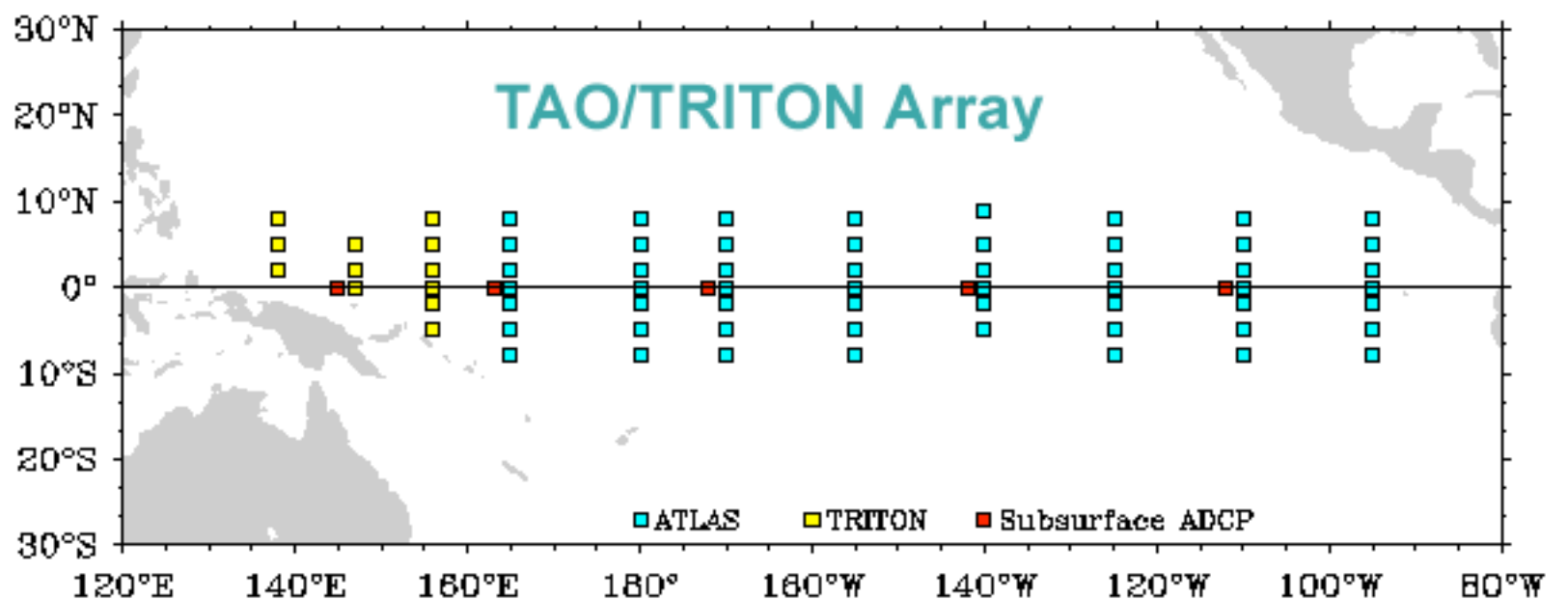


El Niño: How it works, how it affects the South Pacific



William Kessler

NOAA / Pacific Marine Environmental Laboratory
Seattle, USA



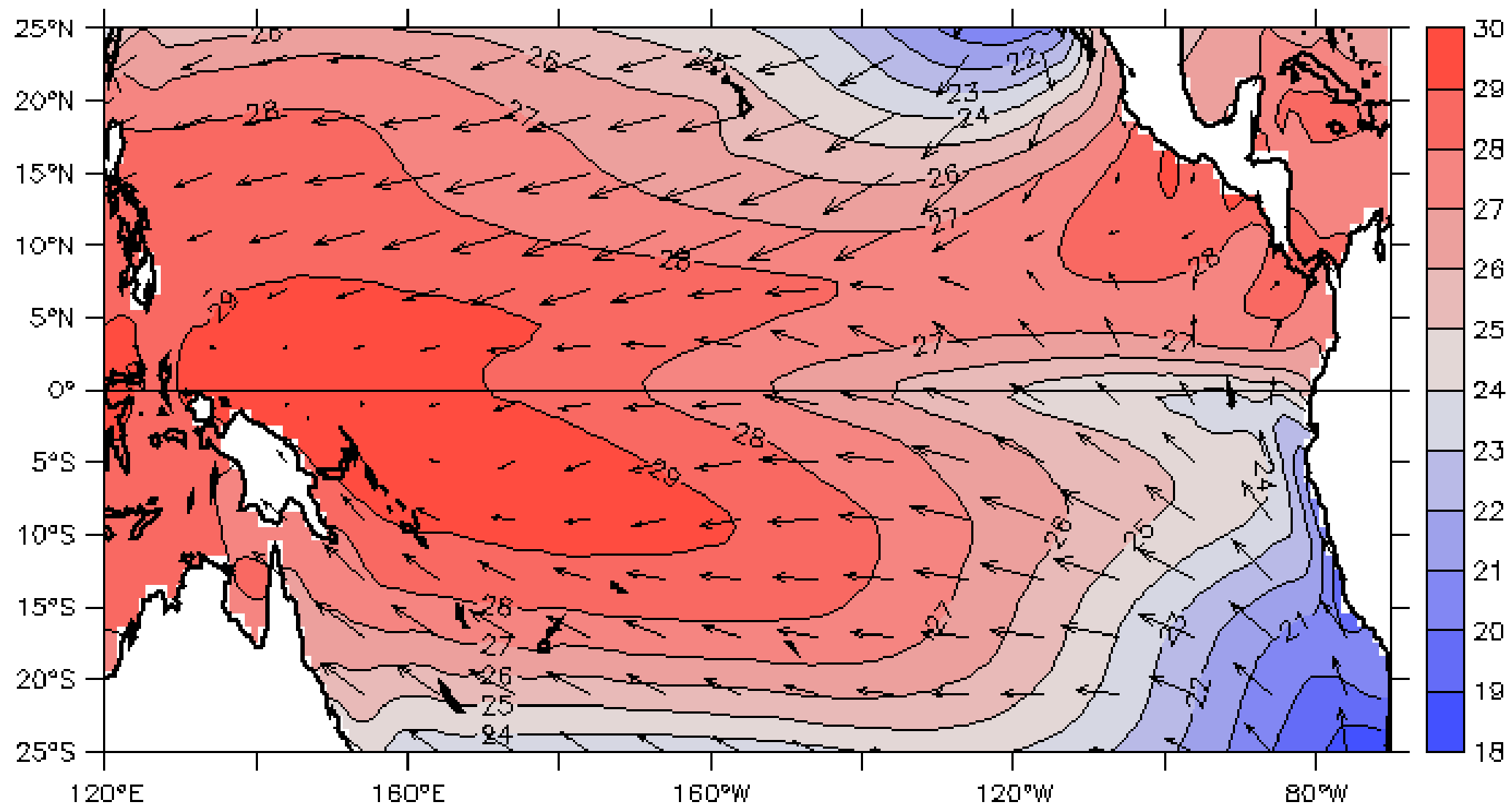
Outline of talk

- The normal situation in the tropical Pacific: a *coupled* ocean-atmosphere system
- How El Niño works
- How we observe and predict El Niño and its consequences
- How El Niño affects the southwest Pacific

The normal situation:

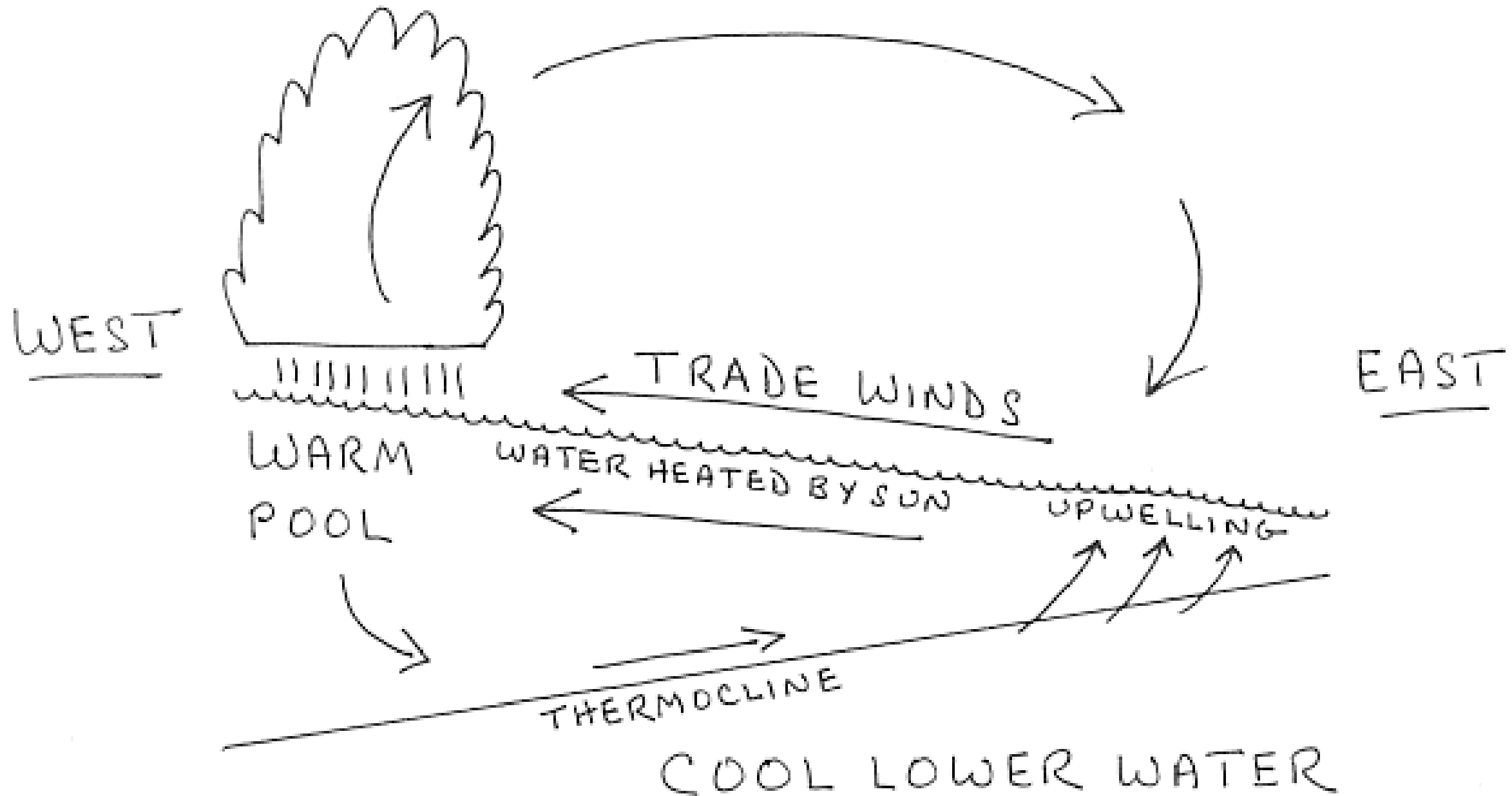
- The warmest water is not at the equator!
- There is a roughly 5°C temperature contrast from west to east.
- Winds blow from the cooler to the warmer water, and converge on the **West Pacific Warm Pool**.

Sea surface temperature in the tropical Pacific



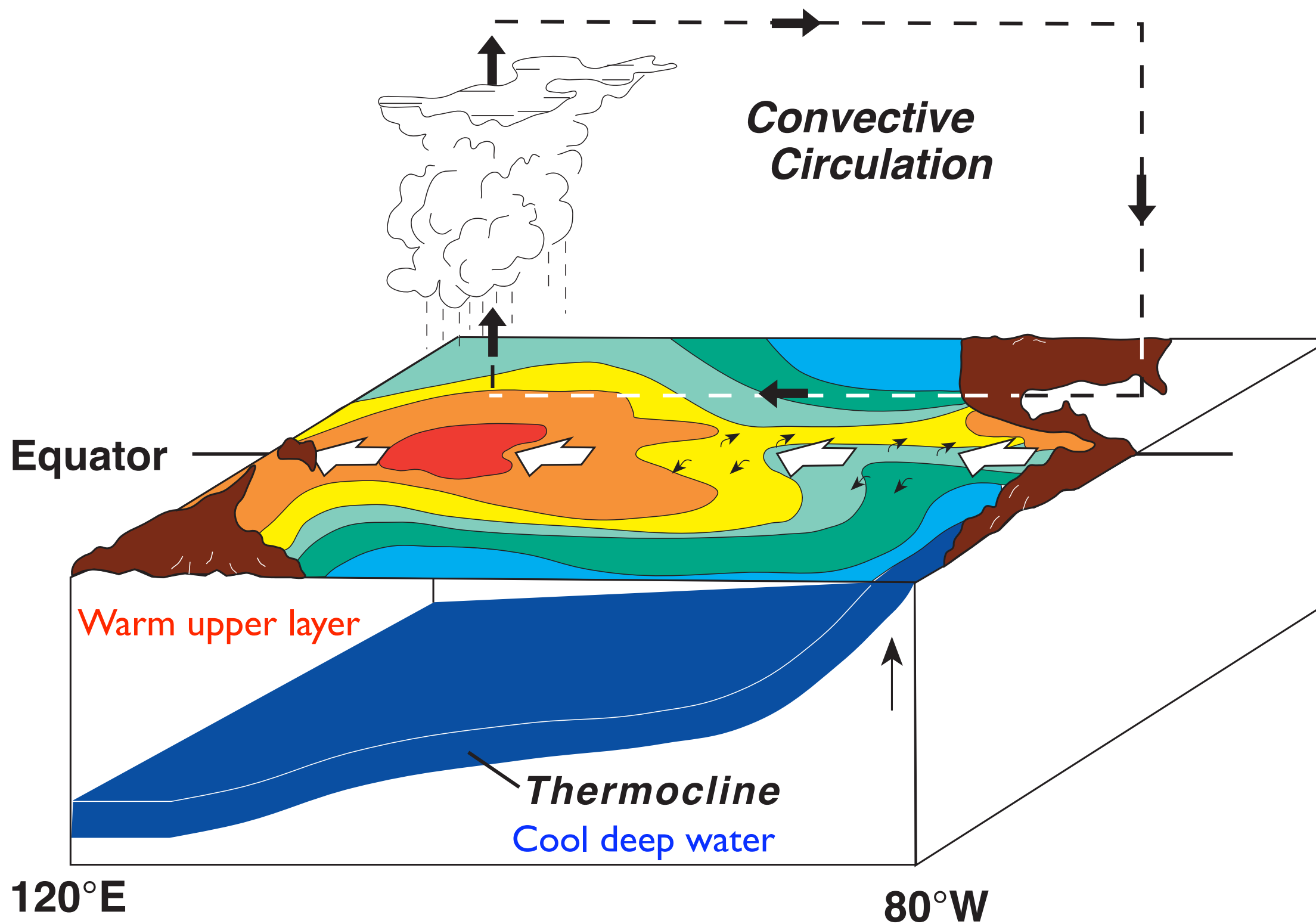
Mean wind vectors overlaid

Schematic diagram of the **coupled** interaction along the Pacific equator



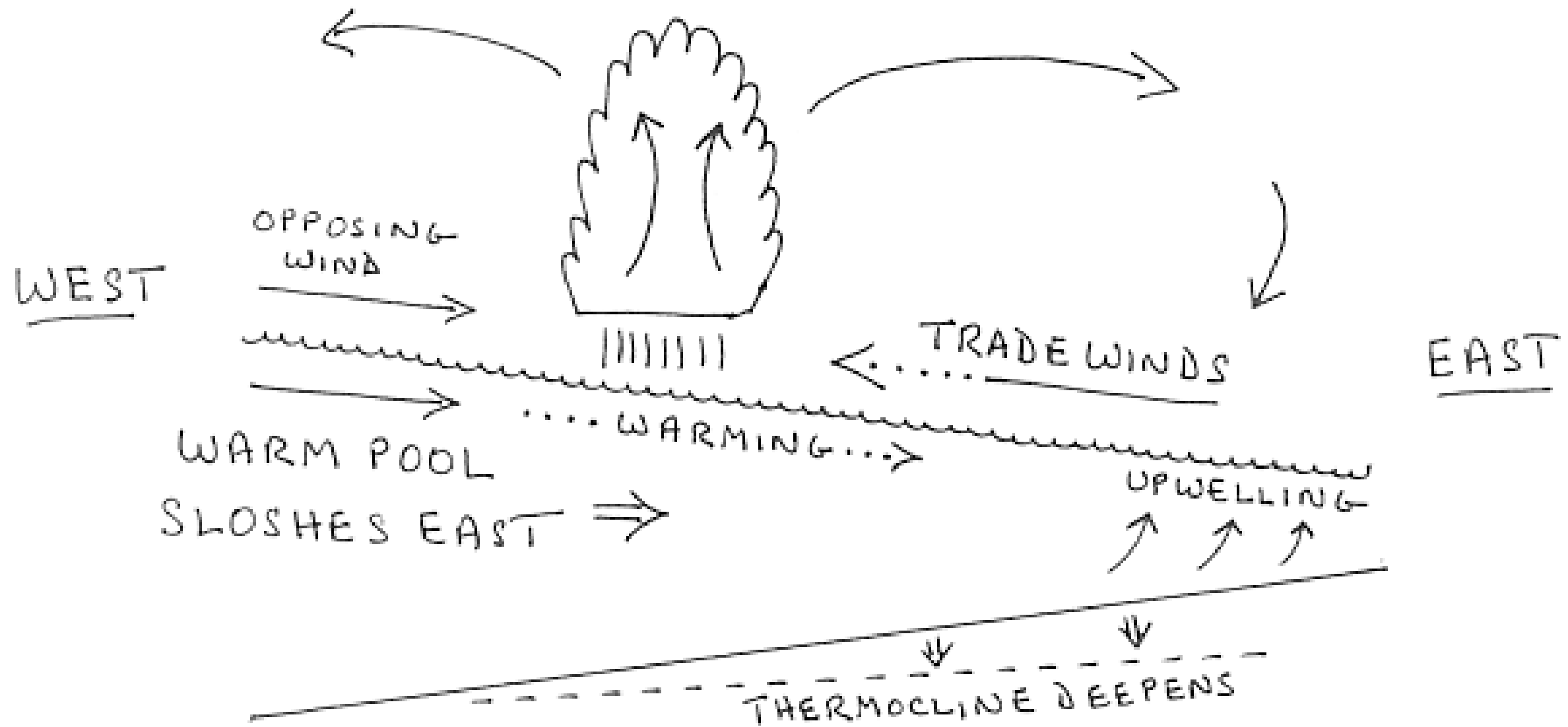
Why are there trade winds? Because the warmest water is in the west.
Why is the warmest water in the west? Because there are trade winds.

Normal Conditions



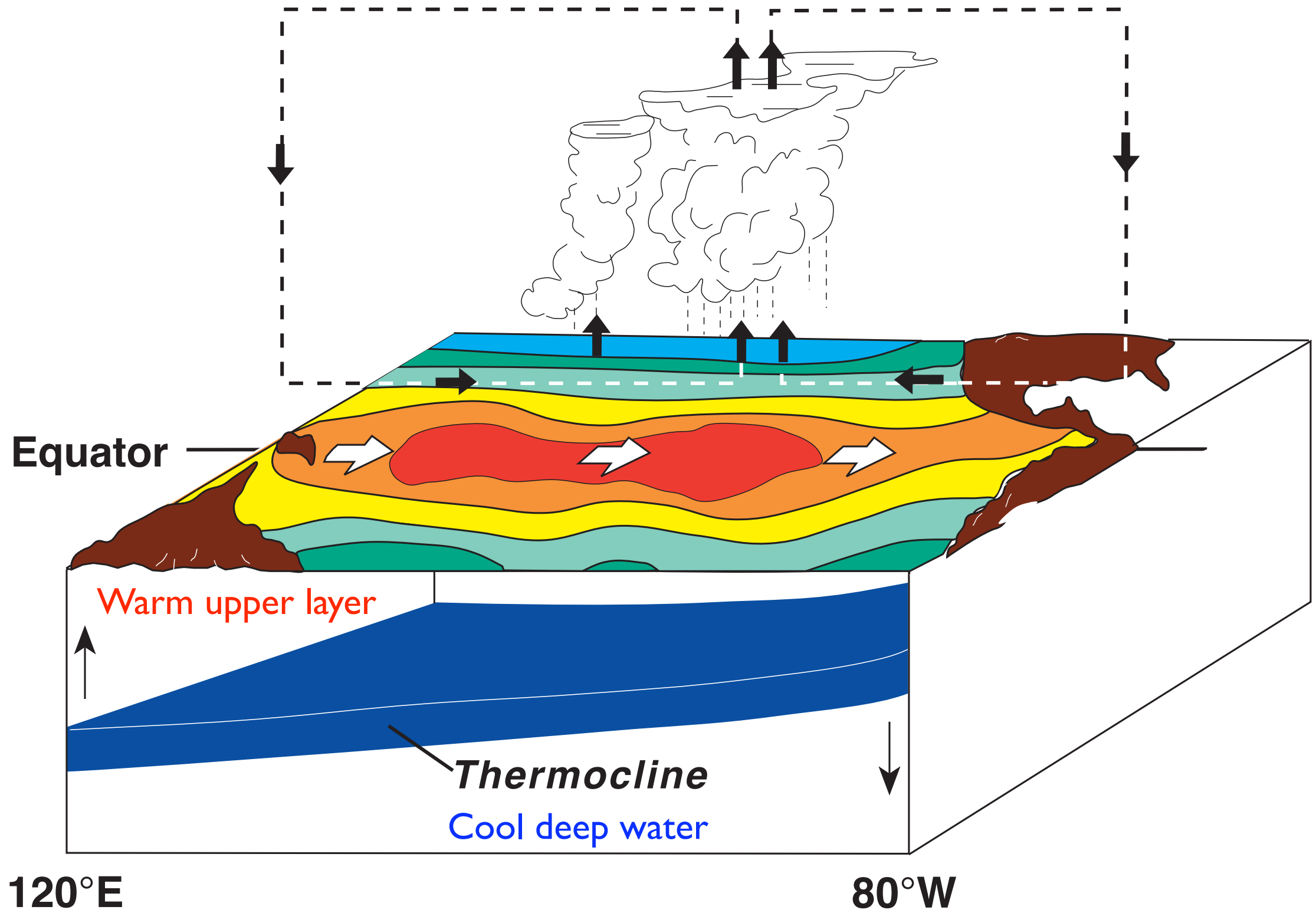
Schematic ocean-atmosphere interaction during El Niño onset:

A “coupled collapse” as the warm pool sloshes east

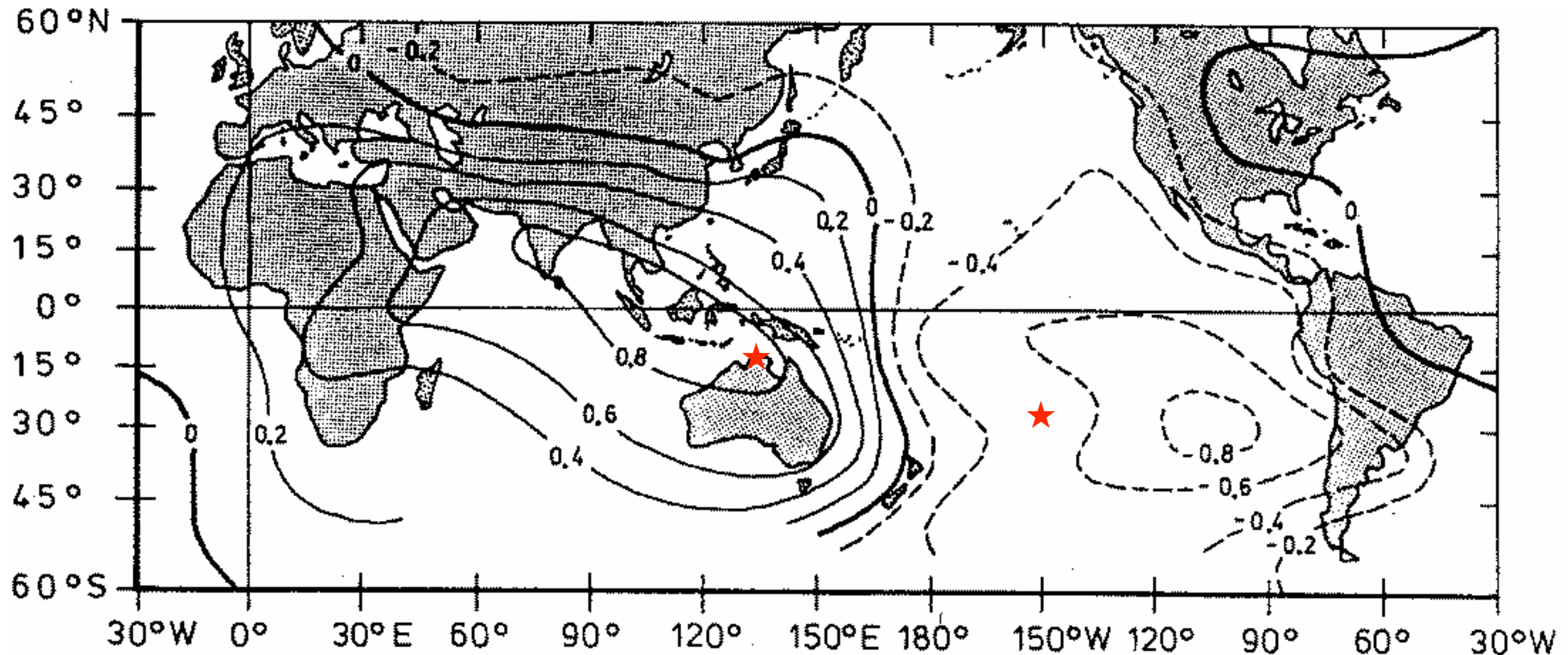


We don't know why El Niños start!

El Niño Conditions

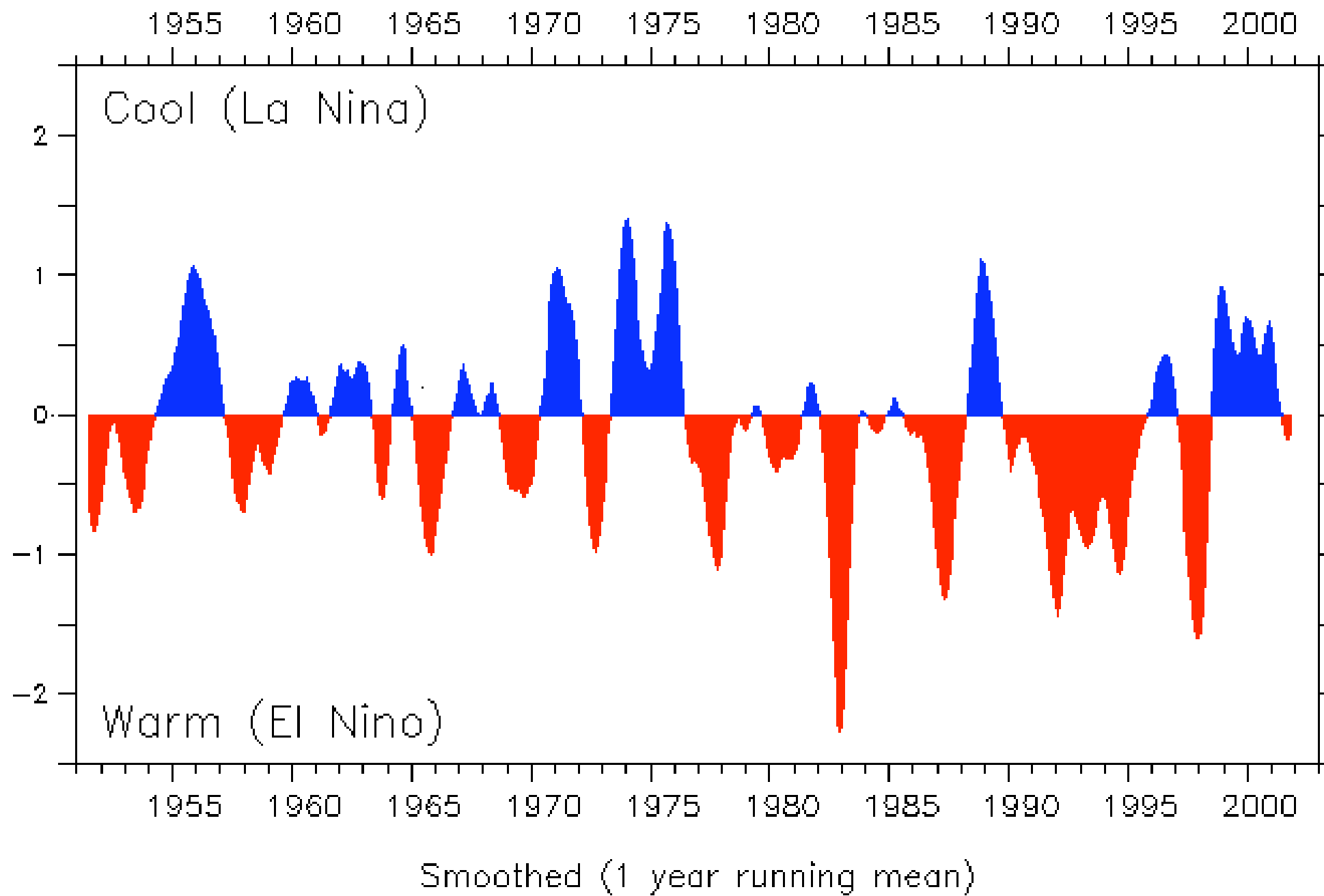


A widely-used index for El Niño is the [Southern Oscillation Index](#), first used in 1923 by Sir Gilbert Walker, Director of Observatories in British India, who noted that “when pressure is high in the Pacific Ocean it tends to be low in the Indian Ocean from Africa to Australia”.

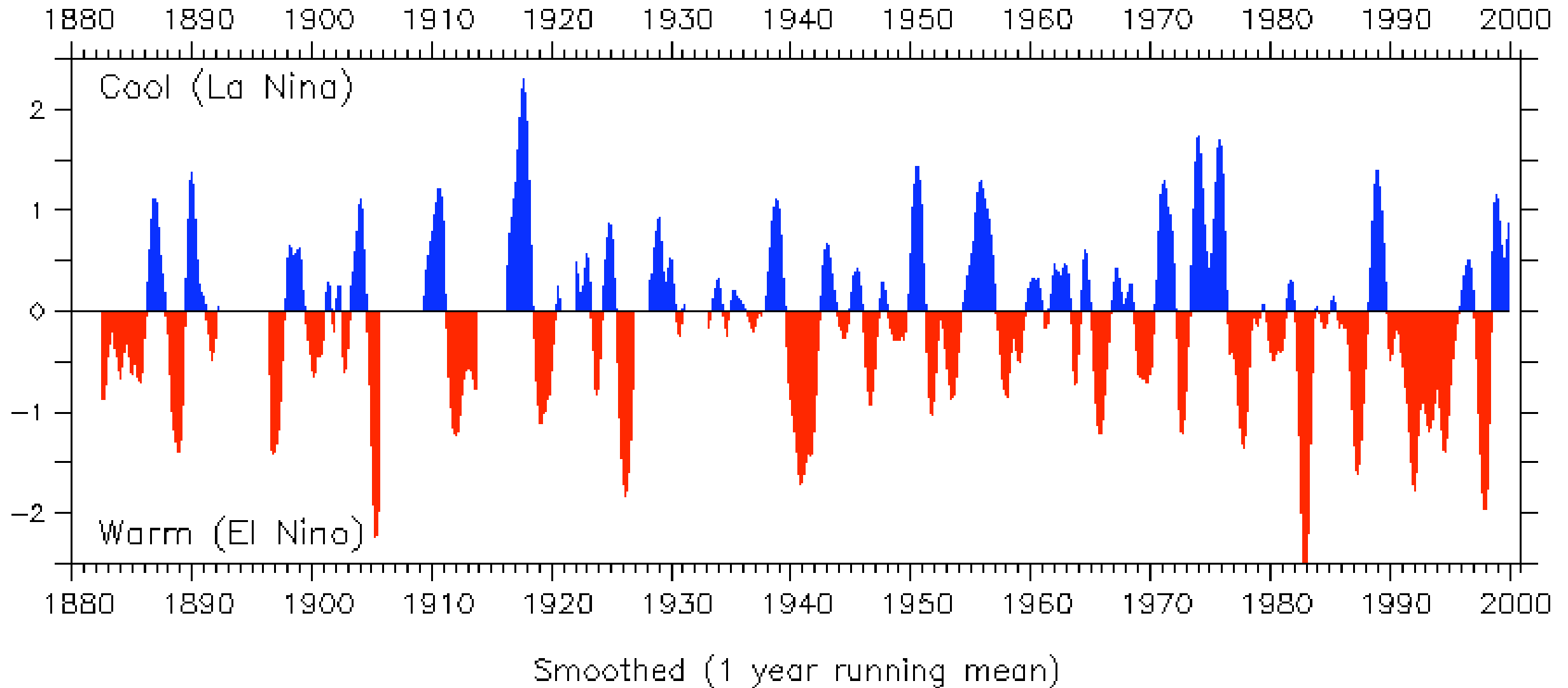


The Southern Oscillation Index is the air pressure difference between Darwin, Australia and Tahiti

Southern Oscillation Index

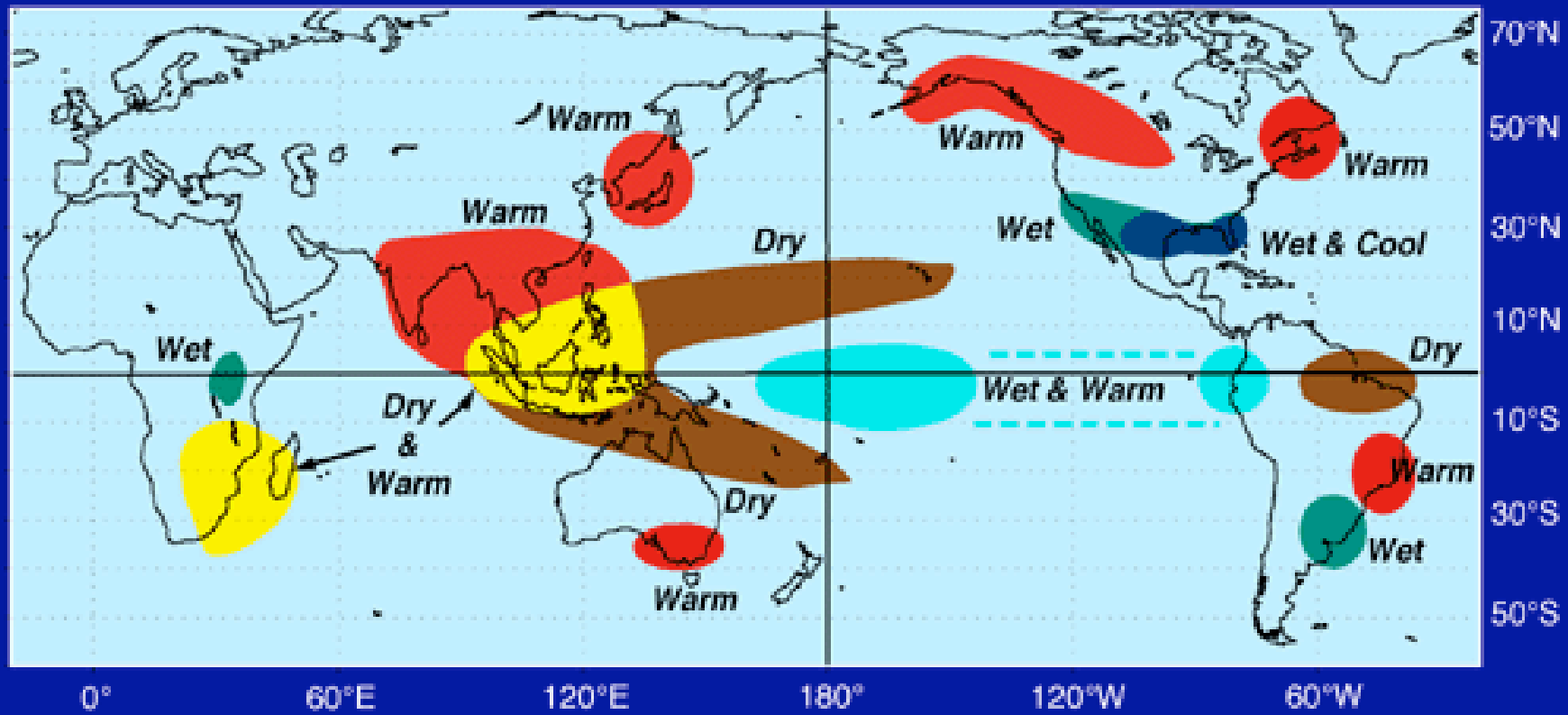


Southern Oscillation Index

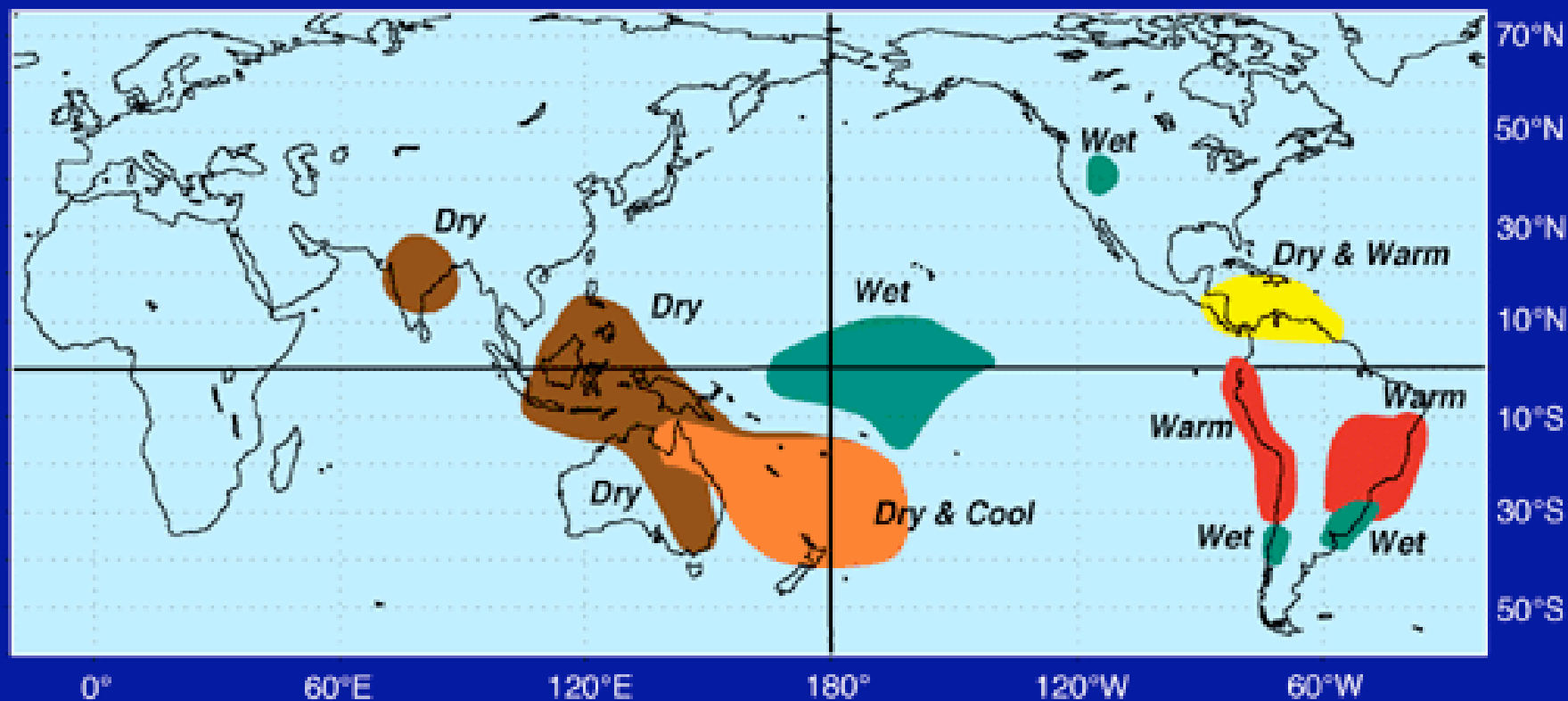


The instrumental record goes back to 1882. Paleo evidence suggests that El Niños have occurred for millions of years.

El Niño Weather Patterns December - February



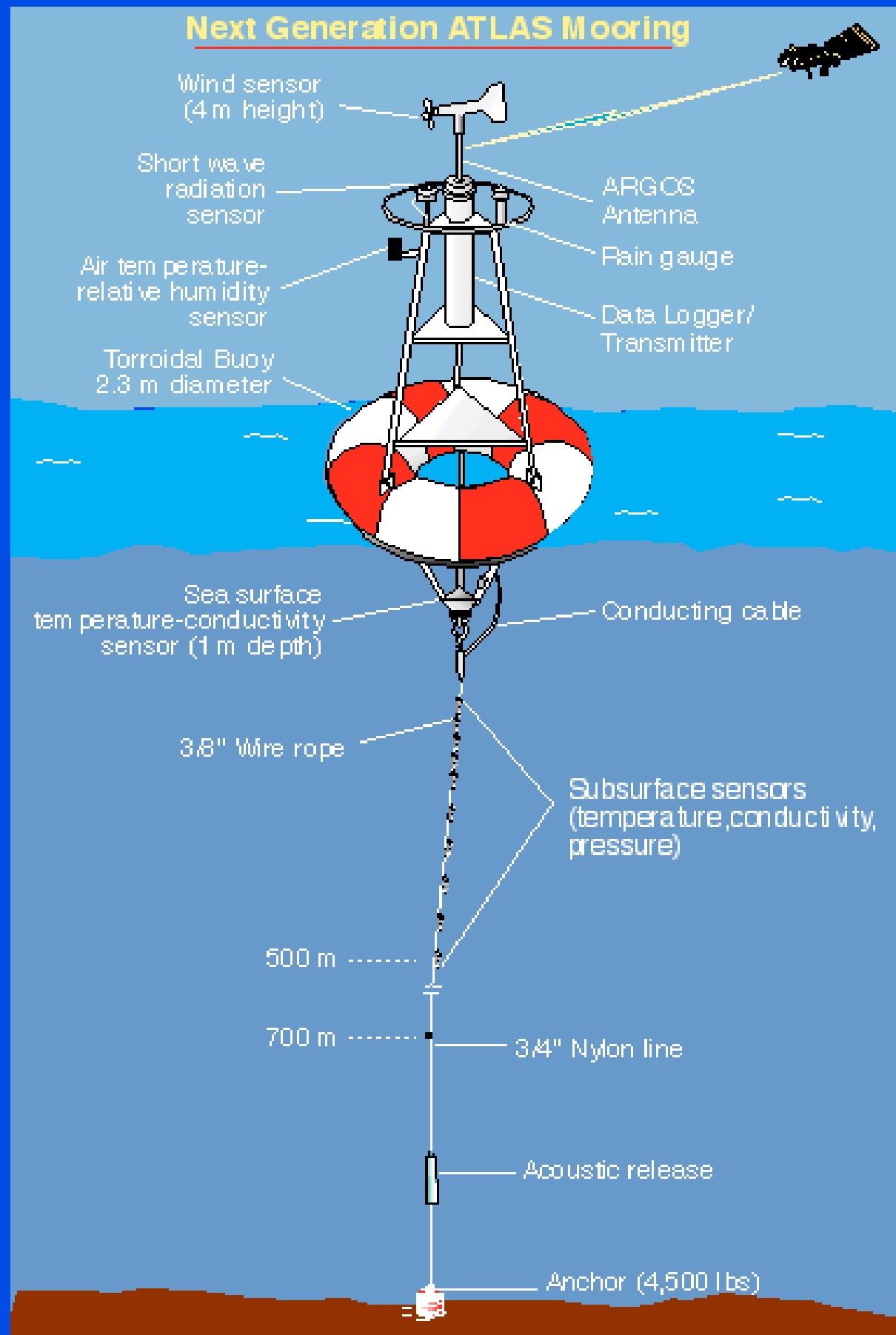
El Niño Weather Patterns June - August



A TAO mooring

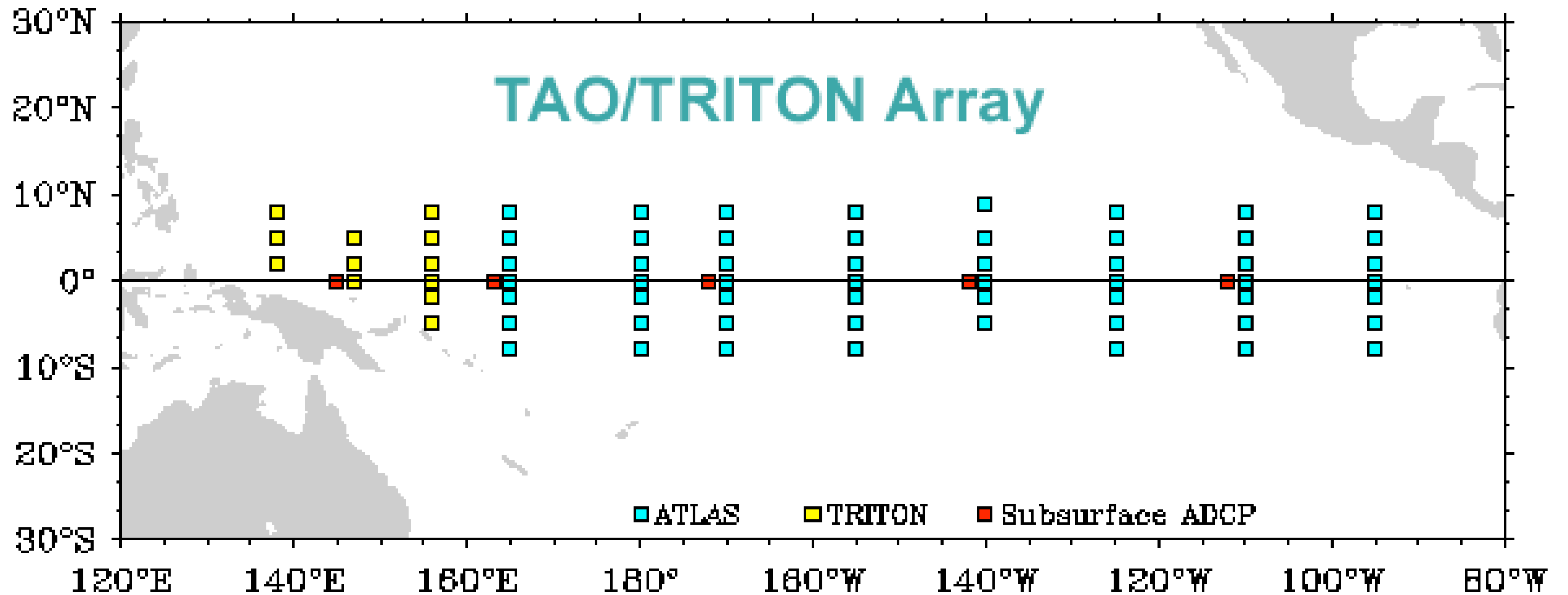
A principal mission of my laboratory is to provide the data sufficient to describe the state of the tropical Pacific for input into the forecast models.

The ATLAS mooring was developed at PMEL in the 1980s and is our primary tool. The moorings last for a year or more (and the parts are reusable), and all data are received in near-real time.





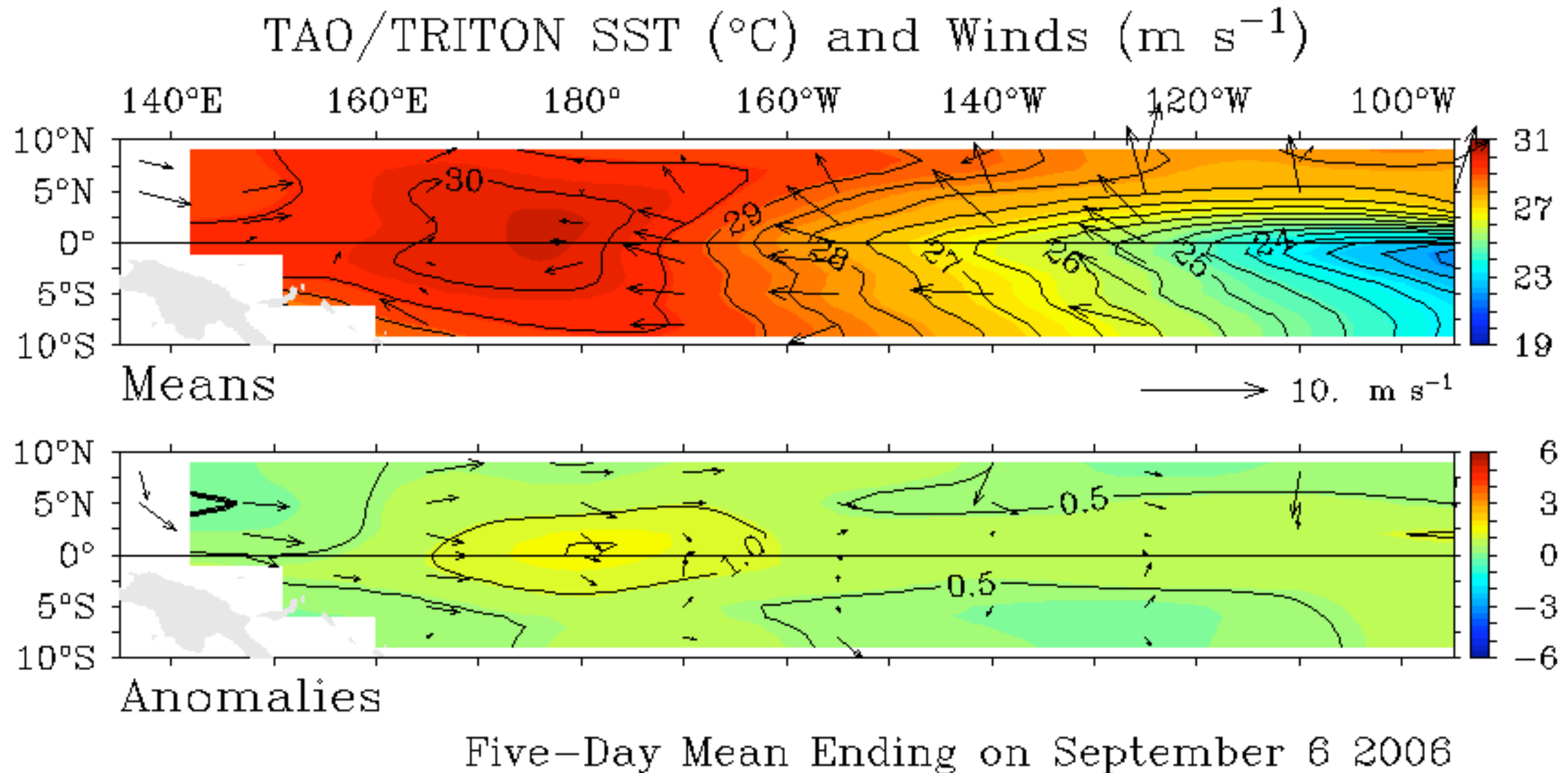
The TAO-TRITON network is a US-Japan project.
There are 70 moorings maintained continuously.



Data plots from the array are available in near-real time:

<http://www.pmel.noaa.gov/tao/jsdisplay>

Recent conditions in the equatorial Pacific



We measure the temperature and winds, but not the currents ...

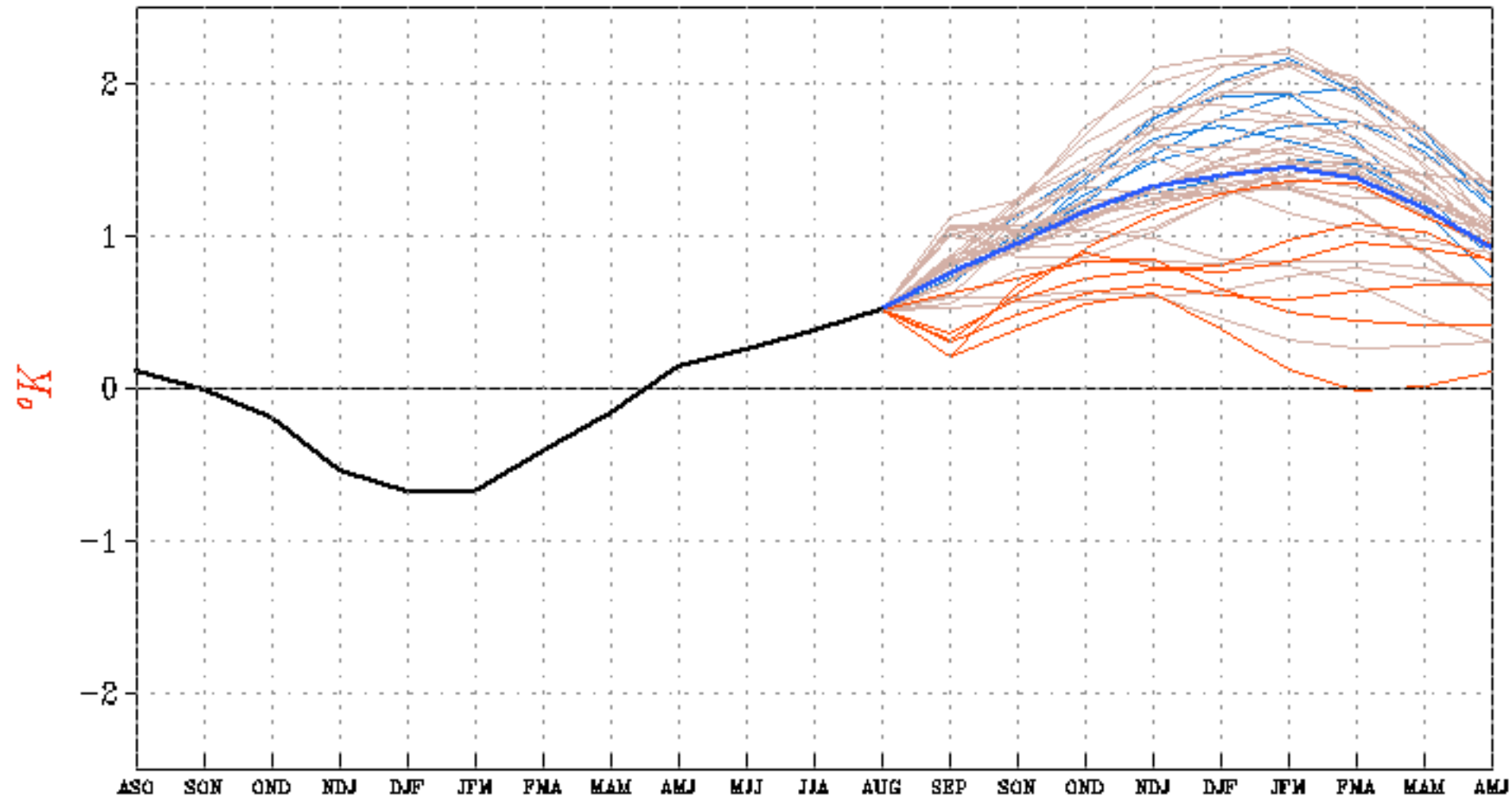
Latest forecasts: weak El Niño



NWS/NCEP

Last update: Thu Sep 7 2006
Initial conditions: 11Aug2006–30Aug2006

Forecast *Nino3.4* SST anomalies from CFS



- Latest 6 forecast members
- Forecast ensemble mean
- Earliest 6 forecast members
- OIv2 observation
- Other forecast members

Forecast initial conditions: 11Aug2006 to 30Aug2006.

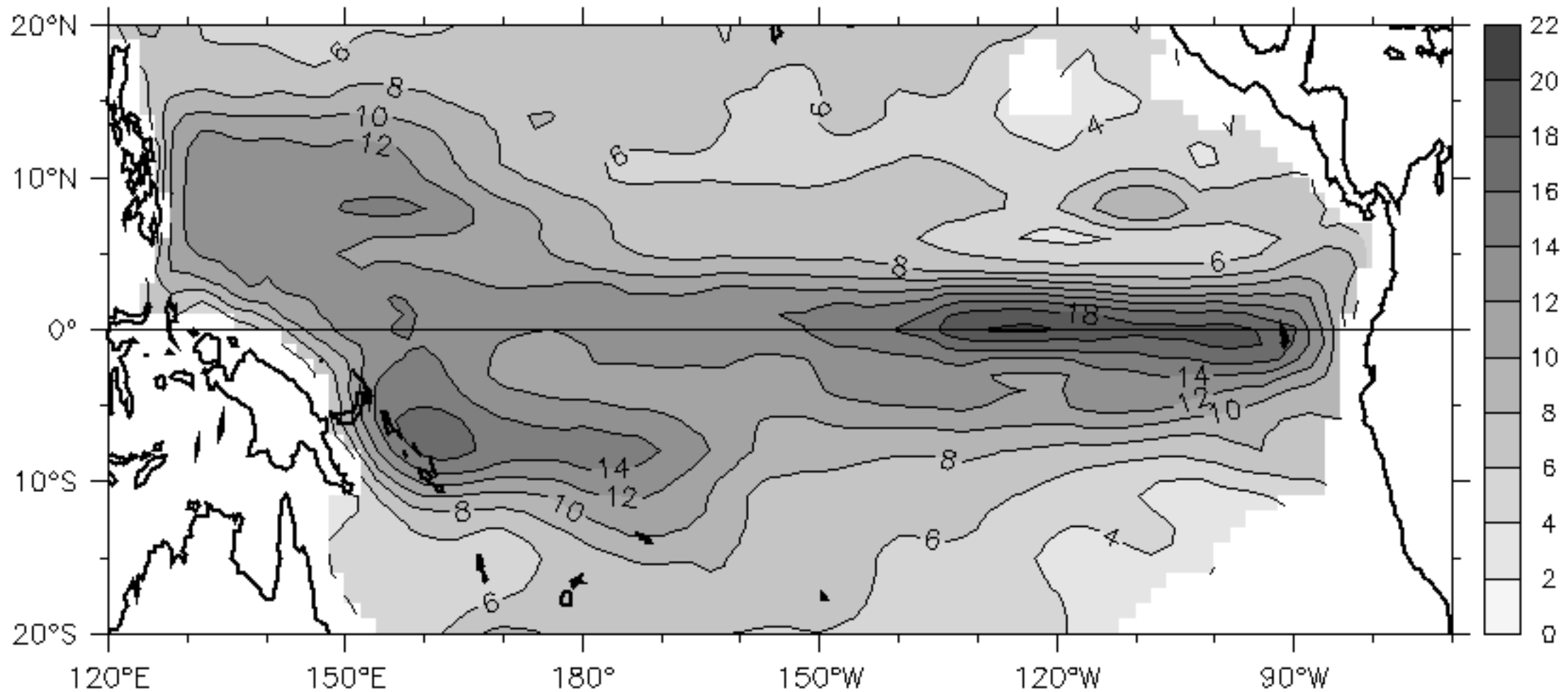
Base period for climatology is 1971–2000. Base period for bias correction is 1982–2003.

How do El Niños end?

Can the warm state just persist?

- Once the warm upper layer water has sloshed east, it spreads out. As it drains, the thermocline comes closer to the surface, which cools. As it cools, the trade winds resume, and the coupling begins again.
- Because the amount of warm water in the warm pool is limited, El Niños have a finite duration (~9 months).
- It is not yet clear exactly how the warm pool is refilled, but most evidence suggests that much of the refilling comes through the Solomon Sea.

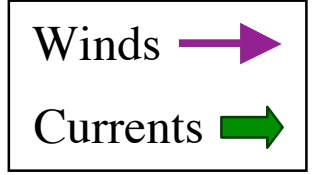
Standard deviation of thermocline depth (20°C isotherm)



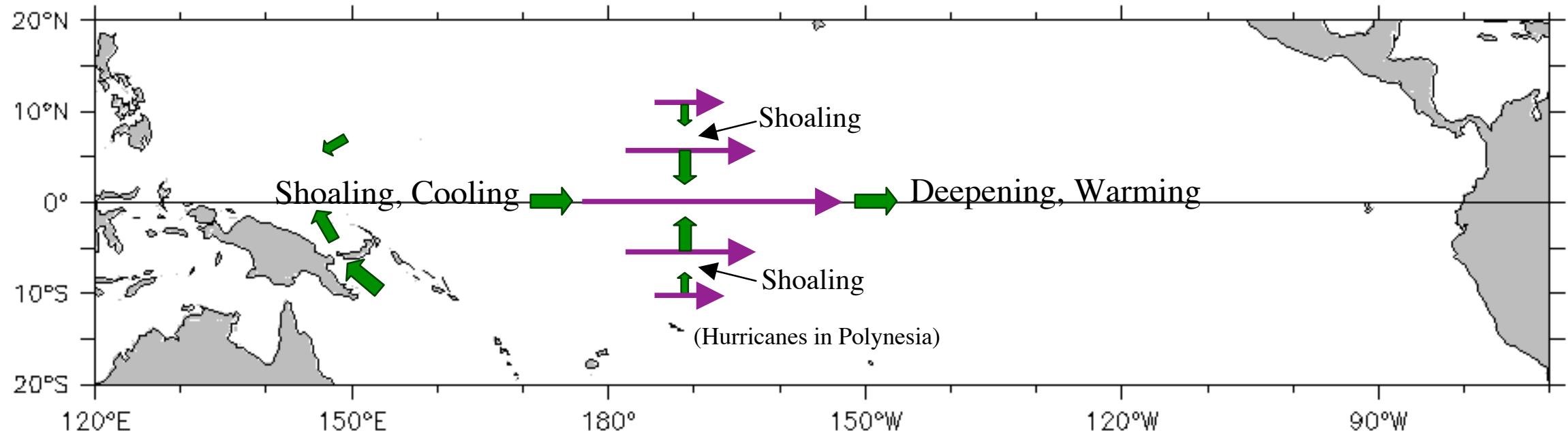
Thermocline depth variability is large on the eastern equator and in the western off-equatorial Pacific.



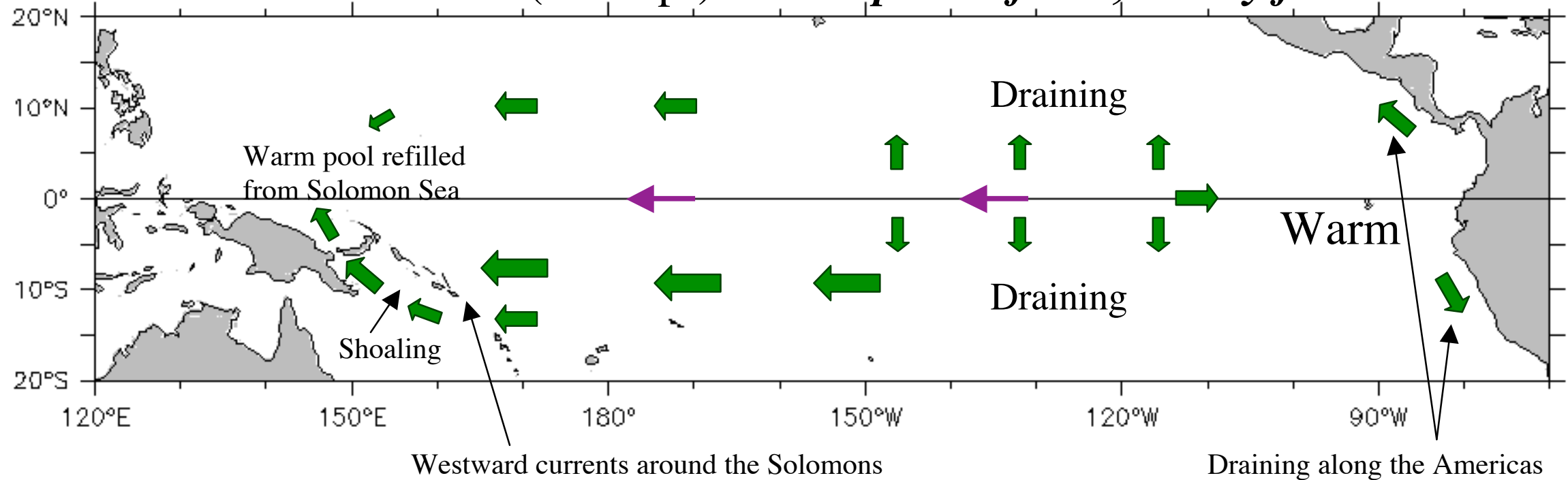
Sequence during an El Niño event



Height of the event (Sep-Dec). *Warm pool drains to the east.*

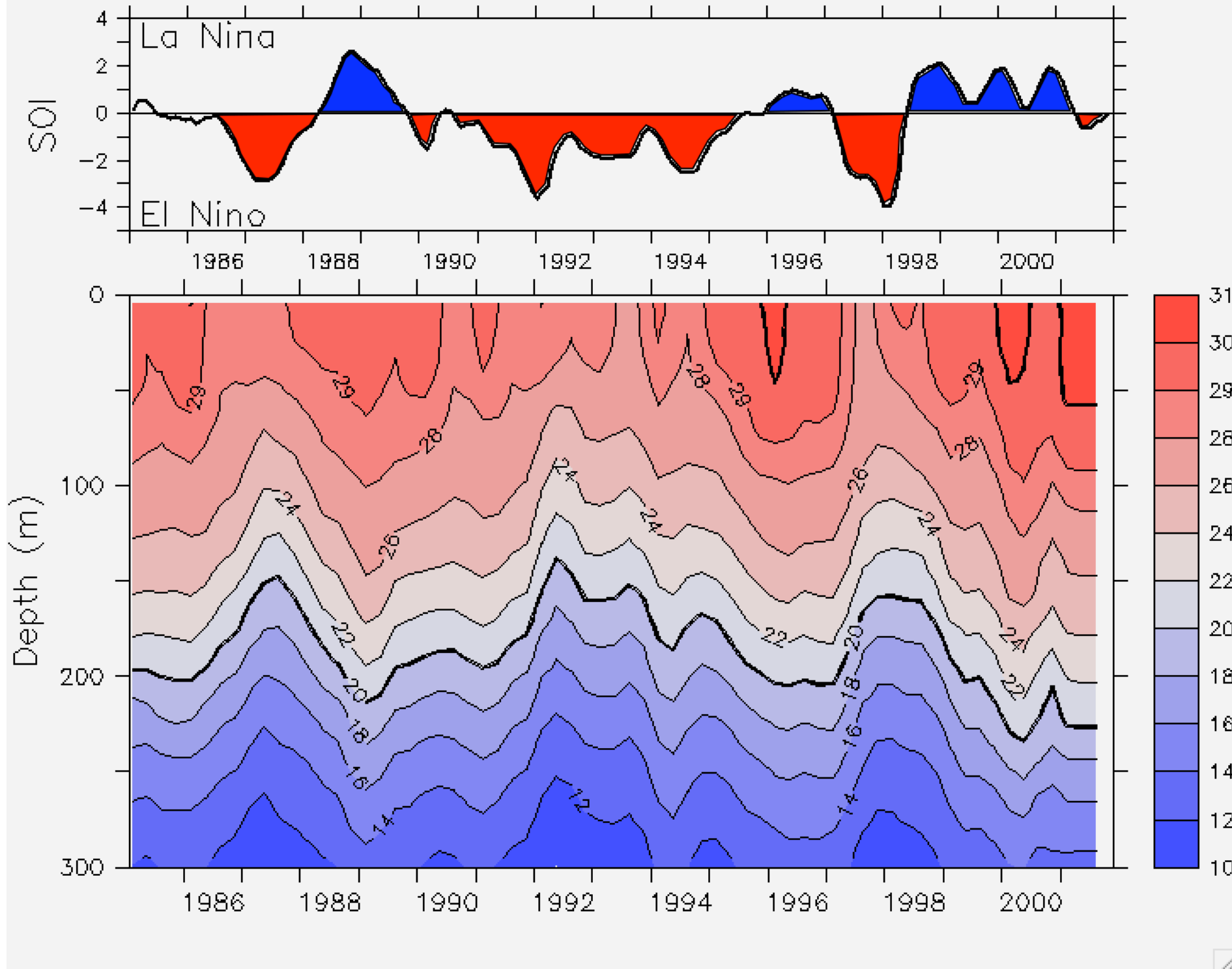


Aftermath of the event (Jan-Apr). *Warm pool refilled, mostly from the south*

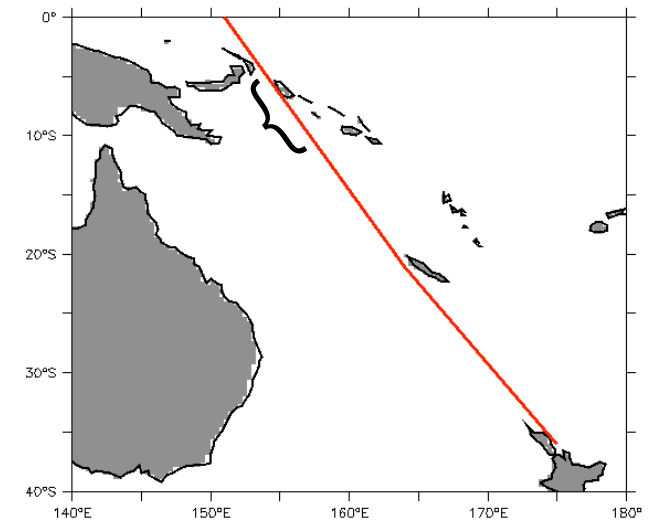


Time series of temperature in the Solomon Sea

During El Niños, the thermocline rises and the surface cools



Data from
 10°S - 5°S
along the
ship track



Conclusion

- The ocean-atmosphere system is *coupled*.
- We don't yet know what initiates an El Niño.
- Once an event begins, we have a good idea of how it evolves. The key to a useful forecast is recognizing the onset early.
- The southwest Pacific sees very strong effects of El Niño: thermocline shoaling, northward currents through the Solomon Sea.

Extra

Figures

Follow....

Remarks by Señor Federico Alfonso Pezet at the Sixth International Geographical Congress (London, 1895):

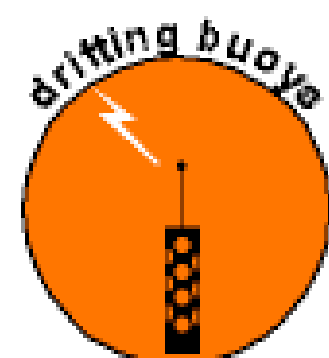
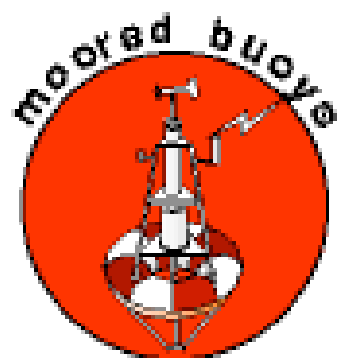
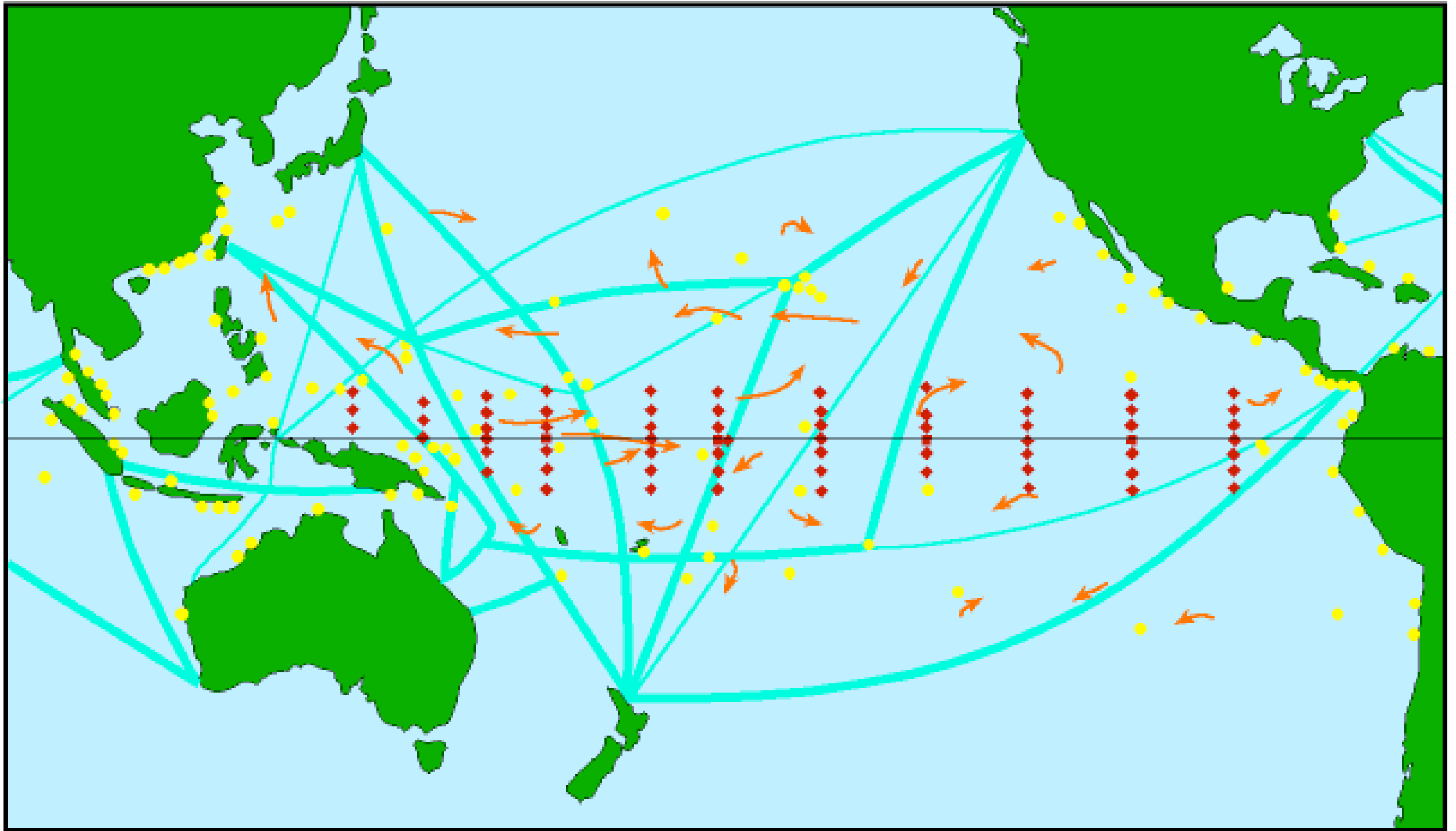
In the year 1891, Señor Dr Luis Carranza, President of the Lima Geographical Society, contributed a small article to the Bulletin of the Society, calling attention to the fact that a countercurrent flowing from north to south had been observed between the ports of Paita and Pascamayo.

The Paita sailors, who frequently navigate along the coast in small craft, either to the north or south of that port, name this countercurrent the current of “El Niño” because it has been observed to appear immediately after Christmas.

During the mid-20th century, the usage of the term “El Niño” changed. The name for a local, seasonal phenomenon was adopted for the basin-scale, interannual phenomenon.

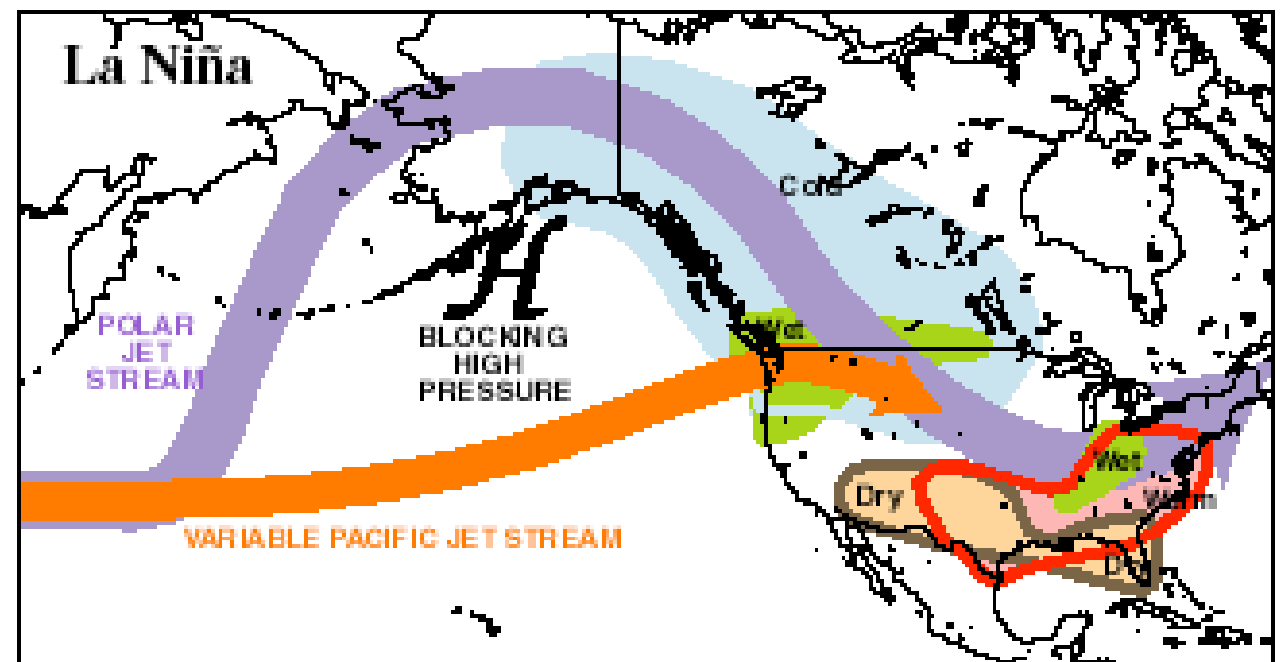
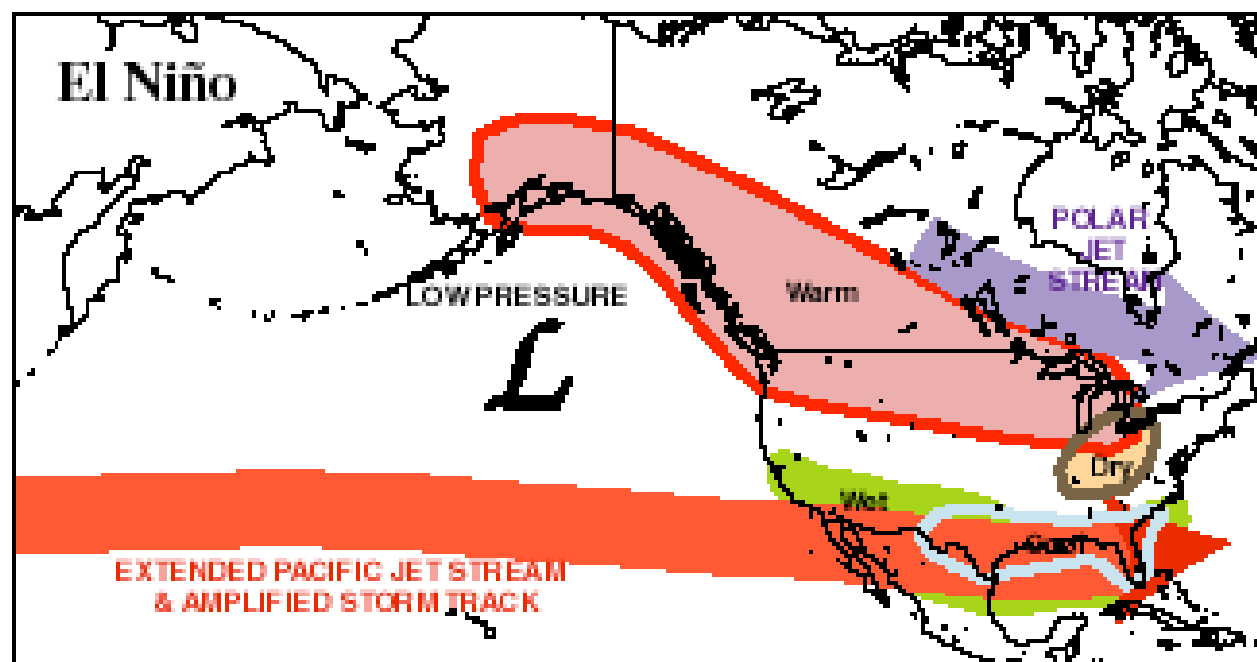
Recently, the term “La Niña” has been used to refer to the opposite (cold) phase, though it is unclear that this is really an oscillation (it may be more like a series of events).

ENSO Observing System



How are El Niño's effects spread from the tropics?

The west Pacific warm pool is a principal heat source driving much of the global winds. When it shifts east, it distorts the jet streams, much as a rock placed in a creek causes waves that extend well downstream from the rock itself.

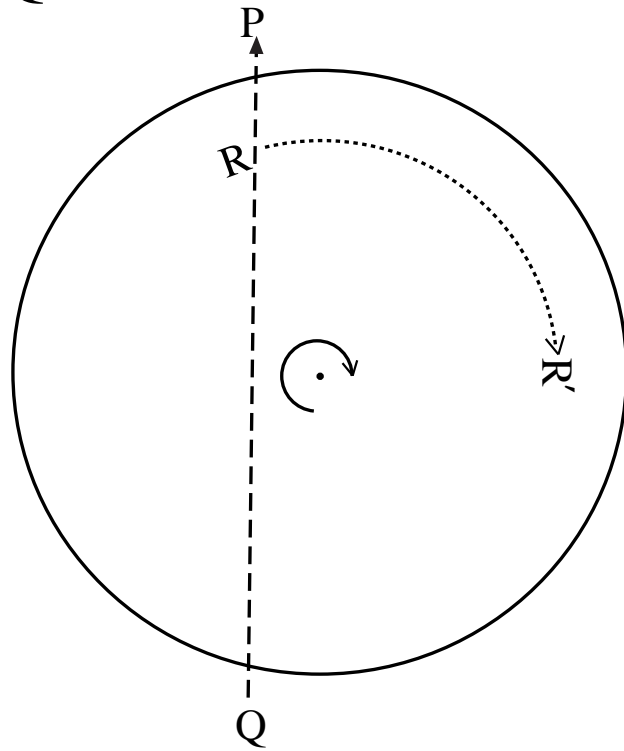


In North America, the effects of the warm SST during El Niño are not felt directly. Instead, mid-latitude weather is modified because the eastward-shifted warm water changes the path of the winter jet streams that bring us our weather systems.

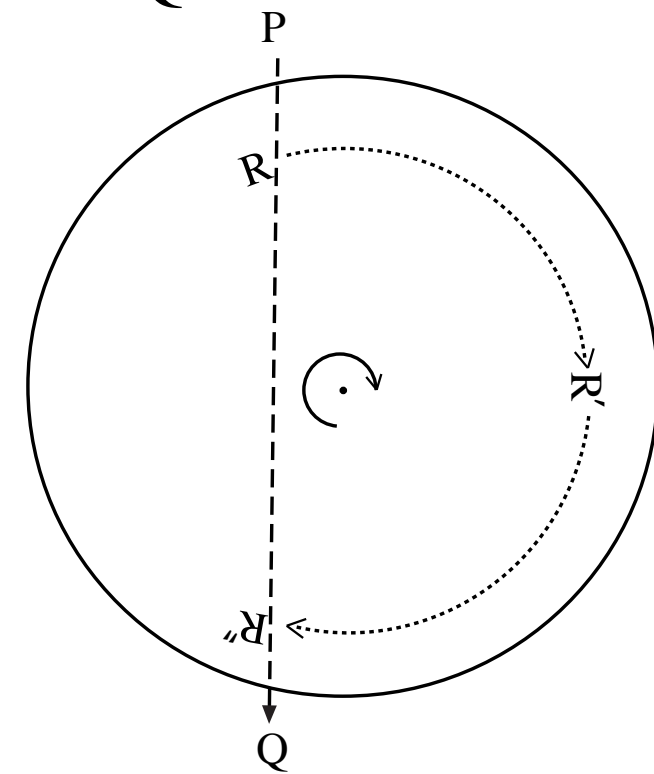
Physical mechanisms: Coriolis Force

Ball thrown
from Q to P

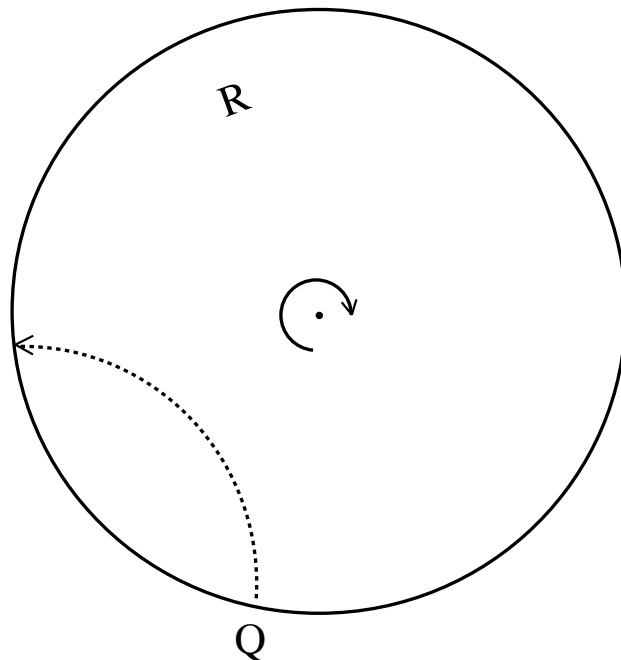
What does R see?



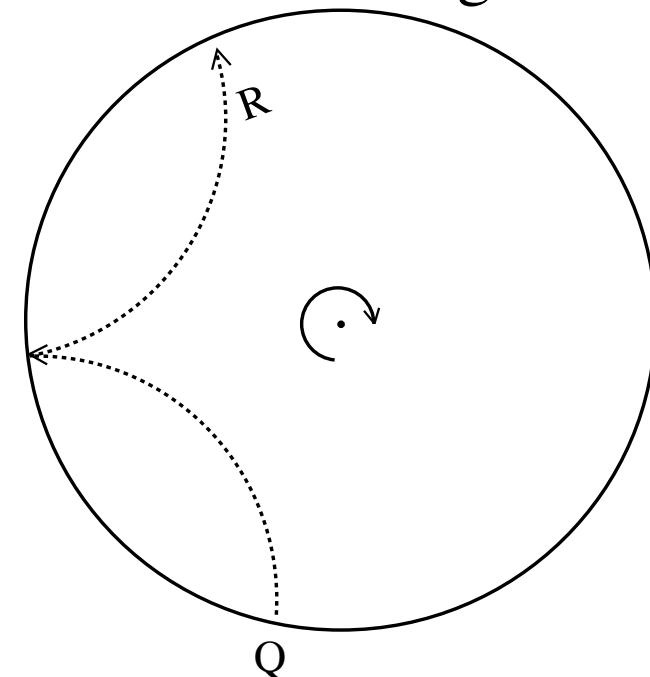
Ball thrown back
from P to Q



From R's point of view,
the ball curved to its left



From R's point of view,
the ball curved again

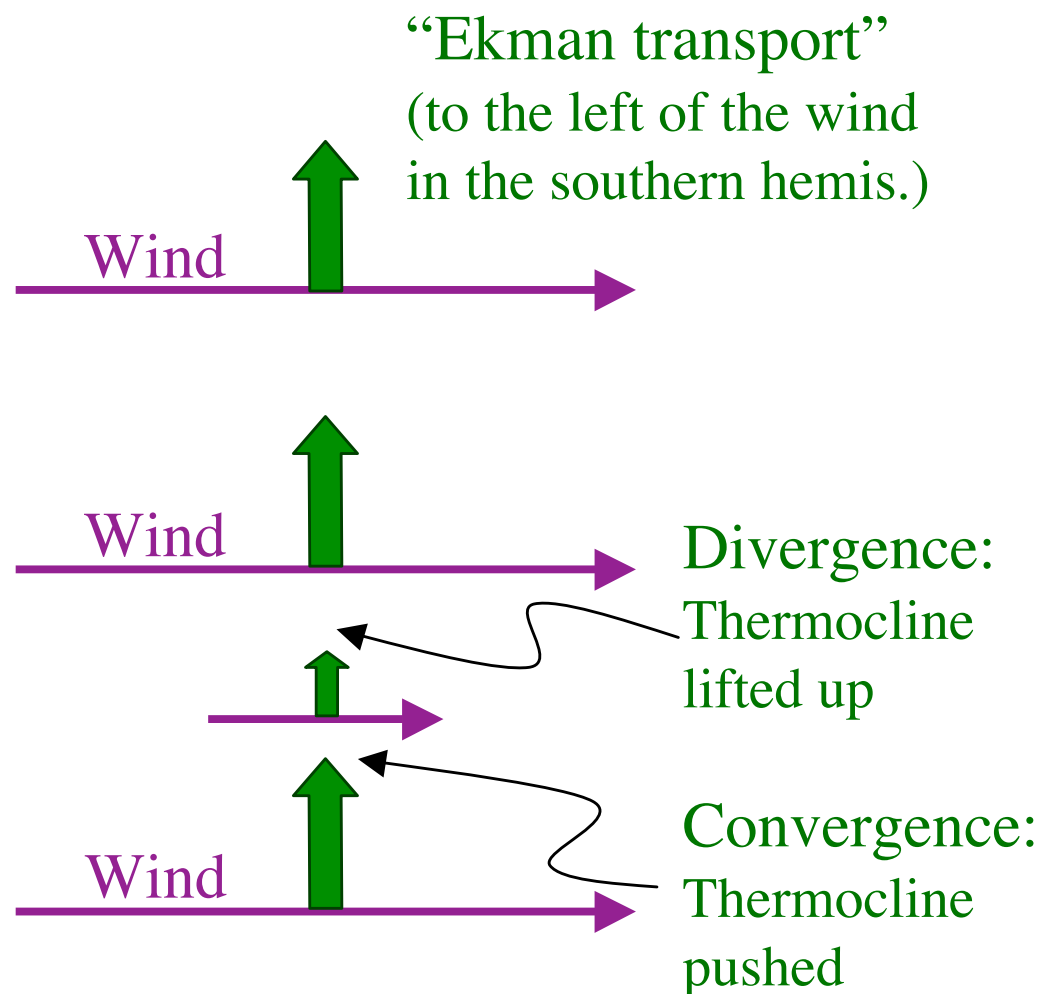


Physical mechanisms: Ekman Pumping

On the equator, water is driven directly downwind:



Off the equator, the Coriolis force drives water perpendicular to the wind:



Planetary waves

New kinds of waves occur on planetary scales, which are unlike the waves that we know on human scales:

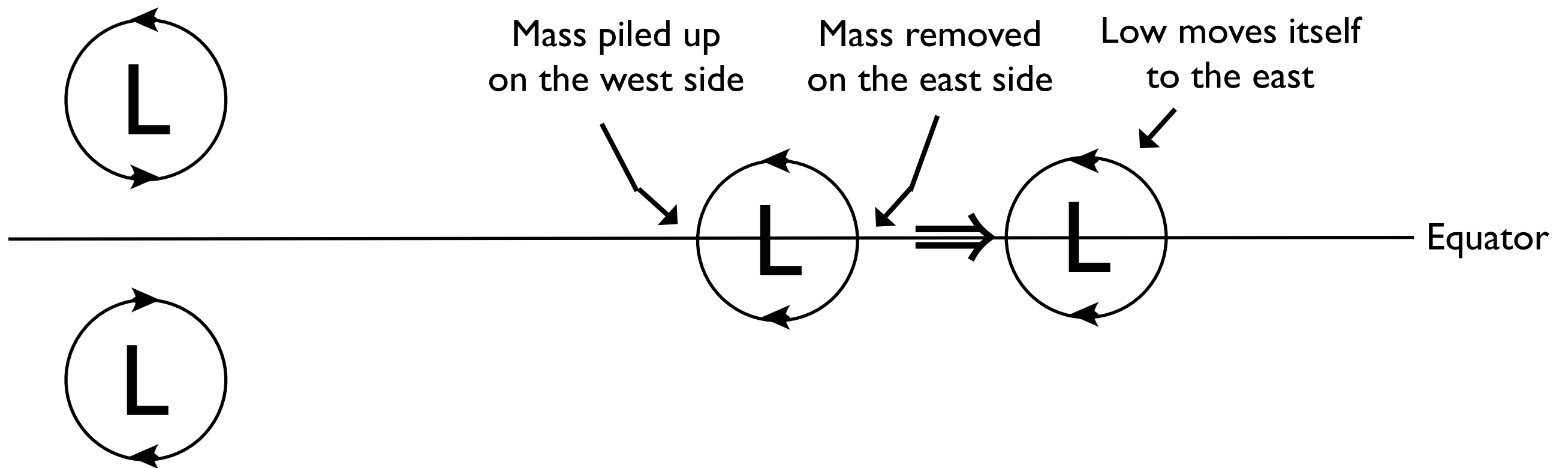
“Kelvin waves” propagate only along the equator, always eastward.

“Rossby waves” propagate only off the equator, always westward.

Mechanisms

Equatorial waves allow rapid and efficient communication across vast distances.

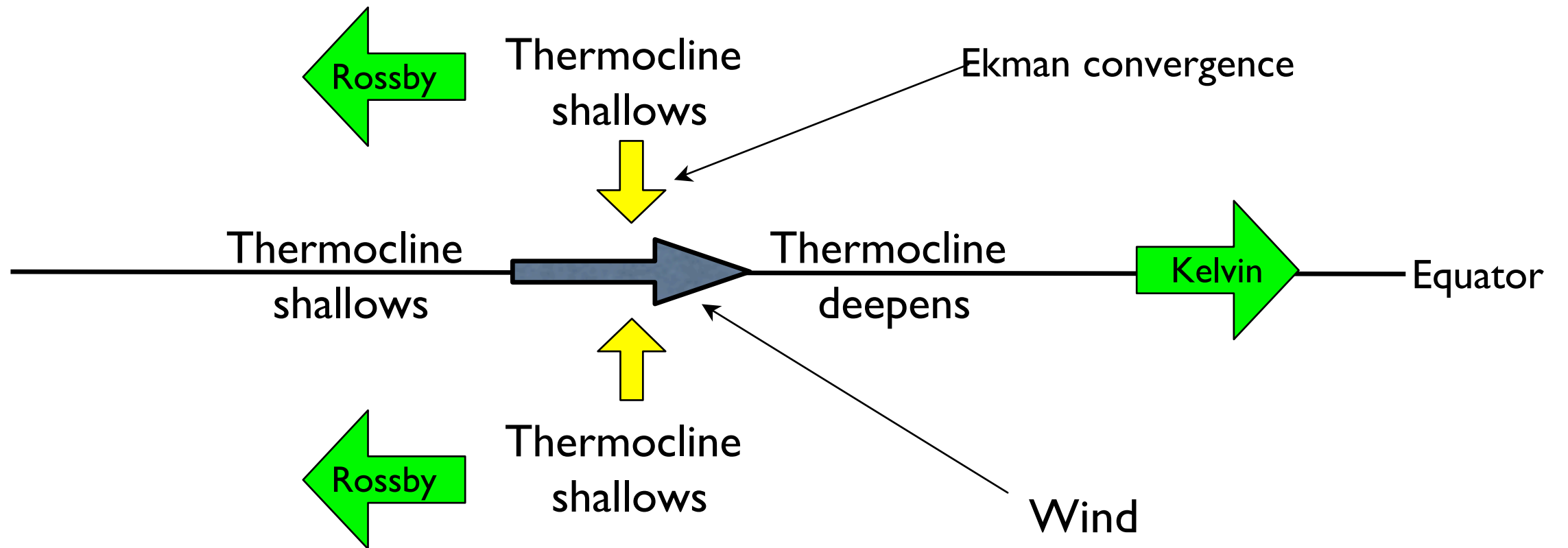
These waves have counterintuitive properties: some only travel west, some only east. For example, the **Kelvin wave** only goes east, right at the equator:



Off-equatorial low sea level bowls rotate because of Coriolis

A low centered on the equator has westward flow on both sides: propagates eastward!

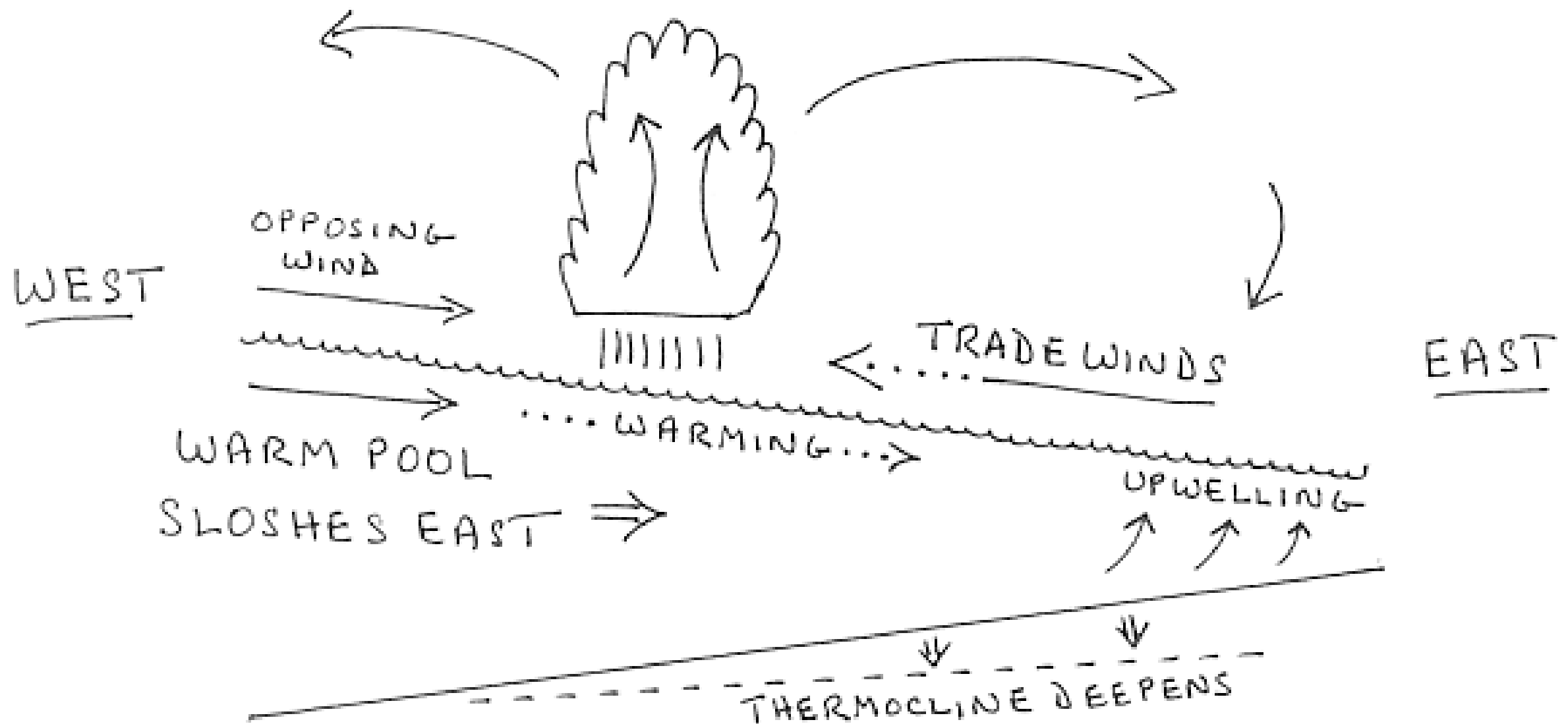
Equatorial winds generate both Kelvin and Rossby waves



Kelvin waves: ~ 2.5 m/s (6500 km/month)

Rossby waves: ~ 0.8 m/s (2000 km/month)

Because of the eastward-propagating Kelvin waves, information preferentially moves east at the equator:
The onset of El Niño (again)



Evolution of an El Niño event

1. An opposing wind in the west Pacific initiates the event
2. The warm pool moves east. As it moves, the trade winds shrink eastward, accelerating the collapse of the normal system. The eastern Pacific warms, removing the east-west SST gradient that supports the trades.
3. As the warm water arrives in the east, it spreads poleward, draining the layer above the thermocline.
4. As the thermocline comes close to the surface, it begins cooling the surface in the east. The renewed SST gradient restores the normal trades, and the event ends.

We don't know why El Niños begin!

Theories fall roughly into two categories:

- The Pacific ocean-atmosphere system has a natural frequency of oscillation (perturbed by weather to be slightly irregular), or
- The system is stable until an event is triggered by outside forcing.

This is a major subject of debate in the climate community today.

However, once an event begins, we have a good idea of how it evolves, which allows us to make socially-useful forecasts.

The effects of El Niños radiate outward from the tropical Pacific as waves through the atmosphere. These take relatively predictable paths, and are the basis for public forecasts.

ENSO Forecasting

There are two steps in forecasting the effects of El Niño:

1. Predicting SST anomalies in the tropical Pacific
2. Using those SSTs to predict the effects on distant weather

Step 1 is based on having high-quality data coverage of the tropical Pacific to initialize models of the ocean-atmosphere system. To a large extent these models rely on projecting waves into the future. Such forecasts can be made for 6-9 months.

Step 2 uses ordinary weather forecast models, initialized with the predicted tropical SSTs.

Since weather is highly chaotic, a large ensemble of model runs must be made to understand the results.