6).

To study precipitation regime over the Russian territory based on homogeneous data series, the dates of changes in precipitation observation procedures were determined, in particular, the time of the replacement of observation instruments and the introduction of different corrections into observation data (Fig. 2.7). This made it possible to create homogeneous data series and, by using these, to obtain reliable information on the changes in precipitation regime.

Snow observations were also subject to modification (Fig. 2.8) (Razuvaev and Shakirzyanov 2000). The effect of changes in observation procedures on the homogeneity of snow data series is not adequately studied yet. It is, however, evident that as the studies of snow effects proceed under the international program *Climate and Cryosphere*, the need for this information will increase.

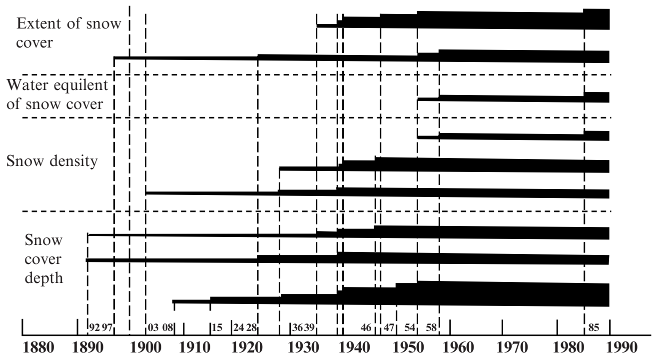

Fig. 2.8. Snow cover observations availability in Russia.

Specialized data sets are used in studying the current state of regional climate and its changes, specifically for climate monitoring (Bulygina 2005, Bulygina et al. 2004), and in analyzing climatic extremes (Bulygina et al. 2007). Of great importance is the proper organization of the data set preparation. The interaction between a user of the data set and its developer at the problem definition stage makes it possible to use original data sets properly, avoid doubling, identify quality criteria of base data sets, and choose the data presentation format that is optimal for the problem defined.

The work on creating the base data sets intended for the projects implemented under the NEESPI program will proceed and the data sets will be available to the scientific community.

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Precipitation Statistics in Ukraine: Sensitivity to Informational Sources

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Abstract. Sensitivity of precipitation estimates to a choice of database and sampling in observations as well as of a parameterization scheme in a model is discussed. Comparison is performed for time series and spatial patterns. Mean annual and seasonal differences between two databases for the period of 1965–1995 years is about 2–4 and 4–7 mm correspondingly. Discrepancy in spatial patterns of precipitation is mostly applied for the Carpathian region, where it achieves the value of about 7 mm. Estimates of a trend in precipitation vary depending on a sampling period and may even change the sign. This suggests that a term like the long-term variability is preferable instead of the trend. Model simulations show that different parameterization schemes provide similar large scale patterns and values of cloud and rain content, but are considerably different in meso scale structures for orders of 100 km and less.

Keywords: precipitation, trend, variability, sampling, parameterization

Introduction

Climate change is considered in current researches of geosciences with a focus on various aspects of this phenomenon (Trenberth 1990; Jones and Moberg 2003; Parker 2006). Temperature change is the most obvious and easily measured component of the climate. Moisture and precipitation are also expected to change as they are the interacting components of the united system. Increasing of temperature leads to increases in moisture-holding capacity of the atmosphere. This alters the hydrological cycle, characteristics of precipitation (amount, frequency, intensity, duration, type) and extremes (Trenberth et al. 2003).

The main problem in climate variations estimation is gaps in long-term data series as well as different sorts of errors including the use of heterogeneous instruments during the observed period, representativeness and biases. This increases uncertainty in results, decreases confidentiality of specified trends and leads to sensitivity to sampling. For example, surface temperature being measured during more than a century was examined globally (Trenberth 1990). It has been

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found that 1976 marked the beginning year of a widely known "climate shift" and seems to mark a moment when global mean temperature began an upward trend that has been at least partly attributed to increasing greenhouse gas concentration in the atmosphere. However, the period after 1979 rather than 1976 is considered as the benchmark of climate changes (Kistler et al. 2001) due to increasing and improving available satellite data (Santer et al. 1999; Bromwich and Fogt 2004; Simmons et al. 2004). Therefore, availability of high quality data led to a focus on the period after 1978, while physically the new regime seems to have begun earlier.

Difficulties in measuring precipitation remain an area of concern in quantifying the extension to which global and regional-scale precipitation has changed. Studies of biases in precipitation measurements by *in situ* rain gauges (Legates and Wilmott 1990) found that light rainfall measurements are strongly underestimated owing to wind-induced acceleration and vertical motion over the rain gauge orifice; most precipitation gauges have trouble reporting the full amount of precipitation that reaches the gauge owing to gauge precision problems, losses (retention and evaporation) and accumulation (condensation) of water in/from the gauge. To account for the above problems, attempts were made (Yang and Ohata 2001; Mekis and Hogg 1999; Adam and Lettenmaier 2003) to adjust precipitation measurements and create new regional and global datasets. However, application of those approaches caused confusion due to unrealistically high precipitation estimates. Additionally, different methods considerably deviated from each other for the same regions using the same data.

Adjustment of precipitation data is much more demanding than for temperature, as the spatial correlation in precipitation fields is much weaker, on one hand, and networks in many regions are not dense enough to find statistically significant relations, on the other hand. Auer et al. (2005) gave typical distances above which adjustment is not possible. This distance is timescale and season dependent, and ranges from 150 km separation at the monthly to 40 km under daily timescale.

Nevertheless, the following has been concluded concerning the precipitation climate changes in the midlatitudes (Trenberth et al. 2007). Precipitation has generally increased over land north of 30° N over the period 1900–2005. It has become significantly wetter in northern Europe, but drier in the Mediterranean. Patterns of precipitation change are more spatially and seasonally variable than temperature change, but where significant precipitation changes do occur they are consistent with measured changes in stream flow.

Data

As mentioned above, different adjustment approaches applied to the same precipitation datasets may lead to contrasting results. This work shows that different databases also provide estimates, which do not completely match each other, and also shows that estimates from the same database are sensitive to the chosen sampling period.

In this work two databases of precipitation have been used. The first is from the Ukrainian Hydrometeorological Service (http://www.cgo.kiev.ua/). This document contains available hourly and daily information as well as monthly and annual mean values for the years from 1961 to 1990, which WMO declared as the reference period of current climate changes. An available observation period varies from 12 to more than 100 years for different stations of network (Fig. 3.1a). Extreme values are included for the entire observed period. It is necessary to note that time series of precipitation are not homogeneous in the manner of their collection and pre-processing. For example, the Nifer rain gauge had been replaced on the network in 1950s by the Tretiakov equipment placed at the 2 m height. In 1966 the correction coefficient was introduced in the pre-processing procedure for taking into account water remaining on the walls of a gauge after the rain gauge volumetric measurements (the so-called "wetting error"). Data collected prior to this date were later re-calculated with the use of this coefficient. The other problem in this database relates to extreme values of the precipitation

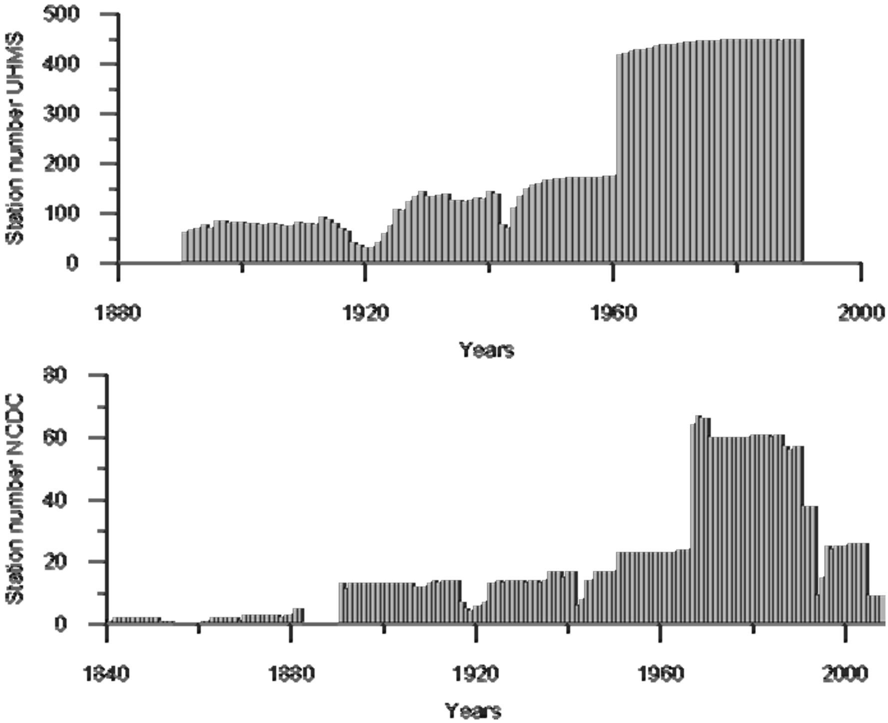

Fig. 3.1. The number of stations measured precipitation over Ukraine from two different databases: the Ukrainian Hydrometeorological Service (UHMS) (*top*), and the National Climatic Data Center (NCDC) (*bottom*).

and rain. The observed daily period is different from the astronomic day; it started at 7 am before 1936, at 7 pm from 1936–1966, and at 9 pm since 1966. This resulted in heterogeneity in time series of extreme precipitation events as well as to disagreement in time series of precipitation associated with the astronomic and observation days.

The other source used in this study is the Global Historical Climatology Network (GHCN) data base of the National Climatic Data Center (NCDC) (http://www.ncdc.noaa.gov/). These data have undergone rigorous assurance reviews including the preprocessing check on source data, time series check that identify spurious changes in the mean and variance, spatial comparisons that verify the accuracy of the climatological mean of the seasonal cycle, and neighbor check that identify outliers from both a serial and a spatial perspective.

The period of record varies from station to station, although this database contains considerably fewer stations, only about 60 (Fig. 3.1b), compared to more than 400 included in the UHMS database. This number of observation stations obviously cannot completely describe the precipitation spatial structure over Ukraine, which covers an area of about 1,300 by 900 km, given that convective and stable precipitation types both are meso-scale phenomena (Ivanov and Palamarchuk 2007; Weusthoff and Hauf 2008). However, it is still enough to describe large-scale features of the precipitation regime in different geographical regions of Ukraine.

Results

Sensitivity to the sampling and databases

Comparison of statistics from two databases shows that main parameters such as the seasonal and annual mean values and standard deviations do not match each other (Table 3.1).

In most cases the difference is minor for the annual values and varies from 2 to 4 mm from station to station, while seasonal values disagree more. Thus, the annual mean values in Uzhgorod differ by 2.6 mm, whereas summer and autumn differences are about 7 mm. Spatial distribution of precipitation for particular years is also considerably different, in particularly when extreme annual values have been observed in some regions. For example, in the west part of Ukraine (Uzhgorod) a maximum annual precipitation above 1,000 mm was registered in 1980, although in other regions annual precipitation did not exceed 800 mm.

Discrepancies in data inevitably lead to different estimations for trends. Figure 3.2 shows the most pronounced difference between the two data bases over the period 1965–1995 for Nikolaev. It is −1.8 mm/10 years in the UHMS compared to −0.6 mm/10 years using the NCDC data.

Table 3.1. Seasonal and annual statistics (mean values and standard deviation) from the two databases at observation stations of different regions of Ukraine.

		DB1		DB2		DB2-DB1	
Station	Season	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
Uzhgorod	Year	754.1	132.0	751.4	141.4	−2.6	9.4
	Winter	173.9	55.4	172.6	56.5	−1.3	1.1
	Spring	164.9	52.9	165.4	56.2	0.5	3.4
	Summer	234.6	80.9	241.2	84.1	6.6	3.2
	Autumn	178.5	70.0	171.7	73.9	−6.7	4.0
Poltava	Year	582.1	118.2	576.0	127.3	−6.1	9.2
	Winter	134.6	60.2	130.6	57.7	−4.0	−2.4
	Spring	130.2	38.1	123.6	36.5	−6.6	−1.6
	Summer	175.8	56.9	176.7	57.9	0.8	1.0
	Autumn	140.0	51.9	139.7	53.8	−0.3	2.0
Chernovtsy	Year	670.4	141.0	671.4	139.4	1.0	−1.6
	Winter	98.4	31.8	96.6	32.0	−1.8	0.2
	Spring	173.4	47.6	172.6	49.7	−0.8	2.1
	Summer	271.8	95.3	266.4	91.5	−5.4	−3.8
	Autumn	124.8	63.8	117.7	59.5	−7.1	−4.2
Nikolaev	Year	463.5	98.6	461.9	93.1	−1.5	−5.5
	Winter	108.6	49.1	107.7	47.6	−0.9	−1.5
	Spring	107.6	44.1	103.5	44.9	−4.0	0.7
	Summer	149.1	72.3	146.3	68.4	−2.8	−3.9
	Autumn	97.0	40.7	97.3	42.0	0.3	1.3

The sensitivity of trend estimations to a sampling period from the same database is shown in Fig. 3.3. For example, the trend in precipitation estimated for the whole available observation period is +0.1 mm per 10 years, while the trend estimated for the period from 1965 to 1985 is equal to −1.4 mm per 10 years. Thus, even the opposite sign may be obtained depending on the period chosen to estimate a trend. Moreover, including two additional years to the later period considerably increases the trend to the value of −3.0 mm per 10 years. This happened due to the fact that those years were extremely dry, and formal statistical calculations are sensitive to the so-called tail effect which may mask the actual physical phenomena. This confirms a suggestion that changes in precipitation are associated with long-term (multi)-decadal variability in the atmosphere.

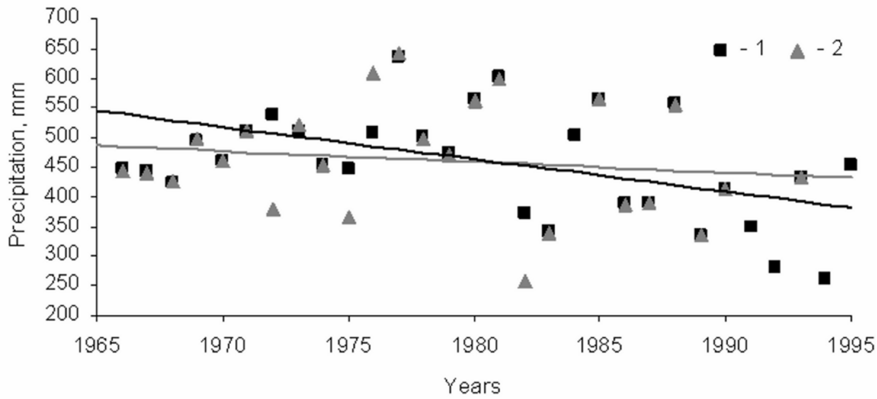

Fig. 3.2. The precipitation trend for Nikolaev over the period of 1965–1995 from the two data bases, the Ukrainian Hydrometeorological Service (1) trend −1.8 mm/10 years, and the National Climatic Data Center (2) trend −0.6 mm/10 years.

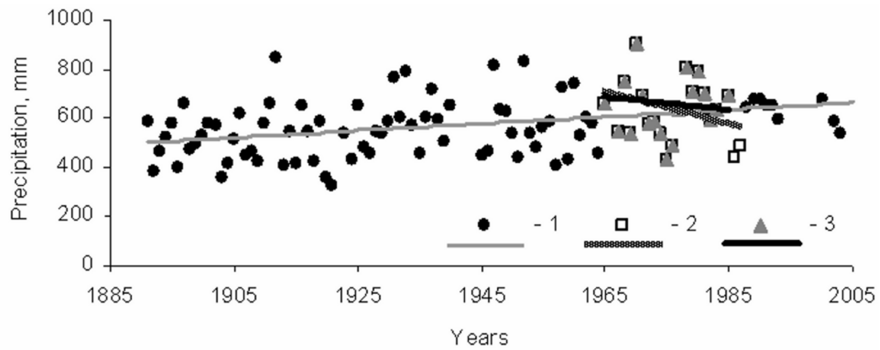

Fig. 3.3. The precipitation trends for Uman over three different sampling periods from the National Climatic Data Center: 1 – period from 1891 to 2004, trend 0.1 mm/10 years; 2 – period from 1965 to 1987, trend –3.0 mm/10 years; 3 – period from 1965 to 1985, trend –1.4 mm/10 years.

The role of parameterizations in simulating precipitation

Current numerical models are based on well-established physical principles and demonstrate observed features of weather patterns and recent climate. There is considerable confidence that those models provide quantitative estimates of atmospheric process at both hemisphere and continental scales. Confidence in those estimates is higher for variables such as geopotential and temperature than for precipitation, especially at meso-scales. Inter-model comparison has confirmed that a primary source of poorly represented precipitation is cloud feedbacks in parameterization schemes with low clouds making the largest contribution (Doutriaux-Boucher and Quaas 2004).

Figure 3.4 shows cloud and rain water contents as well as spatial spectra after difference filtering for the same atmospheric pattern simulated by MM5 model with two different sets of parameterization schemes for the cumulus convection (CC) and planetary boundary layer (PBL). The first set includes the the Grell CC and high-resolution Blackadar PBL schemes, while the second set contains the Kain-Fritsch CC and Eta PBL schemes.

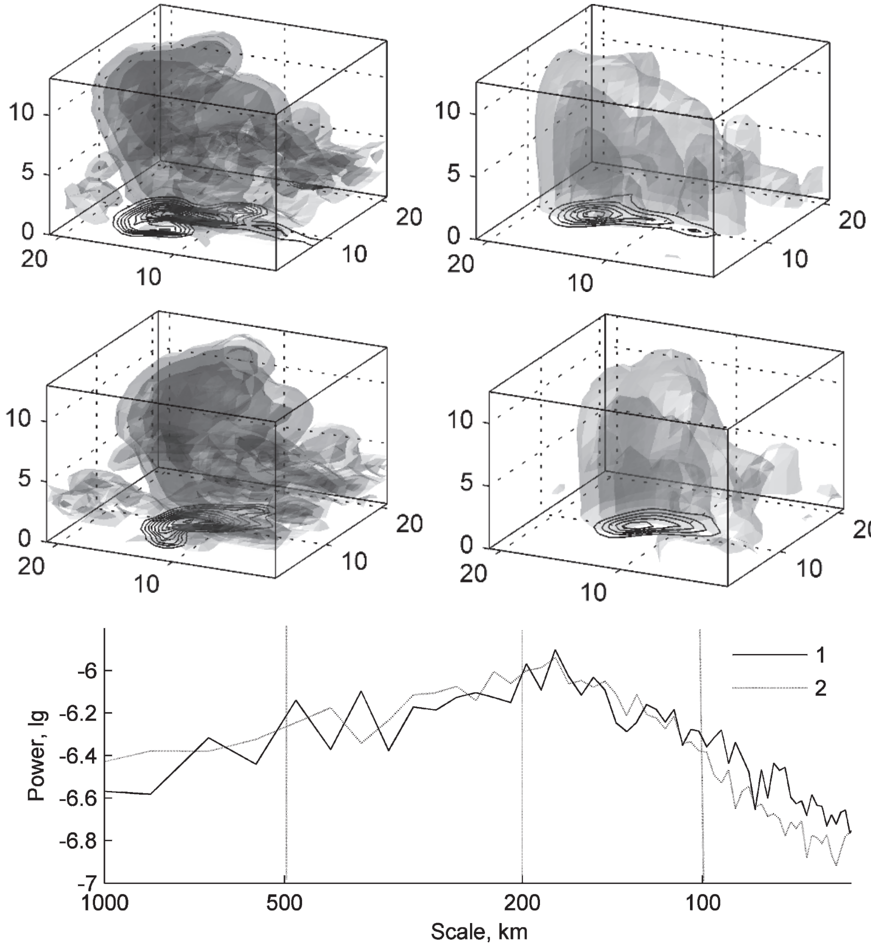

Fig. 3.4. Three dimensional distribution of cloud (*left*) and rain (*right*) water content in the model with Grell cumulus and Blackadar PBL (*top panel*) and Kain-Fritsch cumulus and Eta PBL (middle panel). Spatial spectra after difference filtering for cloud water content (*bottom panel*) with 1 – the parameterizations Grell cumulus and Blackadar PBL and 2 – Kain-Fritsch cumulus and Eta PBL.

Omitting details of each scheme, attention is paid to the main feature. The total water content and large scale structures in both simulations are similar, while the first set reproduces higher variability on the meso-scales for order of 100 km and smaller. The second set smoothes both the cloud and rain water content structures, and decreases their spatial variability on the meso-scales which results in underestimating maximum values. Thus, the modeling of precipitation shows the sensitivity of the spatial distribution in precipitation fields to the choice of parameterization schemes.

Precipitation changes (variations) and circulation epochs

The climate science found that the Earth climate changes over recent decades points to increasing evidence of anthropogenic influences on climate changes (Le Treut et al. 2007). However, it is necessary to keep in mind that the Earth is a complex, interactive system, which consists of many components with numerous feedbacks which favors a high potential to return to the statistically stable mean state in the long term. If this suggestion is correct, than the observed changes should be better considered as variations instead of trends.

The climate changes are most pronounced in surface temperature through both the mean and extreme values and in shifting vegetation belts in the boreal zone. Regarding precipitation, the Global water balance is the conservative value, which means, in particular, stable amount of precipitation over the Globe under interannual time scale, but allows the redistribution of precipitation between certain regions. However, interannual variations in precipitation under the regional scale may also be associated with changes in general circulation of the atmosphere (Girs 1971). Figure 3.5 shows spectra of precipitation for the longest time series in seven locations of different parts of Ukraine, from the Carpathian Mountains to the Central Steppe zone and the Black Sea coast.

All of them clearly show the strong seasonal oscillation, but its amplitude is different. The largest amplitude in precipitation is observed in both the Carpathian (Chernovtsy) and Crimean (Ay-Petri) mountain areas, smaller in the plain steppe zone (Uman, Poltava), and about twice less in the coastal zone (Nikolaev, Izmail).

Spectra also show considerable differences in the interannual variability of periods of 5–7 years and longer. As above, this variability is higher in the western and mountain regions and lower in the eastern plane region including the coastal zone. Although, Izmail located in the western part of the coast region shows the long-term variability as high as in the neighbouring Carpathian region. This can be explained due to its close position to the western region, which is affected by same large-scale circulation patterns (Monahan et al. 2001) and where multi-decadal variability associated with changes in mid-latitude westerlies from Atlantic is evident (Trenberth et al. 2005). Thus, the presence of significant long-term interannual variability in precipitation should be counted in estimates of trends.

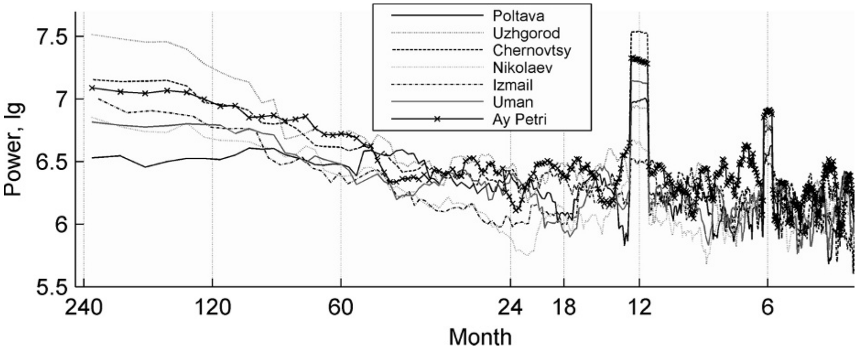

Fig. 3.5. Precipitation spectra in different parts of Ukraine.

Conclusions

Precipitation statistics are sensitive to sampling and pre-processing procedures in databases.

Large scale precipitation structures are mainly properly captured by the present observation net and reproduced in numerical models, while meso scale precipitation is sensitive to chosen parameterization schemes.

The long-term variability term seems preferable over the use of the trend applied to precipitation.

Acknowledgments. This work was supported by the NATO SfP grand 981044 "Extreme precipitation events".

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Section 2

Regional Climate Changes in the Non-boreal Eastern Europe

Ecological Challenges of Climate Change in Europe's Continental, Drought-Threatened Southeast

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Abstract. The present climate change adaptation and mitigation strategy in Europe does not deal with ecological problems of continental Southeast European environments and with the role of terrestrial vegetation cover according to their importance, although the predicted increase of drought frequency will have a profound effect on quality of human life and on the functioning ("services") of ecosystems. In this region the southern border of the closed forest belt forms an ecotone toward the forest steppe. Forests have an effect on the majority of factors causing climatic forcing, such as surface albedo, carbon emission and sequestration, evapotranspiration etc. A recurrent drawback of present forecasting models is the inaccurate parameterisation and the lack of consideration of biotic response mechanisms and of planned forest management.

Keywords: non-boreal temperate forests, limits of distribution, climate envelope models, adaptation, drought tolerance, ecosystem services, forest management

Introduction

The European Commission has issued in summer 2007 a document entitled "Adaptation to climate change in Europe – options for EU action" ("Green Paper"), which is a product of the European Climate Change Program. The objective of the publication was to open a Europe-wide public debate and consultation on modalities to develop adaptation strategies and to promote common research and the exchange of information with partners around the world. The "Green Paper" is the first common European policy document on adaptation to the impacts of climate change, and reflects present priorities and attitudes toward a multiplicity of profoundly intertwined and often contradicting problems. It identifies however, problem areas and challenges from a viewpoint which – according to the opinion of the author – does not represent fully the complexity of diverse natural, ecological, economical and societal conditions of the Union, not to speak of adjoining regions.

P.Y. Groisman and S.V. Ivanov (eds.), *Regional Aspects of Climate-Terrestrial-Hydrologic Interactions in Non-boreal Eastern Europe*,

The approach of the document is primarily urbanite and technocrat. The highlighting of the sectors energy and infrastructure nourishes the impression that the tasks of mitigation and adaptation are nearly exclusively of technical/economic character. Accordingly, the treatment of the biotic environment, its resources and of economy sectors which utilise them is not according to their importance. The *ecological* problems concerning the living natural environment are, however, at least equally serious as those of the technosphere, even if the contribution of biotic resources to the GDP is statistically low, as most of their essential services are not accounted for in monetary terms. Similarly, among the vulnerable social groups, the ones utilizing renewable natural resources (agriculture, fisheries, forestry) should be dealt with similar attention: their activities significantly influence many components of climate forcing.

Ecoregions of Europe are also not equally treated in the document. The increase of drought frequency and severity in the Mediterranean and in continental Southeast Europe should be stressed much more as the effect on conditions and quality of human life and on the functioning ("services") of ecosystems will be profound.

In this paper we propose for consideration some aspects why continental Southeast Europe should get more attention in international research and in the development of national and transnational strategies of adaptation to climate change. We will concentrate on specific aspects of ecological conditions in the so-called ecotone (transitory) zone, which is strongly represented across Southeast Europe. We deal first of all with biological response mechanisms to extreme conditions, and how well these issues are treated by present models.

It should be noted that in addition to the selected climatic/ecological problems discussed here, this region is facing a rapid social and economic transition and restructuring which has a significant effect on land use – again, an important component of climatic forcing.

Climatic and Ecological Challenges at the Xeric Limits

The xeric limit is an ecotone

The distribution range of temperate zone species, as well as the cultivation area of agricultural crops are primarily limited by climate. The "front" and "rear" or upper and lower limits of distribution differ by their key limiting climate factors, temperature and aridity, respectively. The poleward thermal limits are determined by relatively accurately measurable temperature conditions, which makes modelling and prediction of the "front limits" comparatively reliable. Upper or thermal limits manifest themselves in nature relatively clearly, especially on an elevational scale.

Xeric (aridity) limits at the lower latitude end of distribution are determined by climatic aridity. They are more difficult to trace than thermal limits: precipitation conditions and frequency of droughts are elusive. Xeric limits are especially fuzzy on flat terrain, where species and vegetation types occur mosaic-like and follow the pattern of small-scale topographic, water regime and soil variation. In ecology, such transition zones are termed ecotones.

The biotic-ecological factors of the xeric (rear) limits are shaping the physiognomy of natural vegetation and land use of Southeast Europe. Here the closed forest belt forms an ecotone toward the woodland or forest steppe type vegetation, which dissolves eastward into the true steppe of East Europe. The ecotone is dependent on a volatile minimum of rainfall and is sensitive to prolonged droughts. Predicted changes may easily trigger the loss of already sparse forest cover, which may lead to the disruption of vital ecological services forests are providing.

The xeric limits at the southern end of the temperate closed forest belt have been the scene and setting for the industrial age and for high-intensity agriculture across the whole northern hemisphere. In Southeast Europe, the ecotone is a densely populated and agriculturally important zone which has been under human influence for millennia. This belt reaches from East-Central Europe (Moravian, Carpathian Basin) across the plains of Southeast Europe (Romania, the Ukraine, South Russia) far into Southern Siberia.

Contrary to general belief, the trend of rising temperatures and declining summer rainfall will not result in a mediterranisation in continental Southeast Europe because – compared to Mediterranean Europe – the regulating effect of the sea is weak and the predicted climate anomalies will be presumably stronger than the general trends calculated from hemispheric models. Even a relatively minor shift of temperature and precipitation parameters will profoundly affect the available climatic niche of dominant zonal species such as European beech (*Fagus sylvatica*), a climate-sensitive species. In Fig. 4.1, the consequence of the predicted shift of the sensitive parameters summer heat and growing season

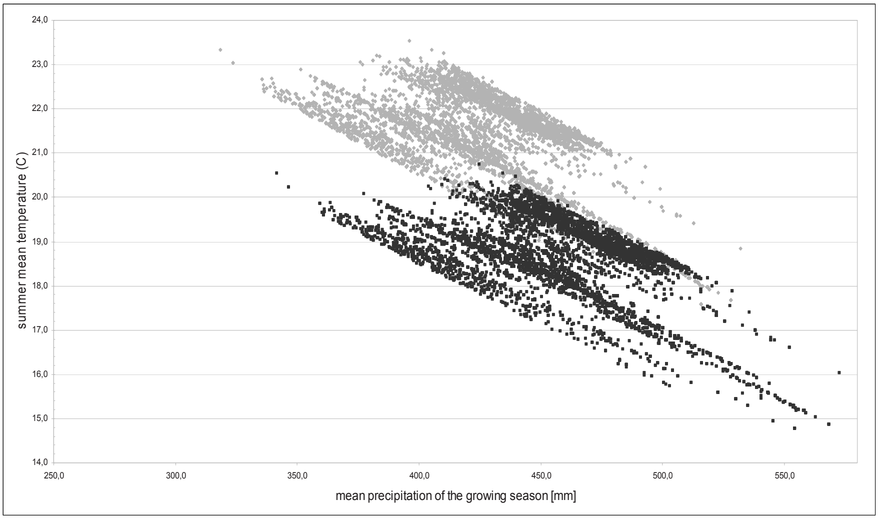

Fig. 4.1. Climate parameters (mean precipitation of the growing season vs. mean summer temperature) of actual beech (*Fagus sylvatica*) occurrences in Hungary (black) and parameters calculated with the Prudence climate model for 2050 (gray) (data by E. Rasztovics).

rainfall is shown for Hungary: until the mid of the present century the climatic niche for the cultivation of the species will be reduced essentially.[1] Climate models predict for the country an area increase of forest steppe climate by more than 50% by the end of the century, which implies that open woodlands could potentially replace a significant part of present-day closed forests (Mátyás et al. 2008). For various reasons, partially discussed in the following, the climate niche shift may not necessarily lead to the total retraction of present ecosystems of the respective habitats (Jump et al. 2009).

Table 4.1. Frequency of recent and predicted drought events for Hungary, according to scenario A2, calculated with MPI's REMO climate model (Gálos et al. 2008)

Period	Drought years		
	number of years	mean of precipitation anomalies (%)	mean of temperature anomalies (°C)
1951–2000	17	–12.42	+0.39
2001–2050	9	–16.52	+1.24
2051–2100	21	–19.07	+3.75
	Drought summers		
	number of years	mean of precipitation anomalies (%)	mean of temperature anomalies (°C)
1951–2000	15	–28.02	+0.95
2001–2050	9	–29.21	+2.00
2051–2100	24	–34.98	+2.86

The hidden threat: Increasing drought

Authors defining climatic limits of distribution or cultivation are generally utilising long-term means of temperature and precipitation parameters. Field observations at the xeric limits indicate however that the sequence of consecutive extreme weather events (Berki et al. 2007) and linked biotic damages will concretely decide over survival or mortality at the xeric limits. Therefore the use of climate (mean) data should be regarded as surrogates only for weather extremes (Mátyás et al. 2008).

Predicted mean precipitation change is of special significance at the xeric limits which are extremely sensitive to relatively minor humidity variations. Central and Eastern Europe will suffer from a further decrease of precipitation (IPCC 2007). Drought events will happen in line with predicted climatic changes but their frequency and severity may change at a rate different from average trends.

[1] Similar climatic shifts are proposed for Central and Northwest Europe as well. The difference lies in the fact that in Southeast Europe the lower end of the present distribution is identical with the distributional limit. At the xeric limit of closed forests, there is no natural tree species spontaneously taking the place of the ones retracting from their lost habitats.

Frequency changes of drought events have been analysed for the territory of Hungary using the REMO climate model of the Max Planck Institute of Meteorology (MPI), Hamburg (Gálos et al. 2007). The predicted frequency of drought years (precipitation decline exceeding 5% of the periodic mean) and of drought summers (precipitation decline exceeding 15% of the seasonal mean) are shown in Table 4.1. The anomalies are averages calculated for the territory of Hungary, related to the 1961–1990 period. The model indicates no frequency increases of drought events for the scenario A2, in the first half of the twenty-first century. Still, the temperatures will rise and precipitation decline will continuously progress. The average precipitation loss of drought summers may reach 30% (related to the predicted averages). It has to be pointed out that the data refer to *average anomalies*, and single drought events may be much more severe. It is highly remarkable in Table 4.1 that from 2050 onward, the REMO model defines every second summer as a drought event: 24 summers out of 50 years (Mátyás et al. 2008, Gálos et al. 2007).

The described shifts in drought frequency may cause drastic changes in lowland regions at the xeric limit. Mass mortality may appear at the rear edges, on sites with unfavourable water regime.

Modelling Expected Land Cover Changes at the Xeric Limits

Modelling climate change impacts with climatic envelopes

Shifts of distributional ranges of plants and animals are direct indications of climate change. Modelling climate envelopes of species offers the possibility to forecast future ecosystem settings according to selected scenarios.

The determination of "climatic envelopes" of plant species has been a long-time topic, in principle since Alexander von Humboldt's observation of links between climate and vegetation physiognomy. Climatic demands of species and of ecosystems have however attained a sudden actuality in the context of adaptation to predicted climatic changes. Recent publications on bioclimatic modelling and predicted climate change-triggered vegetation shifts are abundant (e.g. Beniston and Innes 1998, Strelcova et al. 2008) and have been considered also in the fourth report of IPCC (2007; chapter on Europe).

Models and analyses deal however mostly with the shift of the thermal ("upper" or "front") limits of distribution. Migration at the front, i.e. the shift of the upper vegetation boundary is the most visible and illustrative response to climate change. "Forward" colonisation is more sensitive to climatic changes than retreat at the xeric limits, as the latter is buffered by persistence and plasticity. It's no surprise that investigations at the xeric limits are seldom, mostly dealing with montane-Mediterranean conditions (Mátyás et al. 2008). The report of IPCC (2007) also fails to deal with the retreating rear limits according to their importance.

Forests are well-established indicators of the xeric limits. Still, it is problematic to use the present forest tree species distribution ranges as basis for climate modelling. It has to be emphasised that low elevation distribution limits of tree species and forest types have been under continuous and strong human impact due to high population density and easy accessibility. Therefore, present-day distribution patterns reflect long lasting anthropogenic effects which have to be taken into consideration when evaluating present conditions and forecasting for the future (Jump et al. 2009).

Biological options for response to changes in ecosystems

When modelling responses of vegetation cover, the peculiarities of biotic system regulation should be considered as well. Early symptoms of climate change effects in ecosystems, first of all in forests at the xeric limits, such as loss of vitality, sporadic mortality, increasing frequency of diseases and pests indicate the constraints of adaptability (Mátyás 2007, Berki et al. 2007, Csóka et al. 2007, Hlásny and Turcáni 2008). Standard bioclimatic modelling is based on the concept that vitality and tolerance depend primarily on the physiological tolerance limits to climatic effects. This generally recognised rule has to be extended by the statement that physiological tolerance is unquestionably determined by genetics: tolerance is the ability of a genotype to maintain its fitness despite damage. Limits of tolerance are therefore genetically set and will determine the presence or absence of species.

There are both genetic and non-genetic mechanisms operating on the individual, population, species and ecosystem levels, balancing changes in environmental conditions. On species and ecosystem level, the non-genetic option of responding to large-scale changes in the environment is adjustment of occupied area of distribution (i.e. migration). For sedentary, terrestrial plant species, this means migration through seed dispersal, resulting in species substitution (succession or degradation), provided there are suitable species available. Paleoecological evidence is abundant on plant migration during the epochs of glacials and interglacials (Davis and Shaw 2001), and this is the underlying response mechanism modelled and described by practically all ecologically-oriented future vegetation shift predictions as well.

On the other hand, genetic options of adjustment such as natural selection and acclimation remained until now unconsidered by analysts. Natural selection adjusts the genetic composition of a population to changing conditions to improve future fitness. Acclimation, or more exactly phenotypic plasticity, provides the ability to survive in changing environments, without genetic change in the classic sense. Plasticity means that the expression of genes is influenced by the environment, thus the organism may modify its responses within certain, genetically set limits. Natural selection and acclimation are fast-acting biological possibilities to adjust extant populations to new conditions. As a conclusion, to forecast vegetation cover shifts exclusively on the basis of presently observed climatic niches means the underestimation of the inherited adaptation potential of species. This may be especially true for forest vegetation.

Role of Forests in the Terrestrial Biosphere–Atmosphere Coupling

Climate forcing and forests

A weak point in climatic modelling and deduced forecasts is the assessment of the coupling between the terrestric plant cover and the troposphere. Present, advanced land surface parameterisations include the hydrologic cycle, energy and water flux in the vegetation, the biophysical and physiological controls of evapotranspiration and photosynthesis. Model simulations prove that land cover, i.e. vegetation has an important role in climate regulation. For example, Kleidon and co-workers (2000) modelled interactions of climate types and land surfaces and found that even the ratio of main climatic belts depends strongly on the type of surface cover.

In this respect the climate forcing effect of forests, covering more than one quarter of the land surface of the Earth, is crucial. Still, current views on the role of forests are contradicting and fragmentary: some opinions even state that temperate forests have little to no benefits in climate (Bonan 2008).

Plant cover, especially forests dominate the carbon sequestration process, modify the hydrological cycle, albedo and turbulent fluxes above the land surface. Forest cover influences also the biogenic and human-caused aerosol and particle content of the atmosphere through its sedimentation effect. In addition to forest clearing and forest fires, also forest harvesting and industrial use have an important indirect effect through the creation of additional carbon sinks. Undoubtedly forests have an effect on the majority of factors contributing to anthropogenic climate forcing (Fig. 4.2).

Specific conditions at the xeric limits

For continental Southeast of Europe the shortcomings of land surface parameterisation of the circulation models above terrestrial surfaces have been demonstrated by Hagemann and co-workers (2002). They have compared the predictive power of numerous regionally downscaled climate models. It has been found that the models – except for one – do not properly follow the summer drought conditions, generally underestimating precipitation. The "summer drying phenomenon" is still not properly understood. In numerous models moisture transportation dynamics is modelled erroneously, which may be influenced by the land cover parameters as well. Feedbacks need to be formulated more exactly which needs first of all the in depth analysis of the hydrological cycle (Hagemann et al. 2002).

The cited evaluation of climatic models used the whole Danube catchment area for analysis. Much of this region, at least the western half of it, is still under the influence of Atlantic climate. The identified deviations between predicted and actual climate are therefore presumably more expressed toward the continental eastern part of the region (Gálos et al. 2007).

An important, although mostly an unmentioned component of the greenhouse effect, is tropospheric water vapour content. The positive contribution of forests is presumably significant in regions at the xeric limits, where precipitation is the ecological factor at minimum. Therefore, out of the mentioned factors influenced by terrestrial vegetation (see also Fig. 4.2) evapotranspiration is probably the most essential. For example, on the Hungarian Great Plain, the amount of additional transpiration of the forest cover in the growing period may surpass 60% of the mean annual rainfall, compared to agricultural surfaces (Fig. 4.3).

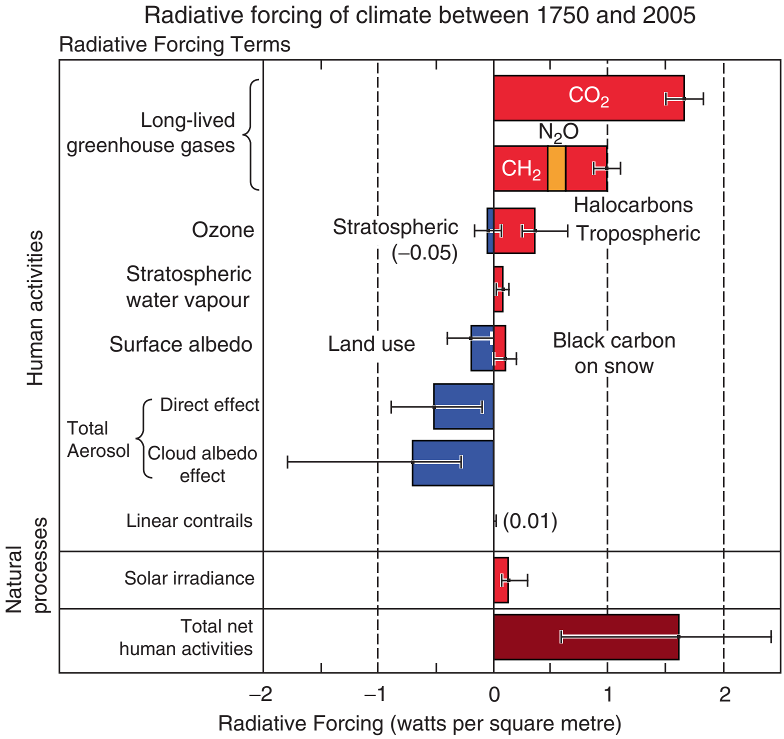

Fig. 4.2. Main components of radiative forcing of climate change in 2005 relative to the start of the industrial era (about 1750). Forest cover has a direct or indirect influence on the majority of human-induced components, such as CO_2 content reduction through carbon sequestration, surface albedo and land use change (forest destruction), aerosols of biomass burning, as well as sedimentation of aerosol particles. The main greenhouse gas, tropospheric water vapour is not shown in the graph. Its regional level is also influenced by forests. (Thin bars represent the range of uncertainty. Adapted from IPCC 2007).

In regions where summer temperatures tend to increase, surface albedo may become critical. Both deciduous and conifer forests have a lower albedo as other forms of land use, which is augmented by the fact that forest canopy also masks winter snow cover. So, from point of view of albedo, forest cover should cause higher summer and winter temperatures, thus worsening drought situations. Model simulations indicate the opposite (Kleidon et al. 2000) which in fact is supported by field observations. Investigations at the Canadian prairie-woodland border prove that forest cover at the xeric limit has a clearly positive effect: summer temperatures are significantly lower where woodland/forest cover remained. Hogg and Price (2000) found that deciduous forest causes anomalies first of all in summer: temperatures are cooler, mean precipitation is higher and length of growing season increases. The input of agricultural surfaces to climate control is less, due to lower water consumption and shorter active vegetative period.

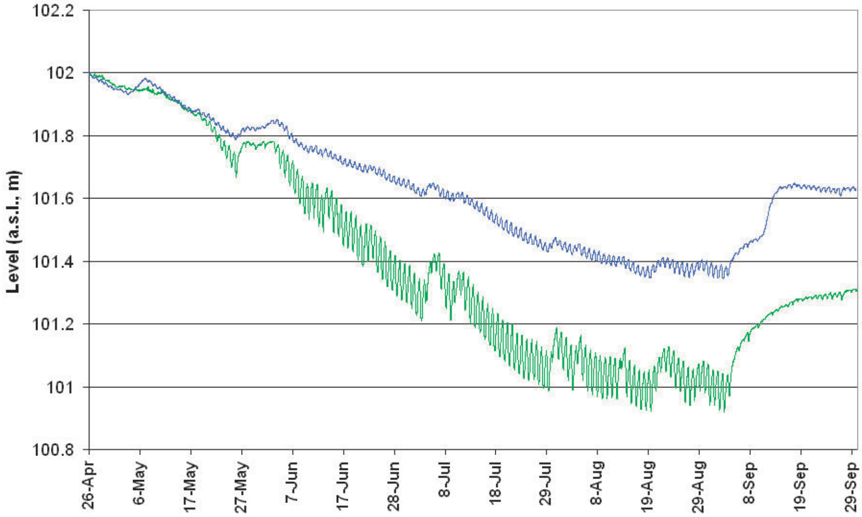

Fig. 4.3. Pulse of the forest: daily soil water-table fluctuation due to evapotranspiration under a pedunculate oak (*Quercus robur*) forest stand (green) compared to a neighbouring agricultural fallow (blue) in East Hungary. At the experimental site (mean annual $P = 505$ mm, mean annual $T = 9.7$°C), the difference in water table level under the forest, due to higher transpiration rate, was 320 mm at the end of the summer season, which amounts to 63% of the mean annual precipitation (data of summer 2007, collected by N. Moricz).

The reason is the cooling effect of higher evapotranspiration and lower surface temperature of forest canopy. Persistence to drought as compared to grass or crop vegetation is the result of deep rooting of trees, utilizing deeper soil water resources. Surface roughness of the crown layer leads to different aerodynamic conductance, which alters cloudiness and causing additional atmospheric feedback.

Photosynthetic activity – i.e. carbon sequestration, growth and contribution to carbon sinks – depends on available water resources and temperature conditions. At the xeric limits, summer temperature rise and falling precipitation amounts are confounded in their effect with increasing CO_2 levels and the fertilizing effect of nitrogen (the deposition of the latter is enhanced in the ecotone zone by usually dominant, intensive agriculture). Higher CO_2 causes photosynthetic enhancement, more efficient water use capacity and increased primary production: this has a negative feedback effect on climate change. (An opposite effect, positive feedback, is caused by soil carbon emission due to increasing temperatures – Tóth 2007.) As a consequence, European forest growth model analyses indicate a significant incremental acceleration across the western half of the continent, although the long-term maintenance of the trend is unclear (Nabuurs et al. 2002). Numerous studies and also IPCC's 2007 report forecast, on the contrary, a decline in growth and production of forest stands for East Europe: however, up to now this tendency is not yet measurable as a general trend. In contrast, dendrochronological analyses in Hungary found instead of negative trends, growth acceleration in the majority of cases (Somogyi 2008). Only for one species, Turkey oak, a decline of growth intensity was found between compared stand pairs of same age (Szabados 2007). The reason for the missing effect of gradually worsening climatic conditions in Southeast Europe has to be sought probably in the improper selection of datasets. Analyses are usually based on large-scale forest inventory data which are not detailed and precise enough to trace complex effects of opposing trends of negative and positive environmental effects acting simultaneously across climatic gradients. Such effects are better discernible in specially established common garden field tests (Mátyás 2007).

Role of forest management

A recurrent drawback of climatic models constructed by ecologists and earth scientists is the lack of consideration of forest management. All over temperate Europe, planned and sustainable forest management has been introduced practically in all forests, except for some inaccessible alpine areas. Even the vegetation of national parks has been strongly influenced by past human use. Planned forestry means that the structure, species composition and demography conditions of forests are determined by current management concepts, strategies and laws. Spontaneous processes are suppressed or tolerated only as far as they fit into the accepted strategies. Planned, sustained harvesting decides the applicable techniques for regeneration (i.e. replanting) of forest stands.

Forest management according to operational plans implies therefore that forest cover changes caused by climatic shifts may and will be canalised: e.g. instead of spontaneous loss of forest cover the artificial planting of an exotic species may be envisaged. Artificial regeneration together with forest protection measures may effectively buffer the spontaneous effects of climatic shifts – needless to say, only until the ecologically–genetically set limits. Consequently, the impacts of forest policy and management, intensity of forest harvesting, timber utilisation etc. have to be considered in forecasts.

All this has an input also on the carbon sink function of the forest vegetation. Primeval forests may be regarded as carbon neutral. The extraction of industrial timber from managed forests creates new sinks in human infrastructure (Matthews et al. 2007). Life cycle (LCA) and economic analysis will help to elucidate its future importance among factors of climate forcing.

Summary: Does Continental Southeast Europe Need Special Attention?

Terrestrial land surface–climate interactions are simulated by models, where the parameterisation of complex biological, chemical, physical processes still remain a challenge to research. Perturbations such as droughts and consequences for ecosystem health (insect and disease outbreaks) in the forest-steppe ecotone need additional attention. In particular, more exact determination of parameters describing the flux of energy and matter over forested land would be essential for models to better support effective adaptation and mitigation measures at the xeric limits.

Although issues of global change are in the focus of international research and politics, mainstream research of well established networks, as well as European mitigation policy consider the specific problems of continental Southeast Europe as low priority, marginal issues. It should be however taken into account that:

- Climatic forecasts for Southeast Europe show higher uncertainties and processes are displaying trends different or even opposite to western or north European forecasts.
- There are extensive plains in the region which are situated in a broad climatic and ecological transition zone (ecotone) towards steppes and arid lands. The vulnerability of this region to climatic changes is high.
- The decline of vitality and stability of vegetation zones, especially forests, in this region may generate ecologically harmful processes (degradation, aridification, decomposition of organic carbon stored in ecosystems etc.).
- The region is densely populated, and plays an important role in food production and industry, at the same time the economical and social restructuring following the political transition has not reached a stabilization phase yet. These facts may enhance expected ecological consequences of changes considerably.
- Most of the region has been under extensive land use for long historic periods, which renders potentially beneficial spontaneous processes of adaptation to changes disfunctional. At the same time, this fact offers the possibility of applying planned, large-scale measures to support natural processes by human interference.

The above problems are common all over continental Southeast Europe. The communication and cooperation of the numerous, mostly small nations of the region is traditionally underdeveloped. Initiatives to promote collaboration in adaptation to climate change would therefore benefit the whole region.

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Climate in the Late Twentieth and Twenty-First Centuries over the Northern Eurasia: RCM and CMIP3 Simulations

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Abstract. The changes in the extreme indices for the mid twenty-first century relative to the late twentieth century have been inferred from CMIP3 daily temperature and precipitation output. It has been found that future projections for the extremes in Northern Eurasia are prone to large uncertainties arising primarily from intermodel differences. The uncertainties for "warm" extremes are larger than those for "cold" extremes not only due to greater model-to-model differences but also due to slower warming of the former. In warm season the models project drier climate conditions over some regions of the northern Eurasia, longer droughts, lesser number of wet days and increased heavy precipitation intensity. The CMIP3 simulated changes in the extremes lack credibility due to low spatio-temporal resolution of current global models. There is a pressing need to further investigate the impact related aspects of regional climate changes over the northern Eurasia using sufficiently large ensembles of regional climate model simulations.

Keywords: climate scenarios, warming, regional models, extremes

Introduction

The territory of northern Eurasia is characterized by complex and still poorly understood climate processes and feedbacks contributing to the challenge which the region represents from the viewpoint of climate modeling. Local and regional climate features, such as enhanced precipitation or winds close to steep mountains and internal water bodies, are poorly captured by global climate models due to their limited spatio-temporal resolution. Physically based methods for local and regional climate simulation rely on high resolution models run over time slices (typically several decades). Such methods can be used to downscale global climate simulations by explicitly describing nonlinear feedbacks between large-scale and mesoscale physics and dynamics. Unfortunately, only very limited high-resolution regional model results for large regions in northern Eurasia are currently available.

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Natural variability in the region is fairly large and could mask climate change due to human activities. This effect of variability could be bigger or smaller depending on the area, climate parameter (temperature, precipitation, snow cover, air pressure etc.) and the time and space scales. To assess the relative importance of natural variability versus a prescribed climate forcing, massive ensembles of differently formulated climate models run from an ensemble of initial conditions should be used. This technique requires additional computing resources especially when high resolution models are employed. The ensembles containing on the order of hundreds of simulations would give a better estimate of climate change probability distributions, including changes in the frequency of winter storms, temperature extremes, flood-producing precipitation etc.

Increased levels of atmospheric greenhouse gases (GHG) will have bigger effects on climate in northern Eurasia than in most of other regions of the Earth. To estimate a climate change potential (notably change in climatic extremes) over the territories of northern Eurasia a suite of comprehensive global (coupled atmosphere-ocean) climate models is used in this assessment. Additional estimates are obtained using Voeikov Main Geophysical Observatory Regional Climate Model (RCM) applied to the two major domains in the northern Eurasia at 50 km grid resolution. The discretization of RCM output at daily or hourly time intervals makes it feasible to investigate future changes in high frequency climate variability and associated rare events (extremes). The extremes at limited modeling resolution are manifested in large-scale slowly evolving climate (weather) anomalies that can be utilized to feed different impact models for more practical assessment. The extremes encompass a wide range of events and can be characterized, for instance, by a maximum (minimum) value of climatic variable over a period of time (e.g. year) or a threshold (e.g. 90th percentile) exceedances. These estimates can be calculated for every modeling grid point to reveal spatial structures of the extremes distributions.

Future concentrations of GHG and aerosol emissions can be estimated assuming demographic, socio-economic and technological evolution through the current century. Within IPCC, a set of emission scenarios has been prepared. Projections with the global and regional models provide a physically consistent quantitative picture of climate change through the twenty-first century. The projected changes over the northern Eurasia in many cases are in agreement with observed tendencies, while increase of their rates as well as inter-scenario differences will be accelerating by the end of the twenty-first century. In this assessment the so called A2 scenario is only considered. Scenarios diverge insignificantly until mid-twenty-first century but they substantially differ by the end of the century when aggressive A2 scenario corresponds to upper range of scenarios provided by the IPCC.

Models and Analysis

The RCM developed at the Voeikov Main Geophysical Observatory is a limited area hydrostatic model with 105 × 121 (157 × 165) horizontal grid and 50 (25) km resolution (Shkolnik et al. 2000). The model includes explicit descriptions of all known physical processes: radiative transfer in the cloudy atmosphere, vertical and horizontal turbulent heat, moisture and momentum exchange, precipitation generation (convective and large-scale), gravitational wave drag, and soil processes. Modeling domains capture most of the northern Eurasia.

Current generation of AOGCM simulations and projections has recently been completed for the Intergovernmental Panel on Climate Change (IPCC) in order to provide input to the IPCC's Fourth Assessment Report (AR4). This has been a major international effort within the framework of WMO's World Climate Research Programme "Coupled Model Intercomparison Project", phase 3 (CMIP3) (Meehl et al. 2007). Numerous diagnostic subprojects aimed at analyses of a great variety of twentieth and twenty-first century climate evolution aspects fed the IPCC AR4, and continue to feed region-focused analyses, like this one, devoted to projected climate change over the territory of northern Eurasia. AOGCM projections are available for large number of climate variables at different temporal scales, and in regular grids all over the world, which is sufficient for many impact assessments.

In this study daily output for surface air temperature maxima and minima and daily precipitation accumulations from 10 CMIP3 AOGCMs and VMGO RCM have been involved. The CMIP3 daily output spans 1980–1999 (baseline) and 2046–2065 time slices. RCM simulations have been conducted for the two domains covering 1991–2000, 2041–2050 and 2091–2100. The output from MGO GCM for these periods has been used to drive the RCM.

Projected changes in temperature and precipitation indices of extremes have been assessed as arithmetic differences between twenty-first century and baseline indices. The analysed indices are the following: annual maximum and minimum temperatures, annual number of consecutive days with daily $T_{max} > T_{max,90}$ in summer, total number of frost days (daily $T_{min} < 0°C$), daily precipitation $P > P_{90}$, and maximum number of consecutive dry days (days with $P < P_{10}$). Besides changes in daily temperature maxima (minima), precipitation variability, and snow cover duration have been investigated using the RCM output at daily resolution.

Climate Change Scenarios for the Twenty-First Century

The RCM demonstrated satisfactory performance skill in reproducing twentieth century climate and its variability over the northern Eurasia. Figure 5.1 shows changes in the tails of summer daily T_{max} (maximum daily temperature at 2 m) distributions in the two partially overlapping regions as simulated by the RCM by the end of twenty-first century. One can find that the upper percentiles warm faster (by 0.3–0.6°C/10 year) as compared against extremely low summer daily maxima (0.1–0.4°C/10 year), notably in Transbaikalia, southern Russia and Ukraine.

Analyses of variability of winter daily mean and daily minimum temperatures using RCM show that in the middle and high latitudes the contribution of changes in lower percentiles (close to yearly temperature minima) to the increase of winter temperatures is the greatest – much greater than those of higher percentiles. The asymmetry of the probability distributions of winter temperatures is thus expected to increase.

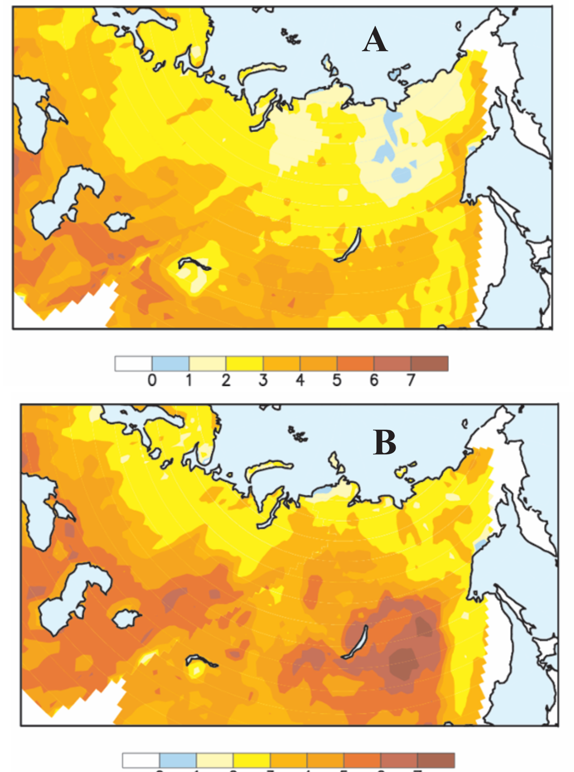

Fig. 5.1. Changes (°C) in summer $T_{max,5}$ (**a**) and $T_{max,95}$ (**b**) by the end of twenty-first century according to RCM projection. Areas beyond the modeling domains are left in white.

The analysis of changes in probability distribution functions of winter precipitation revealed increases in light, moderate and heavy precipitation by 15–30% suggesting the change in the mean precipitation is a good predictor for changes in winter precipitation extremes. In summer a strong increase in heavy precipitation is generally accompanied by smaller changes in lower precipitation percentiles. This implies the future summer showers are expected to be more intense due to enhanced precipitation variability. However, there is a great deal of spatial noise in the extreme precipitation change patterns. Developing the ensemble approach to RCM simulation will serve to provide more reliable estimates.

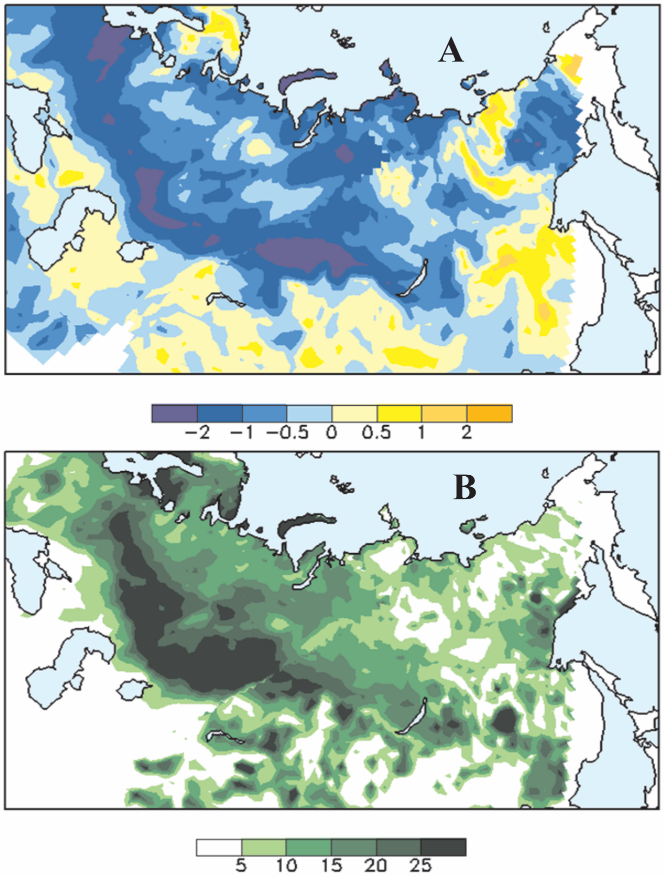

Fig. 5.2. Change of daily minima temperature interquartile range ($T_{min,75} - T_{min,25}$) in winter (ºC) by mid twenty-first century (**a**) and projected decrease in the annual number of snow days (**b**) as simulated by the RCM.

Shown in Fig. 5.2a are changes in the winter temperature minima interquartile range that indicate a decrease of temperature variability and therefore decrease in the cold extremes. A coherence between changes in snow cover duration (Fig. 5.2b) and temperature variability implies the most pronounced changes in variability will likely occur in the areas where snow completely retreats causing rapid increase of heat balance at the surface and, respectively, noticeable increase in lower temperature percentiles.

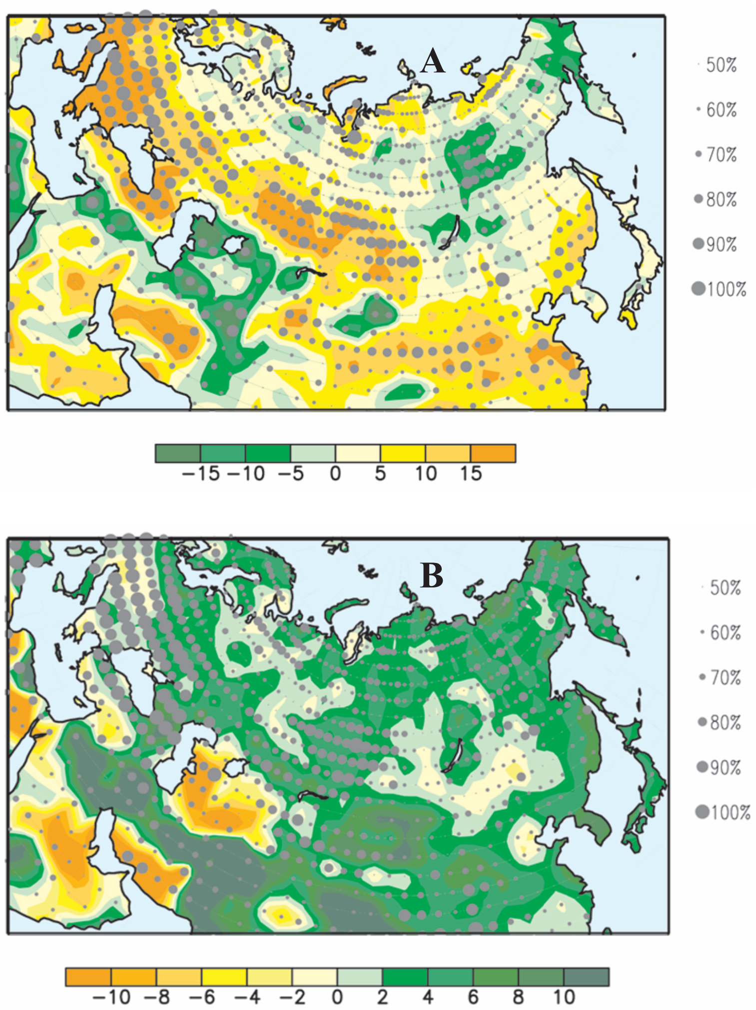

Fig. 5.3. Change in annual maximum "dry" wave duration (number of consecutive days in summer with precipitation below 10th decile of summer precipitation distribution) by the mid-twenty-first century relative to the end of twentieth century (**a**) and change of precipitation intensity above 90th decile in summer as simulated by CMIP3 ensemble. Units are percent. Grey filled circles denote quantity of models in the ensemble that calculate changes of the same sign at a given grid point.

Present estimates of the temperature extremes inferred from CMIP3 models are in reasonable agreement with reanalysis. The temperature yearly minima will considerably increase by mid-twenty-first century over the entire territory of northern Eurasia. The strongest increase (by 4–6ºC) is projected in the South and North-West of European Russia, Baltic countries and Ukraine. In central European Russia, the Urals, and in East Siberia the increase of yearly minima by mid-twenty-first century is projected within the range 2–4ºC. Unlike the increase in the annual mean temperature, the projected increase of yearly minima in Siberia and Russian Far North are relatively small.

The increase of the annual temperature maxima over the northern Eurasia is projected to be almost two times weaker than that of the annual minima. By mid-twenty-first century, over the greater part of the territory the former does not exceed 3ºC. By mid-twenty-first century the duration of extremely low winter temperatures decreases by 6–8 days in Russian North–West and Far North. A pronounced decrease of the number of yearly cold extremes is expected along the Pacific coast, accompanied with the decrease of number of days with minimum temperatures below 0ºC. In Central and East Siberia the decrease of the number of the frost days is the smallest – by 10–15 days, in the European Russia and Central Asia – 15–30 days. The mountainous areas of Central Asia, as well as Baltic region, demonstrate most dramatic decrease of the frost days – by 30–35 in a year, which may have important implications for the mountain snowpacks and glaciers in the region.

An increase is projected in the number of days with daily summer maxima above 90th percentile in the baseline simulation. By mid-twenty-first century, the number of days with extremely high temperatures will increase in Russian Far North (5–10 days), Ukraine and the Black sea region (10–20 days). In the northern Caucasus the duration of extreme heats will increase by 20 and more days per year. At the same time the number of days with daily maxima above the 90th percentile is projected to increase over greater part of Siberia – by 2–4 days, Russian North-West, Central Russia and the northern Caucasus – by 3–5 days.

The changes of the extreme precipitation indices are demonstrated in Fig. 5.3. One can find the southern, Central and European Russia, Ukraine and most of Central Europe will likely experience longer dry periods with consecutive daily precipitation accumulations below 10th decile. This picture is in agreement with projected decrease in summer mean precipitation over these regions.

However, contrary to summer mean precipitation, the intensity of heavy precipitation exceeding 90th summer decile increases almost everywhere, most significantly over the above regions of longer dry periods where 80–100% of models agree on sign of changes. The frequency of such extreme precipitation cases above 90th decile tends to decrease along with total amount of precipitating water, however, at a significantly higher rate. This implies the heavy precipitation cases during summer will be more rare, but more intense.

Summary

State-of-the-art climate projections for northern Eurasia have different credibility for different climate characteristics – e.g., higher for temperature and lower for precipitation, or higher for means and lower for extremes. A more ambitious strategy for ensemble climate simulations is needed in order to better address the problem of natural climate variability and how it may be affected by a global climate change. Changes in the distribution of climatic events are as interesting as changes in the mean when the impacts of climate change are considered.

In this study the results of 10 AOGCMs and one RCM have been used to quantify future changes in the climate over the territories of northern Eurasia. It has been found the changes in temperature extreme indices are prone to considerable uncertainties due to large inter-model differences, notably for warm extremes for which modeling standard deviation appears to be greater than that for cold extremes by 30–50%. Over some regions models tend to project longer summer droughts along with increase in heavy precipitation intensity. However, over most of northern Eurasia not only the magnitude of extreme precipitation changes but even the sign of these changes cannot be estimated at a reasonable level of confidence.

In order to decrease the uncertainties of the projections (including those due to natural variability, model sensitivity to prescribed forcings and due to forcings themselves), much larger samples of simulations are apparently required. Estimates of extreme events and their frequencies of occurrence also require massive ensemble simulations. In addition, it would be advantageous to increase model resolution to better capture physical processes at finer scales and to better describe sharp spatial gradients, which are often in the regions where extreme events occur. Therefore, there is also a pressing need to further investigate the impact related aspects of regional climate changes over northern Eurasia using ensembles of RCM simulations at 10–50 km resolution. Both types of improvements (increasing resolution and ensemble size) are highly computer-intensive. Owing to great diversity of climatic conditions in northern Eurasia, further research is needed to find a reasonable balance between ensemble size, modeling spatial resolution, complexity of incorporated physical parameterizations and additionally, in case of RCM, optimum domain size.

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Projections of Climate Change over Non-boreal East Europe During First Half of Twenty-First Century According to Results of a Transient RCM Experiment

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Abstract. Climate change trends over the southern east-Europe are evaluated according to results of a climate simulation experiment with the ICTP RegCM3 regional climate model driven from the lateral boundaries by results of ECHAM5/MPI-OM1 transient climate simulation from 1960 to 2060 (SRES A1B emission scenario after 2001). The trends projected include – precipitation: winter and spring – rise over the central east-Europe and drop over the eastern Mediterranean region, summer-autumn – drop over east-Europe and northern eastern-Mediterranean, rise over the Middle East (especially in autumn); 2-m air temperature: winter and spring – rise over the whole region with a maximum over its eastern and north-eastern (especially) and south-eastern parts, summer – rise with a maximum over the Middle East and minimum over north-eastern part, autumn – rise with maximum over the Caspian, Black Seas and northern areas of the European Territory of Russia.

Keywords: regional climate model, climatic change, East Europe

Introduction

Anthropogenic emission of greenhouse gases (GHG) has been recognized as the main factor of the global climate change of the post-industrial era (IPCC 2007). Results of a high-resolution regional climate change simulation experiment over southeastern Europe for the period 1960–2060 are discussed below. Description of the experiment's setup is given in the section "Experimental Setup and Data Used". Obtained in the experiment were projections of the climate change process over the region from recent past to near future which are discussed in the section "Results". Discussion and conclusion are given in the last section.

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Experiment Setup and Data Used

Regional climate model (Caya and Biner 2004; Christensen and Christensen 2004; Giorgi et al. 2004; Krichak et al. 2007; Semmler and Jacob 2004) simulation of climate of the southern Europe region has been performed. The model adopted is the state of science, third generation RegCM3 (Pal et al. 2007) of the International Center for Theoretical Physics (ICTP). The following parameters characterize the model configuration: 50 km horizontal resolution, 14 vertical sigma levels, the model top is located at 80 hPa, five levels located below ~1,500 m represent the planetary boundary layer. The model domain covers an area including a large part of Europe, eastern north-Africa and the Middle East (Fig. 6.1). The lateral boundary relaxation zone covers 11 grid intervals. A smoothing of terrain inside of the relaxation zone is performed. The physical parameterizations chosen [radiation (Kiel et al. 1996); land-surface model (Dickinson et al. 1993; Gao et al. 2006); planetary boundary layer (Holtslag et al. 1990); cumulus parameterization (Grell 1993; Fritsch and Chapell 1980); ocean flux parameterization (Zeng et al. 1998), lateral boundary treatment (Davies and Turner 1977) – for references and further details see Pal et al. (2007) are selected according to results of earlier evaluations (Krichak et al. 2007).

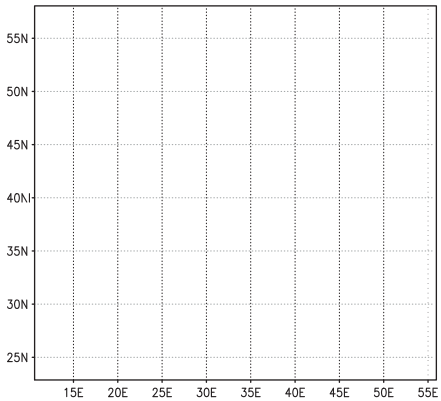

Fig. 6.1. Model simulation domain.

The driving data used are from an atmosphere–ocean general circulation model (AOGCM) experiment with fifth-generation ECHAM5/ MPI-OM model of the Max-Plank Institute for Meteorology, Hamburg (Roeckner et al. 2003). The atmospheric model was run with T63 truncation (1.875° x 1.875° spatial resolution) and 31 hybrid vertical levels (Roeckner et al. 2003). The ocean model uses a conformal mapping grid with a horizontal grid spacing of 1.5° and 40° vertical levels. For the future climate projection (IPCC 2007) the greenhouse gases (GHG) emission scenario A1B (SRES A1B, hereafter A1B) was employed (after 2001) both in the AOGCM and RCM simulations. Results produced in the experiment are presented below in the patterns with differences between multi-year mean precipitation (*Prec*) and 2 m air temperature (*T2m*) determined for the two 30-year time-periods [current (1961–1990, CT) and near-future (2021–2050)]. Area of the analysis is limited by 30° N–57° N; 15° E–50° E.

Results

Simulation of current climate

Results of simulation of *Prec* and *T2m* for warm AMJJASO and cold NDJFM seasons under the current climate (1961–1990) conditions (not presented) have been compared to the data from observation-based archive of the Climate Research Unit of the University of East Anglia, UK (Mitchell et al. 2004). The regional climate model (RCM) reasonably well reproduces precipitation over the Mediterranean region, where differences between simulated and observed precipitation are less than 10 mm season^{-1} . However, RCM results over and northward of the Caucasus area were less successful. A notable overestimation of the precipitation amount (especially during AMJJASO season, i.e. rains of convective origin) has been noted. Annual cycle of precipitation is well reproduced over the whole model domain however (Krichak 2008). The *T2m* patterns both for the warm and cold seasons were also reasonably well simulated – the differences between simulated and observed CT *T2m* are less ~2°C.

Simulation of anthropogenic climate change trend

The simulated in the climate change experiment trends associated with precipitation (in mm) from 1961–1990 to 2021–2050 are in given in Fig. 6.2a–d for winter (DJF), spring (MAM), summer (JJA), autumn (SON) seasons, respectively. During DJF, a negative precipitation trend (down to −60 mm) characterizes the eastern Mediterranean region (Fig. 6.2a). A precipitation rise (20–40 mm) is projected for the northern part of the area of the experiment. An area with the maximum in the positive precipitation trend (60 mm) over the south-eastern part of the Black Sea area may be noted. During spring (MAM) a zone with a precipitation drop (down to 20 mm) is found over the northeastern Mediterranean area (Fig. 6.2b). A significant rise of precipitation is projected for the northern (40 mm) and especially north-eastern (up to 60–80 mm) parts of the non-boreal east Europe.

No changes in precipitation intensity are projected over the major part of the Mediterranean region for the JJA season (Fig. 6.2c). A 20–80 mm reduction of precipitation is projected over the non-boreal east Europe and south-Caucasus areas, although a ~20–40 mm increase in precipitation is projected for the Black Sea area (Fig. 6.2c). A significant rise in the autumn (SON) precipitation is projected for the eastern Mediterranean (up to 60 mm) and Black Sea (40 mm) regions (Fig. 6.2d). A minor precipitation drop is projected for the non-boreal part of the ETR.

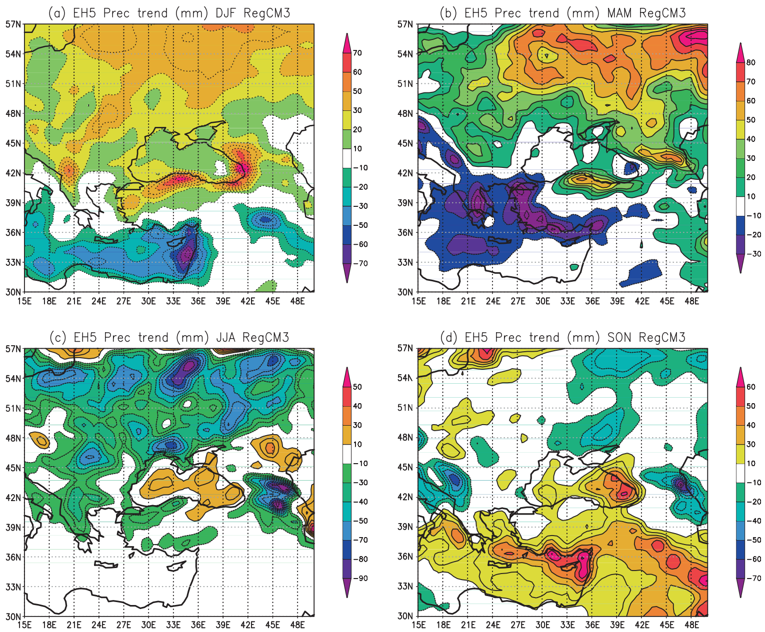

Fig. 6.2. Simulated trend of mean seasonal precipitation (**a**) winter, (**b**) spring, (**c**) summer and (**d**) autumn seasons.

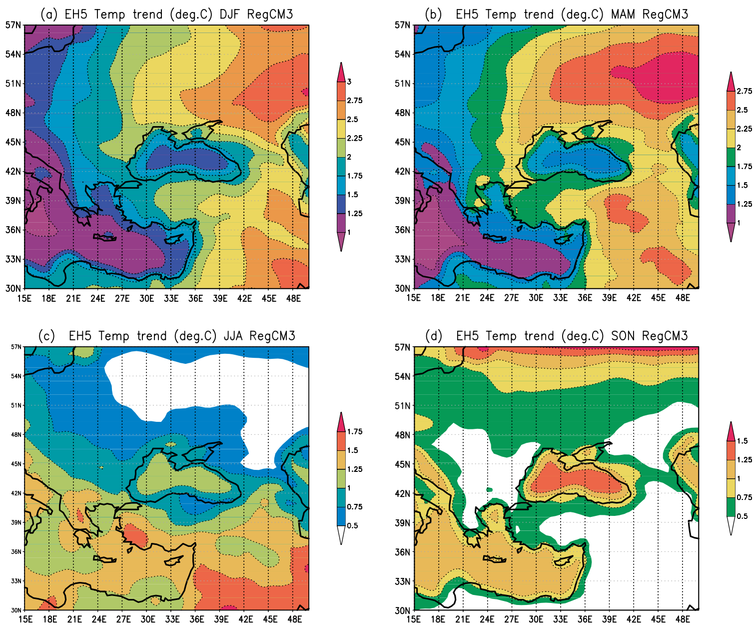

Fig. 6.3. Simulated trend of mean seasonal 2 m air temperature (**a**) winter, (**b**) spring, (**c**) summer and (**d**) autumn seasons.

Projected changes in the seasonal 2 m air temperature *(T2m)* are given in Fig. 6.3a–d. A *T2m* rise (Fig. 6.3a) is simulated over the whole area of the domain for DJF. The magnitudes of the simulated temperature rise are higher (up to ~2.5°C) over the eastern part of the pattern with one center located in the vicinity of the Persian Gulf and the second to the north of Caspian Sea area. A similar pattern of the *T2m* trend over Europe characterizes the MAM season (Fig. 6.3b). The zone with the maximum *T2m* rise (2.0–2.5°C) is found here over the non-boreal Europe northward of the Caspian Sea. Another zone with significant, although lower *T2m* rise (~2.5°C), is found over the Middle East area. A notable *T2m* rise characterizes the pattern produced in the experiment for the summer (JJA) season (Fig. 6.3c). The *T2m* trend is stronger (up to 1.5ºC) over the Middle East but is also notable over the Mediterranean Sea area. Over the east Europe the *T2m* rise is less significant (0.2–0.6°C). The pattern produced in the experiment for autumn (Fig. 6.3d, SON) is characterized by the *T2m* rise over the Mediterranean and Black Seas (~+1.0°C) over the Black Sea), and non-boreal Europe (0.5–1.0°C).

Discussion and Conclusion

A number of factors may be limiting reliability of the results presented. The accuracy of the climate simulation could be affected by the description of sub-grid processes in the relatively coarse-resolution (50 km) RCM run. Also, the physical parameterizations adopted seem to be more appropriate for the simulations of the Mediterranean climate than the more northern part of the area. A new set of the climate change simulation experiments with an optimized set of the RegCM3 physics is currently in process of realization. Reliability of the RCM results could also be affected by that of the AOGCM (i.e. driving) data as well as by that of the GHG emission scenario adopted.

Nevertheless, results of the transient RCM simulation performed for the near-future south-east Europe climate change seem to be providing useful information on the possible climate change perspectives over Europe. The climate conditions simulated for the near-future (2021–2050) differ significantly from those of the twentieth century (1961–1990) over most parts of the area of the analysis. The deduced climate change trends may be summarized as follows. Precipitation: a significant rise in DJF and MAM precipitation is projected for the central and, especially, southern east Europe. A drop in precipitation is projected for the eastern Mediterranean region however. Opposite precipitation trends are projected for the JJA and SON seasons, however, with a precipitation rise over the Middle East (especially during SON) and precipitation drop over central part of the south east Europe.

In may be summarized that the climate change experiment projects drop in the annual precipitation over the eastern and south-eastern Mediterranean region (5–20%) and rise in the parameter over the Middle East (5–20%), Black Sea area (5–

15%) and non-boreal Europe (5–10%). During DJF and MAM seasons the trends projected are characterized by a *T2m* rise over eastern part of the non-boreal Europe. The temperature trend seems to be associated with weakening of the Siberian High system. The area with the maximum *T2m* rise in the JJA pattern (Fig. 6.3c) is found over southeastern part of the domain – indicating the role of the sea surface temperature rise in the Arabian Sea in the projected climate change process over southeastern Europe. A *T2m* rise is projected also over the areas located close to Mediterranean Sea, Black Sea, and Caspian Sea which seem to be playing an important role in the climate change process over east Europe.

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An Assessment of the Recent Past and Future Climate Change, Glacier Retreat, and Runoff in the Caucasus Region Using Dynamical and Statistical Downscaling and HBV-ETH Hydrological Model

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Abstract. The paper discusses the observed and projected warming in the Caucasus region and its implications for glacier melt and runoff. A strong positive trend in summer air temperatures of 0.05°C a^{-1} is observed in the high-altitude areas providing for a strong glacier melt and continuous decline in glacier mass balance. A warming of 4–7°C and 3–5°C is projected for the summer months in 2071–2100 under the A2 and B2 emission scenarios respectively, suggesting that enhanced glacier melt can be expected. The expected changes in winter precipitation will not compensate for the summer melt and glacier retreat is likely to continue. However, a projected small increase in both winter and summer precipitation combined with the enhanced glacier melt will result in increased summer runoff in the currently glaciated region of the Caucasus (independent of whether the region is glaciated at the end of the twenty-first century) by more than 50% compared with the baseline period.

Keywords: glaciers, climate change, climate modeling, water resources, Caucasus

Introduction

The Caucasus region is a mountainous country stretching for 1,300 km from the Black Sea in the west and the Caspian Sea in the east (Fig. 7.1). Elevations in its highest part, the Greater Caucasus, spanning the border between Russia and

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Georgia, exceed 5,000 m above mean sea level (a.m.s.l.). There are about 2000 glaciers in the Greater Caucasus occupying about 1,600 km^2 (Stokes et al. 2006; Fig. 7.1). The southern part, known as Transcaucasia, covers Georgia, Armenia, and Azerbaijan. It has a varied topography and vastly different climates ranging from semi-arid to very humid (Volodicheva 2002). Water availability varies immensely across the region: most of the Greater Caucasus and western Georgia have either sufficient or abundant water resources while most of Armenia and Azerbajan are water deficient. However diverse, regional water resources have one feature in common: most rivers originate in the mountains and glacier and snow melt are important sources of their nourishment.

Glaciers are retreating and perennial snow packs are declining in the Caucasus in response to the observed climatic warming. Between 1985 and 2000, over 90% of the glaciers have retreated and total glaciated area has decreased by 10% (Stokes et al. 2006). Potentially associated with rapid melt, are hazards such as outbursts of glacial lakes and mud flows. The number and extent of glacial lakes have been growing rapidly in the Caucasus (Stokes et al. 2007) and lake outbursts, resulting in a strong damage to property and infrastructure, have already been reported (Shahgedanova et al. 2009). While a number of publications have examined the observed changes in climate and glacial extent in the Caucasus (e.g. Shahgedanova et al. 2005; Stokes et al. 2006, 2007; Shahgedanova et al. 2009), future changes in climate and runoff, important for planning and water resource management, have not been investigated. This paper discusses the observed and projected changes in temperature, precipitation and glacial mass balance in the Caucasus and potential impacts of these changes on runoff. The future climate projections have been developed using dynamic (Jones et al. 2004) and statistical (Wilby et al. 2002) downscaling techniques. The two methods are used because of the large biases in the dynamically downscaled precipitation in the high-altitude areas of the Greater Caucasus. The focus is on two regions: the glaciated sector of the Greater Caucasus (42.5–43.3° N; 42–44.5° E) and the arid region of Armenia and adjacent areas (39–41° N; 43–46° E).

Data and methods

The following observational data have been used in this study:

(i) Air temperature and precipitation records from two high-altitude stations were used for the analysis of the long-term trends, validation of the climate and calibration of the hydrological models: Terskol located in the glaciated region of the Greater Caucasus (43°15’ N; 42°33’ E; 2,141 m a.m.s.l.) and Aragats located further south (40°29’ N; 44°11’ E; 3,227 m a.m.s.l.).

(ii) Glacier mass balance data collected at Djankuat, a valley glacier located at 43°12’ N and 42°46’ E on the northern slope of the central section of the Glavny Ridge, the most heavily glaciated area in the Greater Caucasus. Its elevation lies between 2,700 and 3,900 m a.m.s.l. and its meltwater eventually drains into the Caspian Sea via the Adylsu, Baksan and Terek Rivers. Typical of the Caucasus, Djankuat is a temperate glacier. In 2000, its surface area was 3.01 km^2. Mass balance measurements, reported as millimetres of water equivalent (mm w.e.), refer to the mass balance year beginning in October and ending in September of the following calendar year. Two components are measured: October–May accumulation and June–September ablation (Shahgedanova et al. 2005). The measurements began in 1967 and are ongoing.

(iii) Discharge measurements for calibration of the hydrological model have been obtained from the Tyrnyauz gauging station located on the Baksan River, in its upper reaches (1,281 m a.m.s.l.). The Terskol and Tyrnauz stations and Djankuat glacier are located within approximately 20 km of each other.

Regional climate change scenarios have been developed using an RCM 'PRECIS' (PREdicting Climate for Impact Studies) developed by the UK Met Office (Jones et al. 2004). PRECIS is a hydrostatic, primitive-equation model with a horizontal resolution of 25 km. It derives lateral boundary conditions (LBC) from HadAM3P, a global atmosphere-only model with a resolution of 150 km, which is in turn forced by surface boundary conditions from the global circulation model HadCM3. PRECIS can be forced by ERA 40 reanalysis data. PRECIS has been specifically developed to generate climate scenarios for areas with complex terrain and has been used in high-altitude areas previously (e.g. Frei et al. 2003). Four integrations have been performed for two time slices (i) two for the 1961–1990 period driven by the GCM data and by ERA 40 reanalysis data providing 'baseline' climate and (ii) two for the 2071–2100 period providing the future climate change regional projections based on the A2 and B2 CO_2 emission change scenarios (SRES 2001). The model domain (Fig. 7.1) has been selected in line with recommendations by Jones et al. (1995). The important local sources of cyclogenesis (e.g. the Black Sea and the Caspian Sea) have been included into the RCM domain. Model validation has been performed using station data and gridded data sets (New et al. 2000).

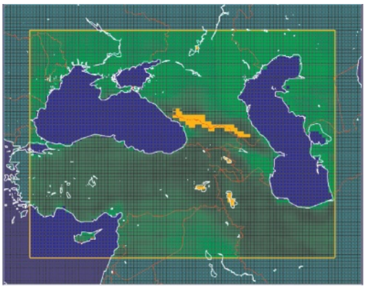

Fig. 7.1. PRECIS modeling domain. Glaciated areas (north) and large lakes (south) are highlighted.

SDSM downscaling software (Wilby et al. 2002) has been used to generate climate scenarios for the Adylsu – upper Baksan catchment where Djankuat Glacier is located. SDSM uses semi-empirical statistical techniques to establish links between the large-scale GCM information and local-scale variables. The observational records from Terskol weather station and outputs from HadCM3 GCM for the baseline (1961–1990) period and the future (2000–2099) have been used. Although PRECIS and SDSM solutions are derived from the same GCM scenarios, the results are not directly comparable because of different modelling techniques and because SDSM provides a point-location solution while PRECIS scenarios are area-averaged.

Runoff in the Baksan catchment has been simulated using a conceptual runoff model HBV-ETH (Bergström 1976; Braun and Renner 1992). The model works on a daily time-step and has a very low data demand: daily means of precipitation and air temperature, and daily discharge for calibration. Model outputs are daily and mean values of all terms of the water balance. A detailed description of HBV-ETH and analysis of its performance in the mountainous regions is given in Hagg et al. (2006) while its validation for the study area is discussed by Shahgedanova et al. (in press).

The observed climate and glacier change in the Caucasus mountains

Glacier melt in the Caucasus is particularly strong in June, July and August (JJA) and variations in JJA temperatures are of particular importance. The long-term observations confirm that these are rising (Fig. 7.2). A strong increase in JJA temperatures has been observed at Terskol and Aragats since the late 1960s. At both sites, in the last 40 years, JJA temperatures have been increasing at a rate of 0.05°C per year and there is strong positive linear trend in the time series explaining 36% of the total variance. The Aragats record, dating back to 1929, confirms that the last 2 decades were the warmest in almost 80 years of observations. This warming is making a profound impact on glaciers. Glacier melt has intensified in the 1990s and its highest values have been recorded in the last 2 decades (Fig. 7.3). Thus, in the summers of 1998, 2000, and 2007 ablation exceeded the long-term average by two standard deviations from the long-term mean, reaching its highest value on record in 2007.

Changes in the cold-season precipitation (Fig. 7.2) do not offset impacts of the observed summer warming. At Terskol, positive anomalies observed in the individual years do not compensate for a rapidly increasing melt. As a result, the cumulative

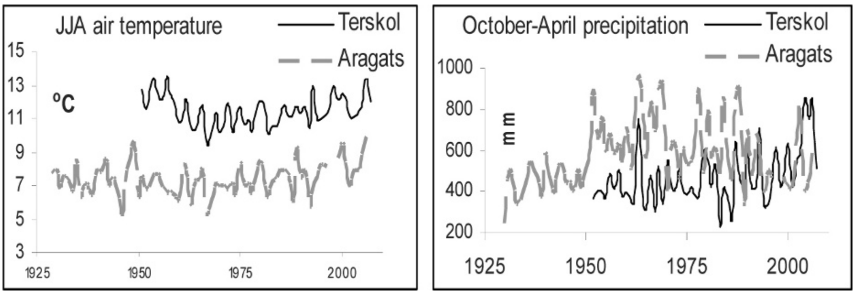

Fig. 7.2. JJA air temperature and October–April precipitation at Terskol and Aragats.

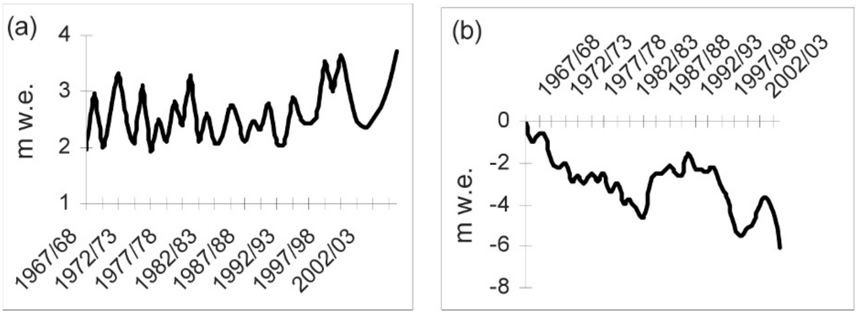

Fig. 7.3. Seasonal ablation totals (**a**) and cumulative mass balance (**b**) of Djankuat glacier.

mass balance of Djankuat is declining and has reached its lowest value on record in the mass balance year of 2006/2007 (Fig. 7.3). At Aragats, the cold-season precipitation has been declining from its maximum recorded in the 1960s (Fig. 7.2).

This trend has been especially strong since the 1980s possibly in response to the strongly positive North Atlantic Oscillation.

Future climatic changes in the Caucasus region

The model outputs for the two case-study regions have been validated against the observations from individual weather stations conducted during the baseline period of 1961–1990 for the case-study areas (Fig. 7.4) and against the New et al. (2000) air temperature and precipitation observational gridded data sets for the modelling domain (not shown). The meteorological network is not dense in the high-altitude region of the Greater Caucasus and only eight stations were used in model validation. This spatial sampling allows one to judge the quality of air temperature simulations but evaluation of precipitation simulations requires higher density observations, particularly in the context of highly variable terrain (Frei et al. 2003). Armenia has a much denser network and 34 stations were used, insuring good spatial representativity. The model performed well with regard to air temperature across the modelling domain. The largest difference between the modelled and the observed data occurred in the spring–summer months and was about 2^{o}. Much lower errors occurred in all other months (e.g. Fig. 7.4a). The quality of precipitation simulations varied across the region. The annual precipitation cycle has been simulated for the semi-arid regions of Transcaucasia (Fig. 7.4b). In the Greater Caucasus, where a precipitation maximum linked to the development of mesoscale convection is observed in summer, results were characterised by a greater bias. The winter precipitation rates have been overestimated and summer rates have been considerably underestimated by the model possibly in response to the hydrostatic restriction as PRECIS failed to simulate convective rainfall. The results of statistical downscaling from HadCM3 reveal smaller biases particularly in January–June period although convective rainfall is strongly overestimated by SDSM (Fig. 7.4c).

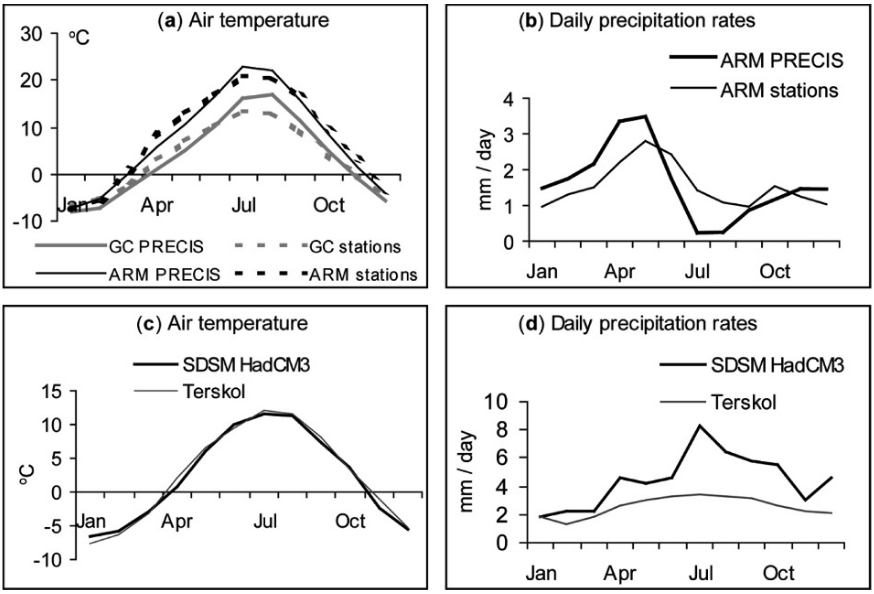

Fig. 7.4. PRECIS versus observed data for 1961–1990 for the glaciated region of the Greater Caucasus (GC; 42.5° N–43.3° N; 42° W–44.5° W) and Armenia and the adjacent regions (ARM; 39° N–41° N; 43° E–46° E) (**a, b**) and SDSM (based on HadCM3) versus observed data for 1961–1990 for Terskol (**c, d**).

Regional climate change scenarios developed using PRECIS have been used to quantify changes in the future climate (2071–2100) relative to the climate of the baseline period (1961–1990) for the A2 and B2 group of scenarios, which assume a rapid increase in the world population to 15.1 and 10.4 billion and an increase in mean CO_2 concentrations to 834 and 601 ppm by 2100 respectively (SRES 2001). Air temperatures will increase across the Caucasus region (Fig. 7.5). Most importantly for glacier and snow melt, the 30-year averages of air temperatures of the warm season (May–August) in 2071–2100 will exceed the 1961–1990 averages by 4–7°C and 3–5°C for A2 and B2 (Figs. 7.5a, b) scenarios respectively resulting in the enhanced glacier and snow melt. The September–August air temperatures are estimated to increase by 2–4°C and 0.5–3°C. The results of statistical downscaling for A2 scenarios are consistent with the PRECIS projections. By contrast, little or no change in winter precipitation is projected (Figs. 7.5c, d). A 10% increase in the cold season precipitation is required to compensate for a 1°C warming if glaciers are to remain stable (Braithwaite et al. 2003). Our projections indicate that the future changes in winter precipitation will not be sufficient to compensate for the summer melt under the B2 and A2 scenarios.

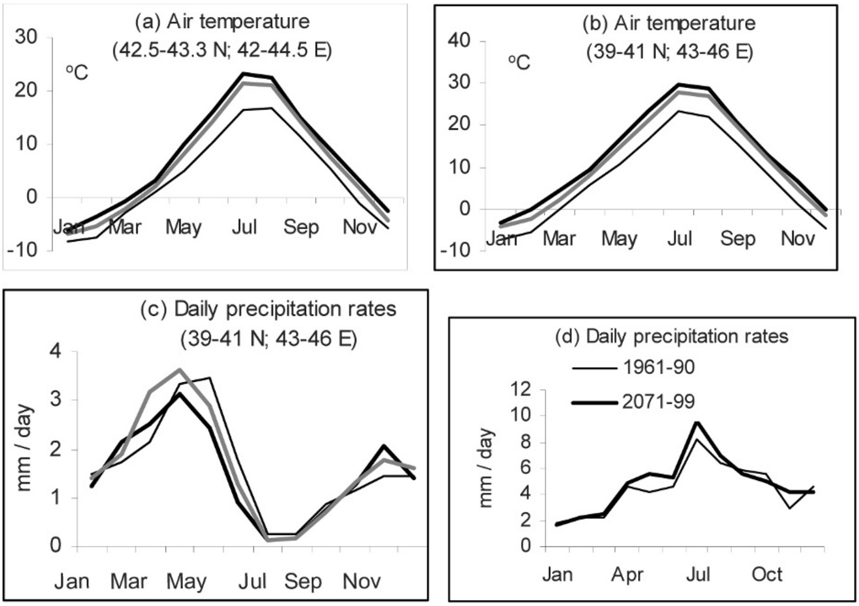

Fig. 7.5. The 1961–1990 (thin line) and 2071–2100 (A2 bold black line; B2 grey line) climatic averages for (**a**) the glaciated region of the Greater Caucasus and (**b, c**) Armenia from PRECIS experiments and (**d**) SDSM-downscaled precipitation for Terskol.

Application of a conceptual runoff model in the Baksan river basin

The HBV-ETH model has been set up to model components of water balance in the Baksan River basin using discharge measurements from Tyrnyauz and air temperature and precipitation data from Terskol for the 1991/92–1999/00 period. Topographic model input has been derived from a SRTM DEM with a ground resolution of 90 m. The size of the catchment has been determined from this DEM as 1,090 km². Glacier outlines have been obtained from the Global Land Ice Monitoring from Space (GLIMS) database (Armstrong et al. 2005). Total glaciated area was 182 km² or 17% of the catchment. The distribution of the area by altitude and exposition classes (North, South, East-West-Horizontal) for the whole catchment and its glaciated parts were determined using GIS. Model calibration was executed by the optimisation runs where free parameters were tuned by comparing modelled and measured discharge. For each combination of parameter values, the Nash-Sutcliffe (R^2) model efficiency criterion was calculated. Worldwide testing of conceptual runoff models (Rango 1992) has shown that R^2 exceeding 0.8 are considered as ‘good’ in a high mountain terrain. For the 1991–2000 period, the mean R^2 value is 0.82.

The SDSM temperature and precipitation projections for the A2 emission scenarios have been used to evaluate potential changes in runoff in (i) 2030–2059 and (ii) 2070–2099 relative to the baseline period defined here as 1980–2009. The baseline data have been downscaled by SDSM from the HadCM3 output to ensure consistency with the projected data. The runoff for the selected reference years within the baseline period model was perturbed using the SDSM projections (Fig. 7.6). To cover various hydrological responses, a range of reference years including those with hot summers and strong glacier melt (e.g. 1999–2000) and cool summers with low ablation (e.g. 1991–1992) have been used. Model runs assuming (i) the current extent of glaciation in the catchment and (ii) without glacier cover have been performed to quantify the influence of glacier water storage on runoff.

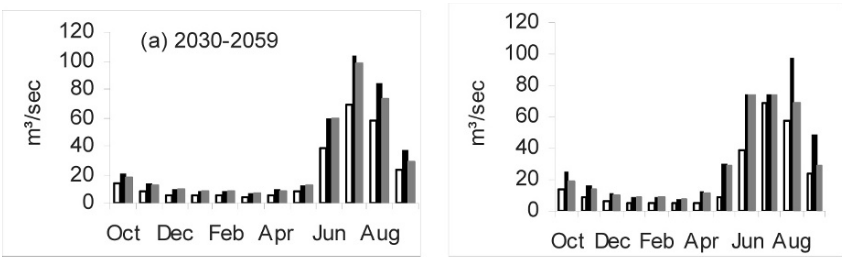

Fig. 7.6. Runoff scenarios for the Baksan River at Tyrnauz for the reference years of the baseline period (white), and the future with glaciers (black) and without glaciers (grey).

The largest runoff changes occur in JJA while in other months changes from the baseline period are moderate. A 43% increase in JJA runoff is projected for the mid-twenty-first century. This is due to a slightly higher summer precipitation (+14%: Fig. 7.5d) and, for the model run with glaciers, to a more intensive ice melt. At higher elevations, the share of liquid precipitation which runs off directly is strongly enhanced in the warmer atmosphere. Model runs without glaciers show lower runoff gains and this discrepancy is growing towards the late summer peaking in August. The JJA runoff projected for non-glaciated conditions is 6–14% lower than the runoff estimated assuming the current glacier extent. This difference, however, is greater at the peak of the melt season in August when a 25% increase in runoff is projected for the non-glaciated conditions compared to a 45% increase with glaciers. By the end of the twenty-first century, these trends will be re-enforced. The JJA runoff is projected to increase by 78% and 52% for glaciated and non-glaciated conditions respectively. At high elevations, summer runoff is controlled by summer and also by the accumulation-season precipitation which is stored as snowpack and released during the ablation season. The November–May precipitation is predicted to increase slightly (Fig. 7.5d) and this will contribute to an increase in summer runoff even if glaciers disappear. Under the non-glaciated conditions, the projected increase in runoff will still be very high in June (107%) due to the enhanced snow melt decreasing to 18% in September. The influence of glaciers on summer runoff appears to be secondary to the effect of projected changes in precipitation. The relatively low degree of the catchment glaciation (17%) seems to be a reason of modest impact of glacier change on runoff.

Summary

A strong climatic warming is observed in the high altitude areas of the Caucasus and JJA temperatures are growing at a rate of 0.05°C a^{-1}. At the same time, winter precipitation has remained the same (Greater Caucasus) or is declining (Transcaucasia). The observed climatic changes have already resulted in glacier retreat. Future climate scenarios indicate that summers will be 4–7°C and 3–5°C warmer in 2071–2100 than in 1961–1990 and that winter precipitation will experience little increase. It is expected that glacier retreat will continue and small glaciers at lower elevations will be most vulnerable to complete disappearance by the end of the twenty-first century. Summer runoff in the currently glaciated catchments will increase, whether glaciers remain or disappear, due to the higher precipitation projected for summer and a small increase in snow accumulation in the high mountains in winter. An over 50% increase is projected for the end of the twenty-first century even without glacier melt contribution increasing to 78% with glacier melt. These projections indicate that while water will be available for agricultural, industrial, and domestic use, property and infrastructure may be vulnerable to flooding.

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Regional Climate and Environmental Change: Moldova Case Study

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Abstract. The practice of environmental management increasingly recognizes the importance of scale and cross-scale dynamics in understanding and addressing global challenges. The problem is not only how to downscale the global modeling results, but how to make them more suitable for the specific applications. The paper shows some approaches to the development and application of regional climate change projections in Moldavian research. The results of six AOGCM experiments, based on SRES A2 and B2 emission scenarios for three time-slices (*2010–2039; 2040–2069; 2070–2099*), served as a basis for downscaling. It was shown that for any sound climate change impact assessment at least four types of information are necessary: the climate change projections for a country on the whole; the expected climate changes in any place within a country's territory; daily projections of key climatic variables, and information satisfying the demands of particular researches. Country-scale projections were calculated as averaged weighted sum of the ensemble of GCM simulations. A special algorithm was proposed to select the 'best' ensemble. The diurnal changes in climatic variables were calculated from their monthly values approximated by high-degree polynomials. The correlation between observed values at weather stations and a corresponding value for the country were used for spatial transformation of the latter. The methods of development of user-oriented projections depended on the system under assessment. Some approaches to vulnerability assessment through integrating climate change projections with systems' sensitivity are demonstrated on the example of natural and agricultural ecosystems.

Keywords: climate change, downscaling, natural ecosystems, agriculture

Introduction

The potential climate change is perceived as a global problem mainly because it would interfere with the world's economic, social, ecological and, eventually, political systems [20]. As a real-world challenge, this problem is necessarily

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multi-disciplinary, full of complex non-linear interactions and uncertainties, multiple causalities and effects [15, 18, 19]. Because climate change is not an isolated issue and only one among many, the vulnerabilities associated with it are rarely experienced independently of nonclimatic conditions. The principal concerns of the international community for climate change risks are described as the United Nation Framework Convention on Climate Change (UNFCCC) ultimate objectives: prevent dangerous anthropogenic interference with the climate system, allow ecosystems to adapt naturally to climate change, ensure that food production is not threatened, and enable economic development to proceed in a sustainable manner [33]. Evidence shows that the most adverse effects will be in developing countries and countries with economies in transition, where populations are most vulnerable and least likely to easily adapt [31].

Also, the practice of environmental management increasingly recognizes the importance of scale and cross-scale dynamics in understanding and addressing global challenges. Changes in climate, economies, populations or institutions converge finally in localities, causing a growing interest in obtaining the regional-scale data as a response to demands on producing policy-relevant information that can be used at local and regional levels. From the cross-scales assessment the scientists are attempting to understand how mitigative and adaptive actions on one scale might constrain or provide opportunities on another [2, 8, 24, 30]. Climatic changes are regional by their manifestation, not by their origin [19]. The problem is not only how to downscale the global modeling results, but also how to make them more suitable for the specific applications, when information about future change of the primary climatic variables is not enough. The scenarios of climate change can be considered user-oriented if they are constructed for the concrete requirements of climate impact studies with an appropriate spatial and temporal resolution.

Despite the growing number of case studies, partly summarized in the National Communications to UNFCCC [32], the understanding of climate change and its impacts at regional and national levels remains limited; much of the present knowledge is quite qualitative. At the same time, any extrapolation of another country's assessment to a 'native' country could be successful if only regional circumstances are carefully taken into account. To better quantify climatic risks is an urgent challenge, both as to their likelihood and regarding the magnitude of the impacts on regional natural and social systems. The improved analysis determines appropriate policy measures [1, 23]. Decision-makers need to be aware of the large range of plausible climate projections when they formulate strategies to cope with climate change risks. These risks will not be distributed equally. Some individuals, sectors, and systems will be less affected or may even benefit; others may suffer significant losses; for some sectors, such as agriculture, uncertainty is large enough, making impossible to assess the sign of impacts [10, 14, 20]. The pattern of relative benefits or losses is not likely to remain constant over time, depending on climate change magnitudes. Attempting to address these and other problems of regionalization, the Moldavian researchers have developed a number of original approaches, some of which are described in this paper.

Research Tools and Approaches

Vulnerability to climate change is a function of exposure, sensitivity of a system, and its adaptive capacity. Exposure varies among regions, sectors and communities; adaptive capacity may be even more variable, also contributing to the difficulty of assessment. Because of the large uncertainties and differences between countries, no "globally" optimal climate change strategy is possible. As a result, although there is a large array of methods and tools pertained to specific sectors and scales of climate change analysis, the prioritization of adaptation options is at early stages of development and needs to be perfected [7, 20].

The Moldavian climate change impacts assessment was designed with a multi-pronged approach involving three major components: regional climate analysis, sectoral analysis, and overall integrated synthesis [11]. *Regional analysis* identifies the likely change and plausible future climatic conditions in the country. *Sectoral analysis* considers the potential consequences of climate changes for major sectors of environment. *Integrated synthesis* draws together the results of both approaches. Complex relationships between these components are reviewed and taken into account through *the corresponding research scheme,* which includes five main themes for assessment:

- *Regional climate change projections* and their relationships with global models
- *Current status and dynamics* of environmental systems that form a background for potential climate change impacts
- *Current stresses* on the environment that cause additional impacts
- *Possible climate change consequences* for the environment, their spatial and temporal distribution as well as potential to exacerbate or ameliorate already existing problems
- *Coping options and response strategies* to be taken to diminish the inevitable adverse impacts

Methodological approaches include computer-aided and statistical modeling, scenario analyses, experts' judgments, and qualitative assessments based on existing experience [3, 5, 7, 22, 27, 34]. *As initial materials,* the abundance of new evidence and research outputs that has come to the scientific communities' attention as well as the outputs and findings of last-years investigations in Moldova are used. The study is based on a range of the most recent coupled atmosphere–ocean general circulation models (AOGCM; in the paper abbreviated as GCM). The results of six experiments, based on the A2 and B2 marker scenarios of the Special Report on Emission Scenarios (SRES) [28] for three time-slices (*2010–2039; 2040–2069; 2070–2099*), served as a basis for downscaling. In the terms of cumulative greenhouse gas (GHG) emissions, these scenarios are considered as "high" and "medium low", respectively. The selected GCM experiments (*HadCM3; CSIRO Mk2; CGCM2; ECHAM4; GFDL-R30* and *CCSR-NIES*) are documented and referred in [19] and can be found at the DDC website [21]. The concrete approaches and research issues depend on the sector under research.

Development of Regional Climate Change Projections

The regional scenarios of future climate change are a key component of any climate change impact assessment, and their construction is one of the greatest challenges for national researchers. Our experience [9, 12, 13] shows that for sound climate change impact assessment at least four types of information are necessary:

- The climate change projections for a country on the whole (*country-scale projections*)
- The expected climate changes in any place within a country's territory (*local projections*)
- Daily projections of key climatic variables
- Information satisfying the demands of particular researches (*user-oriented projections*)

Many modeling tools are available to provide climate change information on a regional scale, but the most credible approach is to use GCMs' simulations [7, 19, 22, 26]. Regional Climate Models (RCMs), while improving the important aspects of local climate simulation and providing resolution to 50 km and smaller, are mostly experimental and popular only as a research tool due to their high cost. The consistent set of RCM simulations that could be used as climate change scenarios for impact assessment, especially in NIS countries, is still not available. However, in spite of great advances, even the most sophisticated GCMs remain very much simpler than the full climate system. While doing a credible job on global and planetary scales, they fail for regional use where important but not properly resolved small-scale processes take place [6]. Increasingly recognizing the limitations of a top-down paradigm, the climate change research community is working, in parallel, to improve the geographic and topical richness of global models and to move their downscaling more carefully and more relevantly to local and regional concerns [4, 5, 16].

Different methods are applied to go from global gridded climatology to the values for a region [4], but in practice, in regional assessments, most climate change impact studies take directly the grid-point GCMs' output, without any additional correction, either from the nearest grid box or through interpolation of values in surrounding boxes. Sometimes such actions are explained by the objective restrictions in availability of baseline information or by questionable methodologies used by researchers. Nevertheless, some '*adjusting'* of grids' information is necessary. We consider the weighted averaging of GCMs' modeling results over a grid boxes cluster as one of the better options.

In particular, Fig. 8.1 shows that Moldova has different positions in the regular grids of different GCMs, occupying very unequal parts of adjacent boxes. Therefore, it was proposed to calculate the climate change projections for the country as the weighted sum of values in corresponding grid-boxes. A box 'weight' is estimated as the ratio of territory lying in the box to Moldova's territory. Such weighting assumes equally reliable values in all boxes that must result from models internal consistency.

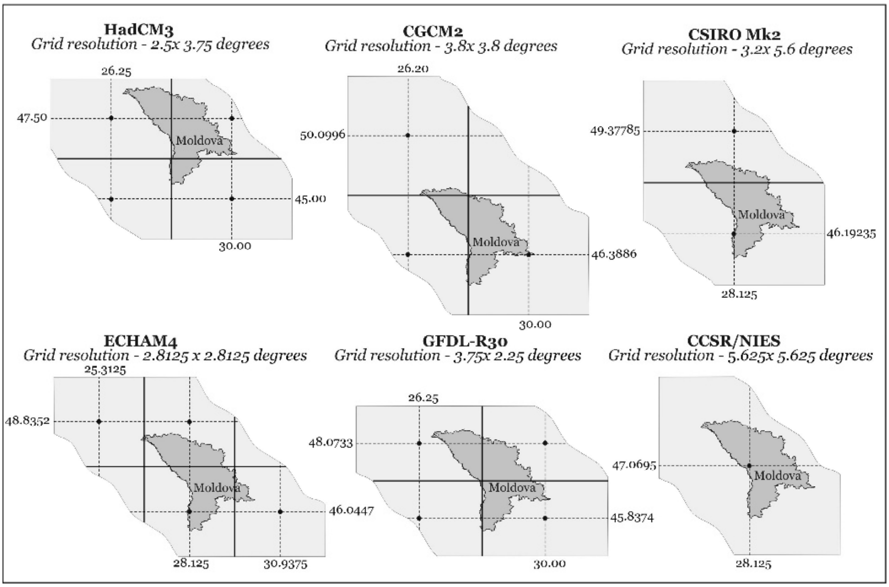

Fig. 8.1. Position of Moldova relative to the regular grids of some general circulation models.

Moreover, the different climate sensitivity of GCMs and regional nature patterns usually act in climate scenarios as sources of uncertainty. As a result, a GCM output combines a forced climate change *"signal"* and an internally generated natural variability. The latter, because of its random and unpredictable character, is considered as "*noise*" on climate long time-scales. That is why, we are sure that *a comprehensive assessment of regional climate change projections needs to be based on collective averaged information from the ensemble of GCM simulations* [13]. Although each model in the ensemble produces a somewhat different projection, an averaged natural variability for a large enough ensemble tends to zero, thereby maximizing the "signal" and improving a "signal-noise" ratio [7]. Plenty of studies show a lot of evidence that mean climatological fields, averaged over the ensemble of models, agree better with observed climatology than the fields produced by any of the individual models, and such collective information could be more reliable in comparison with other solutions [3, 17, 25].

Different techniques are proposed to extract information from the ensembles. The simplest option is to average the ensemble's members to provide a composite ("consensus") future climate. Such a straight approach assigns equal weights to all models, even to those that can be "poor" in the context of a concrete region. To examine statistically the observed differences in climate change responses simulated by GCM experiments for Moldova, a special study [13] has been fulfilled where it was shown that no method being used separately can guarantee the reliable selection of GCMs for regional downscaling, and a complex approach is necessary. In particular, in the case a multi-model averaging, the following algorithm was proposed:

Step 1. For a region under study, through Analysis of Variance, the GCM experiments that answer best of all to a "model convergence" criterion are selected;
Step 2. These experiments, as 'candidates' for the ensemble averaging, through the comparison with observed climate ("model performance" criterion), are used as independent variables in the Regression Model Selection Analysis to identify the most informative *ensemble* of statistically significant GCMs;
Step 3. Through the Ridge Regression Model the "weights" of each GCM in the ensemble is estimated;
Step 4. The calculation of the ensemble-mean projections as the weighted sums of these of the ensemble's members is performed.

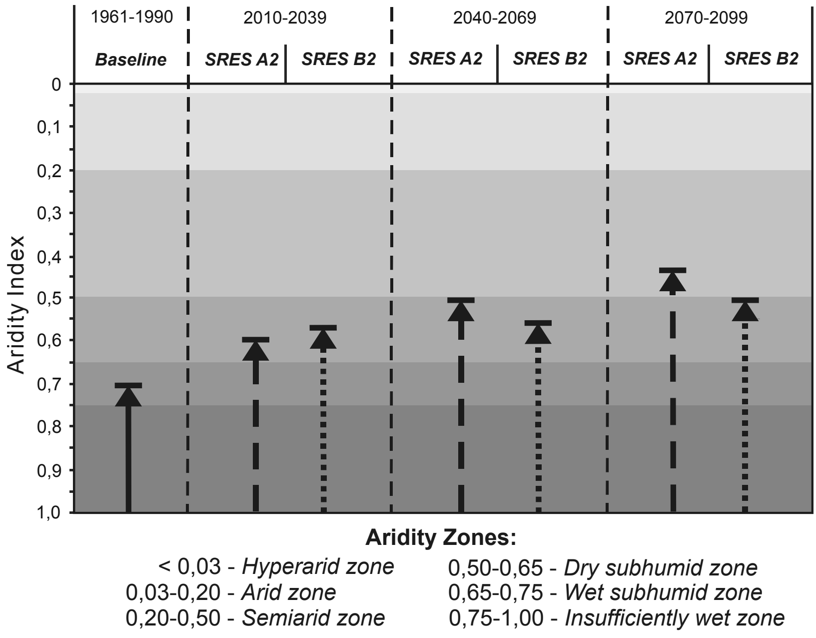

Fig. 8.2. The possible change of Moldova's aridity in the new climatic conditions.

The downscaling shows [12] that Moldova's annual temperature will increase for both emission scenarios; the likely precipitation change will mainly decrease. Maximal relative warming is expected in winter, minimal – in summer. Winter warming, as compared to a baseline (1961–1990 years) climate, can amount up to 2°C by the 2020s and up to 4–5°C – by the 2080s; for summer warming these figures are 2–2.5°C and 5–6°C, respectfully. Some precipitation increase (about 18%) is expected in wintertime, but the summer tendencies are mainly negative (20–30% decrease by the 2080s). On the whole, Moldova moves towards a dryer climate, from insufficiently wet and wet subhumid zones to dry subhumid and semiarid zones. The dynamic of changes in humidity conditions is shown in Fig. 8.2, where annual projections of temperature and precipitation are transformed in *Aridity Index.*

The diurnal changes of solar radiation, temperature and precipitation that served as input information for sectoral estimations were calculated from their monthly values approximated by high-degree polynomials (Fig. 8.3).

Some of the sectoral assessments rely heavily on large-scale *spatial information* that can be extracted from country-scale projections. Two original approaches were proposed [12]: (1) use of some regularity in the fields of climatic variables change, and (2) use of statistical relationships in their spatial distribution. In the first case, the statistically significant polynomial dependence of temperature and precipitation projections on the latitude allowed transition to the digital representation of climate change simulations in any point of territory or in the nodes of an arbitrarily selected regular grid. In the second case, the baseline correlations between the values of climatic variables at Moldova weather stations and a corresponding value for the country were used for spatial transformation of the latter (Fig. 8.4).

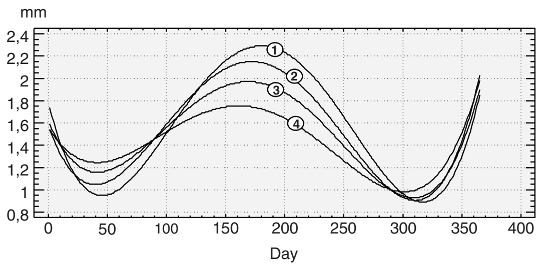

Fig. 8.3. An example of modeled daily precipitation (*Julian day*) for 1960–1990 (1), 2010–2039 (2), 2040–2069 (3) and 2070–2099 (4) time-slices.

Climate Change Impacts on Ecosystems

Natural ecosystems

Assessment of *natural ecosystem* impacts is based on the analysis of their current status, geomorphologic and climatic diversity of locations and plant growth conditions, as well as on their potential sensitivity or intrinsically inherent capacities to adapt. The forests, steppes and grasslands were selected as model ecosystems; the method of ecological successions was used as an approach to solve the problem [29].

A natural plant cover in Moldova, due to unprecedented anthropogenic impacts, has drastically changed and today occupies less than 10% of the national territory. This is significantly lower of the values, critical for ecosystems normal functioning. The assessment of possible behavior of plant communities in the new climate includes four principal steps:

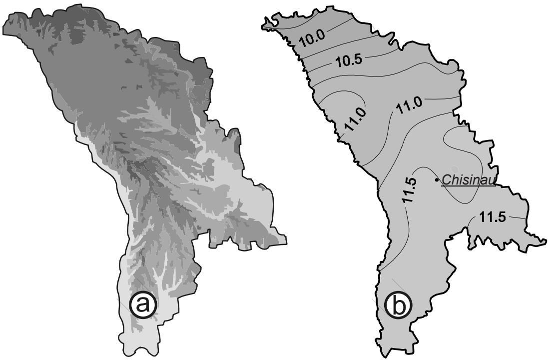

Fig. 8.4. Examples of temperature maps received (**a**) by digital overlapping of baseline and temperature-change fields and (**b**) by statistical transition from a country scale projection (SRES B2 scenario for the 2020s).

- Study of floristic composition and ecosystems spatially-temporal organization.
- Construction and analysis of ecology-phytocoenotic rows.

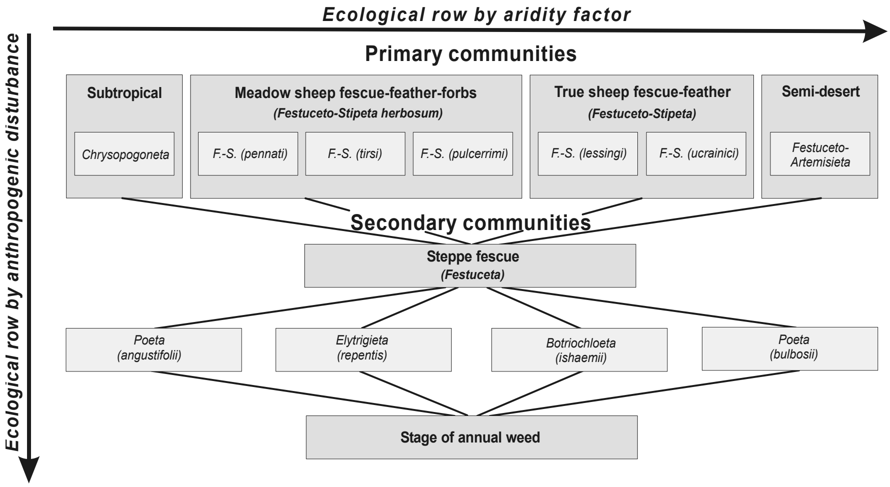

Fig. 8.5. Ecological rows of steppe ecosystems as a model of their likely qualitative changes in new climatic and anthropogenic conditions.

- Determination of the level of an anthropogenic digression and identification of the most vulnerable ecosystems.
- Investigation of possible changes in ecosystems dissemination in accordance with climate change scenarios.

The construction of *ecology-phytocoenotic rows* based on the first step (steppes as an example in Fig. 8.5) is a key moment in the research. The ranking of species by water demands – the major limiting factor of their survival in a new dryer climate – determines the directions of possible changes in plant cover. The hygrophilous steppe communities in the beginning of an ecological row are more vulnerable and will be replaced by the near, more drought-resistant, communities. To quantify the climatic thresholds that can trigger such "shifts", the plants' ecological optimums were identified (Table 8.1).

Table 8.1. Ecological optimum (annual values) of forest edificators.

Species	Air temperature (^{o}C)		Precipitation (mm)	
	Optimum	*Limits*	Optimum	*Low limits*
Fagus sylvatica	700–1,200	500; 1,400	6–9	3
Carpinus betulus	600–700	400; 900	8–10	5
Quercus petraea	600–800	1,000; 1,100	8–10	5
Quercus robur	600–700	440; 1,000	8–10.5	6
Quercus pubescens	500–650	700	–	8

Coupling the ecosystems response and regional climate projections allows identifying a likely plant cover distribution. We can suppose that because of inherit resilience, the forest and steppe communities would reveal themselves as relatively stable, and no irreversible changes resulting in their disappearance are expected at initial stages of climate change.

Agricultural ecosystems

Agriculture impacts assessment included three main steps: the development of likely agroclimate scenarios; the assessment of cultural plant sensitivity to climate change; and the assessment of climate change consequences for agriculture productivity. To receive the agroclimate scenarios, the projections of key climatic variables were transformed into the corresponding changes of heat and water supply [12]. Combining the changes in agroclimate with a culture's response provided the possible impact estimations, thus forming a basis for adaptation policies. Corn, winter wheat and grapevine that represent, respectively, the summer, annual and perennial crops were selected as the case cultures [14]. Statistical and imitation models were used as main research tools. In the *statistical analysis* the yields' response was based on crops sensitivity to temperature and precipitation in the critical phases of plant growth; for *imitation* – the EPIC (Environmental Policy Integrated Climate) model, used in the U.S. National Assessment, was adapted for Moldova. The projections (Table 8.2) show that direct impacts of new climatic conditions would be negative for cereals. CO_2-fertilization effect can compensate for the corn yields decrease but will be insufficient for winter wheat.

Table 8.2. Possible changes (%) in the yields of Moldova’s cereals (without adaptation measures).

***SRES* scenario**	*Time horizon*	*Without CO_2 fertilization*			*With CO_2 fertilization*	
		Winter wheat	*Corn* Statist.	*Corn* EPIC	*Winter wheat*	*Corn*
A2	*1920s*	−24.7	−7.2	−2.5	−14.7	0.3
	1950s	−43.6	−11.3	−7.5	−23.6	3.7
	1980s	−72.9	−21.3	−17.5	−42.9	1.2
B2	*1920s*	−27.6	−5.8	−2.5	−20.9	1.7
	1950s	−38.3	−10.2	−2.5	−28.3	2.3
	1980s	−50.4	−12.7	−7.5	−28.7	4.8

New climate will also be less favorable for grape productivity – the leading national budget forming culture of Moldova – especially for the grape yields that can decrease by 3–5% in the 2020s and by 6–12% in the 2080s (Fig. 8.6). Sugar content in grapes can be diminished in table varieties, but will be practically the same in the sparkling ones.

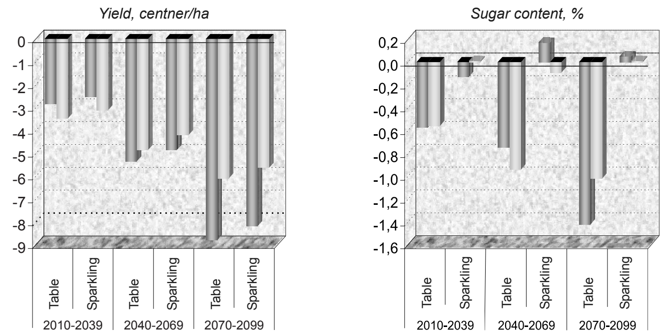

Fig. 8.6. The projections of grapes production in Moldova for *SRES A2* (dark) and *B2* (bright) climate change scenarios.

Conclusions

The generally recognized intricate features of climate change and the emerging need for policy response have triggered a host of research activities and research initiatives undertaken across sectors and regions. However, because of the decision uncertainties and differing interests and values of international parties, there is no unique response to climate change. Coupling the present-day climatic models and national experience, Moldova research provided deeper understanding of potential consequences of climate variability and change in the context of their pressure on regional objectives. The received results help to judge appropriate adaptation responses according to national perceptions of what might constitute the optimum strategy for actions. Baseline and trends information, highlighting the particular vulnerabilities and opportunities that may occur in Moldova regional ecological systems, promotes the answer to key questions in the problem: understanding the nature of possible risks, where and in what degree they are likely to be vulnerable, and the extent and urgency of actions required.

Because the lack of detailed regional information is a major obstacle for sound assessment of climate change consequences in global perspectives, the assessment that was aimed primarily for Moldova's national audience helps to illustrate basic regional and national climate change concerns as well as provide a comprehensive road map to solve the problem on the whole.

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Aspects of Regional Climate Modelling with Focus on Precipitation

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Abstract. This paper discusses some general aspects of regional climate modelling with a special focus on precipitation, and gives an overview of current activities in this area. Furthermore, we present a model evaluation study where we investigate the ability of a specific regional climate model, the COSMO-CLM, to represent statistical characteristics of daily precipitation in Germany. Since the model performance and uncertainty reveals large variability between different regions, we recommend specific evaluation studies before using a regional climate model which has not been applied and tested before in Eastern Europe.

Keywords: regional climate modeling, Europe; precipitation, model evaluation

Introduction

The special interest in precipitation arises from the complexity of the precipitation processes which involve a broad spectrum of temporal and spatial scales, ranging from sub-seconds to several days and from micrometers to several hundred kilometers. Due to its high spatial and temporal variability and its event character, precipitation is difficult to both measure and predict. Consequently, a 'realistic' assessment of the global and regional variations and changes in precipitation constitutes a challenge for climate observation systems as well as for climate modellers.

Up to now, deficiencies still exist in the knowledge of the exact magnitude of the global hydrological cycle as well as its variability and changes. This is caused by the poor coverage of the observational data network on the one hand, and by the coarse spatial resolution and an insufficient representation of physical processes in the global climate models on the other hand (IPCC 2007).

Based on different data sources, diverse estimations of the long-term variability and changes of global precipitation exist, but do not offer a close regional picture of the precipitation trends during the twentieth century. Similarly, the precipitation changes which are projected by global circulation models (GCM) for the twenty-

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first century differ considerably in magnitude, although the signs of the trends are more consistent. In general, the correspondence of the trend signs in different models is better in winter than in summer.

General Aspects of Regional Climate Modelling

Why do we need regional climate models, although a large variety of well-tested global models already exists? The most important reason is that more detailed information from climate projections is desired for better understanding of the climate variability and for targeted adaptation strategies. While the GCMs simulate climate variation and change at a spatial scale of approximately 200 km, stakeholders need information for the assessment of the impacts of the changing climate at the regional/local scale. Another point is the importance of a correct representation of regional and local interactions between atmosphere and surface, including a higher resolution of the orography, which play an important role also for large-scale dynamics. Especially for precipitation, these interactions, together with a correct modelling of small-scale physical processes, are essential.

A less computer-expensive alternative to regional climate models, which is therefore often preferred, is statistical downscaling of the global model output. Statistical downscaling methods relate large-scale atmospheric fields to local weather or climate states by statistical relations. Although these relations might be well defined when enough observational data are available, they are very sensitive to the training period and assume stationarity of the climate system. For the application to future conditions, the dynamical downscaling methods should outperform statistical methods because of the inclusion of non-linear effects in climate change, provided that they represent reality reasonably well.

Regional climate models are either derived from global climate models or from limited-area forecast models. In the first case, this can be done simply through resolution enhancement or by self-nesting of a limited-area version of the model in the coarse model. Then, however, the treatment of the boundary conditions needs to be specified. If necessary, non-hydrostatic extensions are also made to the small-scale models. When derived from forecast models, the handling of the lateral boundary conditions already exists, but the correct representation of slowly varying fields such as carbon dioxide, plant cover or other vegetation and soil characteristics need to be adapted. Furthermore, the numerical schemes might need improvement since even very small errors in the mass and energy balances become much more important in long-term model integrations than in short-term numerical weather prediction.

The application of regional climate models started in the late 1980s with simulations of limited-area models nested in general circulation models for longer integration periods than a few days (Giorgi and Bates 1989; Dickinson et al. 1989). Due to recent advances in modelling and in the understanding of physical processes of the climate system, as well as due to technical progress, the use of regional models in climate change studies has become feasible nowadays with increasing popularity. Their added value compared to global models has already been demonstrated in several studies, especially in situations when regional forcing is strong (e.g., Jones et al. 1995; Castro et al. 2005).

By now, a large variability of regional climate models in very different configurations and parameterizations exists. RCMs currently used in Europe include e.g. HadRM3, HIRHAM, REMO, COSMO-CLM, MM5, CHRM, CNRM-RM4, RegCM and RCAO. Some of them are non-hydrostatic which becomes important for simulations with grid spacings below 10 km. In Germany, the REMO and COSMO-CLM are preferably used for scenarios of future climate in Europe and other parts of the world. In the framework of IPCC (Intergovernmental Panel on Climate Change), several high-resolution scenario simulations have recently been conducted for Europe with the COSMO-CLM. For this, the model version 3 with a grid spacing of 0.165° (approximately 18 km) is nested into the IPCC/AR4 scenarios of the coupled atmosphere ocean global climate model ECHAM5(T63/L31)/MPIOM(1.5°/L40) (Böhm et al. 2006[1]). Currently, seven different runs are available: three realizations for the present climate (1960–2000), two realizations for the A1B scenario (2000–2100) and two realizations for the B1 scenario (2000–2100).

The investigation of the usability of the different models for climate change studies and their ongoing improvement is still a subject of current research. Several projects also focus on model inter-comparison studies (e.g., PRUDENCE,[2] QUIRCS[3] or ICTS[4]).

Precipitation in Regional Climate Models

Apart from near-surface temperature, precipitation is the essential climate parameter because it is an important branch of the global water cycle and it affects human life directly. Estimation of trends in precipitation is difficult, however, due to its large spatial variability and strong inter-decadal variations. Furthermore, the results from different models can differ substantially for this parameter.

In the last IPCC report in 2007, not many results from regional climate model simulations were available yet. The coupled ocean atmosphere GCMs indicate opposed precipitation changes in Europe for the end of the twenty-first century (2080–2099) which vary between an increase of up to 50% in northern Europe and a decrease of about 50% in southern Europe compared to average precipitation in

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[1] See also http://www.mad.zmaw.de/projects-at-md/sg-adaptation/clm/, accessed 11/11/08

[2] http://prudence.dmi.dk/, accessed 11/11/08

[3] http://www.tu-cottbus.de/meteo/Quircs/home.html, accessed 11/11/08

[4] http://icts.gkss.de/, accessed 11/11/08

the period 1980–1999 (Christensen et al. 2007, chapter 11.3). Concerning extreme precipitation, regional and seasonal differences are even more important. Although most of the regional models investigated in the PRUDENCE project simulate an increase of precipitation extremes in Central Europe in summer, the inter-model variability is large and projections with negative trends exist as well (Frei et al. 2006).

Since precipitation is also very difficult to simulate in short-term weather prediction, the question arises how well regional climate models are able to simulate precipitation statistics over longer periods. This is still subject of current research and is often only tested for monthly mean precipitation, although more and more impact studies focus on precipitation extremes on a daily scale.

A Model Evaluation Study

We investigate how well a specific state-of-the-art regional climate model is able to reproduce daily precipitation characteristics including extremes. For this analysis, we apply the non-hydrostatic regional climate model COSMO-CLM, which is in use as a community model in Germany, in a version similar to the above-mentioned regional climate scenario simulations. The general characteristics of the model as well as a short description of the scenario simulations can be found in Böhm et al. (2006).

Model configuration, simulations and observations

The COSMO-CLM has been run for 11 selected summer seasons between 1959 and 1992 at a horizontal grid spacing of 1/6 degree, corresponding to approximately 18 km. The simulation domain covers large parts of central Europe. Initial and boundary conditions for these runs are provided by the ERA-40 reanalysis data (Uppala et al. 2005) in order to keep the errors from the driving model as small as possible.

For comparison with observations, we use station records of the dense network of the German Meteorological Service (DWD). Station density is very high in Germany with on average about four stations per model grid box.

Evaluation methods

We analyze six different indices of daily precipitation for the summer months June, July and August (JJA) as averages over the eleven simulated summers, which are based on the definition of a wet day as a day with a rainfall amount of at least 1 mm:

- Wet-day frequency (FREQ, in %)
- Mean intensity, i.e. the average precipitation per wet day (INT, mm/day)
- The 90th percentile value, estimated from the empirical distribution, i.e. the daily precipitation amount which is exceeded on 10% of the wet days (Q90, mm/day)
- The largest 5-day precipitation total (RX5day, mm)
- The maximum number of consecutive dry days, i.e. the duration of the longest dry period in the season (CDD, 1) and
- The extreme precipitation total, which is the fraction of total precipitation due to days with precipitation exceeding the 90th percentile value (R90pTOT, %)

The indices are calculated for each grid box of the model output in four selected regions in Germany which cover an area of 12 x 12 grid boxes or 220 x 220 km² each. For the observations, measured daily precipitation amounts are averaged from all stations located in each grid box. Subsequently, the indices listed above are calculated from this average. Simulated and observed indices are compared for the spatial averages in these four regions. Additionally, the accordance in the spatial structure of the indices within the region, i.e. on the grid-box scale, is evaluated by means of simple diagnostics such as bias, root-mean-squared error and deviation in spatial variability. The significance of differences between simulated and observed characteristics is estimated by bootstrap resampling methods (Efron and Tibshirani 1993).

Results

The model performance with respect to the daily precipitation characteristics is found to be very variable. Most significant differences between simulated and observed indices appear in the region with highest elevations and the most complex orographic structure. The total summer precipitation amount and the wet-day frequency are also poorly simulated: the total precipitation is significantly underestimated by the model in three of the four considered regions, and the wet-day frequency in all four regions. Part of this bias, however, might be induced by the driving data. The other indices exhibit different behaviour in different regions. The mean intensity and the 90th percentile value, for example, are underestimated in two regions and overestimated in the other two, although the difference is only statistically significant in one of the four regions. This indicates some skill of the model with respect to both mean and extreme precipitation intensities. In addition, the spatial structure of the indices fields within the four regions reveals some region-specific problems, such as overestimation of spatial variability by up to

100% in certain cases. This leads to the conclusion that localized structures smaller than about 200 x 200 km² cannot yet be simulated accurately by regional climate models.

Additionally, we have estimated the model uncertainty which is due to imperfect parameterizations of physical and subgrid-scale processes by comparing an ensemble of runs with 12 different configurations in the parameterizations for each summer. These runs include changes due to different namelist settings in the convection, grid-scale precipitation, turbulence, radiation and soil scheme. We find that the uncertainty is substantial, with a relative sensitivity of at least 15%, especially for the index describing extremely dry periods (Fig. 9.1).

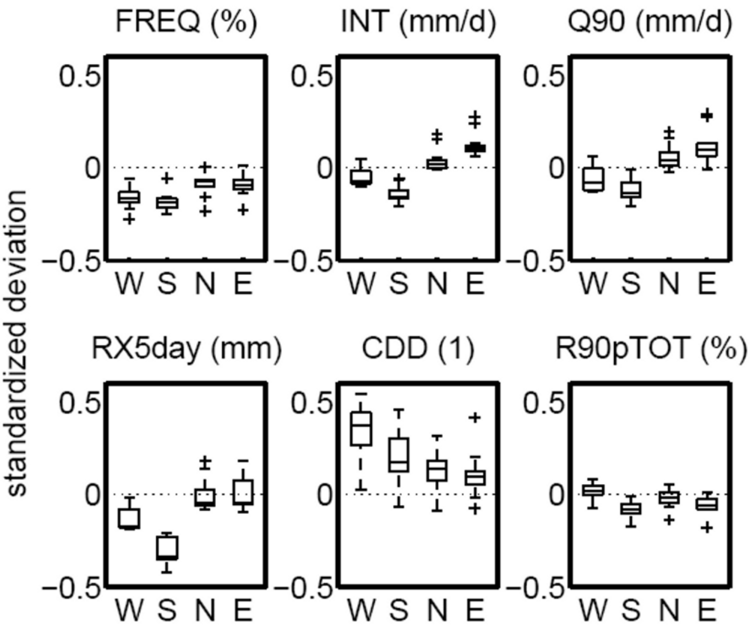

Fig. 9.1. Range of estimates for the six precipitation indices from the ensemble of 12 sensitivity simulations. Values are standardized deviations of simulated to observed indices. The letters on the x-axis represent the four regions. The region 'S' is the one with the highest elevations.

For most cases, the uncertainty amounts to approximately 20% relative to the observed values. Considering the individual runs, some specific changes can be found, e.g. with respect to the spatial structure of the index fields when the convection parameterization is modified. Nevertheless, it is not possible to determine one configuration which performs best for all indices and all regions.

In summary, the large variability of the results suggests that for each application a specific evaluation study is required for the estimation of model biases and model uncertainty. Overall, results are promising, however, for the use of regional climate models to future scenarios, also regarding extreme precipitation characteristics. More details on this analysis can be found in Bachner et al. (2008) and Ebell et al. (2008).

Final Remarks

Regional climate models are indispensable for the analysis of climate processes and climate change on regional scales. Many RCMs with different development chains are available now, but for a meaningful use of their output, extensive validation is required, especially when transferring them to different regions. Furthermore, several model evaluation studies show that different types of uncertainty need to be taken into account, such as the choice of boundary conditions and parameterizations. More effort is still needed on how these uncertainties can be quantified. An essential element for this is the use of ensemble simulations.

For Eastern Europe, an area which has not been treated yet in much detail in previous studies, we therefore strongly recommend a thorough model evaluation study before using one of the existing RCMs for climate change assessment. When analyzing daily precipitation, non-negligible uncertainties have to be expected which need to be taken into account properly.

Acknowledgments. We would like to thank the CLM community for the model code and assistance in the use of the model, and the DWD for the provision of the computation environment and the observational data.

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Long-Term Forecasting of Natural Disasters Under Projected Climate Changes in Ukraine

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Abstract. An approach is proposed that allows the development of coherent scenarios of climate changes, ecosystems evolution, and trends of hydrological and hydro-meteorological disasters. This provides the base for more adequate and accurate forecasting of disasters, and to integrate the developed forecasts into the decision making systems. The approach allows the examination of regional risks features in the context of global changes, permits the analysis of both the general and separated peculiarities of dangerous processes and, finally, builds the disaster management measures into the regional land-use and development strategies.

Keywords: natural disaster, climate change, Ukraine, projection, risk assessment

Introduction

The interim results of research of Centre for Aerospace Research of the Earth of National Academy of Sciences of Ukraine in the field of long-term natural disasters risks analysis and forecasting are presented. The aim of this paper is to demonstrate the research methodology of disasters risks analysis in the context of global changes of climate and evolution of terrestrial ecosystems. The approach we developed allows us to build a number of correlated scenarios of climate change, corresponding ecosystems response, and disaster escalation.

The appropriate models are developed for analysis of hydrologic and hydro-meteorological disasters (mainly floods, inundations, and partly windstorms, droughts, extreme temperatures and fires) as well as the induced phenomena such as landslides, avalanches, surface subsidence etc. The purpose of our studies is to estimate the future disaster escalation on the base of the developed multi-scale models of climate and earth covers.

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Research and Modeling Concept

Implementation of the adequate strategies of long-term risks management and natural disasters mitigation in the paradigm of sustainable development requires (Rio Declaration on Environment and Development 1992) application of the integrated approach to systems comprehension of the disasters origin and its escalation. The multi-scaled models of basic parameters of atmospheric, ocean and terrestrial ecosystems changes as well as the models of genesis and expansion of hydrologic and hydro-meteorological disasters are proposed.

The basic information for modeling is the Earth observations data. These data are the most user friendly through their operability, methodological homogeneity and wide applicability. Moreover international initiatives such as GMES and The Global Earth Observation System of Systems (GEOSS 2005) open encouraging perspectives for information exchange, research networking, and capacity building. Scientific based techniques of satellite surveys interpretation allow us to utilize (WMO 2001; NOAA 2001) the data more multifariously and to extract more information about important bio-geophysical processes. Remote sensing data were chosen as the principal research tools. It will be shown that satellite measured parameters such as NDVI, EVI, albedo, radar reflectance and others are successfully applicable for the global change modeling.

The basic requirements, to which the model should be responsive, are the possibility of multi-scale calculations defining the applicability in the different areas of scientific activity; computer resources optimized for the required calculations; wide operability of the Earth Observation data; capability for in-flow improvement and calibration; and applicability to policy-making.

Using as a basis the measured and estimated parameters such as reference height, normal wind, potential temperature, given humidity and pressure, radiation characteristics, and current structure of the precipitation, the set of climatic parameters can be calculated (WMO 2001; IPCC 2007). At the current stage of this research we are able to calculate enlisted parameters with grids 100 x 100, 75 x 75 and 50 x 50 km on the global scale with 1-month temporal resolution. The length of our forecasting period is 75 years with an expected reliability of better than 70%. With improvements in our calculation capacity we plan to obtain weekly temporal resolution.

On this foundation we were able to estimate the density of vegetation, surface albedo, soil erosion, surface water balance (runoff and transpiration) and soil moisture which is necessary for assessment of the accumulation capability of landscapes and ecosystems vulnerability. Six scales of modeling from local (10 x 10 m) up to trans-regional and global (100 x 100 km) have been used for calculation of natural and socio-ecological parameters.

For the modeling of local natural systems we used the known approach which includes the estimation of water and energy balance of basins (Lyalko et al. 2002). The main processes described are the soil water balance (filtration and groundwater exchange), surface and riverbed runoff, and transpiration. The digital elevation model and lines of the hydro-meteorological measurements are required.

Modeling Results

The calculated climate scenarios allow us to project disasters from a long-term perspective and, on the other hand, to estimate the conditioned change of natural landscapes – ecosystems changes. Using this information and utilizing the local models of heat and water balance, it is possible to develop mid and short range disaster forecasting. The resulting foresight helps to improve the development strategies aimed to risks management and mitigation.

As a result of climate modeling the change scenarios have been calculated. These scenarios are averaged and coordinate well with known IPCC scenarios (IPCC 2007). The calculated temperatures at the surface and 10 m and also the expected average air humidity for years 2010, 2015, 2020, and 2025 in Europe are presented in the paper. The scenarios were compared with the measured temperatures for the region of the Danube river basin. For validation we have used measurements from 12 stations for the period since 1886.

Calculated data for 2015 is interesting showing some decrease of average temperature in 2014–2016. This decreasing associated with some smoothing of seasonal temperature changes relative to previous years. Results show that for the period extending until 2025 no critical changes of key climatic parameters should be observed.

On the basis of the climate scenarios presented it is possible to forecast the spatial distribution of the behavior of the important parameters. As an important example, the forecasting of the surface runoff for the Black Sea region and Ukrainian territory has been calculated. As it was shown, the change of this regional parameter until 2020 will be not significant. However, the seasonal variability is quite large. This could lead to the increase of seasonal disasters, for example, caused by heavy precipitation. This forecast is calculated using the 10 x 10 km grid. Based on the forecasts presented, the changes in natural conditions can be shown. The appropriate prognostications for Ukraine are presented in Fig. 10.1. As it is shown, the landscape vulnerability toward the climate changes is highest in the regions with highest anthropogenic impact.

Earth observation data for the mid-range (seasonal) floods forecasting

Using the detailed models of local natural systems and forecasting of tendencies of general parameters change, it is possible to utilize the remote sensing data for development of inter-seasonal flood forecasting. The usual length of this type of forecasting is 1 year, and spatial resolution is 1 km. In our investigation the remote sensing data utilization structure is traditional for this type of task (WMO 2001; NOAA 2001).

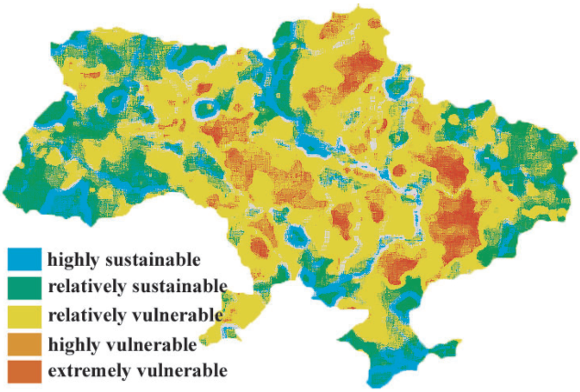

Fig. 10.1. Landscapes vulnerability toward the climate changes for 2015.

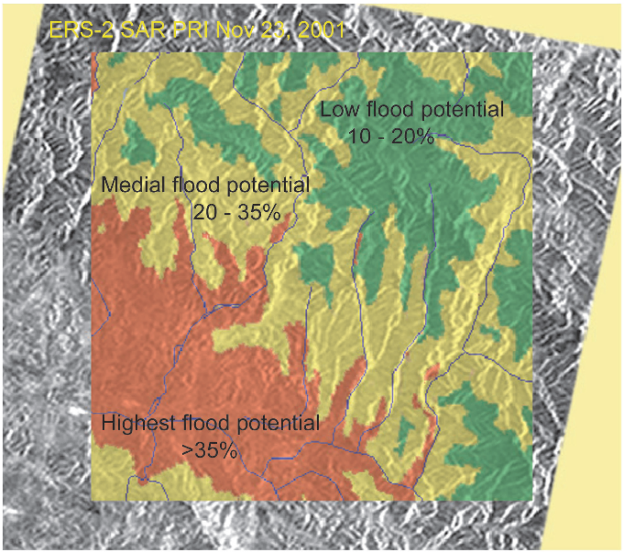

Fig. 10.2. Flood & inundation potential assessment for upper Tisza river basin using EO data (autumn 2001–spring 2002 season).

In particular, the method to estimate the water storage of snow-pack in upper Tisza river basin (Ukrainian part) using LandSat optical data is demonstrated. The radar data is also applicable for this purpose. The method of detection of the additional moisture sites, which should be excluded from analysis of filtration and which have a large negative influence on groundwater exchange and surface runoff is also developed and presented.

Taking into consideration the above presented parameters, it is possible to calculate the probability of flood using the given meteorological conditions – so called regional flood potential. The results of these calculations are presented in Fig. 10.2 (Lyalko et al. 2002, 2006). Using the basic ground data, the following set of observations has been utilized:

- Soil moisture measurement: landscape related measurements averaged by month and by season at the test sites
- Snow cover measurement: 1-week point measurements averaged data at the test sites
- Meteorology: seasonal and monthly averaged data for decades by the runoff basins
- Hydrology: channel runoff measurements for last decade averaged by weeks by the runoff basins
- Cartography: comprehensive maps with scale of 1:50,000 on region and 1:10,000 for submerged areas
- Geology: geological maps on scale 1:100,000
- Landscape research: landscape maps and soil maps with scale of 1:100,000

These ground data were used for land hydrology & water objects investigation calibration.

Risk assessment tools: Indicators correlation, analysis & forecasting of the disasters escalation

The analysis of the satellite surveys data and disaster files in the framework of our proposed analysis approach allows us to determine the stable correlations between the basic parameters of land cover and disasters (Lyalko et al. 2006). The temperature variation (T_{VAR}), number of disasters (N_T), vegetation indexes EVI and NDVI, albedo (A), summation of annual losses (d_E), and annual number of affected people (N_{AF}) were analyzed. The result of the analysis is presented in

Table 10.1. Global change parameters correlation coefficients.

	T_{VAR}	N_T	NDVI	EVI	A	d_E	N_{AF}
T_{VAR}	1	0.72	0.66	0.82	0.89	0.0067	0.0511
N_T	0.72	1	0.9	0.91	0.82	0.0005	0.0115
NDVI	0.66	0.9	1	0.84	0.75	0.0009	0.0135
EVI	0.82	0.91	0.84	1	0.91	0.0025	0.026
A	0.89	0.82	0.75	0.91	1	0.005	0.031
d_E	0.0067	0.0005	0.0009	0.0025	0.005	1	0.51
N_{AF}	0.0511	0.0115	0.0135	0.026	0.031	0.51	1

Table 10.1. Poor correlation between the indicators of disaster (such as losses) and natural features shown in this table is interesting. It can show that anthropogenic input to global changes is a bit over emphasized.

By analyzing the trends of disaster occurrences, scenarios of climate and ecosystems changes, the set of forecasting of future disasters escalation can be calculated. There are three basic scenarios which were calculated on a global scale: (a) saving the current tendencies without the essential GHG emission management; (b) the so-called "responded" scenario, with minimization of the gap between climatic and ecosystems changes (parallel evolution), also requiring non-structural landscape management strategies; and (c) a "fast drying" scenario without relevant ecosystems response, which presumes the decrease of the number of total disasters but escalation of the seasonal number. These scenarios are presented in Fig. 10.3.

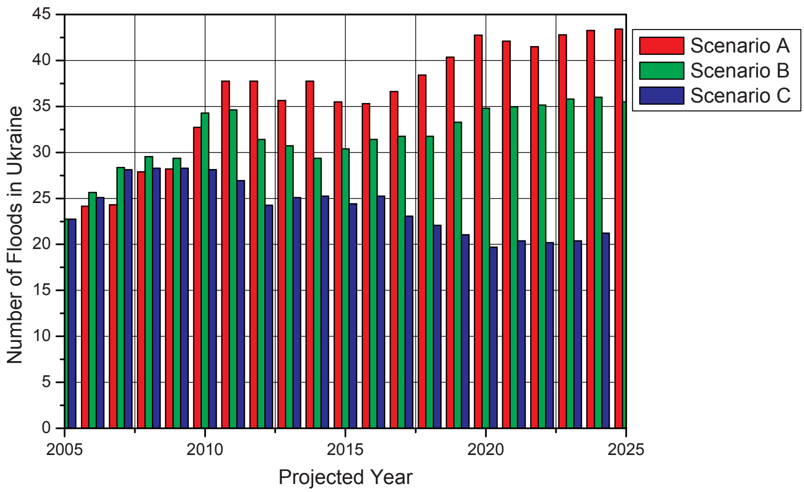

Fig. 10.3. Calculated floods and inundations escalation scenarios for Ukraine (Lyalko et al. 2006).

Using the results obtained, the parameters of risks can be calculated. Relevant probability of disasters could be determined as in (Lyalko et al. 2006):

$$P(n,t) = \frac{(N_d^F \cdot t)^n}{n!} \exp(-N_d^F \cdot t); \quad n = 0,1,2,....,N_d^F \tag{1}$$

where the number of disasters is:

$$\mathrm{N_d^F} = S_A \frac{\sum_{i-k}^{i+k} (\mathrm{N_d})_i}{(2k+1)\cdot S_{tot}} \tag{2}$$

In the Equations (1) and (2):
S_A – square of region; S_{tot} – projective square; N_d – annual disasters number; i_0 – current year; i – calculated year; k – smoothing coefficient, which defining according to:
$k = 1$ if $(i_0 - i) \le 5$; $k = 2$ if $5 < (i_0 - i) \le 10$; $k = 3$ if $10 < (i_0 - i) \le 15$; and $k = 4$ if $15 < (i_0 - i) \le 20$.
The risks function in this case is:

$$\mathrm{H} = 1 - \mathrm{P}(0,1) = 1 - \exp(-\mathrm{N_d^F}\cdot t) \tag{3}$$

So the disaster risk should be determined as the following:

$$\mathrm{R} = \mathrm{H}\cdot \iint_{\mathrm{S_{x,y}}} \int_0^t \int_{I_{\min}}^{I_{\max}} \mathrm{f_v}(\mathrm{I})\cdot \psi(x,y)\cdot \mathrm{f}^{\alpha}(\mathrm{I},\psi)\, dIdtdxdy \tag{4}$$

where S_{xy} – area modeled; ψ(x, y) – point site with vulnerable infrastructure; I – intensity parameter; fα(ψ, I) – density of the probability distribution of damages inside the square ψ(x, y); fv(I) – damage function, parametrical description of affection.

The proposed approach allows us to calculate the relevant disaster risks for each projected year per unit of investigated river basin in terms of possible damage.

Conclusions

Based on the appropriate modeling and stable correlations of model results with observations, it is possible to determine and to investigate the relationships between the disasters genesis probability (in particular in the framework of separate catchments) and global changes of climate and ecosystems. Furthermore, the forecasting of ecological and socio-economical risks of natural disasters might be incorporated into the regional development management system. The proposed approach allows us to develop coherent scenarios of climate changes, ecosystems evolution, and trends of hydrological and hydro-meteorological disasters. This provides the base for more adequate and accurate forecasting of disasters, and to integrate the developed forecasts into the decision making systems. Key results are the following:

- The modeling framework for determination of natural systems vulnerability toward the climate changes and natural disasters was formulated.
- The appropriate techniques and satellite observation systems response scenarios for the natural hazardous events for the seasonal and long-term forecasting were developed.
- The stable correlations of disasters risks, climate change and land-use have emerged.
- The separate phenomenological models were completed, and combined into the method-oriented system model for the river basins.

The pilot results of our investigations are encouraging and we believe that the further development and improvement of the proposed research will be fruitful too.

The approach presented allows the examination of regional risks features in the context of global changes, permits the analysis of both the general and separated peculiarities of dangerous processes and, finally, builds the disaster management measures into the regional land-use and development strategies.

Further development of this research requires verification of the proposed approach using other regional data, expansion of the mid-scale calculations to other basins, calibration of scenarios through ground measurement of critical parameters, rectification of the disasters data-base, and development of the social – economy issues of the risks analysis.

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Section 3
Air Pollution in Eastern Europe

Air Pollution in Eastern Europe

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Abstract. This paper provides a brief review of existing levels and trends in the air pollution in selected East-European countries. Its significant part is based on the data downloaded from the net but some characteristics for Russia, Belarus and the Ukraine are original estimates.

Keywords: air pollution, Eastern Europe

Introduction

Projected climate changes could significantly influence the air pollution in Eurasia resulting in changes in the impact on the environment and human health. To detect these changes, one should know characteristics of the present air pollution, which could be estimated using monitoring data and/or modeling results. Eastern Europe including Russia is a substantial part of the NEESPI European region that is highly "inhomogeneous" in respect to the air pollution problems as well as the abatement strategies.

The problem of the air pollution is of importance for practically all European countries. Numerous national and international agencies collect data characterizing the air pollution on the national and European scales. Unfortunately, there are no unified strategies, policies and approaches to mitigation of air pollution problems across whole Eastern Europe. The level of general coordination of corresponding environmental authorities in this region is comparatively low. As a result, the information on the air pollution in this region is rather patchy, in particular, because there is no data bank that would collect all the variety of types of data available at the moment.

Data covering all European countries, especially emission data, can be found at the web site http://www.emep.int of the European Monitoring and Evaluation Programme (EMEP). However, this program operating in the framework of the Long-range Transboundary Air Pollution Convention is focused mainly on the "computational monitoring" (i.e., on modeling the air pollution) outside the cities and provides only a limited amount of information based on the instrumental monitoring (actually, also outside the cities). The rest of data including the

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characteristics of the urban air pollution are gathered at different locations. In particular, the information related to the EU countries is partially presented at the site of the European Environment Agency; some additional data could also be found at the national sites. European NIS countries have not organized any similar agency and each of them collects the data only at the national level.

Due to historical, economical and social reasons, the level of the air pollution and the essence of the corresponding problems are different in different European regions. However, the contemporary regional aspects of the European air pollution have not been analyzed comprehensively, especially when talking about Eastern Europe. Even the publication [1] provides mainly the information about the institutions and persons, dealing with the monitoring data, rather than the data analysis. In this paper we are trying to present a preliminary short review of existing levels and trends in the air pollution in selected East-European countries. Its significant part is based on the data downloaded from the Internet but some characteristics for Russia, Belarus and the Ukraine are original estimates.

Current Air Pollution in Eastern Europe

Coverage

There is no generally accepted single list of countries constituting Eastern Europe. Here we accept the definition of the United Nation Statistics Division [2]. It assumes that Eastern Europe consists of the following ten countries: Belarus, Bulgaria, Czech Republic, Hungary, Moldova, Poland, Romania, Russia, Slovakia, and Ukraine. There are other definitions that either expand this list to include "East-Central" and "South-East" European countries like Albania, Bosnia and Herzegovina, Croatia, Serbia, Slovenia etc., or reduce it referring to Russia as a "transcontinental country", but it is unnecessary to go into all these details. In connection with the approach in use in the EMEP data bases, we will consider mainly the emissions from the western regions of Russia indicated as "Russia West" that includes Kola Peninsula, Karelia, St. Petersburg, and Leningrad – Pskov – Novgorod – and Kaliningrad oblasts because the corresponding sources of the air pollution are the closest to the rest of East-European sources.

Emissions

Total emissions of four "major" atmospheric pollutants, i.e. CO and NO_x (left-hand panel) and SO_x and NMVOC (right-hand panel) in Tg per year from the sources of East-European countries for 2006 are shown on Fig. 11.1 [3]. Here, the left-hand and right-hand axes correspond to emissions of CO and SO_x, and NO_x and NMVOC, respectively. As one can see from this figure, the major emitters in

Eastern Europe are Poland, Ukraine, Bulgaria, Czech Republic, and, certainly, Russia (one should notice that the total emissions from all Russian sources are approximately ten times larger then those accounted for as “Russian West”).

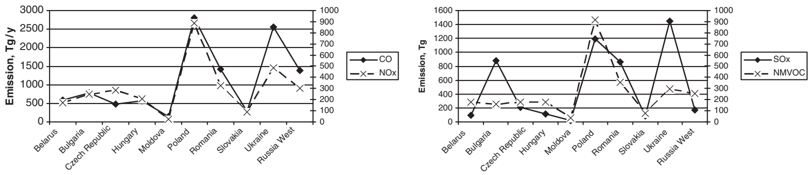

Fig. 11.1. 2006 emissions of CO, NOx (*left-hand panel*), SOx and NMVOC (*right-hand panel*) for East-European countries.

Hazards

A significant part of Eastern Europe is marked on Fig. 11.2 published in [4] as either areas contaminated by the Chernobyl explosion or areas under environmental stress, highly polluted coastal areas etc. Here the “atomic trefoils” indicate nuclear power plants, dark-grey areas are contaminated by the products of Chernobyl explosion, shaded domains correspond to highly-polluted coastal areas, curved lines show the environment and security priority areas, stars indicate past and current (frozen) conflicts, opened and filled circles correspond to interstate- and inter-ethnic disputes. Only a part of these indices is directly linked to the air pollution problems. On the whole, however, Fig. 11.2 illustrates the importance of

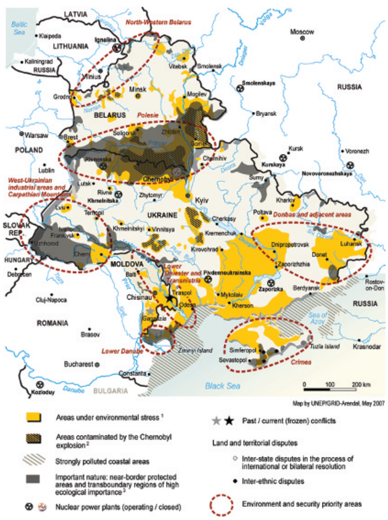

Fig. 11.2. Environment and security priority areas in Belarus, Moldova, Ukraine, and the coastal zone of The Black and Azov Seas. Notes to the legend: 1 - Medium to high stress according to national indices of environmental conditions. 2 - Caesium-137 activity above 555 kBq/m^2. 3 - Shown only outside of areas under medium to strong environmental stress.

urgent development of coordinates measures aimed for reducing the environmental risks and corresponding abatement strategies.

Emission trends and corresponding changes in air pollution

Emission trends in Eastern Europe are closely related to the collapse of the Soviet Union that led to the sharp decrease of the industrial output and, consequently, of the industrial emissions as well as to the increase of the car fleet and corresponding vehicular emissions. Corresponding changes in concentrations of sulphur-containing substances are characterized in Table 11.1.

Table 11.1. Changes in measured SO_2 and sulphate particle concentrations in four East-European countries in relation to emission reductions in the period 1980–2000 (after [5]).

Country	Decrease in emissions (%)	Decrease in observed SO_2 (%)	Decreased in observed SO_4 (%)
Belarus	80	60	50
Czech Republic	85–90	80	50
Poland	60–65	65–80	60–70
Slovak Republic	85	65	50–65

Similar trends found in total emissions (M) and corresponding average concentrations (q) of sulfur dioxide over Russia are shown on Fig. 11.3 [6].

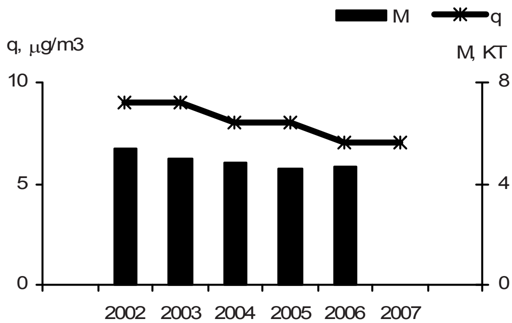

Fig. 11.3. Trends in emissions and mean annual concentrations of SO_2 in Russia.

Country features

Among the most polluted East-European countries one could mention Bulgaria, Poland, Russia, and Ukraine. In particular, the daily air quality index (the highest of the ratios of daily averaged concentrations of different pollutants to their ambient air quality standards), DAQI, in Sofia was as high as up to 11.5 in 2006 [7]. The data presented in [8] indicated that mean daily PM10 concentration in Polish cities reached up to 170 μg/m^3 and higher (compare with the EU limit of 50 μg/m^3).

Characteristics of the urban air pollution in Russia, which can be found in [6, 9], are based on the data measured in more than 600 monitoring sites located in more than 200 Russian cities. Trends in these characteristics are presented in Table 11.2.

Table 11.2. Trends in concentrations of atmospheric pollutants in Russian cities in 2002–2006.

Pollutant	Number of cities	Trend (% per year)
Particulate matter	228	0.0
Sulfur dioxide	229	−22.0
Nitrogen dioxide	234	+5.1
Nitrogen oxide	134	−10.0
Carbon monoxide	205	−6.8
Benz(a)pyrene	166	+2.4
Formaldehyde	141	0.0
Ammonia	66	+17.8

The highest levels of the air pollution in Russian cities could usually be attributed to "industry-specific" (i.e., related to certain industrial processes) pollutants and/or to vehicular emissions. The priority list of cities with the highest concentrations includes mainly those located in Siberia, Far-Eastern, and Urals regions.

Long-term variations of the mean annual concentrations of CO and NO_2 are presented on Fig. 11.4 with figures corresponding to the most polluted monitoring sites in St. Petersburg and Yakutsk. The tendency of decreasing the urban air pollution could be attributed here to changes in the structure and mean age of the car fleet and to improvement of the quality of the gasoline in use.

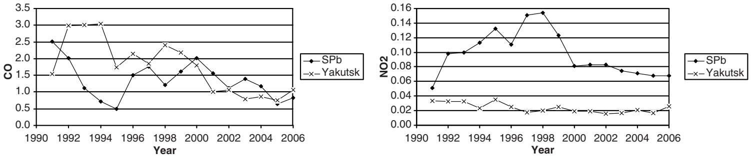

Fig. 11.4. Trends in mean annual concentrations of CO (*left panel*) and NO_2 (*right panel*) in St. Petersburg (diamonds) and Yakutsk (crosses).

Anthropogenic emissions significantly influence the environment in Russia. This can be seen, in particular, from the map shown in Fig. 11.5. It depicts the deposition on the ground (in kg S/(km^2 year)) of sulfur contained in the snow cover. Please note the "dirty spots" surrounding the major cities and industrial regions.

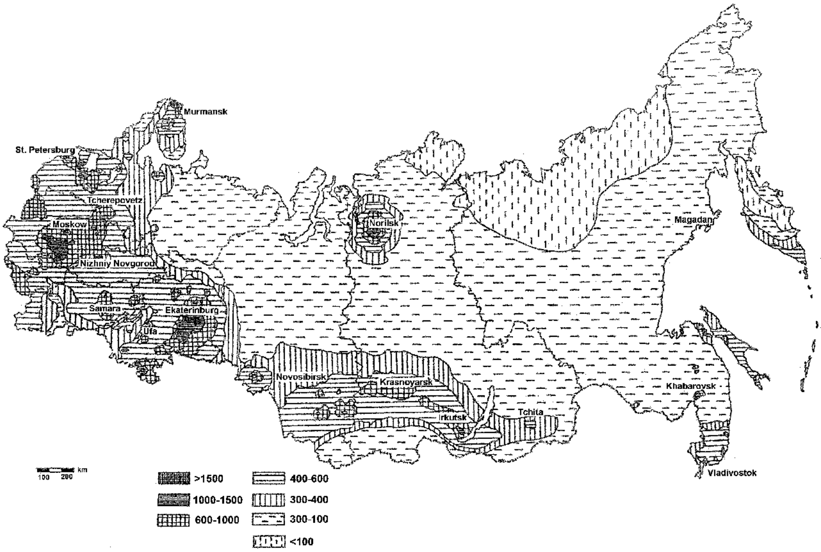

Fig. 11.5. Mean annual sulfur deposition in Russia in the snow cover, kg S/(km^{2}year).

It should be emphasized that the amount of pollutant washed out with the snow is only a fraction of its total wet deposition. The total annual wet depositions of sulfur and nitrogen in Russian North-European regions are given in Table 11.3.

Table 11.3. Total annual deposition of sulfur and nitrogen in Russian North-European regions.

Regions	Area (km^2)	S (KT/year)	N (KT/year)
Murmansk oblast	145	65.5	30.0
Karelia and Komi republics, Archangelsk and Vologda oblasts	1,321	325.5	405.2

As it was mentioned earlier, the Ukraine is one of the most significant European polluters, and it is not only due to its substantial industrial emissions. March 2007 Ukrainian forest fires together with farmland erosion resulted in hourly PM10 concentrations up to 170 mg/m^3 in the UK and up to 200–1,400 mg/m^3 in Slovakia, Poland, the Czech Republic and Germany.

Air pollution observations (the grand total of 20 pollutants) in the Ukraine are carried out in 52 cities at 172 stationary, 6 routing and 37 "plume-following" mobile observation sites. As it is indicated in [10], "costs of air pollution in Ukraine are sizable and in the nearest future may offset the economic growth. Recovery of the Ukrainian economy based on restoration of polluting industries may lead to stagnation since mortality and morbidity risks not only put a burden on the economy, but also reduce the labor force". Indeed, the relative mortality risk attributed to air pollution is about 55–59 cases per 100,000 population (appr. 6% of the total mortality), and corresponding damage accounts for approximately 4% of GDP.

High levels of the air pollution in the Ukraine result in a substantial pressure on the environment reflected, in particular, in the chemical composition of precipitation. Corresponding data will be presented here in comparison with those measured in Belarus. In this connection, a short explanation about the air pollution in this country should also be given here.

In 2003 the composition of anthropogenic emissions in Belarus looked as follows [11]: CO – 732.5 KT, hydrocarbons – 247.5 KT, NOx – 140.1 KT, SO_2 – 126.4 KT, others – 81 KT. The main sources of pollution are traffic, energy sector and industry, and traffic alone accounts for 75% of all CO, NOx and VOC emissions. One should remember that the Chernobyl accident affected 23% of the territory of Belarus. Presently, 100,000 people receive doses of 1–5 mSv per year, and some adverse effects have been observed, e.g., an increase in thyroid cancer in children. The expenditures related to the accident are still at about 3% of the GDP.

In 2007 the system of monitoring of the urban air pollution in Belarus included 58 monitoring sites operating in 17 cities. Mean annual concentrations of several urban pollutants in Belarus are compared in Table 11.4 with corresponding averages over European cities. Judging from these data (see also [12]), Belarus could be considered as a "comparatively clean" European country.

Table 11.4. 1995–2000 mean concentrations of urban atmospheric pollutants ($\mu g/m^3$) in Belarus in comparison with those over all European cities.

Data	PM	NO_2	SO_2	Formaldehyde
Belarus	73	30	3	5.6
Europe	90	55	40	9

The variations of the total mineralization of atmospheric precipitations over the decade are shown in Fig. 11.6. The data used correspond to the regions of three Ukrainian cities (Donetsk, Odessa, Yalta), one Belarus city (Berezino), and the Berezino Nature Reserve (BRN) located in Belarus near the aforementioned city. Presented data reflect the fact that Donetsk is a big industrial city and a "regional capital" of the highly industrialized oblast, Odessa is one of the major Ukrainian cities with population of about 2.5 million, Yalta is mainly a resort city, and Berezino is a small town near the Berezino Nature Reserve. Similar results indicating much higher anthropogenic pressure on the environment in the industrial regions of the Ukraine and in the vicinity of big cities were obtained with other characteristics of chemical composition of precipitation like sulfate- and nitrate ions etc. As an example, the ratio of concentrations of sulfur- to nitrogen ions for different sites and years is presented in Table 11.5. It is evident from this table that this ratio could be considered as an indicator of the anthropogenic pressure on the environment.

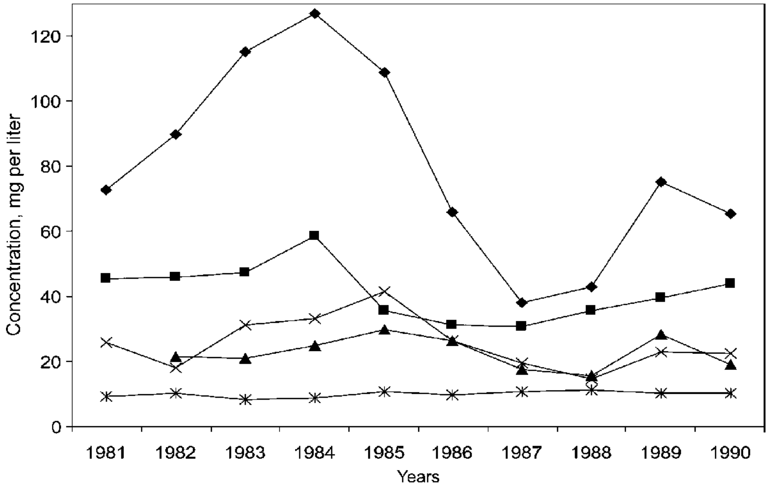

Fig. 11.6. The total mineralization (mg/l) of atmospheric precipitations at Donetsk (diamonds), Odessa (squares), Yalta (triangles), Berezino (crosses), and Berezino Nature Reserve (asterisks).

Table 11.5. Ratios of sulfur to nitrogen in atmospheric precipitations.

Year	Donetsk	Odessa	Yalta	Berezino	BNR
1981	6.8	3.1		1.5	1.9
1982	6.2	6.6	2.7	1.7	2.2
1983	11.0	5.8	2.7	1.3	1.7
1984	10.7	4.6	3.1	0.7	1.3
1985	7.1	2.3	3.0	0.8	1.1
1986	5.0	3.1	2.5	1.1	0.8
1987	3.6	4.0	1.7	1.4	0.9
1988	6.2	7.0	2.6	3.6	0.7
1989	3.8	2.9	2.7	2.4	0.7
1990	3.3	3.7	2.0	1.4	0.7
Mean	6.4	4.3	2.5	1.6	1.2

Conclusion

The results presented above should be considered as a proof of the fact that East-European countries face rather serious problems related to their air quality. Certain features of these problems are similar for different East-European countries, and it could be a reason for enhancing the regional cooperation in this area.

Data discussed in this paper were obtained mainly as a result of instrumental monitoring of the air pollution carried out in all East-European countries. Corresponding monitoring networks, however, are rather sparse, and the number of pollutants registered at monitoring sites is really limited. The last circumstance is especially important in East-European NIS countries because the list of the ambient air quality standards, inherited by these countries from the USSR times, amounts up to 2,000 pollutants. That is why the "computational monitoring" based on the use of emission data and mathematical models is such an important instrument for evaluation of the air quality in Eastern Europe. All East-European countries are involved in the activities related to mathematical modeling of the air pollution. It could be of interest to review the corresponding results but such a work is outside the framework of this paper.

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Section 4
Land Cover and Land Use Changes in the Non-boreal Eastern Europe

The NASA Land-Cover/Land-Use Change (LCLUC) Program's Support of the Northern Eurasia Earth Science Partnership Initiative (NEESPI): Focus on Non-boreal Europe

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Abstract. Currently, the Northern Eurasia Earth Science Partnership Initiative (NEESPI) includes over 120 international projects involving more than 200 scientific institutions from over 30 countries. The program involves national government agencies, academia and private organizations in the U.S., Europe, Japan and Northern Eurasia (Gutman 2007). The NEESPI science is directed at evaluating the role of anthropogenic impacts on the Northern Eurasia ecosystems, the hemispheric-scale interaction and assessing how future human actions would affect the global climate and ecosystems of the region. Projections of the consequences of global changes for regional environment in Northern Eurasia are also in the center of the scientific foci of this initiative. The Land-Cover/Land-Use Change (LCLUC) Program is an interdisciplinary science program in the Earth Science Division of the Science Mission Directorate supporting several regional initiatives, including NEESPI. The NASA LCLUC currently funds over 30 NEESPI projects. The NEESPI program links to several international projects, such as GLP, iLEAPS and others, under major international programs: IGBP and WCRP. The NEESPI covers a large geographic domain, which includes the former Soviet Union, northern China, Mongolia, Scandinavia and Eastern Europe. This contribution provides a short description of the ongoing NEESPI studies in the non-boreal European sub-region of the NEESPI geographic domain that are supported by the NASA LCLUC program. More information on the projects can be found at http://neespi.org and http://lcluc.hq.nasa.gov.

Keywords: land cover, land use change, non-boreal Eastern Europe

Introduction

The National Aeronautics and Space Administration (NASA) is among the NEESPI major partners, with several NASA programs contributing to this initiative. The NASA LCLUC Program has been supporting the NEESPI since its

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inception. The non-boreal Europe is of particular interest for studying LCLUC processes due to the dramatic socio-economic shifts in the former Soviet-block countries during the past 17 years. The rapid land-use and land-cover changes observed from space and their impacts on the environment and ecosystems are the focus of several NEESPI projects encompassing various sectors, including forestry, coastal zone and agriculture. The changes in water quality and vegetation-cover and the shifts in agricultural practices with the consequent changes in carbon emissions in non-boreal zone of Northern Eurasia are especially important in the NEESPI science agenda.

In addition to supporting research projects NASA also contributes to the NEESPI by supporting the NEESPI Project Scientist, the International Project Office and in organizing and sponsoring regional NEESPI meetings, such as the non-boreal Europe meeting in Odessa in September 2008. Additionally, NASA is playing the leading role in facilitating access to data and derived products to NEESPI participants.

The global land surveys

Regional studies in the LCLUC program in general, and in the NEESPI projects, in particular, strongly depend on the availability of Landsat and Landsat-like data. To satisfy the data needs for regional and global studies USGS and NASA are jointly developing a Global Land Survey (GLS)-2005 dataset (also known as the Mid-Decadal dataset) similar to the Geocover 2000, which has been available for several years. The goal is to develop a global orthorectified dataset from Landsat observations based on measurements during the 2004–2007 period with 30-m spatial resolution. The project uses Landsat-5 ground station data where available, Landsat-7 composites, and ASTER and EO-1/ALI to fill the gaps and over islands (Gutman et al. 2008). The completion of the GLS-2005 is planned for the end of 2008. LCLUC products based on this new dataset are being developed in the projects selected recently by NASA. NEESPI scientists will make use of the developed land-cover classification and land-cover change products as soon as they become available.

The NEESPI non-boreal projects

Gutman (2007) described the early developments in the NEESPI program. Most of the studies at the early stage were devoted to the boreal zone. Several projects, however, were focused on studying processes in the European non-boreal zone. Below are some results from these investigations.

A team consisting of scientists at Columbia University and IIASA with Ukrainian collaborators conducted a project on carbon, climate and managed land in Ukraine. The project put forward the following science question: What are the consequences to carbon storage from changes in agricultural management due to both socio-economic trends and climate change impacts? This study found no strong dependence on fertilizer use (soils are rich, less dependent on fertilizer application for optimal crop production), but significant dependence on irrigation in southern regions (Tubiello et al. 2007a, b). Projections of changes in suitability of spring and winter wheat in Ukraine, under both rainfed and irrigated conditions, were computed for 2020, 2050 and 2080 projections with four different GCMs, and compared to the current climate (Tubiello and Fischer 2007).

An international team led by Boston University conducted a project studying the effects of land-use change on terrestrial carbon budgets in the Black Sea region. The region was selected because of reported intensive land-use/land-cover change activities following the collapse of the Soviet Union, as well as prior lack of attention to the temperate zone within NEESPI. The results indicate that both Romania and Georgia have low intensity forest-cover change between 1990 and 2000 but this activity increases with continued changes in forest management rules and political priorities in both countries. Remote sensing based analysis of Black Sea forests of Turkey at the southernmost limit of the NEESPI domain, on the other hand, shows very little to no change over the same time period, primarily because of strong government control of forest resources and obvious lack of post-soviet transformation. When these changes are incorporated within a well-established carbon model, results suggest that forests of all three countries act as a carbon sink at least for a few more decades (Baccini et al. 2008). These results improve our current knowledge of the region in terms of land-use dynamics and minimize the uncertainties associated with the carbon cycle dynamics related to land-use change. This research also included a significant methodological component to improve current ability to monitor change in temperate forests and also many other environments using remote sensing. For example, evaluation of the concept of signature extension from this region to other environments suggests that image seasonality, choice of atmospheric correction method, and input variables significantly affect classification accuracy across time and space. The gained experience helps advancing methods for semi-automated monitoring of environmental change.

The University of Wisconsin, Madison, in collaboration with German (Humboldt University in Berlin) and East European scientists, conducted a project on socio-economic effects on biodiversity in post-Soviet land-cover change in Eastern Europe during the last decade and developed some future scenarios. The results showed marked differences in forest cover, dominant forest species, and agricultural fragmentation. Project participants conclude that socialist forest management explains these differences. Post-socialist land-cover change was greatest in Ukraine, where there was high agricultural fragmentation and widespread early-succession shrublands indicating extensive land abandonment. The abundance and pattern of arable land and grassland were attributed to land tenure in socialist times and economic transition since 1990. These results suggest that broad-scale socioeconomic and political factors are of major significance for land-cover patterns in Eastern Europe. (Kuemmerle et al. 2007)

Flooding related to land-cover changes in the Carpathian mountains has been studied by University of Maryland's Appalachian Laboratory with the above mentioned Humboldt University-University of Wisconsin group in collaboration with scientists in Eastern Europe. The goal is to assess the potential hydrologic ramifications of recent changes associated with deforestation in this region. An analytical remote-sensing based approach is applied to the assessment of land-cover change in the High Tatras Mountains of Slovakia based on the forest disturbance index of Healey et al. (2005) and several other methods (e.g., Townsend et al. 2004; de Beurs and Townsend 2008). The team relates the landscape properties to differences in stream discharge among watersheds with differing disturbance histories. The Landsat images for the entire High Tatras region for three time periods (1990, 2000, 2005) are being processed. Historical daily stream discharge data for six catchments and daily precipitation data for 12 stations in this region were obtained from the Slovak Hydro-meteorological Institute. The next step is to conduct broader analysis of land-cover change using data generated by the German-University of Wisconsin team (Kuemmerle et al. 2007, 2008) to identify forested watersheds that have experienced relatively large changes in forest cover (either losses or gains) that may be related to increases in flooding in the Carpathian region. At present, that team has completed mapping for much of the region (especially Ukraine and Poland), with other areas still in development. The work on image acquisition and processing, including adding information from Slovakia to their database, is ongoing.

In a pilot project on Latvia, land-cover and land-use dynamics in 90,000-ha Gauja National Park (GNP) were examined for Latvia's Soviet-to-post-Soviet transition period from the mid-1980s through 2002. Land-cover change in the Park was assessed through analyses of Landsat TM images in conjunction with multiple ancillary Geographic Information Systems (GIS) data layers. Changes in land-cover composition and patterns were measured using post-classification change analyses and by computing landscape pattern metrics. Statistical regression models were developed to determine effects on the landscape of spatially explicit variables representing social, biophysical, geographic, and political drivers of land-cover change in GNP. Qualitative interviews were conducted to investigate GNP stakeholder group interests, and results from a landowner survey conducted by the GNP Administration were geocoded and statistically analyzed with respect to geographically explicit variables to understand important factors affecting landowner attitudes to GNP land-use policies. Land-cover change analyses showed an increase in forest cutting immediately after Latvia's independence in 1991, and, following, a consistent overall growth in forested lands, particularly in the more protected zones of the Park. A decrease in the amount of fields and meadows was evident since Latvian independence, resulting in a deterioration of Latvia's cultural landscape and the associated biodiversity. Regression analyses showed that the most important predictor variables of the type of land-cover change, on a per pixel basis, were the Park management zones in which the land was located, the distance from large water bodies, the distance to the nearest road, the municipality, and the slope of the land. Contrary to expectations, cross-tab analyses showed that landowners in zones with more land-use restrictions were more likely to be supportive of GNP land-use policies than were landowners in zones with fewer land-use restrictions (Taff 2005).

Land-cover/land-use change effects on water quality in Dnieper and Don river basins has been the subject of a project conducted at the University of Nebraska and South Dakota State University with collaborators in Ukraine and Russia with two objectives: (1) to assess the magnitude and variability of the linkage between LCLUC and dynamics of surface water quality, and (2) to develop the capability to use SeaWiFS and MODIS data to retrieve chlorophyll-a and suspended solids in turbid productive waters. The study area includes Don River Basin (450,000 km^2) and Dnieper River Basin (530,000 km^2) and uses 1982–2000 AVHRR NDVI datasets. For 2003 MODIS NBAR NDVI data are being used. Selected Landsat scenes 1974–2006 are also used in this study, especially studying water quality: 1982–2001 – MSS and TM Landsat data. For the period since 1997 SeaWiFS data are used and from 2001 to present the project employs MODIS data. The methodology is based on the statistical framework to partition the variation arising from interannual climatic variability, changes in sensors, and of institutional change (de Beurs and Henebry 2005). To retrieve chlorophyll-a concentrations from remotely sensed data an inversion technique is used described in Dall'Olmo and Gitelson (2005, 2006) and Gitelson et al. (2008). This study produced characterization of land surface phenologies in Don and Dnieper river basins using AVHRR image time series and developed calibration and validation of model for chlorophyll retrieval in a wide range of optical properties of water bodies. The current effort includes using Landsat image time series since 1982 to investigate changes in land cover at finer spatial resolution in areas of significant change identified in the coarser grained analysis. Additionally, the work will develop a change product for chlorophyll-a and total suspended matter concentrations in key Dnieper and Don reservoirs and Gulf of Taganrog. Within the project, atmospheric correction of MODIS ocean red and NIR radiances and algorithms calibration for chlorophyll and total suspended matter retrieval from MODIS imagery (see http://snr.unl.edu/neespi). Recently, two more projects on the non-boreal European NEESPI sub-region joined the program: a additional project on the changes in temperate forests was launched at the University of Wisconsin with European collaborators and a continuation project on interactions between land use and hydrology has started at the University of New Hampshire in collaboration with Russian scientists. Note that as a requirement to enter the program every NEESPI project has collaborators in the NEESPI region. The program is also growing; its members interact and build new teams and produce new exciting results. A synthesis paper of the results on non-boreal European NEESPI sub-region is expected over the course of next few years.

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Non-boreal Forests of Eastern Europe in a Changing World: The Role in the Earth System

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Abstract. In spite of the fact that forests of non-boreal Eastern Europe occupy relatively small areas and are extremely non-uniformly distributed across the region, they serve as a major stabilizing element of natural landscapes by regulating and protecting hydrological regimes of the territory, preventing soil erosion, maintaining major biogeochemical cycles of terrestrial ecosystems, and fulfilling many other resources like social, ecological and environmental services. Expected climate changes will very likely negatively impact the condition, functioning and resilience of the forests, particularly in the long run. The region requires a special program of adaptation of natural landscapes to, and mitigation of, the negative consequences of climate change. Such a program should include system activities directed to improving the ecological state of the region's territories and optimizing the structure of agroforestry landscapes, including development of complete systems of protective forests (shelter belts, afforestation of sands and ravine areas, etc.).

Keywords: forests, climate change, non-boreal Eastern Europe

Introduction

Non-boreal Eastern Europe (including Moldova, Ukraine, Belarus, South and South-Eastern European Russia, Georgia, Armenia and Azerbaidjan), is a region bounded by 40–55^{o} northern latitude (n.lat.) and 24–50^{o} eastern longitude (e.L.), that occupies the central and southern part of the Russian plain with three mountain regions, i.e., the Eastern Carpathian on the western edge, the Crimea, and the Caucasus in the south. The region includes the southern part of the temperate forest zone, transitional forest steppe, and almost completely two provinces of the steppe zone: Southern Russian and Near-Black Sea provinces (Kurnaev 1973). The territory's climate is substantially impacted by the Atlantic as humid air from the Mediterranean also comes quite often. However, anticyclones

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are rather frequent: in winter from Siberia and in summer from the Azores. This results in a relatively mild, moderately humid climate, although the continentality of the climate and lack of precipitation often occurs in vast territories of the region and substantially increases towards the south-east.

The region is situated in the most populated and industrially developed territories of the former USSR. Intensive agriculture is a specific feature of rural territories. Population density by administrative units on average varies from about 40 persons per square kilometer (km^2; Rostov oblast, Stavropol kray of Russia) to above 200 persons/km^2 (Donetsk oblast of Ukraine). The transformation level of land cover and natural vegetation is the highest in Europe. On average, about one fourth of the region's territory is under substantial industrial pressure – index of technogenic loads varies from about 10–20 in southern agricultural regions to 30–40 and more in industrial conglomerations in south-east Ukraine (Kljuev 2001).

The number, specifics, and distribution of forests in the region, from the total area of 65 million hectares (ha), substantially differ with bioclimatic zones. Pine forests mixed with spruce and birch are most presented in the northern part of the region and are transitional to the boreal zone. Broad-leaved mixed forests, dominated by oak and mixed with hornbeam, maple, ash, lime, etc., dominate in the subzones of deciduous forests and forest steppe as well as in the foothills of the mountains. Dark coniferous forests, dominated by spruce and fir, as a rule generate the altitudinal belt in the mountains. Intensive harvest in the past caused the low average age of forests in plain territories (e.g., 50 years in Ukraine, 40 in Moldova, 45 in Belarus). The average age of forests of the Caucasian countries is higher, and in the range of 85–100 years. A distinguishing feature of the region's forests is the high share of planted forests (e.g., close to 50% in Ukraine).

The productivity of forests is high (average growing stock volume is ~190 m^3 ha^{-1} in Ukraine, from 120 to 160 m^3 ha^{-1} in territories of other countries of the region). Average density of forest live biomass varies from 4.5 kg C m^{-2} in Moldova to 6.4 kg C m^{-2} in Ukraine. Net primary production on average varies from 400 to 600 g C m^{-2} $year^{-1}$, with the highest country-wide average in Ukraine's forests (545 g C m^{-2} $year^{-1}$). The annual net growth of the countries varies from ~2.0 to 3.5 m^3 $year^{-1}$. The annual total harvest (including thinning) did not exceed 70% during the last decades. Such dynamics provide a substantial amount of carbon sequestration and, as a rule, the forests serve as a net carbon sink from 0.7 to 2.0 t C ha^{-1} $year^{-1}$ (Lakida et al. 1995; Lakida 2003; Shvidenko et al. 2008a, b).

Irregularity of the spatial distribution of forests, with an overall decreasing forested area from north to south, is a distinguishing feature of the land cover. While forest cover percentage (FCP) of Belarus and Central Federal *okrug* of Russia is 38% and 35%, respectively, this indicator for Ukraine is 15.7% (together with shelter belts and other tree dominated protective components of landscapes), Moldova 10.0% and Southern Federal *okrug* of Russia 7.4%. The southern steppe in Ukraine is practically forestless (four administrative regions have FCP less than 5% – Dnepropetrovsk 4.8%, Zaporizzja 3.9%, Mikolaev 3.9%, Kherson 4.6%, and another three with 5–10%). Further to the east, in southern European Russia, the amount of forest even deceases – the FCP in Rostov oblast' is 2.5%, Astrakan' 1.8%, Stavropol 1.5%, and Kalmikia 0.2%. These four regions have the lowest FCP over the whole of Russia. FCP is low in the mountains of Armenia and Azerbaidjan with 10.0% and 11.3% respectively, and only Georgia's forests occupy 39.7%. Overall, the number of forests in major territories of the region is not sufficient to provide satisfactory protection of the land and the environment.

The Role of Forests in the Region

The specifics of the region define the special role that forests have in the functioning of natural landscapes and particular features of societal requirements to forest services and, consequently, to predicting future trajectories of non-boreal forests in a changing world. In addition, ongoing political, social, and economic changes in the region's countries impact the transition to sustainable forest management under global change, mostly in a negative way.

Forest ecosystems of the region are a source of wood from valuable tree species as well as diverse non-wood forest products. However, the pivotal importance of forests and trees outside of forests is in their role of being the major stabilizing element of the environment. Forests of the region play an exceptionally important role in the stabilization and regulation of interactions of the major ecological systems of the biosphere: water protection and water regulation, prevention of soil erosion against water and wind elements, maintenance of major biogeochemical cycles, sanitation, recreation and many other diverse services. Over the last 20 years, the area of protective forests throughout the region has nearly doubled, mainly at the expense of forests which were formerly industrially exploited.

The role of forests is highlighted by the overall unsatisfactory state of the environment in the region. So, the area of critical ecological situations in the Russian part of the region exceeds a quarter of the territory (Kljuev 2001). The situation in Ukraine is not better: due to recent estimates, 11% of the entire country's territory has a favorable ecological condition, 18% satisfactory, 22% conflict situation, 25% before-crises, and 24% crises state (Yukhnovsky 2003).

The processes of active degradation of soil cover, particularly of agricultural lands (increasing soil erosion; negative transformation of soil water regime; desertification; contamination; dehumification and decline of humus horizon; secondary carbonization; losses of nutrients, etc.) are typical for land in practically all densely populated areas. This is accelerated by the negative structure of agricultural landscapes (the share of ploughed agricultural land in major agricultural territories of European Russia is in the range 60–70%). There the area of agricultural and arable lands threatened by erosion comprises 65% and 75%, respectively. More than 50 million hectares of agricultural land (including 35 million hectares of arable land) suffers from water and wind erosion basically in regions of steppe and semi-desert zones. This leads to annual decreases of the humus content on arable land at 0.7 t ha^{-1}. About 45% of arable land has an insufficient amount of humus. Intensive processes of desertification are observed in practically all administrative regions of the southern part of the region. The first desert in Europe has arisen and is dramatically increasing in Kalmykia and along the lower areas of the Volga River. The areas of salty soil are increasing in many regions, particularly on irrigated land. Many regions suffer from soil contamination by heavy metals, sulfur, radionuclides, and other industrial impacts (Shvidenko 2006).

Ukraine could serve as a second illustrative and typical example. The quality of agricultural arable lands, accounting now for 69.5% of the total land fund of the country, was historically classified as the best in the world (68% of arable lands are represented by the famous Ukrainian *chernozyom* – "black fertile soils"). However, in previous decades agricultural lands have been gradually and steadily deteriorating. The share of plough lands is 57.5% of the total land area, and approximately 80% for agricultural lands. This is the highest index in the world. In the USA, for instance, plough lands constitute only 15.8% of the entire territory and in the developed countries of Europe their share does not exceed 32%, while in the southern regions of Ukraine–Kherson, Cherkas, Kirovograd, Vinnitsa and Zaporizja *oblasts* – plough lands account for 85–89%. In order to provide sustainable use of agricultural land, the share of arable lands, by major bioclimatic zones of Ukraine, should constitute: for Polissja (southern part of forest zone) 15–25% of the total area, for forest steppe and northern steppe 40–45%, southern steppe 35–40%, and dry steppe 25–35%. Due to this estimate, in order to stabilize condition of soils, the total area of arable lands should be reduced in Ukraine to almost 10 million hectares (Medvedev and Laktionova 1998). In the 20 years between 1961 and 1981, the content of humus in the soil decreased from 3.5% to 3.2%. Erosion has affected 32.8% of plough land, and the territory of eroded and washed-away lands has grown in the last 25 years by a quarter. Lands of deflation constitute 54.2%, acid lands and heavily saline lands account for 41.9%. An intensive ravine-formation process involves 18% of the total land area, and the area of eroded lands, according to the estimates from the mid 1990s, is annually increasing by 80–100,000 ha (MEPRS 1992–1997). Although areas of irrigated land somewhat decreased (from 15% to 25% during 1991–2000), irrigation impacts the irrigated agriculture soils in a clearly negative way. During recent years, the level of air pollution, water and soil contamination remains high, and even increases in some regions.

The condition of the atmosphere, rivers and water reservoirs is unsatisfactory across territories of the region. In spite of the considerable recession in industrial production during the last decade of the twentieth century, the level of atmospheric pollution in towns of the Donetsko–Pridnieprovsky industrial region of Ukraine several times exceeds the maximal admissible allowable concentration with respect to many substances (sulphur, zinc, lead, etc.). Hydrobiological observations that were conducted on 59 rivers and water reservoirs of Ukraine did not reveal a single case where the water quality could be classified as "pure".

Water of all rivers in the Rostov region can be classified as “moderately contaminated” to “heavily contaminated” (Kljuev 2001). The problem of water supply remains precarious in large territories of the south and south-east, particularly in the industrial regions.

Three countries of the region; almost all of Belarus, 17 administrative regions in Ukraine, and 14 adjoining regions of Russia are facing specific problems resulting from the explosion at the Chernobyl atomic power station, the consequences of which have affected or are likely to affect the lives of more than 35 million people. Currently, the area of radioactive contaminated forests comprises about 3.5 million hectares in Ukraine, about 2 million hectares in Belarus, and above 0.5 million hectares in Russia. Almost half of these territories have substantial restrictions on forest management activities and use of forest products, and about 350,000ha (where the level of contamination exceeds 15 Ki/km^{-2}) are completely excluded from any use.

Due to the high capacity of forests to absorb radionuclides and to involve these in interim biological turnover, forest ecosystems serve an efficient biogeochemical barrier which plays a substantial role in regulation of nuclear fall-out on territories that suffered from nuclear accidents, both in short and long terms. Having accumulated 80% of the Chernobyl accident’s radionuclides, the forest in contaminated areas is currently a stable radiation source. This also needs care and protection (Ipatyev 1999).

Environment pollution caused by various chemical and radioactive substances possesses high synergism, which endangers the health of the nation as a whole. This is among the principal social problems in the Ukraine, Belarus and adjoining regions of Russia. In recent years, an increase has been observed in the incidence of blood infections, cancer, inborn pathological conditions in children, and other diseases (MEPRS 1992–1997).

During the last decades, two processes contributed to land use and land cover change in the region. About 15 million hectares of forests have been planted after 1950s. During the Soviet era, some parts of the region (mostly in Ukraine, Moldova, and southern European Russia) have accumulated unique experiences of successful soil erosion control and demonstrated impressive results in improving the structure of their natural landscapes through massive forest planting under difficult climatic conditions of the steppe zone. For instance, almost 200,000 ha have been afforested at wind-blown sands in the lower streams of the Dnieper River, along the Siverski Donets, along the Dniper–Donbass canal and elsewhere. Complete systems of field-protecting (shelterbelt) plantations have been developed in territories of nearly 4,000 agricultural enterprises. About 1.6 million hectares of protected forests are growing on the lands of agricultural enterprises, including 150,000 ha of shelter belts along the banks of small rivers, and 440,000 ha of agro-protective shelter belts which protect 13 million hectares of arable lands. Large areas of shelter belts have been developed in other steppe and forest steppe areas of the region. However, political, social and economic changes of the last 2 decades substantially halted these activities and any proper management of forest and tree dominated systems of agroforestry landscapes is practically absent now. Information about the state of protective tree elements of agricultural landscapes is incomplete and obsolete.

Another consequence of recent developments is the large area of abandoned lands which have arisen on previous agriculture land during 1900s–2005. The area of such lands in the region is estimated at about 12 million hectares. These lands are not managed and they become infested with weeds and rodents.

Climate Change's Impacts, Adaptation and Mitigation Measures

The warming trend across the region is well documented, about +1°C for the twentieth century (Gruza and Ran'kova 2001), with a considerable higher trend during the recent period of 1979–2003 +0.4°C/decade (Jones and Moberg 2003). The temperature is increasing more in winter than summer. For about 95% of the entire territory, the precipitation trend is the opposite: the annual amount of precipitation remains stable or slightly decreases. All climatic predictions for the region confirm these trends in future – increase in the temperature and decrease in the amount of precipitation. Such trends will lead to a substantial increase in aridity. A typical picture is revealed in the territories of Ukraine. We used two periods for analysis: 1950–2000 for describing the "current climate" and a prediction for 2020 ("future climate"). The latter has been done based on the model HADCM3, IPCC Scenario A2A. The climatic data was used from *worldclim.org* (Hijmans et al. 2005).The following conclusions resulted from this analysis.

1. A substantial increase in temperature is expected practically over the whole region, particularly in the southern part. The annual average temperature is expected to increase by 20% (from 7.5°C to 9.0°C). A similar trend is expected for summed degree days' temperatures during the growth period (April–September).
2. An opposite tendency is predicted for precipitation: the amount of precipitation tends to slightly decrease (several percents) for both the annual amount and for the growth period, particularly in the southern regions, which experience a lack of precipitation even under "current" climate.

The tendency of increasing climate aridity becomes more evident if we compare the change in heat and hydrological regimes during the growth period. Figure 13.1 contains the difference of hydrothermal index between "current" and "future" climates $HTI = 10\ \Sigma\ P/sumT$ where P and $sumT$ are total amount of precipitation and sum of daily temperature for the period from April to September, respectively. For the entire area of Ukraine, the difference is negative and clearly shows increasing climate aridity over all the country. The above tendencies become stronger in the long-term – by the middle and end of the current century.

Assessments of the impacts of climate change on the environment and vegetation of Ukraine that were made based on a number of IPCC Scenarios (A1F1, A2, B2 and B1) and an ensemble of global circulation models showed that the adverse effects of a long period of climate change will very likely be even worse than the considered above change until 2030 (Ruosteenoja et al. 2003). Overall, the major impacts of climate change on East-European forests are diverse, involving zones, sites and forest type specifics, and include:

- Geographical and landscape changes in the location of areas suitable for the growth of certain tree species (shift or disappearance of some productive species)
- Changes in type, extent and severity of disturbance regimes (pest and diseases outbreaks, forest fire, etc.)
- Increases or decreases in nutrient retention and turnover
- Increases or decreases in stability and vitality of forest ecosystems, as well as changes in the production of timber and non-wood product per unit area; balance forecasts of the above processes for the region are mostly negative
- Alteration of ecosystem ecological functions (e.g., impacts on biogeochemical cycles; impacts on biodiversity) and
- Changes in species' reproduction cycles, regularities of succession dynamics, and changes in environmental and social services (e.g., changing values of forest ecosystem as a tourist attraction, vitality and resilience of shelter belts, etc.)

Fig. 13.1. Difference of HTI for growth period (April–September) between prediction from 2020 and average for the period 1950–2000.

Overall, the expected impacts are mostly negative and require development of special adaptation and mitigation measures. Taking into account specifics and the role of the region's forests, adaptation and mitigation measures in the forest sector should be part of a wider strategy which would involve all relevant sectors of national economy, particularly energy, industry, agriculture, tourism, etc., combined with common political and institutional frameworks.

The identification of activities and strategy that are able to provide minimizing negative consequences of climate change is a primary task of adaptation. The overall goals of a relevant adaptation and mitigation strategy in the region are maintenance and improvement of environmental services of forests (impacts on major biogeochemical cycles, biodiversity, water protection, soil protection, others); resource services (production of wood, non-wood forest products, hunting); and other socioeconomic functions (recreation, social interaction with agricultural and forest industry sectors, etc.). Major adaptation and mitigation measures include the following major options.

Optimization of the structure of agro-forestry landscapes

There is a common opinion that the existing area of forests in the region (outside the forest zone) is not sufficient for environmental protection. While recommendations of different studies vary, the overall background is that on average the optimal forest cover by bioclimatic zones should be from 7–10% in plain territories and 12–20% in hilly territories of the steppe zone, depending on soil and slope; about 25–30% in forest steppe; and 40–50% in mountains (e.g., Pasternak et al. 1987). For instance, the regional estimates for Ukraine suggested that 7.7 million hectares of new protective forests should be planted during the next 30 years that would result in an average FCP of 25% (Pilipenko and Yukhnovsky 1998; Yukhnovsky 2003). A very important component is a mixture of agroforestry measures for the protection of agricultural land from erosion (anti-erosion plantations on degraded lands, shelter belts). However, after the 1990s, anthropogenic pressure, decreased governance in agriculture and a negative socioeconomic condition of the region's countries resulted in a decrease in the field protective forest cover from 1.5% to 1.3% under the optimal value of 3–3.5% (Yukhnovsky 2003). Under current circumstances, when neither renovation of the agricultural machinery is possible in a short period of time nor any shifts from unsatisfactory agricultural management, forests and shelter belts remain the only reliable method of protecting soils from erosion and agricultural landscapes from deterioration. The countries of the region took a number of decisions on the topic at the top level. However, practically all these decisions have been realized to an insignificant extent.

Increase in productivity of existing forests

Practically all of the measures aiming at increasing forest productivity are coherent with the carbon management paradigm and maintain the environmental services of forests. They include:

1. Use of genetically improved seeds and seedlings
2. Introduction of tree species with high productivity and vitality in conditions of a changing environment
3. Optimization of species composition of planted forests
4. Development of special carbon sequestering plantations with a short rotation period
5. Improvement of forest management regimes aiming at optimization of stand structure
6. Use of mineral fertilizers
7. Optimization of major technical indicators regulating sustainable forest harvest (e.g., age of final felling) and
8. Introduction of ecologically safety technologies of final felling (particularly using a combination of clear, gradual and selective cutting) in forests of different regions, species and functional destination

Improvement of the protection of forests

Substantial areas of forests are affected by pests and diseases (e.g., about 1.5 million hectares in 2004). The changing climate decreases resilience and vitality of forests in many large regions. For instance, the process of drying spruce stands in Carpathian is accelerated, particularly in secondary forests which were developed outside indigenous sites. The planted forests developed in harsh growing conditions (e.g., on bare sands) require specific anticipatory protection measures. Forest fires become more dangerous taking into account increasing aridity of the climate. The majority of ignitions is provided by the population that proves the insufficient level of ecological education of the population. Forest protection monitoring needs substantial improvements.

Management of forests and landscapes contaminated by radionuclides

The sanitary state of territories which have been excluded from any use is not sufficient. Dead stands are the source of a high fire threat. Weeds on former agricultural lands are also the source of secondary contamination. Natural forest regeneration was insufficient in these areas during the last year. Afforestation remains the only way for improving the environmental condition. There are plans to plant forests on land contaminated by radionuclides inside the abandonment zone (so-called "30 km zone"), but it will require special technologies and machinery. The major goals of adaptation and mitigation measures here includes: (a) fixation of radioactive substances in forest ecosystems; (b) regulation of run-off and decreasing wash-out of radionuclides, (c) decreasing wind and water erosion, and (d) transformation of contaminated agricultural lands in forests and natural grasslands. The continuity of forests and avoiding forest fires are the major tasks.

Improvement, scientific and information support of forest management

Measures for increasing the productivity and vitality of forests requires relevant improvements in forest management regimes, manuals and instructions (e.g., regulation of harvest age; regulation of age distribution of forests; requirements for the optimal relative stocking of stands; rules for forest protection; availability of forests for recreation; etc.). Research and information support should be oriented to appropriate fields of selection, development of plantations, new methods of forest protection against pests and diseases; etc.

Conclusions

Forests of non-boreal regions of Eastern Europe are one of the major factors which maintain the regional stability of the biosphere: they serve as a major stabilizing element of the environment. This role is strengthened by the unsatisfactory ecological state of major parts of the region's territories.

Forest ecosystems substantially impact major biogeochemical cycles. They serve as a net sink of carbon, on average ~70 Tg C year^{-1}. However, the pivotal impact of forests on major biogeochemical cycles is revealed in maintaining the stability of agricultural landscapes. Potentially, under sustainable land use, the impact of forests on the global carbon cycle could be two or three times higher than the impact of forests themselves.

Very likely, climate change will provide mostly negative impacts on forests, particularly in southern parts of the region that has forest cover which is clearly not satisfactory for protecting the environment. In addition, the current management of regional forests and tree dominated protective elements on agricultural landscapes is far from sufficient. The strategic problem of the region is the need for development and implementation of a program for improving the structure of agroforestry landscapes. Such a program should include substantially increasing areas of protective forests and shelterbelts and consider relevant measures of adaptation of forests to, and mitigation of, negative impacts of climate change.

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Global Land Project: Major Scientific Questions for Coupled Modeling of Land Systems

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Abstract. This chapter describes some scientific challenges for coupled modeling of land systems at the interface of human and environmental systems. These include examining the character and operation of drivers of change and processes representation of drivers in models. A variety of examples of land use change, primarily from rural areas, are used to examine drivers of land use change and identify processes. The drivers examined are (i) technology, (ii) economic and structural/policy, and (iii) societal factors. These identify processes of innovation, adoption and diffusion, in relation to technology, and decision making for all socio-economic drivers. Decision making is founded on both economic and social criteria, including individual preferences, values and behaviours that influence choice and decision-making.

Keywords: land system, drivers of change, Scotland

Introduction

This chapter explores challenges for coupled modeling of land systems as coupled human and environmental systems. Case studies and meta-analyses of land change have provided insight into factors that lead to change, allowing generalization about the nature and extent of factors as 'drivers of change' and their operation at a variety of space, time, and organizational scales. Geist and Lambin identify a small set of underlying causes of change common to 152 published studies of tropical deforestation (Geist and Lambin 2002) and 132 studies of desertification (Geist and Lambin 2004). A similar analysis of 91 published studies of agricultural land intensification in the tropics recorded a detailed and varied list of drivers associated with agricultural intensification (Keys and McConnell 2005). Underlying causes are described as ultimate factors and represent fundamental causes of change. Five broad groups of underlying factors are common to these three meta-analyses:

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demographic, economic (including markets), technological, policy and institutional, and cultural. Environmental change, identified through climatic factors for case studies of desertification, can also be included.

In this paper, examples are used to identify some of the processes behind these drivers of change. The intention is to establish a process-based view of drivers of change to support analysis and modeling of change in land systems as coupled human and natural systems. The examples focus on the varied processes that produce changes with the aim of developing a process-based explanation, rather than a factor or driver-based account, of land change. The data used for several examples are for agricultural land use in Scotland and have been collected annually since 1866 in the Agricultural (June) Census.

Drivers and Processes of Change

Examples of change associated with (i) technology, (ii) economic and structural/ policy, and (iii) societal factors identify processes that result in change.

Technological change

Technological change is a significant driver of change in land cover and land use and represents innovation through development and application of new technologies. In addition to change in use or cover, diffusion and adoption of new technologies can also produce changes in land management practices without major change in land use or land cover.

Crop breeding and yield/production

In the period after the Second World War considerable efforts were put into improving agricultural production. Technological innovation improved crop yields through development of new crop cultivars, changes in husbandry and other land management practices, use of synthetic pesticides and herbicides, and changes in the nature and use of fertilizers. Technological change also included investment to grow and develop institutions focused on R&D to support the goal of increased agricultural production.

Barley, oats, wheat, turnips, and potatoes are all major crops in Scotland. Figure 14.1 shows the annual mean yield (tonnes/hectare) for wheat, oats and barley; yields have increased notably since the 1950s. Although total production has fluctuated, partly in response to other drivers of change, including structural and policy changes and economic change related to market demands, the general pattern of post-war technological change is clearly seen. Models that can accommodate this form of technological development are needed.

Mechanization of agriculture

Combustion engines provided a technology that produced a step change in the nature of cultivation and harvesting practices in many land uses, but notably in agriculture. The pattern of impact of this technological change was closely related to the cost of the technology and to its diffusion and adoption into agricultural practice. Figure 14.2 shows the number of horses in agricultural use, and number of tractors and combine harvesters in Scotland and the pattern of change in each over time. Number of horses in agricultural use appears to have been relatively constant during the nineteenth century, statistical accounts from 1810 reporting about 250,000 horses. A decline in horse use from the 1920s onwards was reported in survey reports which include notes identifying increased mechanization of agriculture and associated decline in horse use from 1921 (before statistics on tractors and combines were systematically collected). Tractor and combine numbers (and use) increased rapidly immediately after World War 2. The consequence of this change in technology was transforming, for both agricultural land use and for landscapes since mechanization was more efficient with larger fields and with single crops.

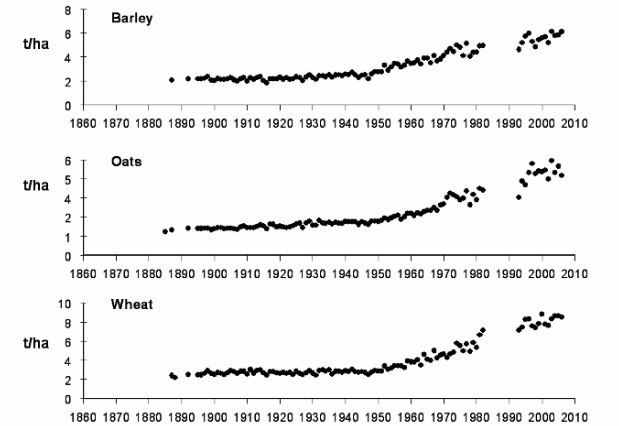

Fig. 14.1. Mean annual yields for barley, oats and wheat fro Scotland from the late nineteenth century to 2007.

The major processes associated with technological change for these examples include *innovation* in technology, developing new techniques, practices, and other technologies, and then *adoption* and *diffusion* of these new technologies into farming practices.

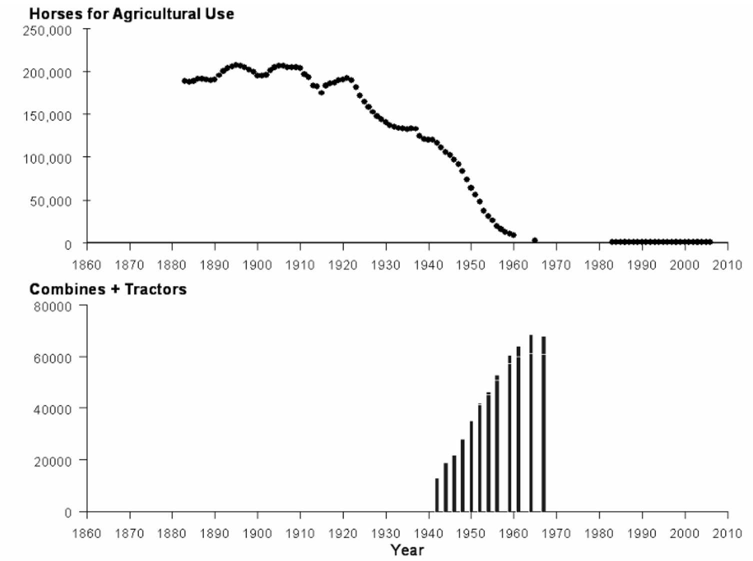

Fig. 14.2. Horses for agricultural use and combine/tractor numbers (1940s–1970s) for Scotland.

Economic change and structural/policy change

The Common Agricultural Policy of the EU provides an example of a structural mechanism intended to achieve specific goals (and other outcomes) related to agricultural production (Clark et al. 1997) and has had major consequences for land use and land cover across Europe. One example of the operation of CAP is provided by set-aside.

Set-aside

Overproduction was a consequence of the Common Agricultural Policy and protection of markets in the 1980s. Set-aside was a policy introduced in the European Union in 1988, initially for 5 years, but then as a comprehensive scheme following the McSharry reforms in 1992. The primary goal of set-aside was to control the production of surplus cereals in European agriculture. Secondary objectives of set-aside policy were the promotion of environmental improvement (Sotherton 1998; Hansson and Fogelfors 1998) and production of industrial crops (Entwistle et al. 1998).

Figure 14.3 shows the area of set-aside (and bare ground/fallow) by year for Scotland. The impact of the introduction of the voluntary (5-year) scheme and the McSharry reforms are clearly seen in an increase in the area of land in these categories. Bare ground/fallow was recorded at a reasonably consistent area of about 0.2% (sd 1.6%, maximum 1.2%) of the total area of crops and grassland from the late nineteenth century until 1988. The increase from 1989 is clearly evident and was at an average of 4.0% (sd 1.5%, maximum 5.6%) of the total area of crops and grassland between 1989 and 2006.

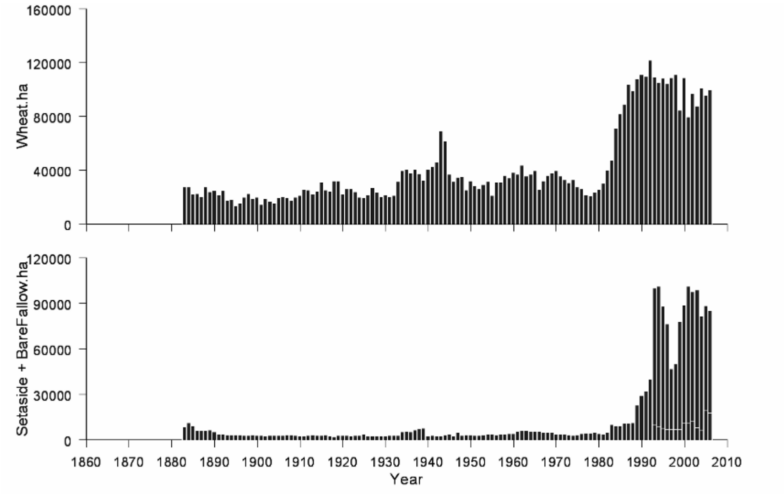

Fig. 14.3. Bare fallow and set-aside land (*lower graph*) and area of wheat (*upper graph*) in Scotland from the late nineteenth century to 2007.

Set-aside shows the operation of structural (policy) and economic change. The process by which set-aside policy is implemented at farm and landscape scales includes farmer *decision-making* as a *response to incentives* (payments for set-aside) that support the policy.

Societal change

Amenity and lifestyle have emerged as important criteria in choices that lead to change in land use and land cover. This is particularly apparent in areas of high scenic quality, such as the Rocky Mountains in the USA (Gude et al. 2006; Rasker 1993), but also in areas with particularly attractive cultural identity associated with lifestyle (Mather 2001), or other environmental quality (Johnson and Maxwell 2001; Marcouiller et al. 2002). Decision-making around lifestyles is complex and associated with a variety of factors including length of residency (Johnston et al. 2003).

Gallatin County in the Rocky Mountains of Montana, USA, has experienced rapid population growth and associated expansion of rural homes (Hansen et al. 2005). An empirical modeling study for the area explored a series of different models reflecting drivers of change at different periods in the history of the area

(Aspinall 2004). Time-period specific models provide multiple working hypotheses describing the effects social, economic and environmental drivers of land use change, and temporal changes in the effects of the spatial variables as the drivers of change evolve over time. Results show that models are not invariant over time and that amenity factors were found to be of importance in changes that took place since 1966, and particularly since 1985 (Aspinall 2004).

Amenity and lifestyle, as social drivers of change, operate through *individual preferences* and circumstances influencing *choice and decision-making* (Pichon 1996). Developing a process-based understanding of amenity and lifestyle as elements of a suite of social drivers of land change requires attention to decision-making.

Discussion

Analysis and modeling of land use change, for understanding past changes and projection of possible future changes, should draw on a broad range of scientific methodologies and enabling technologies, and must adopt a fully integrated approach that couples human and environmental science perspectives (GLP 2005). Identification of a suite of common underlying factors and drivers from case studies provides an ability to generalize beyond case studies and a framework for comparative analysis and synthesis of change and reasons for change. To expand analysis and modeling of land change requires, however, approaches that move beyond empirical analysis of specific case studies to more generalized approaches based in theories that can address land systems as linked human and environmental systems. A process-based understanding of drivers of change is necessary for this.

In addition to a process-based understanding, a range of other issues needs to be addressed to support research on dynamics of land change, especially if the goals are improved understanding of processes and changes produced and better modeling of place-based change in land systems. For example, it is recognized that change in land systems, and in land use and land cover, are inherently spatial and dynamic. The magnitude and impact of changes in land use and cover are such that land use change is global in extent and impact (Foley et al. 2005). Land use dynamics is also recognized as a grand challenge in environmental science (NRC 2001) and is central to the International Human Dimensions Programme/International Geosphere-Biosphere Programme Global Land Project (GLP 2005), as it was to the Land-Use and Land-Cover Change (LUCC) program from 1995 to 2005 (Lambin and Geist 2006). Study of land use dynamics is complex since land use systems, as well as the underlying factors and processes may change through time. This produces a variety of path dependence (Brown et al. 2005) and legacy effects (Aspinall 2004), resulting in land use patterns and systems that may reflect a variety of not only contemporary processes, but also processes and responses to historic drivers of change. Additionally, change may be gradual or episodic (Lambin et al. 2003).

To address processes, as well as the influence of scale in space, time and organization, will require new experimental and observational designs as well as research protocols that support quantitative and qualitative analysis of change. This will enable closer and direct comparison of results from different case studies, leading to improved meta-analyses and synthesis between case studies. There is also a need for research into how spatial and temporal dynamics might best be represented to support quantitative and qualitative analysis. Other issues that land system research should aim to address includes differences and inter-relationships between land use and land cover (Brown and Duh 2004; Brown et al. 2000), the interaction of socioeconomic and biophysical processes (Riebsame et al. 1996), the multiple spatial and temporal scales at which processes operate (Walsh et al. 1999) and their interaction across multiple organizational levels (Bousquet and Le Page 2004), as well as the importance of individual, social, demographic, economic, political, and cultural factors in decision making (Geist and Lambin 2002, 2004).

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Assessment of Ukrainian Forests Vulnerability to Climate Change

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Abstract. This is an investigation on forest vulnerability and possible adaptations strategy to the climate change impacts in the Ukraine. Estimations are made for potential forests distribution, main tree species distribution, forests growth response and economic impacts, based upon a baseline climatic scenario, as well as scenarios based on CCCM, GISS, GFDL and UK89 models. The data source of estimation consists of mean monthly temperature and precipitation data from 66 meteorological stations in Ukraine. These input variables are averaged observations data from 1951 to 1980. The next step is a comparable analysis of the values obtained with estimates that use the same methods, but for global data at 0.5° × 0.5° spatial resolution. The Holdridge life zones classification model and original Vorobjov climates' classification model by forest types were both used to map potential land cover. A study of differences between the models shows that the Vorobjov model is more detailed in terms of forest types. Yet, the model can not be used correctly outside of its empirical validation area, i.e. sub polar, boreal and partially cool temperate latitudinal belts of Europe and Asia. Maps of potential forest distribution prepared with Holdridge and Vorobjov classification models were used for direct impact assessment and to find regional analogies of present and future climate. For projecting species distribution was used an empirical model of species potential climatic ranges, based on mapping of current species ranges and the Vorobjov classification model's climatic variables. An evaluation of economic impacts was based on differences of conditional income between mixed forest, forest steppe and steppe forestry management models. Changes in the proportion of territories occupied by different forestry management models impose changes on overall and local conditional income. Potential biological productivity of forests in climate change condition is difficult to estimate because of the lack of an appropriate analytical model. Modeling of forests dynamics has been done with help of computer program for implementing Gap models. This program was adopted for defining initial forest stand composition and tree age distribution.

Keywords: forest vulnerability, climate change impact, Ukraine

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Materials and Methods

Climatic input to the models

The source data base consists of mean monthly temperature and precipitation data of observations from 1951 to 1980 from 66 meteorological stations of Ukraine. Averages of these data compose a baseline climatic scenario and were used to develop climatic scenarios from CCCM, GISS, GFDL and UK89 models.

The geostatistical kriging method with a linear variogram is used for two dimensional interpolation of climatic variables from irregularly spaced climatic data. Kriging produces a regularly spaced array of values of a climatic variable. These data are input to a smooth surface model. Thus, with the use of a smooth surface model for a climatic variable evaluation a climatic variable with the required resolution has been done. This is important particularly for calculating boundaries of climatic zones. The global data was modeled with the same technique. Still, the reliability of interpolation of the results required evaluation.

Vorobjov climate classification by forest types

Professor Dmitriy Vorobjov [3, 6] has established accurate dependences between a climate and distribution of types of forest. For territory of the former USSR he has analyzed a considerable quantity of an empirical material and has proved that the climate is one of the primary factors defining formation and distribution of forest types. In the humidity climatic conditions, especially moist forest types are formed in these conditions, than the climatic conditions are warmer, especially rich forest types are formed in such conditions.

The type of forest that grows at a flat site on a primary relief with undisturbed soils indicates the forest type of the climate. This type of forest is known as a zonal type of forest. There are many other types of forest in this climate, but their variability depends on relief, soil and water conditions. For example, one zonal type of forest in the Ukrainian steppe is dry grud (see Table 15.2). But there in the valleys we can see fresh grud and at the bottomland wet grud occurs.

Two climatic indices are used to describe forest type of climate. These are heat index T and humidity index W. Heat index is the annual sum of mean monthly temperatures for months with positive mean monthly temperature. Vorobjov climate humidity index is $W = R/T - 0.0286 * T$, where R is sum of precipitation values for months with positive mean monthly temperature.

Scales of variables W (Table 15.1) and T (Table 15.2) form a grid of Vorobjov climates. Grades on T scale are equal to 20°C and grades on W scale are equal to 1.4. Each cell has its own code that is formed of a digit corresponding to humidity index on W scale, and a letter corresponding to heat index on T scale (e.g. **1d**, **2e**).

Table 15.1. Scale of humidity index **W** of the Vorobjov classification.

Index	Range	Name for humidity index
−3	−6.4 −5.0	Ultra dry
−2	−5.1 −3.6	Extremely dry
−1	−3.7 −2.2	Particularly dry
0	−2.3 −0.8	Very dry
1	−0.9 0.6	Dry
2	0.7 2.0	Fresh
3	2.1 3.4	Moist
4	3.5 4.8	Damp
5	4.9 6.2	Wet

Table 15.2. Scale of heat index **T** of the Vorobjov classification.

Index	Range	Name of corresponding forest type or non-forest zone
a	24–44	Bor (original name in Russian)
b	45–64	Subor (original name in Russian)
c	65–84	Sugrud (original name in Russian)
d	85–104	Grud (original name in Russian)
e	105–124	Steppe
f	125–144	Dry steppe
g	145–164	Semi desert
h	165–184	Deserts

The spoken name for a zonal forest type is composed of a humidity index name (Table 15.1) and a forest type or non forested natural zone name (Table 15.2). For example, forest types are damp bor, fresh subor, very dry steppe. Names “bor”, “subor”, “grud” and “sugrud” are original names introduced by Ukrainian forest typologists Alekseyev, Pogrebnjak, Vorobjov (see Appendix). Actually, these names are referring to forest types with soil fertility: name “bor” is associated with forest growing in poor soil conditions and “grud” with the most fertile soil condition. Subor and sugrud are in an intermediate condition between “bor” and “grud”. Originally, these names were used for edaphic gridding of forest sites.

Silviculture practice shows that it is possible to derive from a zonal type of forest all of the types of forest that can occur in a chosen forest climate zone. It is key to projecting changes of vegetation pattern in terms of forest types. Distribution of forest forming species relates with the zonal type of forest too, and additionally it is restricted by the continentality index of climate (see below). Continentality index A is a difference between mean monthly temperature of most warm and most cold months.

The Vorobjov climates classification is empirically validated for sub polar, boreal and partially cool temperate latitudinal belts of Europe and Asia within the boundaries of former USSR. The original forest types climates grid did not include the negative heat indices and humidity indices **e**, **f**, **g**, **h**. They were added and partially validated in later research work [4].

Holdridge life zones classification model for Ukraine

The Holdridge life zones [2] have been defined for Ukraine on the base of annual precipitation and biotemperature data – both for current and for projected climate condition. There are seven different Holdridge life zones has been defined for territory of Ukraine: Cool Temperate Steppe (index 14), Cool Temperate Moist Forest (index 15), Cool Temperate Wet Forest (index 16), Warm Temperate Desert Scrub (index 19), Warm Temperate Thorn Steppe (index 20), Warm Temperate Dry Forest (index 21), and Subtropical Thorn Woodland (index 27).

Study of differences between the Holdridge life zones classification model and the Vorobjov climates classification by forest types shows that the Vorobjov model is more detailed in terms of forest types. Yet, the model may not be used correctly outside its empirical validation area which is the sub polar, boreal and partially cool temperate latitudinal belts of Europe and Asia. General approach for methodology of forest vulnerability assessment has been described in [1].

Results

Vorobjov model of contemporary Ukrainian climate

On the basis of the actual long-term meteorological database the model of zonal types of forest for contemporary Ukrainian climatic has been constructed with help of a personal geographic information system (Fig. 15.1). The constructed model of contemporary Ukrainian climatic reflects realistically the distribution of zonal types of forest in Ukraine.

Model of species potential climatic ranges

The location to develop the model for a given species is within the geographical boundaries of the species range where it forms forest stands. A set of combinations of climatic indices **W**, **T** and **A** at points within species range forms a unique

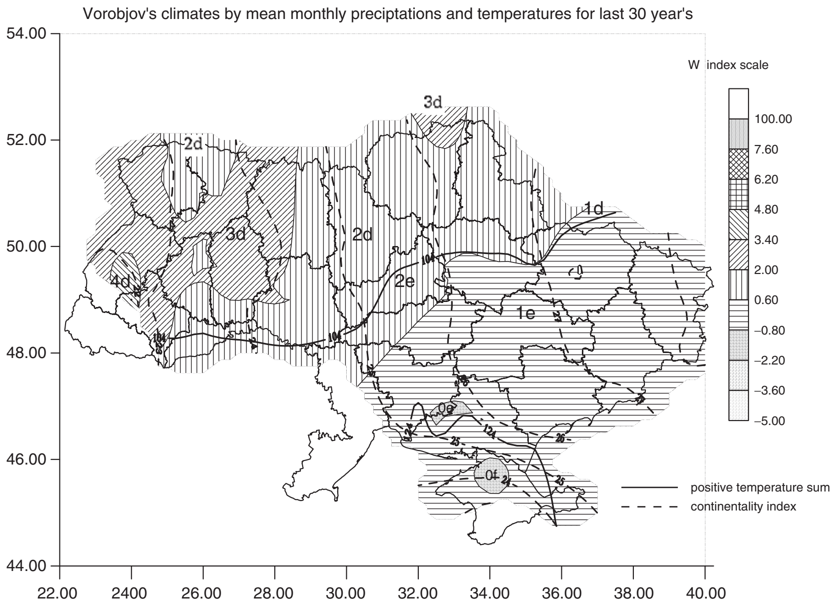

Fig. 15.1. Contemporary Ukrainian climate according to Vorobjov classification.

geometric shape in three-dimensional coordinate space of **W**, **T** and **A**. We are calling this geometric shape a species climatic figure. Accurate definition of the model requires a full geographical species range as input.

Inverse mapping of a species climatic figure from space **W**, **T** and **A** into geographical space gives the required species potential climatic range. As a rule, some part of species potential climatic range occupies additional territories that are out of original geographical species range. That is why it is not only climate conditions that are restricting species range.

The model is applicable for mapping future species potential climatic range. The future range may contain sites with appropriate relief, water and soil conditions where species may survive or be introduced. On the other hand, shrinkage of a climatic range shows that the species in future will experience decline or withdraw from old range territories not intersecting with new range.

We are using a computer implementation of the model with a personal geographic information system. This method employs techniques for mapping from a geographic coordinate system to a plain coordinate system and vice versa.

Dealing with Gap-models

The common drawback of the computer program for Gap-modeling is its non-suitability especially to applications in different regions. At the very first step the program code have been changed to do input of initial values for forest stand composition and tree age distribution. Thereafter, the program has been tested with actual data for forest stands in Kharkiv administrative region. Because the results were looking unrealistic we began to study code for trees' response simulation. Conclusions are that code for optimal growth functions must be adopted to simulate growth of Ukrainian tree species more accurately, the mortality function must be adapted depending on tree population density, there is no input for number of drought days, and dependence of tree growth from soil moisture is correct only for boreal forests.

Impact estimations

CCCM scenario

Canadian Climate Centre Model (CCCM) has the climate sensitivity lower than many models – it shows a temperature increase of 3.5°C when CO_2 level in atmosphere doubles. CCCM scenario (Fig. 15.2) indicates increasing temperatures all through Ukraine, especially in the south. Precipitation will increase to the north-northwest and decrease to the south. Xerophilization will be more intensive in the south part of forest steppe and steppe zone, which will transform to semi desert and desert according to Vorobjov classification (climates **0g**, **0h**, **1g** and **1h**). A map displaying the Holdridge classification shows that current forest steppe will be replaced by warm temperate thorn steppe (index 20) and warm temperate dry forest (index 21). Subtropical Thorn woodland (index 27) will be established in Crimea. Most of current forest zone (index 15 – cool temperate moist forest) will not change and the remainder will be replaced by warm temperate thorn steppe and warm temperate dry forest zones (index 20 and 21).

Thus the non-forest zone will increase, and trees will be able to survive there only in favorable sites (river valleys or relief falls). For the area which remains forested, forest types and species composition will change drastically. However, this forest productivity may grow in the northwest as result of humidity increase and transformation of Vorobjov zones **2d**, **3d** and **4d** to **3f** и **4f**. At the same time humidity will fall in Kiev, Chernigov and Zhitomir regions where zone **2d** will change to **2g** and **2f** (zone 21 after Holdridge).

A Holdridge classification map shows that Ukraine, European, and eastern USA forests are in zone 15, Spanish and East USA States steppes are in zone 20, and non-forest lands of central USA are in zone 21. Vorobjov model gives more precise analogies, if we also take into account the continentality index. Analogies are found in Hungary for climate **2f**, Central Spain for climate **3f**, Central Serbia for climate **4f**, and steppe regions of USA for climate **2g** and **3g**. Non-forest climates **0g** and **1g** have regional analogies in Middle Asia.

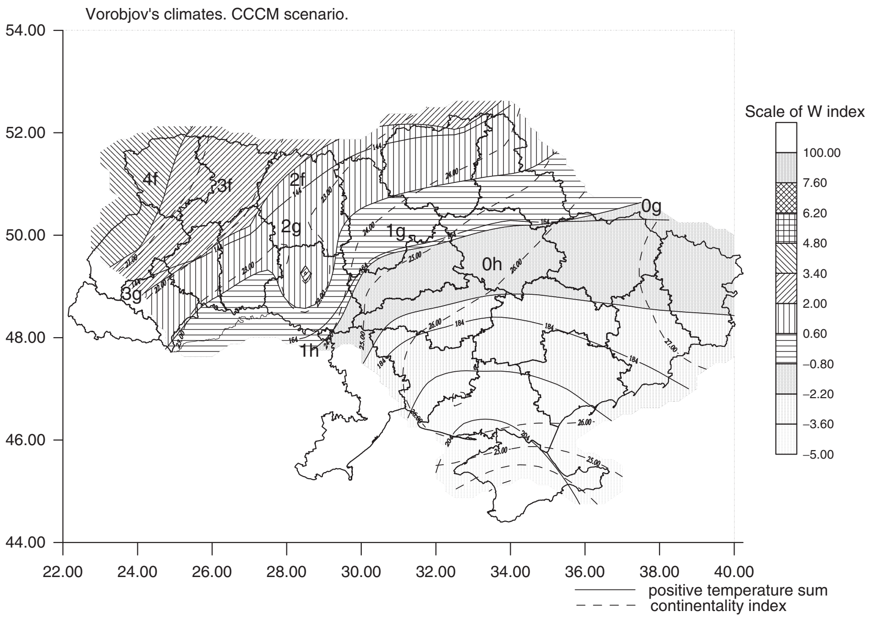

Fig. 15.2. Changes of climate in Ukraine according to Vorobjov classification in CCCM scenario.

GFDL scenario

Geophysical Fluid Dynamics Laboratory (GFDL) model has the climate sensitivity which run is 4.0°C when CO_2 level in atmosphere doubles. According to the GFDL scenario (Fig. 15.3) it will become warmer especially in the southeast forest steppe. Precipitation will decrease over most of Ukraine except the northwest part of Vinnitsa region (20 mm increase of rainfall). Continentality index will be equal to 340°C in the west and over 410°C in northeast. .Thus the current forest steppe will be preserved for almost 10% of Ukraine territory. Warm temperate desert scrub (Holdridge index 19) will remain in Crimea and a zone with Holdridge index 20 will replace the current southeast forest steppe. Forest zone will be preserved in the West but most of it (to the east of Zhitomir region) will transform to zone 14. Thus according to Holdridge classification, most of the territory will transform to steppe and desert whereas Vorobjov zoning gives a more optimistic prognosis assuming preservation of wood plants in favorable sites of southeast Ukraine. In the central part of the country existing tree species will be gradually weakened, stands will desiccate and be invaded by pests and diseases, and land productivity will fall. The role of forests in environment protection will be preserved but forest cultivation will be more expensive. For forest climates by Vorobjov we have found analogies in the northwestern part of Xinxiang Province of China (thereafter, West Dzungaria) for climate **1e**, Winnipeg (Canada) and northeastern China for climate **2e**, Omaha (USA) and Barnaul (Russia) for climate **1f**, and Altai for **2f**. Non-forest climates **0g** and **1g** have analogs in Middle Asia.

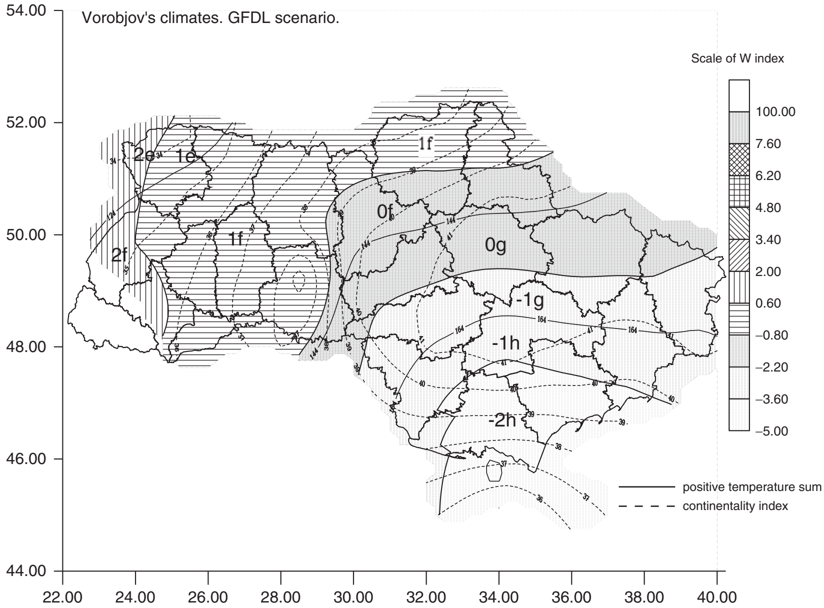

Fig. 15.3. Changes of climate in Ukraine according to Vorobjov classification in GFDL scenario.

GISS scenario

Goddard Institute for Space Sciences (GISS) model has sensitivity 4.2°C when CO_2 level in atmosphere doubles. GISS scenario shows that for most of Ukraine the climate will be warmer and more humid (Fig. 15.4). Continentality of climate will decrease, which will be favorable for forest growth.

Classification by the Holdridge model shows that all of the country will belong to forest zone index 15 and only the southern part of the Kherson region and Crimea will belong to zone index 21. Classification with Vorobjov model shows climates from **2e** to **5e**, **3f** and 4f that may be referred as forest climates, and **2f**, **1g** и **2g** that refer to forest steppe. Thus in the case of GISS scenario realization, all territory will be suitable for forest. The region southeast of Ukraine, where there is forest steppe recultivation now, will be suitable for productive forest, but special investigations must be done to define optimal stand composition. Analogies for Vorobjov climates are found in Cherkassy region for climate **2e**, East Canada for climate **3e**, Switzerland for **4e**, Pacific Ocean side of Canada for **5e**, Hungary for **2f**, former Yugoslavia for **3f** and **4f**, and the eastern part of USA for **1g** and **2g**.

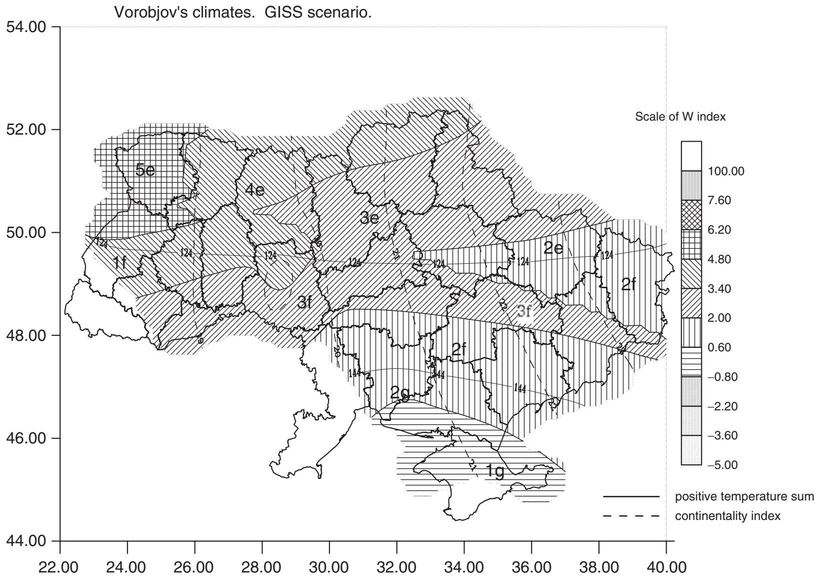

Fig. 15.4. Changes of climate in Ukraine according to Vorobjov classification in GISS scenario.

UK89 scenario

United Kingdom Meteorological Office completed the model run in 1989 (UK89). This model has sensitivity 3.5°C when CO_2 level in atmosphere doubles. The UK89 scenario realization also leads to warming. Diversity of forest type climates will increase: current climates with heat index d and e will be preserved and new climates with heat index f and h will appear (Fig. 15.5). In some regions humidity will increase: the new climate classification by Vorobjov is climate 5d or by Holdridge is humid forest. Somewhere it will fall: the new climate classifications by Vorobjov are 0f, 0g, 0h, -1h or by Holdridge classification is zone with index 21. Continentality will increase everywhere but form of contour lines for continentality variable does not seem reliable in the southeast: the increment of continentality change is approximately 3^0C on every 1’ of latitude.

On all of forest and non-forest lands, forest distribution will not shift drastically although forest type diversity will increase. The forest zone will move somewhat to the southeast and the steppe forest recultivation zone area will be reduced. In the southeast part of Ukraine, forests will survive only in favorable sites. Humidity increase in the west and replacement of **3d** with **4d** will lead to productivity growth too. Species composition will change due to continentality increase. An increase of pest and disease outbreaks will be observed and we’ll be able to preserve some species in the stands composition only by forestry means.

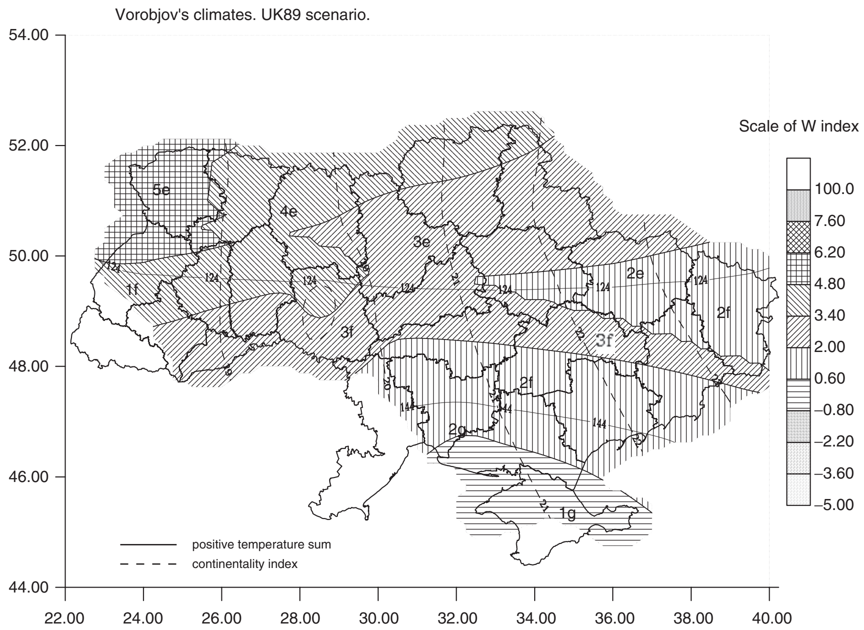

Fig. 15.5. Changes of climate in Ukraine according to Vorobjov classification in UK89 scenario.

Mapping by the Holdridge model shows the future zones: 15 (corresponds to present forest zone), 16 (present Belarus), and 21 (present Central states of USA). According to Vorobjov classification the future zones will be: **3d** (present Chernigov region – east-north part of Ukraine, but with more high continentality), **4d** (present Ivano-Frankovsk region – western part of Ukraine), **5d** (present Balkan), **1e** (West Dzungaria), **2e** (remains invariable in Poltava region – central part of Ukraine), **3e** (as East of Canada), **4e** (as Switzerland) and non-forest lands with climates **0f** (as Kuldja in Dzungaria, 43.88° N, 81.25° E), 1f (as Kansas prairies, USA), **2f** (as Hungary), **0h** (as Middle Asia).

Potential species climatic ranges in future

A model of species potential climatic ranges was used for potential area change projection for main Ukrainian forest-forming species: *Pinus sylvestris*, *Quercus robur*, *Carpinus betulus* and *Fagus silvatica*. It appears that only under UK89 scenario will the potential climatic ranges of *Pinus, Quercus* and *Carpinus* intersect Ukraine territory. Climate under CCCM, GFDL and GISS scenarios will be unsuitable for current main forest-forming species.

Under UK89 climate change scenario, all the main forest-forming species will experience shrinkage of their climatic ranges. The potential species range of

Quercus robur will be split into three isolated pieces: north half of Chernigov and Sumy administrative regions, a spot in Vinnitsa region and four administrative regions in the western part of Ukraine (Volyn, L'vov, Zakarpatje, Ivano-Frankovsk). Boundary of *Carpinus betulus* will shift west and thus occupies Volyn', L'vov, Zakarpatje, and Ivano-Frankovsk administrative regions of the Ukraine. *Pinus sylvestris* will shift to north and west and will occupy a narrow strip of the Ukrainian Polessye and western regions of Ukraine including Carpathian region.

Economic impacts

An evaluation of economic impacts was based on differences of conditional income between mixed forest, forest steppe and steppe forestry management models. Changes in proportion of territories occupied by different forestry management models impose changes on overall and local conditional income. Conventional forest income will increase by 28.2% and 10.3% in the case of GISS and UK89 scenario realization respectively. It will decrease under GFDL scenario by 43.1% and under CCCM scenario by 39.8%.

Discussion

Here were obtained preliminary results and performed a further step to do more detailed analysis. It is necessary to use only one or two most representative scenarios to effectively develop methodology and obtain representative data. Vorobjov climate classification model is meaningful to reconstructing forest types' distribution under future changed climate conditions. This method must incorporate regional analogies and imitation modeling techniques (for example, Gap-model). It is useful to apply Gap-simulation technique not only for the forest at particular site but also at other abstraction levels: to forest stand of given type of forest with defined species composition and tree ages distribution; especially if it looks useful for solving the problem of reconstructing the future forest types' distribution.

Conclusions

For the Ukrainian territory under the CCCM scenario, for the areas which cease to be forest there will be stands disintegration and partial change of species composition. Forest management affectivity will decrease due to aridization. Forest types and species composition will change in forest lands too, which will lead to a decrease of main forest-forming species productivity. After stabilization of new forest composition, productivity can increase in the northwest of Ukraine and decrease in the east.

GFDL scenario provides changes as previously mentioned but the area with dry sites will be somewhat less.

GISS scenario realization will be favorable to forest growth and expansion. Zone of steppe forest recultivation will decrease and forest zone area and its productivity will increase after stabilization. However, drastic climate change will be the cause of large-scale pest and diseases invasion and result in the cessation of natural forest renewal.

In the case of UK89 scenario forest type diversity will increase. The forest boundary will move southeast, species composition will change to a small degree, and forest productivity will somewhat increase.

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Appendix

Ukrainian forest type classification: An introduction

In certain climatic conditions forest stand composition as well as productivity depend mainly on soil and topography (terrain position) features. Properties of soil and geologic substratum (hard bedrock) determine the diversity of stand composition and structure in natural forests. Therefore, forests can be classified by their habitats and more precisely, by properties of forest soils.

Ukrainian forest type system was developed as a tool for forest classification to address needs of forest inventories at the end of nineteenth century and in early 1900s. A. A. Krudener first proposed advanced forest type classification in 1916–1917. In this classification forest type classes were differentiated in uniform climate conditions according to changes in stand composition and characteristic properties of tree growth (bonitet) which were related to changes in parent material composition, in moisture supplies and in humus types. Forest types supported by soils with similar fertility properties but in different climatic conditions were considered as analogues. Soil texture was regarded as a main indicator of soil fertility in the Krudener's classification. This classification scheme was designed as a two-dimensional grid with parent material type and moisture supply type plotted on the axes. So, in this classification the concept of forest type combines type of forest vegetation with its type of habitat. Later, in 1920s, E.V. Alekseev simplified the Krudener's classification. He proposed a grid for classifying forest types with only soil texture and water table taken as grid dimensions.

P.S. Pogrebnyak finally modified the grid in 1931 when he defined the limits of a certain forest type in the grid on the base of changes in stand productivity and composition only. Any quantitative data on soil properties were excluded from his scheme. Forest habitat types were defined by two variables only: soil fertility and soil moisture regime but changes of these variables were revealed only by changes in natural forest vegetation.

In the Ukrainian forest type classification scheme there are four classes of forest habitat types distinguished by soil fertility, which is considered as soil richness in nutrients. These classes are the following: poor (A), relatively poor (B), relatively fertile (C) and fertile (D). Types A are represented by natural stands composed of species with low nutrient requirements e.g. pine. The productivity of such forests is rather low. In types B the first story is formed by trees with low demands for nutrients but the second story comprises trees with medium requirements like, for example, spruce or oak. In types C the first story is formed by species with low to medium demands but some species requiring large amounts of nutrients appear in the third story. Highly productive stands formed by species of medium to high requirements for nutrients are characteristic for types D. Trees with high demands for nutrients, such as ash, can occur in the first story in such stands.

The second variable for forest habitat type differentiation is soil moisture. Six classes are distinguished by this parameter. These classes are the following: 0 – very dry, 1 – dry, 2 – moist, 3 – damp, 4 – wet, 5 – swampy (arranged according to rise of water availability). Soil moisture regime, in its turn, is determined by climate, topography, water table and such soil property as water retention.

A combination of soil fertility and soil moisture classes forms a forest habitat type class, which is indicated by two characters e.g. A1 or D2. Thus, a forest habitat type class is considered as a set of conditions, which can support a certain type of forest vegetation that is characterized by particular productivity, composition and structure.

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Evaluating Vegetation Cover Change Contribution into Greenhouse Effect by Remotely Sensed Data: Case Study for Ukraine

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Abstract. The analysis of the current approaches for Greenhouse Effect forecasting is performed. New methodology has been proposed to estimate the Greenhouse Effect and its change through coupled ground experimental CO_2 flow assessment and satellite data analysis. The multi-temporal variations of the areas under the different vegetation species with their photosynthetic activity features are considered. The CO_2 flow values are determined to convert them into the temperature changes and to use in the models of energy–mass exchange in the geo-spheres for computer forecasting of global and regional climate changes.

Keywords: regional greenhouse effect, remote sensing, Ukraine

Introduction

Modern information pertaining to climatic changes has revealed a trend of global warming (~0.7ºC for 100 years) that is confirmed by centenary instrumental observations. The cause of this phenomenon could be a temporal warming event of anthropogenic origin due to excess input of greenhouse gases (e.g. CO_2, CH_4, etc.) into the atmosphere on the background of a likely 1,000-year cyclic tendency of climate conditions changes caused by peculiarities of the Earth's orbit around the Sun and variations of solar radiation intensity [1, 7].

The objectives of this study are to: (a) identify the tendencies of climatic changes over Ukraine, (b) investigate scenarios which may make it possible to forecast their development, and (c) recommend timely countermeasures to mitigate their impact on socio-economic processes.

The Ukrainian Hydrometeorological Institute (UkrNDGMI) archives climate records for more than 100 years at 70 hydro-meteostations. The records show that the Ukraine is very sensitive to global climate changes [4]. Average annual air

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temperature has increased during that time: for the Polissya and Lisostep regions ~+0.8ºC; and the Steppe ~+0.3ºC. The main warming occurs in winter (+1.2ºC). The annual precipitation has increased for 100 years as much as 20% (~+100 mm/year). The frequency of extreme weather phenomena (winds, rains, snowfalls, floods, etc.) is also increasing bringing about multi-million money amount goes here losses to the national economy.

In the future the climate over Ukraine will likely continue to be characterized by weather anomalies typical of those observed over the second half of the past century. Based on the recent past, it could be expected that regional temperature in Ukraine will increase by 1.0–1.5ºC over the next 2 or 3 decades. Some international programs such as GEOSS; GMES, GEO (with involvement of Ukraine elaborating own National climatic program, and GEO-UA) are being developed now with the aim to improving the forecasting of climatic changes.

Preliminary results of the study in which the Scientific Centre for Aerospace Research of the Earth at IGS NAS of Ukraine is involved, indicate that based upon atmospheric CO_2 content over the country, the state of vegetation cover changes. For this region there is reason to believe that CO_2 emissions by industrial enterprises are having an anthropogenic impact on the formation of a greenhouse effect which indeed has taken place for Ukraine's territory in particular [10].

Problem Definition

- Assessment of greenhouse effect changes using new methodology applying ground measurement data of CO_2 fluxes as a proxy for space-born information.
- Analysis of surface cover characterized by different types of vegetation and peculiarities of their photosynthetic activity.
- Conversion of CO_2 concentration changes in the atmosphere into temperature values for further application to energy mass transfer models in the geospheres and numerical forecasting of global and regional climate changes.

Vegetation Cover Photosynthetic Parameters for Main Species

The recent global carbon cycle consists of two smaller ones. The first sub-cycle is stipulated by interaction of carbon dioxide and water. The second one is stipulated by photosynthesis and breathing – two fundamental biological processes in the biosphere – and based on carbon dioxide consumption due to photosynthesis and its rejuvenation in the animal and plant life cycle and decay of organic remnants.

Photosynthesis is a basic and governing link in the global biogenic cycles of carbon, nitrogen and water. Bulk mass of plants forms not only the main reservoir of organic carbon but also acts as a significant climatic factor on a global scale [8]. Vegetation cover is one of the leading carbon storage reservoirs which partially damps the consequences of the greenhouse effect. Annual result of photosynthesis is equal 120 Gt of CO_2 where half the amount of it is of continental origin [6, 9, 12, 15].

Most of Ukraine's territory is comprised of steppe vegetation and agro-coenoses where cereals and technical crops dominate. There are other types of vegetation of lesser importance that are involved in the carbon sink as well. To calculate the share of main vegetation cover types in the sink of carbon over Ukraine using an integral approach coupling instrumental remote sensing techniques and available knowledge of ground measurements, we have analyzed a wide spectrum of scientific publications devoted to eco-physiology of photosynthetic activity for certain plant groups [3, 6, 9, 12, 15].

Changes of Vegetation Cover in the Western Ukraine Based Upon the Results of Landsat TM/ETM+ Images Classification for 1990–2000

The thematic interpretation of these space-born images has shown the existence of some spatial-temporal tendencies in vegetation cover change (Figs. 16.1 and 16.2). They are mainly manifested by substitution of coniferous forests with deciduous ones and cultivated lands. The result of which is characterized by the potential for a decreased sink of carbon dioxide from the atmosphere, i.e. increasing input into a greenhouse effect.

In the context of the above mentioned vegetation changes, it appears that the problem of adequate integral monitoring of vegetation assemblages development and landscape changes be addressed as a first priority task. The rapidly changing land use practices over the past 30 years demonstrate the importance of space-born observations for such monitoring.

Measurement of Atmospheric CO_2 Concentrations from Space

In the frame of CASRE research programs we evaluated information capacity of specialized satellite data to determine CO_2 content in the atmosphere and over Ukraine in particular. To solve this task an analysis of available data was conducted. It was found that data from the SCIAMACHY sensor installed onboard the ENVISAT satellite are most suitable for this task.

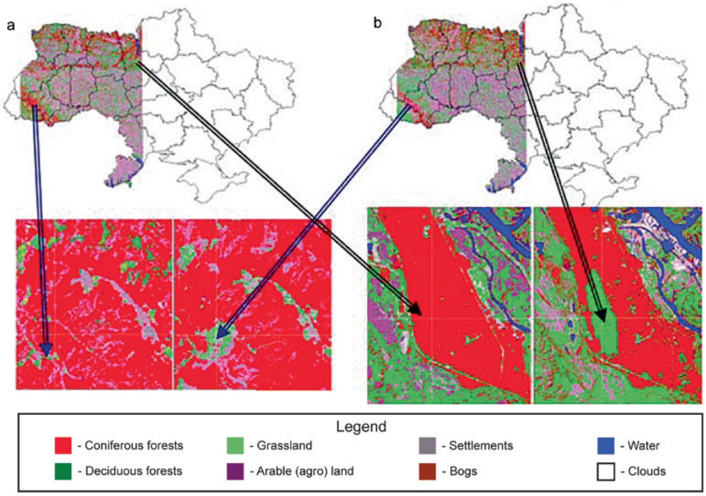

Fig. 16.1. An example of vegetation cover change in the Polissya and Carpathian regions featured by Landsat TM (1990) (**a**) and Landsat ETM+ (2000) (**b**) images.

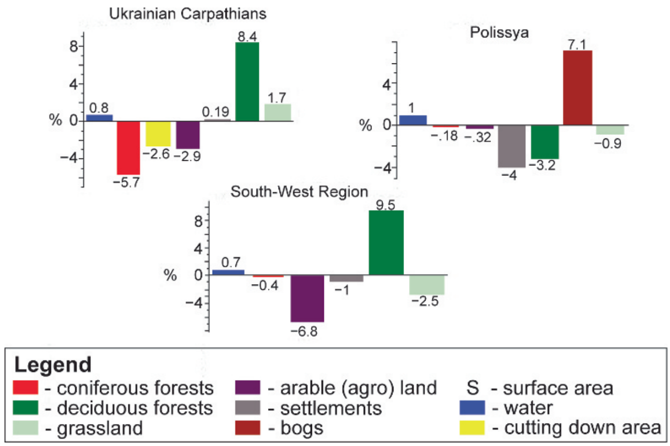

Fig. 16.2. Changes of vegetation cover (%) for 1990–2000.

Using SCIAMACHY data the researchers of Institute of Environmental Physics – (IUP) in Bremen have obtained the first maps featuring global distribution of atmospheric CO_2 [2]. It is necessary to note that IUP is an authorized agency to conduct SCIAMACHY project analysis and has the exclusive right for first processing of the data on global distribution of greenhouse gases concentration. On the basis of the maps obtained, the monthly distribution of atmospheric carbon dioxide was computed for the period from January 2003 to December 2005 inclusive [2, 5, 11, 14].

Based on these data we have tested an applicability of SCIAMACHY data to evaluate atmospheric CO_2 content over Ukraine. The analysis allowed extraction of the monthly distribution of carbon dioxide over Ukraine from the original IUP dataset for the 3 years listed above. Additional analysis allowed monthly-averaged distribution of atmospheric CO_2 concentration over Ukraine within administrative regions to obtain the results shown in Fig. 16.3.

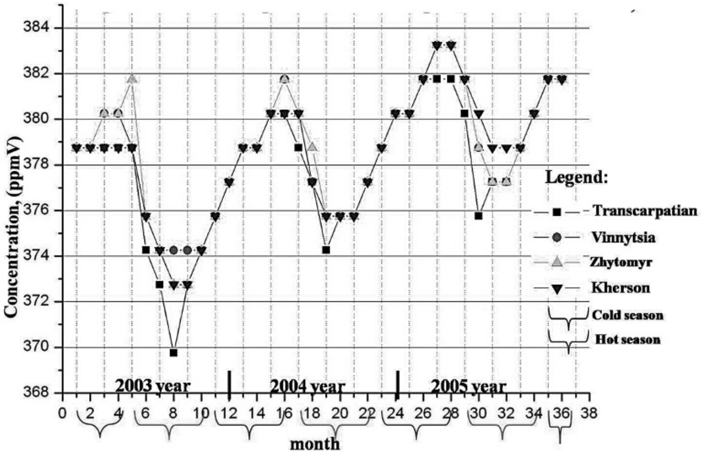

Fig. 16.3. Change of atmospheric CO_2 concentration within administrative regions.

Next step was to determine the interannual increase of atmospheric CO_2 concentration within administrative regions of Ukraine (Fig. 16.4). The conclusion resulting from these data is that the distribution of atmospheric CO_2 concentrations is correlated with physiographic subdivisions of the territory, and distribution of vegetation cover and structure of land use [13]. The results also show that atmospheric CO_2 concentration has increased over Ukraine for the 3 study years. The highest increase is detected in the west and in the industrial east of Ukraine. Over most of Lviv oblast territory the growth has reached 5.083 ppmV and over the industrial oblasts of Donetsk, Zaporizhzhya and Luhansk the increase reached 4.834 ppmV. The lowest value of atmospheric CO_2 increase is detected in the Polissya zone at 3.4 ppmV. For 2005 the highest mean annual atmospheric CO_2 concentration was detected over the Crimean Peninsula, 381 ppmV (compared to 376.3 ppmV in 2003). Industrially developed oblasts such as Donetsk, Zaporizhzhya and Luhansk also had high values of mean annual concentration in 2005 at 380.9 ppmV (compared to 376.1 ppmV in 2003). The lowest level of atmospheric CO_2 concentration for 2005 was detected over Transcarpathian oblast where it was 379.9 ppmV (compared to 375.3 ppmV in 2003). It is worth mentioning that the obtained results correspond well with estimates made by IUP experts; i.e. in the range of mean annual CO_2 increase of 0.5–1.5% from 2003 to 2005 [2].

Fig. 16.4. Increasing of mean annual concentration of CO_2, (ppmV) from (from January 2003 to December 2005).

After a comparison of CO_2 distribution in the atmosphere and mean annual distribution of wind speed and direction (Fig. 16.5), it can be presumed that atmospheric CO_2 in the western oblasts is impacted by additional CO_2 brought by winds from industrially developed areas of central and southern Europe.

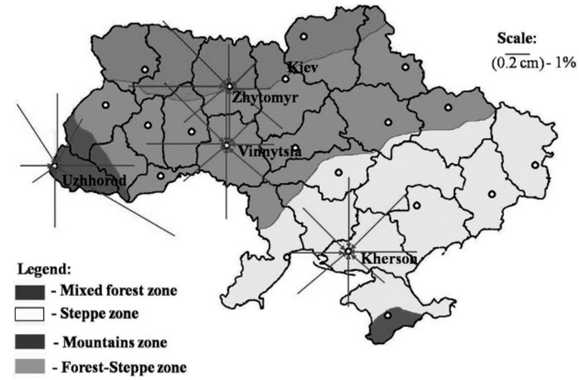

Fig. 16.5. Wind frequency roses over Ukraine (excluding calms) [13].

Taking into account these tendencies of atmospheric carbon dioxide concentration change over Ukraine for 2003–2005 it is possible to perform a preliminary and approximate forecast for air temperature change (T) over Ukraine's territory for the next 30 years. We apply a rather simple dependence taken from [4] that we justified for Ukraine's conditions:

$$\Delta T(t) = -0{,}1 + 3\ln\frac{C(t)}{C(t_0)} \tag{1}$$

where t – time, years; C_0 initial concentration of CO_2 in the atmosphere (375 ppmV) for the time moment t_0 (2003); $C(t)$ – forecasted concentration of CO_2 (420 ppmV) for the time moment t (2030) (according to the data from Fig. 16.4). For example, such a preliminary forecast of temperature increase from 2003 to 2030 (with C(t2003) = 375 ppmV; C(t2030) = 420 ppmV) can be expressed as:

$$\Delta T(t_{2030}) = -0{,}1 + 3\ln\frac{420\text{ppmV}}{375\text{ppmV}} = -0{,}1 + 0{,}3 \approx 0{,}2^{\circ}\text{C} \quad (2)$$

The forecast results in a regional air temperature increase of 0.2ºC over Ukraine by 2030 which is less than that forecasted by Ukrainian hydrometeorologists (1.0–1.5ºC) [4]. The difference can be explained because our calculations are based solely on the atmospheric CO_2 concentration and did not consider the influence of other greenhouse gases, albedo and atmospheric aerosols on air temperature change.

Conclusions

1. We examined how temporal changes in vegetation cover have influenced CO_2 balance over Ukraine. We looked at the variation in intensity of carbon dioxide absorption by different species under photosynthesis. This process was compared to the time series of space images acquired by Landsat satellite (1990–2000) to evaluate changes of atmospheric CO_2 content using SCIAMACHY sensor of ENVISAT satellite (2003–2005).
2. This allowed us to formulate several conclusions about certain climate-forming factors within Ukraine's territory:

- The character of vegetation cover change for 1990–2000 in the western part of Ukraine (depleting of coniferous forests and growth of deciduous vegetation and agro-coenoses) favors accumulation of CO_2 in the atmosphere.
- The character of CO_2 changes in the atmosphere over Ukraine's territory for 2003–2005 demonstrates that the quantity of atmospheric CO_2:
  - Is subjected to seasonal oscillations governed by the seasonal pace of vegetation development.
  - Has a tendency to increase for seasonal as well as for mean annual indexes.
  - Has a tendency to increase over western regions of Ukraine due to wind transfer from industrial regions of Europe. An increase is also observed over industrial regions of Ukraine (Donbas, Prydniprovya).

3. It is shown that the greenhouse effect over Ukraine territory is caused not only by carbon dioxide that is generated by domestic industry and brought by winds from European industrial centers, but also by changes in vegetation cover with less CO_2 absorption capability.
4. Preliminary results indicate that the temperature effect derived from atmospheric CO_2 increase over Ukraine can promote an increase of mean annual air temperature of 0.2ºC by 2030.
5. Further research should be directed to design and implement the GEO-Ukraine National Program as a part of relevant subprograms of International GEO

Program. Within that framework, the following tasks should be fulfilled in Ukraine in cooperation with the international scientific community:

- Establishment of the test sites network for ground measurements of CO_2 fluxes from different landscape and climate regions.
- Comparison of ground measured CO_2 fluxes with atmospheric CO_2 and other greenhouse gases concentrations detected by the SCIMACHY sensor over test sites.
- Building of regional and global energy mass transfer models between Earth's geospheres using acquired hydrometeorological and other information accompanied by metering and validation procedures at the test sites aimed to computer forecasting of likely scenarios of climate change and elaboration of decision-making approaches to optimize socio-economic processes caused by climate changes.

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Soil Moisture Changes in Non-boreal European Russia: In Situ Data

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Abstract. Soil moisture observations in the USSR began the middle of 1950s. At the peak of the network extent (in the middle of 1980s) more than 2,000 stations performed these observations operated over Russia. Since that time the number of stations in this network was significantly reduced, especially at soil plots with natural vegetation. Therefore, in this study soil moisture changes over the non-boreal European Russia during 1970–2000 (2001) are presented using the data of only 52 long-term stations. It is concluded that: (1) Soil moisture changes within the upper 0–10 and 0–20 cm have no systematic component. Only when the thicker layers (starting with the upper 50 cm) are used, systematic changes (trends) can be found. That is why soil moisture of the upper 20 cm layer cannot be considered as characteristic of a moistening regime of the active soil layer. (2) Over most of non-boreal European Russia, soil moisture increase is observed for layers 0–50 and 0–100 cm both in spring and during the summer (i.e., during the entire growing period). Moreover, trends in soil moisture for the upper meter of soil (layer 0–100 cm) are more apparent when compared to those in layer 0–50 cm. (3) Only in the zone of mixed and broad-leaved forest areas are decreasing levels of soil moisture observed during the entire growing period.

Keywords: non-boreal European Russia, soil moisture, trends

Introduction

It is known that soil is the product of the climate. Its formation is the result of interaction of various natural physical processes which means that soils could be considered as an integral indicator of the environmental humidity regime. Soil moisture controls interactions between the land surface and the atmosphere, as changes in soil moisture affect both the energy and water cycles.

Stations' network for soil moisture observations began to form in the USSR from the middle 1950s. At the middle of the 1980s more than 2,000 stations performed these observations operated over the Russian territory. Moreover, observations both at soil plots with natural, mostly meadow, vegetation and at agricultural

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fields were made at most of these stations. The choice of plots at each station was made to satisfy the following conditions: (1) the plot is a flat piece of land with an area greater than or equal to 0.10 ha, (2) the soil type is representative of the main soil type and landscape of the region and does not differ significantly from prevailing soil type and landscape of the climate zone, and (3) the mean depth of the water table and its seasonal variations are typical for a large area (Guidance for Hydrometeorological Stations and Posts 1973). The temporal resolution of the observations is 10 days in the warm season and 1 month during the winter. Unfortunately, at present the number of these stations decreased, and it is of special concern for observations at plots with natural vegetation. Moreover, existing data are unavailable because publication of reference-books was stopped. Within the non-boreal part of the European Russia, data exist for only 20 stations with observations made at natural vegetation sites and having time-series of approximately 30 years for the period 1970–2000. This fact determined the choice for the study period. To increase available stations, data from soil plots with winter crops were added to the analysis. Thus, the station count was increased to 52 (Fig. 17.1).

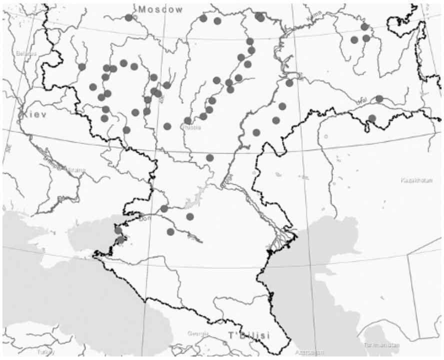

Fig. 17.1. Stations with observations on soil moisture made at soil plots with natural (mostly meadow) vegetation and winter crops.

Major Results

Over the study region five main types of soil are selected (Fig. 17.2): (1) derno-podzolic and gray forest soil (zone of mixed and broad-leaved forest), (2) podzolized and leached chernozem (zone of forest-steppe and meadow steppe), (3) ordinary, typical and fertile chernozem (zone of fertile steppe), (4) precaucasian and southern chernozem (zone of forb steppe), and (5) dark chestnut – light chestnut soil (zone of dry steppe). However, mechanical composition of soil in these zones varies greatly from sandy loam to heavy loam and even to clay. To exclude impact of diverse soil mechanical compositions, data on the so-called plant available soil moisture (i.e. water amount that can be extracted by vegetation cover and evaporated) were used for the analysis. Data from stations within every zone and selected regions were averaged according to results from researches (Kelchevskaya 1983; Meshcherskaya et al. 1982).

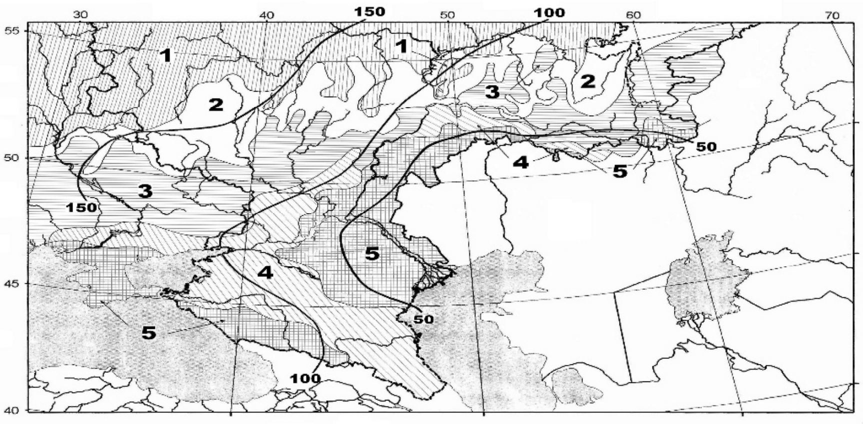

Fig. 17.2. Types of soil and spatial soil moisture changes over non-boreal territory of European Russia. (1) derno-podzolic and gray forest soil (zone of mixed and broad-leaved forest), (2) podzolized and leached chernozem (zone of forest-steppe and meadow steppe), (3) ordinary, typical and fertile chernozem (zone of fertile steppe), (4) precaucasian and southern chernozem (zone of forb steppe), (5) dark chestnut - light chestnut soil (zone of dry steppe).

Over the territory, soil moisture logically decreases from the north-west to the south-east that reflects availability of water and thermal resources within each zone (see Fig. 17.2). Character of temporal changes in soil moisture during 1970–2000 (2001) for each zone has specific features, however. Thus, in the zone of derno-podzolic and gray forest soils (zone 1) two regions are selected where soil moisture changes are of different directions. In the zone of podzolized and leached chernozem (zone 2) soil moisture changes are of the same type but there also exist two regions in this zone that differ by soil moisture values. For the zone of ordinary, typical and fertile chernozem (zone 3) soil moisture changes are similar over the whole territory. In the zone of precaucasian and southern chernozem (zone 4) two regions are selected where characters of soil moisture changes are various. Within the zone of dark chestnut – light chestnut soil (zone 5) changes in soil moisture are similar over the whole territory.

Soil moisture fluctuations within the upper 0–10 and 0–20 cm layers have no systematic component (Fig. 17.3). Soil moisture changes in the upper 20 cm are caused by interaction of two opposite processes: seepage and evaporation (Rode 1965). Water from precipitation quickly infiltrates into soil and the process of evaporation starts within the upper soil layers immediately after seepage stops. This is precisely why within the upper layers “rapid” moisture fluctuations occur that block the formation of any directional tendencies.

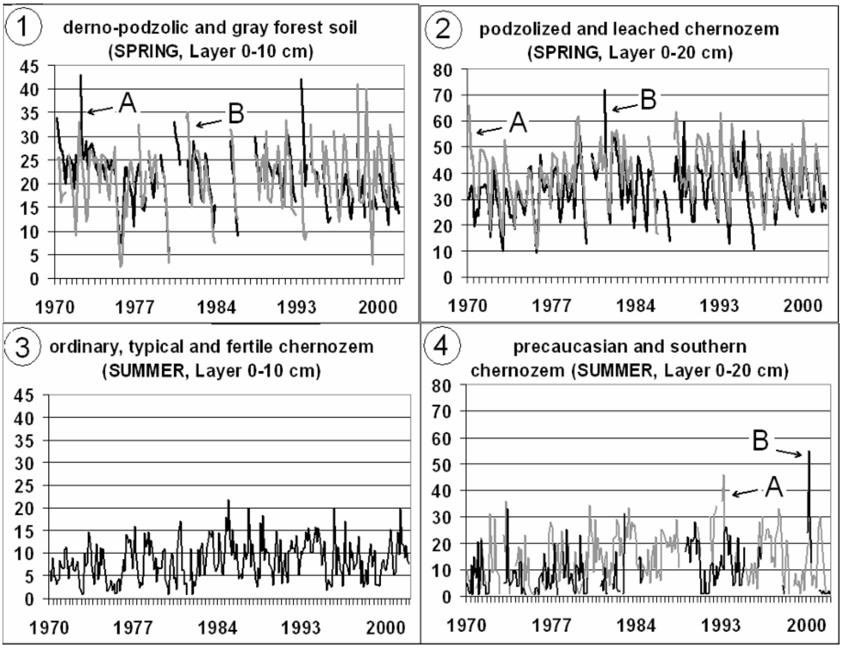

Fig. 17.3. Soil moisture changes in layers 0–10 and 0–20 cm within the study zones: (1) **zone 1**: A – main part of zone, B – close to the south boundary; (2) **zone 2**: A – west part of zone, B – east part of zone; (3) **zone 3**: whole territory; (4) **zone 4**: A – west part of zone, B – east part of zone.

Below only slow moisture seepage into the underlying layers occurs. Besides, moisture moving from these layers to the soil surface is also observed during a sufficiently long time (Rode 1965). This is precisely why common features of temporal soil moisture changes for various soil types can be determined only from the layer 0–50 cm. Analysis is focused on soil moisture changes at the beginning of the growing period (April–May) and during the summer season (June–August).

Soil moisture changes during spring (April–May) within the layers of 0–50 and 0–100 cm are given in Figs. 17.4, 17.5 and Table 17.1. At the beginning of growing period water content in soil is sufficiently high due to water from thawing saturating the soil. Soil moisture decreases from 110 (layer 0–50 cm) and 220 mm (layer 0–100 cm) in the zone of mixed and broad-leaved forest (zone 1) to 50 and 95 mm (layers 0–50 and 0–100 cm correspondently) in the zone of dry steppe (zone 5). Moreover, interannual variability of soil moisture within the layer of 0–100 cm is a bit more than in the layer of 0–50 cm, and elicited regularities are more evident.

Within the layer of 0–50 cm (Fig. 17.4 and Table 17.1) stable soil moisture decrease is observed over most of zone 1. Only at the southern boundary of this zone, decreasing soil moisture changes to increasing, but not as intensive. In the zone 2 a soil moisture increase occurs. Moreover, in the western part of the zone

Table 17.1. Parameters of linear trends (mm/30 years) of soil moisture for layers 0–50 and 0–100 cm within the study zones for spring (April–May) and summer (June–August).

Region	Layer 0–50 cm		Layer 0–100 cm	
	Spring	Summer	Spring	Summer
Zone 1. Derno-podzolic and gray forest soil (zone of mixed and broad-leaved forest)				
Main part of zone (A)	−31	−16	−49	−25
Close to the south boundary (B)	21	11	69	30
Zone 2. Podzolized and leached chernozem (zone of forest-steppe and meadow steppe)				
West part of zone (A)	10	19	27	35
East part of zone (B)	15	17	35	30
Zone 3. Ordinary, typical and fertile chernozem (zone of fertile steppe; whole territory)	19	17	51	33
Zone 4. Precaucasian and southern chernozem (zone of forb steppe)				
West part of zone (A)	0	11	6	11
East part of zone (B)	44	10	82	17
Zone 5. Dark chestnut – light chestnut soil (zone of dry steppe; whole territory)	13	11	39	24

Note: All estimates of linear trends' parameters are statistically insignificant at the level 0.05, but some of them are close to this level.

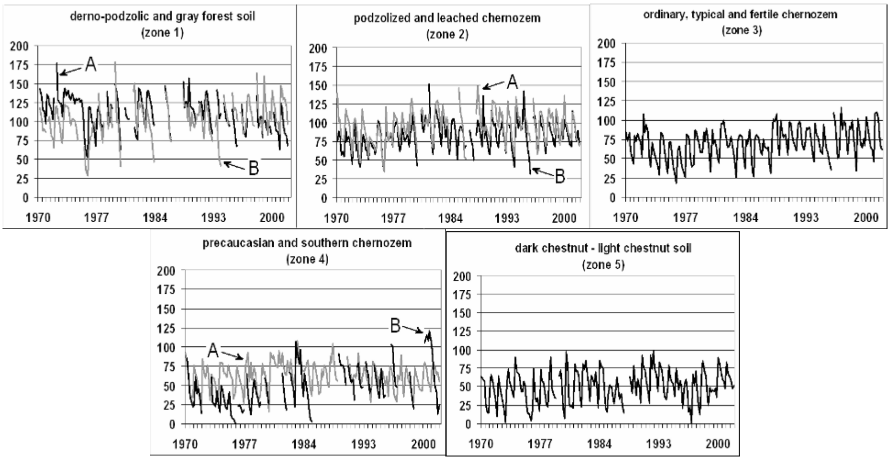

Fig. 17.4. Soil moisture changes in the layer 0–50 cm at the beginning of growing period (April–May) within the study zones: **zone 1**: A – main part of zone, B – close to the south boundary; **zone 2**: A – west part of zone, B – east part of zone; **zone 3**: whole territory; **zone 4**: A – west part of zone, B – east part of zone; **zone 5**: whole territory.

moisture changes are a bit less evident than in the eastern part, though soil moisture values are a bit higher in the west than in the east. For the zone 3 the soil moisture increase is characteristic and over the whole territory this increase is similar and more intensive compared to zone 2. Towards the south soil moisture values increase less, but the tendency for increasing moisture remains as well. Within the zone 4 intensive increasing soil moisture is observed in east regions while in the west part of the zone there are no directional soil moisture changes. Zone 5 is also characterized by soil moisture increasing, but theses changes are not as evident as in previous zones, and soil moisture storage is very small even in spring.

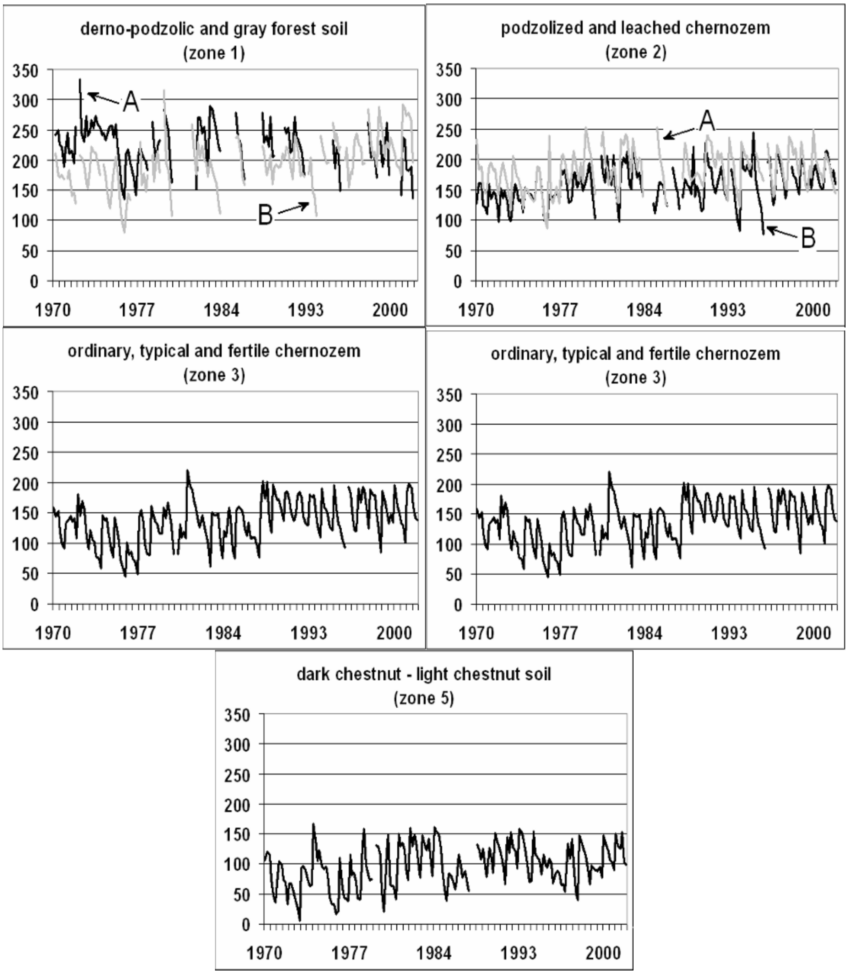

Fig. 17.5. Soil moisture changes in the layer 0–100 cm at the beginning of growing period (April–May) within the study zones; **zone 1**: A – main part of zone, B – close to the south boundary; **zone 2**: A – west part of zone, B – east part of zone; **zone 3**: whole territory; **zone 4**: A – west part of zone, B – east part of zone; **zone 5**: whole territory.

Within the upper 1 m layer (Fig. 17.5 and Table 17.1) soil moisture decrease is still observed over most of zone 1, and soil moisture increase occurs only close to the southern zone boundary. Unlike the layer 0–50 cm, soil moisture decreasing is, however, less intensive than its increasing. On the background of soil moisture increase in the zone 2, difference in soil moisture values between western and eastern parts grows. Similar to the layer 0–50 cm, soil moisture increasing in the east part of the zone is higher than in the west, and intensities of moisture increasing are three times more than those in the layer 0–50 cm. The zone 3 is characterized by a similar soil moisture increase over the whole territory, but here moisture increasing is also more intensive if compared to the layer 0–50 cm. Similar to the layer 0–50 cm, in the zone 4 intensive soil moisture increase is observed in the east part, while directional changes of soil moisture in the west part are negligible. Soil moisture values and intensity of its increasing in the zone 5 are two times higher than in the layer 0–50 cm.

In the summer season (June–August) soil moisture values rapidly decrease compared to spring values due to consumption of thaw water accumulated in soil during winter and at the very beginning of spring. Main tendencies of soil moisture changes, however, remain (see Figs. 17.6, 17.7 and Table 17.1). As before, soil moisture decreasing from the north-west to south-east is apparent: from 75 and 165 mm (layers 0–50 and 0–100 cm respectively) in the zone of mixed and broad-leaved forest (zone 1) to 20 mm (0–50 cm) and 40 mm (0–100 cm) in the zone of dry steppe (zone 5). Amplitude of interannual soil moisture fluctuations, however, slightly decreases compared to spring.

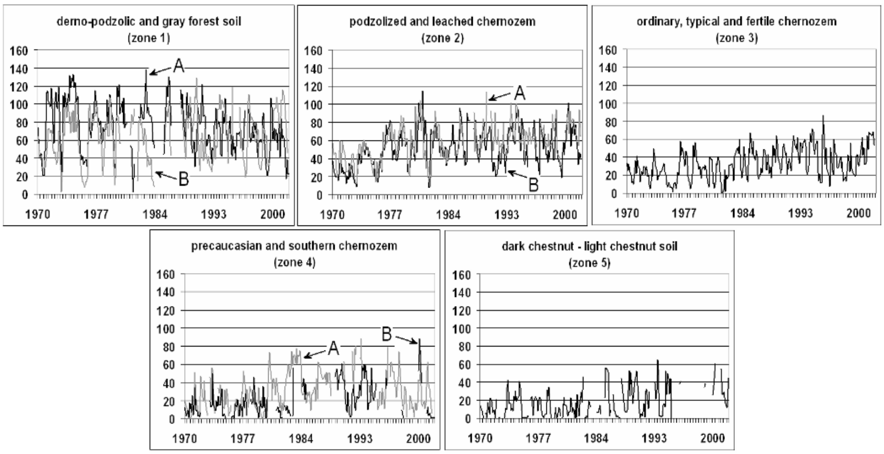

Fig. 17.6. Soil moisture changes in the layer 0–50 cm during the summer (June–August) within the study zones; **zone 1**: A – main part of zone, B – close to the south boundary; **zone 2**: A – west part of zone, B – east part of zone; **zone 3**: whole territory; **zone 4**: A – west part of zone, B – east part of zone; **zone 5**: whole territory.

In the layer of 0–50 cm (Fig. 17.6) within the zone 1, two parts with differently directed changes in soil moisture are detected as before. Intensity of these changes is less high, but like spring, soil moisture is decreasing over the main part of the zone, however, more intensively than it is increasing near the southern boundary of the zone. In the zone 2 the difference between soil moisture values within selected parts decreases, and positive tendencies of moisture changes in the west of the zone become a bit more intensive if compared to spring. Tendency and intensity of soil moisture changes in the zone 3 are practically the same as those in spring. The most important changes occurred in the zone 4. In the west part of the zone an obvious tendency towards a soil moisture increase manifested itself, and intensity of moisture increase in the east part of the zone decreases, by practically four times in contrast with spring. Soil moisture changes and their intensity in the zone 5 are similar to those obtained in spring.

Interannual fluctuations of soil moisture during summer within the top 1 m layer are practically two times higher than in layer 0–50 cm (Fig. 17.7 and Table 17.1). Areas of soil moisture increasing and decreasing in the zone 1 still remain. Moreover, moisture increase near the southern boundary of the zone is more intensive than its decrease over the main territory; however, the rate of these changes is lower than in spring. Comparing changes in layers 0–50 and 0–100 cm, it should be noted that the soil moisture increase in the latter is more intensive. In the zone 2, the difference in soil moisture values between two parts of the zone decreases compared to spring, and moisture increasing in the west part becomes more intensive similar to layer 0–50 cm. Intensity of soil moisture growth in the east part of the zone slightly decreases in contrast with spring. Soil moisture increase in the zone 3 is less intensive than in spring, but rate of moisture growth is practically two times higher than corresponding value for layer 0–50 cm. In the zone 4, tendency to soil moisture increasing is also observed in the west part of the zone, and the positive trend of soil moisture in the east part is almost five times less compared to spring. Soil moisture increasing in the zone 5 becomes less intensive than in spring but is still more than that in the layer 0–50 cm.

Some features of soil moisture changes can be explained, while others need to be additionally studied. Thus, difference in soil moisture values between two parts of the zone 2 (forest-steppe and meadow steppe zone) is mainly explained by the fact that soil types of these parts are associated with various moistening regimes (Kelchevskaya 1983). Lack of directional changes in the west part of the forb steppe zone (zone 4) is apparently related to absence of any tendencies for spring precipitation in steppe regions of the Central Northern Caucasus and to temperature increasing during the cold period of the year (Ashabokov 2008). Occurrence of positive tendency in summer in the west part of this zone (zone 4) is mostly related to combined effect of sufficiently evident growth of precipitation and negligible changes in air temperature (Ashabokov 2008) establishing favorable conditions for soil moisture increasing. Soil moisture decrease in the zone 1 (mixed and broad-leaved forest zone) can be explained only after additional research on the relationship and interaction of tendencies in precipitation and air temperature. Various intensities of soil moisture increase in different zones of non-boreal European Russia also need to be understood. In all circumstances, soil moisture increasing over most of the study region agrees well with humidity conditions changes over the large part of European territory of Russia which has been observed in the past years.

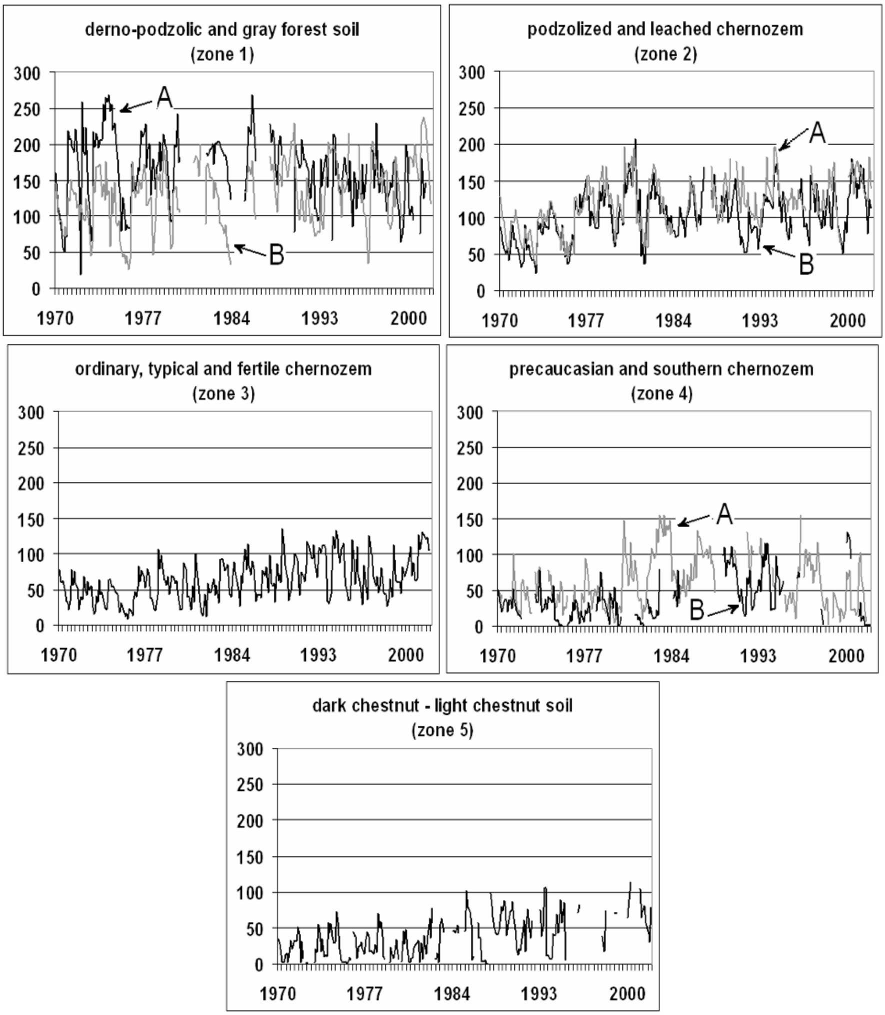

Fig. 17.7. Soil moisture changes in the layer 0–100 cm during the summer (June–August) within the study zones; **zone 1**: A – main part of zone, B – close to the south boundary; **zone 2**: A – west part of zone, B – east part of zone; **zone 3**: whole territory; **zone 4**: A – west part of zone, B – east part of zone; **zone 5**: whole territory.

Conclusions

Analysis of soil moisture changes over non-boreal territory of European Russia during 1970–2000 (2001) allows us to make the following conclusions:

1. Soil moisture changes within the upper 0–10 and 0–20 cm have no systematic component. Soil moisture fluctuations are closely related to the current precipitation and air temperature. Only from the layer 0–50 cm can some features of temporal changes in soil moisture regime be selected for one soil type. That is why soil moisture of the upper 20 cm layer cannot be considered as characteristic of a moistening regime of the active soil layer.
2. Over most of the study territory soil moisture increase is observed for layers 0–50 and 0–100 cm both in spring and during the summer (the whole growing period). Moreover, directional changes in soil moisture for layer 0–100 cm are more obvious if compared to those in the layer 0–50 cm.
3. Only in the zone of mixed and broad-leaved forest (zone 1) has it been observed that soil moisture is decreasing during the whole growing period.
4. Detected soil moisture changes need to be additionally comprehended and studied in more details.

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The Effects of Land Use Change on Terrestrial Carbon Dynamics in the Black Sea Region

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Abstract. The effects of land use change on terrestrial carbon budgets for the Black Sea Region were investigated using remote sensing, forest inventory data, and a carbon model. We focus on three countries in the region: Romania, Georgia and Turkey. Rates of land use change between circa-1990 and circa-2000 were quantified by analyzing Landsat imagery. A carbon book-keeping model was used to quantify these effects in Romania. In Georgia, illegal logging and state-controlled forest harvest are the main sources of land use change. Our analysis shows a small amount of land use change – in the relatively populous Ajdara region, 2.5% of the forested area in 1990 had been converted to non-forest in 2000. Even less land use change was found in Turkey – for the Northeastern part

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of the country bordering Georgia, 0.28% of the forested land (1,113 ha) had been converted to non forest over the period 1990–2000. For the whole country of Romania, the corresponding number was 2.4%. Integrating this harvest rate with forest inventory data in the carbon book-keeping model indicates that Romanian forests are currently a carbon sink and will remain so until about 2080 if current harvesting rates persist. The current carbon sink of 2.54 TgC/year is approximately 10% of the anthropogenic emission from fossil fuels in Romania.

Keywords: land use, carbon dynamics, Black Sea region, remote sensing

Introduction

Land-use change, and particularly land-use change involving forests, is a key component of the terrestrial carbon budget. Remote sensing provides a means to monitor land use change, but there remain significant areas of the earth where the nature and rates of land-use change are poorly understood. Thus, the uncertainties associated with quantifying the effects of land-use change on the carbon budget are large. Our aim is to significantly minimize those uncertainties for the Black Sea Region. We use remote sensing to better quantify the rates and kinds of land use change and a well-developed carbon model to estimate the net fluxes from these regions resulting from land use change.

We are interested in the Black Sea Region for a number of reasons: (1) more attention has been focused on the temperate forests of Western Europe and North America, where long-term forest inventories provide data for carbon accounting, and hence there is less information on the role of land use change in the carbon budget of Eastern European and Asian temperate-zone forests (Nabuurs et al. 1997; Pacala et al. 2001; Goodale et al. 2002; Janssens et al. 2003); (2) the temperate zones are believed to be a large sink of carbon, yet the underlying trends related to land-use change have yet to be quantified in many areas (Nabuurs et al. 1997; Pacala et al. 2001; Goodale et al. 2002; Houghton and Hackler 2003; Janssens et al. 2003); and (3) there have been dramatic political and economic changes in this regions over roughly the last decade, and we propose to explore their effects on rates and kinds of land-use change.

To evaluate the effects of various kinds of land-use change (deforestation, forest harvest, and reforestation) on the carbon budget, we use a model that has been used previously in other nations and regions to estimate the net annual fluxes of carbon associated with changes in land use (see e.g. Houghton et al. 1983; Houghton and Hackler 2003).

Little is known about the rates and locations of change in region's forests and their effect on the regional carbon budget. Following the collapse of the Soviet

Union the Black Sea region experienced a significant political/institutional transformation and the consequences of this transformation for forest resources remain uncertain. For example, in Romania, a large portion of forest holdings of the state have been privatized since 1990 as part of larger land ownership reform. While the economic value of these forests is high and provides an incentive for timber production, such restitution without adequate legal and institutional mechanisms may result in significant loss of forest cover and significantly influence carbon fluxes in the region for decades to come. The lack of Russian lumber and energy has also pressured some Black Sea countries to rely increasingly on their own forests to meet domestic demand for forest products. For instance, the shortage of energy sources has dramatically increased the consumption of firewood in Georgia, and consequently, illegal timber cutting has dramatically increased. In Turkey, the overwhelming majority of forests are state property and this limits forest harvesting. Also, there are significant government sponsored reforestation/afforestation programs. The net effect of all these factors in terms of forest change is not well known. There is little comprehensive information for the region regarding the amount of forest land, the rates of timber harvest and rates of conversion of forests to other land uses, or the effect of the collapse of the Soviet Union on the region's forests.

Methodology

Remote sensing

In this study we used a set of orthorectified Landsat scenes with a spatial resolution of 28.5 m. These data are freely available (GLCF), and include global coverage for the time periods of circa 1990 and circa 2000 (Tucker et al. 2004). A combination of multispectral transforms of brightness, greenness, wetness (Crist and Cicone 1984) for the year 2000 and change in brightness, greenness and wetness (Collins and Woodcock 1996) derived from atmospherically corrected data served as input to a supervised neural network classifier to map land cover and land cover changes. The Landsat scenes were individually classified to identify areas of stable forest and forest to non-forest areas. A representative set of training sites was visually identified for each of the land cover and change classes and used to train a neural network classification algorithm (Carpenter et al. 1997). The neural network assigns a land cover or change class to each pixel in the dataset. The output was segmented into polygons with a minimum mapping unit of approximately one hectare (11 pixels). A minimum mapping unit larger than the spatial resolution of the data minimizes confusion in the identification of land cover change resulting from minor misregistration of the two dates of imagery. The accuracy of the segmented maps was manually edited to remove errors, mainly in the forest change class. The methods used follows those outlined in

(Woodcock et al. 2001). The change map for Romania was assessed using 829 stratified random samples and the marginal error totals were used to revise the area estimates of the classes using the methods Card (1982).

Carbon modeling

The carbon book-keeping model employed in this study has been used for tracking changes in carbon pools due to land use change since the beginning of the 1980s (see e.g. Moore et al. 1981; Houghton et al. 1983; Houghton 1987; DeFries et al. 2002). The term "book-keeping" stems from the fact that the model tracks changes in carbon stocks from year to year rather than trying to model the individual biological processes that constitute the carbon balance, i.e. photosynthesis and respiration (Moore et al. 1981). As a consequence, it is not possible to verify the model results with direct flux measurements such as flux tower measurements. Furthermore, there is no way to study interannual variability in forest regrowth. Although the structure and input demands of the model are rather straight forward, the model makes use of long term integrated harvest and clearing estimates and to growth rates, and takes into account the time lags associated with decomposition of wood products for calculation for carbon flux. It also takes the depletion/ accumulation of soil carbon into account. For the above-mentioned reasons, the model is suitable for quantifying the effects of land use change on the terrestrial carbon budget of Romania. The coupling of remote sensing is evolutionary as satellite data offers the possibility to obtain explicit measurements of changes in forest area.

Rates of land use change (forest harvest and clearing, and abandonment), expressed as time series in hectares per year, are used as input to the model. Each one could be regarded as an event, or disturbance, in the ecosystem generating a response in the system expressed in terms of carbon being released or accumulated. The model will output the final uptake and release (and flux) as a yearly time series.

For example, consider the event of forest harvest: an undisturbed ecosystem is harvested with reforestation taking place immediately after (Fig. 18.1). Part of the harvested wood will be used within a year after harvest. Another part is assumed to decay within 10 years. The final and third part will end up as long-lived wood products, which are assumed to decay within 100 years of harvest. Accordingly, the harvested material is distributed among three different carbon pools with three different decay rates. Since the harvest is followed by reforestation, carbon will be sequestered in the regrowing trees (represented by the gray lower bars in Fig. 18.1). In addition to the above, carbon is released from slash left at the scene after harvest, resulting in a fourth source of carbon release. A fifth and last source of carbon release is included in the model since soil organic matter is lost following forest harvest. However, since there is little evidence of recent land use change in Romania and inconclusive evidence of change in soil carbon in the absence of land use change (Johnson and Curtis 2001), we do not attempt to model or account for changes in soil carbon.

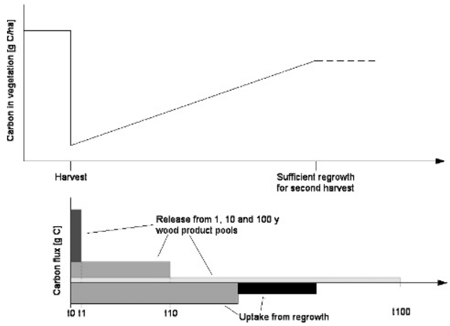

Fig. 18.1. Harvest event. The upper graph shows the amount of carbon per hectare in the vegetation, and the lower the amount of carbon released or sequestered by the ecosystem following the harvest. The dashed line indicates that several responses are possible.

Another important event in the model is related to the transformation of forest to stable non-forest. When a forest is cleared in favor of, for example, a cropland or pasture, the ecosystem will lose carbon stored in both soil and vegetation. The latter is treated as in the event of forest harvest – the wood material is assumed to end up in the three carbon pools, and will decay at different rates depending on its fate. But since the cleared forest is not replaced, there will be no carbon uptake from regrowth of new trees. This course of events is illustrated in the third graph in Fig. 18.2. As depicted in Fig. 18.2 (second graph), the system will experience a loss of soil organic matter throughout the event.

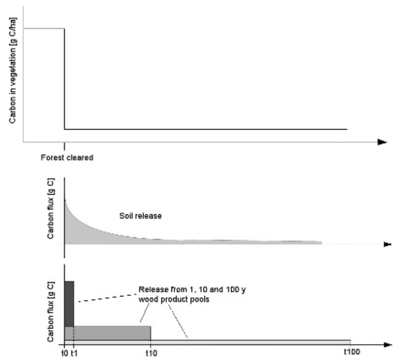

Fig. 18.2. Clearing event. The upper graph shows the amount of carbon per hectare in the vegetation, the second the amount of carbon released from the soil, and the third the release from the wood product pools.

Finally, when a cropland or pasture is abandoned, trees are assumed to start growing, resulting in carbon being sequestered without any simultaneous release of carbon from the ecosystem. When trees start growing, soil organic matter starts to accumulate, adding to total carbon uptake (Fig. 18.3). Hence, there is no release of carbon associated with the event of abandonment of agricultural fields.

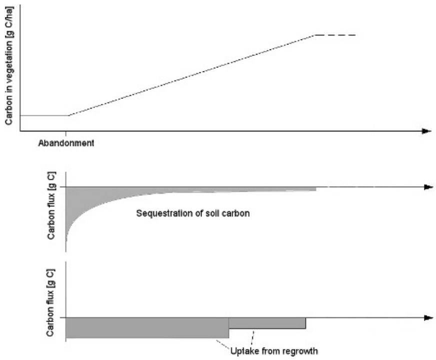

Fig. 18.3. Abandonment event. The upper graph shows the amount of carbon per hectare in the vegetation, the second the amount of carbon sequestered in the soil, and the third the uptake from forest regrowth.

Results and Discussion

A very limited amount of land cover change was found for Northeastern Turkey. Results show that over the period 1990–2000, 1,113 ha (0.28% of the forested land) have been converted to non-forest. The changes mainly involve forest areas cleared for urban and agricultural uses and water resources development in forested areas. Preliminary results indicate that forests in the region are carbon sinks.

Georgia has, since its independence from the Soviet Union in 1991, experienced dramatic changes. The rate of illegal logging has increased since the collapse of the Soviet Union, primarily due to shortage of natural gas for households and less strict control of logging activities. Illegal logging and state-supervised harvest of forest are the main sources of land cover change. Analysis of satellite imagery shows a relatively small amount of land cover change – for the southwestern region of Adjara, 2.5% of the forested land in 1990 was converted into non-forest by 2000. The relatively populous region of Adjara is bordering Turkey – the main importer of wood from Georgia – and preliminary results indicate that the clearing rate is less in other parts of the country. With the initial results for Georgia being similar to the ones for Romania, it is hypothesized that the situation in terms of carbon fluxes is rather similar to ones found for Romania.

Over the course of the last 15 years, Romania was also affected by significant political and economic changes. Results from the change analysis show that during the period circa 1990–2000, 2.4% (147,290 ha) of the forested land in 1990 was harvested. Much of the change is observed in private lands, while the public forested land shows few changes. The average forest clearing is 7.9 ha. About

80% of the clearings have a size smaller then 250 m. The above numbers, together with data on biomass and growth rates, were used as input to the carbon bookkeeping model to estimate the annual flux of carbon. The model estimates that the forests have absorbed an average of 8.4 Tg of carbon per year between 1990 and 2000, while the release from decay or oxidation of wood products and harvest debris was around 5.8 Tg/year for the same period. Accordingly, the Romanian forests have acted as carbon sinks by absorbing 2.5 Tg/year in average between 1990 and 2000. If assuming that the harvest rate for 1990–2000 continues, the model estimates that the current sink will decline and reach equilibrium around 2080. In comparison, the emission of carbon from fossil fuel burning is currently 27 Tg/year in Romania, indicating that the terrestrial sink is about 10% of the anthropogenic emissions. Figure 18.4 shows the evolution of the carbon fluxes of the different pools over time. Negative numbers indicate a sink, positive numbers indicate a source. Figure 18.4 also shows two different scenarios – the gray line shows the carbon flux assuming that the harvest rate will double after 2000, while the black line shows the scenario of zero forest harvest after 2000. Although there is a rather big difference in carbon flux for about 50 years, the two curves converge after about 60–70 years. And for the remaining years of the century, a higher carbon uptake is observed if the harvest rate is doubled in 2000.

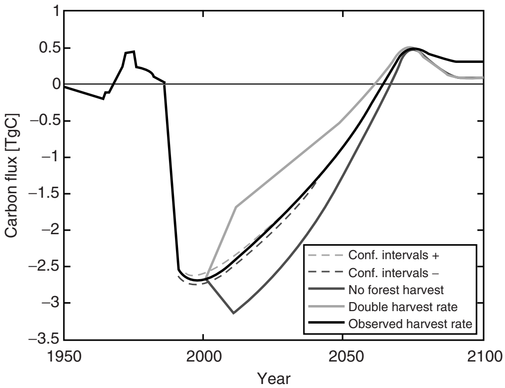

Fig. 18.4. Model results for Romania. Dark gray line shows the output when the observed harvest rates are used as input. Grey and black lines show the scenarios no harvest and double harvest rate after 2000, respectively.

Conclusions

- Rates of land use change are low in the forests of Turkey, Romania and Georgia for the period 1990–2000.
- Remote sensing observations are central to our ability to monitor land cover change.

- Romania is a carbon sink currently, and our preliminary results indicate that Turkey and Georgia will be, too.

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Recent Trends in Land Surface Phenologies Within the Don and Dnieper River Basins from the Perspective of MODIS Collection 4 Products

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Abstract. During the past 2 decades Eastern Europe has been going through one of the most abrupt socioeconomic transformations in recent times. As core areas for regional agricultural production, the basins of the Dnieper and Don Rivers, the institutional changes have impacted the terrestrial vegetation cover dynamics. As regional economies entered recovery phases starting around the year 2000, the observed trends in land surface phenologies have, in some locations, changed their previous downward direction. We analyze here image time series of MODIS Normalized Difference Vegetation Index (NDVI) and Land Surface Temperature from Collection 4 data products. Our main objective is to characterize and summarize the extent of negative and positive trends in land surface phenologies across the study area and draw linkages between trends in indicators of surface vegetation and those in the radiometric skin temperature.

Keywords: phenology, Don and Dnieper Rivers, land cover changes

Introduction

Land surface phenology (LSP) focuses on how the vegetated land surface develops and interacts with the boundary layer of the troposphere as modulated by climate, recent weather, and human activities viewed from the perspective of spaceborne sensors (de Beurs and Henebry 2004a; Fisher and Mustard 2007; Knight et al. 2006). LSP research is done for numerous purposes, from different perspectives, and across a variety of temporal scopes and spatial scales. Unless assessing prognostic plant growth models (Bondeau et al. 2007; Kathuroju et al. 2007), studies of phenology use time series of remotely sensed imagery retrospectively to characterize the land surface dynamics with functional indicators such as the Normalized Difference Vegetation Index (NDVI), Leaf Area Index (LAI), Fraction of absorbed Photosynthetically Active Radiation (FPAR), and so on. Determining

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the timing of events such as beginning, ending, duration, and peak of the vegetated surface constitutes a primary objective of LSP studies (White et al. 2003; White et al. 2005). The statistical analyses are used to assess temporal trends and spatial heterogeneity in LSP variables (de Beurs and Henebry 2005a; Reed 2006) or to link LSP variables with climate modes (de Beurs and Henebry 2008).

Testing for LSP trends requires choosing an appropriate methodology that is robust in the face of multiple confounding sources of variability (de Beurs and Henebry, 2005b). The temporal variability in the dynamics of the vegetated land surface can arise from land cover land use change (LCLUC), climate change, interannual variability in growing season weather, or some admixture of these influences. Here we study the interplay of these factors in two major river basins in Eastern Europe. The basins of the Dnieper and Don Rivers are among the more industrialized regions of the former Soviet Union and, at the same time, central to agricultural production. After major crises in the agricultural sector following the collapse of the USSR and the difficult years of socio-economic transition (de Beurs and Henebry 2004a), the region is currently redeveloping its crop growing capacity. Loss of government subsidies coupled with access to new, competitive markets have induced changes in agricultural practices, choice of crops, and the timing of planting, canopy development, and harvesting, which leads, in turn, to manifest changes in regional patterns of LSP. In this brief study we investigate the LSP trends as revealed by NDVI and land surface temperature (LST) image time series from MODIS Collection 4 data products.

Study Area

Both the Dnieper and Don Rivers belong to the Black Sea drainage basin. Historically, these basins have been the most populated regions of the former Soviet Union. Average population density within the Don basin is 47 persons km^{-2} with seven cities having more than 100,000 inhabitants (Revenga et al. 2003). Average population density within the Dnieper basin is 64 persons km^{-2} with 16 cities with more than 100,000 inhabitants (Revenga et al. 2003). Despite the high level of industrialization, the area is and was heavily exploited in agricultural production: 83% of the area in the Don basin and 87% in the Dnieper basin are in agricultural land cover. In the central and southern parts of each basin, arable land constitutes almost 90% of total land resources in agriculture.

During the Soviet period very large hydrotechnical works were developed on both rivers, primarily for hydroelectric power generation. As a result, a large portion of farmland came to rely on irrigation water available from these reservoirs. Collapse of the Soviet Union removed the financial supports of the infrastructure for irrigation and resulted in sharp declines in water consumption. With the beginning of the new millennium, the economy of the region entered the recovery phase. Slowly, the agricultural infrastructure of Don and Dnieper River basins is redeveloping.

Data Source, Preparation, and Analysis

In this study we relied on Collection 4 of MODIS land products:

– MODIS land cover type global 0.05° CMG 2004 MOD12Q1
– MODIS Nadir reflectance BRDF-adjusted 16-day L3 0.05° CMG (2000–2006)
– MODIS land surface temperature/emissivity 8-day L3 1 km (2000–2006)

All data products were obtained from Land Processes Distributed Active Archive Center: EOS data gateway (http://edcimswww.cr.usgs.gov/pub/imswelcome/).

We prepared and analyzed the data in six steps. First, the 17 land cover classes of the IGBP scheme from MOD12Q1 product were aggregated to 8 super-classes with each super-class masked separately for each river basin. The super-classes were Water, Forests, Shrublands, Grasslands, Wetlands, Croplands, Urban and Built-Up, and Not Vegetated. We restricted the analyses to Forests and Croplands super-classes due to an insufficient abundance of other land cover types within the study areas. Second, reflectances from MODIS bands 1 and 2 were extracted from the NBAR product, and NDVI was calculated. Third, land surface temperature (LST) was extracted from MOD11A2 product. Our analysis focused on a seasonal period from April through October using 16-day composites that are standard with Collection 4. Fourth, the NDVI and LST image time series were arranged to submit to the Seasonal Mann–Kendall (SMK) test adjusted for first-order autocorrelation, a non-parametric trend test that is superior to the commonly used approach of simple linear regression (de Beurs and Henebry 2004b, 2005a). We used a version of SMK test of image time series implemented in IDL by Dr. K.M. de Beurs and P. de Beurs. Fifth, resulting datasets were reclassified into three categories based on the significance and direction of trends. Sixth, confusion matrices were constructed to illustrate the linkages between NDVI and LST trends.

Results and Discussion

The trend analyses yielded two sets of raster images representing the SMK test scores and the associated significance values. During the period of 2000–2006, the land surface phenology trends varied across the study area. Most forested land in the Dnieper basin exhibited significant positive NDVI trends while significant negative trends were restricted to few croplands in the south (Fig. 19.1, left). A contrasting picture was observed for the Don basin where only small islands of

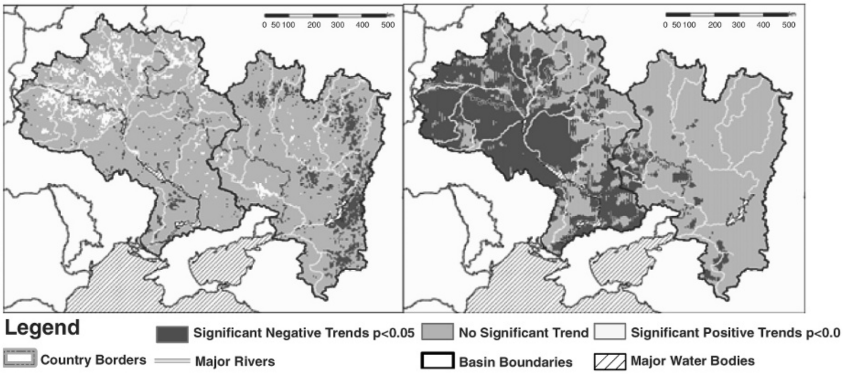

Fig. 19.1. Land surface phenology trends (2000–2006) revealed by NDVI (*left*) and land surface temperature (*right*) within the basins of the Dnieper and the Don Rivers.

Table 19.1. Confusion matrices for trends detected in NDVI and LST in the Dnieper basin (**a**), the Don basin (**b**), and the combined area (**c**).

(A) *Dnieper River basin*

LST ► NDVI▼	%significant negative trends	%not significant trends	%significant positive trends	*Sum for LST*
%significant negative trends	0.8	49.1	7.4	57.4
%not significant trends	1.6	38.1	3.0	42.6
%significant positive trends	0.0	0.0	0.0	0.0
Sum for NDVI	2.4	87.2	10.4	100.0

(B) *Don River basin*

LST ► NDVI▼	%significant negative trends	%not significant trends	%significant positive trends	*Sum for LST*
%significant negative trends	0.0	9.1	0.3	9.5
%not significant trends	12.1	77.1	1.3	90.5
%significant positive trends	0.0	0.0	0.0	0.1
Sum for NDVI	12.1	86.3	1.6	100.0

(C) *Entire study area*

LST ► NDVI▼	%significant negative trends	%not significant trends	%significant positive trends	*Sum for LST*
%significant negative trends	0.5	30.7	4.1	35.3
%not significant trends	6.4	56.1	2.2	64.7
%significant positive trends	0.0	0.0	0.0	0.0
Sum for NDVI	6.9	86.8	6.3	100.0

significant positive NDVI trends showed up in the western part of the basin and significant negative trends were distributed in an arc along the northern and eastern flanks of the basin. Most of the area in either basin showed no significant trends (Table 19.1). On a proportional basis, the forests in the Don basin exhibited considerably less area with significant positive trends (~7,000 km^2) than the forests within Dnieper basin (~52,000 km^2).

The SMK test on the LST image time series revealed presence of significant negative trends on one third of the study area (Fig. 19.1, right and Table 19.1). Most of the area with negative LST trend was within the Dnieper basin covering almost 60% of the basin and spreading across both forests and croplands. Yet the occurrence of significance was higher in forested than cropland areas. Don basin had only a few patches of significant negative LST trends in croplands adjacent to the eastern boundaries of Dnieper basin and on the very south of Hoper river (biggest left tributary) watershed. Most of the area of the Don basin (85%) exhibited no significant trend in LST. At the spatial resolution of the input data, only a few spots of significant positive LST trends were observed dispersed along the southwestern flank of the Don basin.

The vertical streaking pattern and blockiness evident in LST trend maps (Fig. 19.1, right) appear to be artifacts of the Collection 4 LST product and it raises doubts about the validity of the detected LST trends. We will be applying this analysis to the recently released Collection 5 data and expect to find an LST trend pattern that more closely complements the NDVI trends. We expected significant positive NDVI trends to be associated with significant negative LST trends, because increasing vegetation activity at the surface should be associated with increasing evapotranspiration and thus cooler surface temperatures. Similarly, increasing LST trends we expected to be associated with areas of decreasing NDVI trends: less vegetation yields less evapotranspiration causing higher surface temperatures.

Conclusions and Next Steps

Given several observational periods within a year, nonparametric seasonal trend analysis can leverage data from even a handful of years to reveal changing land surface dynamics. For the forests in the northern reaches of the Dnieper River basin, the period 2000–2006 brought significant positive NDVI trends following several years of frequent forest fires at the end of 1990s (Ostapchuk 2005). No negative trends were seen in the Dnieper forests. In the Don River basin more than 12% of the basin showed significant negative NDVI trends and less than 2% had positive trends. For the croplands of Ukraine, the first years of the twenty-first century saw a rebalancing of enterprise ownership in the agricultural sector (Ostapchuk 2004): only one third of agricultural production now comes from state owned farms. Inflow of private capital stabilized the agricultural production in the region, preventing degradation of vegetation cover. A slightly different situation is observed in Russia where Russian Federal Statistics Service reported slower growth in agricultural production than in Ukraine (Badalyan 2008; Ostapchuk 2008). These socioeconomic differences may explain the observed significant negative trends within croplands of southeastern part of Don Basin. A more detailed study of spatial particularities of agricultural transformations in Russia must be done to confirm to this hypothesis.

The final message from this study is that special attention needs to be paid to data quality in trend analyses, particularly regarding the temporal and spatial resolution. Streaking in LST results strongly suggests noise or artifacts in the underlying data series. Yet the conclusions of the analysis may still be valid for this level of noise in image time series. Thus, next steps include the evaluation of the robustness of the SMK trend test to various levels of noise, the analysis of the MODIS Collection 5 products, and a comparison of the trend results from Collections 4 and 5.

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Soil Erosion Induced Degradation of Agrolandscapes in Ukraine: Modeling, Computation and Prediction in Conditions of the Climate Changes

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Abstract. Description of negative consequences of processes of soil erosion in the world and Ukraine is given. It is shown that erosion of soils is the most widespread soil degradation process taking place in one fourth of the territory of Ukraine, and this area continues to increase. In accordance with the modern tendencies of climate change, the intensity of soil erosion processes in the near future in Ukraine will grow. In this connection, the problem of estimation and prognosis of the rates of erosive destruction of soils and increasing of eroded areas takes on special significance. It is shown that for the examination of natural-economic terms of Ukraine the spatial-distributed mathematical model of erosion-deposition, developed in Odessa National I.I. Mechnikov University, is the most adequate tool. It is also shown that the progressive increase of area of eroded soils necessitates quantitative evaluation of their influence on climate formation process.

Keywords: soil erosion, Ukraine, modeling, prediction, climate change

Introduction

Soil erosion is one of the most widespread and dangerous soil degradation processes in the world. As a result of sheet water erosion the soils lose the most valuable upper part of their profile; the content of humus (soil organic matter) and nutrients in soils diminishes, and physical and chemical properties of soils get worse. In particular, as the absorptive power and moisture-holding capacity of soils diminish, it negatively influences not only the water regime of soils but also on the hydrological regime of territories as a whole. As a result of development of linear erosion – ravines, sometimes having a depth of several tens of meters, part of the land is fully withdrawn from agricultural use while parts become marginal

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for further use. The products of erosive destruction of soils entering rivers contributes to the turbidity of river water and worsens water quality due to adsorbed and dissolved matters in eroded soil particles, including pesticides and radionuclides. The silting of river valleys and reservoirs and the disappearance of small rivers are unfavorable processes which are linked with the products of erosive destruction of soils. Soil erosion, thus, is a degradation process, having negative influence not only on upper soil and, consequently, on quality of land resources, but also on other components of landscapes such as topography, water resources, vegetation, and climate.

The total and final effect of soil erosion can be marked as desertification. Wide distribution of soil erosion in the world and in Ukraine exemplifies this problem in connection with the modern changes of climate.

Soil erosion in the world and in Ukraine

As evaluated within the project Global Assessment Human-Induced Soil Degradation (GLASOD) of UN Program on the Environment (UNEP), executed in 1987–1990 (GLASOD 1990), more than 1 billion (1,093.7 million) hectares of eroded (i.e. in a different degree destroyed by erosion) soils were counted in the world. Soil erosion by water takes first place among other soil degradation processes (56% of area of all degraded soils). Second place among these processes results from "deflation" which is the destruction and transference of soil by wind, often named "wind erosion". This type of erosion accounts for 550 million hectares of destroyed soils (28% of area of all degraded soils).

Therewith, as evaluated by FAO, the annual losses of productive soils from erosion in the world are approximately 5–7 million hectares. Taking into account these rates, presently the area of eroded lands in the world occupies 1.2–1.3 billion hectares, which is approximately 10% of the ice-free dry land. If the deflated lands are taken into account, this number increases to approximately 14%. However in separate countries this percent substantially differs from the median value. For example, in the USA, where soil erosion was acknowledged as a national calamity in the mid 1930s, about 9% of territory (44% of cultivated lands) is exposed to erosion, in Russian Federation – 2.2% of territory (but 28% of arable lands), and in China – about 20% of the territory (The World Factbook 2003). In the countries of East Europe the eroded soils occupy from 3.2% (Estonia) to practically 40% (Bulgaria) territory (Table 20.1). Besides Bulgaria, soil erosion also has wide distribution in Moldova, Hungary, Romania, and Czech Republic.

In accordance with data of the Ukrainian State Committee of Land Resources, on January 1, 2000 in Ukraine there were counted 13.9 million hectares of eroded agricultural lands, that was 33.2% of their area. Taking into account, that agricultural lands in Ukraine occupy about 70% (69.3% on 1.01.2004) of the territory, practically one fourth (23%) is eroded. Besides this, more than 6 million hectares (14.3% agricultural lands) are systematically exposed by wind erosion, and in years with excessive dust storms – up to 20 million hectares.

Table 20.1. Relative extent of water erosion (% of country area) in accordance with SOVEUR Project (2000).

Country	W_t[a]	W_d	W_0	W_{we}
Belarus	8.5	0.2		8.7
Bulgaria	39.8			39.8
Czech	15.1			15.1
Estonia	3.2			3.2
Hungary	21.2			21.2
Latvia	11.4			11.4
Lithuania	10.4		0.4	10.8
Moldova	34.8	1.0		35.8
Poland	6.7	2.5		9.2
Romania	18.2	8.6	4.0	20.8
Russia[b]	4.2	6.8		11.0
Slovakia	5.4	6.8		12.2

[a]W_t – sheet erosion, W_d – terrain deformation by gully and/or rill erosion or mass movement, W_o – off-site effects of water erosion in downstream area (sedimentation of reservoirs and waterways, pollution of water bodies with eroded sediments etc.), W_{we} – all kinds of water erosion.
[b]Within its European part.

The soil erosion is widespread in all regions of Ukraine, but the most widespread is within the North of Steppe and the South of Forest-Steppe zones, where the elevated relief, intensive thundershower activity and high fraction of cultivated territory (60–70% from a general area on the average) combine. Area of eroded lands here consists 50–60% of the area of agricultural lands and 35–45% of the total area. For the last 35–40 years the area of such lands in the country has increased by 1.5 times. Annually, the area of eroded soils in Ukraine was increasing by 80,000–100,000 ha.

Thus, soil erosion is the most widespread and dangerous soil degradation process in Ukraine. Annual harm to agriculture alone in the country by different estimates equals US$5–10 billion. That is why the rational usage of land and water resources and sustainable development in practically all regions of Ukraine, especially the central and southern parts, is impossible without substantiation of the system of measures providing prevention of erosion destruction of the soil cover. This is possible only with the use of an adequate mathematical model (or models) of soil erosion, that takes into account all basic natural and economic factors of the process in conditions based upon realistic considerations. The important result should also have the possibility of the model(s) taking into account the spatial distribution of soil erosion factors, allowing it to give estimation of actual distribution of intensity of soil erosion losses within the limits of the examined territory, and the possibility of the model(s) to estimate the influence of modern and forthcoming changes of climate on the processes of soil erosion.

Modeling and calculation of water soil erosion

As is generally known, there are different approaches to the modeling, calculation and prognosis of water soil erosion. Most of the details can be done on the basis of compound physically based models like the soil erosion model of WEPP (USA) (Nearing et al. 1989) or European Soil Erosion Model (EUROSEM) (Morgan et al. 1998). However, due to the absence of the required information base for soil protection the empiric models are widely used in different countries of the world.

Among mathematical models of soil erosion, which have been developed in the former Soviet Union and then in Ukraine, that were recommended and/or used for estimation of erosion losses of soil and soil protective designing in Ukraine, the model, which was developed in Odessa National I.I. Mechnikov University (Shvebs 1974, 1981), has been the most theoretically and experimentally accepted. In recent years on the basis of this model with assistance of modern geoinformation technologies, a spatially distributed soil erosion/deposition model has been developed (Svetlitchnyi 1999; Svetlitchnyi et al. 2004; Pjatkova 2008).

The model belongs to the class of physical-statistical empirical models, which includes the well-known Universal Soil Loss Equation (USLE). However, this one takes into account the brilliantly expressed non-stationary nature of the process of thundershower sediments formation with features of the process of washing off on slopes of complex form and is adapted to the natural-economic terms of Ukraine. Spatial GIS-realization of the model with usage of PCRaster package (Utrecht University, The Netherlands) (PCRaster Manual 1998), allows us to take into account the features of spatial distribution of all basic factors of erosion. It enables the calculation of an estimation of modern intensity of erosion-sedimentation on slopes of arbitrary form. The model has been verified with the use of data from observations on experimental runoff plots and slope watersheds located in different parts of the territory of Ukraine. The model is widely approved and commended.

In Fig. 20.1 an example of calculation of average annual erosion-deposition rate within the limits of a plot of arable land (900 x 900 m) under a plowed condition without vegetation. The greater part of the plot located on the right slope of Small Katlabuh River valley (Odessa region) with the soil cover presented by ordinary chernozem in different degrees eroded and slope gradients changing from 0.003 up to 0.137. The analysis of the map created shows that the average within the plot erosion-induced soil losses equal 6.4 t/ha per a year, but the range of soil losses within this relatively small area changes from (−5) t/ha/year (deposition) to 63 t/ha/year (very strong erosion).

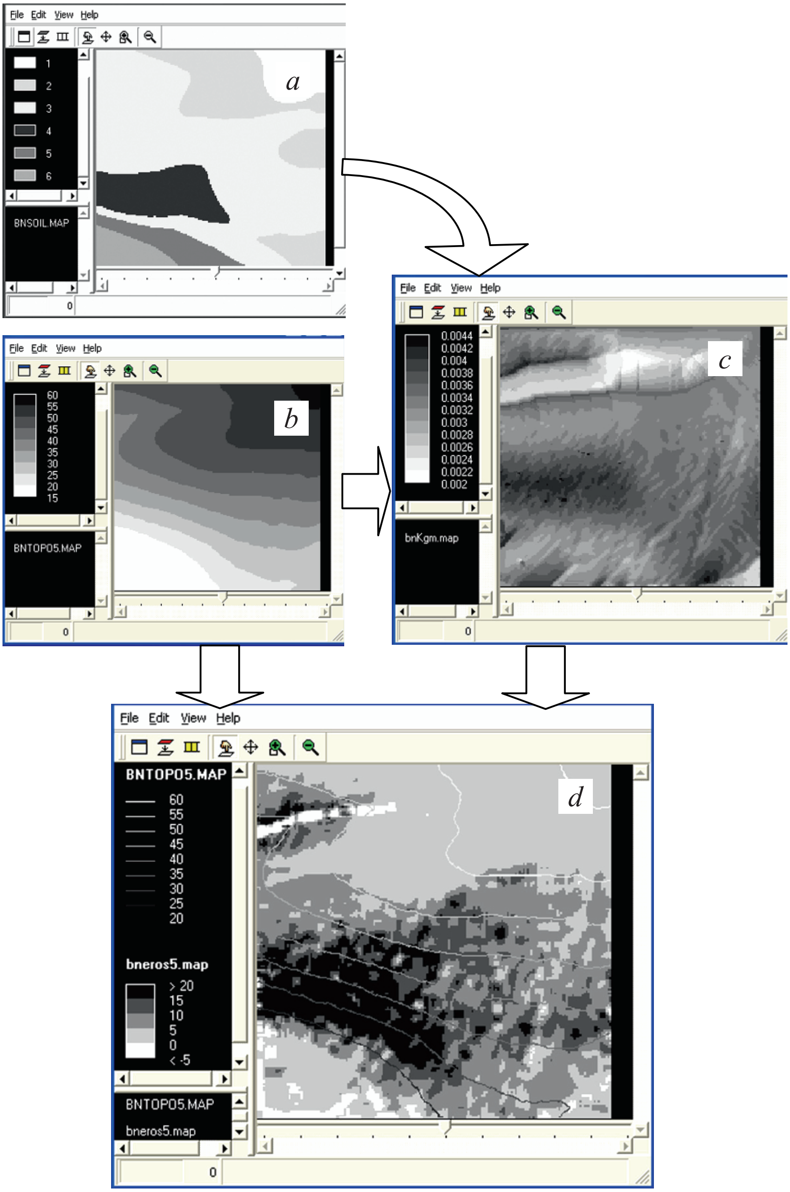

Fig. 20.1. Soil map (*a*), digital elevation model (*b*), map of mean annual value of hydrometeorological factor K_{HM} (*c*) and calculated map of mean annual erosion-deposition (in t/ha) with the superimposed contour lines (*d*) within the test area by a size 900 x 900 m.

The climate change and soil erosion

Modern rise in temperature, which is going on in many regions of the world, including Ukraine, is accompanied by an increase in precipitation (Bojchenko et al. 2000; Climate of Ukraine 2003; IPCC 2007). As research has shown, there has been an increase in the number and intensity of showers, causing an increase in erosive destruction of soils. Figure 20.2 shows the changes of annual precipitation and two indices of daily precipitation extremes (European Climate Assessment 2008) – number of days with precipitation, exceeding 20 mm (R20mm), and maximum daily precipitation (RX1day) for the warm period of year in accordance with data of observations on weather-station Odessa-observatory (which is located on the south of Ukraine, on the north-western coast of the Black Sea) during 1900–2007.

All of them are characterized by ascending linear trend. But, if the increase of annual precipitation for this period equals about 10% of the mean value, the values of indexes R20mm and RX1day for this period were increased by more than two times. As modern research shows (Allan and Soden 2008), the further rise in temperature will result in a greater increase of thundershower activity, which will be substantially greater than it was assumed before.

For the prognosis of changes of intensity of soil erosion and area of distribution of the eroded soils in connection with the climate change, a mathematical model is needed which explicitly takes into account the influence of changes of climatic terms on the rate of soil erosion. For Ukraine, the spatial physical-statistical model of erosion/deposition described can be used.

The influence of climate factors on intensity of soil erosion in the model is carried out with the help of our experimentally observed original hydrometeorological factor of the shower washing off of soil (K_{HM}), in the basis of which there is a model of elementary sediments formation for a separate rain. The hydrometeorological factor for a separate rain k_{HM}' has a kind:

$$k_{HM}' = \left[\sum_{i=1}^{N} (1+17.5Ar_i)(r_i - r_{ci})^{2.7} \Delta t_i + \sum_{\xi=1}^{M+1} (1+17.5Ar_\xi)(r_{\xi-1} - r_{c\xi-1})^{2.7} \lambda^{2.7} \Delta t_\xi \right], \quad (1)$$

where – r_i – intensity of rain during time interval i from beginning of the rain, for which sediment formation took place, mm/min; r_{ci} – critical intensity of precipitation for the soil, accepted as a standard (ordinary clay non eroded chernozem), such that washing off soils begins, mm/min; r_ξ – intensity of precipitation during Δt_ξ time interval for which $r_\xi < r_{c\xi}$, mm/min; λ – coefficient of spatial concentration of slope runoff during of its recession; A – coefficient of soil protective efficiency of vegetable cover; N – amount of rain intervals with washing off of soil, i.e. of intervals of rain, for which $r_i > r_{ci}$; M – amount of continuous groups of intervals of rain, for which $r_\xi < r_{c\xi}$. The last ($M + 1$) element in (1) characterizes the contribution of the washing off during the gradual recession of flow after termination of rain.

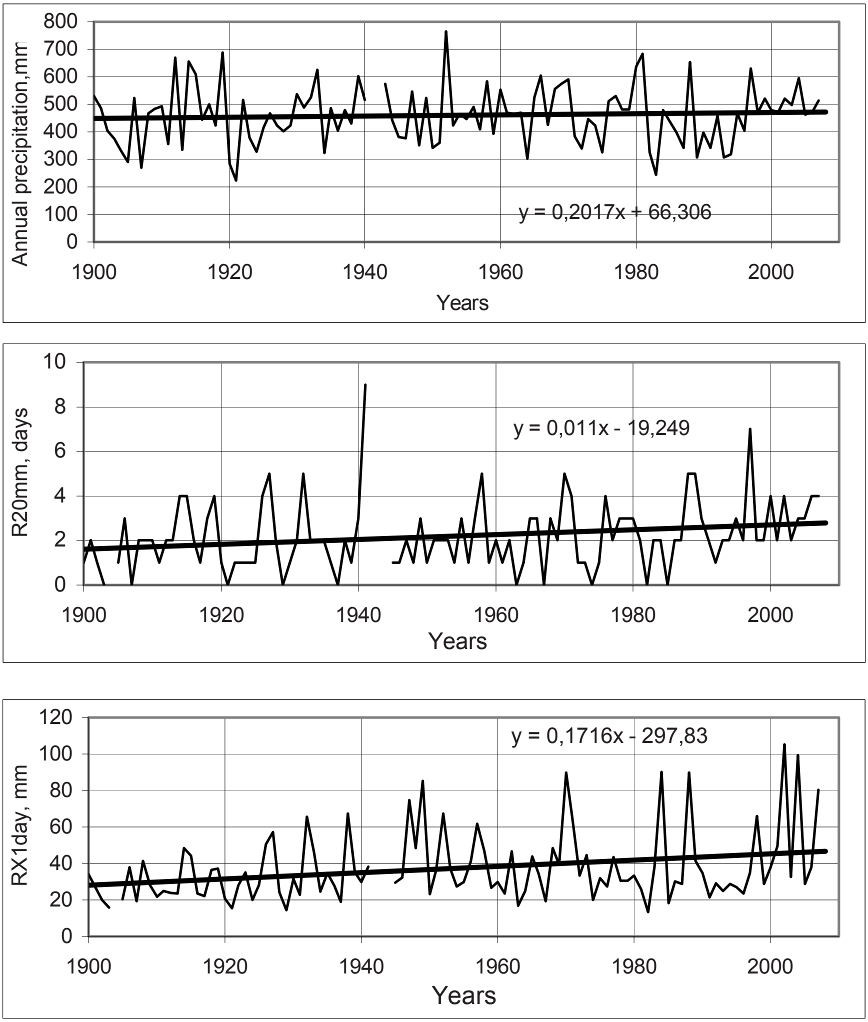

Fig. 20.2. Change of annual sum of precipitation and two indices of daily precipitation extremes during 1900–2007 in Odessa.

Critical intensity r_c for every interval of rain for the soil changes depending on the antecedent moisture content of active soil layer $B_{0,}$ and amount of precipitation fallen for the given time interval i ($\sum_{j=1}^{P} \Delta X_j$):

$$r_{\text{см}i} = 0.08 + 5.92\exp\left[-0.151\left(B_0 + \sum_{j=1}^{P} \Delta X_j\right)\right], \tag{2}$$

where P – amount of the preceding time intervals j.

Values of the hydrometeorological factor of shower washing off for all showers, able to form washing off of soils, computed by the formulas (1–2), are then summarized for every year. These annual values of the hydrometeorological factor are used for calculation of K_{HM} norm (long-term average) and its values of different repetition or probability of appearance by the methods of mathematical statistics.

In accordance with this method, the evaluation of K_{HM} norm for the Steppe zone and the South of Forest-Steppe zone of Ukraine with the use of data observations at all weather-stations of this area for the period 1949–1990 have been carried out. On the basis of generalization of these data, the maps of spatial distribution of the K_{HM} norm were built (Svetlitchnyi et al. 2004). Evaluation of K_{HM} norm for different scenarios of the soil moisture content change in relation to actual values, which has been carried out for separate long term weather-stations of the area, has shown the sensitivity of the hydrometeorological factor norm to the change of soil humidity is less than the change in shower activity.

The problem of soil erosion in connection with the climate change has another important aspect. It is related to the progressive increase of the area of eroded lands with the diminished amount of humus, more low permeability and water capacity and, accordingly, with higher albedo of soil cover and reduced water content of soils. Undoubtedly, all this influences elements of water and heat budgets of the Earth's surface.

In accordance with (Structure, Dynamics and Distribution of the Land Fund of Ukraine 2000) it has already been observed that at the end of past decade the area of eroded lands in Ukraine was increasing at an annual rate of 80–100 million hectares, which equals 0.13–0.16% of the country. If this rate of increase continues for 30 years (for "climatic" period), the increase of eroded lands on the average will equal 4–5% of the general area of the country, and within individual regions, practically two times more. If we take into account the wind erosion, these numbers will be increased by approximately one and a half times. In the near future, judging from the present prognoses of the climate change, this increase will be greater still. In this connection, carrying out the research of the influence of modern and forecast changes of the area and structure of eroded lands on the factors of climate and elements of water and heat budgets of the territory appears important and topical.

Conclusions

1. Soil erosion is a basic soil degradation process responsible for enormous economic and ecological damage to many countries of the world, including Ukraine and some other countries of Eastern Europe.
2. For estimation of rates of erosive losses of soils within the limits of Steppe and Forest-Steppe zones of Ukraine, which are the main territories of distribution of

water erosion in the country, the physical-statistical spatial GIS-realized model of soil erosion/depositions has been developed. The model can also be used for estimation of the influence of current and forecast changes of climate on rates of erosive destruction of soils and on a value of area of eroded lands.

3. Progressive increase of the area of eroded soils necessitates quantitative evaluation of influence of this process on hydrological cycle and climate formation process as a whole.

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Land Distribution and Assessment in the Ukrainian Steppe Within the Dnepropetrovsk Region

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Abstract. The investigations were conducted at rural and urban sites of the Dnepropetrovsk Region (Ukraine) and were aimed at an assessment of land stock changes and soil pollution to protect land resources and improve land management. The main type of soil was the black soil – chernozem. The following themes were considered in the study: structure of land stock, soil degradation, erosion, and dissemination of humus.

Keywords: steppe soils, land use, land degradation, land management, Ukraine

Introduction

Good land is the most important factor in promoting a sound agricultural economy. Good soil, good farms and good living naturally follow each other and provide the living and reproduction conditions for human generations following one another as the principal means of production in agriculture. Our soil is the foundation of our happiness, prosperity and progress.

The total area of Ukraine's land cover is 60.4 million hectares, of which about 40% is plowed cropland. The steppe is most heavily cropped, and occupies most of the southern part of the territory (25 million hectares on average).

The high fertility primary steppe soils occupy 15.5 million hectares. The chernozems occupy 77% or 11.9 million hectares of the territory [1]. Chernozems fall into the broad grouping of mollisoils according to the USDA system.

P.Y. Groisman and S.V. Ivanov (eds.), *Regional Aspects of Climate-Terrestrial-Hydrologic Interactions in Non-boreal Eastern Europe*,

There are several reasons to make changes in forests and agricultural lands distribution here. The main reason is connected with a need to provide the biological conservation for washed soils, etc. Unfortunately, erosion processes within steppe landscapes reach 40–50% [2]. The Ukraine steppe can be divided in two subzones: northern and southern parts. Two industrial regions: Prydneprovie (Dnepropetrovsk, Kirovograd, Zaporizzhya regions) and Donbass (Lugansk and Donetsk regions) – are situated in northern part of Ukraine. The natural steppe landscapes have been disturbed here during the last century [3]. The soil pollution affects the plants, surface and ground water. Today, the best utilization of land is of utmost importance with the view to conservation of soil fertility and prevention of soil pollution.

Materials and Methods

Dnepropetrovsk Region (province) is situated in the southeastern part of Ukraine on both banks of the river Dnepr and occupies an area of 31,923 km^2 . The Region has 22 administrative districts (rural areas) and 13 municipalities. The geographical location of the Region and the numbers of administrative regions, where investigations have taken place, are shown in Fig. 21.1.

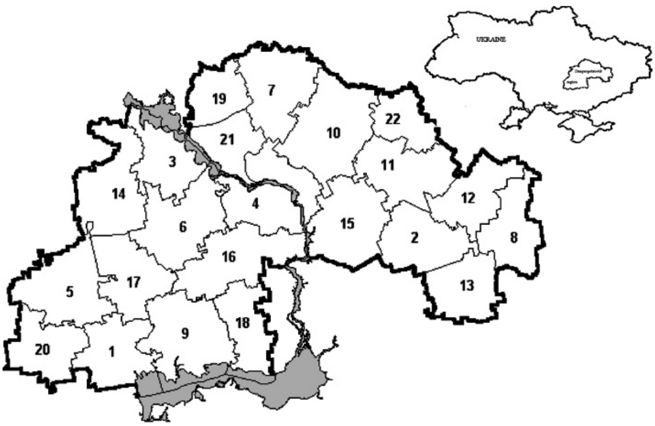

Fig. 21.1. Geographical location of the Dnepropetrovsk region in Ukraine and its administrative districts (the district names are provided in Tables 1 and 2).

Dnepropetrovsk Region holds a wealth of natural resources including mineral resources, black coal, water resources, very fertile soils and favorable climatic conditions. Natural resources formed the basis for leading industries of the economy at the national and regional level. Two of the metal ore reserves are among the largest in the world: iron ore in Krivoy Rog and manganese ore in the vicinity of the city of Nikopol. The conditions of soil formation in the Region are in accordance with geographical zonality. The main type of soil is black soil – chernozem. About

80% of the territory is occupied by chernozems of different subtypes: 48% of full-profile chernozem of the plain areas, 42% of typical chernozem, 6% of southern chernozem and others. The fertility of the black soil is famous around of the world. Because of that the greatest part of Dnepropetrovsk Region can be characterized as arable. The content of humus in the soils was determined by the relevant chemical-analytical method. Statistical methods were applied to describe quantitatively the relationships between soil components and some factors (such as using of organic fertilizers, irrigating, the amount of arable land etc.).

Results and Discussion

The structure of the land stock of the Dnepropetrovsk Region is shown in Fig. 21.2.

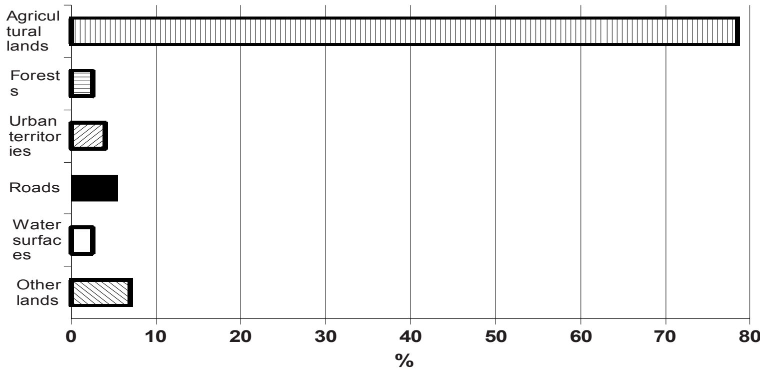

Fig. 21.2. Structure of the land stock in the Dnepropetrovsk region.

The land has been extensively changed by man. Human activities changed almost all of the landscapes of Southeast Ukraine. Only 0.8% of Dnepropetrovsk Region area remains more or less natural. Because of the prevalence of highly fertile soils and favorable climatic conditions, the average level of agricultural development of the land is very high – 79% – more than 25,000 km$^{\mathbf{2}}$, but in places it reaches up to 90% (Figs. 21.2 and 21.3).

The level of arable land varies from 55% to 80% (Fig. 21.4). On average there are 0.006 km^2 of agricultural land and 0.005 km^2 of arable land per person in the Region (Ukrainian standard is 0.0015 km^2 per person). Long-term degradation of the steppe grass ecosystems is also a part of the general process of environmental degradation in Ukraine. The increasing of areas of agricultural land (especially arable) has led to the decreasing of areas of natural steppe, forests and other vegetation. But natural areas determine the stability of the biosphere, agricultural production, water exchange, cycle of substances, and energy flow. There are several reasons to make changes in forests and agricultural lands distribution here. The main reason is connected with a need to provide the biological conservation for washed soils, etc. In the steppe zone, to form the underground water flow and to protect the soil from erosion, it is required that approximately 10% of the land be occupied by forests [4]. However, the actual average forest cover of the Region is only about 3–8%. The data on the agricultural lands and forests distribution within Dnepropetrovsk region can be taken into account as a reason to offer regrassing and reforestation measures (Table 21.1).

Due to location of the Region in the semiarid zone, the lands need to be irrigated. There are 2,240 km^2 of irrigated lands in Dnepropetrovsk Region. It is 7.0% of the total area and 10.6% of the arable lands (Fig. 21.4). The distribution of irrigated lands over the territory is shown in Fig. 5.

Table 21.1. Site planning for land transformation in the Dnepropetrovsk region.

Districts	Arable land (thousand hectares)	To do grassing to year 2010		Pasture square (thousand hectares)	To do reforestation to year 2010	
		Thousand hectares	%		Thousand hectares	% of pasture square
Apostolovsky	84.3	9.7	11.5	10.3	1.7	16.5
Vasilkovsky	92.3	11.7	12.7	16.2	2.6	16.0
Verkhnedneprovsky	61.6	19.7	32.0	13.7	8.2	59.8
Dnepropetrovsky	85.0	16.8	19.8	11.5	4.4	38.3
Krivorozhsky	80.5	10.2	12.7	10.7	1.6	15.0
Krinichansky	120.0	13.6	11.3	18.2	6.5	35.7
Magdalinovsky	110.8	5.4	4.9	12.7	1.0	7.9
Mezhevskoy	87.4	7.0	8.0	16.4	2.7	16.5
Nikopolsky	105.3	17.5	16.6	14.5	4.4	30.3
Novomoskovsky	113.5	13.0	11.6	19.0	6.5	34.2
Pavlogradsky	80.9	13.5	16.7	21.0	2.9	13.8
Petropavlovsky	31.1	5.5	17.7	14.4	3.2	22.2
Petrikovsky	84.9	12.1	14.2	14.9	1.4	9.4
Pokrovsky	84.8	9.9	11.7	12.5	2.6	20.8
Pyatikhatsky	112.7	19.6	17.4	16.2	6.5	40.1
Sinelnikovsky	116.0	17.0	14.6	18.4	8.3	45.1
Solonyansky	127.2	10.5	8.2	15.3	6.6	43.1
Sofievsky	100.2	10.7	10.7	12.5	3.3	26.4
Tomakovsky	80.3	11.2	13.9	9.2	3.6	39.1
Tsarichansky	50.1	5.6	11.2	12.7	3.3	26.0
Shirokovsky	77.1	10.3	13.4	11.9	1.6	13.4
Yurievsky	63.1	10.5	16.6	11.3	3.5	31.0
Total	1,949.1	261	13.4	313.5	86.4	27.6

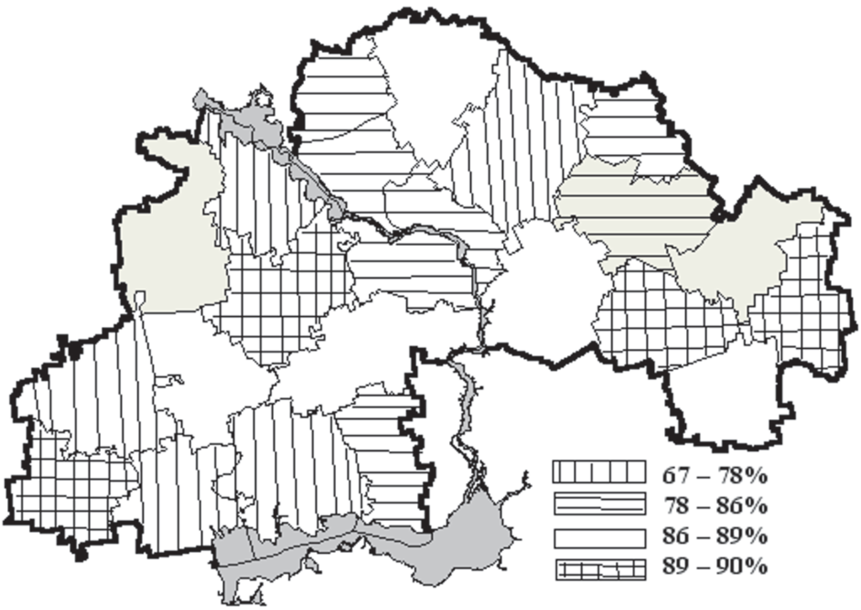

Fig. 21.3. Agricultural development of land in the Dnepropetrovsk region.

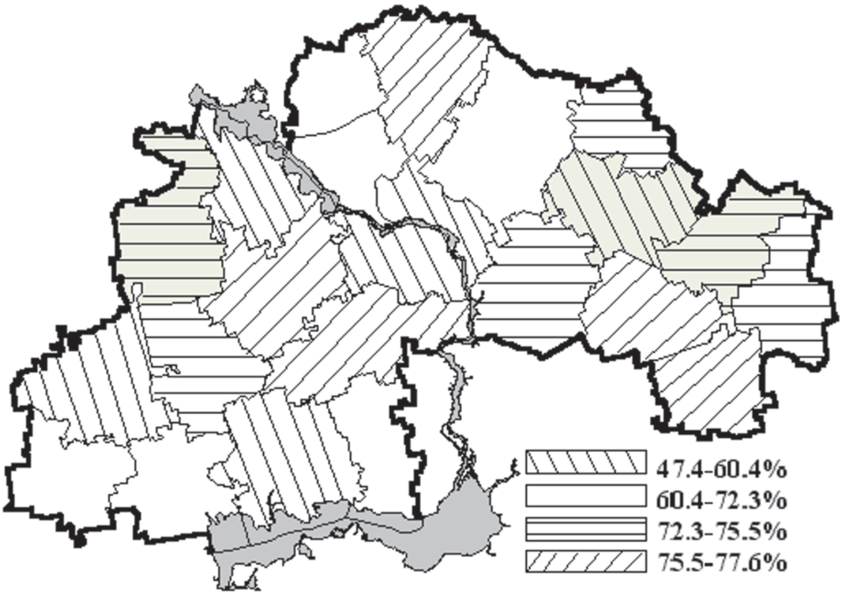

Fig. 21.4. Arable land in the Dnepropetrovsk region.

The soil covering has been severely damaged by mining of mineral ores and black and brown coal. The total area of detrimentally affected land in the Region is about 340,000 km^2 – the highest amount in Ukraine! In terms of the level of land damaged, the mining industry is the main source [5, 6]. During approximately the past 100 years the intensive exploitation of the iron ore basin in Krivoy Rog has led to the accumulation of about 2 billion cubic meters of waste resulting from the enrichment processes. Vast areas of fertile land are covered with waste rock and tailing dumps. There are eight tailing ponds in Krivbas, which occupy an area of 90 km^2. The total amount of coal mining waste is about 50 million tons, which occupies 0.2 km^2 of land. The metallurgical industry is another large source of wastes. In the Region there are more than 11 million tons of blast-furnace slacks, which occupy 2.3 km^2 of land. More than 8 million tons of ferro-alloy slacks occupy the area of 0.1 km^2. On an area of 6.2 km^2 about 10 million tons of mixed chemical wastes have been stored. About 8.5 km^2 were occupied by 60 million tons of ash from the Dnepropetrovsk power station.

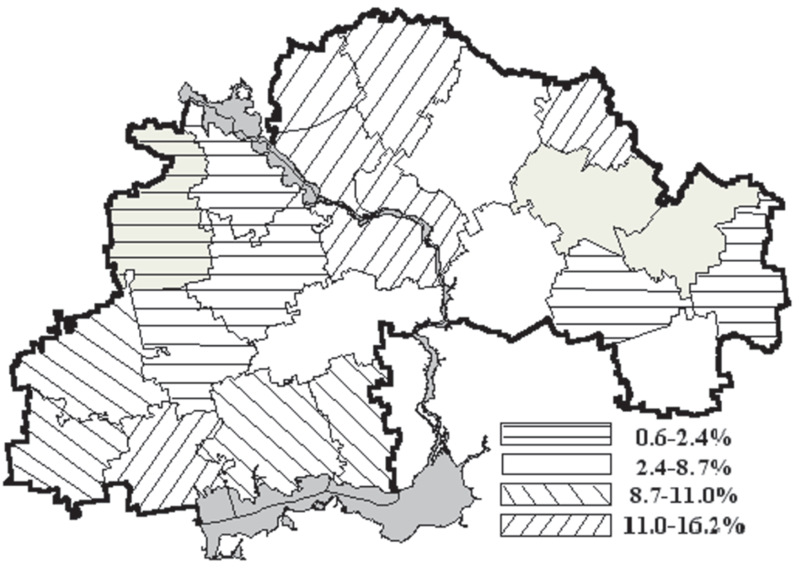

Fig. 21.5. Irrigated land in the Dnepropetrovsk region.

Soil contamination from industrial activities can occur through site-specific effects. A production site may have lasting effects on the soil or the land at particular site long after production has ceased, giving cause to site-specific effects from the location of the industrial activity. A major contributor to toxic metal contamination in Dnepropetrovsk is the mining industry, contributing to degradation in the mining areas by means of spoil heaps of tailing from mining operations and slags from smelting.

Of the wastes produced by Dnepropetrovsk industry, a large part is considered to be hazardous waste. There is no single generally accepted definition of hazardous wastes, but categories of industrial wastes considered as such include solvents, waste paint, waste containing heavy metals and acids as well as oily waste. As a result of inadequate organization and control of temporary storage of hazardous waste on the premises of industries and factories and the lack of hazardous waste management systems, some of this waste finds its way into the groundwater supply to depth and to the migration of mobile contaminants already in the soil.

But during last years the dynamics of land alienation has had a tendency to decrease (Fig. 21.6).

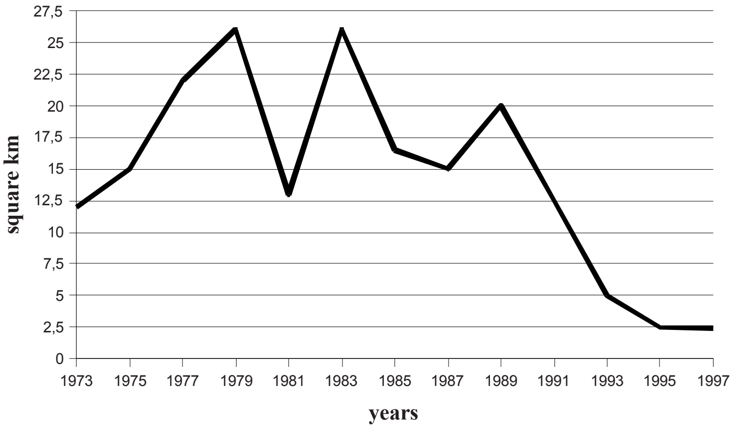

Fig. 21.6. Dynamics of land alienation in the Dnepropetrovsk region.

Nature protects the land by covering it with vegetation. Man has destroyed natural covering by cutting down forests and plowing up the land, exposing it to the full forces of water and wind. Two categories of erosion are recognized. The first, called geologic erosion, is a natural process that takes place independent of man's activities. This kind of erosion is always active, wearing away the surface features of the Earth. The second kind, referred to as accelerated erosion, occurs when man disturbs the surface of the Earth in any way. Erosion of soils leads to reduction of trace elements concentration [7]. Unfortunately, erosion processes within steppe landscapes reach 40–50% in Ukraine. Every year water and wind wash and blow away about 20,000 t per km^2 of soil material. That is more than 43.5% from the total territory of eroded land in the Region. For instance the process of the washed soils formation in Dnepropetrovsk region increased dramatically for the last 33 years (Table 21.2).

The high level of the soils erosion dynamic for some districts is connected with intensive agriculture development in spite of non-favorable landscape conditions. This increase in erosion has accelerated during the process of agricultural reform that began at Ukrainian independence in 1991. Collective farms have not had the money to invest in erosion control, even though they have the technical experience to fight erosion effectively. Private commercial farms often have little incentive for soil conservation since they rent most of the land they farm from others, without long-term commitments. Since independence, subsistence farmers have produced a large amount of the total agricultural product (60% in 1998). They often lack capital, machinery or technical awareness to effectively combat erosion, and may lack motivation if they are using a specific plot only temporarily. Soil erosion can be checked by maintenance of an effective cover, contour plowing, rotation of crops, creation of wind-breaks, and pipe drainage to prevent gullying. Keeping land covered with a growing crop of grass increases intake of water and reduces runoff. The extent of erosion control will be roughly in proportion to the effective cover.

Table 21.2. The soils erosion dynamic in the Dnepropetrovsk region for the last 30 years.

№.	District	Soils erosion dynamic		
		Thousand hectares	% of total square	Δ(%) of total square
1.	Apostolovsky	42.5	40.7	−4.6
2.	Vasilkovsky	57.3	48.9	+18.0
3.	Verkhnedneprovsky	62.6	72.5	+20.8
4.	Dnepropetrovsky	45.3	42.6	+2.3
5.	Krivorozhsky	49.0	47.5	+1.3
6.	Krinichansky	81.5	54.3	+3.2
7.	Magdalinovsky	16.6	12.0	+0.3
8.	Mezhevskoy	48.1	42.8	+21.1
9.	Nikopolsky	74.0	55.4	+12.0
10.	Novomoskovsky	44.3	30.0	+7.0
11.	Pavlogradsky	41.7	37.1	+10.7
12.	Petropavlovsky	52.2	47.9	−3.0
13.	Petrikovsky	1.8	3.3	–
14.	Pokrovsky	43.1	40.8	+18.2
15.	Pyatikhatsky	70.3	48.4	+7.5
16.	Sinelnikovsky	77.4	53.4	+6.5
17.	Solonyansky	87.5	56.8	+0.5
18.	Sofievsky	56.2	46.2	+3.2
19.	Tomakovsky	50.3	52.8	+4.2
20.	Tsarichansky	3.1	4.2	0.0
21.	Shirokovsky	37.1	38.3	−4.9
22.	Yurievsky	41.7	52.5	–
Total within the region		1,083.6	42.2	+5.7

Land-use planning demands increasing attention. More interchange and adaptation should take place between the space design orientation of the city planner, architect, and landscape designer and the resource capability orientation of the resource planner. The overlapping areas must be planned to meet the basic regional needs for water, waste disposal, transportation and open spaces for light, air and recreation. More regard to the natural capability of each landscape is needed to sustain an optimal level of regional economic opportunity and social value. Community requirements and the environment capability should find reconciliation in a new type of integrated regional design. Standards and criteria to guide land-use allocations must be developed by the scientists and practitioners of land-use planning and become incorporated in public land policies. If the land planning is to be made an instrument of democracy, improvements are required in the methods by which social choices of the majority can find expression in the planning process without ignoring individualism and diverse goals of a pluralistic society.

The most important property of soil is its fertility. Soil fertility may be defined as that quality of a soil, which enables it to provide nutrient elements and compounds in adequate amounts and in proper balance for the growth of specified plants, when other growth factors such as light, moisture, temperature, and the physical condition of the soil are favorable. One of the most important properties of black soil is high content of humus, it is approximately up to 5.3% (Fig. 21.7).

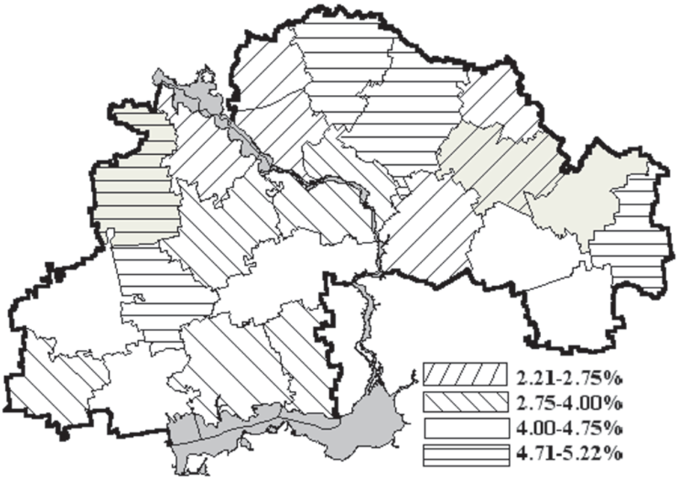

Fig. 21.7. Content of soil humus in the Dnepropetrovsk region.

Soil humus, commonly referred to as organic matter, represents an advanced stage in the decomposition of organic material. Many, many years are required to produce a single inch of topsoil. This good work of nature may be destroyed by man in a relatively few years by careless land management. Long extensive exploitation of black soils, use of heavy agricultural machines, application of fertilizers and pesticides, influence of industrial and agricultural pollution have affected the soil properties and soil forming process, potential fertility and brings down the production and nutrition worth of agricultural products. In 1881 the humus content was 7.6%. After 100 years, in 1981, it was 5.5%, and in 1991 – 4.5% [5]. Now the average regional content of humus is 3.5%. During the last 30 years the content of humus in the soil has decreased by 10–70%. Annual losses of humus are 60 t/km^2 roughly. The losses recover to 50 t/km^2 by using organic fertilizers, and as a result, the annual deficiency of humus is about 10 t/km^2.

A significant correlation has been found between the amount of arable lands and humus content in the soils (R = 0.53). There was no correlation between humus content and irrigating (R = 0.11).

Conclusion

The soil conservation and proper land-use is a fairly important problem of the Dnepropetrovsk Region. Ensuring a sustainable total agricultural product is impossible without the agri-environmental policy implementation including biological land transformation, monitoring, restoration, to reserve areas for new parks and recreation zones creation.

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Development of Mathematical Approaches to the Ecological Differentiation of Arable Land in the Dnipropetrovsk Area of Ukraine

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Abstract. While studying the impact of soil, climatic and weather factors on the crop yield, we have defined some criteria. They afford background for the selection of ecologically uniform territories and their differentiated use by separate crops. Taking into consideration the ecological potential defined and the possibilities of the use of separate agroecosystems (species, varieties and hybrids) Dnipropetrovsk region territory is divided into three agricultural zones with the subdivision into six agricultural subzones. The relationships between ecological parameters and crops yield have been established. The yield data on strain testing stations and collective and private farms were analyzed as well. All this also was the basis for the construction of a mathematical model. The math modeling method was used to define the quantitative dependence of the yield upon agro-and-climatic conditions.

Keywords: yield, crops, weather conditions, land differentiation, modeling

Introduction

Ukraine consists of three major ecological zones – forest, forest-steppe and steppe. Within the forest-steppe and steppe, there is a substantial amount of rich black soil, classified as chernozeom. Of Ukraine's total land of 60.4 million hectares, about 40% is plowed cropland. The steppe is most heavily cropped, and occupies most of the southern half of the country (25 million hectares). Of Ukraine's 15.5 million hectares of high fertility soils, the primary steppe soils, the chernozeoms, occupy 77% or 11.9 million hectares [1, 2]. The steppe zone average annual precipitation averages 470 mm, but varies by year from less than 350 mm to more than 550 mm. Yields vary widely from year to year due to this marginal and erratic precipitation. Erosion increases yield instability by reducing the capacity of the soil to store moisture [3, 4]. The mathematical modeling was applied for territories agroecological potential assessment.

P.Y. Groisman and S.V. Ivanov (eds.), *Regional Aspects of Climate-Terrestrial-Hydrologic Interactions in Non-boreal Eastern Europe*,

Materials and Methods

Comparative and mathematic modeling approaches have been applied to differentiate arable lands productive potential. The case study to define the dependences of the corn and winter wheat yield upon the steppe zone soil-climate conditions has been done. The generalized eco-biological statement that abiotic factors and, especially, derivatives of their ecological resources are rather variable in space and time was taken into account. In this connection, there is necessity to precisely define borders between subzones and districts. Each of them carries features of both the neighboring areas and its own unique features. That is one of the deciding conditions of the differentiated use of land resources, as well as the rational replacement of agricultural crops, their breeds, and hybrids.

To develop mathematical approaches to the eco-biological differentiation of territories, we have made an analysis of the arable lands cover. The comparison characteristic of using such stable parameters as, the depth of humus profile, humus reserves, the soil texture, efficient deposits of moisture and the general wetted depth have also given. In particular we had analyzed weather conditions for 30 years. In the region's territory there was determined their distribution in the periods of vegetation, reaction of agro- and eco systems, as well as the degree of their environmental concordance to individual territories. We have also defined ecologically unimodal lands and the degree of limiting factors occurring there. The relationships between ecological parameters crops yield have been established. The yield data from strain testing stations and collective and private farms were analyzed to do it. Then these were compared with agro-and-ecological resources. This provides the establishment of functional dependences between nature-and-climatic factors, as well as the crop's yield. Mathematical dependence was searched with *Microsoft Exel* by means of a package called "*Data Analysis*" [5]. As the instrument of the analysis we used "*Regression*". For the analysis we assigned input and output intervals with a reliability level of 95%. Dependent magnitudes were input in natural and non-dimensional values. To define the model adequacy Fisher's ratio test (estimated and tabulated) was used. The significance of regression parameters was estimated according to estimated and tabulated *t-statistics*.

Results and Discussion

One of the major problems the country is currently facing is the state of the land resources. Agricultural land occupies 72% of the country's territory, out of which 69% is arable land, including 54.4% of tillage, 0.4% of virgin land, 1.6% of perennial plantations, 3.8% of hayfields and 9.1% of pasturelands. Forests and other plantations take up 17.2% of all the territory, swamps 1.6%, land without any plantation 1.8%, and territory under water reservoirs 4.0%. It is necessary to take into account the process of the continuing land privatization. In the past few years the rate of the soil degradation has accelerated [2]. Agroenvironmental policies are needed to encourage farmers to combat erosion and other forms of soil degradation, and to encourage research to develop and transfer appropriate soil and crop management technologies. That is why new regional agroenvironmental policies should be connected with changes in the agricultural lands & forests distributions to reserve areas for new parks, recreation and agroecological zones creation and use. The calculation to recommend land transformation in the Dnipropetrovsk region has been made (Table 21.1).

There are several reasons to make changes in forests and agricultural lands distribution here. The main reason is connected with a need to provide the biological conservation for washed soils, etc. Unfortunately, erosion processes within steppe landscapes reach 40–50% [3]. Several district's soils were tested on the humus content depending on erosion occurrence (Table 22.1). The experiments reported before compared soils from three types of landscapes: level soils (0–1% slope) with no observable erosion (E0), mildly sloped soils (1–3%) with mild erosion (E1 = 10 cm topsoil loss), and moderately sloped soils (5–7%) with moderate erosion (E2, up to 30 cm topsoil loss).

Table 22.1. Humus content depending on erosion severity in the soils of Dnipropetrovsk region.

Soil	Vasilkovsky district	Novomoskovsky district	Magdalinovsky district	Sofievsky district	Pyatikhatsky district	Sinelnikovsky district	In average
No erosion observed	*5.4* 4.7–5.6	*4.4* 4.0–4.6	*5.4* 4.3–5.6	*4.8* 4.1–5.6	*5.0* 4.2–5.8	*5.0* 4.1–5.5	*5.0* 4.2–5.4
Mildly sloped soils (1–3%)	*4.4* 3.8–4.9	*3.6* 3.6–3.7	*4.6* 4.1–5.1	*3.9* 3.2–4.3	*4.2* 3.3–4.8	*4.2* 3.3–4.8	*4.1* 3.0–4.6
Moderately sloped soils (5–7%)	*4.0* 3.3–4.2	*2.9* 2.4–3.0	*3.7* 2.5–4.0	*3.6* 2.9–4.0	*3.9* 2.3–4.4	*3.9* 2.6–4.0	*3.7* 2.4–4.0

Note: numerator – average; denominator – minimum and maximum

On average, the region humus content was 5.0% (4.2–5.4) in the case with no observable erosion. Negative erosion impact lead to humus decreasing up to 3.7% (2.4–4.0). Dnipropetrovsk region territory stretching for only 200 km from north to south and 270 km from east to west is characterized by the wide variety of ecological conditions which predetermine its division into separate agricultural zones and subzones [6, 7]. North region's nature differs greatly from the nature of the southern territory in several ways: substantially greater humus profile (25–30 cm more), greater humus provision (170–200 t more per ha), greater precipitation

(89–95 mm more), less amount of heat (positive temperature sums, PTS, are less by 438–511°), greater hydro-thermal coefficient (0.18–0.21 more), greater depth of moisture penetration into soil (37–39% more), greater amount of productive moisture supply (40–45 mm more), and higher (by 33 soil bonitet points) soil estimation. On the whole, the southern forest-steppe zone is gradually becoming very similar to the northern one – middle steppe zone. The ecological volume of the northern territory embraces – as for weather conditions – the features of three nature sub-zones: 50% of years are characterized as typical northern steppe, 27% of years – as southern forest – steppe, and 23% – as forest-steppe. The southern territory has the features of the four nature subzones: 14% of years – southern steppe, 40% – middle-steppe, 30% – northern steppe and 16% – forest-steppe. This accounts for the high variability of the ecological resources (per years and vegetation periods) and as a result – agricultural crops variability: agroecosystems vegetate under conditions close to the forest-steppe in one type of years, in another – the northern steppe, and in the third type – the southern and middle steppe. There are some years when under extreme conditions the plants partially or completely perish.

Taking into consideration the ecological potential defined and the possibilities of the use of separate agroecosystems (species, varieties and hybrids) Dnipropetrovsk region territory is divided into three agricultural zones with the subdivision into six agricultural subzones (Fig. 22.1).

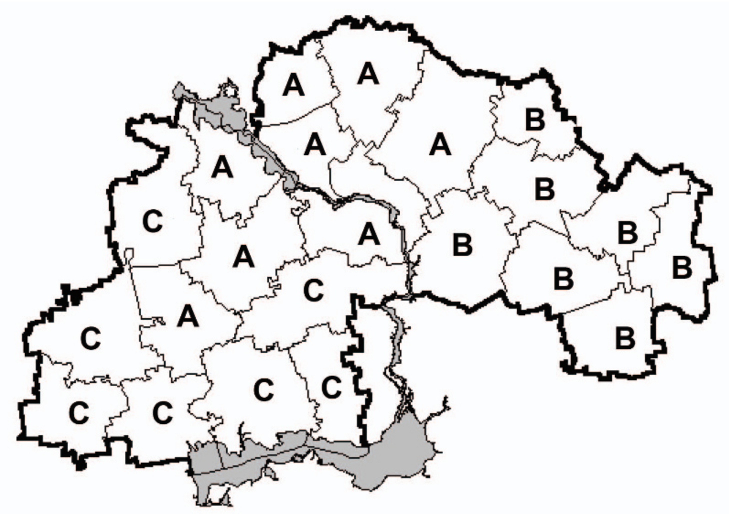

Fig. 22.1. The administrative districts distribution within three agricultural zones.

The maize agricultural zone (A) is represented by two agricultural districts: maize-wheat-soybeans (with the high portion of sugar beet, sunflower, small grain crops, and perennial grass) and maize-wheat with the high portion of perennial legume grass bare and non-bare fallow. The maize gives the highest yield in this agricultural zone. It is 300–350 kg higher than winter wheat, 860–1,150 kg per hectare (ha) higher than spring barley. The biological potential of the first agricultural district is 5–16% higher for grain crops, 9–10% – perennial grass and 26–42% – sugar beet. The possibility of obtaining high yields (more than 75 t ha^{-1}) is provided for 32% of years in the maize zone (the first agricultural district) and 24% of years (the second one), more than 5 t ha^{-1} – 73% and 62% of years correspondingly.

The wheat agricultural zone (B) is located to the south and divided into two agricultural districts: wheat-maize-beet and wheat-maize-beet-sunflower with great share of perennial grass. The winter wheat gives the highest yield in this zone (320–480 kg more than maize and 626–720 kg ha^{-1} more than spring barley. The biological potential difference between these agricultural zones is 8–15% as for grain crops, 10% – sunflower, 17% – sugar beet and 25% – perennial grass.

Probability of obtaining high yields (5.4–6.7 t ha^{-1}) is provided for 19–24% of years, and average yields (3.5– 4.8 t ha^{-1}) – 26–58% of years.

In the wheat-maize agricultural zone (C) with the subdivision into two agricultural districts (wheat-maize-barley and wheat-maize-sorghum with large proportion of perennial legume grass, peas, bare and non-bare fallow) the winter wheat yield is 230–370 kg ha^{-1} more than maize, and spring barley – 686–810 kg ha^{-1}. The biological potential of the first agricultural district is 7–16% higher as for grain crops, 10% – sunflower and 14% – perennial grass.

The case study to define the dependences of a corn and winter wheat yield upon the steppe zone soil–climate conditions has been done. The generalized eco-biological statement that abiotic factors and, especially derivatives of their ecological resources are rather variable in space and time, was taken into account. In this connection, there was a necessity to precisely define borders between subzones and districts. Each of them carries features of both the neighboring areas and its own unique features. That is one of the deciding conditions of the differentiated use of land resources, as well as the rational regionalization of agricultural crops, their breeds, and hybrids. While studying the impact of soil, climatic and weather factors on the crop yield, we have defined some criteria. They afford background for the selection of ecologically uniform territories and their differentiated use by separate crops.

These criteria for corn and cereals were for precipitation and temperature:

1. Rainfall:
   (a) Total (mm)
   (b) Total during the growing season (mm)
   (c) Allocation on stages of organogenesis: for corn they are precipitations for X + XI + (50% XII–II) + II + IV; May–June, July–September
   For winter wheat: the amount of August–October, March–April, May–June (mm)

2. The air temperature and warmth, PTS, observed during the warm season (April–June, July–September).
3. The sum of negative temperatures for November–February.
4. The fertility of four genetic groups of chernozem soils on bonitet.

It is known that to receive a top corn and winter wheat yield the following conditions are necessary (Tables 22.2 and 22.3).

High crop yields of corn are received, when in June in addition to typical zonal norm, there falls (average perennial) 17 mm (or 26%) of precipitation; in July it is 11 mm (21%), and in August it is 19 mm (42%).

Table 22.2. Precipitation and temperature to obtain maximum corn yield.

Factors	V	VI	VII	VIII	IX	In total
Rainfall (mm)	57	78	67	57	39	Rainfall Sum: 298 mm
Temperature (C^0)	15.8	18.8	20.8	20.1	13.5	Warmth Ensuring: (°C) V–VI = 1,054; VII–IX = 1,672

Table 22.3. Precipitation and temperature to obtain maximum winter wheat yield.

Factors	VIII	IX	X	III	IV	V	VI
Rainfall (mm)	35	40	56	38	43	43	75
Temperature (C^0)	444	220	45	50	321	486	570
Negative temperatures sum (C^0)	321–400						

A lack of moisture in July–September causes a harmful influence on the yield formation because biochemical processes associated with grain formation take place in this period.

The critical periods for the development of winter wheat are: sowing- shoots and autumn tillering. The precipitation amount is 120 mm, warmth providing 715^0; the rainfall output from wintering is 91 mm; leaf tube formation – heading – complete ripeness – amount of precipitation is 105 mm, warmth ensuring providing is $1{,}057^0$.

The statistical data of a corn and winter wheat yield for 28 years on five strain testing stations, as well as the climatic parameters in critical periods of the development of plants has been used. For the model construction for corn yield the number of factors was reduced to five:

1. The rainfall amount in the autumn–spring term
2. The rainfall amount in May–June
3. The rainfall amount in July–September
4. The sum of temperatures in May–June
5. The sum of temperatures in July–September

The mathematical model is received as the second degree polynomial, which is given by:

$$Y = a_0 + a_1 \cdot x_1 + a_2 \cdot x_2 + a_3 \cdot x_3 + a_4 \cdot x_4 + a_5 \cdot x_5 + a_6 \cdot x_1^2 +$$
$$+ a_7 \cdot x_2^2 + a_8 \cdot x_3^2 + a_9 \cdot x_4^2 + a_{10} \cdot x_5^2,$$

Where $Y -$ crop yield, centner/ha

$a_i -$ Regression coefficients;

$x_i -$ Factors.

For the definite model regression coefficients mean:

$$Y = 55.2 + (-6.2)x_1 + 13.0 \cdot x_2 + (-7.66) \cdot x_3 + 5.5 \cdot x_4 + (-0.8) \cdot x_5 +$$
$$+ 11.8 \cdot x_1^2 + 9.1 \cdot x_2^2 + (-17.6) \cdot x_3^2 + 10.7 \cdot x_4^2 + (-3.4) \cdot x_5^2,$$

Absolute values of factors $(x_1 - ...x_5)$ for the use by the polynomial have to be reduced to dimensionless values by means of the following formula:

$$X = \frac{x_1 - \left(\frac{x_i \max + x_i \min}{2}\right)}{\frac{x_i \max - x_i \min}{2}},$$

where $x_i \max, x_i \min -$ the maximal and minimal value of this factor is among its values.

For example: in the locality near the meteorological station of Gubinikha (north of the region) with appropriate values of criteria the crop yield of corn may be:

$$Y = 55.2 + (-6.2) \cdot 0.24 + 13.0 \cdot (-0.66) + (-7.66) \cdot (-0.13) + 5.5 \cdot 0.17 +$$
$$+ (-0.8) \cdot (-0.09) + 11.8 \cdot 0.24^2 + 9.1 \cdot (0.66)\_(-17.6) \cdot 0.13 + 10.7 \cdot 0.17^2 +$$
$$+ (-3.4) \cdot (-0.09)^2 = 51.8 centner / ha,$$

The actual crop yield was 59.8 centner/ha. The absolute error is 8 centner/ha. In the central region's part the relative error is 16%, and in the southern it is 20% with a correlation ratio of 0.72.

When building a mathematical model for winter wheat, the following factors were used:

1. The rainfall amount for the autumn term of August–October
2. The rainfall amount for the term of March–April
3. The rainfall amount for May–June
4. The sum of temperatures for May–June
5. The sum of negative temperatures for November–February

The mathematical expression obtained is similar to that for corn.
For the definite model regression coefficients have values:

$$Y = 49.5 + 6.42 \cdot x_1 + 3.66 \cdot x_2 + 1.48 \cdot x_3 + (-3.39) \cdot x_4 + (-9.03) \cdot x_5 +$$
$$+ 9.27 \cdot x^2 + 0.69 \cdot x^2 + (-2.51) \cdot {x_3}^2 + 1.54 \cdot {x_4}^2 + (-7.3) \cdot {x_5}^2,$$

For example: in the locality near the meteorological station of Gubinikha with appropriate values of criteria the crop yield of corn may be:

$$Y = 49.5 + 6.42 \cdot 0.019 + 3.66 \cdot (-0.332) + 1.48 \cdot (-0.195) +$$
$$+ (-3.39) \cdot 0.053 + (9.03) \cdot 0.071 + 9{,}27 \cdot (0.019) + 0.69(-0.332)^2 +$$
$$+ (-2.51) \cdot (-0.0195)^2 + 1.54 \cdot (0.053)^2 + (-7.3) \cdot 0.071^2 =$$
$$= 47.2 \text{ centner ha}^{-1}$$

The actual crop yield was 48.8 centner/ha. The absolute error is +1.6 centner ha^{-1}; that of relative is 3.3%. The correlation coefficient is 0.82.

Thus, both the estimated and the actual crop yield of corn in northern region is higher than that of the winter wheat. It confirms our conclusion about the assignment of the region's northern territory to the corn zone. In the central zone the estimated and the actual crop yield of winter wheat is higher, than that of corn. This zone is referred to that of wheaten, that is, with the recommendation to increase the share of winter wheat in crop rotations. The reference of the southern zone to that of wheaten-and-corn is also confirmed by mathematical calculations.

Conclusion

Agricultural zones differences are caused by latitude, ecological effect of soils of different granular composition under different climatic conditions. The calculations prove that the rational uses of nature's resources (without additional costs) can provide a 10–15% increase of the soil productivity in the region. Test criteria are connected with abiotic factors occurrence monitoring including yield, climate, soil peculiarities, etc. Therefore, having the formula of dependence of the crop yield of the considered crops upon natural and climatic conditions, it is possible to make calculations of the eventual expected yield, as well as to optimize the ratio of the areas for the cultivation of corn and winter wheat in this territory.

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Causes of Cropland Abandonment During the Post-socialist Transition in Southern Romania

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Abstract. We analyzed the causes of cropland abandonment in Argeş County, Romania, after the fall of the Iron Curtain in 1989. Cropland changes were derived from LandSat classifications for 1990, 1995, and 2005. Total net abandonment amounted to 21% of the 1990 cropland. Land cover data were integrated with environmental and socioeconomic variables and jointly analyzed using spatially explicit logistic regressions to estimate the determinants of cropland abandonment. Results suggest that abandonment was more likely on isolated cropland patches and rougher terrain throughout the transition period. Market forces increasingly shape the patterns of cropland abandonment in later stages of the post-socialist transition, as witnessed by the increasing contribution of variables affecting the profitability of cultivation.

Keywords: land abandonment, LandSat, post-socialist, Southern Romania

Introduction

Changing socioeconomic, political, and demographic conditions in Eastern Europe and the former Soviet Union after the breakdown of socialism triggered widespread land use change (Bicik et al. 2001; Ioffe et al. 2004; Lerman et al. 2004). Most notably, vast areas of cropland were abandoned in the post-socialist period, and are now partly reverting to forests (Peterson and Aunap 1998; Nikodemus et al. 2005; Kuemmerle et al. 2008). Cropland abandonment has widespread, location-specific effects on ecosystem services, including carbon storage (Houghton et al. 1999), soil stability (Tasser et al. 2003), and water quality (Hunsaker and Levine 1995), and impinges on biodiversity (Laiolo et al. 2004). Cropland abandonment threatens traditional cultural landscapes (Government Service for Land and Water

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Management 2005; Palang et al. 2006) and their biodiversity (Brouwer et al. 2001; Cremene et al. 2005).

Despite these effects, few studies have embarked on spatially explicit analysis to improve our understanding of post-socialist cropland abandonment. As a result, the rates, spatial patterns, and underlying processes of abandonment are not well understood. In this paper, we analyze the determinants of cropland abandonment in one county in Southern Romania. Romania is particularly interesting as it has the largest share of farmland and of population living in rural areas among the new member states of the EU (World Bank 2008).

Study Area

The empirical analysis focuses on Argeş County (*judetz*). Argeş covers an area of 6,826 km^2 and was selected, because it encompasses a wide range of environmental conditions ranging from alpine zones in the Southern Carpathian Mountains (>2,500 m) in the north of the study area to the plains (<150 m) in the south (Fig. 23.1). Argeş is dominated by a strong topographic gradient from a mountainous, undulating terrain in the north to the flat southern part (Fig. 23.1, left).

Data

Land use maps

We used LandSat Thematic Mapper (TM) and Enhanced Thematic Mapper Plus (ETM+) images to map post-socialist cropland abandonment in our study. Individual cropland maps were derived for the years 1990, 1995, and 2005 using hybrid image classification (see Kuemmerle et al. forthcoming, for details of the classification procedure). The cropland class had overall accuracies between 90% and 95% (conditional Kappa statistics between 0.87–0.93) based on 765 ground control points mapped in the field and from very high-resolution Quickbird images. We delineated cropland abandonment for 1990–1995 and 1995–2005 as all pixels that were cropland at the beginning of a change period, but not at the end. All other pixels were merged into the category ‘other’. We used these two binary maps as the dependent variables in our logistic regression models (Müller et al. forthcoming).

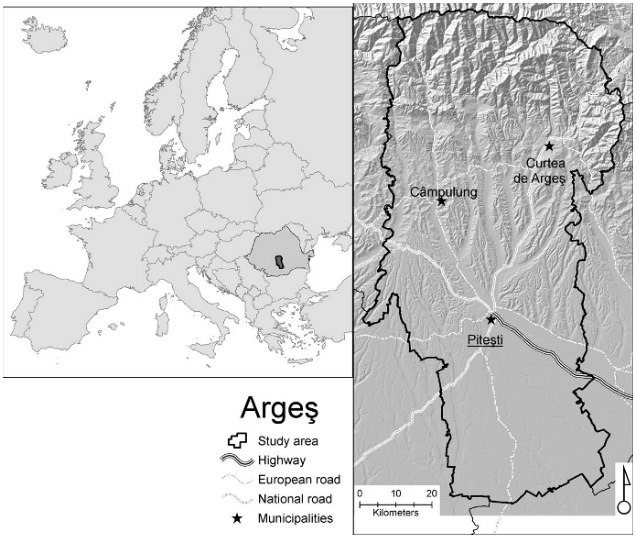

Fig. 23.1. Study area

Explanatory variables

Topography was proxied using the Shuttle Radar Topographic Mission (SRTM) data (Slater et al. 2006). We calculated terrain roughness from the SRTM as the slope curvature. The available soil and temperature data were collinear with elevation and therefore dropped from the regressions. We calculated three Euclidean distance measures to different roads categories: European roads (1), national roads (2), and county roads (3). Each road distance variable included all superior road categories. The three distance measures proxied the influence of market access on cropland abandonment. An additional variable measured the distance from each location to the northern-most data row to control for spatial dependence in the model residuals (Tasser et al. 2007).

Land use at a particular location often depends on land use in its surrounding. In our case, the decision to abandon a cropland pixel may depend on the structure of cropland at surrounding locations. To account for this, we constructed a variable containing the number of neighboring cropland pixels in a 3 x 3 window that were covered by cropland at the beginning of each change period. This temporally lagged incidence of cropland density also control for the temporal dependence of land use change on the state of land use at the start of the change period.

We conducted a primary census at the commune level to capture the effects of the changing political, economic and social setting on cropland abandonment. The census covered socioeconomic and demographic developments, input use, farm fragmentation, and productivity parameters (see Müller et al. 2009, for a description of these data). From these data we calculated livestock units for cattle, sheep, and goats for each commune and for 1989 and 1996, based on the standard livestock unit coefficients (Chilonda and Otte 2006). To derive the spatial distribution of the human population in the study area, we interpolated point data of village population for 1989 and 1996 (Müller et al. 2009). The number of individuals that left a commune permanently and the number of temporary emigrants quantified demographic changes due to emigration.[1] We also used the number of tractors per commune to proxy agricultural input intensity.

Two variables assess the legacies of the Romanian land reforms in 1991: First, the average number of plots per farmer to indicate the level of farmland fragmentation. Second, we compute the share of cropland owned by individuals within each commune to account for the type of agricultural production organization.[2]

Methods

The census data were integrated with the spatially explicit data based on the commune boundaries, the finest administrative unit in Romania. All calculations were conducted using the spatial resolution of the LandSat images (28.5 x 28.5 m, see Müller et al. forthcoming). To reduce the number of observations and to avoid spatial autocorrelation in the response variable, we applied a spatial coding scheme that selects non-adjacent pixels at a specified distance from the nearest selected neighbor (Besag 1974). Such sampling does not affect regression coefficients and allows for using standard estimation techniques within the discrete choice framework. To avoid arbitrariness in selecting the distance between observations (Anselin 2001), we tested a range of different coding schemes and used a final distance of 228 m (i.e., eight pixels) as a compromise between the correction of spatial dependency among observations and the rapidly decreasing number of observations. In addition, only pixels covered by cropland at the beginning of the respective change period were selected (Müller and Munroe 2008). Finally, we applied disproportionate sampling and selected 1,000 observations both from abandoned and from stable cropland pixels (Maddala 1983).

To assess the causal determinants of cropland abandonment in Argeş at the pixel and commune level, we fitted maximum likelihood-based binary logistic regression models. The spatially explicit raster data and the commune-level vector data reflect the hypothesized drivers of cropland abandonment at a particular location. Two logistic regression models of cropland abandonment were estimated, one for the period 1990–1995, and one for the period 1995–2005. This allowed describing the temporal changes in the drivers that affected the use of

[1]Temporary emigrants were non-existent in Argeş in 1989 and therefore not included in the estimations for 1990–1995.

[2]Both land reform proxies were only included in the regressions for the1995–2005 period.

cropland. All time-variant variables were included as temporal lags that describe the state of the variable at the start of the respective change period. This reduces the endogeneity bias arising from a possible simultaneity of cropland abandonment and the covariates (Müller and Zeller 2002; Perz and Skole 2003). The inherent assumption was that subsequent abandonment did not influence the state of the explanatory variables at the beginning of the change period. In that way, we are able to derive one-way causal influences from the independent variables to the dependent variable.

The multi-level data structure consisting of pixel and commune-level data requires statistical corrections to account for the violation of the independence of observations. Pixels within communes may exhibit dependence while pixels across communes are more likely to be independent (Müller and Munroe 2008). To control for such within-group effects we employed robust estimation techniques. These account for potential correlations of observations within the communes. We used a modification of the Huber and White robust sandwich estimator that affects the variance-covariance matrix by estimating robust standard errors, but leaves the estimated coefficients unaffected (Williams 2000; Gutierrez and Drukker 2005). This adjustment also controls for potential spatial autocorrelation in the residuals (Gellrich et al. 2007).

The variance inflation factor (VIF) revealed no serious multicollinearity in the estimation sample with mean VIFs always below 1.5 and the largest VIF well below 10. Four common goodness-of-fit statistics quantified the explanatory power of our models: First, McFadden's adjusted R^2 (adj. R^2) was used (Ben-Akiva and Lerman 1985). Second, the percentage of correctly predicted observations (PC) was calculated from the predicted probabilities by assuming the highest predicted probability as the predicted value. Third, the area under the curve (AUC) of the receiver operating characteristics (ROC) was assessed using the nonparametric ROC curve (Metz 1978). Last, the Kappa statistic quantified the positional accuracy between predicted and observed data, compared to a random map (Pontius 2000). Our disproportionate sampling strategy (see above) ensured that PC and Kappa are not biased (Pontius and Milliones 2008), because of the same amount of observation in the presence and absence group.

Results

Spatial variation of cropland abandonment

Cropland abandonment varied considerably in the study area with distinct geographical patterns (Fig. 23.2). Between 1990 and 1995, clusters of abandonment were found across the entire study area, with the exception of the foothills of the Carpathian Mountains in the north of the study area that were largely forested. Particularly high levels of abandonment occurred in the hilly area north of Piteşti.

The 10-year interval between 1995 and 2005 was characterized by lower abandonment rates. Abandonment clusters were scattered and frequently occurred next to cultivated areas (Fig. 23.2). The net cropland decrease amounted to 417 km^2 between 1990 and 1995, compared to 98 km^2 between 1995 and 2005. In total, 21% of the cropland used in 1990 was abandoned until 2005 (Müller et al. 2009).

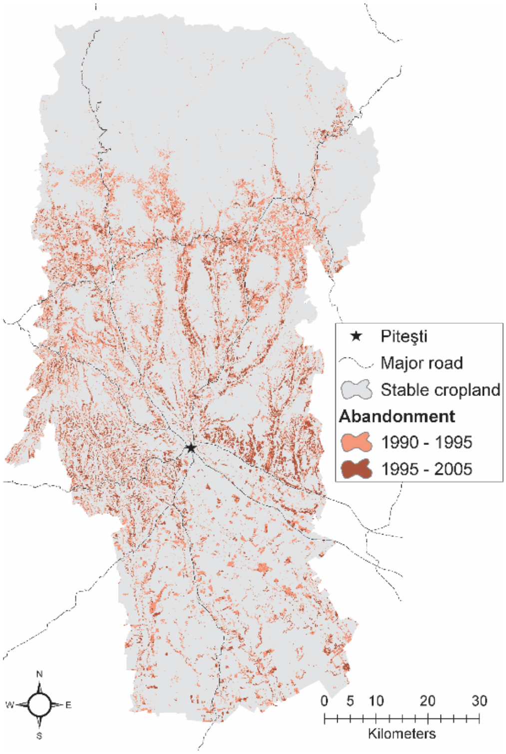

Fig. 23.2. Spatial patterns of cropland abandonment during the 1880–1995 and 1995–2005 periods.

Causes of cropland abandonment

The goodness-of-fit statistics (Table 23.1) suggest that the model fit was similar in both periods. Adj. R^2 was at 0.3 (0.35) AUC values stood at 0.85 (0.88) for 1990–1995 (1995–2005); 75% (69%) of the abandoned pixels in between 1990 and 1995 (1995 and 2005) were correctly predicted, and Kappa amounted to 0.49 (0.39).

The regression results (Table 23.2) confirm that cropland abandonment was more likely towards the northern part of Argeş (significant Y coordinate). Higher terrain undulation had the expected strong influence on cropland abandonment in both periods, but the effect was stronger (by 4%) in the later stage of the transition. The occurrence of abandonment also showed a strong and significant association with the concentration of cropland. One additional pixel of cropland in the immediate vicinity of a location decreased the likelihood of abandonment by almost 19% in the first and by 28% in the second period. Other analyses using the same data showed that this effect was particularly pronounced in the plains (Fig. 23.2, see also Müller et al. 2009). The distance to the European and to main roads (category 1, 2 and 3) were insignificant for abandonment between 1990 and 1995, but in the second period the probability of abandonment increased by 5% with every kilometer farther from the main road and by 2% for every kilometer further from the European road. Our models did not suggest a strong relation of cropland abandonment with the population and migration variables. The population density surface was insignificant in both periods. However, the household density at the commune level had a small negative effect on abandonment in the first and small positive effect in the second period. Finally, a lower density of livestock units and more land owned individually (as opposed to other land ownership regimes) fostered abandonment in the second period, but not in the first.

Table 23.1. Goodness-of-fit statistics.

Period	Adj. R^2	PC	AUC	Kappa
1990–1995	0.30	0.75	0.85	0.49
1995–2005	0.35	0.69	0.88	0.39

Table 23.2. Logistic regression results (odds ratios) for cropland abandonment.

Variable		1990–1995		1995–2005	
		Coefficient	P>|z|	Coefficient	P>|z|
Distance from northern edge (pixels)		999***	0	0.999***	0
Roughness (slope curvature)		1.066***	0	1.109***	0
Distance to European road (100 m)		1.002	0.177	1.002*	0.056
Distance to main road (100 m)		1.002	0.265	1.005***	0.005
Distance to county road (100 m)		1.008	0.192	0.992	0.303
Cropland in neighborhood (pixels)	1990|1995	0.813***	0	0.725***	0
Population (interpolated)	1989|1996	0.998	0.854	0.994	0.174
Households (per km^2)	1989|1996	0.983***	0.008	1.016**	0.011
Emigration (persons)	1989–1996|1996–2004	0.999*	0.053	1.001	0.401
Temporary emigration (persons)	n.a.|1996	n.a.	0.996	0.157	
Livestock density (units)	1989|1996	1.006	0.301	0.983*	0.069
Tractors (numbers)	1989|1996	1.002	0.399	0.999	0.75
Cropland owned individually (%)	n.a.|1996	n.a		1.008*	0.087
Parcels (number)	n.a.|1996	n.a.		1.048	0.357

*p < 0.10, **p < 0.05, ***p < 0.01; n.a. = not assessed

Conclusions

Cropland decreased by 21% between 1990 and 2005 with distinct temporal and spatial patterns (Kuemmerle et al. forthcoming). Most abandonment occurred at the start of the transition from the socialist command to a market-oriented economy. Overall, cropland became more stable between 1995 and 2005, but there were still high abandonment rates in some areas. While hilly areas experienced the highest absolute decrease in cropland during the post-socialist period, the highest rates of abandonment (i.e., as percentage of cropland at the start of the transition period) were found in the mountainous foothills of the Carpathians (Müller et al. forthcoming). The major determinants of cropland abandonment in Argeş during the post-socialist transition were the undulation of terrain and the spatial homogeneity of cropland use. Cropland on less undulating terrain was more likely to remain cultivated, indicating the importance of topography in shaping the spatial extent of cultivation. A spatially contiguous structure of cropland may possibly help exploiting economies of scale in farming, thereby obstructing abandonment. Likewise, the higher labor and capital requirements associated with higher transportation costs caused by adverse road access may have reduced the competitiveness of farming and induced farmers to give up cultivation in later stages of the transition period. In brief, the reaction of farmers to the changes in economic incentives caused widespread abandonment as an immediate response to the political upheaval. In later stages of the transition process, the growing importance of market forces shaped the spatial composition of cropland, similar to processes observed in other transition economies of Eastern Europe (cf. Müller and Munroe 2008, for Albania).

More suitable natural conditions and better market access may have benefited the development of profitable farming in the southern plains in Argeş County. Farming structures there include larger management units that possibly helped farmers to remain competitive and thus reduced abandonment rates. The maintenance of farming may be under highest threat in the hilly areas where the economically active left to the close-by county capital Piteşti with various non-farm income opportunities. Adverse topographic conditions limit the natural suitability for farming in the hilly areas. In combination with the dominance of small-scale holdings, this may have obstructed the emergence of more profitable farming structures that are able to compete with other income earning strategies. Abandonment may proceed at unprecedented rates in the hilly areas without outside interventions (Müller et al. 2009).

Considerable limitations remain in the spatial analysis of cropland abandonment. First, we were unable to separate pasture and grazing areas from grassland due to the spatial mismatch of animal densities, calculated at the commune level, and the land cover data. Second, a spatially explicit quantification of production intensities may better represent the diverse farming strategies inherent in a pixel classified as "cropland". The lack of pixel-level data on input intensity may have also contributed to the insignificance of the variables capturing demographic changes. Despite the emigration of the young and economic active, the remaining elderly still cultivate the land. Yet, they use less labor and capital per unit of land and often reverted to subsistence cultivation. Only in-depth observations of local actors can capture such underlying processes of dis-intensification that lead to low-input production, augmented by income from newly emerging economic activities.

In summary, the findings of this integrated study of human–environment interactions in the land system show that the overall amounts of cropland changes were brought about by broader economic developments and affected by the socialist legacy. The heterogeneous local environment translated these broad-scale influences into the observed spatial variation in cropland use. In that way, we have effectively described cropland change patterns and explained the revealed trajectories and processes of change. Such empirical evidence contributes important case study knowledge of a land change process that has so far received comparatively little attention.

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Section 5
Changes in The Black Sea and Its Coastal Zone

Black Sea Forecasting System: Current State and Prospect

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Abstract. An operational system permitting nowcasting and forecasting of the real-time Black Sea circulation and surface wave dynamics is presented. The system is based on the regional atmospheric model with 24 km grid step, primitive equation model of the Black Sea circulation with 5 km grid step, WAM model of the surface waves coupled with circulation model with the same spatial resolution, and the set of local circulation models with resolution 1 km nested near the coast of riparian countries. An important part of the operational system is assimilation of space remote sensing data including sea surface height anomalies provided in near real time mode, a multi-satellite data active archive dedicated to space oceanography, and surface temperature. The output of the system includes near surface meteorology (10 m wind, latent and sensible heat flux, cumulated solar and thermal radiation flux, instantaneous flux of solar and thermal radiation, evaporation, large scale and convective precipitation), three dimensional hydrophysical fields (temperature, salinity, current velocities), surface chlorophyll concentration, and surface wave characteristics. Data from surface drifting buoys and deep profiling floats are used for validation of the model output. Surface drifting buoys provide data for validation of surface current velocity and sea surface temperature. Eight profiling floats deployed at the parking depths 200, 750 and 1,550 m are used for validation of weekly mean velocity, temperature and salinity profiles. The model validation shows that the real time products of the system have reasonable accuracy. The regional weather prediction model implemented by National Meteorological Administration of Romania and marine basin-scale nowcasing/ forecasting system provides good basis for the development of operational nowcast and forecast of coastal dynamics with high spatial resolution. Ongoing national initiatives concerning oceanographic modeling of the most important regions along the Black Sea coast are considered as the base of the nesting strategy development in the basin. Regional POM models near Bulgarian, Turkish, Georgian, Romanian, Russian and Ukrainian coasts are nested to the basin-scale circulation model of MHI. Every model specifies open boundary conditions from the basin-scale circulation model. The Black Sea observing/forecasting system is applied for the hindcast of the long-term evolution of the Sea fields. Evidence of the decadal evolution of the stratification and circulation is presented by the system output. Two more examples demonstrate the extreme events in the coastal

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regions of the Black Sea: intense upwelling near the Crimea coast and severe storm event.

Keywords: Black Sea monitoring and modeling, sea water biogeochemistry

Introduction

The strategy of the Black Sea nowcasting/forecasting system development is based on the available resources in the region and broad international collaboration. There is extended initial observing system in the basin operating in the near-real time. It includes remote sensing component consisting of AVISO altimetry, IR AVHRR data received and processed at Marine Hydrophysical Institute National Academy Sciences of Ukraine (MHI NASU) in Sevastopol, Ukraine, JPL/QUIKSCAT scatterometry and SeaWiFS/MODIS sea color data available via the Internet. Remote sensing data are complemented by international programs of surface drifting buoys and NICOP/ONR profiling floats. The Black Sea basin-scale circulation model of MHI NASU assimilates remote sensing data for the real time nowcasting and forecasting of three-dimensional temperature, salinity and current fields. The upper surface boundary conditions are specified by the high resolution regional atmospheric model operated at the National Meteorological Administration (NMA) of Romania based on Meteo-France ALADIN family. The use of high-resolution regional atmospheric model makes possible medium-range forecasting of the Black Sea circulation.

Initial observing system

The Black Sea GOOS project has now developed an initial observing system based on the general GOOS principles (GOOS abbreviation stands for Global Ocean Observing System). Realization of the initial observing system is achieved through the set of national and international projects and consists of three components. The most important is remote sensing component of the Black Sea observing system combining data from several space missions. Data of space altimeter missions are processed by both NASA Ocean Pathfinder project and AVISO service and adjusted to the Black Sea basin by Korotaev et al. (2001). The output of the altimeter data processing is the dynamical topography of the Black Sea surface, which describes surface geostrophic currents in the basin. It is shown by Korotaev et al. (2001, 2003) that geostrophic currents are highly accurate and reproduce well a broad range of variability of the basin starting from mesoscales.

Data of IR scanner AVHRR are available in the Black Sea region through the direct reception on HRPT receiving stations in Turkey and Ukraine. MHI NASU processes these data regularly retrieving and mapping of the Black Sea surface temperature. Ground truth validation of IR SST against in situ data shows its rms accuracy around 0.5–0.7° (Ratner et al. 2004).

Wind observations over the Black Sea are an essential part of the observing system. There are two sources of the wind data, either scatterometric observations or atmospheric model reanalysis. Both datasets are available through Internet. Scatterometric data have spatial resolution of 10–20 km while the larger scale atmospheric model data are presented on the 1° x 1° grid. Comparative analysis of wind fields provided by different larger scale atmospheric models and by QUIKSCAT spacecraft is presented by Ratner et al. (2003).

Insight into the problem of the mesoscale wind structure is also provided by observations of the real aperture radar of the Ukrainian–Russian mission "Sich". The real aperture radar has spatial resolution of about 2 km, which is much better than resolution of all other datasets. High resolution observations of wind are especially important in the eastern part of the Black Sea near the Caucasian coast where mesoscale wind jets brought forth by the mountainous coastal orography are often observed.

Modern satellite multi-spectral devices observing sea surface in the visible spectrum, such as SeaWiFS and MODIS are considered as the basic source of information about ecological and biochemical processes taking place in the Black Sea. Standard NASA sea color data are mainly used in the Black Sea region. However there is the difference of real atmospheric aerosol and biooptical properties in the Black Sea region from its models that are recommended by NASA for processing of satellite observations. The regional algorithm whose application increases reliability of the information processing obtained by means of multi-channel (multi-spectral) scanners of the optical band is also applied for the processing of remote sensing data. Application of the regionally adjusted algorithms raises accuracy of the surface chlorophyll determination.

Free-drifting platforms are another important component of the Black Sea observing system. The most intense International project "Experimental monitoring of the Black Sea for operational meteorology and oceanography using surface drifting buoys" with participation of Ukraine, Russia, USA, France and partial support of Turkey, Romania, Bulgaria and Georgia makes it possible to launch five to ten surface drifting buoys per year in the Black Sea starting from 2000 year (Eremeev et al. 2002). Drifting buoys deployed in the Black Sea are developed following the WOCE principles. They have a sail set at the 15 m depth and positioning of buoys by ARGOS system permits determination of the velocity of surface currents. Sensors displaced on drifting buoys measure atmospheric pressure and sea surface temperature. Data of drifting buoys are transmitted through the GTS to the regional hydrometeorological centers and are assimilated by global atmospheric models.

Surface drifting buoys with thermistor chain, a new efficient tool for the study of the Black Sea upper layer, was developed by MHI NASU within the framework of the project Science and Technology Center in Ukraine "Remote Sensing of Marine Ecological System" (Tolstosheev et al. 2004). Six such buoys were launched starting from the end of August 2004 and have shown good potential for continuous observations of the upper mixed layer dynamics.

Supporting of the profiling floats in the Black Sea basin is carried out by Office Naval Research Europe in frame of the project "Observing the Black Sea with Profiling Floats" which is funded by the NICOP program. Project participants are Turkey, Ukraine and USA. Three PALACE profiling floats developed by the group of School of Oceanography, University of Washington deployed in the Black Sea in September 2002. Two more floats were launched in spring of 2005. All five profiling floats are deployed in the Western part of the basin at the depths between 100 m and 1600 m to monitor the surface and intermediate-depth characteristics of the flow fields and water mass structures. The data are recovered from the floats via the ARGOS system (cf., http://www.argosinc.com). Data are transmitted weekly. The temperature and salinity profiles via pressure and T-S relation together with float trajectories are presented in near-real time on the web site http://flux.ocean.washington.edu/metu.

Basin-scale nowcasting/forecasting system

The Black Sea nowcasting/forecasting system is developed by the consortium of the riparian countries. Black Sea GOOS, EC ARENA, ASCABOS, ECOOP, and SESAME projects were used for the coordination of ongoing national activity and

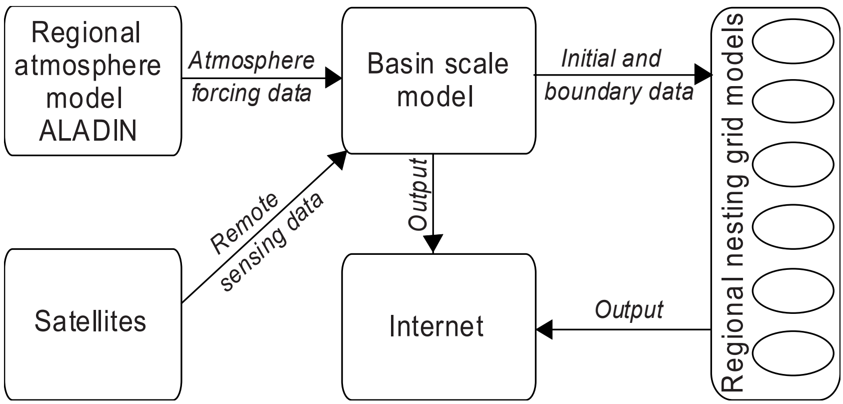

Fig. 24.1. Simplified scheme of the Black Sea nowcasting/forecasting system.

Examples of the system products are presented in Fig. 24.2.

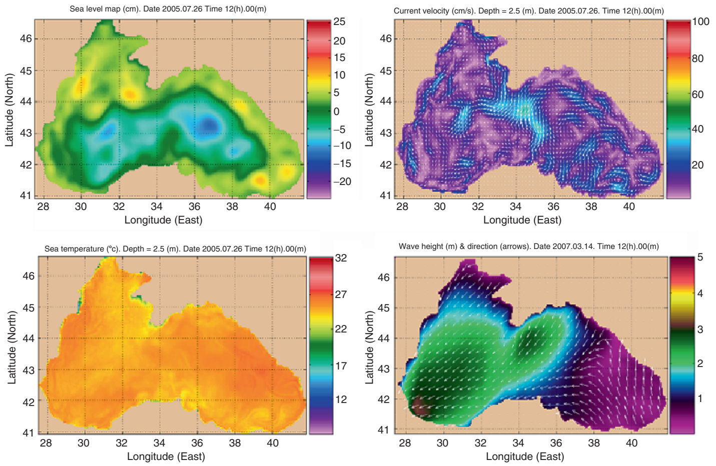

Fig. 24.2. Examples of the basin-scale Black Sea circulation and WAM models output.

some of other international programs sponsoring investigations of the Black Sea. The Black Sea nowcasting/forecasting system (Fig. 24.1) now includes regional high-resolution atmospheric forecasting, basin-scale nowcasting and forecasting of marine dynamics and ecosystem, and high-resolution of near-coastal circulation and stratification forecast.

Regional Atmospheric Model

A new high resolution (24 x 24 km) regional atmospheric model developed and supported by National Meteorological Administration of Romania is available for the Black Sea community during the last year. The model belongs to the ALADIN family and is integrated with open boundary conditions which are supplied operationally by the global model of Meteo-France. Romanian regional atmospheric model provides not only reanalysis but also 2-day forecasts both in GRIB and ASCII formats. Forecasted fields over the Black Sea include: 10 m wind components, latent and sensible heat flux, cumulated solar and thermal radiation flux, instantaneous flux of solar and thermal radiation, evaporation, and convective precipitation in liquid and frozen forms.

Circulation Model and Data Assimilation

The Black Sea circulation model, which is used as the element of the observing system, was developed by the MHI group (Demyshev and Korotaev 1992). It is based on the traditional primitive equations. Finite-difference quantization of the model equations is done on the C-grid. The model has 33 non-uniformly spaced levels, which are more frequent near the surface and near the bottom of the basin. Horizontal resolution is uniform with 5 km grid step whereas the Rossby radius is equal to 25 km in the deep part of the Black Sea basin. Therefore, the horizontal resolution of the model and selected viscosity and diffusion coefficients allow to resolve mesoscale variability of the Black Sea circulation (Dorofeev et al. 2001). The circulation model operates with upper boundary conditions following from the regional atmospheric model and climatic data about river runoff and water and salt exchange through the Bosporus Strait. The model assimilates altimetry and sea surface temperature. The assimilation procedure is based on the theory of the Kalman filter. Full application of the three-dimensional Kalman filter is unrealistic from the point of view of computer power. Therefore we apply here a simplified version, which is based on the optimal interpolation of the sea level for the correction of both temperature and salinity fields. The hindcast of the Black Sea circulation with assimilation of the altimeter sea level is carried out for the period from the spring of 1992.

The assimilation of sea surface temperature derived from AVURR scanners is now carried out by the replacing of simulated temperatures within the upper mixed layer by the observed ones. Bear in mind that clouds are impenetrable for IR radiation and some gaps can appear on SST maps. Therefore, the SST assimilation permits to simulate continuous evolution of sea surface temperature.

WAM and Ecosystem Models

The WAM base, basin-scale surface wave prediction component is implemented to Black Sea nowcasting/forecasting system. The WAM is coupled in one way to the circulation model which makes it possible to take into consideration the refraction of waves on currents. Experimental real-time runs of the surface wave prediction started in September 2007. The three-dimensional ecosystem model is coupled with circulation model. The coupled circulation and ecosystem model is part of the Black Sea nowcasting/forecasting system but still is in the pre-operational mode. The ecosystem module is based on the one-dimensional bio-geo-chemical model, described by Professor T. Oguz in the set of publications (Oguz et al. 1999a, b, 2001a, b). The model is based on the nitrogen cycling. It is able to reproduce seasonal cycling of the Black Sea ecosystem with relevant accuracy at different periods of its evolution including an eutrophication stage and invasive species pressure. However, the current state of the Black Sea ecosystem is relatively healthy which permits us to avoid unnecessary complication of the trophic structure. Therefore the three-dimensional ecosystem model includes nine compartments, namely, diatom and flagellete presenting phytoplankton, micro- and meso-zooplankton, bacteria, dissolved nitrogen, particulate nitrogen, nitrates and ammonium. The model run with 5 km grid step provides a very realistic distribution of surface phytoplankton and other components on meso and seasonal scales.

Validation of the Model Outputs

Independent data of surface drifting buoys and profiling floats are used to validate simulated currents, salinity and temperature distributions. The comparison of surface currents measured by drifting buoys and simulated by the model shows that the drifting buoys trajectory corresponds well to the current structure predicted by the model. The evolution of current velocity along the trajectory of drifting buoys also demonstrates good reproduction of the low-frequency flow variability by the model (Dorofeev et al. 2004). Data of profiling floats allow evaluation of the weekly averaged deep velocity accuracy. In general, relative accuracy of the current speed simulation by the model is highest at the depth of 200 m. However, weekly mean currents even at the depth of 1,550 m measured by profiling float and simulated by the model are in good consistency (Dorofeev and Korotaev 2004a; Korotaev et al. 2004).

Accuracy of SST simulation by the model was estimated by means of the comparison with the data of surface drifters. It is shown (Ratner and Bayankina 2004) that rms error lies in the range 0.5–0.6°, which is the same as the accuracy of SST retrieved from AVHRR data. An error of temperature or salinity simulation varies with depth approximately repeating the profile of mean temperature or salinity gradients. This is natural because in the regions of high vertical gradients even a small inaccuracy in the isoline depth produces a large error in the parameter. However topography of isosurfaces is in rather good agreement with observations as it was shown by (Dorofeev and Korotaev 2004b) by means of the comparison of simulations with COMSBlack hydrographic surveys. Assimilation of generalized profiles of temperature and salinity measured by PALACE floats is introduced at the latest version of data assimilation to reduce systematic error in simulation of temperature and salinity fields. Thus, the model operating on the base of altimetry assimilation provides rather realistic fields.

Regional nested models

Regional weather prediction model implemented by National Meteorological Administration of Romanian and marine basin-scale nowcasing/forecasting system provides good basis for the development of operational nowcast and forecast of coastal dynamics with high spatial resolution. Ongoing national initiatives concerning oceanographic modeling of the most important regions along the Black Sea coast were the base of the nesting strategy development in the basin. The improvement of the nowcasting/forecasting of circulation at the coastal zone is carried out in the framework of ECOOP project. Five sub-regional models, which are nested to the basin-scale model, are based on POM. They have unified spatial resolution of 1 × 1 km. Basin-scale circulation model provides initial and boundary conditions. Atmospheric forcing is provided by Romanian NMA.

Models for coastal nowcast and forecast are nested near Bulgarian coast-Bosporus Strait mouth, Romanian coast and North-West shelf, South of Crimea to the Kerch Strait mouth, and Russian and Georgian coasts. High-resolution coastal forecasts should start in real-time in February 2009. Every model was able to specify open boundary conditions from the basin-scale circulation model of MHI.

Reanalysis of the decadal variability of the Black Sea

Significant amount of hydrographic data collected at the Black Sea provides an opportunity to reconstruct long-term evolution of the basin stratification and dynamics. Archive observations of temperature and salinity profiles are assimilated to the basin-scale circulation model for that goal. Relatively regular hydrographic surveys of the Black Sea basin were carried out from 1957–1994. Here we present the reanalysis of the basin-scale dynamics and stratification for 1985–1994.

Hydrographic surveys of the Black Sea basin were carried out irregularly in space and time. Therefore some preliminary steps were carried out before the beginning of data assimilation in the circulation model. These include: simulation of the regular climatic seasonal cycle by means of assimilation in the model monthly climatic arrays of temperature and salinity fields; evaluation of temporal and spatial correlation functions; preparation of monthly temperature and salinity arrays by means of their optimal interpolation on the regular grid using climatic fields as the reference; and evaluation of accuracy of the obtained fields at every grid point. Next the monthly fields obtained were assimilated to the circulation model using reduced (without simulation of the error of forecasts) Kalman filter approach. The analysis of the basin stratification and dynamics during 1985–1994 has shown positive linear trends in the basin-average temperature and salinity whereas kinetic energy manifests a decrease in the layer until 150 m. There was a tendency of intensification of the Cold Intermediate layer for the period 1991–1993. The long-term evolution of the mixed layer manifests relative cooling in 1987, 1992 and 1993 and warming in 1988 and 1994.

Extreme phenomena in the Black Sea region

Although usually relatively quiet, the Black Sea region nevertheless is subjected to the manifestation of extreme phenomena of anthropogenic or natural origin. An example of the extreme anthropogenic influence is a well-known catastrophic eutrophication of the basin which drastically changes its healthy ecosystem. The most dangerous natural processes are extreme storms that often result in damage to ships and even the loss of human lives. Natural extreme phenomena provide an excellent opportunity to validate qualitatively the efficiency of the marine nowcasting and forecasting. Here we present unusual intense upwelling near the Crimea coast accompanying a strong storm event. The unusual situation arose near the South Crimea coast in June–July 2003. Stable westerly winds during a month and a half formed a broad belt of coastal upwelling. The width of the upwelling reaches 30 km. The sea surface temperature near the coast was in the range 10–14° C. The Black Sea nowcasting/forecasting system has correctly reproduced the unusual upwelling event (Fig. 24.3). Figure 24.4 shows that an intense anticyclonic eddy situated at that time near the Crimea pushed the Rim Current offshore and assisted the rise of cold water in addition to the westerly winds. The Black Sea forecasting system was able to reproduce the intense storm event which occurred in the basin on 10–11 November 2007. Circulation model demonstrates high intensity inertial oscillations occupying the entire basin (Fig. 24.4a). The high amplitude surface waves near the mouth of the Kerch Strait (Fig. 24.4b) were predicted by the model. High intensity of waves is explained by the large fetch length due to the disposition of atmospheric cyclone center west from the Crimea coast.

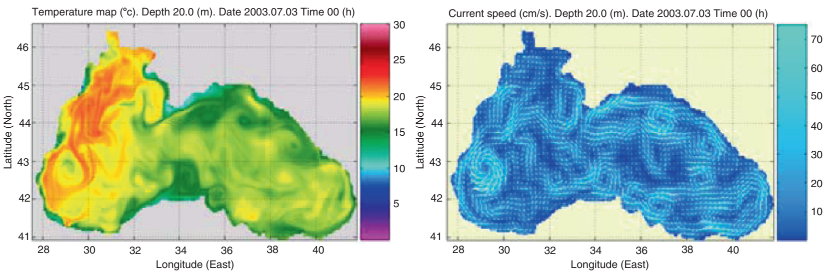

Fig. 24.3. SST (*left*) surface and velocity field in July 2003 simulated by the Black Sea nowcasting/forecasting system.

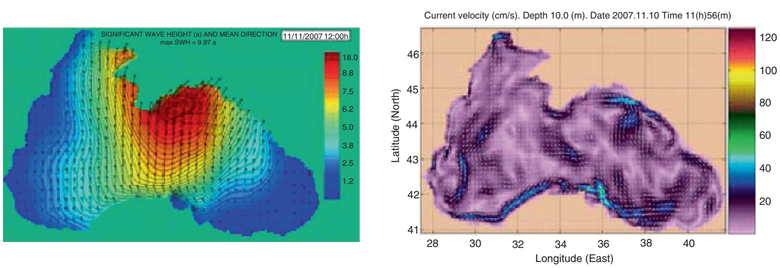

Fig. 24.4. (**a**) Surface wave amplitude and direction (*left*); (**b**) surface currents during the storm (*right*).

Conclusion

An improved version of the Black Sea nowcasting/forecasting system is operational and has constructed projections in real-time during the past 2 years. SST, surface currents and surface wave amplitude and direction are the major system products now. Their quantitative validation against independent measurements of free floating buoys and qualitative validation during the manifestation of extreme storms shows that the system is able to provide practical and useful information.

Acknowledgments. Author is grateful to EC ECOOP, ASCABOS and SESAME projects for the support of the collaborative efforts on the coordination of the reanalysis, nowcasting and forecasting activity in the Black Sea.

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Comprehensive Assessment of Negative Factors Affecting the Black Sea Shallow Water in the Danube Area

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Abstract. Major factors that have negative influence on the coast ecosystem of the Black Sea are assessed in this paper. Anthropogenic eutrophication caused by additional input of nutrients via the river runoff and (mostly via the Danube runoff) has been the main problem for the ecosystem during the last 30 years. Climate changes in Europe in the 2000s became an additional source of negative impact upon the shelf ecosystem. Both these factors are now changing the hydrophysical conditions of the Northwestern part of the Black Sea. In addition to these factors, we observe now a direct human impact upon the shelf ecosystem by construction of deep shipping routes in the Danube Delta towards the Black Sea. In the paper, variants of these routes in the Ukrainian part of the Delta are assessed as well as the consequences of their construction.

Keywords: Black Sea, Danube Delta, anthropogenic influence

Introduction

Northwestern shelf ecosystem was the most productive part of the Black Sea. There were the storages of seaweeds, invertebrates and fishes. It was an important spawning region for food fish species. At present, this area is under strong anthropogenic influence. There is an excessive quantity of inflow of nutrients and contamination.

Main Section

Drainage area is 23 times more than the Northwestern part itself; the volume of river runoff is approximately one fourth of the water volume itself. Runoff from

P.Y. Groisman and S.V Ivanov (eds.), *Regional Aspects of Climate-Terrestrial-Hydrologic Interactions in Non-boreal Eastern Europe*,

the Central and Eastern Europe rivers including the Danube, the Dnipier together with the Southern Bug and the Dniester makes up 80% of the fresh water runoff into the Black Sea. This fresh water influence forms the ecological conditions of the Northwestern part of the Sea. The Danube, the main river of the Black Sea basin, provides 60% of the total fresh water runoff and is the largest influence on the marine ecosystem. Under the influence of the main Black Sea circulation the Danube waters flow to the marine shelf of Romania and Bulgaria, and sometimes they reach the central part of Western halistasa (which is a stationary large-scale cyclonic rotation in the Western part of the Black Sea). As a result of the Danube water eutrophication during the period 1970–1980, nutrient concentrations in the Black Sea coastal zone have increased and provoked a so-called "water blooming". Maximum concentrations of the mineral compounds of nitrogen and phosphorus were recorded in the area of the Danube influence in the 1970–1980s coinciding with development of eutrophication in the northwestern part (Fig. 25.1). During

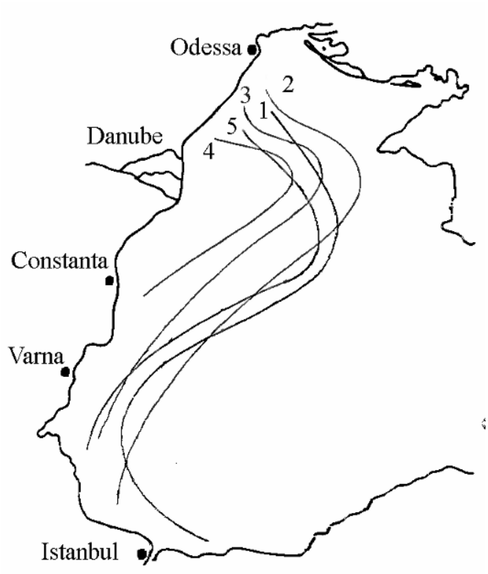

Fig. 25.1. The Danube influence to the Black Sea: (1) isohaline 17‰; (2) phosphates – 0.03 mg l^{-1}; (3) nitrates – 0.04 mg l^{-1}; (4) pH – 8.75; (5) outside border of blooming (during the period of 1973–1987) [1].

this period at the surface layer there were recorded water "blooms" caused by intensive development of phytoplankton–algae "blooms". The dissolved oxygen concentrations at this area were 150–200% of saturation and pH – 8.6–9.3. The total phytoplankton biomass was more than 400,000 t on an area of ~40,000 km^2 during the summer period [8]. Under conditions of density and temperature stratification of water masses which occur in the summer time, decay of dead phytoplankton leads to oxygen depletion – near bottom hypoxia. The area of near bottom hypoxia is the same as the area of nutrients max concentrations in the Black Sea coastal zone. It is also the area of benthic organism's mass mortality (Fig. 25.2).

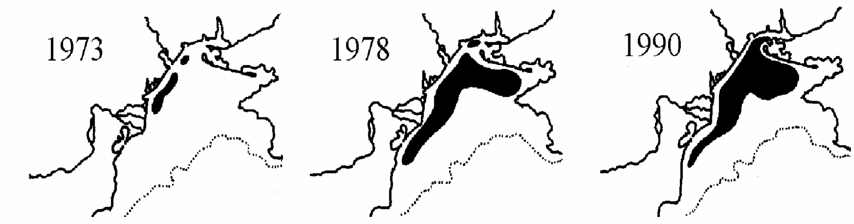

Fig. 25.2. Near bottom hypoxia development in northwestern part of the Black Sea [1].

It is obvious that the problem of benthic hypoxia at present and in the future is the mass death of the benthic organisms which has already happened for some time. First mass benthic organisms mortality was observed in 1972 [3] and at the present time this phenomenon has continued in the summer and autumn. It's not clear, whether this is a permanent condition or whether it is necessary to expect the revival of the northwestern shelf ecosystem with renewal of the hydrochemical regime and biological productivity, as it was in the middle of the past century. After disintegration of the socialist system, the input of mineral and organic fertilizers was sharply reduced from agricultural fields of Ukraine, Romania, Bulgaria, Yugoslavia and Hungary. It was caused by the sharp price rise of fertilizers and their more rational use. Growing ecological requirements reduced the runoff of fertilizers into the rivers in practically all of the catchment area of the Danube. Accordingly, the input of nutrients from the Danube into the Black sea was curtailed, thus diminishing the level of eutrophication; the end of near bottom hypoxia and death of the benthic organisms was expected. Unfortunately, these expectations did not prove to be correct. Chronic "algal blooms" at the zone of the Danube waters influence lead to accumulation of the mineral and organic compounds of nitrogen and phosphorus in the bottom sediments of the Danube coastal zone. Here their concentrations are dozens of times greater than in the water column [3]. During the period of reduced nutrient inflow conditions into the near-shore water, fluxes of ammonia nitrogen, phosphates and silicon from the bottom sediments were observed. This is an additional source of eutrophication for marine waters. These fluxes are compared with the nutrients coming from the Danube [1].

The name itself, anthropogenic eutrophication, describes the origin of this phenomenon as a result of human activities. At present there is new serious issue affecting the shelf ecosystem of the Black Sea, namely the global rise of temperature. It was first revealed by the alteration of the vertical gradients of density in the sea. For the estimation of these changes, research on the following climatic factors was done: estimation of representative long-term changes of temperature, salinity, and dissolved oxygen for the period 1963–1992 during May–October. A preliminary analysis has shown that this period can be divided from 1963 to 1977 and from 1978 to 1992. The average density gradient from May to August was 25% larger than in September–October. The reason for this is decreasing of salinity on the surface and the temperature near the bottom layers (Fig. 25.3).

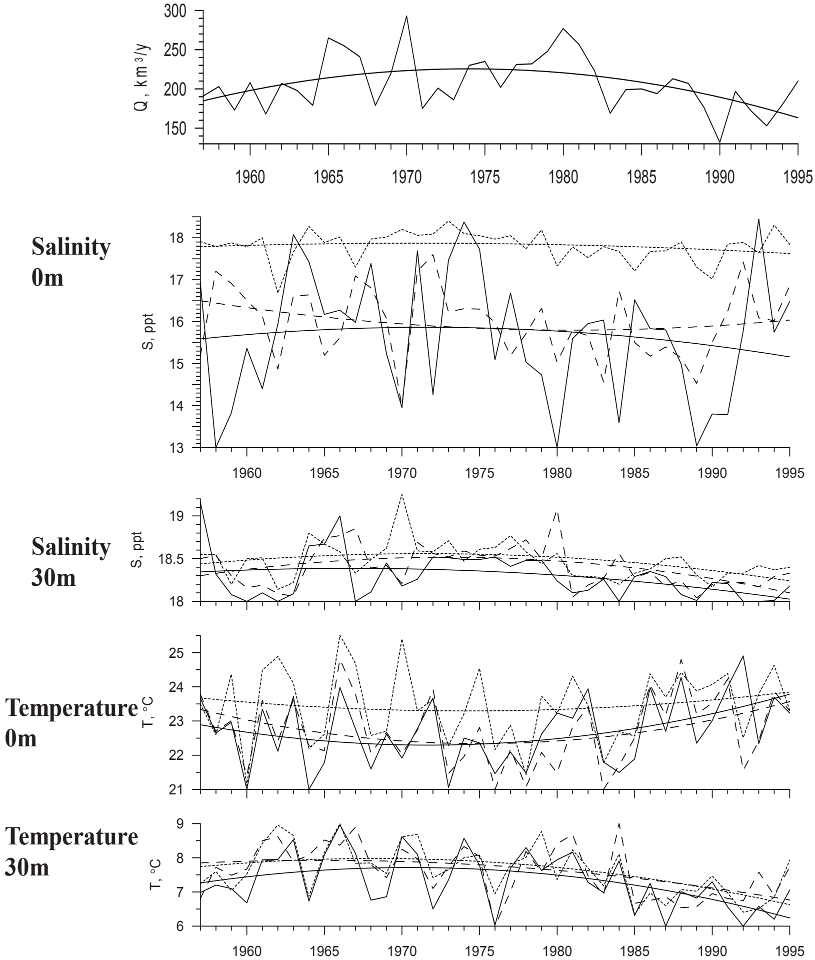

Fig. 25.3. Long-term time series and quadratic trends of the Danube run of (*top panel*, km^3/year), salinity (% salinity) and temperature, (°C) of the waters on horizons 0 and 30 m depth, averaged on the different districts of the northwestern part of the Black sea: west (continuous lines), east (dashed lines) and on continental slope (dotted lines) in August [2].

Long-term variation is a superposition of two types of processes: quasi periodical variation, for instance – El-Niño, fast changing from one condition to another in a short period 1–3 years, for instance – atmospheric circulation regime in Europe, increasing of water temperature on the surface in the Mediterranean and Black Seas, water level increasing in the Caspian Sea etc. [6]. The increase of the duration of the hypoxia period indicates that the Danube shallow water region is under the influence of climate change of the open sea hydrological structure [7]. Hydrological change is directly linked with atmosphere circulation intensification. In the area between the Danube and the Dniester mouth and also in the area in front of the Danube delta, the vertical hydrological structure changed the most. At the same time they are the areas with prolonged and permanent hypoxia. Near-bottom oxygen distribution reflects the invasion of open sea water with a small concentration of oxygen (less than 3 ml/l) because of advection of the deep water masses from the depth 100–150 m along the slope. It is possible that in autumn both areas – with eutrophicated hypoxia origin and deep water hypoxia origin can combine. In this situation the summary influence for marine ecosystem will be extremely negative.

As for the problem in northwestern part of the Black Sea there is exploitation of shipping all the way from the Romania part of the Danube delta through Sulina arm and Tulcha system of Danube. In the Ukrainian part of the delta there is a new shipping route through Bysry arm of Kilia system. The Romanian shipping route has existed for about 150 years. For silting reduction parallel jetties more than 10 km long were built. As a result, at the present time, an area of accumulation has formed to the north of parallel jetties on the adjacent area of Romania and Ukraine, and to the south, an area of erosion. Thus a new island appeared, accompanied by intensive silting of Musura bay and complete degradation of the marine coastal zone ecosystem. For the resolution of this problem joint participation of both countries, Ukraine and Romania, is required. Importance of this question is linked both by the location of state boundary in conjunction with the most valuable area of bilateral biosphere preserve of UNESCO in the Danube delta. From the other side in Ukraine in 2004, work started on organization of its own shipping route that is needed for the development of the poorest region in Ukraine. Ecological safety issues of the new shipping route using Bystry arm raised questions in the international scientific circles and require a serious discussion.

For a long time (approx. 10 years) there were hard discussions about the best alternative of this route. Ukrainian specialists, western experts, NGO, and mass media etc. were involved in these discussions. The best route or optimal variant means balancing economic advisability while at the same time minimizing the anthropogenic impact. At present there are enough scientific facts and arguments for detailed analysis of the situation and for making a final decision.

What are the kinds of problems? The first problem must deal with all the possibilities for new Ukrainian shipping routes crossing the area of the Danube Biosphere Reserve. The next problem deals with the necessity of dredging in the shallow water of the bar zone for marine entrance channels. Therefore, it is necessary to organize the best routes from an economic standpoint while at the same time minimizing the anthropogenic impact. There are problems dealing with nature which must be taken into consideration as well. As for natural problem's factors there are also two (and we must take it in to consideration).

The first has to do with long term delta evolution. The second involves the process of water discharge redistribution in the Delta. The human influence on the first factor is limited while on the second factor influence can be unlimited, meaning it can be accomplished by jetties or dams construction. A very important factor for deep water route (DWR) organization is the state border between Ukraine and Romania, Biosphere Reserve location, and location of the Danube cities and settlements that need economic and social development. Alternatives are options for a few artificial channels around the Delta, one of them is presented on Fig. 25.4.

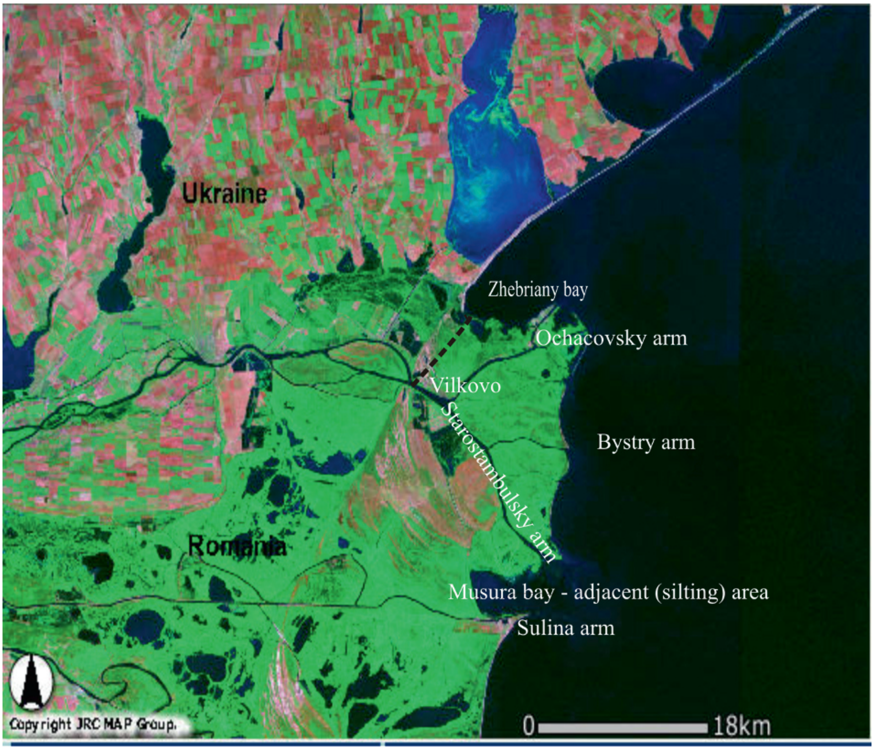

Fig. 25.4. Danube delta is under direct human influence. Two shipping routes (Romanian – via Sulina arm, Ukrainian – via Bystry arm), Dashed line shows a new artificial canal proposed by National Ukrainian Academy of Sciences.

The artificial canal which crosses the wetlands area of the Danube Biosphere Reserve, redistributes the water discharge from the Danube up on 16.6% from the Danube run off (from the total = 3,000 m^3/s, cross-section 54 km distance from the mouth). Hydrological regime in the whole delta will change and ecological conditions will be sharply worsened. In case of canal construction with locks, water discharge redistribution from the Danube will be increased by 2–3%. All these canals are artificial and pass via land (by the way it is the territory of Biosphere Reserve). The damage from this construction will be too high and

DWR organization will be too expensive. Besides, it is planned to build a new port in Zhebriany Bay with railway connection and a large bridge, because Vilkovo city becomes an island. This activity can destruct natural wetlands and the marine ecosystem. But the main damage is waste of water runoff which will be withdrawn from the Kilia system and diverted into the Sea. According to the project documentation, the width of the canal (on bottom) is 60 m, the depth is 8.5 m, so the water runoff in this canal will be approx. $Q = 500\ m^3/s$. This is half of the natural arm Bystry water runoff. This new canal construction will stimulate redistribution of water runoff, about 16.6% from the Danube run off (compared with $Q = 3{,}000\ m^3/s$, cross-section 54 km distance from the mouth). This very large value (16.6%) will cause decreased water flow to the inner delta (lower Vilkovo, 18 km). Also, it will have a bad impact upon the situation in the Ukrainian part of the delta and will provoke a negative reaction from Romania because this redistribution of water runoff will sharply decrease the water flowing to the Romanian part of delta. In case of new canal with locks, the water loss will make up to 3%. This is a large enough value to cause all of the above mentioned problems to occur. At the same time the water runoff in common (Romanian–Ukraine) Starostambulsky arm will be decreased and that provokes the silting of Musura Bay where silting is an ecological problem at present.

The other variants of DWR are linked with Ochakovsky and Starostambulsky arms systems. The Ochakosky system is a dying system from a geological point of view [5]. The long term decrease of water runoff in this system presented in Fig. 25.5.

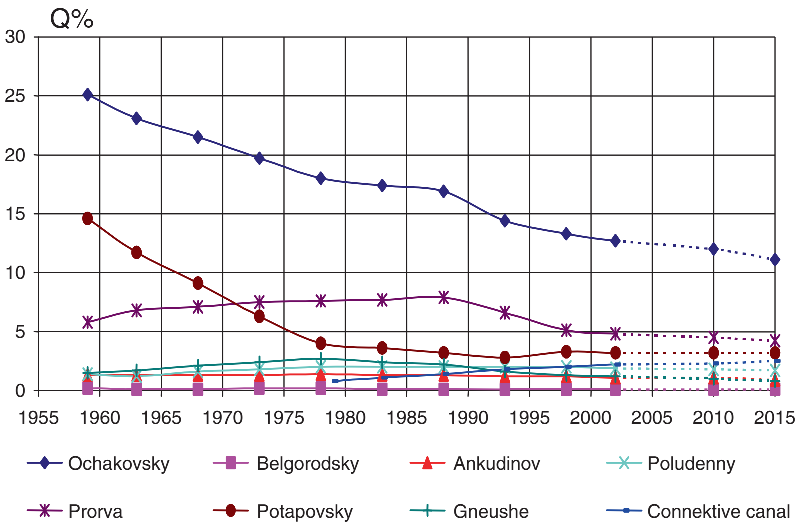

Fig. 25.5. The water runoff distribution in Ochakovsky system (data of Hydrometeorological Observatory in Ismail, Ukraine) [4].

The last alternative variants are linked with Starostambulsky system itself. The problem for DWR organization through Starostambulsky arm is that it is the place for marine dumping. For DWR it is necessary to use marine dumping for permanent disposal of bottom sediments. According to the hydrological regime, the general direction of sea currents in this area is from North to the South. Therefore, the place for dumping must be only to the South of the marine canal through the bar's zone. No doubt that dragging works on the marine canal and activity in the dumping place will have a strong effect on the neighbor's (Romanian) Sulina DWR. The dumping place must be located close to Romanian state border and the silting process will take place in Sulina marine canal. It will provoke a justifiable protest from the Romanian side.

Evidently all kinds of industrial activity are negative for the environment. However, the case of using Bystry arm for DWR can only have negative influence reflected on the marine ecosystem because not 1 m^3 of bottom sediments was dragged from Bystry arm. It was not necessary. Bysrtry arm is one of the natural Danube branches. Natural depths in this arm are 12–14 m, and that is more than enough depth (8.5 m) for navigation. Bystry arm has long term increasing trend of water runoff (Fig. 25.6). Real dredging works took place in the open sea in front of the Bystry mouth. This area is not part of Biosphere Reserve and located far enough from the UNESCO heavily protected zones (Starostambulsky and Ochacovsky mouths, approx. 8 km) as well as Romania Sulina mouth (approx. 20 km).

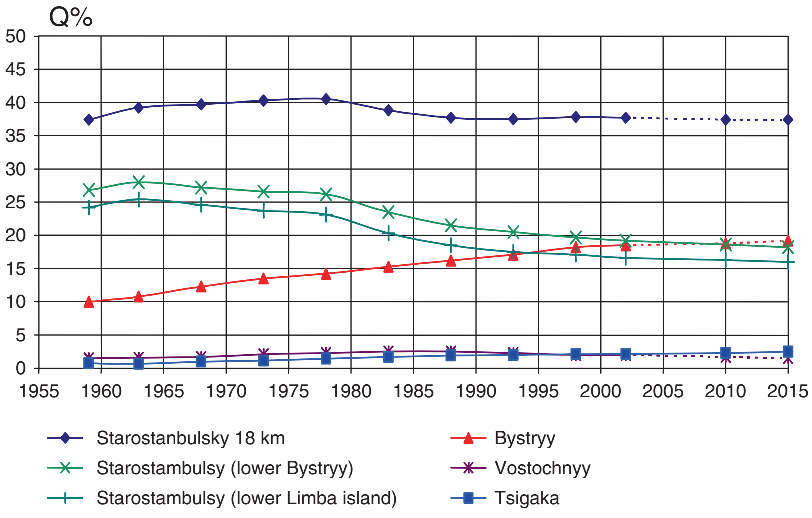

Fig. 25.6. The water runoff distribution in Starostambulsy system (data of Hydrometeorological Observatory, Ismail) [4].

Direct measurements have shown that suspended matter as a result of dragging works and dumping activity in the marine ecosystem is limited by the distance not more than 800 m and therefore, can't reach the Romanian border (20 km far from the Bystry).

Conclusion

All kind of alternative variants of DWW are dangerous for ecological conditions of the Kilia delta because a considerable part of fresh water will be withdrawn from Ukrainian part of delta (upper 20 km). This will provoke degradation of living condition for water plants and animals in the delta and Biosphere reserve. Ukrainian DWR in Starostambulsky arm could be the reason for ecological and economic problems on the Romanian side (silting of Sulina DWR). Therefore, the safest project is Bystry DWR, because its environment is created by nature itself and doesn't need additional artificial construction.

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Changes of Thermohalinity Characteristics in the North-West Black Sea Shelf During the Last 50 Years

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Abstract. Spatial-temporal changes of hydrophysical and hydrobiological characteristics in the North-West Black Sea shelf are considered using the last 50 year time series with more detailed analysis of certain periods. The results show significant temperature and salinity trends for the winter season. Temperature substantially increased about 2˚C in the surface level of 0–10 m, and more than 3˚C in the benthonic level, moreover, the vertical density gradient has doubled. Also, an increasing level of organic forms of nitrogen has been observed. It is found that qualitative and quantitative structure of phytoplankton depends on the seasonal and long-term changes.

Key words: Temperature, salinity, wind, trend, variability, Zmiyinyy Island

Introduction

The last decades of the twentieth century have shown large and rapid climatic changes affecting the structure of the large-scale atmospheric circulation (Polonsky 2008). It led to changes in precipitation over some areas of land, and reflected on the thermohaline conditions of the seas, especially the shallow and partially isolated water areas – such as the North-Western region of the Black sea (NWBS). Long-term trends of NWBS oceanographic characteristics are mainly formed by two external factors governing the physical mechanisms leading to temperature and salinity changes: river discharge volume and atmosphere's thermodynamic conditions near the sea surface.

Data

Current assessment is based on 51-years series of daily measurements of water temperature, salinity and density at stations and also results of observations during

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research cruises done by Ukrainian Scientific Centre of Ecology of the Sea (UkrSCES) (total 3,600 NWBS stations). Here we use statistical characteristic of inter-annual summer and winter timescales variability of oceanographic processes in three regions of the NWBS that were recognized as separate research areas: Western (45°00' N–46°00' N, 30°00' E–31°00' E), East (45°00' N–46°00' N, 31°00' E–32°00' E) and Southern (44°20' N–45° N, 31° E–33° E) areas (Fig. 26.1).

The case of investigating the changes and trends in physical oceanographic processes around Zmiyinyy Island (sea area in the shape of a square with sides of 52.5 km and with the island in the centre 45°15' N, 30°12' E) had been considered separately. The average decade hydrological and hydro-chemical values (1986–1995 and 1996–2005) were used to analyze summer and winter season's parameters. This study uses the data of measurements made under the supervision of Southern Research Institute of Marine Fisheries and Oceanography (Kerch).

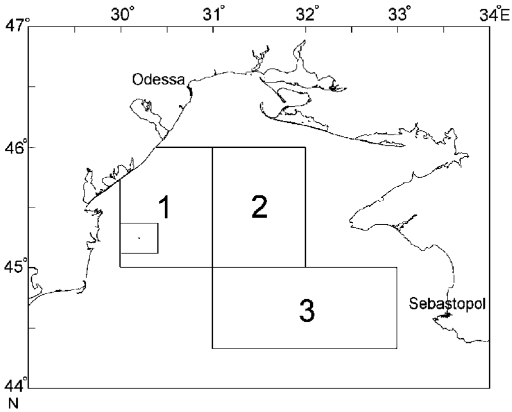

Fig. 26.1. The scheme map of the research regions.

The calculated time series of average seasonal values for the areas described above were used to identify and estimate the tendency in temperature and salinity prior to 1992, and UkrSCES during the full research period on 357 oceanographic stations in the first decade and on 197 stations during the second decade.

Results

The analysis of changes in water temperature and salinity showed the formation of a trend mainly for winter period data. The temperature increases both in the surface (0–10 m) layer of the Eastern and benthonic layer of Western research area (Fig. 26.2).

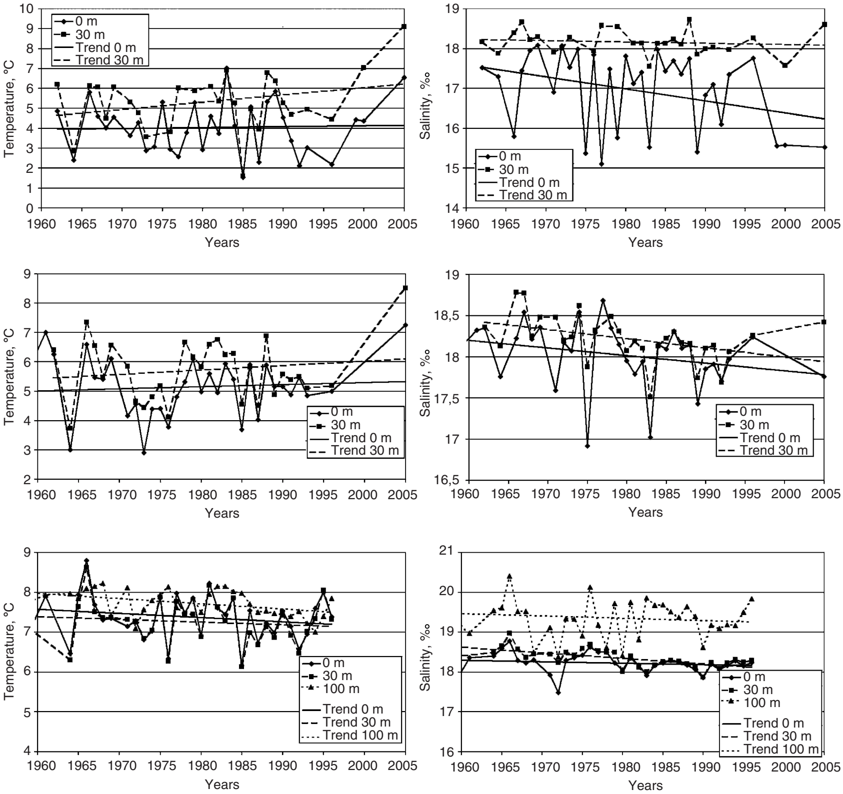

Fig. 26.2. Interannual values of winter period water temperature and salinity in the research areas (1) (upper row of panels), (2) (middle row of panels), and (3) (bottom row of panels).

However, there were no appreciable changes observed in average summer temperature through nearly the whole water column (Fig. 26.3). Long-term variability of winter surface water salinity of all three investigated areas had shown clear negative trends, which we believe indicates a climatic decrease of salinity (Fig. 26.2). In the benthonic layer the tendency of salinity decrease also was observed for the Eastern and Southern areas but not for the Western research area. Summer season variability of water salinity for surface and benthonic layers shows a positive trend for Western area (Fig. 26.3). It has shown that both trends in the researched areas of the Black Sea are clearly season-dependent and also such differences indicate that long-term water salinity variability has different mechanisms of formation.

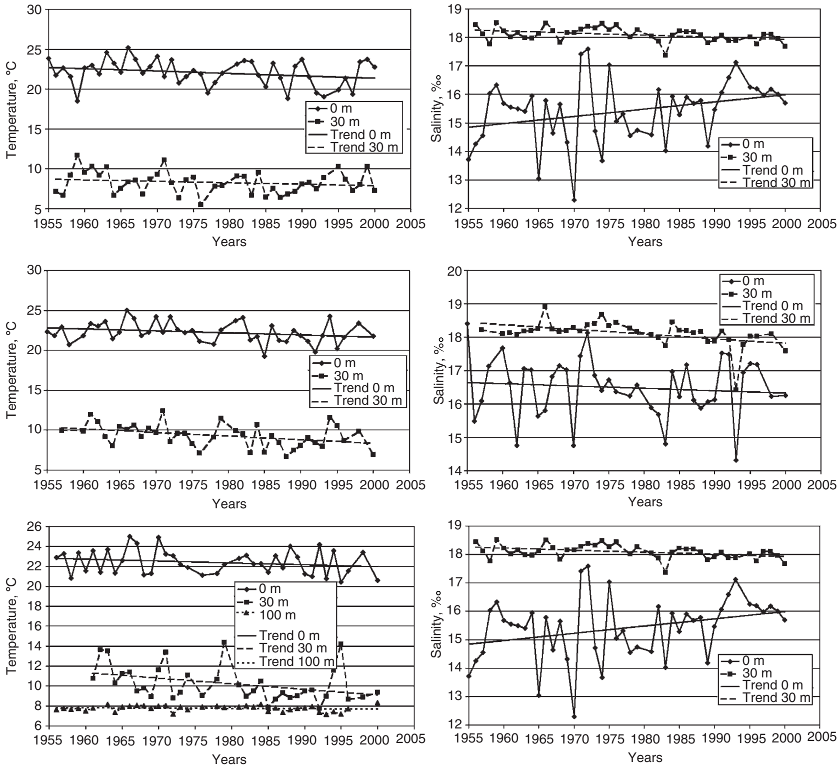

Fig. 26.3. Interannual values of summer water temperature and salinity in the allocated areas (1) (upper row of panels), (2) (middle row of panels), and (3) (bottom row of panels).

The major impacts of climate variability were identified in Western research area and certainly a key factor is the increase of outflow from the Danube River. The Danube River carries and discharges into the Danube Delta waste waters from eleven European states with the strongest anthropogeneous pressure being felt in the Black Sea region. In conjunction with this impact we take a closer look in variation of hydrophysical fields based on the analyses of data in Zmiyinyy Island research area.

The fact that attracts attention is the increase of average and extreme winter temperatures in 1996–2005 in comparison with 1986–1995 values (Table 26.1). Data suggest a relationship to climatic change in both the atmosphere and sea waters.Visualization of the data demonstrates more than 2°C increase in average winter surface water temperature and more than 3°C increase in the benthonic layer for the same period. Also it is indicated that the average value for the benthonic water temperature during last decade is higher than its maximum value over the 1986–1995 period (Fig. 26.4).

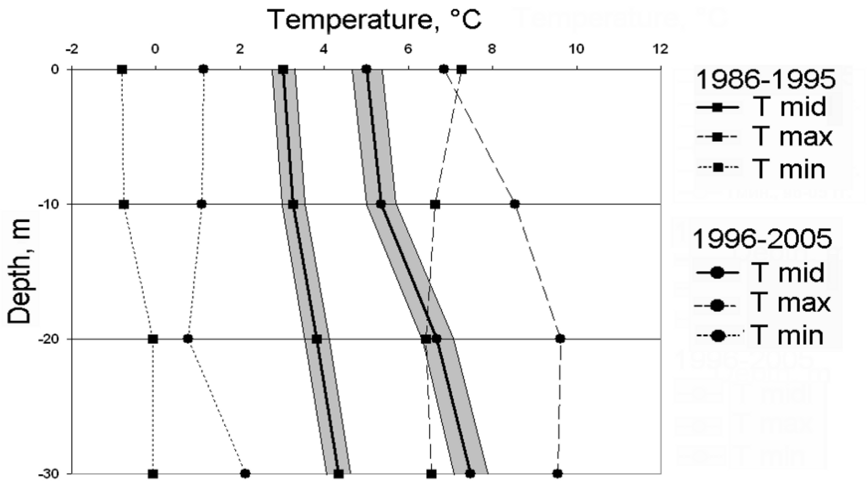

Fig. 26.4. Vertical distribution (from surface to benthonic) of average for the winter and summer periods (1986–1995 and 1996–2005) mean and extreme values of water temperature (grey colour indicates area of 99% confidence level for average values).

Analyses of the vertical structure of average and extreme temperatures for the summer periods had shown very little, practically insignificant increase for all research areas while the comparison of the average seasonable salinity revealed 0.2–0.96‰ decrease for the period 1996–2005 (Table 26.1). This relates to the increase of Danube river outflow during this period. The summer values demonstrate an opposite picture; the average for the period 1996–2005 surface salinity had slightly increased in comparison with the previous decade values. It is necessary to point to the fact that during the period 1986–1995 the minimum salinity of a surface layer near Zmiyinyy Island had dropped to about 4‰ which suggests that highly polluted Danube river waters had reached this area without much change.

In 1996–2005 the minimum value salinity was 11.50‰, but for the decade 1986–1995 salinity has been observed below the 11.40‰ value 25 times which is a consequence of large-scale changes in atmospheric circulation and wind mode.

The graphs in Fig. 26.5 represent the characteristics of the wind mode variations based on measurements at Odessa-Port station which illuminates the decreasing trend in average value of wind speed for both seasons. For summer period it also revealed a simultaneous increase of the northern component and decrease of the western component. Analyses of the variation of the 5 year periods average index of North Atlantic fluctuation (+0.29 in 1991–1995 and –0.14 in 1996–2000) also revealed the changes in structure of the large-scale circulation. Identified changes of temperature and salinity are very well related to the increased (about twice) gradients of water density during the winter period (Table 26.1) and, as a result, to the decrease of intensity of vertical convection. During the summer the reduction of the vertical density gradient creates preconditions to reduction of hypoxia occurrence in the benthonic layer.

Table 26.1. Seasonable average values of temperature – °C (1), salinity – ‰ (2), conditional density (3) of sea water near Zmiyinyy Island based on the data collected during 1986–1995 and 1996–2005 periods.

H m	Summer 1986–1995 (years)			Winter 1986–1995 (years)			Summer 1996–2005 (years)			Winter 1996–2005 (years)		
	1	2	3	1	2	3	1	2	3	1	2	3
0	22.03	15.27	9.29	3.02	16.75	13.35	22.67	15.56	9.35	5.02	15.79	12.44
10	20.21	16.44	10.6	3.25	17.33	13.80	18.36	16.56	11.10	5.35	16.83	13.24
20	11.78	17.66	13.13	3.81	17.70	14.05	12.36	17.28	12.74	6.68	17.50	13.64
30	7.34	17.98	13.95	4.33	18.00	14.24	8.40	17.65	1,357	747	18.32	14.20
Av. density gradient 0.16				**Av. density gradient** 0.03			**Av. density gradient** 0.14			**Av. density gradient** 0.06		

Next we consider the impact of such changes in oceanographic characteristics of sea water in NWBS region on the phytoplankton variability and tendency for the region. A long-term tendency of increase of the phytoplankton species diversity and amount is observed for the whole NWBS, especially for coastal waters. It especially concerns heterotrophic and mixotrophic species and it indicates the raised concentration of biogenous sediments in the water environment. Average concentration of total nitrogen has increased considerably in the last decade (by four to five times) in comparison with the previous decade. This similar tendency is identified based on the data of regular measurements and analysis during 2000–2008 in a coastal zone of the Odessa region. The ratio of the organic form of nitrogen to mineral ($N_{org.}/N_{min.}$) in the last decade has increased and now in the surface layer is about 7, and in benthonic −12 on average. In the decade 1985–1996 the ratio in the surface and benthonic layers was about one on average.

The increase in organic nitrogen and concentration of organic substances has led to considerable reduction of water transparency around Zmiyinyy Island. The average water transparency indicated by white disk measurements in the area investigated in 1986–1995 was 3.8 m, and in 1996–2005 has decreased to 1.8 m. Even during the winter period (according to January shooting at 2005) it was only 2.5 m. Amount of microalgae during 2002–2007 has considerably increased compared with 1993–1999. Species diversity also increased, especially owing to freshwater species, due to the average salinity decrease of NWBS surface water.

The increase of average winter temperature of surface water, in the milder winters observed since 1996, led to displacement of a spring maximum of phytoplankton from May (until 1999) to the end of March.

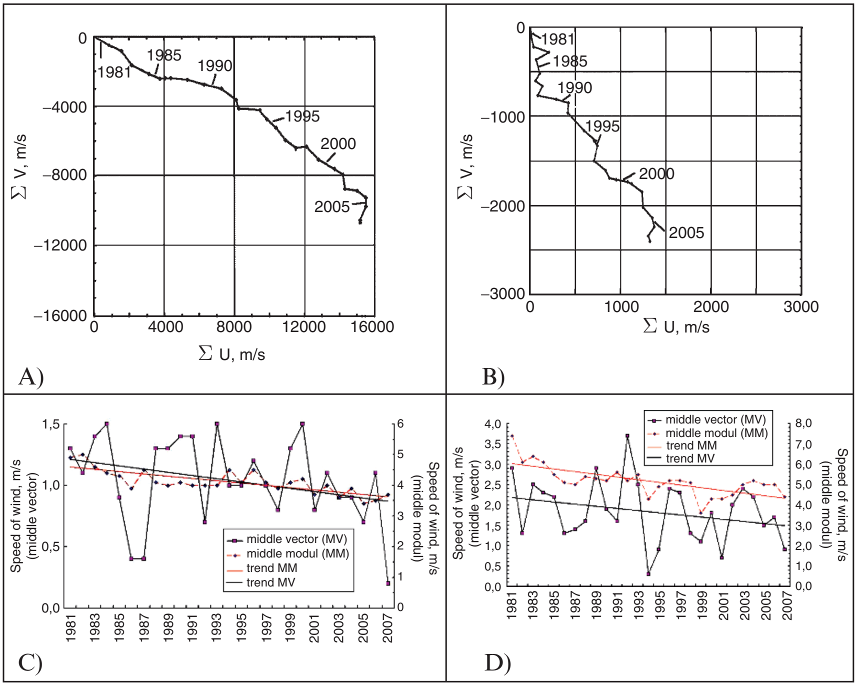

Fig. 26.5. The diagrams of summer (**a**) and winter (**b**) wind progressive-vectors and inter-annual variation of summer (**c**) and winter (**d**) average scalar and vector values of wind speed for the Odessa-Port station.

Conclusions

Results of the analysis indicate considerable changes of hydrological conditions in NWBS which are caused by climatic factors (change of wind mode, temperature rise in the winter period and increase of Danube drain). As a result of decreasing winter water convection, more hypoxic waters of a benthonic layer during the subsequent seasons of year can be created.

Salinity reduction and rise in temperature of surface water has led to structure and quantitative changes in biocenoses. The increase in the concentration of organic nitrogen and organic substances on the whole has led to a double reduction of water transparency that also influenced hydro biological conditions.

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Specificity of Romanian Black Sea Coast Changes Under Climate and Human Impact

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Abstract. The Black Sea and its coastal lakes are well-known from ancient times as “*unicum hidrobiologicum*” due to its specific features having impact on coastal area. Romanian coast is different than other areas because of being under the Danube freshwater and load influence. A variety of valuable natural resources are concentrated along the Romanian Black Sea Coastal Zone making the coast an attractive living, working and recreational environment with substantial economic and ecological value. This extended abstract outlines major points of the presentation at the NATO Advanced Research Workshop in Odessa (August 2008).

Keywords: Romania, coastal zone, Black Sea, coastal lakes

Research Objectives of Romanian Studies of the National Coastal Zone

Our objective is to create sustainable coastal zone development on the Romanian Sea Coast. Challenges that we foresee are multiple and intertwined, their sources being both local activities effects and global environmental changes. Activities of local communities (such as urban development, marine transport, hydro-technical

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works, natural resources extraction etc.) and tourism activities result in pollution, fish-overexploitation and river embankment (Figs. 27.1 and 27.2). The negative outcomes are progressive ecosystem degradation and loss of biodiversity (reducing the fish spawning and growing area, limiting fish migration lines) with a severe perturbation on population activities, structure, density and life. These multiple and interconnected factors need to be managed through an integrated approach that brings all coastal sectors, level of government and coastal users into rational goal settings and decision making framework.

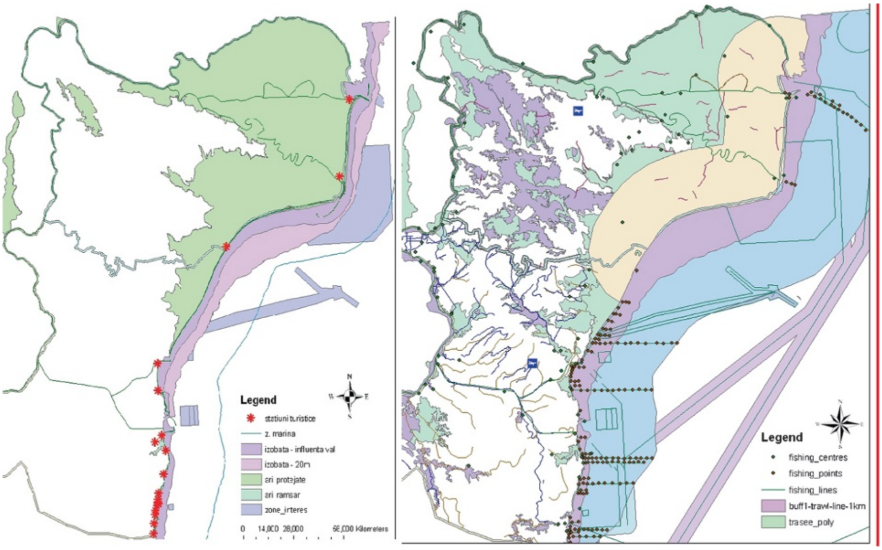

Fig. 27.1. A few thematic maps of Romanian coast, left: urban settlements, right: major fishing and fisheries areas.

The main threats to the Romanian coastal zone

- Fast coastal urbanization, mainly as a result of population concentration, holiday houses building.
- Uncontrolled tourism and growth of recreational activities are in developing (e.g., north of Mamaia, Eforie sand bar).
- The uncontrolled development has negative effects on coastal environment and landscape. Its increasing induce pressure on the ecosystem which lead to the loss of habitats ultimately.
- Furthermore the destruction of the natural shoreline defense (dunes) relate to rapid and extended urban development.
- Pollution is the most critical problem on the Romanian coast due to the development of the industry and the urban centers.

- The lack and uncontrolled disposal of the solid waste and sewage discharge have negative impact on the quality of sea water taking into account that seawater renewable time is slowly and consequences on the marine environment are obviously.
- Decrease of the renewable and non renewable resources induces alteration of key ecological processes.
- Water resources are large overexploited to satisfy the increase demands in water consumption for agriculture and tourism.
- Increasing environmental and other risks due to climate change and sea level rise and consequently increased occurrence of storms, coastal erosion, changes in seawater temperature and salinity and biological diversity reduction.
- Increasing threats, heritage and diversity of the area due to new uncontrolled buildings of coastal areas.
- With consequent impacts on traditional socio-economic structure.
- Natural and man-made landscapes have deteriorated significantly.

Solutions

For the elaboration of the development plans and for the determination of the indicators of sustainability we began with the stakeholders' engagement, understanding in the community's vision, its acquaintance and its relations with the environment, and the identification of the community's needs in the aim to find new solutions in order to create mutual and continuous agreements by an "adaptive management" based on a long-term consultation.

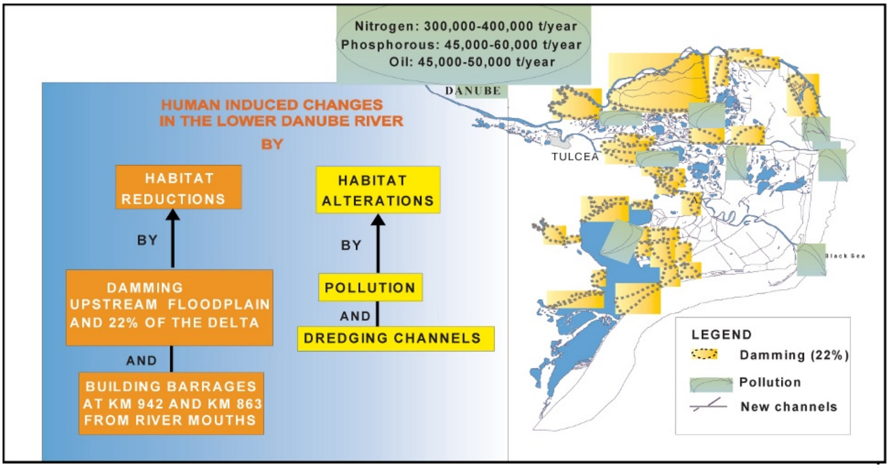

Fig. 27.2. Human induced changes in Danube Delta.

The environment protection and conservation wish to be based in present on scientific (NIMRD more than 40 years of coastal monitoring), educational, informational and recreational activities in the aim to equilibrated harmonization and accommodation to the human desires, needs, and interests with unpredictable climate changes impact (Fig. 27.3).

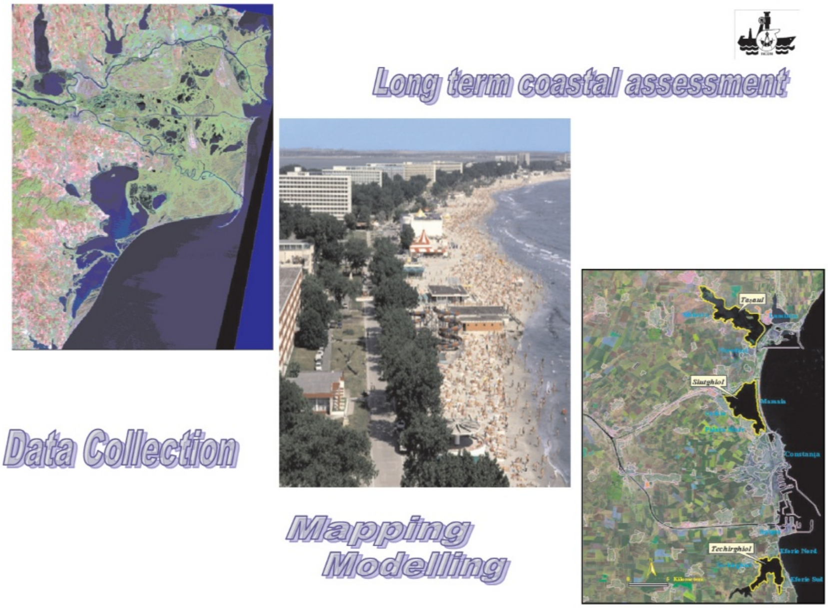

Fig. 27.3. Three major steps to secure environment protection of the Romanian coastal zone.

A review of research results on local manifestations of global environmental changes and their impact on human communities along the Romania coast and, in particular, in the Danube Delta are published (Petranu et al. 1999; Nicolaev et al. 2004; Nicolaev and Baloga 2005, 2007). These papers also present solutions that the scientists of National Institute for Marine Research and Development "Grigore Antipa" have used, and are planning for sustainable development of Romanian coastal zone.

Future steps

As an urban settlement is not closed system, but an entity which requires a management system aimed at urban development, the strategic urban planning will be carried out the following principles:

- Strengthening of institutional capacities by effective management, defining and restructuring o of public services according to current financial resources, the sustainable development objectives and the demands of the community
- Connecting the municipality to a network which provides information about municipalities' best practices (in urban or project management)
- Vertical and horizontal integration of policies aimed at developing the city, as well as at the development of the county and its surrounding areas
- Sustainable architectural protection by which one establishes regulations regarding construction materials, building architecture, bio climate, density of buildings in a certain areas, green space surrounding buildings, microclimate, efficiency of use energy
- Establishment of regulations for rational use of lands in all development projects of the Urban Management Plan, as an instrument for space planning; and
- Analysis of the technical execution capacity

Ecological Unbalance of Romanian Coastal Lakes: Causes and Effects

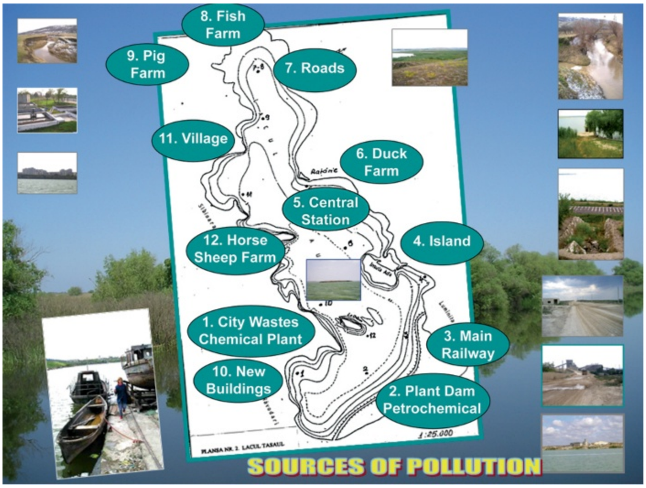

Fig. 27.4. Twelve major sources of pollution of coastal lakes and wetlands along the Romanian coast.

The natural and anthropogenic, both continental and marine pressure, due of the geographical position and anthropogenic impact, like hydro-technical works (road, railway, building works and consolidation, freshening) industrial pollution (chemical agents, detergents, pesticides), wastewater products and deposits; agricultural (crops fertilizing, private vegetable gardens, zootechnique activities), tourism, (recreation, sailing, nautical sports), use of therapeutical sludge and seasonal bathing areas; overexploitation of natural resources, mainly fish production) have had a big influence on the present ecological statement of the inland water at the Romanian Black Sea coast. Adding to these causes, the wrong application or the lack of environment legislation control, it is easy to explain the human impact consequences in the area of coastal inland waters:

(a) aquatic environment degradation,
(b) ecosystems balance disturbance,
(c) traditional biodiversity diminishing,
(d) natural resources quality decline, and
(e) traditional activities disorganization.

Samples of water and sediments have been collected from ten natural lakes (Tasaul, Corbu, Siutghiol, Tabacarie, Agigea, Techirghiol, Costinesti, Tatlageac, Limanu, Mangalia, a swamp: Herghelia, and a lagoon: Sinoe Lagoon. The stations were settled on important anthropogenic impact points or on connection places between border areas of interest, as well as between important areas from the point of view of the system, sources, objectives, or break through important points.

The results obtained on the Tasaul, Siutghiol, Techirghiol Lakes and Sinoe Lagoon can be compared with the former years hydro-chemical and hydro-biological analysis. Concerning the other eight inland waters, it has to be mention that the assessment is a premiere after more than 15 years of research gaps.

Conclusions

Results of assessment of the ecological state of Romanian coastal zone (including coastal inland waters), obtained under the NIMRD "G.Antipa" Constanta coordination, stress the necessity to take urgent measures of rehabilitation for water quality and natural resources of this zone with a huge social and economical importance. Solutions proposed for ecological recovery, in accordance with European legislation concerning the environment protection, conservation and use, have as a target sustainable development to support future human health.

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