The El Niño/ Southern Oscillation (ENSO) Cycle

Outline

(1) Seasonal Cycle of Sea Surface Temperature and Precipitation

(2) El Niño - Southern Oscillation (ENSO): Historical Context

(3) Comparison between El Niño/ Low SO Phase VS. La Niña/ High SO Phase

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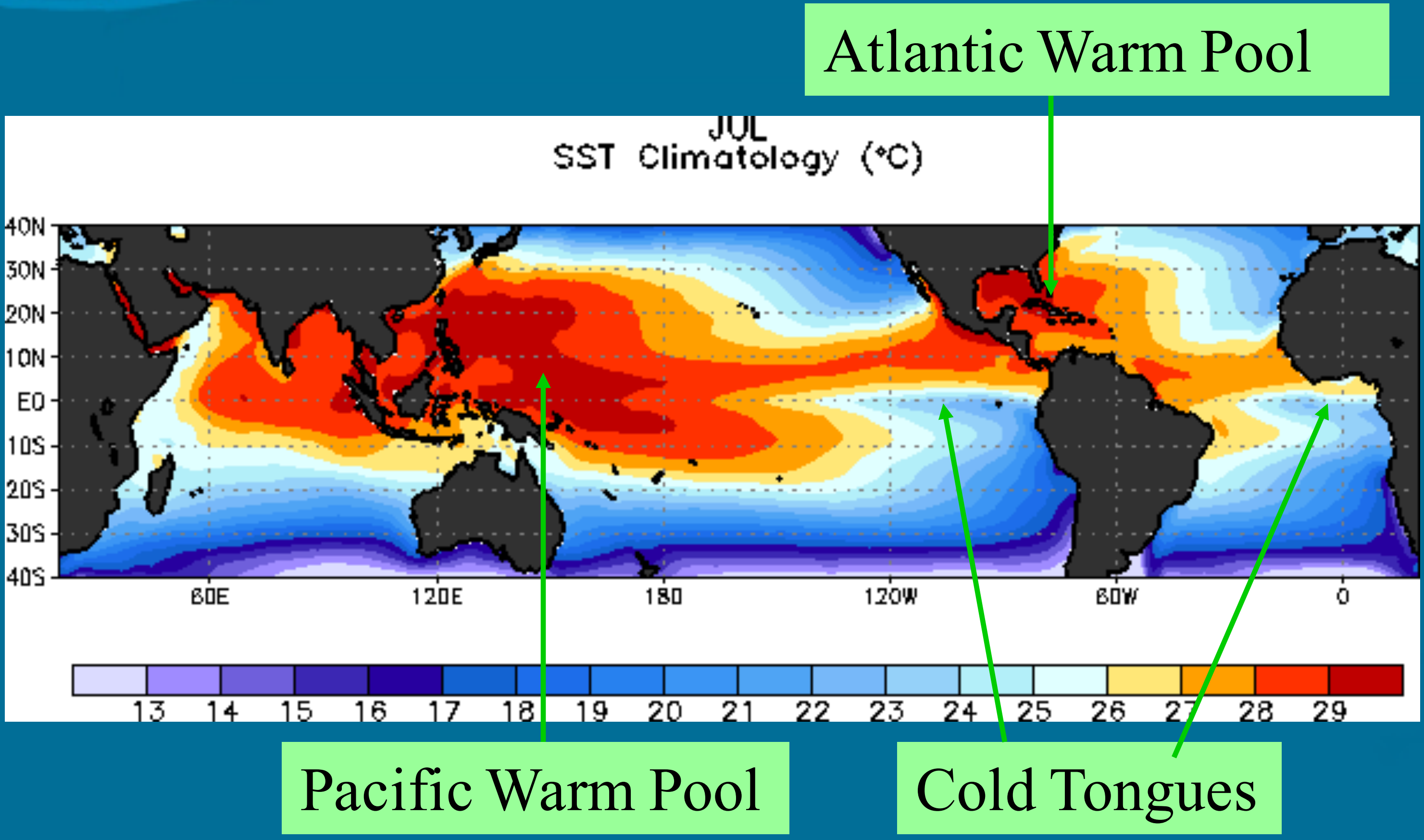
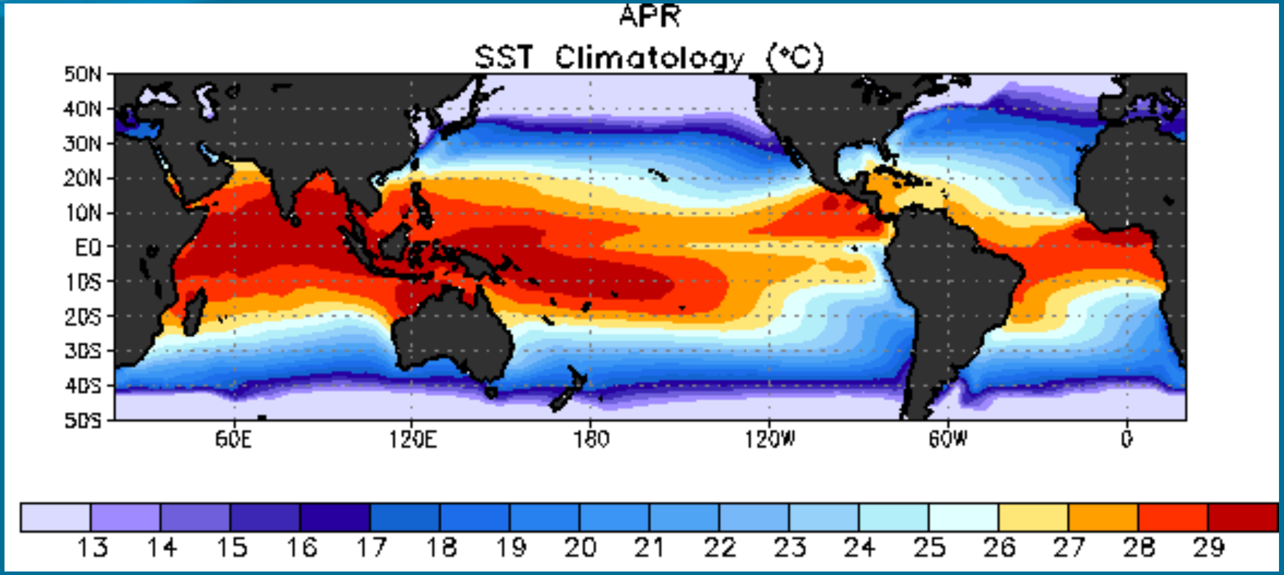
Sea Surface Temperature (SST): Major Features

- Equatorial cold tongues prominent in the eastern Pacific and Atlantic (strongest during the SH winter/spring – July-October)
- Globally, tropical waters are warmest during the NH late winter and early spring seasons
- North-south seasonal shifts of warm tropical waters are observed in the western portions of tropical oceans

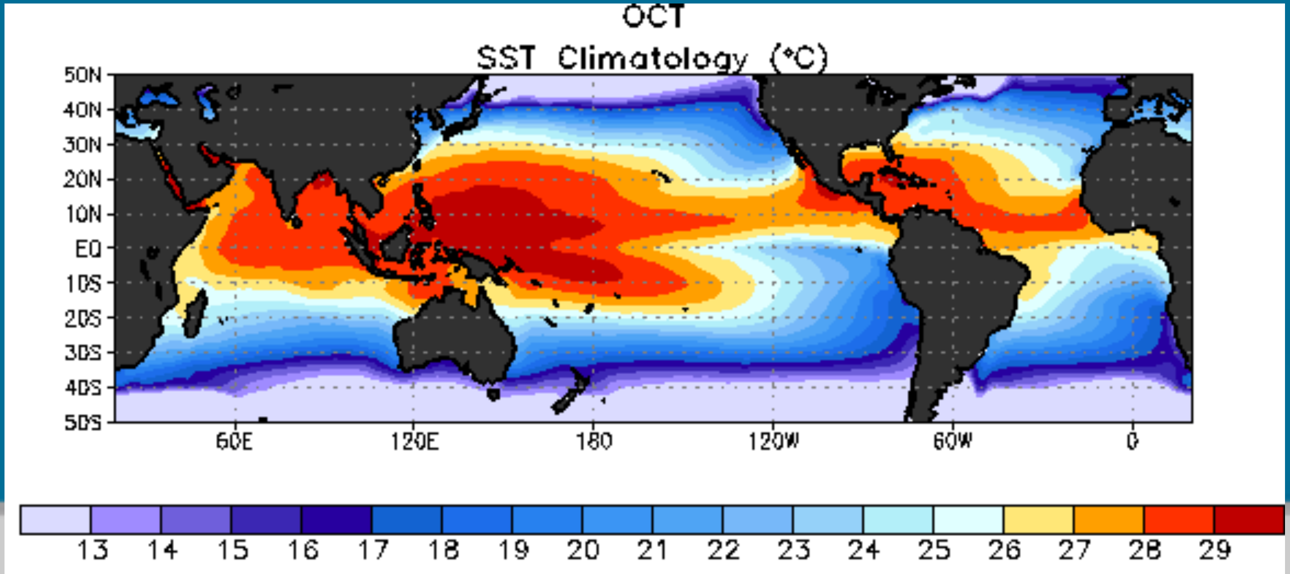
SST: Major Features



SST: Extremes in the Annual Cycle

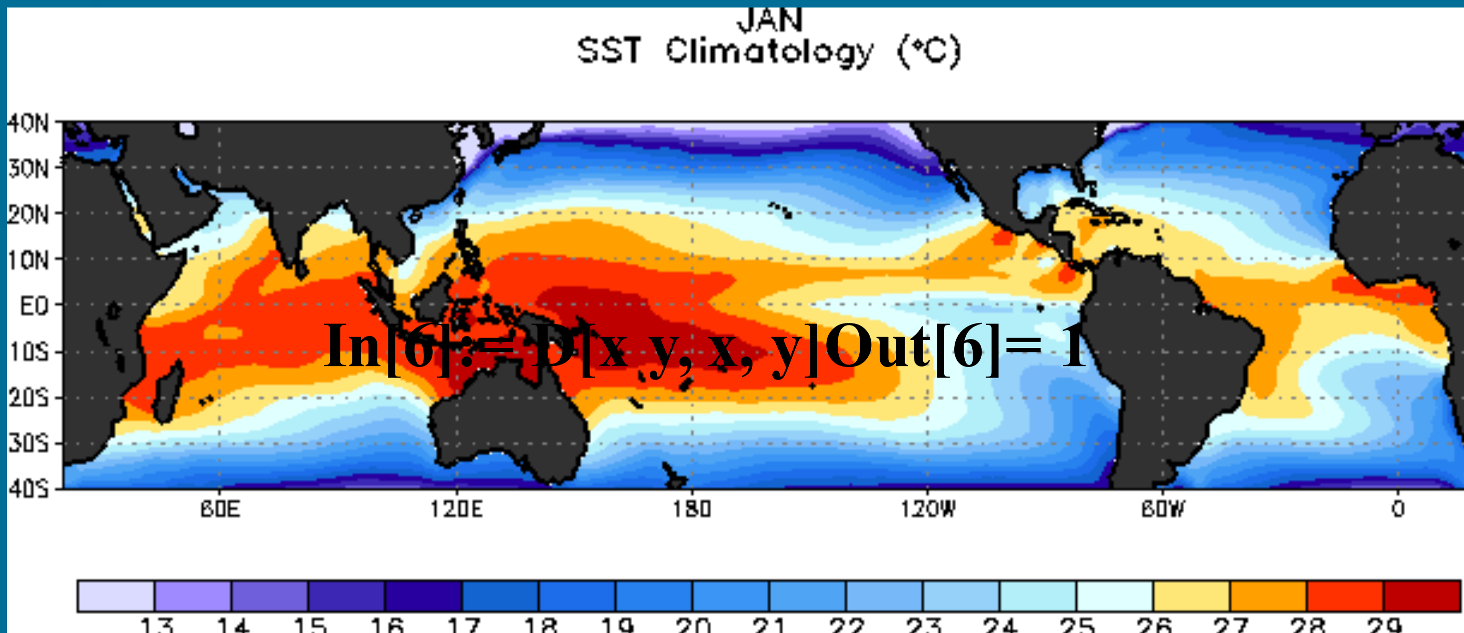


Equatorial SSTs are warmest in April



Equatorial cold tongues are strongest in Jul.-Oct.

SST Animation



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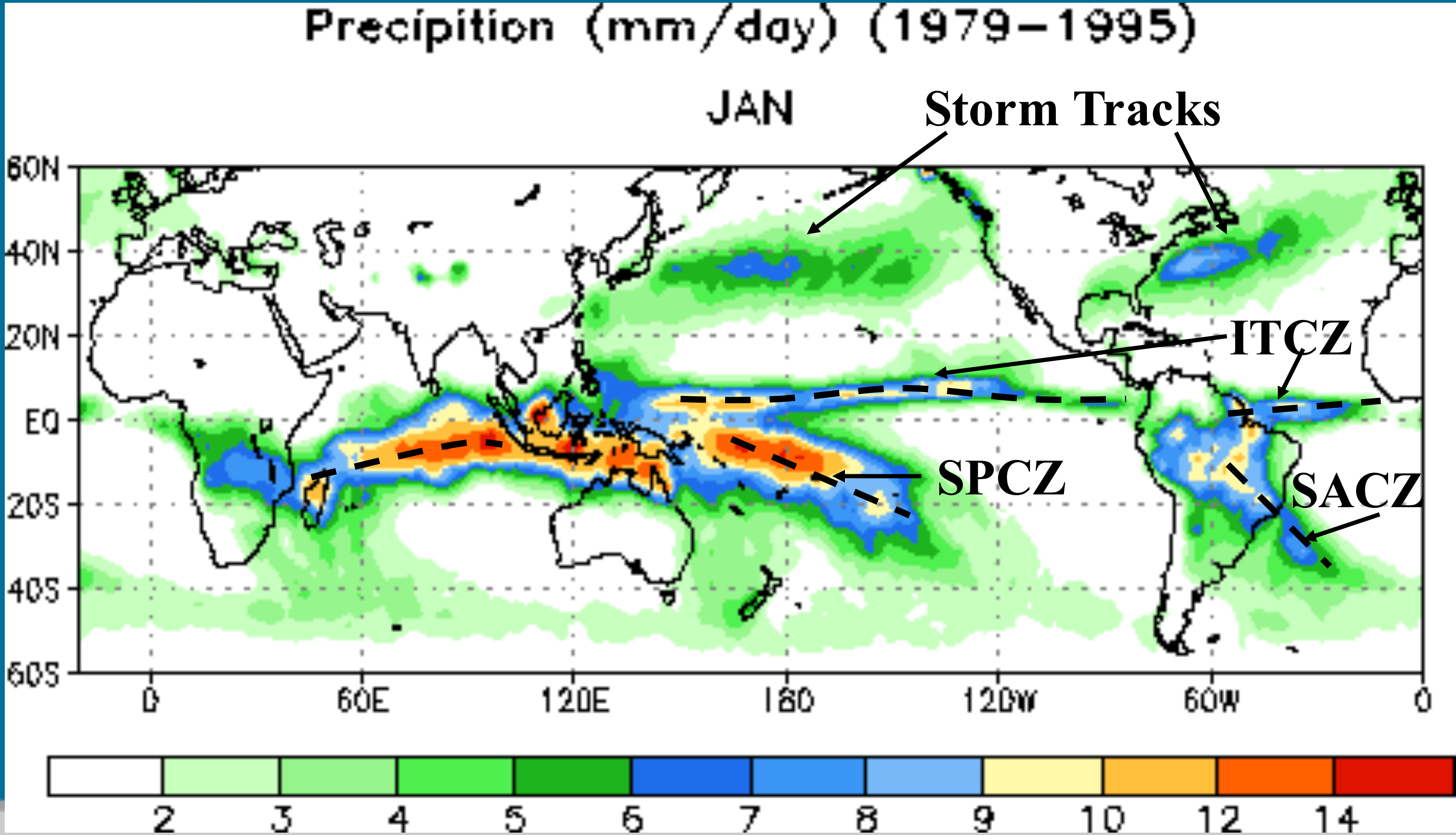
Precipitation

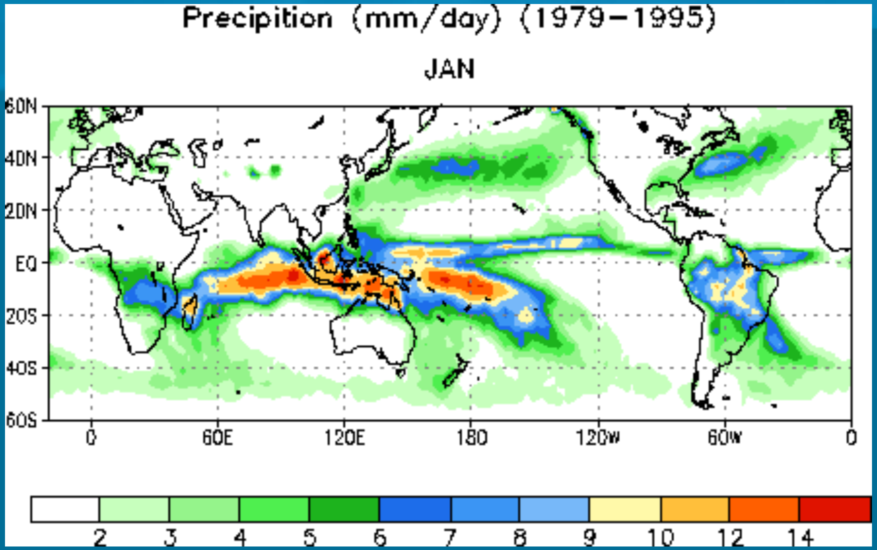
Global precipitation analyses based on station data and satellite-derived estimates

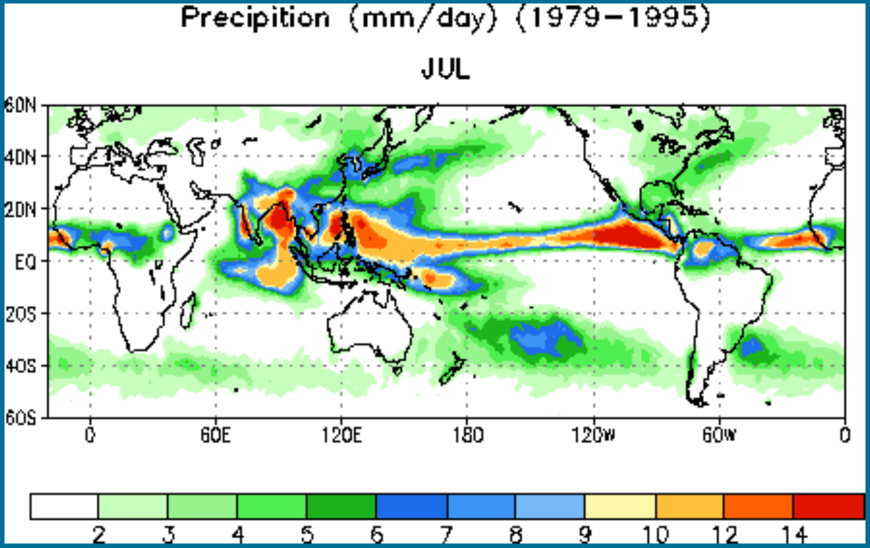
- Greatest precipitation over warm surfaces where ample moisture is available, and in areas of mid-latitude storm activity
  - Tropical land masses
  - Intertropical Convergence Zones (ITCZs)
  - South Pacific Convergence Zone (SPCZ)
  - South Atlantic Convergence Zone (SACZ)
  - Mid-latitude winter storm tracks

Precipitation: Major Features



Precipitation: January vs. July





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History of El Niño

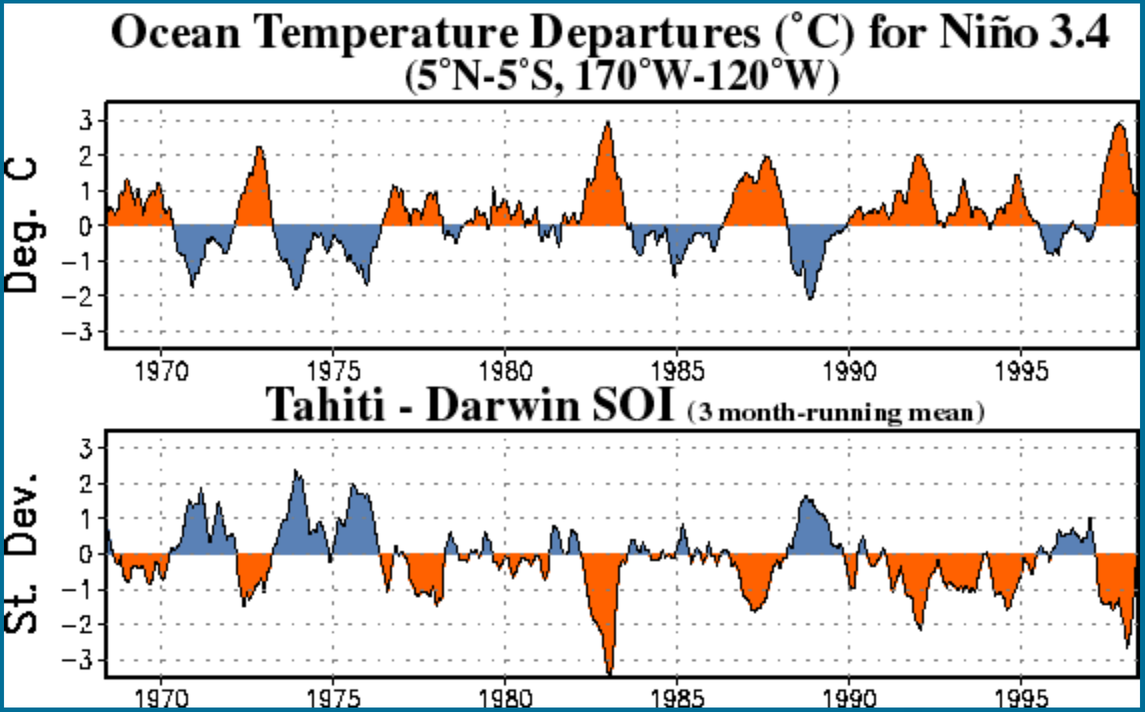
- El Niño, as a oceanic phenomenon along the coasts of northern Peru and Ecuador, has been documented since the 1500s.
- Originally, the term El Niño was used to describe the annual appearance of warm waters around Christmastime.
- In some years the warm waters appeared earlier and lasted longer. Eventually, the term El Niño was used to describe these periods of anomalous warming.
- The stronger events disrupted local fish and bird populations

History of the Southern Oscillation

- Beginning in the late 1800s scientists began to describe large-scale pressure fluctuations.
- Sir Gilbert Walker and colleagues extended the early studies and established that a global-scale pressure fluctuation (the Southern Oscillation) is related to rainfall anomalies in many areas of the Tropics (e.g., India and South America.
- The SO was used as the basis for seasonal rainfall predictions (ca 1930s).

Discovery of the "El Niño-Southern Oscillation (ENSO)"

- El Niño and the Southern Oscillation were studied as separate phenomena until the 1950s-1960s.
- Important works by Berlage (1956) and J. Bjerknes (late 1960s) demonstrated a link between the two phenomena.
- Studies at that time also showed that the anomalous warming of the waters during El Niño extended over a large portion of the equatorial Pacific.



The ENSO Cycle

- Naturally occurring phenomenon
- Equatorial Pacific fluctuates between warmer-than-average (El Niño) and colder-than-average (La Niña) conditions
- The changes in SSTs affect the distribution of tropical rainfall and atmospheric circulation features (Southern Oscillation)
- Changes in intensity and position of jet streams and storm activity occur at higher latitudes

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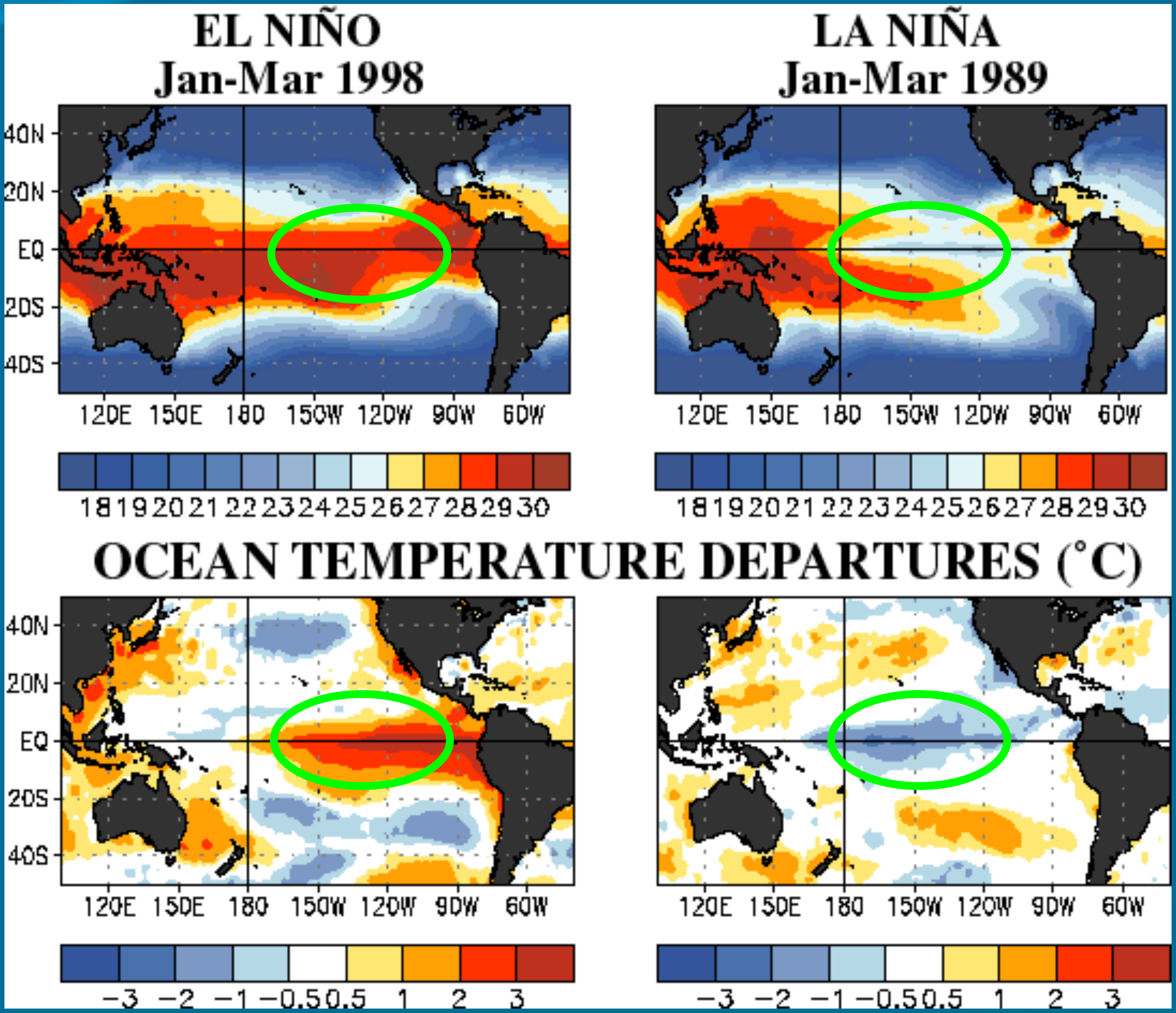
El Niño/ Low Southern Oscillation Phase
VS.
La Niña/ High Southern Oscillation Phase

Signals in Tropical Pacific:

- Sea surface temperatures (SSTs)
- Precipitation
- Sea Level Pressure
- The Southern Oscillation (High vs. Low Phases)
- Low-level Winds and Thermocline Depth

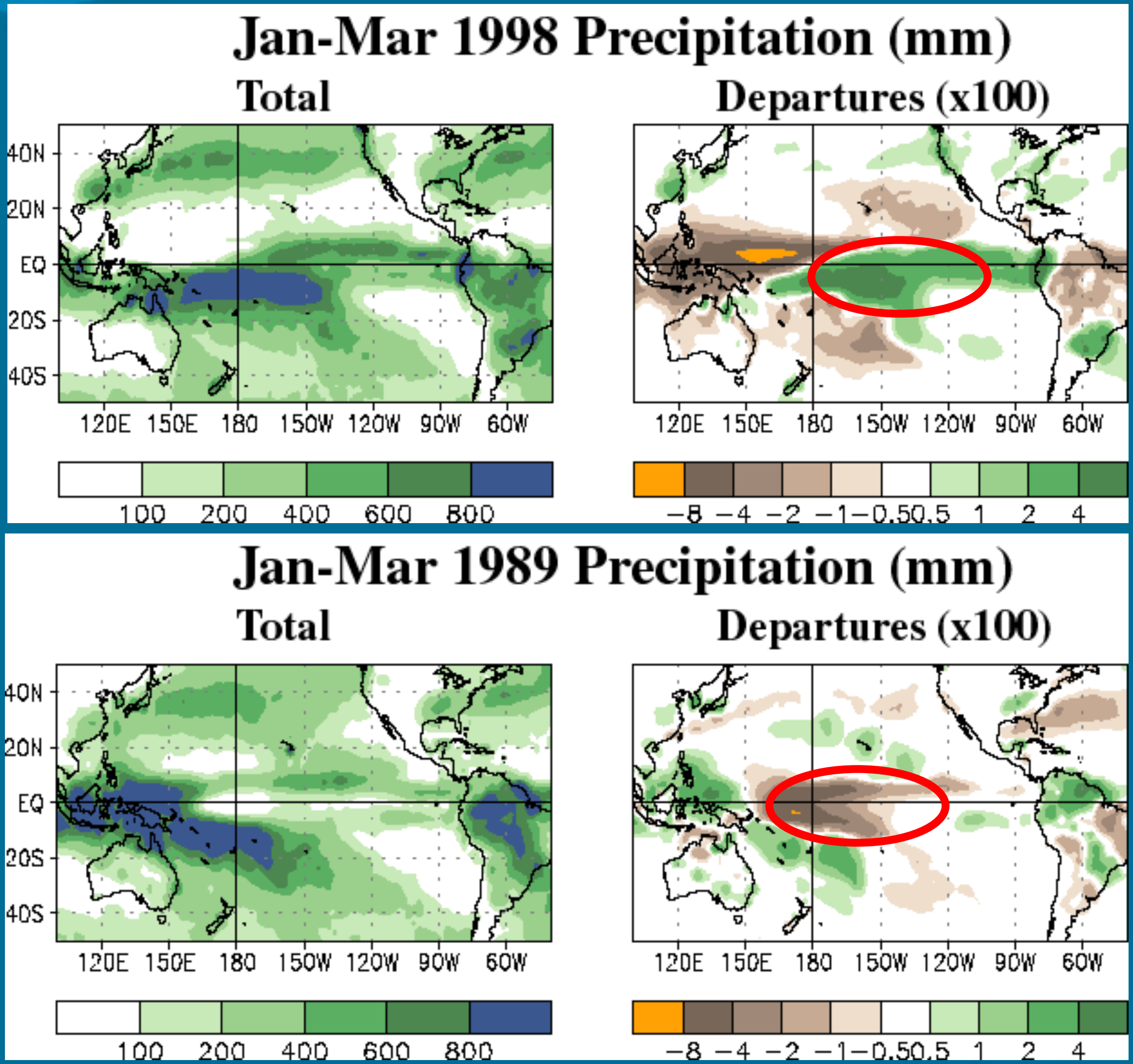
Sea Surface Temperatures

Equatorial cold tongue is weaker than average or absent during El Niño, resulting in positive SST anomalies



Equatorial cold tongue is stronger than average during La Niña, resulting in negative SST anomalies

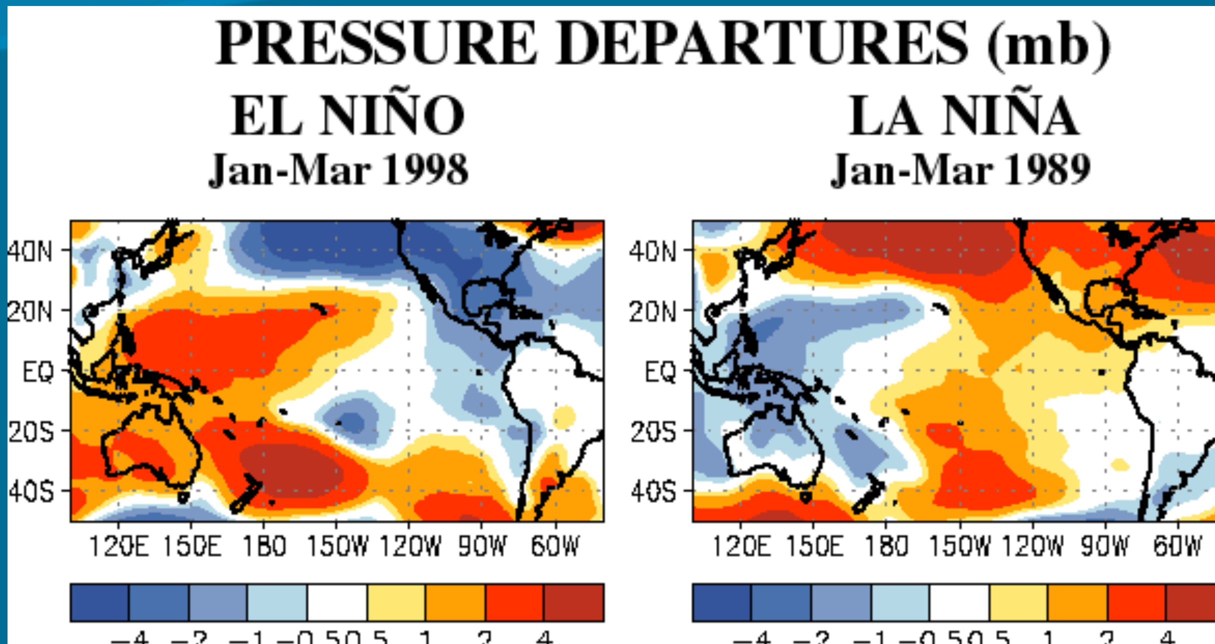
Precipitation



Enhanced rainfall occurs over warmer-than-average waters during El Niño.

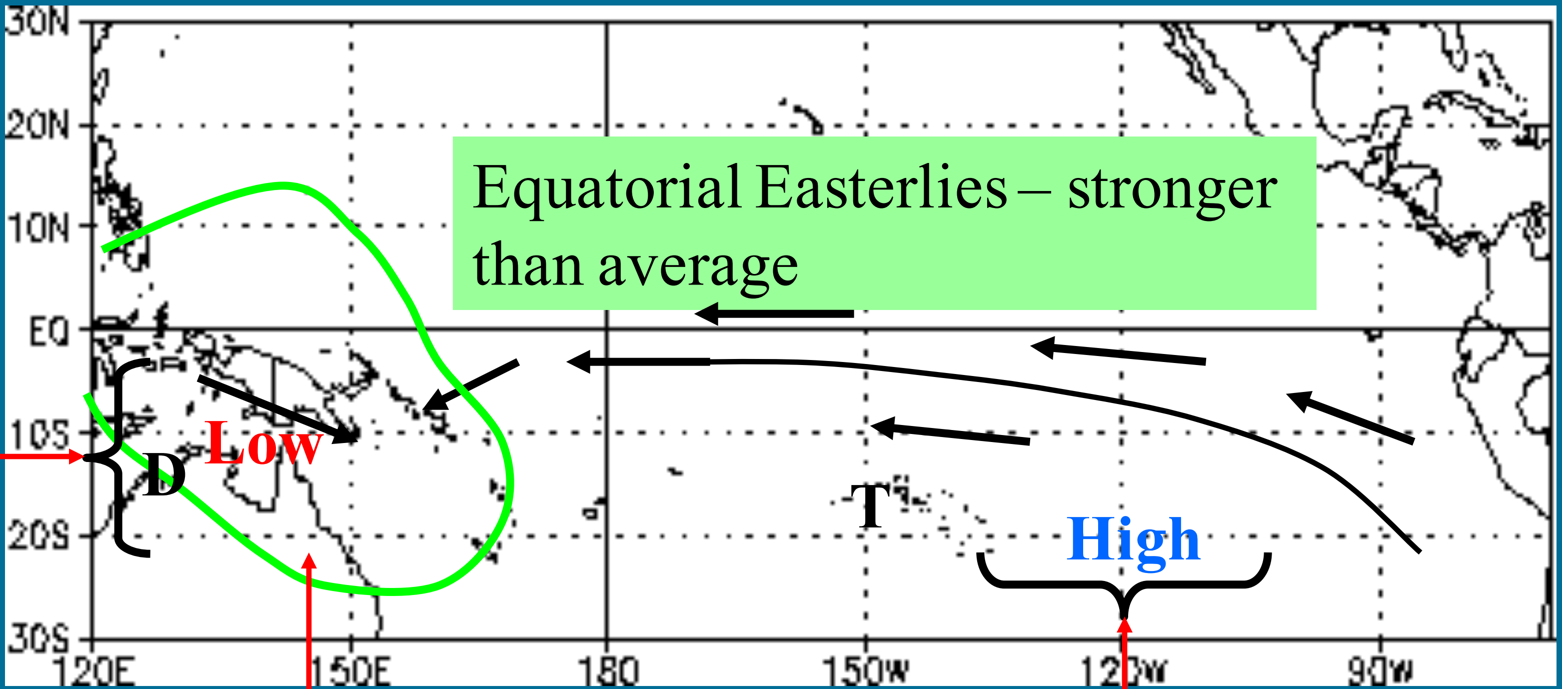
Reduced rainfall occurs over colder-than-average waters during La Niña.

Sea Level Pressure



<u>El Niño</u>: Positive SLP anomalies over the western tropical Pacific, Indonesia and Australia. Negative SLP anomalies over eastern tropical Pacific, middle and high latitudes of the North Pacific, and over U.S. Opposite pattern for <u>La Niña</u>. The pressure see-saw between the eastern and western tropical Pacific is known as the <u>Southern Oscillation</u>.

Southern Oscillation – High Index Phase (La Niña)



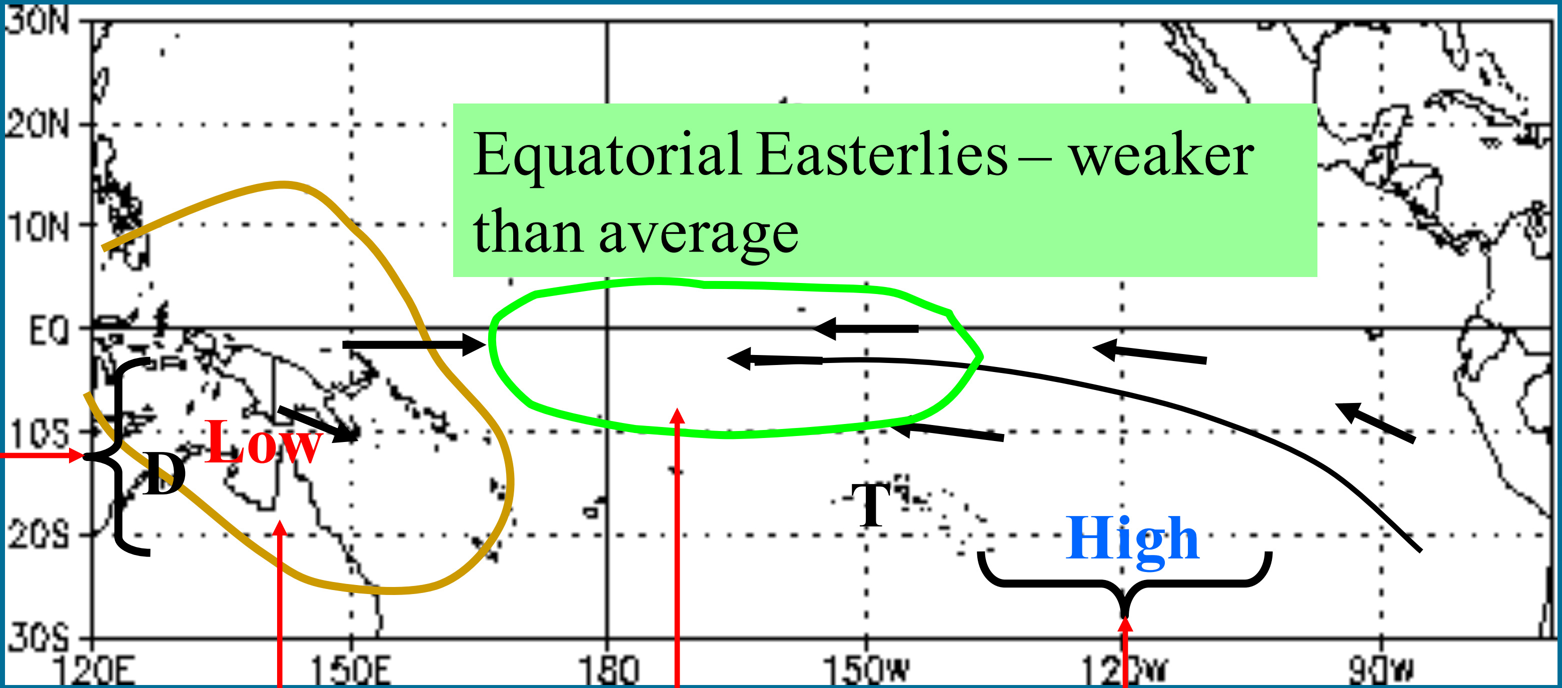
SLP – below average

Enhanced Precipitation

SLP – above average

Southern Oscillation – Low Index Phase (El Niño)

SLP – above average

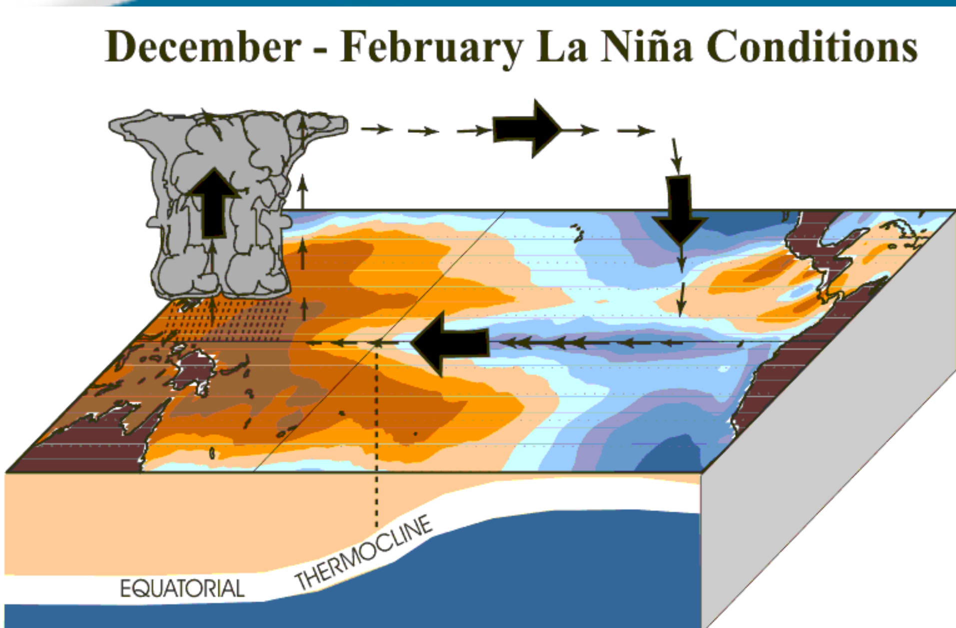


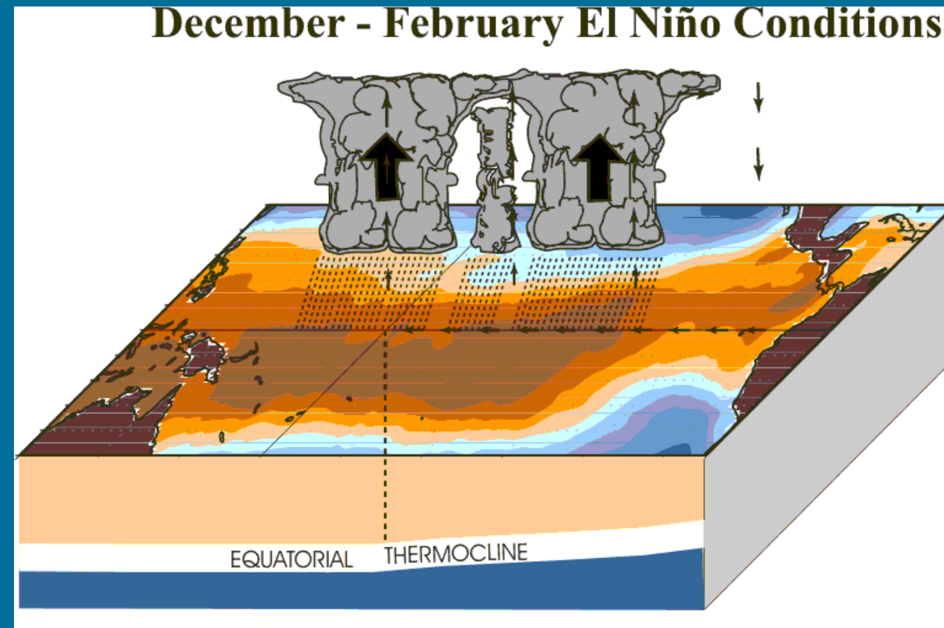
Reduced Precipitation

Enhanced Precipitation

SLP – below average

Low-Level Winds & Thermocline Depth





La Niña: stronger-than-average easterlies lead to a deeper (shallower)-than-average thermocline in the western (eastern) eq. Pacific.

El Niño: weaker-than-average easterlies lead to a deeper (shallower)-than-average thermocline in the eastern (western) eq. Pacific.

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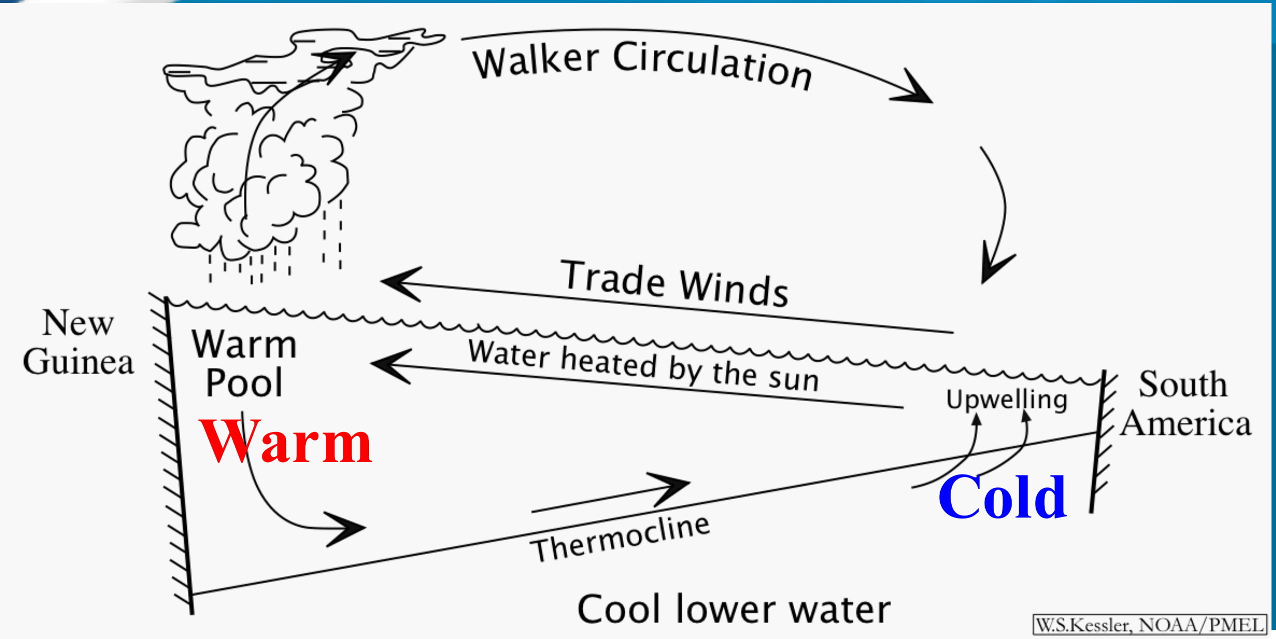
ENSO: A Coupled Ocean-Atmosphere Cycle

ENSO is a "coupled" phenomenon: atmosphere drives the ocean and the ocean drives the atmosphere.

"Positive Feedback" between ocean and atmosphere. Example:

Weaker equatorial trade winds → cold water upwelling in the east will decrease → surface warming of the ocean → reduced east-west temperature gradient → Weaker equatorial trade winds

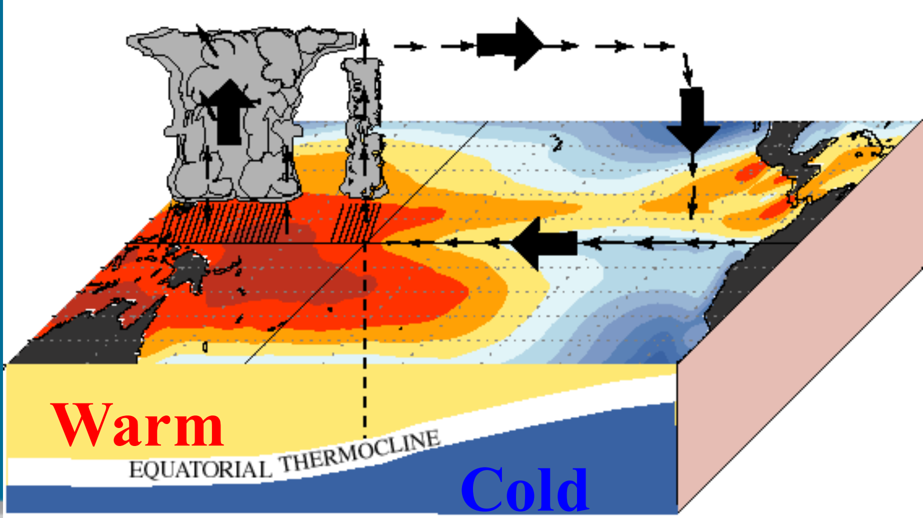
What is "Normal?"



(2) Warm water heats the atmosphere and makes it rise, so low-level trade winds blow towards warm water to fill the gap. Subsiding air occurs in the eastern basin.

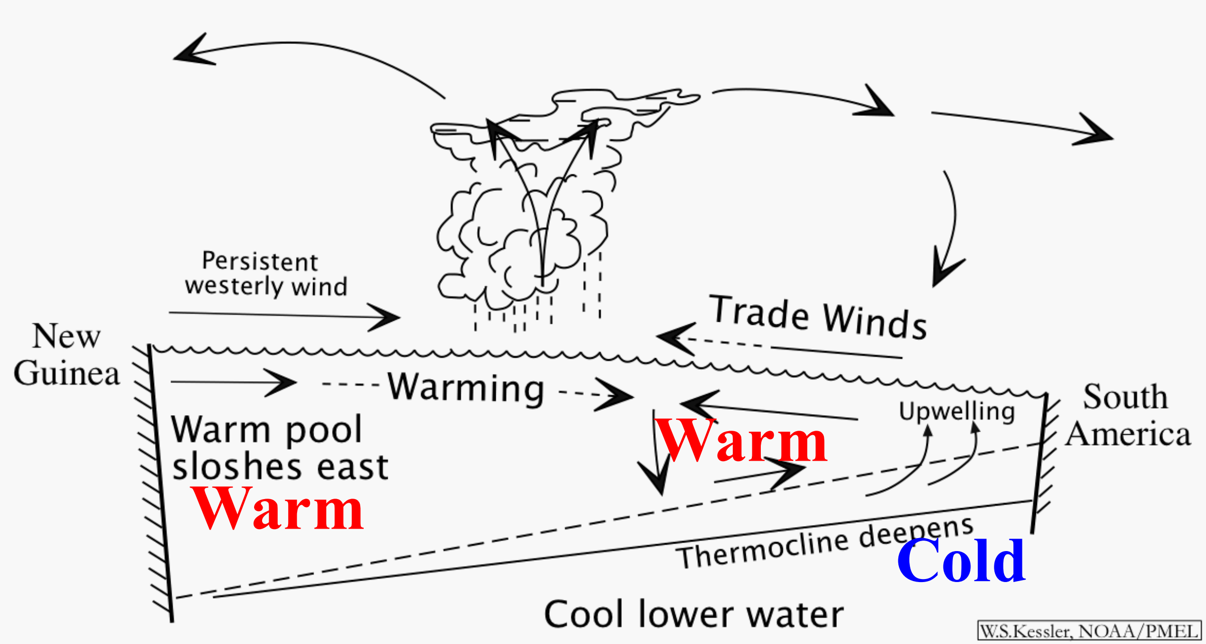
Winds and Sea Surface Temperature are <u>COUPLED.</u> The SSTs determine the winds and vice versa.

(1) Easterly trade-winds help push warm water to the western Pacific and upwell cold water in the eastern Pacific Ocean.



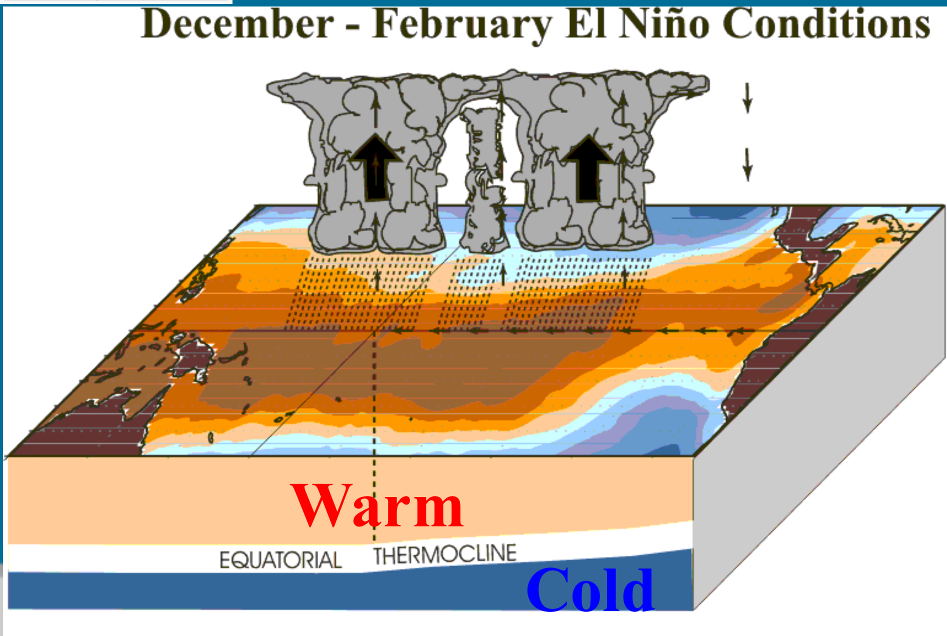
“El Niño”

NOTE: Location of the warmest SSTs (>28°C) determines where tropical convection will be located.

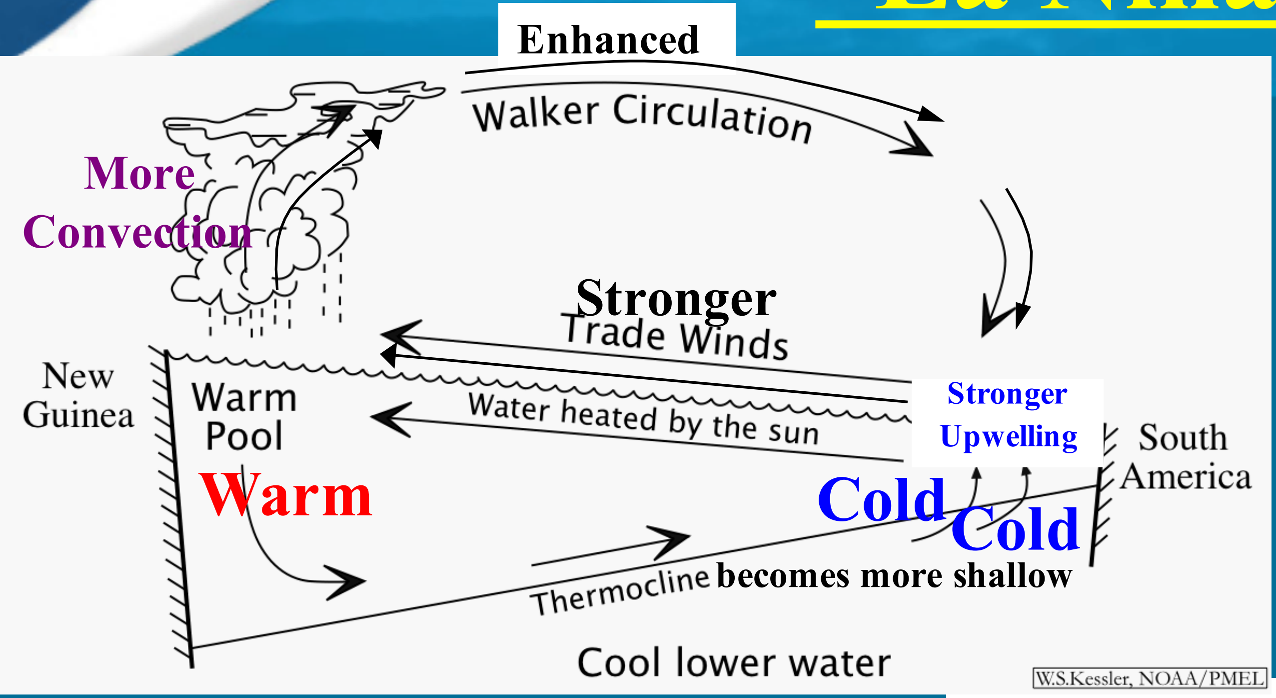


- Convection shifts eastward over the central and/or eastern Pacific Ocean. Convection becomes suppressed over the far western Pacific/ Indonesia.

- Easterly trade winds weaken
- Thermocline deepens and the cold water upwelling decreases in the eastern Pacific.



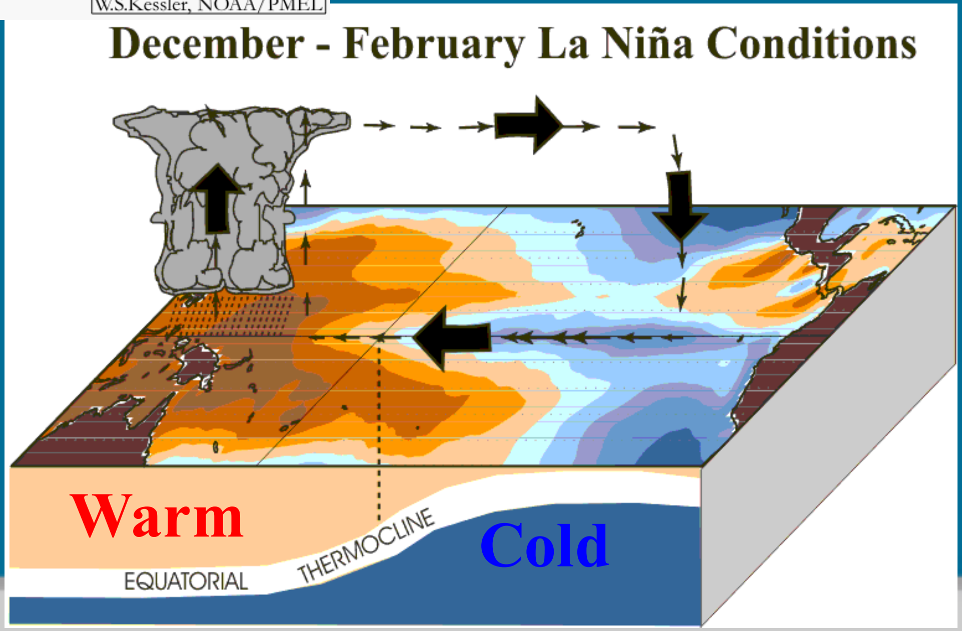
"La Niña"



- Convection becomes stronger over the far western Pacific Ocean/ Indonesia and more suppressed in the central Pacific.

- Easterly trade winds strengthen

- Thermocline becomes more shallow and the cold water upwelling increases in the eastern Pacific.



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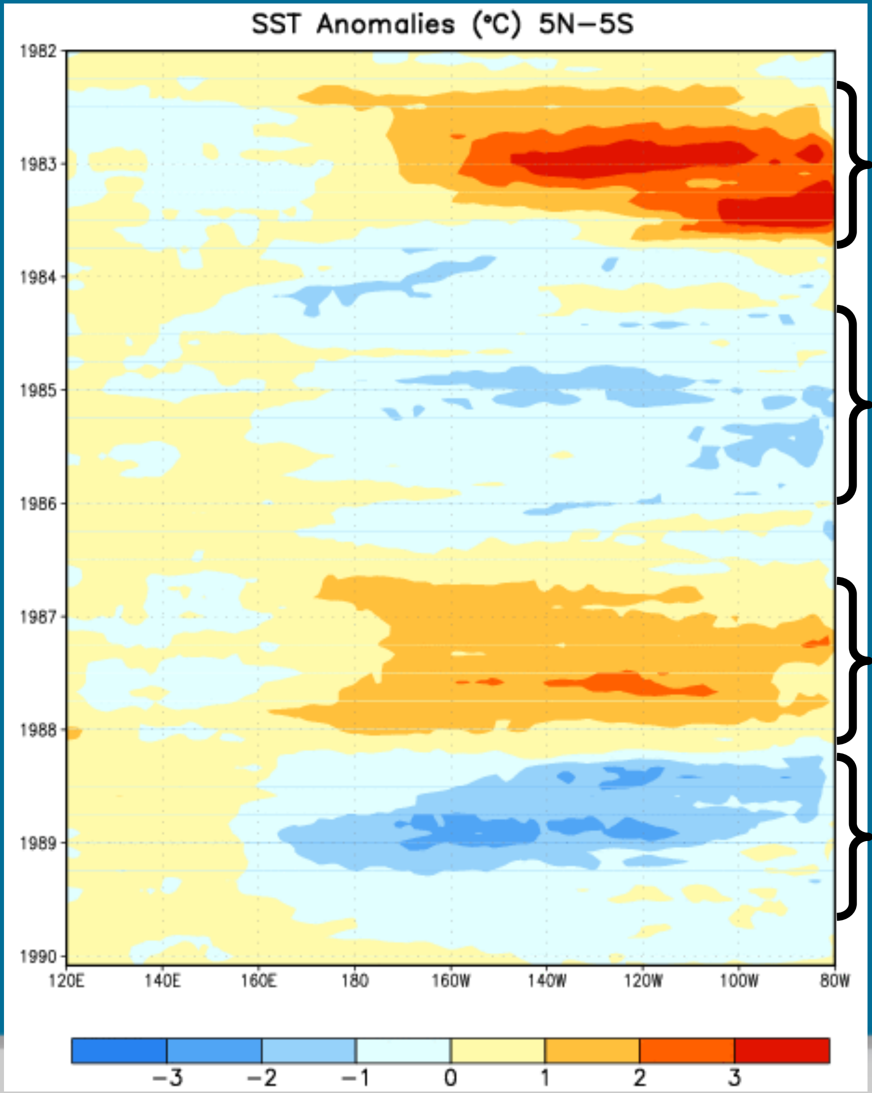
Typical Evolution of the ENSO Cycle

- Irregular cycle with alternating periods of warm (El Niño) and cold (La Niña) conditions
- El Niño tends to occur every 3-4 years and generally lasts 12-18 months
- Strongest El Niño episodes occur every 10-15 years
- La Niña episodes may last from 1 to 3 years
- Transitions from El Niño to La Niña are more rapid

The Evolution of Equatorial SST Anomalies: 1982-1990



1982-83 El Niño

1984-85 La Niña

1986-87 El Niño

1988-89 La Niña

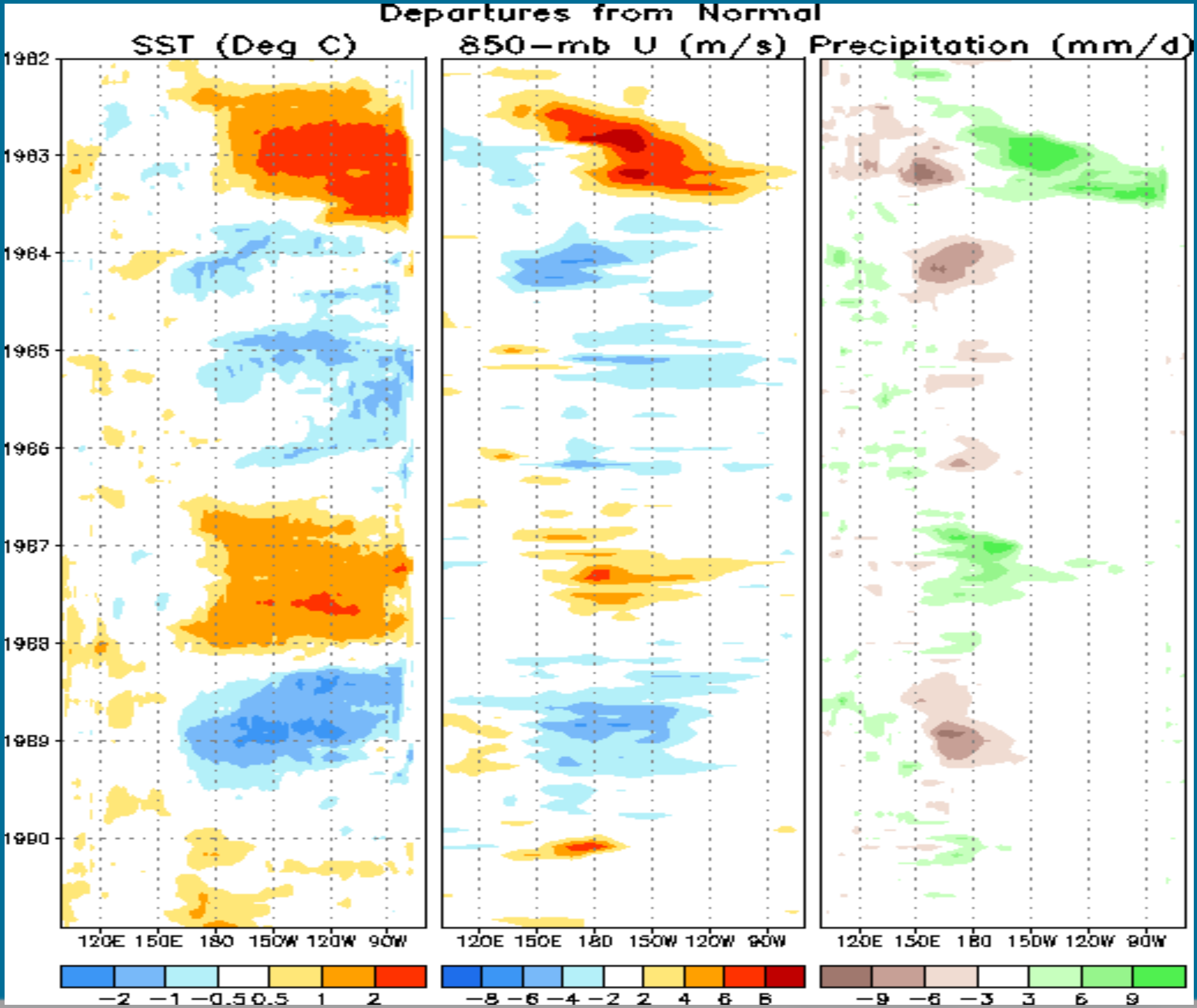
Evolution of the ENSO Cycle: 1982-1990

El Niño:

Positive SST anomalies, enhanced precip, weaker than average easterly winds

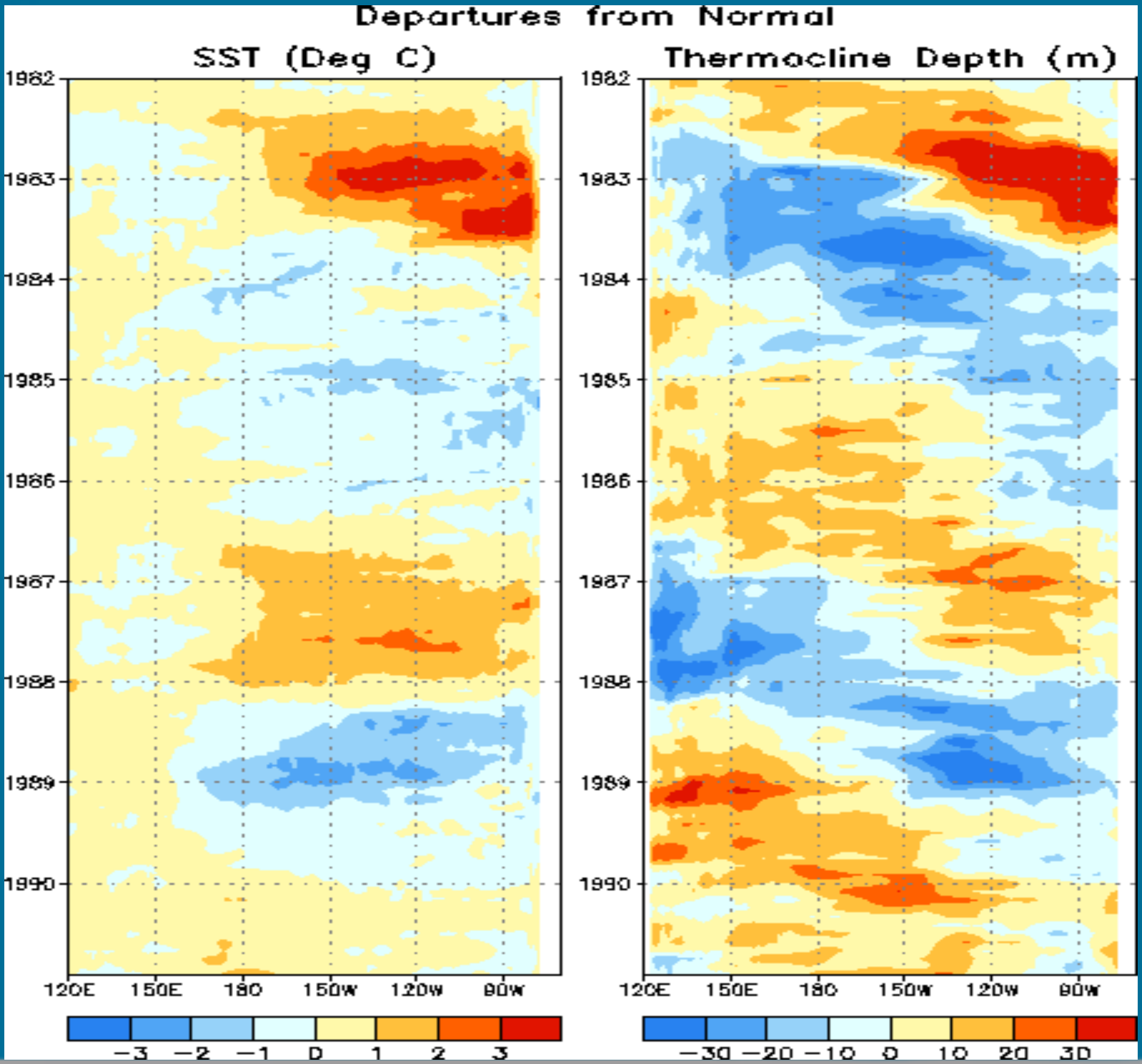
La Niña:

Negative SST anomalies, reduced precip, stronger than average easterly winds

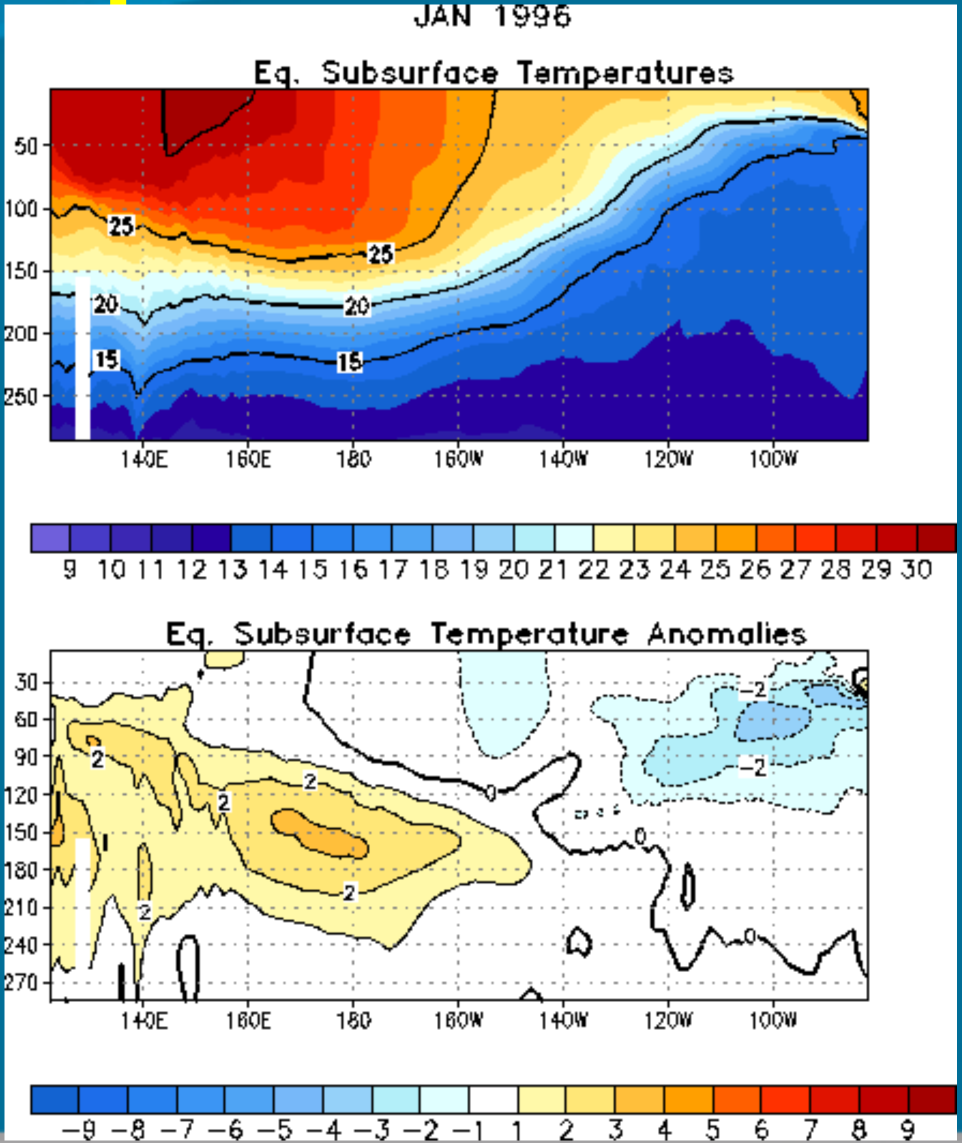


Thermocline Depth: 1982-1990

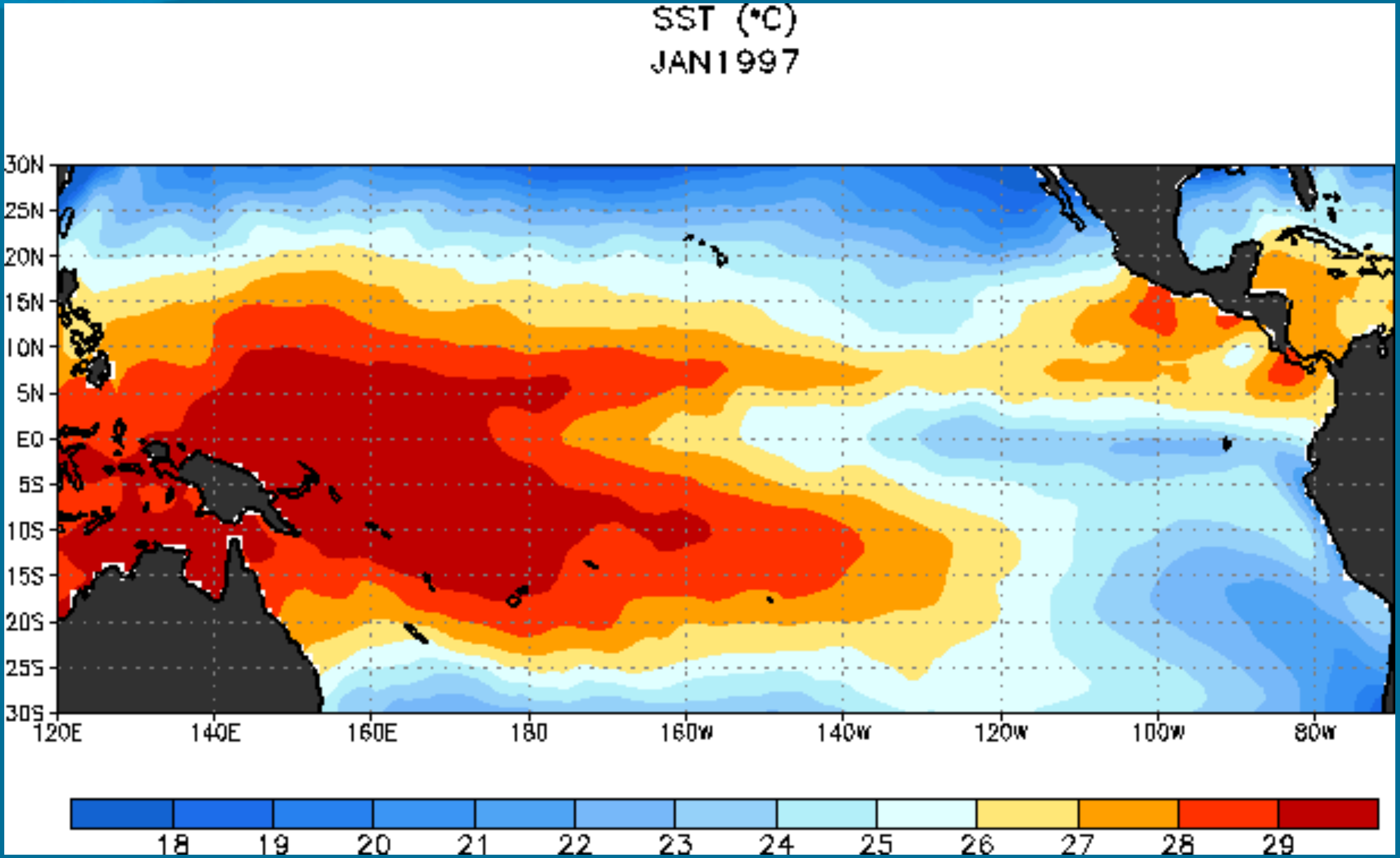
Thermocline depth (upper-ocean heat content) anomalies lead SST anomalies



Animation of Subsurface Temperatures: 1996-1999



SST Animation: 1997-1998



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ENSO Teleconnections

Tropical convection/heating can lead to "wavetrains" that can influence the global circulation.

Schematic from Horel and Wallace (1981)

EXAMPLE:

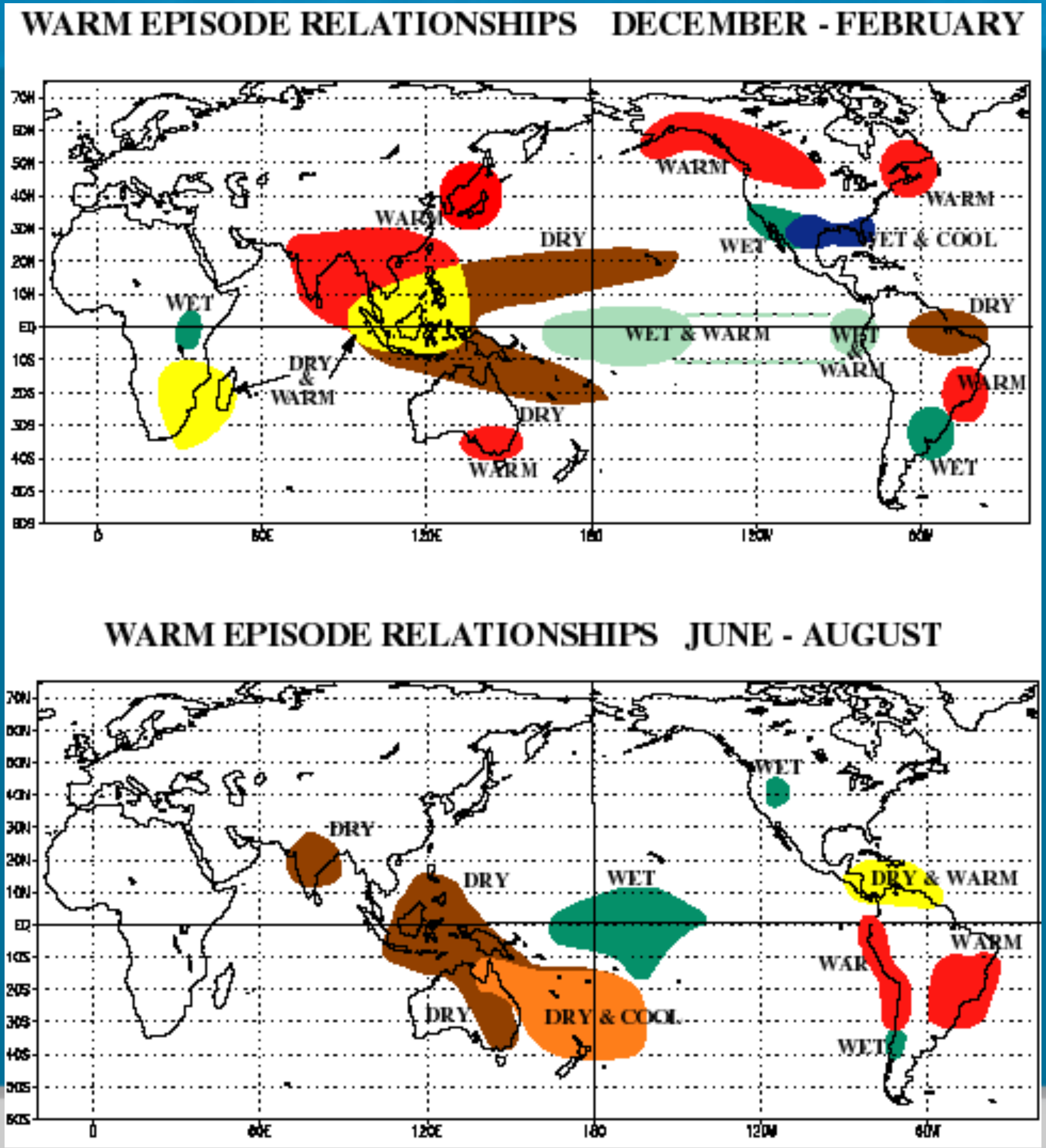
Eastward expansion of warm sea surface temperatures during El Niño can result in an anomalous eastward shift of convection.

Enhanced thunderstorm activity in the central Pacific will perturb the upper-level flow resulting in an anticyclonic "couplet" straddling the equator.

Poleward of the ridge, an anomalous trough forms in the central North Pacific Ocean.

Global El Niño Impacts

Impacts are generally more extensive during the northern winter.

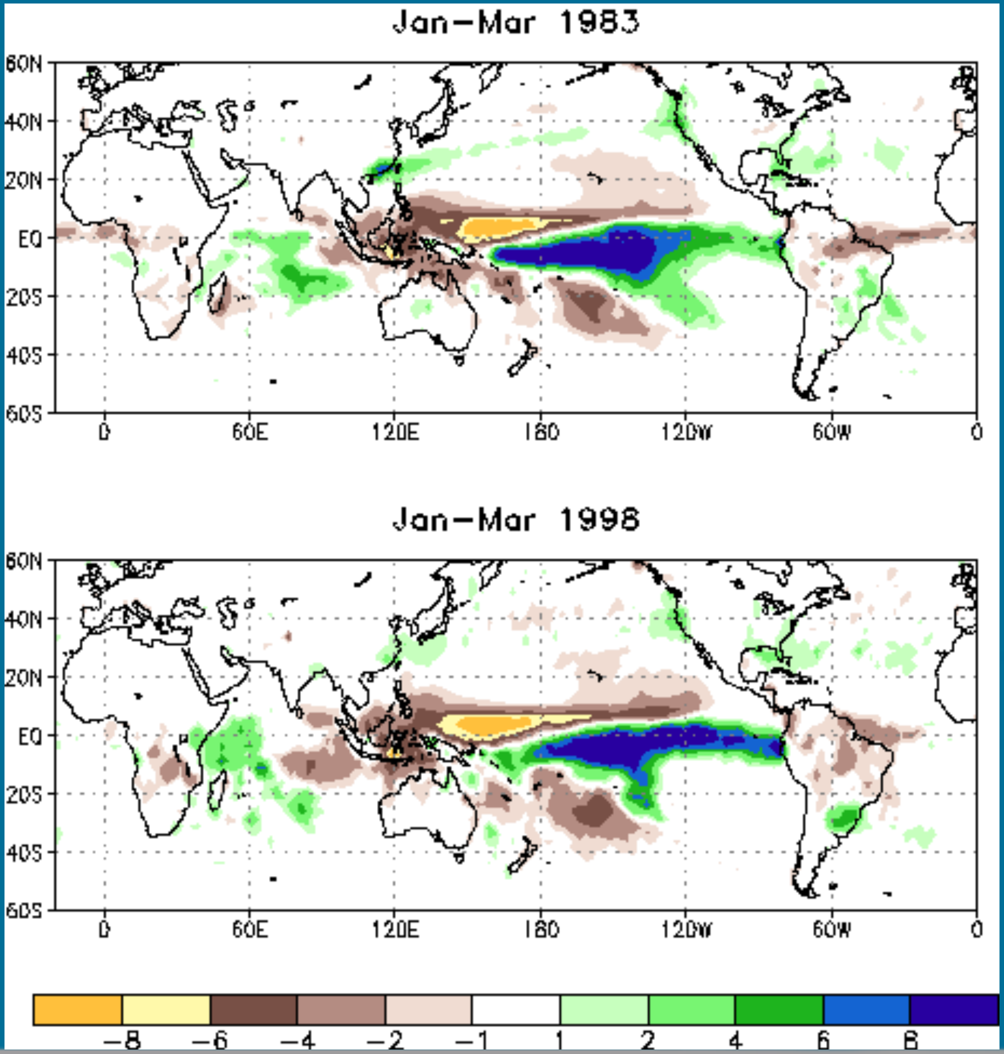


Typical Global El Niño Impacts

Region	Period	Impact
Indonesia	Life of event	Drier
Northeast Brazil	March-May	Drier
Central America /Mexico	May-October	Drier
West Coast South America	March-May	Wetter
Central South America	June-December	Wetter
Southeast Africa	December-February	Drier

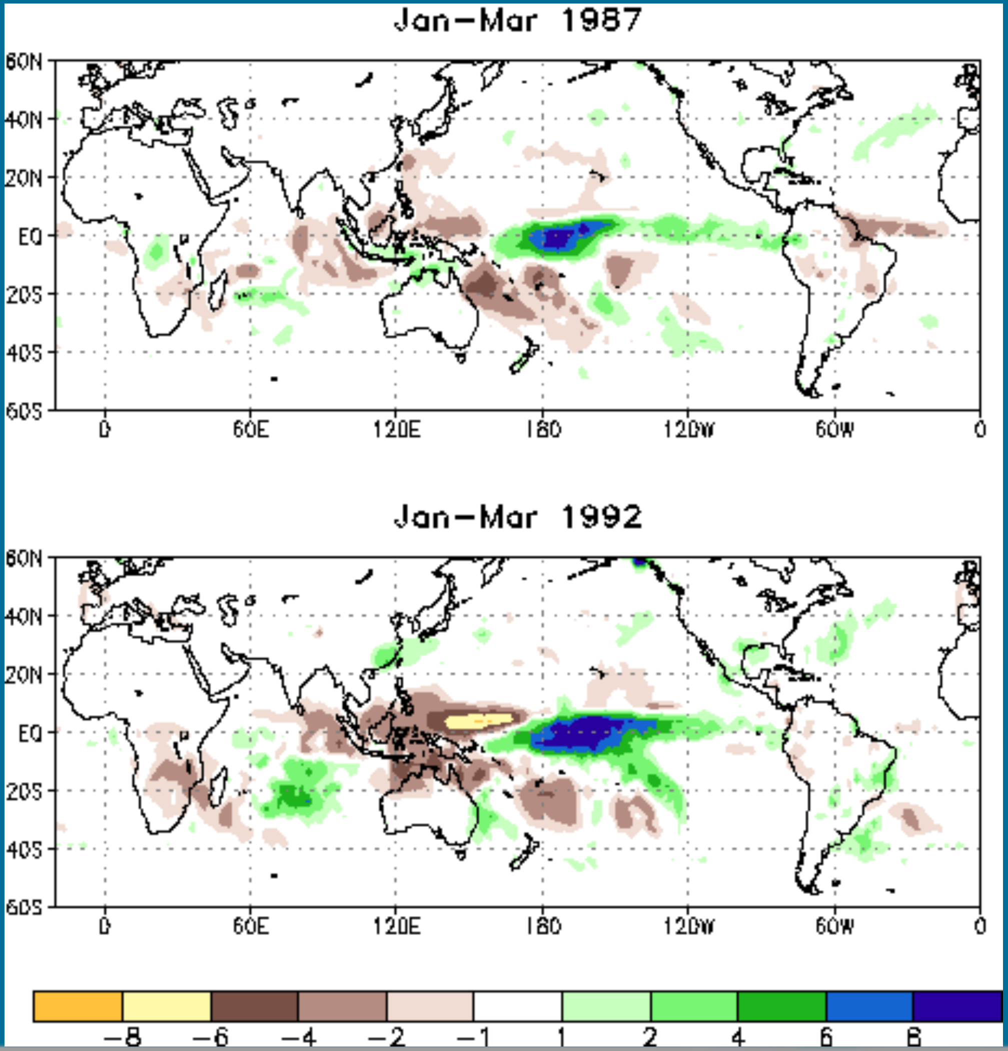
Anomalous Precip. (mm/d): Strong El Niño Episodes

Rainfall departures, as large as ± 8 mm/d (30 inches in a season), result in changes in the pattern of tropical heating, and changes in the positions and intensities of mid-latitude jet streams and planetary waves.



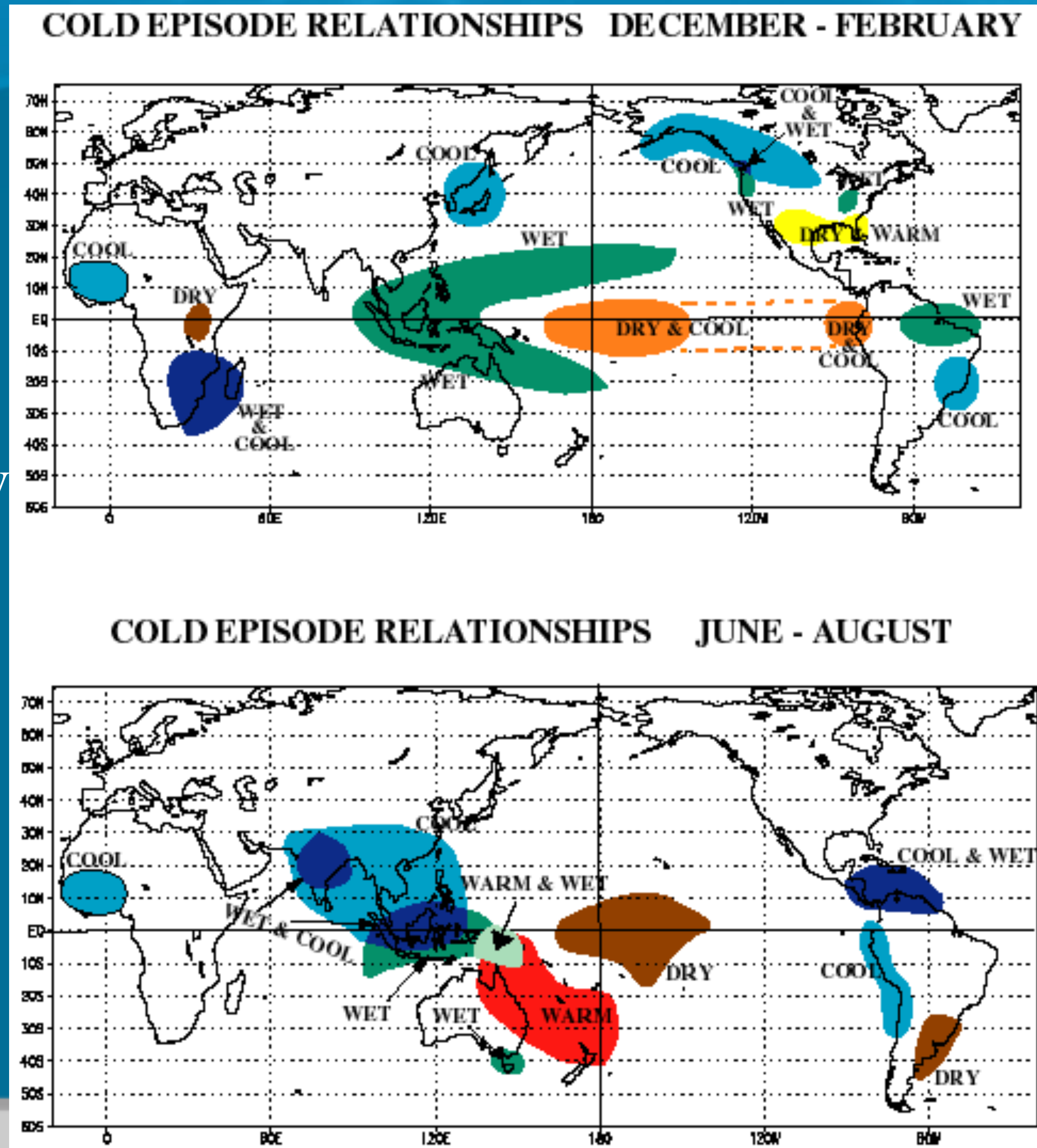
Anomalous Precip. (mm/d): Moderate El Niño Episodes

Rainfall departures are less during weak/ moderate warm episodes. Smaller changes occur in the pattern of tropical heating, and in the mid-latitude jet streams and planetary waves.



Global La Niña Impacts

Mid-latitude impacts generally occur during the winter season (NH – DJF; SH-JJA).

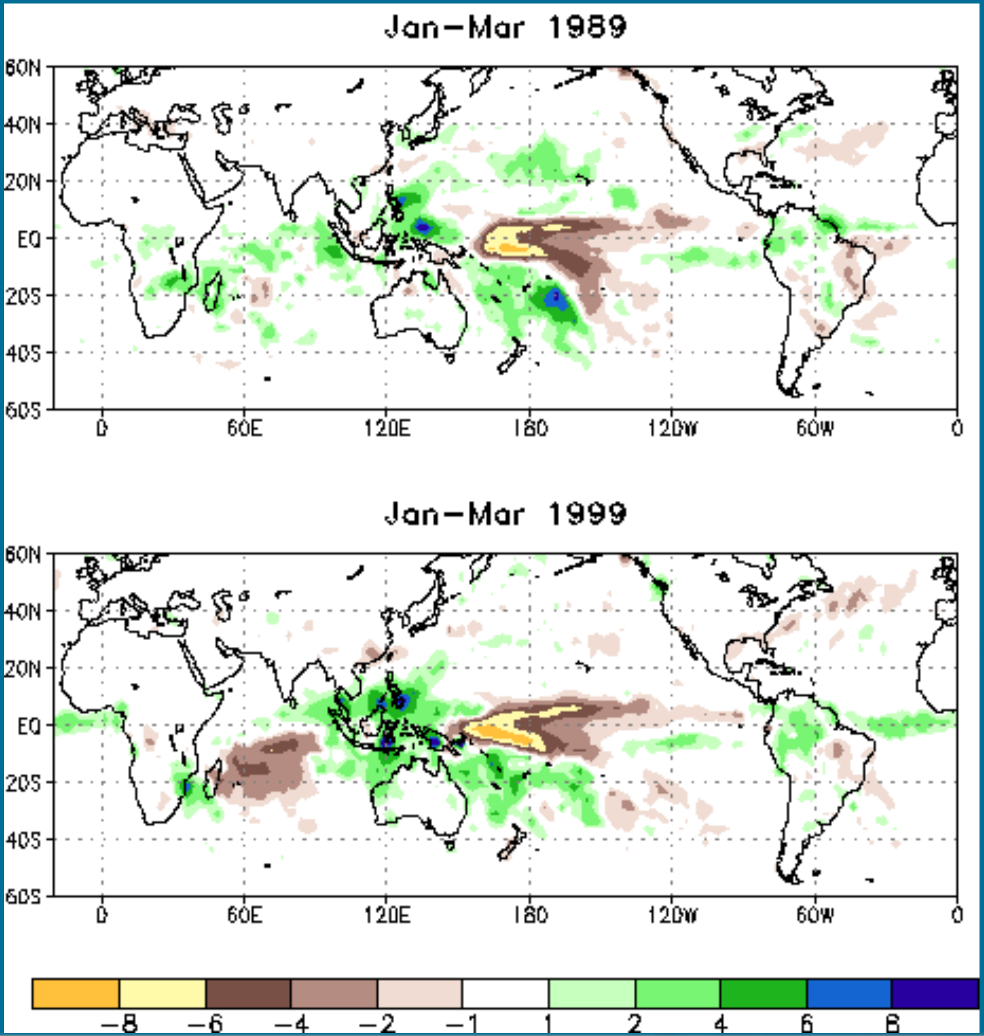


Typical Global La Niña Impacts

Region	Period	Impact
Indonesia	Life of event	Wetter
Northeast Brazil	March-May	Wetter
Central America /Mexico	May-October	Wetter
West Coast South America	March-May	Drier
Central South America	June-December	Drier
Southeast Africa	December-February	Wetter

Anomalous Precip. (mm/d): La Niña Episodes

Rainfall departures, as large as ± 8 mm/d (30 inches in a season), result in changes in the pattern of tropical heating, and changes in the mid-latitude jet streams and planetary waves.



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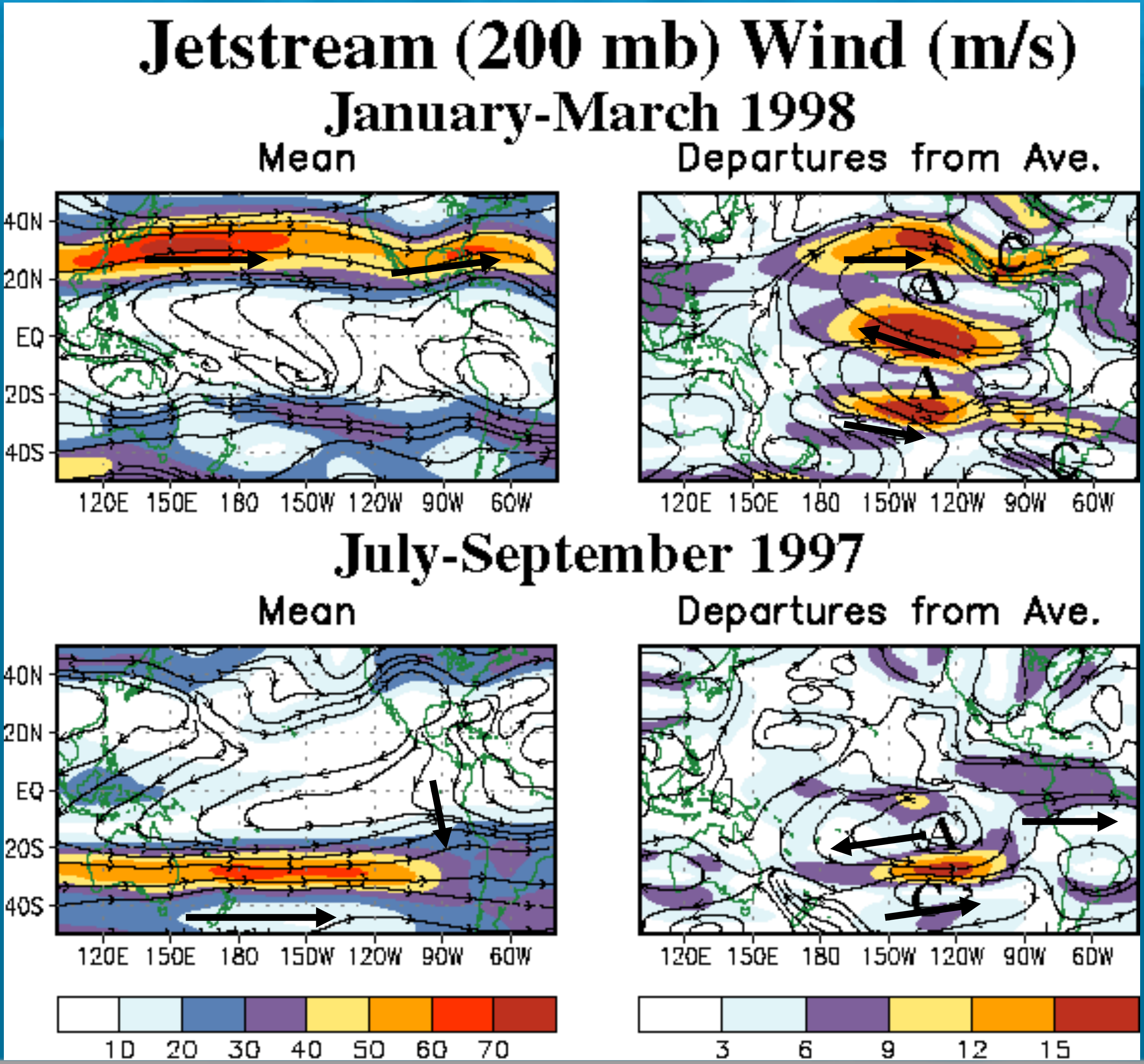
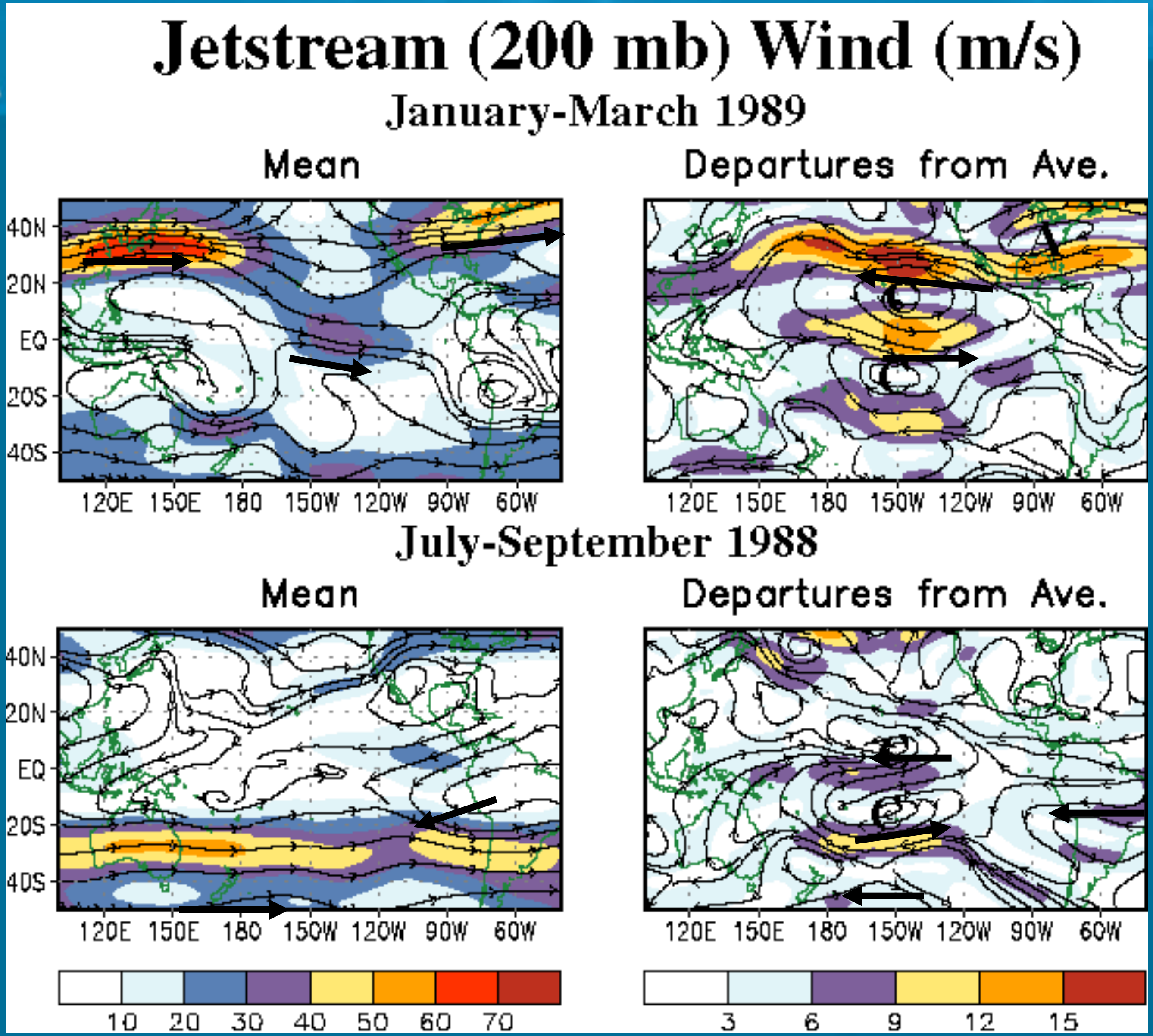
Typical Upper-Level Circulation Changes over the North Pacific and North America

- **El Niño: Jet stream over North America is stronger than average and shifted *equatorward*. Flow is more *zonal* than average from the central Pacific eastward across the U.S.**
- **La Niña: Jet stream over North America is shifted *poleward* from its normal position. Flow is more *meridional* than average over the central and eastern Pacific.**

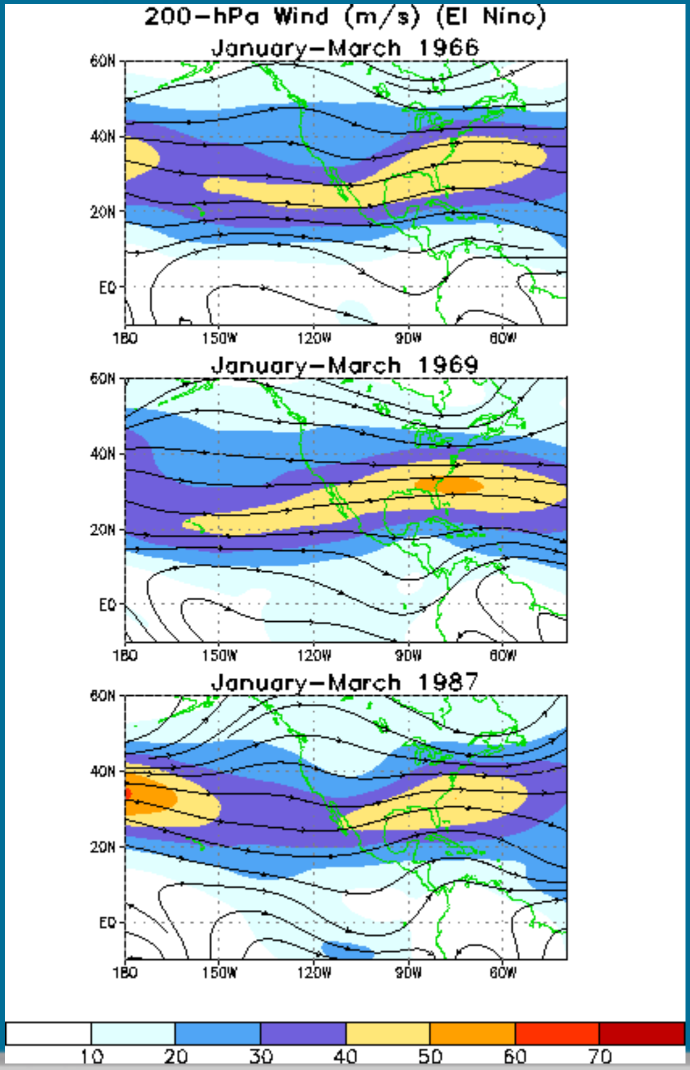
Upper-level Winds: El Niño

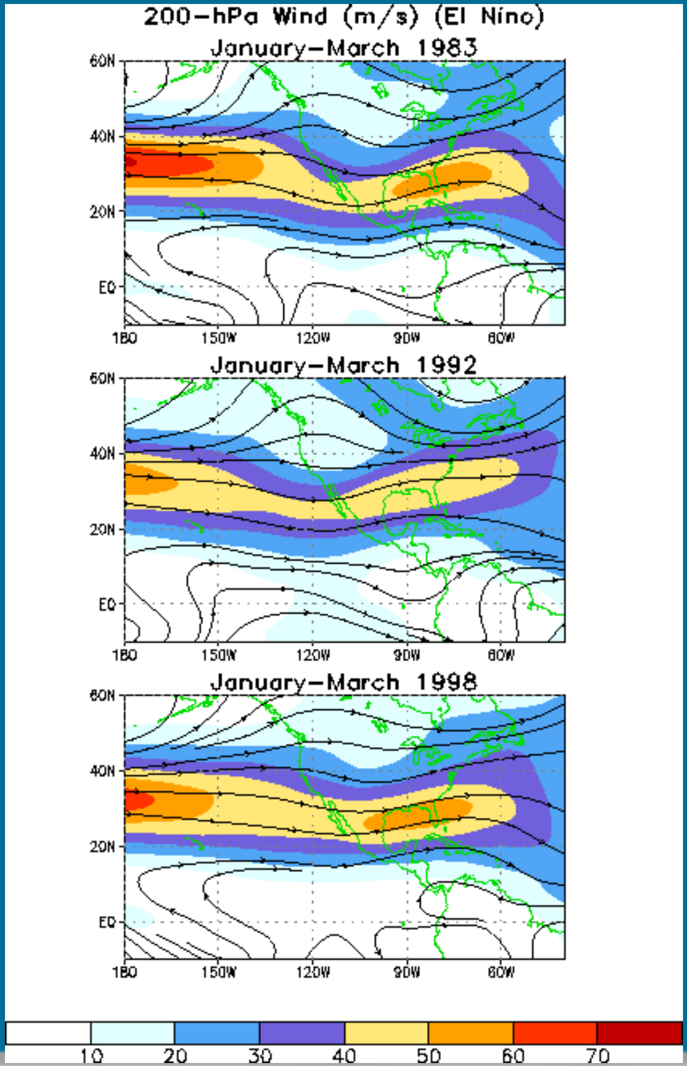


Upper-level Winds: La Niña

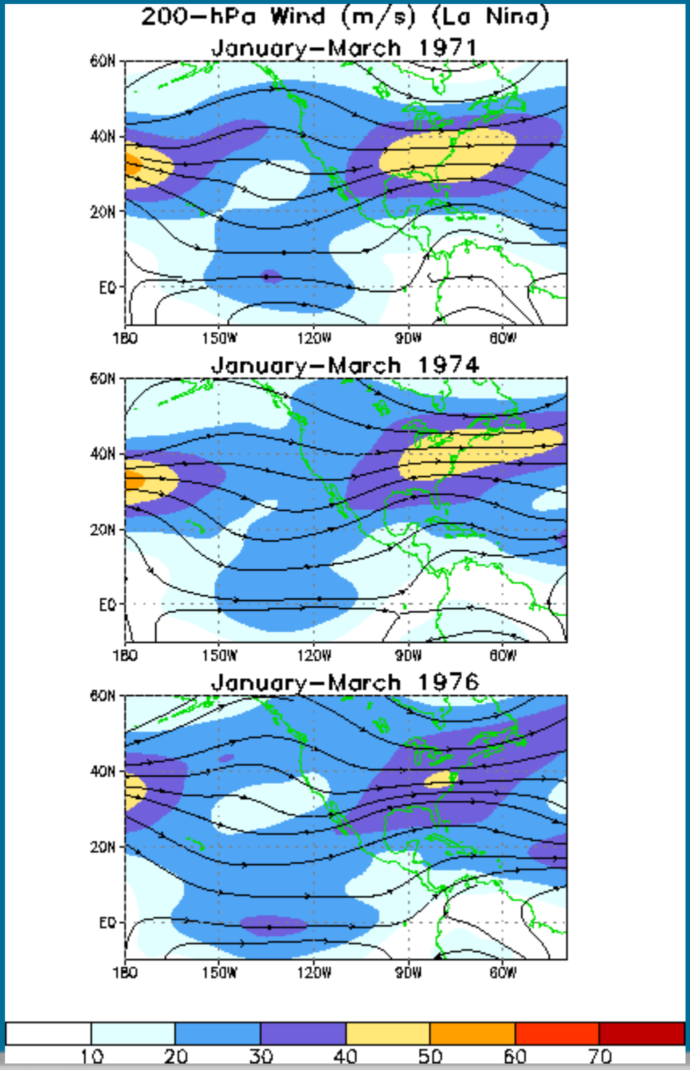


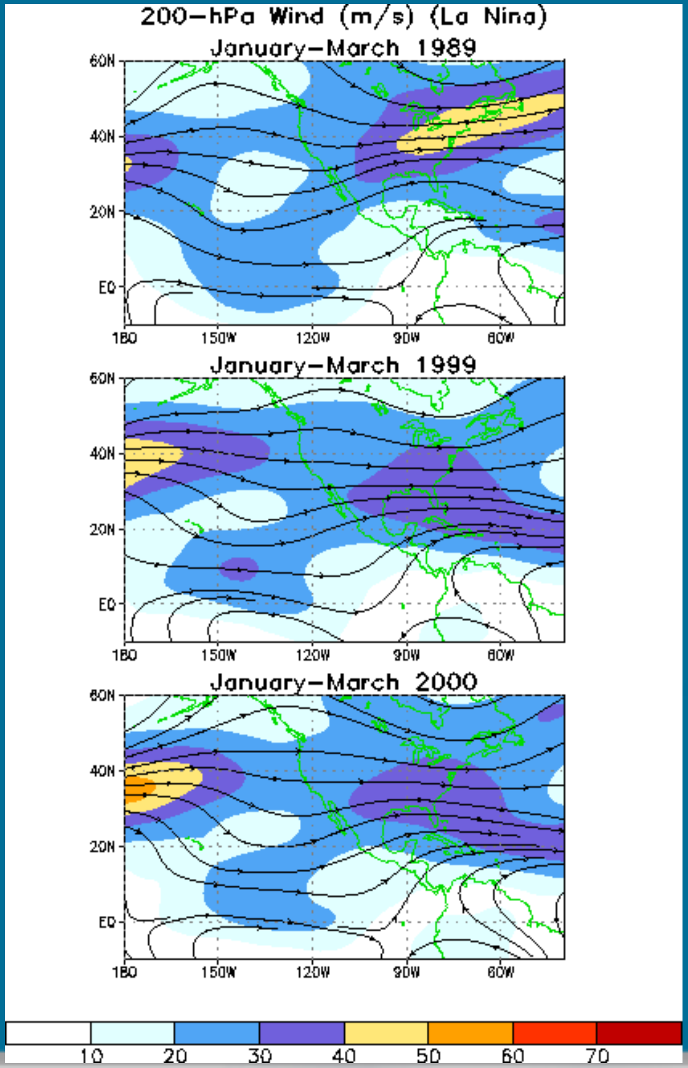
Upper Level Winds
El Niño Episodes

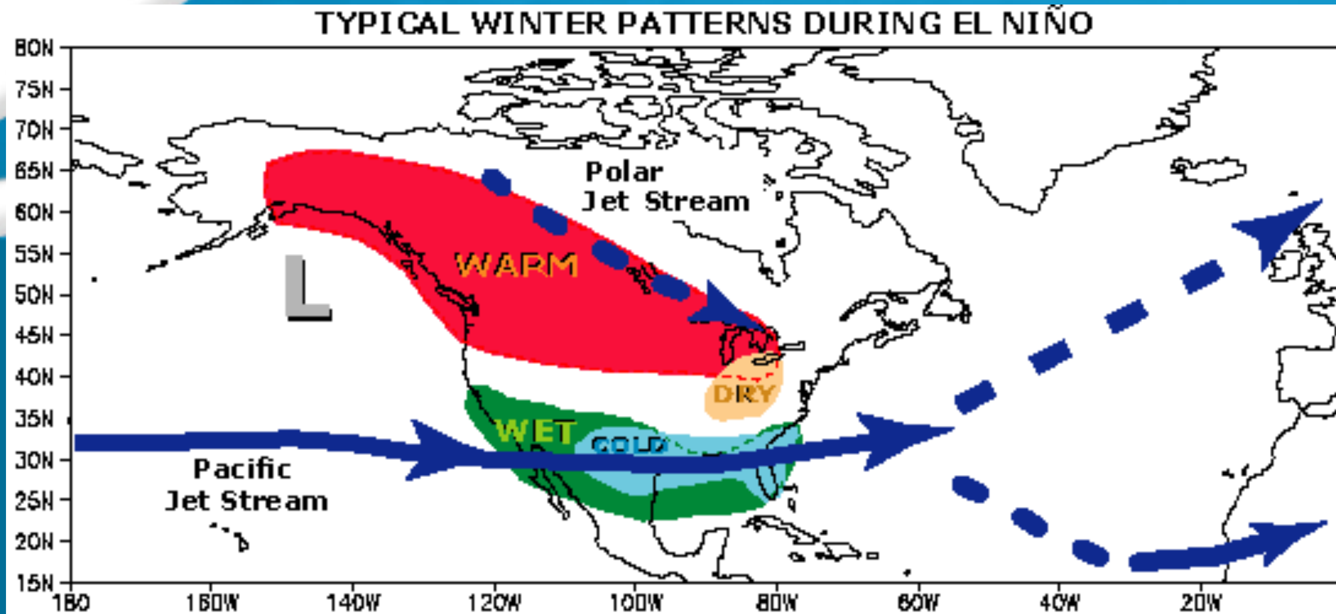




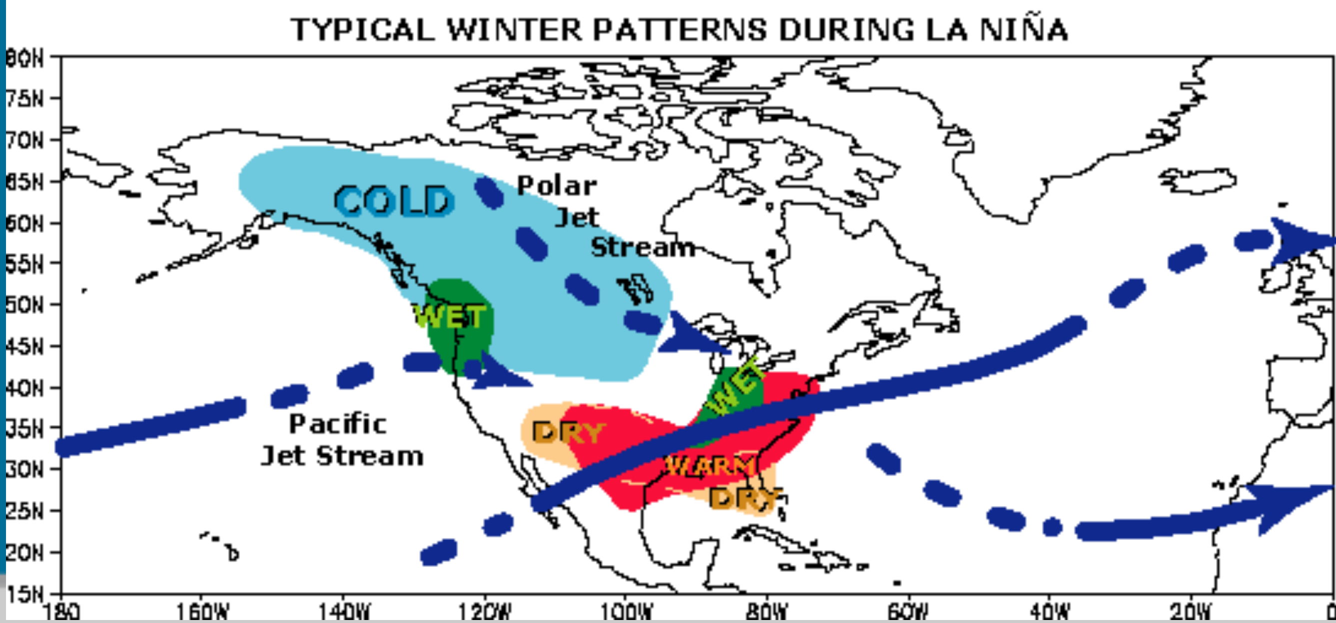
Upper Level Winds
La Niña Episodes







El Niño



La Niña

Typical Impacts of El Niño on North America and the Atlantic Basin

- North American summer monsoon region (northern Mexico) – drier than average
- U.S. Pacific Northwest fall and winter -- drier than average
- Atlantic hurricane season: suppressed activity
- Gulf Coast states and, in strong events, central and southern California winter -- wetter than average
- Northern Plains, Pacific Northwest, Southern Alaska, and western and central Canada -- warmer than average

Typical Impacts of La Niña on North America and the Atlantic Basin

- North American summer monsoon region (northern Mexico) – wetter than average
- U.S. Pacific Northwest fall and winter -- wetter than average
- Atlantic hurricane season: enhanced activity
- Southeast U.S., Gulf Coast states and central and southern California winter -- drier than average
- Southwest and Southeast U.S. -- warmer than average

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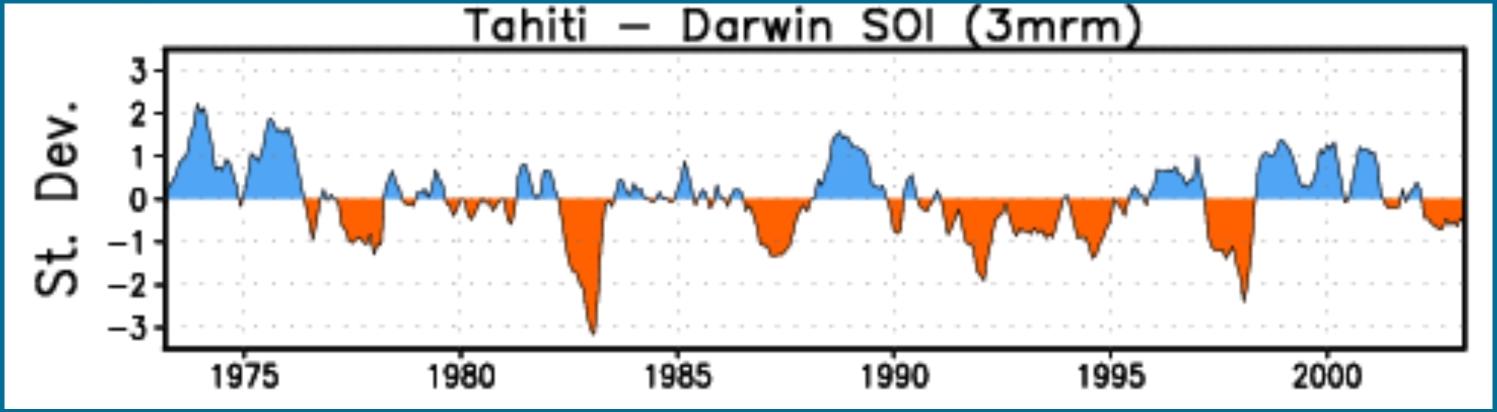
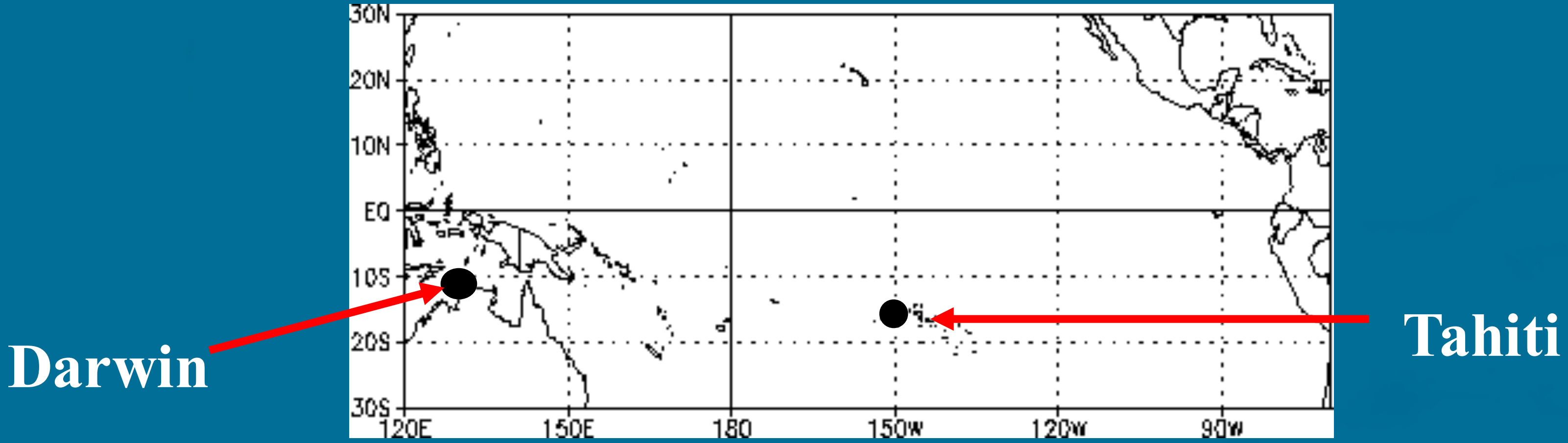
Application to Monitoring and Forecasting at NOAA CPC

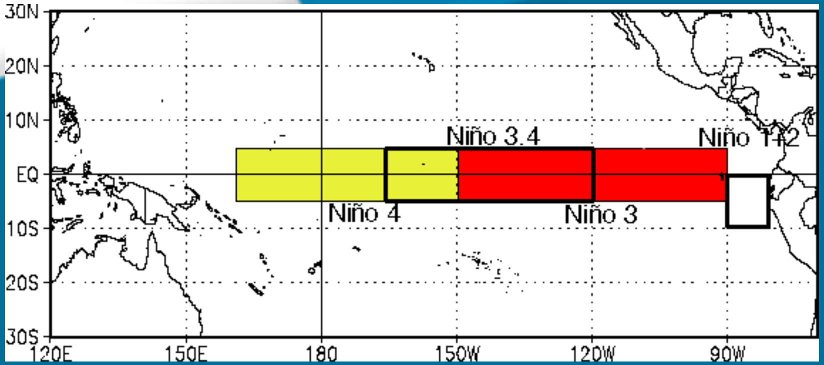
- A sampling of atmospheric and oceanic ENSO indices: SOI, Nino-1+2, Nino-3, Nino-3.4, Nino-4, ONI
- NOAA CPC definitions for ENSO
- ENSO Alert System
- Forecasting ENSO and its Impacts on the United States
- Climate Change and ENSO

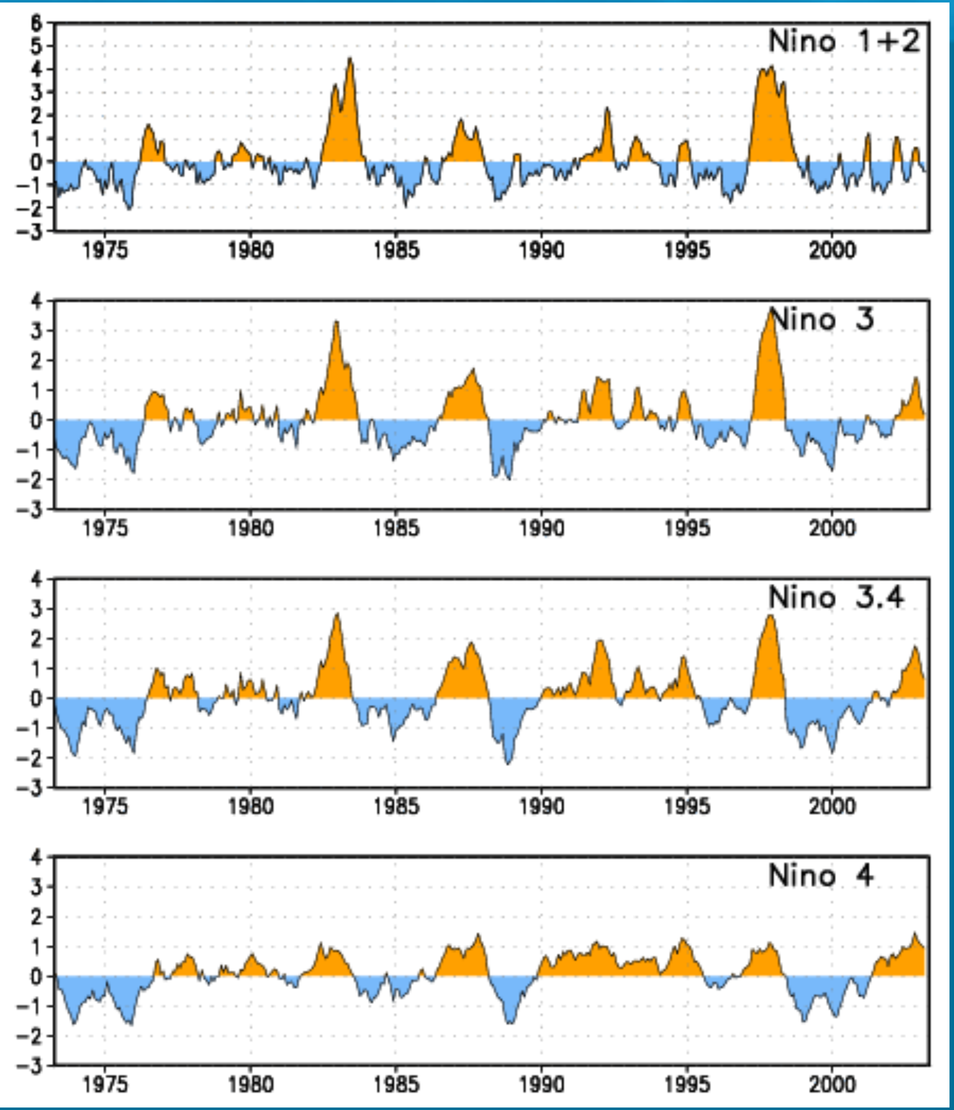
Tahiti-Darwin SOI





Niño Regions





Largest positive anomalies occur in the eastern equatorial Pacific (Niño 1+2 and 3 regions).

Negative anomalies have roughly the same magnitude in all regions.

NOAA Operational ENSO Definition

- The Oceanic Niño Index (“ONI”) is based on SST departures from average in the Niño 3.4 region, and is a principal measure for monitoring, assessing, and predicting ENSO.

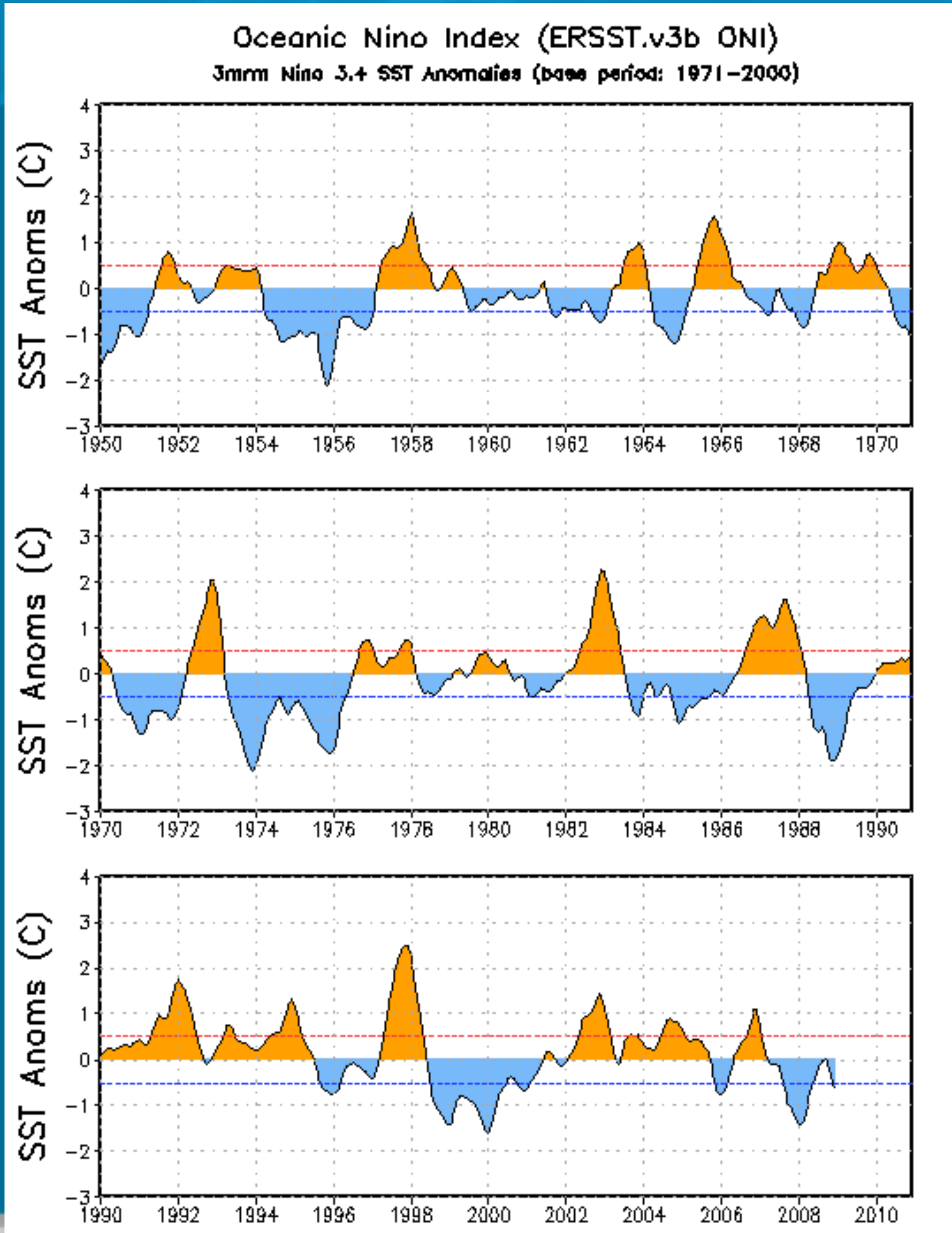
- ONI is defined as the 3-month running-mean SST departures in the Niño-3.4 region. Departures are based on a set of improved homogeneous historical SST analyses (Extended Reconstructed SST – ERSST.v3b).

El Niño: characterized by a *positive ONI* greater than or equal to +0.5°C.

La Niña: characterized by a *negative ONI* less than or equal to −0.5°C.

To be classified as a full-fledged El Niño or La Niña “episode” these thresholds must be exceeded for a period of at least 5 consecutive overlapping 3-month seasons.

ONI: Evolution since 1950



CPC Working Definition for ENSO

- The <u>Oceanic Niño Index (ONI)</u> is used to put current events in historical context. Because it is calculated as a 3-month running mean SST departure it is a "lagging" index, which works better in a retrospective fashion.
- For real-time use, CPC uses "conditions:"

<u>El Niño conditions:</u> one-month positive SST anomaly of +0.5 or greater in the Niño-3.4 region and an expectation that the 3-mth ONI threshold will be met.

<u>La Niña conditions:</u> one-month negative SST anomaly of −0.5 or less in the Niño-3.4 region and an expectation that the 3-mth ONI threshold will be met.

<u>AND</u>

An atmospheric response typically associated with El Niño/ La Niña over the equatorial Pacific Ocean.

The ENSO Alert System is based on **<u>El Niño and La Niña "conditions"</u>** that allows CPC to be able to issue watches/advisories in real-time.

ENSO Alert System: Types of Alerts

An El Niño or La Niña Watch:
Issued when the environment in the equatorial Pacific basin is favorable for the development of El Niño or La Niña conditions within the next three (3) months.

An El Niño or La Niña Advisory:
Issued when El Niño or La Niña conditions in the equatorial Pacific basin are observed and expected to continue.

Final El Niño or La Niña Advisory:
Issued after El Niño or La Niña conditions have ended.

NA:
The ENSO Alert System will not be active when El Niño or La Niña conditions are not observed or expected to develop in the equatorial Pacific basin.

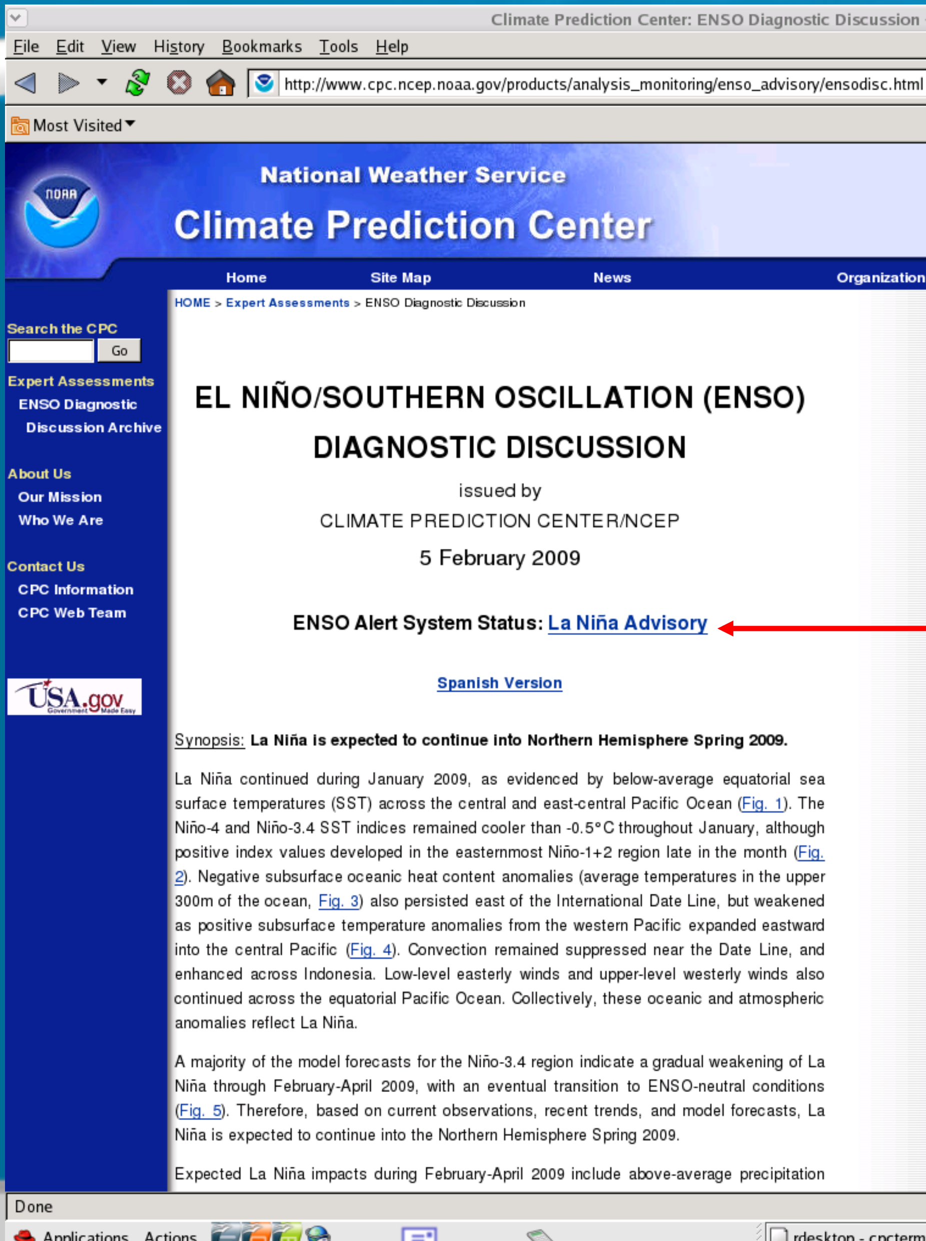
What triggers an ENSO Watch or Advisory?

- The ENSO Alert System is based on El Niño and La Niña "conditions" that allows CPC to be able to issue watches/advisories in real-time.

- "Conditions" requires a 1-month SST value and corresponding atmospheric response, along with the expectation that the 3-month threshold (ONI) will be met.

- NOAA's official Oceanic Niño Index (ONI) is not used to trigger a Watch or Advisory because it is calculated as a 3-month running mean SST departure. It is a "lagging" index, which puts ENSO events in a historical context.

Example of Alert System Status



Climate Prediction Center: ENSO Diagnostic Discussion -

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http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/enso_advisory/ensodisc.html

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EL NIÑO/SOUTHERN OSCILLATION (ENSO)

DIAGNOSTIC DISCUSSION

issued by

CLIMATE PREDICTION CENTER/NCEP

5 February 2009

ENSO Alert System Status: La Niña Advisory

Spanish Version

Synopsis: **La Niña is expected to continue into Northern Hemisphere Spring 2009.**

La Niña continued during January 2009, as evidenced by below-average equatorial sea surface temperatures (SST) across the central and east-central Pacific Ocean (Fig. 1). The Niño-4 and Niño-3.4 SST indices remained cooler than -0.5°C throughout January, although positive index values developed in the easternmost Niño-1+2 region late in the month (Fig. 2). Negative subsurface oceanic heat content anomalies (average temperatures in the upper 300m of the ocean, Fig. 3) also persisted east of the International Date Line, but weakened as positive subsurface temperature anomalies from the western Pacific expanded eastward into the central Pacific (Fig. 4). Convection remained suppressed near the Date Line, and enhanced across Indonesia. Low-level easterly winds and upper-level westerly winds also continued across the equatorial Pacific Ocean. Collectively, these oceanic and atmospheric anomalies reflect La Niña.

A majority of the model forecasts for the Niño-3.4 region indicate a gradual weakening of La Niña through February-April 2009, with an eventual transition to ENSO-neutral conditions (Fig. 5). Therefore, based on current observations, recent trends, and model forecasts, La Niña is expected to continue into the Northern Hemisphere Spring 2009.

Expected La Niña impacts during February-April 2009 include above-average precipitation

Done

Applications Actions rdesktop - cpcterm

CPC's ENSO Diagnostic Discussion and Climate Diagnostics Bulletin are the primary vehicles used to disseminate real-time information concerning the ENSO Alert System status to the scientific community and general public.

User can click on status to get detailed information on Alert System definitions

http://www.cpc.noaa.gov/products/analysis_monitoring/enso_advisory/ensodisc.html

Forecasting ENSO

ENSO Forecasters rely on:

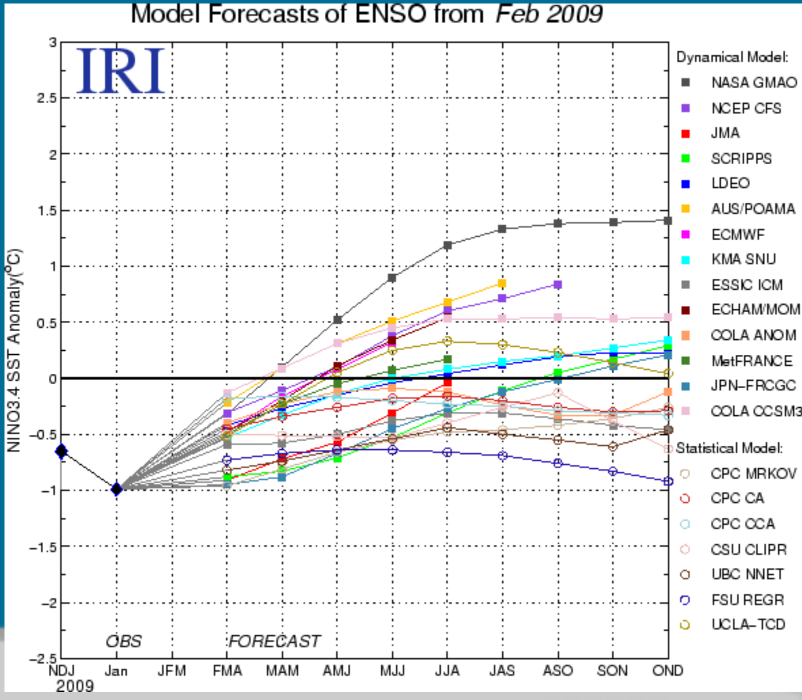
(1) Real-time data from the equatorial Pacific Ocean (collected from buoys, satellites, etc) and their knowledge of previous ENSO episodes

(2) Dynamical models: mathematical equations combined with current observations and run on a computer

- NCEP Climate Forecast System (CFS): a "coupled" computer model (ocean and atmosphere interact)

(3) Statistical models: use observations of the past to make predictions of the future

- Consolidated Forecast Tool ("CON"): statistically combines different models to take advantage of independent information provided by each model



How well do models predict ENSO?

- Statistical and Dynamical models have comparable forecast skill.
- Models have trouble with transition timing and predicting amplitude of ENSO events.
- Stronger ENSO events tend to be better predicted than weaker ones.
- "Spring barrier:" historically, forecasts before the Northern Hemisphere Spring have low skill.
- Intraseasonal variability (i.e. MJO) is not captured in most of these models and these phenomenon can have considerable impact on ENSO evolution.

How well do models predict ENSO?

NCEP Climate Forecast System (CFS) Model

IC= "Initial Condition"

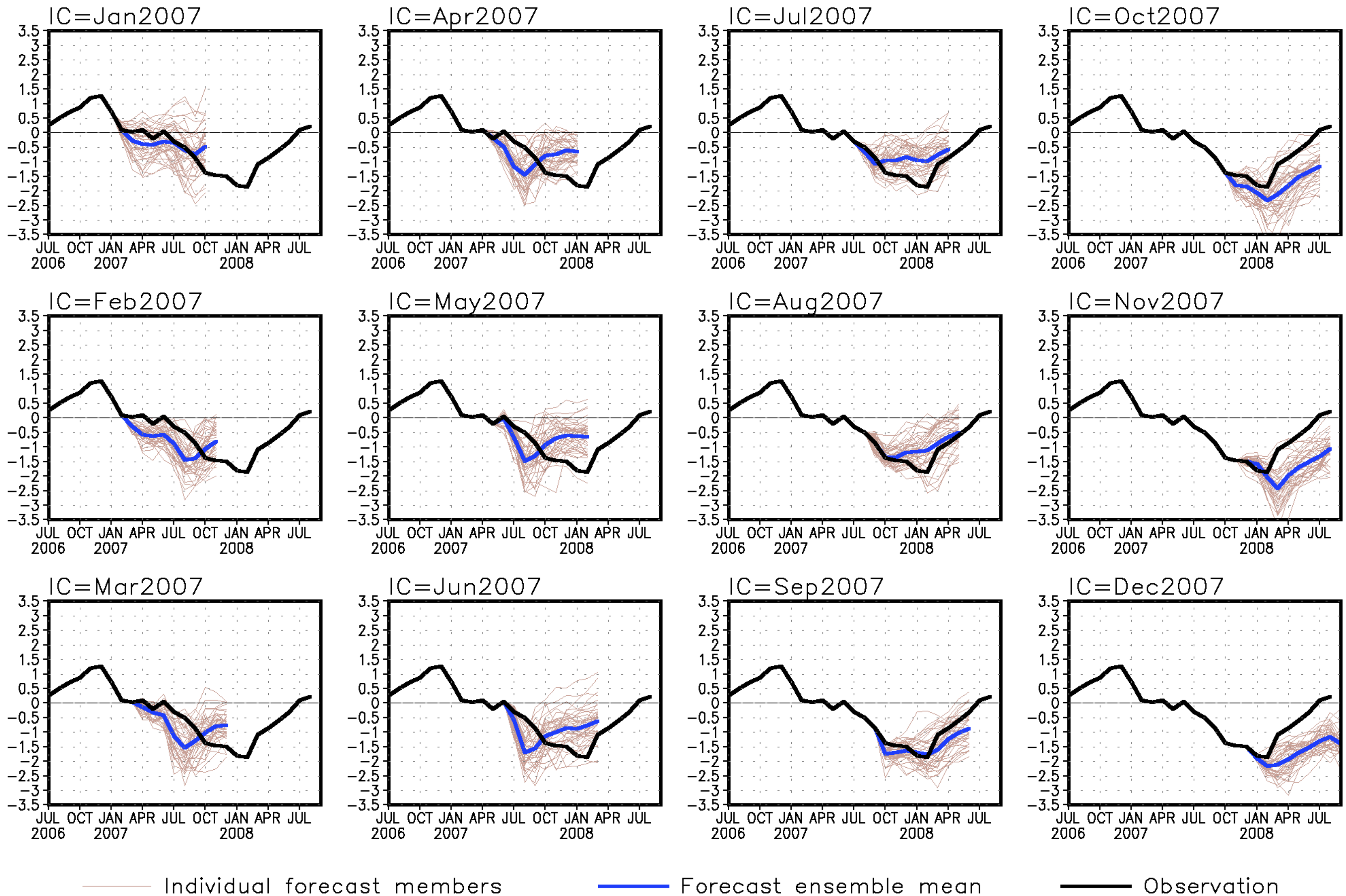
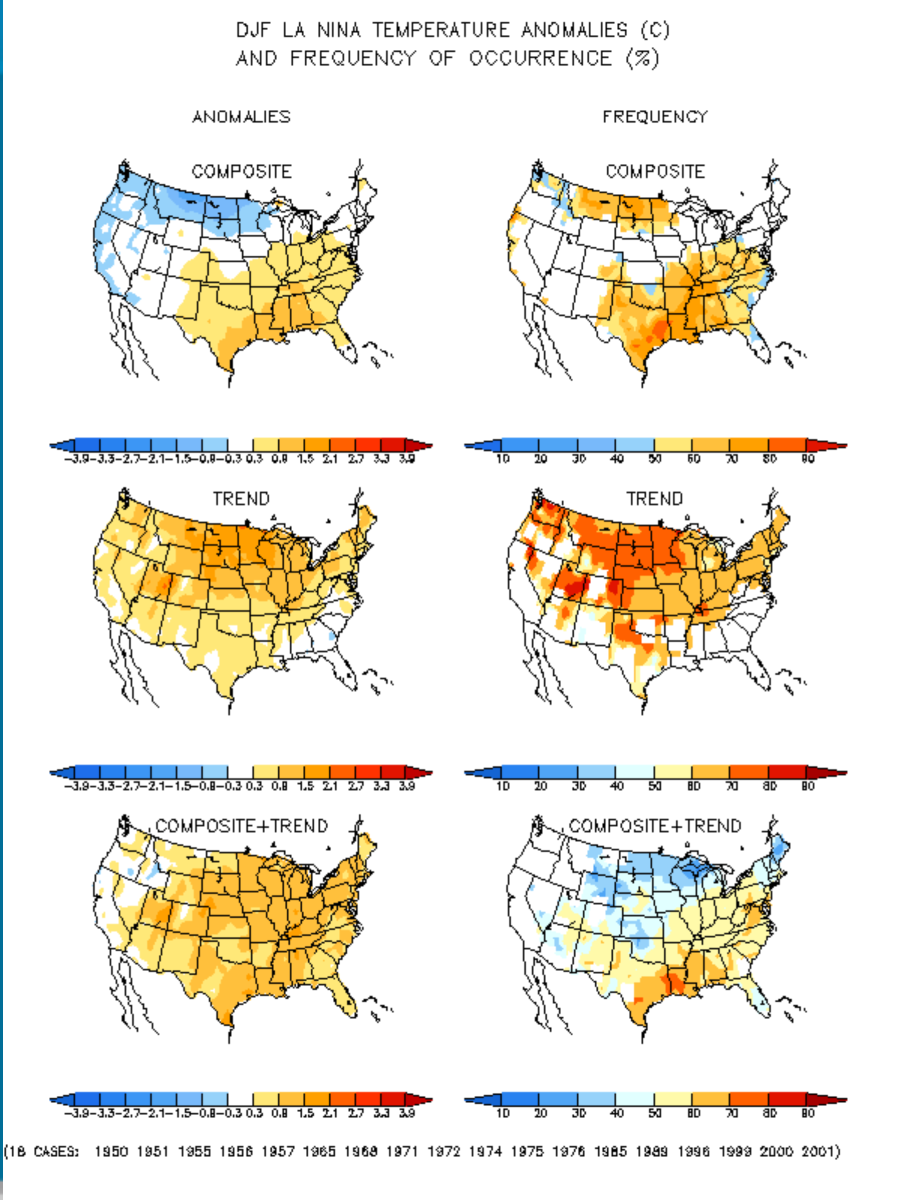


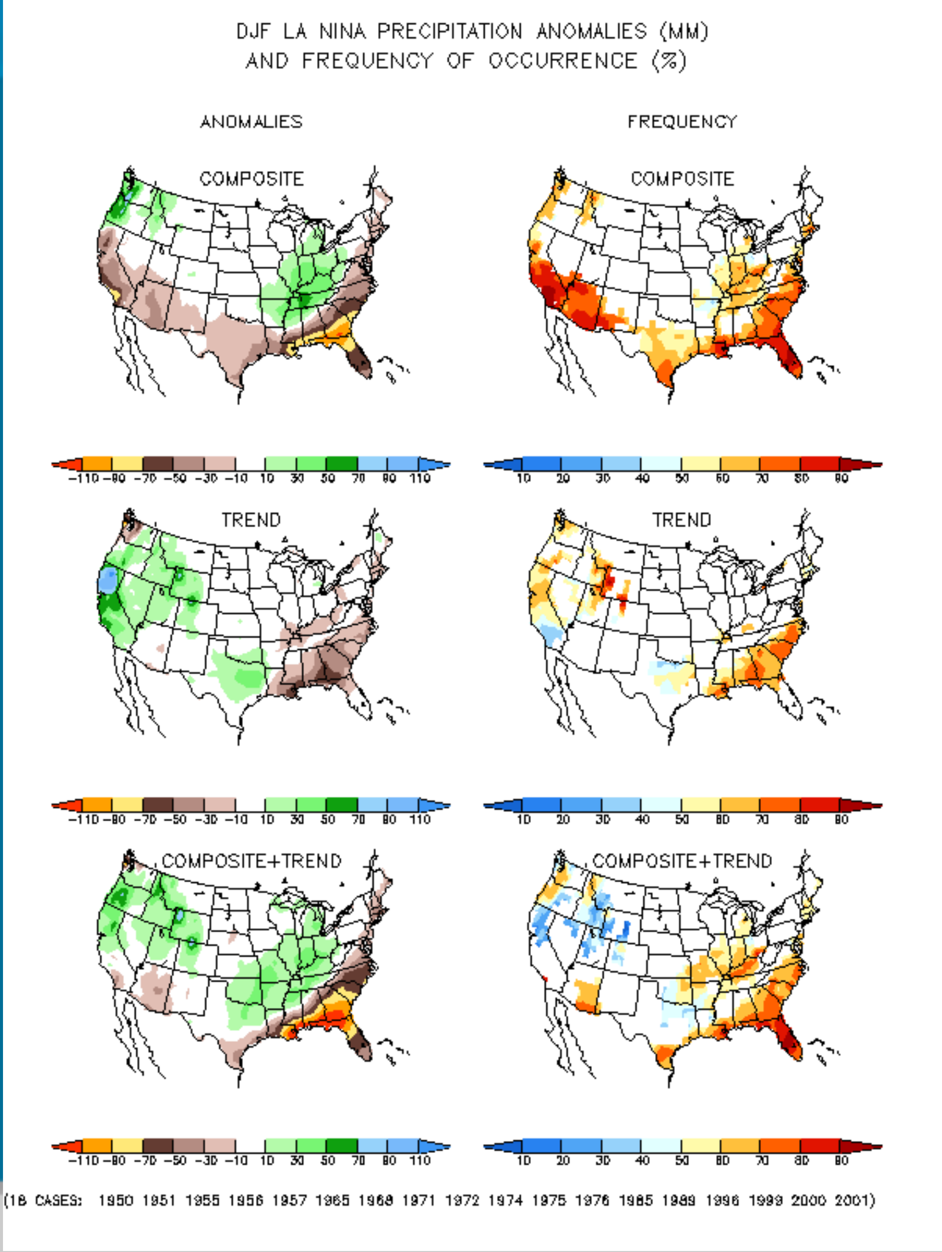
Figure courtesy of Wanqiu Wang, NOAA CPC

Forecasting ENSO-related Impacts



http://www.cpc.ncep.noaa.gov/products/precip/CWlink/ENSO/composites/

Forecasting ENSO-related Impacts



http://www.cpc.ncep.noaa.gov/products/precip/CWlink/ENSO/composites/

Climate Change and ENSO

- **IPCC-AR4:** "No consistent indication at this time of discernible changes in projected ENSO amplitude or frequency in the 21st century."
- ENSO projections differ from model to model
- Continued ENSO variability in the future even with changes to the background state

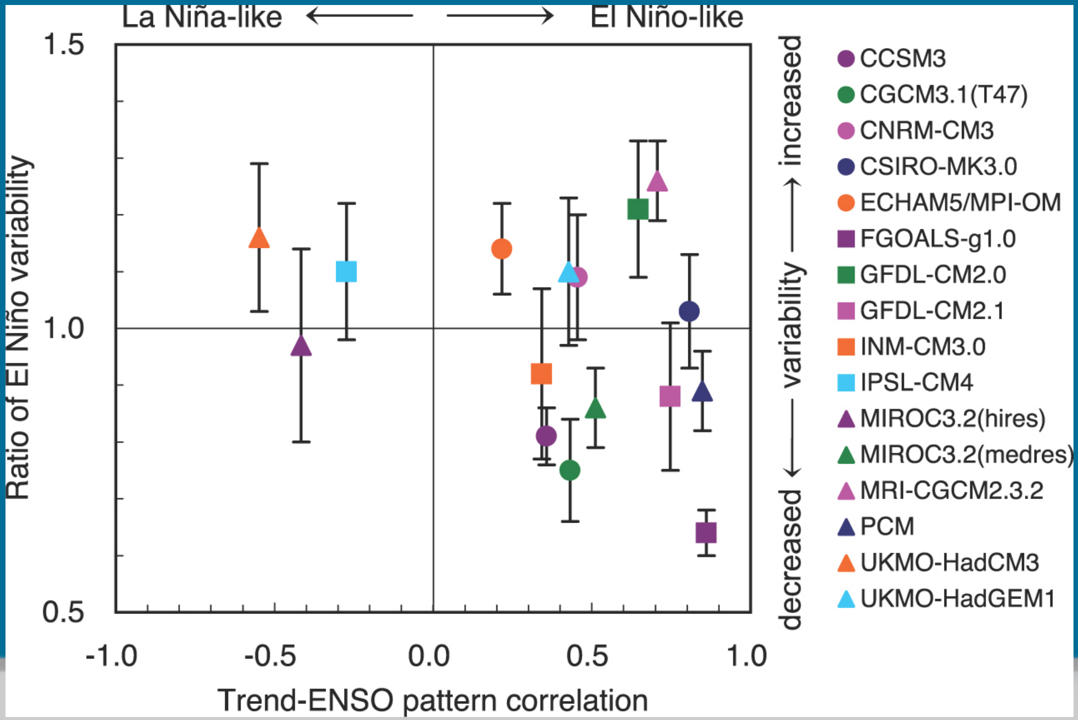


Fig. 10.16 from Chapter 10- IPCC AR4

Summary

- ENSO is a naturally occurring phenomenon
- Equatorial Pacific fluctuates between warmer-than-average (El Niño) and colder-than-average (La Niña) conditions
- The changes in SSTs affect the distribution of tropical rainfall and atmospheric circulation features (Southern Oscillation)
- Changes in intensity and position of jet streams and storm activity occur at higher latitudes