

NATS 101
Section 13: Lecture 20

Atmosphere-Ocean Interactions

In El Niño is an example of an atmosphere-ocean interaction—perhaps the most important one.

Such interactions are important for climate variability across the globe, including here in Arizona.

Why is the ocean important?

Heat transport

Ocean currents transport heat from equator to pole (~40% of the total).

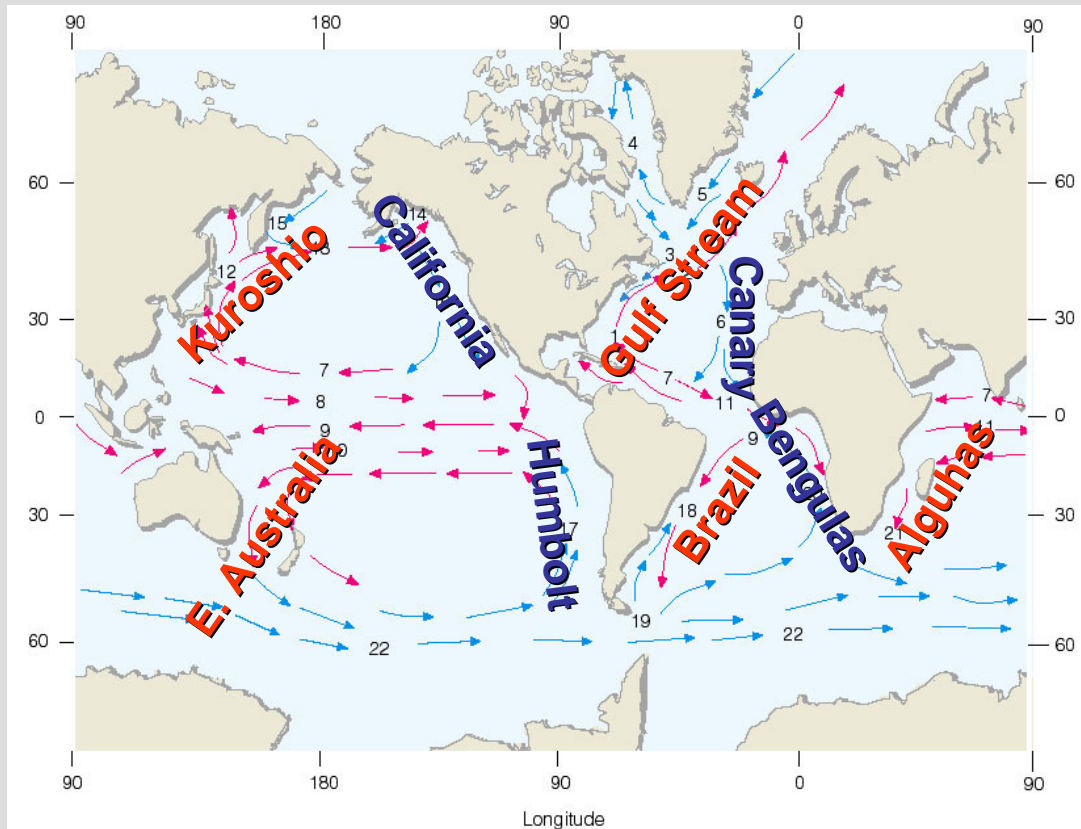
A climate regulator

Water moderates climate in areas near it. Ocean supplies moisture to the atmosphere which produces clouds, storms, and precipitation.

A source of “memory” in the climate system

Because variability in the ocean occurs on very long timescales relative to atmospheric phenomena (like years to centuries), it makes climate potentially more predictable (months in advance).

Major Ocean Currents



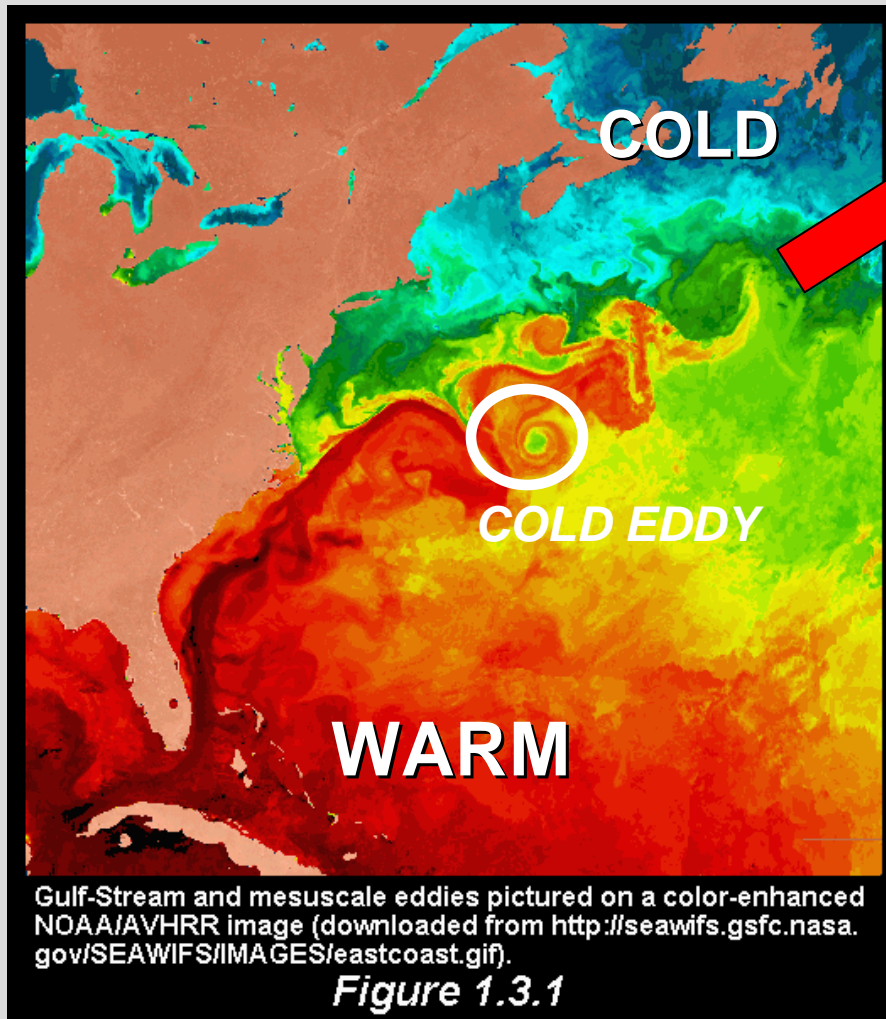
The ocean currents are forced by the prevailing surface winds

What is the function of the gyres?

The warm side of a gyre is typically along the east coast of a continent.

The cold side of a gyre is typically along the west coast of a continent.

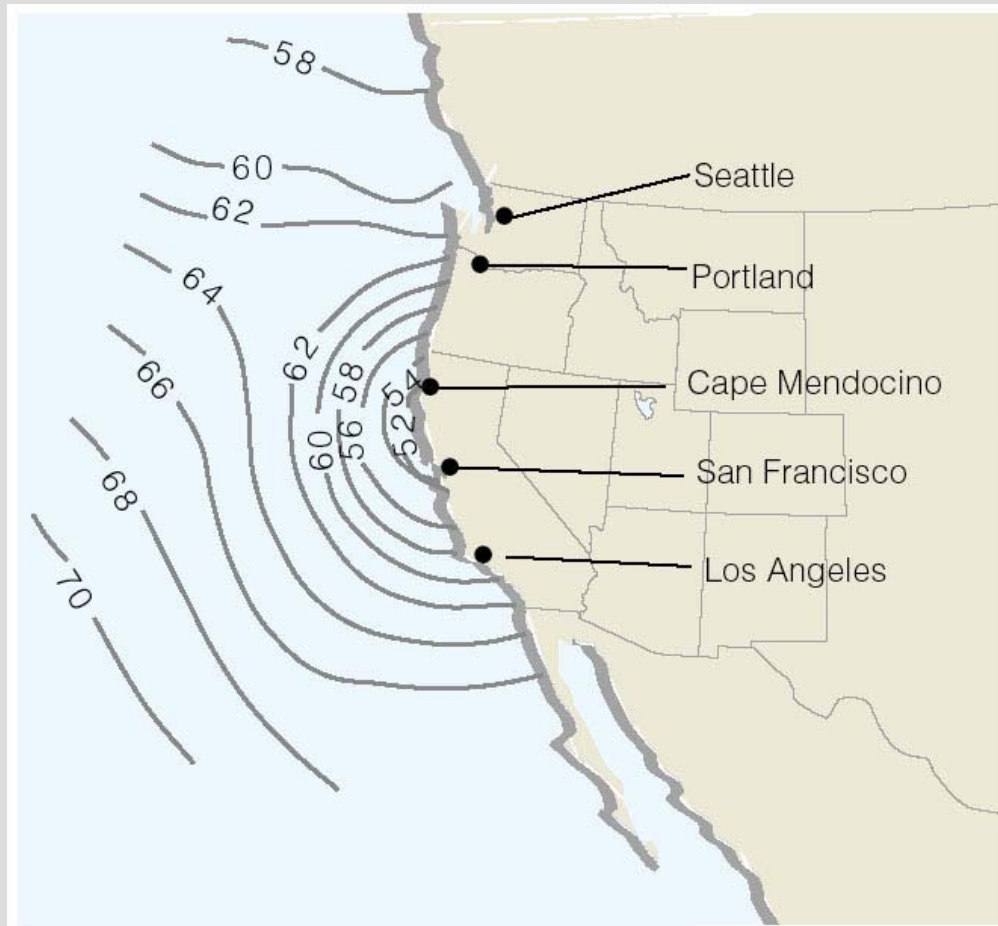
European Climate and the Influence of the Gulf Stream



What is the function of the Gulf Stream?

Aside: note how the current breaks down into a series of eddies as the current proceeds across the Atlantic.

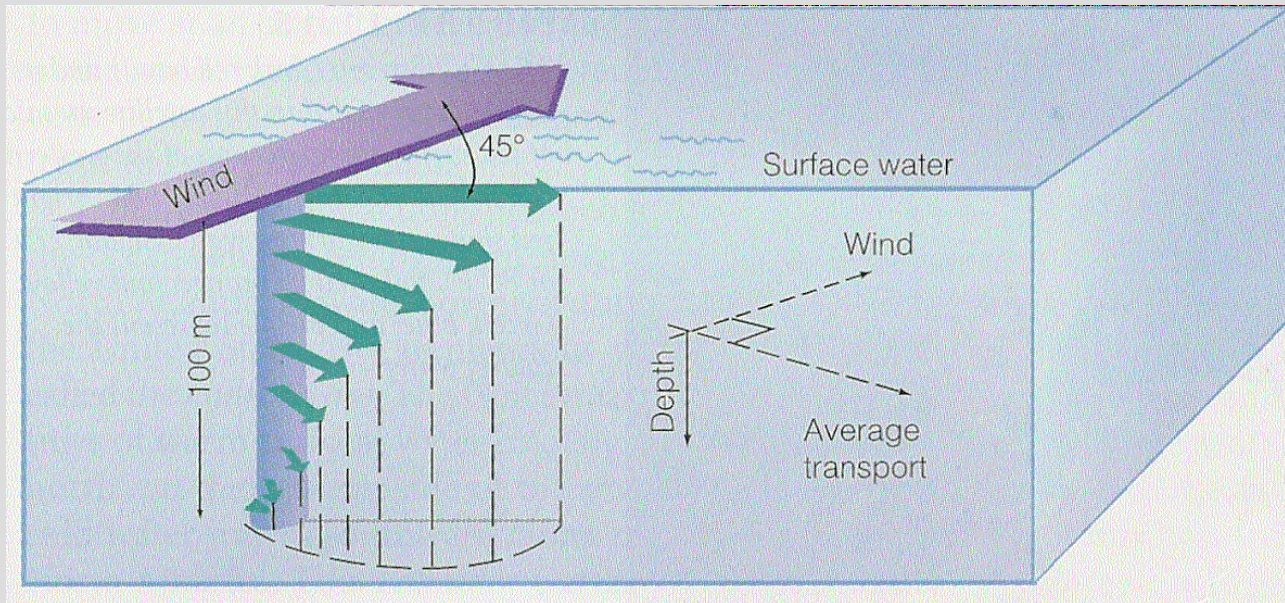
Cold sea surface temperatures along west coast of continents



Locally colder sea surface temperatures are found along the west coast of continents.

Cold ocean currents on the western side of continents cause upwelling of water from below.

Ekman Spiral in Northern Hemisphere

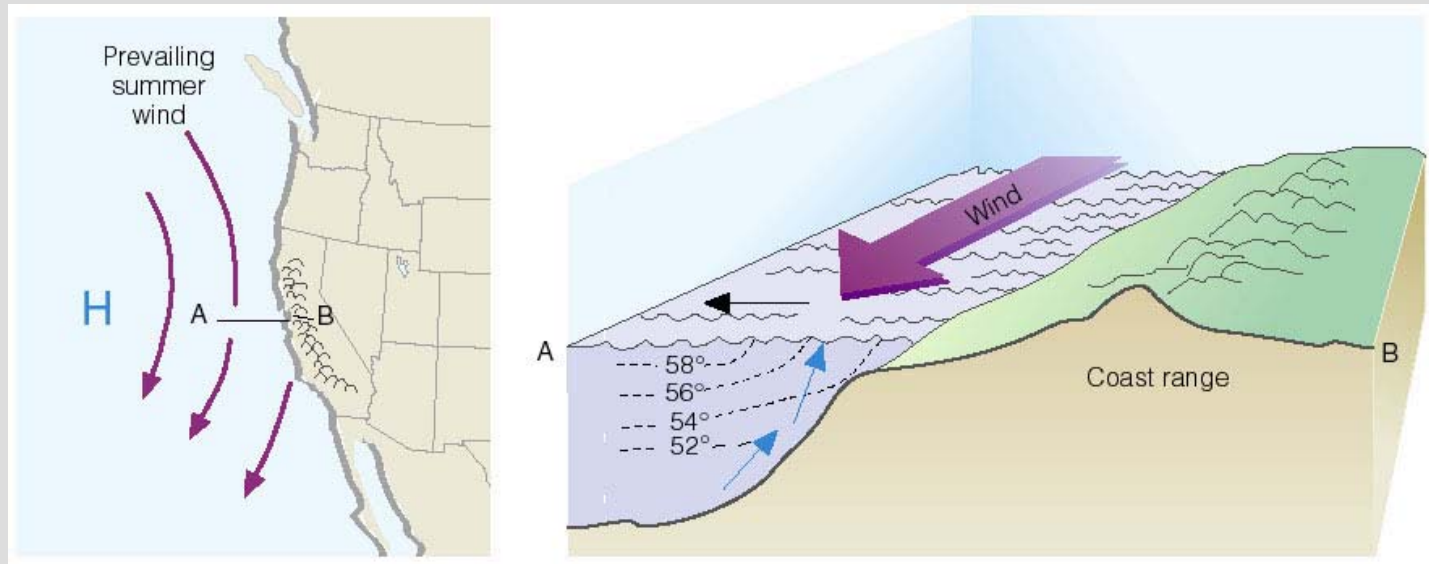


As wind blows across the water, the water is deflected to the _____ of the mean wind by the Coriolis force.

Each successive layer of water below bends a little more towards the _____ as it is forced by the layer above.

Net result: water is transported at approximately 90° to the wind.

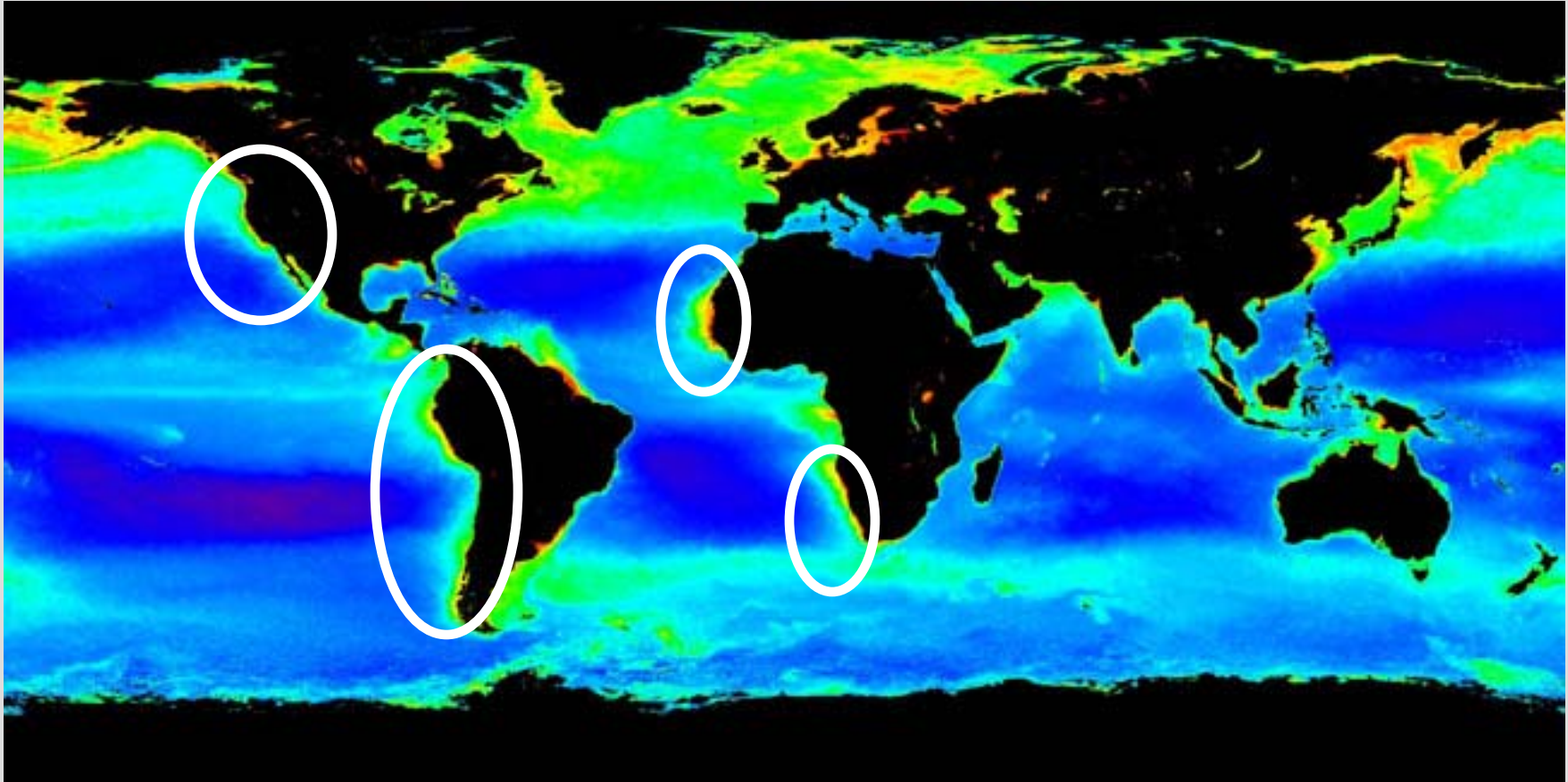
Upwelling due to Ekman pumping along west coast of continents



By mass conservation, as water is transported away from the shore, it is replaced by cold water from below—or *upwelling* occurs.

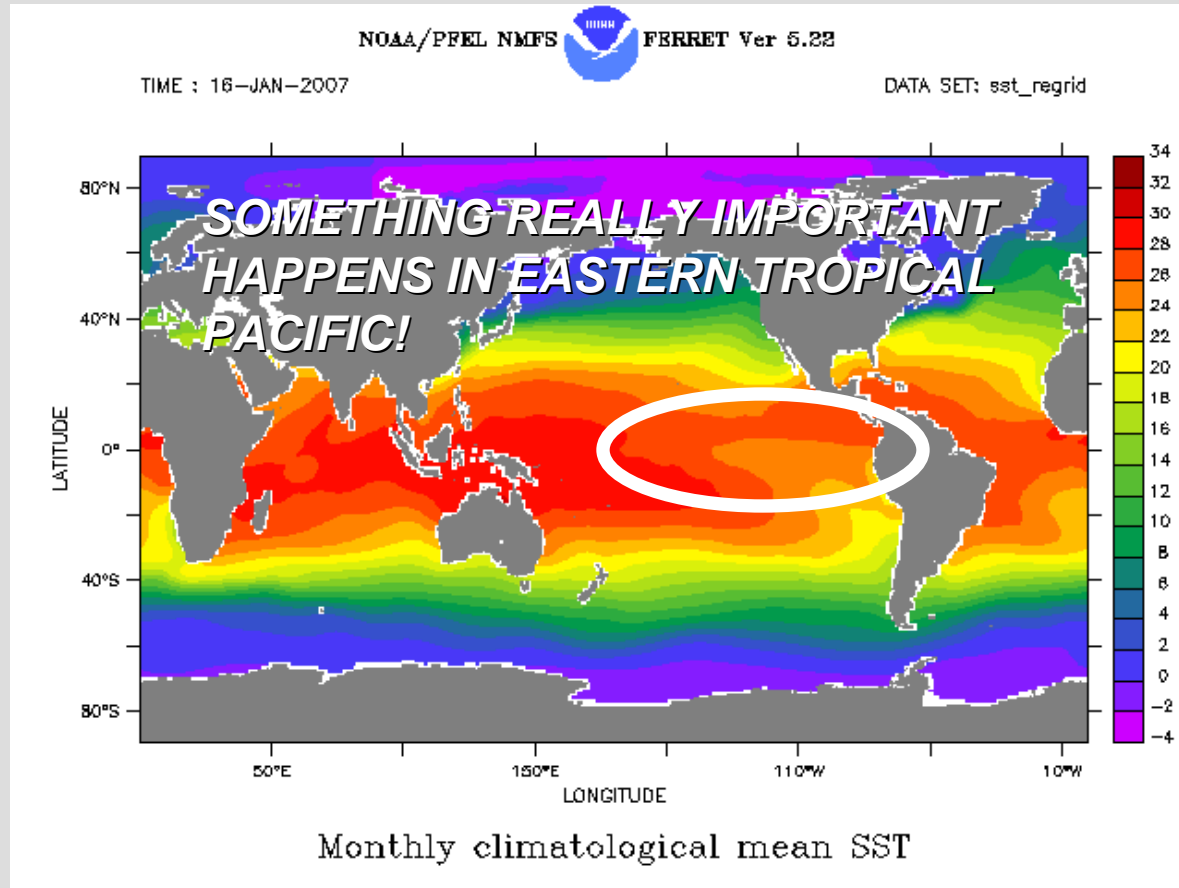
Cool water is typically rich in nutrients, which make areas where this happens very biologically productive.

Global Phytoplankton Productivity



Phytoplankton generally favored in _____ water. NASA Image
Productivity peaks along west coasts of most continents.

Global Average Sea Surface Temperature



**Warm near the equator, cold near the poles.
Colder on the west coasts of continents due to upwelling.**

Something odd happens every so often (3-5 years) off the west coast of South America...

The cold upwelling current STOPS and is replaced by warm water.

Because this occurred around Christmas, the locals referred to it as *Corriente del Niño*, or Current of the Christ Child—and they knew about it for a long time because it's coming brought heavy rainfall and poor fishing.

Search for causes of Indian Monsoon failure



***Sir Gilbert Walker
British naturalist***

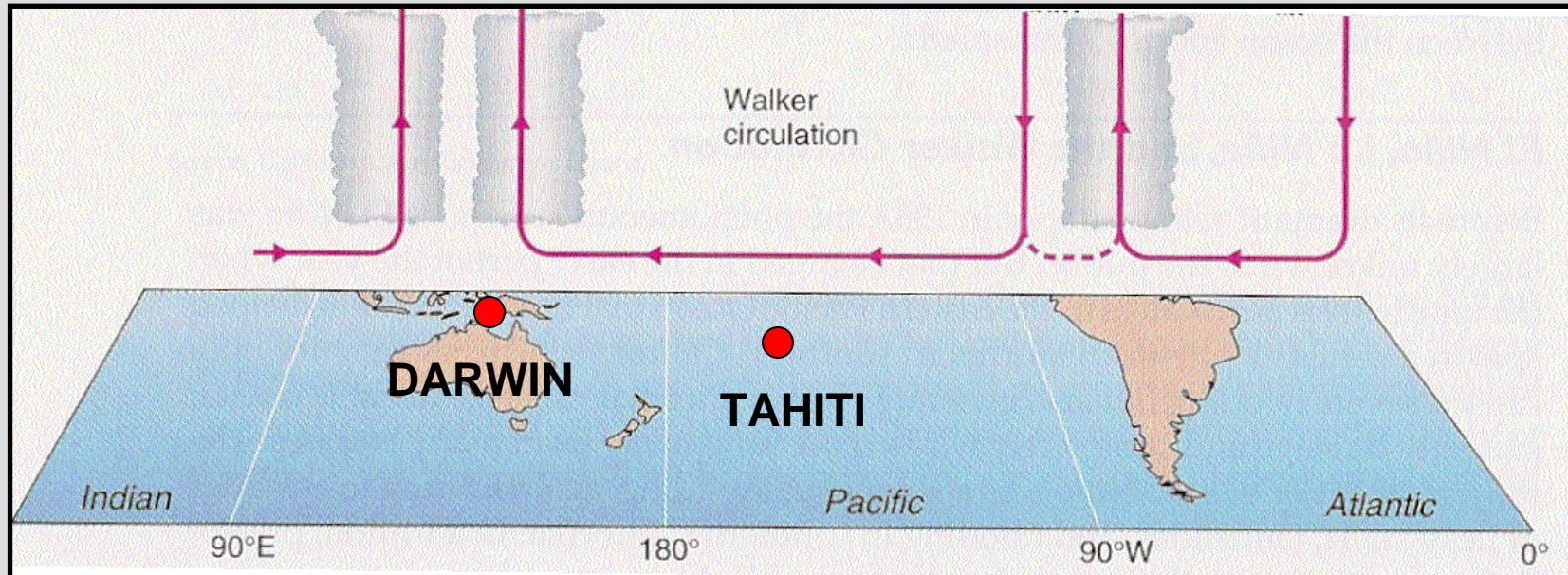
He note that in some years the Indian monsoon completely failed.

In his search of the causal factor, he discovered that surface pressure variability across the Pacific followed a large-scale pattern.

Walker called the pattern the Southern Oscillation and hypothesized it was linked to the monsoon failures.

The scientific community initially dismissed his idea...

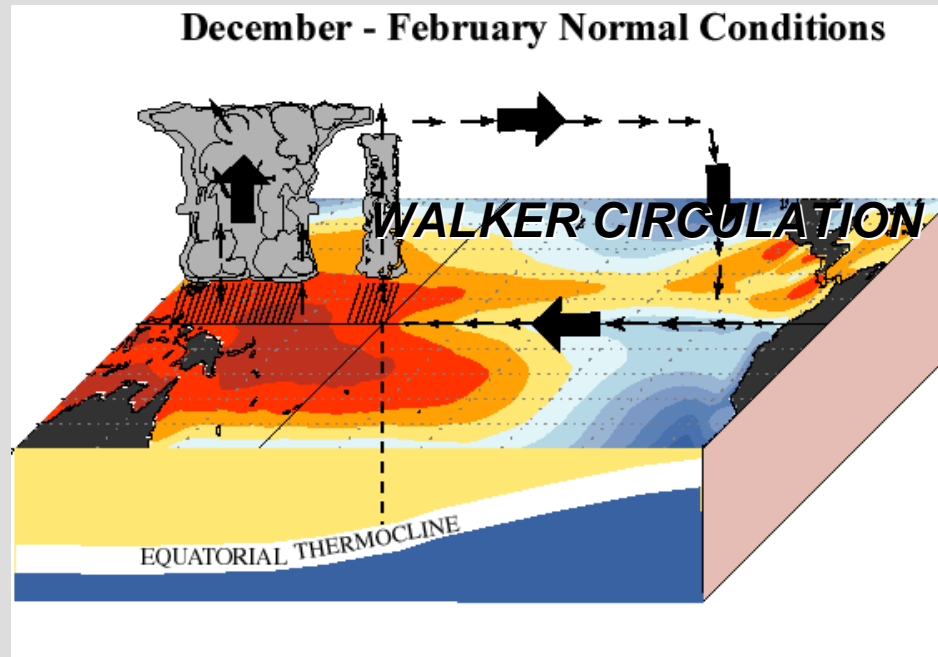
The Southern Oscillation Index (SOI)



SOI = Surface pressure at DARWIN – Surface pressure at TAHITI

What wasn't figured out till later (1960s): The Southern Oscillation and El Niño *both* reflect coherent changes which take place in the atmosphere and ocean across the Pacific Basin.

The entire phenomenon is called the El Niño-Southern Oscillation (ENSO).



Atmosphere

Ocean

Easterly trade winds.

Walker circulation arises from asymmetry in ocean temperatures.

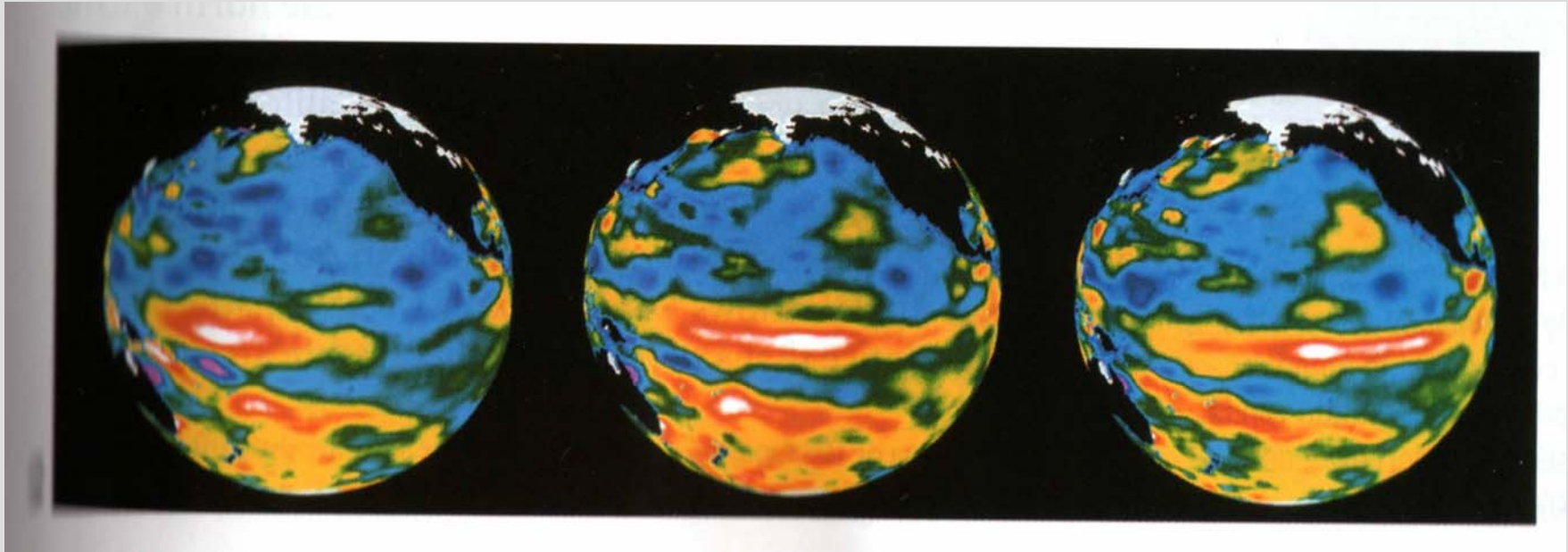
Rising motion and convection on western side, subsidence on eastern side.

Western side of basin: warm water and downwelling

Easterly side of basin: cold water and upwelling.

An El Niño begins when warm surface water starts to surge eastward along the equator due to a Kelvin wave.

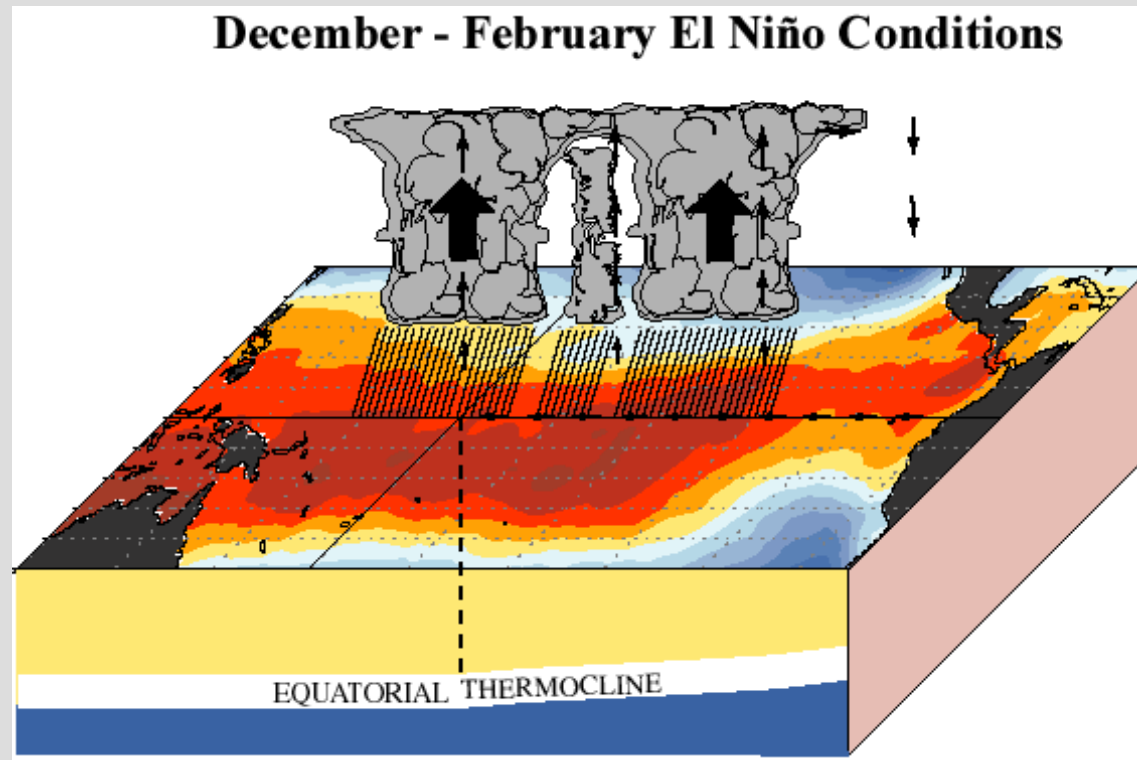
Kelvin wave surge: Sea height analyses from satellite



(Topex Poseidon satellite imagery)

Higher sea height (warm colors) = warmer water

What exactly is the trigger (or triggers) for the Kelvin wave surge is still an area of active research!



Eastern Pacific warms.

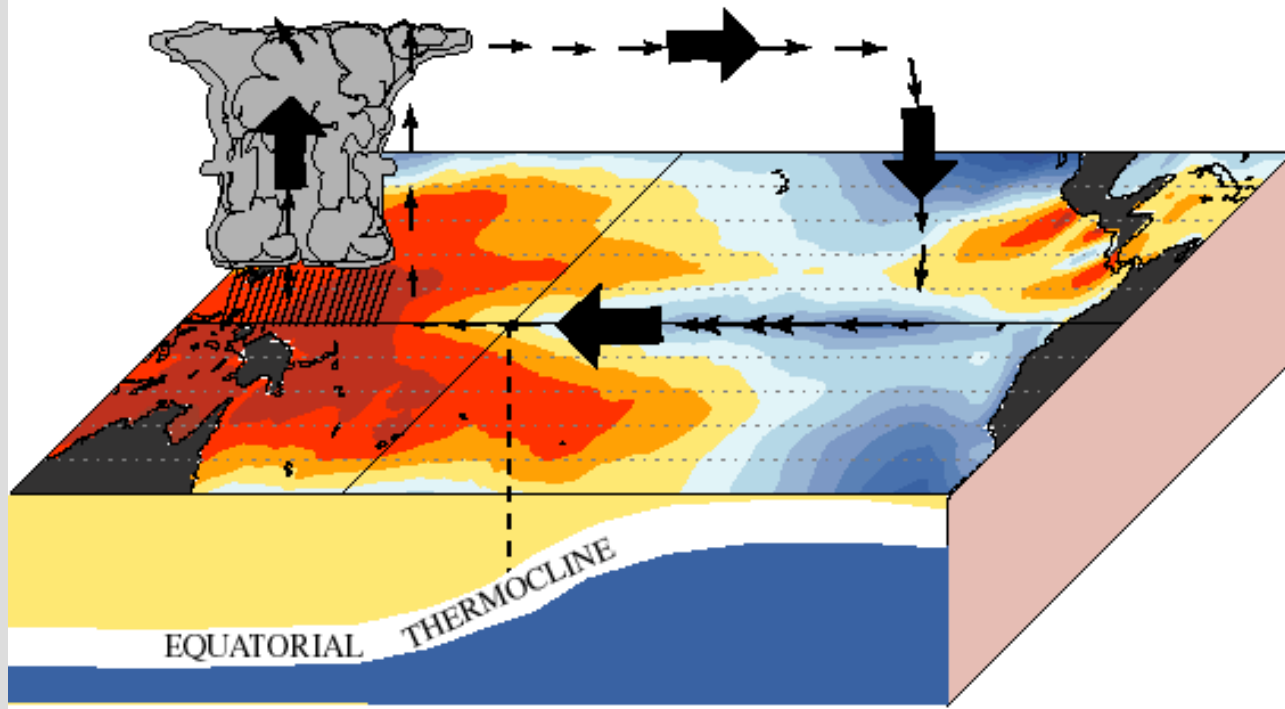
Walker circulation shifts eastward, favoring convection in the central and eastern Pacific instead of the western Pacific.

Easterly trade winds weaken.

Coastal upwelling along the west coast of South America weakens.

The reverse of El Niño conditions is called La Niña...

December - February La Niña Conditions



Eastern Pacific is cooler than normal

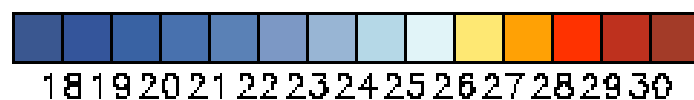
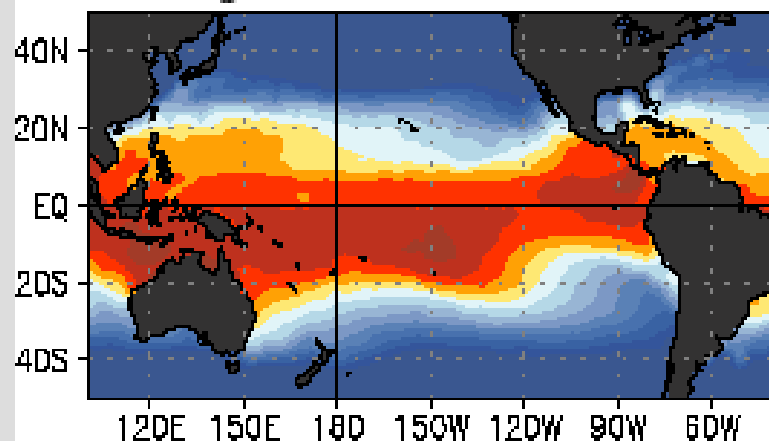
Walker circulation is stronger with enhanced convection in the west Pacific.

Easterly trades strengthen

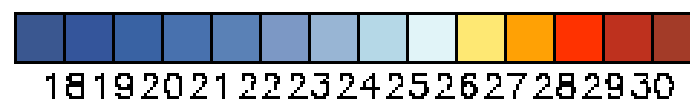
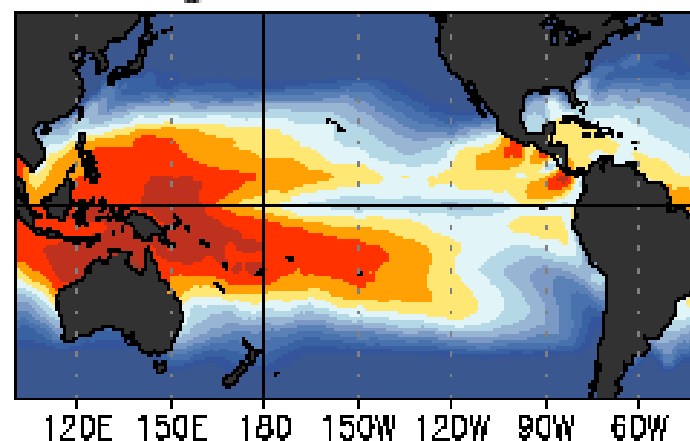
Enhanced upwelling along the west coast of South America.

OCEAN TEMPERATURES (°C)

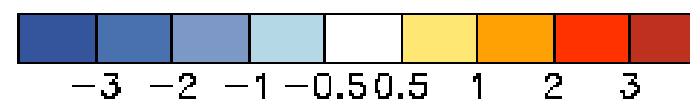
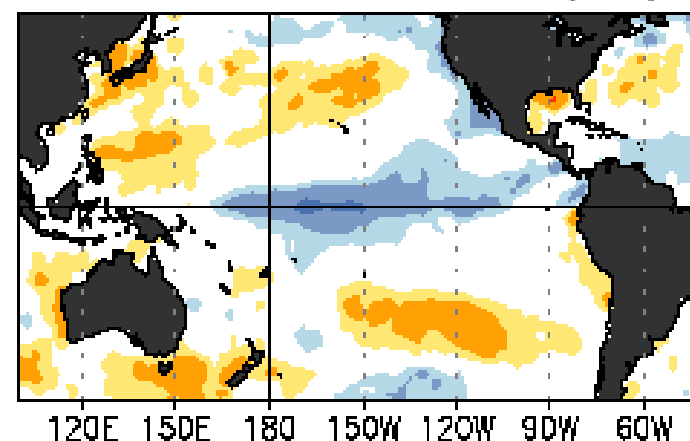
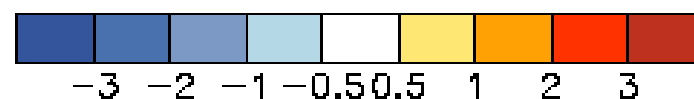
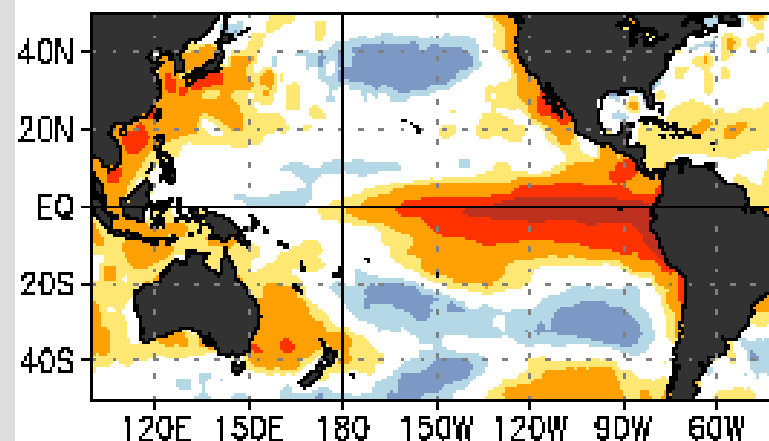
EL NIÑO Jan-Mar 1998



LA NIÑA Jan-Mar 1989

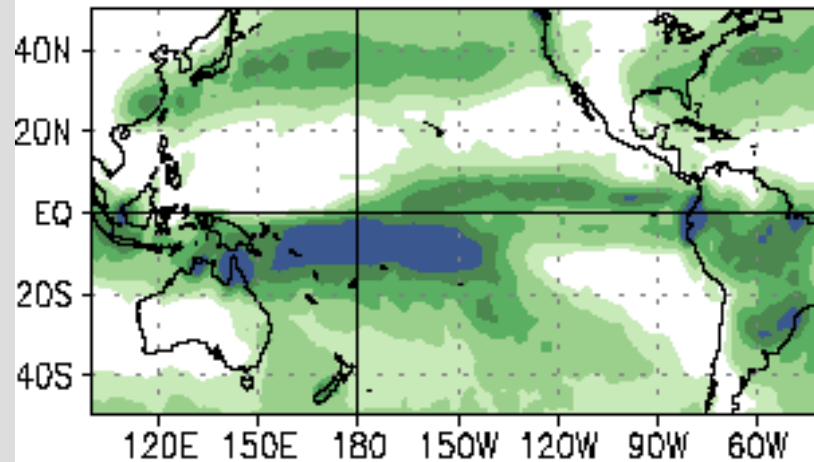


OCEAN TEMPERATURE DEPARTURES (°C)

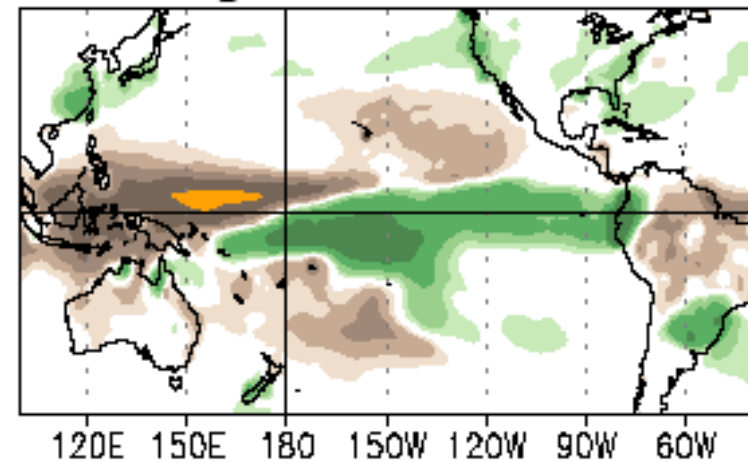


Jan-Mar 1998 Precipitation (mm)

Total

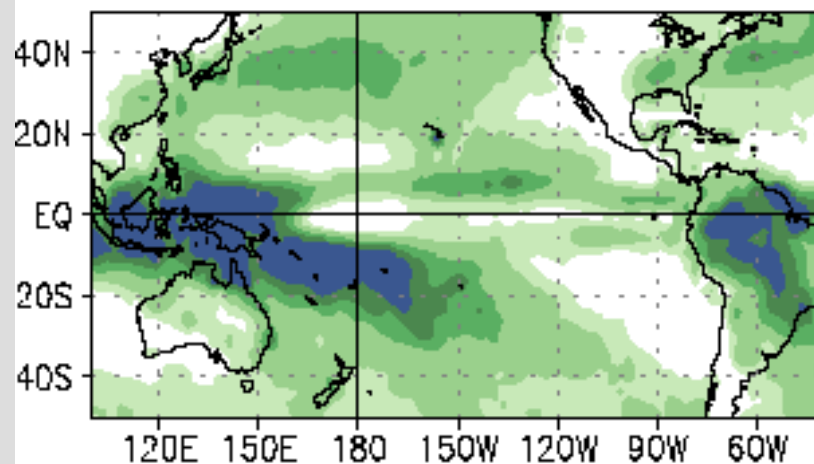


Departures (x100)

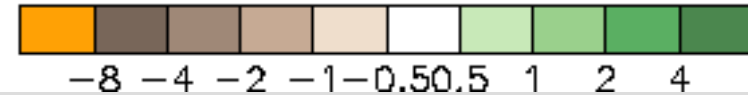
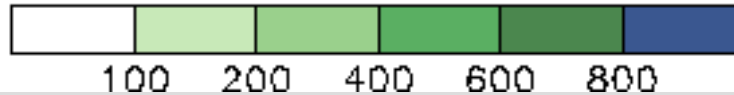
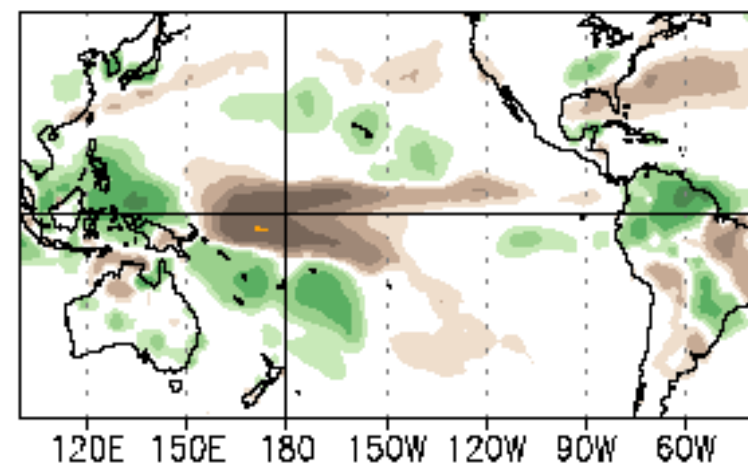


Jan-Mar 1989 Precipitation (mm)

Total



Departures (x100)



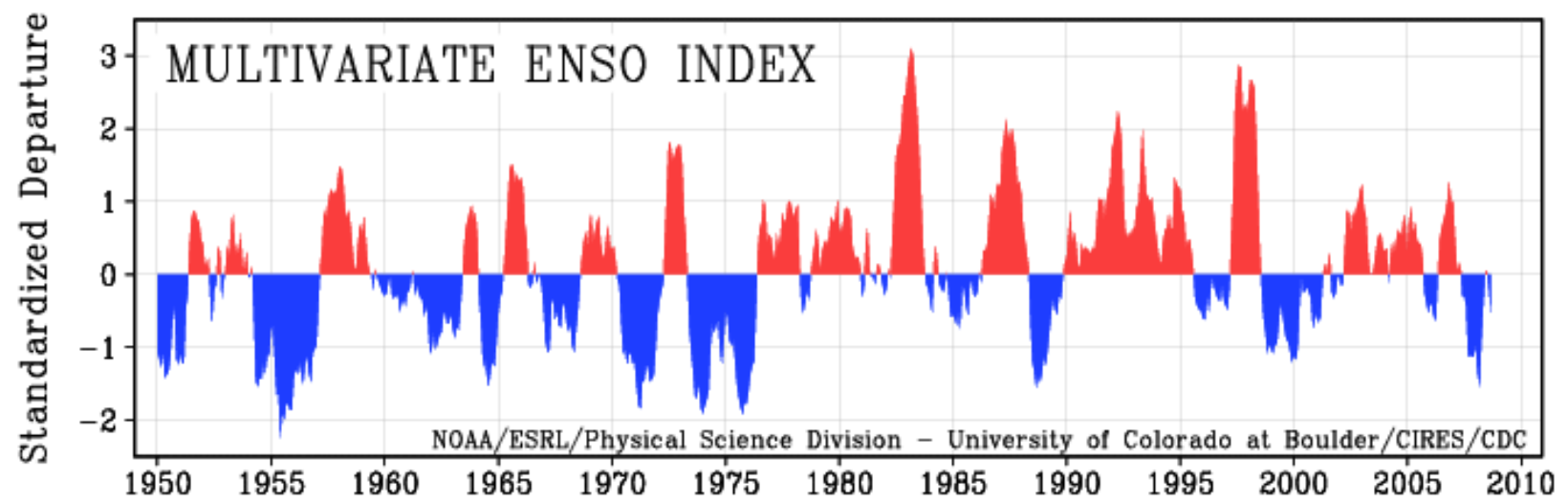
Measures of ENSO

Southern Oscillation Index: Walker's original index based on surface pressure at Darwin minus surface pressure at Tahiti

Niño indices: based on sea surface temperature anomalies in specific locations in the central and eastern Pacific Ocean (Niño 1, Niño 2, Niño 3, Niño 3.4, Niño 4).

Combined indices: take into account atmospheric conditions and ocean conditions (e.g. multivariate ENSO index, or MEI).

All of these indices are readily available over the web...

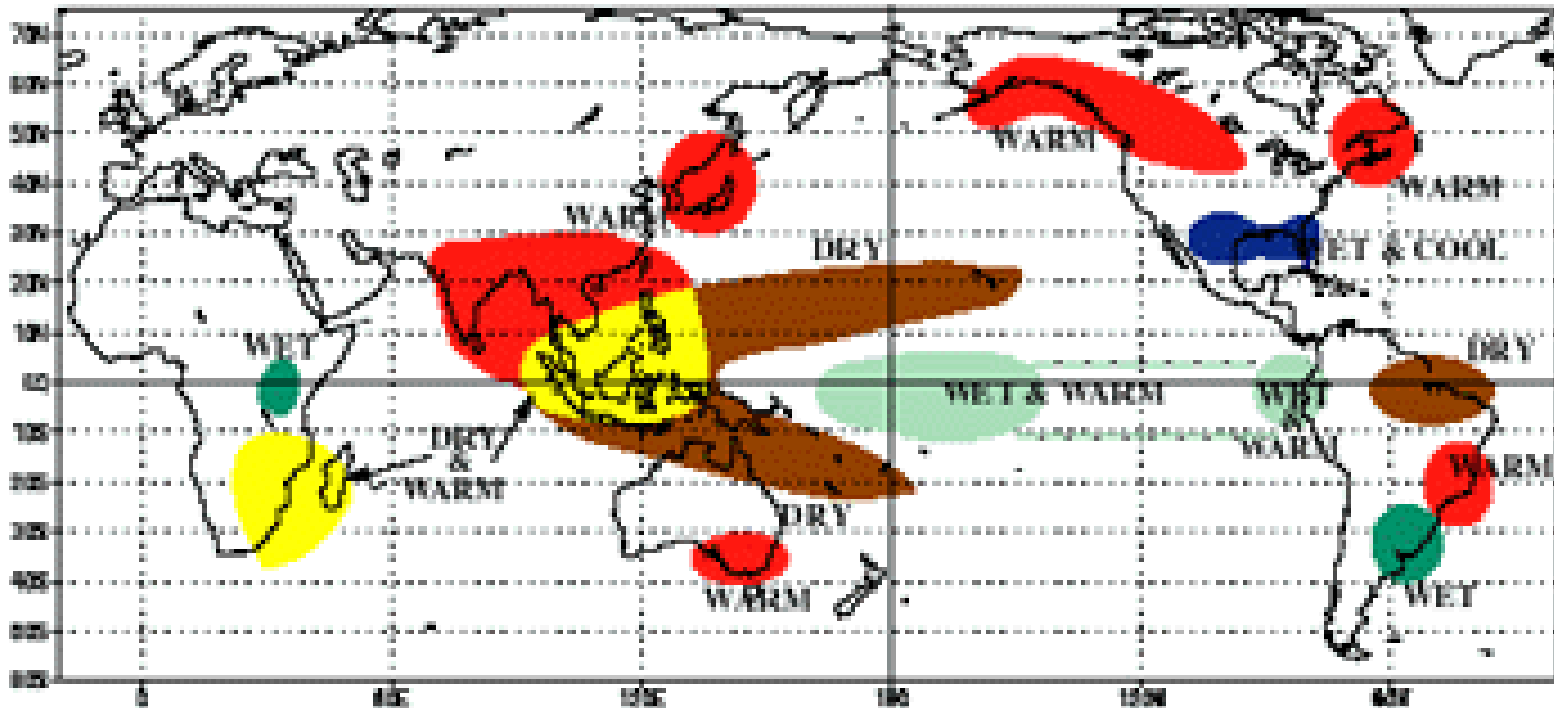


ENSO does not just affect areas in and around the Pacific—it alters the atmospheric circulation patterns and weather across the globe

These are called *teleconnections*

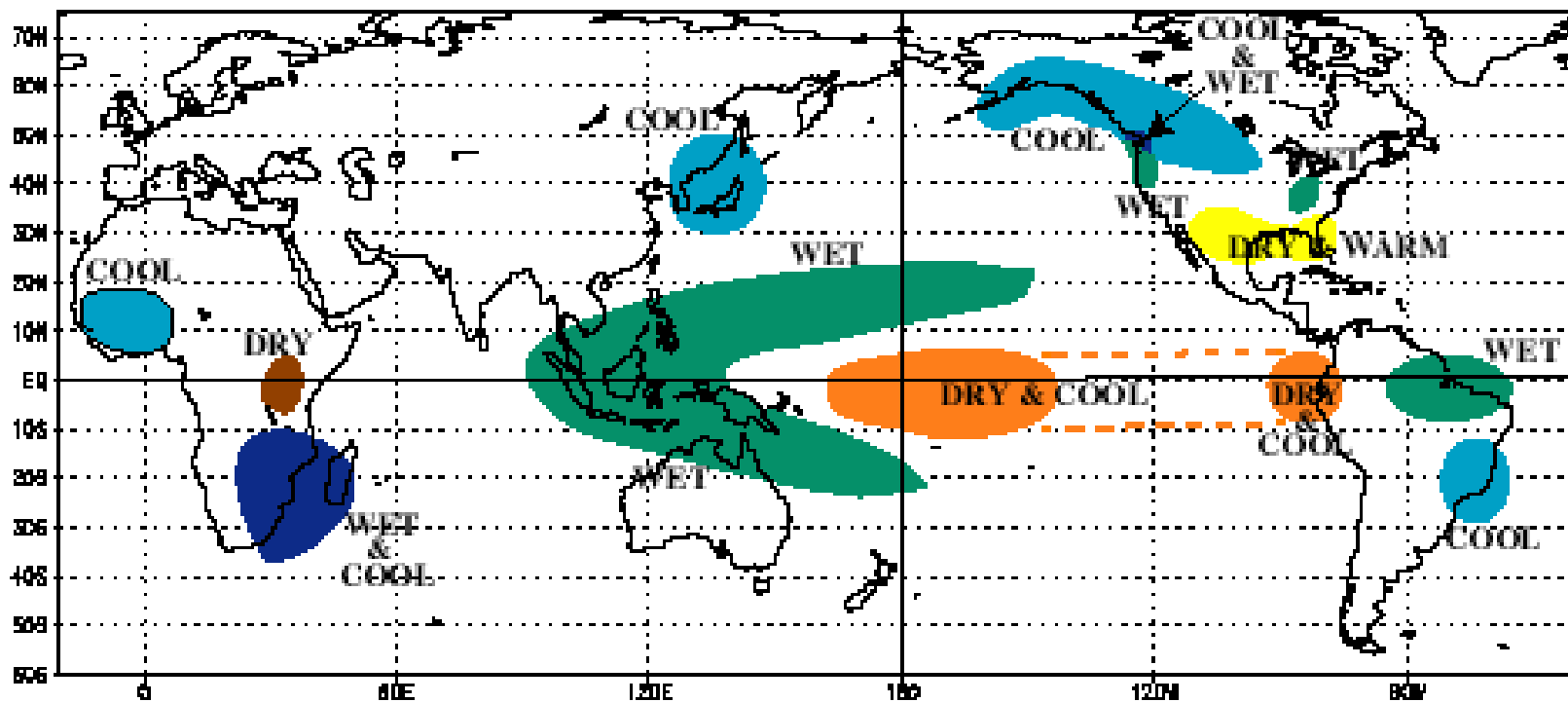
El Niño

WARM EPISODE RELATIONSHIPS DECEMBER - FEBRUARY



La Niña

COLD EPISODE RELATIONSHIPS DECEMBER - FEBRUARY

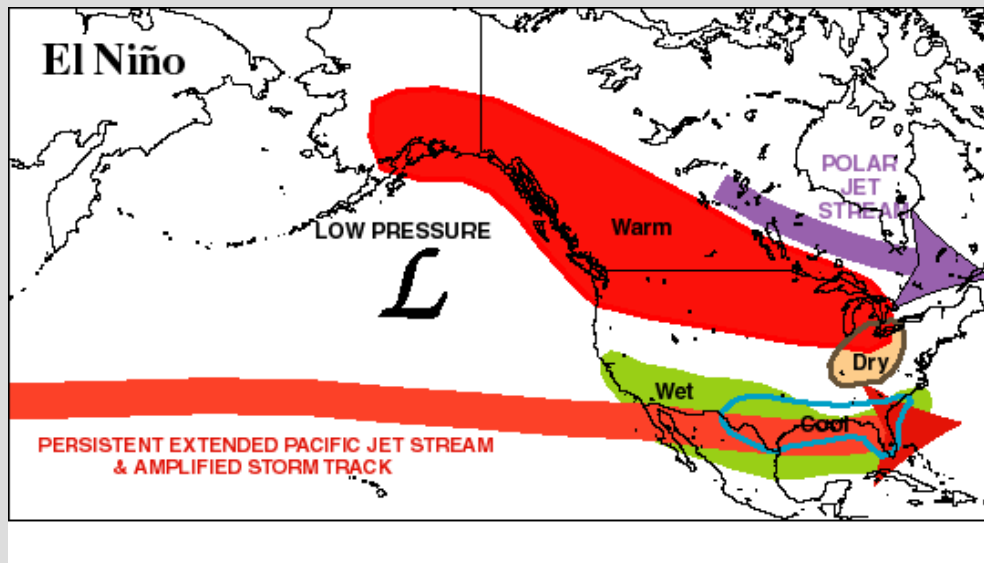


How does ENSO impact the United States?

***Most coherent signal is in winter—but it
does impact the summer too.***

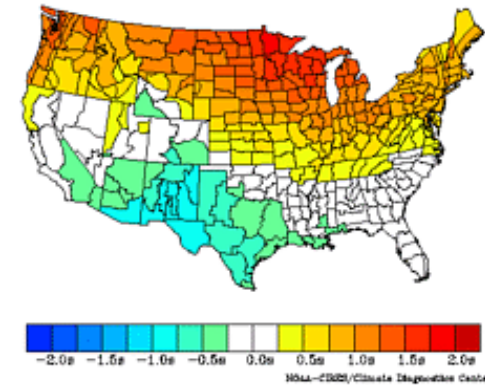
El Niño Impacts on United States: Winter

TEMPERATURE ANOMALY



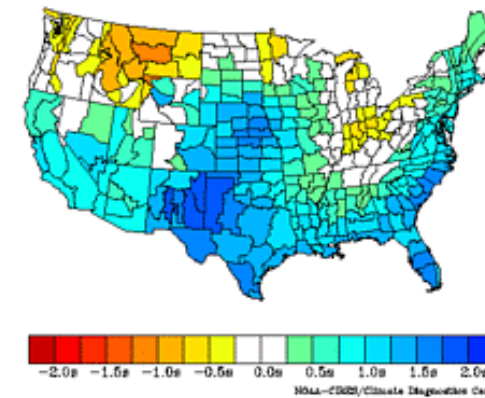
(NOAA CPC)

Composite Standardized Temperature Anomalies Nov to Mar Versus 1950-1995 Longterm Average
1957-59, 1972-73, 1982-83, 1986-87, 1991-92, 1997-98



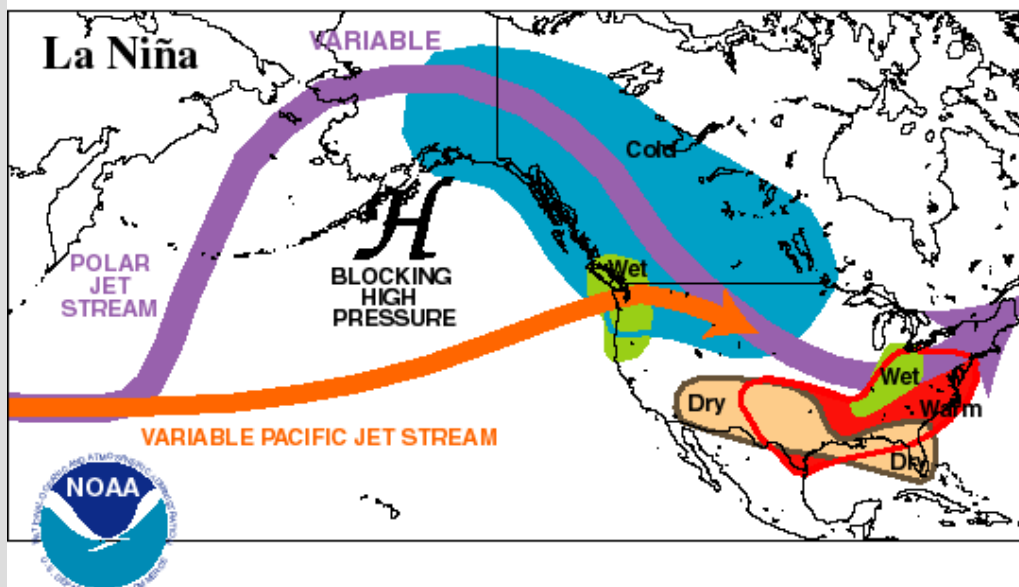
RAINFALL ANOMALY

Composite Standardized Precipitation Anomalies Nov to Mar Versus 1950-1995 Longterm Average
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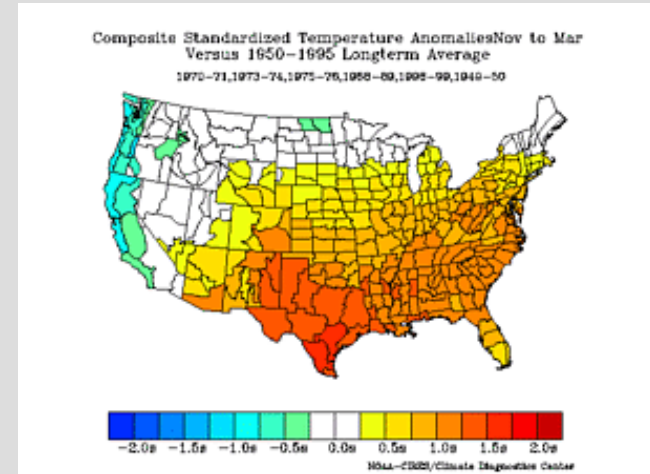
(NOAA CDC)

La Niña Impacts on United States: Winter

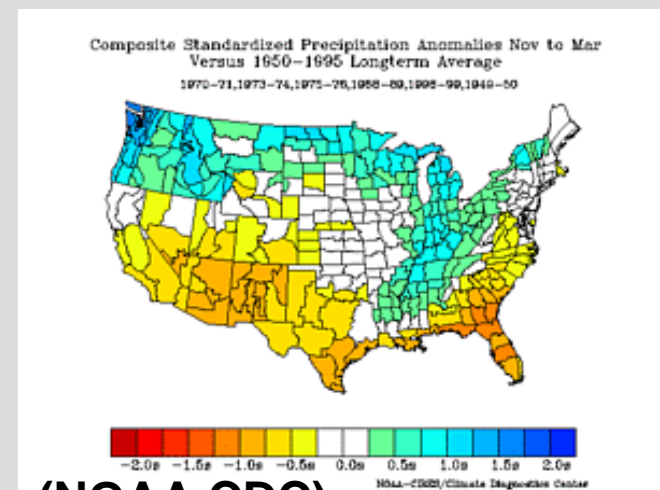


(NOAA CPC)

TEMPERATURE ANOMALY



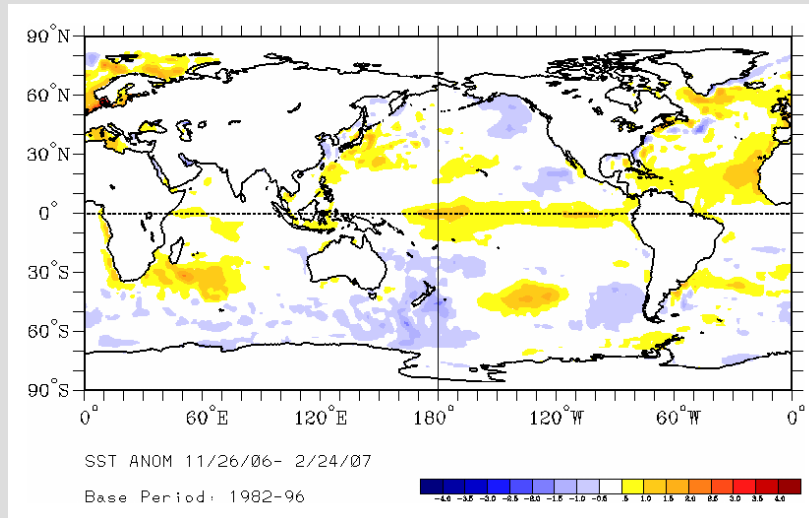
RAINFALL ANOMALY



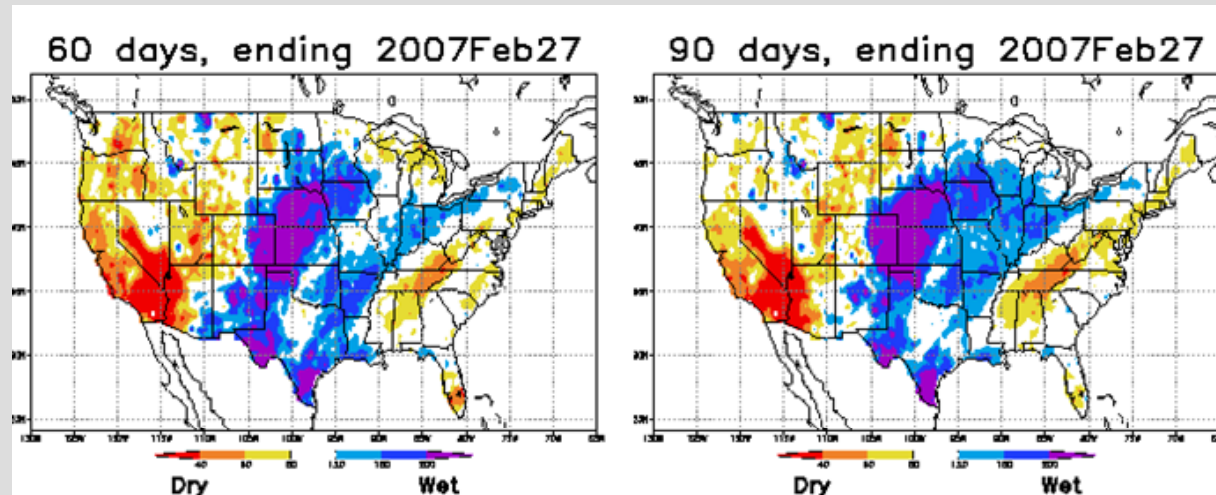
(NOAA CDC)

ENSO vs. U.S. Precipitation Anomalies Late winter 2007

**Seasonal SST
Anomaly**



**Corresponding
precipitation
anomalies for
past two and
three months**



(NOAA CDC)

**ENSO is *not* the only
ocean-atmosphere interaction ...**

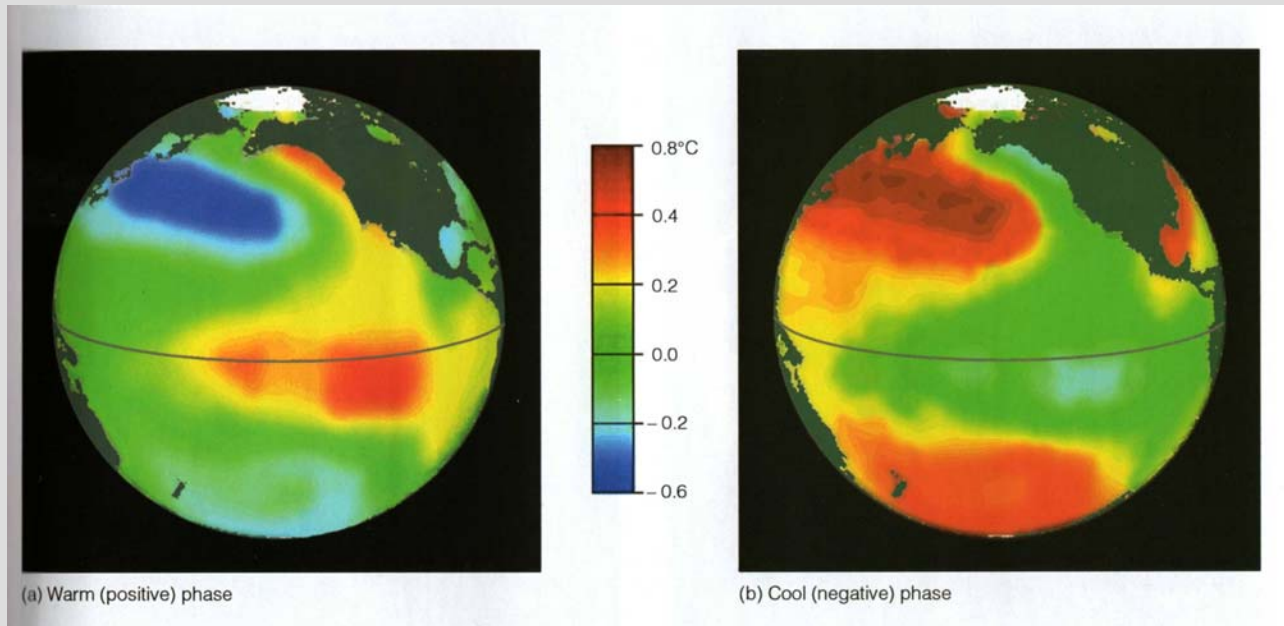
Pacific Decadal Oscillation (PDO)

North Atlantic Oscillation (NAO)

Pacific Decadal Oscillation (PDO)

POSITIVE PDO

NEGATIVE PDO



Shift in Pacific ocean sea surface temperatures and pressure on a timescale of 20 to 30 years

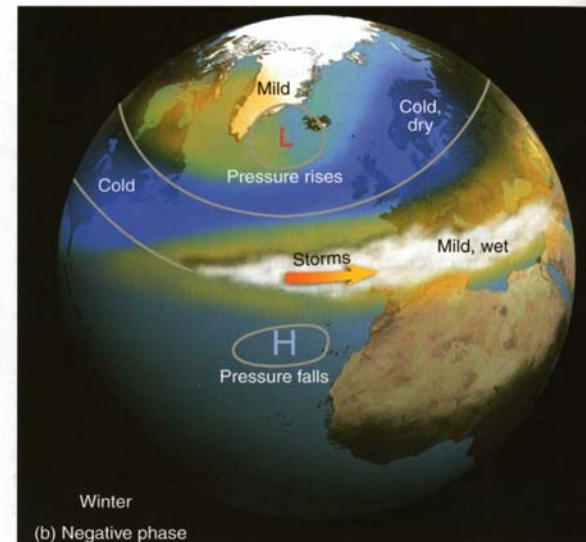
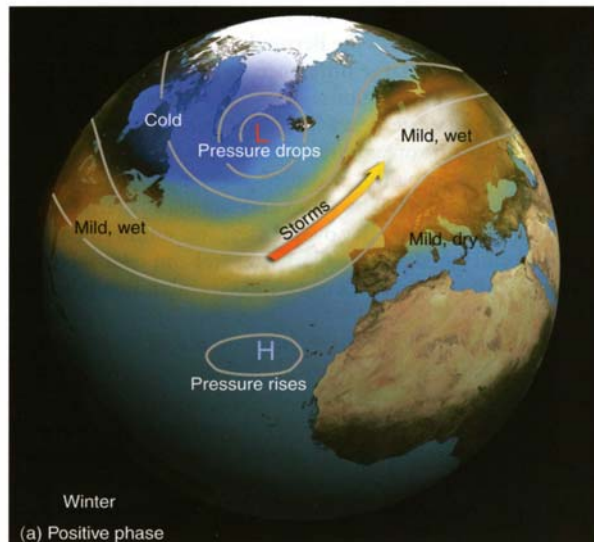
Tends to reinforce ENSO impacts over North America and is perhaps important for summer climate.

Physical mechanism is still an area of active research!

North Atlantic Oscillation (NAO)

POSITIVE NAO

NEGATIVE NAO



• FIGURE 10.26

Change in surface atmospheric pressure and typical winter weather patterns associated with the (a) positive phase and (b) negative phase of the North Atlantic Oscillation.

Basically reflects the strength of the Icelandic Low

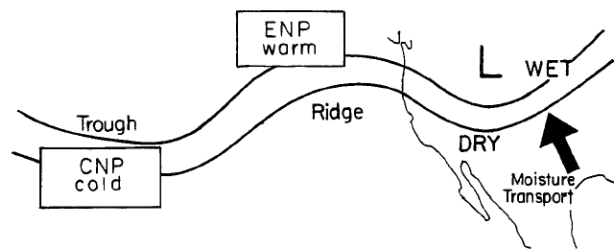
A control on jet stream position and climate over Europe and eastern North America

Also a reflection of the strength of the polar vortex (Arctic Oscillation).

**Which brings me back to the North
American Monsoon...**

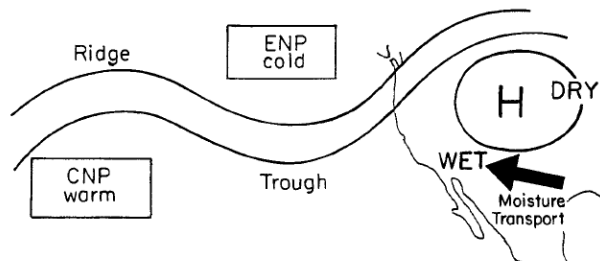
***How it varies is related to what
happens in the Pacific,
specifically ENSO and the PDO.***

North American summer climate teleconnection to Pacific SST



El Niño

El Niño
High NPO Phase



La Niña

La Niña
Low NPO Phase

FIG. 14. Idealized relationship of monsoon ridge position and midlevel moisture transport to Pacific SSTs at monsoon onset.

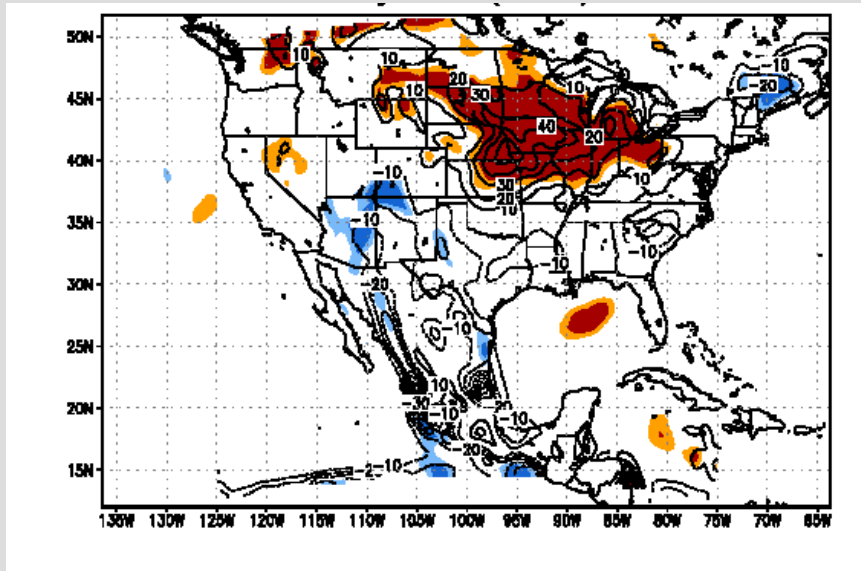
What happens in the Pacific Ocean controls the position of the monsoon ridge in the early part of the summer.

THIS AFFECTS THE ONSET OF THE MONSOON AND EARLY SUMMER RAINFALL IN ARIZONA.

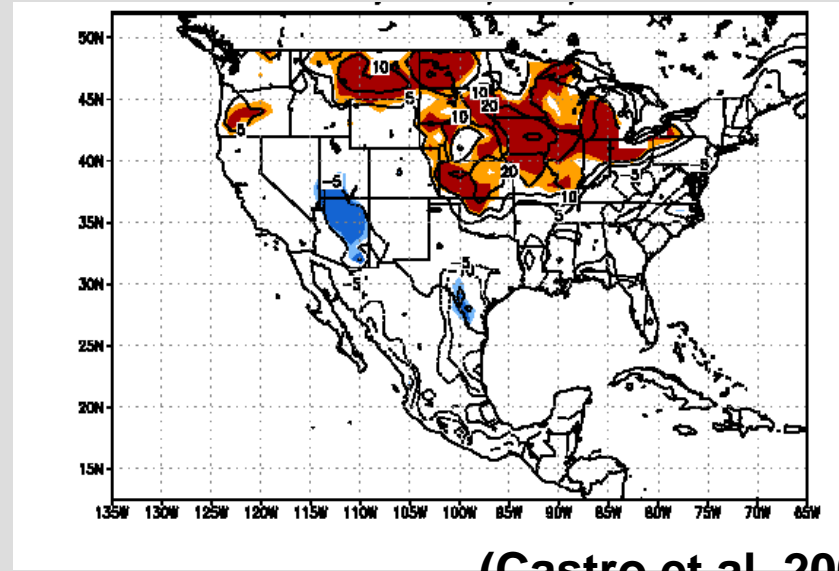
(Castro et al. 2001)

Early Summer Precipitation Anomaly Associated with Pacific SST

REGIONAL CLIMATE MODEL



GAUGE OBSERVATIONS



(Castro et al. 2007)

A DRY AND DELAYED MONSOON IN AZ = WET AND COOL IN CENTRAL US

WET AND EARLY MONSOON IN AZ = DRY AND HOT IN CENTRAL US

***IT ALL TIES BACK TO LARGE-SCALE FORCING OF THE ATMOSPHERIC
CIRCULATION FROM THE TROPICAL PACIFIC—AND IT MAY BE
PREDICTABLE!!***

Summary of Lecture 20

The ocean is important to weather and climate because it transports heat, acts as a climate regulator, and provides a source of memory in the climate system.

Major ocean currents are part of gyres that transport heat from equator to pole. Warm (cold) water currents occur on east (west) side of continents

Water is relatively colder along west coasts of continents due to upwelling.

In a normal year, the Walker circulation arises from an asymmetry in Pacific SSTs. This favors convection in the western tropical Pacific.

El Niño Southern Oscillation (ENSO) refers to a 3-5 year shift in oceanic and atmospheric circulation patterns in the tropical Pacific. Be familiar with El Niño and La Niña and how they differ from the normal year.

Besides the tropical Pacific, ENSO affects weather and climate across the globe, including the U.S.

Other important atmosphere-ocean interactions include the PDO and NAO. The PDO reinforces climate anomalies associated with ENSO.