Arbaminch Water Technology Institute
Faculty of Meteorology and Hydrology

Climate change: Impact, adaptation &Mitigation

Course code: MHF1303.

Course credit: 6

Target group: UG3_MHS

Instructor: *Gizachew K*

Observed Climate Variability and Change

Lecture Note2:

❖ This chapter focuses on six questions

- Has the climate warmed?
- Has the climate become wetter?
- Are the atmosphere/ocean circulations changing?
- Has the climate become more variable or extreme?
- Is the 20th century warming unusual?
- Are the observed trends internally consistent?

Observed Weather and Climate Change

- **Observed Climate Variations**

- Scientists expect climate change, but what changes have they observed?

- Analysis of global observations of surface temperature show that there has been a warming of about 0.6°C over the past hundred years

- The trend is toward a larger increase in minimum than in maximum daily temperatures.

- The reason for this difference is apparently linked to associated increases in **low cloudiness** and to aerosol effects as well as the **enhanced greenhouse effect.**

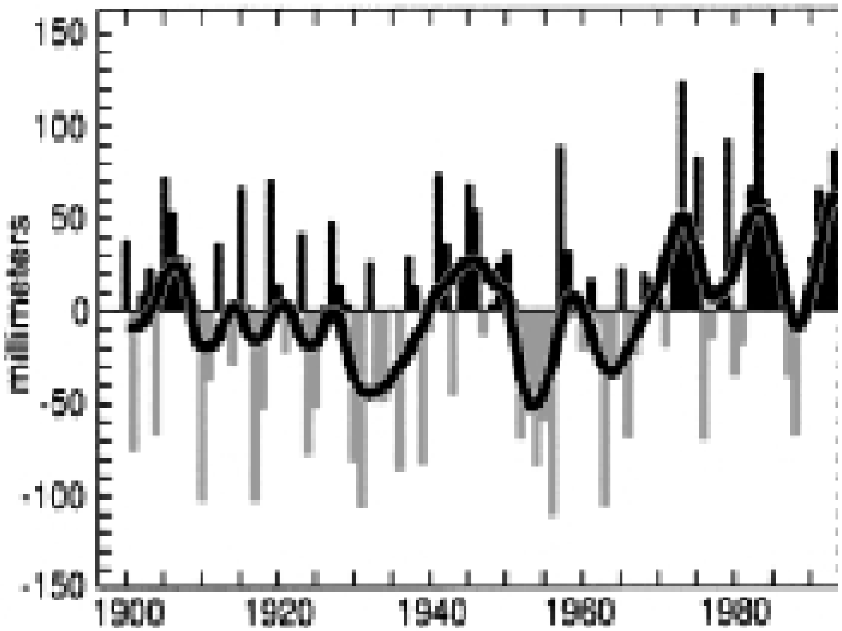
- Changes in precipitation and other components of the hydrological cycle are determined more by changes in the weather systems and their tracks than by changes in temperature.

Cont.

- Because weather systems are so variable in both space and time, patterns of change in precipitation are much more complicated than patterns of temperature change.
- Precipitation has increased over land in the high latitudes of the Northern Hemisphere, especially during the cold season.

Cont.

- a) b)



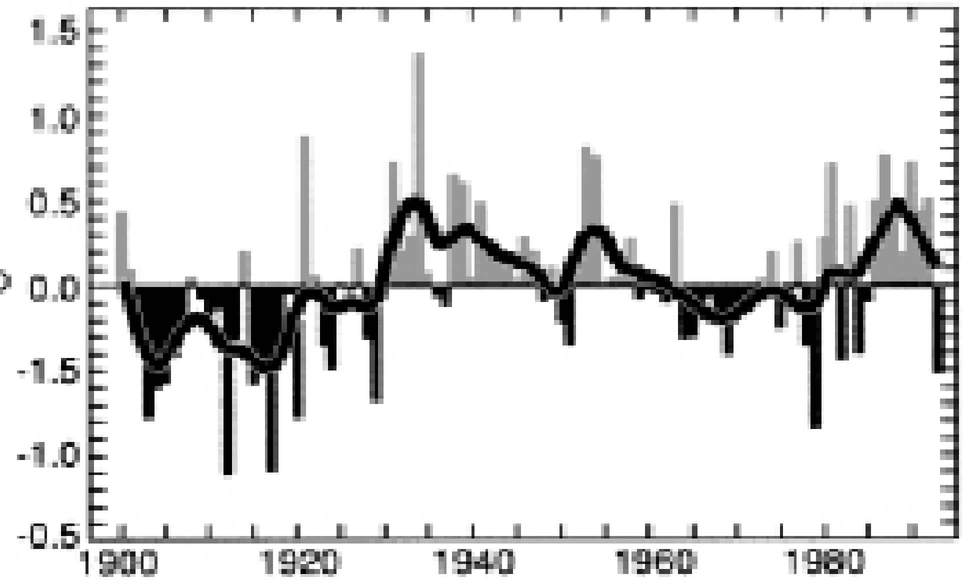


Figure2.6 Average annual precipitation(a) and Temperature anomaly (b).

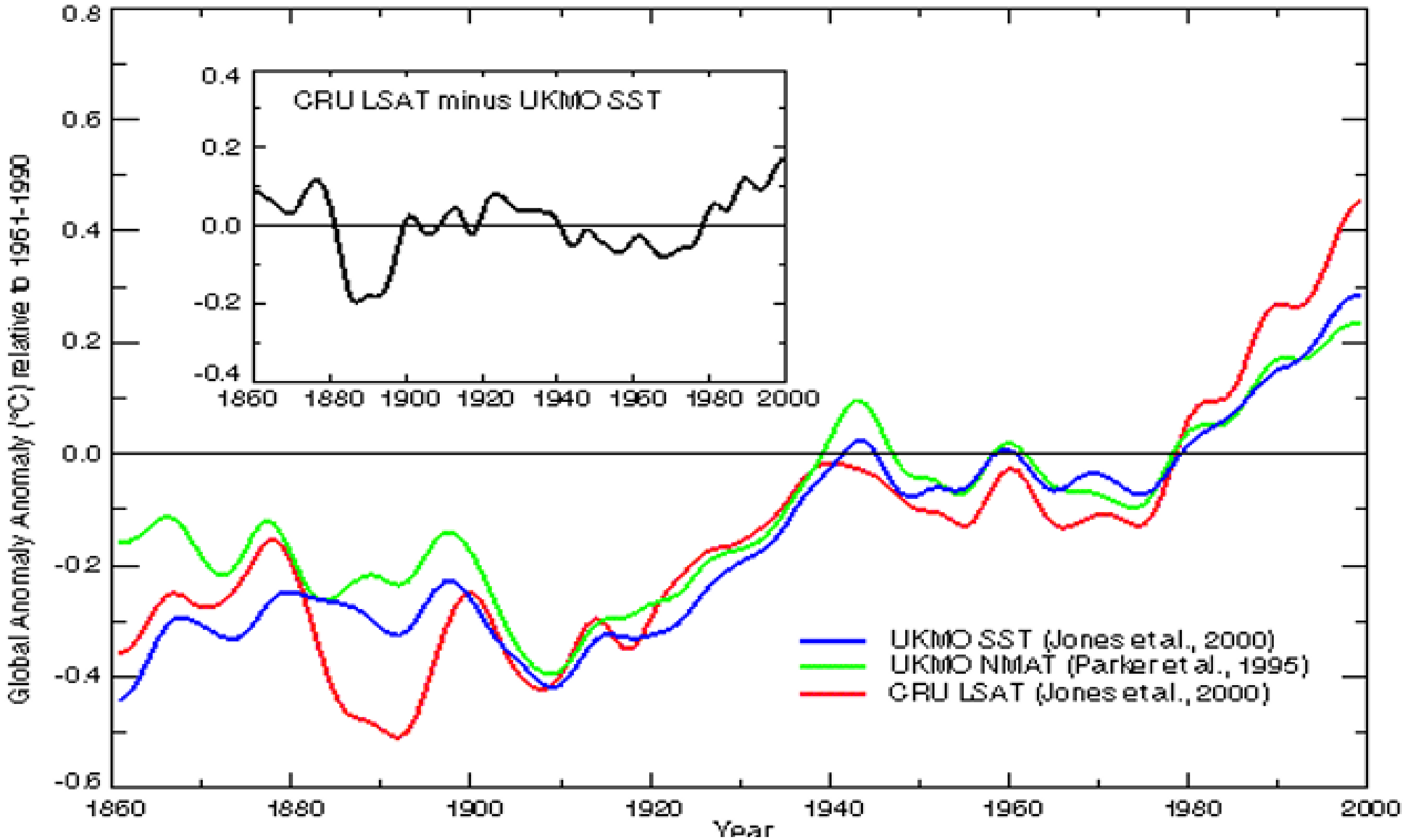
1. Has the Climate Warmed?

A. Land and Sea Surface Temperatures Combined:

❖ Figure1 below summarizes the relative changes of:

- UKMO Sea Surface Temperature (SST),
- UKMO Night Marine Air Temperature (NMAT) and
- Climate Research Unit (CRU at University of East Anglia in the U.K.) *land surface air temperature*.

✓ All three curves have a generally similar shape except that modest cooling of NMAT in the late nineteenth century is not seen in the SST data.



- Figure1 Summarizes the Land, Sea surface and Night temperature.

B. **Spatial Distribution of ST Trend**:

- Most of the warming of the 20th century occurred in two distinct periods separated by several decades of little overall globally averaged change.
- The figure above highlights the worldwide behavior of temperature change in the three periods.
- These linear trends have been calculated from a gridded combination of UKMO SST and CRU temperatures.

- ✓ The periods chosen are:

- 1910-1945 (1^{st} warming period),
- 1946-1975 (period of little global temperature change),
- 1976-1999 (second warming period) and the 20th century, 1901-1999.

- It can be seen that there is a high degree of local consistency between the SST and land air temperature across the land-ocean boundary, noting that the corrections to SST are independent of the land data.

C .**Trends in Tropospheric Temperature**

- The surface, tropospheric and stratospheric temperature variations since 1958 using representative data sets are shown in the figure2 below.

- Especially consistent is the relative shift to warmer temperatures in the troposphere compared to the surface around 1977, followed by large variations due to ENSO (particularly in 1998) and volcanic events (El Chichon in 1982 and Mt. Pinatubo in 1991).

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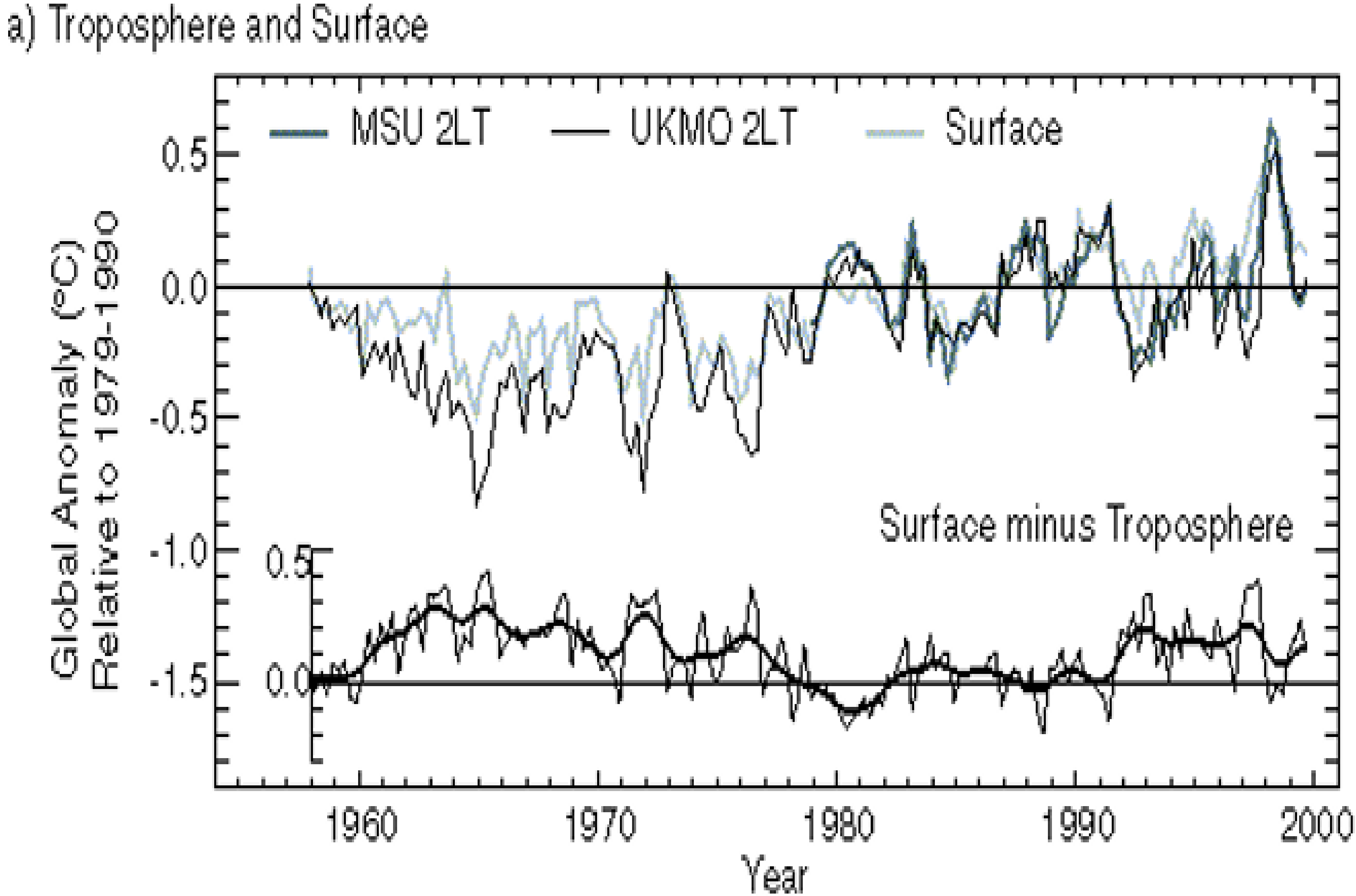

a) Troposphere and Surface
MSU 2LT
UKMO 2LT
Surface
Surface minus Troposphere
Global Anomaly (°C)
Relative to 1979-1990
0.5
0.0
-0.5
-1.0
-1.5
0.5
0.0
1960
1970
1980
1990
2000
Year

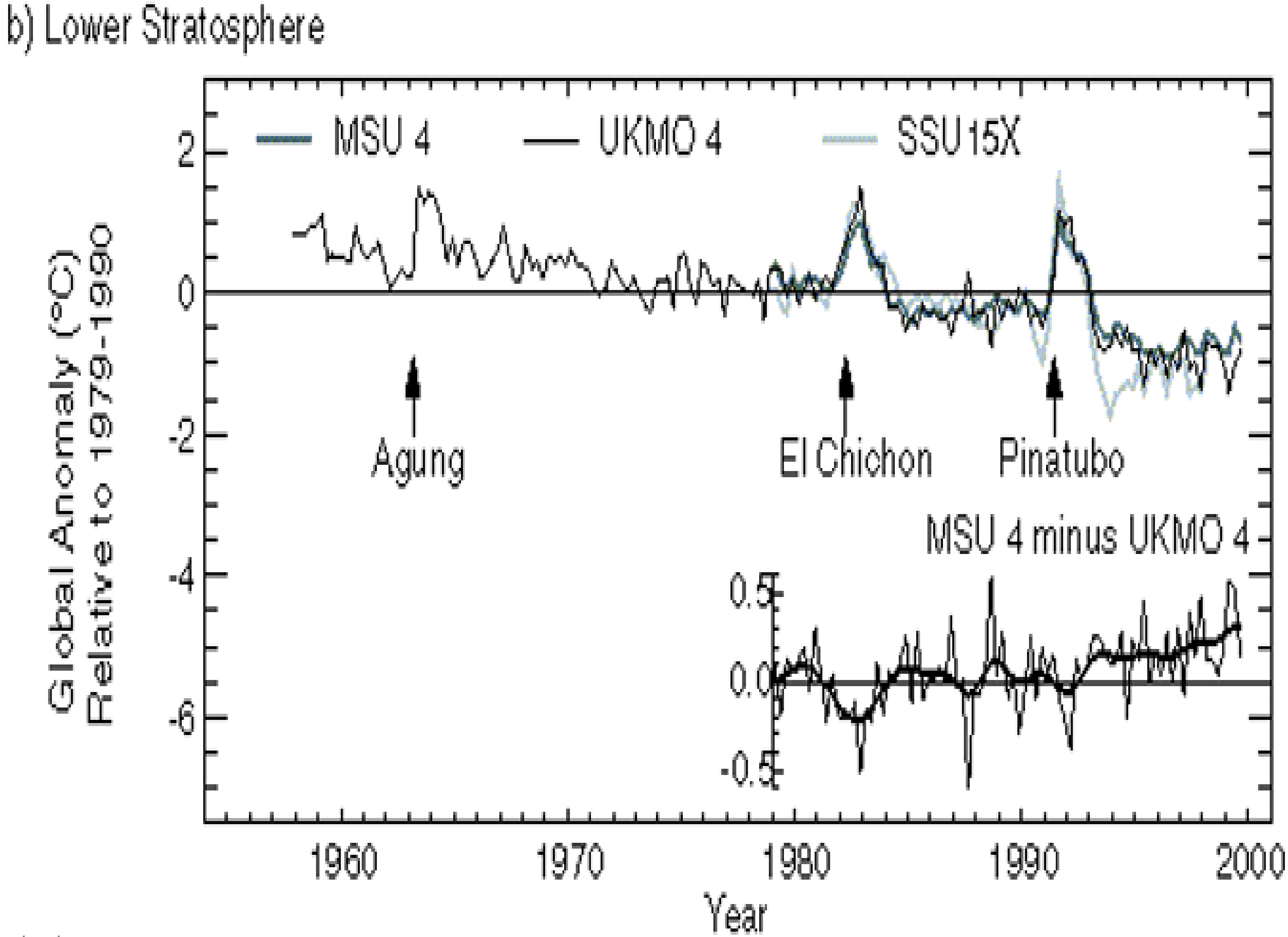
- Global variations and trends in the lower stratosphere are temporally more coherent than in the troposphere (see figure3 below).

- The warming effects due to the volcanic eruptions are clearly evident.

- All stratospheric data sets indicate significant negative trends.

- Blended information for 5 km thick levels in the stratosphere at 45N show a negative trend temperature increasing with height:

Cont.



b) Lower Stratosphere
MSU 4
UKMO 4
SSU 15X
Agung
El Chichon
Pinatubo
MSU 4 minus UKMO 4
0.5
0.0
-0.5
2
0
-2
-4
-6
Global Anomaly (°C)
Relative to 1979-1990
1960
1970
1980
1990
2000
Year

- 0.5C/decade at 15 km, -0.8C/decade at 20-35 km, and -2.5C/decade at 50 km.

- These large, negative trends are consistent with models of the combined effects of

- Ozone depletion and increased concentrations of

- infrared radiating gases,

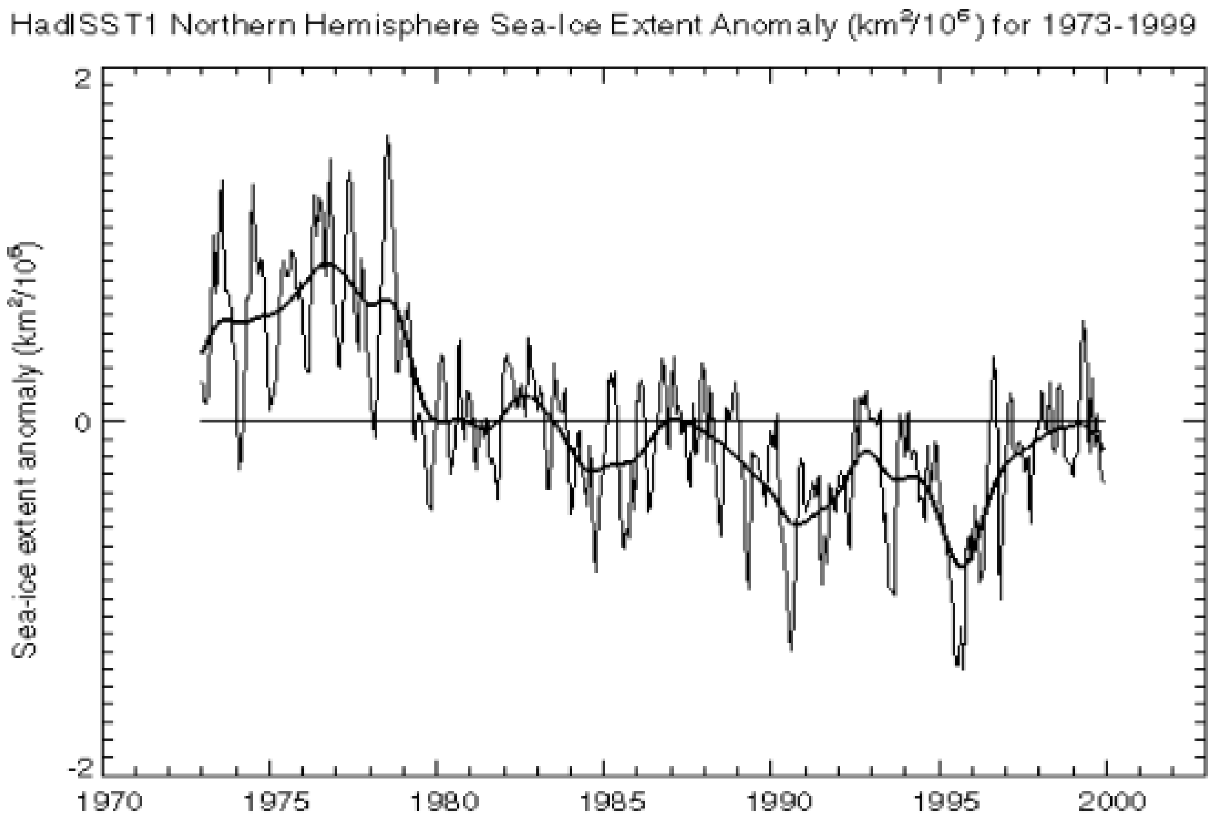
- mainly water vapor and carbon dioxide.

D . Changes in the Cryosphere

- **Snow cover**: Satellite records indicate that NH annual snow cover extent (SCE) has decreased by about 10% since 1966 largely due to decreases in spring and summer since the mid-1980s over both the Eurasian and American continents.
- **Sea-ice extent**: During November 1978 through December 2000, the sea ice extent over the Northern Hemisphere showed a decrease of -2.8% +/- 0.3% per decade (figure below).

Cont.

- Related to the decline in sea ice extent is a decrease in the length of the sea ice season and an increase in the length of the Arctic summer melting season.



- **Lakes and river ice**:

- A recent analysis has been made of trends in very long Northern Hemisphere Lake and river ice records over the 150-year period 1846-1995.
- Ice break-up dates now occur on average about nine days earlier in the spring than at the beginning of the record, and
- autumn freeze-up occurs on average about ten days later.

- **Glaciers:**

- The general picture is one of widespread retreat.
- In a few regions a considerable number of glaciers are currently advancing very likely due to increases in precipitation due to the positive phase of the North Atlantic Oscillation.

summary

- Global surface temperatures have increased between 0.4 and 0.8C since the late 19th century, but most of this increase has occurred in two distinct periods, 1910-45 and since 1976.
- The rate of temperature increase since 1976 has been almost 0.2C per decade.
- New analyses of mean daily maximum and minimum temperatures continue to support a reduction in the diurnal temperature range with minimum temperatures increasing at about twice the rate of maximum temperatures.

- Seasonally, the greatest warming has occurred during the Northern Hemisphere winter and spring, but the disparity of warming between summer and winter has decreased.
- Largest rates of warming continue to be found in the middle and high latitude continental regions of the Northern Hemisphere.
- Analyses of overall temperature trends in the low to mid troposphere and near the surface since 1958 are in good agreement, with a warming of about 0.1C per decade.

- Low to mid troposphere temperatures have warmed in both satellites and weather balloons at a global rate of only about 0.05 C/decade
- This is about 0.15 C/decade less than the rate of temperature increase near the surface since 1979.
- About half of this difference in warming rate is very likely to be due to the combination of differences in spatial coverage and the real physical effects of volcanoes, ENSO.

2. Has the Climate Become Wetter?

- Increasing global surface temperatures are very likely to lead to changes in precipitation and atmospheric moisture because of:
- changes in atmospheric circulation, a more active hydrologic cycle, and increases in the water holding capacity throughout the atmosphere.
- Atmospheric water vapor is also a climatically critical greenhouse gas, and
- an important chemical constituent in the troposphere and stratosphere.

A. Land Precipitation:

- Overall, global land precipitation has increased by about 2% since the beginning of the 20th Century.
- The increase is statistically significant but has neither been spatially nor temporally uniform.

✓ **Mid and High Latitudes:**

- During the 20th Century, annual-zonally averaged precipitation increased between 9% and 16% for the zones 30N to 85N and by about 2 to 5% between 0S to 55S during this time.

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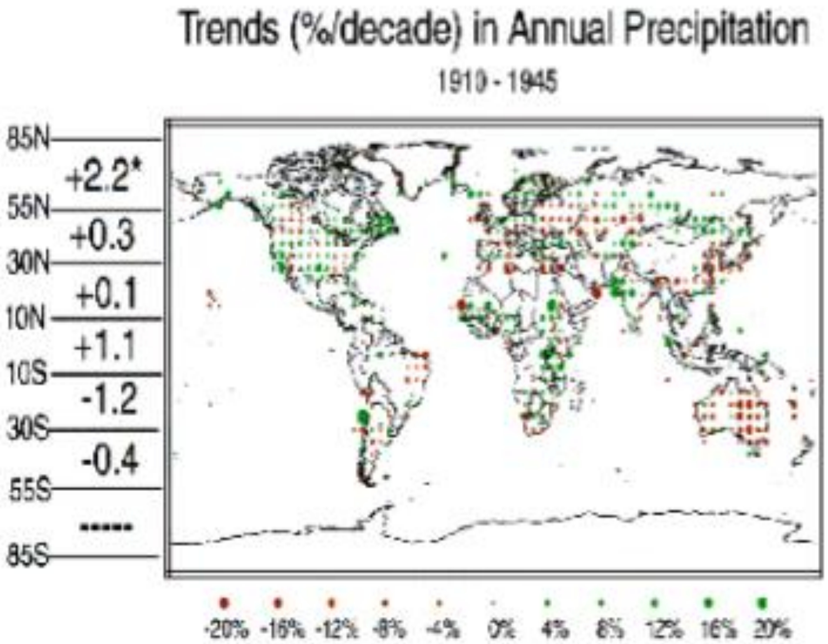
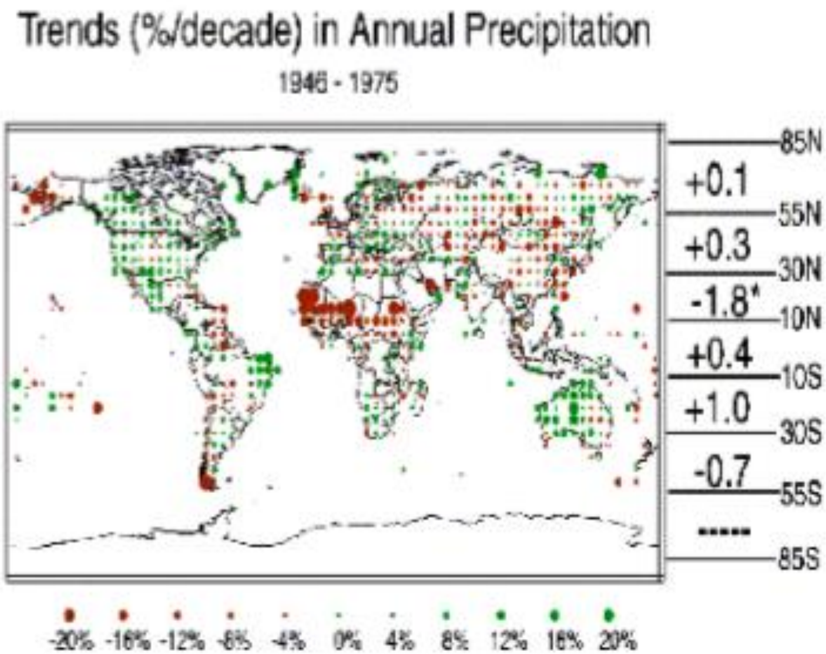
- The figure below shows mostly increasing precipitation in the Northern Hemisphere mid and high latitudes, especially during the autumn and winter, but these increases vary both spatially and temporally.





- **Tropics and Sub-Tropics**:

- The increase of precipitation in the middle and high latitudes contrasts with decreases in the northern subtropics.
- There is little evidence for a long-term trend in Indian monsoonal rainfall but there are multi-decadal variations.
- There has been a pattern of continued aridity since the late 1960s throughout North Africa south of the Sahara.
- The driest period was in the 1980s with some recovery occurring during the 1990s.

B. Ocean Precipitation:

- The strong spatial variability inherent in precipitation requires the use of estimates based on satellite observations for many regions.
- Thus satellite data are essential to infer global changes of precipitation,
- as the oceans account for 70% of the global surface area.

Summary

- Since IPCC-1995, land surface precipitation has continued to increase in the Northern Hemisphere mid and high latitudes;
- over the subtropics, the drying trend has been ameliorated somewhat.
- Where data are available, changes in annual streamflow relate well to changes in total precipitation.

- Little can be said about changes in ocean precipitation as satellite data sets have not yet been adequately tested for time-dependent biases.
- Changes in water vapor have been analyzed most for selected Northern Hemisphere regions, and show an emerging pattern of surface and tropospheric water vapor increases over the past few decades.

3. Are the Atmosphere/Ocean Circulations Changing?

❖ Changes or fluctuations in atmospheric and oceanic circulation are important elements of climate.

- Such circulation changes are the main cause of variations in climate elements on a regional scale.
- El Nino Southern Oscillation (ENSO) and the North Atlantic Oscillation (NAO) are such examples.

- ENSO is the primary global mode of climate variability in the 2-7 year time band.
- El Nino is defined by SST anomalies in the eastern tropical Pacific while the Southern Oscillation (SO) is a measure of the atmospheric circulation response in the Pacific Indian Ocean region.
- Multiproxy-based reconstructions of the behavior of ENSO have recently been attempted for the past few centuries.

- The figure below compares the behavior of two such reconstruction series with recent ENSO behavior.
- The two reconstructions, based on *independent methods* and *partially independent* data, have a linear correlation r=0.64 during the pre-calibration interval.
- While the estimated uncertainties in these reconstructed series are substantial,
- they suggest that the very large 1982-83 and 1997-98 warm events might be outside the range of variability of the past few centuries.

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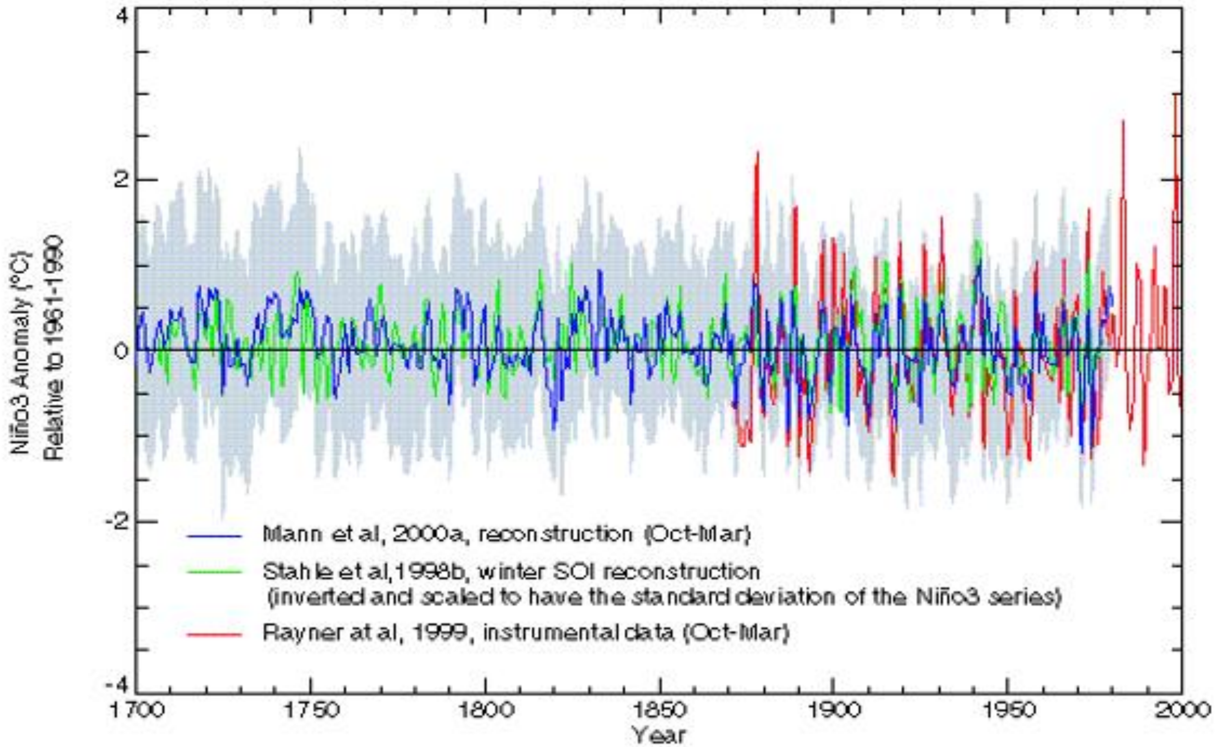


Summary:

- The inter annual variability of ENSO has varied substantially over the last century,
- with notably reduced variability during the period 1920-60, compared to adjacent periods.

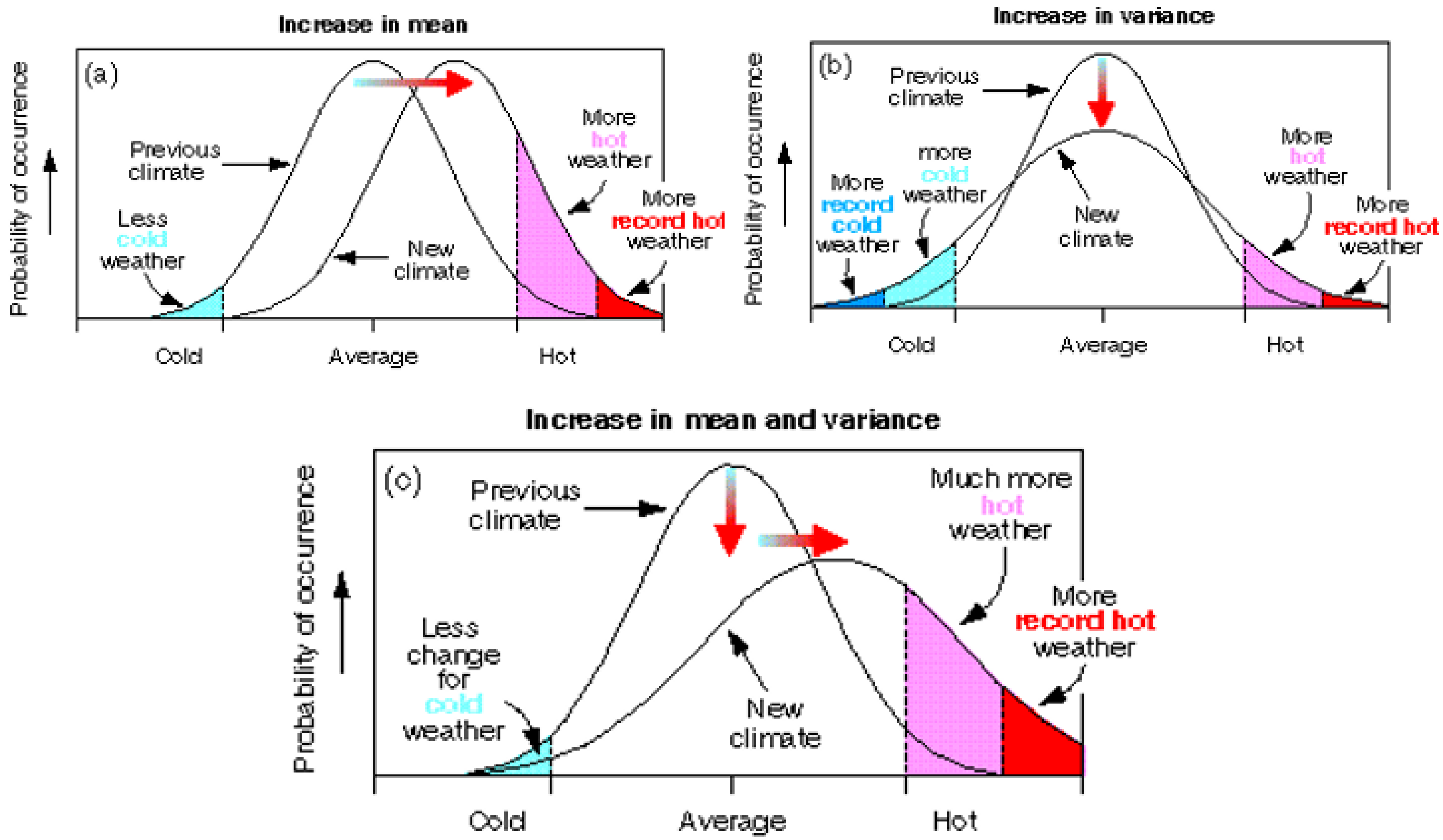
4. Has the Climate Become More Extreme or Variable?

- Changes in climate variability and extremes of weather and climate events have received increased attention in the last few years.

➢ Understanding changes in climate variability and climate extremes is made difficult by interactions between the changes in the mean and variability.

- The distribution of temperatures often resembles a normal distribution.

- An increase in the mean leads to new record high temperatures (Panel A), but a change in the mean does not imply any change in variability.
- For example, in Panel A,(figure below) the range between the hottest and coldest temperatures does not change.
- An increase in variability without a change in the mean implies an increase in the probability of both hot and cold extremes as well as the absolute value of the extremes (Panel B) figure below..



- Increases in the mean have often been found to be amplified in the highest precipitation rates total.

- Increases in both the mean and the variability are also possible (Panel C),
- which affects (in this example) the probability of hot and cold extremes,
- with more frequent hot events with more extreme high temperatures and fewer cold events.
- It is likely that there has been a widespread increase in heavy and extreme precipitation events in regions where total precipitation has increased, e.g., the mid and high latitudes of the Northern Hemisphere.

- In some regions, increases in heavy rainfall have been identified where the total precipitation has decreased or remained constant, such as eastern Asia.
- This is attributed to a decrease in the frequency of precipitation.
- New record high night-time minimum temperatures are lengthening the freeze-free season in many mid and high latitude regions.

Cont.

- Changes in some weather and climate extremes are attributable to human-induced emissions of greenhouse gases.

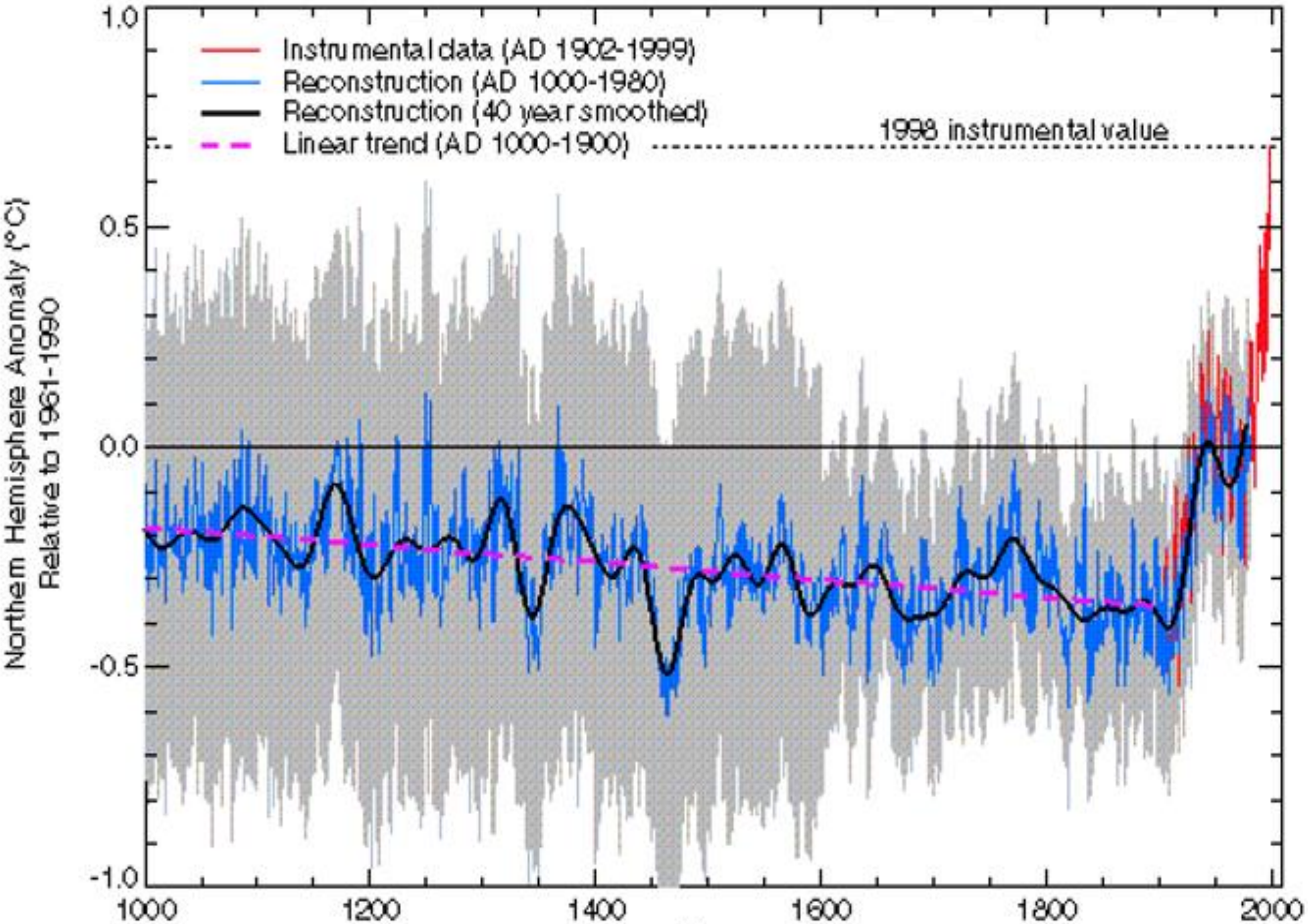
- It is very likely that the human-induced increase in greenhouse gases has contributed to the increase in sea surface temperatures in the hurricane formation regions.

- Climate models are important tools for understanding the causes of observed changes in extremes, as well as projecting future changes.

5. Is the 20th Century Warming Unusual?

- To determine whether 20th century warming is unusual, it is essential to place it in the context of longer-term climate variability.
- Owing to the sparseness of instrumental climate records prior to the 20th century (especially prior to the mid 19th century),estimates of global climate variability during past centuries must often rely upon indirect proxy indicators - natural or human documentary archives that record past climate variations,

- but must be calibrated against instrumental data for a meaningful climate interpretation.



Summary:

- The warming of the 20th century has a convincing global signature and is **consistent** with the **paleoclimate** evidence that the rate and

- magnitude of global or hemispheric surface 20th Century warming is very likely to have been the largest of the millennium,

- with the 1990s and 1998 likely to have been the warmest decade and year, respectively, in the Northern Hemisphere.

6. Are the Observed Trends Internally Consistent?

- It is very important to compare trends in the various indicators to see if a physically consistent picture emerges as this will critically affect the final assessment of our confidence in any such changes.

- A number of qualitative consistencies among the various indicators of climate change have increased the historical climate record:

- The two figures below summarize the changes in various temperature and hydrological indicators respectively, and provide a measure of confidence about each change.

- Temperature over the land and oceans, with two estimates for the latter, are measured and adjusted independently, yet all three show quite consistent increasing trends (0.51 to 0.61 C/Century) over the 20th Century.
- The nearly worldwide decrease in mountain glacier extent and mass is consistent with 20th century global temperature increases.
- A few recent exceptions in maritime areas have been affected by atmospheric circulation variations and related precipitation increases.

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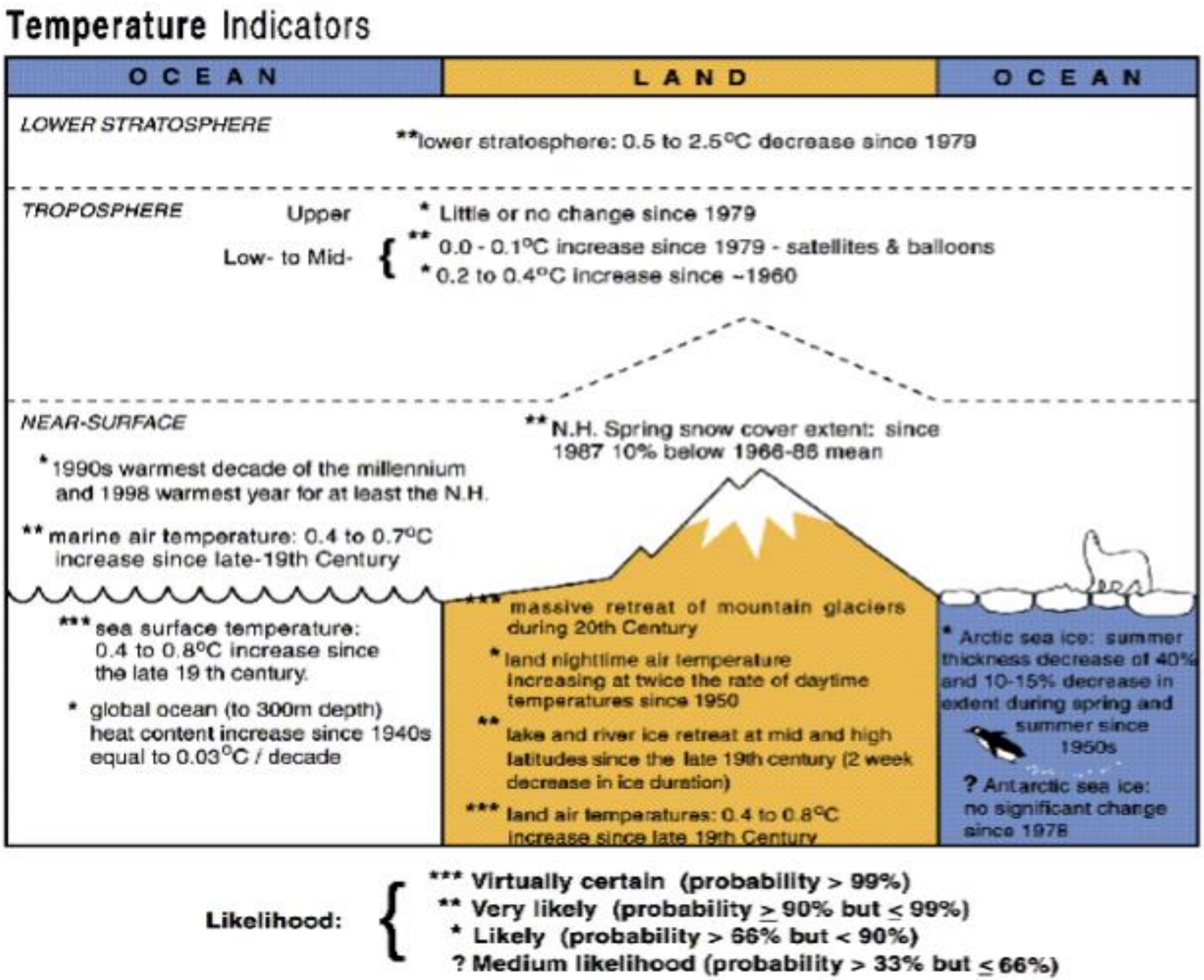

Temperature Indicators
OCEAN
LAND
OCEAN
LOWER STRATOSPHERE
**lower stratosphere: 0.5 to 2.5°C decrease since 1979
TROPOSPHERE
Upper
* Little or no change since 1979
Low- to Mid-
** 0.0 - 0.1°C increase since 1979 - satellites & balloons
* 0.2 to 0.4°C increase since ~1960
NEAR-SURFACE
** N.H. Spring snow cover extent: since 1987 10% below 1966-86 mean
* 1990s warmest decade of the millennium and 1998 warmest year for at least the N.H.
** marine air temperature: 0.4 to 0.7°C increase since late-19th Century
*** sea surface temperature: 0.4 to 0.8°C increase since the late 19 th century.
* global ocean (to 300m depth) heat content increase since 1940s equal to 0.03°C / decade
*** massive retreat of mountain glaciers during 20th Century
* land nighttime air temperature increasing at twice the rate of daytime temperatures since 1950
** lake and river ice retreat at mid and high latitudes since the late 19th century (2 week decrease in ice duration)
*** land air temperatures: 0.4 to 0.8°C increase since late 19th Century
* Arctic sea ice: summer thickness decrease of 40% and 10-15% decrease in extent during spring and summer since 1950s
? Antarctic sea ice: no significant change since 1978
Likelihood:
*** Virtually certain (probability > 99%)
** Very likely (probability ≥ 90% but ≤ 99%)
* Likely (probability > 66% but < 90%)
? Medium likelihood (probability > 33% but ≤ 66%)

Cont.

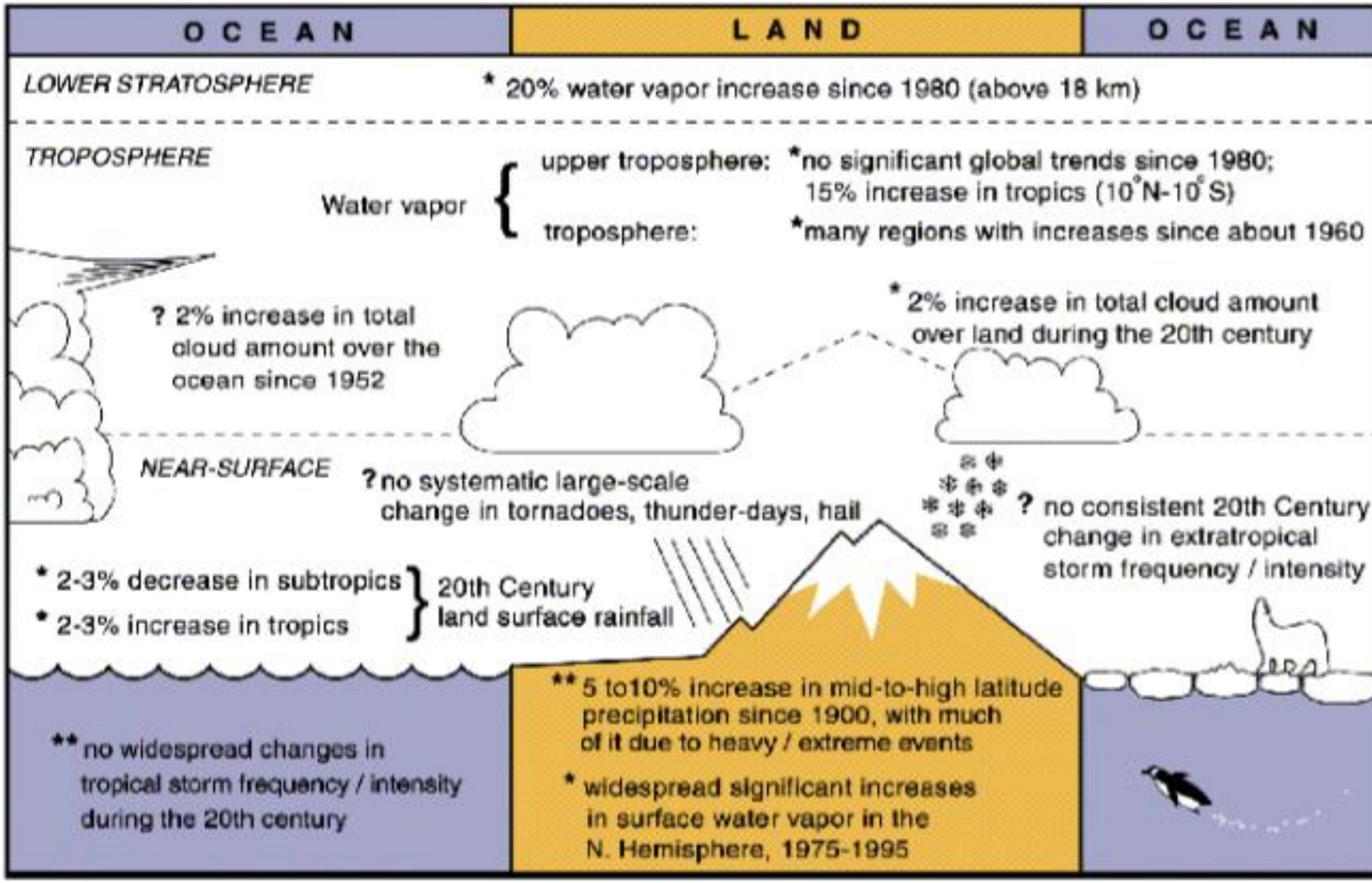
- Though less certain, substantial proxy evidence points to the exceptional warmth of the late 20th Century relative to the last 1000 years.
- The 1990s are likely to have been the warmest decade of the past 1000 years over the Northern Hemisphere as a whole.
- Trends of world-wide land surface temperatures (as opposed to combined land and ocean temperatures) derived from weather stations are in close agreement with satellite derived temperatures of the low-to-mid troposphere.

- Decreases in spring snow cover extent since the 1960s and in the duration of lake and river ice over at least the last century, relate well to increases in Northern Hemispheric surface air temperatures.

- The systematic decrease of spring and summer Arctic sea-ice extent in recent decades is broadly consistent with increases of temperature over most of the adjacent land and ocean.

Cont.

Hydrological and Storm-Related Indicators



Likelihood:
- *** Virtually certain (probability > 99%)
- ** Very likely (probability ≥ 90% but ≤ 99%)
- * Likely (probability > 66% but < 90%)
- ? Medium likelihood (probability > 33% but ≤ 66%)

- The increases in lower tropospheric water vapor and temperature since the mid 1970s are qualitatively consistent with an **enhanced hydrologic cycle**.
- This is in turn consistent with a greater fraction of precipitation being delivered from extreme and heavy precipitation events,
- primarily in areas with increasing precipitation, e.g., middle and high latitudes of the Northern Hemisphere.

- Where data are available, changes in precipitation generally correspond with consistent changes in streamflow and soil moisture.

- Summary: We conclude that the variations and trends of the examined indicators consistently and very strongly support an increasing global surface temperature over at least the last century,

- though substantial shorter term global and regional **deviations** from this warming trend are very likely to have occurred.

Prediction and Modeling of Climate Changes

- In general, climate changes cannot be predicted simply by using observations and statistics.
- They are too complex or go well beyond conditions ever experienced before.
- For the most detailed and complicated projections, scientists use computer models of the climate system called **numerical models**.

- These models are based on physical principles, expressed as **mathematical formulas** and evaluated using computers.

❖ Global climate models attempt to include the atmospheric circulation, oceanic circulation, land surface processes, sea ice, and all other processes.

- They divide the globe into three-dimensional grids and perform calculations to represent what is typical within each grid cell.

- For climate models, owing to limitations in today's computers, these grid cells are quite large
- —typically 250 kilometers in the horizontal dimension and a kilometer in the vertical dimension.
- As a result, many physical processes can only be crudely represented by their average effects.

Climate Predictions

- The climate is expected to change because of the increases in greenhouse gases and aerosols, but exactly how it will change depends a lot on our assumptions concerning future human actions.
- When developing countries industrialize, they burn more fossil fuels, generate more electricity, and create industries,
- most of which produce some form of pollution
- Developed countries are currently the largest sources of pollution and greenhouse gases.

- Because future changes are not certain, climate models are used to depict various possible "scenarios."
- These are not really predictions but projections of what could happen.
- If a projection indicates that very adverse conditions could happen, policy actions could be taken to try to change the outcome.

- For assessing impacts, what are most needed are projections of local climate change.
- However, producing such projections represents a considerable challenge.
- Climate predictions are especially difficult regionally because of the large inherent natural variability on regional scales.

Impacts of Weather and Climate Changes on Human Activities

- Human activities and many sectors of economic activity depend on weather and climate in different ways.
- Some rely on average conditions.
- Others are sensitive to extremes.
- Yet others depend upon variety and so weather sequences can be important.

Cont.

- Aside from choosing the climate by selecting the right location,
- there are other ways we can attempt to cope with climate change and its consequences for agriculture, fisheries, and so forth.

Atmospheric Teleconnections

- The term "teleconnection pattern" refers to a recurring and persistent, large-scale pattern of pressure and circulation anomalies that span vast geographical areas.
- Teleconnection patterns are also referred to as preferred modes of low-frequency (or long time scale) variability.

Cont.

- Although these patterns typically last for several weeks to several months,
- They can sometimes be prominent for several consecutive years,
- thus reflecting an important part of both the interannual and interdecadal variability of the atmospheric circulation.

Cont.

- Teleconnections are a way of summarizing atmospheric patterns and interactions
- as well as describing the transport processes for heat, moisture and momentum- the ‘fuels’ of the Earth’s climate.
- They are important to understand as vectors of climate variability that derive conditions affecting land and ocean.

Cont.

- They also provide a way of integrating and quantifying climate variability in to a small set of indices.
- Finally, recognizing teleconnection patterns as they occur and evolve allows better understanding of reginal climate change,
- assessments at the ecosystem scale and the likely consequences to marine populations.

Cont.

- Atmospheric teleconnections transmit climate signals over very long distances to remote ecosystems,
- where local environmental conditions and physiography modify their impacts on the biology.

Thank You for Attention