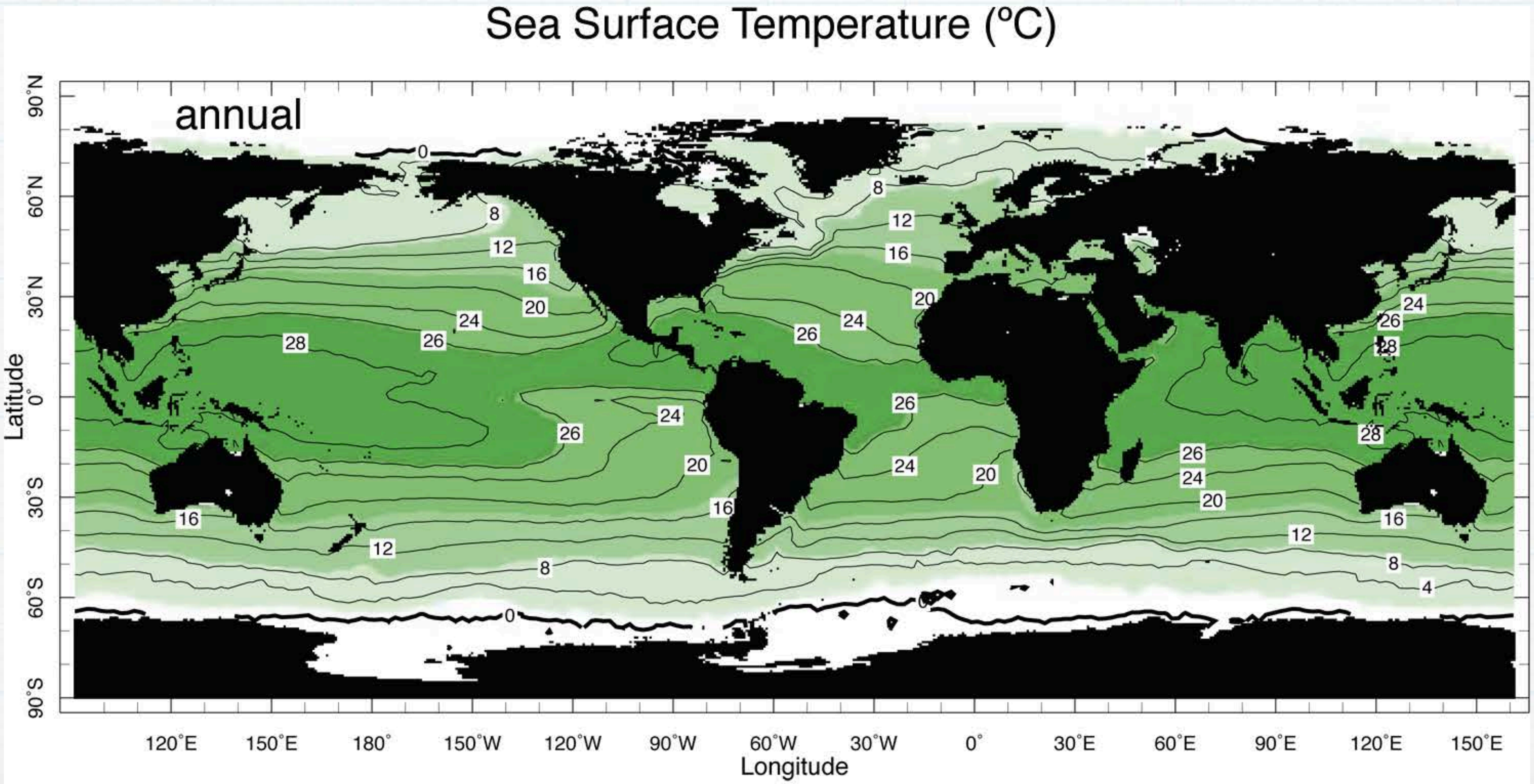
Air-sea interaction: #1
Natural climate variability

El Niño and the Southern Oscillation

- In tropical latitudes, changes in SST and tropical air temperatures and wind are more in phase with one another.
- The ocean is active, meaning that SST changes can modulate the atmospheric states.
- Occasional failures of the Indian monsoon (extensive droughts in Indonesia and much of Australia) occurs with unusual rainfall and wind patterns across the equatorial Pacific Ocean as fa as South America.
- A known phenomenon for a long time, for example by Charles Darwin during *Voyage of the Beagle* (1831~1836)
- Named as *Southern Oscillation* by Gilbert Walker
- El Niño, a warmer surface waters in the eastern equatorial Pacific

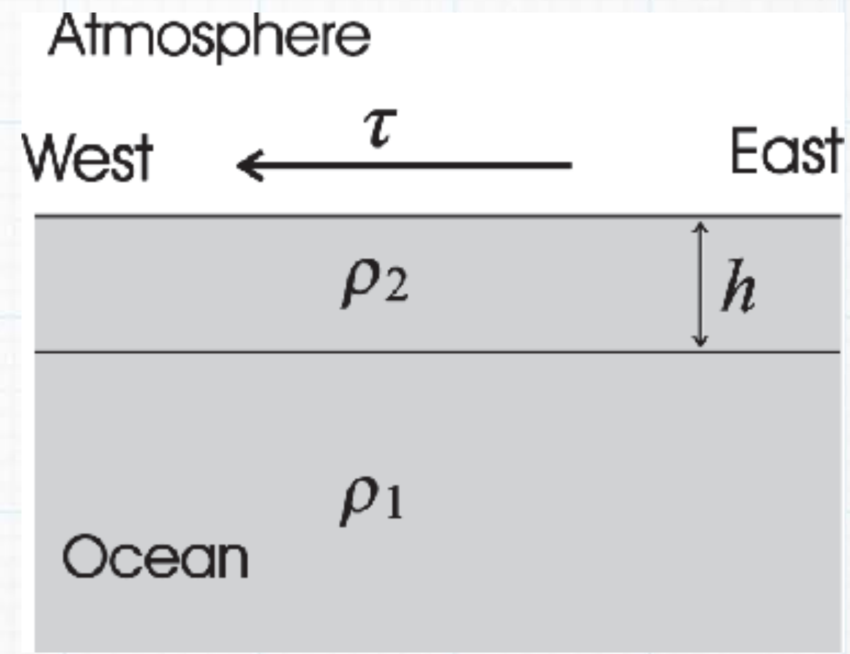
Normally…

- Wet climate in Indonesia
- Warm sea surface temperature in the western equatorial Pacific (Warm pool)
- Relatively colder sea surface temperature near Peru (Cold tongue))
- Trade wind from the east to the west



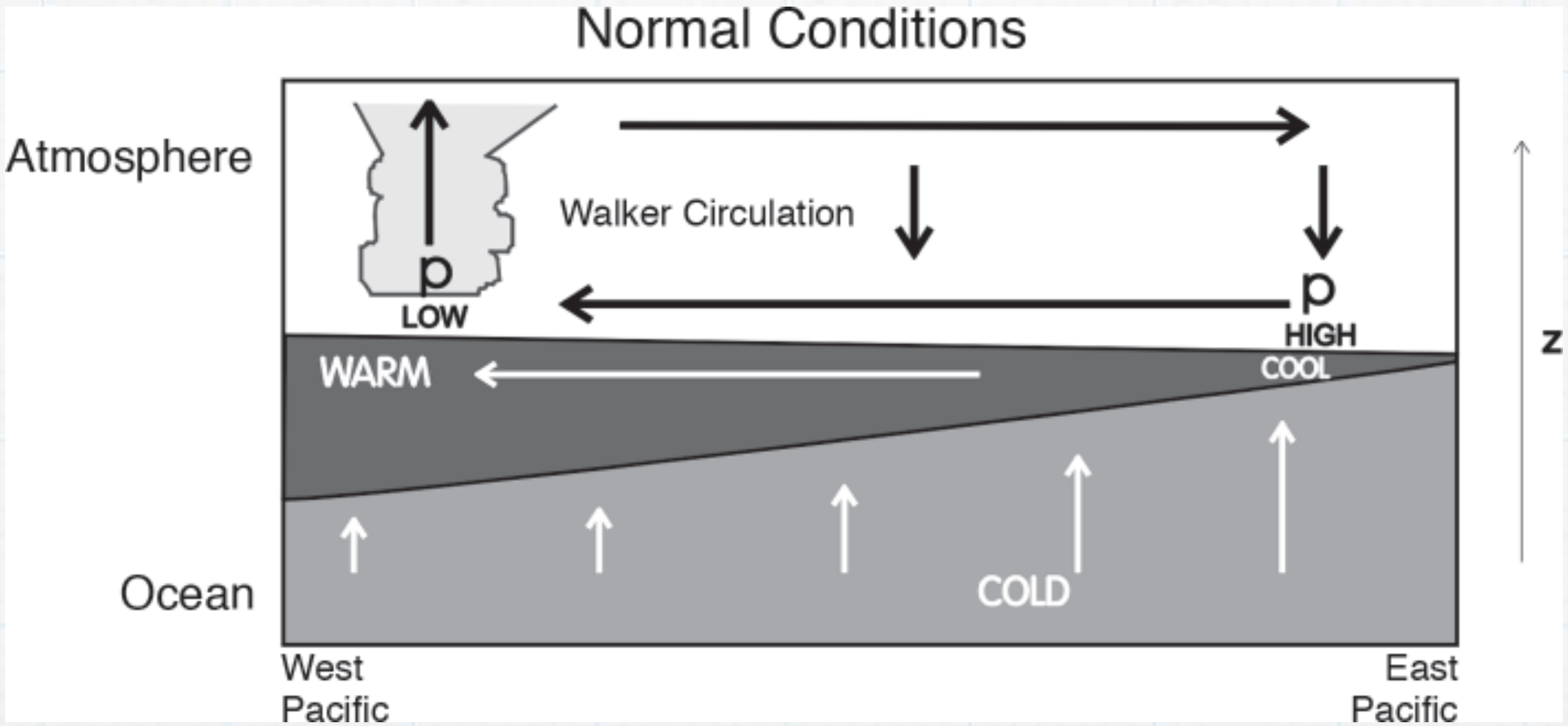
Divergence of the water at the equator

- Consider no continent
- $f \approx \beta y$
- $-\beta y v = \dfrac{1}{\rho_{ref}}\left(-\dfrac{\partial p}{\partial x} + \dfrac{\partial \tau_x}{\partial z}\right)$
- $-\beta y \displaystyle\int_{-h}^{0} v dz = \dfrac{\tau_x}{\rho_{ref}}$ in the zonal average sense (the solution is independent in x direction). → zonal wind stress drives the meridional transport near the equator.



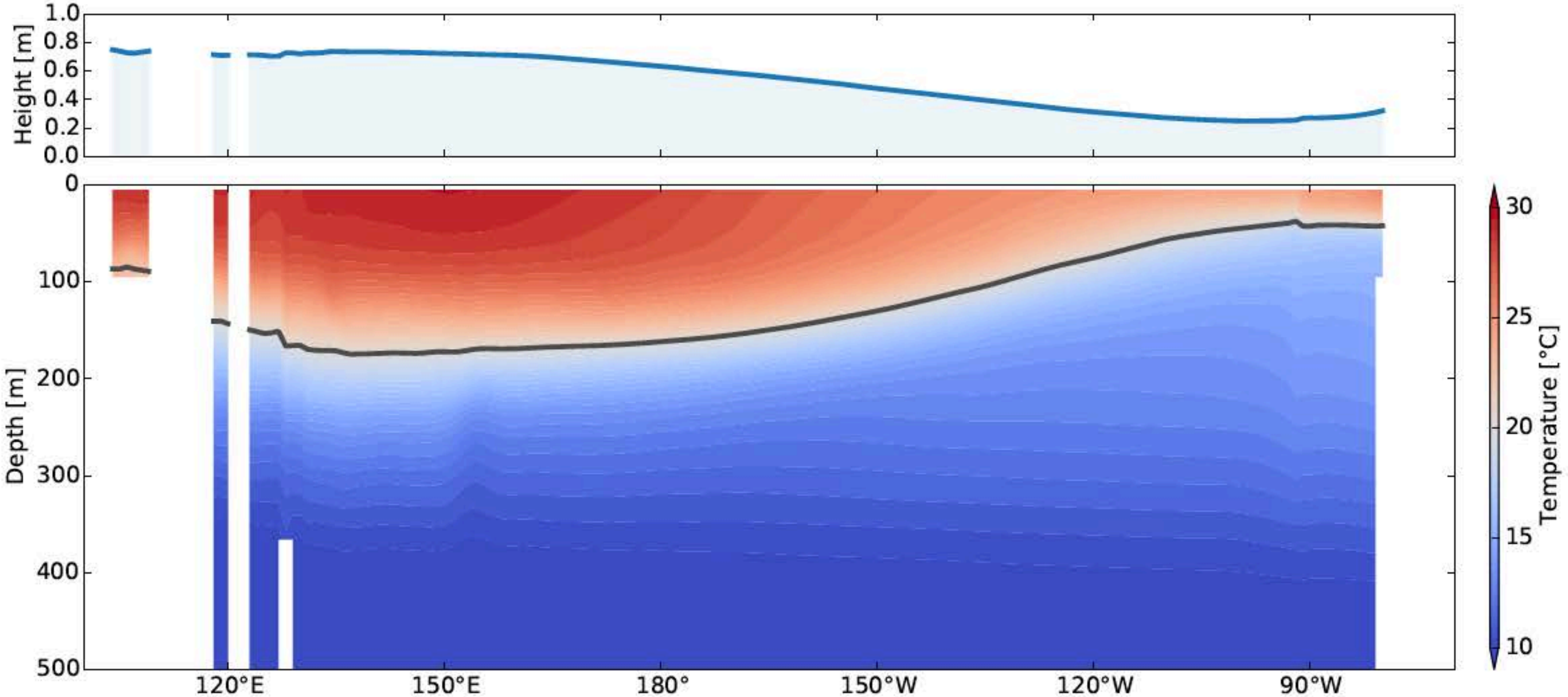
Upwelling along the equator

- The tropical Pacific Ocean is bounded to the east and west.
  - Thermocline is deeper in the west and shallower in the east.
- The "cold tongue" in the east, and the "warm pool" in the west.



Normal conditions

- Sea surface height is 40–50 cm higher in the west than in the east
- The thermocline (indicated by the 20°C isotherm) is ∼135 m deeper in the west than in the east

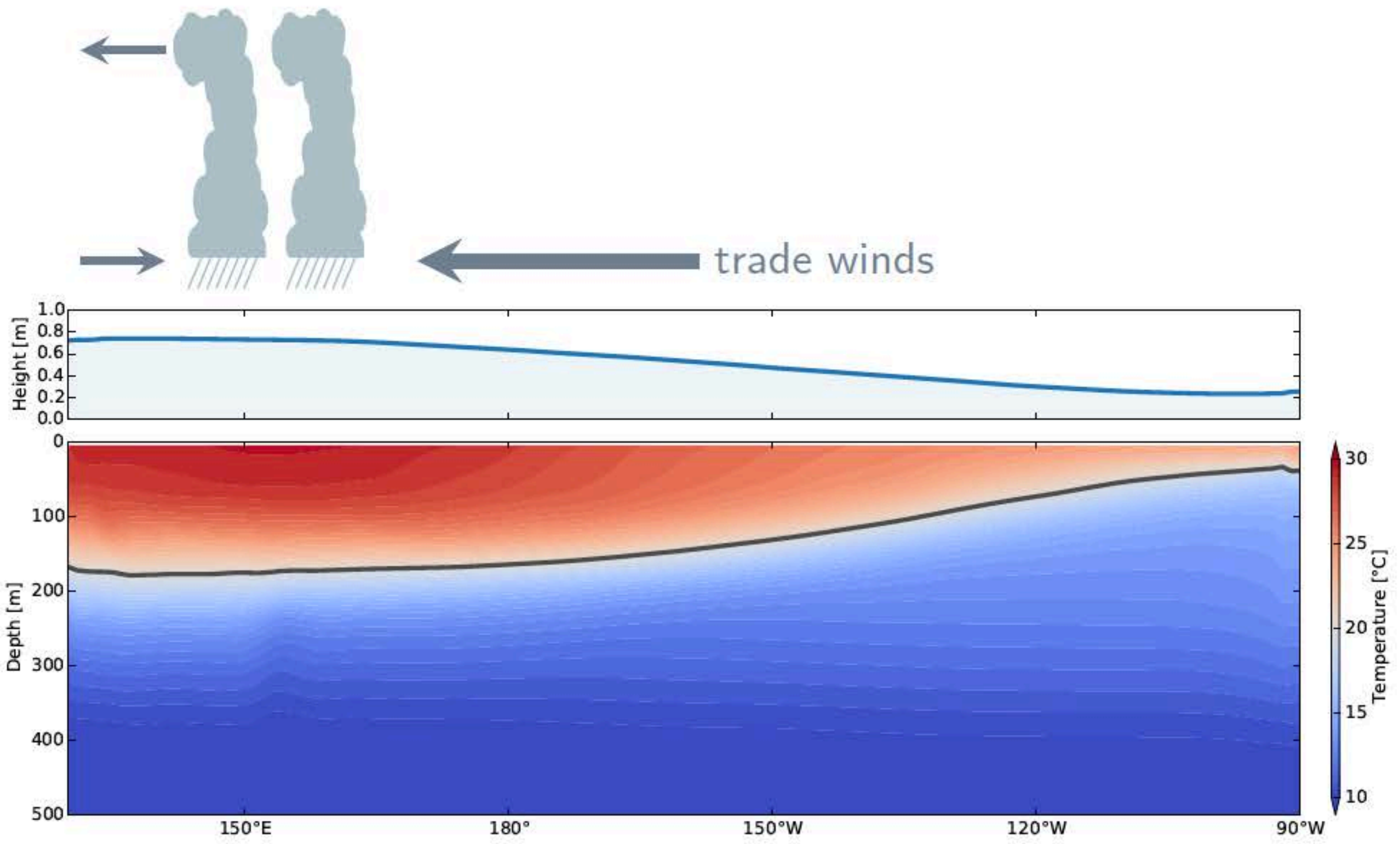


data from C

Slide by Jonathan Wright

Normal conditions

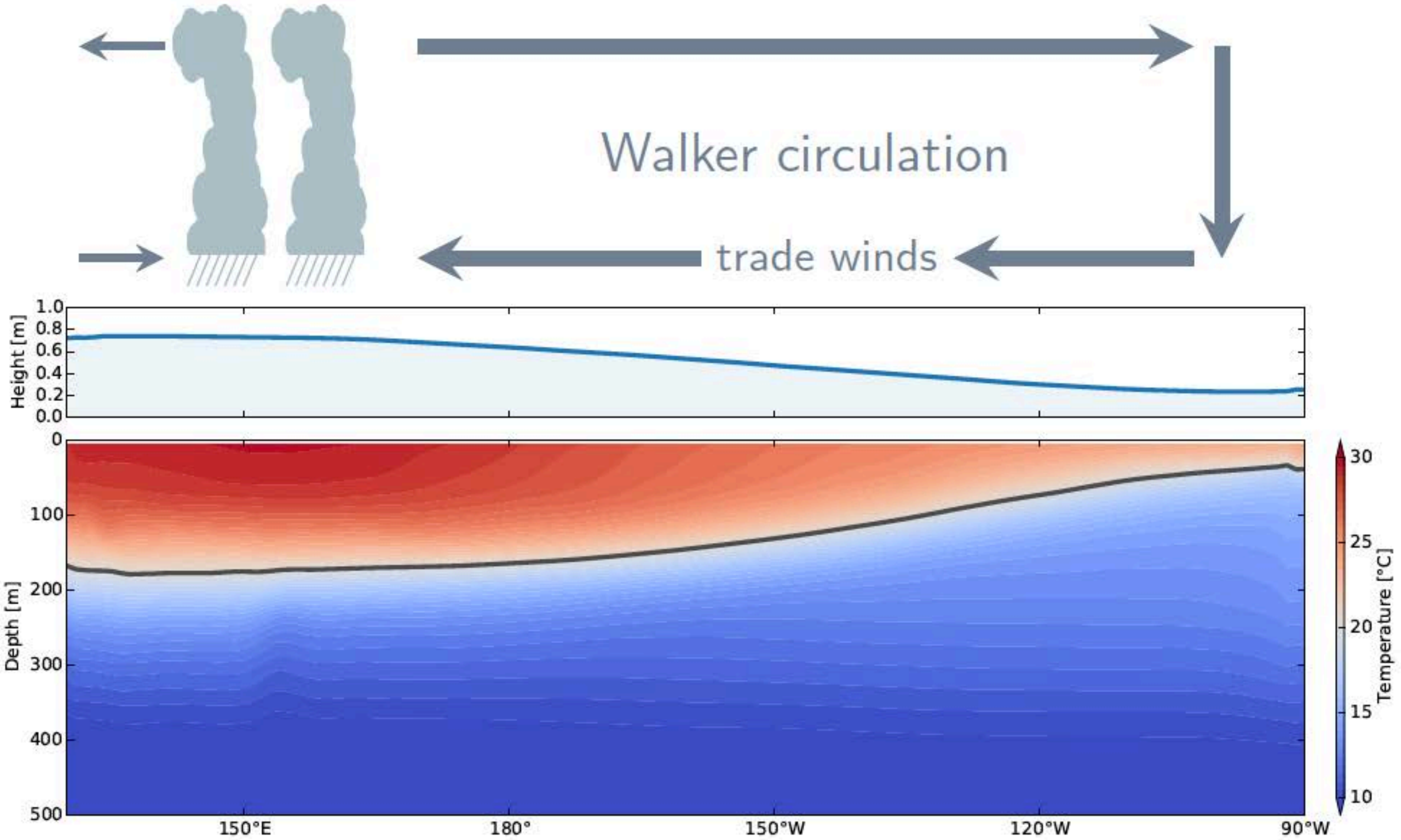
Convection is located over the Western Pacific warm pool



Slide by Jonathan Wright

Normal conditions

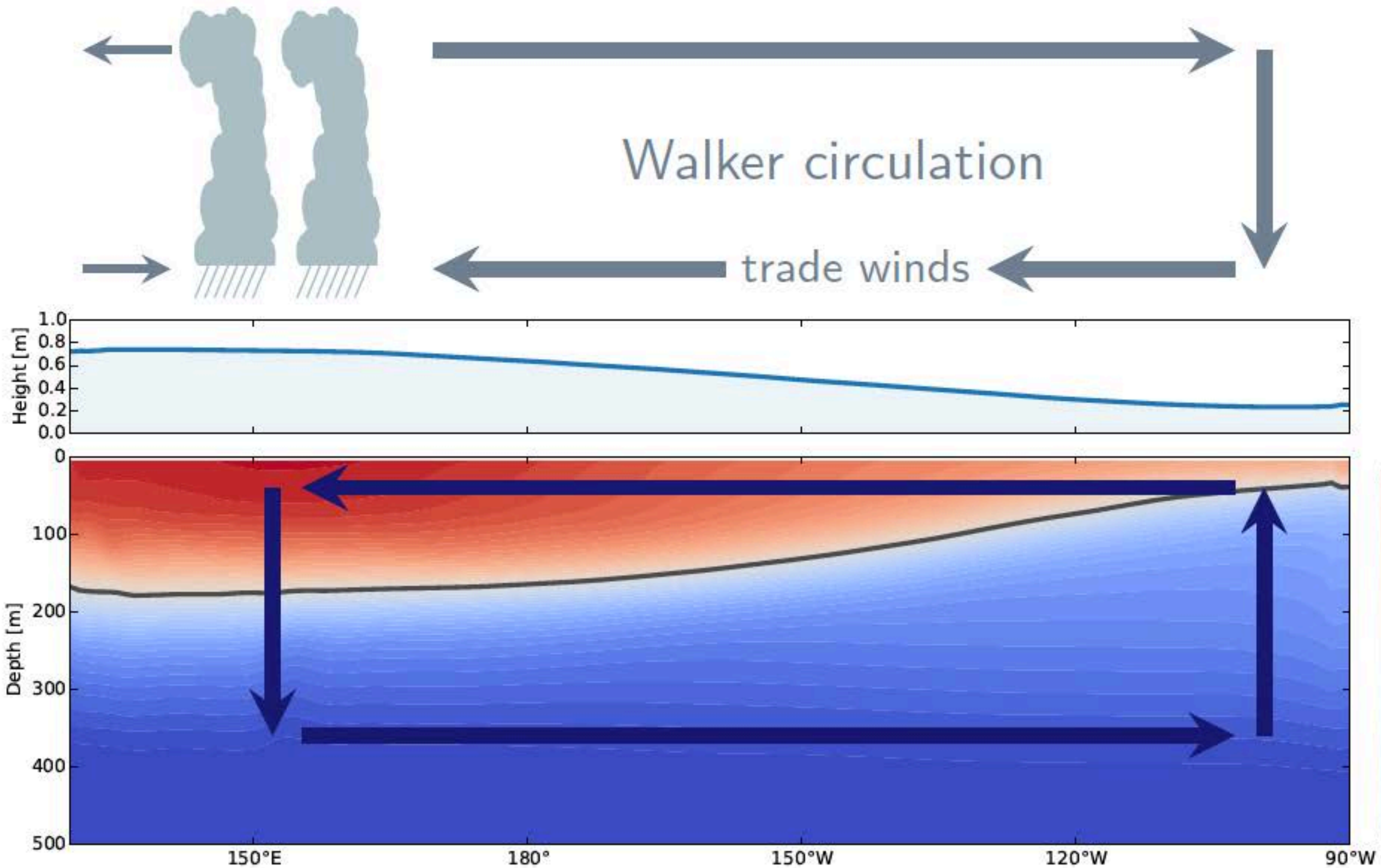
Convection is located over the Western Pacific warm pool



Slide by Jonathan Wright

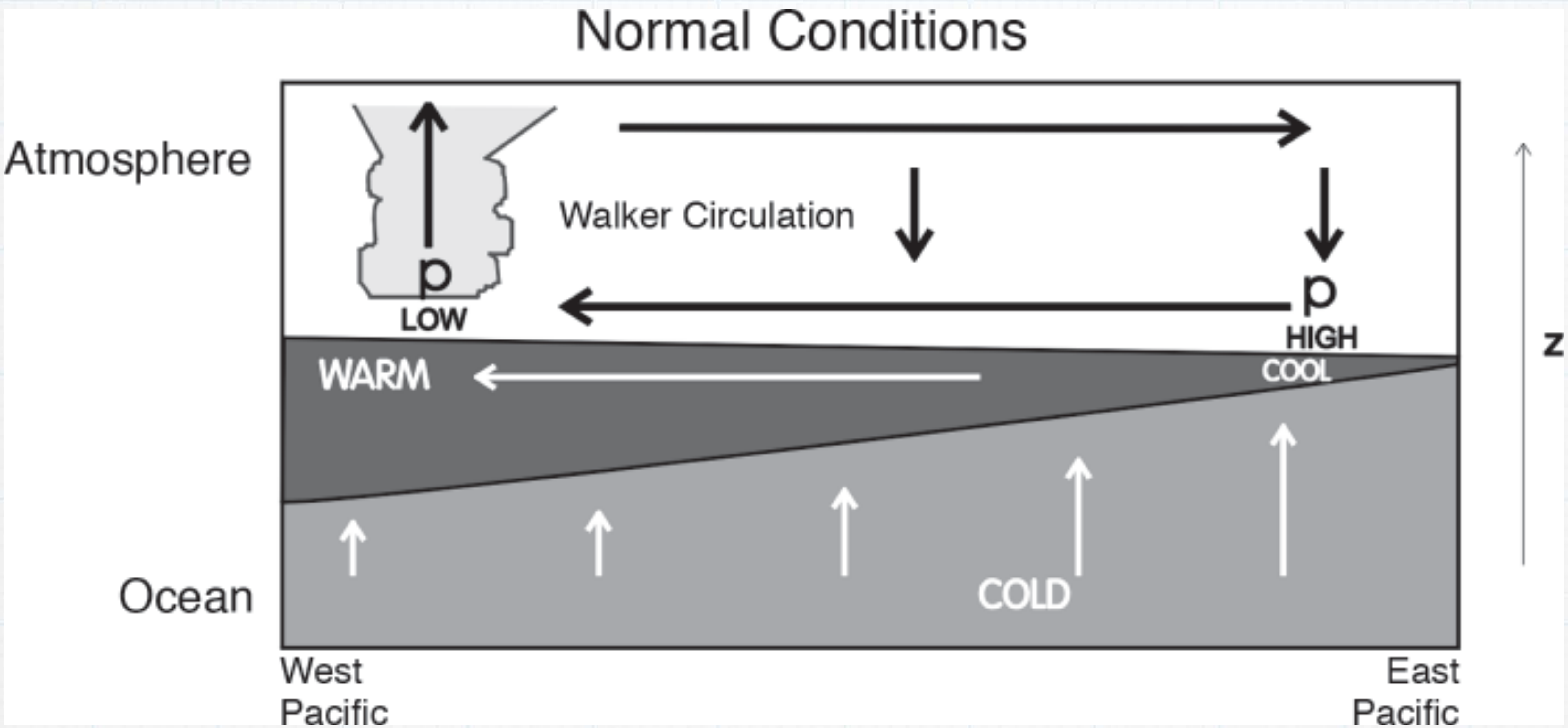
Normal conditions

Convection is located over the Western Pacific warm pool



Slide by Jonathan Wright

Normal conditions



The Bjerknes feedback

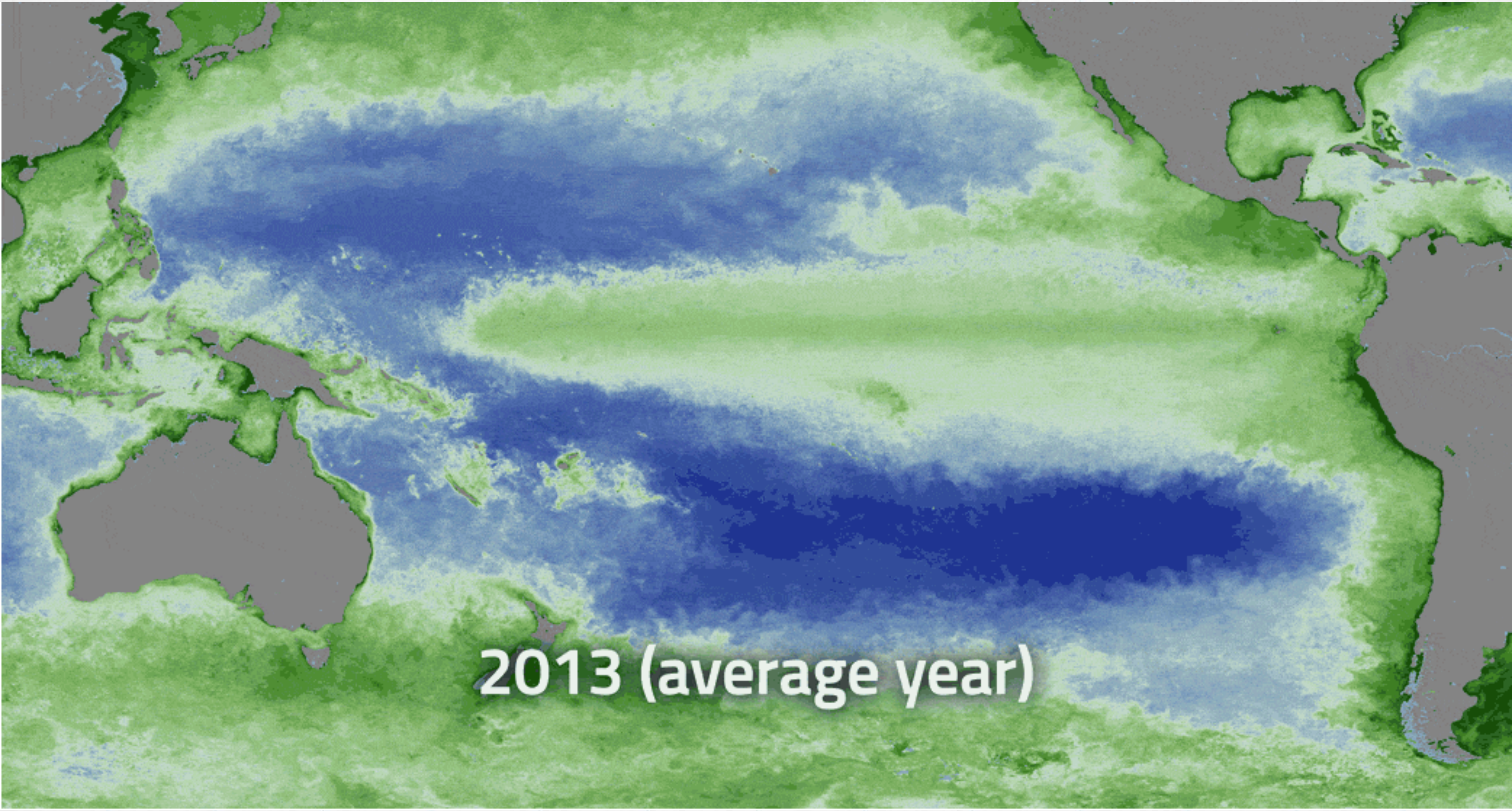
Slide by Jonathan Wright

1. Winds flow from low SST to high SST ...
2. which causes upwelling under low SST and downwelling under high SST ...
3. which enhances cooling in the region of low SST and warming in the region of high SST ...
4. which strengthens the winds that flow from low SST to high SST

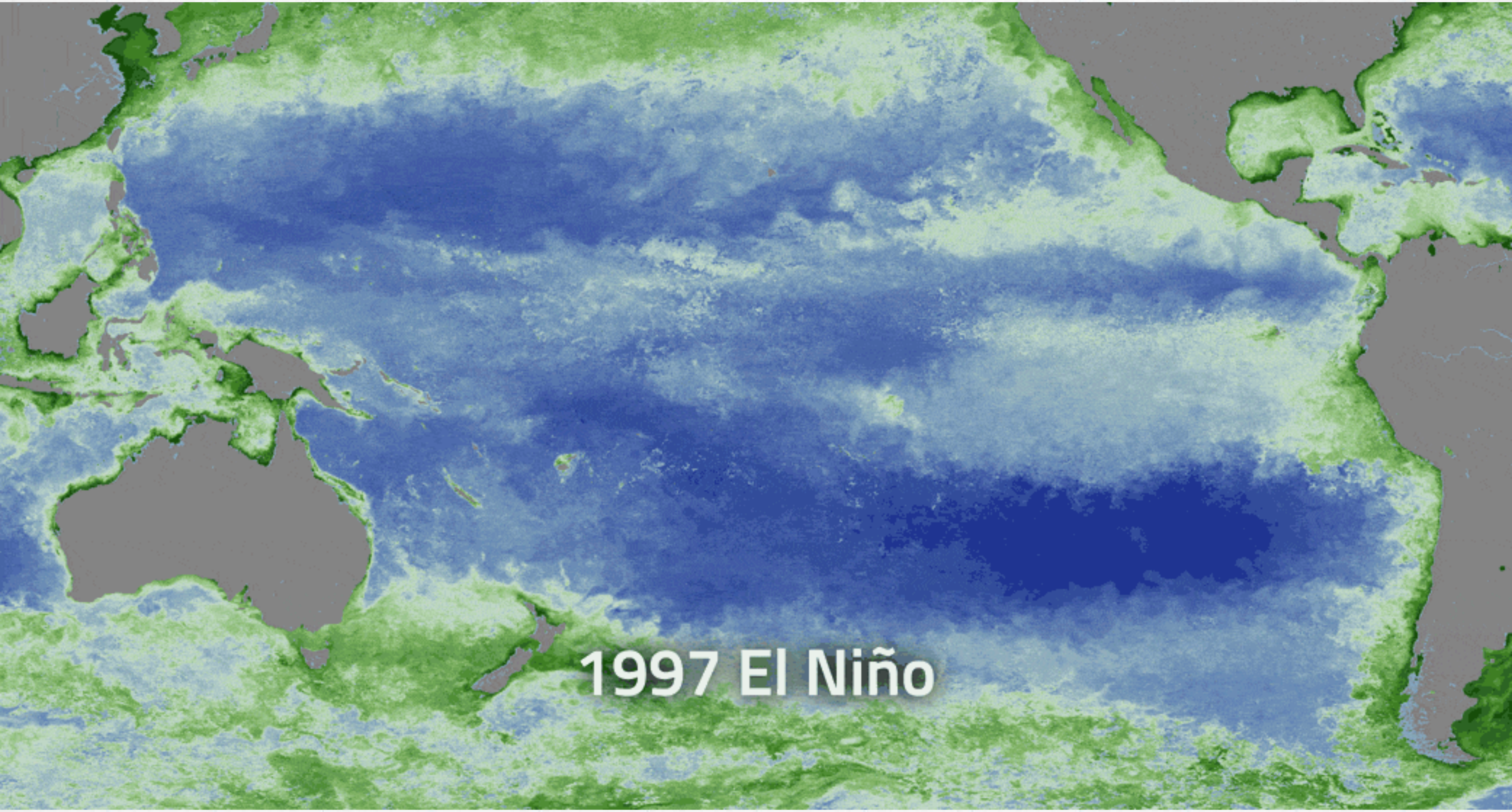
Interannually varying climate in the tropics

- Failures of the Indian monsoon
- Extensive droughts in Indonesia and much of Australia
- Unusual rainfall and wind patterns
- Warm surface water temperature in the eastern Pacific
- Poor fishing

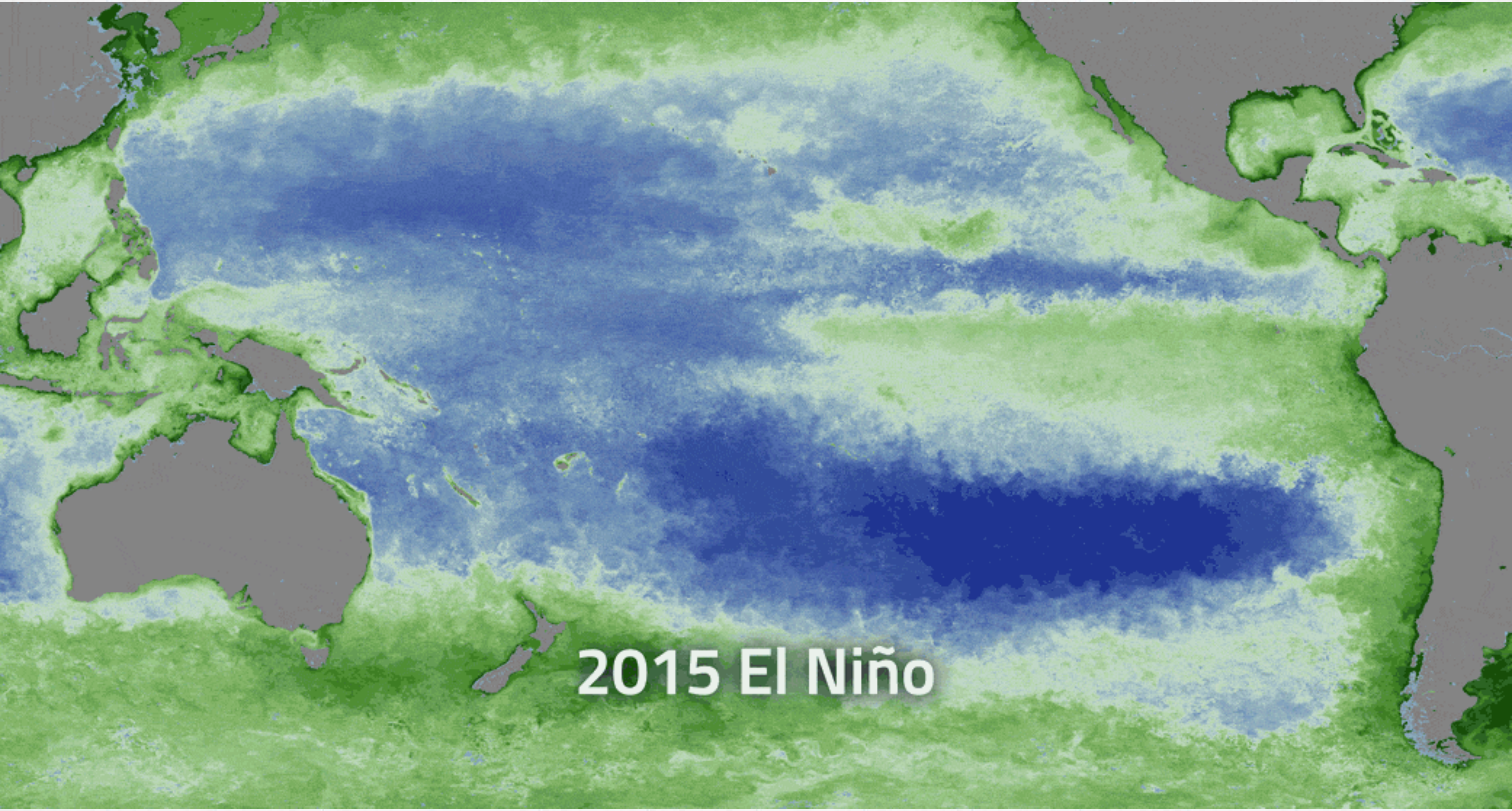
Satellite chlorophyll

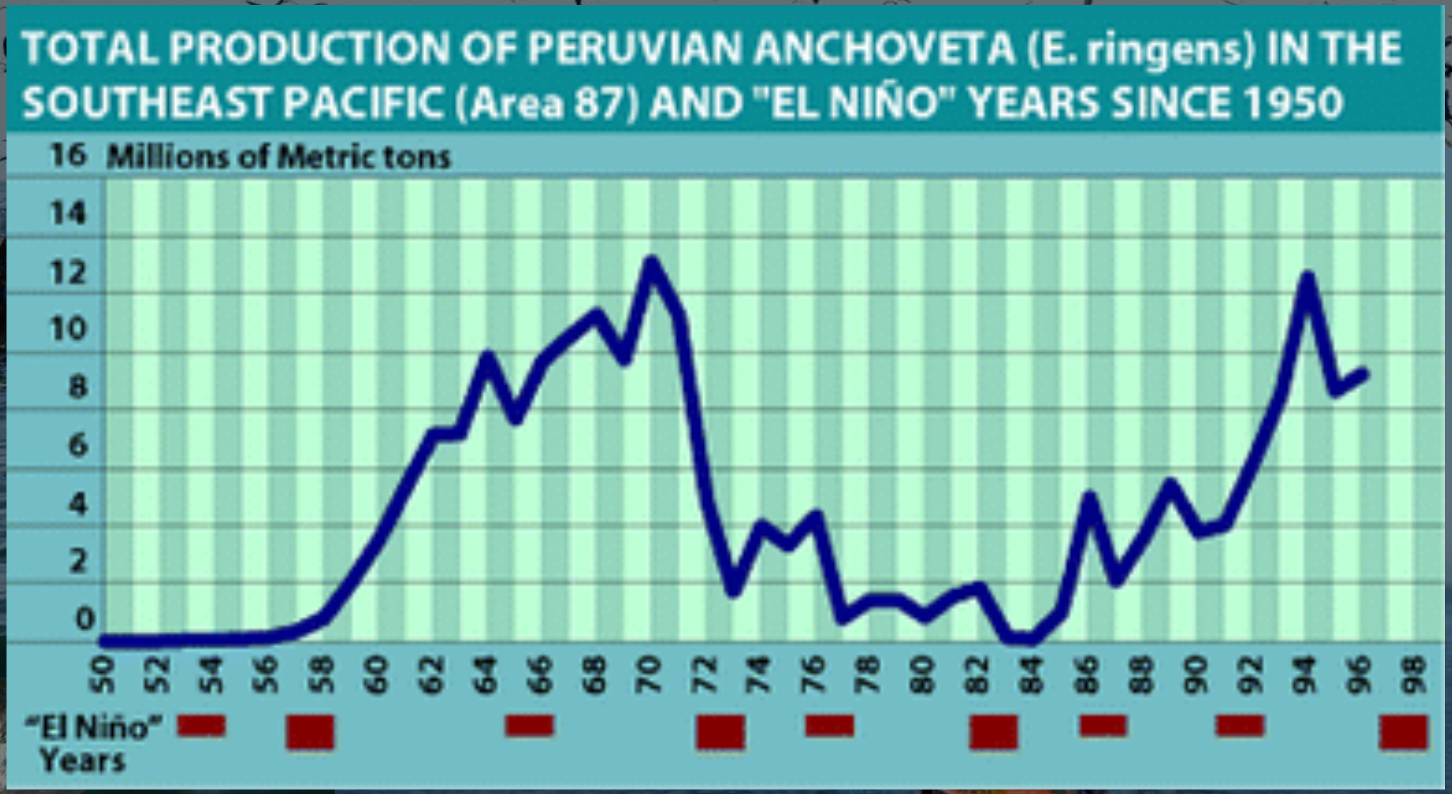


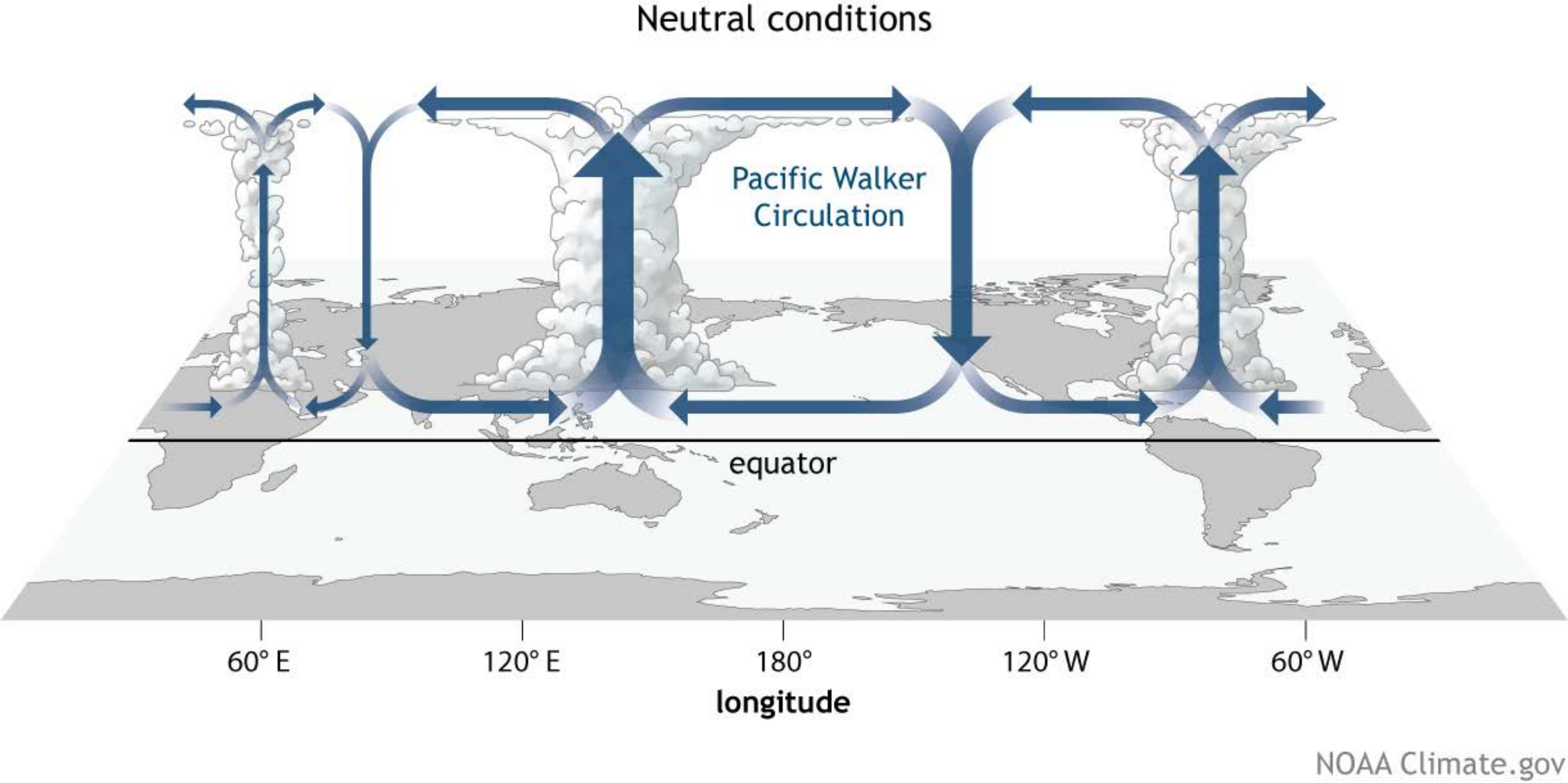
Satellite chlorophyll

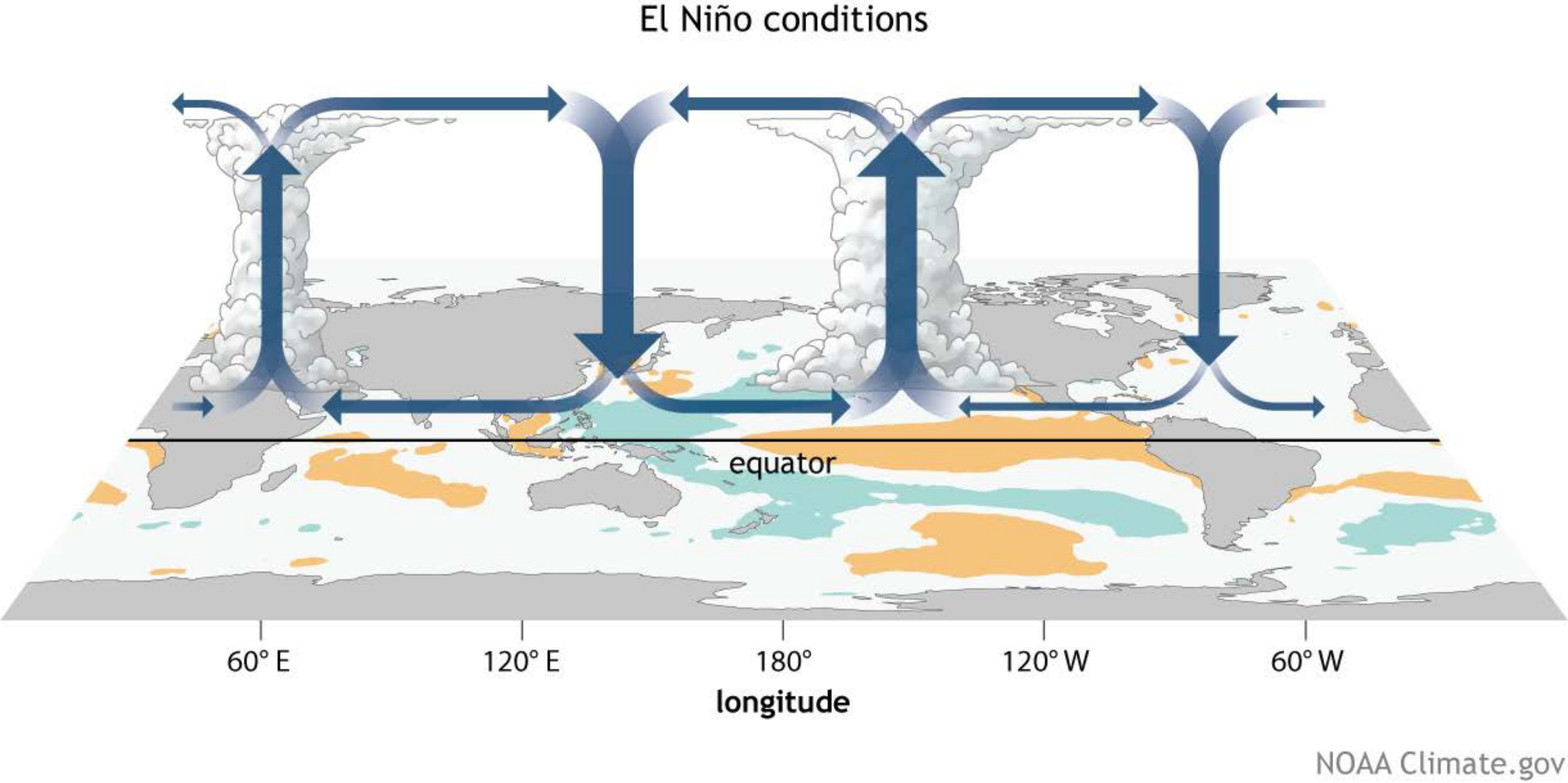


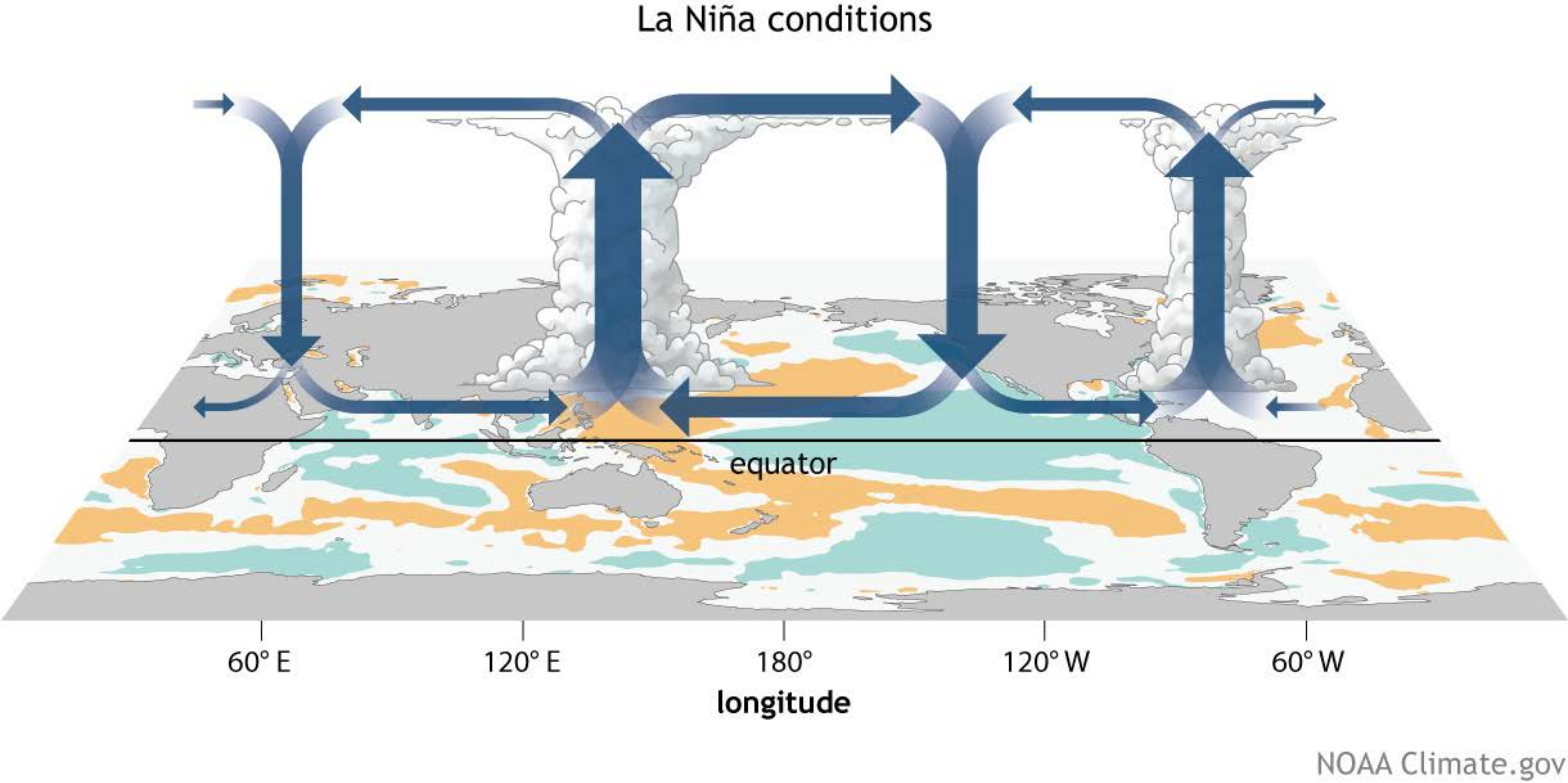
Satellite chlorophyll

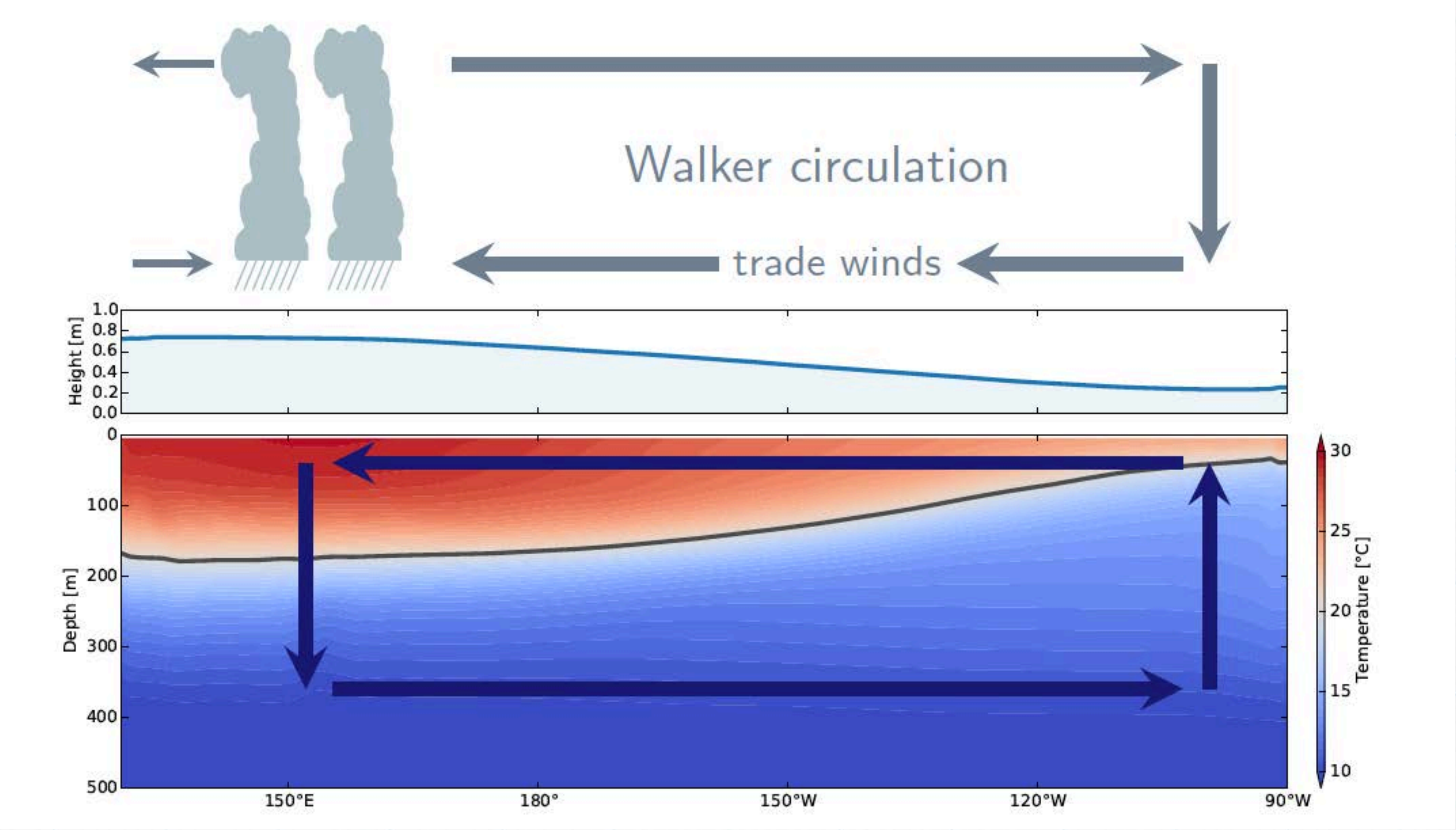



TOTAL PRODUCTION OF PERUVIAN ANCHOVETA (E. ringens) IN THE SOUTHEAST PACIFIC (Area 87) AND "EL NIÑO" YEARS SINCE 1950
16 Millions of Metric tons
14
12
10
8
6
4
2
0
50 52 54 56 58 60 62 64 66 68 70 72 74 76 78 80 82 84 86 88 90 92 94 96 98
"El Niño" Years

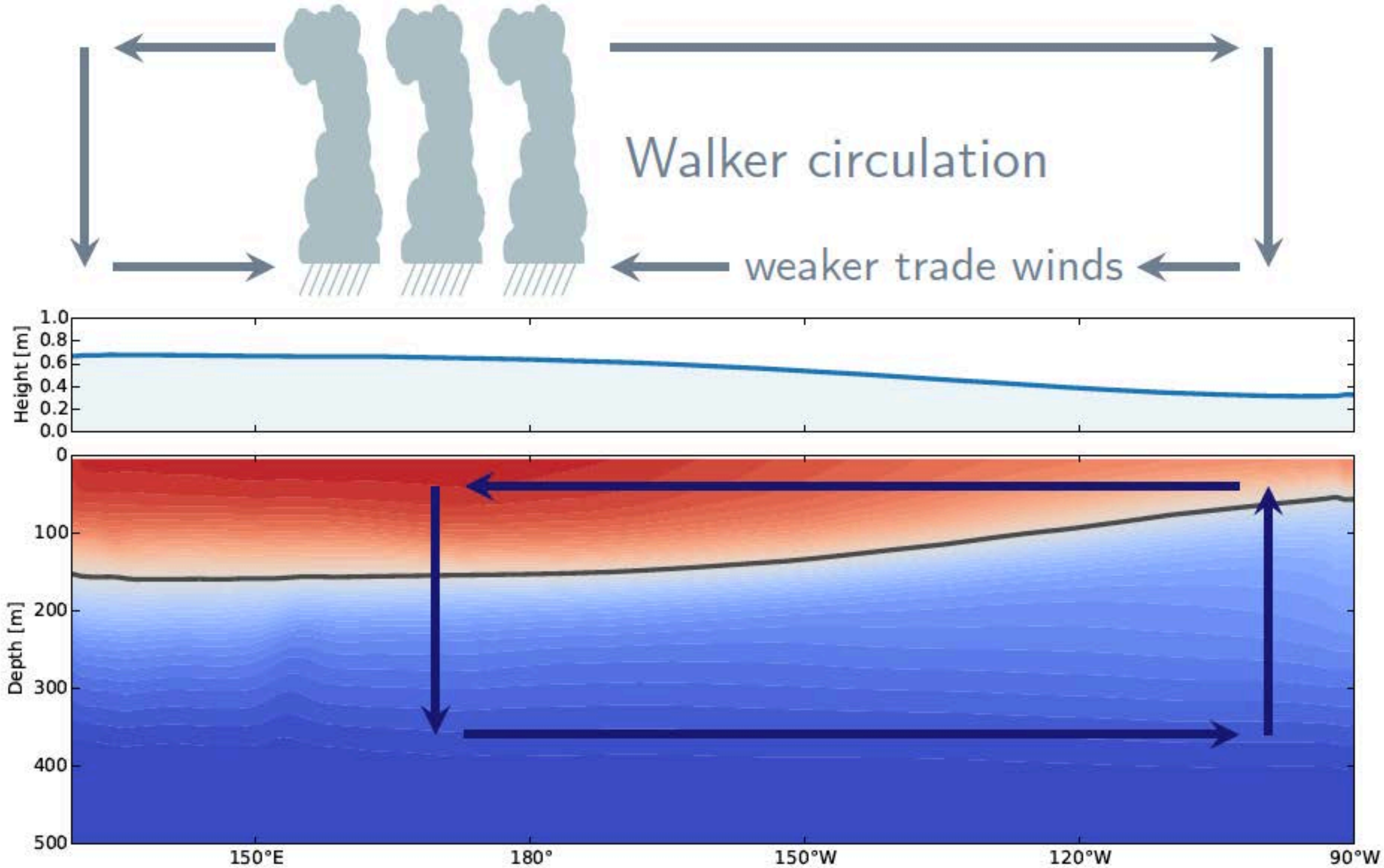

Neutral conditions
Pacific Walker
Circulation
equator
60° E
120° E
180°
120° W
60° W
longitude
NOAA Climate.gov


El Niño conditions
equator
60° E
120° E
180°
120° W
60° W
longitude
NOAA Climate.gov

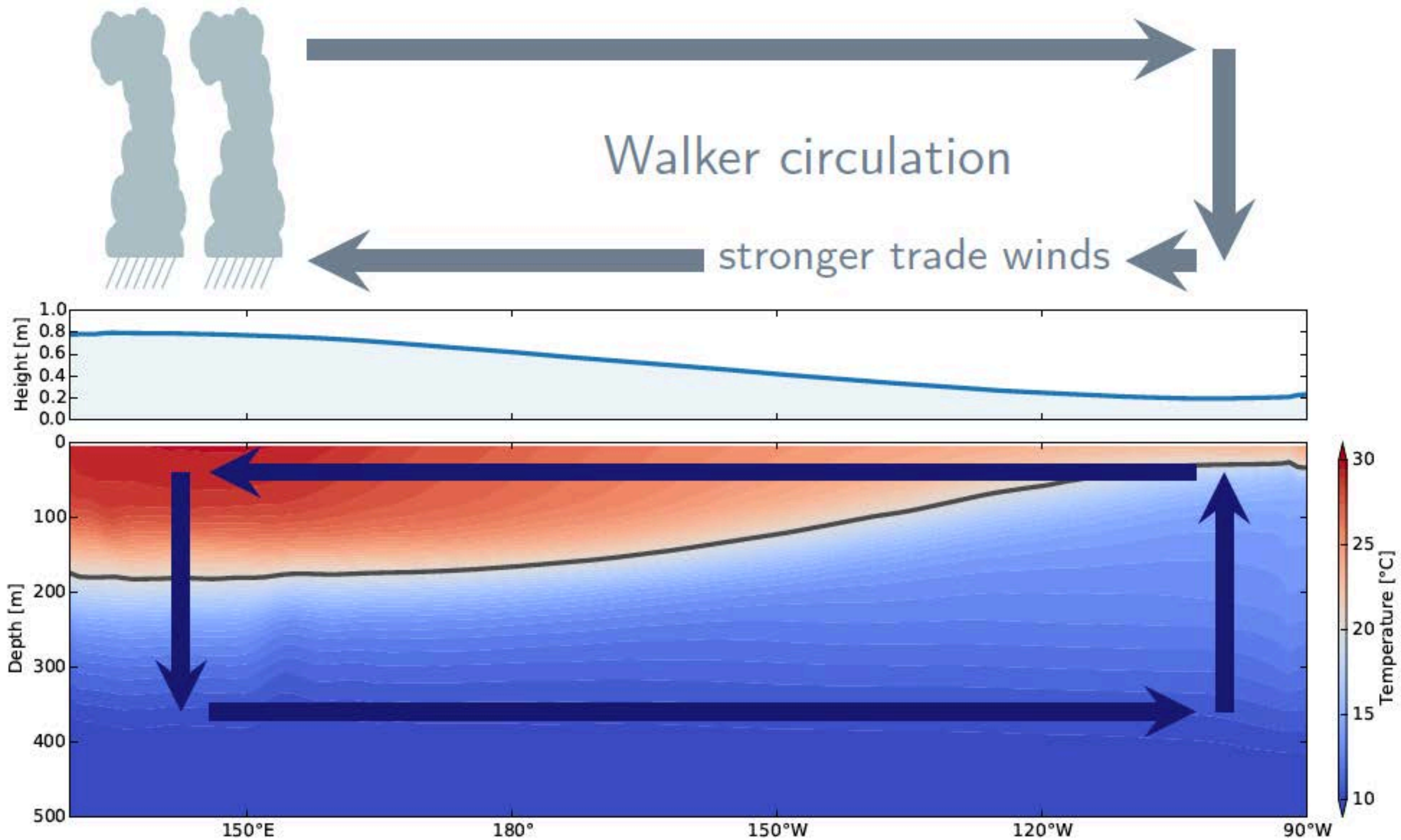

La Niña conditions
equator
60° E
120° E
180°
120° W
60° W
longitude
NOAA Climate.gov



Slide by Jonathan Wright

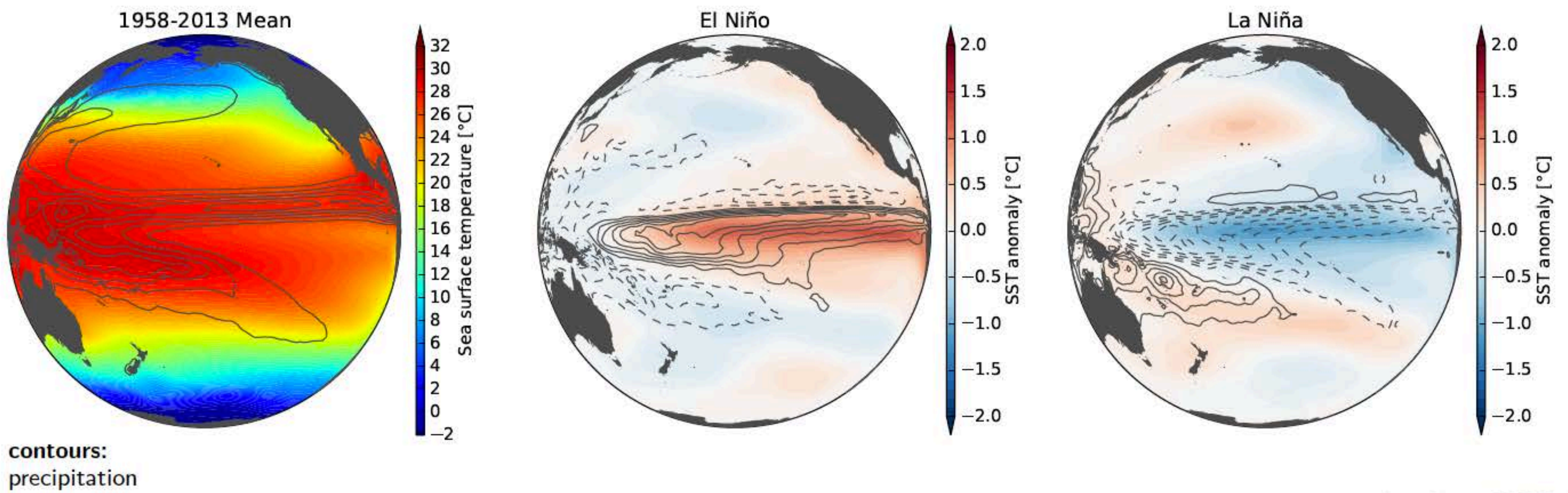


Slide by Jonathan Wright



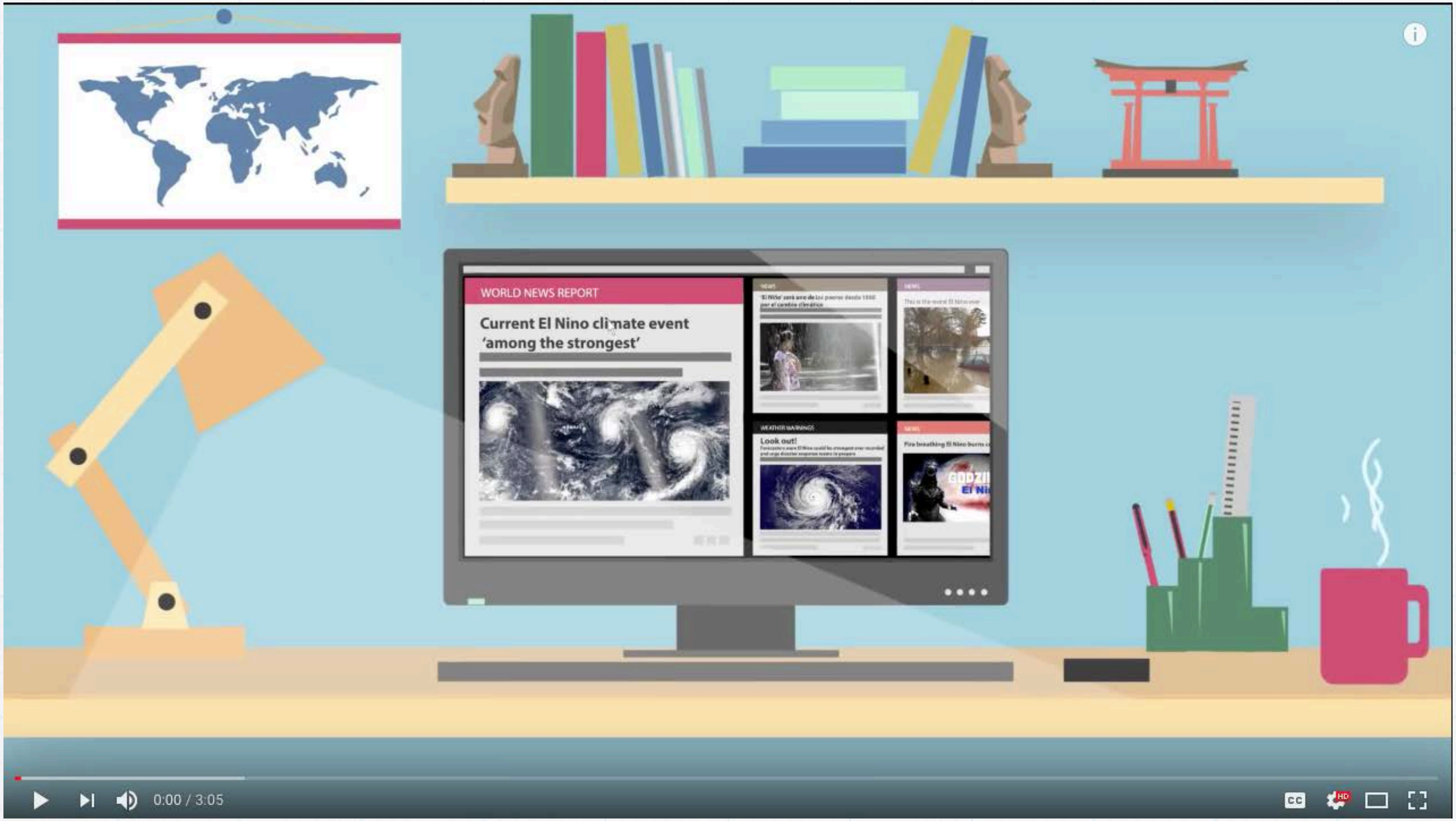
Slide by Jonathan Wright

- ENSO-related SST anomalies lead to precipitation anomalies in the equatorial Pacific
- Dynamic changes associated with the precipitation anomalies dominate outside of the equatorial Pacific

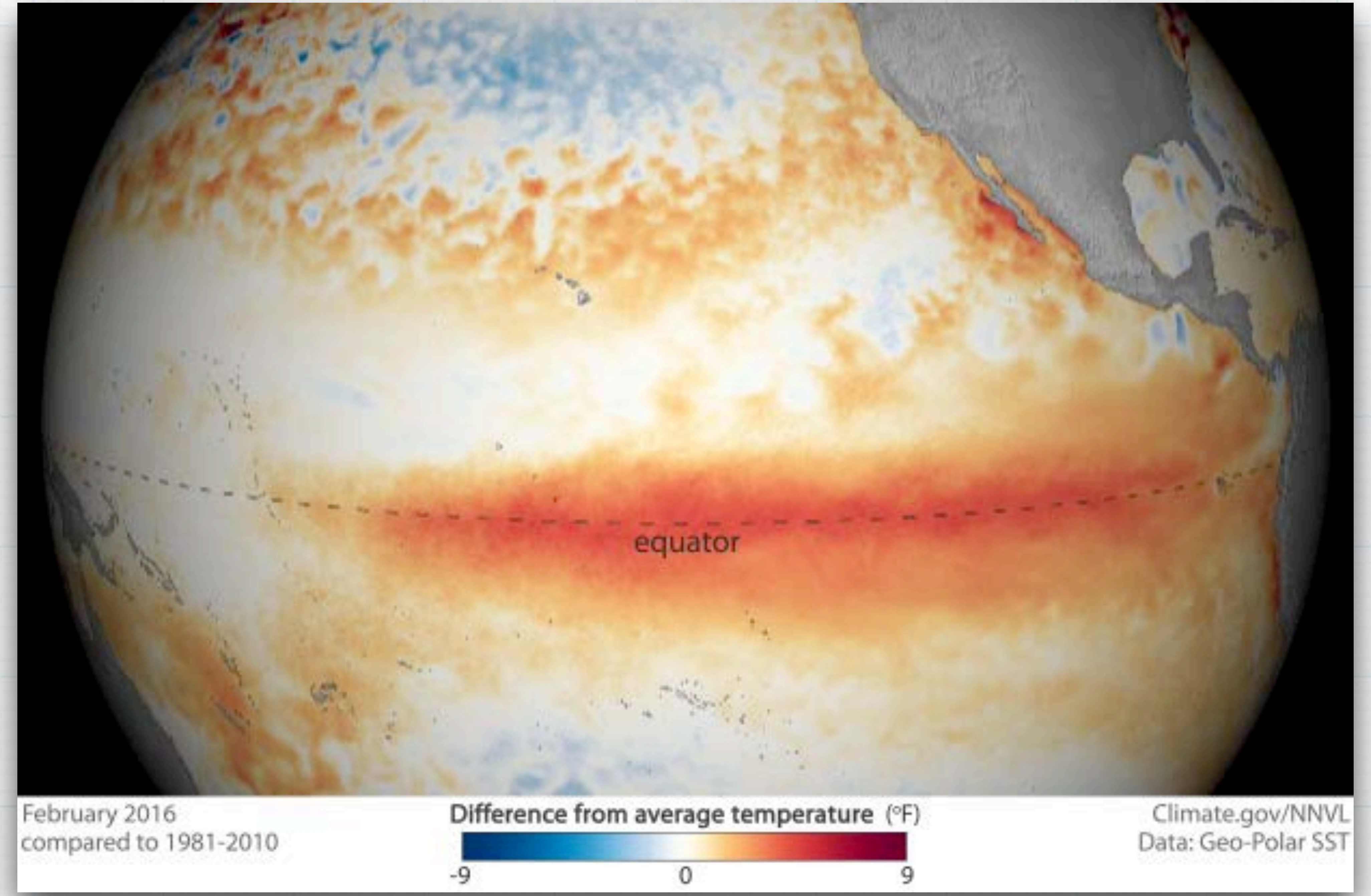


data from COBE & JRA-55

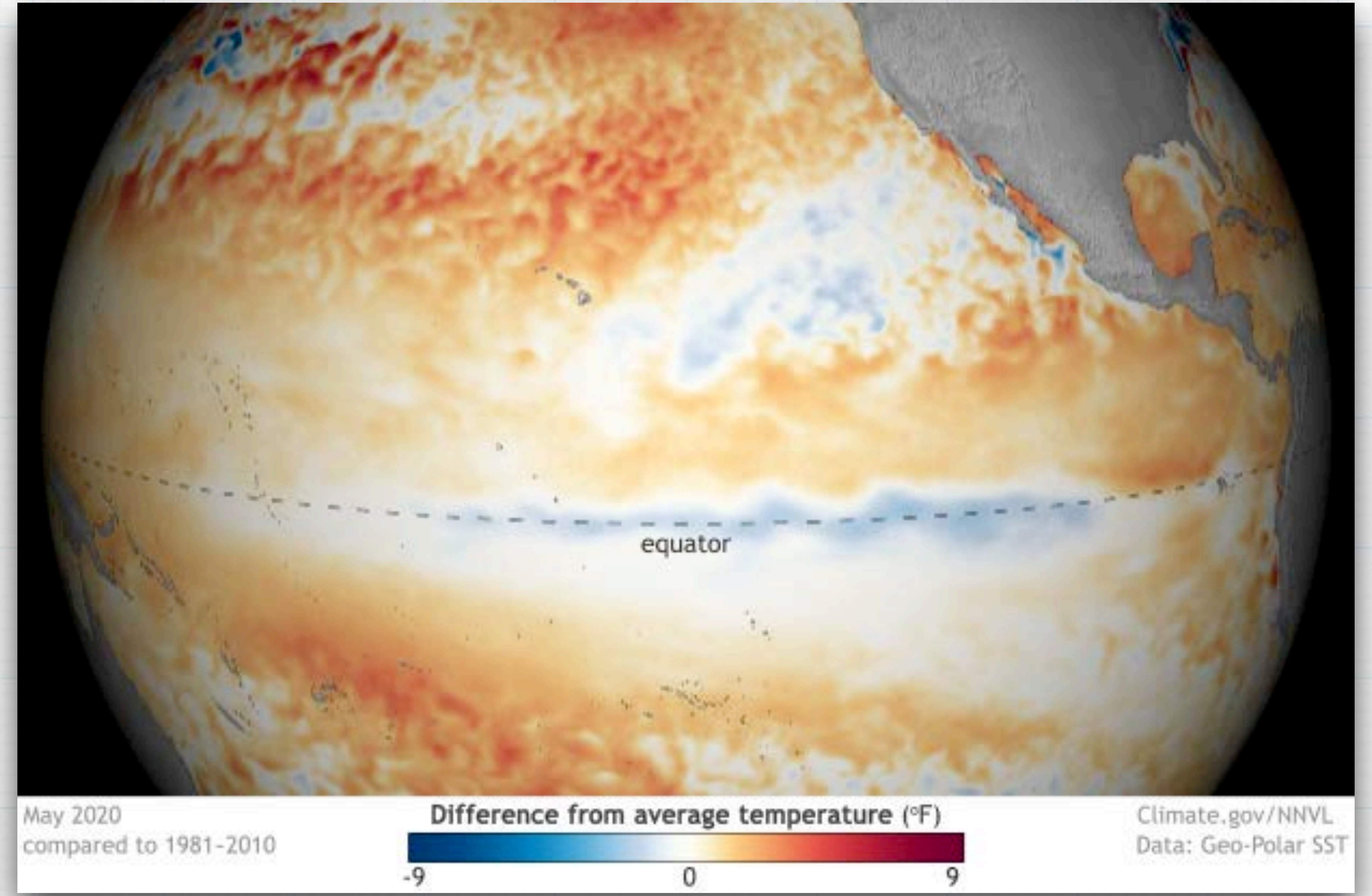
Slide by Jonathan Wright



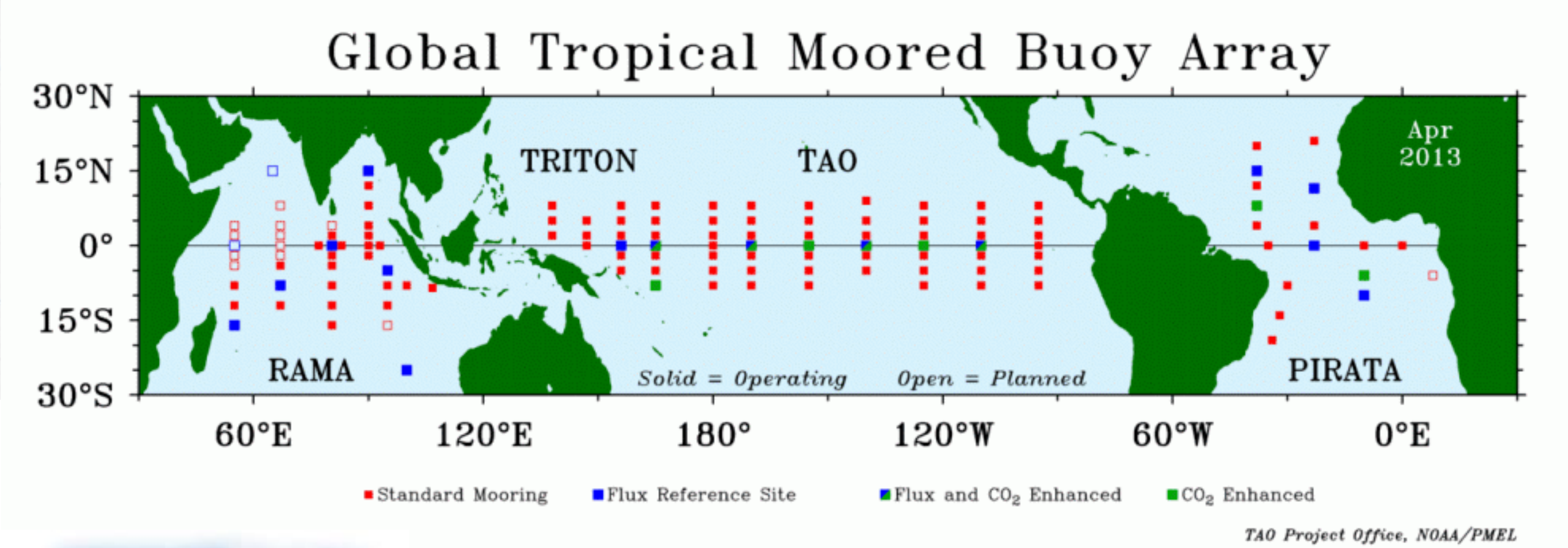
https://youtu.be/v92Iqihct98



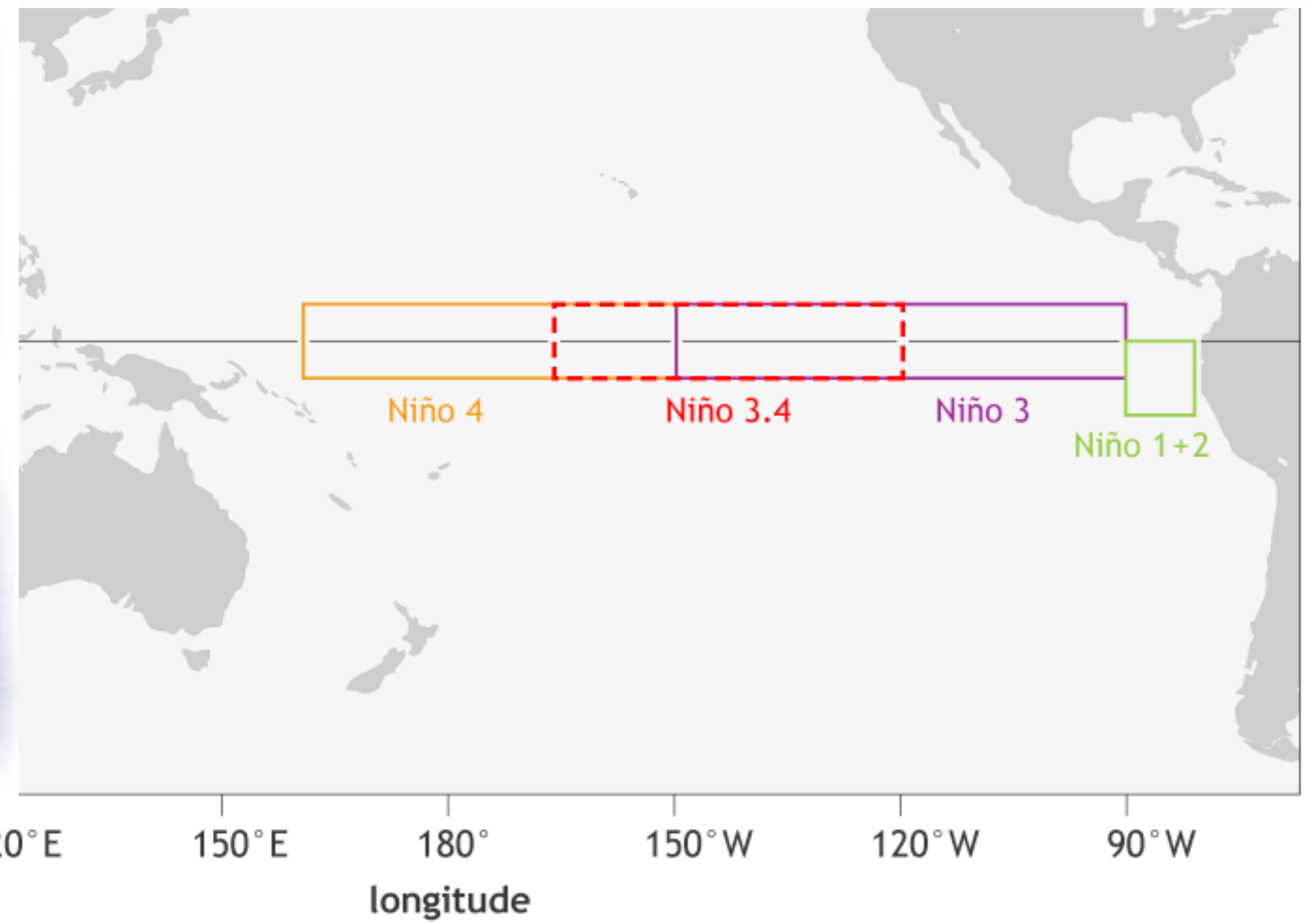
Sea surface temperature anomaly during the 2015-16 El Nino.

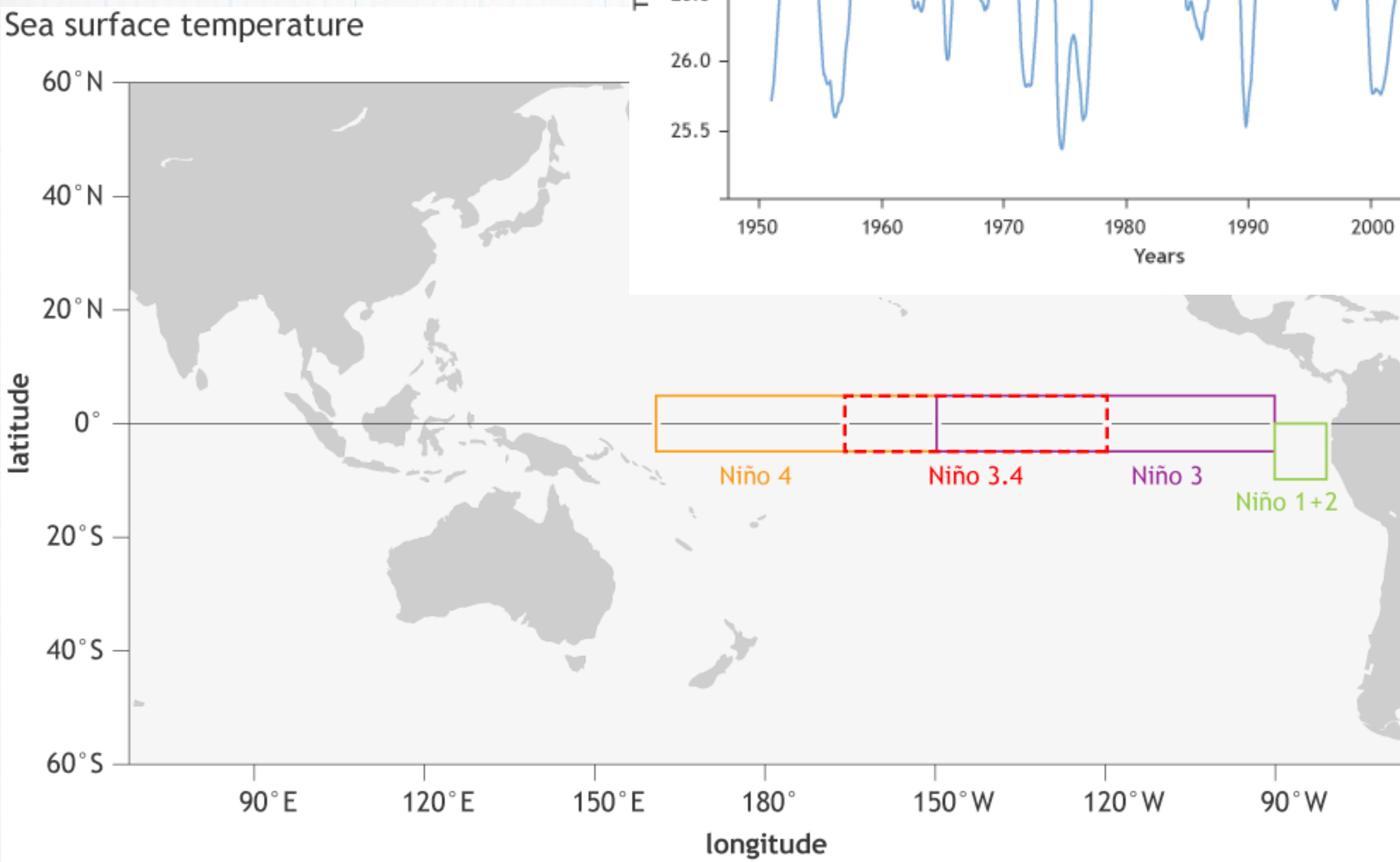


"In May, the warm anomaly across the surface of the central tropical Pacific was replaced by a strip of cooler than average waters. Still, the ENSO forecast team estimates a 60% chance that the tropical Pacific will continue in neutral this summer. The odds are evenly split for either a La Niña winter or an ENSO-neutral one."

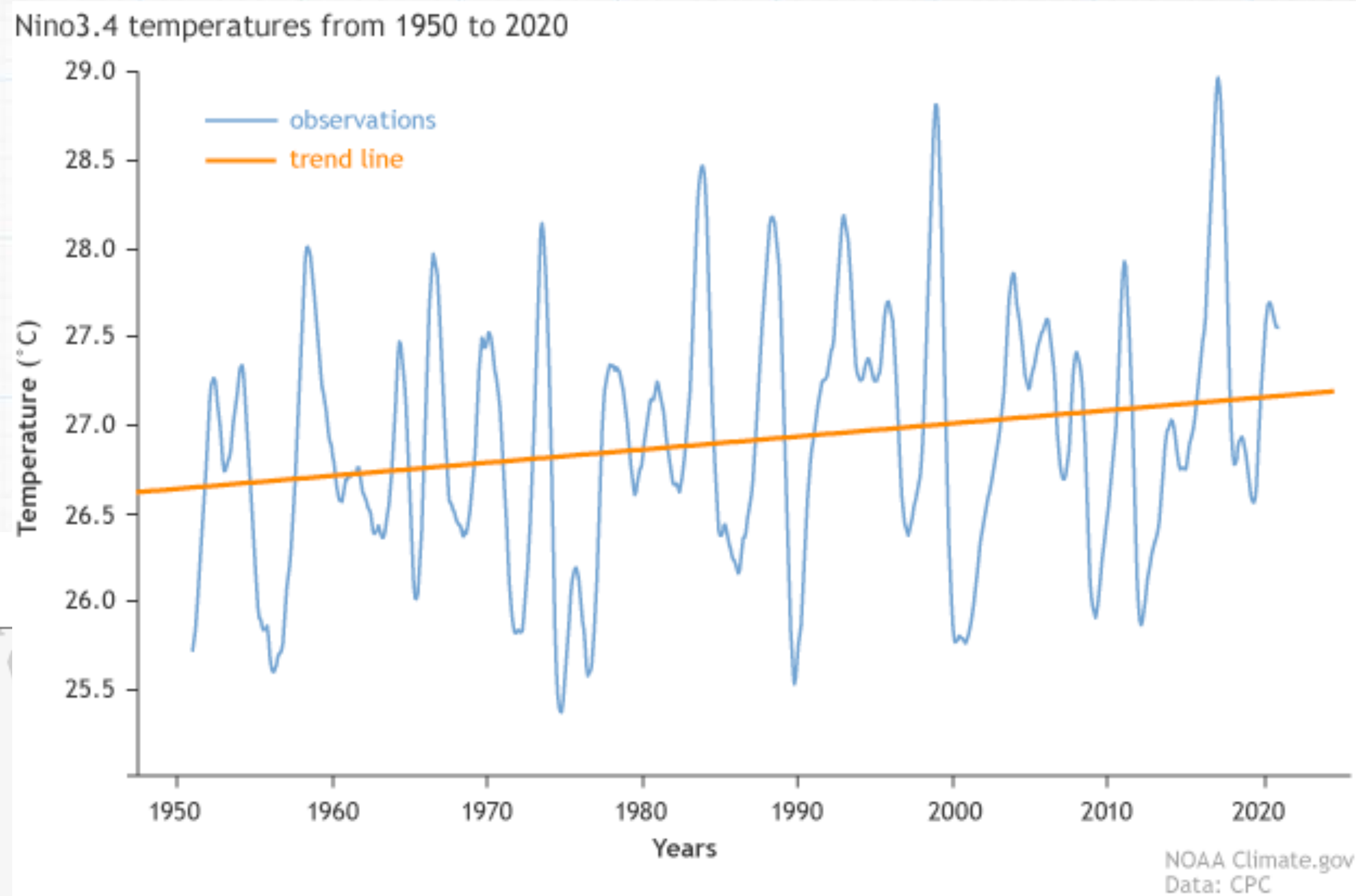

Global Tropical Moored Buoy Array
30°N
15°N
0°
15°S
30°S
60°E
120°E
180°
120°W
60°W
0°E
TRITON
TAO
RAMA
PIRATA
Apr 2013
Solid = Operating
Open = Planned
Standard Mooring
Flux Reference Site
Flux and CO_2 Enhanced
CO_2 Enhanced
TAO Project Office, NOAA/PMEL


-TAO

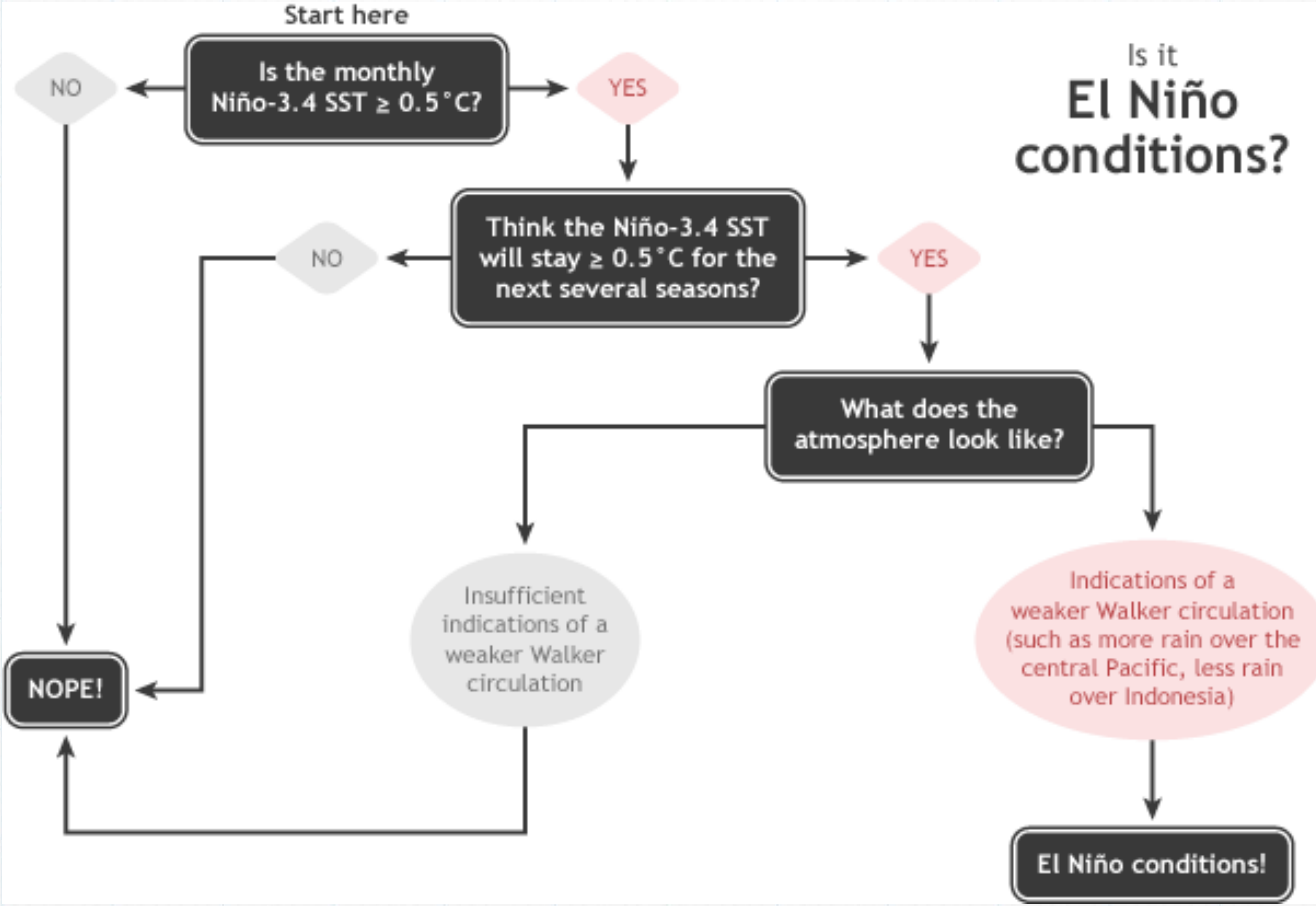

Niño 4
Niño 3.4
Niño 3
Niño 1+2
90°E
120°E
150°E
180°
150°W
120°W
90°W
longitude



Sea surface temperature
60°N
40°N
20°N
0°
20°S
40°S
60°S
latitude
90°E
120°E
150°E
180°
150°W
120°W
90°W
longitude
Niño 4
Niño 3.4
Niño 3
Niño 1+2



Nino3.4 temperatures from 1950 to 2020
29.0
28.5
28.0
27.5
27.0
26.5
26.0
25.5
Temperature (°C)
observations
trend line
1950
1960
1970
1980
1990
2000
2010
2020
Years
NOAA Climate.gov
Data: CPC



Start here
Is the monthly Niño-3.4 SST ≥ 0.5°C?
NO
YES
Is it
El Niño
conditions?
Think the Niño-3.4 SST will stay ≥ 0.5°C for the next several seasons?
NO
YES
What does the atmosphere look like?
Insufficient indications of a weaker Walker circulation
Indications of a weaker Walker circulation (such as more rain over the central Pacific, less rain over Indonesia)
NOPE!
El Niño conditions!

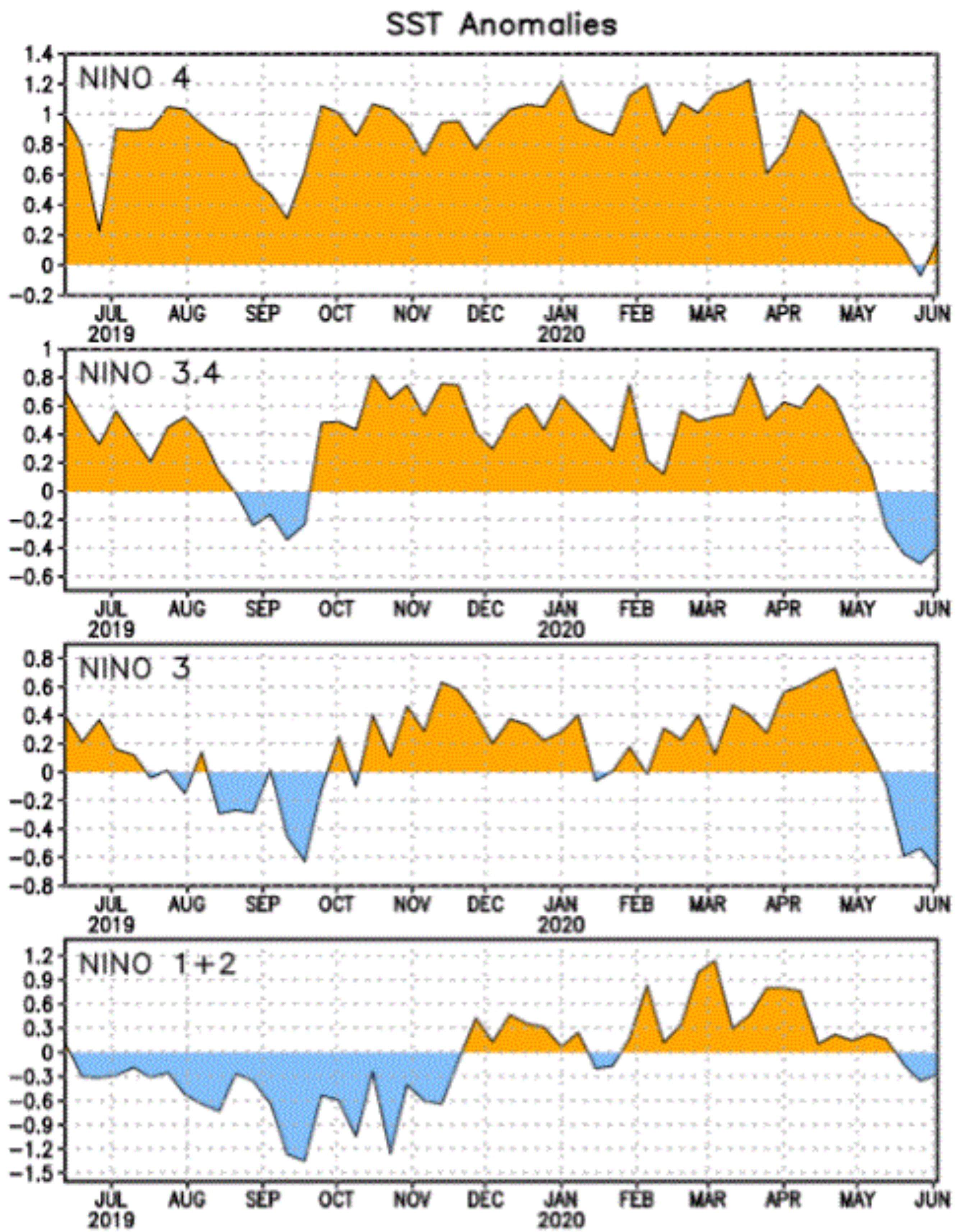


Figure 2. Time series of area-averaged sea surface temperature (SST) anomalies (°C) in the Niño regions [Niño-1+2 (0°-10°S, 90°W-80°W), Niño-3 (5°N-5°S, 150°W-90°W), Niño-3.4 (5°N-5°S, 170°W-120°W), Niño-4 (5ºN-5ºS , 150ºW-160ºE)]. SST anomalies are departures from the 1981-2010 base period weekly means.

From NOAA NWS

Year	DJF	JFM	FMA	MAM	AMJ	MJJ	JJA	JAS	ASO	SON	OND	NDJ
2000	-1.7	-1.4	-1.1	-0.8	-0.7	-0.6	-0.6	-0.5	-0.5	-0.6	-0.7	-0.7
2001	-0.7	-0.5	-0.4	-0.3	-0.3	-0.1	-0.1	-0.1	-0.2	-0.3	-0.3	-0.3
2002	-0.1	0.0	0.1	0.2	0.4	0.7	0.8	0.9	1.0	1.2	1.3	1.1
2003	0.9	0.6	0.4	0.0	-0.3	-0.2	0.1	0.2	0.3	0.3	0.4	0.4
2004	0.4	0.3	0.2	0.2	0.2	0.3	0.5	0.6	0.7	0.7	0.7	0.7
2005	0.6	0.6	0.4	0.4	0.3	0.1	-0.1	-0.1	-0.1	-0.3	-0.6	-0.8
2006	-0.8	-0.7	-0.5	-0.3	0.0	0.0	0.1	0.3	0.5	0.7	0.9	0.9
2007	0.7	0.3	0.0	-0.2	-0.3	-0.4	-0.5	-0.8	-1.1	-1.4	-1.5	-1.6
2008	-1.6	-1.4	-1.2	-0.9	-0.8	-0.5	-0.4	-0.3	-0.3	-0.4	-0.6	-0.7
2009	-0.8	-0.7	-0.5	-0.2	0.1	0.4	0.5	0.5	0.7	1.0	1.3	1.6
Year	DJF	JFM	FMA	MAM	AMJ	MJJ	JJA	JAS	ASO	SON	OND	NDJ
2010	1.5	1.3	0.9	0.4	-0.1	-0.6	-1.0	-1.4	-1.6	-1.7	-1.7	-1.6
2011	-1.4	-1.1	-0.8	-0.6	-0.5	-0.4	-0.5	-0.7	-0.9	-1.1	-1.1	-1.0
2012	-0.8	-0.6	-0.5	-0.4	-0.2	0.1	0.3	0.3	0.3	0.2	0.0	-0.2
2013	-0.4	-0.3	-0.2	-0.2	-0.3	-0.3	-0.4	-0.4	-0.3	-0.2	-0.2	-0.3
2014	-0.4	-0.4	-0.2	0.1	0.3	0.2	0.1	0.0	0.2	0.4	0.6	0.7
2015	0.6	0.6	0.6	0.8	1.0	1.2	1.5	1.8	2.1	2.4	2.5	2.6
2016	2.5	2.2	1.7	1.0	0.5	0.0	-0.3	-0.6	-0.7	-0.7	-0.7	-0.6
2017	-0.3	-0.1	0.1	0.3	0.4	0.4	0.2	-0.1	-0.4	-0.7	-0.9	-1.0
2018	-0.9	-0.8	-0.6	-0.4	-0.1	0.1	0.1	0.2	0.4	0.7	0.9	0.8
2019	0.8	0.8	0.8	0.7	0.6	0.5	0.3	0.1	0.1	0.3	0.5	0.5
Year	DJF	JFM	FMA	MAM	AMJ	MJJ	JJA	JAS	ASO	SON	OND	NDJ
2020	0.5	0.6	0.5	0.3								

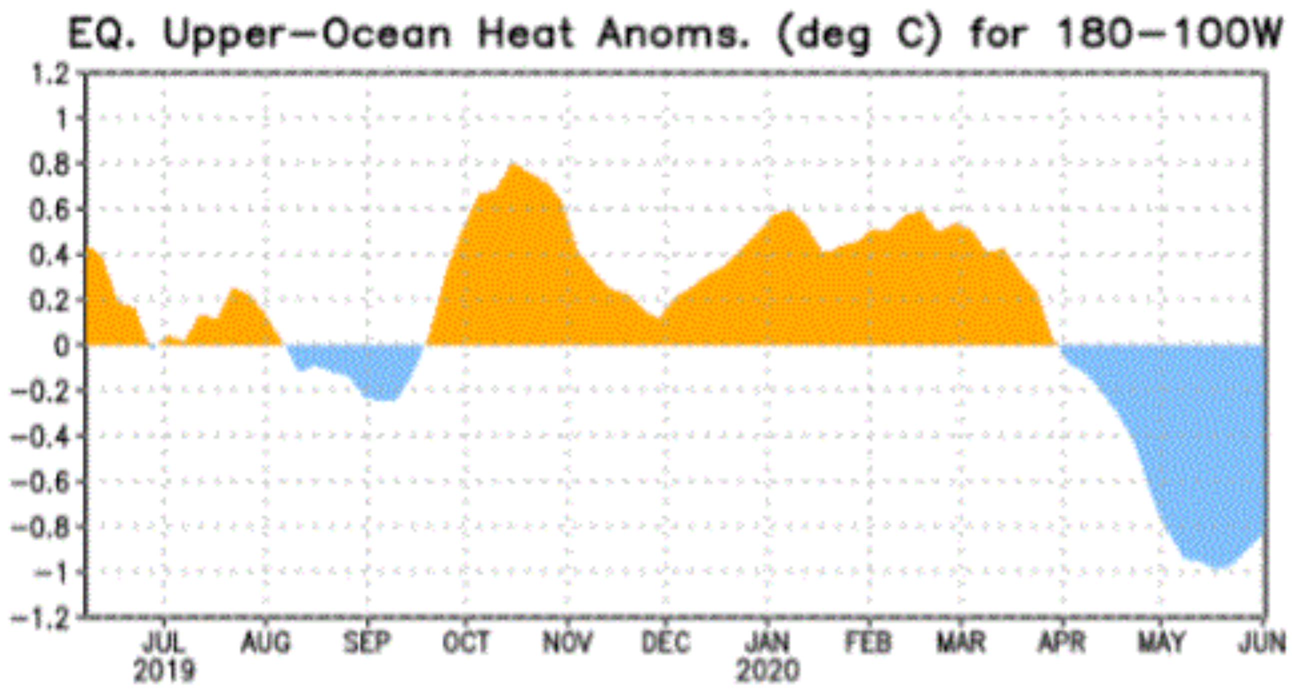


Figure 3. Area-averaged upper-ocean heat content anomaly (°C) in the equatorial Pacific (5°N-5°S, 180º-100ºW). The heat content anomaly is computed as the departure from the 1981-2010 base period pentad means.

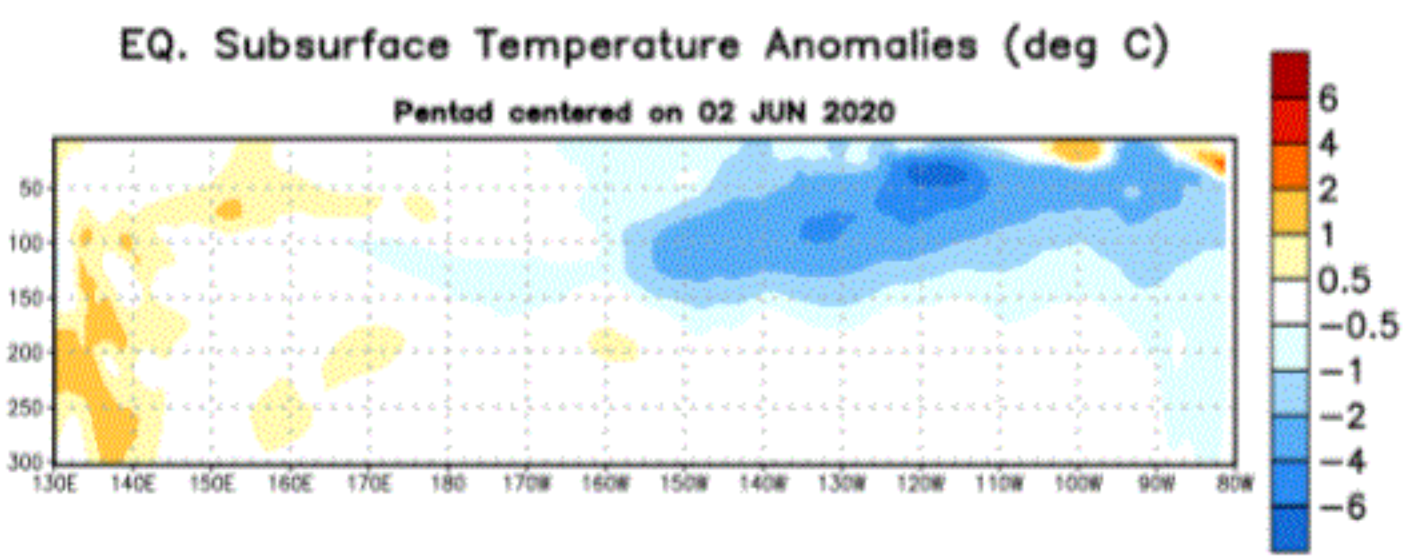
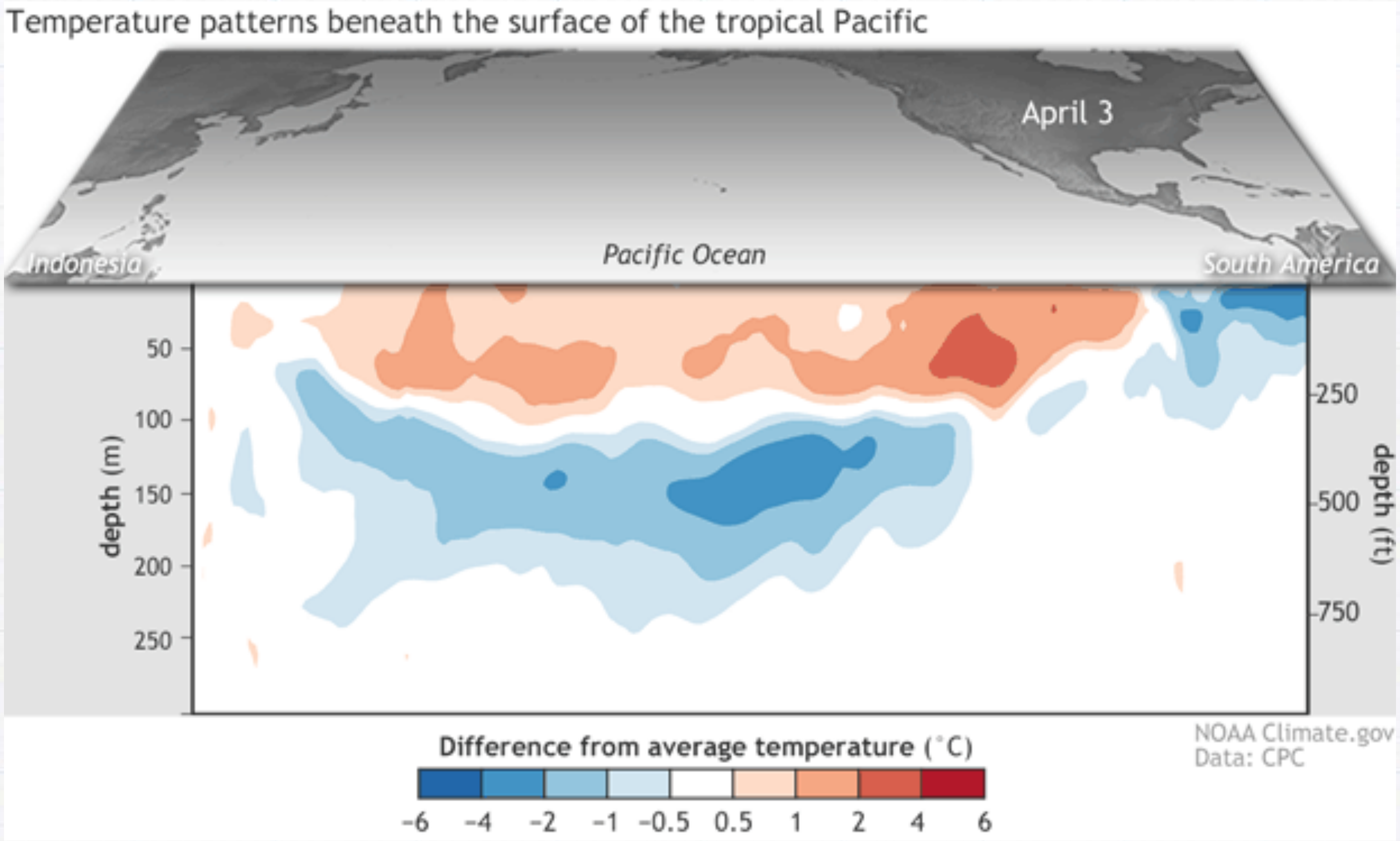


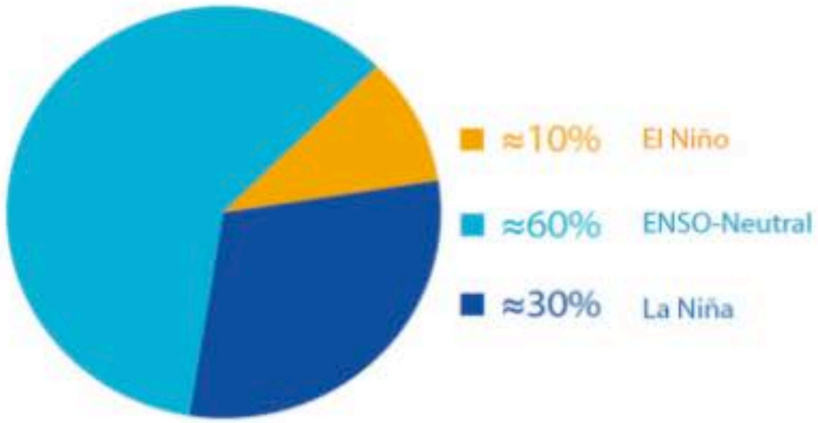
Figure 4. Depth-longitude section of equatorial Pacific upper-ocean (0-300m) temperature anomalies (°C) centered on the pentad of 2 June 2020. Anomalies are departures from the 1981-2010 base period pentad means.


Temperature patterns beneath the surface of the tropical Pacific
April 3
Indonesia
Pacific Ocean
South America
depth (m)
50
100
150
200
250
depth (ft)
250
500
750
Difference from average temperature (˚C)
−6 −4 −2 −1 −0.5 0.5 1 2 4 6
NOAA Climate.gov
Data: CPC

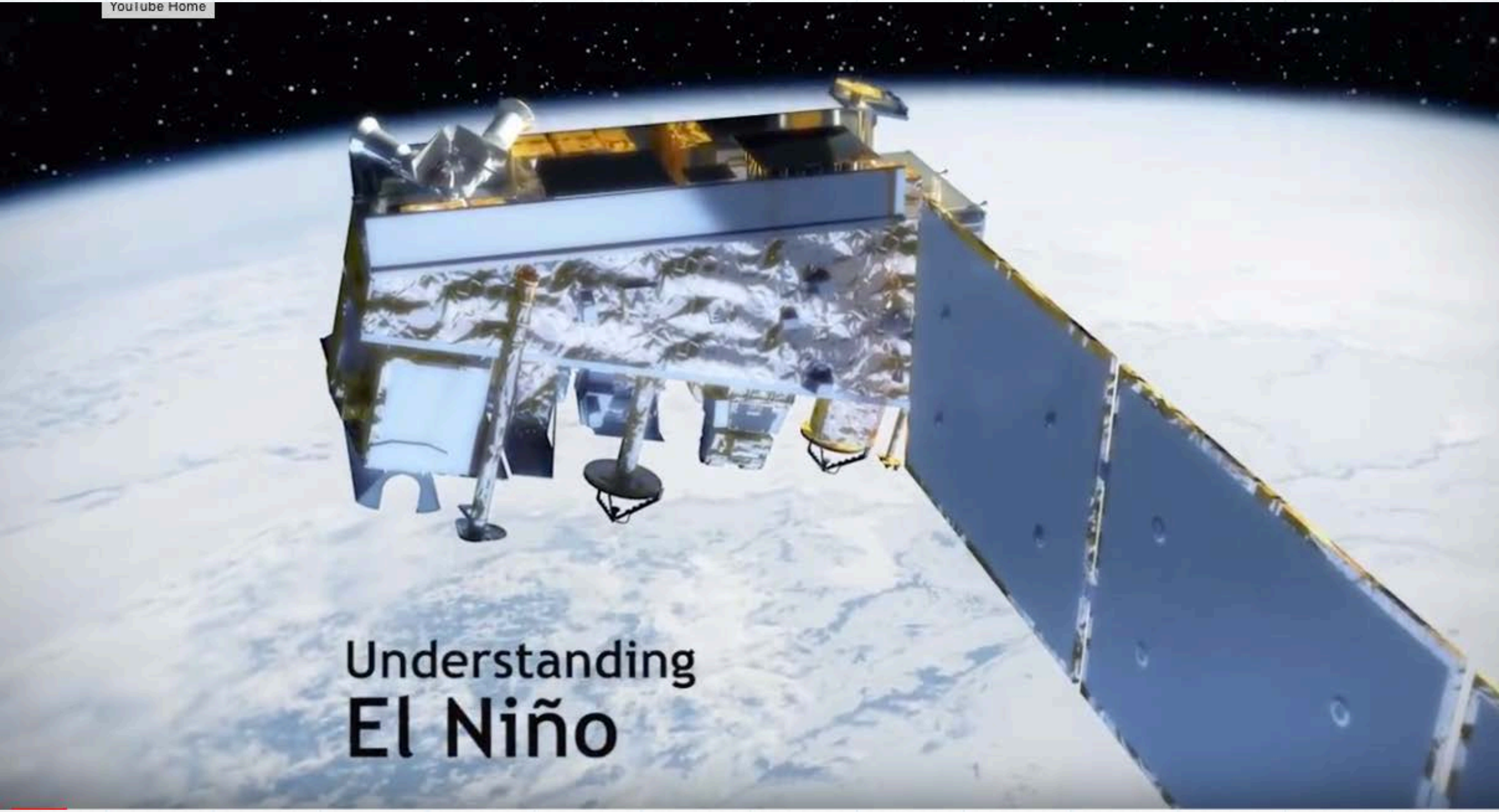
In summary:

- The tropical Pacific has been ENSO-neutral since July 2019. Near-to-above-average sea surface temperatures were observed from October 2019 until April 2020, after which temperatures returned to near-average levels.
- Current observations show below-average sub-surface water temperatures in the tropical Pacific, suggesting a likely tendency towards further decreases in sea surface temperature, with some chance of approaching La Niña thresholds during the second half of 2020.
- Model predictions and expert opinion indicate a 60% chance of ENSO-neutral conditions continuing during June-August 2020, while that for La Niña is 30% and for El Niño is 10%. For the September-November 2020 season, the chance for ENSO-neutral is 50%, and that for La Niña is 40% and for El Niño is 10%.

ESTIMATED ENSO PROBABILITIES FOR JUNE-AUGUST 2020



- Sea surface temperature departures from the average in the east-central Pacific Ocean are most likely to be in the range from -0.6 to +0.3 degrees Celsius during June-August 2020, and from -0.9 to +0.1 degrees during September-November 2020.



https://youtu.be/_Tuou_QcgxI

ENSO arises from changes across the tropical Pacific Ocean. So why does ENSO affect the climate over sizable portions of the globe?

Warmer SST in the central and eastern tropical Pacific Ocean

↓

Warmer air, more moisture

↓

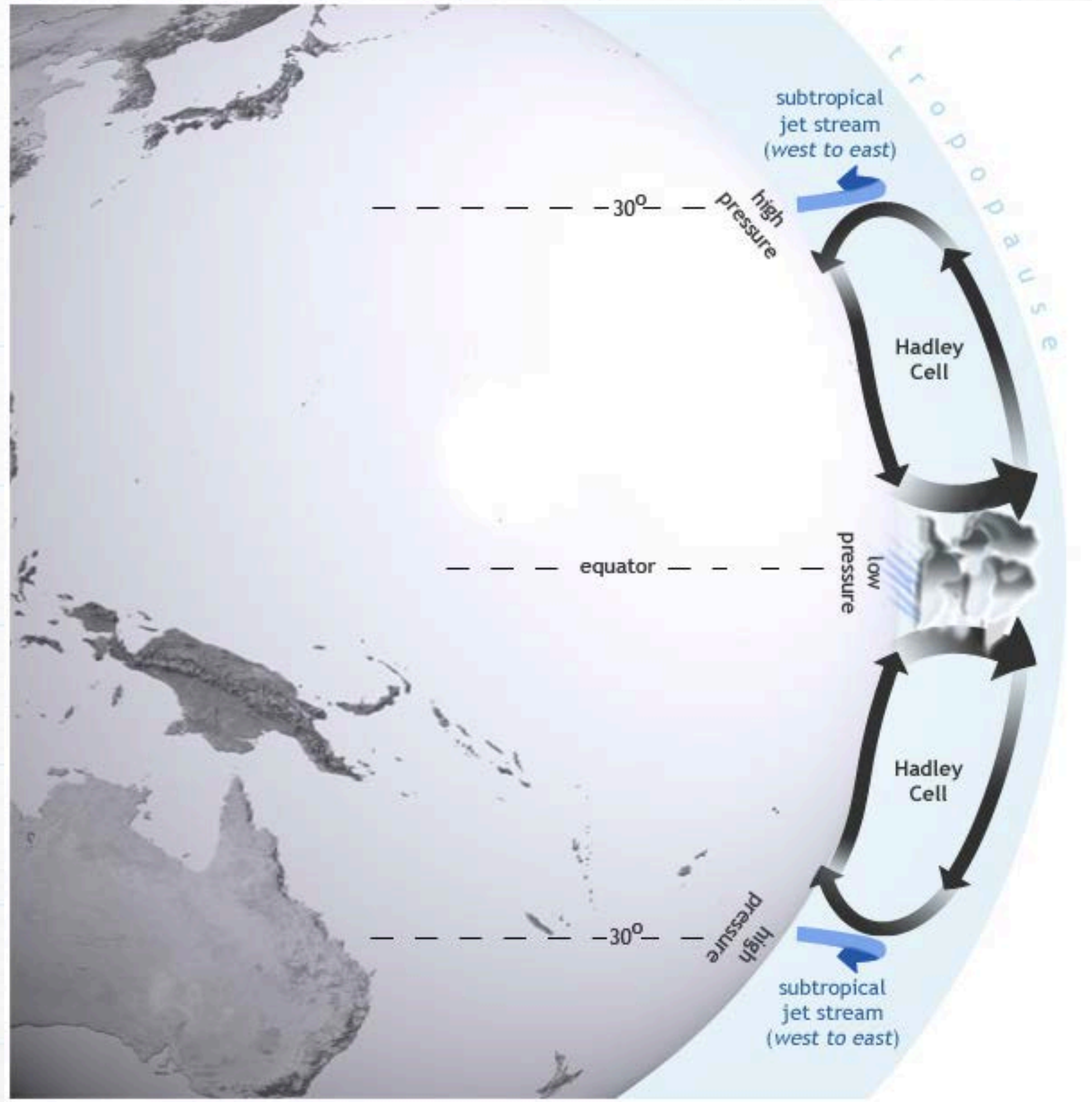
Convection and precipitation, Latent heat release

↓

Stronger Hadley circulation

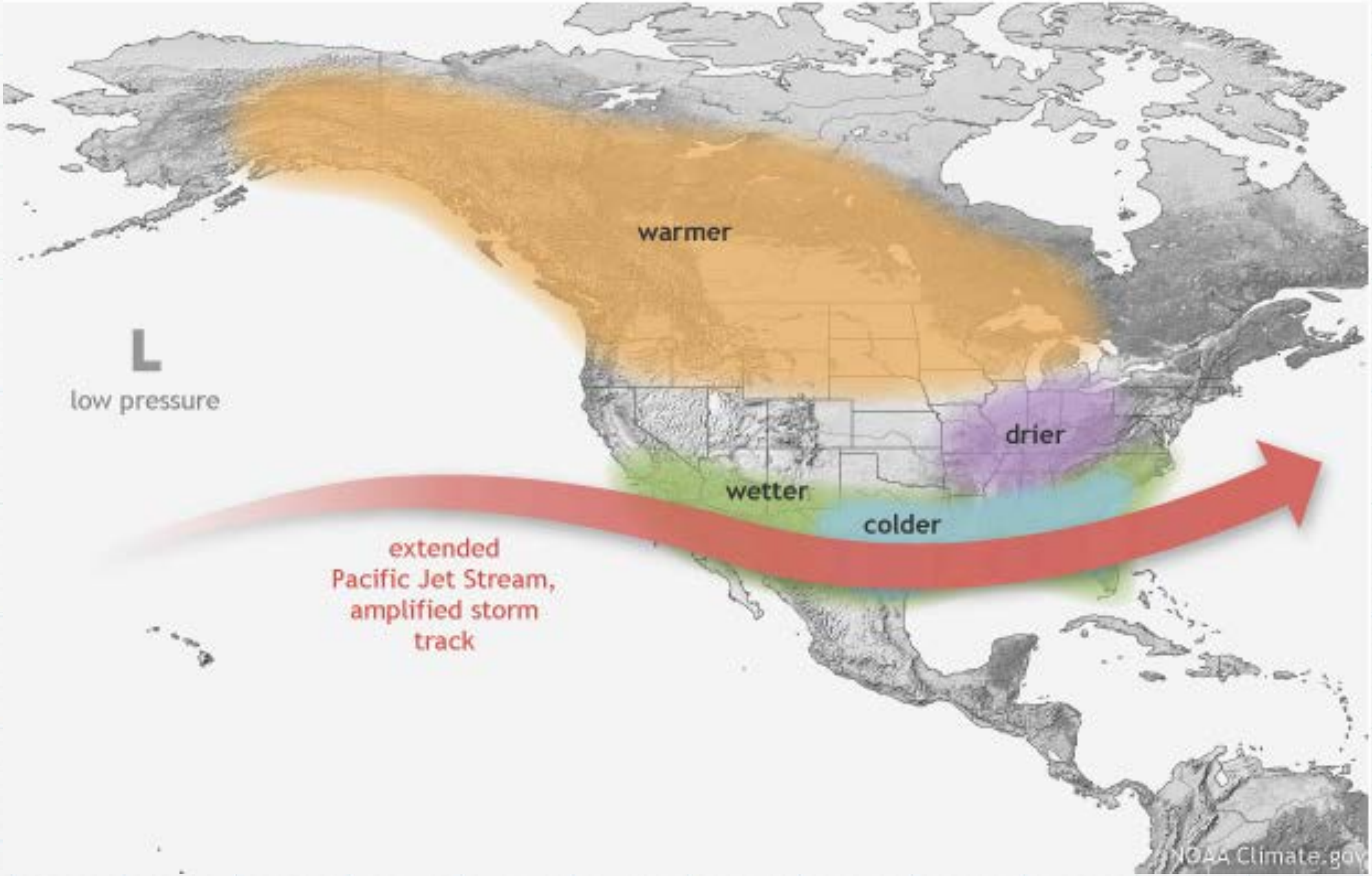
↓

Stronger Hadley circulation, affecting jet stream

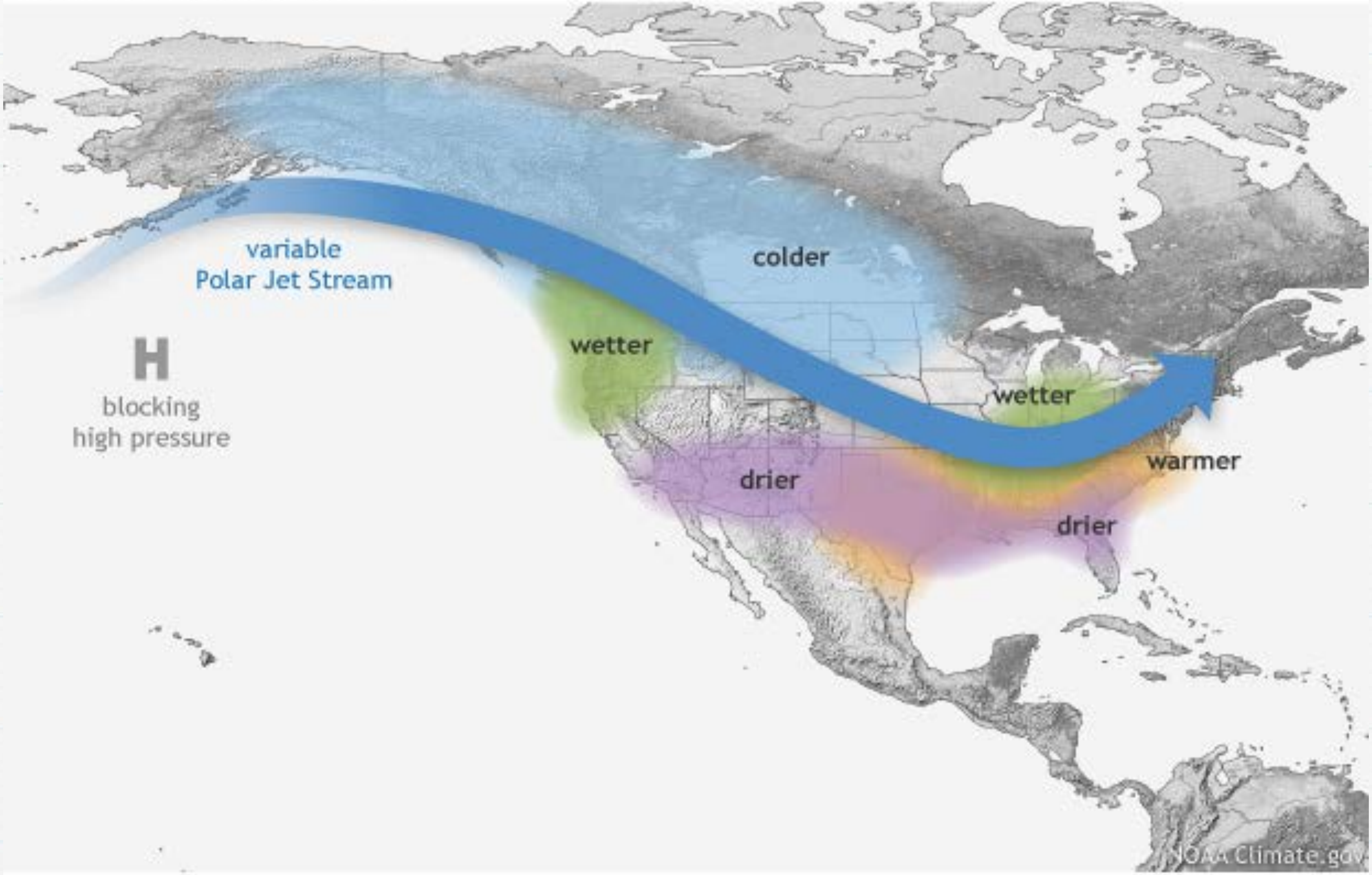


El Niño influences global atmospheric circulation by intensifying the Hadley circulation, in which heat is transferred from the Earth's surface to the upper atmosphere through convection and latent heating. Map by NOAA Climate.gov.

WINTER EL NIÑO PATTERN

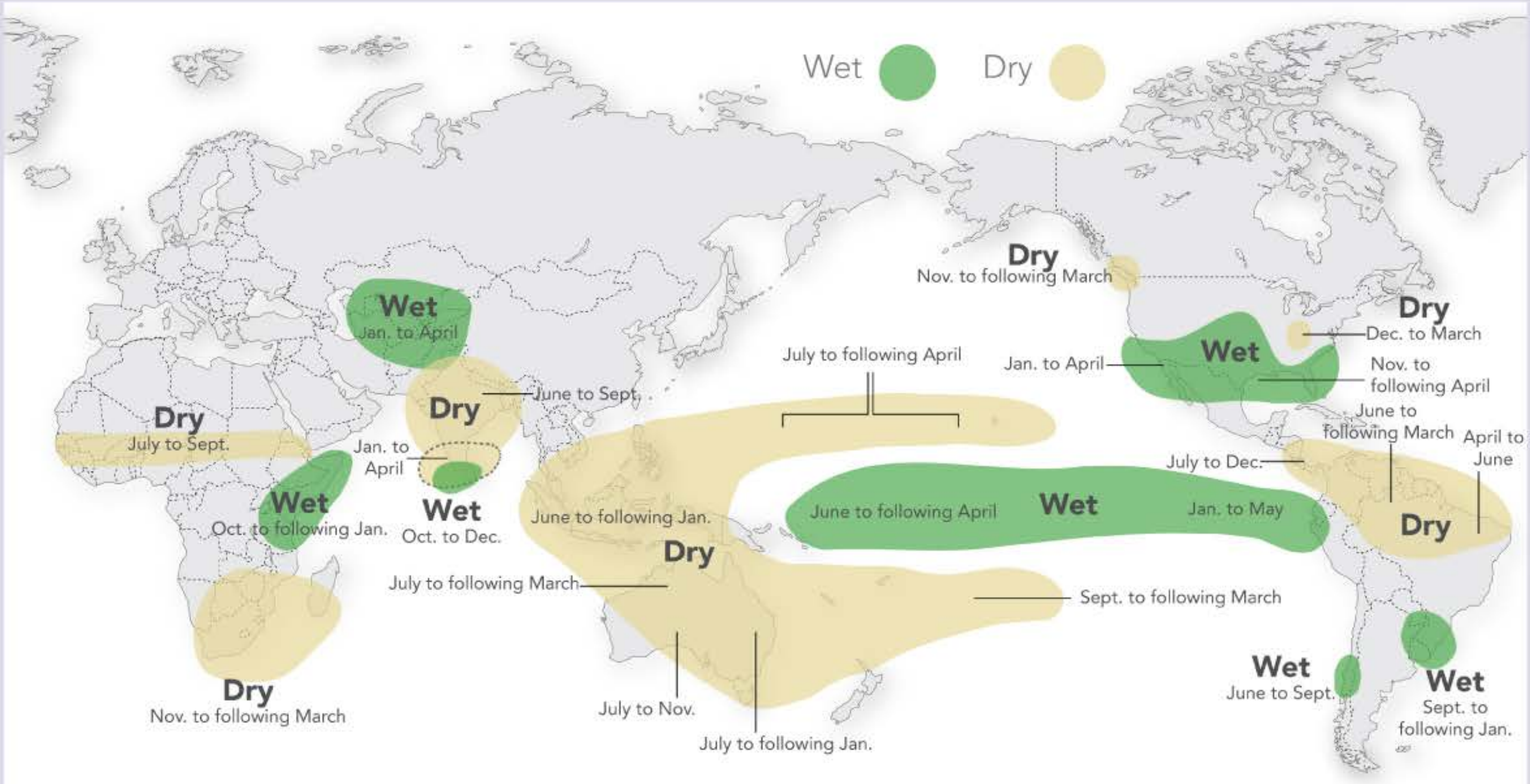


WINTER LA NIÑA PATTERN



El Niño and Rainfall

El Niño conditions in the tropical Pacific are known to shift rainfall patterns in many different parts of the world. Although they vary somewhat from one El Niño to the next, the strongest shifts remain fairly consistent in the regions and seasons shown on the map below.



For more information on El Niño and La Niña, go to: http://iri.columbia.edu/enso/

Sources:
1. Ropelewski, C. F., and M. S. Halpert, 1987: Global and regional scale precipitation patterns associated with the El Nino Southern Oscillation. Mon. Wea. Rev., 115, 1606-1626;
2. Mason and Goddard, 2001. Probabilistic precipitation anomalies associated with ENSO. Bull. Am. Meteorol. Soc. 82, 619-638

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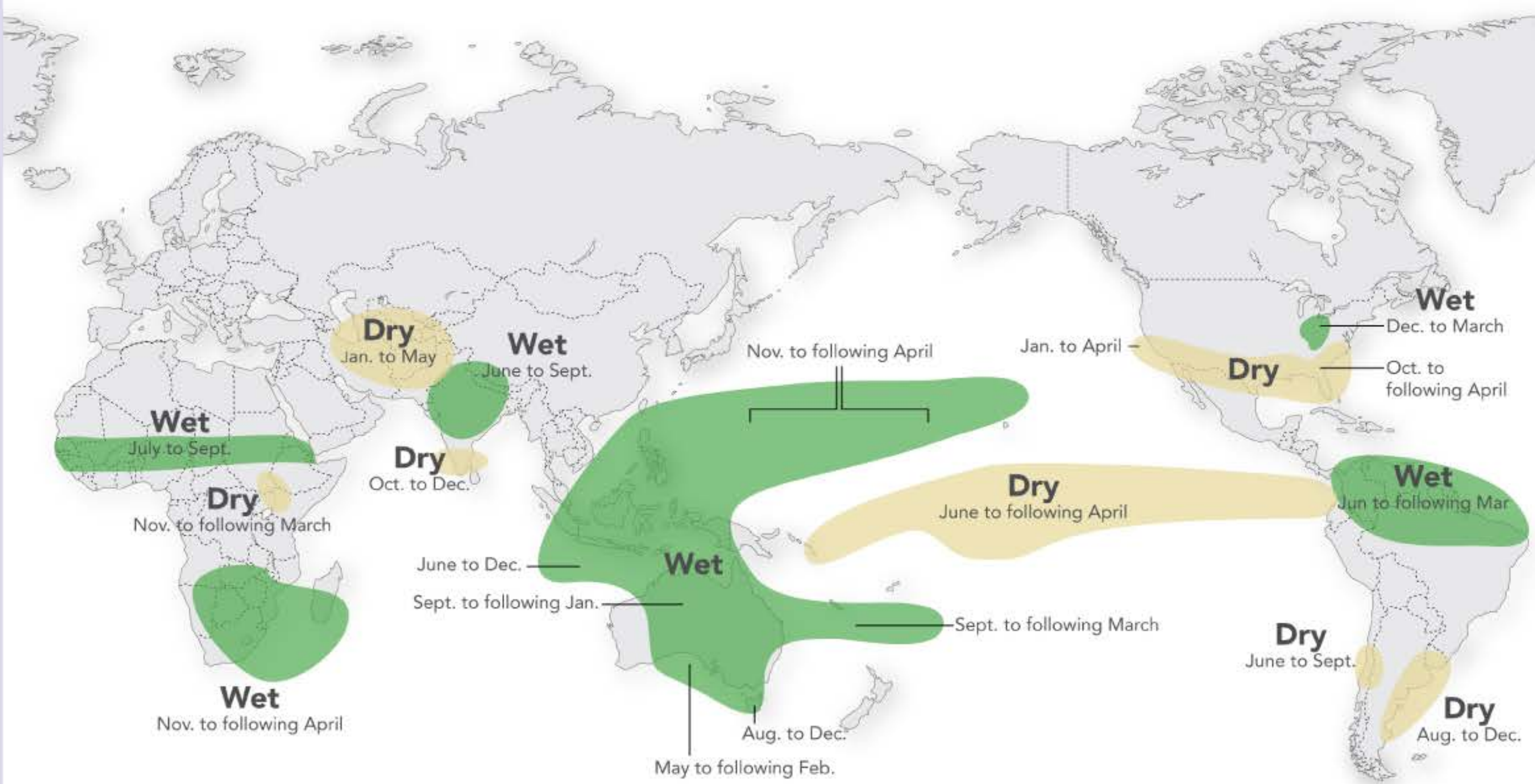
La Niña and Rainfall

La Niña conditions in the tropical Pacific are known to shift rainfall patterns in many different parts of the world. Although they vary somewhat from one La Niña to the next, the strongest shifts remain fairly consistent in the regions and seasons shown on the map below.



For more information on El Niño and La Niña, go to: http://iri.columbia.edu/enso

Sources:

1. Ropelewski, C. F. and M. S. Halpert, 1989: Precipitation patterns associated with the high index phase of the Southern Oscillation. J. Climate., 2, 268 284,
2. Mason and Goddard, 2001. Probabilistic precipitation anomalies associated with ENSO. Bull. Am. Meteorol. Soc. 82, 619-638

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