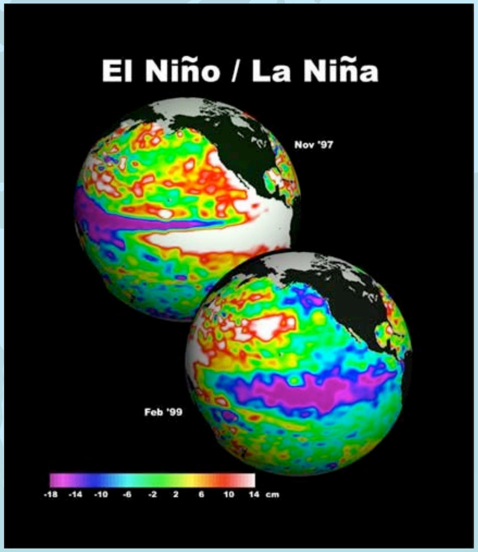
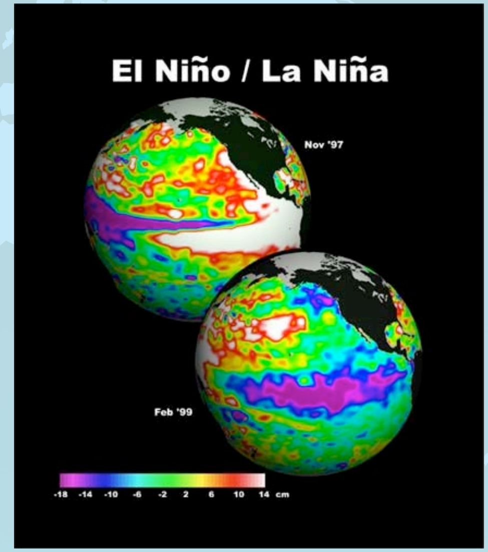
MFE 659 Lecture 2b El Niño/La Niña Ocean-Atmosphere Interaction

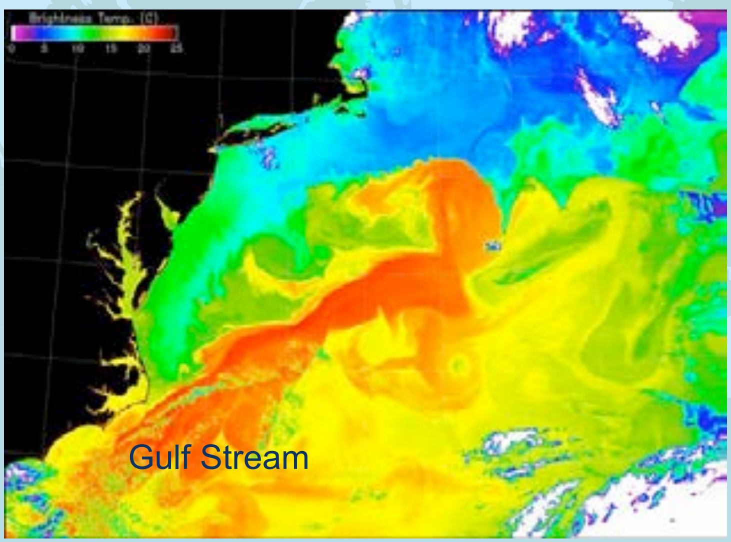


El Niño – La Niña Ocean-Atmosphere Interaction

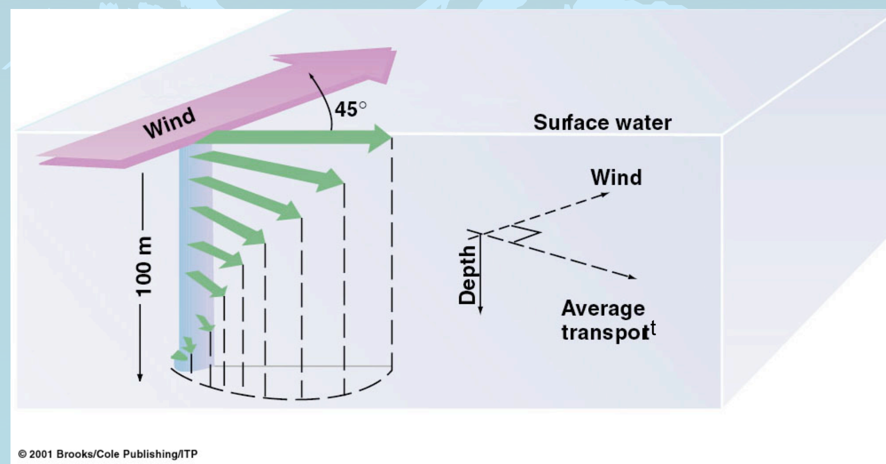
Outline
- Ocean Circulation
- El Niño
- La Niña
- Southern Oscillation
- ENSO



Intro to Ocean Circulation

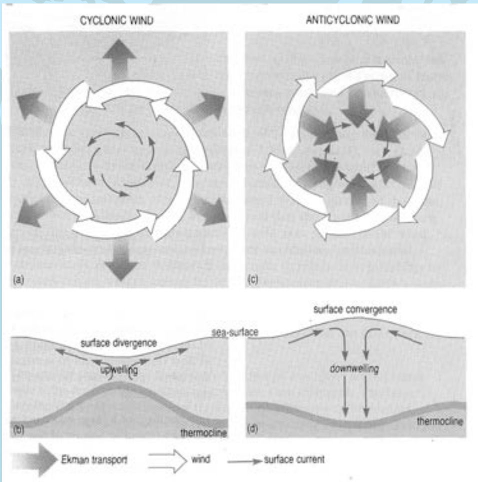


The Ocean Currents are Driven by Winds



Layer-mean water flow is at right angles to wind (to right in NH) as a result of the Coriolis force on the current.

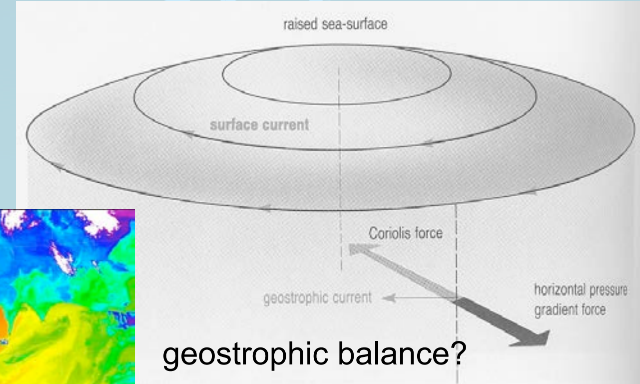
Formation of Ocean Gyres

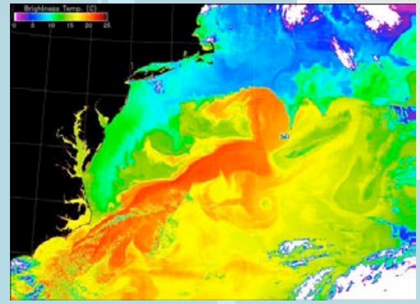


Anticyclonic winds cause water to pile up. Cyclonic wind result in a trough.

The thermocline is marked by strong vertical temperature change with cold water below. Piling up of water lowers the thermocline.

Force Balance in an Ocean Gyre

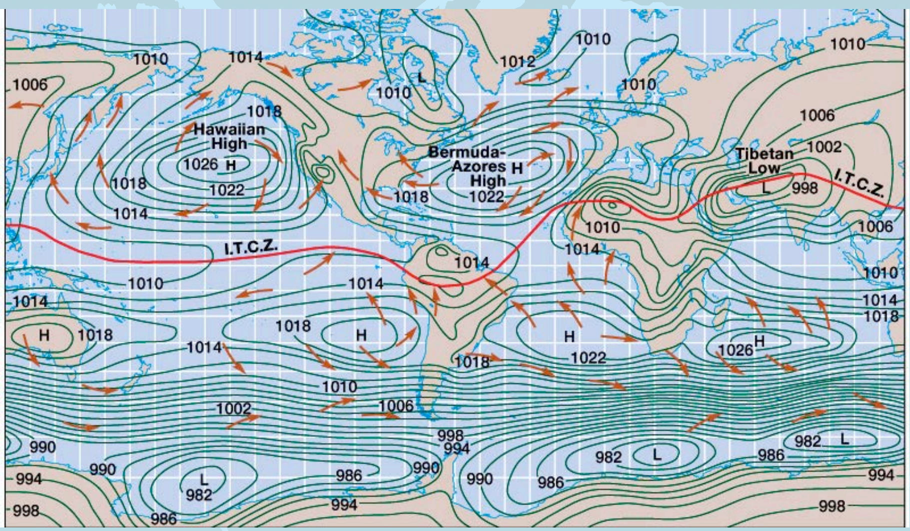




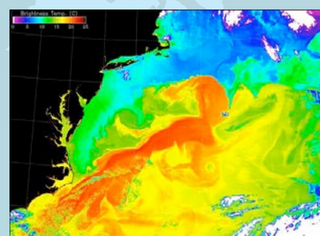
geostrophic balance?

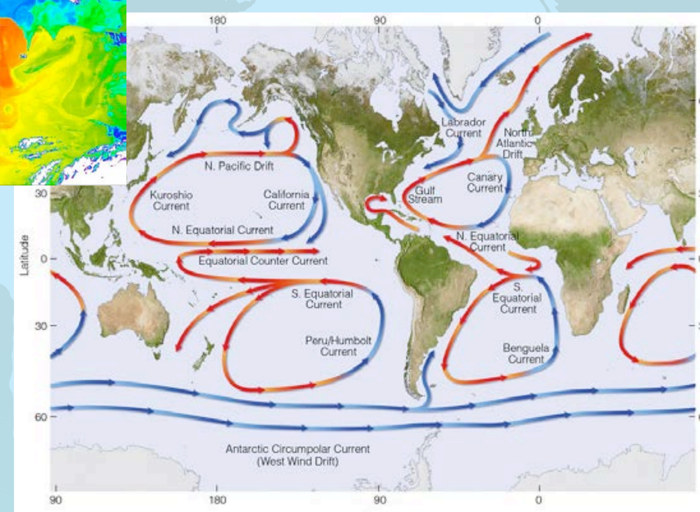
The wind-driven North Atlantic ocean gyre has clockwise (anticyclonic) flow in NH and is in ~geostrophic balance.

General Circulation - July

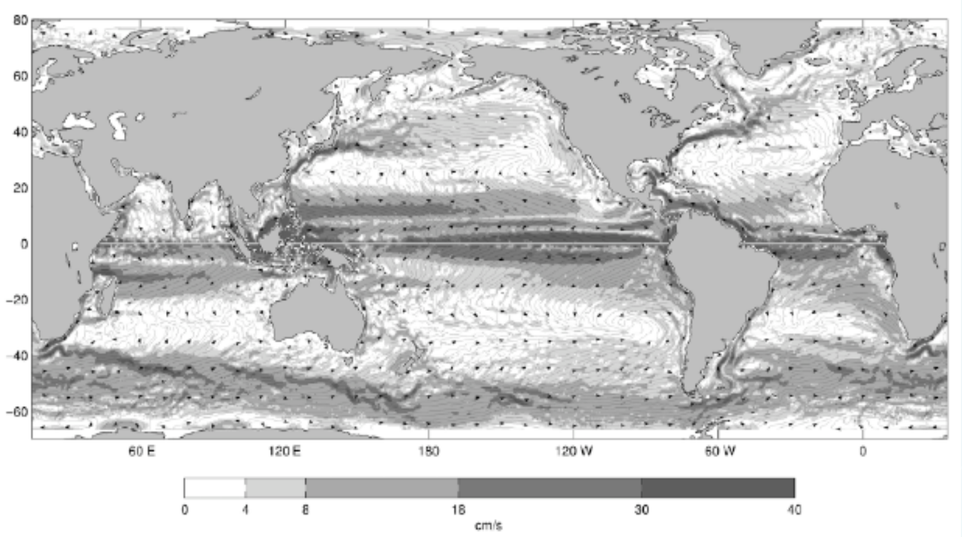


Average surface ocean currents





Long term mean current speed (shaded)

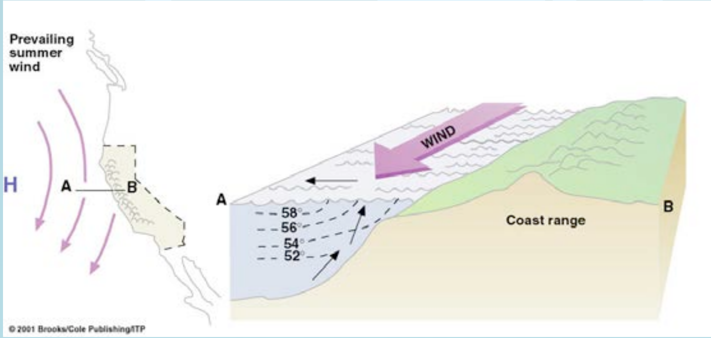


- This is a long term mean – and streamlines derived from satellite altimetry and near-surface drifters. Nikolai Maximenko, IPRC.

9

Coriolis force and upwelling

- Prevailing along-shore winds drive currents away from shore, producing upwelling of colder water from below.
- Cold upwelling is prevalent along the West Coast of the US (e.g., California) and Europe (Portugal).
- The resulting cool near-shore ocean water helps produce the dry Mediterranean climate these areas are known for. Why? Cold water supports low humidity.



Coastal upwelling brings cold water to the surface

10

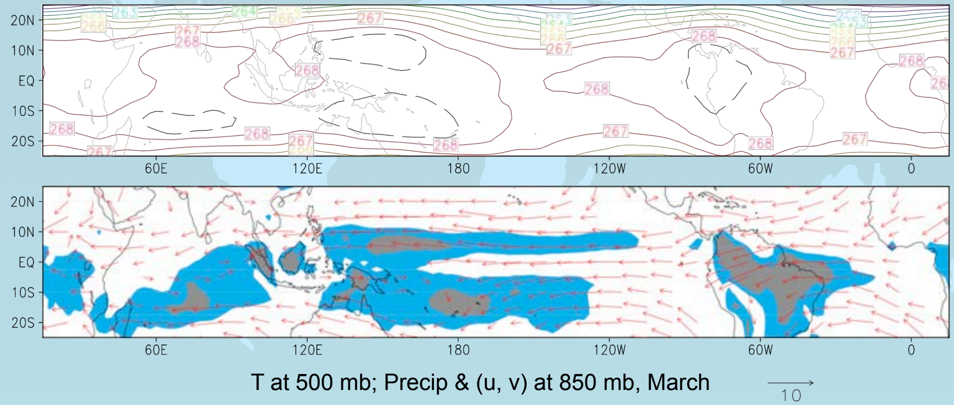
Winds and Ocean Currents

Summary
High pressure dominates the subtropical North Atlantic and North Pacific in summer.
This leads to the formation of an ocean gyre and clockwise currents in the ocean basins, and warm ocean currents on the east side of continents and cold currents on the west side of continents.

11

Key Dynamical/Thermodynamical Balance in the Tropics

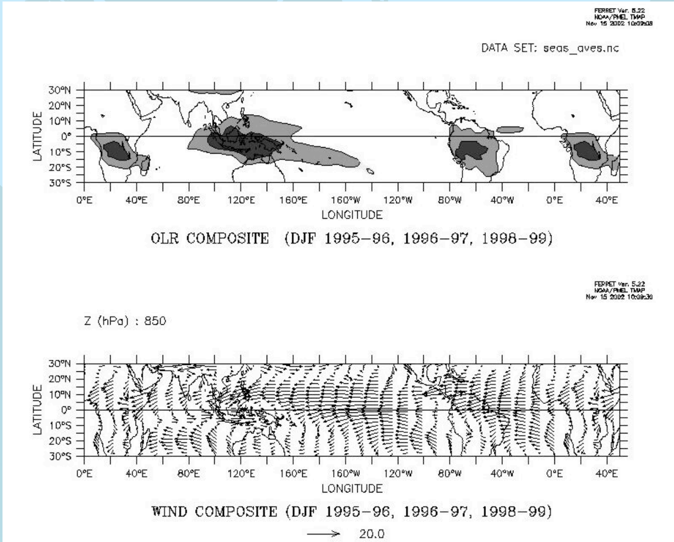
1. Coriolis force reduces to zero at the equator – no geostrophic balance.
2. As a result, temperature is nearly uniform in the horizontal in the free tropical troposphere, a fact confirmed in observations. → Lower free troposphere is nearly moist adiabatic (waves flatten temperature variations in the horizontal).
3. In the tropics, diabatic heating drives circulation, and is nearly in balance with adiabatic cooling (5 K/day in convective regions & -1 K/day in subsidence):



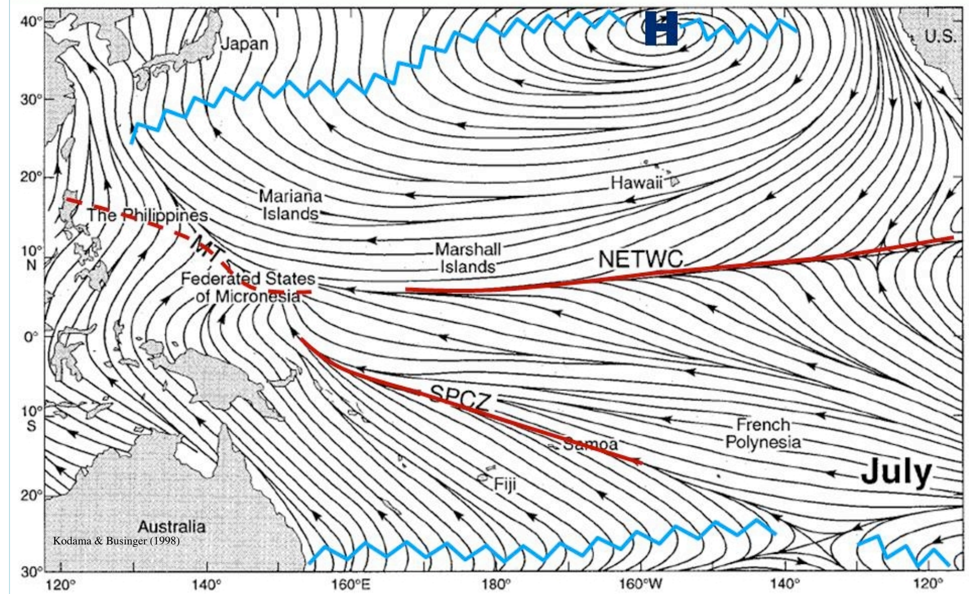
T at 500 mb; Precip & (u, v) at 850 mb, March

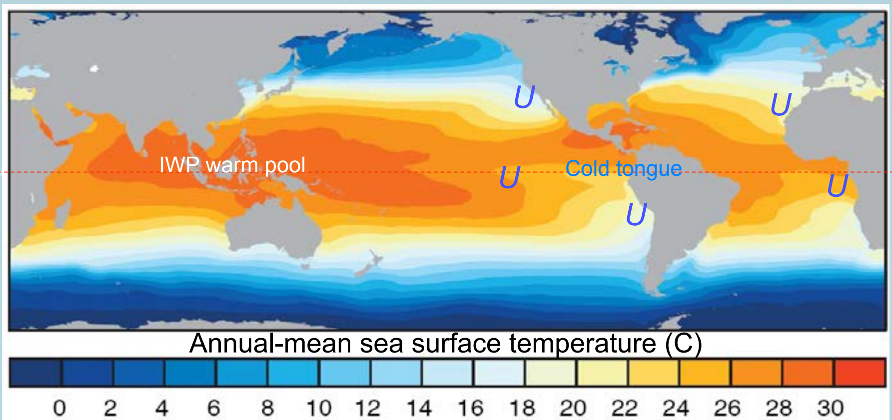
12

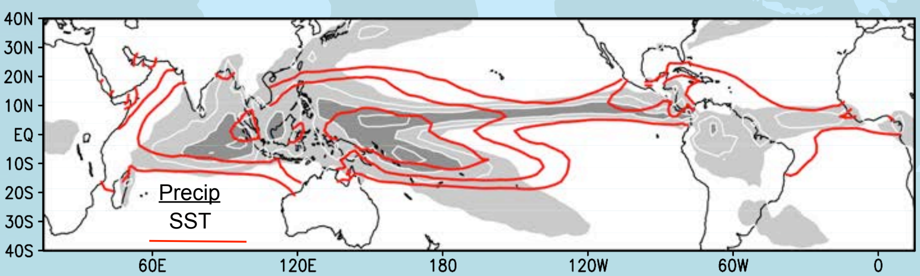
Observed Outgoing Longwave Radiation and Near Surface Winds



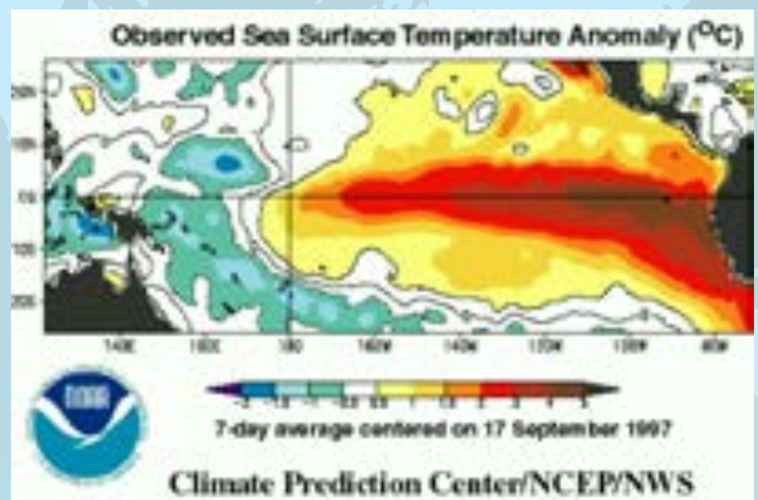
Climatological Features of the Pacific







Why do we care about El Niño-Southern Oscillation (ENSO)?



Impacts of El Niño

- Droughts
  - Increased Wild Fires
  - Water supply
- Extreme Precipitation
  - Floods
  - Erosion
  - Disease
  - Transportation
- Impacts food chain and economy
  - Agricultural productivity

Impacts of El Niño

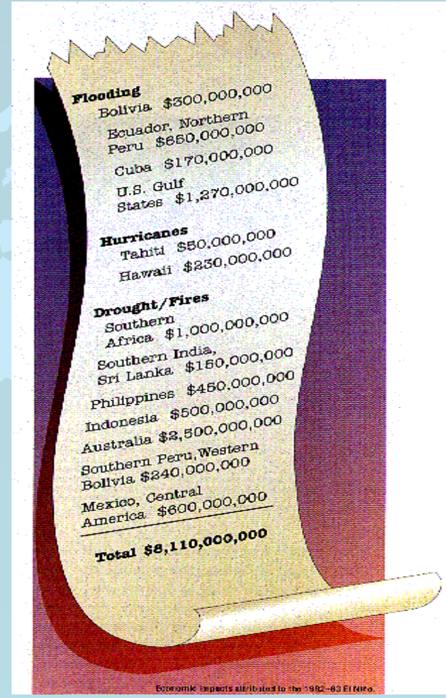
An Example of

Estimated Losses

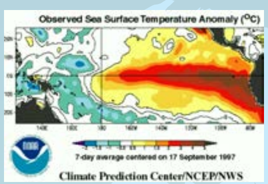
from 1982/83

El Nino Event

$8.11 Billion



El Niño-Southern Oscillation (ENSO)



- Every few years El Niño, a sea-surface temperature (SST) warming over the central equatorial Pacific Ocean, persists and is widespread.
  - Alters weather patterns globally.
  - Large ecosystem impacts and economic losses.
- Long timescale of ENSO (months) yields improved seasonal prediction.
- Better insight into coupled behavior of ocean and atmosphere may lead to better overall understanding of climate and climate change.

What is El Niño?

The name El Niño (referring to the Christ child) was originally given by Peruvian fisherman to a warm current that appeared every few years around Christmas.

The term El Niño refers to a rapid, dramatic warming of the sea-surface temperatures (SSTs) in the eastern and central equatorial Pacific, beginning along the north-central coast of South America and extending westward, that results in large-scale changes in the winds and rainfall patterns.

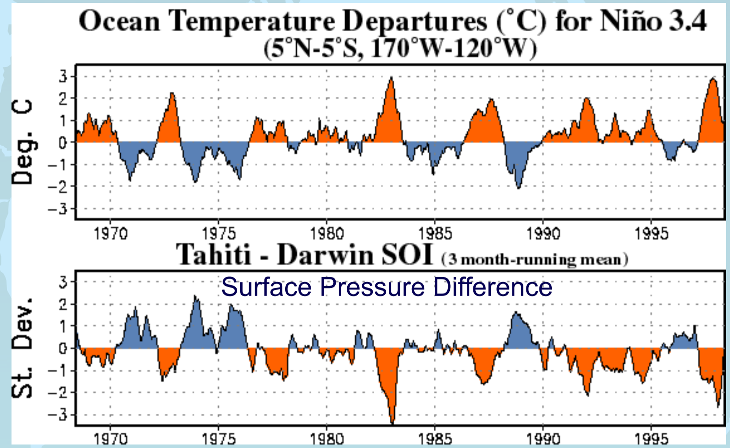
Southern Oscillation

The Southern Oscillation was named by Sir Gilbert Walker in 1923, who noted that "when pressure is high in the Pacific Ocean it tends to be low in the Indian Ocean from Africa to Australia". Walker was Director of Observatories in India and was mostly concerned with variations in the Indian monsoon. His was the first recognition that changes across the tropical Pacific and beyond were not isolated phenomena but were connected as part of a larger oscillation in equatorial SST that we now refer to as El Niño and La Niña.

ENSO Indices Correlate

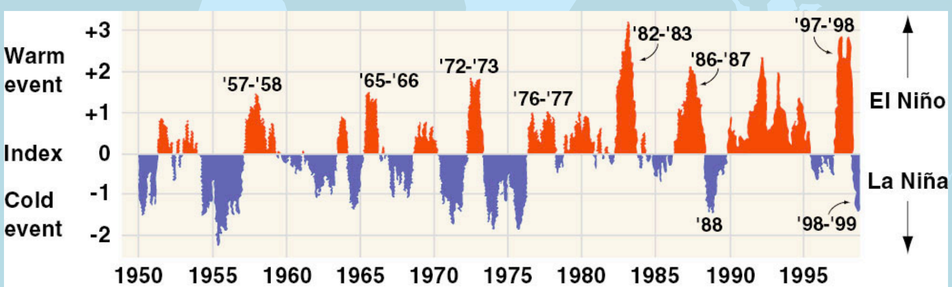
Ocean

Atmosphere



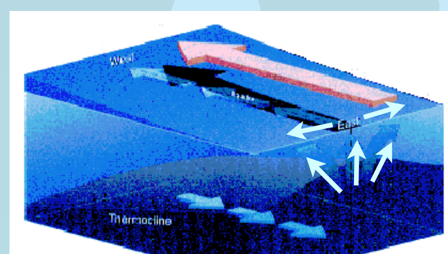
ENSO

The complete phenomenon is known as the El Niño – Southern Oscillation, or ENSO. The warm El Niño phase typically lasts for 8 -10 months or so. The entire ENSO cycle lasts usually about 3 -7 years, and includes a cold phase, known as La Niña, that may be similarly strong. However, the ENSO cycle is not a regular oscillation like the change of seasons, but can be highly variable in strength and timing.

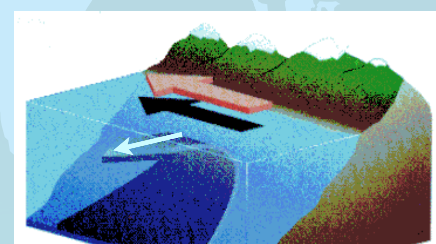


Physical Explanation for ENSO

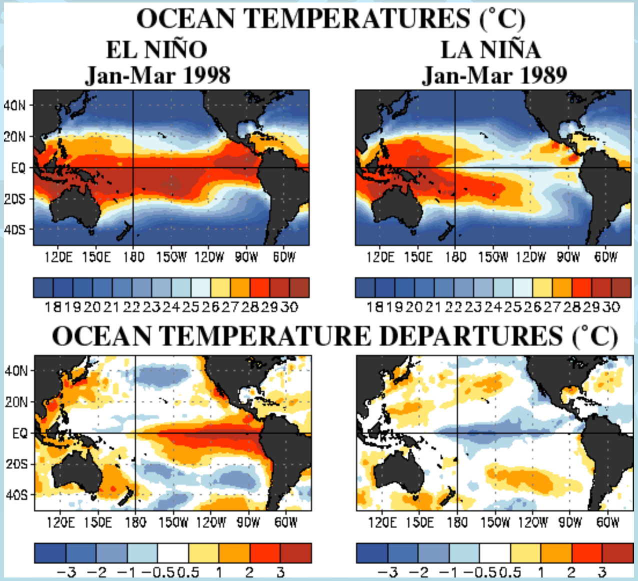
- Trade winds promote cold water upwelling in eastern tropical Pacific as a result of Coriolis force on currents.
  - Cool, deep water is nutrient rich and supports rich ecosystem (plankton, fish, birds,…)
- Weaker trades lead to weaker upwelling. Warm nutrient-poor tropical water replaces the cold, nutrient-rich water.
  - called El Niño (the boy in reference to its occurrence near Christmas)



Along Equator

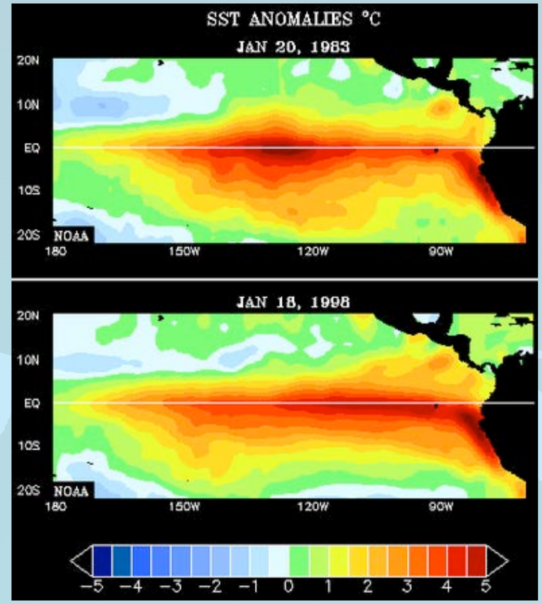

Along Peru

SST Maps During NH Winter



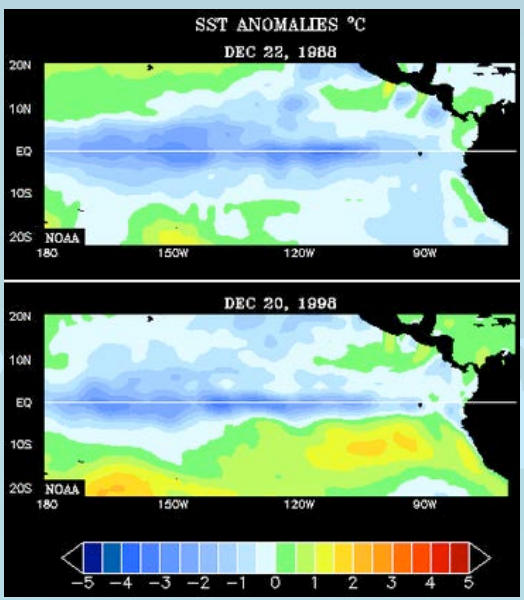
El Niño SST Anomalies

During el niño weaker easterly winds over the equator result in less upwelling and warmer SST.

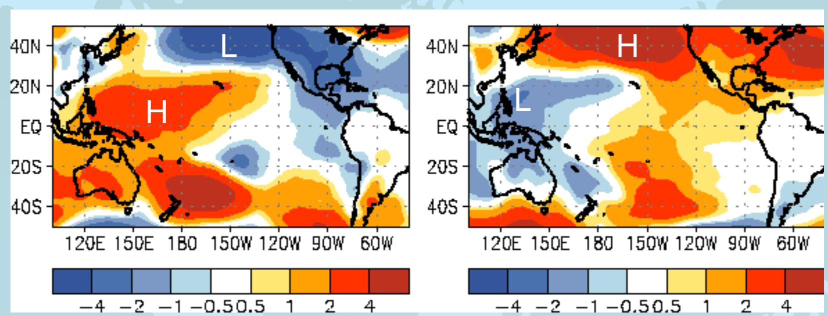


La Niña SST Anomalies

During la niña stronger easterly winds over the equator result in more upwelling and colder SST.



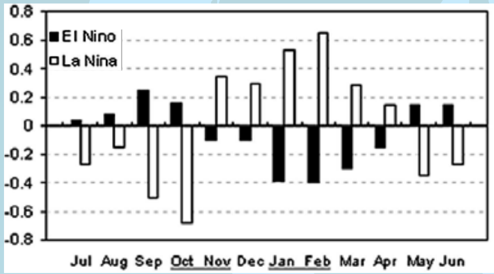
ENSO Pressure Anomalies



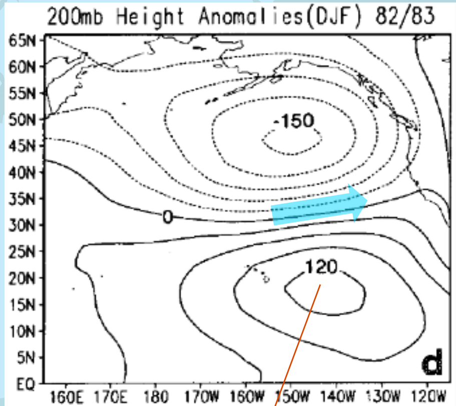
Average Sea-Level Atmospheric Pressure Anomalies (mb) for January through March associated with El Niño (left) and La Niña (right).

El Niño's Influence on Hawaii Climate

Dry in the El Niño Winter

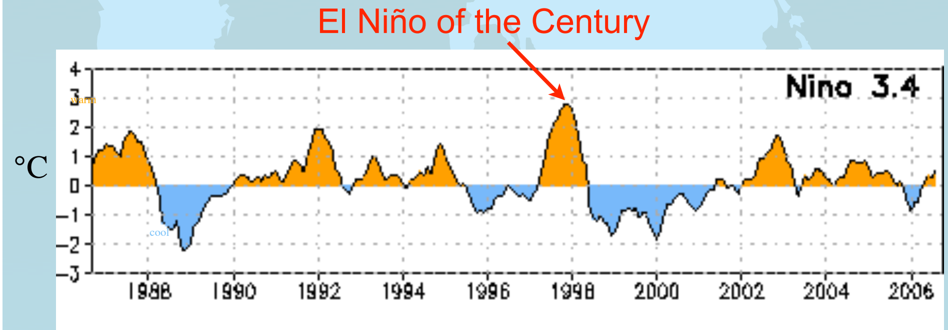


Normalized Hawaii rainfall index

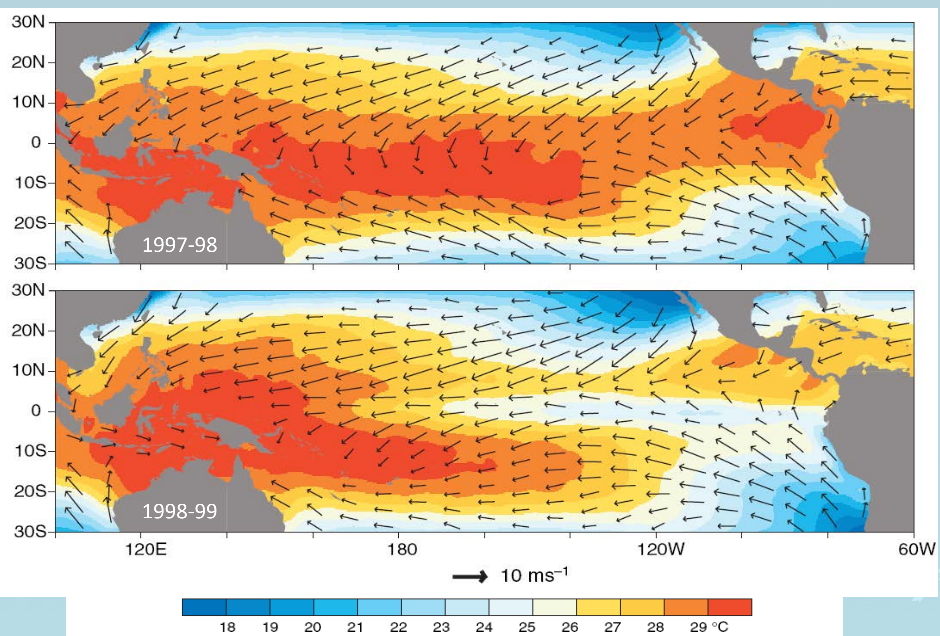


Enhanced subsidence due to strong convection in the central and eastern equatorial Pacific

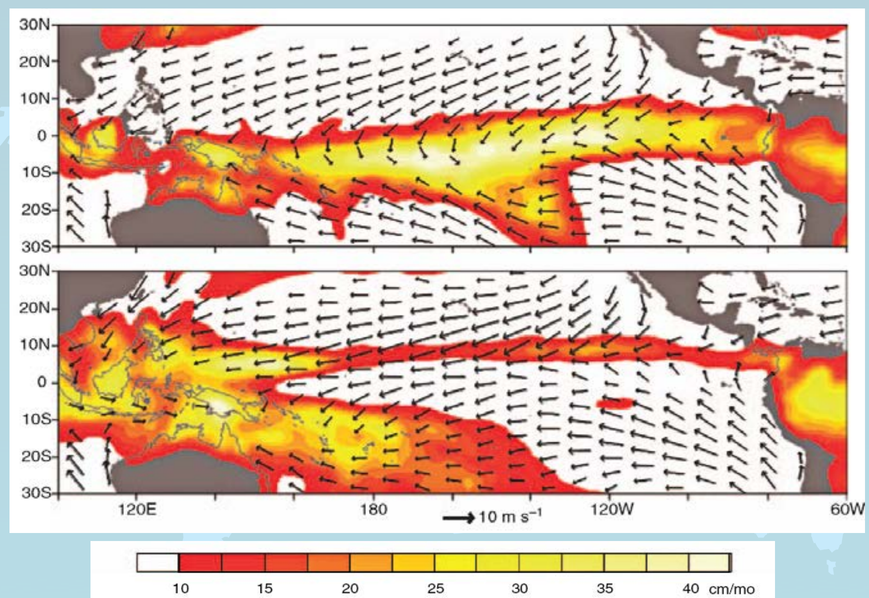
Time series of El Niño Index



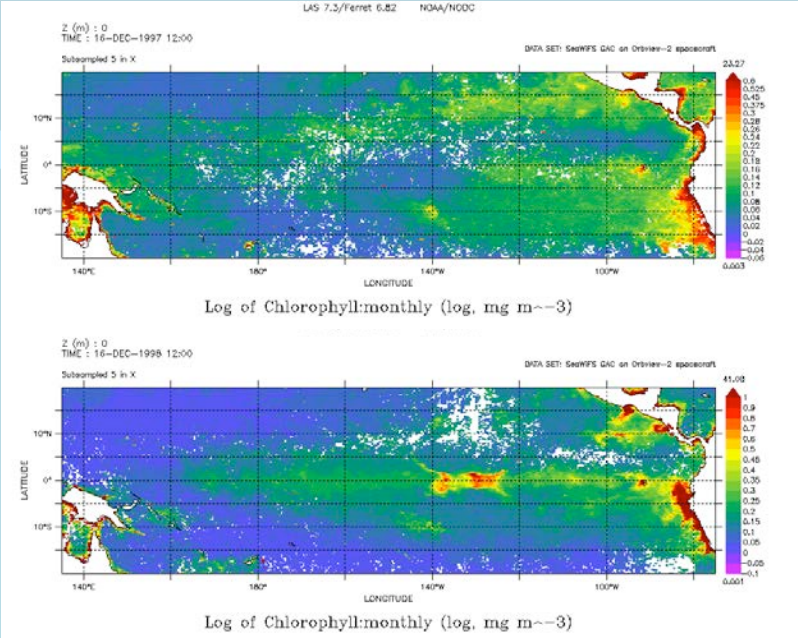
El Niño: peaks in the northern hemisphere winter months (Dec., Jan. Feb.)



Sea surface temperature and surface winds during November-April of 1997-98, and 1998-99.

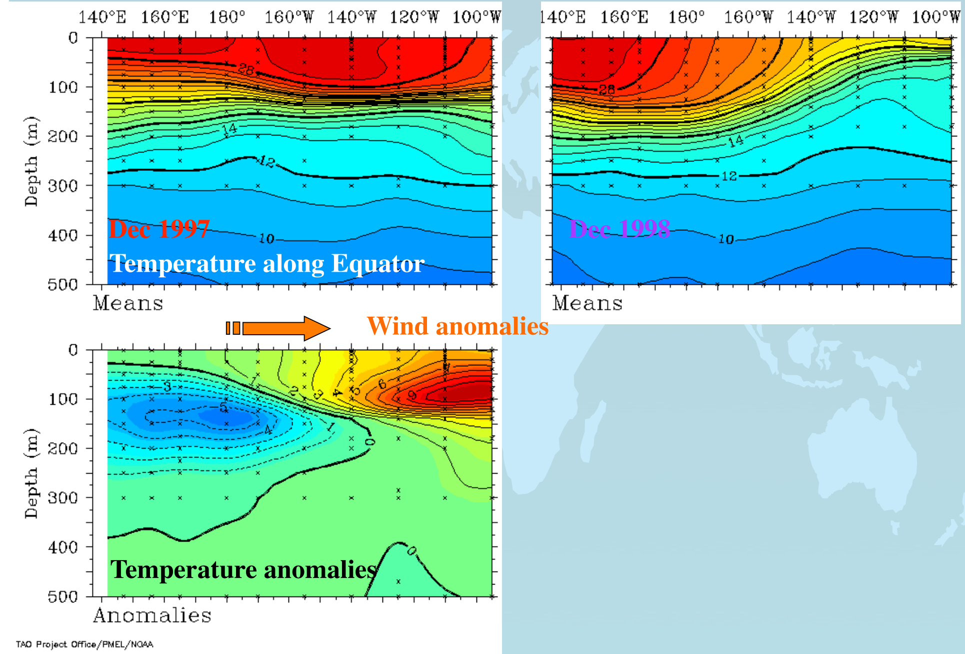


Precipitation (CMAP) and surface winds (ERS-2) during Nov.-April of 1997-98, and 1998-99.



Chlorophyll – shows where nutrient upwelling is taking place in Dec. 1997 and Dec. 1998

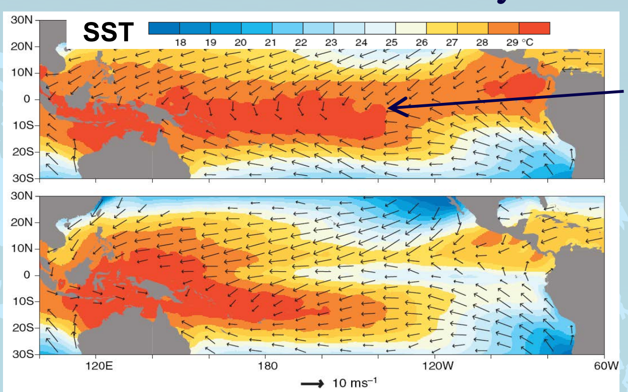
Interaction of thermocline depth, SST and winds



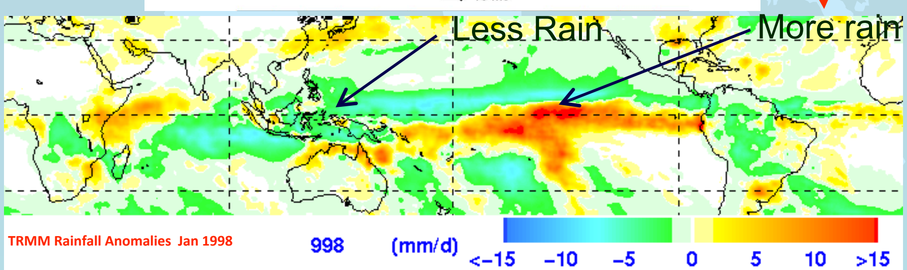
El Niño of the Century

1997-1998
Nov.-April
El Niño
weak winds

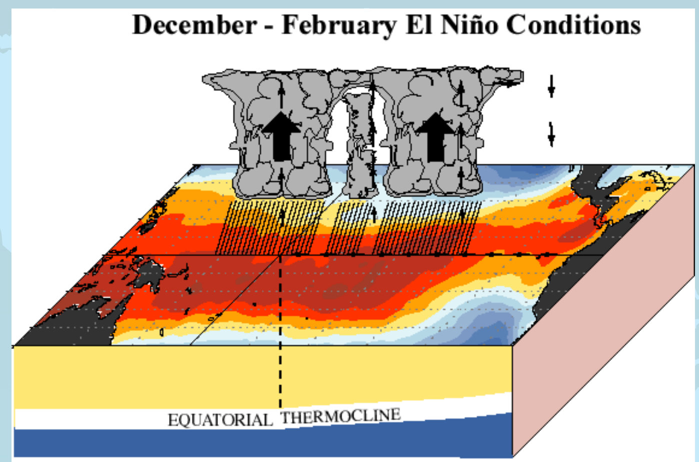
1998-1999
Nov.-April
normal
winds



Warmer
Ocean

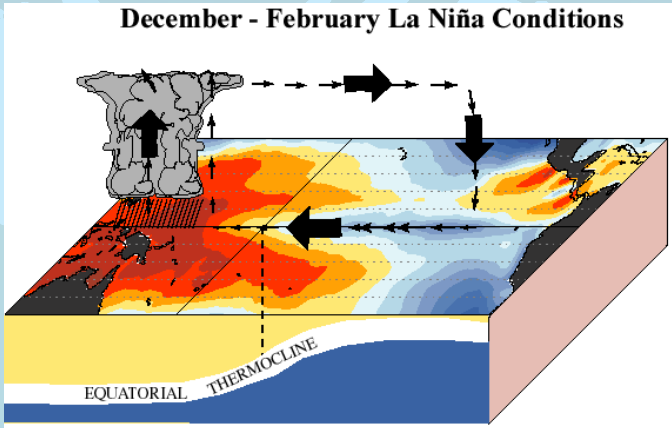


El Niño (Warm Phase)



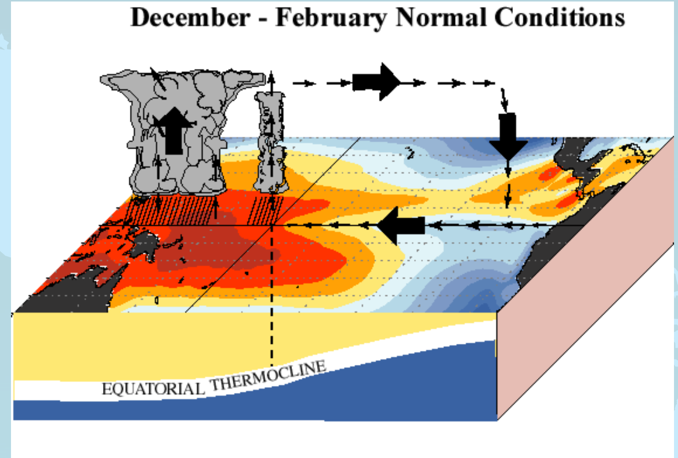
- Weaker tradewinds leads less upwelling
- Warmest SSTs, convection & rainfall shift to central Pacific
- Warmer SST's in eastern Pacific

La Niña (cold phase)



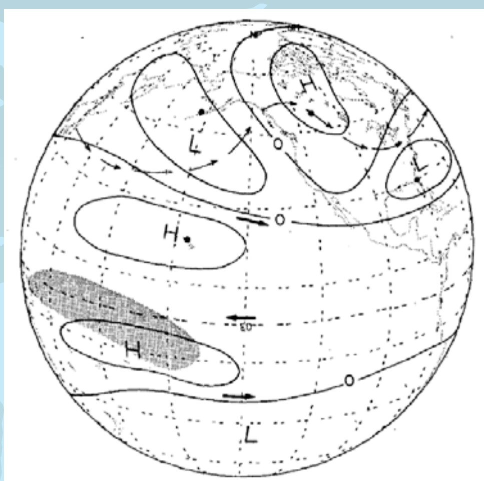
- Winds and surface water flow toward west, upwelling
- Warmest SSTs, convection & rainfall shift to Western Pacific
- Colder SST's in eastern Pacific

ENSO Neutral (Average)



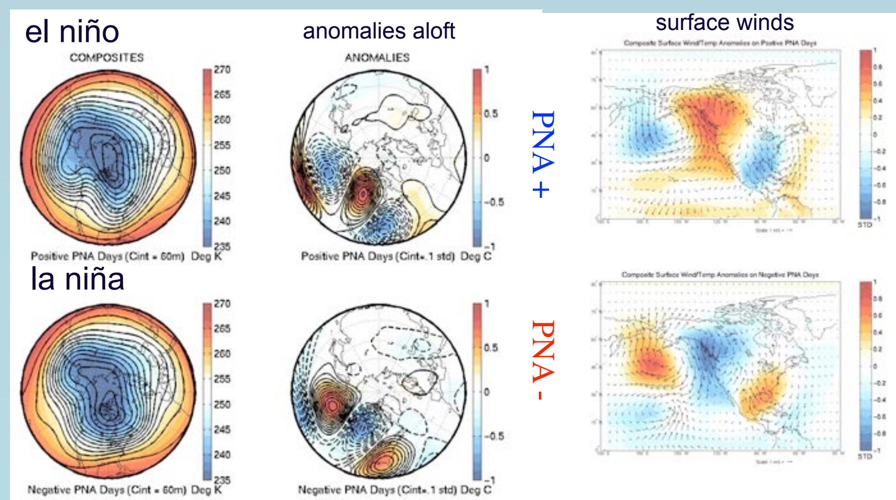
- Surface water flow from east toward west, upwelling
- Deep thermocline and warm water in western Pacific (associated deep convection & rainfall)
- Shallow thermocline and cool SST's in east Pacific

Rossby Wave Forcing by El Niño



Enhanced convection over the central equatorial Pacific during el niño results in a ridge aloft and a Rossby wave train called the Pacific North America (PNA) pattern (Horel and Wallace 1981).

Rossby Wave Forcing



Enhanced convection over the central equatorial Pacific results in a ridge aloft and a Rossby wave train called the Pacific North America (PNA) pattern. La Niña results in a -PNA pattern.

Planetary Wave Forcing

PNA+ leads to

drought over Hawaii with large surf.

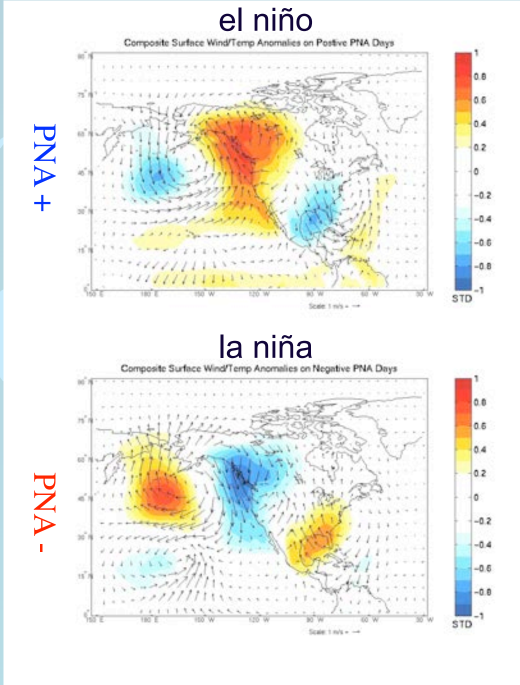
Warm and dry in the Pacific NW.

Wet over CA and wet and cold over the SE US.

PNA- leads to

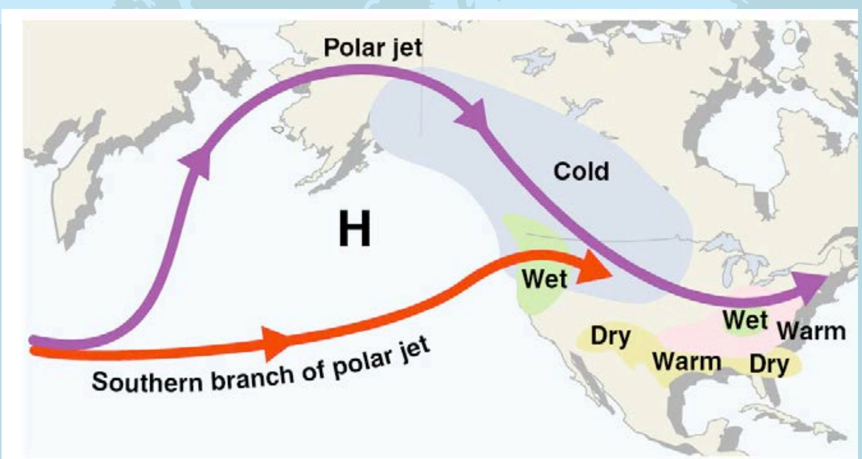
Wet for Hawaii

Cold and snowy over the Pacific NW and dry over the SE US

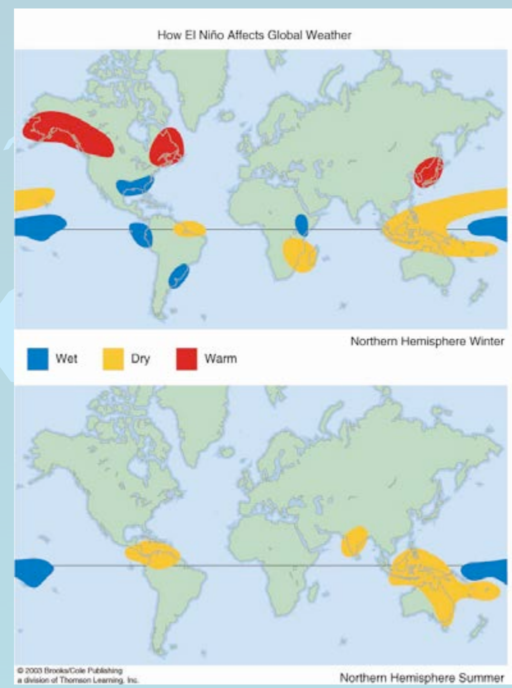


Winter Weather Impacts of El Niño

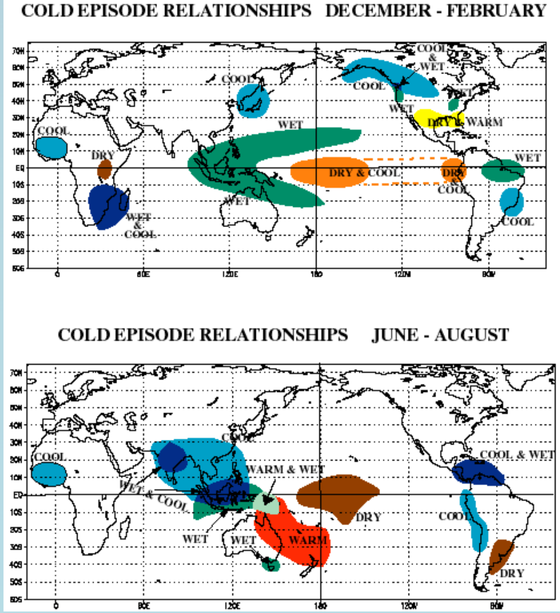
Winter Weather Impacts of La Niña



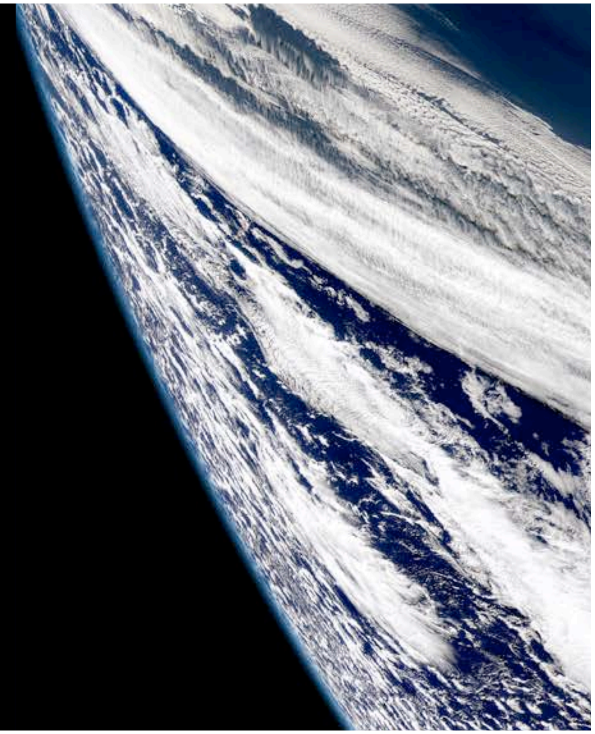
El Niño Climate Anomalies



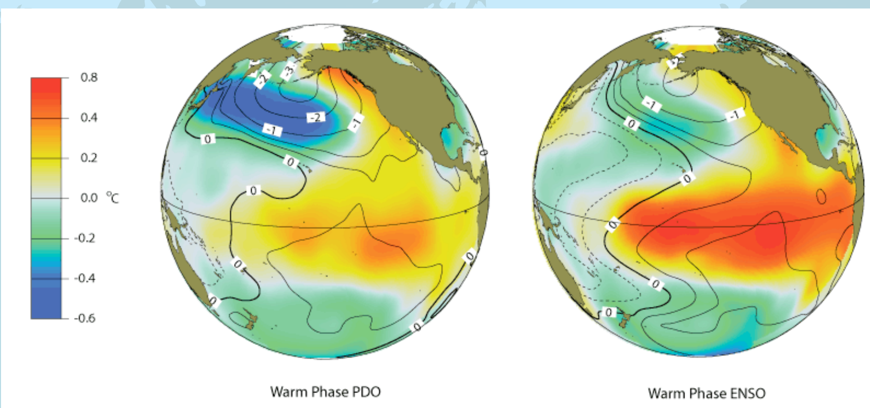
La Niña Climate Anomalies



Questions?

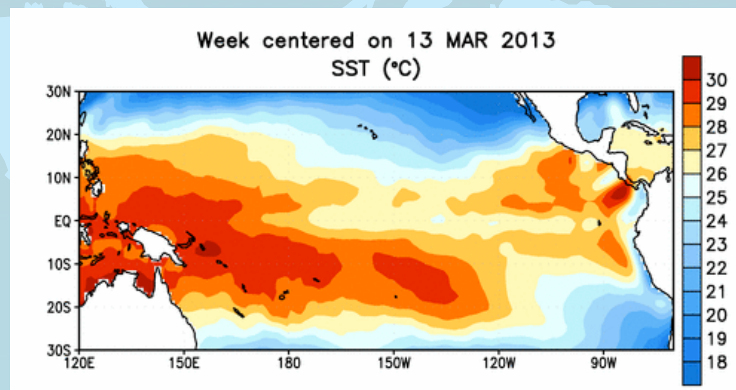


Ocean-Atmosphere Interaction and Inter-annual Variability



The ocean provides forcing for atmospheric circulations. Since the ocean has large heat capacity and thus the SST changes slowly, coupled ocean-atmosphere models have shown skill in seasonal scale modeling.

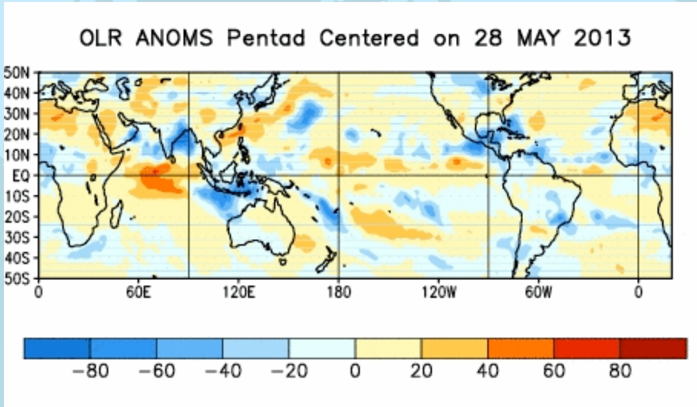
El Niño Watch for this Winter



SST anomalies

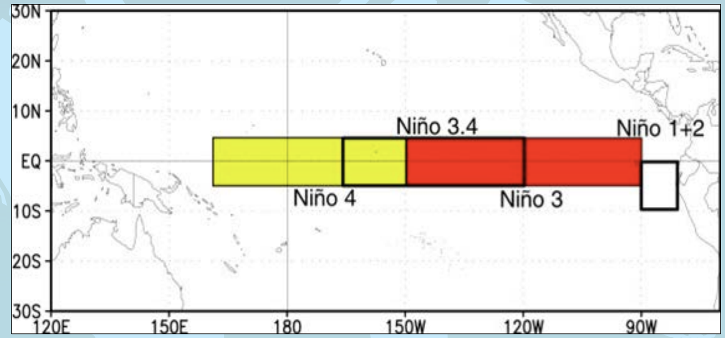
NOAA Climate Prediction Center (CPC) Synopsis: ENSO near neutral conditions are forecast to continue.

El Niño Watch for this Winter



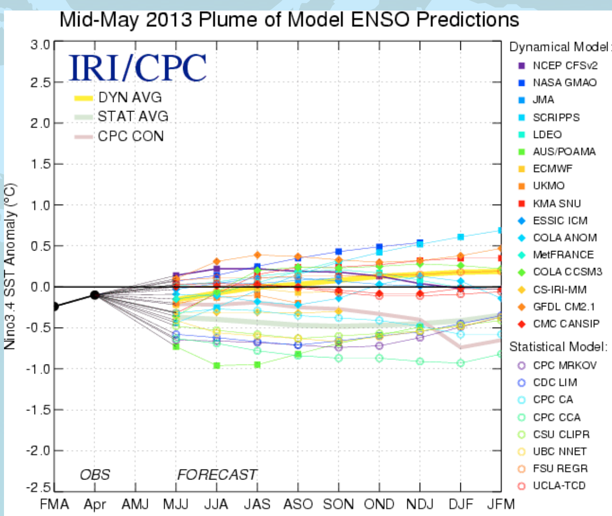
The atmosphere will often lag the ocean in its response

Oceanic Niño Index (ONI)

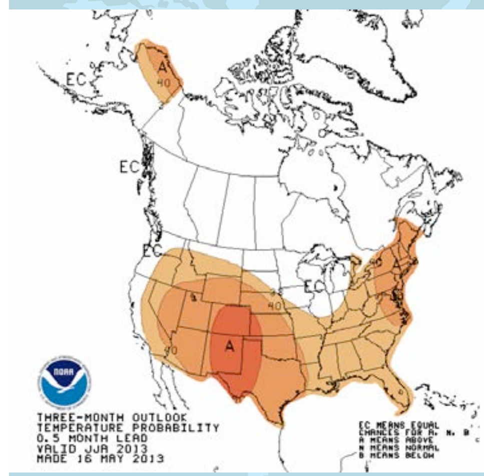


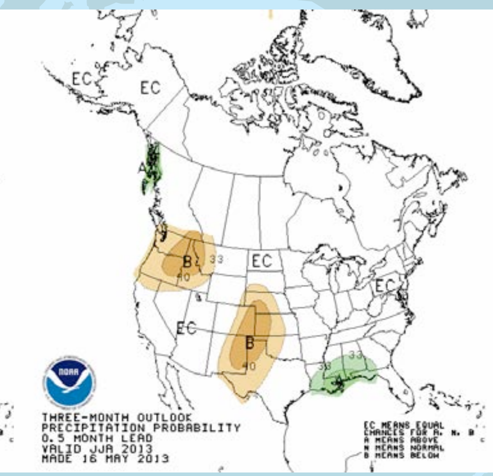
- The ONI is based on SST departures from average in the Niño 3.4 region, and is a principal measure for monitoring, assessing, and predicting ENSO.
- Defined as the three-month running-mean SST departures in the Niño 3.4 region.
- Used to place current events into a historical perspective
- NOAA's operational definitions of El Niño (>=+0.5) and La Niña (<=-0.5) are keyed to the ONI index.

NWS Forecast SST Anomalies



3-Month Forecast for US

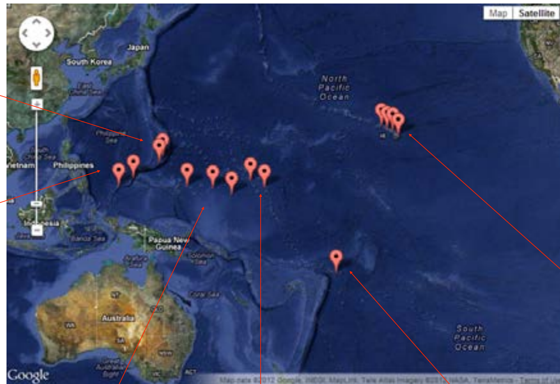




Pacific ENSO Applications Climate (PEAC) Center

UOG/WERI

NOAA



Palau

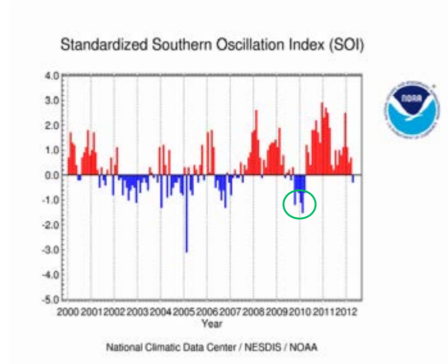
Federated States of Micronesia

Marshall Islands

Marshall Islands

UNIVERSITY of HAWAI'I MĀNOA

- A research group that uses ENSO forecasts to predict rainfall and sea level in the U.S.-Affiliated Pacific Islands

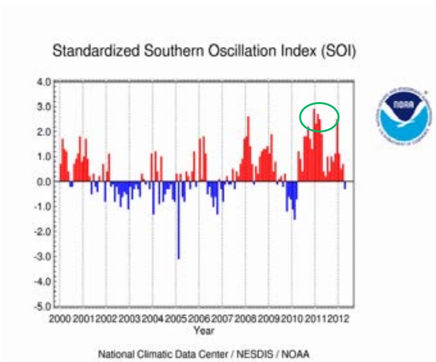


U.S. State, Territories, and Affiliated Countries - Experimental Rainfall Forecast February-April 2010

Updated 02/16/2010

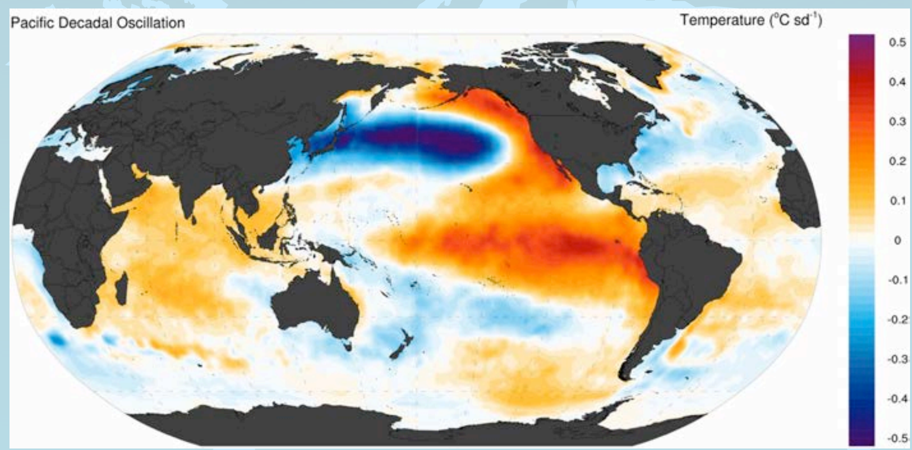
Location	UKMO	ECMWF	CA	NASA	NCEP	IRI	PRIDE	Rainfall Outlook	Final Probs
Palau									
Koror 7° 22' N, 134° 32' E	Avg-below	Avg-below	Below	Below	Avg-below	Below	Clim.	Below	40:35:25
FSM									
Yap 9° 29' N, 138° 05' E	Avg.	Below	Below	Below	Avg-below	Below	Below	Below	40:35:25
Chuuk 7° 28'N, 151° 51'E	Avg-below	Below	Below	Below	Avg-below	Below	Clim.	Below	40:35:25
Pohnpei 6° 59'N, 158° 12'E	Avg-below	Below	Below	Below	Avg-below	Below	Below	Below	40:35:25
Kosrae 5° 21'N, 162° 57'E	Avg.	Below	Avg.	Below	Avg-below	Below	**	Below	40:35:25
RMI									
Kwajalein 8° 43'N, 167° 44'E	Avg.	Below	Below	Below	Avg-below	Clim.	Clim.	Below	40:35:25
Majuro 7° 04' N, 171° 17'E	Below	Below	Avg-below	Below	Avg-below	Below	Avg-below	Below	40:35:25
Guam and CNMI									
Guam 13° 29'N, 144° 48' E	Avg.	Avg-below	Below	Avg-below	Avg-below	Below	Below	Below	40:35:25
Saipan 15° 06'N, 145° 48' E	Avg.	Avg.	Below	Avg.	Avg.	Below	Clim.	Below	40:35:25
American Samoa									
Pago Pago 14° 20'S, 170° 43'W	Clim.	Above	Above	Avg.	Avg.	Clim.	Avg-below	Avg-above	30:35:35
State of Hawaii									
19.7° - 21.0' N, 155.0° - 159.5' W									
Lihue	Below	Below	Avg-below	Below	Avg-below	Below	Below	Below	40:35:25
Honolulu	Avg-below	Below	Avg-below	Avg-below	Avg-below	Below	Below	Below	40:35:25
Kahului	Avg.	Below	Avg.	Avg-below	Avg-below	Below	Clim.	Avg-below	35:35:30
Hilo	Avg.	Below	Avg.	Avg-below	Avg-below	Below	Below	Below	40:35:25

Clim. indicates equal chances of below normal rainfall-average rainfall-and above average rainfall.



All levels in Inches Tide Gauge Station	Seasonal DJF forecast (mean1 dev.)	DJF Forecast (max2 dev.)
Marianas, Guam	+8	+22
Malakal, Palau	+6	+45
Yap, FSM	+5	+35
Chuuk, FSM***	+5	+33
Pohnpei, FSM	+8	+33
Kapingamarangi, FSM	+6	+24
Majuro, RMI	+5	+45
Kwajalein, RMI	+5	+45
Pago Pago, American Samoa	+4	+32
Honolulu, Hawaii	-3	+23
Hilo, Hawaii	-1	+39

Pacific Decadal Oscillation (PDO)



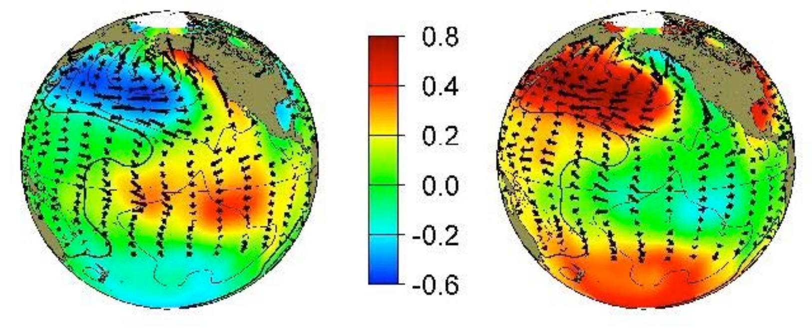
Positive phase of the PDO showing SST anomalies.

Pacific Decadal Oscillation (PDO)

- The Pacific Decadal Oscillation (PDO) is a pattern of change in the Pacific Ocean's climate.
- The PDO is detected as warm or cool surface waters in the Pacific Ocean, north of 20° N.
- During a "warm", or "positive", phase, the west Pacific becomes cool and part of the eastern ocean warms; during a "cool" or "negative" phase, the opposite pattern occurs.
- The PDO shifts phases on at least inter-decadal time scale, usually about 20 to 30 years.

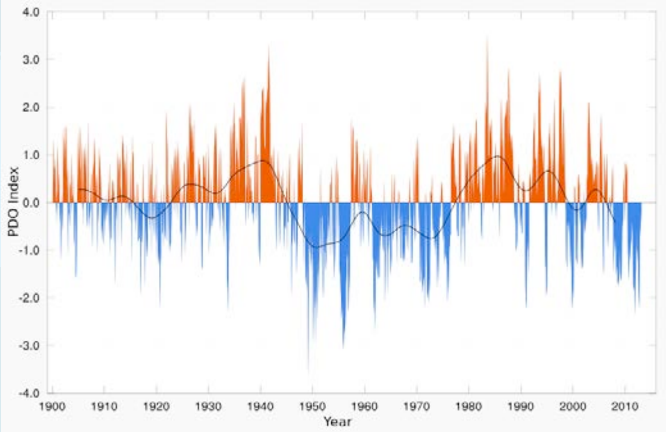
PDO Patterns

Warm Phase | Cool Phase



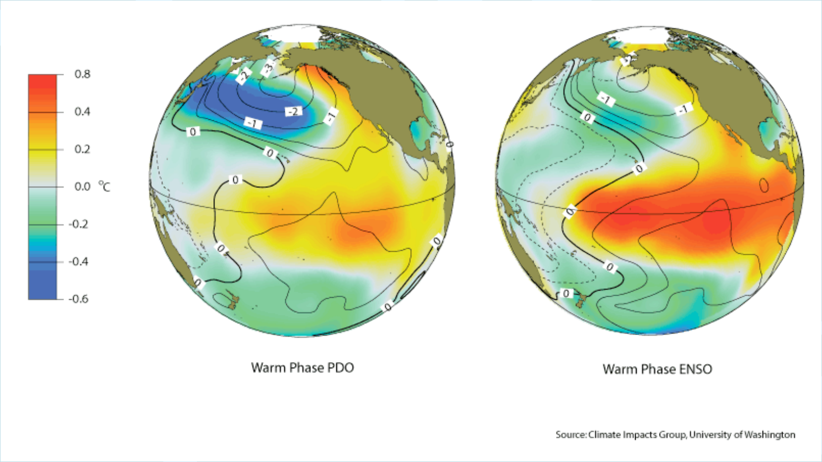
Fisheries scientist Steven Hare coined the term "Pacific Decadal Oscillation" (PDO) in 1996 while researching connections between Alaska salmon production cycles and Pacific climate

Pacific Decadal Oscillation (PDO)



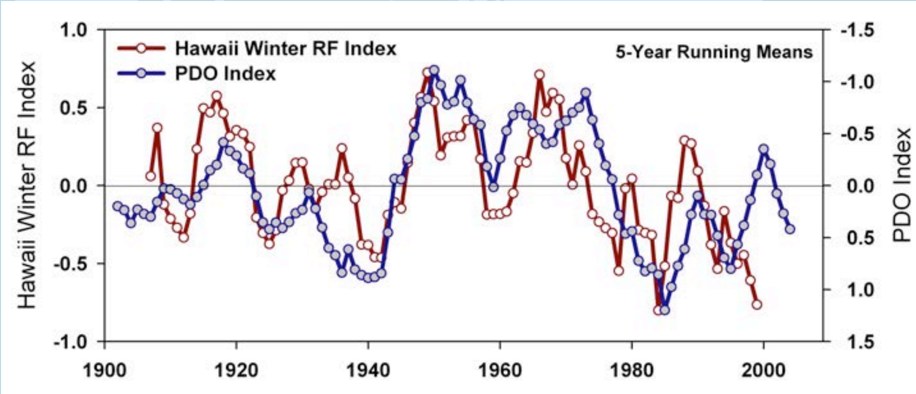
- The PDO index has been reconstructed using tree rings and other hydrologically sensitive proxies from west North America and Asia.
- Variability of the Pacific decadal oscillation (PDO), on both interannual and decadal timescales, is well modeled as the sum of direct forcing by El Niño–Southern Oscillation (ENSO), the “reemergence” of North Pacific sea surface temperature anomalies in subsequent winters, and white noise atmospheric forcing.

Comparing PDO and ENSO Patterns



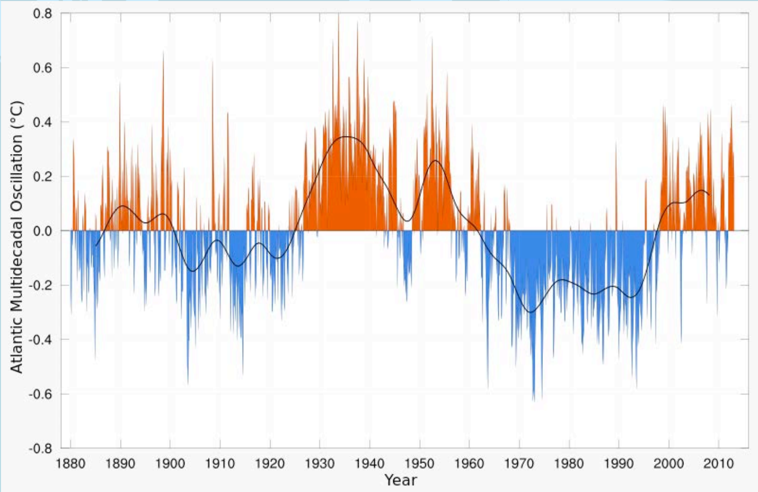
Recall that the PDO has a period of decades whereas ENSO has a period of years.

Rainfall Correlation with North Pacific SST



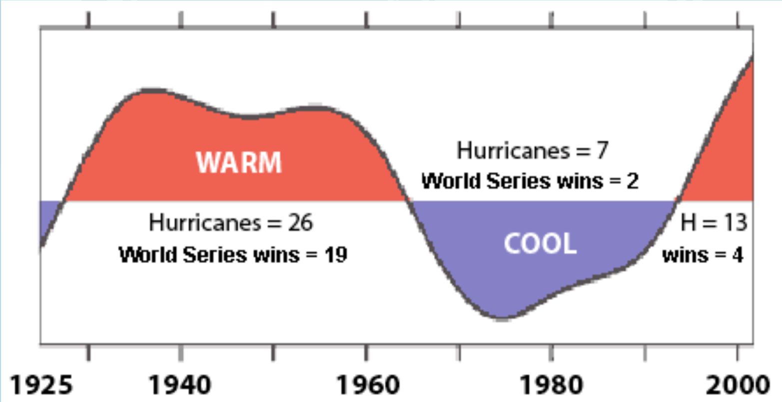
Time series of Hawai'i Rainfall and the Cyclical Change Linked to Pacific Decadal Oscillation of the Sea-Surface Temperature

Atlantic Multidecadal Oscillation (AMO)



Time series of AMO showing SST anomalies.

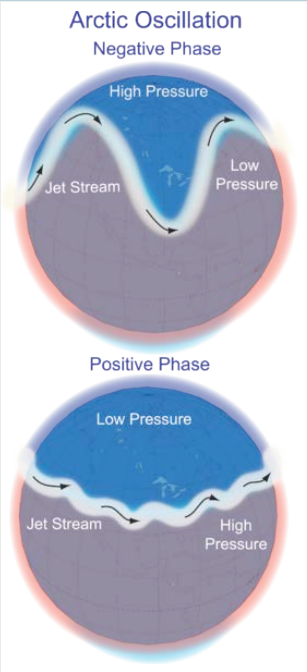
Atlantic Multidecadal Oscillation (AMO)



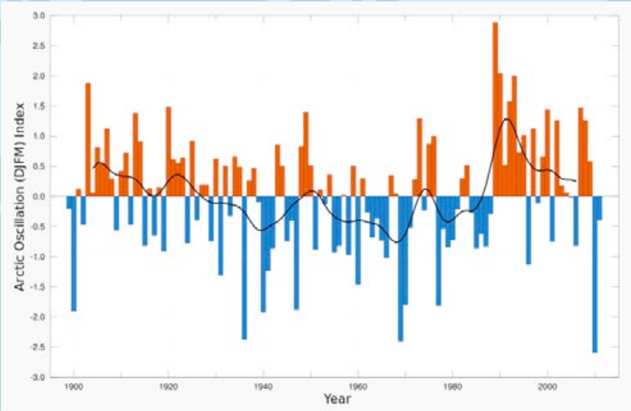
Why the AMO may be of interest

Arctic Oscillation Index

- The degree to which Arctic air penetrates into middle latitudes is related to the AO index, which is defined by surface atmospheric pressure patterns.
- When the AO index is positive, surface pressure is low in the polar region. This helps the middle latitude jet stream to blow strongly and consistently from west to east, thus keeping cold Arctic air locked in the polar region.
- When the AO index is negative, there tends to be high pressure in the polar region, weaker zonal winds, and greater movement of frigid polar air into middle latitudes.



Arctic Oscillation Index



Arctic Oscillation (AO) time series for the extended (DJFM) winter season 1899–2011. AO is characterized by pressure anomalies of one sign in the Arctic with the opposite anomalies centered about 37–45˚N.

Questions?