El Niño

➢ ENSO

- Acronym for the coupled phenomena of **El Niño** and the **Southern Oscillation**.

➢ Oceanic Nino Index (ONI)

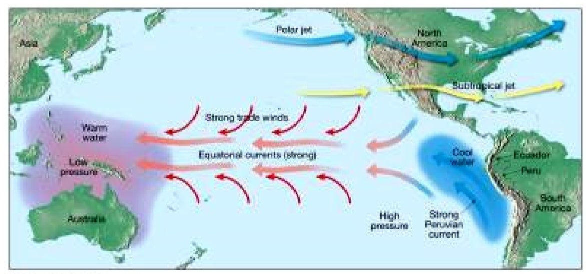
- based on the principal measure for monitoring, assessment, & prediction of ENSO (SST departures from average in the Nino 3.4 region).
- Used to replace current conditions in historical perspective.
- NOAA's operational definitions of El Nino and La Nina are keyed to the index

➢ Southern Oscillation

- A reversal of airflow between normally low atmospheric pressure over the western Pacific and normally high pressure over the eastern Pacific
- The cause of **El Niño**.

➢ Normal

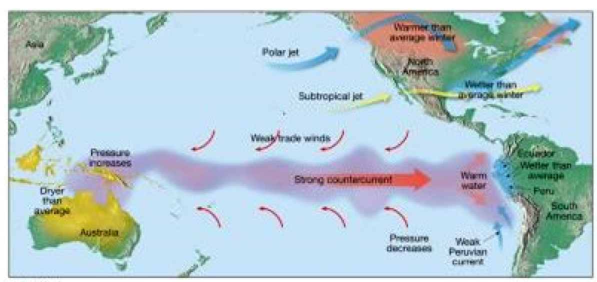
- Normally, the trade winds & strong equatorial currents flow towards the west.
- At the same time, an intensive Peruvian current causes upwelling of cold water along the west coast of South America.



(a) Normal conditions

➢ El Niño

- A southward-flowing nutrient-poor current of warm water off the coast of western South America, caused by a breakdown of trade-wind circulation.
- **El Niño** is a disruption of the above ocean-atmosphere system in the Tropical Pacific having important consequences for weather and climate around the globe.
- December – January , Every 3-7 years, lasts 8- 10+ months
- **Unusually warm ocean waters** in the equatorial Pacific
- Reduction in Anchovy Fishery
- Amount & duration of warming can vary greatly

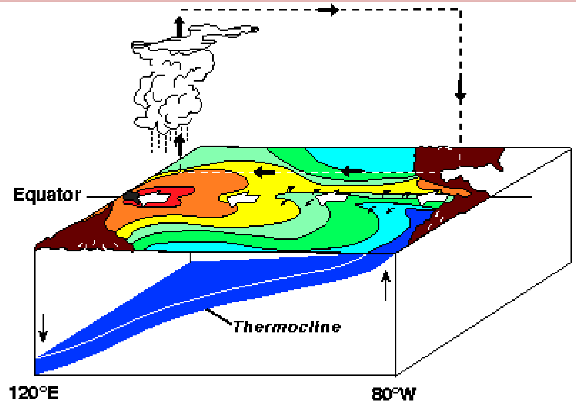
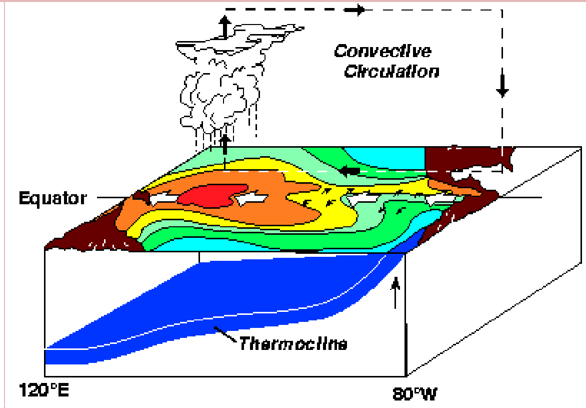
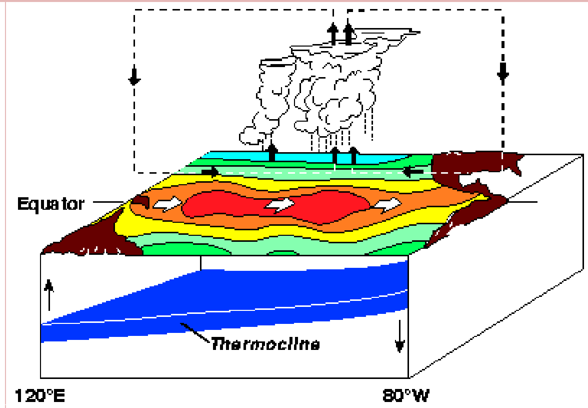
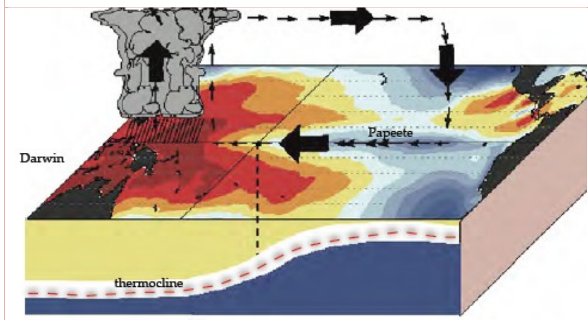
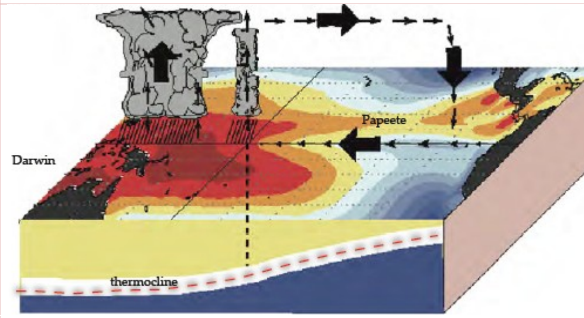
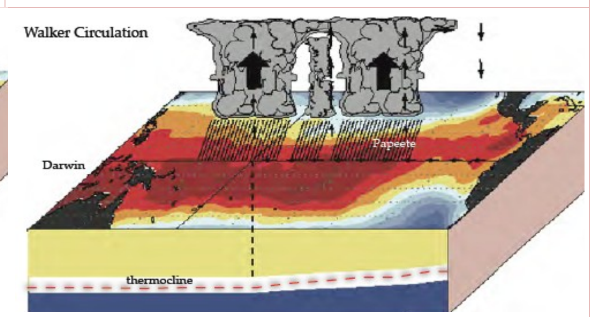


(b) El Niño

➢ La Niña

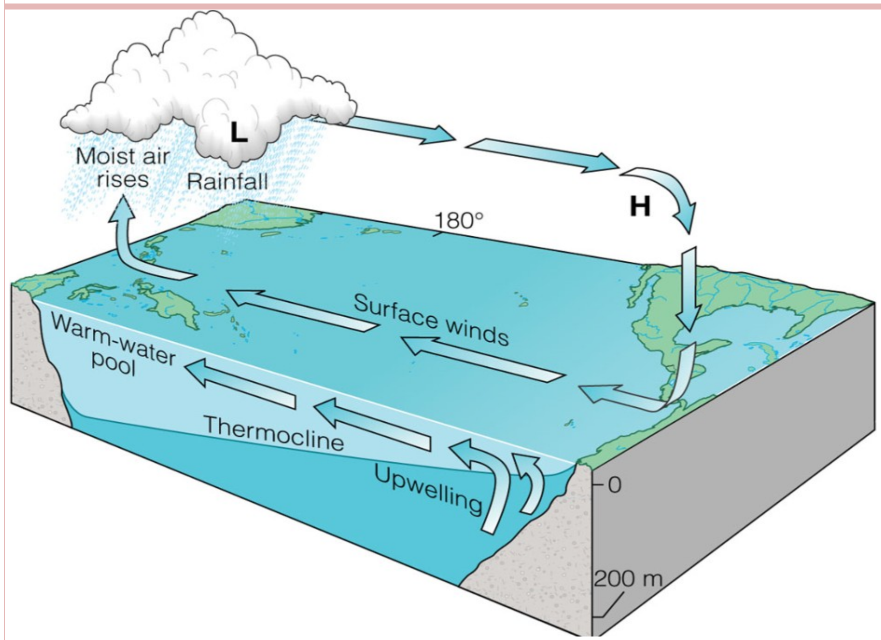
- An event during which normal tropical Pacific atmospheric and oceanic circulation strengthens and the surface temperature of the eastern South Pacific drops below average values; usually occurs at the end of an **ENSO** event.

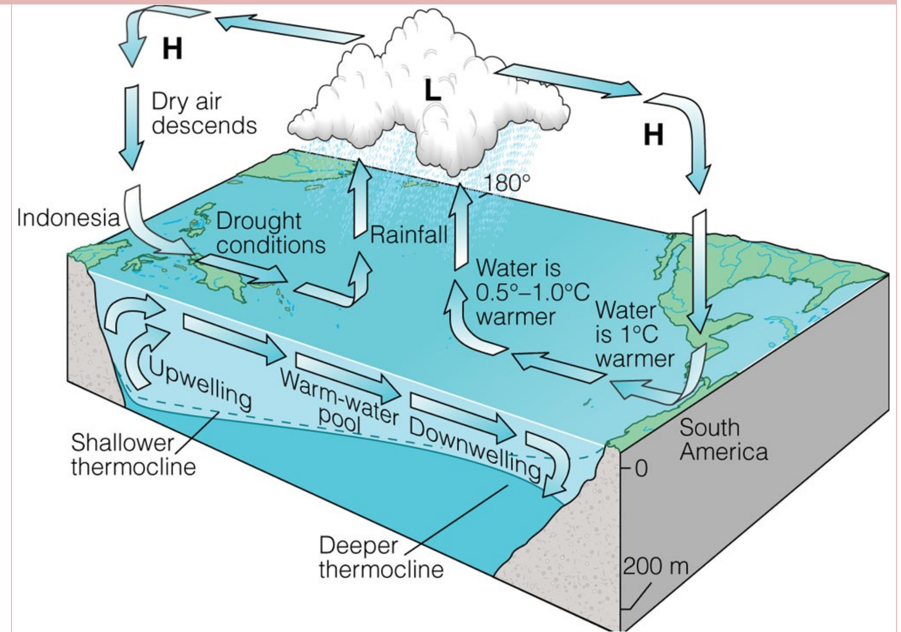
El Niño

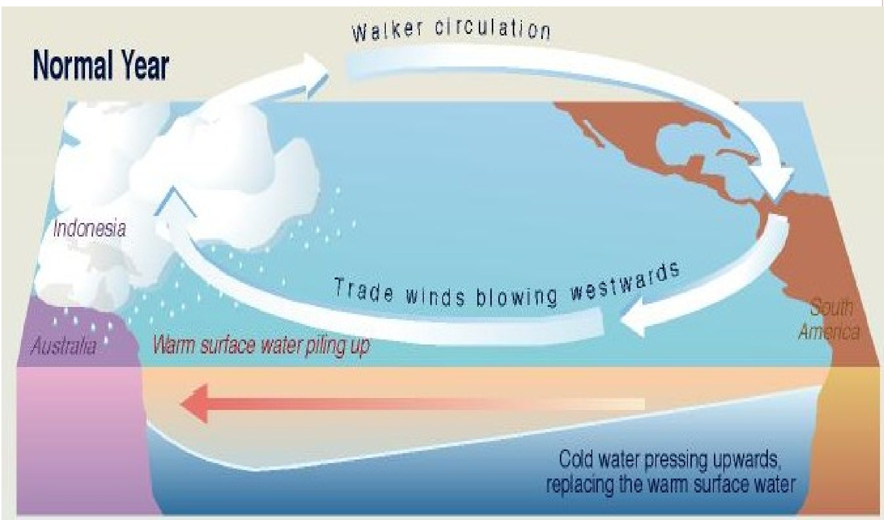
La Niña Conditions	**Normal** Conditions	**El Niño** Conditions
		
- **unusually cold** ocean temperatures in the Equatorial Pacific - global climate impacts tend to be the **opposite of El Nino yrs** - characterized by a **negative ONI** (≤-0.5˚C) -	- **cold water** (**plume**) coming up from the South and carried by the equatorial current west. - As it moves towards Indonesia it warms & becomes **more humid** → **low pressure**, tropical conditions in Indonesia	- tropical rains usually centered over Indonesia shift eastward, influencing global atmospheric wind patterns - **Warmer** & **drier winter** at **high latitudes** - **cool** & **wet winters** for the **Gulf Coast** - characterized by a **Positive ONI** (≥ +0.5˚C)
		
- <u>**Even higher**</u> **air pressure** over Papeete, Tahiti, relative to Darwin, Australia → Easterly Trade winds → The pool of **warm water** in the Western Pacific becomes even <u>**more confined**</u>. → The **thermocline** in the Eastern Pacific has become <u>**even more**</u> **shallow.** - <u>**Strongly**</u> **Positive SOI**	- <u>**Higher**</u> **air pressure** over Papeete, Tahiti, relative to Darwin, Australia → the well-known <u>**easterly**</u> **trade winds** → **Warm water** <u>**pools**</u> in the Western Pacific, fuels **convection** & **Rainfall** in this region → The **thermocline** in the Eastern Pacific becomes **shallow** - <u>**Positive**</u> **SOI**	- **Reversal** of **air pressure** differences between Papeete, Tahiti, relative to Darwin, Australia → **Trade winds** also **reverse,** becoming <u>**westerly**</u> → an **eastward shift** in **warm water**, which may now **extend across** the entire equatorial Pacific → The **thermocline** in the Eastern Pacific has become <u>**much deeper**</u> - <u>**Negative**</u> **SOI**

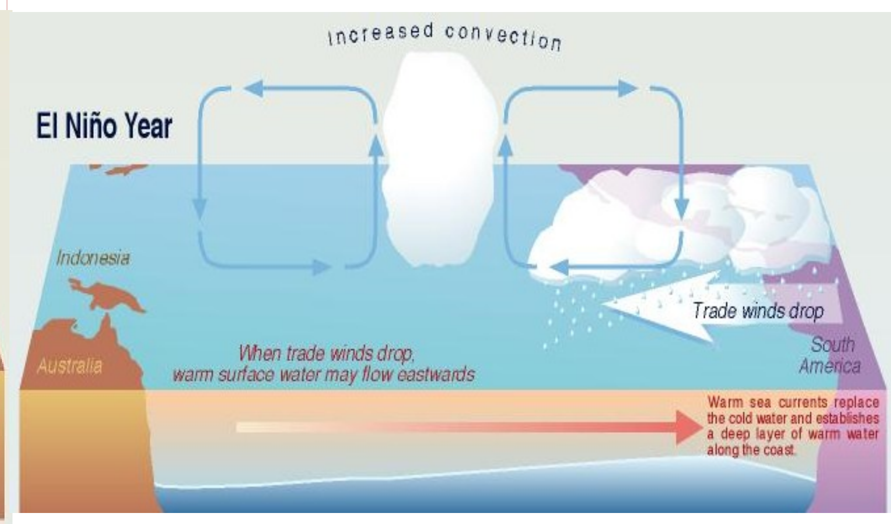
El Niño

Normal Conditions	**El Niño** Conditions

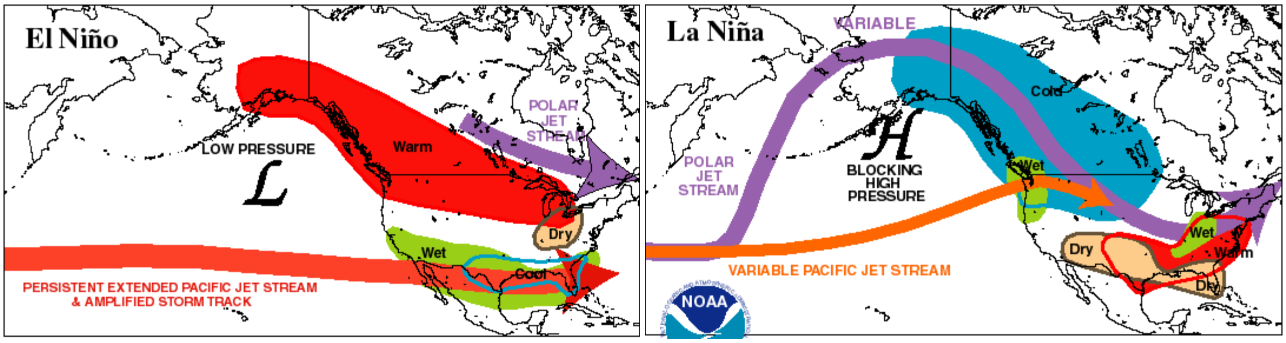


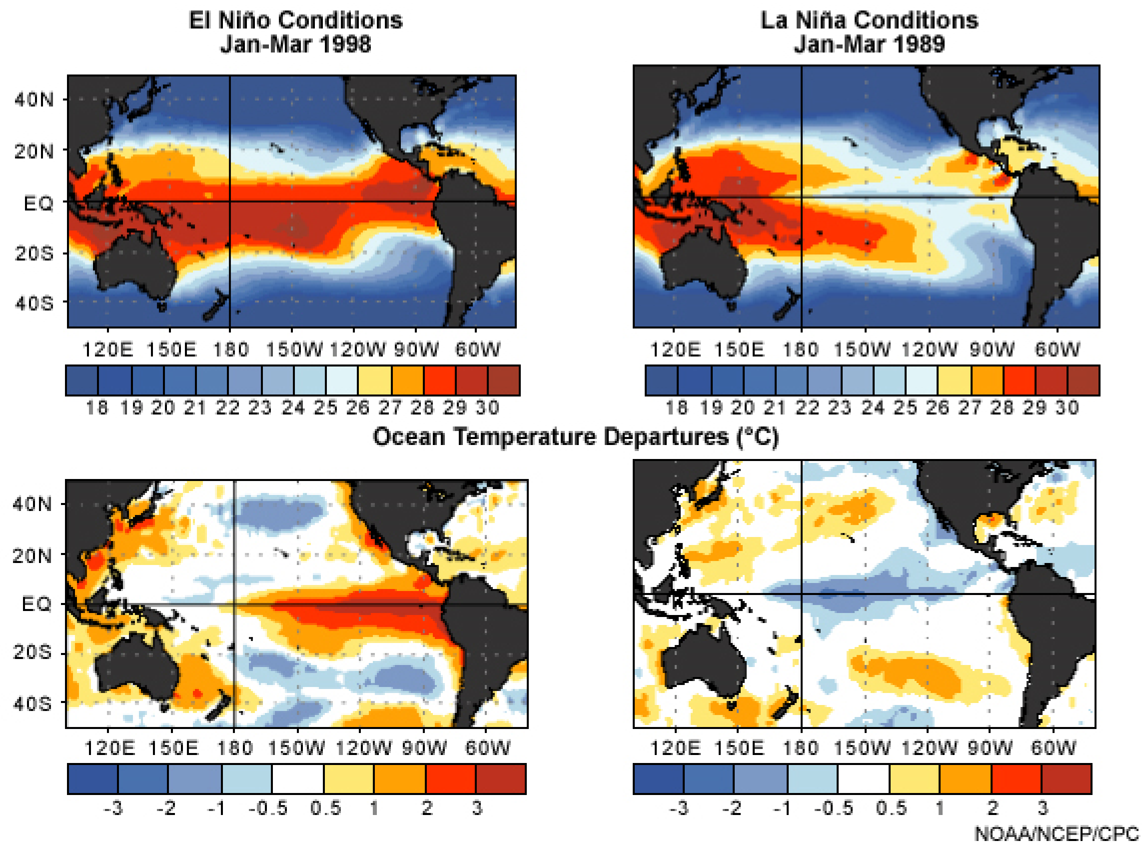


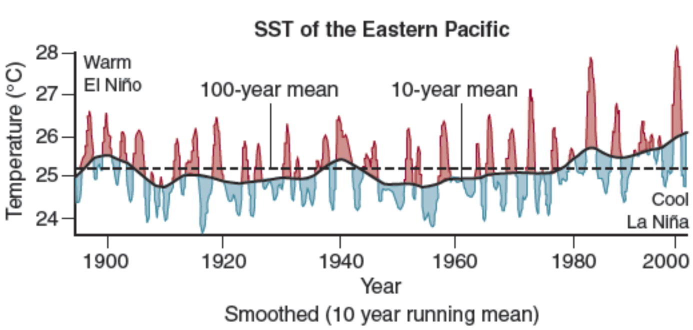




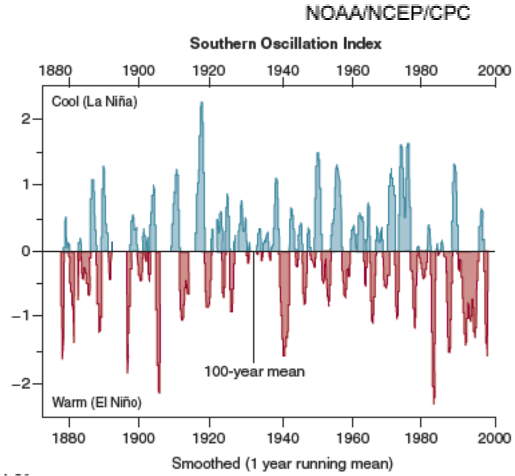
Typical January-March Weather Anomalies & Atmospheric Circulation During Moderate to Strong El Niño & La Niña







Measurements of SSTs in the eastern Pacific since the late 1800s reveal a cycle of warmer-than-average and colder-than-average temperatures. Some scientists advocate that the 10-year running mean gives a better indicator of the intensity of El Nino and La Nina events.



Terminology

- **Coastal Upwelling**
  - Upwelling adjacent to a coast, usually induced by wind
  -
- **Downwelling**
  - Circulation pattern in which surface water moves vertically downward
  -
- **Equatorial Upwelling**
  - Upwelling in which water moving westward on either side of the geographical equator tends to be deflected slightly poleward and replaced by deep water often rich in nutrients.
- **Upwelling**
  - Circulation pattern in which deep, cold, usually nutrient-laden water moves toward the surface.
  - Upwelling can be caused by winds blowing parallel to shore or offshore.
  -
-
  -
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-
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El Nino and the Southern Oscillation (ENSO)

The ENSO is one of earth's mechanisms for redistributing excess heat from tropics to higher latitudes.

"**El Nino," which** literally means "**the little boy**" in Spanish, refers to the Christ Child and has been used by Peruvian fishermen since the l9th century to describe the appearance of warm water in the coastal region of Peru and Ecuador around Christmastime. This was a regular annual event. However, in some years (at intervals of 2-7 years), the accumulation of anomalously warm water becomes excessive, often leading to disastrous results for the anchovy fishery in Peru. Soon, those anomalous years with excessive warming became to be known as "El Nino" years. During El Nino sea surface temperature along the South American coast could rise by 1 to 5 ^{o}C or higher than normal. Thus **El Nino means "warm event"**. The strongest El Nino event in the last 150 years, occurred in 1997/98. The 1998 winter in California was marked by stormy conditions, floods, mudslides, etc., while Louisiana experienced the wettest January of this century. There are "**cold events**" known as "**La Nina**" (meaning **the little girl**) when the eastern Pacific is very cold, the western Pacific is very warm, and the trade wind is very strong.

Early studies had viewed El Nino as primarily an oceanic event important only to the west coast of South America. More recent studies contributed toward linking El Nino to the atmospheric phenomenon known as the **Southern Oscillation (SO)**, briefly described as a "**massive seesaw" of atmospheric pressure between the eastern (Tahiti) and western South Pacific (Darwin)**.

The Southern Oscillation was first noted by **Sir Gilbert Walker** in his studies on the Indian monsoon in the 1920s. He observed that when ***low air pressure is located in the western Pacific, high air pressure tends to occur in the eastern Pacific; and when high pressure is located in the western Pacific, low pressure tends to occur in the eastern Pacific***. He termed this phenomenon the "**Southern Oscillation**" (because this phenomenon tends to be centered in the southern hemisphere).

Based on studies of El Nino events since 1957, **Bjerknes** (1966) developed the concept of the **Walker Circulation** in the atmosphere, which is characterized by large-scale zonal, west-east, circulation in the equatorial plane. The average global tropical atmospheric circulation is characterized by **three major convection zones** (convective areas of rising motion, clouds and rain). They are located over Southeast Asia and the Western Pacific (area of warmest ocean waters), tropical South America (over the tropical rainforest of Amazon) and Africa (over the tropical rainforest in the Congo region). Air rises to the upper troposphere (about 12 km.) and sinks in the descending branches of the planetary-scale East-West overturning cells over the eastern Atlantic and the eastern Pacific which are usually colder and dry. Consequently, air pressure in the areas of ascending motion becomes low while air pressure in the areas of descending motion becomes high. ***Under this "normal" atmospheric circulation, the western Pacific is characterized by warm sea surface temperature, low air pressure, and cloudy and rainy climate, while the eastern Pacific is characterized by low sea surface temperature, high air pressure, and dry climate.*** The lower branch of this Walker cell over the Pacific gives rise to the trade wind blowing from east to west (i. e., blowing from high pressure to low pressure). This steady trade wind piles up warm water in the western Pacific, thus contributing to the self-maintenance mechanism for sustaining this trade wind. Bjerknes consequently developed an idea, which links El Nino (i. e., anomalous warming along the South American coast) and the Southern Oscillation (a large-scale seesaw in the atmospheric pressure field). Due to the intense research efforts in the last 10-15 years, we came to realize a close coupling between those two phenomena, and now we refer to the whole event involving those two phenomena as "**El Nino-Southern Oscillation (ENSO)**."

A better understanding of the dynamics of ENSO focuses on how the ocean responds to fluctuations in trade wind. Under "normal" easterly trade wind conditions over the Pacific, the trade winds pile up warm water in the western Pacific. Consequently, sea surface temperature in the eastern Pacific tends to be cooler. If the trade winds are stronger than normal, more warm water is accumulated in the western Pacific (La Nina). On the other hand, ***a typical ENSO warm event is characterized by weakening trade winds in the Pacific Ocean***. ***This results in the "sloshing back" of warm water accumulated in the western Pacific toward the eastern Pacific. This sloshing back of warm water takes a few months to reach the South American coast. It should be noted that sloshing back of warm water toward the South American coast is confined near the equator.*** Upon the arrival of warm water at the South American coast, El Nino onset takes place (i. e., appearance of anomalously warm water along the South American coast).

Once, "sloshing back" is initiated by a weakening trade wind, atmospheric circulation will be affected. ***As the warm water sloshes back toward the South American coast, the atmospheric convection zone, that used to be located in the western Pacific, will migrate eastward as well, following the eastward movement of the warm water pool***. Consequently, the zone of rainfall will accompany this eastward migration of the convection zone. As this zone of convection and rainfall passes the central Pacific Ocean, those tropical paradise islands, such as Tahiti, that are usually known for "good weather all year around," will be subjected to stormy and rainy conditions. When this convection and rainfall zone arrives at the South American coast, the eastern Pacific and the neighboring South American countries will experience heavy rainfall (even the dessert regions of Peru and Ecuador often experience flooding).

When the warm water reaches the eastern Pacific, everything reverses between the western Pacific and the eastern Pacific. Sea surface temperature is now warmer in the eastern Pacific and colder in the western Pacific. A large atmospheric convection is now located in the eastern Pacific, and the air is descending in the western Pacific. Consequently, air pressure is low in the eastern Pacific, and high in the western Pacific. Wind blows from west to east (opposite to the normal direction of trade winds). A zone of rainfall is located in the eastern Pacific while the western Pacific experiences dry conditions ("drought"). Now, we can understand why El Nino and the Southern Oscillation are closely coupled. ***Once the trade winds weaken, sloshing back of warm water from the western Pacific toward the eastern Pacific is initiated. This alters the Walker circulation. When the warm water reaches the South American coast, air pressure pattern is completely reversed*** (i. e., low in the east and high in the west, in contrast to normal conditions with low in the west and high in the east). ***It is important to remember that the normal easterly winds may switch to westerly or may just weaken enough to trigger the sloshing back of warm water.***

Upon reaching the South American coast, some portion of the warm water propagates poleward along the North and South American coasts. In fact, during the 1982/83 El Nino (one of the two strongest El Nino events of this century with the other one being the 1997/98 El Nino), the warm water propagated all the way to Alaska, carrying many tropical fish species with it. As the reflected warm water spreads out in the tropical Pacific, storm formation region expands. Consequently, places usually associated with good weather, such as eastern Pacific off Mexico and Hawaiian Islands, are often hit by strong hurricanes during El Nino. ***The reflected warm water will also travel back toward the western Pacific at speeds much slower than the initial pulse of warm water that traveled toward the South American coast. The reflected warm water eventually arrives at the western Pacific, leading to the refilling of the warm water pool in the western Pacific. It takes about one year for the warm water to travel from the western Pacific to the South American coast and back to the western Pacific.*** Note that ***as the reflected warm water arrives at the western Pacific, the atmospheric convection zone (which follows the movement of the warm water pool) returns to the western Pacific, and the "normal" trade winds returns in the tropical Pacific*** (i. e., air pressure becomes low in the west and high in the east), leading to the "normal" pileup of warm water in the western Pacific. This signals the end of an El Nino event. Events last about one year, but can last longer.

Warm water migration throughout the Pacific Ocean during the life cycle of El Nino, will disrupt the global weather pattern, simply due to the massive amount of warm water involved in the process and the major changes in atmospheric convection that results. For example, during the 1982/83 El Nino, Australia had the worst drought of this century, with record bushfires and dust storms. The drought in Indonesia, Philippines, India, Sri Lanka and Southern Africa affected crop production resulting in food shortages and associated miseries. In Ecuador and Peru, heavy rainfalls led to floods, landslides, even loss of human lives. The west coast of the U. S. experienced stormy conditions. The western states of the U, S. experienced floods, snowmelts, and mudslides. Marine and bird life in South America, coral reefs across the Pacific all suffered from this climatic anomaly. During an El Nino event, Jet Stream in the atmosphere over the Pacific Ocean strengthens as the water warms. During El Nino, the Jet Stream often splits into two branches with the southern branch (known as a subtropical Jet Stream) often making a large southward excursion. Consequently, ***winter storms coming from the Pacific Ocean follow this southern branch Jet Stream and bring more precipitation into California, southwestern and southeastern U. S. El Nino reduces hurricane formation in the NW Atlantic Ocean, Caribbean Sea and the Gulf of Mexico as winds at upper levels in the atmosphere prevail from the west, which is not conducive to hurricane formation (called wind shear).***

We now know that anomalous weakening of trade winds in the tropical Pacific precedes the onset of an ENSO. What causes anomalous weakening of trade winds in the first place? ***It appears that the large-scale ocean-atmosphere interaction in the western Pacific is very unstable due to the presence of very large volume of warm water there*** (i. e., warm water leads to large evaporation, transferring large amount of heat energy between ocean and atmosphere), and ***this instability appears to be enhanced as the size of the warm water pool in the western Pacific increases.*** Hence, ***as the warm water pool in the western Pacific becomes abnormally large, ocean-atmosphere interaction in the western Pacific becomes progressively unstable.*** Eventually, the ocean-atmosphere interaction becomes very unstable, then, trade wind collapses, leading to the onset of the next event. Another way to interpret the instability associated with the ocean-atmosphere interaction leading to the onset of El Nino is based on the observation that ***during an El Nino event, significant amount of warm water leaks out of the equatorial Pacific toward the higher latitudes, thus leading to the net heat loss from the tropics to the higher latitudes***. This might suggest that during the normal (non-El Nino) condition, perhaps too much heat accumulates (due to incoming solar radiation) leading to the instability, and the Earth needs El Nino events to remove excess heat from the equatorial region (i. e., equatorial Pacific) toward the polar region. ***This interpretation suggests that El Nino events are one of the necessary ingredients in maintaining the heat budget for the entire Earth***.

Beginning in 1997, National Climate Center has been running an operational long-term (up to one year in advance) weather forecasting model based on their El Nino forecast model. The El Nino forecast model includes a simplified representation of the Pacific Ocean and the atmosphere, and the forecasters let the model ocean and atmosphere to evolve. This forecasting model is regularly updated by feeding the newly available observations of ocean and atmosphere. ***If the model predicts an imminent occurrence of an El Nino event, an El Nino warning will be issued. Based on their El Nino forecast, regional long-range weather forecast based on an El Nino warning can be issued one year in advance.*** They cannot say, for example, "what will be the weather on March 1, 1999, in New Orleans." However, they should be able to say, for example, whether or not this coming winter months over the southeast U. S. will experience cooler and wetter than normal weather.

Two examples of ocean-atmosphere global teleconnections

- Hurricanes, intense *tropical cyclones* whose wind speeds exceed 74 miles per hour, owe the frequency and intensity of their occurrence to sea temperature conditions in the tropical and subtropical Atlantic ocean.
- El Nino, the multidecadal climate phenomenon that shifts jet streams and influences a number of oceanic and atmospheric processes, is the poster child of global teleconnections. It's effects on regional weather are worldwide. Even hurricanes are affected by El Nino, which tends to reduce their frequency and intensity.

Climatological Variability

- North Atlantic SSTs exhibit a *multidecadal pattern* (multiple decades long) of colder-than-average periods, called *cold regimes*, and warmer-than-average periods, called *warm regimes*. The periods 1900 to 1925 and 1970 to 1994 were cold regimes that brought fewer and less intense hurricanes. Warm regimes have occurred from 1926 to 1969 and 1996 to present, thus generating more frequent and more intense hurricanes.
- There is considerable scientific debate on the degree to which global warming may contribute or may be contributing to hurricane activity. Some studies cite a greater duration, greater energy content, and greater force of hurricanes in recent decades. Other studies question the metrics used to assess hurricane intensity and frequency. The relationship is complicated because SSTs are only one factor among many that affect hurricane formation, intensity, and duration. It may be decades before we know for sure.

The Pacific El Nino

- Multiannual (over periods of years) variations in oceanic and atmospheric conditions in the equatorial Pacific have come to be known as *El Nino*, "the small boy", referring to the Child Jesus. This name was given by Peruvian fishermen who associated warmer currents with better fishing. It's not clear why they thought this, as El Nino usually reduces fish populations.
- With the invention and deployment of satellite-based and mooring-based sensors, El Nino now has a specific scientific meaning. An El Nino condition is declared for a specific region of the equatorial Pacific when SSTs exceed 0.5 degrees C above average for a three-month period.
- El Nino is not confined to the Pacific. An El Nino-like condition also occurs off the coast of Benguela along the west coast of Africa in the South Atlantic.

The Pacific El Nino (cont'd)

- To track El Nino, SSTs are often expressed as *temperature anomalies*, that is, the difference between the measured temperature and the mean (average) temperature. For example, if the 100-year mean temperature is 20.o degrees C and the measured temperature is 20.1 degrees C, then the temperature anomaly is 0.1 degrees C.
- Don't be misled! El Nino is more than a simple rise in SST. It involves shifts in atmospheric pressure, changes in trade wind strength and direction, changes in the depth of the tropical thermocline, reductions in upwelling, and changes in global weather patterns.

The Pacific La Nina and ENSO

- Over the past couple decades, oceanographers have also observed colder-than-average SSTs in the equatorial Pacific. This condition has come to be known as *La Nina* ("the small girl, whoever she is!). Officially, a La Nina is declared when SSTs are 0.5 degrees lower than the 100-year mean for a period of 3 months in a given region.
- El Nino and La Nina are part of a coupled ocean-atmosphere phenomenon that oscillates over periods of 2-3 years or more. The related atmospheric phenomenon is known as the *Southern Oscillation*, which refers to a shift in air pressure between Papeete, Tahiti and Darwin, Australia.

Driving Force: Ocean or Atmosphere?

- The causes of El Nino and La Nina are a kind of a "chicken and egg" problem. Do atmospheric conditions cause the change in SSTs or is it the other way around? Oceanographers and meteorologists are not sure. But they do have a fairly good description of what happens.
- Shifts in atmospheric pressure differences between the Indian and Pacific Ocean were first noted by Sir Gilbert Walker in 1923. In modern times, meteorologists track the differences in atmospheric pressure between Papeete, Tahiti, and Darwin, Australia. The difference is known as the *Southern Oscillation Index* (SOI). A positive SOI (higher pressure at Papeete) is typical of normal or La Nina conditions. A negative SOI portends El Nino conditions.

> "Our biggest challenge is to give appropriate weight to the inevitable uncertain scientific information when making policy decisions. This is too serious a matter to be left to scientists and economists. It is the joint responsibility of all of us because the policies we adopt reflect our values…Much can be learned from El Nino. We need to do so in a hurry before we succeed in changing him."
>
> George Philander, *El Nino, La Nina, and the Southern Oscillation*, (1990)