Chapter 6:Oscillation and Teleconnection

Main objectives

At the end of this chapter, students expect to know the following concepts

- **Different types of waves in the atmosphere that helps atmospheric circulation**
- **ENSO and its process (ElNino,LaNina and Normal condition)**
- **The concepts of teleconnection and climate variability**

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Introduction: Sound wave, Gravity wave and Rossby wave

The atmosphere exhibits many wavelike motions with a variety of space- and timescales ranging from slow-moving planetary scale waves to much faster and smaller gravity waves, each playing important roles in the behavior of the stratosphere.

It has long been known that conditions in the stratosphere are controlled by wave driving from the troposphere

What is a “wave”?

A wave is a disturbance or variation which travels through a medium

The medium through which the wave travels may experience some local oscillations as the wave passes, but the particles in the medium do not travel with the wave.

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Basic Properties of Waves

Aphysicalrestoringforceandamediumforpropagationarethetwofundamental elements of all wave motion in solids, liquids, and gases, including atmospheric waves, oceanic waves, sound (acoustic) waves, wind-induced waves, and seismic waves.

Wave motions may be characterized by several fundamental properties, such as wave frequency, wave number, phase speed, group velocity, and dispersion relationship (which relates the wave frequency to the wave number)

The period of oscillation(τ) of a wave determines the wave frequency while the horizontal and vertical spatial scales of a wave determines its horizontal and vertical wave numbers

($k=2\pi/Lx$;$l=2\pi/Ly$;$m=2\pi/Lz$), where k, l, andm are wave numbersand Lx, Ly, andLz are wavelengths in the zonal (x), meridional (y), and vertical (z) directions, respectively.

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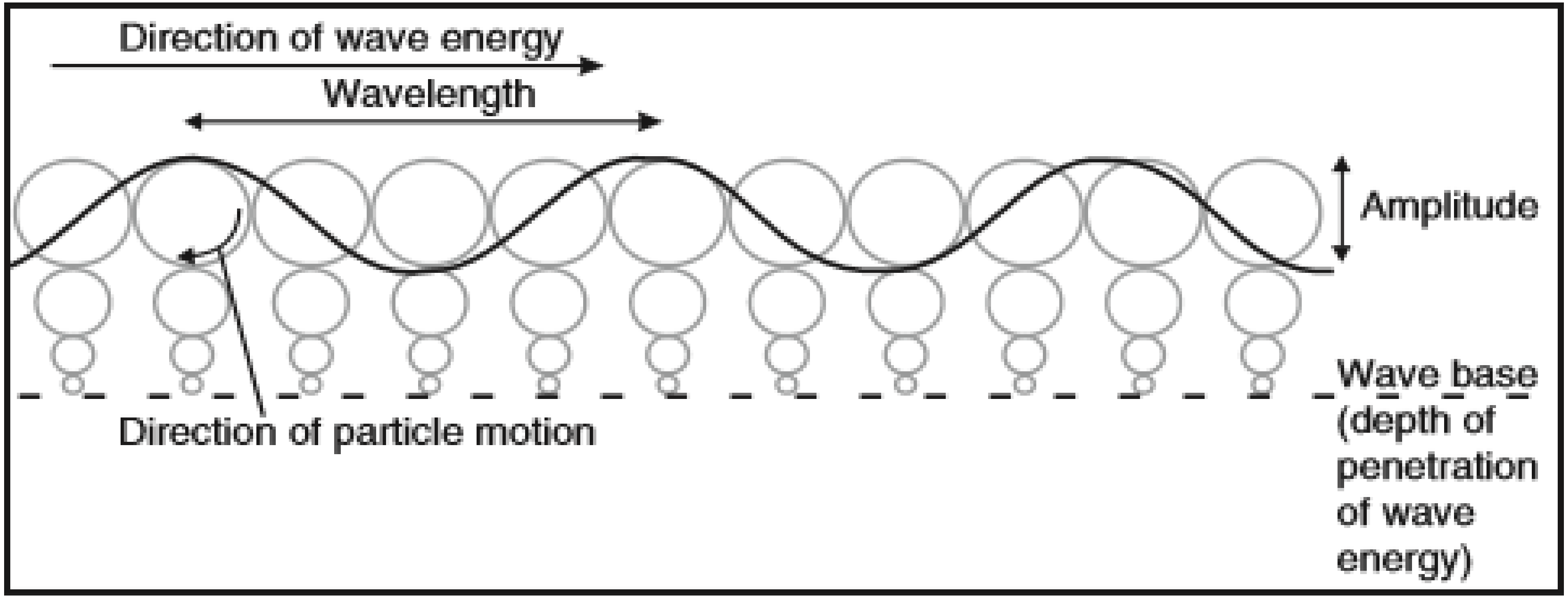
A typical wave motion is represented



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Waves in the Atmosphere

There exist four basic modes of atmospheric wave propagation that are of interest in atmospheric science. The four types are:

Acoustic waves – speed controlled by temperature

Gravity waves – speed controlled by stability

Inertial waves – speed controlled by Coriolis parameter

Rossby waves – speed controlled by latitudinal variation of Coriolis parameter

Waves in the stratosphere and troposphere include gravity (buoyancy) waves, Rossby waves, inertio-gravity waves, forced stationary planetary waves, free traveling planetary waves, equatorialwaves, and mid latitude gravity waves.

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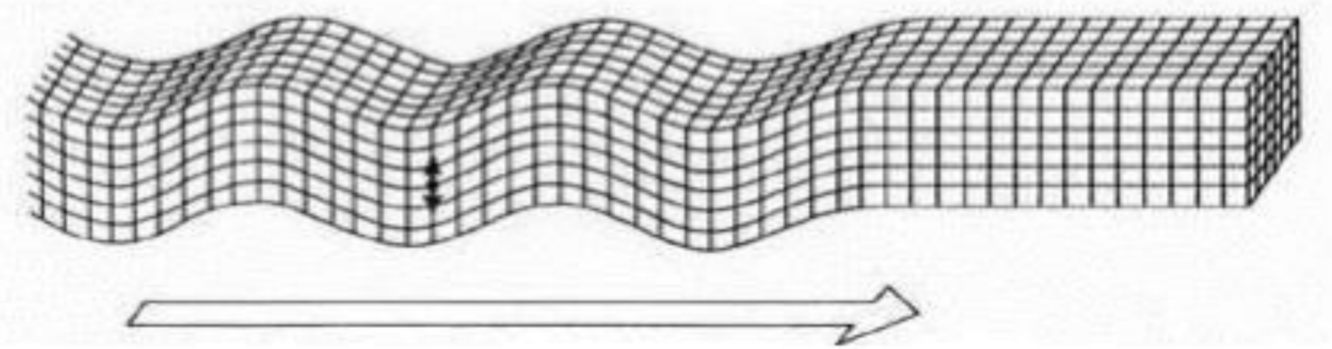
Gravity wave

- Gravity wave is generated by a perturbation in the density field.
- It is a transverse wave and oscillate in a direction normal to the direction of propagation.
- The restoring force is pull of gravity of the earth.



- Transverse waves on a string are best example of gravity wave.
- The string is displaced up and down as the wave travels from left to right, but the string itself

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Shallow water gravity waves

Shallow water gravity waves can exist only if the fluid has a free surface or an internal density discontinuity.

Internal gravity (buoyancy) waves

Atmospheric gravity waves can only exist when the atmosphere is stably stratified so that a fluid parcel displaced vertically will undergo buoyancy oscillations.

Because the buoyancy force is the restoring force responsible for gravity waves, the term buoyancy wave is actually more appropriate as a name for these waves. However, in this text we will generally use the traditional name gravity wave. The oceanic analogue of this buoyancy waves is said to be internal waves.

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Internal gravity waves are responsible for the occurrence of mountain lee waves. They also are believed to be an important mechanism for transporting energy and momentum into the middle atmosphere, and are often associated with the formation of clear air turbulence (CAT).

Topographic waves

This is formed when air with mean wind speed u is forced to flow over a sinusoidal pattern of ridges under statically stable conditions, individual air parcels are alternately displaced upward and downward from their equilibrium levels and will thus undergo buoyancy oscillations as they move across the ridges.

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ROSSBY WAVES

Rossby waves are planetary-scalewaves which are most important for stratospheric transport. Rossby waves develop where there are large-scale variations in potential vorticity, all of whose components (relative vorticity, stretching, and planetary vorticity) can be active.

These waves are also referred to as rotational waves and, on the gravest dimensions, planetary waves. The restoring force for Rossby waves is provided by the variation with latitude of the Coriolis force. It links them to the Earth’s rotation.

The Rossby waves are the one which are of greater meteorological interest because of their association with synoptic scale weather. The wave type that is of most importance for large-scale meteorological processes is the Rossby wave, or planetary wave

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Rossby waves can be either stationary planetary waves that are forced by orography or traveling free waves, in which the stationary planetary waves are the most important.

The wave forcing is the is entropic gradient of potential vorticity(i.e.,the change of the Coriolis parameter f with latitude).

Steady planetary waves conserve potential vorticity, just as steady buoyancy waves conserve potential temperature.

Propagation characteristics of Rossby waves in the atmosphere

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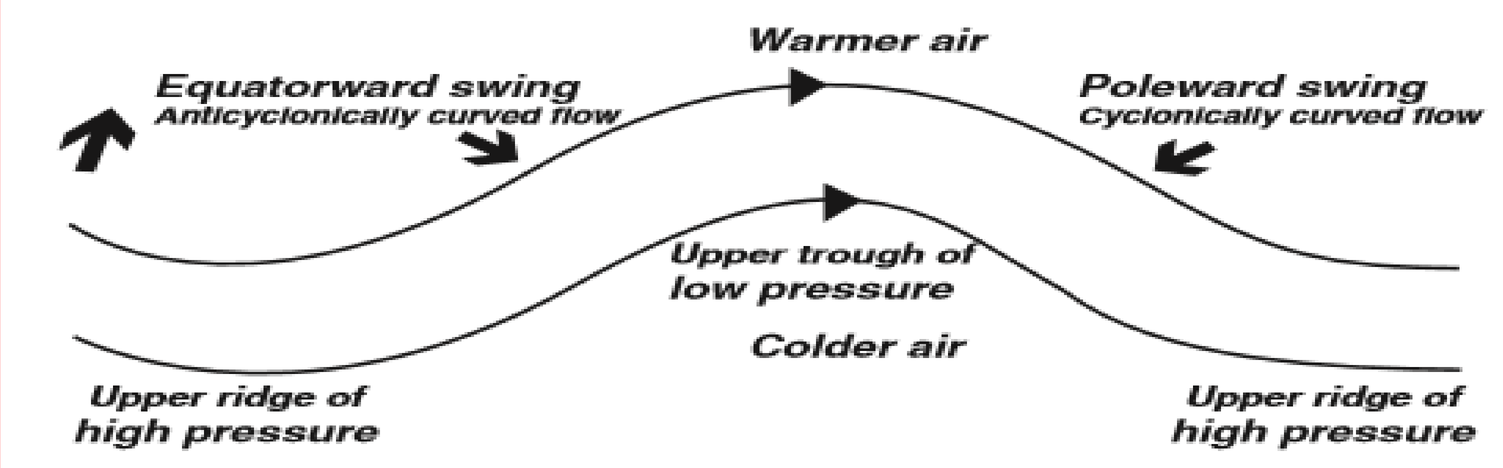
Planetarywavespropagatewestwardrelativetothemeanwind.Rossbywavesare dispersive. The phase speeds increase rapidly with decreasing wave number (and thus increasing wavelength). Waves that are generated by orography are fixed to that location:



Propagation characteristics of Rossby waves in the atmosphere

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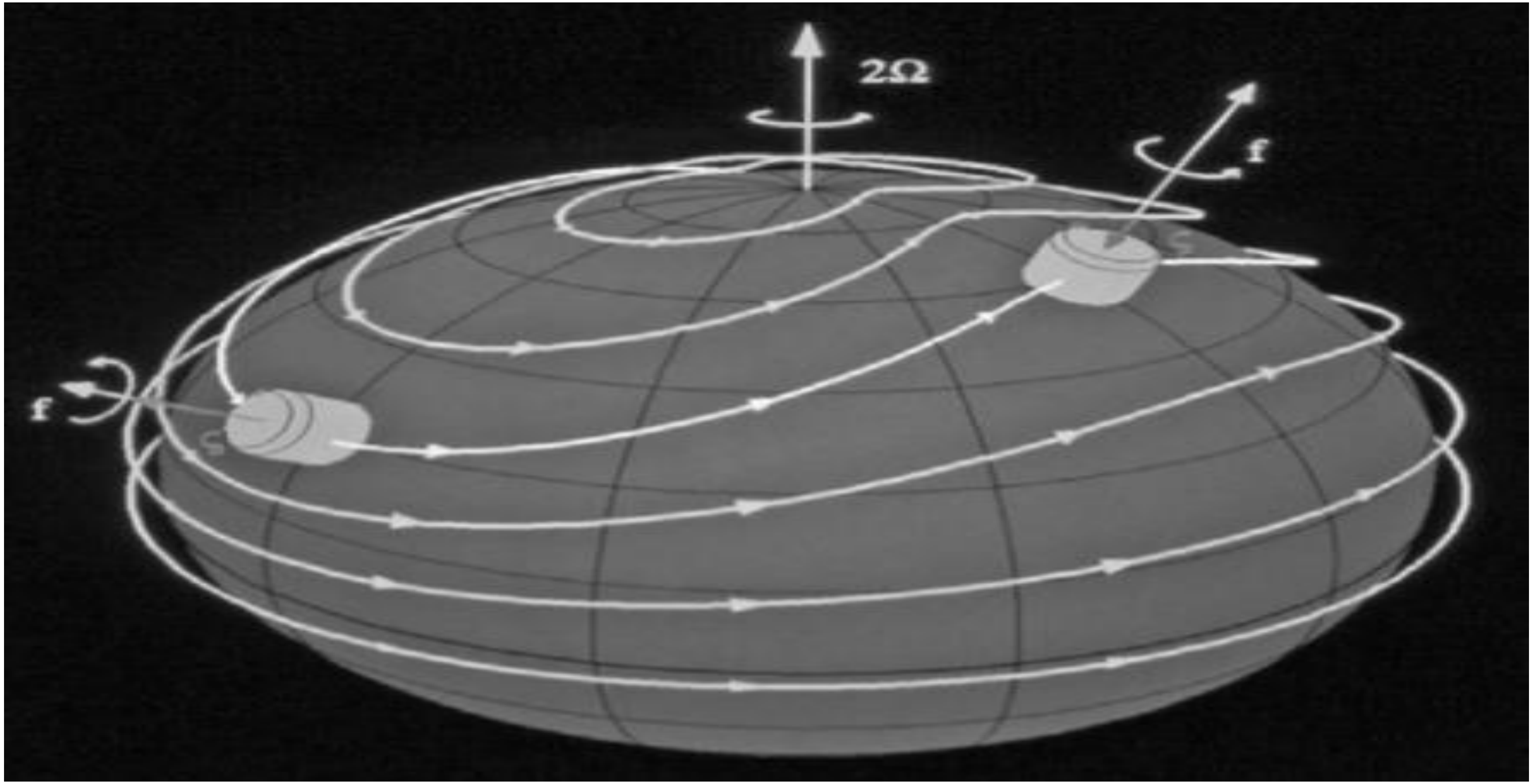

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El Niño-Southern Oscillation (ENSO)

ENSO is a large scale, low frequency oscillation in the equatorial atmosphere and ocean. It occurs every 2 to 7 years

- Found in varying intensity over all the global oceans
- However, it develops most strongly in the equatorial Pacific ocean.
- Because of a pronounced zonal anomaly in ocean surface temperature between the eastern and western parts of the equatorial pacific ocean
- It influence events at higher latitudes through the tropical Hadley Circulation
- Southern Oscillation: a seesaw-type oscillation in atmospheric surface pressure between the eastern and western parts of the tropical oceans , specifically in the Pacific.

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Physical ENSO processes

A. El Niño-Southern Oscillation (ENSO)

El Niño: episodic atmospheric and oceanic phenomenon of the equatorial Pacific

1. particularly prominent along the west coast of South America

2. major event 1982-83 impacts;

a. droughts, floods, and destructive cyclones in parts of the Pacific

b. ocean temperature 14oF above normal in equatorial Pacific

c. massive die-offs of fish, seabirds and coral d. cost 1500 human deaths and $9 billion

3. strong El Niño 1997-1998 a. cost: 2,100 human deaths; $30 billion b. U.S. impacts:

1) severe blizzards in Midwest
2) 2) devastating tornadoes in southeast 3) heavy rainfall in California

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B. Normal Pattern

1. wind and pressure patterns off west coast of South America are dominated by subtropical high and trade winds that flow from east to west across the Pacific

2. airflow drags warm surface water westward

upwelling of cold nutrient-rich ocean water into the Peru current and elevated sea level in Indonesia

3. persistent low pressure and convective thunderstorms develop in ITCZ around Indonesia and northern Australia, producing high annual rainfall

Walker Circulation: rising air at ITCZ in western Pacific flows eastward in upper atmosphere antitrade winds, eventually subsiding along the eastern side of the Pacific Ocean

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C. El Niño Pattern

1. Southern Oscillation (ENSO: El Niño-Southern Oscillation): reversal of pressure in which high pressure develops over Australia and low pressure to the east near Tahiti
2. Kelvin waves, slow moving bulges of warm water, travel east along the equator to the coast of South America → warm water pools and rising sea level
3. upwelling no longer brings cold water to surface
4. high pressure and southeast trade winds weaken or reverse

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opposite of El Niño: unusually cold temperatures off South America coast and strong trade winds

southwest US drier than usual

E. Causes of ENSO

1.unclear whether the change in ocean temperature or the change in pressure and wind comes first: which is the trigger?

2.effects not completely predictable

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F. Teleconnections

1. clear coupling between atmospheric and oceanic circulations

2. teleconnections: coupling of weather and oceanic events in one part of the world with those in another

3. El Niño occurs on average every 2-7 years

4. becoming more frequent and progressively warmer: 1997-97 event strongest El Niño in last 200 years – speculation that global warming is impacting it

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An example of Tele-connection

El Niño in the Eastern Tropical Paci

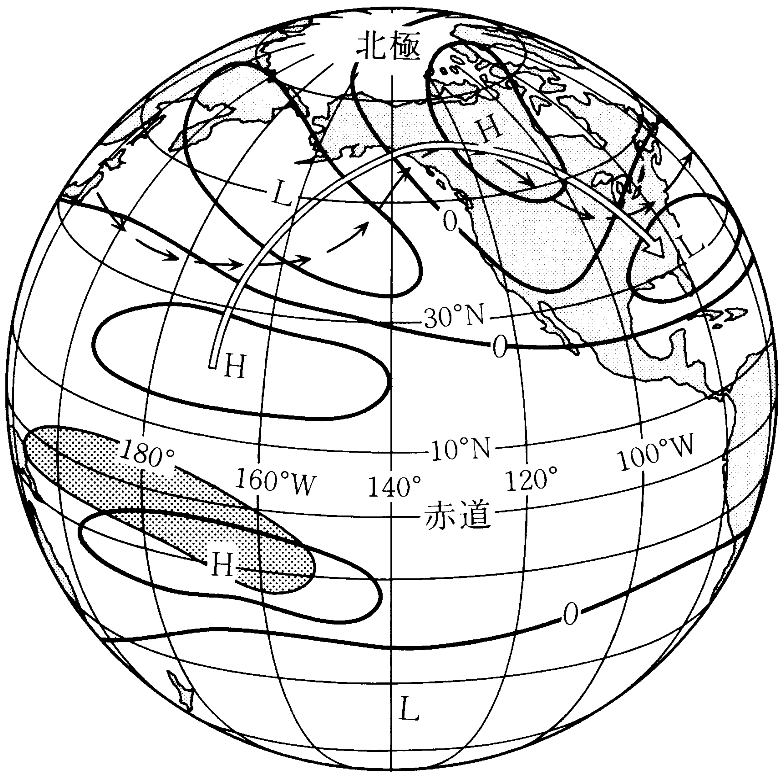
-----> Convective area shifts towards
mid- and eastern Pacific

-----> High is formed

-----> Strengthened Aleutian Low

-----> High over Rocky Mts.

-----> Low in the eastern USA



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- El Niño-Southern Oscillation (ENSO) – increases in sea surface temperatures (SST) in the eastern and central Pacific, over characteristic periods of 2–7 years, for durations typically of a few months or more, also linked to cooler La Niña episodes
- Madden Julian Oscillation (MJO) – intraseasonal patterns of atmospheric circulation, and enhanced and suppressed tropical rainfall, which progress eastwards from the Indian Ocean into the western Pacific Ocean and, to a lesser extent the Atlantic Ocean, with a timescale variously estimated to be 40–50 or 30–60 days, but with strong variations from year to year (e.g. Madden and Julian 1994)
- Inter Tropical Convergence Zone (ITCZ) – the convergence zone between the trade winds in the northern and southern hemispheres, which results in an uplift of air and generation of heavy convective rainfall and thunderstorms around the equator, and which moves north and south with the progression of the seasons
- Monsoon – linked to the seasonal variations in prevailing winds driven by temperature (and hence air pressure) differences between the oceans and land surfaces, resulting in increased rainfall during the period when winds are on-shore, and affecting many regions where large land masses are adjacent to the ocean (e.g. in Africa, the Americas, and particularly in Asia)
- North Atlantic Oscillation (NAO) – a mainly atmospheric phenomenon, although linked to ocean surface conditions, which appears as an oscillation which can persist for several years in the relative positions and strengths of the permanent high pressure region around the subtropical Atlantic (the Azores High) and the low pressure in Arctic regions (the Iceland Low)

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Quasi-biennial Oscillation (QBO)

QBO: a regular alternation of the zonally symmetric easterlies and westerlies

- Occurs in the mean zonal winds of the equatorial stratosphere

The quasi-biennial oscillation (QBO) is a quasi-periodic oscillation of the equatorial zonal wind between easterlies and westerlies in the tropical stratosphere with a mean period of oscillation ~ 26 months (20 to 36 months).

The alternating wind regimes develop at the top of the lower stratosphere and propagate downwards at about 1 km (0.6 mi) per month until they are dissipated at the tropical tropopause of the westerlies.

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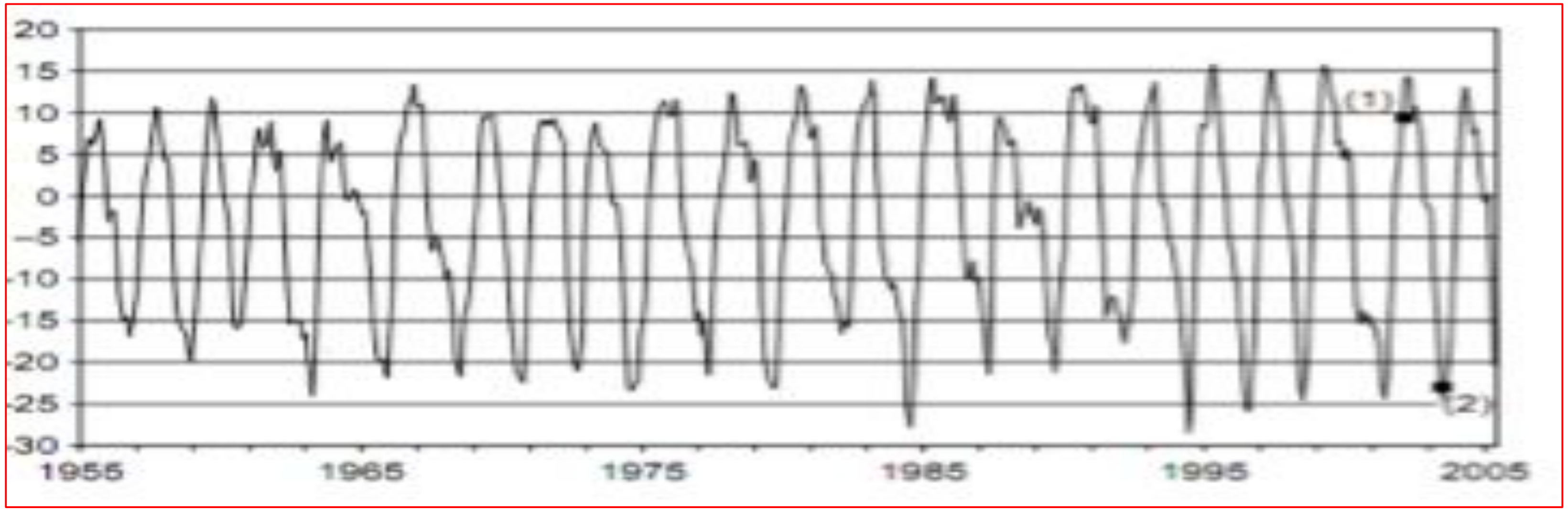
The amplitude of the easterly phase is about twice as strong as that of the westerly phase. At the top of the vertical QBO domain, easterlies dominate, while at the bottom, westerlies are more likely to be found.



The zonal mean zonal wind at equator, at an altitude corresponding to 30 hpa level, from 1995 to 2005,showing the QBO between easterlies (negative) and westerlies (positive)

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Mechanism

- The equatorially trapped Kelvin wave provide s the westerly momentum.
- Combined Rossby gravity wave provide the easterly momentum.
- Stratospheric ozone variations are also important for the generation and maintenance of QBO.

Importance

- Affects rainfall pattern in Sahel.
- Prediction of El Niño events and monsoon strength.
- Affects the frequency of tropical cyclone s, in the Pacific, Atlantic and Indian ocean

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Madden-Julian oscillation (MJO)

Named after co-discoverer, Madden and Julian (1971, 1972).

Madden and Julian discovered MJO based on 10year daily analysis of rawinosonde data for Canton island (3oS,172oW)

MJO is a broad band intera-seasonal tropical oscillation

Structure of MJO

(a)Wind

- Peaks in the variance spectra of the zonal wind were found to be strong in the lower troposphere,
- weak or non-existent in the 700–400mb layer, and
- strong again in the upper troposphere.

(b) Pressure

- The spectrum of station pressure showed a peak in this frequency range(0.0245 -0.010day-1).
- The oscillation is in phase with the lower tropospheric zonal wind oscillation

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(c)Temperature

- The tropospheric temperature exhibited similar peak with the station pressure oscillation
- Positive station pressure anomalies associated with negative temperature anomalies throughout the troposphere

Properties:

- The MJO is of global scale but restricted to tropics.
- Resulted from an east ward movement of large scale circulation cell oriented in the zonal plane.
- Accompanied by strong fluctuations of deep convection.
- The energy source for this oscillation is the large scale convection associated with the seasonally migrating Inter tropical convergent zone (ITCZ).

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Importance:

- A major contributor to intera seasonal weather variability in equatorial region from east Africa eastward to the central pacific.
- The meridional v-component of this wind transports mass (moisture) from the convective region of the summer hemisphere ITCZ to the winter hemisphere

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Impact of ENSO on Ethiopia rainfall

ENSO affects both the JJAS (Kiremit) and FMAM (Belg) rainfall of Ethiopia. The SST over the eastern pacific is related to Kiremit rainfall (Gissila,2004;Korecha and Barnston,2007 and Segele and Lamb,2005).

The contemporaneous correlation between SST and rainfall shows that for all regions of Ethiopia, except South and South Eastern (which is dry for this time of the year) the correlation values are highest, suggesting a strong link with ENSO (Diro et al.,2011).

- The effect of a warm equatorial eastern pacific (El Niño) depends on the season of occurrence and region of Ethiopia.
- El Niño in the previous winter is associated with excess Kiremit rainfall.
- Whereas El Niño in the contemporaneous summer is associated with deficit Kiremit rainfall.
- For the Northwest , El Niño is always associated with deficit Kiremit rainfalls irrespective of season of occurrence.

Thank You

End of the course