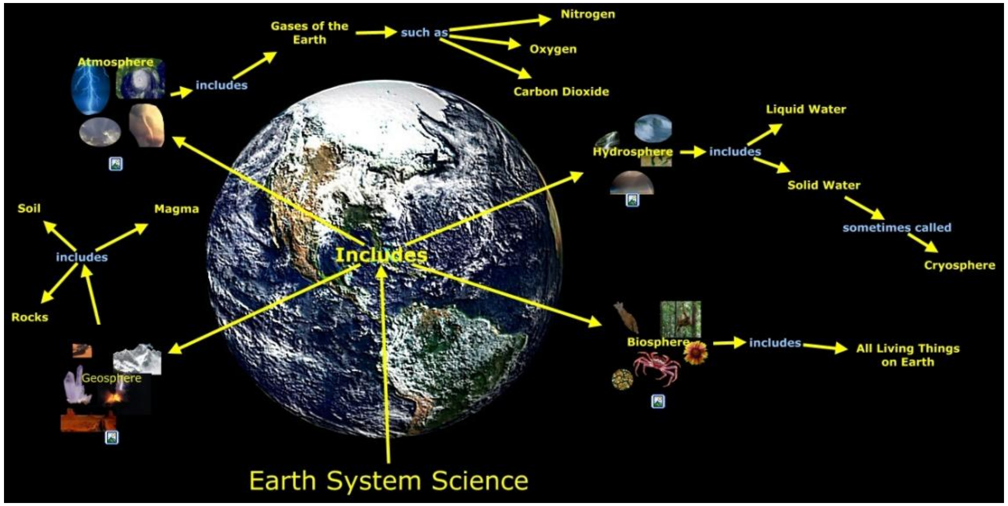


Lecture

The Ocean – Atmosphere – Land system

Known Atmospheric Oscillations

Lecturer: **Dr Evangelos GERASOPOULOS**
Research Director IERSD/NOA

Lecture contents

- Milankovich cycles
- The 11 year cycle of solar activity
- El Niño Southern Oscillation (ENSO)
- La Niña
- North Atlantic Oscillation (NAO)
- Quasi Biennial Oscillation (QBO)

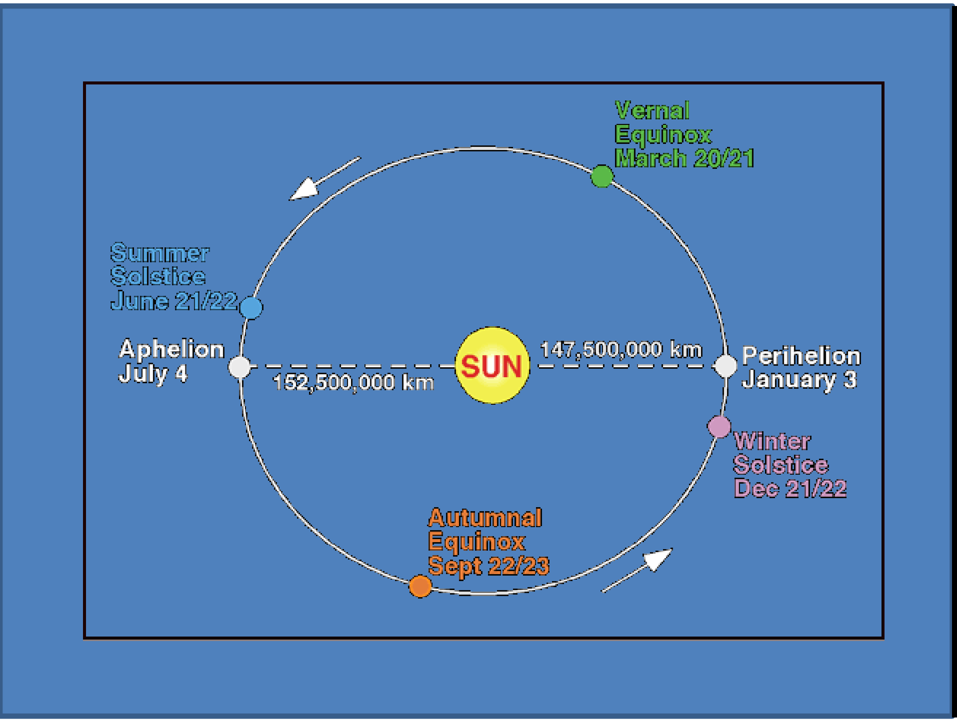
When time matters!

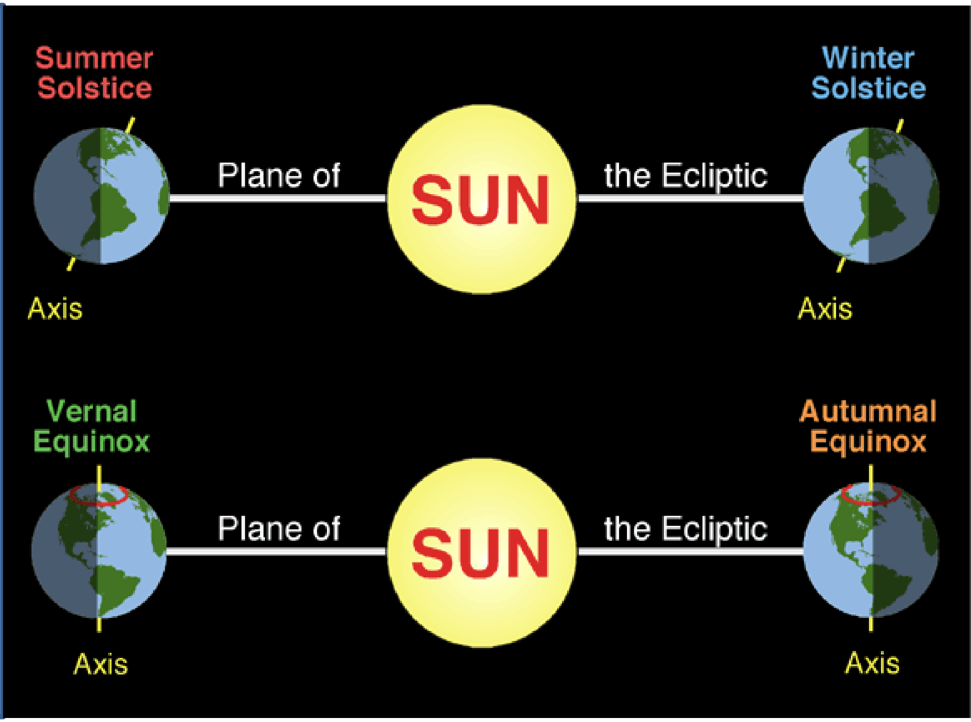
List of known or proposed climatic oscillations:

- the *glacial periods* of the last ice age – period around 100 000 years
- the *North African climate cycles* – tens of thousands of years
- the *Atlantic Multidecadal Oscillation* – around 50 to 70 years, but unpredictable
- the *El Niño Southern Oscillation* – 2 to 7 years
- the *Pacific decadal oscillation* – 8 to 12 years? (not clear)
- the *Interdecadal Pacific Oscillation* – 15 to 30 years? (not clear)
- the *Arctic oscillation* – no particular periodicity
- the *North Atlantic Oscillation* – no particular periodicity
- the *North Pacific Oscillation* – ?
- the *Hale cycle or sunspot cycle* – about 11 years
- the *Quasi-biennial oscillation* – about 30 months
- a *60-year climate cycle* recorded in many ancient calendars

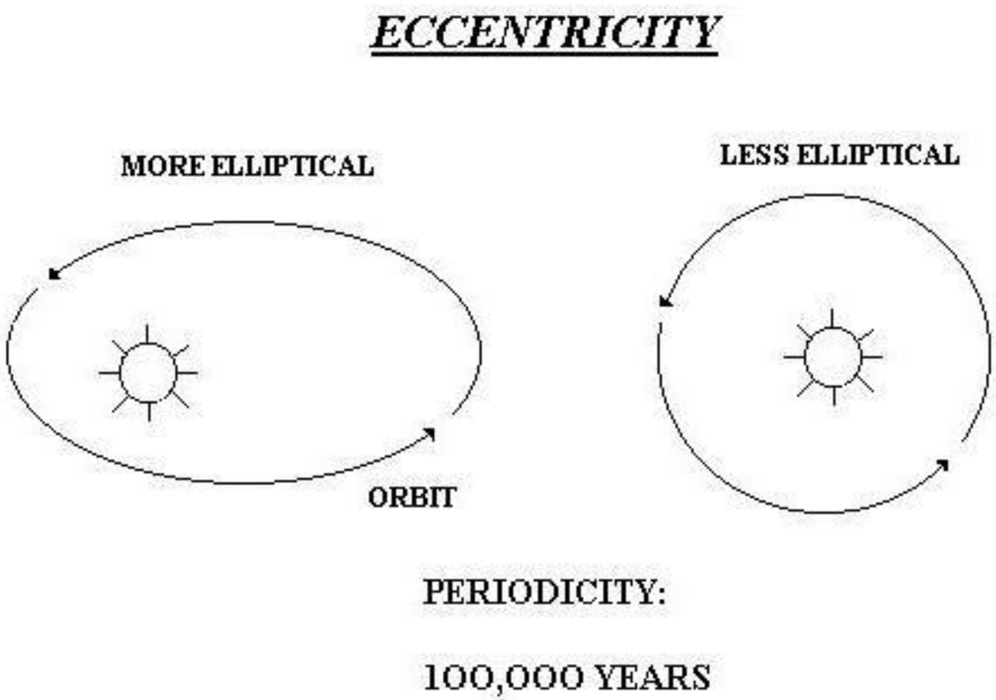
Milankovitch cycles

Earth's rotation and the seasons





Milankovitch cycles

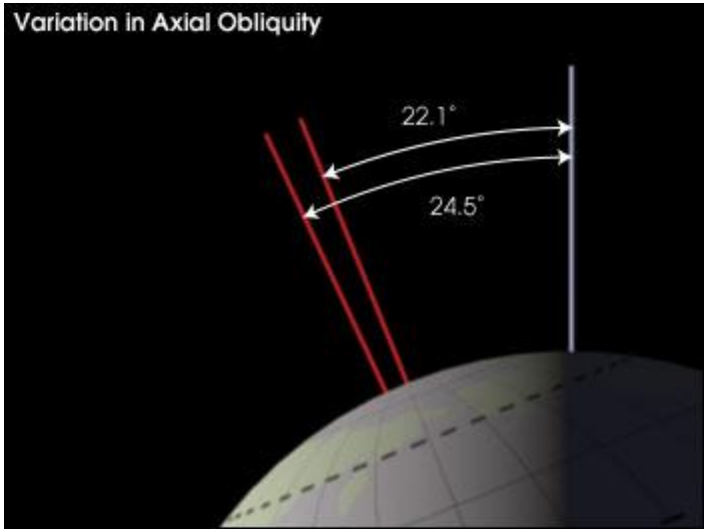


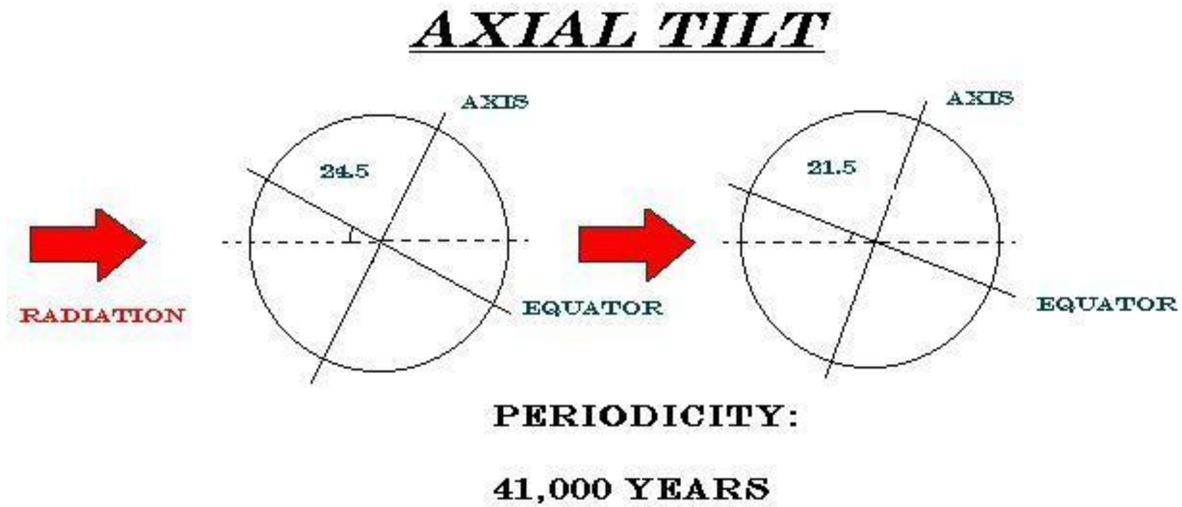
- Eccentricity is the amount of which an orbit is elliptical rather than circular
- Varies between .01 and .07 eccentricity
- Changes over a period of a period of approximately 100,000 years

➢ Currently: 3% eccentricity => 6% change in solar radiation between January and July

➢ For max eccentricity the change can reach up to 20-30%. Eccentricity is responsible for **Ice Ages**.

Milankovitch cycles





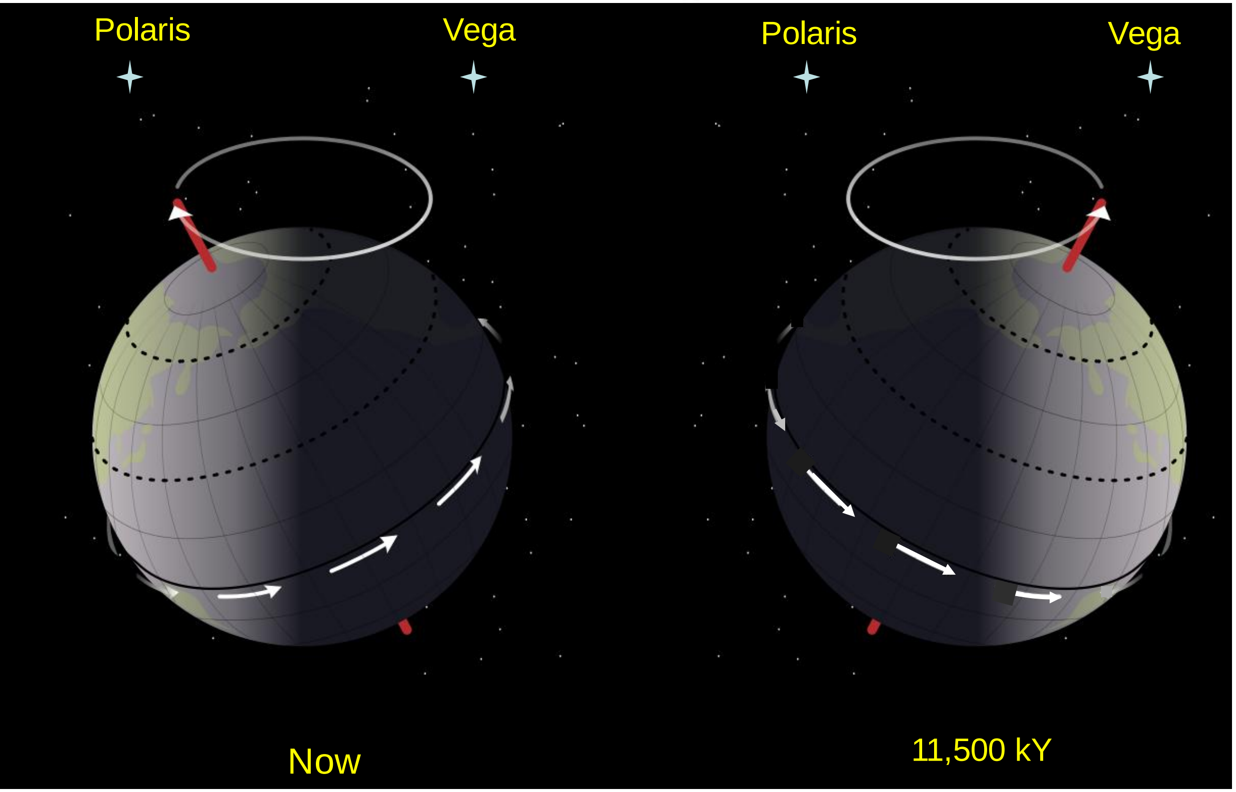
- Obliquity is essentially the angle of inclination of the Earth's equator with respect to the plane of its orbit
- Current axis is 23.5°
- Varies between 21.5° and 24.5°
- Changes over a period of 41.000 years

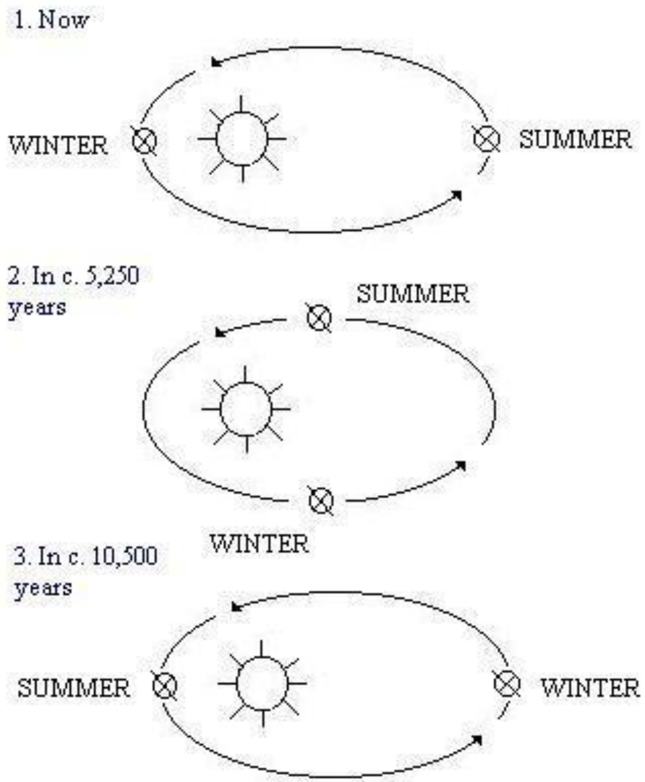
➢ Greater tilt = more severe seasons

➢ Lesser Tilt = milder seasons

Milankovitch cycles

PRECESSION





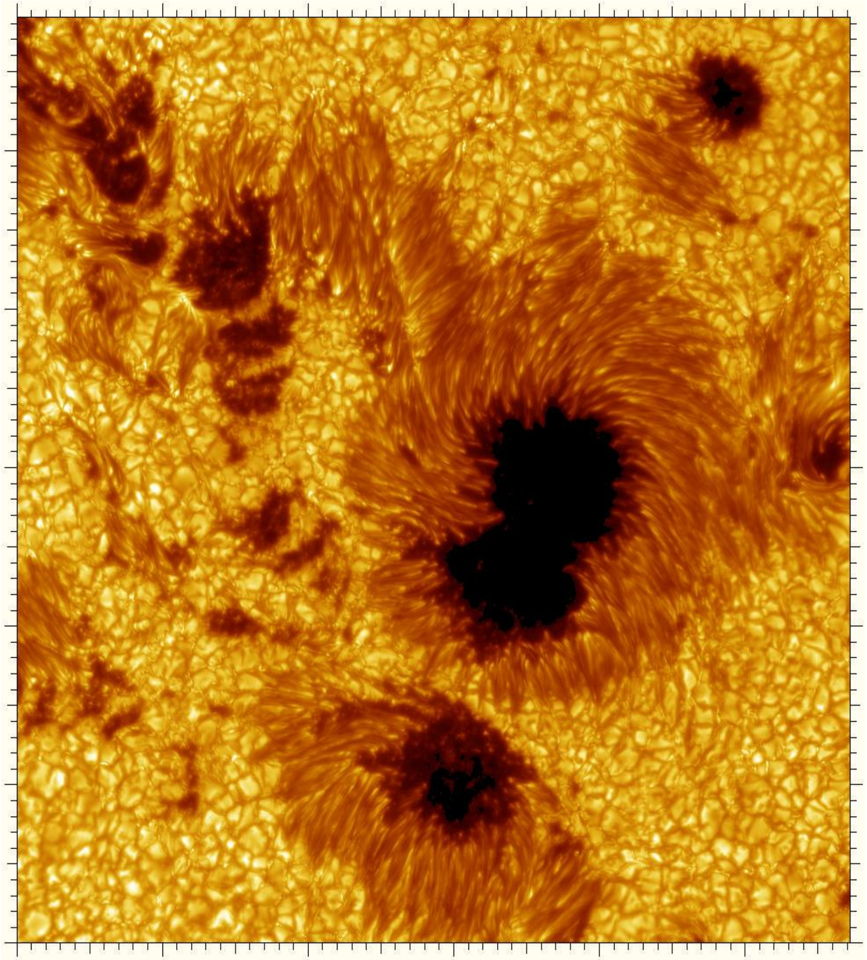
• Precession is a change in the orientation of the rotational axis of Earth – Changes over a period of 23.000 y.

➢ Caused by gravitational moment from the moon and the sun on the rotation of the slightly flattened Earth.

➢ If the axis is directed to Polaris or Vega seasons are closer to Aphelion or Perihelion.

The 11-year solar cycle

The solar cycle - sunspots

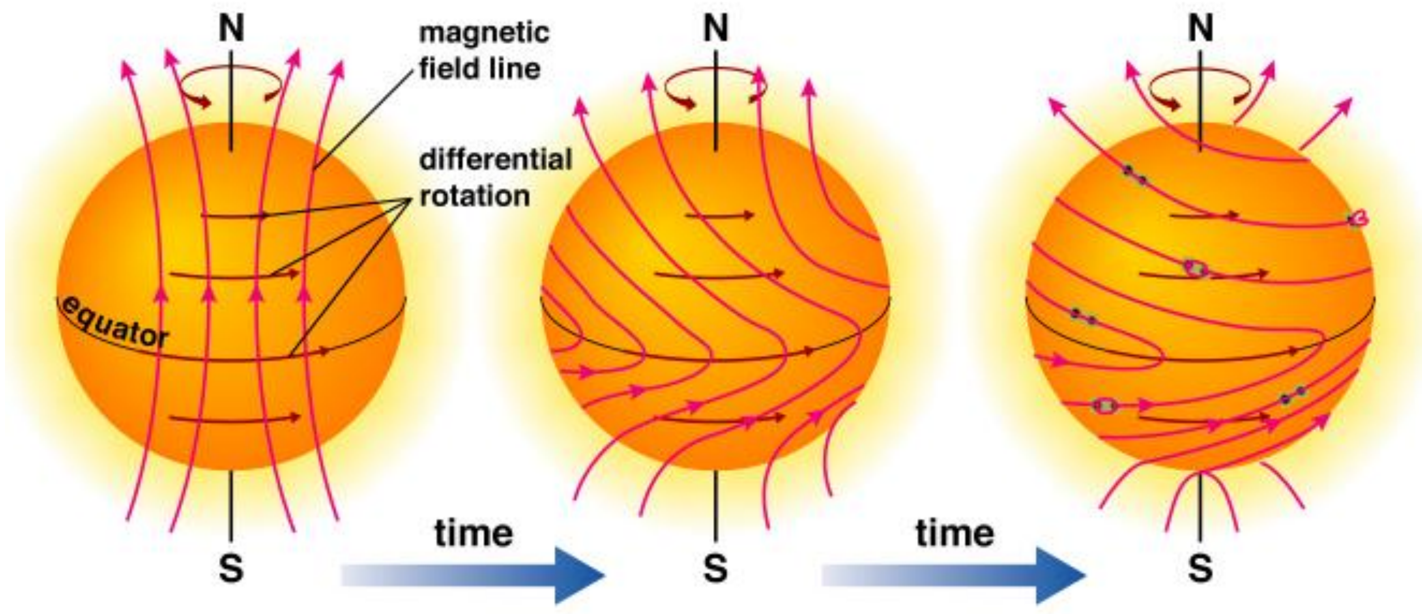


Sunspots: areas on the sun with strong magnetic fields.

It takes 11 years between solar maximum (11 years) and solar minimum (11years) – making one entire cycle 22 years long (Hale's observations revealed that the complete magnetic cycle spans two solar cycles, or 22 years).

Sunspots are forming mainly in groups around the solar equator.

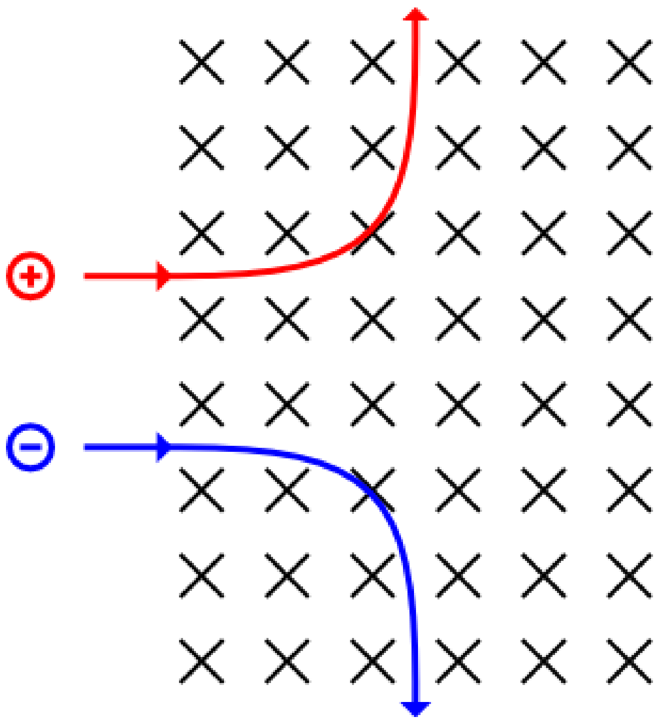
Magnetic Winding



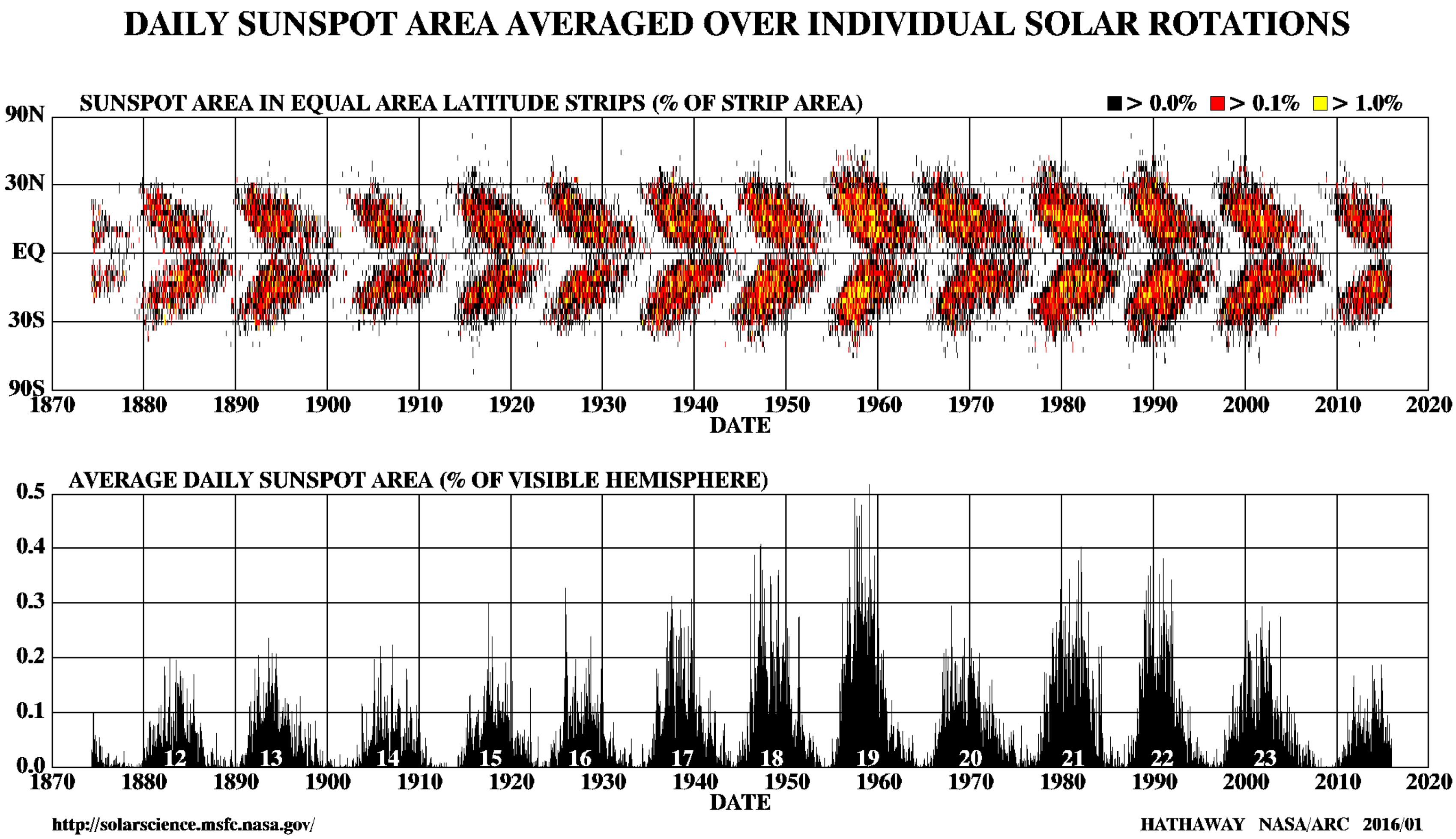
- The sun rotates faster at its equator than at its poles.
- The sun's strong magnetic field gets wound up causing part of the fields to rupture the surface where they cause sunspots.

Magnetic Winding

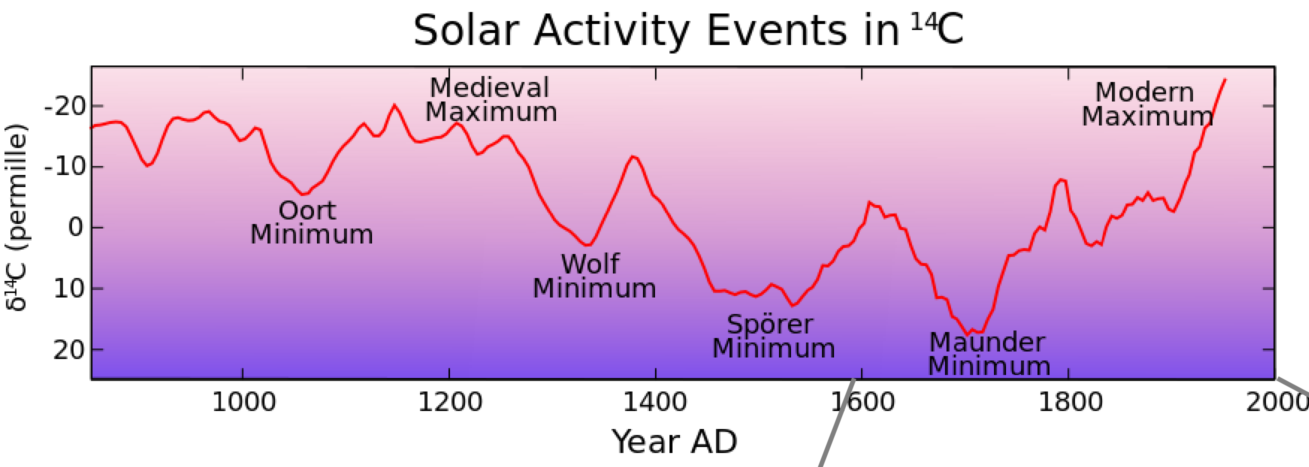
- Magnetic fields make cool zones.
- Fast-moving charged particles are deflected by magnetic fields.
- The magnetic fields of sunspots deflect hotter gases allowing only cooler gases that experience less of this deflective force.
- Sunspots are cooler regions on the photosphere. Since they are 1000--1500 K cooler than the rest of the photosphere, they do not emit as much light and appear darker

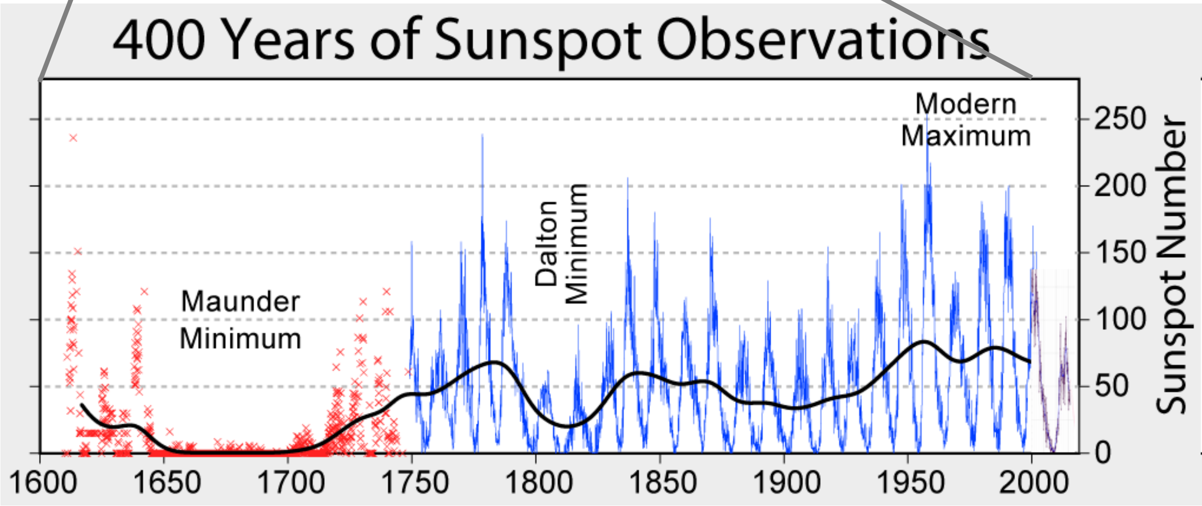


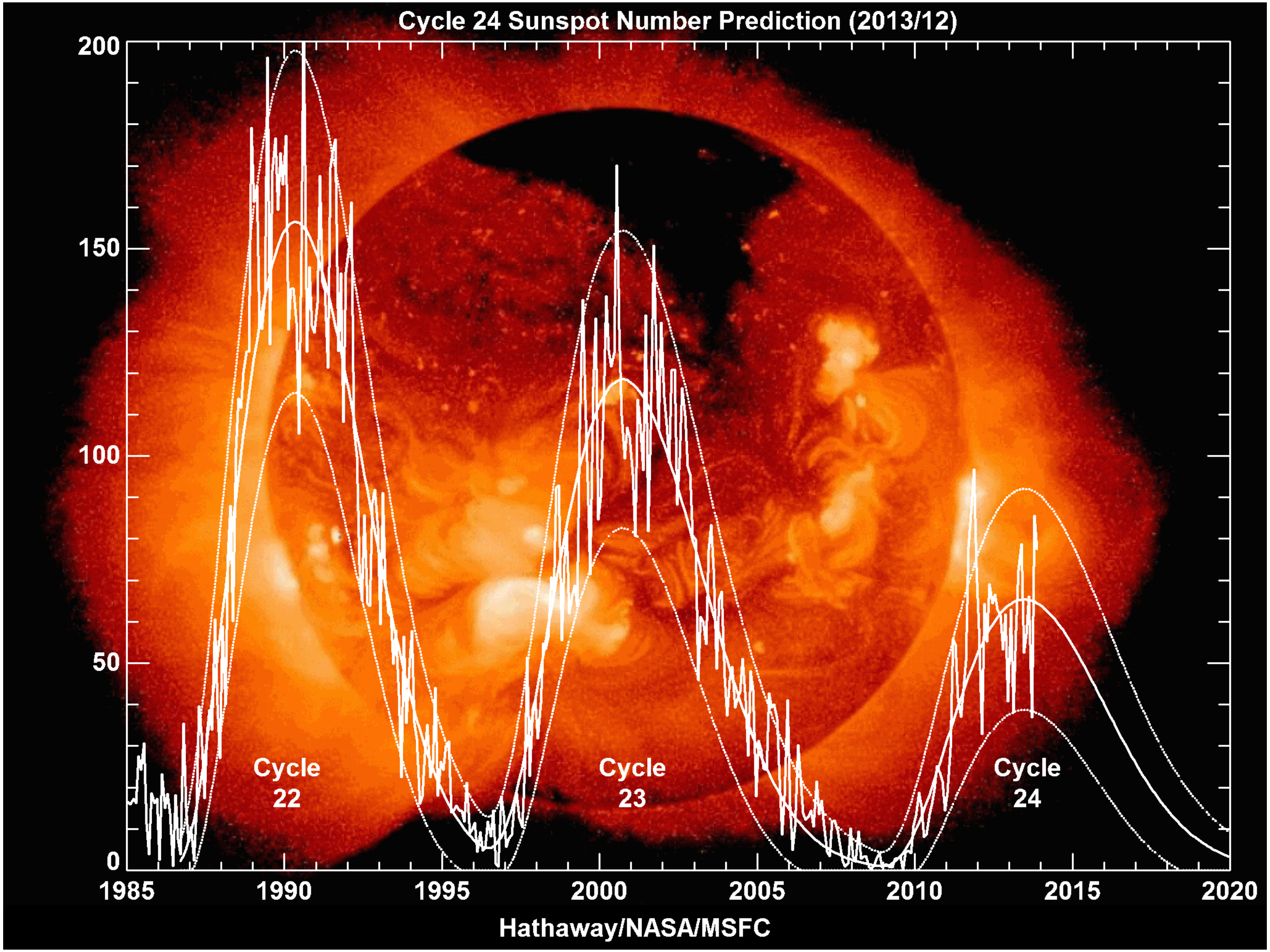
Butterfly Diagram



The solar cycle - sunspots






Cycle 24 Sunspot Number Prediction (2013/12)
200
150
100
50
0
1985
1990
1995
2000
2005
2010
2015
2020
Cycle 22
Cycle 23
Cycle 24
Hathaway/NASA/MSFC

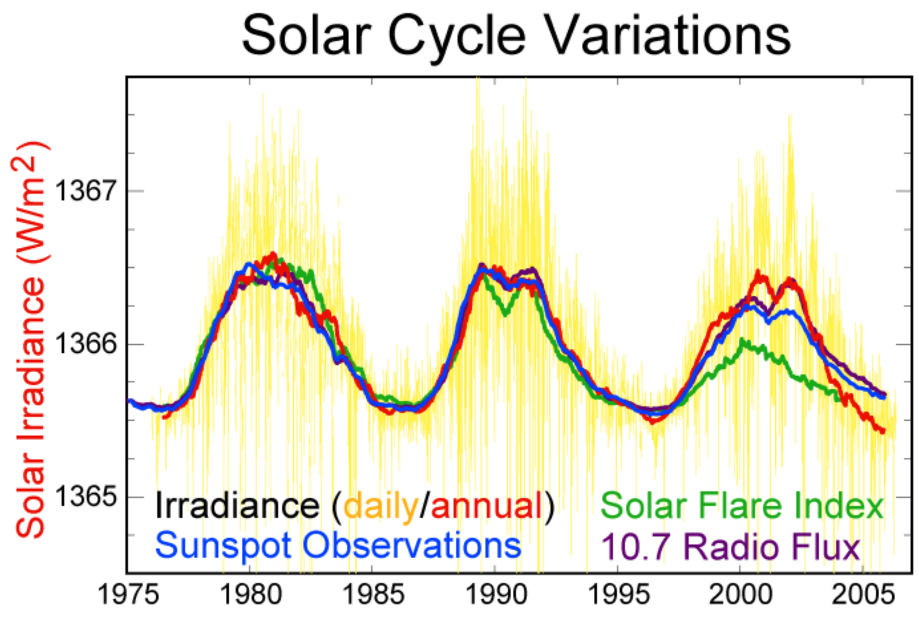
Impacts on Earth's atmosphere

✓Solar irradiance varies over the solar cycle, both in total irradiance and in its relative components (UV vs visible and other frequencies).

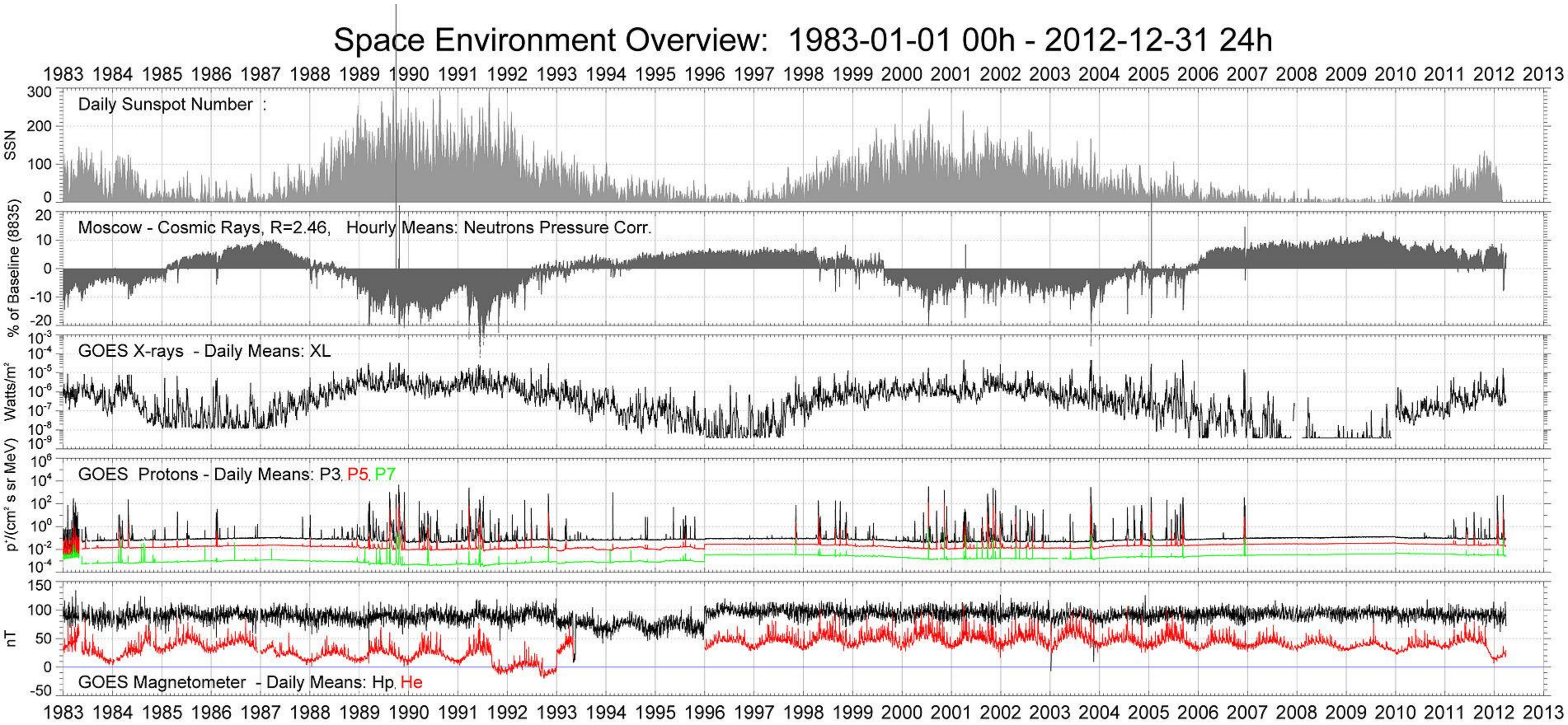
✓ The solar luminosity is an estimated 0.07 percent brighter during the mid-cycle solar maximum than the terminal solar minimum.

➢ **TSI is higher at solar maximum, even though sunspots are darker (cooler) than the average photosphere.** This is caused by magnetized structures other than sunspots during solar maxima, such as faculae and active elements of the "bright" network, that are brighter (hotter) than the average photosphere.

➢ During a sunspot cycle the faculae actually win out over the sunspots and make the Sun appear slightly (about 0.1%) brighter at sunspot maximum that at sunspot minimum.



Shielding effect



An overview of three solar cycles shows the relationship between the sunspot cycle, galactic cosmic rays, and the state of our near-space environment.

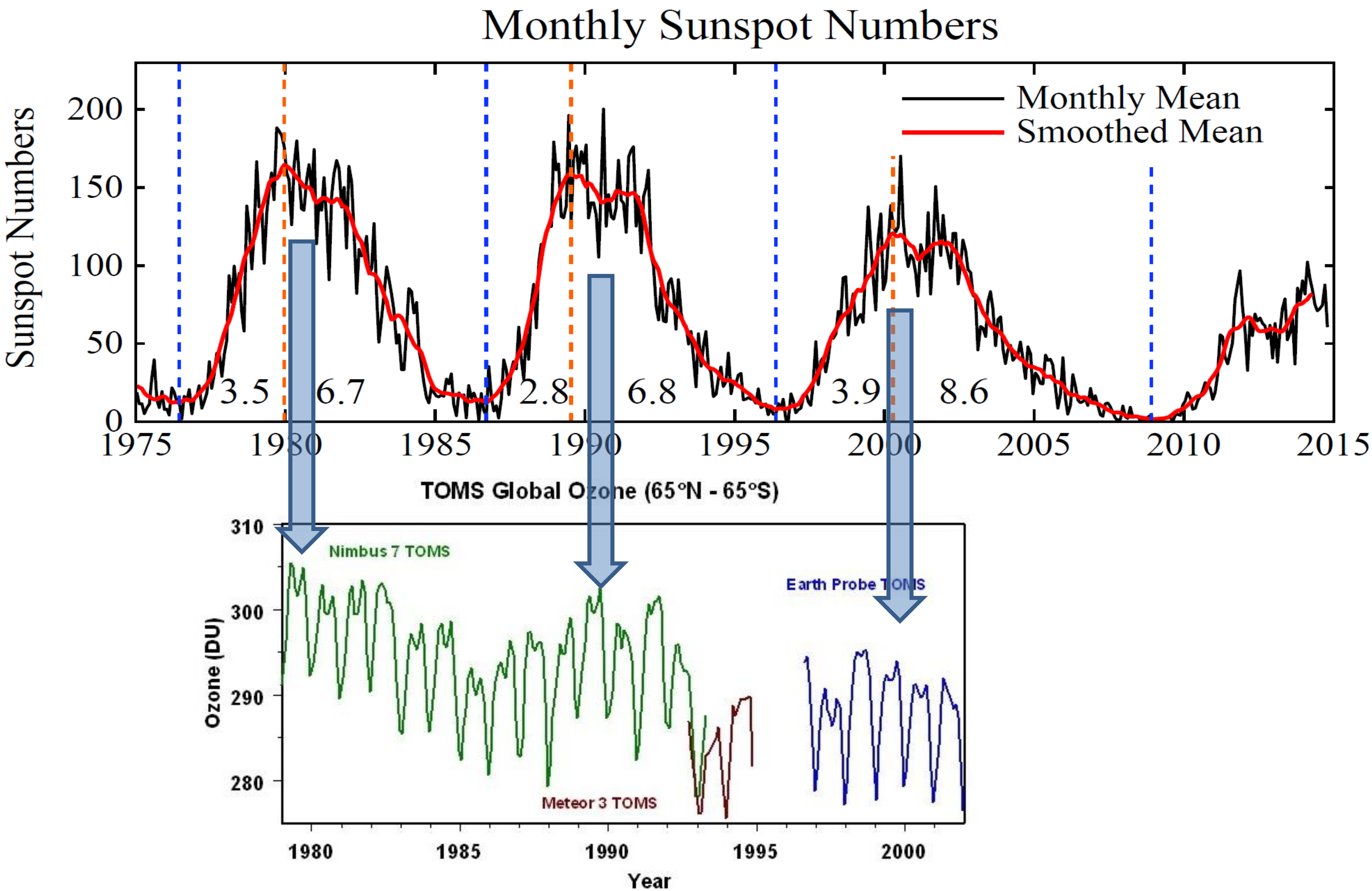
Impacts on Earth's atmosphere

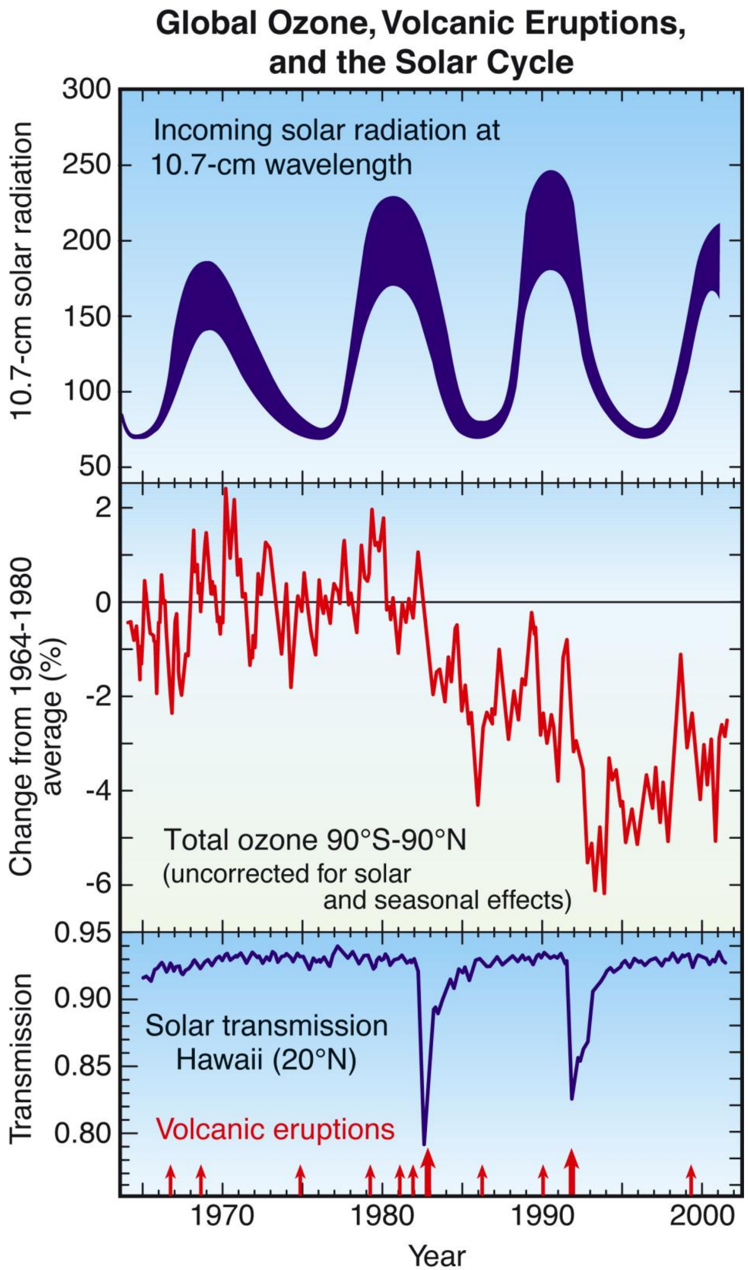
✓Energy changes in UV irradiance involved in production and loss of ozone have atmospheric effects.
✓ UV irradiance increase caused higher ozone production, leading to stratospheric heating and to poleward displacements in the stratospheric and tropospheric wind systems.

Speculations about cosmic rays include:
✓Changes in ionization affect the aerosol abundance that serves as the condensation nucleus for cloud formation. During solar minima more cosmic rays reach Earth, potentially creating ultra-small aerosol particles as precursors to CCN
✓Clouds formed from greater amounts of condensation nuclei are brighter, longer lived and likely to produce less precipitation.
✓A change in cosmic rays could cause an increase in certain types of clouds, affecting Earth's albedo.

Current scientific consensus:

(a) solar variations do not play a major role in driving global warming (the measured magnitude is much smaller than the forcing due to GHGs)
(b) solar activity in the 2010s was not higher than in the 1950s, whereas global warming had risen markedly
(c) the level of understanding of solar impacts on weather is low.


Monthly Sunspot Numbers
Sunspot Numbers
Monthly Mean
Smoothed Mean
0
50
100
150
200
3.5
6.7
2.8
6.8
3.9
8.6
1975
1980
1985
1990
1995
2000
2005
2010
2015
TOMS Global Ozone (65°N - 65°S)
Ozone (DU)
310
300
290
280
Nimbus 7 TOMS
Earth Probe TOMS
Meteor 3 TOMS
1980
1985
1990
1995
2000
Year


Global Ozone, Volcanic Eruptions, and the Solar Cycle
Incoming solar radiation at 10.7-cm wavelength
10.7-cm solar radiation
300
250
200
150
100
50
Change from 1964-1980 average (%)
2
0
-2
-4
-6
Total ozone 90°S-90°N
(uncorrected for solar and seasonal effects)
Transmission
0.95
0.90
0.85
0.80
Solar transmission Hawaii (20°N)
Volcanic eruptions
1970
1980
1990
2000
Year

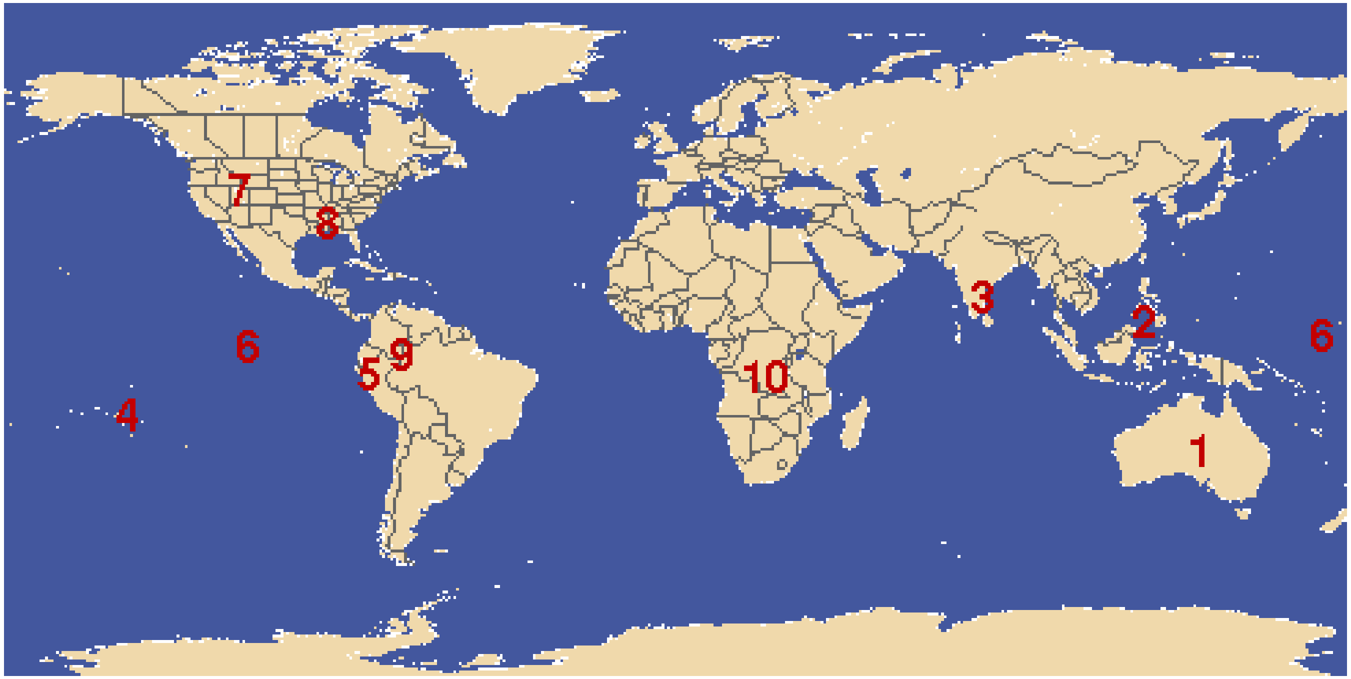
El Niño Southern Oscillation - ENSO

The first signs!

1982-1983

- Abnormally warm waters over a 13.000 km stretch of the equatorial Pacific
- Adult seabirds abandoned their young on Kiribati
- Australia’s worst drought in 200 years, $2 billion in crop damage

1. Australia - Drought and bush fires
2. Indonesia, Philippines - Crops fail, starvation follows
3. India, Sri Lanka - Drought, fresh water shortages
4. Tahiti - 6 tropical cyclones
5. South America - Fish industry devastated
6. Across the Pacific - Coral Reefs die
7. Colorado River basin - Flooding, mud slides
8. Gulf states - Downpours cause death, property damage
9. Peru, Ecuador - Floods, landslides
10. Southern Africa - Drought, disease, malnutrition



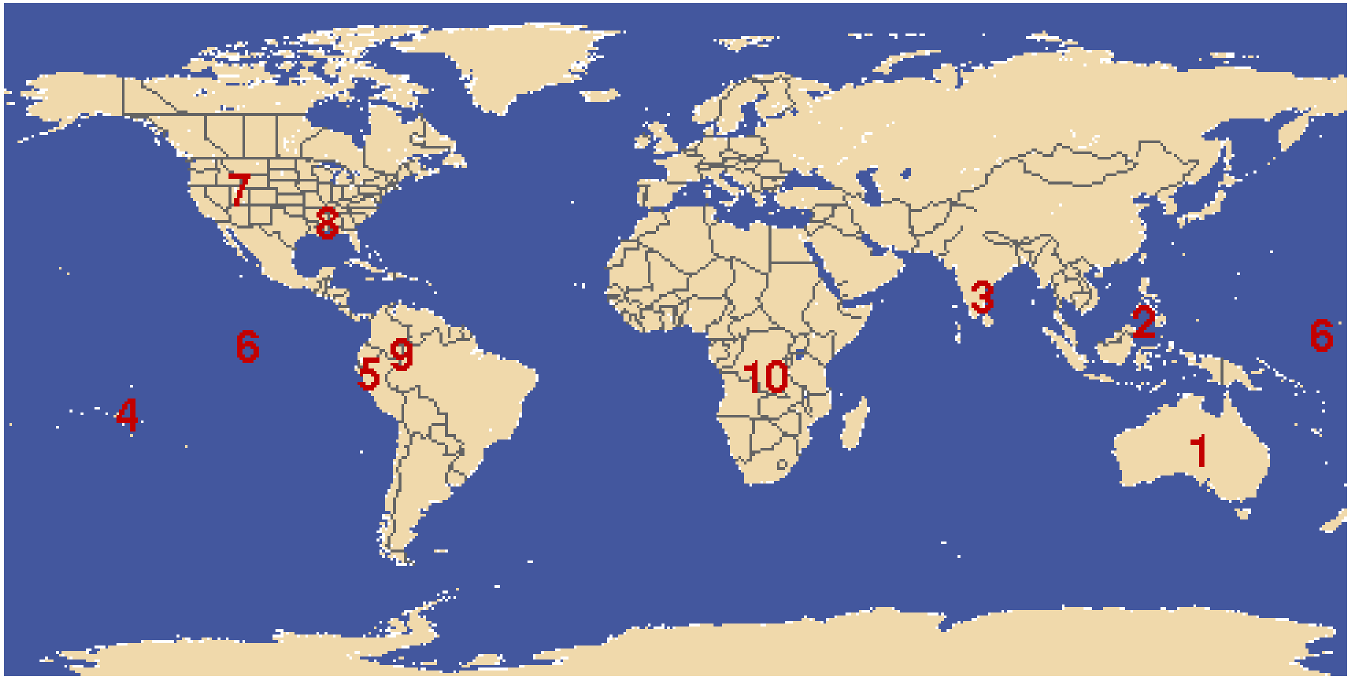
The first signs!

1982-1983

Collapse of plankton population →
collapse of the anchovy population →
collapse of other fish populations →
collapse of seabird and marine mammal populations

1. Australia - Drought and bush fires
2. Indonesia, Philippines - Crops fail, starvation follows
3. India, Sri Lanka - Drought, fresh water shortages
4. Tahiti - 6 tropical cyclones
5. South America - Fish industry devastated
6. Across the Pacific - Coral Reefs die
7. Colorado River basin - Flooding, mud slides
8. Gulf states - Downpours cause death, property damage
9. Peru, Ecuador - Floods, landslides
10. Southern Africa - Drought, disease, malnutrition

"The most disastrous in recorded history," weather-related events, costed 2000 human lives, about $13 billion in damage, and vast ecological havoc



Residents of the area had known about the specific weather pattern for a while

Peruvian fishermen in the late 1800's called it El Niño (Christ child or little boy)

Bad news in the western coast of Ecuador and Peru since there was no food for fish … thus no fish!!!

The rest of the world knew about it after 1982-1983.

LITTLE BOY AT PLAY AGAIN

Here's all you need to know about El Nino which literally translates into Little Boy in Spanish

WHAT IS IT?

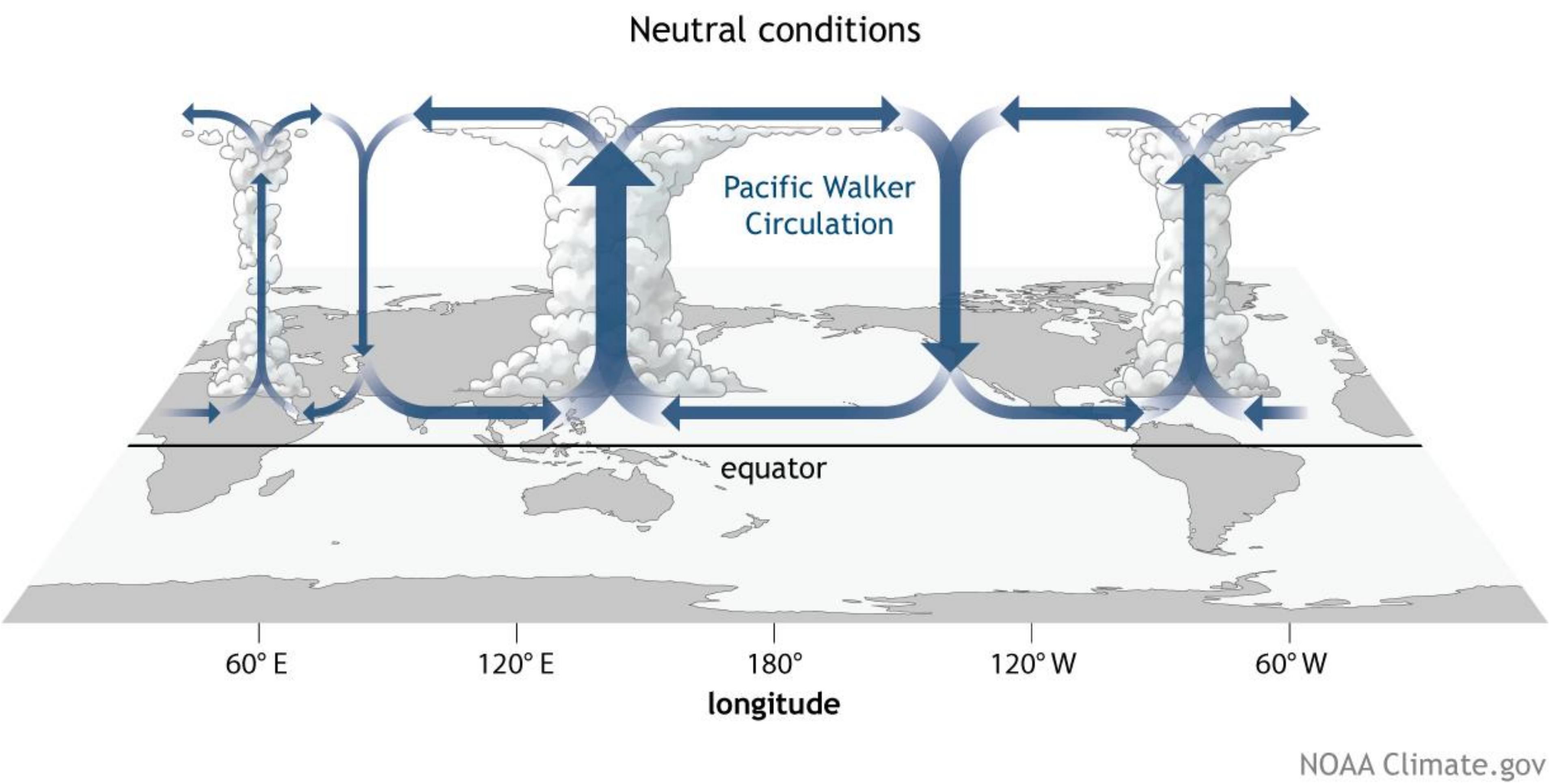
- A weather glitch marked by higher-than-normal temperature in equatorial Pacific directly south of Mexico
- The phenomenon can parch parts of India and Australia, but cause surplus rains in Latin America

DOES IT ALWAYS CAUSE DROUGHTS IN INDIA?

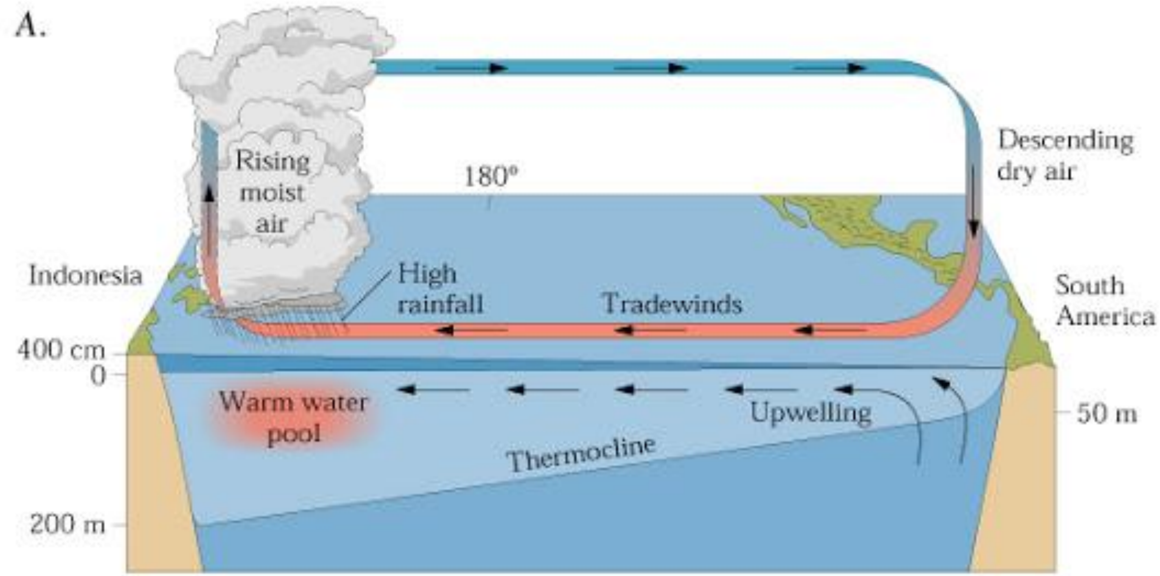
- No. Between 1880 and 2005, less than half of El Nino occurrences have resulted in poor monsoon
- However, of the 13 droughts in the country since 1950, 10 have coincided with it

WHY IS THE RISK HIGH THIS TIME? Most climate models predict the dreaded weather system to arrive by June, right at the start of the Indian monsoon

Walker circulation – Southern Oscillation



Walker circulation – Southern Oscillation



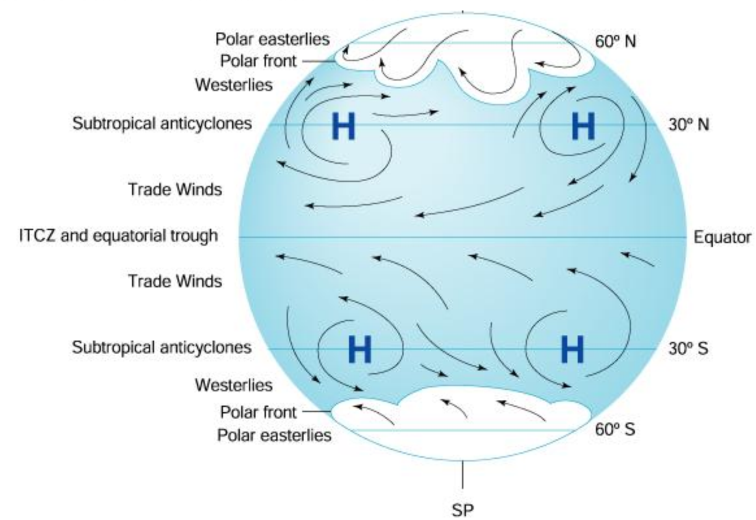
"Normal" conditions in the tropical Pacific

Normal pattern:

✓ Dominance of the subtropical high in the eastern Pacific causes westward movement of the trade winds toward low pressure cell in the western Pacific.

✓ Trade winds create frictional drag on the Pacific Ocean and create westward moving warm equatorial current.

✓ The removal of surface water near the western coast of South America allows cold water to upwell.

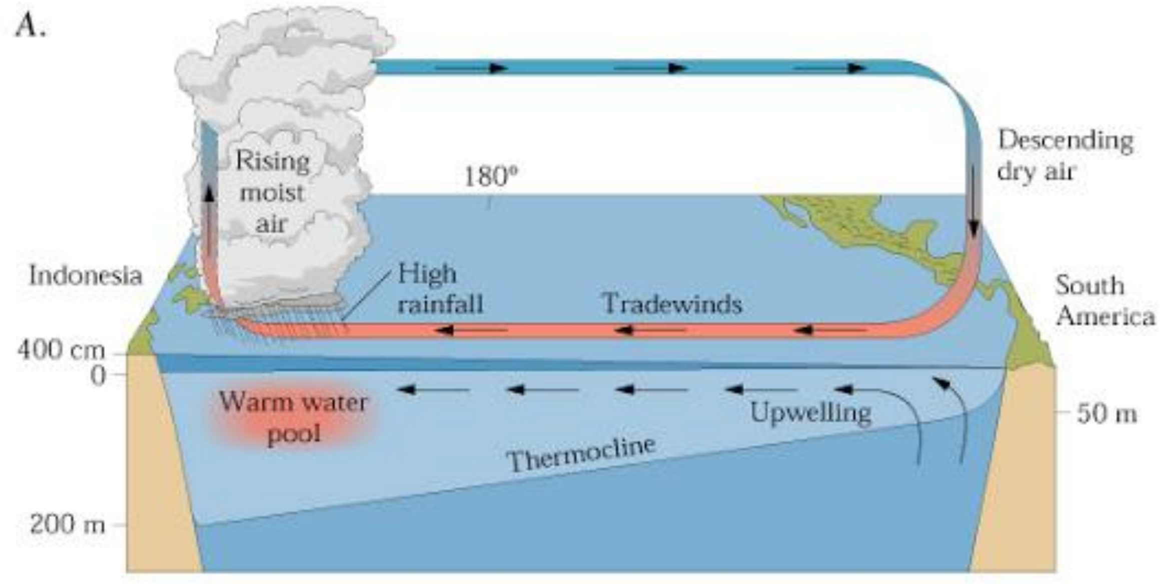


Walker circulation – Southern Oscillation

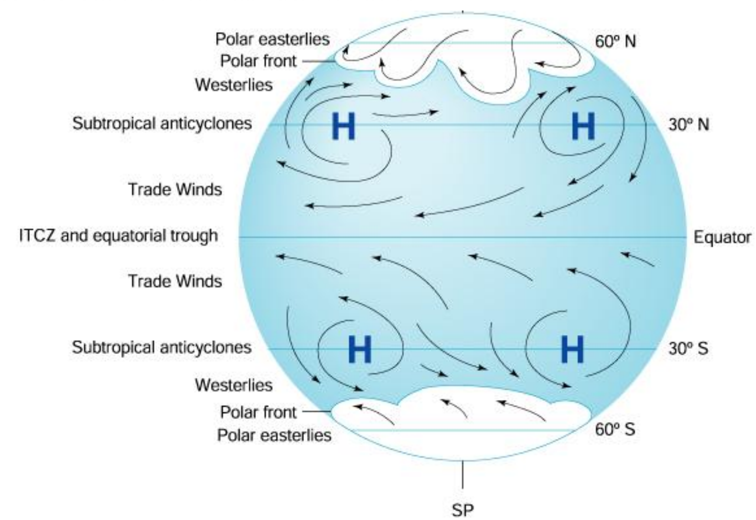
Normal pattern:

✓ This phenomenon is known as the **Southern Oscillation**, a large-scale fluctuation in sea-level atmospheric pressure that occasionally occurs in the eastern and western tropical Pacific; caused by differences in water temperature.

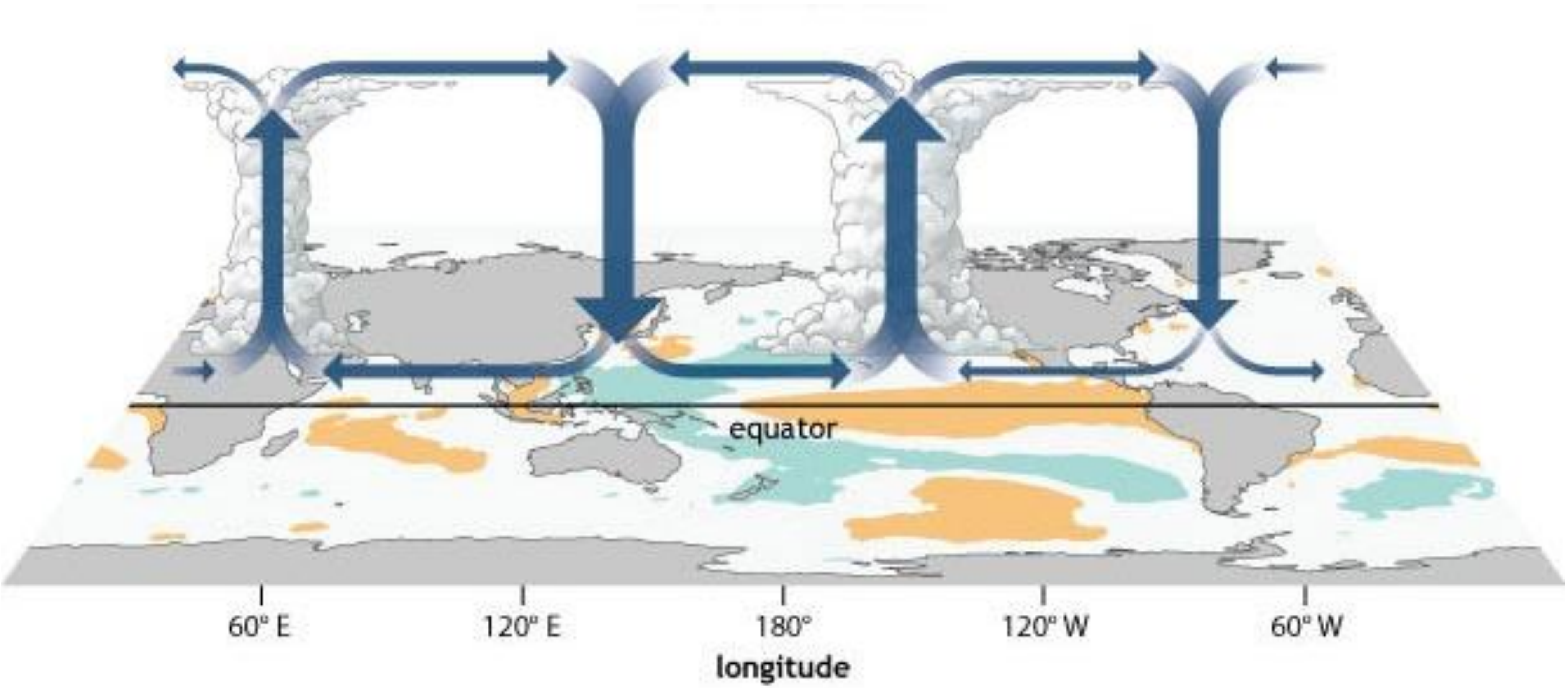
✓ The **Walker circulation**, is the relevant atmospheric cell, describing the air flow in the tropics in the lower atmosphere (troposphere), caused by differences in heat distribution between ocean and land.



"Normal" conditions in the tropical Pacific



El Nino conditions

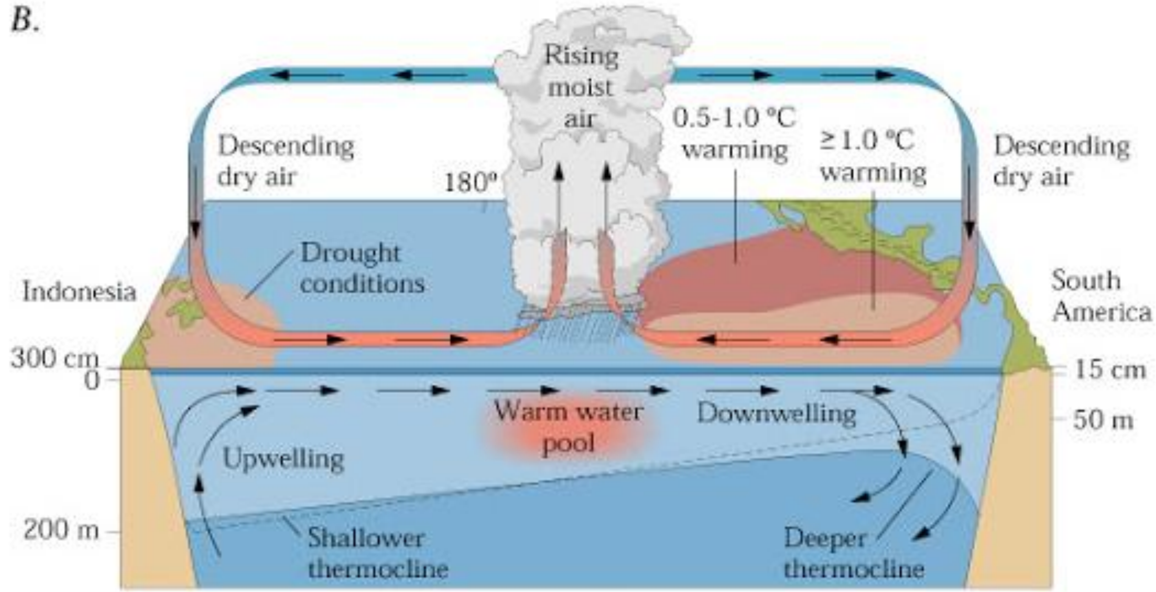


El Nino conditions

During El Nino:

✓ Southeastern trades abnormally weaken or reverse direction.

✓ This triggers a warm surface flow, which displaces the cold, nutrient-rich upwelling.



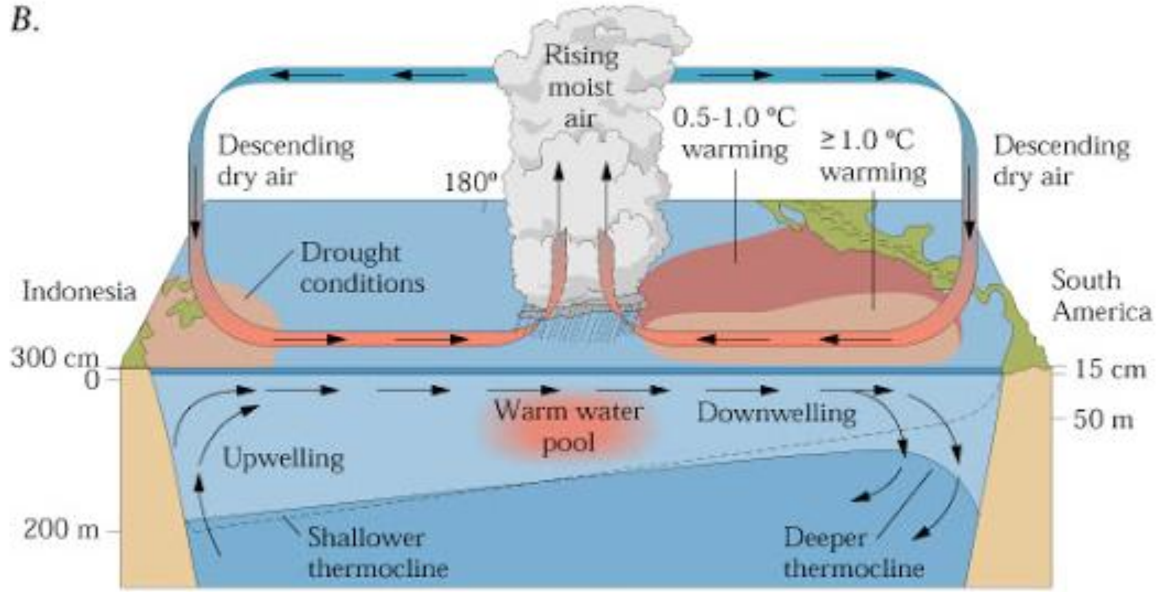
El Niño conditions in the tropical Pacific

El Nino conditions

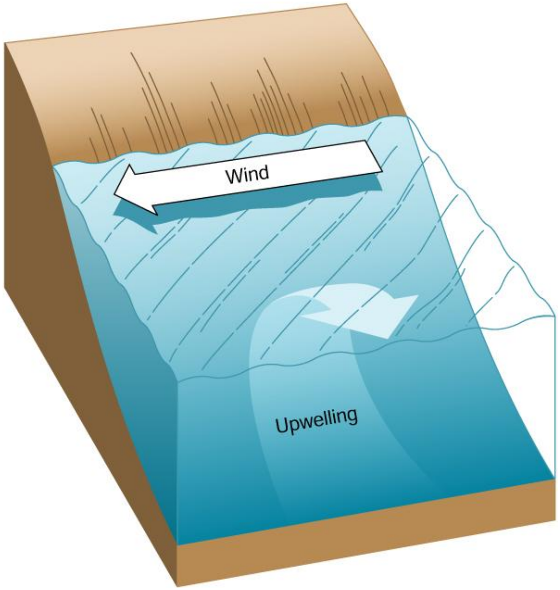
During El Nino:

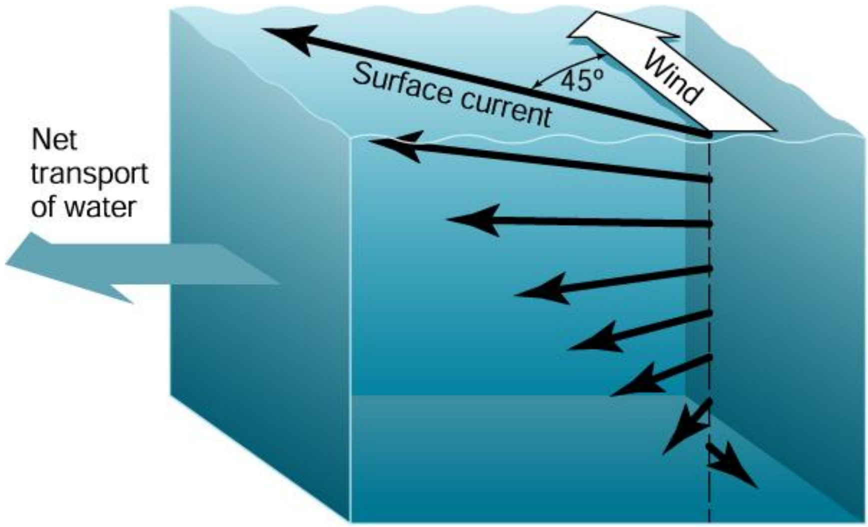
✓Upwelling is driven by Ekman transport, in which prevailing winds parallel to the coast trigger transport of water from the depths to the surface

✓ Transport is in a spiral motion with depth referred to as an Ekman spiral.

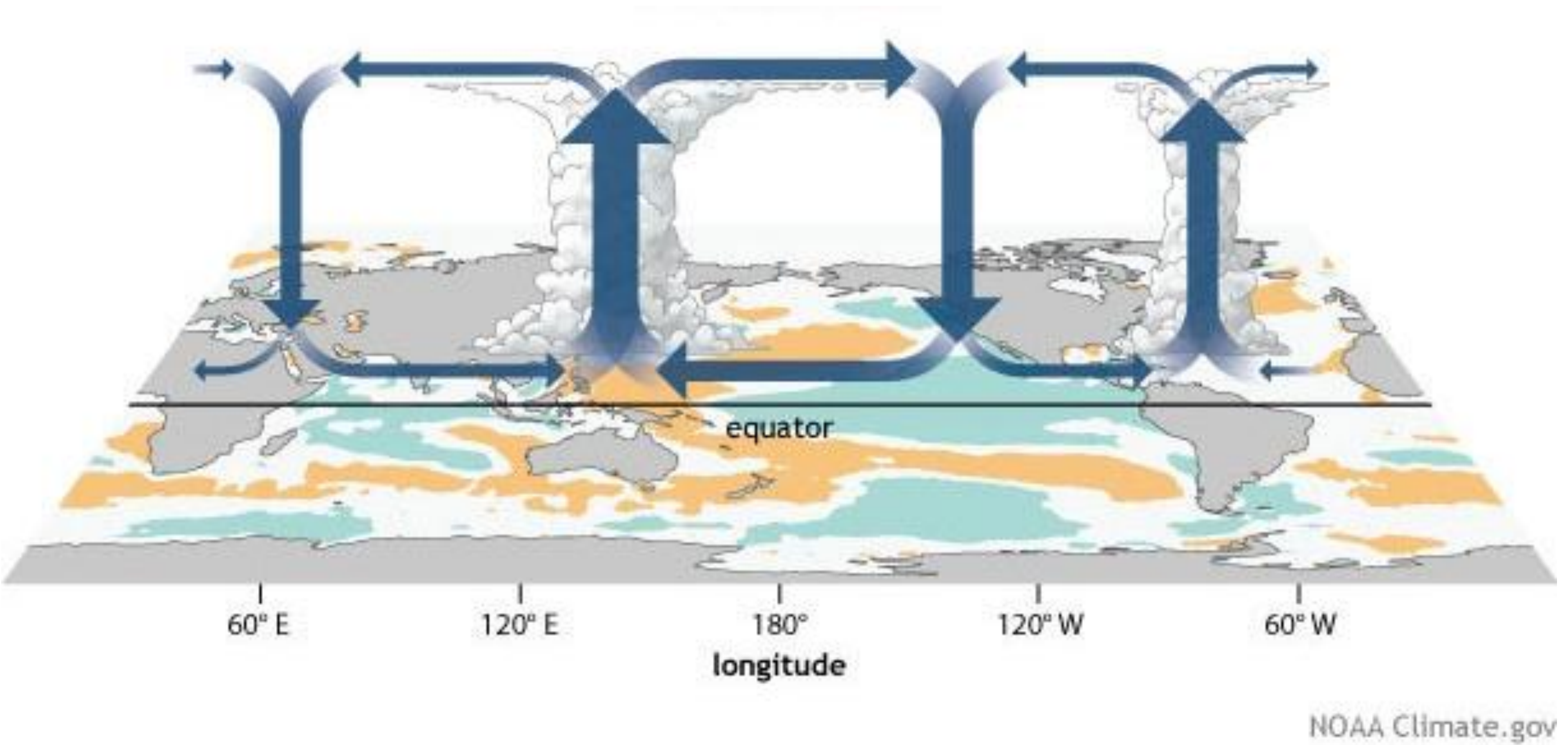


El Niño conditions in the tropical Pacific





La Nina conditions



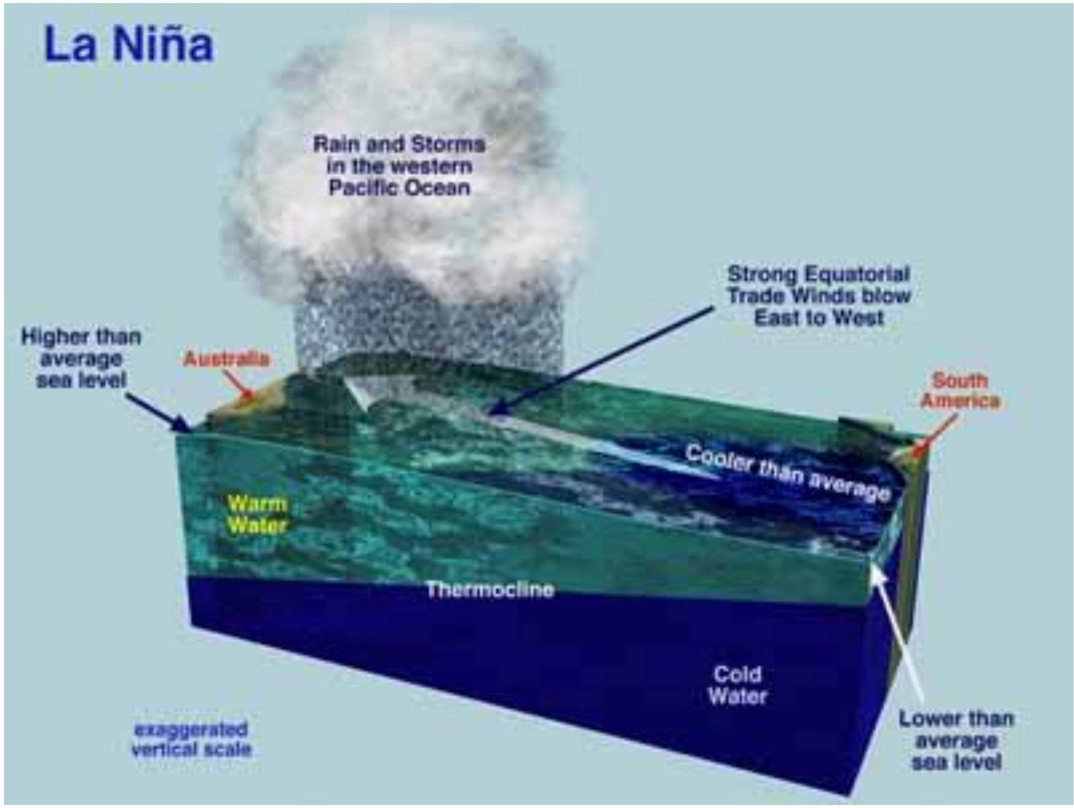
La Nina conditions

During La Nina:

✓ Unusually cold temperatures in the eastern Equatorial Pacific.

✓Both El Niño and La Niña are extreme cases of a naturally occurring climate cycle that involves large-scale changes in sea-surface temperatures across the eastern tropical Pacific.

✓ La Niña is not as predictable as El Niño.

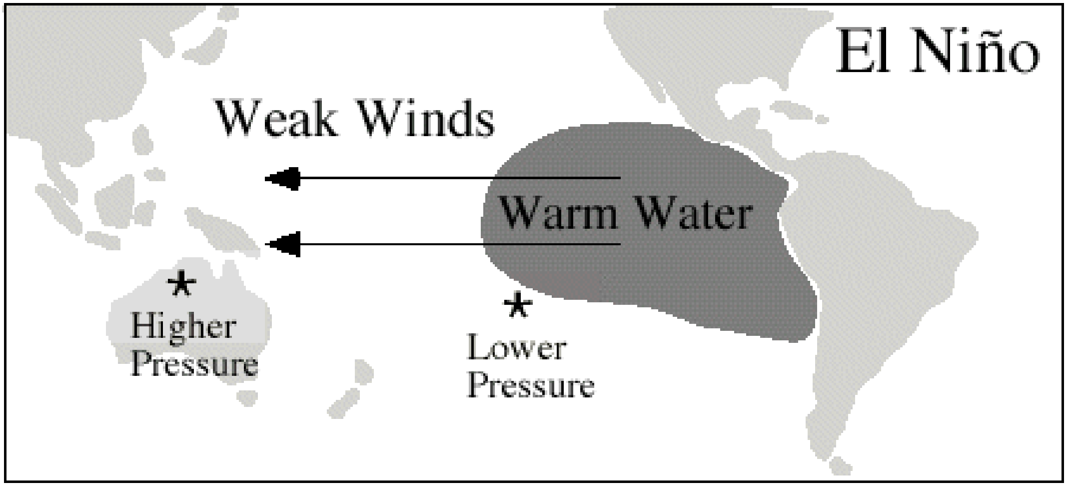


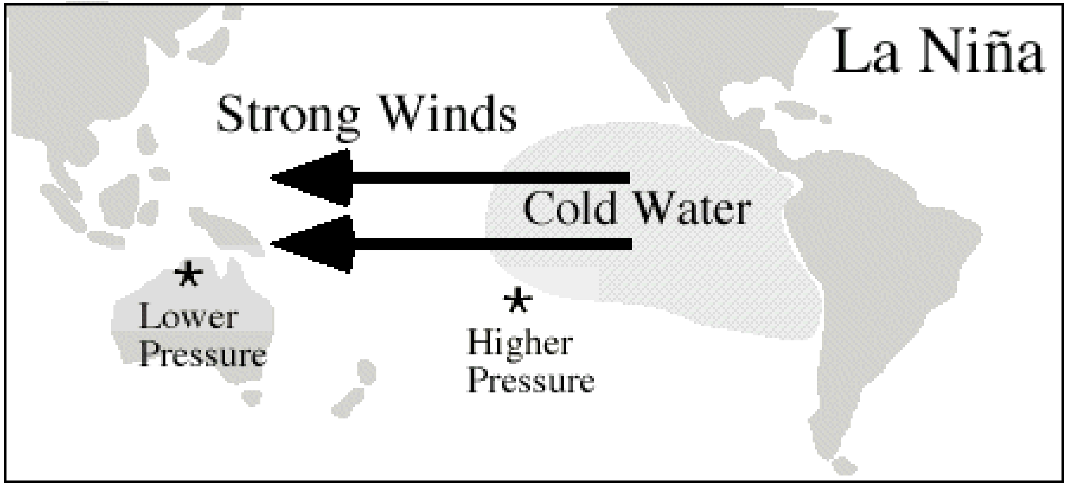
Summing up ENSO

✓Every few years the normal pressure pattern changes.

✓High pressure develops over northern Australia, and low pressure develops to the east over Tahiti.

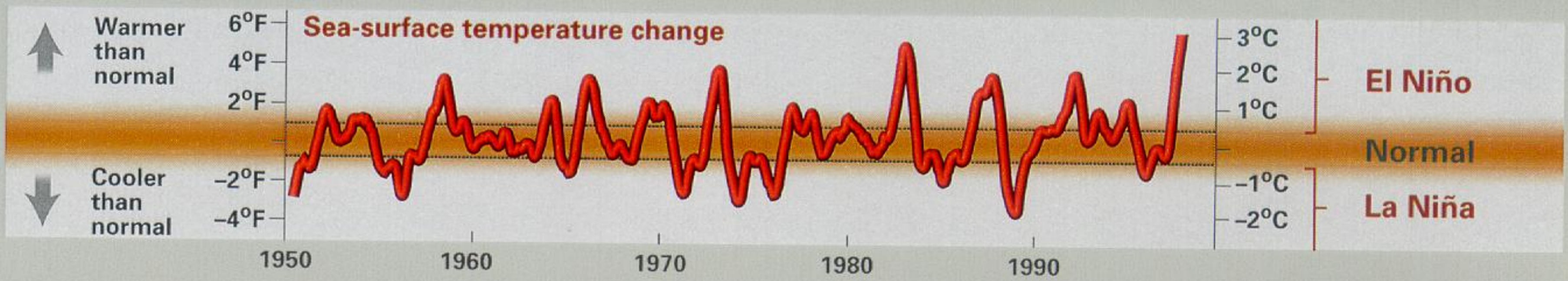
✓The pressure reversal causes the trade winds to reverse direction, and this allows warm water from the western Pacific to "backwash" toward the eastern Pacific.



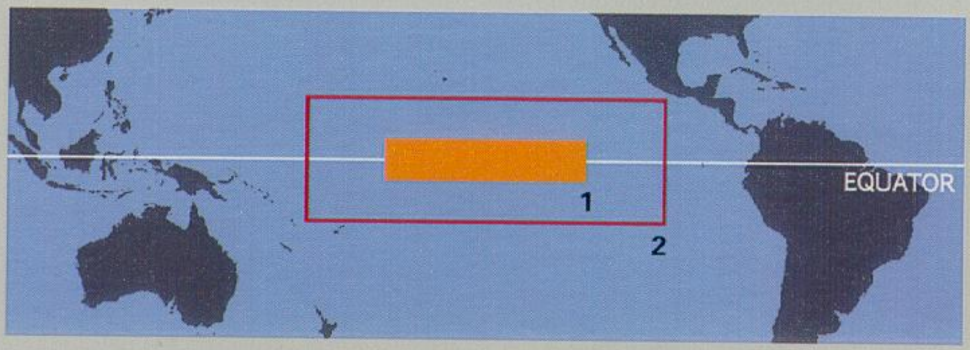


Summing up ENSO

Running Hot and Cold



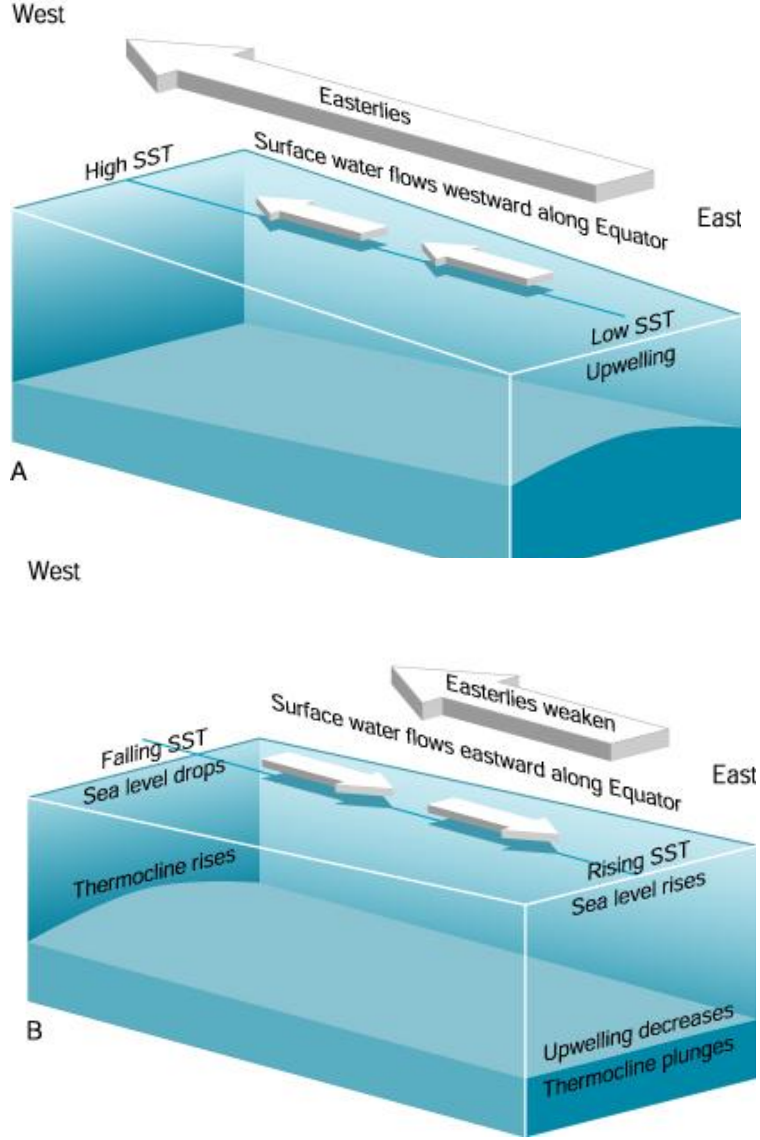
Like a giant saucer with liquid sloshing back and forth across it, the Pacific Ocean contains huge masses of contrasting cool and warm water. During the past 50 years their slow cycle has created El Niño conditions 31 percent of the time and La Niña conditions 23 percent of the time.



1. Information shown in the graph above is based on data from an area west of Peru. 2. Rectangle defines area depicted in cross sections below.

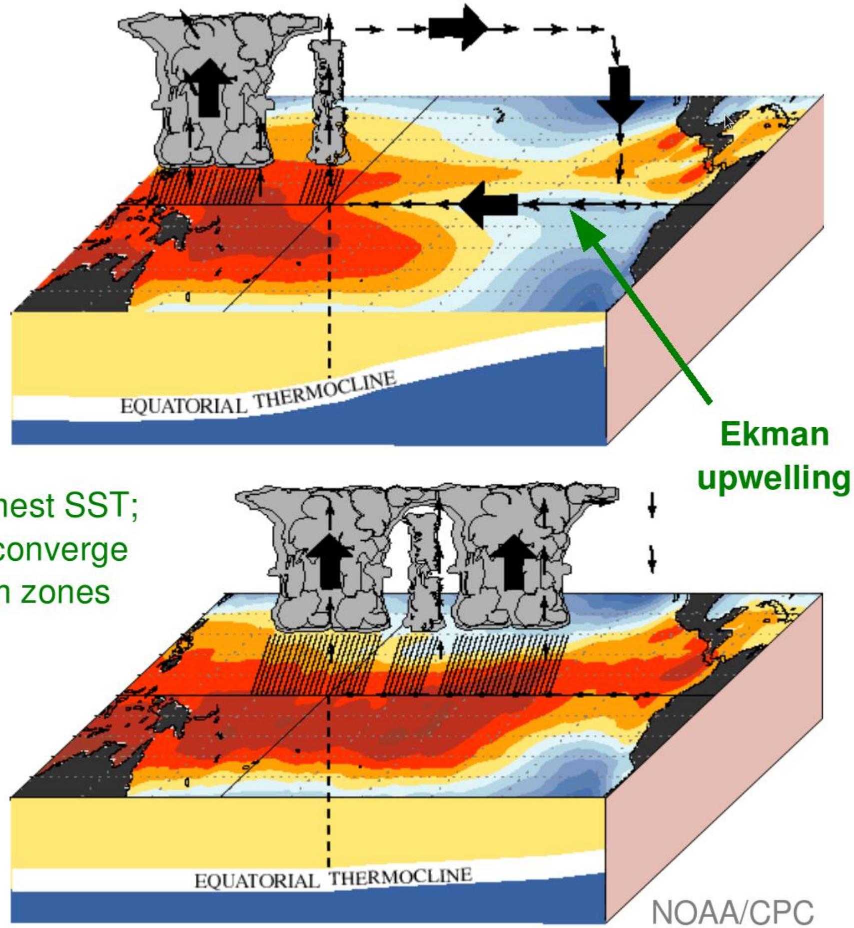
Summing up ENSO

- ✓For many months before the onset of El Niño, the trade winds pile up warm water in the western Pacific, and then a bulge of warm equatorial water about 25 cm high moves eastward in a series of bulges known as Kelvin waves.
- ✓These waves can take 2-3 months to arrive off the coast of South America.
- ✓This causes the sea level to rise off the coast of South America as the warm water pools.
- ✓This impedes the upwelling of cold water off of the coast, and thus causes temperatures off the coast of South America to rise.



Summing up ENSO

Normal



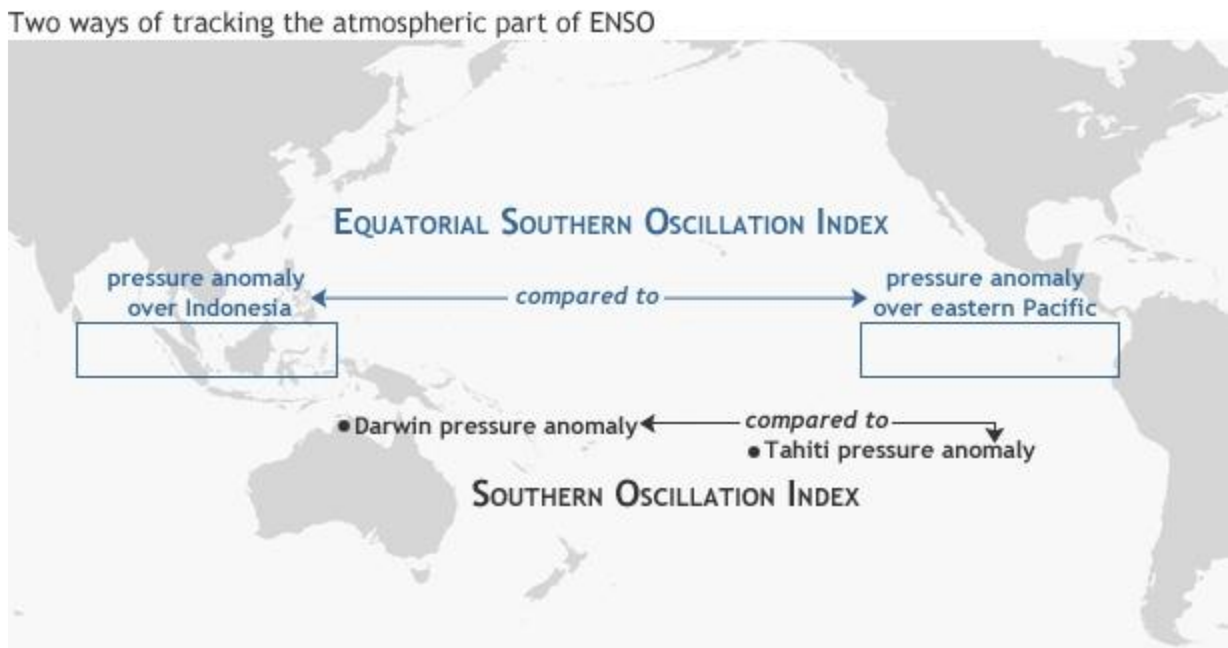
Asymmetric:
cold tongue, warm pool;
ITCZ north of equator;
easterly trade winds;
sea level slopes **up** to west,
thermocline **down** to west

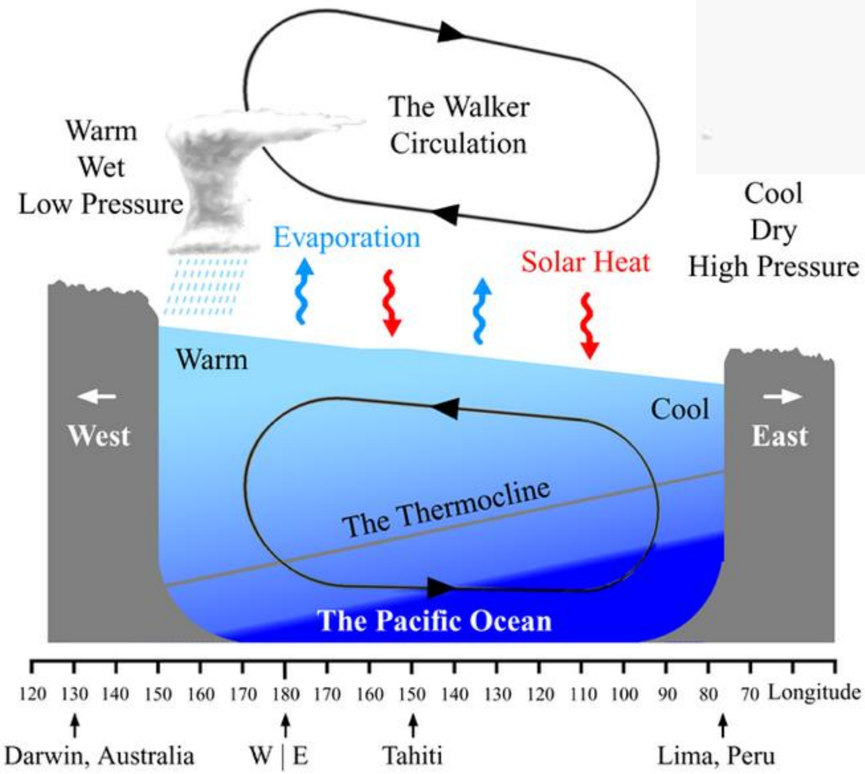
rain follows warmest SST;
surface winds converge
onto rainy/warm zones

El Niño

Events occur at
irregular intervals (2-8yr);
peak around Nov-Dec;
last about a year;
often followed by La Niña

Quantifying ENSO



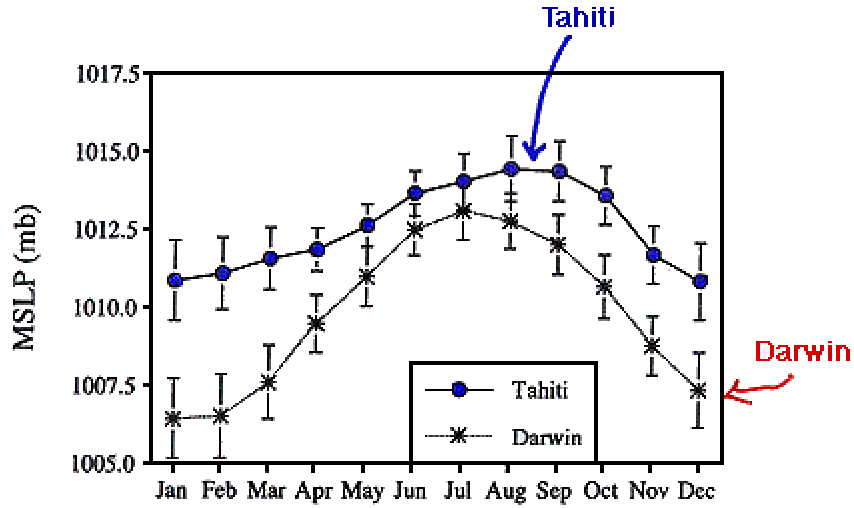


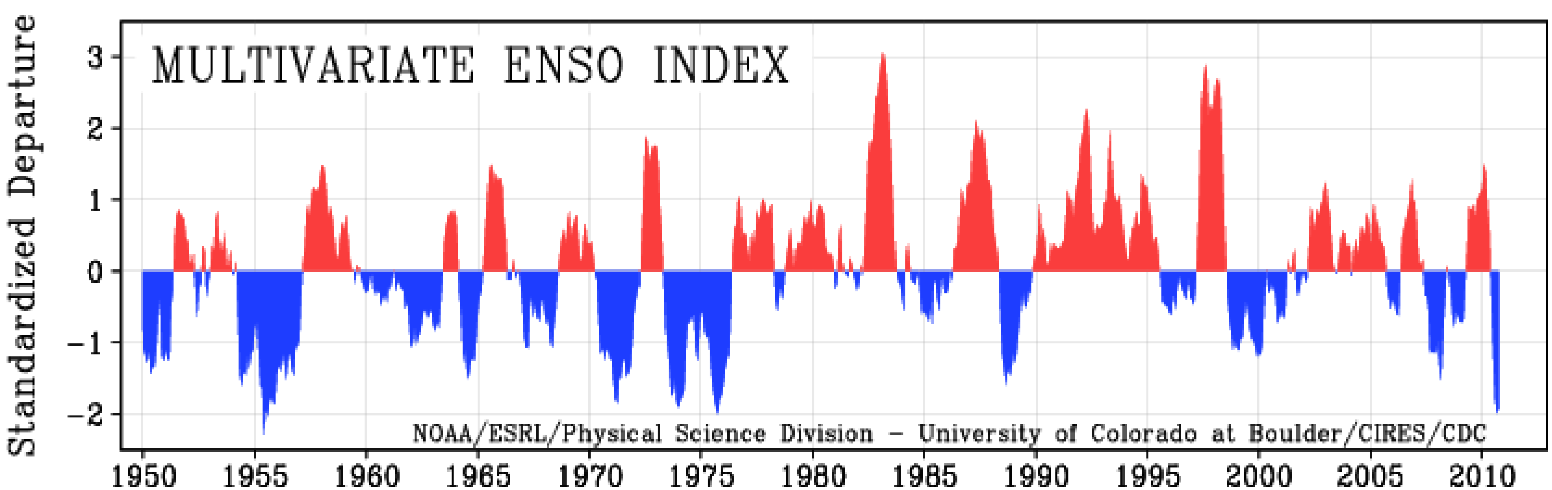
Quantifying ENSO

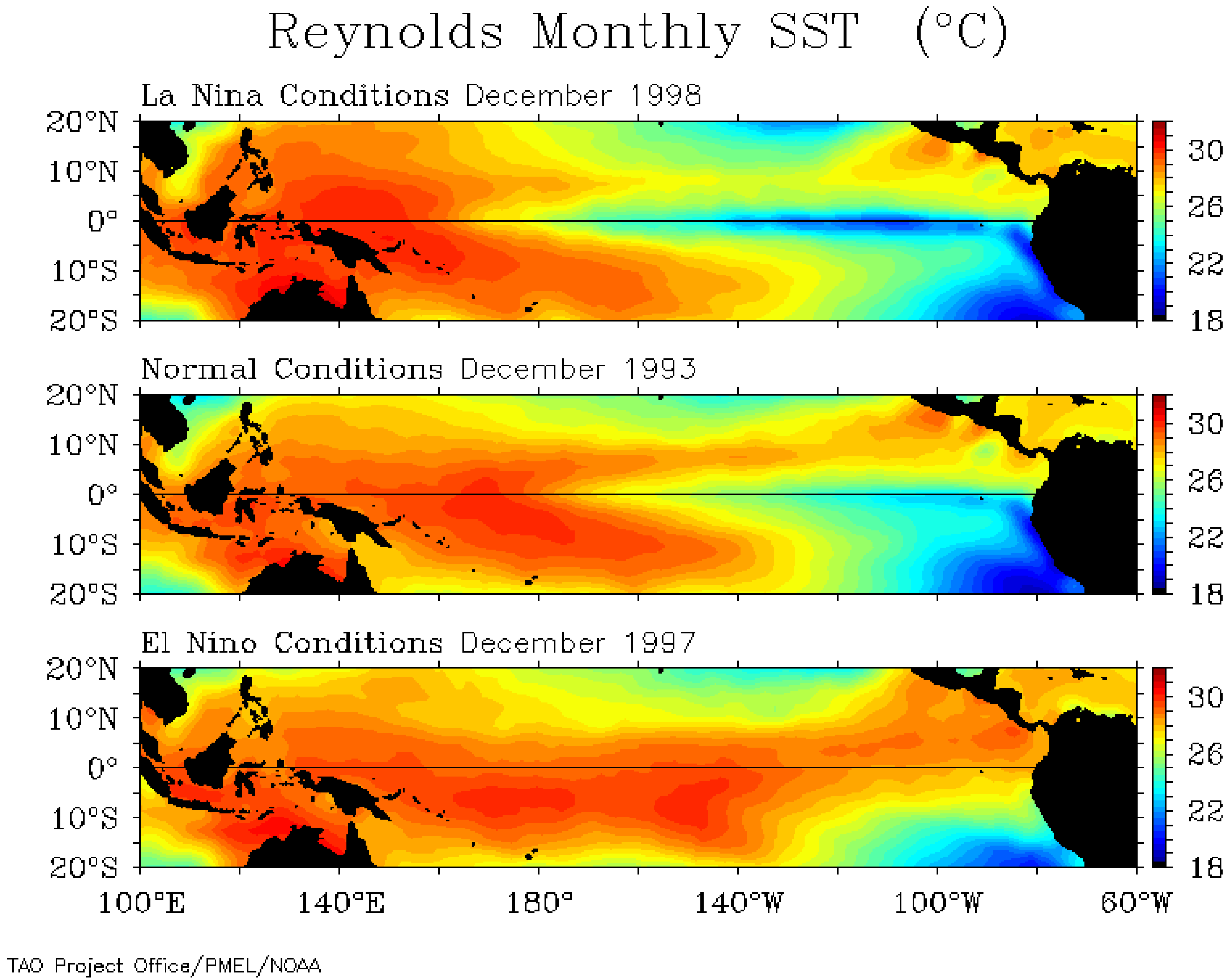
$$\text{SOI} \propto \frac{(\text{Tahiti - Darwin})}{\text{SD (T-D)}}$$

Southern Oscillation Index

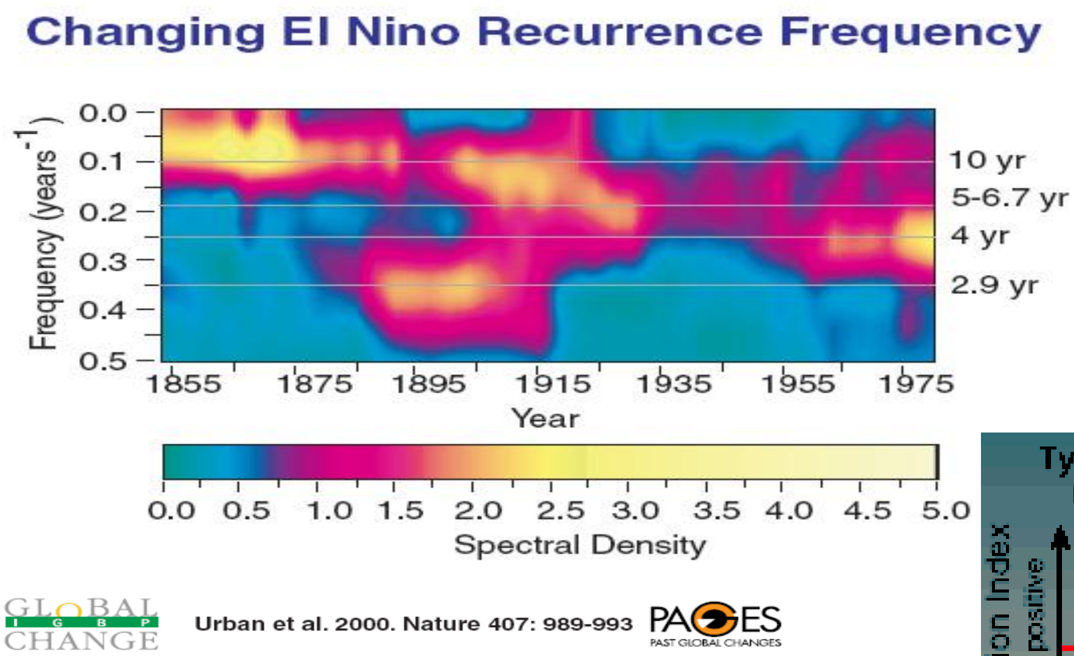
El Niños are progressively becoming more frequent and warmer in the last decades. The 1997-98 El Niño was the most intense in the last 40 years, and it developed more rapidly than any other.

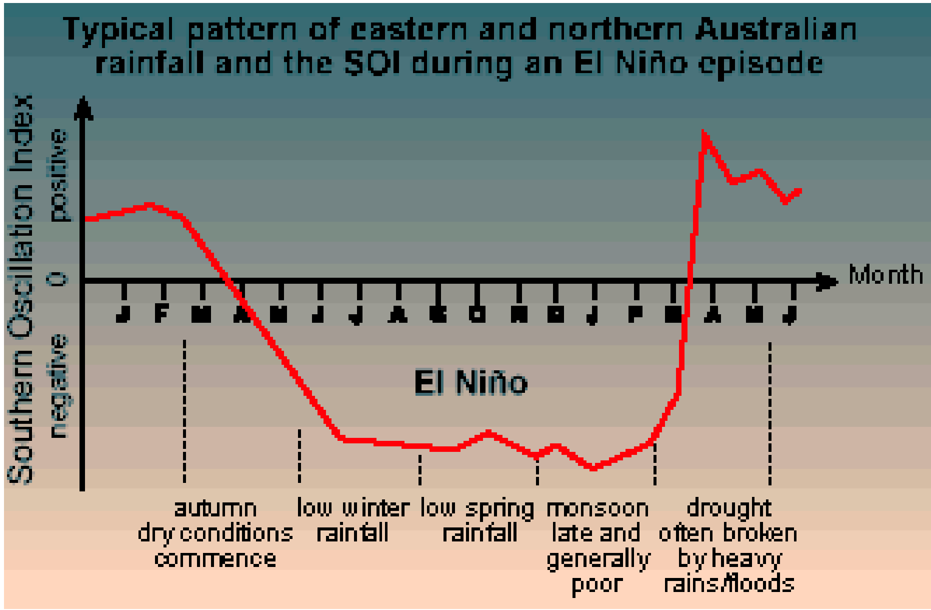




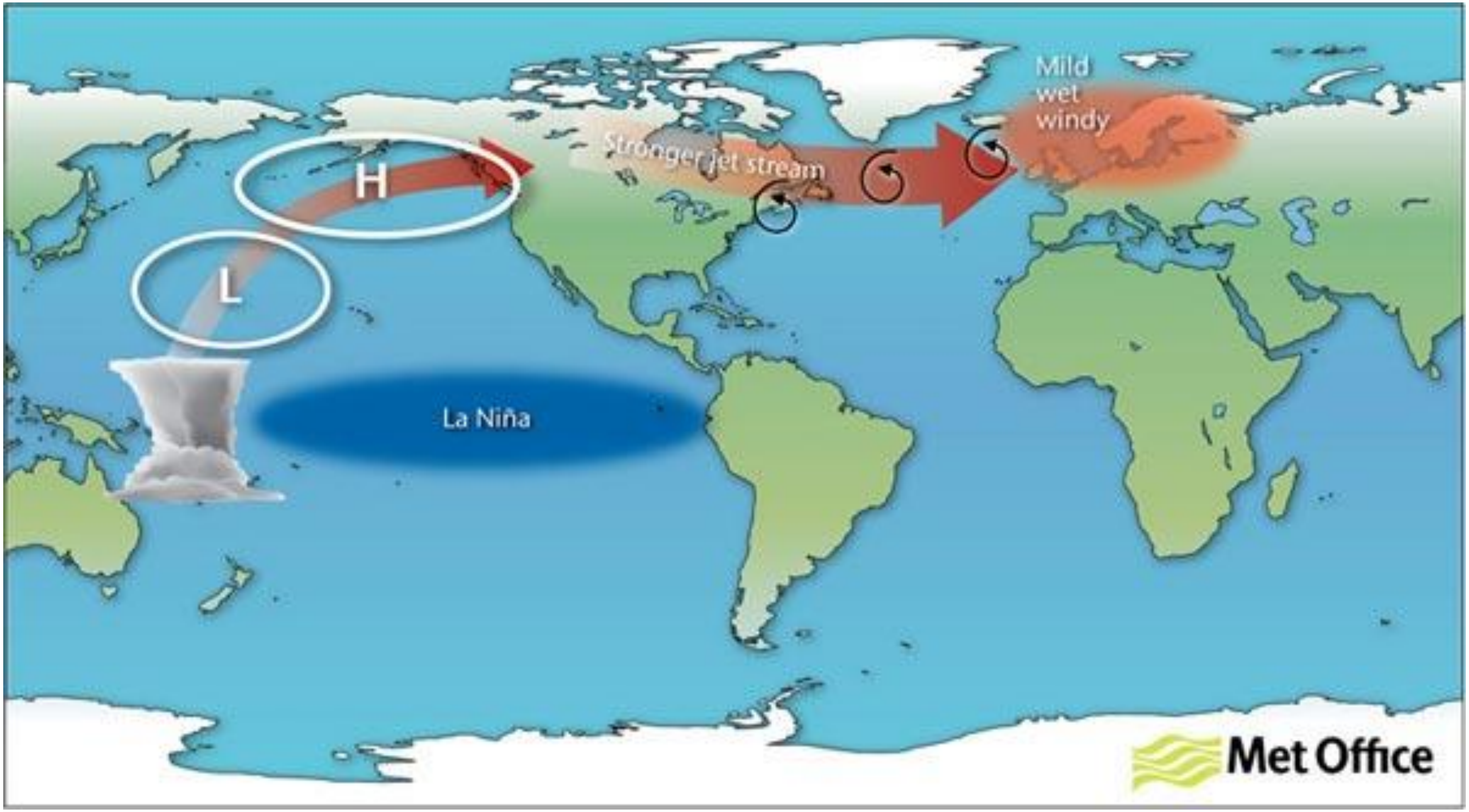

Reynolds Monthly SST (°C)
La Nina Conditions December 1998
Normal Conditions December 1993
El Nino Conditions December 1997
20°N
10°N
0°
10°S
20°S
100°E
140°E
180°
140°W
100°W
60°W
30
26
22
18
TAO Project Office/PMEL/NOAA

➢ ENSO includes El-Niňo and La-Niňa, it has a periodicity between 2 and 7 years and lasts for 12-18 months. The effects of ENSO are not completely predictable.



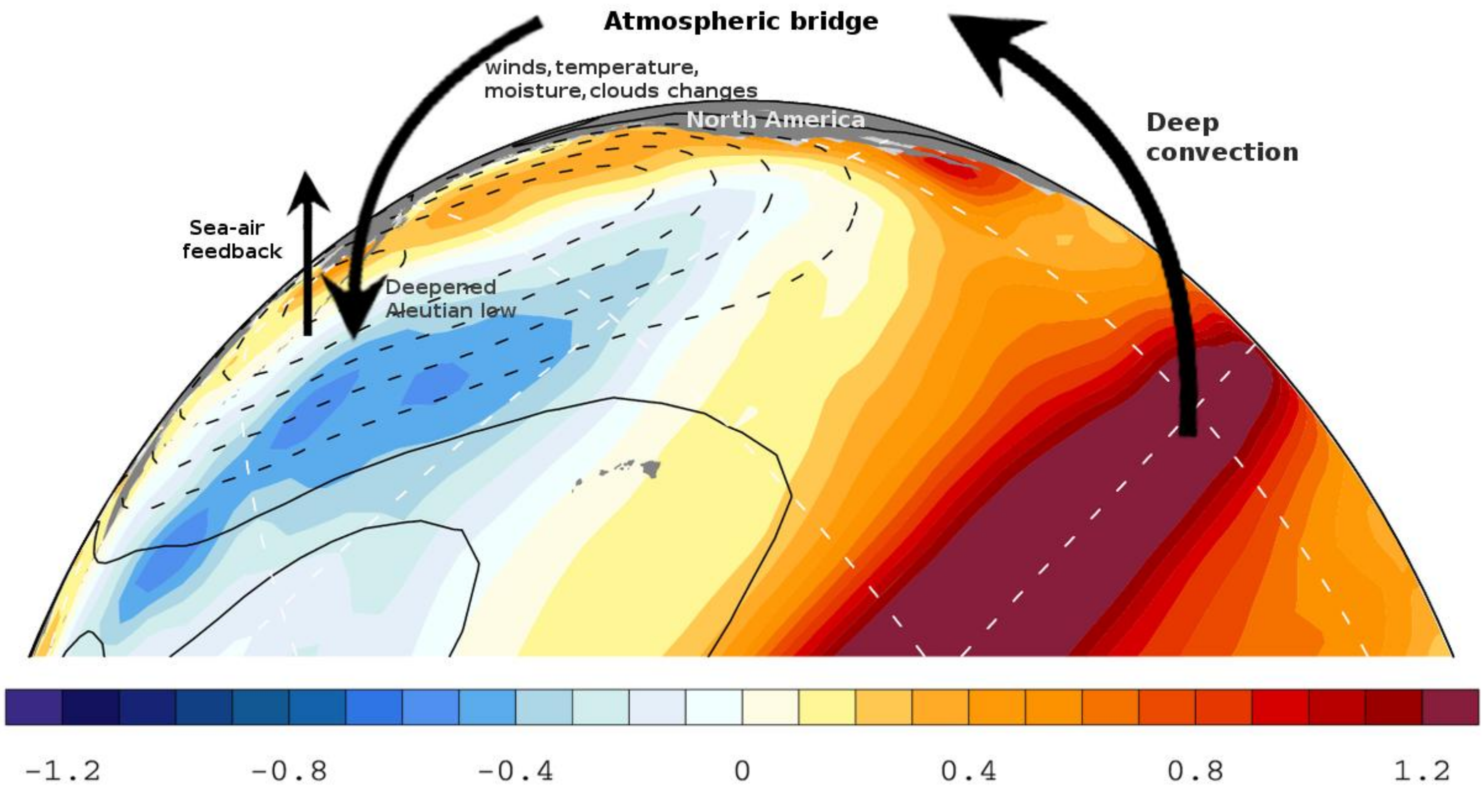


ENSO may be influenced by other ocean-atmosphere cycles such as the North Atlantic Oscillation and the Pacific Decadal Oscillation. There is increasing recognition of El Niño connections with atmospheric and oceanic conditions outside of the Pacific. **These connections are known as teleconnections.**



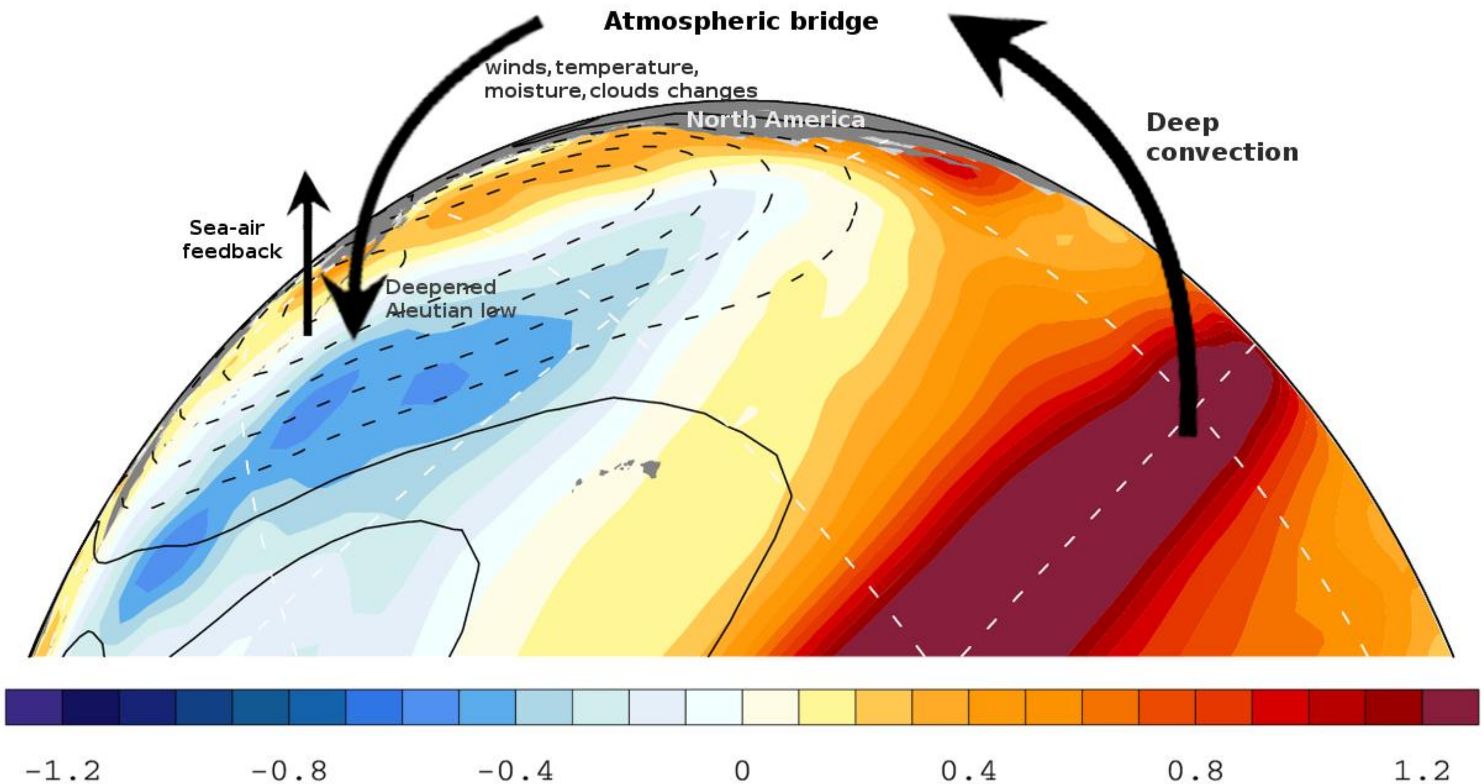
ENSO teleconnections, **the atmospheric bridge**

ENSO can influence the global circulation pattern thousands of kilometers away from the equatorial Pacific through the **"atmospheric bridge"**.
During El Nino events, deep convection and heat transfer to the troposphere is enhanced over the anomalously warm sea surface temperature, this ENSO-related tropical forcing generates Rossby waves that propagate poleward and eastward and are subsequently refracted back from the pole to the tropics.



ENSO teleconnections, **the atmospheric bridge**

The planetary waves form at preferred locations both in the North and South Pacific Ocean, and the teleconnection pattern is established **within 2–6 weeks**.
ENSO driven patterns modify surface temperature, humidity, wind, and the distribution of clouds over the North Pacific that alter surface heat, momentum, and freshwater fluxes and thus induce sea surface temperature, salinity, and mixed layer depth (MLD) anomalies.



The Pacific–North American teleconnection pattern (PNA)

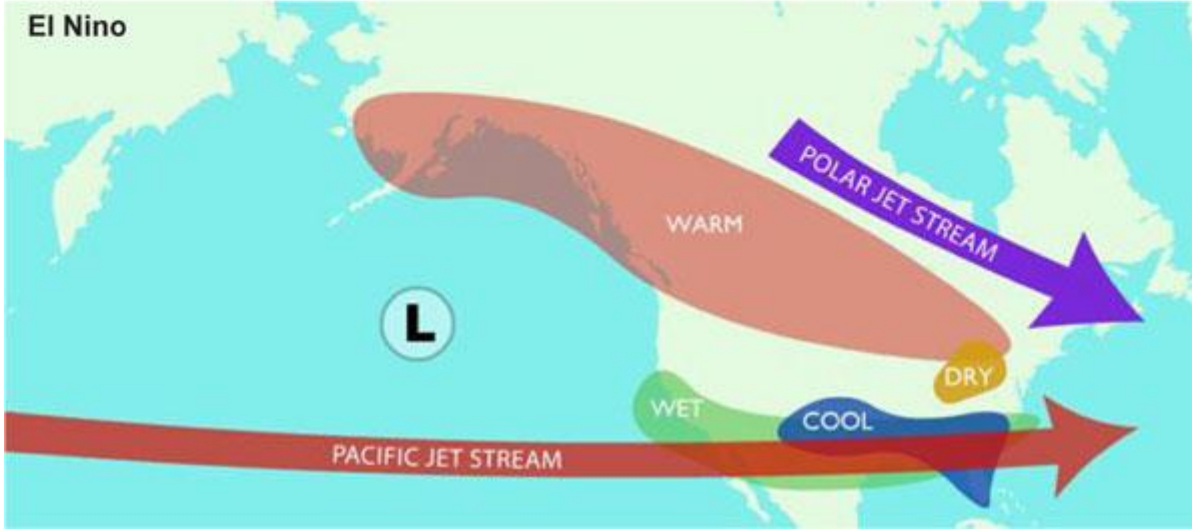
PNA is a climatological term for a large-scale weather pattern with two modes, denoted **positive and negative**, and which relates the atmospheric circulation pattern over the North Pacific Ocean with the one over the North American continent. The PNA pattern is associated with strong fluctuations in the strength and location of the East Asian jet stream.

Although the PNA pattern is a natural internal mode of climate variability, it is also strongly influenced by the El Niño-Southern Oscillation (ENSO) phenomenon.

The positive phase of the PNA pattern tends to be associated with Pacific warm episodes (El Niño), and the negative phase tends to be associated with Pacific cold episodes (La Niña).

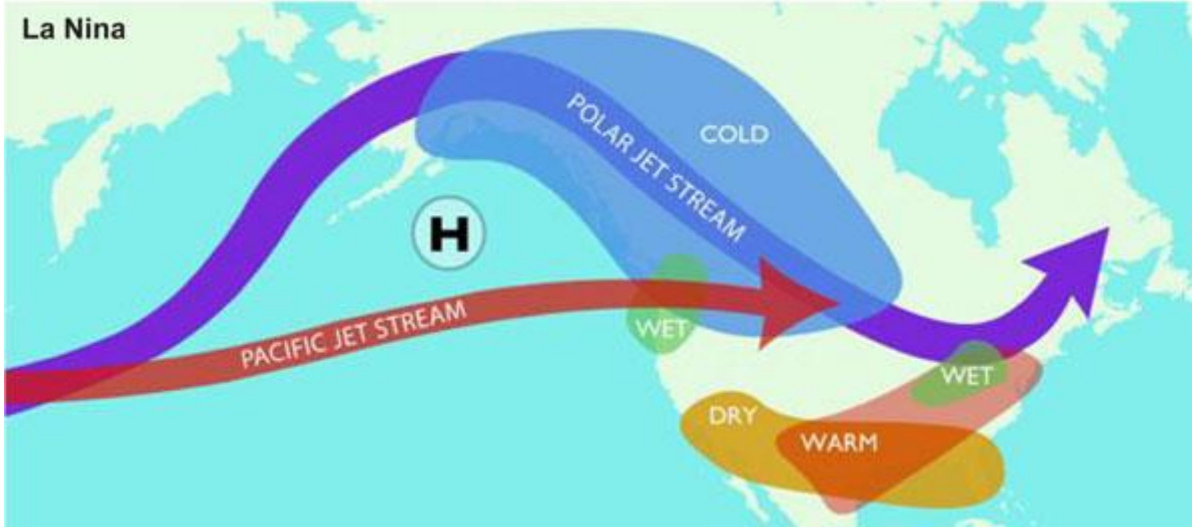
Positive phase of the PNA:

- Above-average barometric pressure heights in the vicinity of Hawaii and over the inter-mountain region of North America .
- Below-average heights located south of the Aleutian Islands and over the southeastern United States.
- Enhanced East Asian jet stream and with an eastward shift in the jet exit region toward the western United States.



Consequenses:

- ✓ Above-average temperatures over western Canada and the extreme western US.
- ✓ Below-average temperatures across the south-central and southeastern US.
- ✓ Above-average precipitation totals in the Gulf of Alaska extending into the Pacific Northwestern US.
- ✓ Below-average precipitation totals over the upper Eastern US.



Negative phase of the PNA:

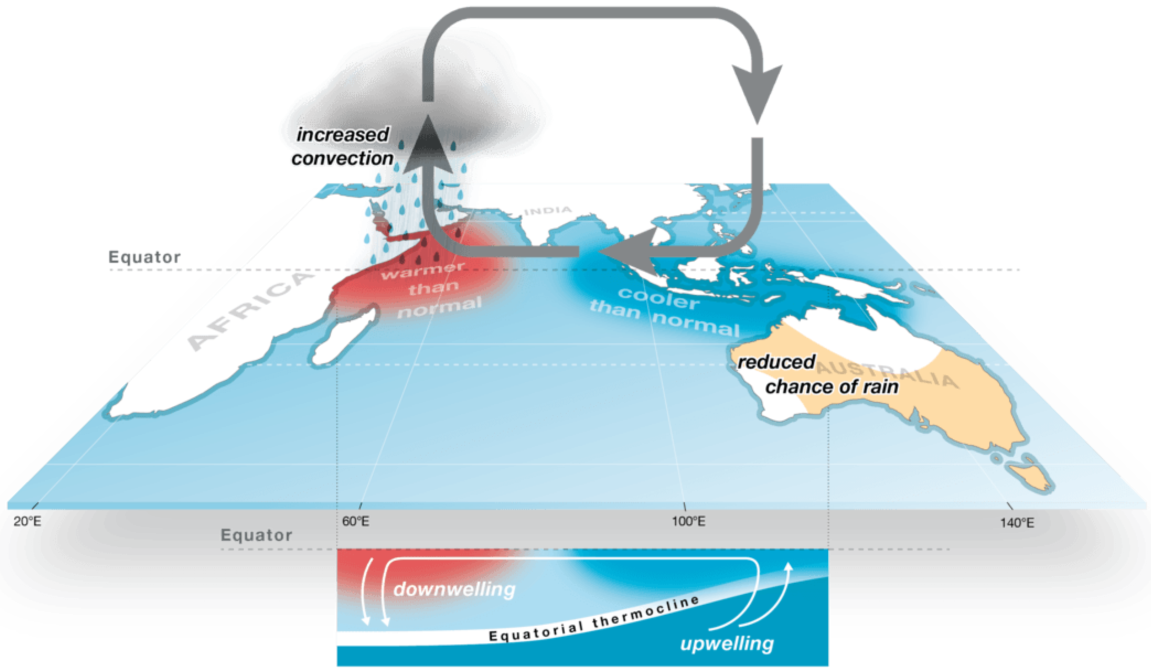
- Westward retraction of that jet stream toward eastern Asia.
- Blocking activity over the high latitudes of the North pacific.
- Strong split-flow configuration over the central North Pacific.

Consequenses:

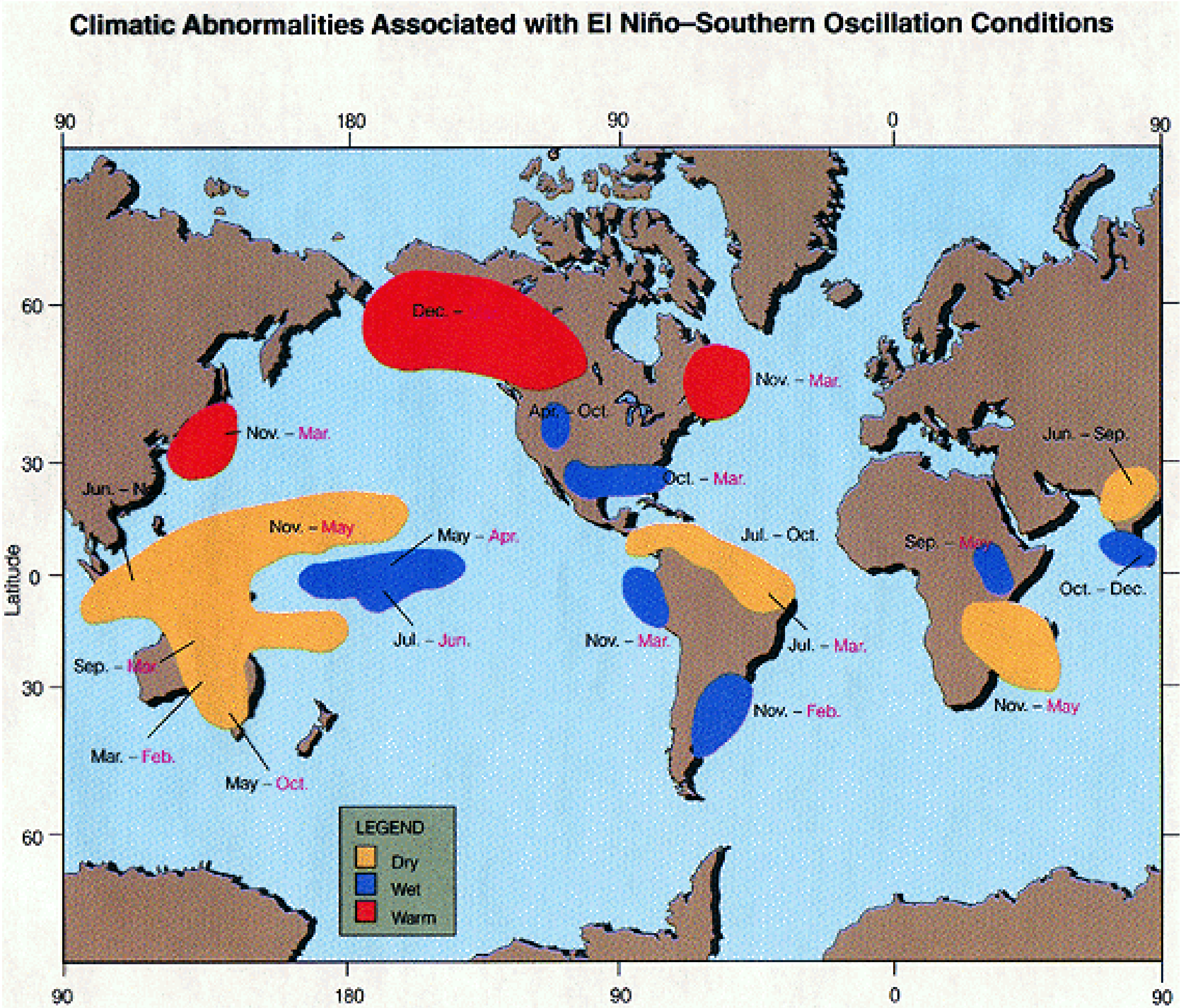
- ✓ Below-average temperatures over the Canada and the extreme western United States.
- ✓ Above-average temperatures across the south-central and eastern US.
- ✓ Below-average precipitation totals in the southern US.
- ✓ Above-average precipitation totals over parts of the north western and eastern US.

Indian Ocean Dipole (IOD)

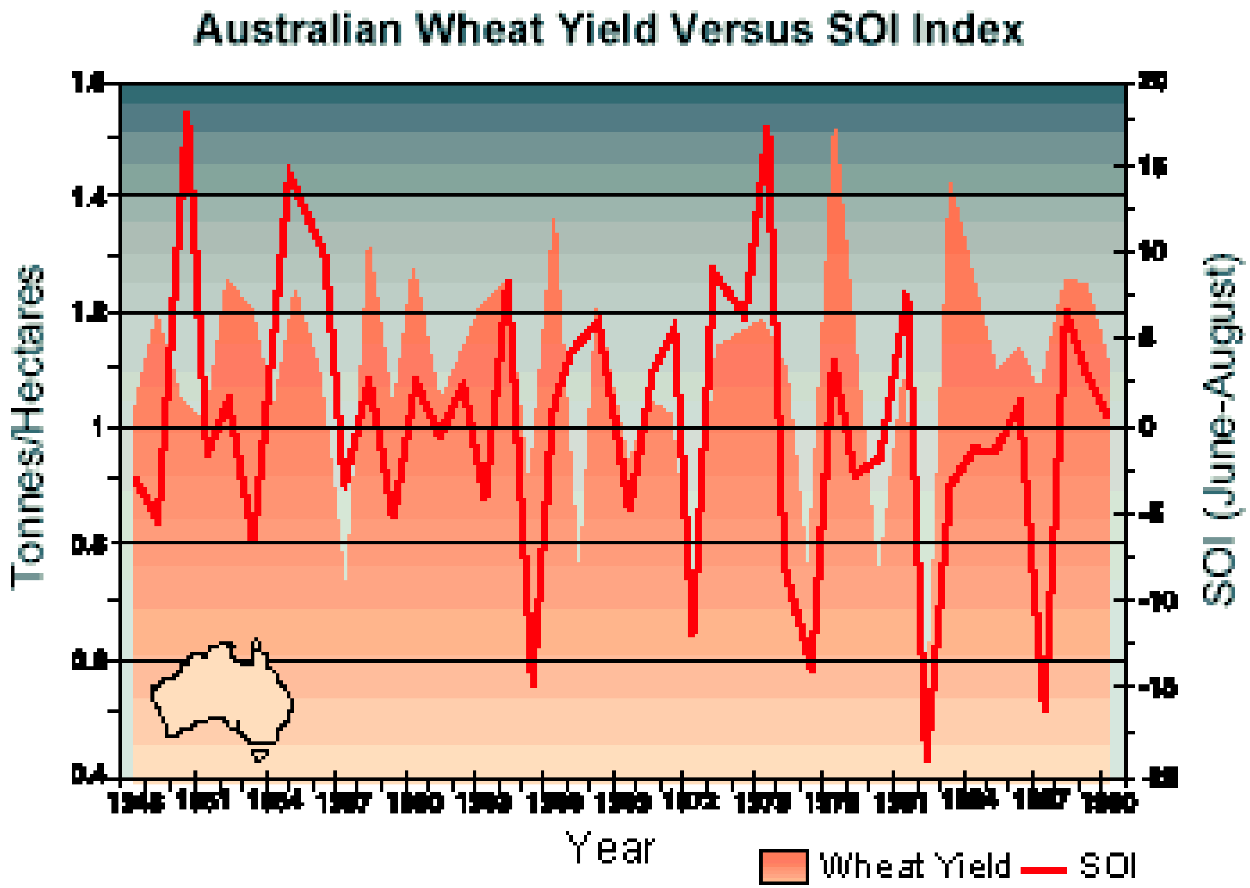
Positive phase



Australian Government
Bureau of Meteorology


Climatic Abnormalities Associated with El Niño–Southern Oscillation Conditions
90
180
90
0
90
Latitude
60
30
0
30
60
Dec. –
Nov. – Mar.
Apr. – Oct.
Oct. – Mar.
Nov. – Mar.
Jun. – Sep.
Nov. – May
May – Apr.
Jul. – Oct.
Sep. – May
Oct. – Dec.
Jul. – Jun.
Nov. – Mar.
Jul. – Mar.
Sep. – Mar.
Nov. – Feb.
Nov. – May
Mar. – Feb.
May – Oct.
LEGEND
Dry
Wet
Warm

Climatic side effects



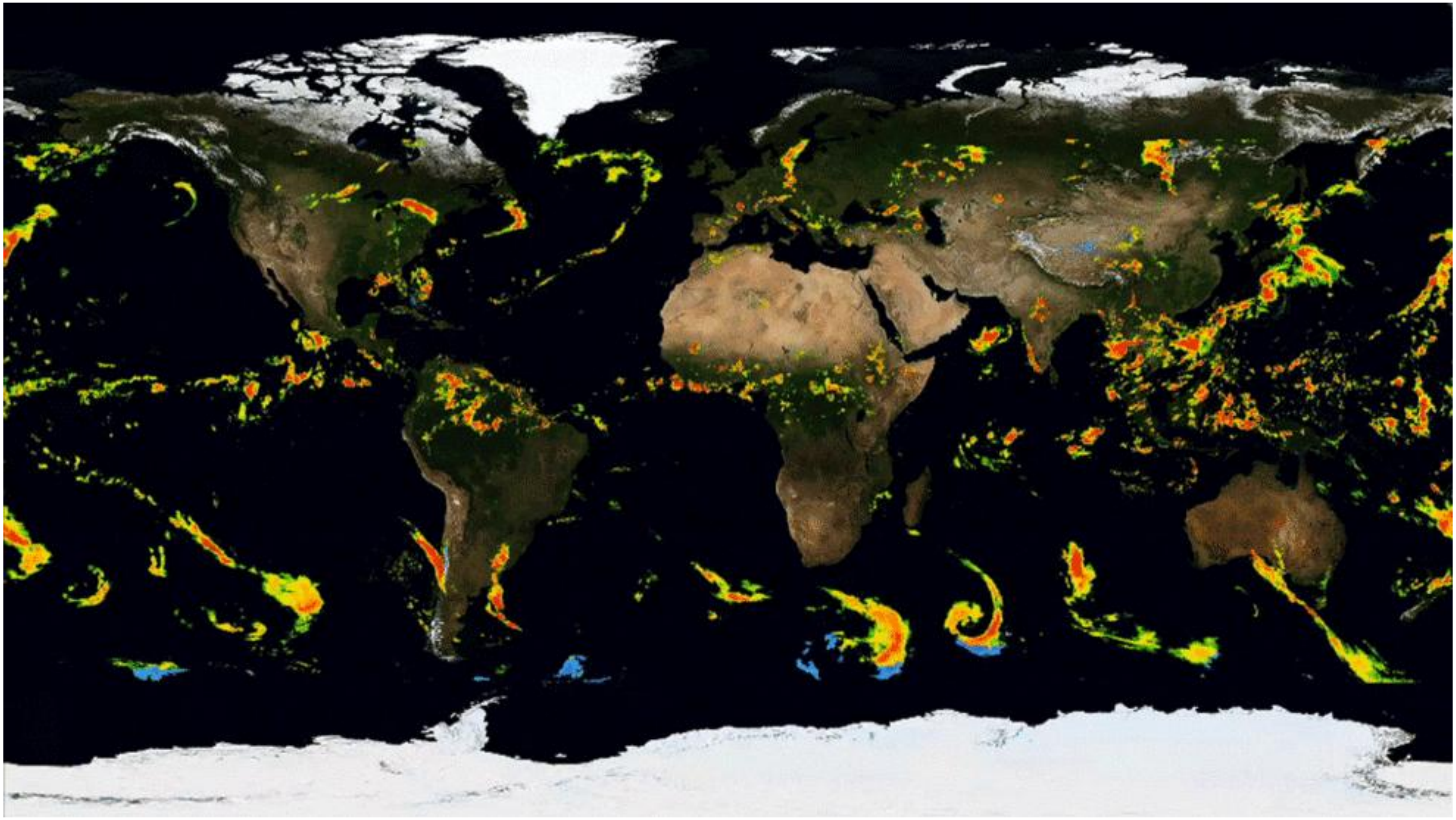
ENSO impacts on rainfall

✓ Induced changes in rainfall patterns across the globe (subsequent flooding, landslides and droughts

✓ NON El Niño: Evaporation of warm ocean water → increase of air moisture → trigger annual monsoons in South Asia

✓ El Niño: Water at SE Asia and Australia is cooler than normal → often drought / Water remains warm near S. America → often triggers storms and flooding / Southern US tend to receive more rain

The Global Precipitation Measurement mission (GPM), a joint effort of NASA and Japan Aerospace eXploration Agency, tracks precipitation worldwide and creates global precipitation maps updated every half-hour using data from a host of satellites.

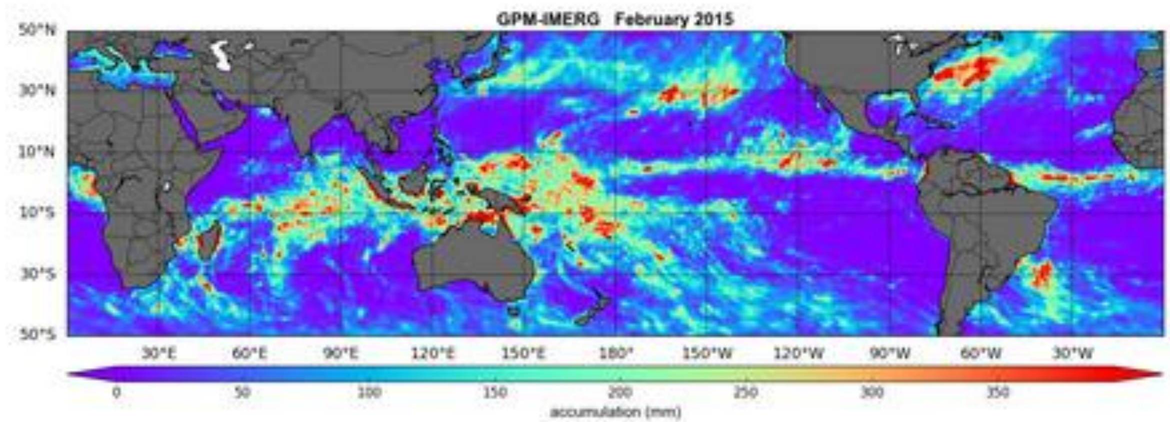


Credit: NASA Goddard's Scientific Visualization Studio

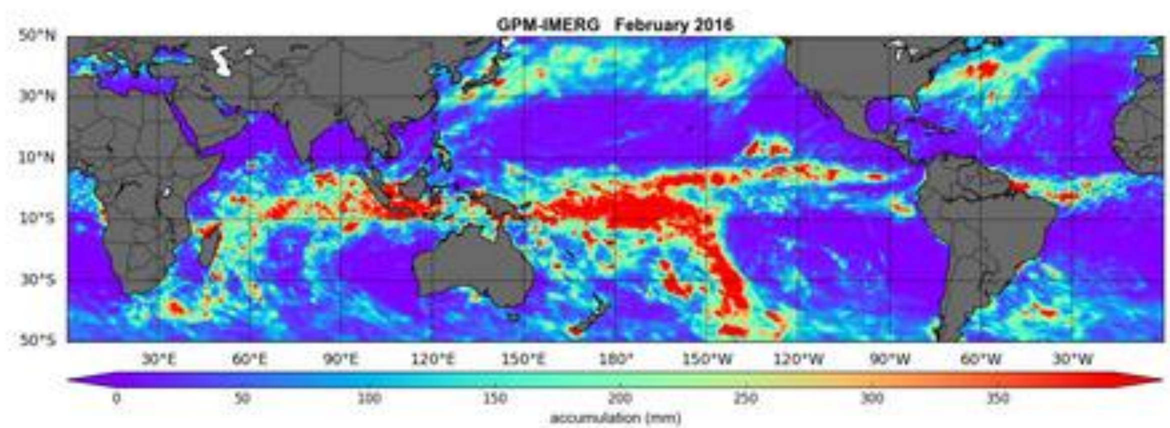
During 2014-2015 winter, the majority of the precipitation near the equator in the Pacific was concentrated westward of 180-degrees longitude.

This year (2015-2016 winter) the tropical precipitation has been concentrated further eastwards, in response to the warmer waters.

February 2015



February 2016

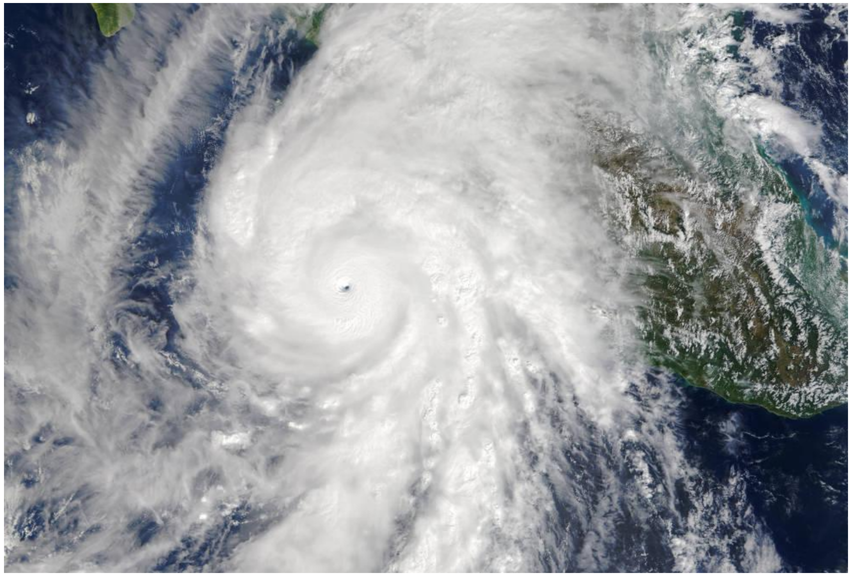


ENSO impacts on hurricanes

✓ El Niño: change in the formation of tropical storms → fewer hurricanes in the Atlantic, more hurricanes and typhoons in the Pacific.

✓ Tropical cyclones typically grow stronger over warm water and dissipate over cold water. During El Niño, the average temperature in the Pacific is warmer than normal and aids the formation of tropical storms.

✓ The 2015 hurricane season in the North Pacific was particularly busy, partially due to this year's El Niño.



The Moderate Resolution Imaging Spectroradiometer (MODIS) instrument on NASA's Terra satellite captured Hurricane Patricia— the 9th hurricane in the E. Pacific to reach categories 4-5 status during 2015

Credit: NASA's Earth Observatory

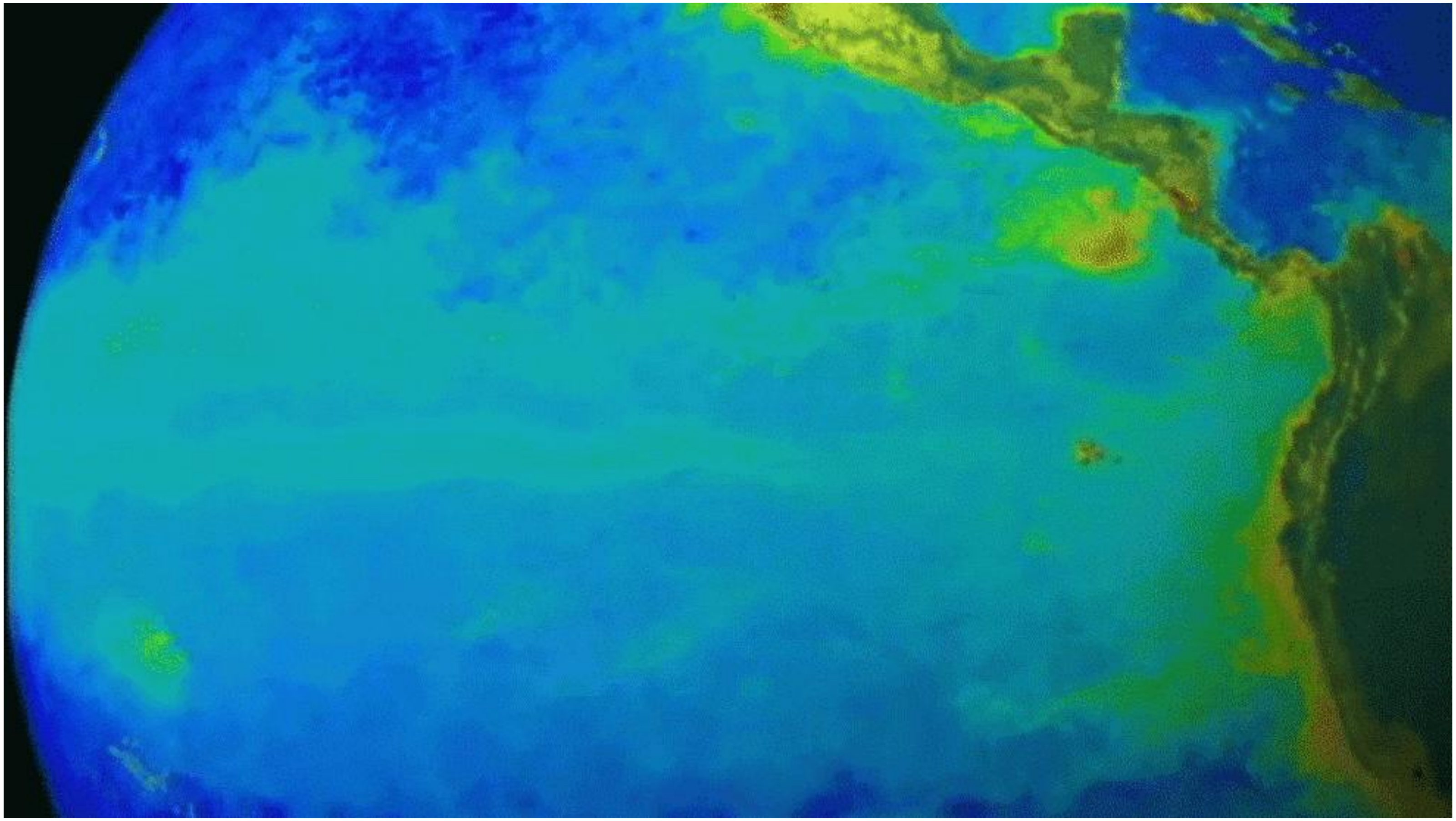
ENSO impacts on ocean ecology

✓El Niño affects the marine food web, as evidenced in the color of the ocean— the water hue is influenced by the presence of tiny plants, sediments and colored dissolved organic material.

✓ NON El Niño: Deep ocean waters upwell in the eastern Equatorial Pacific → nutrient-rich, cold water is brought to the surface → abundant nutrients and sunlight aids phytoplankton productoin → microscopic algae, the base of the marine food web, grows up.

✓ El Niño: Upwelling is suppressed → deep, nutrient-rich waters do not reach the surface → less phytoplankton productivity → fish population declines → animals up the food chain starve.

In the visualization below from NASA's Sea-Viewing Wide Field-of-View Sensor (SeaWIFS) instrument, there is a decline in (surface chlorophyll) phytoplankton during the El Niño of 1997-'98 and an increase during the La Niña event of 1998-99.



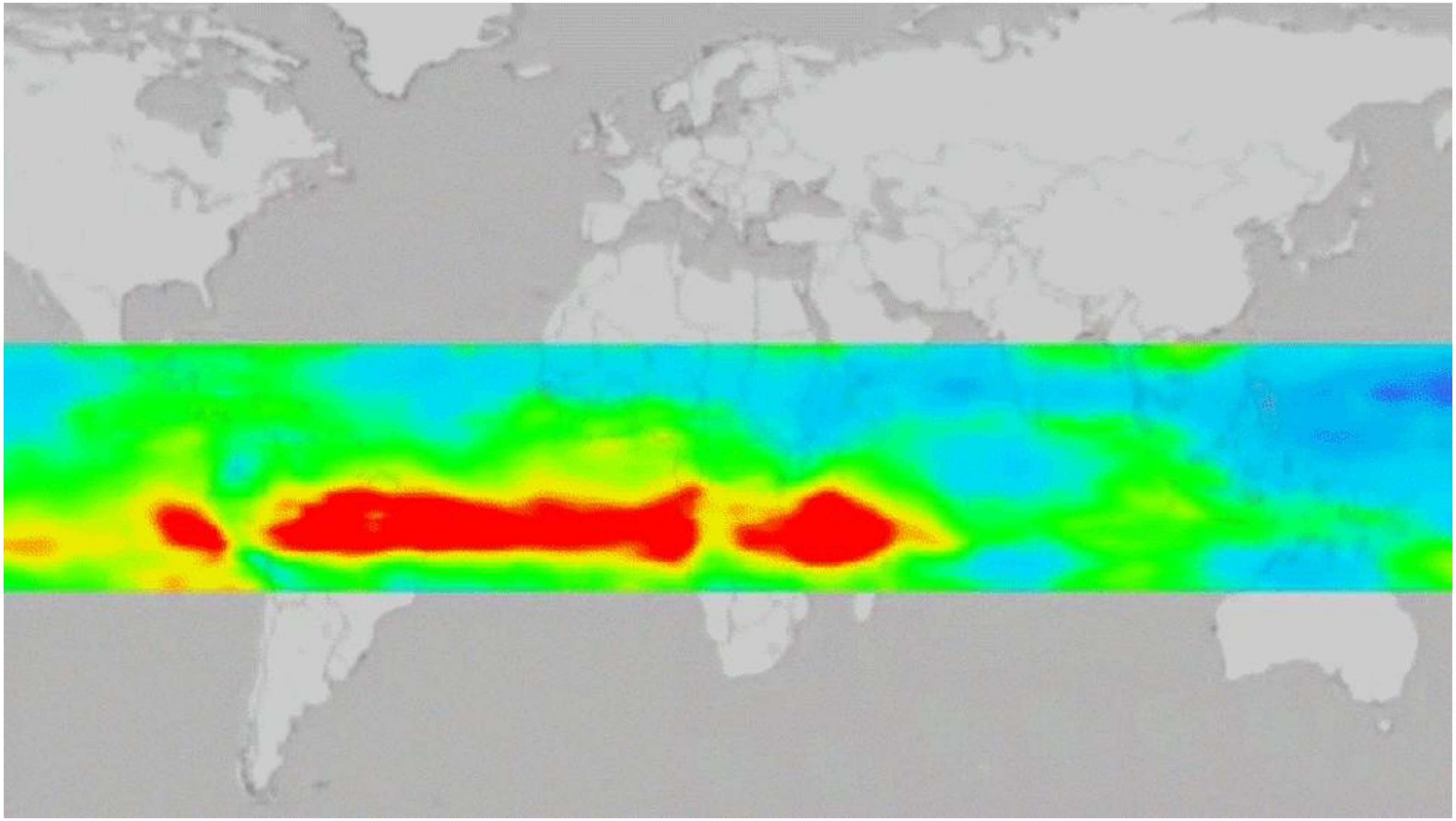
Credit: NASA Goddard's Scientific Visualization Studio

ENSO impacts on ozone

✓El Niño: change in the major east-west tropical circulation → significant redistribution of atmospheric gases like ozone.

✓ These changes occur vertically throughout the troposphere / higher ozone levels over Indonesia and lower levels over much of the tropical central and eastern Pacific Ocean

With more than a decade of Aura data, researchers are able to separate the response of ozone concentrations to an El Niño from its response to changes in human activity, such as manmade fires. They are learning how it modifies ozone concentrations in the stratosphere, sometimes changing concentrations in the tropics by about 15 percent.



[Credit: NASA Goddard's Scientific Visualization Studio]

ENSO impacts on fires

✓ El Niño: shift patterns of rainfall and fire across the tropics → the number and intensity of fires increases, especially under drought conditions in regions accustomed to wet weather.

✓ During past El Niño events, Indonesia, Central America and the southern and central Amazon experienced more fire activity than normal.

✓ Due to fires, GHGs, carbon dioxide and methane are emitted → heat in the atmosphere is trapped → global warming .

✓ During the 2002 and 2006 El Niño events, fire emissions in equatorial Asia increased by a factor of 10.

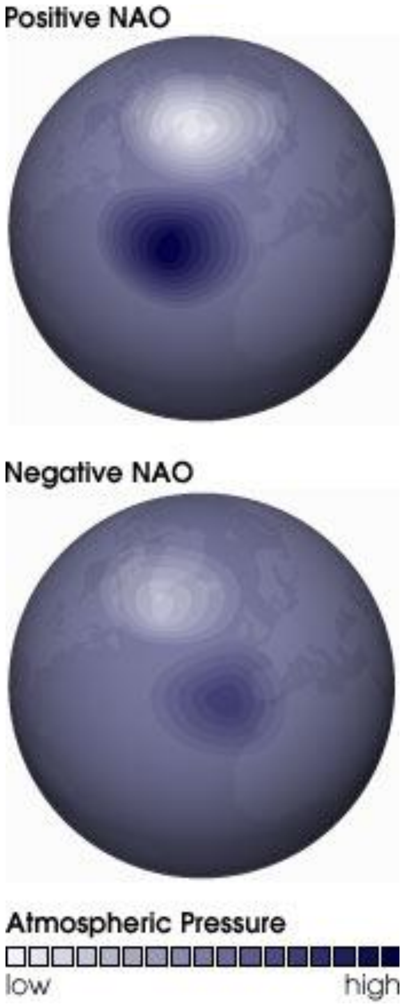
MODIS instruments on Aqua and Terra satellites provide a global picture of fire activity. The long time series of MODIS data (2000-present) now covers a strong El Niño event, linking estimates of changing fire activity to the amounts of particles and gases that fires release into the atmosphere.

[Credit: NASA Goddard's Scientific Visualization Studio]

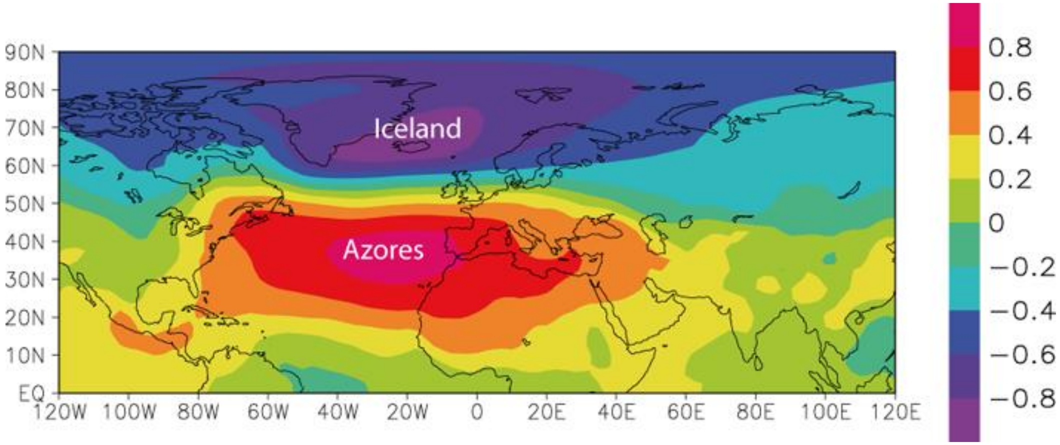
North Atlantic Oscillation - NAO

North Atlantic pressure systems setting

- ✓ Azores high and Icelandic Low are the central pressure systems of action in the area
- ✓ They both weaken or strengthen periodically
- ✓ There is a tendency among them to be negatively correlated
- ✓ They cause westerly wind



North Atlantic pressure systems setting



Winter SLP (averaged over December, January, and February). http://climexp.knmi.nl/ (Oldenborgh et al., 2004) using NCEP-NCAR reanalysis.

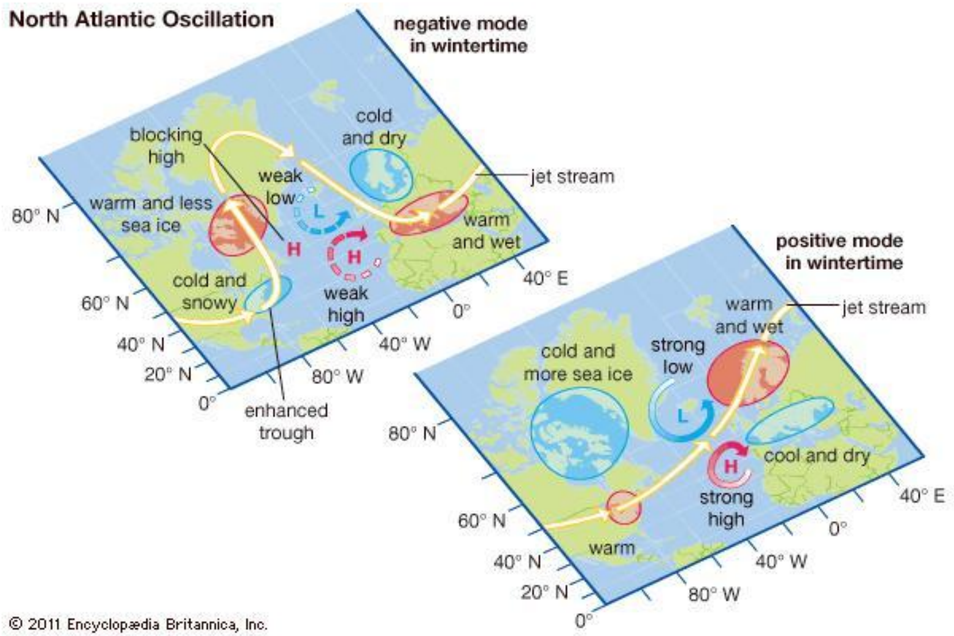
✓Westerly winds blowing across the Atlantic bring moist air into Europe.

✓In years when westerlies are strong, summers are cool, winters are mild and rain is frequent.

✓If westerlies are suppressed, the temperature is more extreme in summer and winter leading to heat waves, deep freezes and reduced rainfall.

Changes in the mass and pressure fields lead to variability in the strength and pathway of storm systems crossing the Atlantic from the US East coast to Europe.

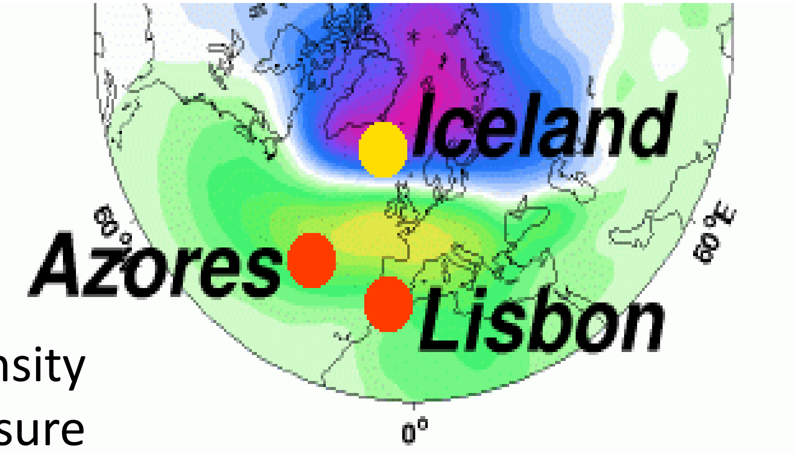
The North Atlantic Oscillation



The irregular fluctuation of intensity and location between the two pressure systems (Azores High and Icelandic Low) and its subsequent changes in atmospheric mass pathways which alternates between the polar and subtropical regions, defines the North Atlantic Oscillation.

NAO is most noticeable during the winter season (November - April) with maximum amplitude and persistence in the Atlantic sector.

The NAO Index

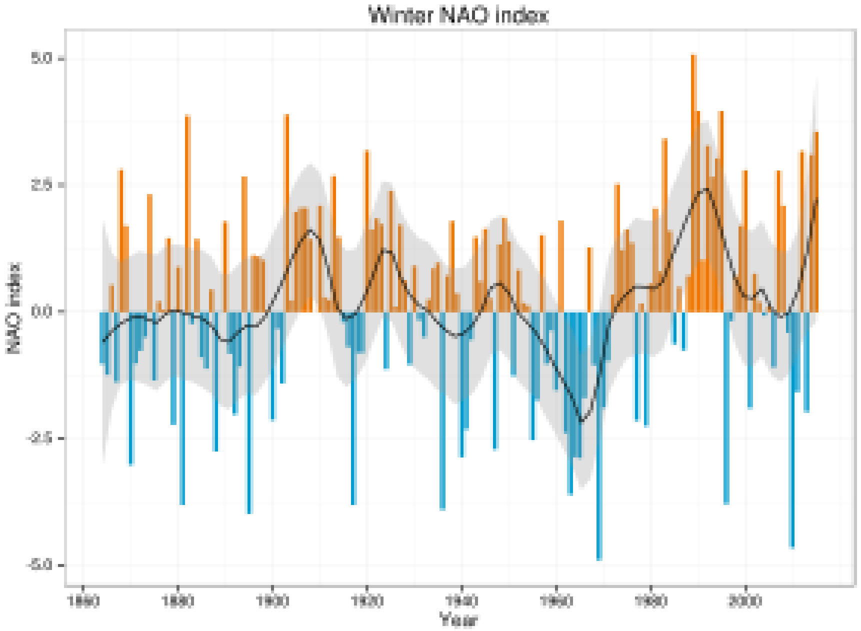


The easiest way to track changes in NAO intensity is by measuring the seasonal average air pressure difference between two stations:

Stykkisholmur/Reykjavík vs Lisbon
Stykkisholmur/Reykjavík vs Ponta Delgada
Stykkisholmur/Reykjavík vs Azores
Stykkisholmur/Reykjavík vs Gibraltar

These definitions all have in common the same northern point (because this is the only station in the region with a long record) in Iceland; and various southern points. Because of the longer time series available, the station in the Azores is sometimes replaced by Lisbon.

The NAO Index



Interannual signal

Decadal variability (quite strong at the beginning and end of the 20th century)

The recent 30 years trend possibly linked to "global warming".

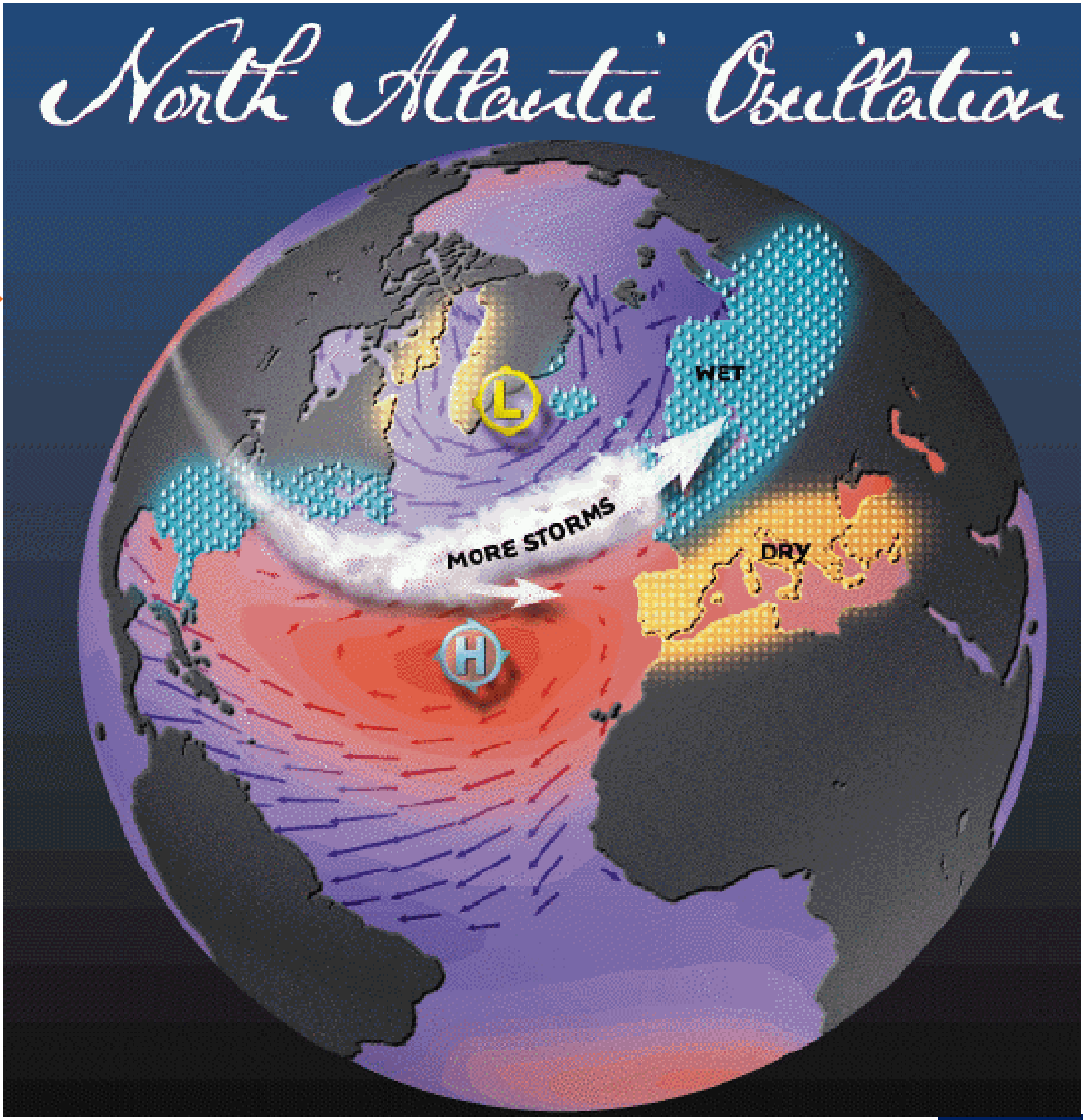
Winter index of the NAO based on the difference of normalized sea level pressure (SLP) between Lisbon,Portugal and Stykkisholmur/Reykjavík, Iceland since 1864, with a loess smoothing (black).

The twice daily reading are averaged from November through March and the difference in then the winter NAO index.

The positive NAO phase

At a glance

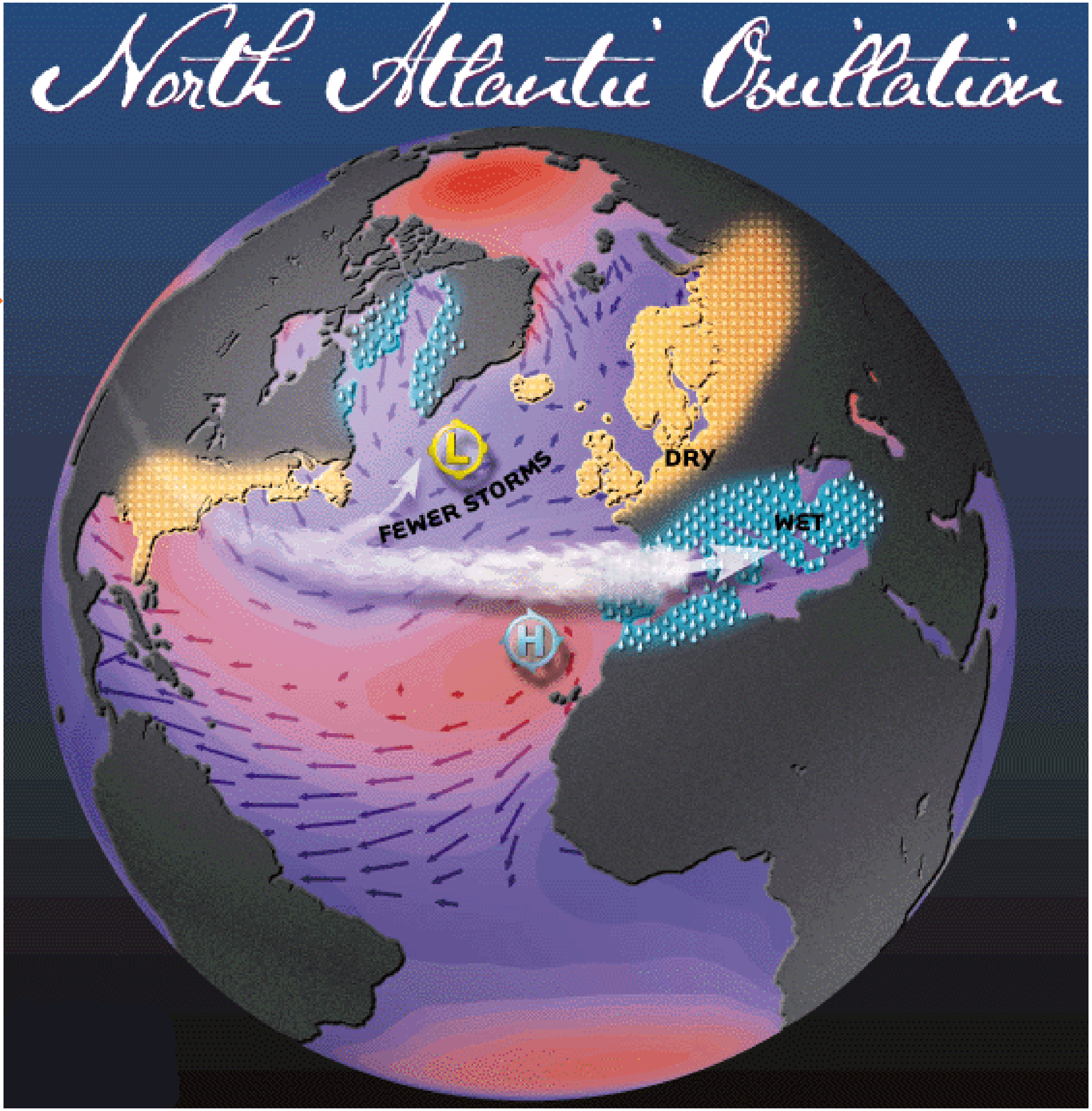
- Azores High strong
- Icelandic Low deep
- increased westerlies
- cool summers and mild and wet winters in Central-NW Europe
- dry conditions in Med and N Africa
- Dry and cold in N Canada and Greenland
- Eastern USA wet and mild

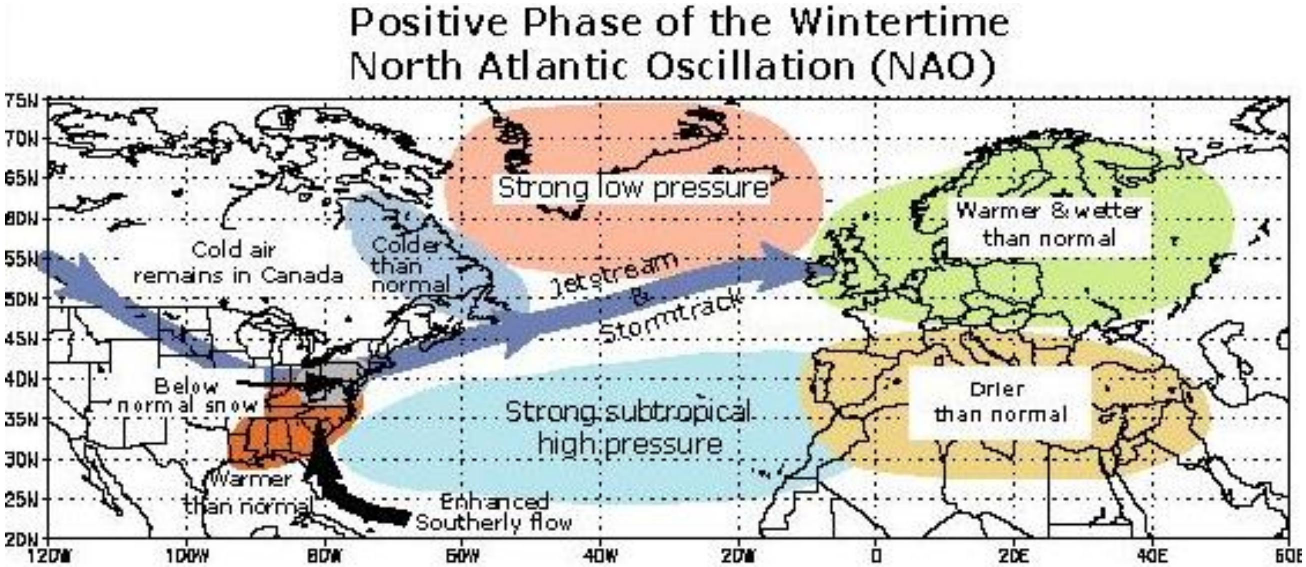


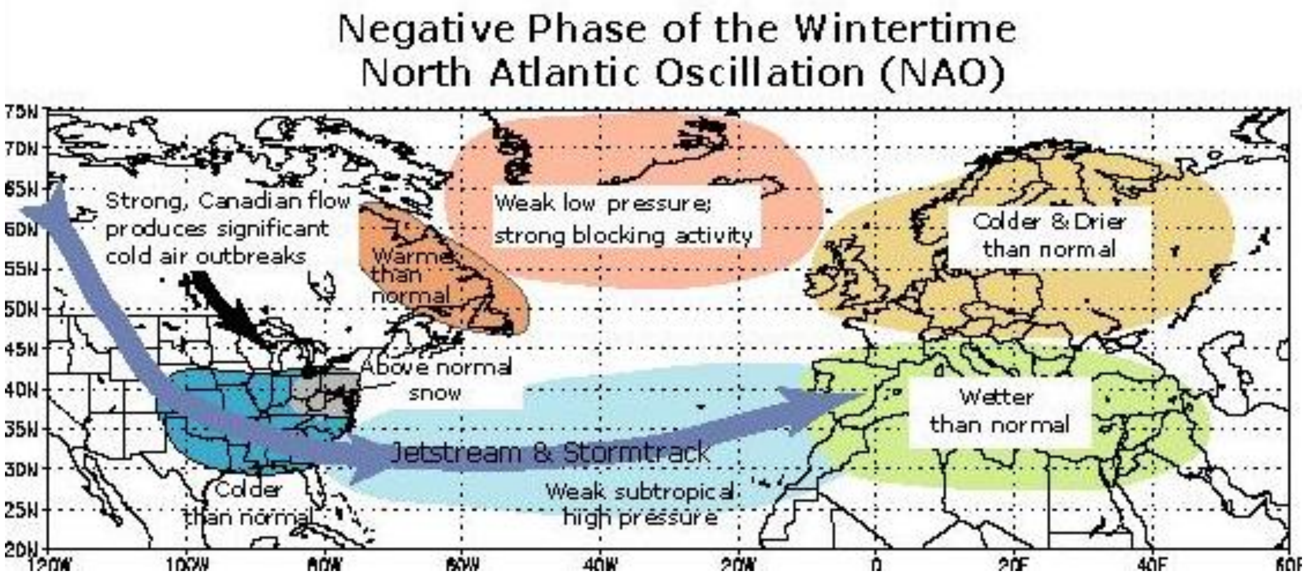
The negative NAO phase

At a glance

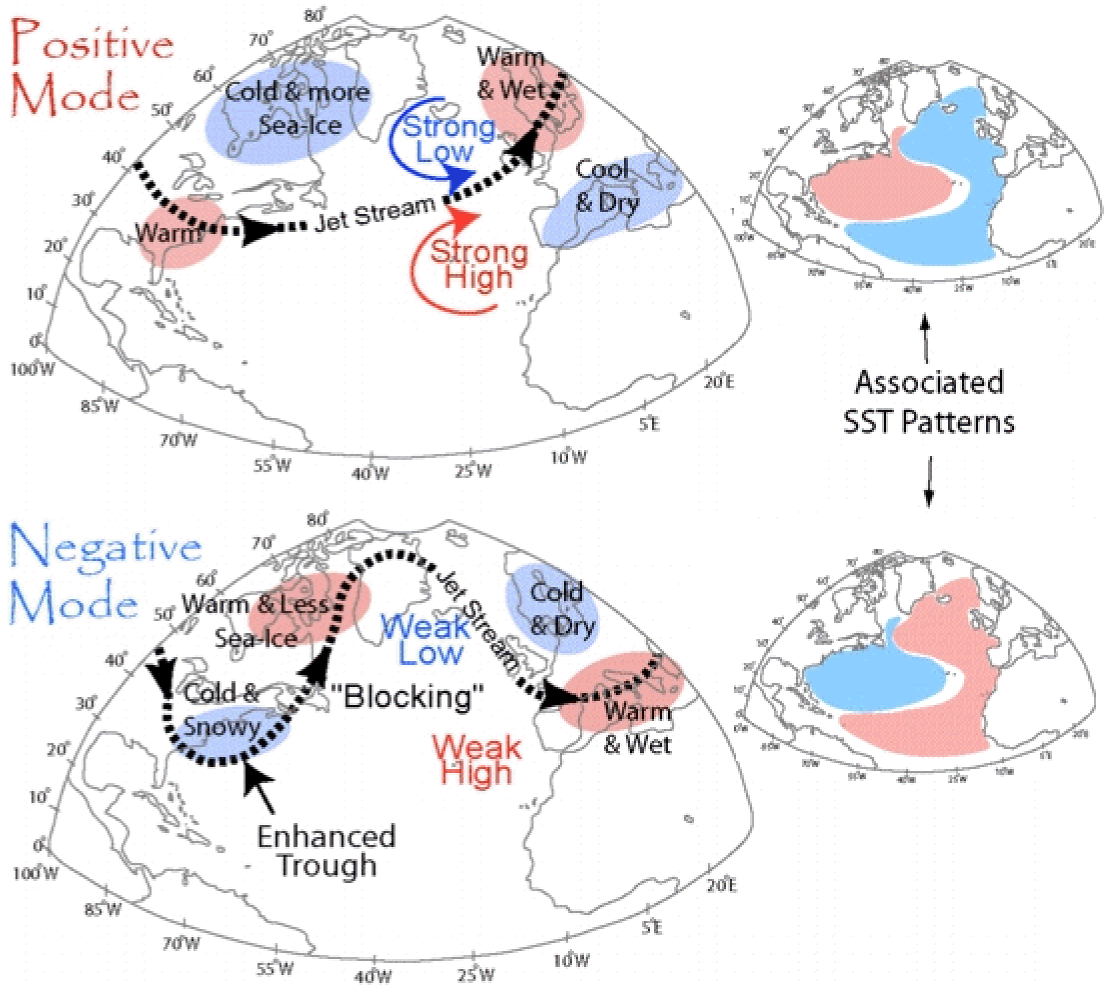
- Azores high weak
- Icelandic Low shallow
- suppressed westerlies
- N-NW Europe suffers cold dry winters
- storms track southwards toward the Mediterranean
- increased storm activity and rainfall to S Europe and North Africa.
- US east coast cold outbreaks and snow
- Greenland mild conditions




Positive Phase of the Wintertime
North Atlantic Oscillation (NAO)
Strong low pressure
Warmer & wetter than normal
Cold air remains in Canada
Colder than normal
Jetstream & Stormtrack
Below normal snow
Strong subtropical high pressure
Drier than normal
Warmer than normal
Enhanced Southerly flow
75N
70N
65N
60N
55N
50N
45N
40N
35N
30N
25N
20N
120W
100W
80W
60W
40W
20W
0
20E
40E


Negative Phase of the Wintertime
North Atlantic Oscillation (NAO)
Strong, Canadian flow produces significant cold air outbreaks
Weak low pressure; strong blocking activity
Colder & Drier than normal
Warmer than normal
Above normal snow
Wetter than normal
Jetstream & Stormtrack
Colder than normal
Weak subtropical high pressure
75N
70N
65N
60N
55N
50N
45N
40N
35N
30N
25N
20N
120W
100W
80W
60W
40W
20W
0
20E
40E

Associated Sea Surface Temperature patterns



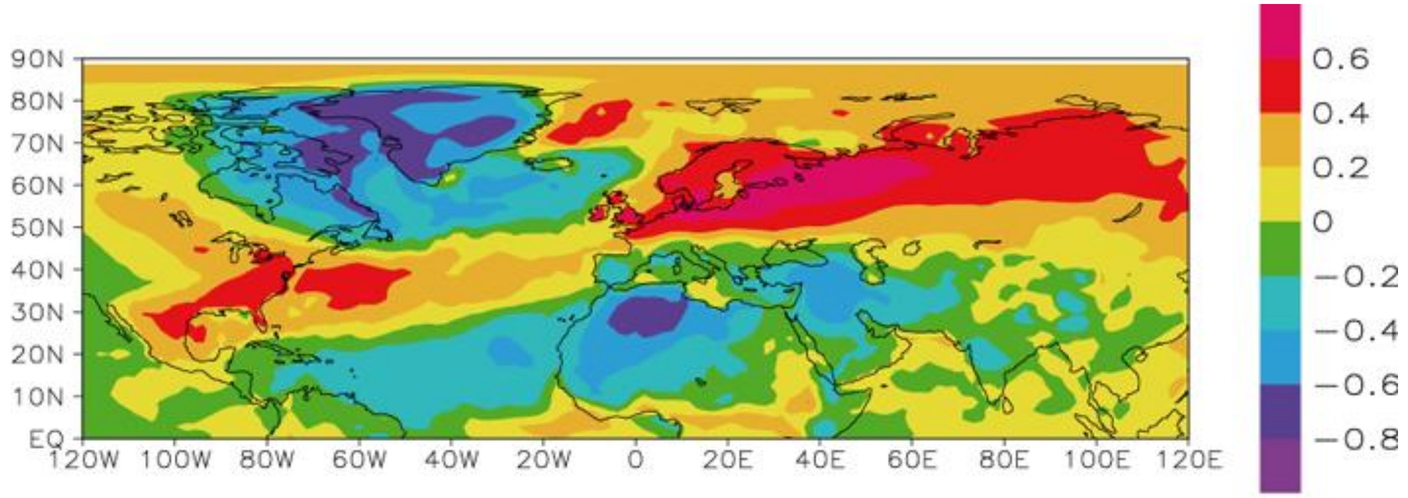
Associated Surface Air Temperature patterns

A tripole is associated with positive NAO index over the Atlantic Ocean:

✓ the temperature anomaly is positive around 30°-40°N

✓ the temperature anomaly is negative southward and northward of this latitude band.

The dominant cause of this pattern appears to be the air-sea interactions. Indeed, the SSTs tend to be lower in areas where the wind speed is higher, leading to higher evaporation rates and heat losses from the ocean to the atmosphere.



Correlation between the winter NAO index and the winter surface air temperature (averaged over December, January, and February).
http://climexp.knmi.nl/ (Oldenborgh et al., 2004) using NCEP-NCAR reanalysis.

Other NAO effects

on North Atlantic sea level

Under a positive NAO index (NAO+), regional reduction in atmospheric pressure results in a regional rise in sea level due to the 'inverse barometer effect'.

on North Atlantic hurricanes

A position of the Azores high farther to the south tends to force storms into the Gulf of Mexico, whereas a northern position allows them to track up the North American Atlantic Coast

Ecological effects

❖ Until recently, the NAO had been in an overall more positive regime since the late 1970s, bringing colder conditions to the North-West Atlantic, which has been linked with the thriving populations of Labrador Sea snow crabs, which have a low temperature optimum.

❖ The NAO+ warming of the North Sea reduces survival of cod larvae which are at the upper limits of their temperature tolerance, as does the cooling in the Labrador Sea, where the cod larvae are at their lower temperature limits.

❖ On the East Coast of the United States an NAO+ causes warmer temperatures and increased rainfall, and thus warmer, less saline surface water. This prevents nutrient-rich upwelling which has reduced productivity. Georges Bank and the Gulf of Maine are affected by this reduced cod catch.

❖ The strength of the NAO is also a determinant in the population fluctuations of the intensively studied Soay sheep.

Amplification of effects - teleconnections

Combination with the El Niño:

During the winter (NAO+), the Icelandic low draws a stronger SW circulation over the eastern half of N. America preventing Arctic air from its southward move. This may produce significantly warmer winters over the northeastern United States and southeastern Canada.

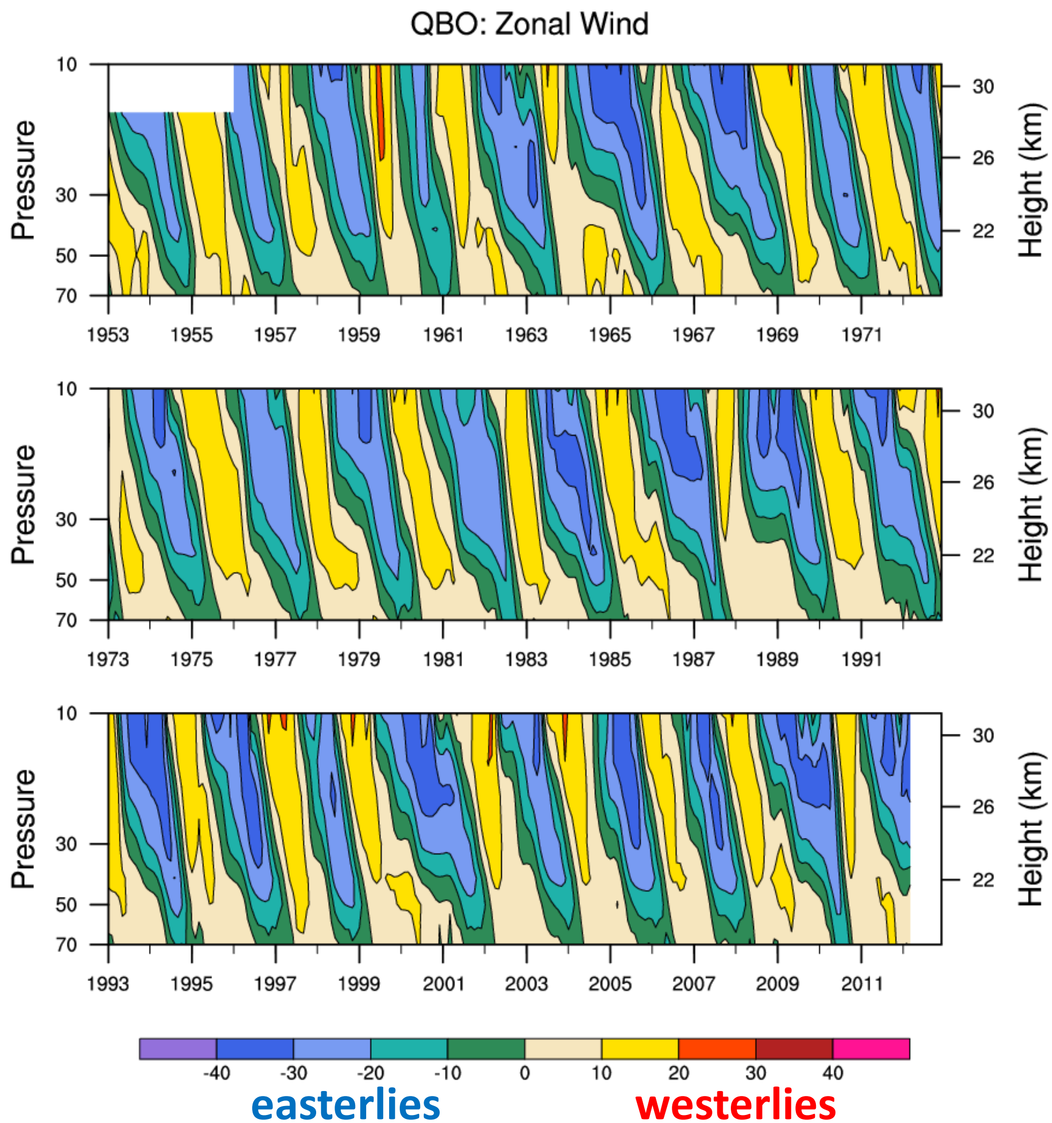
Conversely, at (NAO-), the eastern seaboard and SE US can incur winter cold outbreaks more than the norm with associated heavy snowstorms in Appalachia/mid-Atlantic region and sub-freezing conditions into Florida.

Combination with the solar activity, El Niño and QBO:

The winter of 2009–10 in Europe was unusually cold (UK coldest winter for 30 years). It is hypothesized that this may be due to a combination of low solar activity, a warm phase of the El Niño Southern Oscillation and a strong easterly phase of the Quasi-Biennial Oscillation all occurring simultaneously. This coincided with an exceptionally negative phase of the NAO. **This has become known as a "Hybird El Niño".**

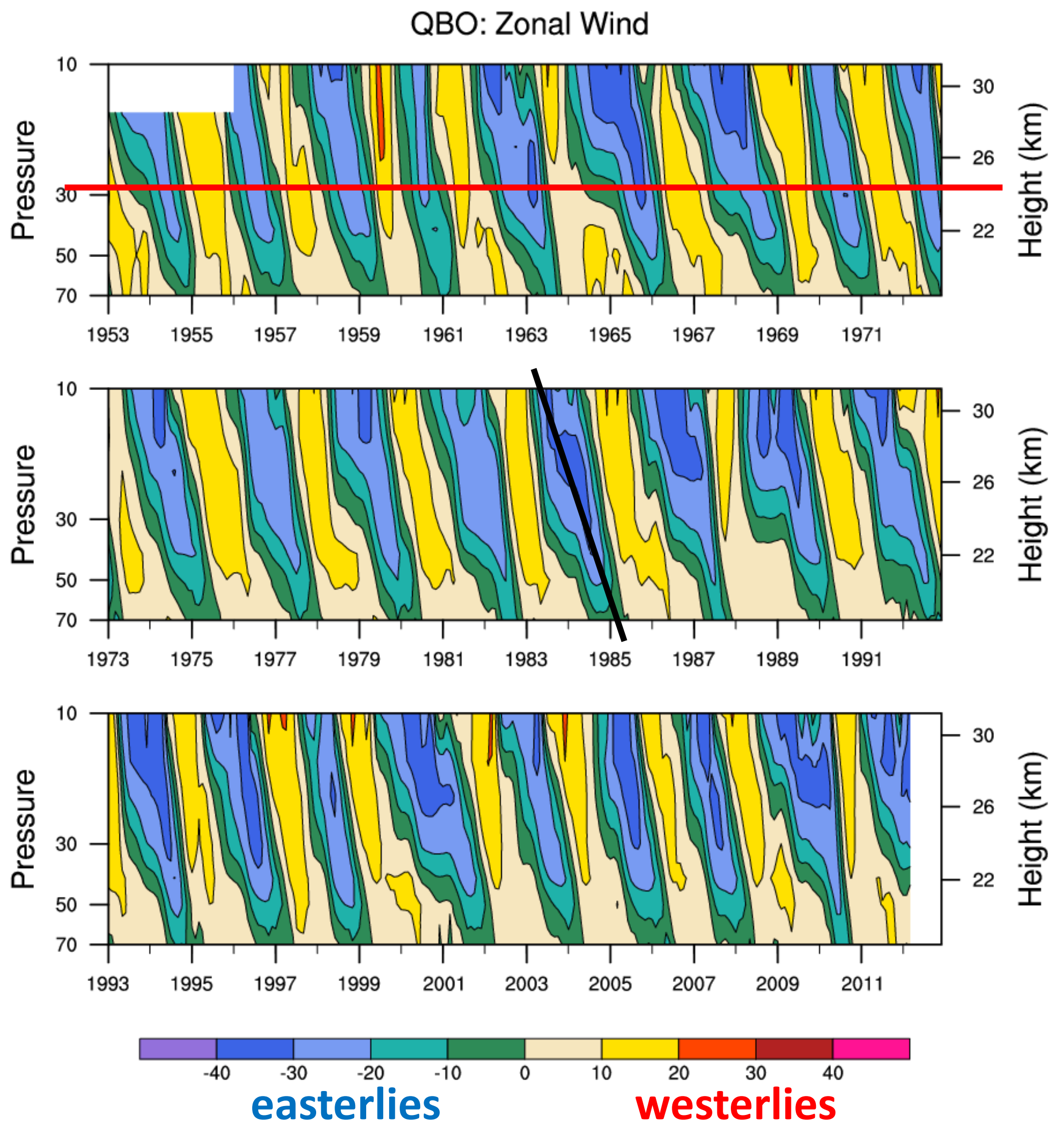
The quasi biennial oscillation - QBO

- High above the equator, in the stratosphere, strong zonal winds blow in a continuous circuit around the Earth.
- 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 28 to 29 months.



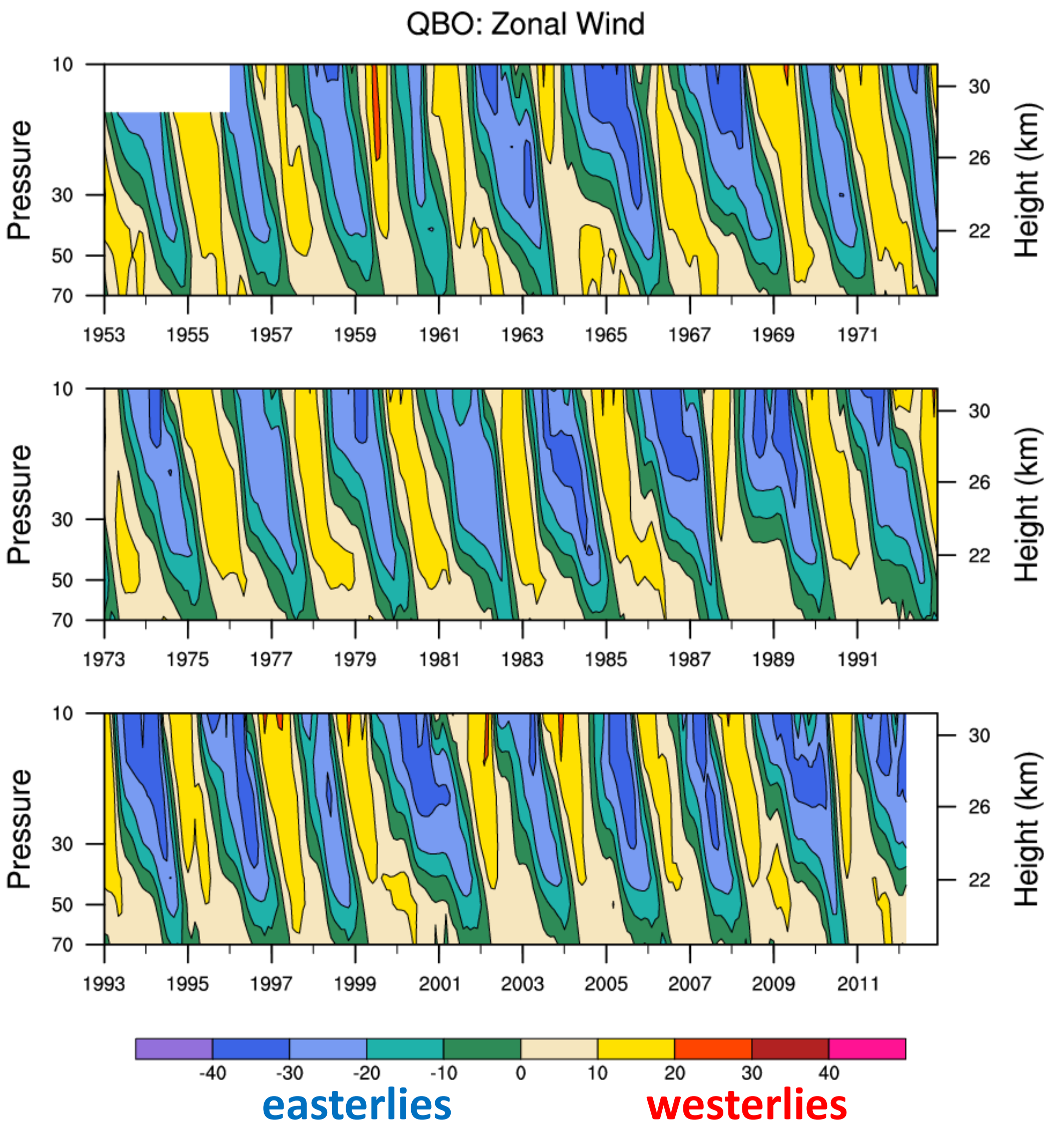
QBO for 1953-2012. Data source (Freie Universitat, Berlin)

- At a given altitude, the winds might start as westerlies, but over time they weaken and eventually reverse, becoming strong easterlies.
- Looking at different heights, we see that the peak amplitude of the westerly winds migrates slowly downwards, with the zone of easterly winds coming behind it also migrating downwards.



QBO for 1953-2012. Data source (Freie Universitat, Berlin)

- The alternating wind regimes develop at the top of the lower stratosphere (10 hPa) and **propagate downwards at about 1 km per month** until they are dissipated at the tropical tropopause (80 hPa).
- At any one time, there is one region of easterlies and one region of westerlies.
- Downward motion of the easterlies is usually more irregular than that of the westerlies.
- 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.

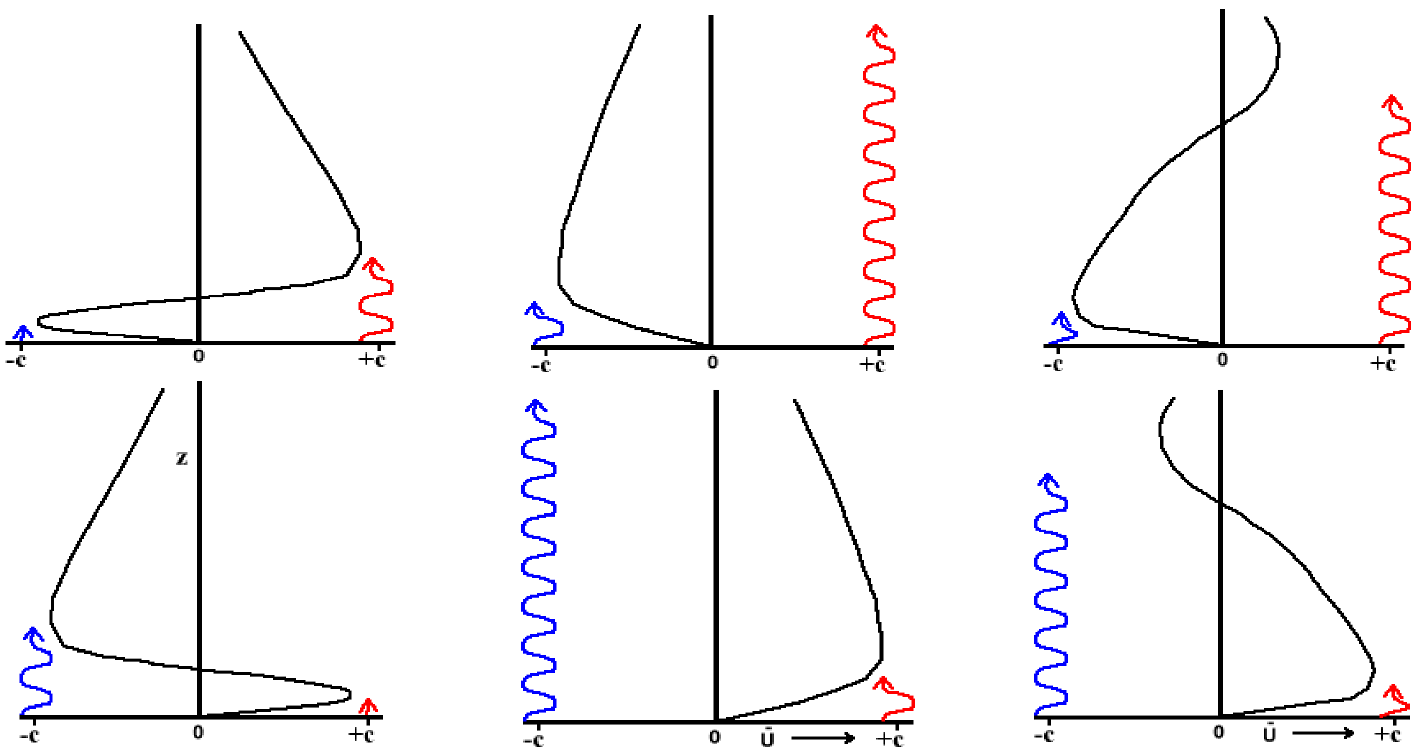


QBO for 1953-2012. Data source (Freie Universitat, Berlin)

What is the reason behind QBO?

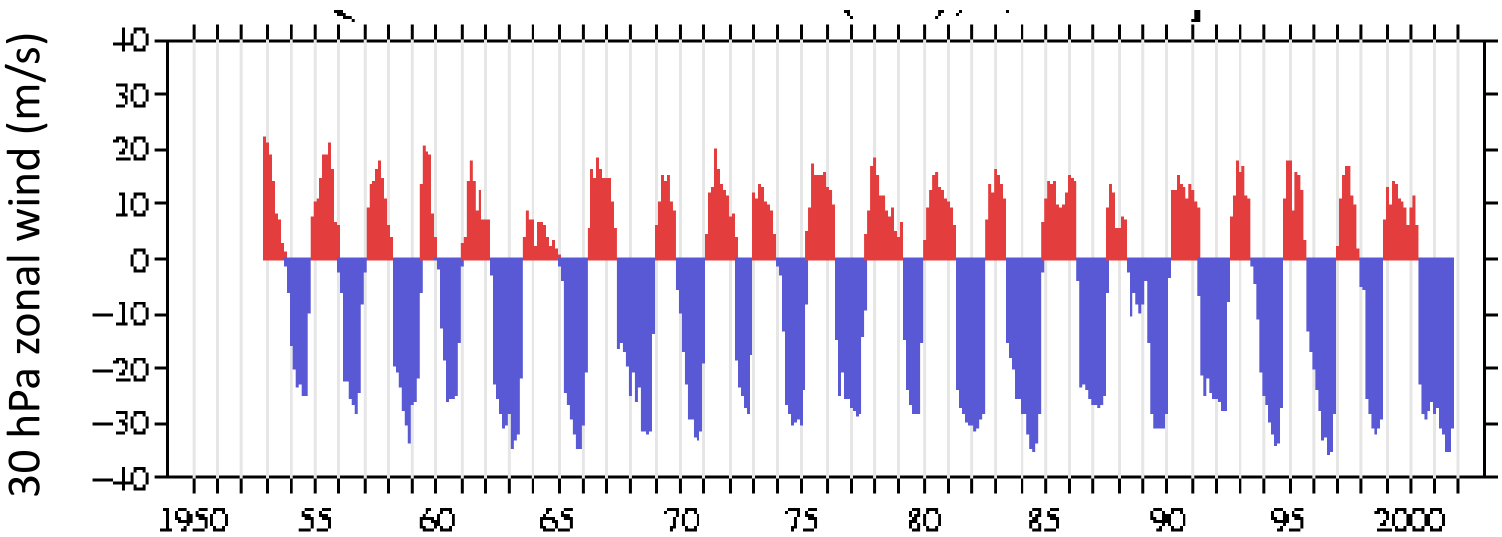
Waves propagate up from the troposphere into the stratosphere and, by a process known as **critical layer absorption**, some of these waves break and deposit momentum at just the right altitude to reinforce the zonal winds and cause them to migrate downwards. The waves carry both eastward and westward momentum, but the absorption process extracts the momentum at different levels, giving the alternative easterly and westerly winds.

Equatorially trapped Kelvin waves provide westerly momentum and Yanai or Rossby-gravity waves provide easterly momentum to produce the QBO oscillation.



Wavy blue and red lines indicate the penetration of easterly and westerly waves

Quantifying QBO



Quasi-Biennial Oscillation (QBO) Zonal Wind Index

Why is the Quasi-Biennial Oscillation important?

- Relevant for seasonal prediction where the state of stratospheric winds affects interactions between the tropics and the mid-latitudes
- May also affect the tropical troposphere directly and possibly how the solar cycle interacts with the atmosphere.

Hurricane Forecasts

West: Increased activity in the Atlantic and NW Pacific

East: Increased activity in the SW Indian basin

- Modulate transport out of the tropical stratosphere to higher altitudes, thus influencing the concentration of gases in the stratosphere, which in turn might lead to further climate feedbacks.

Stratospheric Winter Warmers

Holton and Tan (1980)

West: Cold undisturbed polar vortex

More stratospheric Ozone loss

East: Warm disturbed polar vortex

More tropospheric `cold snaps’

Evidence of different oscillations in an atmospheric application

PERGAMON

AE International – Europe

Atmospheric Environment 37 (2003) 1745–1756

ATMOSPHERIC ENVIRONMENT

www.elsevier.com/locate/atmosenv

Low-frequency variability of beryllium-7 surface concentrations over the Eastern Mediterranean

E. Gerasopoulos[a,*], C.S. Zerefos[b], C. Papastefanou[a], P. Zanis[b], K. O'Brien[c]

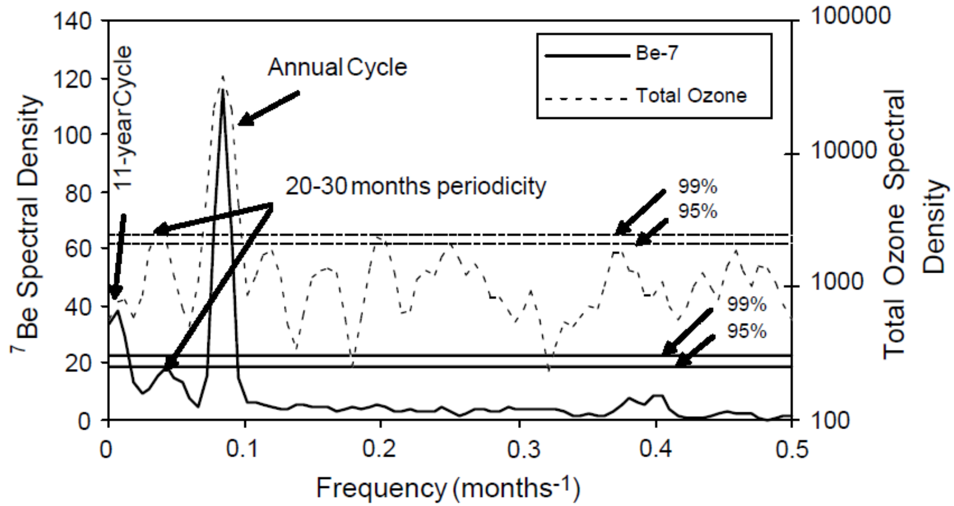
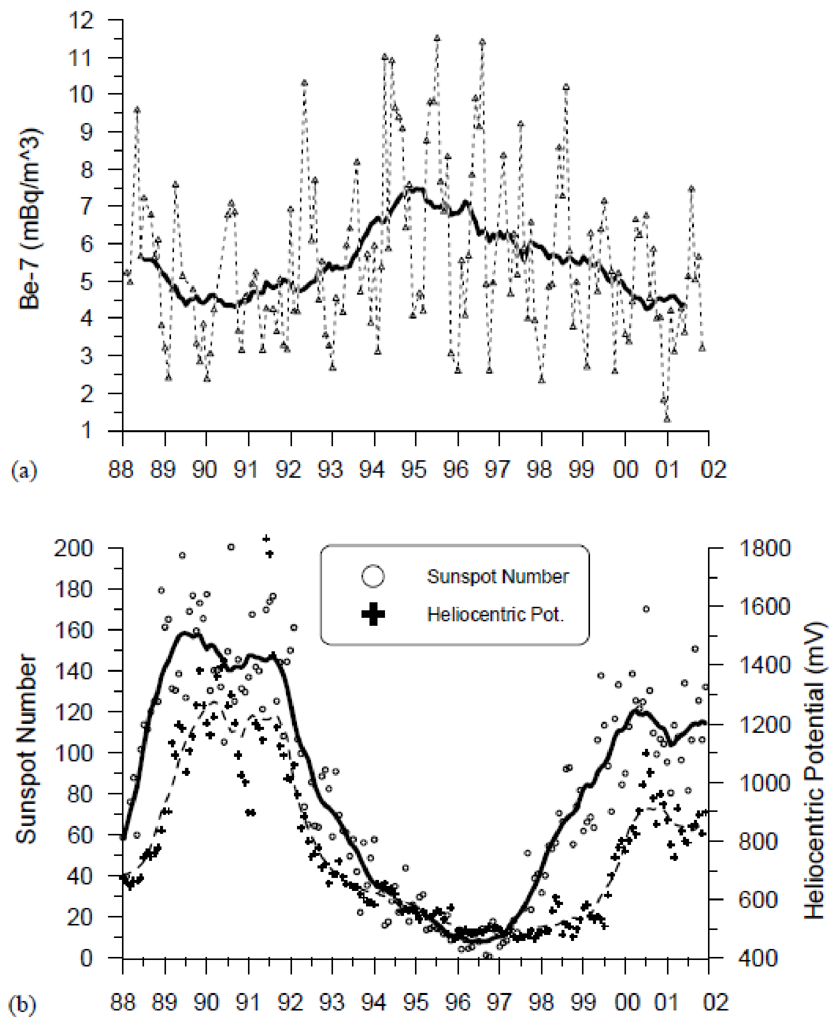


Fig. 1. Spectrum analysis on equal length time series of ^{7}Be and total ozone where the characteristic periodicities are presen
of spectral densities. For each spectrum the respective 95% and 99% confidence levels are also shown.



The 11 year solar cycle

Fig. 2. Time series of (a) ^{7}Be, (b) sunspot number and heliocentric potential. Triangles, circles and crosses represent the initial data whereas the lines correspond to a 2-year moving average for ^{7}Be and a 1-year moving average for the sunspot number and the heliocentric potential.

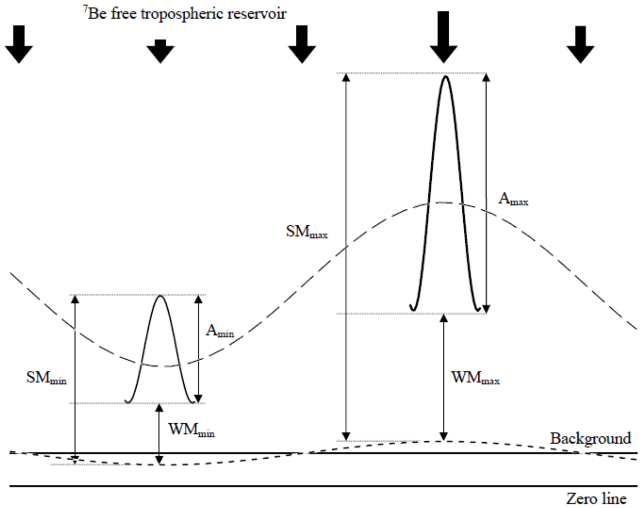


Fig. 5. Schematic representation of the simplistic model explaining the amplitude modulation (A_{min}, A_{max}) of the ^{7}Be annual cycle. Both a constant and a fluctuating background are shown. The thick arrows correspond to the modulated reservoir of ^{7}Be in the upper troposphere.

The annual cycle

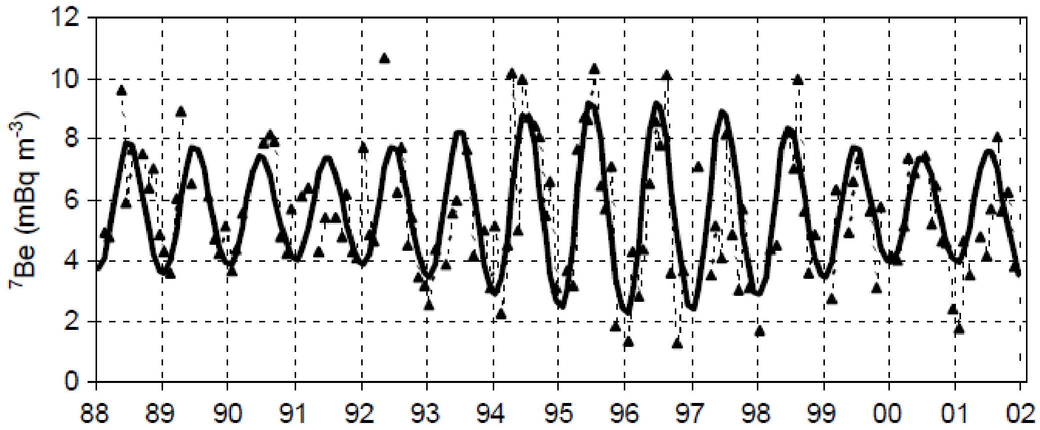


Fig. 4. ^{7}Be concentrations after removing the 11-year periodicity (triangles) and fitted annual cycle according to Eq. (1) (solid line).

The QBO

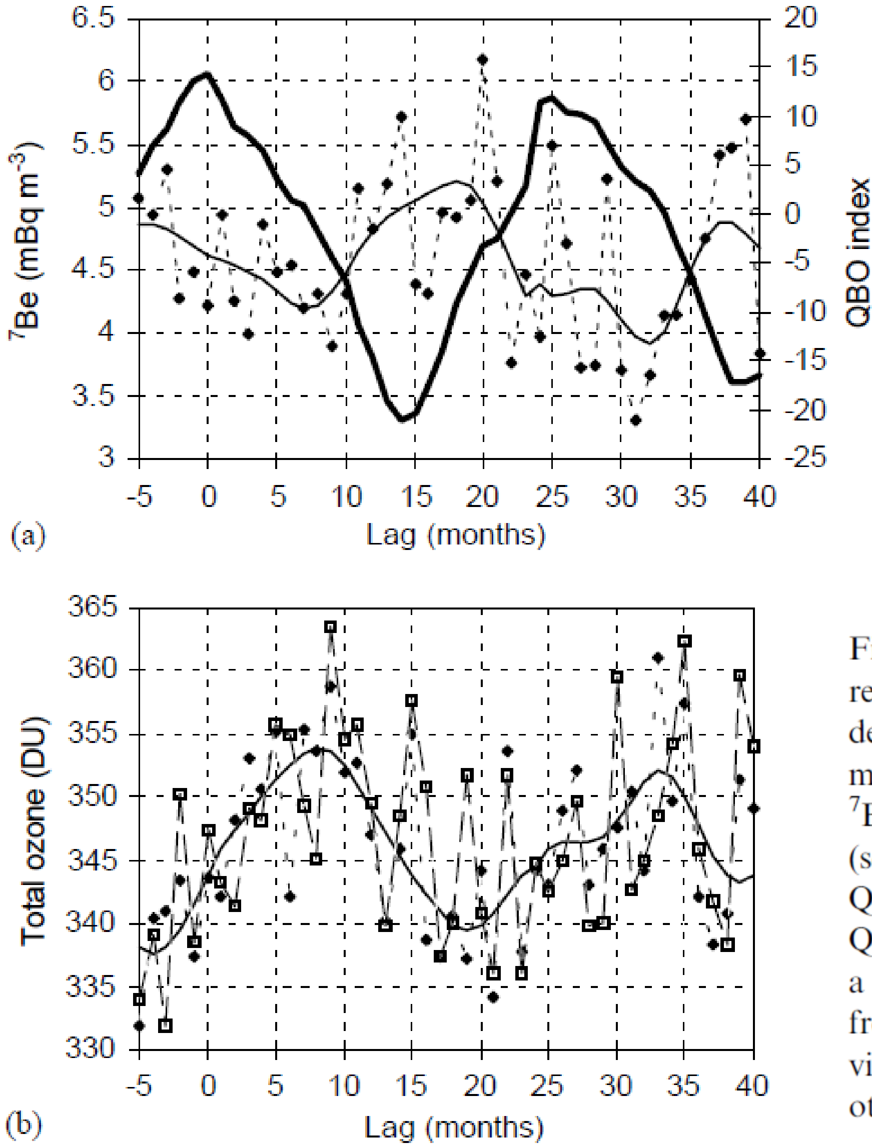


Fig. 7. Superposed epoch technique on (a) ^{7}Be time series after removing the annual and the 11-year cycles (rhombuses) and (b) deseasonalized values of total ozone monthly means (MTO—monthly total ozone) (rhombuses) and the total column for the ^{7}Be sampling days (DTO—1 day per month total ozone) (squares), using as key dates those months corresponding to QBO maxima. The thick solid line in (a) corresponds to the QBO index whereas the solid lines in both (a) and (b) represent a 40% FFT filtering of the noise by zeroing the highest frequency channels on the ^{7}Be and the DTO, for better visualization of their relationship with QBO and between each other.

The End