Monitoring the El Niño - Southern Oscillation (ENSO)

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(1) Axiom for the NOAA/WPC International Desks

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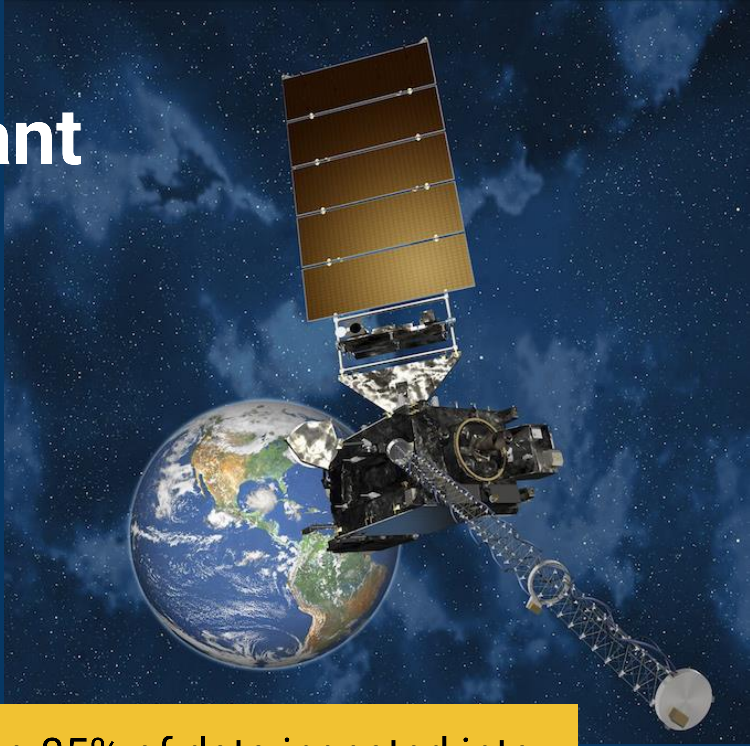
Sponsored by the AMS Committee on Satellite Meteorology, Oceanography, and Climatology

Why are satellite tools important for ENSO monitoring?

- Satellite tools are key for the monitoring of the ocean-atmospheric system.
- The key advantage is their high resolution in space and time.
- Disadvantage: potential biases in comparison with in situ observations from ships, buoys and Argo Floats.



…also 85% of data ingested into numerical models comes from satellites! Models would be terrible without satellite data.

Outline of Today's Presentation

- This session will focus on a general overview of the El Nino - Southern Oscillation (ENSO) and the teleconnections, regional trends, and effects, including drought, flooding, etc.

- We will present different satellite tools that can be used for the monitoring and forecasting of ENSO. This includes a description of the tool, access and application methods.

- We will look into some exercises that consider evaluating some satellite product fields to discuss what might happen with evolution of SST that might affect the ENSO system.

The WPC International Desks: Who are we?

NOAA-WMO Training program on weather analysis and forecasting to support capacity building in National Weather Services in the Americas, since 1988.

https://www.wpc.ncep.noaa.gov/international/intl2.shtml

Mission: to enhance forecasting practices by

- Providing onsite training to forecasters from institutions of the Americas via the Tropical and South American Desks
- Workshops and virtual training sessions.
- Providing IDSS before and during extreme events, including Tropical Cyclone Emergencies.
- Developing and facilitating forecasting tools (R2O)
- Strengthening ties in the international weather community.
- Collecting feedback from international partners to improve US NWS Services such as NWP and satellite product improvements.

Contact us at wpc.international@noaa.gov

Workshops and Training

What makes a workshop spectacular ?

- Considering it as an open shared discussion, where anyone can contribute equally. Lets converse because every comment is a contribution.

- In Geoscience there are no rights and wrongs. We are far from knowing 100% and probably never will. There is no such thing as a bad or unnecessary question or comment.

- The more we share and discuss, the more we learn as a group.

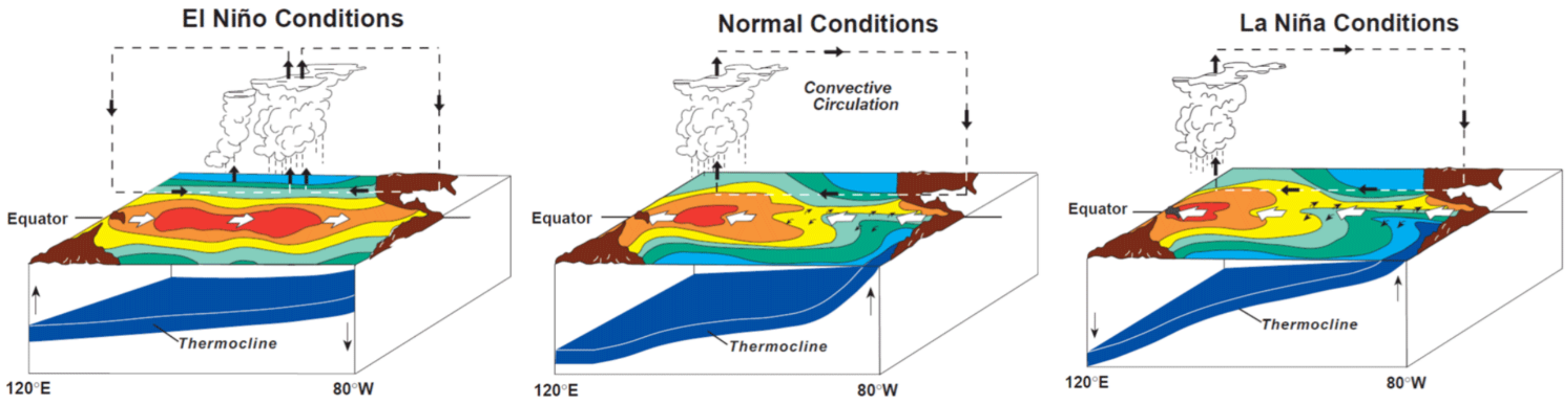
Part I

Overview of the El Nino - Southern Oscillation (ENSO)

and Global Impacts

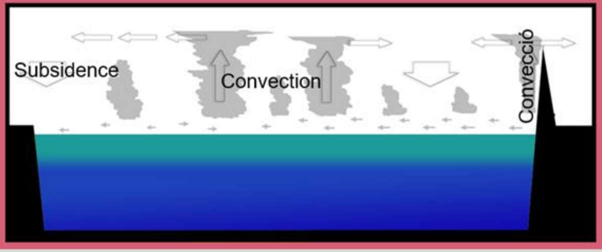
El Niño-Southern Oscillation (ENSO)

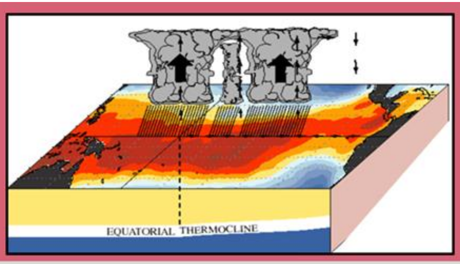
- ENSO is the dominant interannual variability of Earth's climate system.
- It is an oscillation of warming **(El Niño)** and cooling **(La Niña)** changes in the sea surface temperature (SST) in the central and eastern tropical Pacific ocean, which associate with changes in atmospheric circulations and climate.



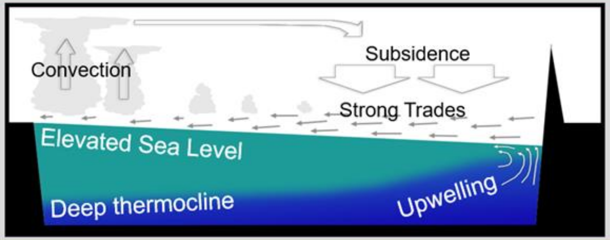
Phases of ENSO

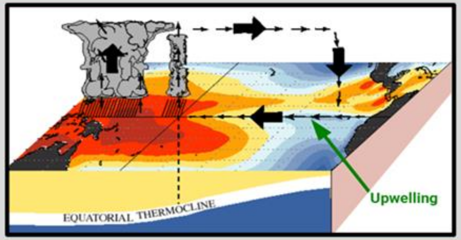
El Niño





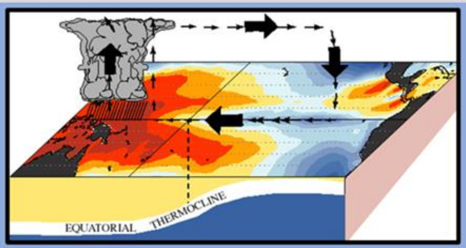
Normal or Neutral





La Niña

… is an exacerbation of the assymetries seen in normal conditions.



Why the name? El Niño Southern Oscillation

El Niño (EN)

Peruvian fishermen in Spanish Viceroyalty times (1600-1800's), used the term **"El Niño current"** to describe an annual warming of the ocean that occurred near Christmas time ("Jesus child" or "El Niño Jesús").

They used the term **"El Niño Phenomenon"** when on occasions, the warming was extreme and caused heavy rainfall, floods and changes in the fisheries.

Southern Oscillation (SO)

Severe droughts in India in 1877 and 1888 prompted research. After several contributors, Sir Gilbert Walker made the most coherent analysis and named the oscillation. The SO Refers to a 'seesaw' of the atmospheric pressure between the Pacific and Indian Oceans.

S. Hastenrath, in Encyclopedia of Atmospheric Sciences, 2003

ENSO

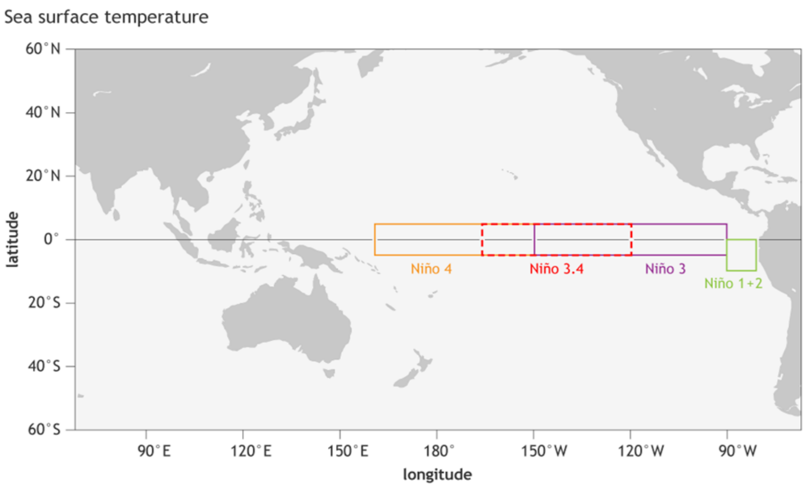
Jakob Bjerknes is who made the first link between El Niño and the Southern Oscillation in the 1960's

ENSO Monitoring

ENSO is complex. Not easily measured with one index.

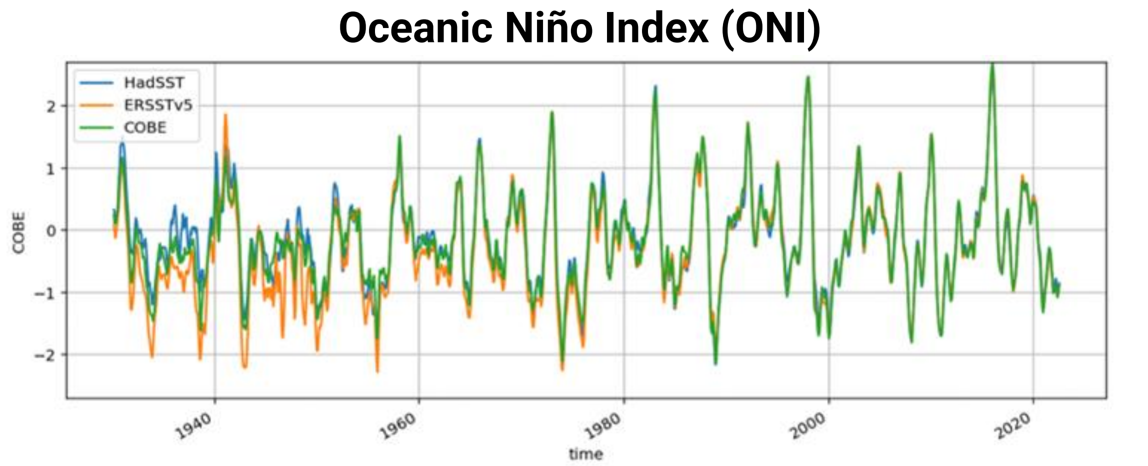
Regardless Niño-3.4/ONI CPC's official index because:

- Highly correlated with other components of ENSO (pressure, winds, convection).
- Computational simplicity.
- Considerable development effort went into creating long, quality-controlled records of SST (ERSST, HadSST, COBE) that increase sample size and enable comparisons with previous ENSO events.
- The +/-0.5C threshold enables NOAA to declare the occurrence of El Niño and La Niña (*user requested definition)*

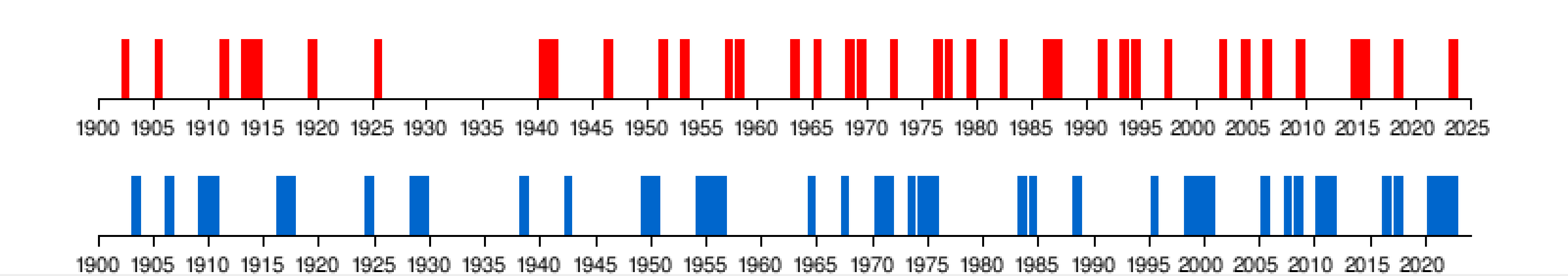


ENSO Recurrence

ENSO warm or cold conditions occur every few years and last for about a year, but they are non-periodic.



Courtesy of Michelle L’Heureux (CPC)



But WHY do we care so much about ENSO?

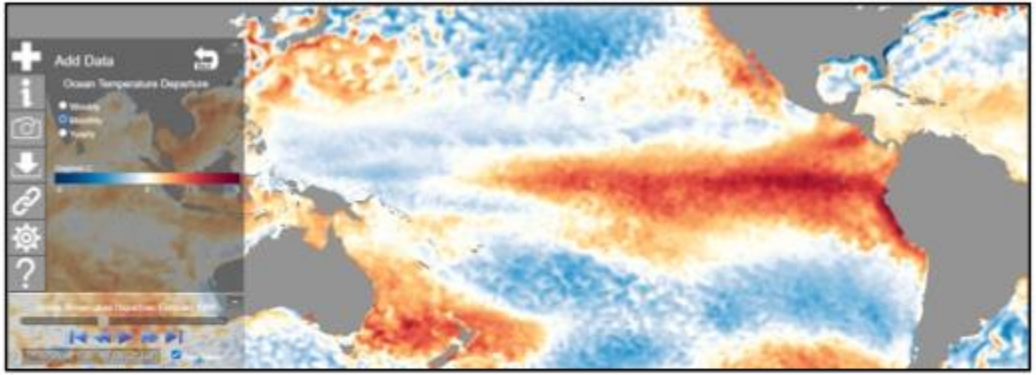
Because ENSO Impacts the weather and climate globally, and these impacts can be significant.

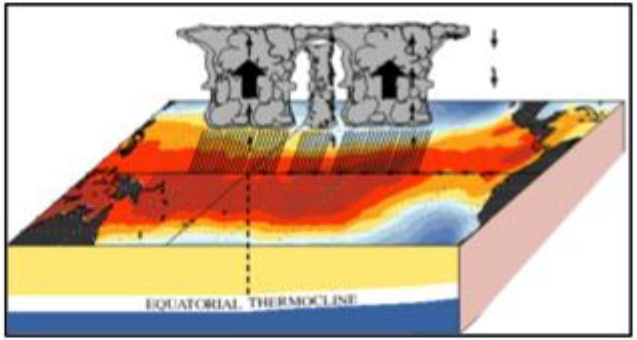
But these impacts depend as well on interactions with other components of the climate system. We cannot blame a weather event JUST on ENSO

ENSO Impacts

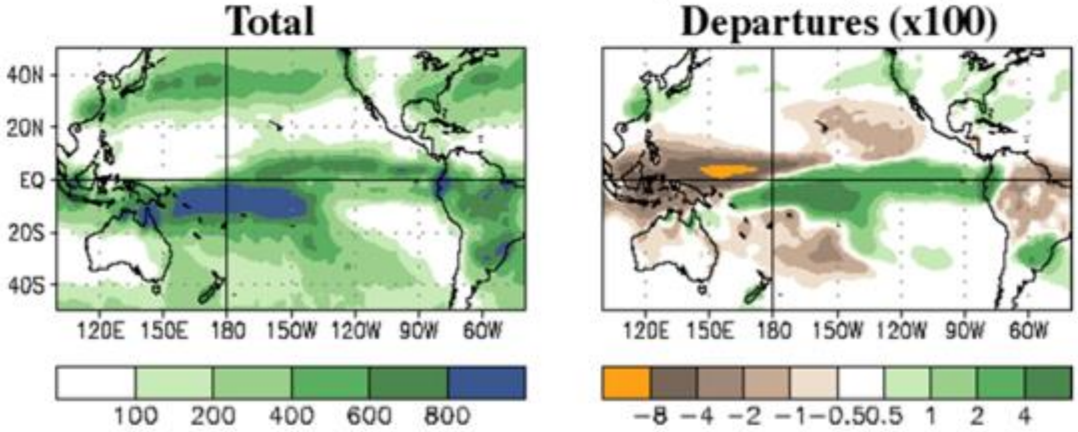
1998 El Niño

Feb 1998 SST Anomalies



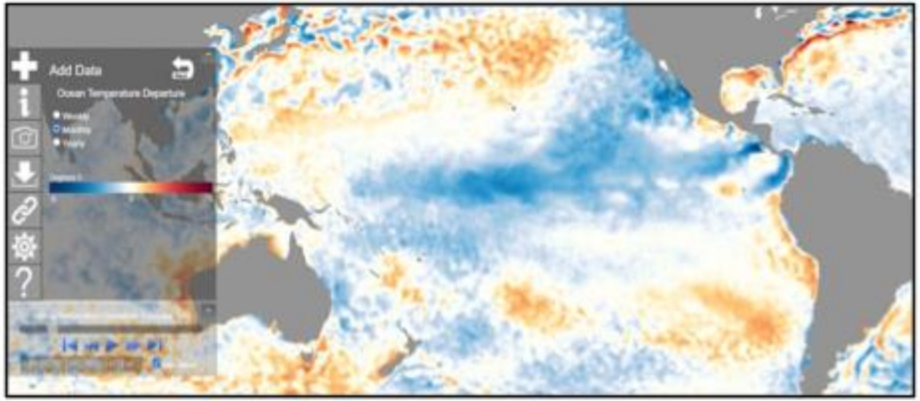


Jan-Mar 1998 Precipitation (mm)



1989 La Niña

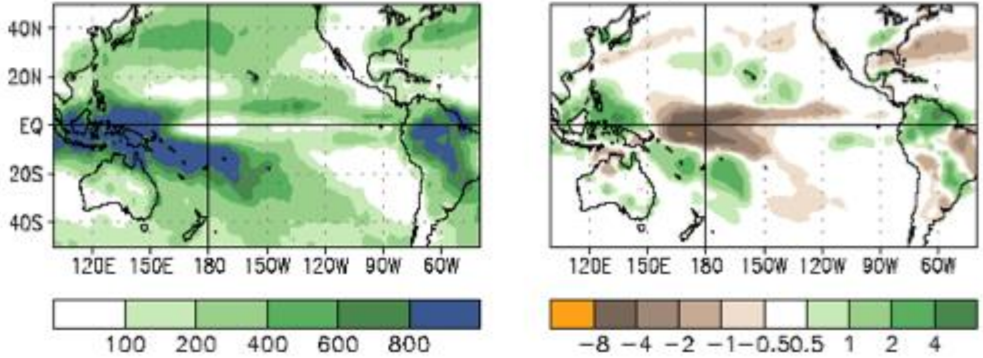
Feb 1989 SST Anomalies

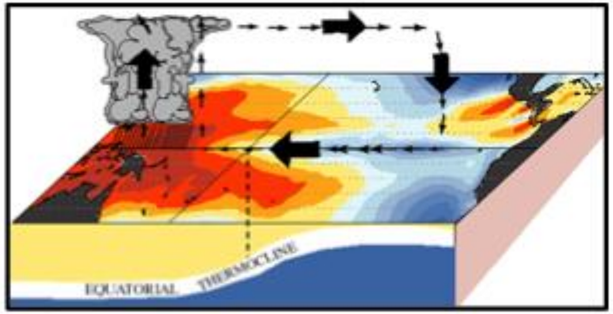


Jan-Mar 1989 Precipitation (mm)

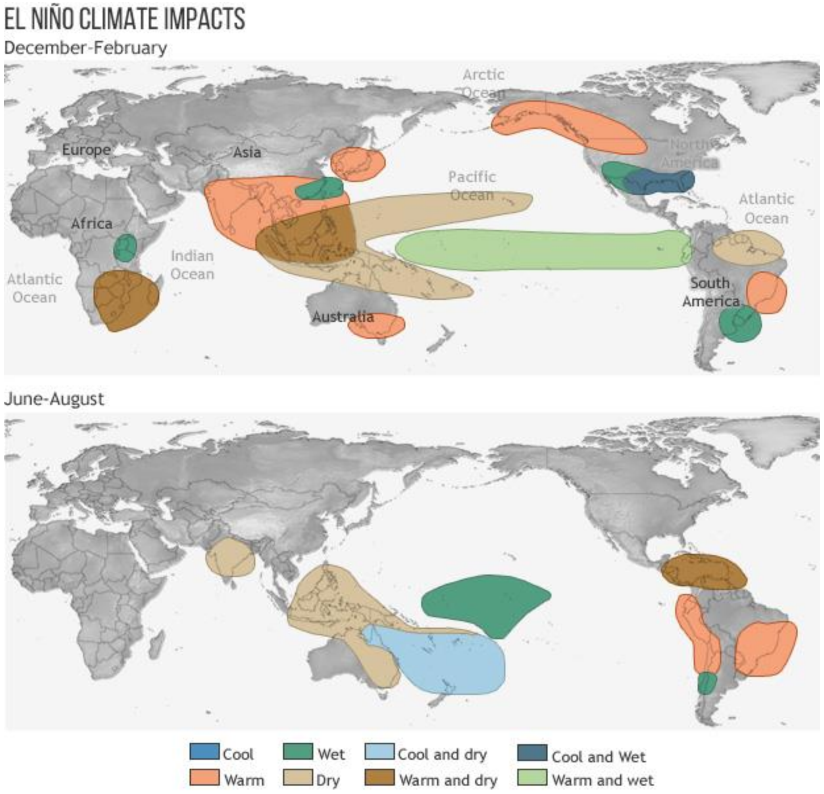
Total

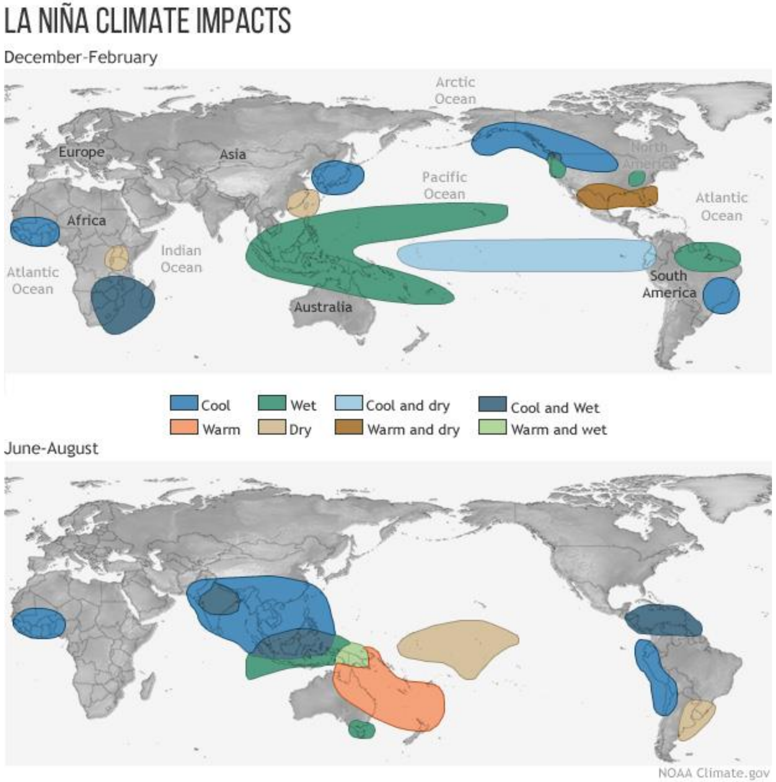
Departures (x100)





Impacts occur Globally

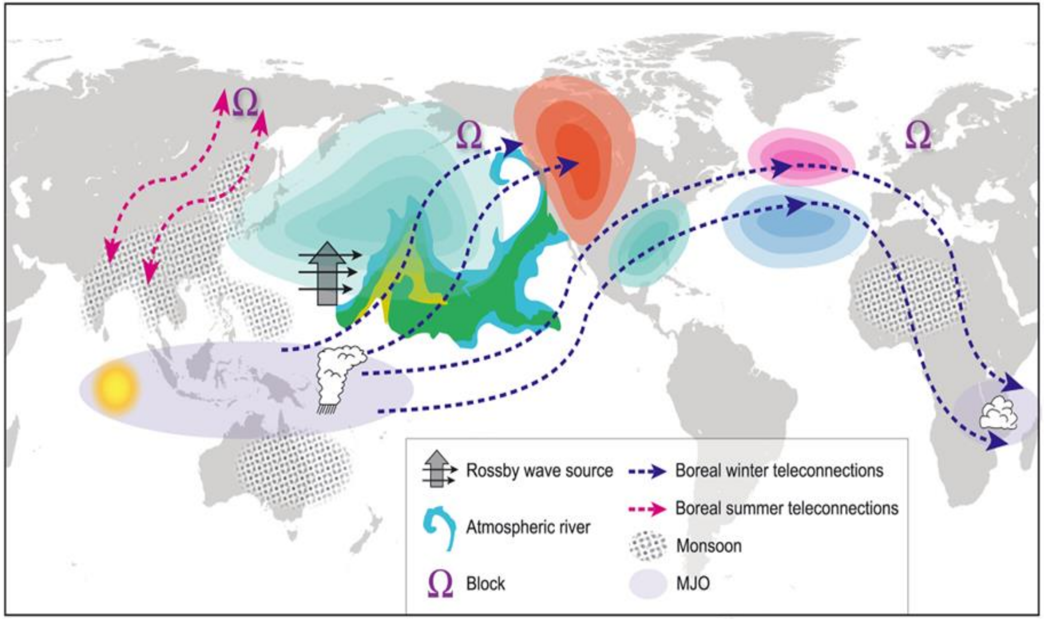




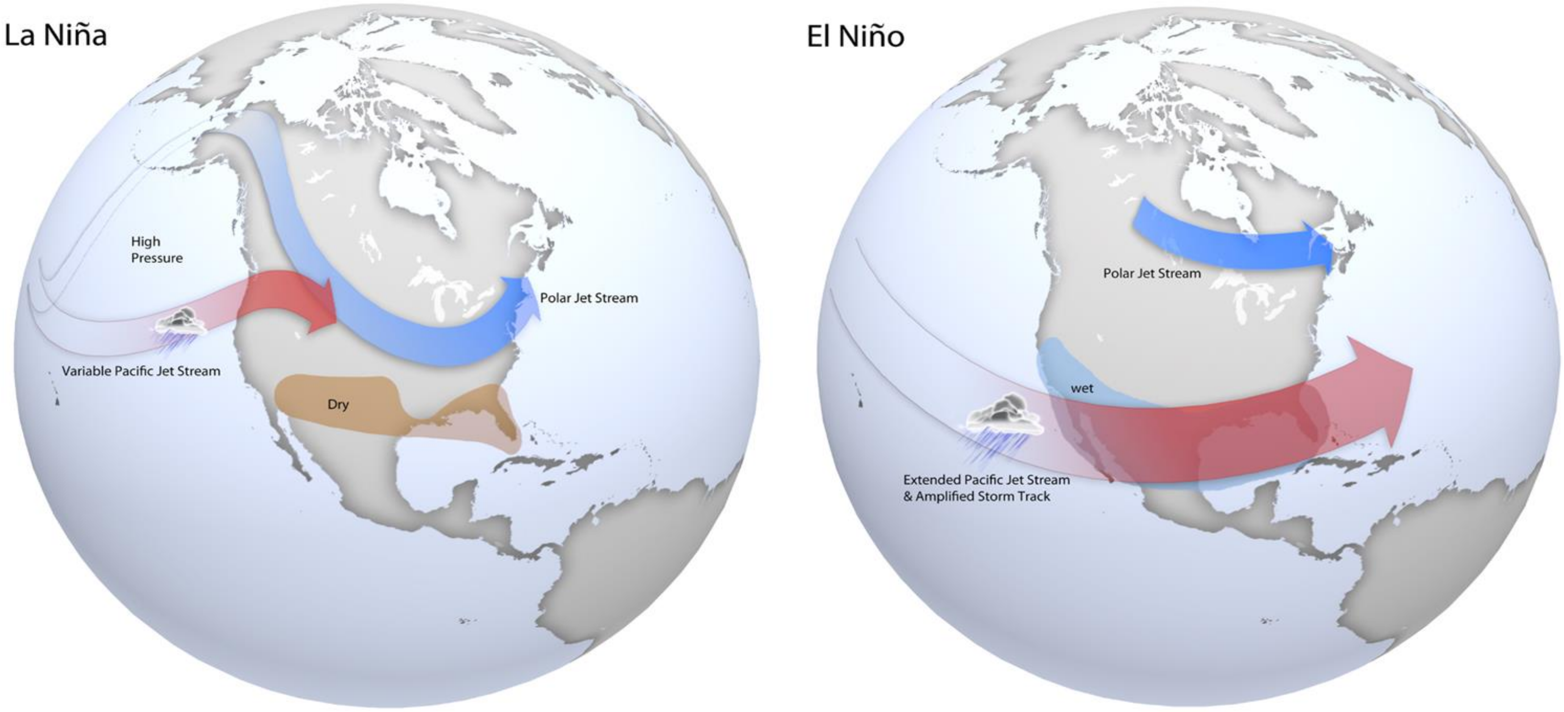
Teleconnection

“Relationship between changes in the climate in areas separated by very long distances.”

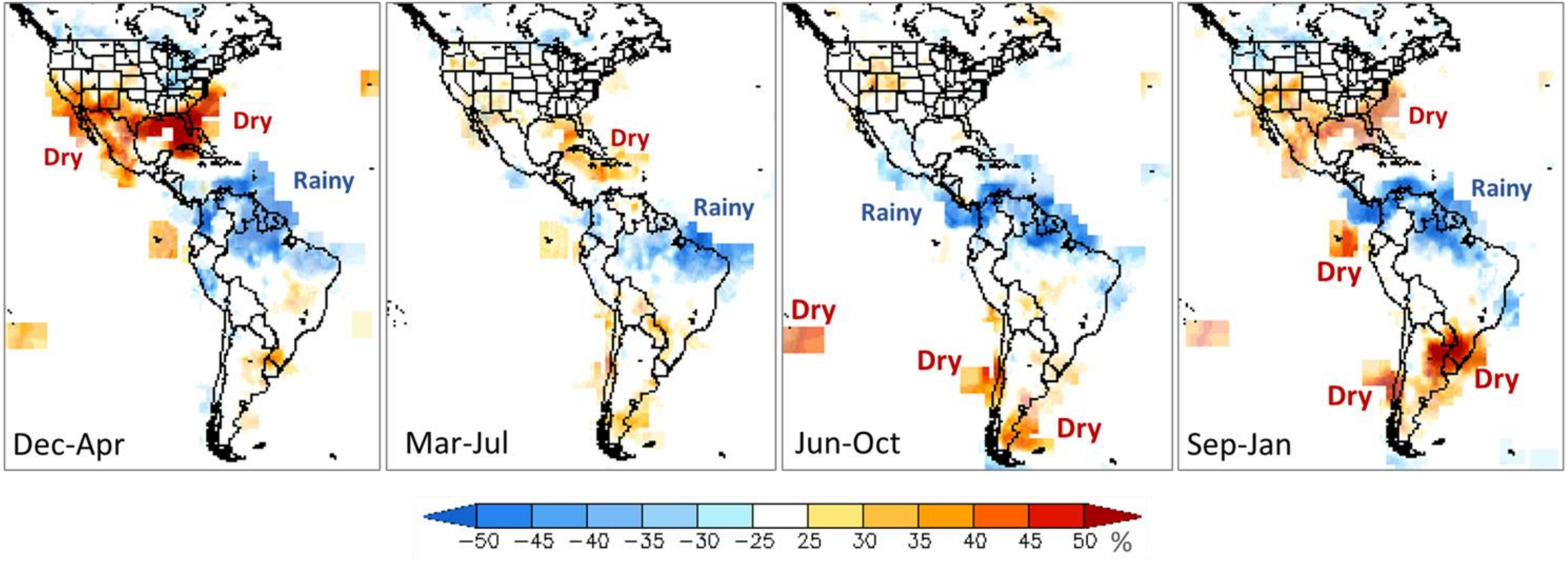
Meteorological processes (such as deep convection) can alter circulations which, in term, propagate downstream.



Teleconnection



Impacts: Rainfall during La Niña

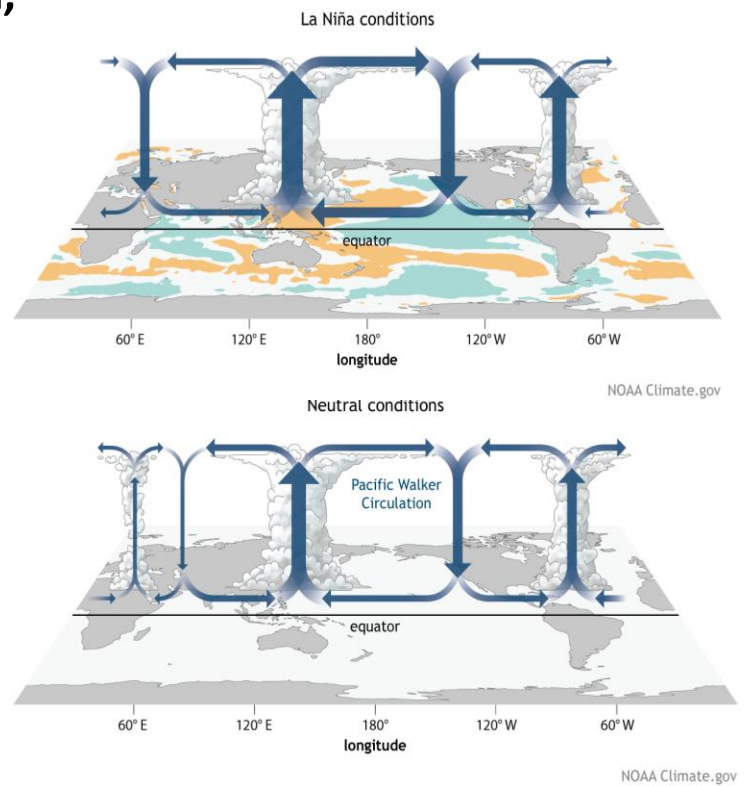


Tropical Americas: Changes in the Walker Circulation

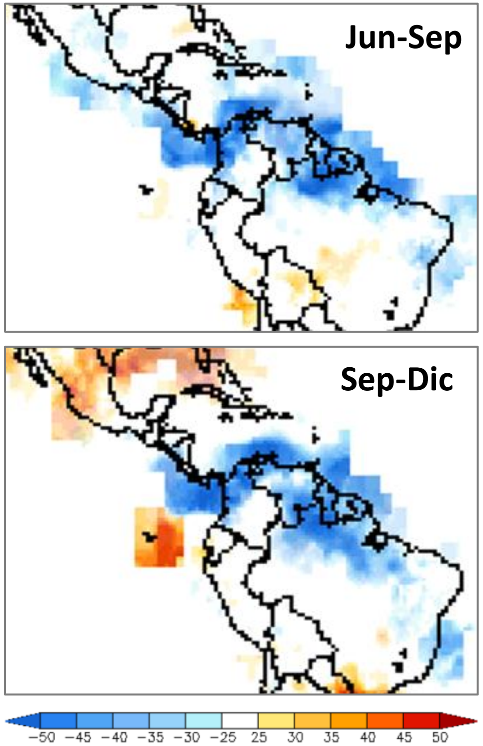
Very rainy in the Caribbean, Central America and northern South America

- Stronger Walker Circulation.
- Ascending Branch of the Walker Circulation favors more rain.

Intense rainy season→



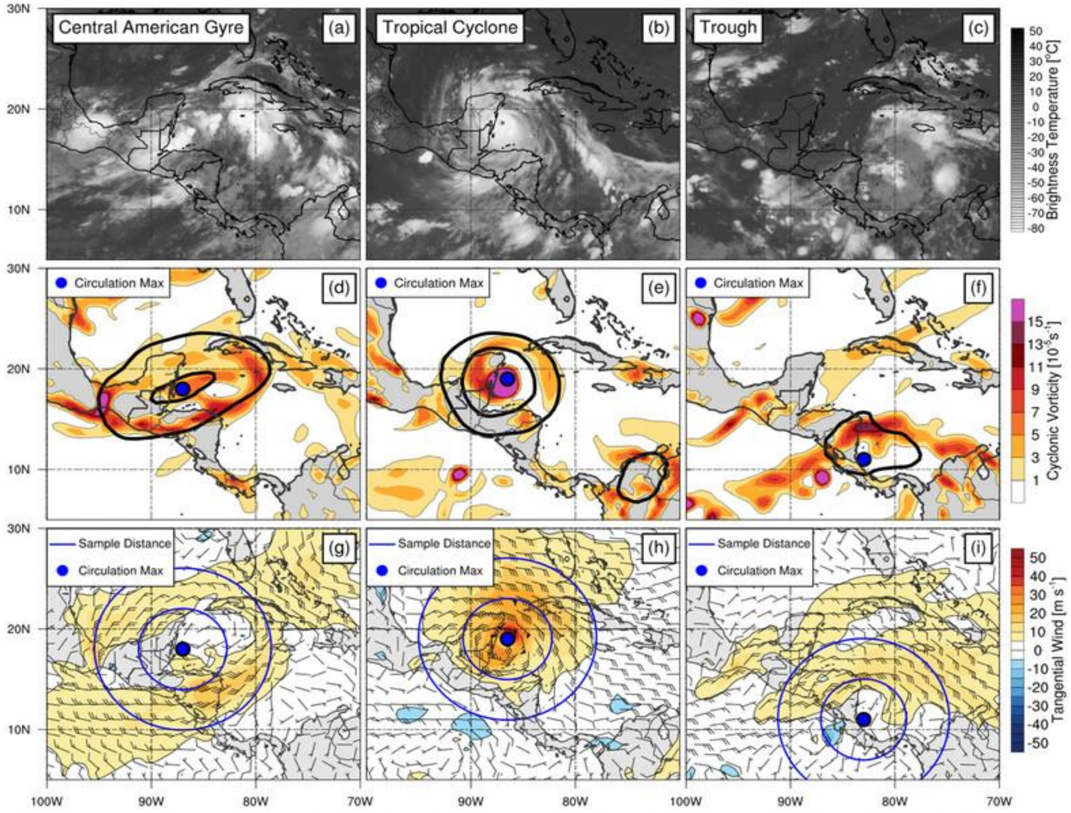
Correlación TSM Niño 3.4 - Lluvias



Central American Gyre - CAG

May to October

- Low pressures that form in Central America. They extend thousands of km, can generate extreme Rainfall and they can spun tropical ciclones.
- Convergence of long-fetch moist onshore winds can produce extreme Rainfall once interacting with the mountains of Central America.
- La Niña associates with more frequent and intense CAG events



Reference: Papin, Bosart and Torn, 2017: “A Climatology of Central American Gyres”. https://doi.org/10.1175/MWR-D-16-0411.1

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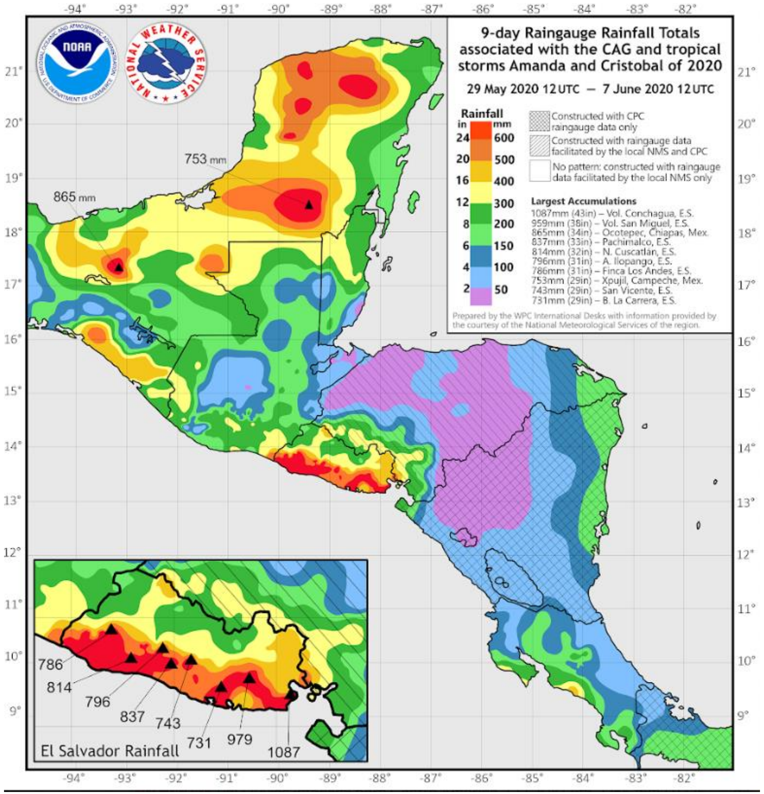
Evento de Giro Centroamericano (CAG, “Central American Gyre”) durante La Niña de 2020.

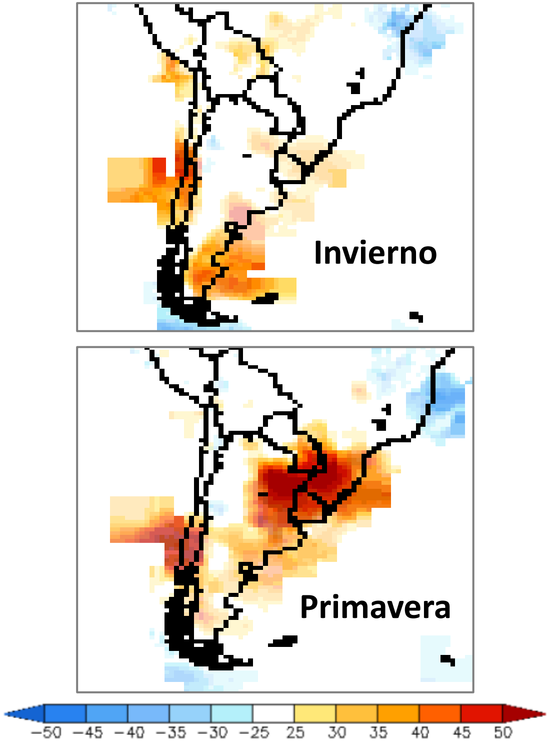


Spring drought in southeast South America

Junio a Noviembre

- Se debilita el chorro subtropical y desplaza muy al sur la trayectoria de ciclones extra tropicales.
- Esto debilita el SALJJ (chorro de capas bajas Amazonía-Argentina) limitando la fuente de humedad.
- Las tormentas pasan muy al sur y produciendo menos precipitación en el centro de Chile y en la mayor parte de Argentina.
- Primavera: Sequías extremas en Argentina/sur de Brasil/Uruguay, donde usualmente suelen darse muchos sistemas convectivos con lluvias intensas.

Correlación TSM Niño 3.4 - Lluvias



Impactos especialmente en cultivos de soya y maíz ocurren entre setiembre y noviembre, durante la primavera.

Central Chile is generally drier during La Niña

Mayo a Octubre

- Central and southern Chile generally receive les rain during La Niña and more during El Niño winters.
- La Niña dryness: Storm tracks usually develop further south and atmospheric rivers tend to be weaker, drier.

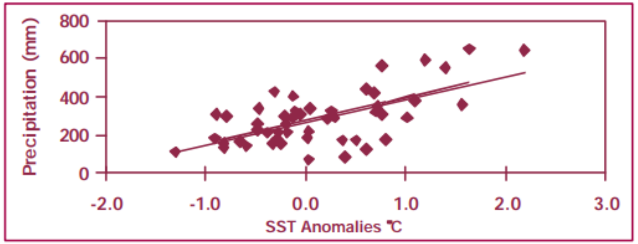


Figure 2. Precipitation for Santiago correlated with anomalies of the SST (Niño 3), April–September 1950–98.

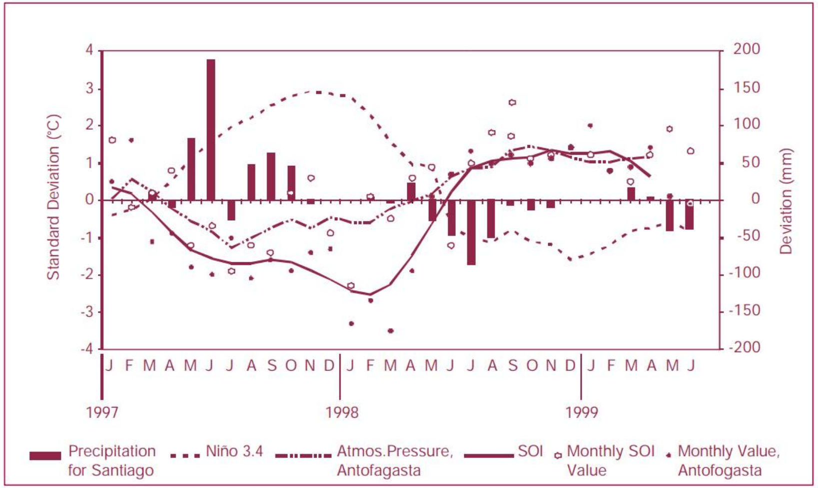
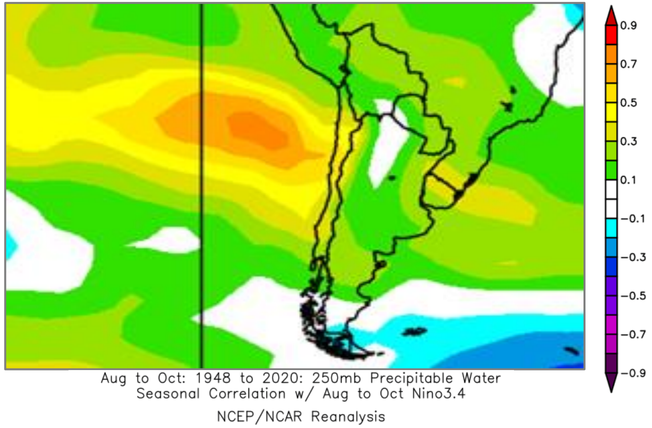


Figure 4. Sea surface temperature in the central equatorial Pacific, atmospheric pressure in Antofagasta, and precipitation in Santiago, January 1997–July 1999.

Correlación TSM Niño 3.4 – Agua Precipitable

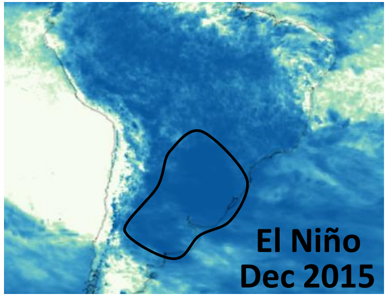


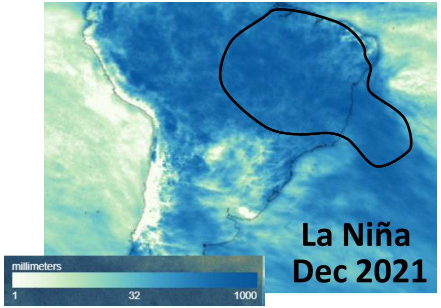
La Niña: Rainy Summer in Brasil with South Atlantic Convergence Zone (SACZ)

November-March

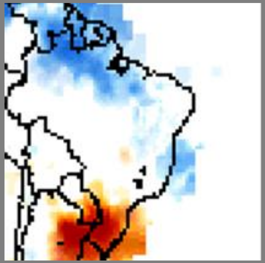
During La Niña, South Atlantic Convergence Zone and an ascending branck of the Walker Circulation favor more precipitation in eastern Brasil.

- Descending air and drought in northeast Argentina/south Brasil compensate with ascending air and rainy conditions in central and Eastern Brasil.
- SACZ more prominent and recurrent.



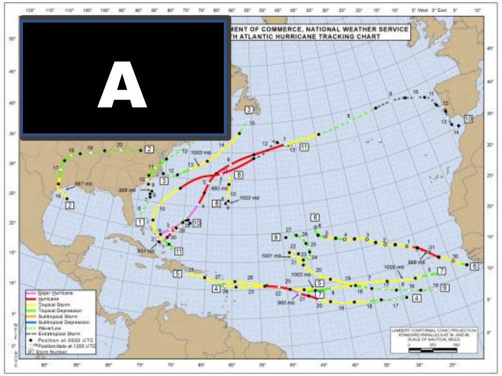


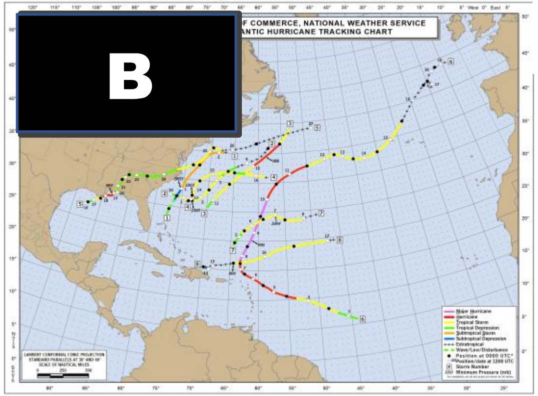
Flooding in eastern and central Brazil becomes more frequent during La Niña. The converse situation occurs in southern Brazil during El Niño.

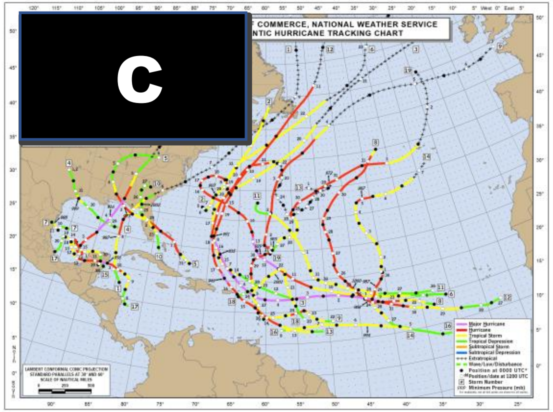


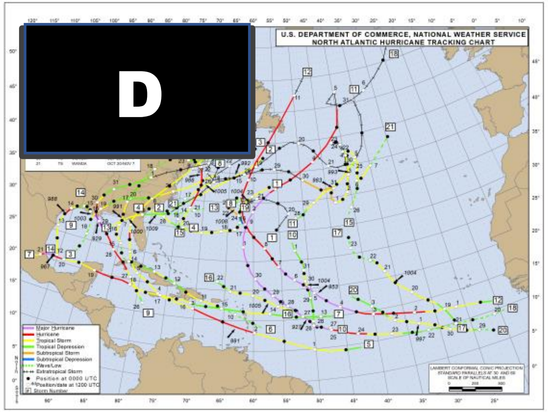
ENSO and Hurricane Season in the Caribbean

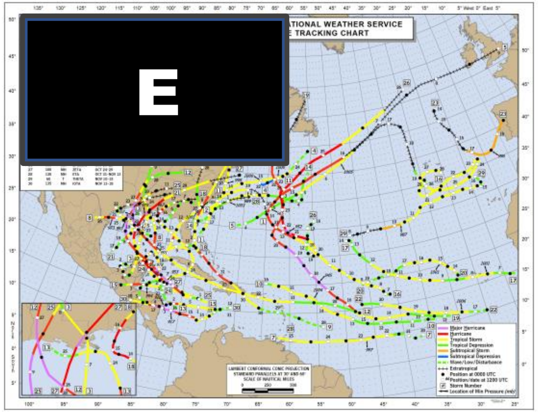
Which years are La Niña and which El Niño?











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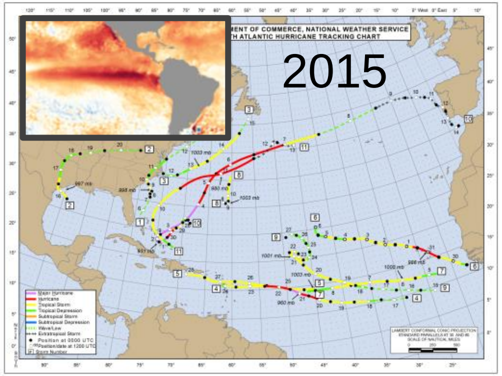
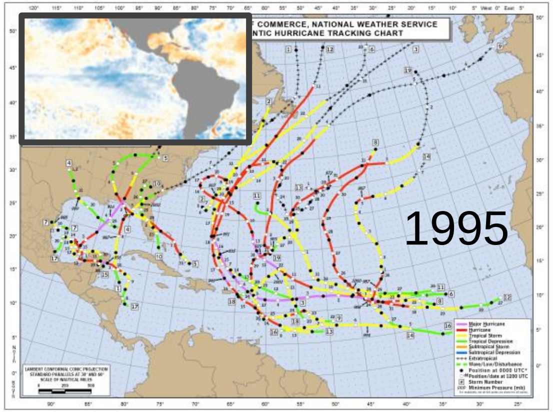
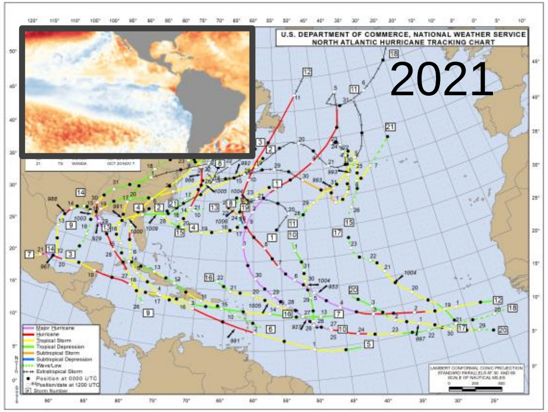
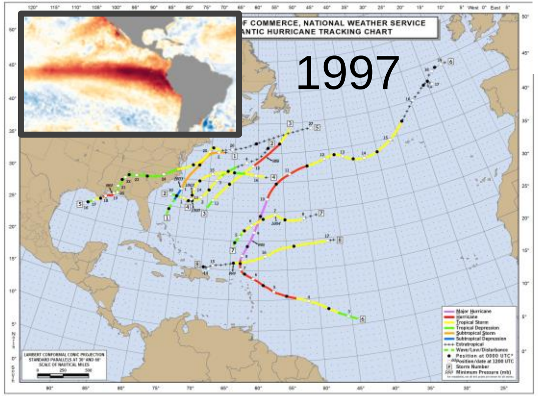
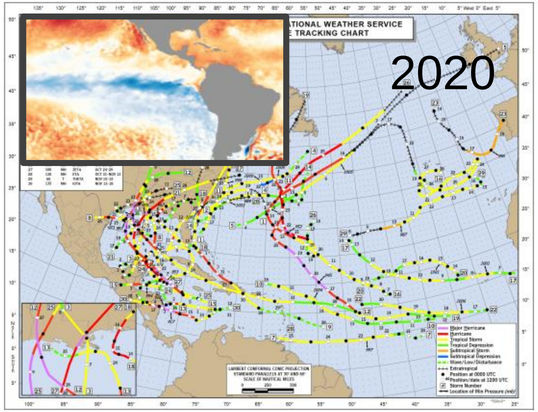




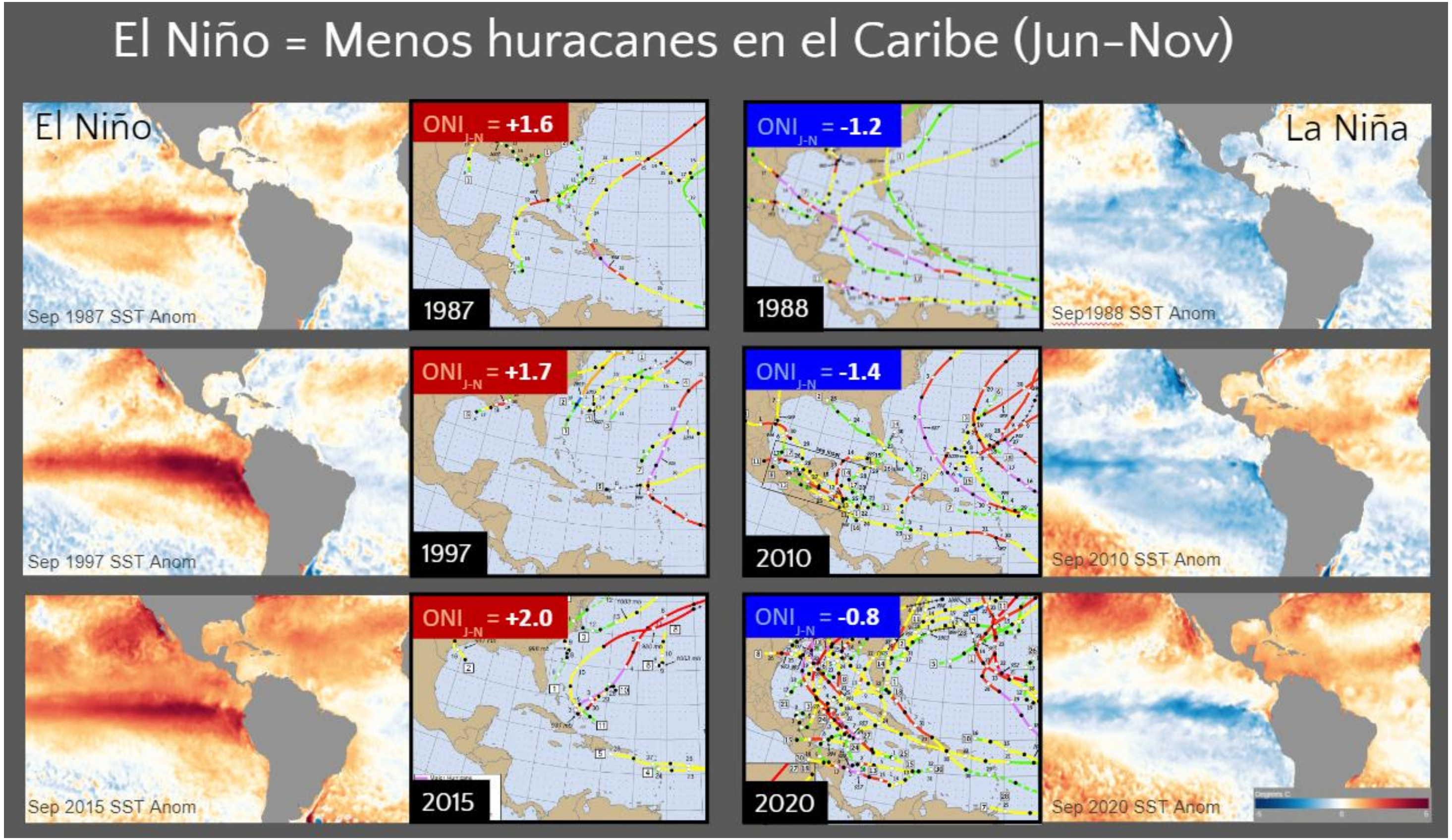




Atlántico más activo durante La Niña



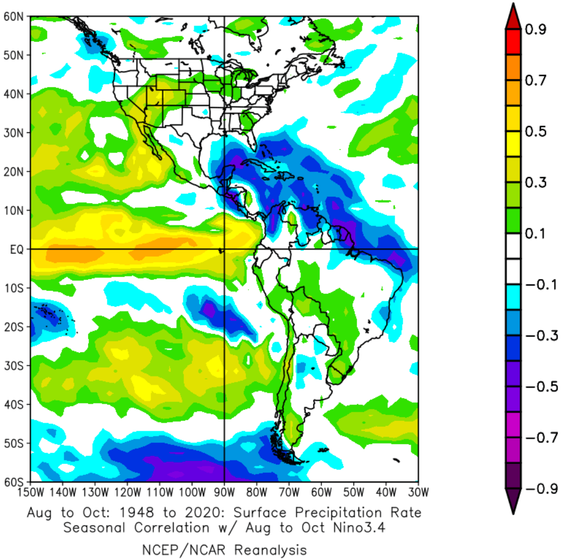
ENSO and the Hurricane Season in the Caribbean



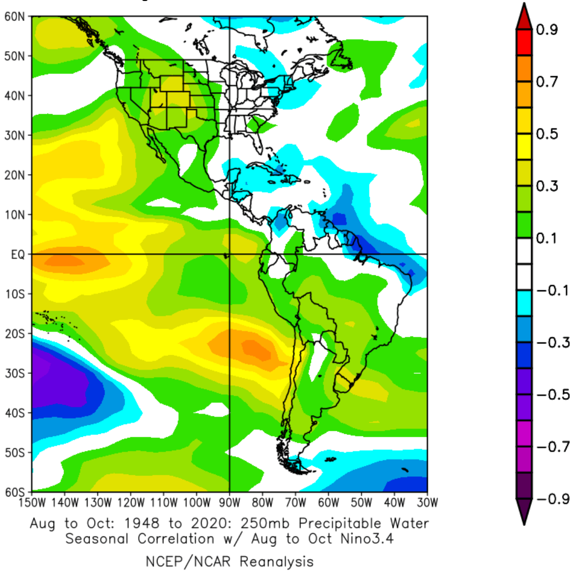
ENSO and the Hurricane Season in the Caribbean

Correlations with Niño 3.4 SST

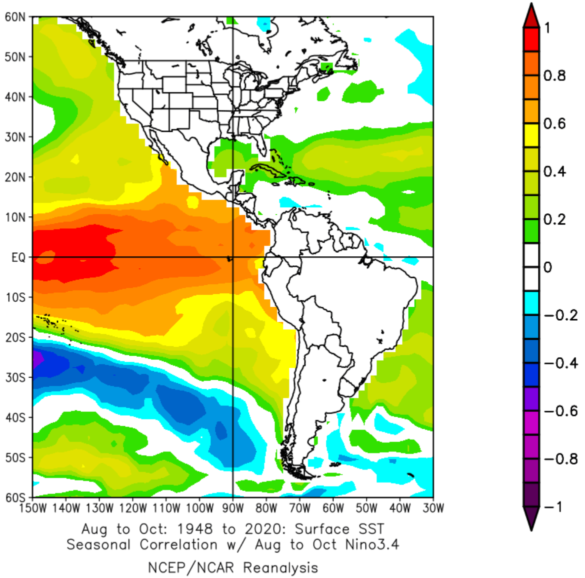
Rainfall



Precipitable Water



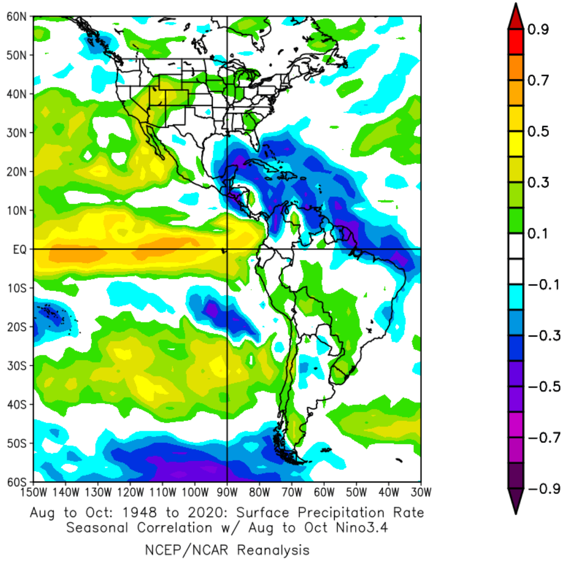
SST



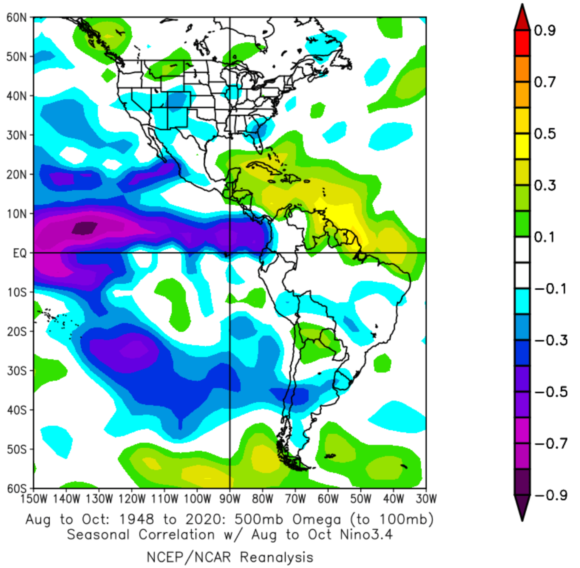
ENSO and the Hurricane Season in the Caribbean

Correlations with Niño 3.4 SST

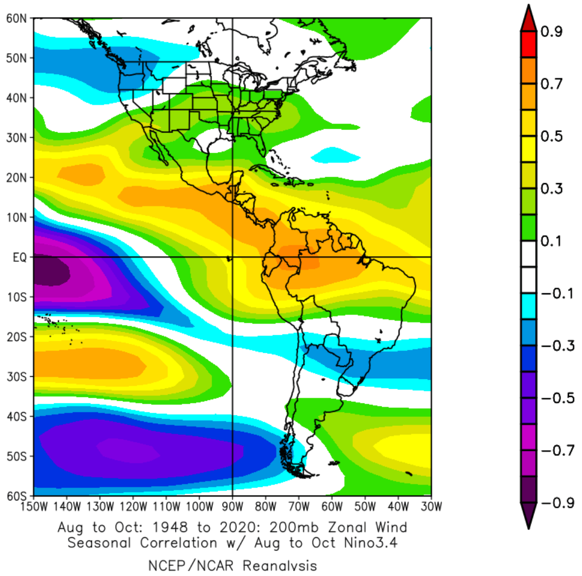
Rainfall



500hPa Ascent



Zonal Wind 200hPa



Background Concepts

- Ocean coupling.
- Wind stress.
- Sea Surface temperatures and their role in atmospheric thermodynamics.

Ocean Coupling

How do the ocean and atmosphere communicate?

- The atmosphere "reads" the ocean by the impact of sea surface temperatures (SST)

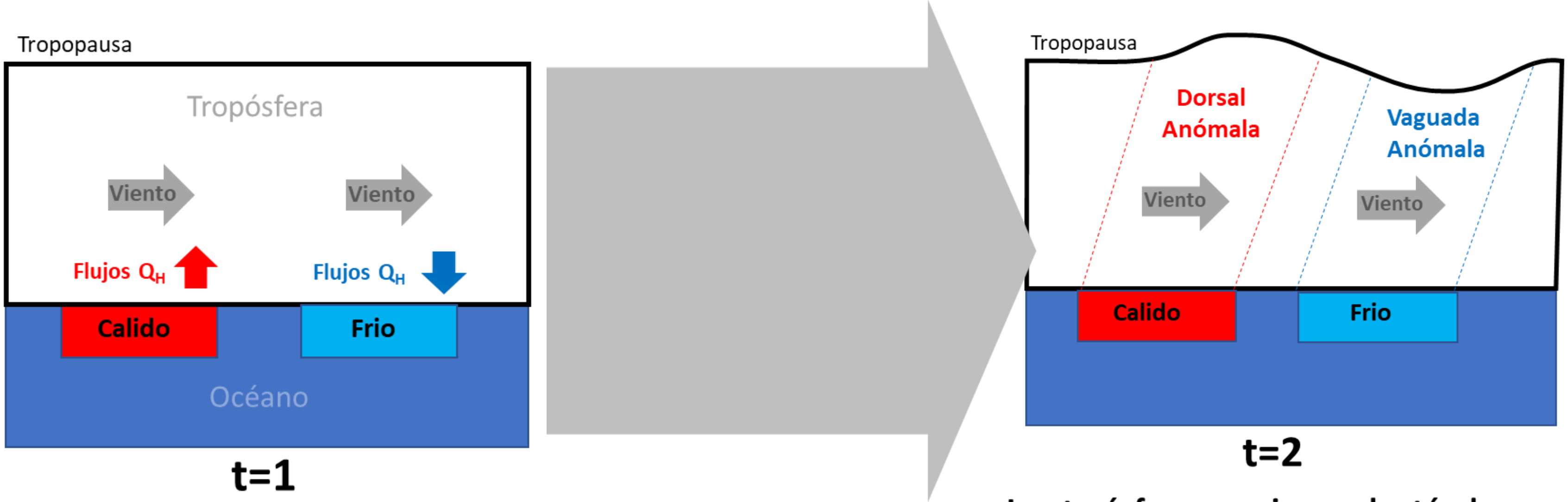
SST modulate atmospheric stability and thermodynamics, eventually inducing changes in the winds

- The ocean "reads" the atmosphere by the impact of surface winds "pushing" the ocean surface.

This is called wind stress (τ) and stirs superficial ocean currents.

Bjerkness Feedback: " Atmospheric changes alter the sea temperatures that in turn alter the atmospheric winds in a positive feedback."

Role of fluxes and atmospheric reactions

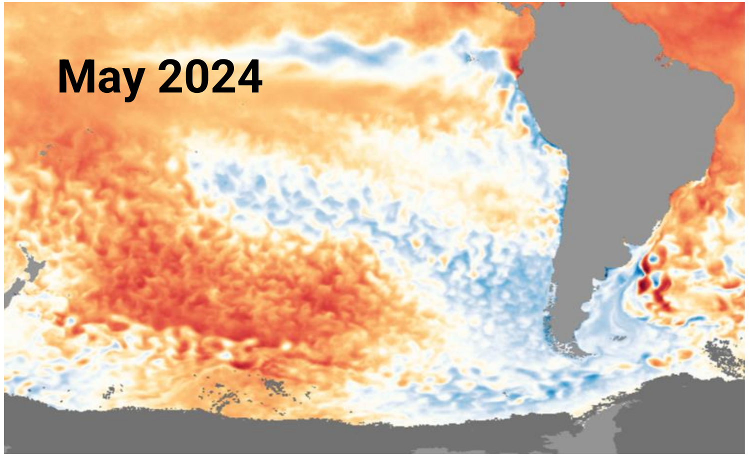


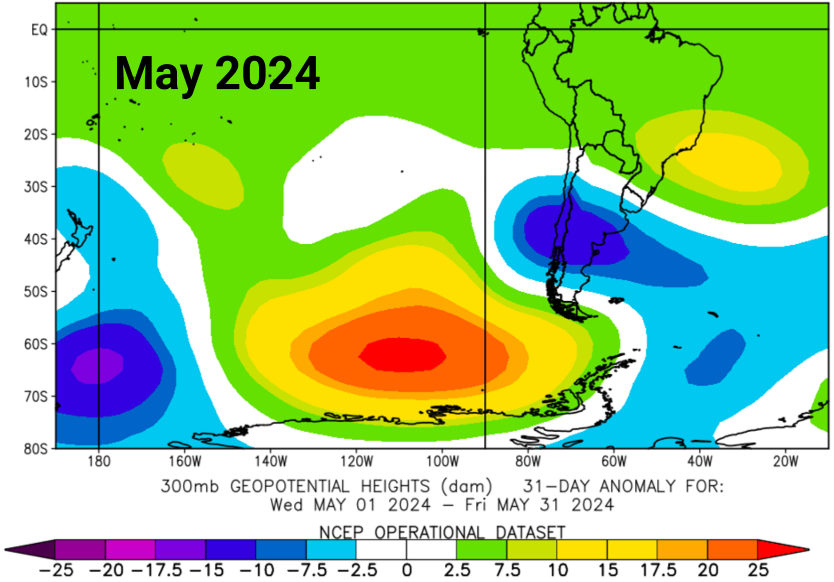
Se desarrollan anomalías cálidas y frías de mar

La atmósfera reacciona calentándose y enfriándose flujo abajo, desarrollando dorsales y vaguadas anómalas

Role of fluxes and atmospheric reactions

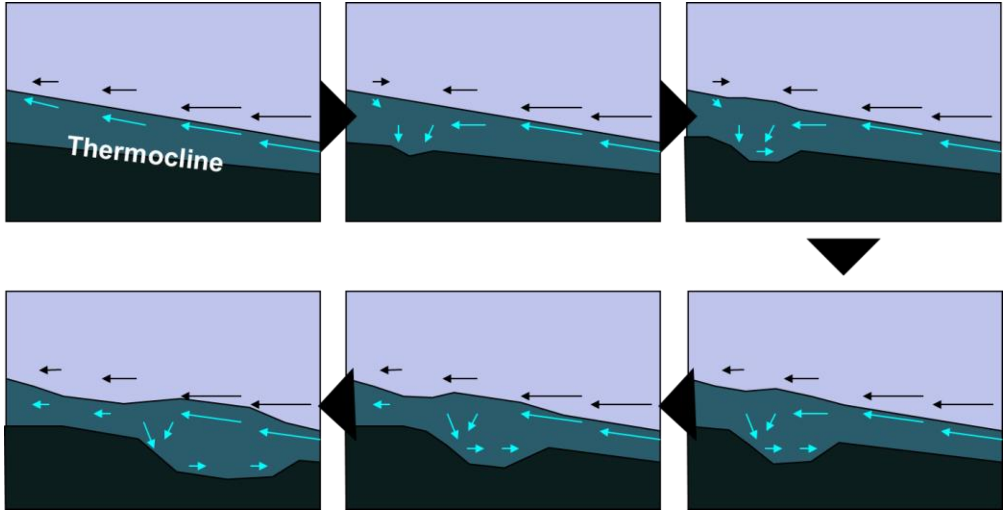
Rossby Train favored by extensive coherent SST Anomalies

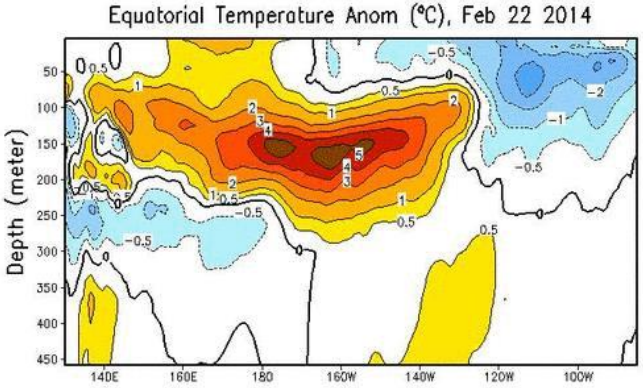


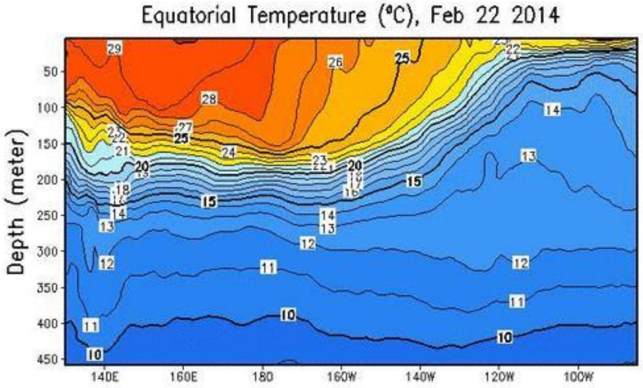


Kelvin Wave Generation Mechanism

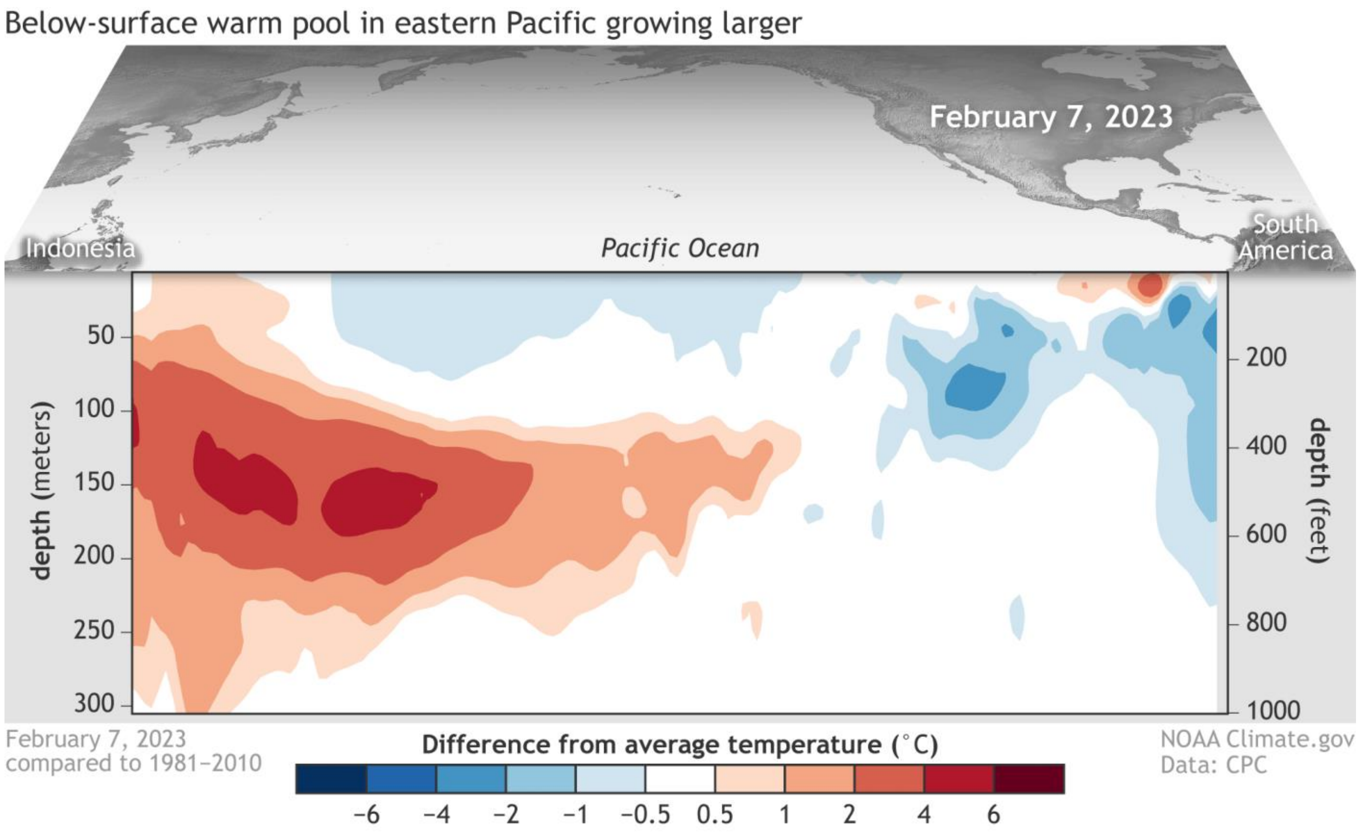
Westerly Wind Bursts can trigger an oceanic Kelvin Waves by inducing a bulging of the thermocline



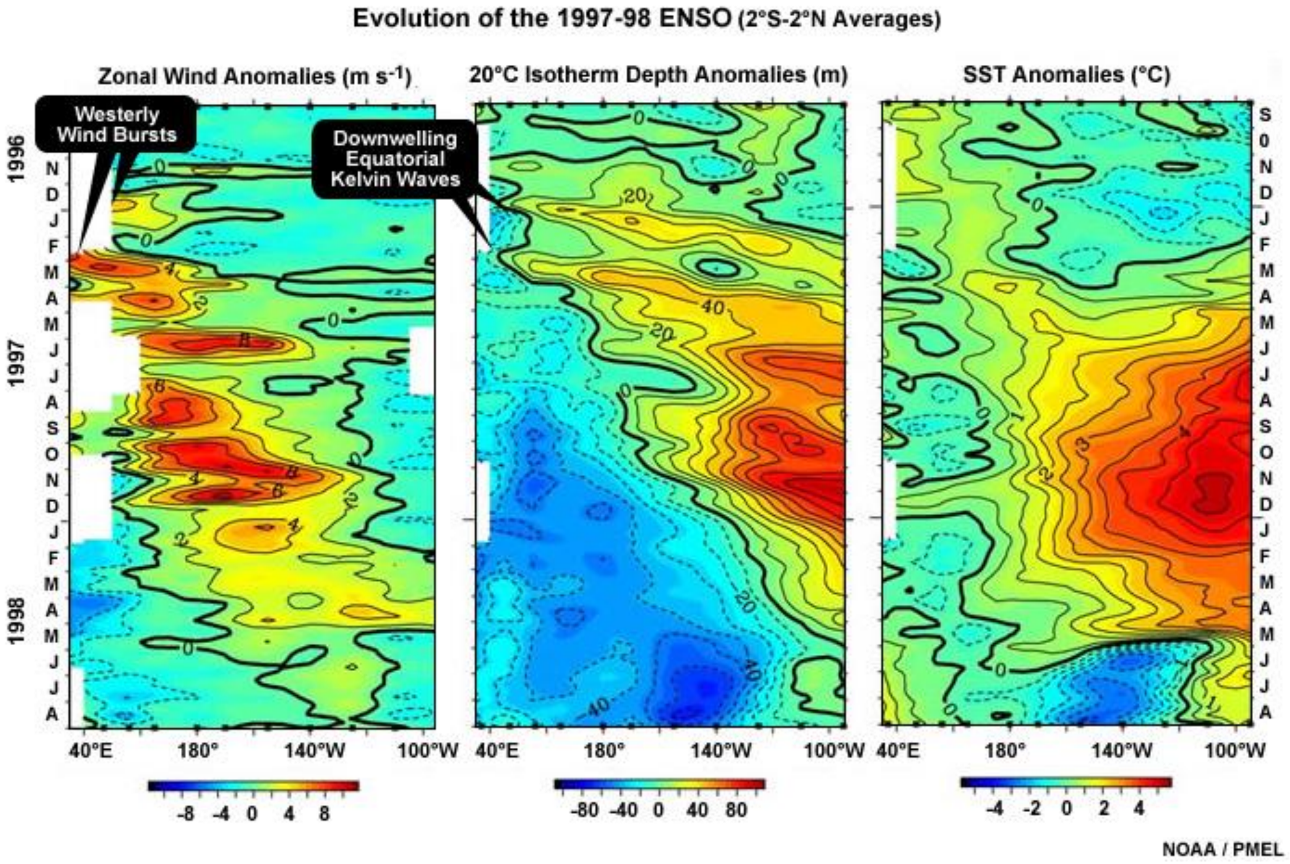




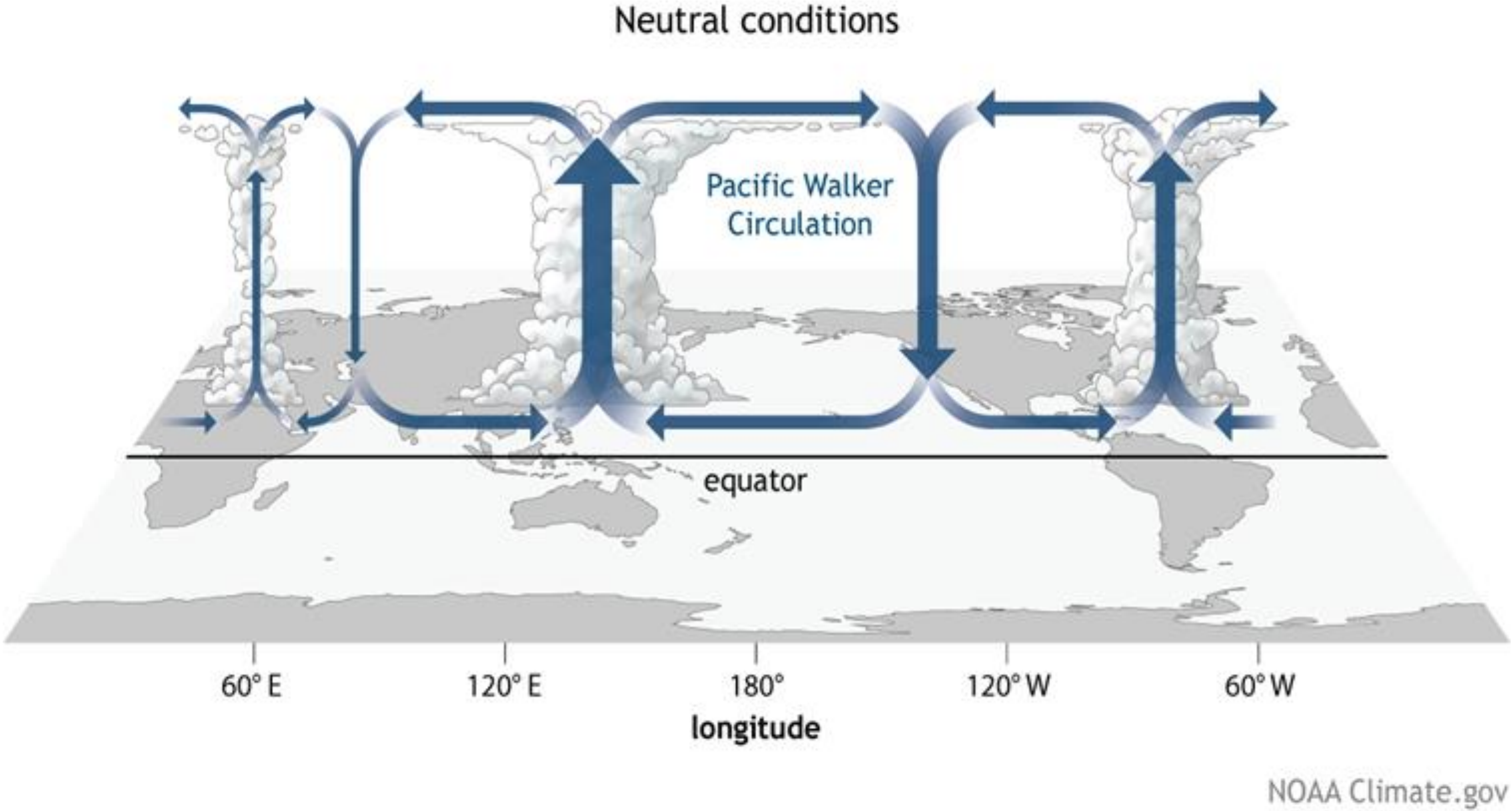
Kelvin Wave Generation Mechanism



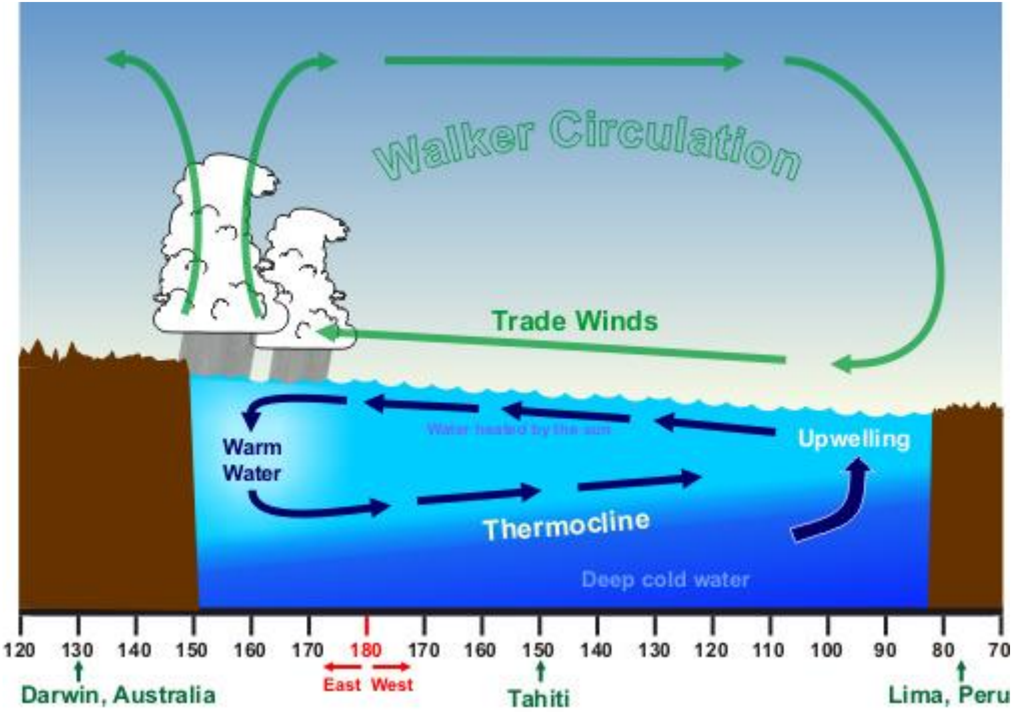
Kelvin Wave Generation Mechanism



The Walker Circulation



The Walker Circulation



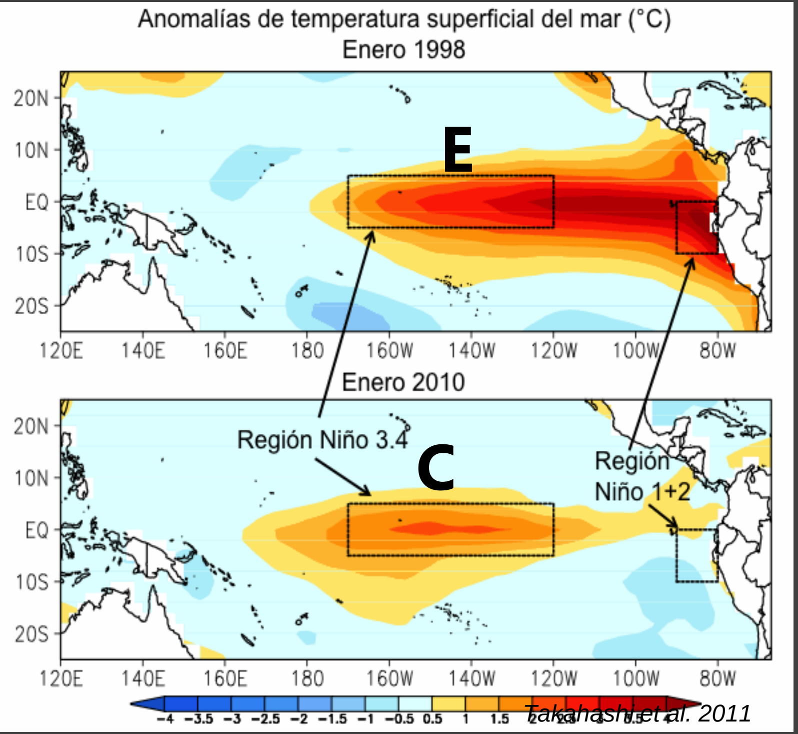
ENSO Modes

- For an ENSO Warm or Cool Phase to be declared, SST in Niño 3.4 needs to be >0.5°C or <-0.5°C over three consecutive trimesters.

- All that matters is what happens in Niño 3.4.

- The two main modes (not types) of ENSO that result in Niño 3.4 warmings and coolings are:
    1. Niño for the entire basin, with a peak in the Eastern Pacific (Mode E)

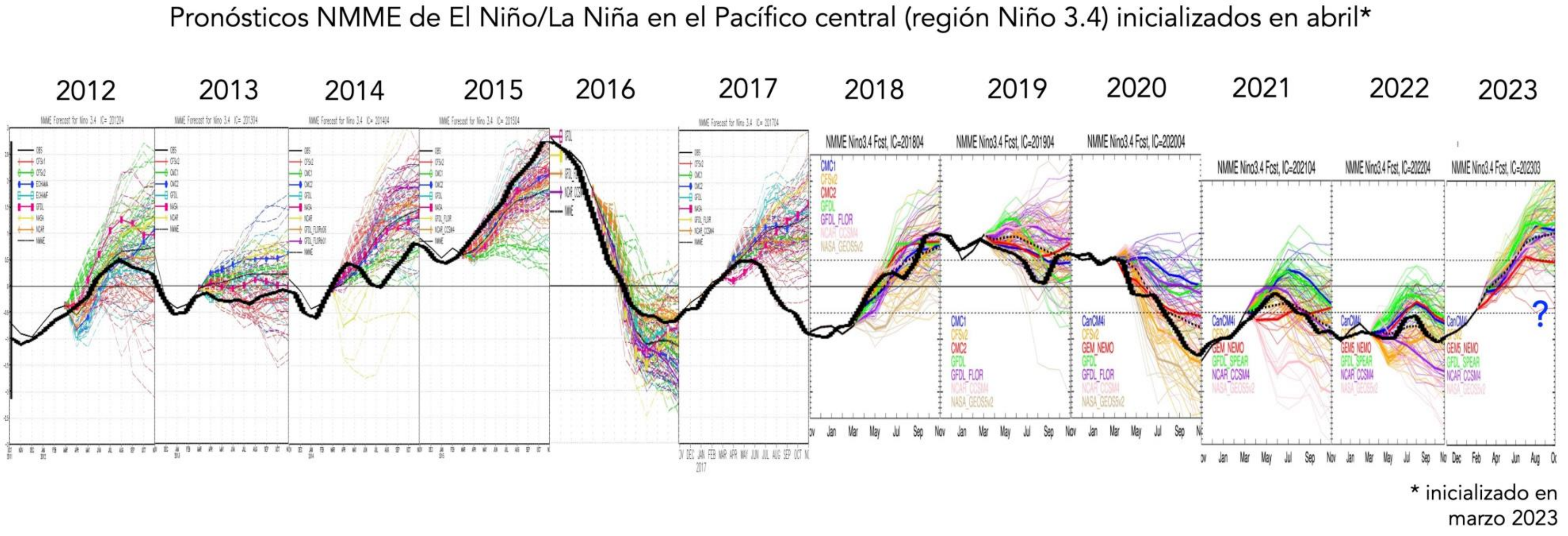
    2. The Central Pacific (Mode C)



ENSO Predictability

There are still struggles. Models tend to exaggerate the probability of warm phases (El Niños).

April is a low predictability month due weak SST gradients and hard-to-forecast non-linear processes generated by deep convection near the equator.



Part II
Satellite Products to Monitor ENSO

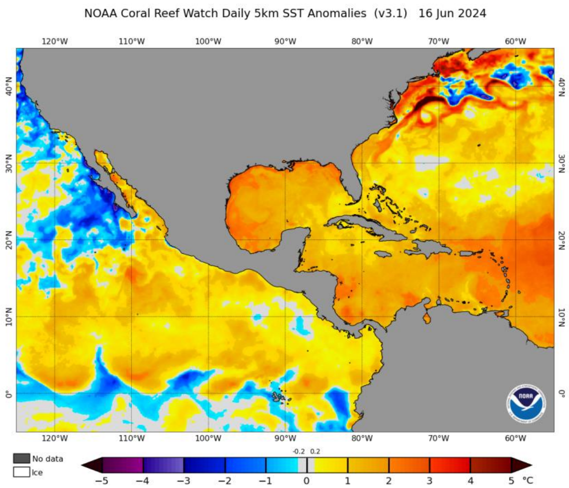
Satellite Products for Monitoring ENSO

- It is complicated to speak about each instrument and what they do
- In reality, products that we use are generated by a combination of different satellite fields
- We can start with the following question: What are the main fields we can measure with satellite products?

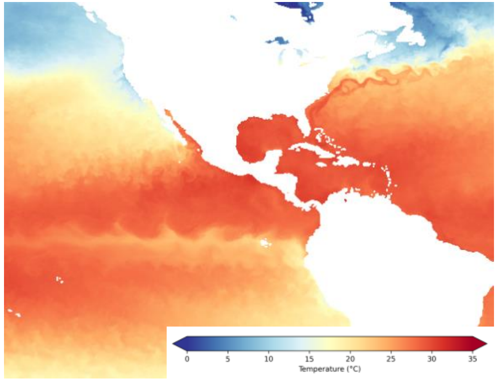
    - Sea Surface Temperatures
    - Sea Level Height (Altimetry) ←Do we have a Kelvin wave?
    - Surface Winds ←Mechanical forcing of the ocean surface
    - Outgoing Longwave Radiation (OLR) / Precipitation products ←Deep convection over the ocean

Satellite Products: Sea Surface Temperatures

- Used to monitor SSTs, SST Anomalies, Coral Bleaching, Degree Heating Week



- **Products:**
  - SST Contour Charts and *CoralTemp* SST by NESDIS: obtained from Infrared radiometer and microwave on board of Sentinel-3a, Sentinel-3b, Metop-B/C, GOES-East/West, NOAA -18 & 19, GOES-16, GOES-18, Himawari-9, and Meteosat-10.

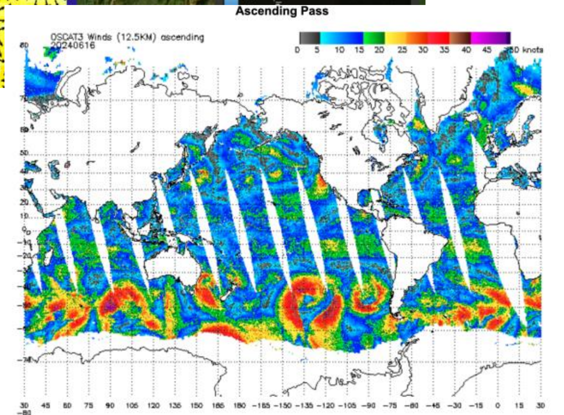


  - OSTIA: obtained from 10 different sensors such as the Tropical Rainfall Measuring Mission Microwave Imager (TMI), on board GCOM-W AMSR2, Metop-B/C, Sentinel 3A & 3B.

Satellite Products: Altimetry

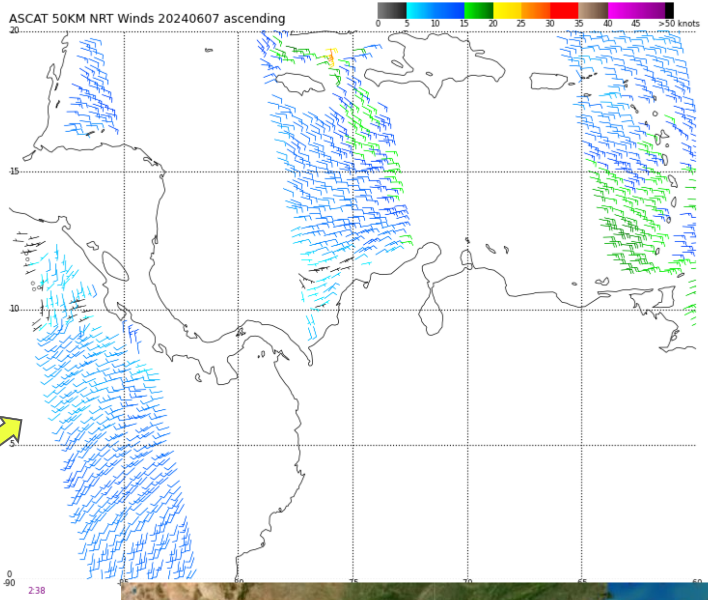
- The measure of the height of ocean features such as: **(1) *Sea level height anomaly, (2) Significant wave height, (3) Tidal height and Ocean Currents***

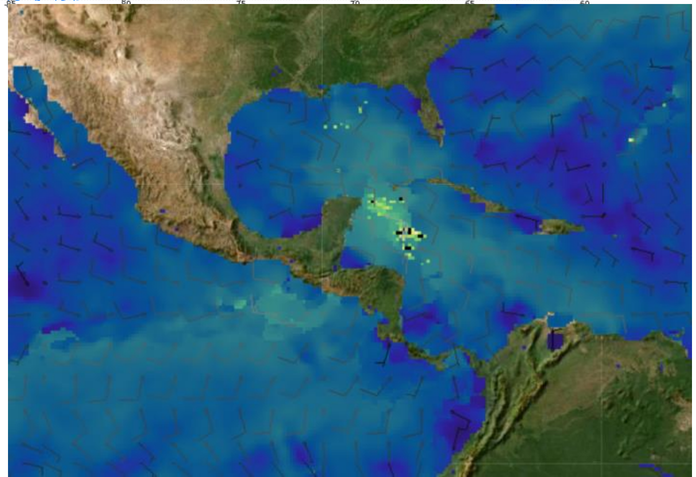
- **Products:**
  - Radar Altimetry Database System (RADS) from NOAA Coast Watch Data Portal: obtained from radars on board of Jason-3, AltiKa, Cryosat-2, Sentinel-3A, and Sentinel-3B
  - OSCAR-3: obtained from scatterometer on board of GPM and Metop-B/C, Aqua, GCOM-W, SMAP, DMSP, Oceansat-3 (coming very soon)



Satellite Products: Surface Wind

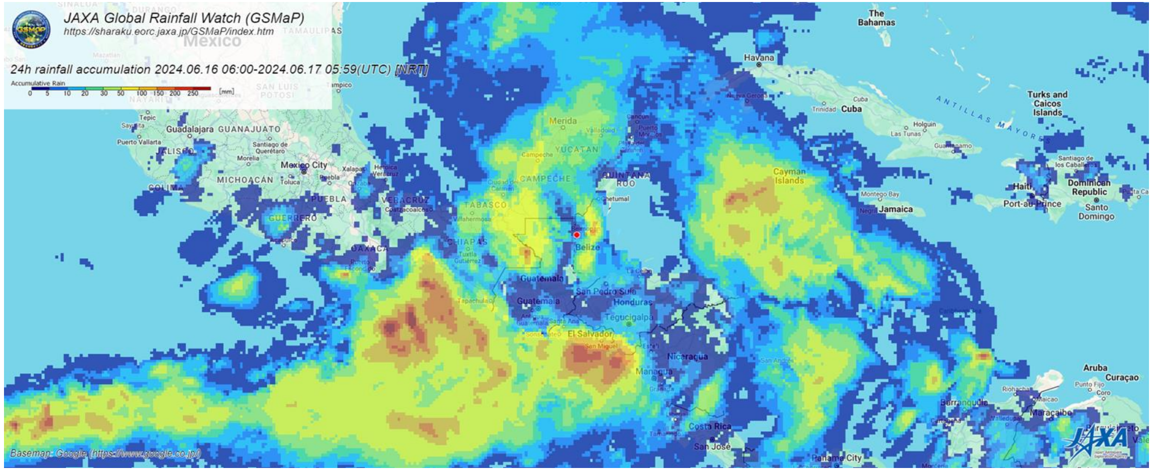
- Monitors the movement of winds over the ocean surface
- **Products:**
  - ASCAT - Advanced Scatterometer from NOAA/NESDIS: obtained from scatterometer on board of GPM and Metop-B/C, Aqua, GCOM-W, SMAP, DMSP, Oceansat-3 (coming very soon)
  - NOAA NCEI Blended Seawinds (NBS): obtained from the synthesization of observations from multiple satellites to create gridded wind speeds (10m, neutral)





Satellite Products: Precipitation/Deep Convection

- To determine deep convection/heavy rainfall/ over the ocean
- **Products:**
  - Hydro-Estimator Rainfall by NOAA OSPO
    - Uses IR brightness temperatures from geostationary satellites (GOES, METEOSAT, MTSAT) while using NCEP model fields
  - JAXA Global Rainfall Watch



Exercises

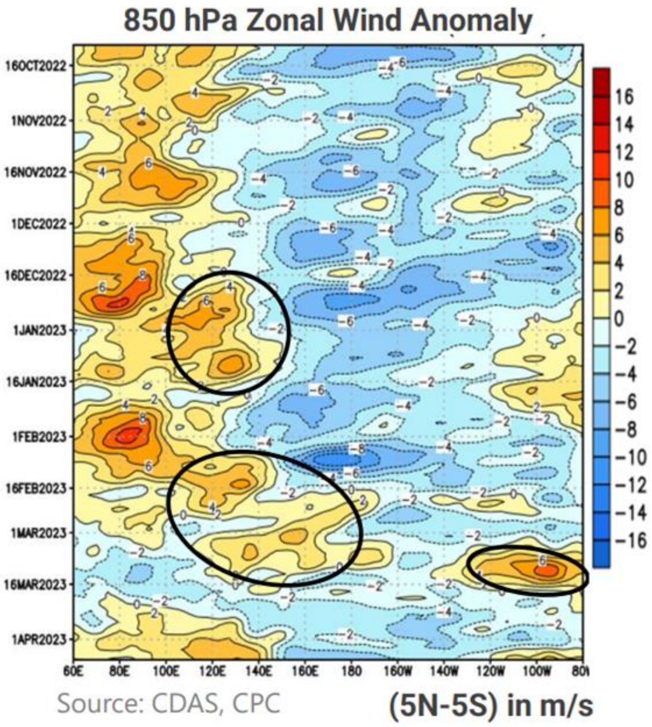
Exercise

Winds and their effects in triggering Kelvin Waves

Ascat Winds in the Equatorial Pacific

Question to discuss: what could this situation cause in the ENSO system?

Kelvin Waves: Hovmöller of Winds and Heat Content

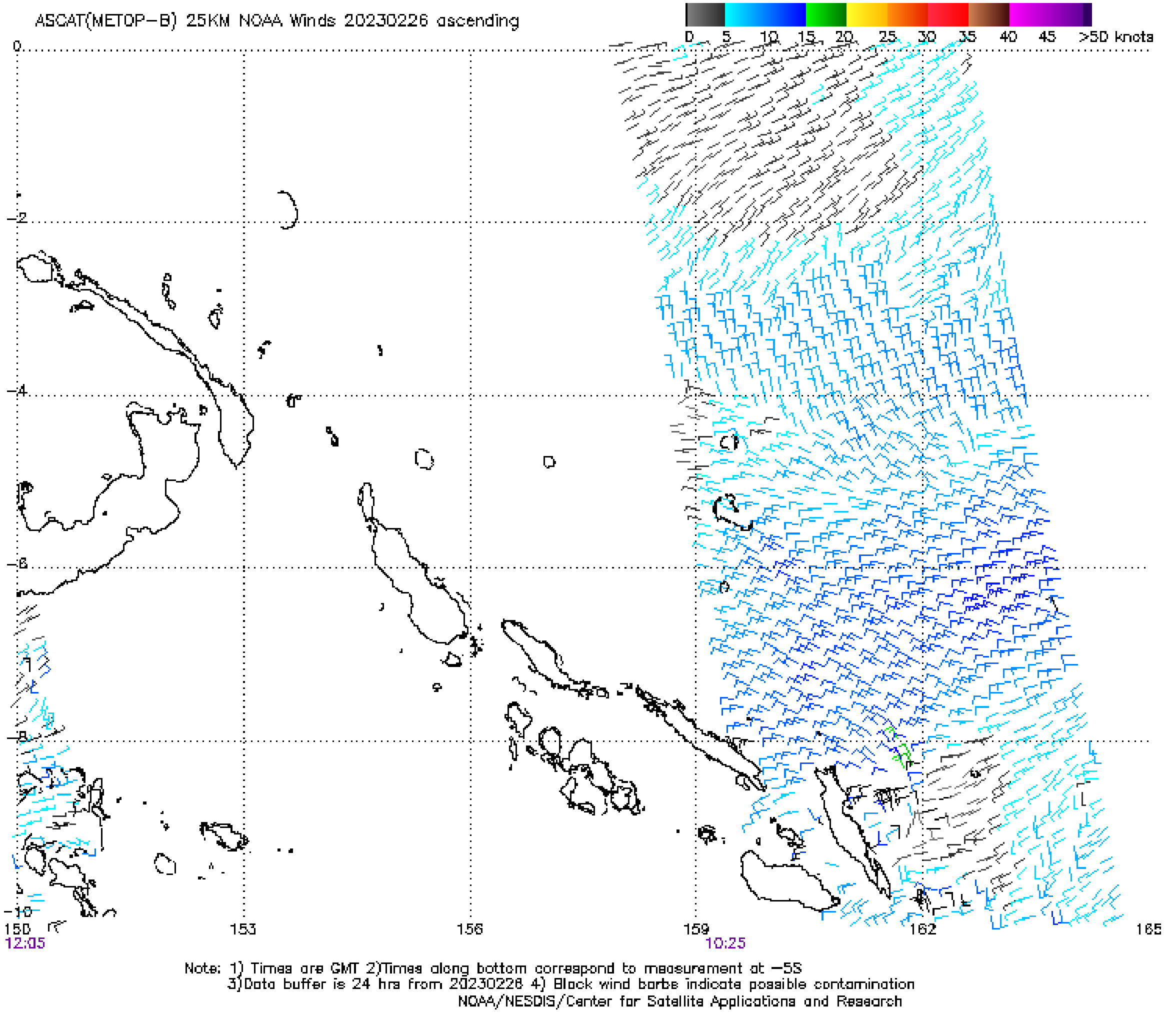


Westerly wind burts sometimes trigger oceanic downwelling (warm) Kelvin Waves.

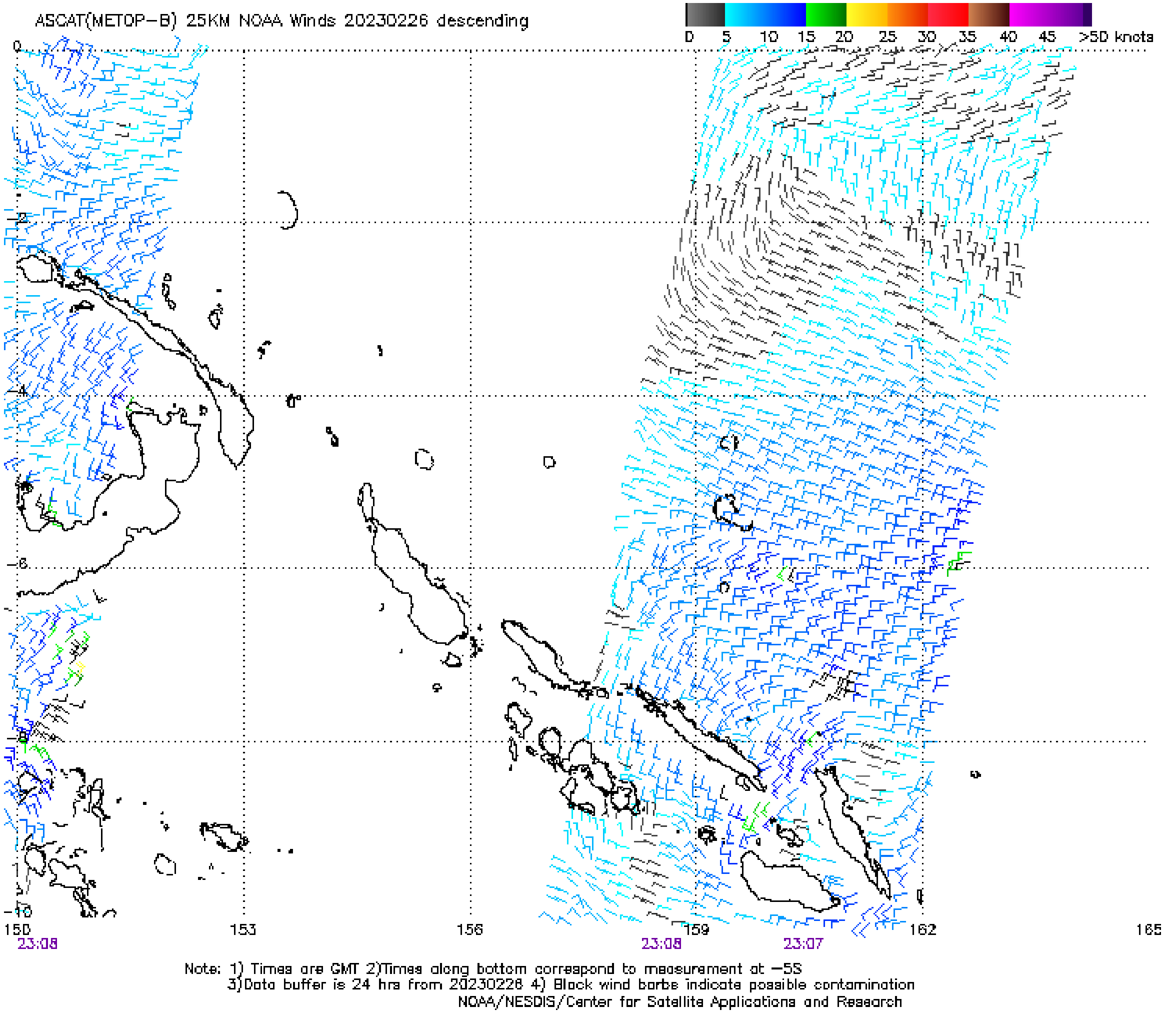
This happens especially when these bursts occur over the equatorial Pacific east of 140E or east of Papua New Guinea

Anomalies are calibrated generally using 850 hPa winds, which are often related to surface winds but not always.

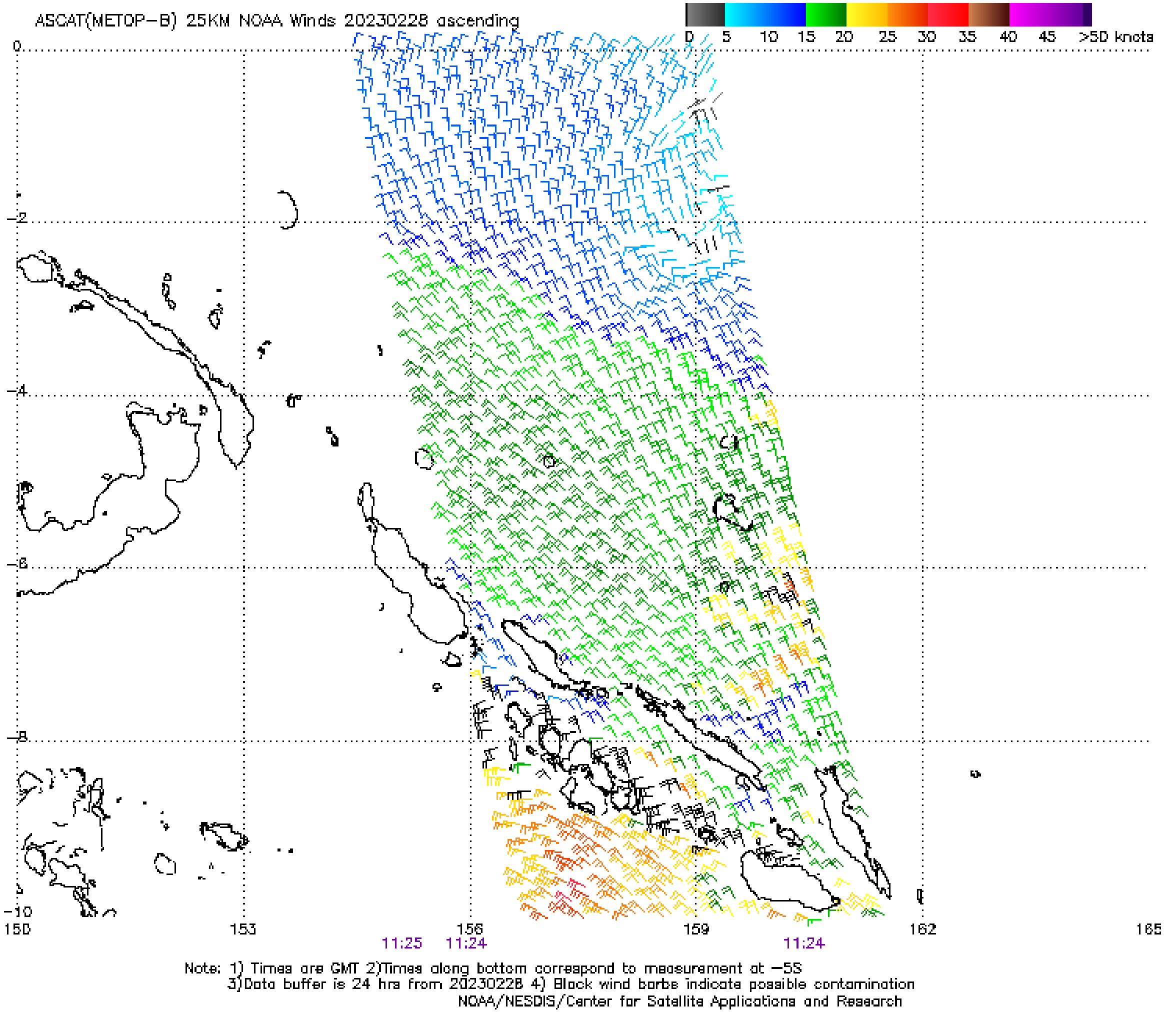
How do we analyze surface winds? Lets look at ASCAT…



Feb 26, 2023
Ascending



Feb 26, 2023
Descending



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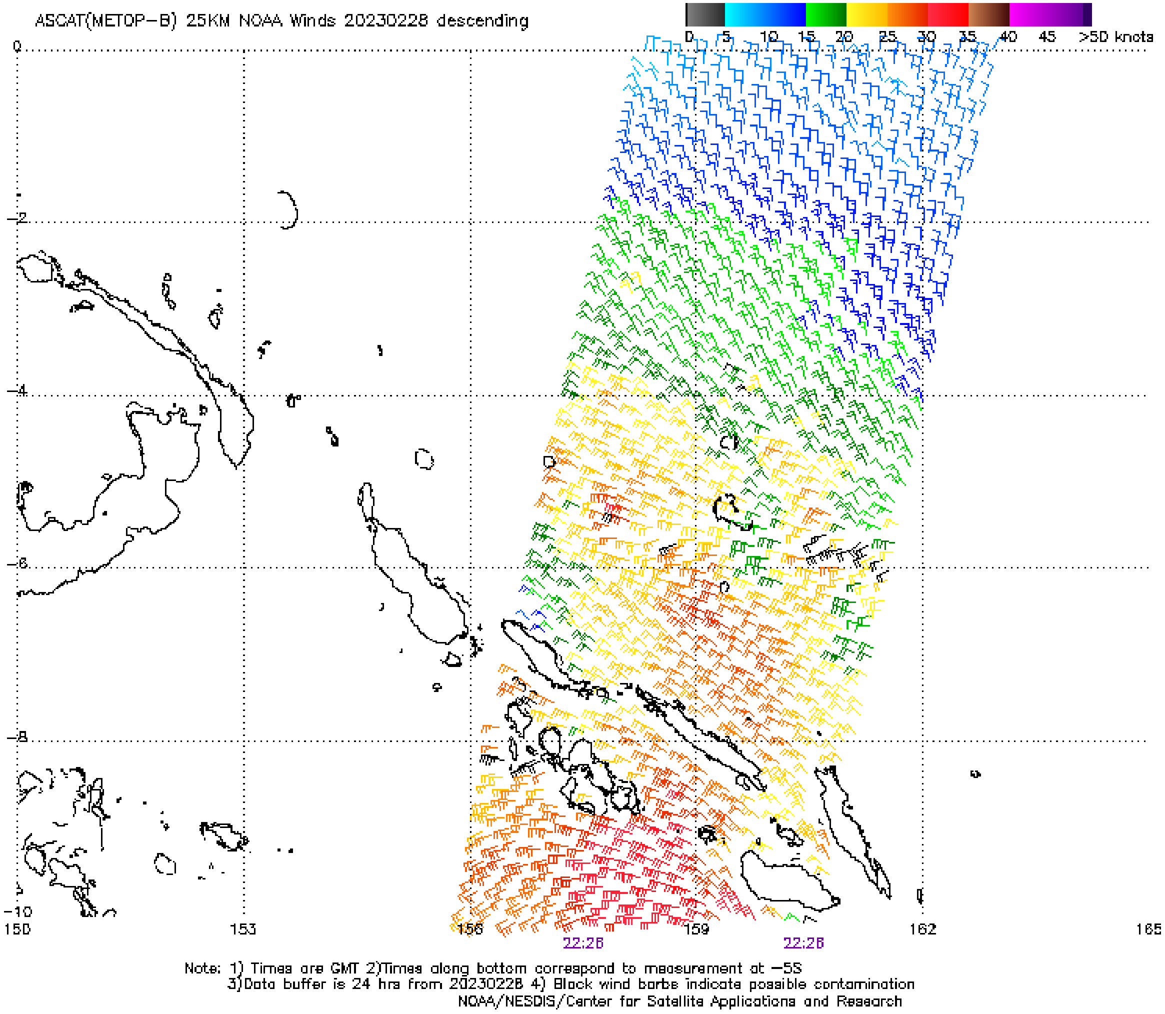
Ascending



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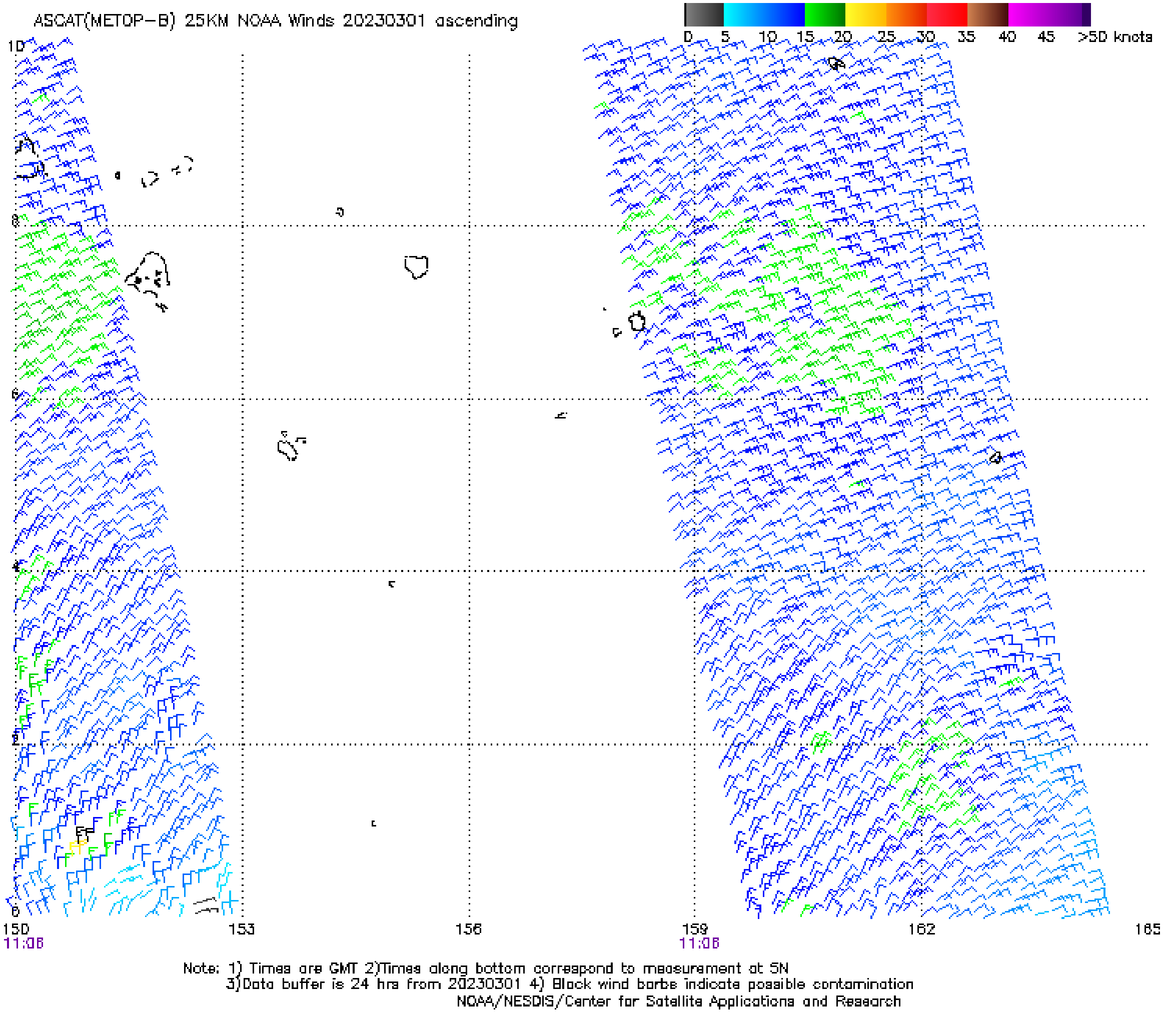
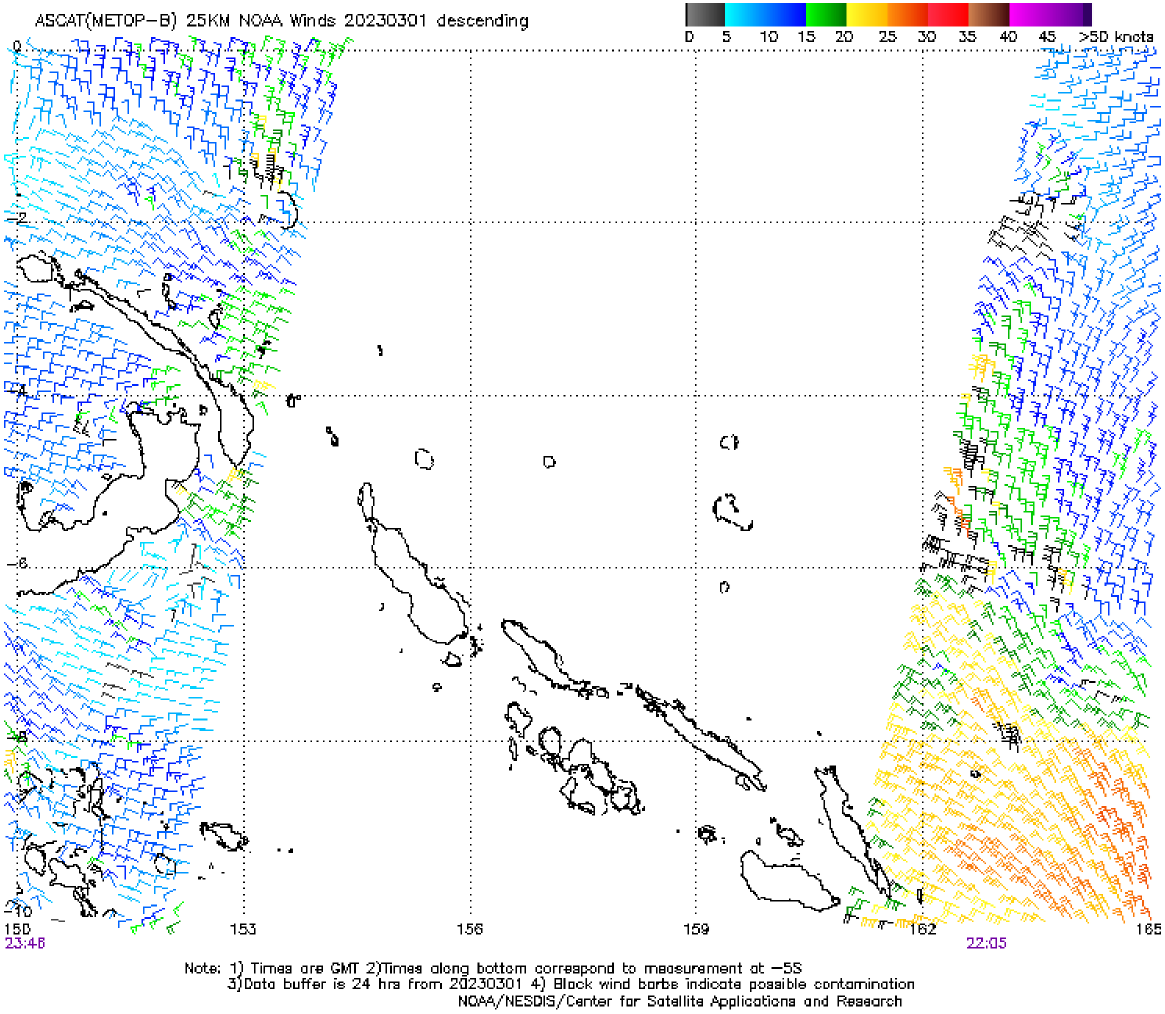


March 1, 2023
Ascending



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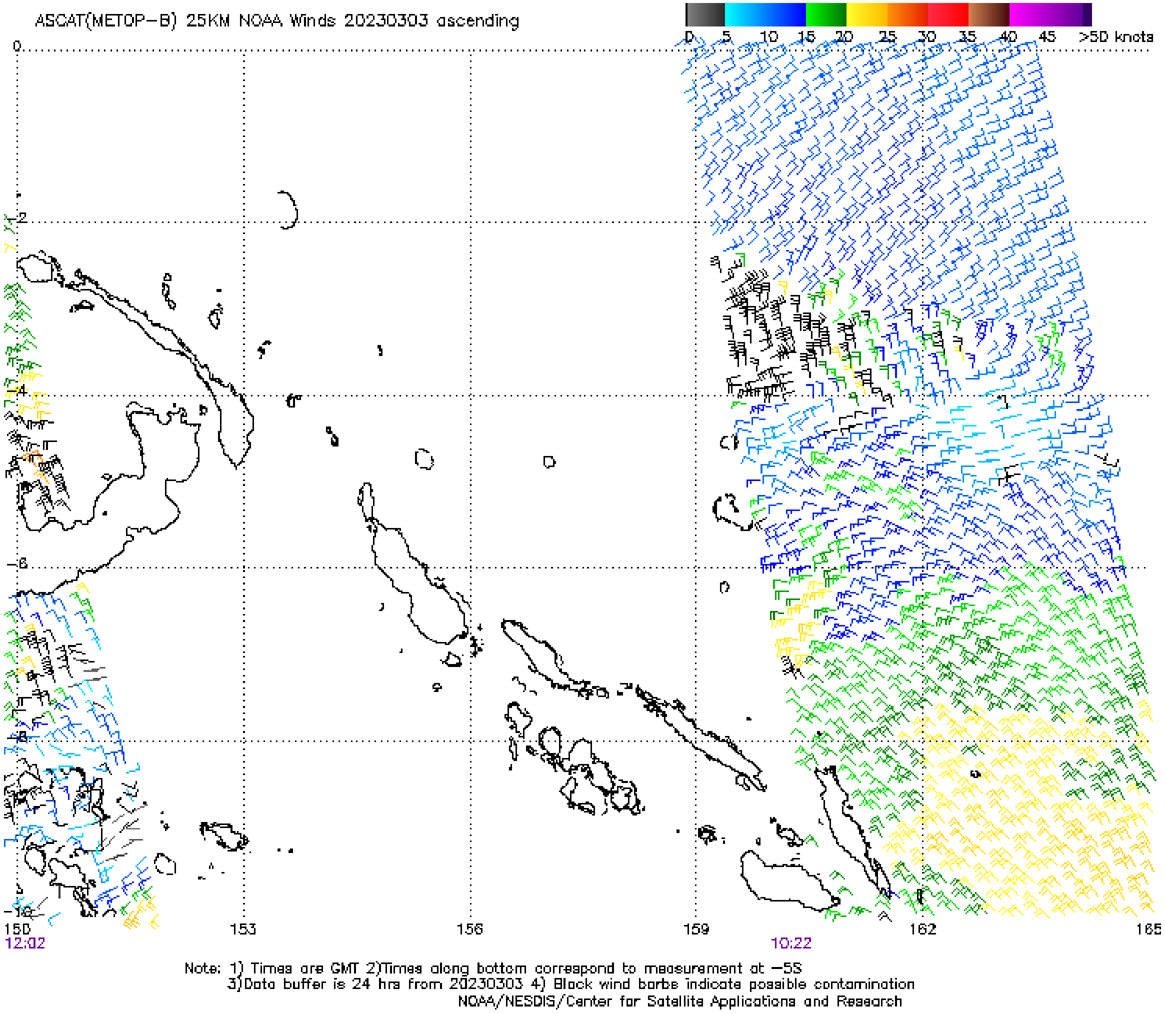

March 3, 2023
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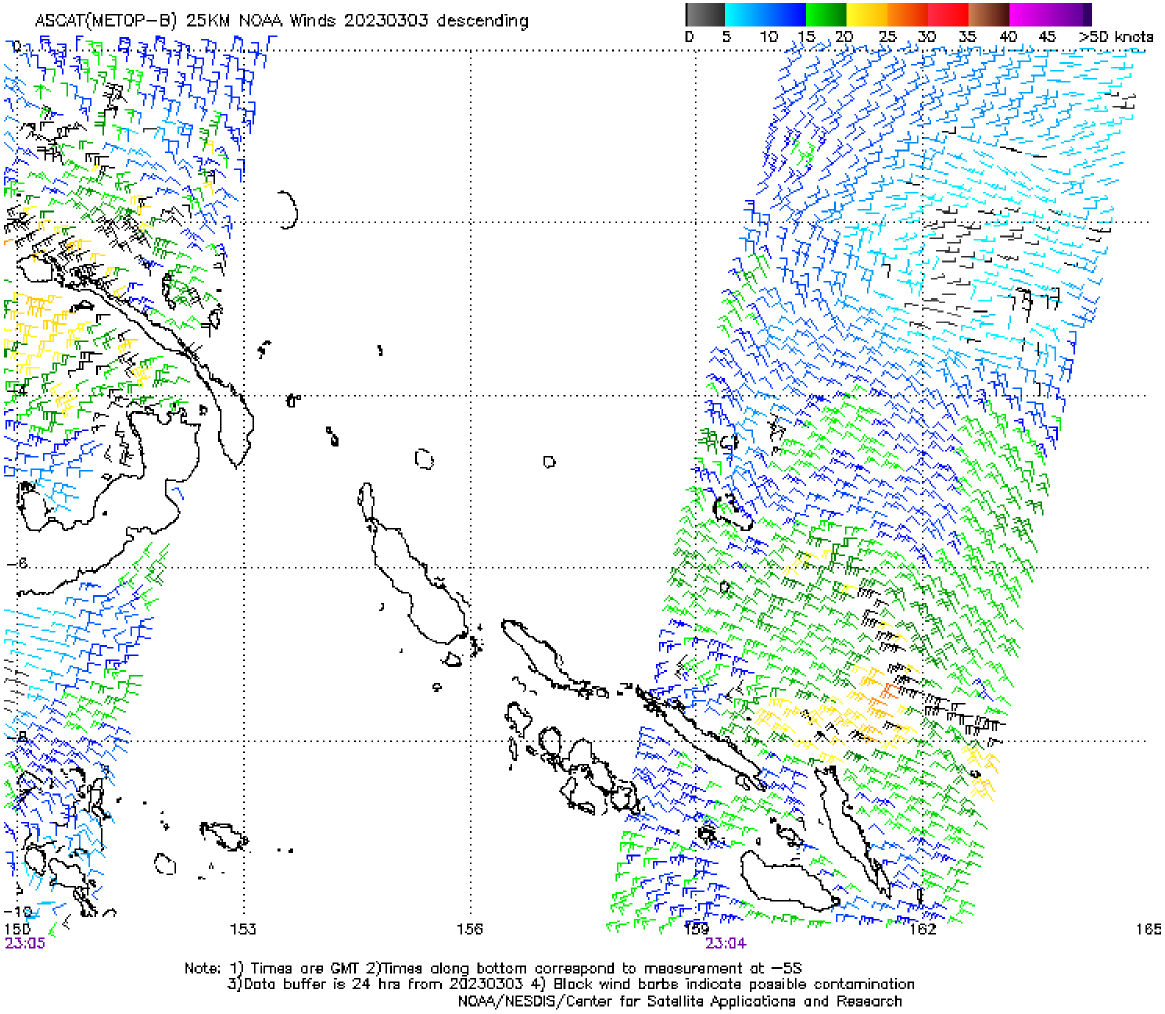
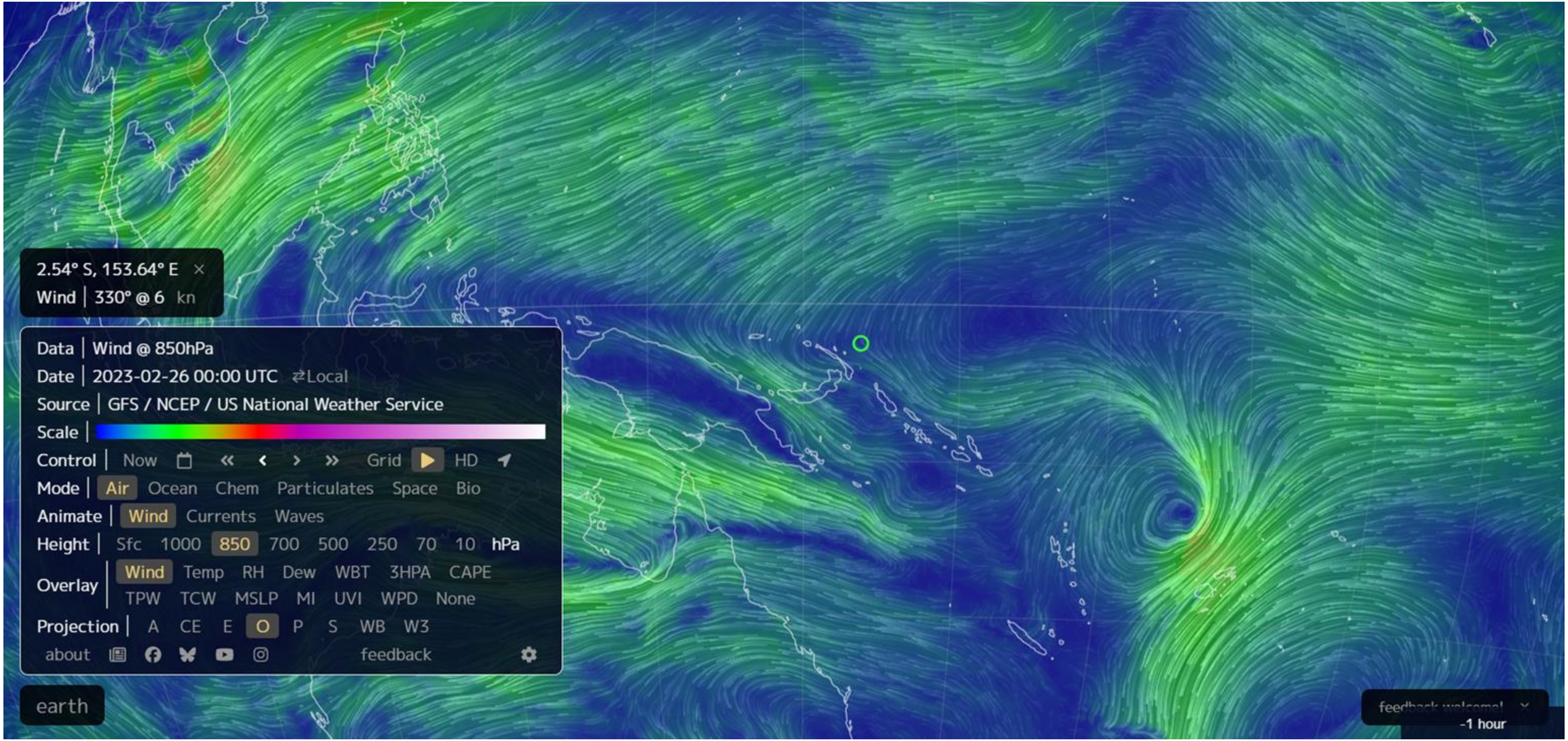
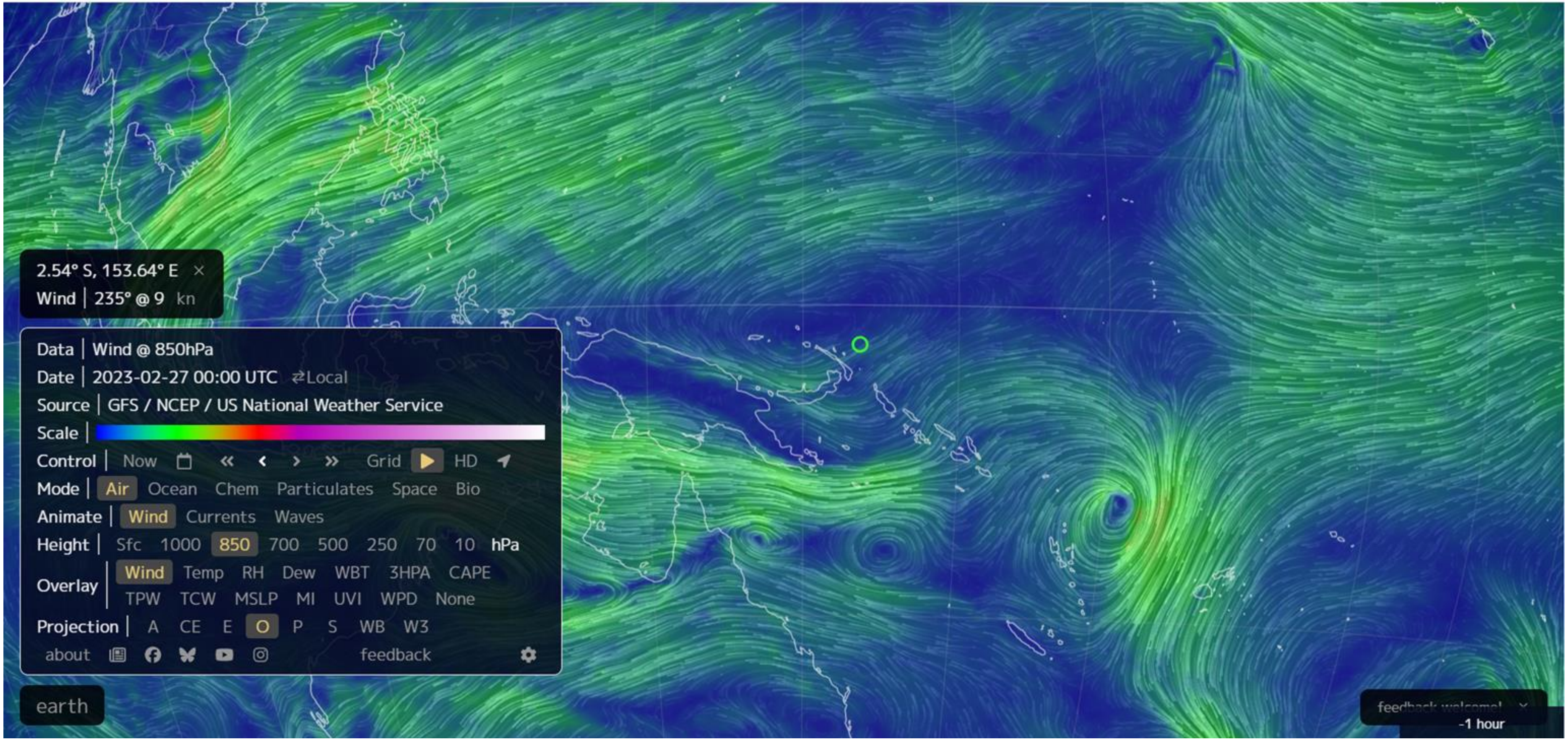


March 1, 2023
Descending

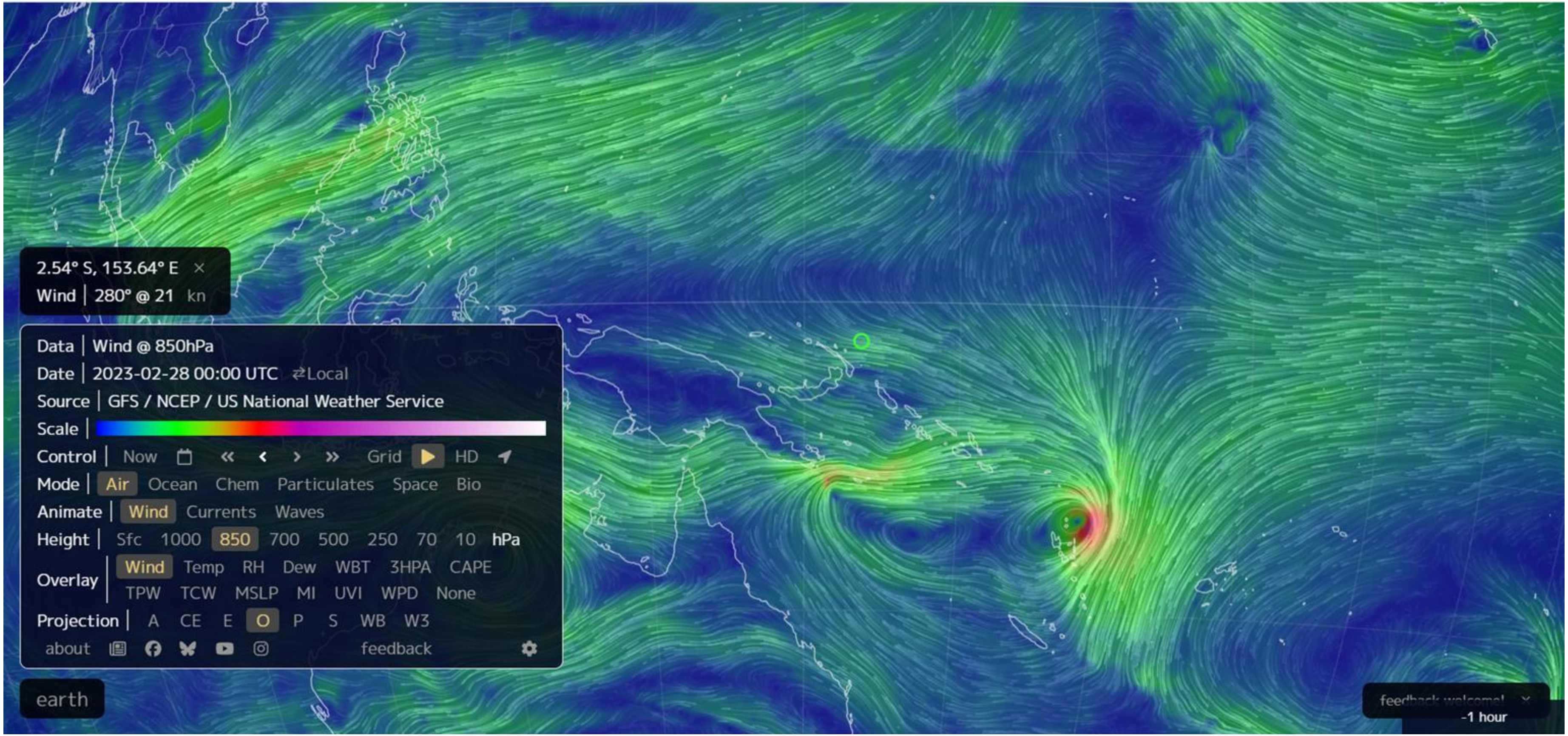
February 26, 2023 - 850hPa



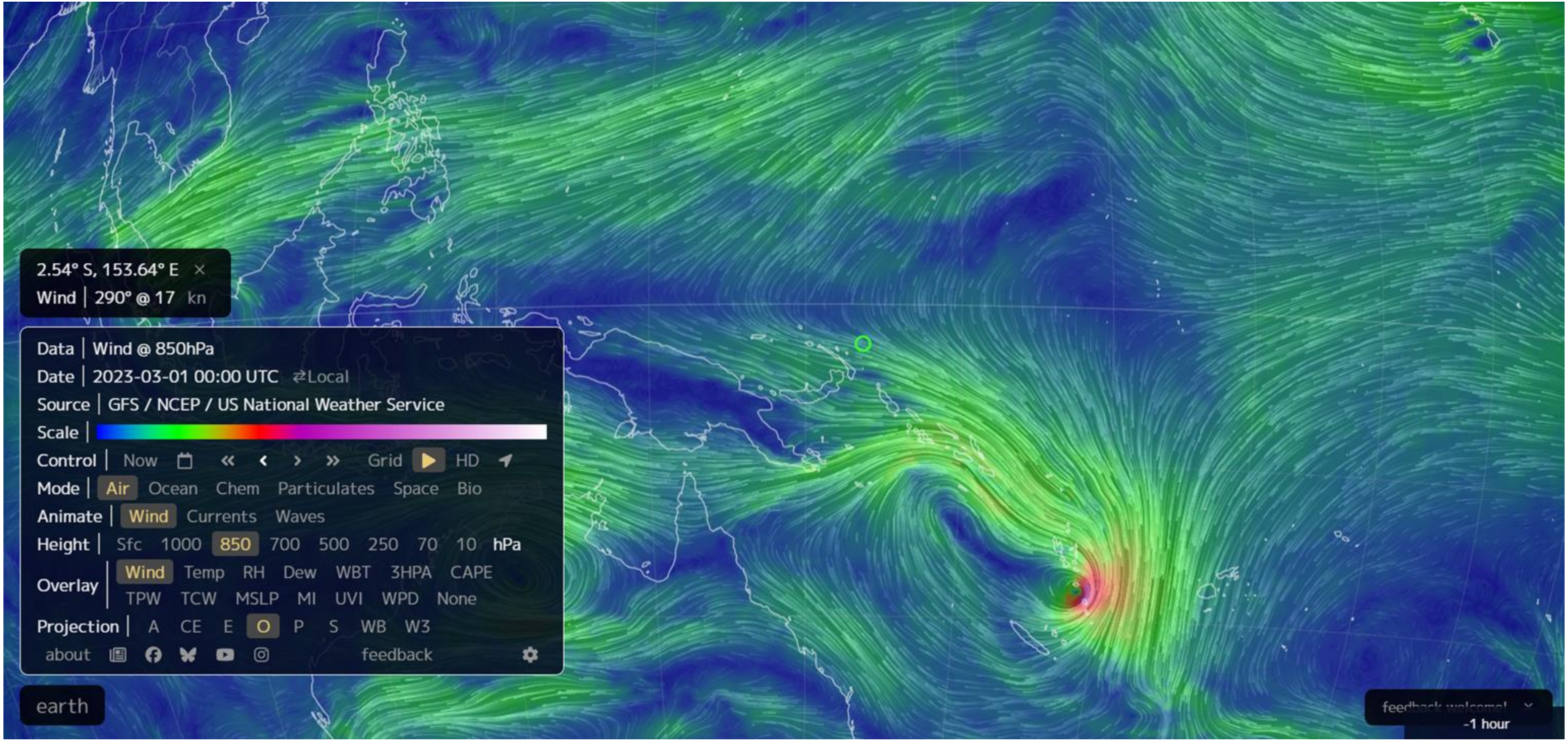
February 27, 2023 - 850hPa



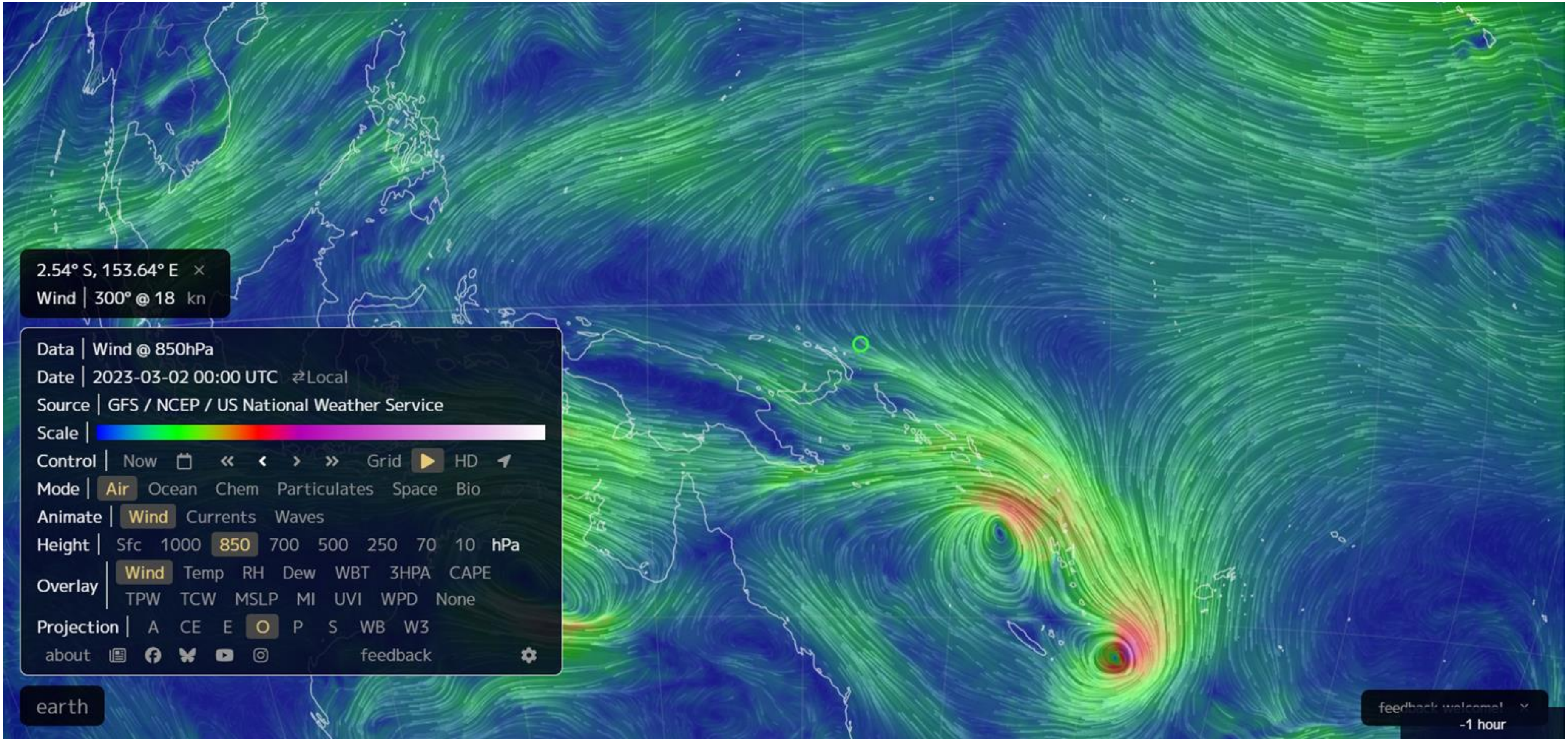
February 28, 2023 - 850hPa



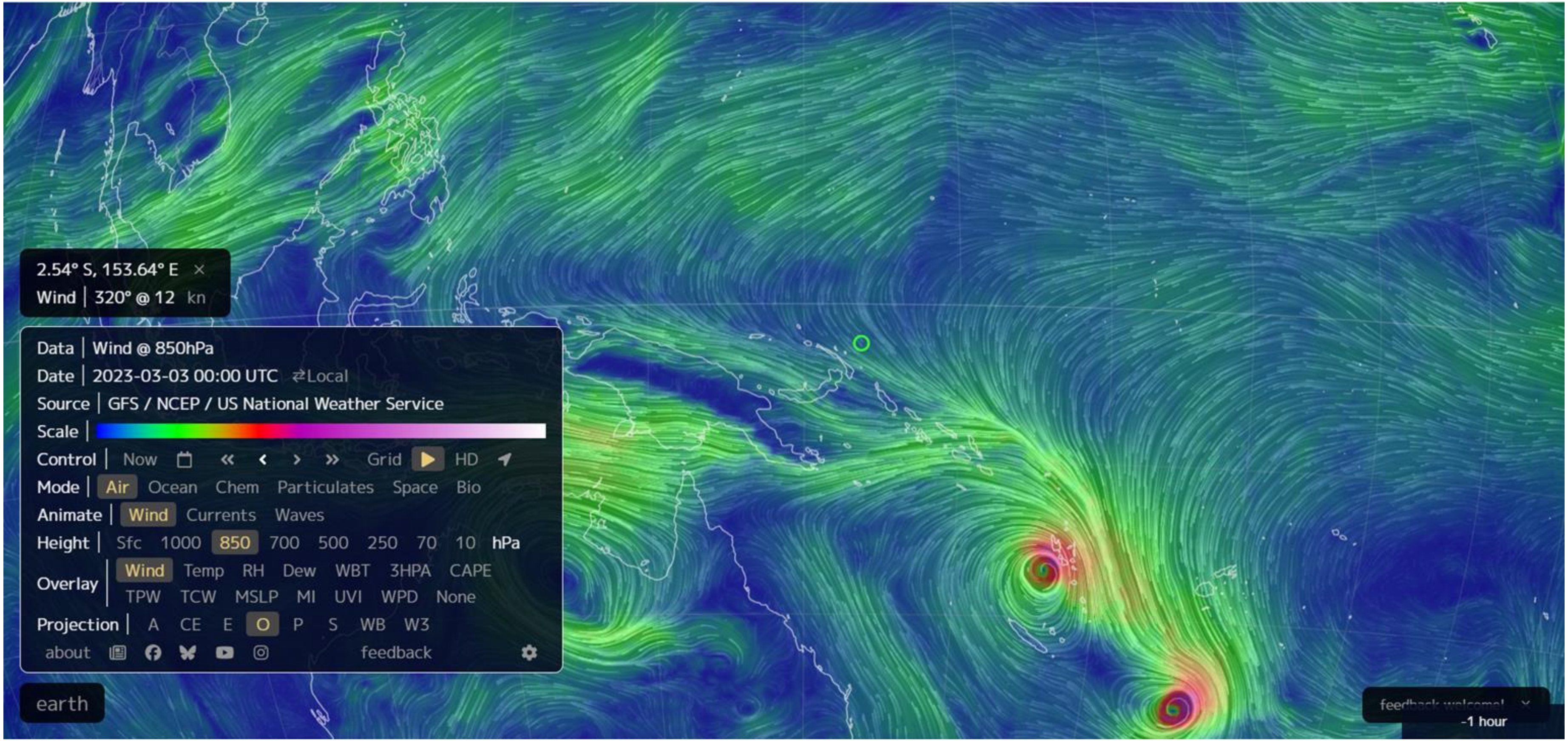
March 01, 2023 - 850hPa



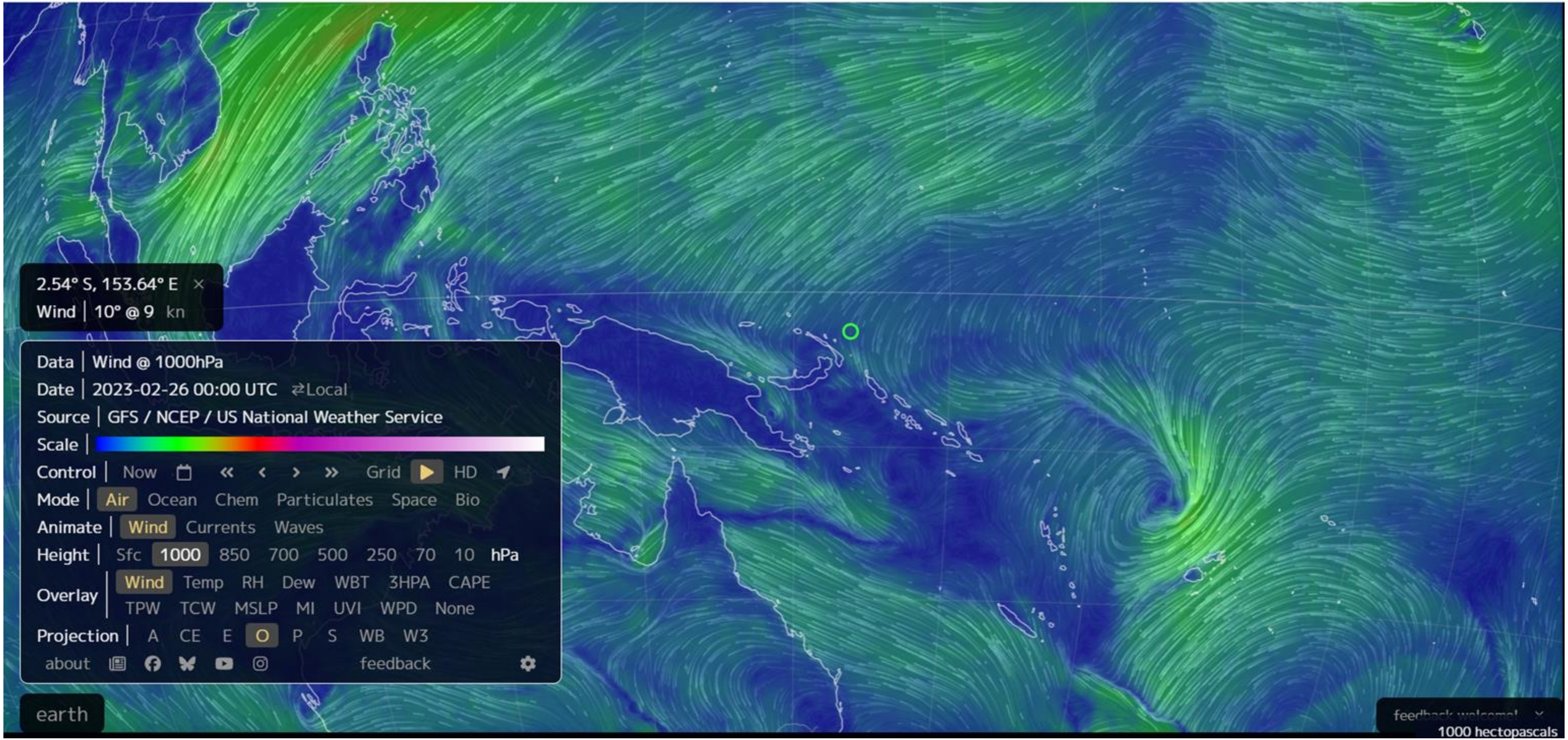
March 02, 2023 - 850hPa



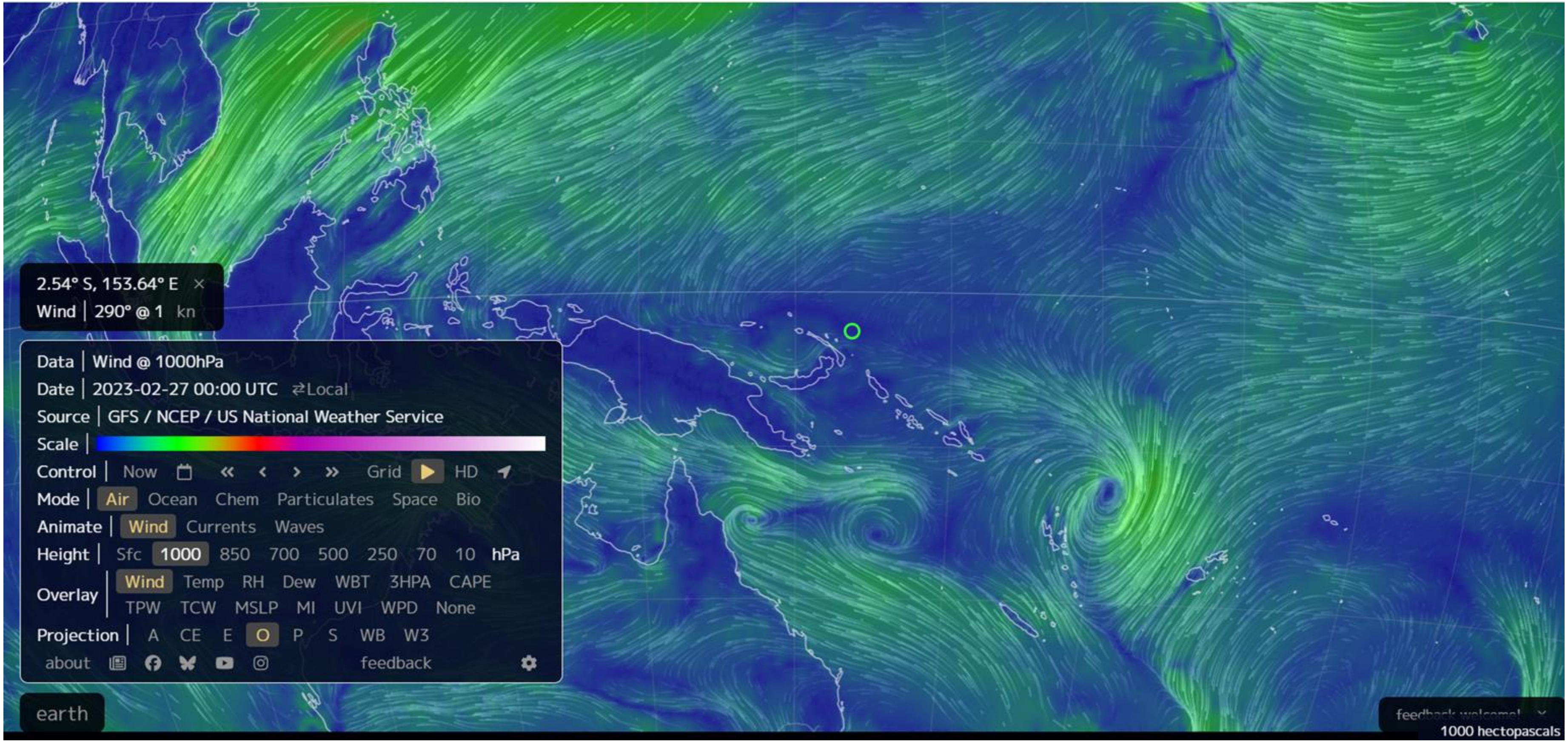
March 03, 2023 - 850hPa



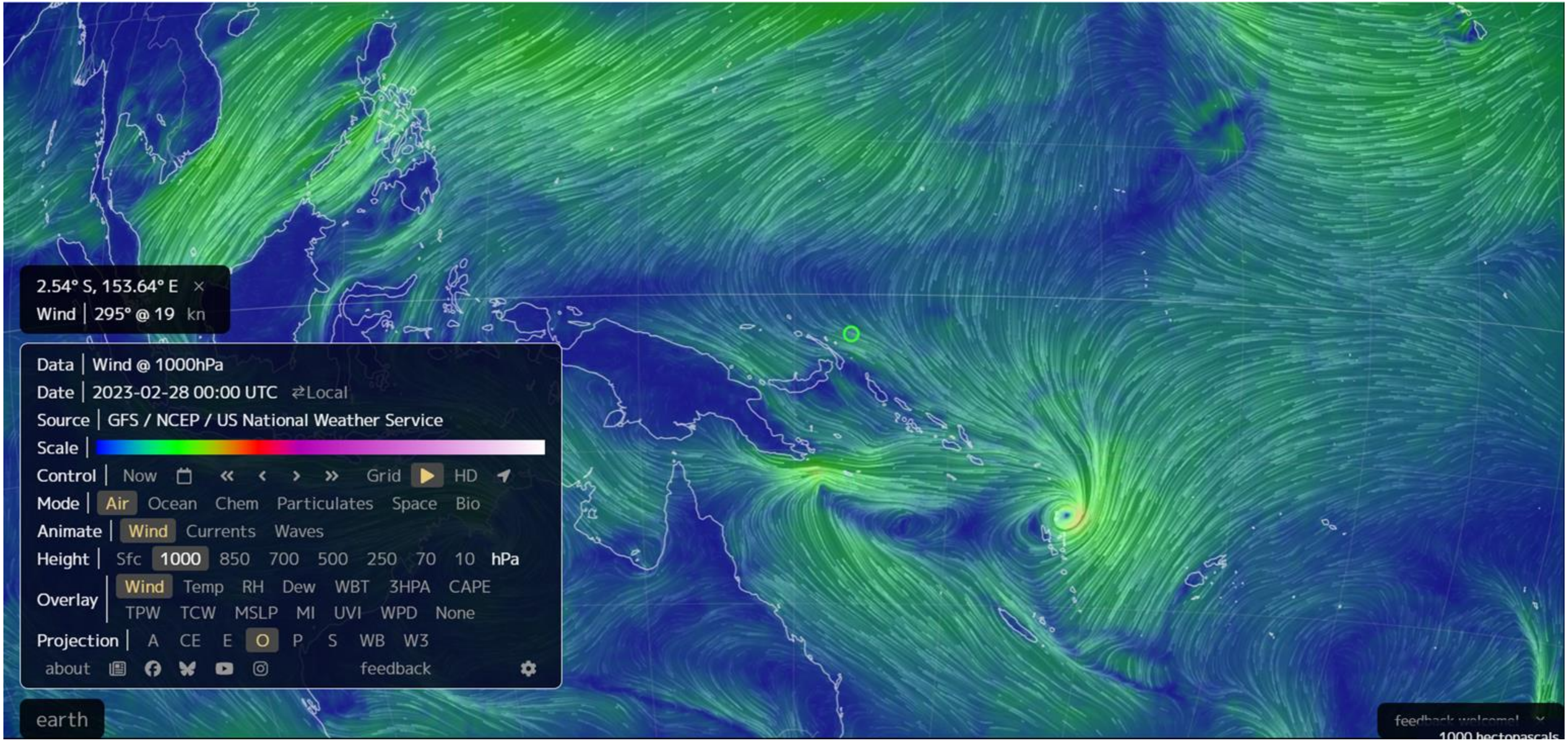
February 26, 2023 - 1000hPa



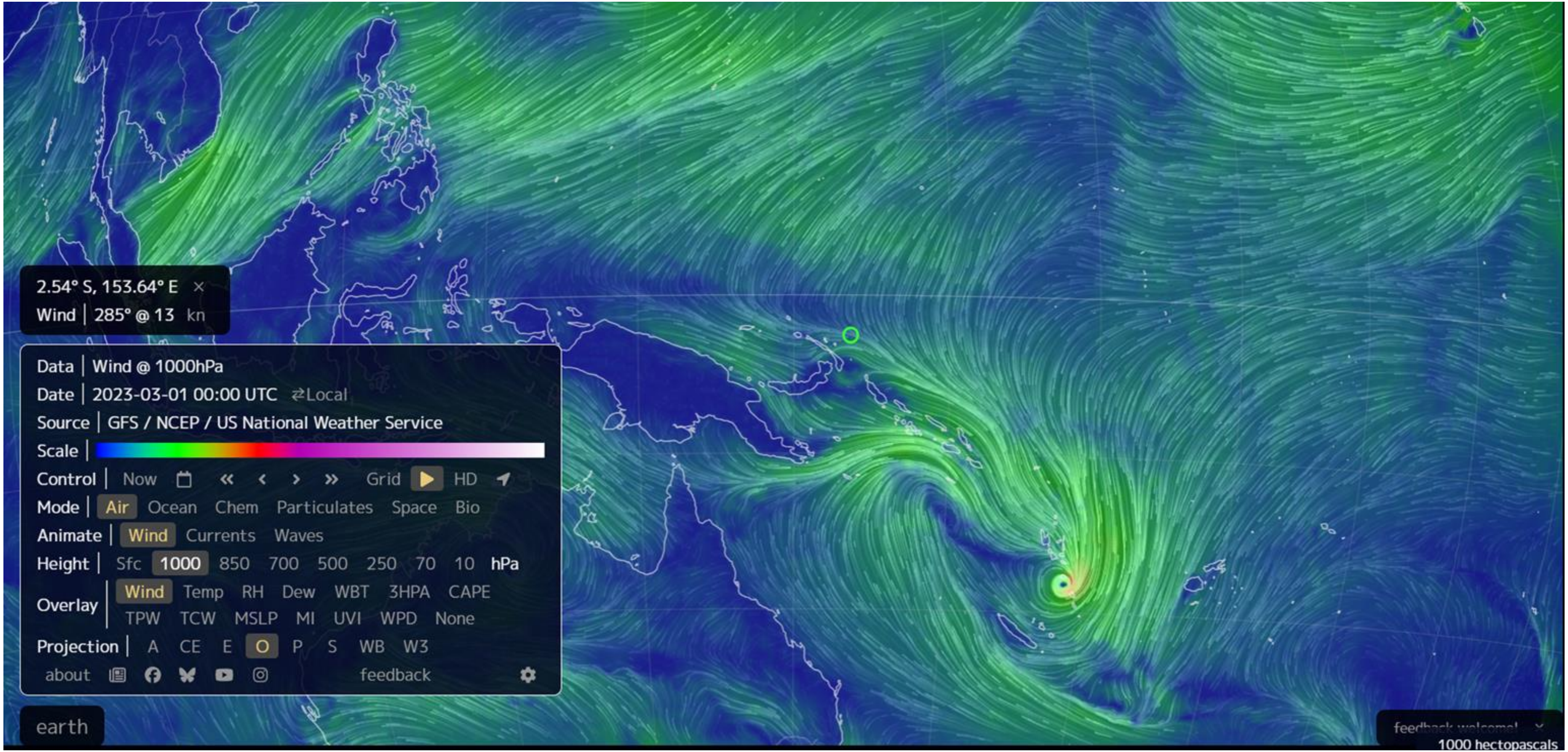
February 27, 2023 - 1000hPa



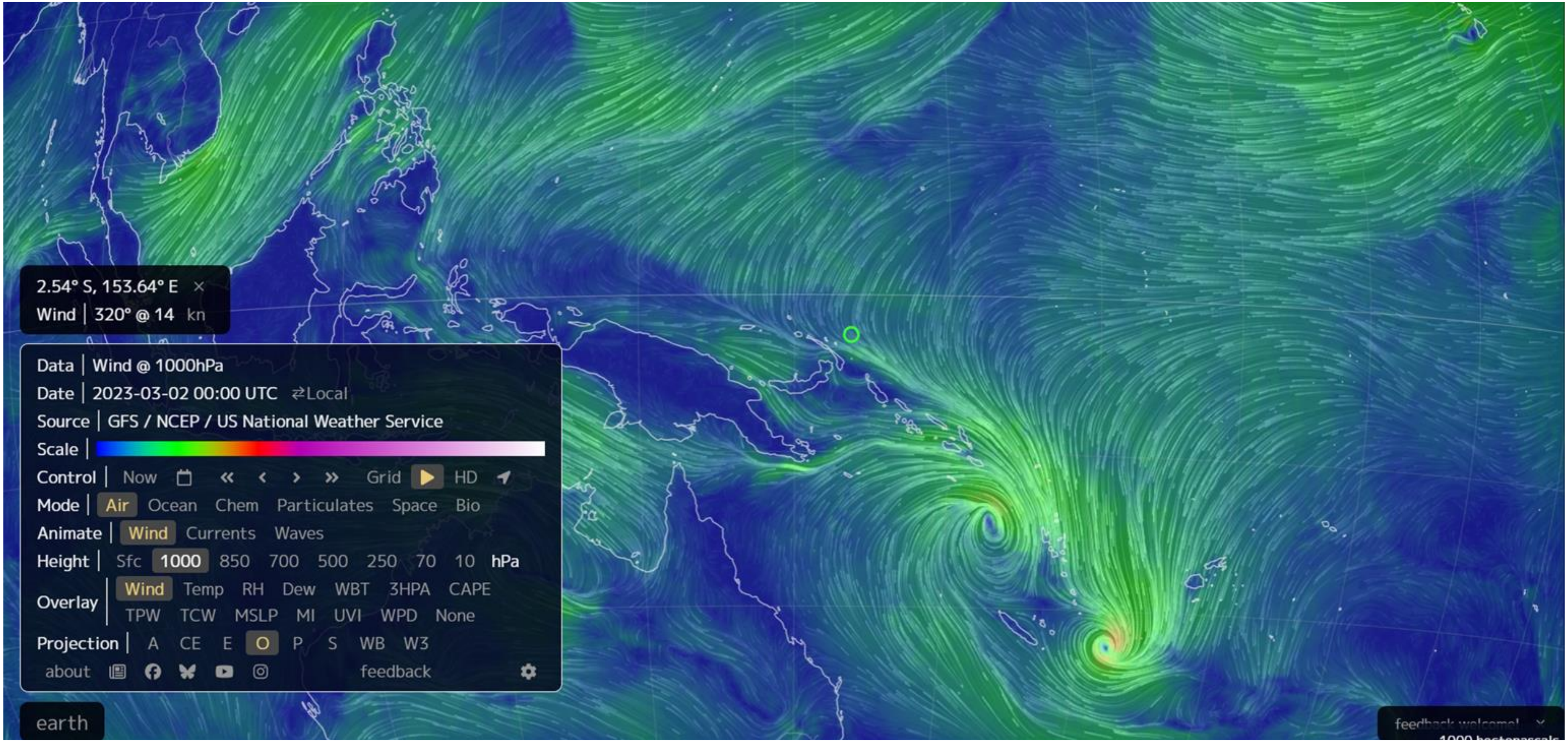
February 28, 2023 - 1000hPa



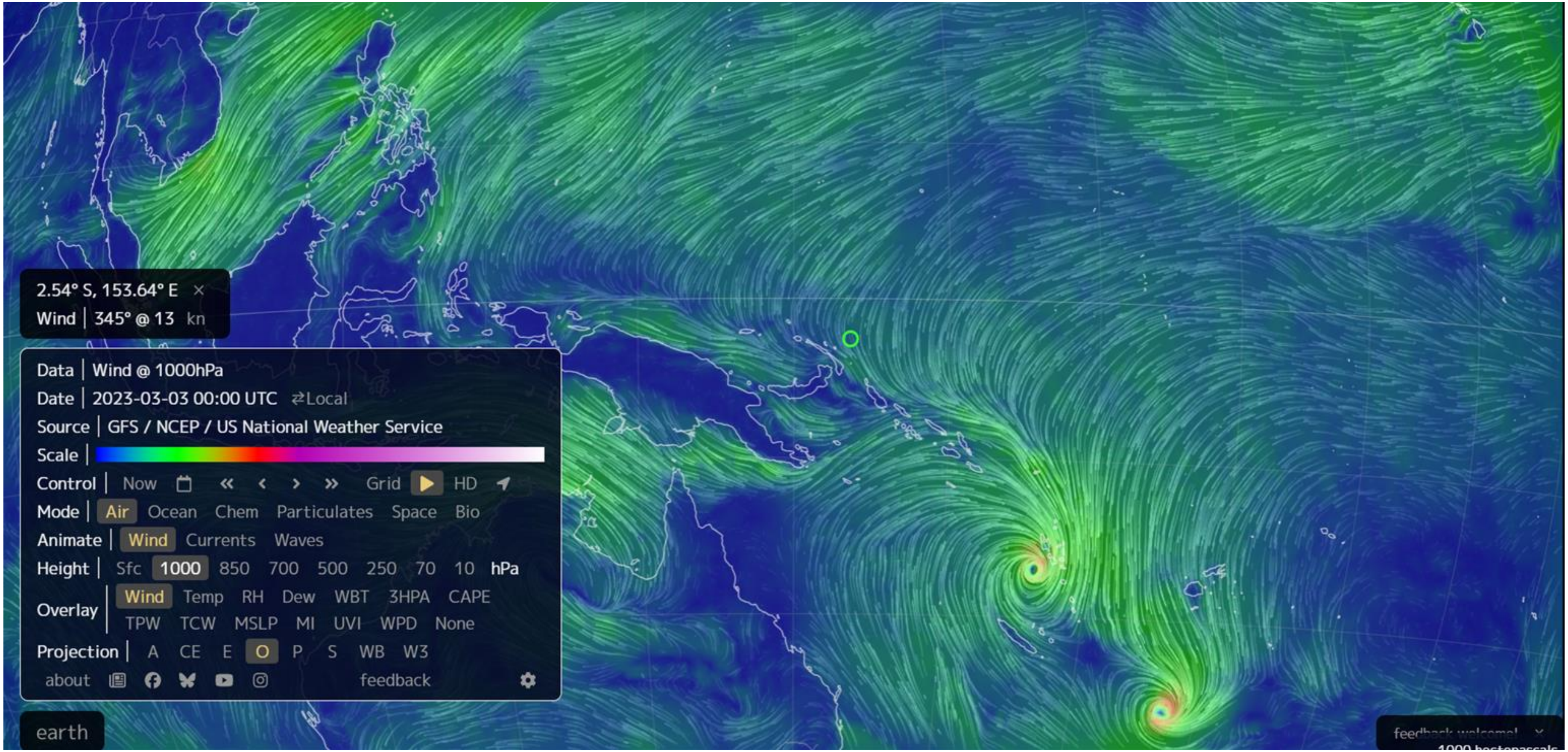
March 01, 2023 - 1000hPa



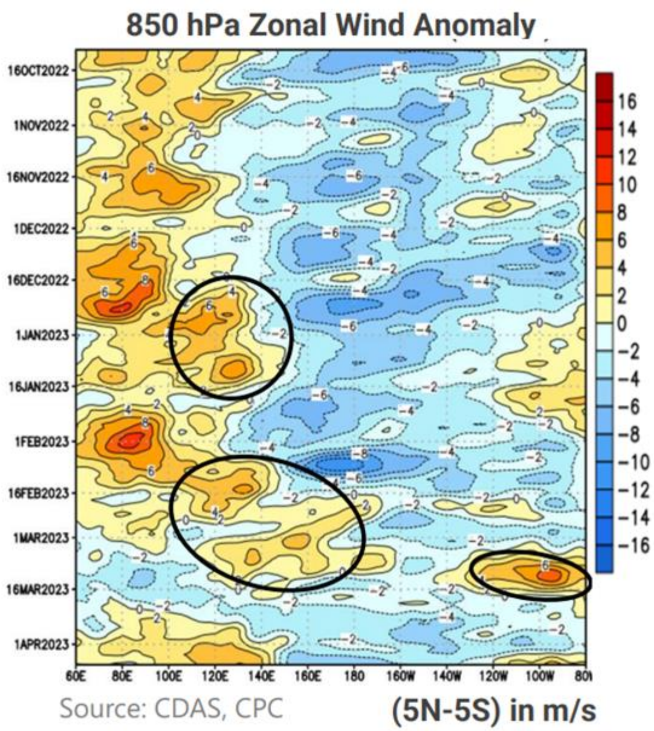
March 02, 2023 - 1000hPa

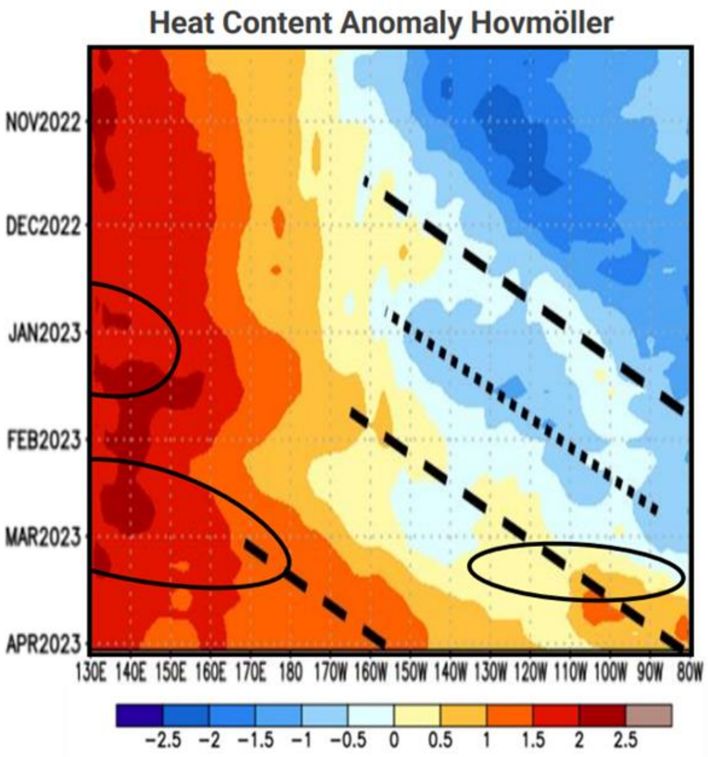


March 03, 2023 - 1000hPa



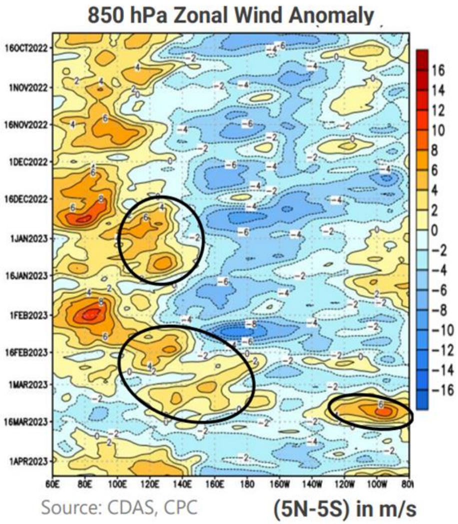
Kelvin Waves: Hovmöller of Winds and Heat Content

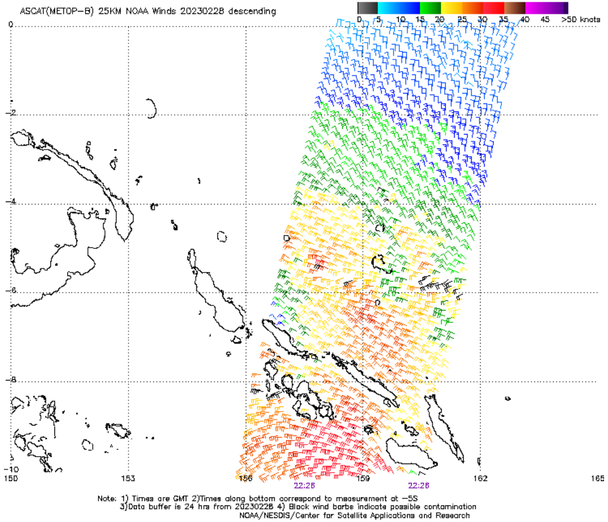


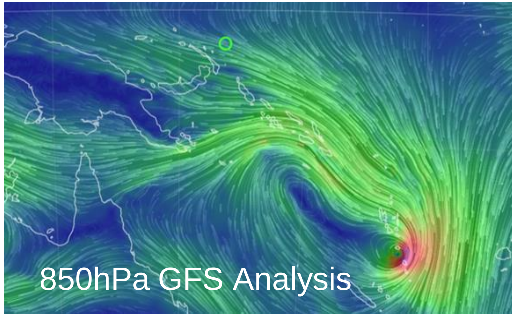


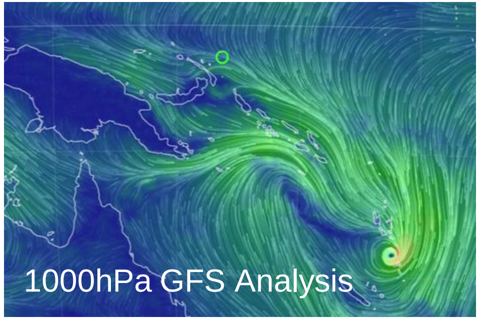
- Westerly wind bursts (oranges) can trigger downwelling (warm) Kelvin Waves that propagate towards South America.
- Heat Content Anomalies suggest potentially 3 of these processes since January: The latest warm Kelvin is propagating already into 120°W.

Exercise 1 Summary









Westerly wind bursts that trigger Kelvin Waves do not need to occur ONLY in the equator, in the 5°N-5°S latitude belt or even 10°N-10°S latitude belt.

ASCAT winds from polar satellites are great tools to evaluate these westerly wind bursts.

It is best to compare to 850 hPa signals.

Tropical cyclones and/or an active South Pacific Convergence Zone (SPCZ) can trigger these westerly wind bursts that, in term, can trigger warm Kelvin Waves that propagate along the equator.

Exercise

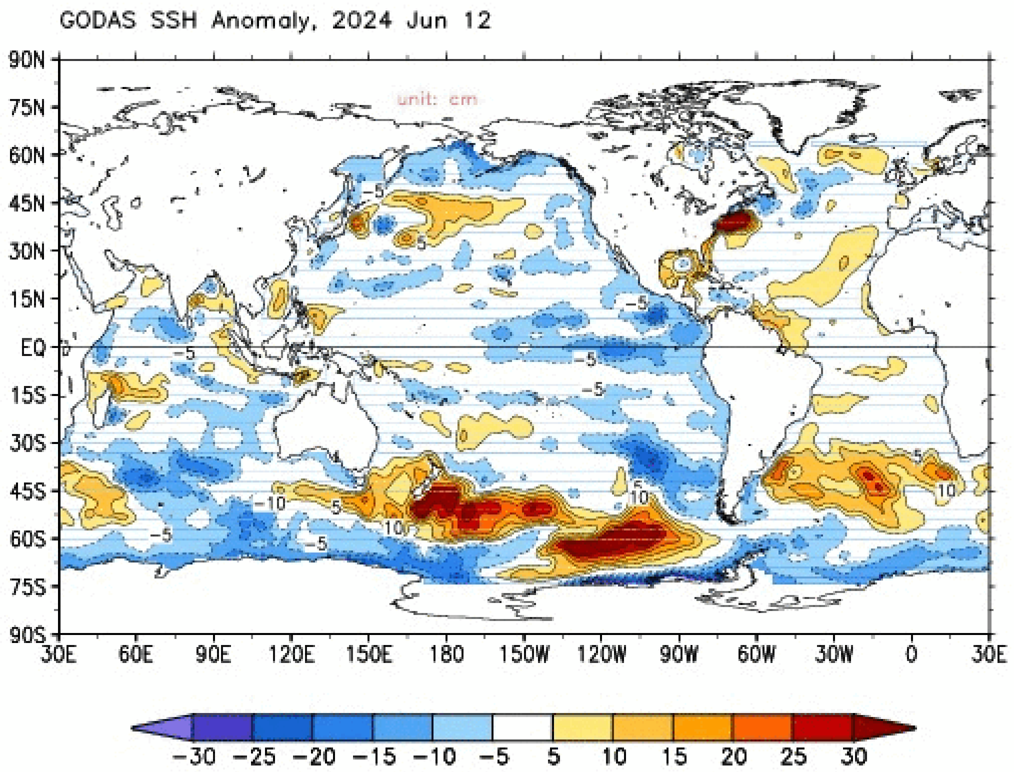
Altimetry: What is going on in the Equatorial Pacific?

What could the anomalously low sea level in the Eastern Pacific Mean?

When along the equator, a zonally-oriented region of below-normal sea level can indicate the presence of an Oceanic Upwelling (cold) Kelvin Wave, which sometimes relates to a developing La Niña.

Cold (warm) Kelvins do not always mean that a La Niña (El Niño) are developing.

Altimetry data, from polar satellites, is great to evaluate sea level anomalies that can relate to these cold (warm) waves and their potential impacts on the ENSO system. Evaluating propagation is important.



Exercise

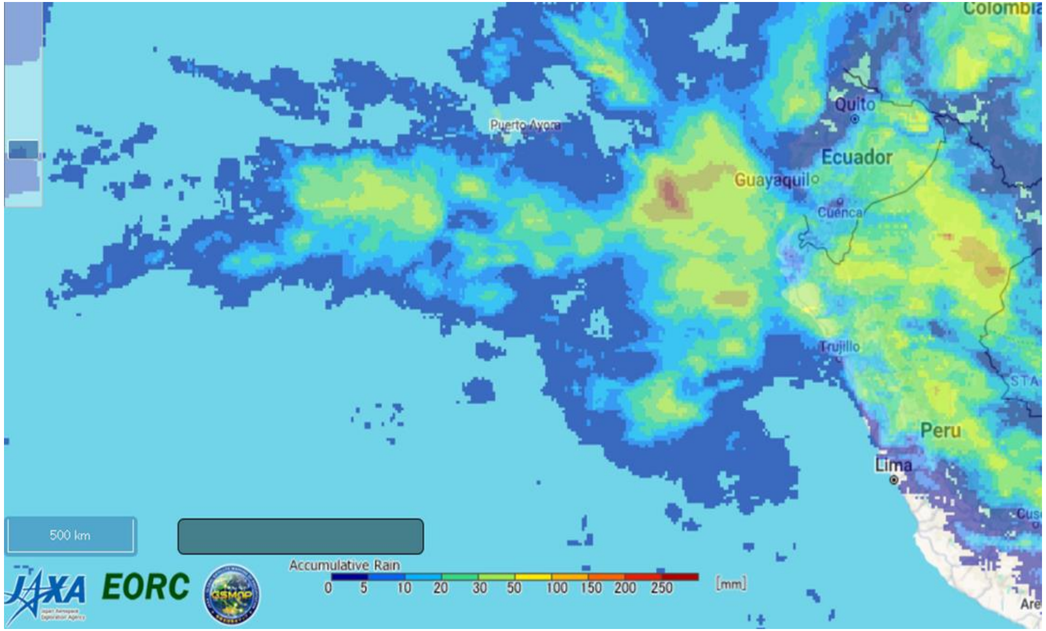
Deep convection in Niño 1+2. What happens next?

Cyclone Yaku forms in Niño 1+2, March 2023

Question to discuss: what could this cyclone do to SST along the South American coast?

Cyclone Yaku forms in Niño 1+2, March 2023

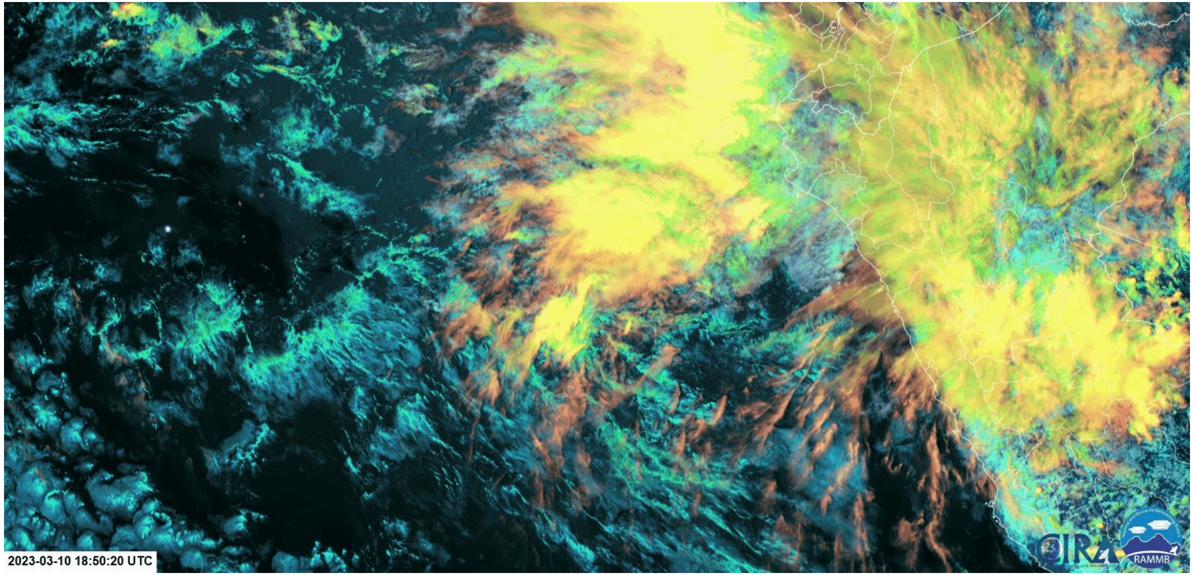
Satellite estimated rainfall (March 10)



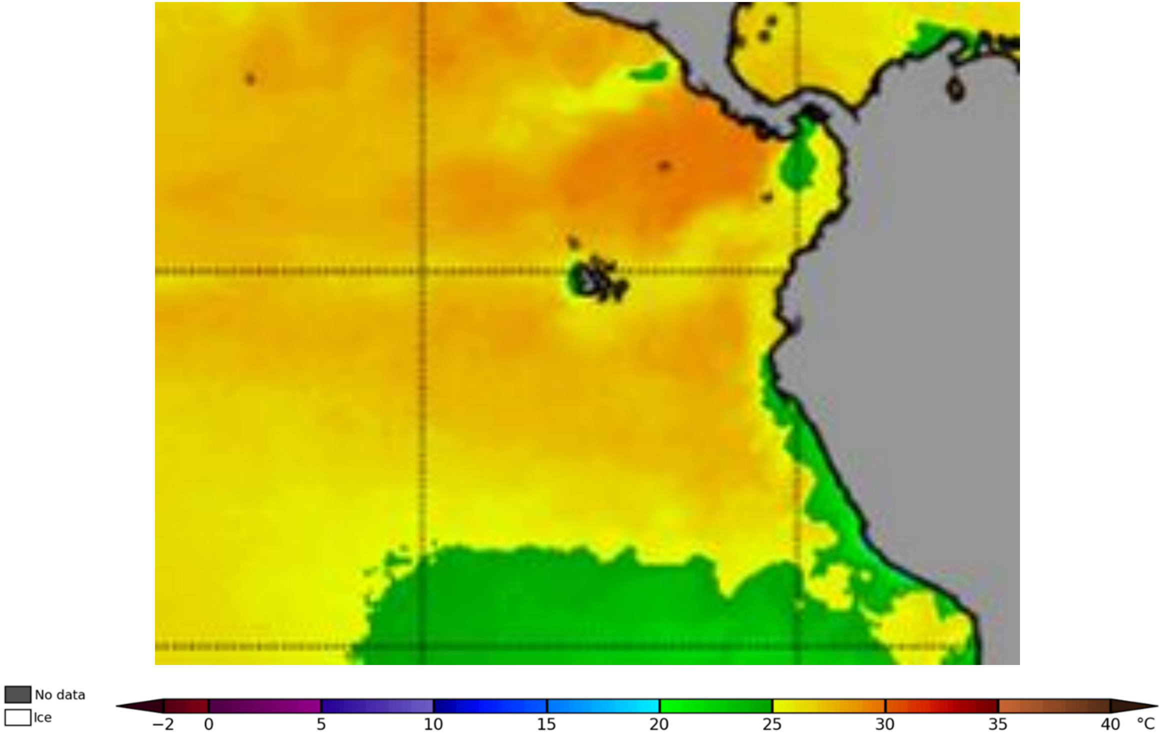
- What weather situation is occurring off the north coast of Perú?
- How could this affect surface winds?

Cyclone Yaku forms in Niño 1+2, March 2023

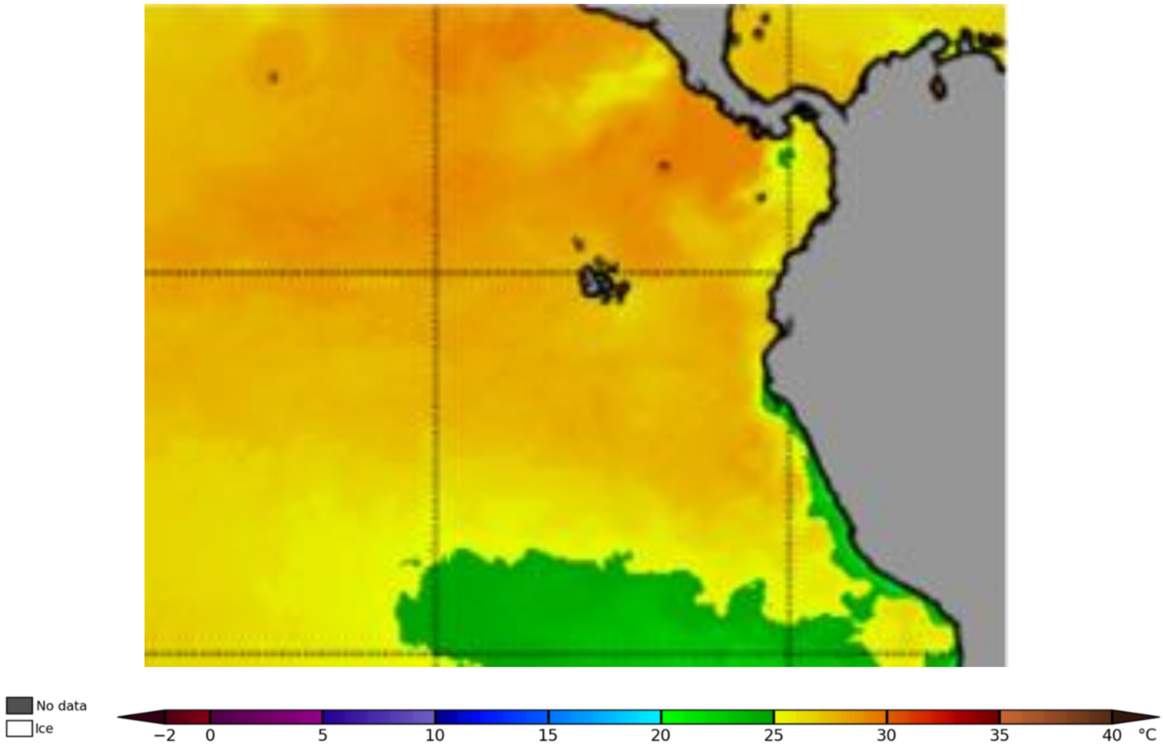
The Day-Cloud-Phase RGB shows ice clouds in yellows and reds and water clouds in light blues



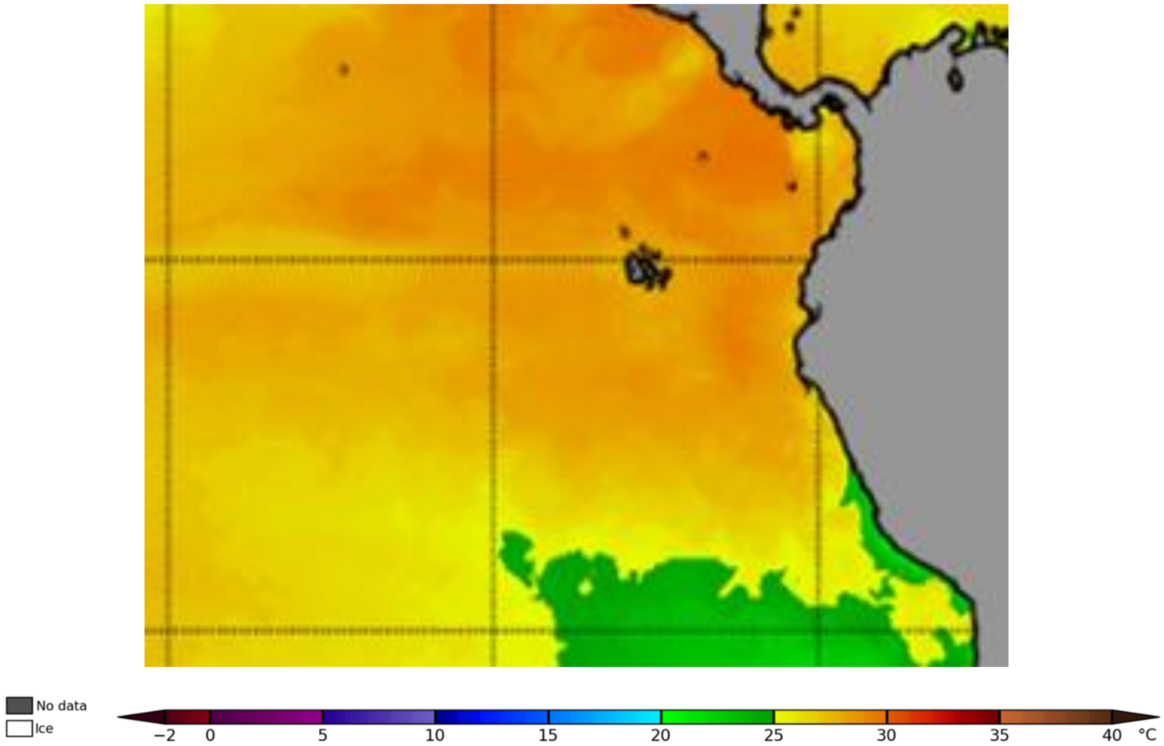
NOAA Coral Reef Watch Daily 5km Sea Surface Temperatures (v3.1) 7 Mar 2023



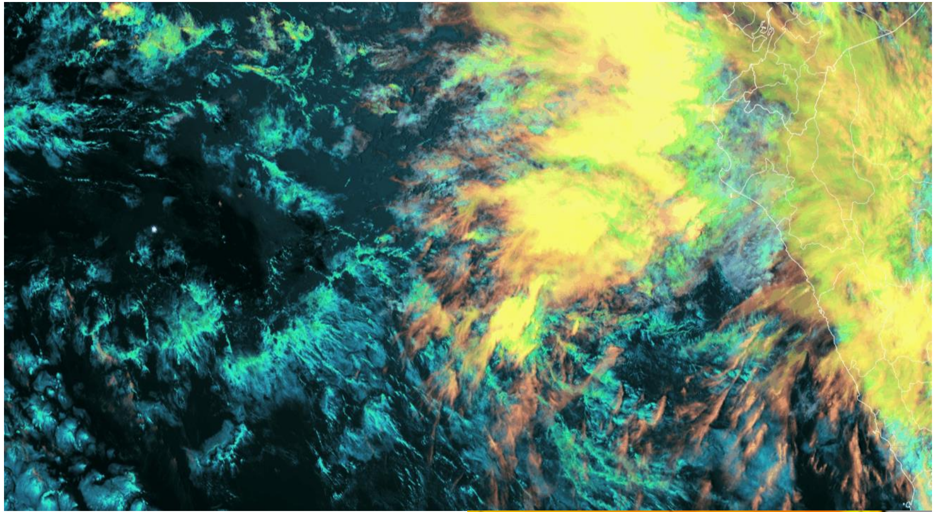
NOAA Coral Reef Watch Daily 5km Sea Surface Temperatures (v3.1) 13 Mar 2023

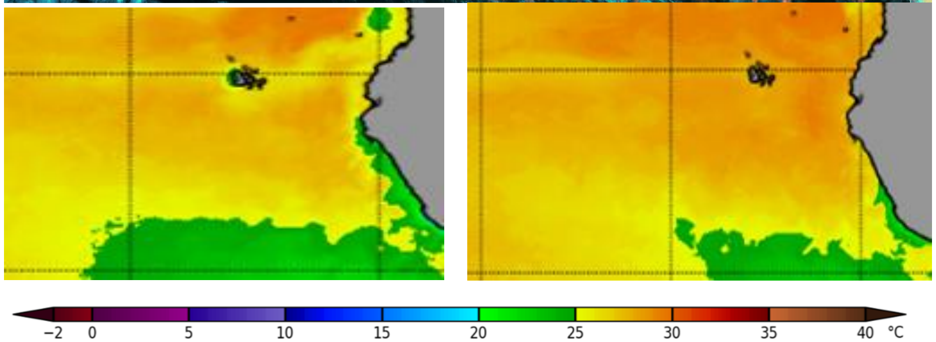


NOAA Coral Reef Watch Daily 5km Sea Surface Temperatures (v3.1) 20 Mar 2023



Exercise 3 Summary





Westerly wind bursts associated with a weak tropical cyclone-like feature (“Yaku”) developed a local warming along the coasts of Peru and Ecuador in March 2023.

These winds can trigger Kelvin Wave-like features that catapult a deep-layer warming.

Since the sub-superficial layers were warmer than normal already, the warming was very strong and ended up triggering the beginning of the 2023-4 El Niño, in combination with other processes present in the western Pacific.

The Madden-Julian Oscillation and an active South Pacific Intertropical Convergence Zone played a role enhancing Yaku’s impact on exacerbating the warming.

Some New Developments

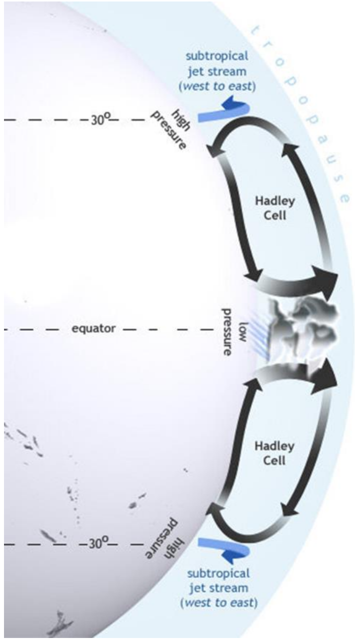
CPC has worked on a new index, the RONI

Above the atmospheric boundary layer in the tropics, there is little horizontal variation in temperature (small Coriolis). Tropical atmosphere quickly smooths out temperature gradients.

Surface conditions throughout the entire tropical basin (by modifying deep convection) sets the tropical temperature in the free troposphere.

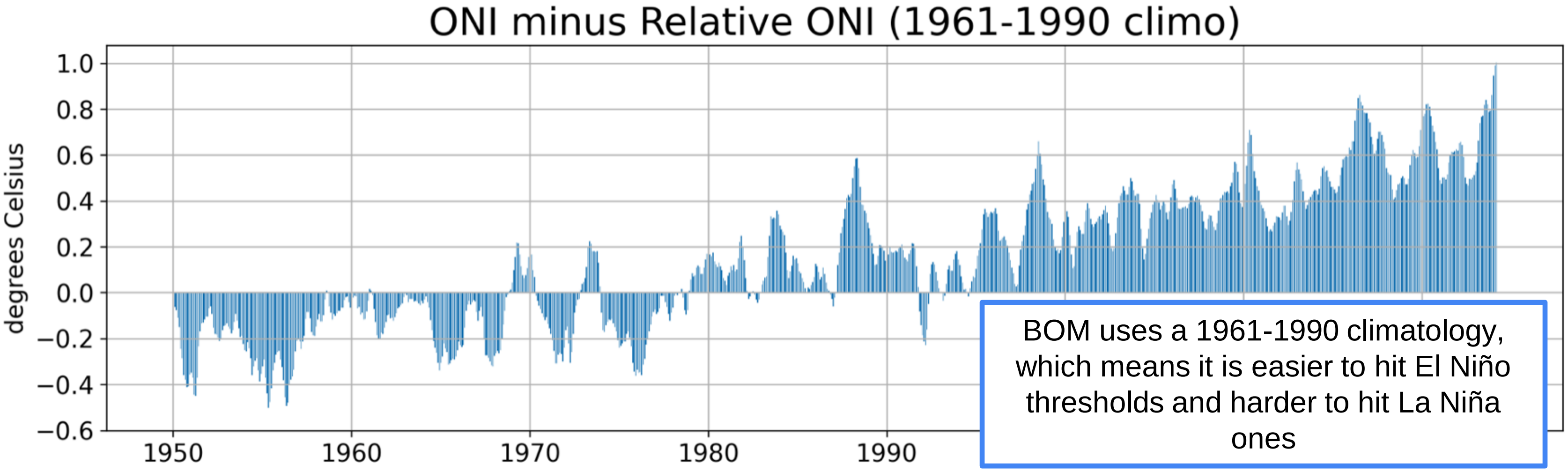
The free tropospheric temperature (or average SST across the entire tropics) is very important for the local instability, determining whether conditions are more/less conducive for rainfall.

Relative SSTs take in account the average conditions across the entire tropics and the local SSTs in a single measure.



BOM is currently transitioning to use a relative SST index.

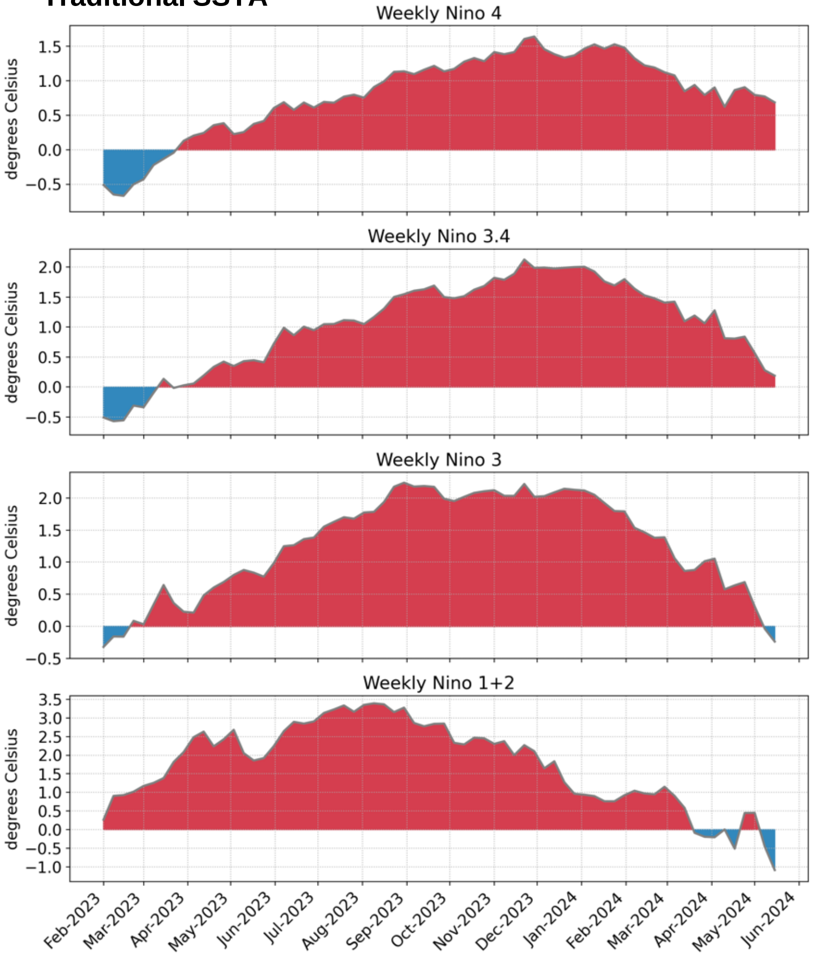
Their public-facing sites will display the relative SST index as their official ENSO index.



Data: ERSSTv5

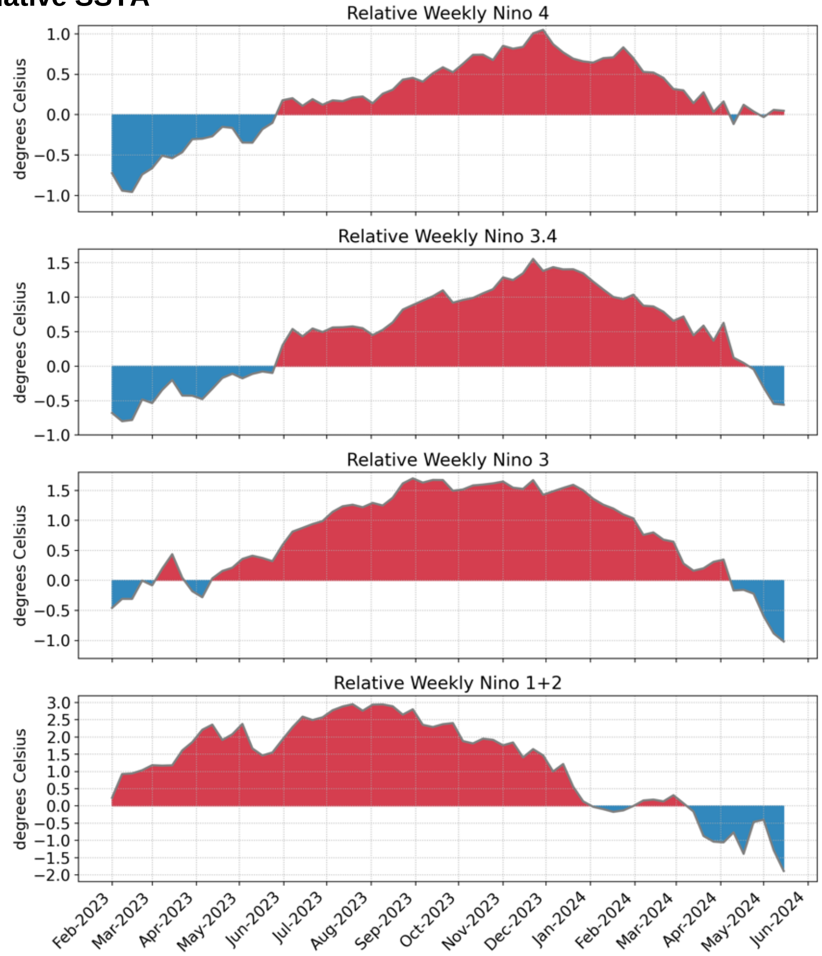
Weekly OISSTv2.1 Differences Are Large As Well

Traditional SSTA



~0.7˚C difference in weekly Niño3.4 centered on 15 May 2024

Relative SSTA



Acknowledgements!

Special Thanks to:

- Karimar Ledesma-Maldonado, WPC International Desks
- Chris Smith, GOES-R Satellite Liaison
- Michelle L'Heureux, CPC
- Dr. Boyin Huang, NOAA NCEI

Additional Slides

These slides are not organized, but contain information that could be of use to you for understanding ENSO.

How ENSO impacts the weather and climate globally?

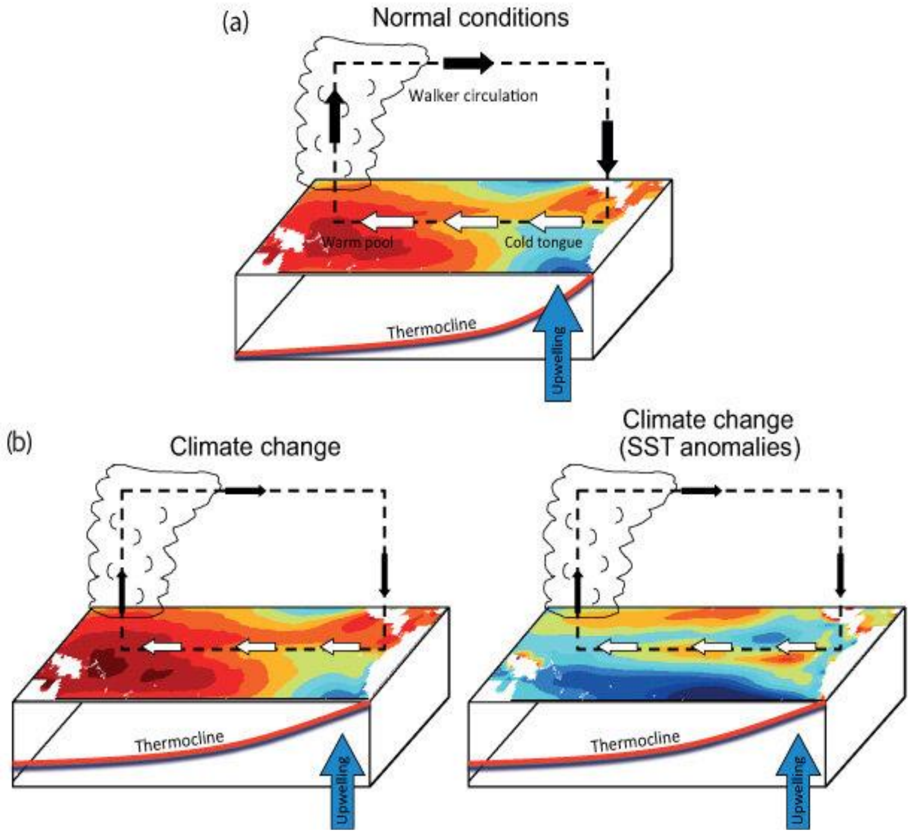
- The impact on the tropics, the Pacific, and the Indian Ocean and surrounding landmasses is well established. However the impact can many parts of the world.
- ***Each phase can lead to severe droughts and devastating floods in different parts of the world.***

Warm Phase	Rainfall decrease in Indonesia	Rainfall decreases In Central and Eastern Tropical Pacific Ocean	Easterly winds weakens or change to westerly winds	Increase zonal wind vertical shear in the Atlantic	Inhibits tropical cyclogenesis in Atlantic basin.
Cold Phase	Rainfall increases in Indonesia	Rainfall decreases in Central and Eastern Tropical Pacific Ocean	Stronger easterly winds	Decrease zonal vertical shear in the Atlantic	Enhance tropical cyclogenesis in the Atlantic basin

➢ ***Neutral phase*** is been associated with strong SST anomalies in global oceans outside the tropical Pacific, and significant anomalies of land surface air temperature and precipitation over all the continents (Lin et al. 2019)

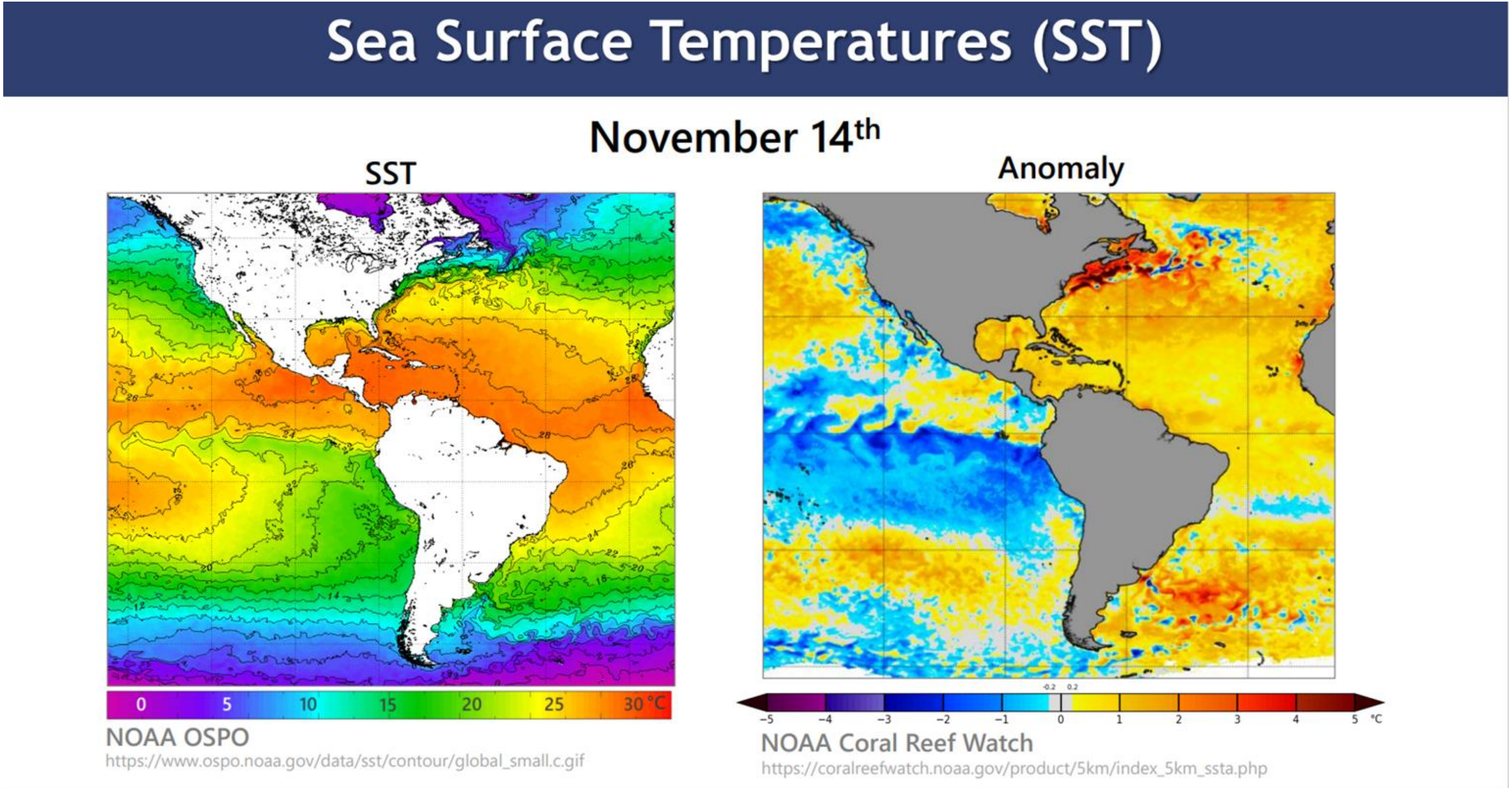
El Niño-Southern Oscillation (ENSO)

- The El Nino-Southern Oscillation (ENSO) is the dominant interannual variability of Earth's climate system.
- An oscillation of warming and cooling changes in the sea surface temperature (SST) in the central and eastern tropical Pacific ocean.
- There are two extreme phase called ***El Niño the warming phase*** and ***La Niña the cooling phase*** and between these two a ***neutral or normal phase.***
- ENSO warm or cold conditions occur every few years and last for about a year.



Adapted from Collins et al. (2010) and IPCC AR5 (2013).

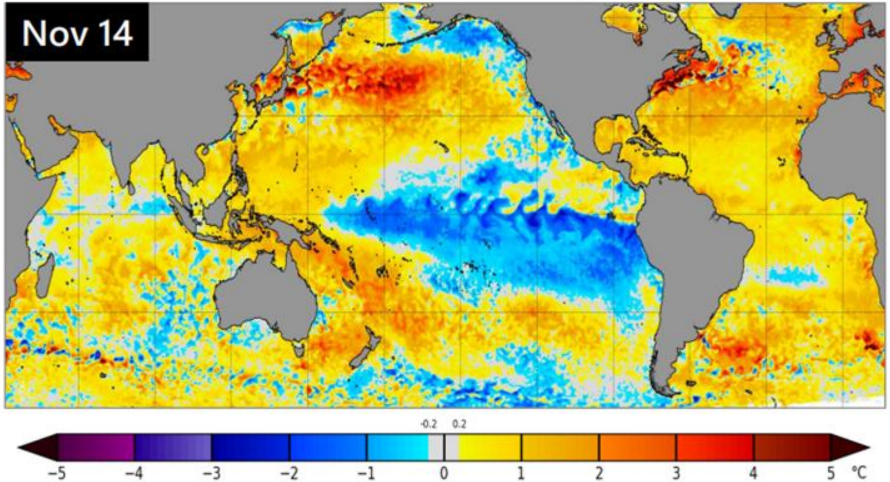
Example of Warming in the Pacific



Sea Temperature Anomalies in top layer

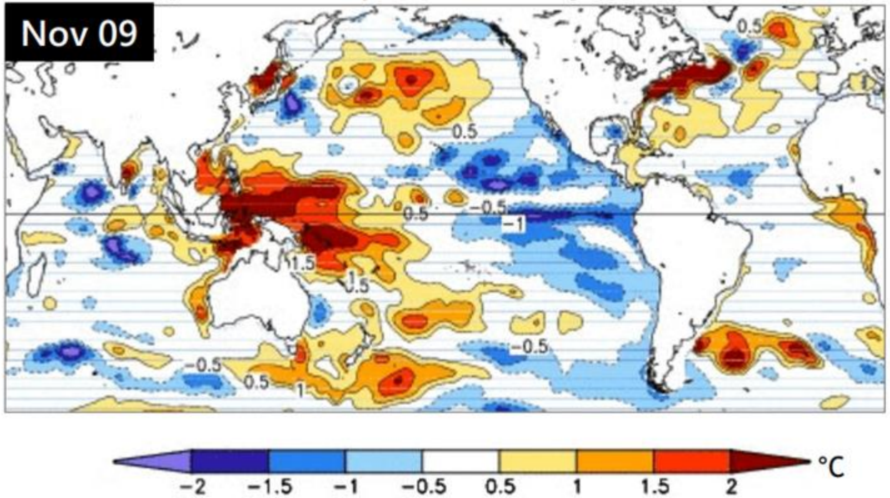
DEEP ANOMALIES LAST LONGER, THUS USEFUL FOR SUBSEASONAL FORECASTING

Surface Anomaly

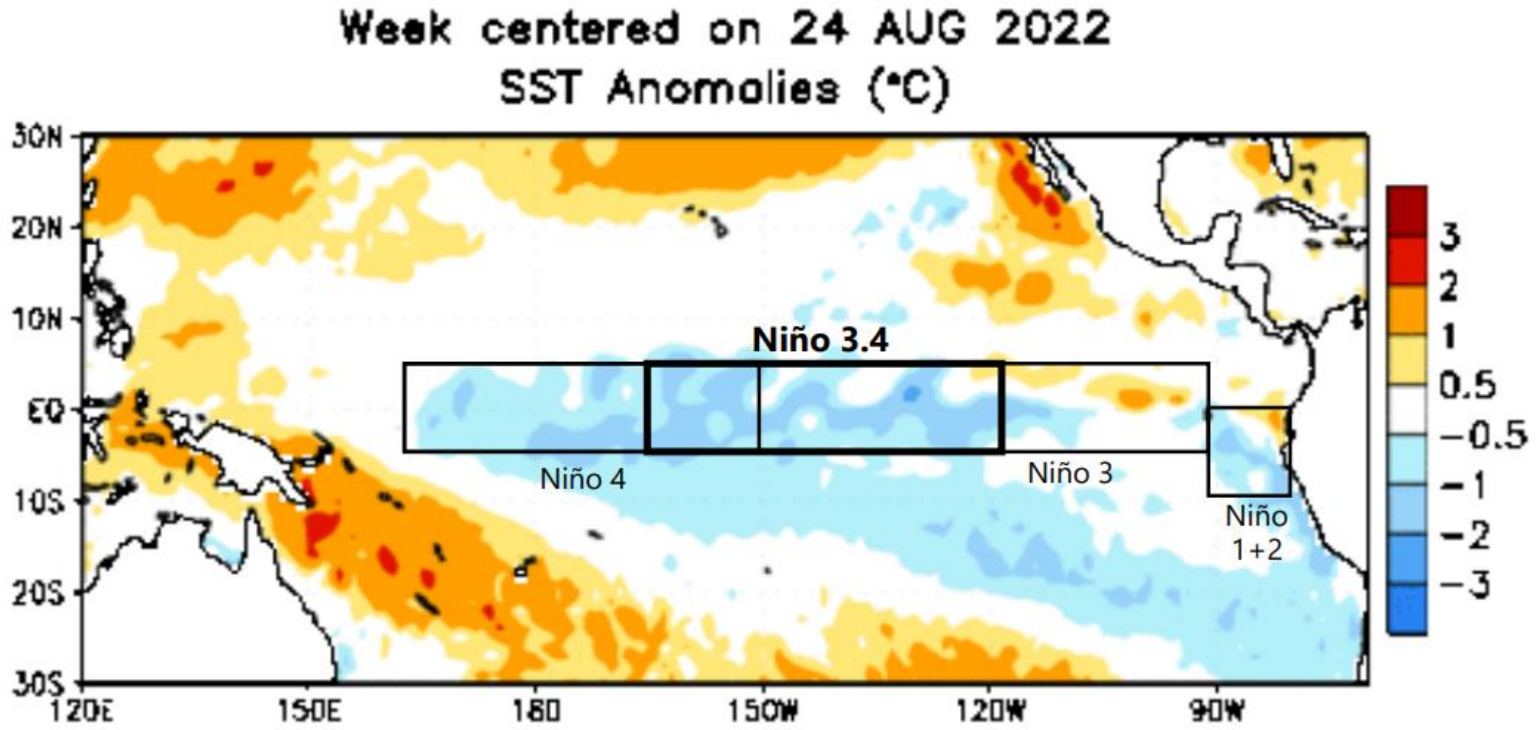


NOAA Coral Reef Watch
https://coralreefwatch.noaa.gov/product/5km/index_5km_ssta.php

Top 300m-Layer Anomaly (GODAS)



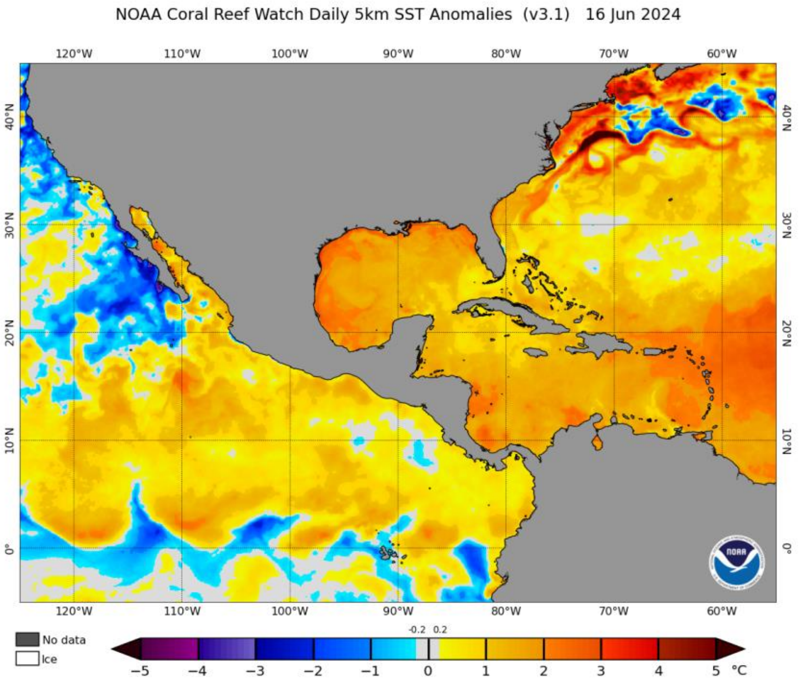
NOAA CPC
Source: CPC GODAS, https://www.cpc.ncep.noaa.gov/products/GODAS/



Week centered on 24 AUG 2022
SST Anomalies (°C)
30N
20N
10N
EQ
10S
20S
30S
120E
150E
180
150W
120W
90W
Niño 3.4
Niño 4
Niño 3
Niño 1+2
3
2
1
0.5
−0.5
−1
−2
−3

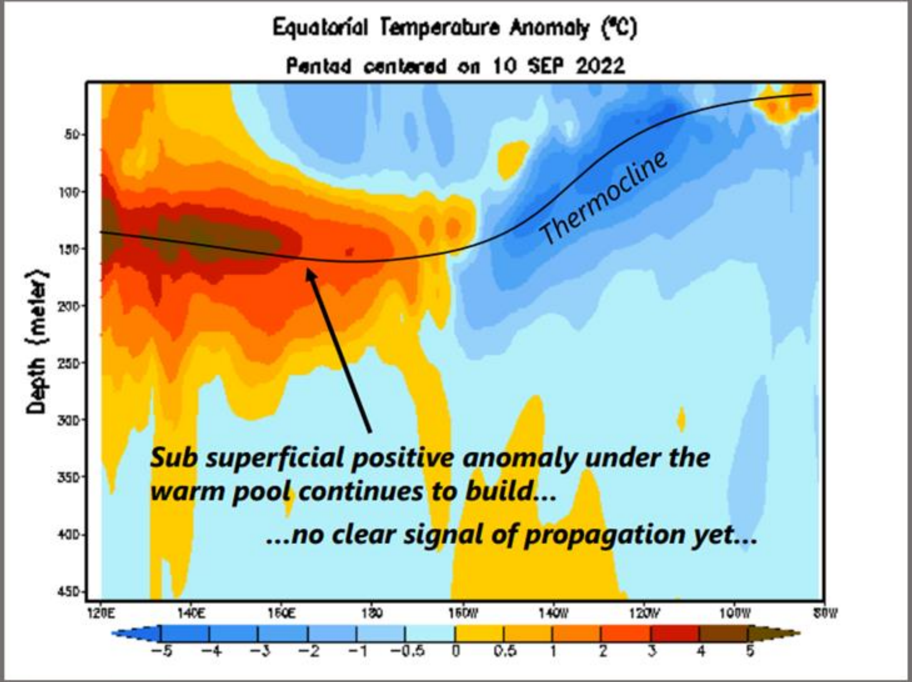
Satellite Products: Sea Surface Temperatures

- Monitoring SSTs to see a shift in cooler or warmer temperatures in the four geographic regions of the equatorial Pacific over a period of time.
- Used to monitor SSTs, SST Anomalies, Coral Bleaching, Degree Heating Week
- Satellite products are helpful with in situ observations
- Products:
  - CoralTemp SST by NESDIS: obtained from Infrared radiometer and microwave on board of Sentinel-3a, Sentinel-3b, Metop-B/C, GOES-East/West, NOAA -18 & 19, GOES-16, GOES-18, Himawari-9, and Meteosat-10. It provides the nighttime ocean temperature at the sea surface
  - SST Contour Charts by NESDIS/OSPO



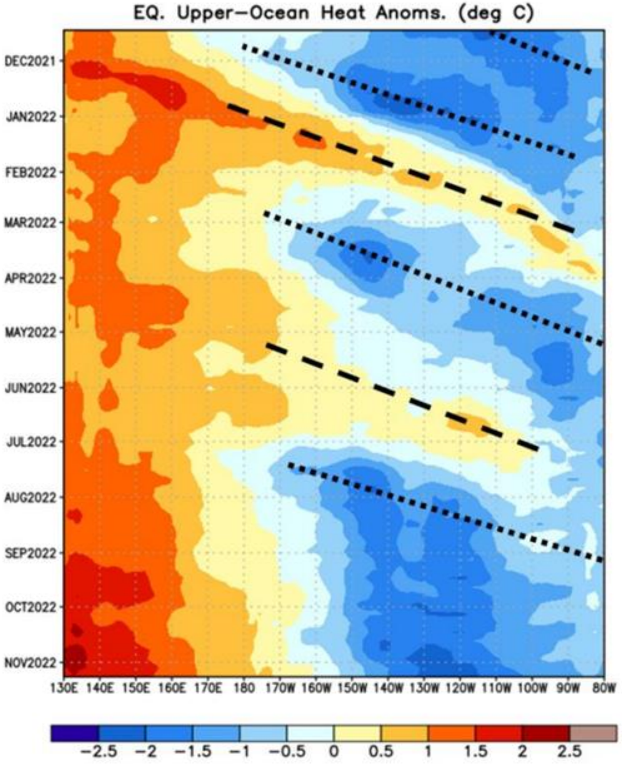
ENSO: Oceanic Kelvin Waves

Equatorial Pacific Temperature Anomaly Cross Section

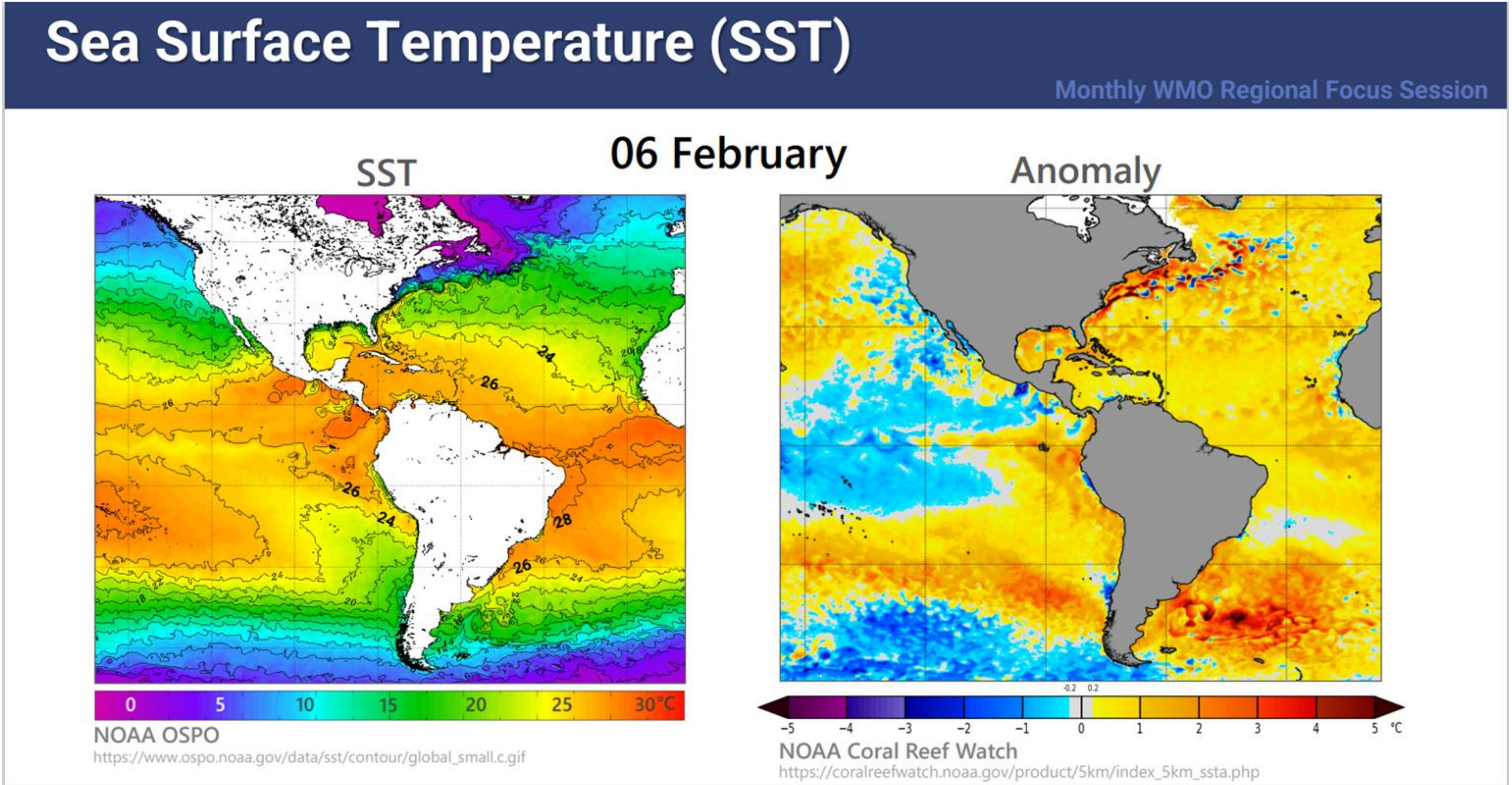


Source: CPC

Heat Content Anomaly Hovmöller



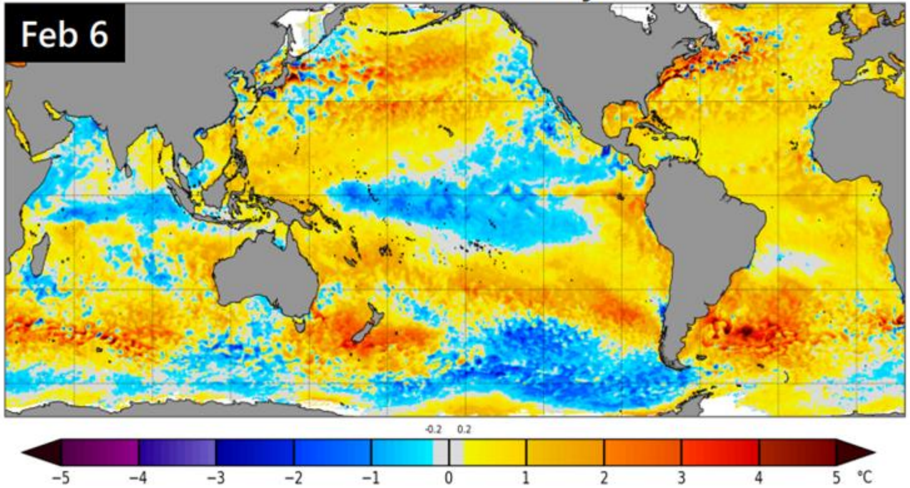
A few months later…



Temperature Anomaly in Top Layer

DEEP ANOMALIES LAST LONGER, WHICH MAKES THEM USEFUL FOR SUBSEASONAL FORECASTING

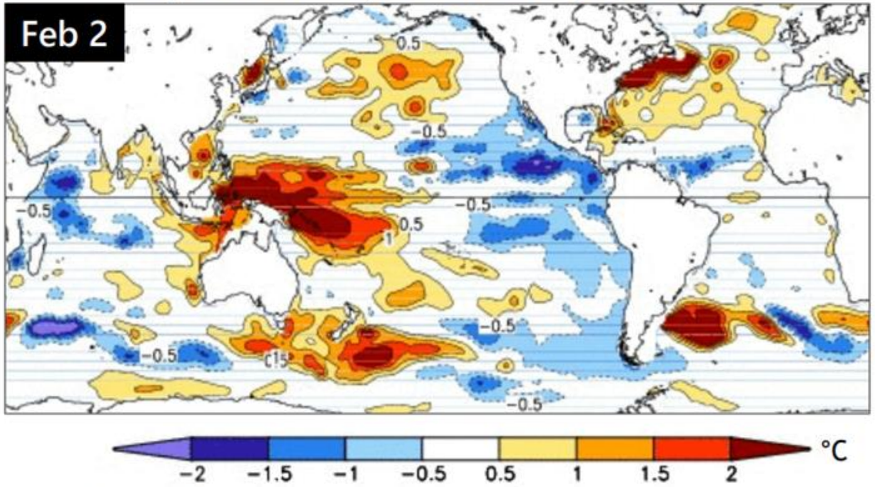
Surface Anomaly



NOAA Coral Reef Watch

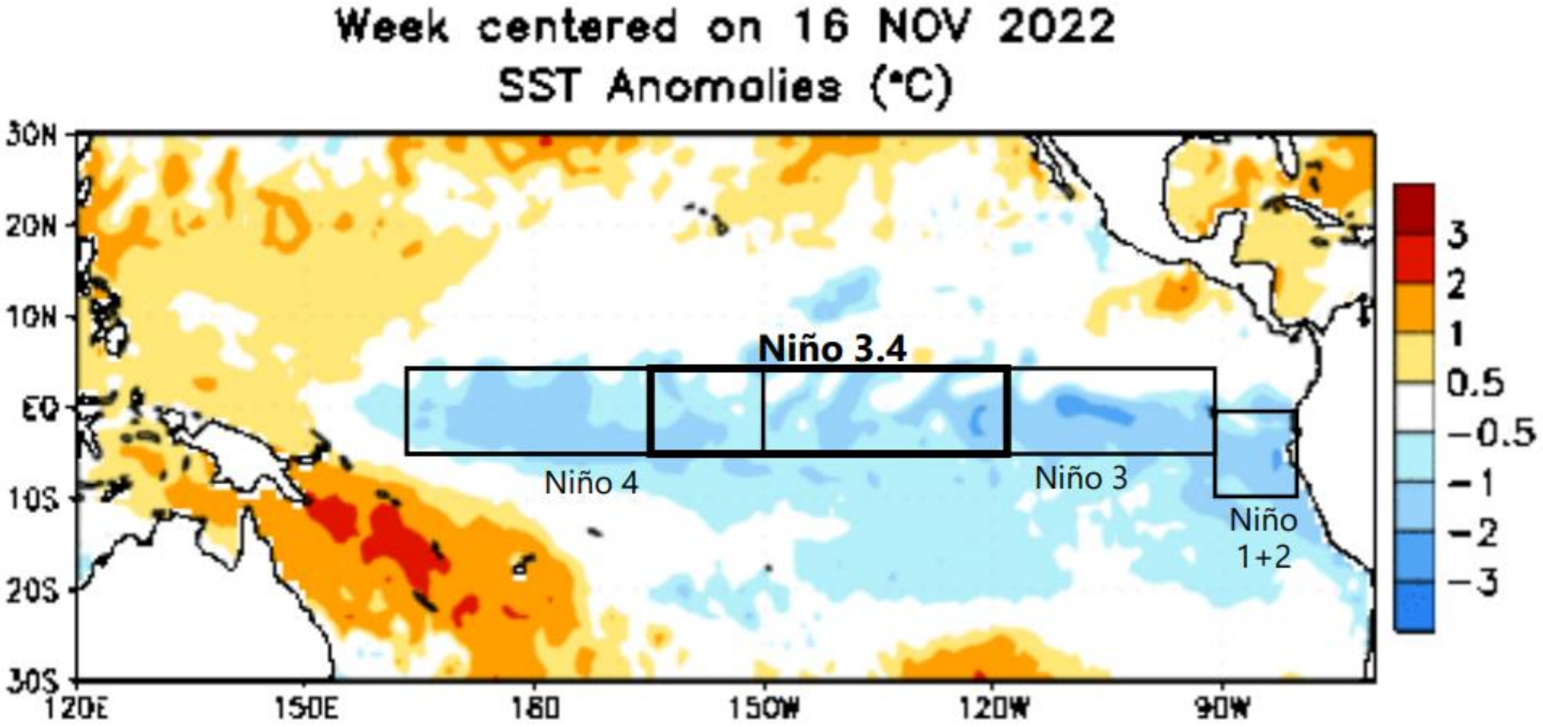
https://coralreefwatch.noaa.gov/product/5km/index_5km_ssta.php

Top 300m-Layer Anomaly (GODAS)



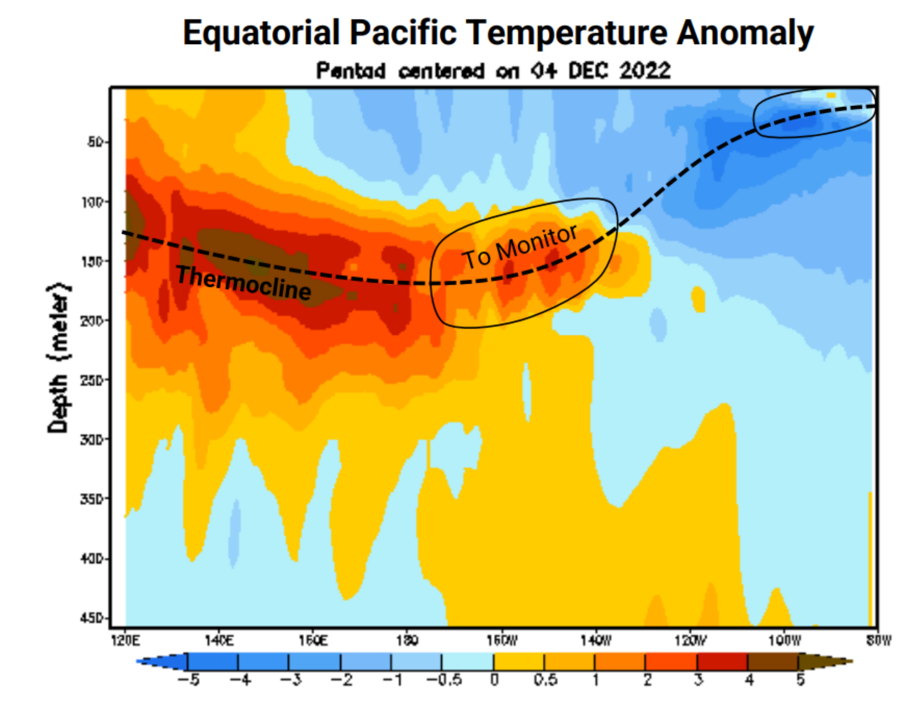
NOAA CPC

Source: CPC GODAS, https://www.cpc.ncep.noaa.gov/products/GODAS/

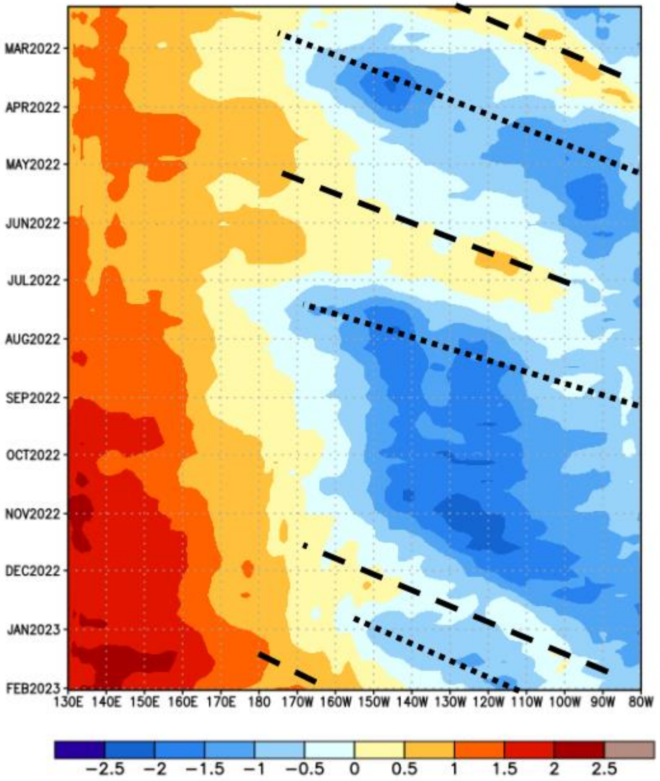

Week centered on 16 NOV 2022
SST Anomalies (°C)
30N
20N
10N
EQ
10S
20S
30S
120E
150E
180
150W
120W
90W
Niño 3.4
Niño 4
Niño 3
Niño 1+2
3
2
1
0.5
−0.5
−1
−2
−3

ENSO: Oceanic Kelvin Waves

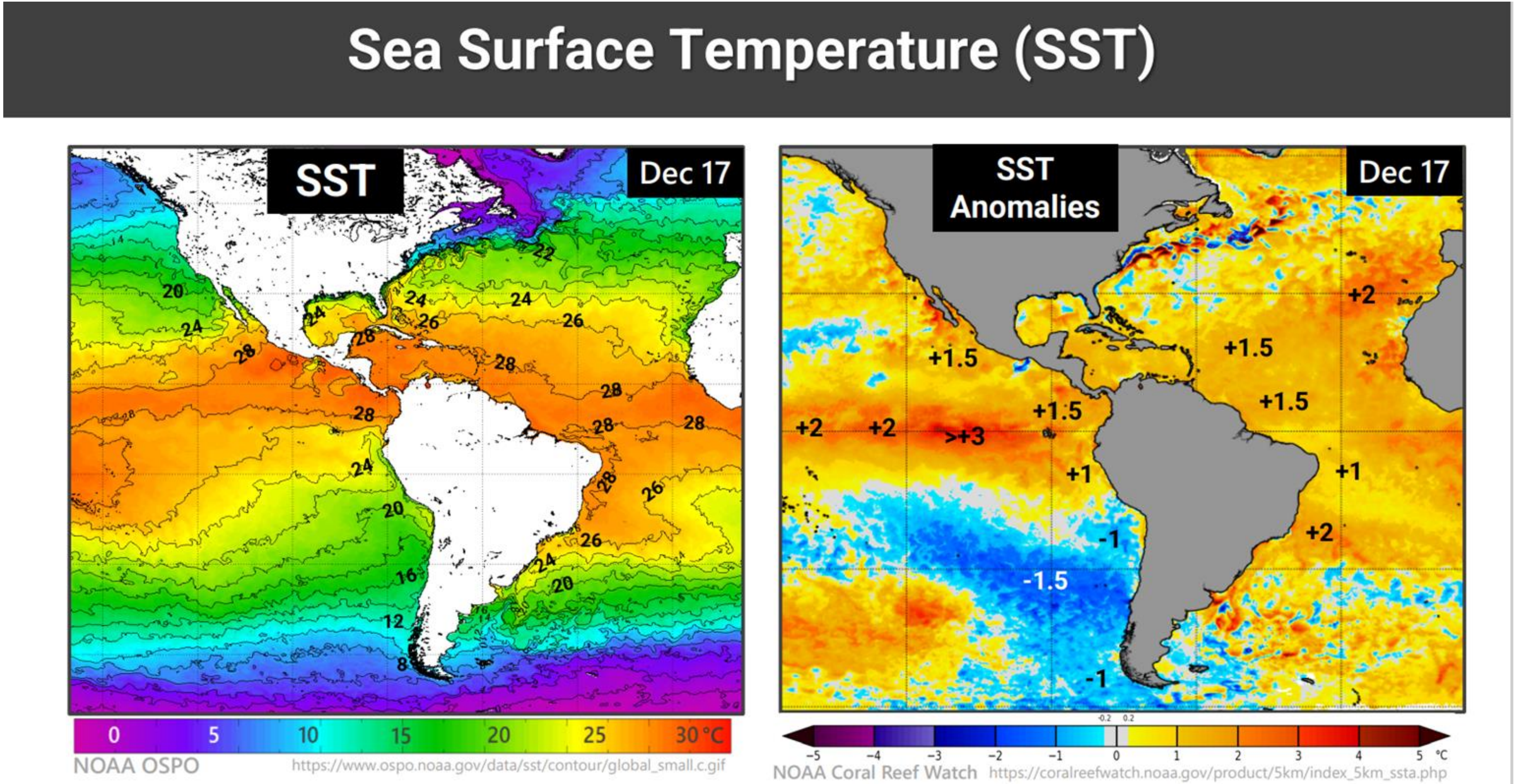
Equatorial Pacific Temperature Anomaly Cross Section



Heat Content Anomaly Hovmöller



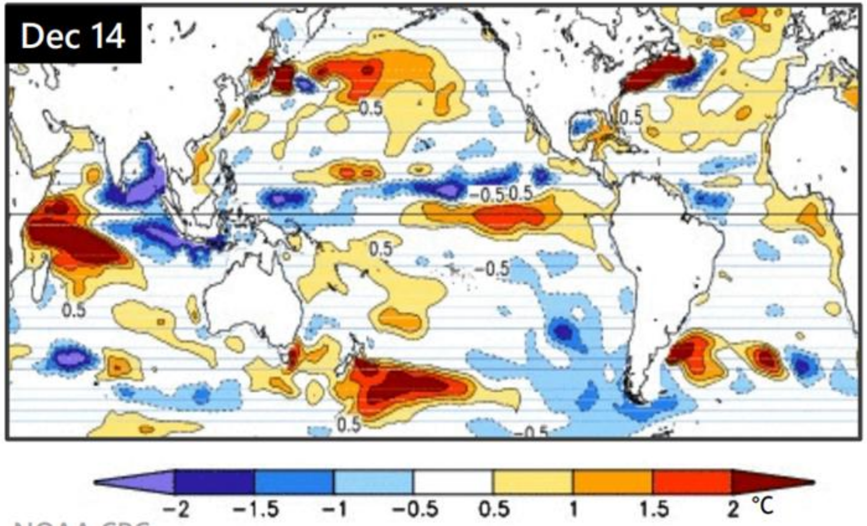
Example of Cooling in the Pacific



Top Layer Temperature Anomaly

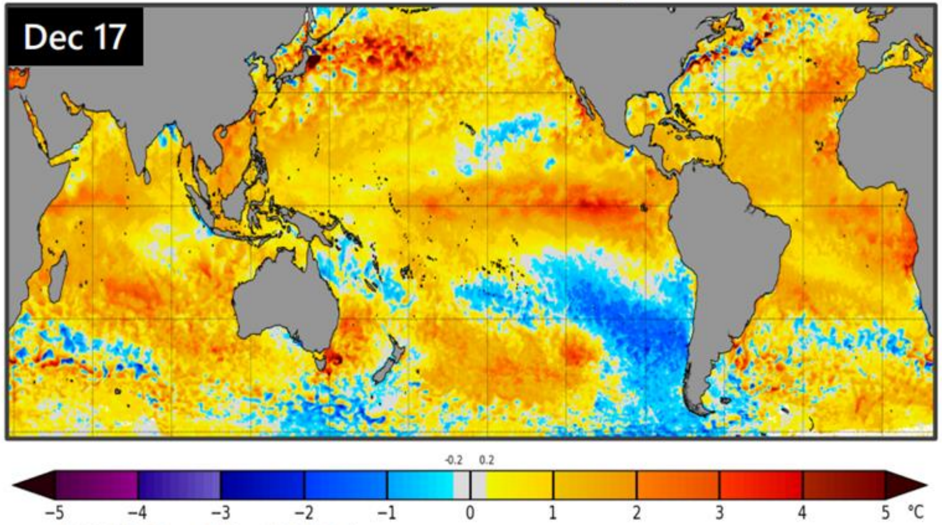
Anomalies in a layer take longer to dissipate than superficial ones, and can last for weeks.

Top 300m-Layer Anomaly

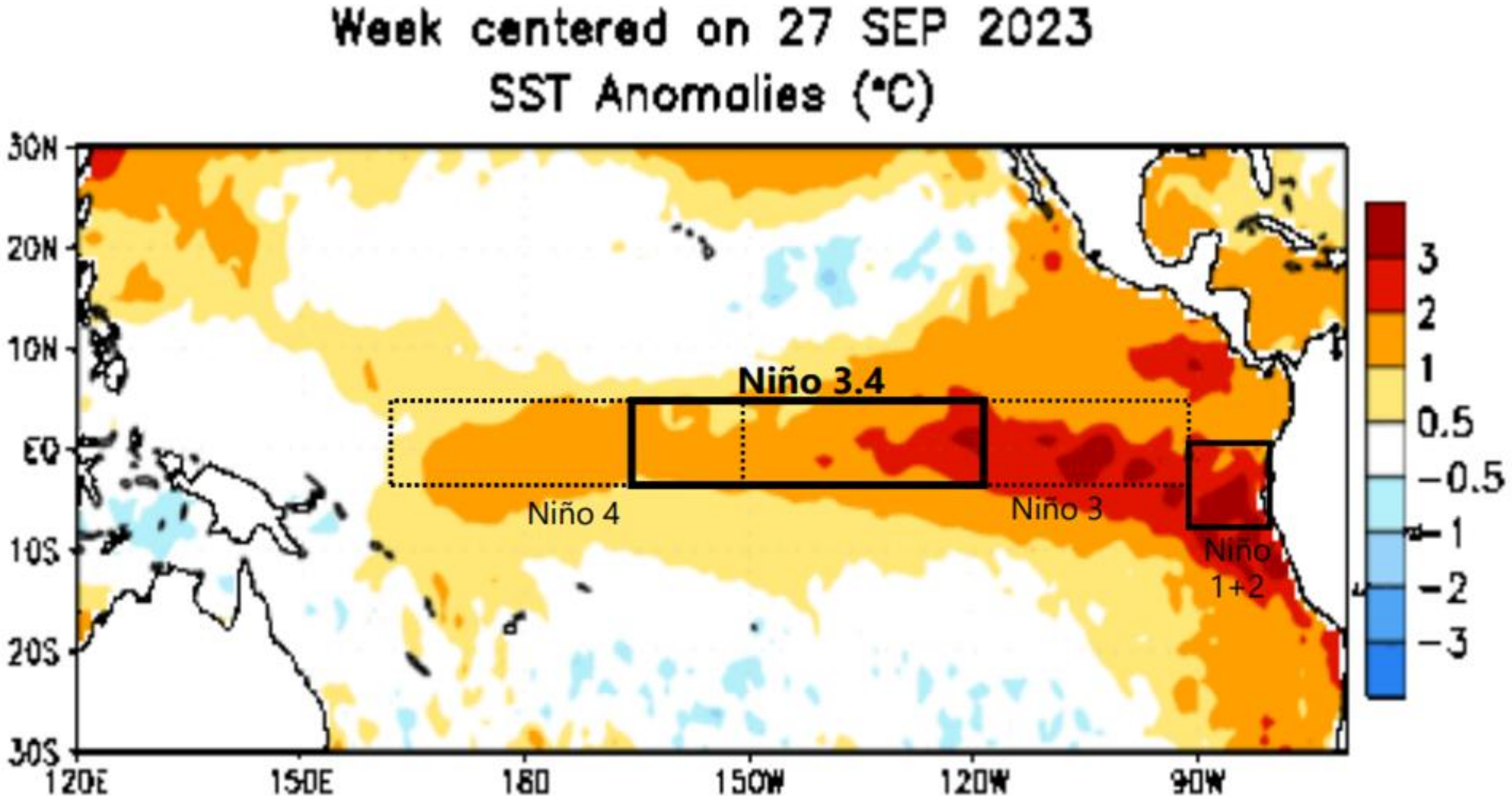


NOAA CPC
Source: CPC GODAS, https://www.cpc.ncep.noaa.gov/products/GODAS/

Surface Anomaly



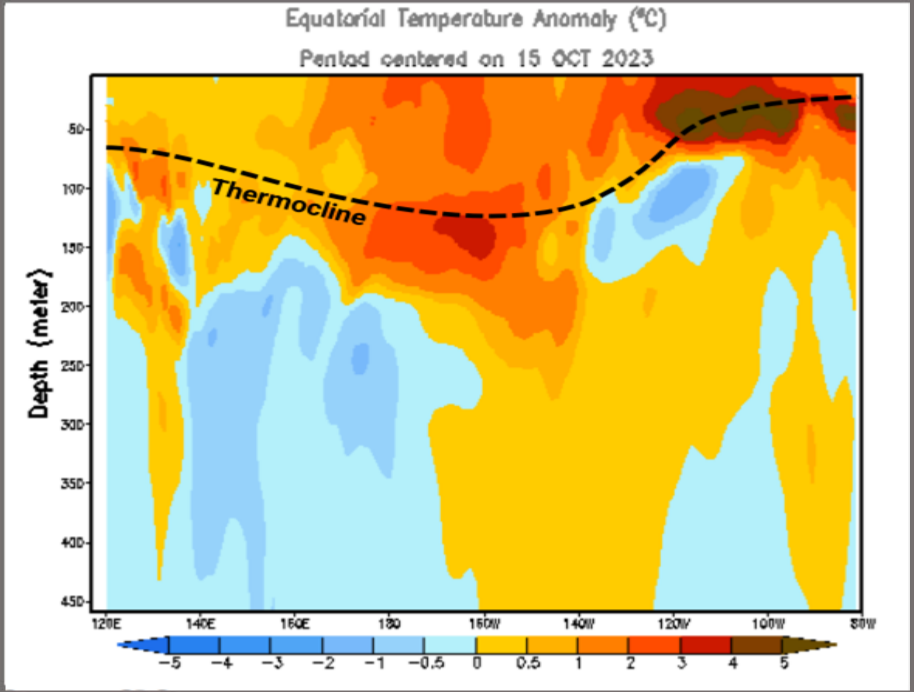
NOAA Coral Reef Watch
https://coralreefwatch.noaa.gov/product/5km/index_5km_ssta.php



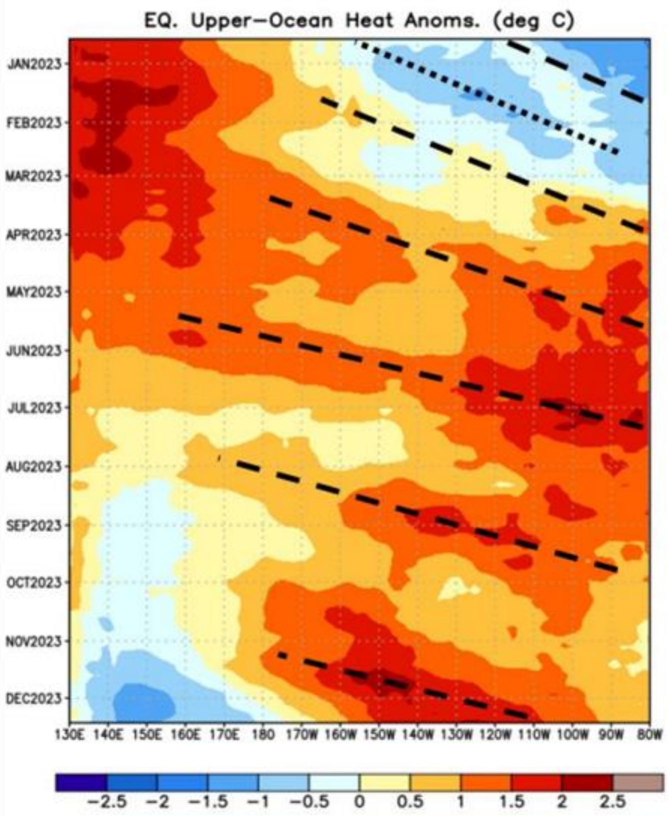
Week centered on 27 SEP 2023
SST Anomalies (°C)
30N
20N
10N
EQ
10S
20S
30S
120E
150E
180
150W
120W
90W
Niño 3.4
Niño 4
Niño 3
Niño 1+2
3
2
1
0.5
−0.5
−1
−2
−3

ENSO: Oceanic Kelvin Waves

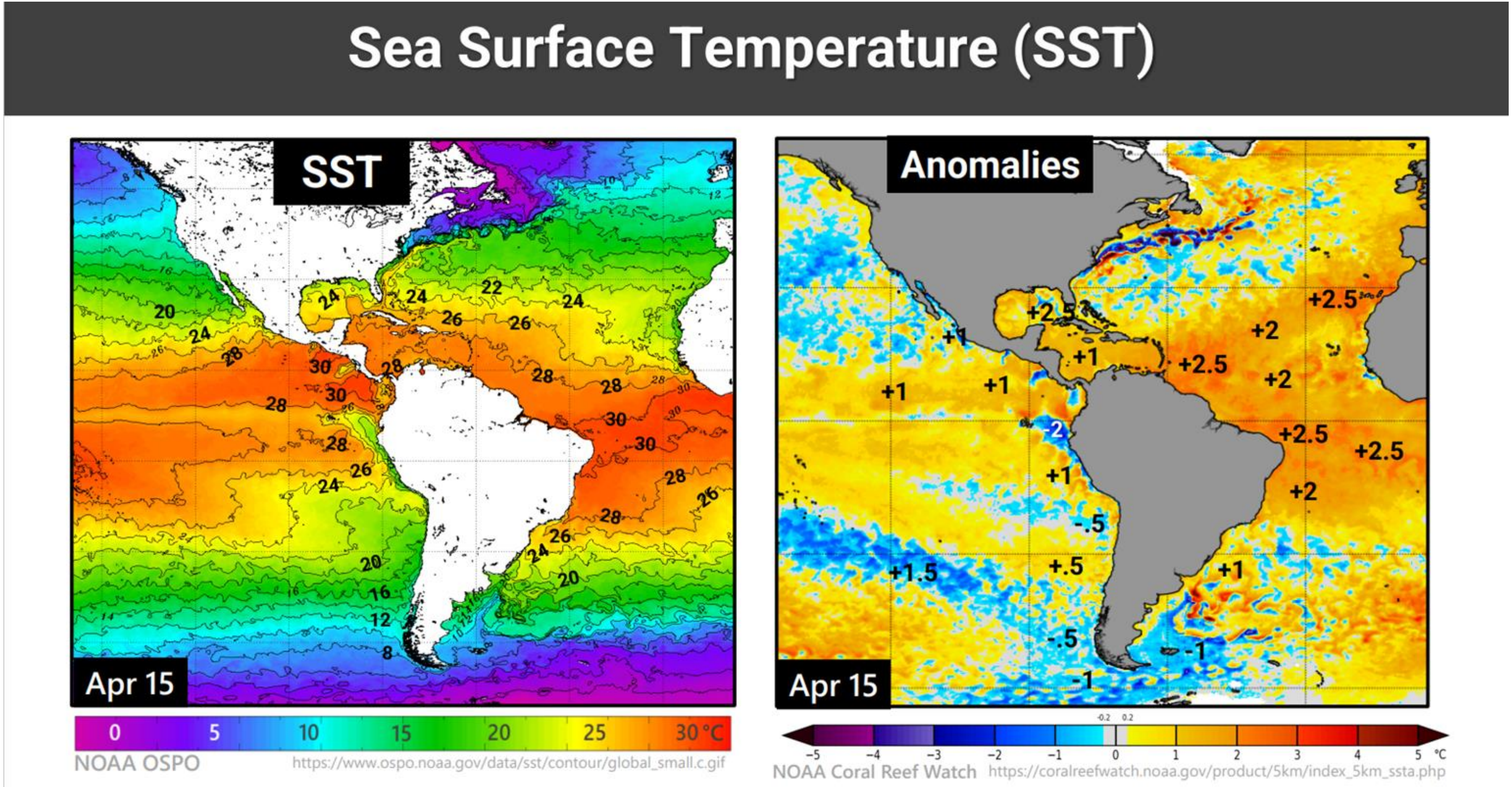
Equatorial Pacific Temperature Anomaly Cross Section



Source: CPC



A few months later…



Top Layer Temperature Anomaly

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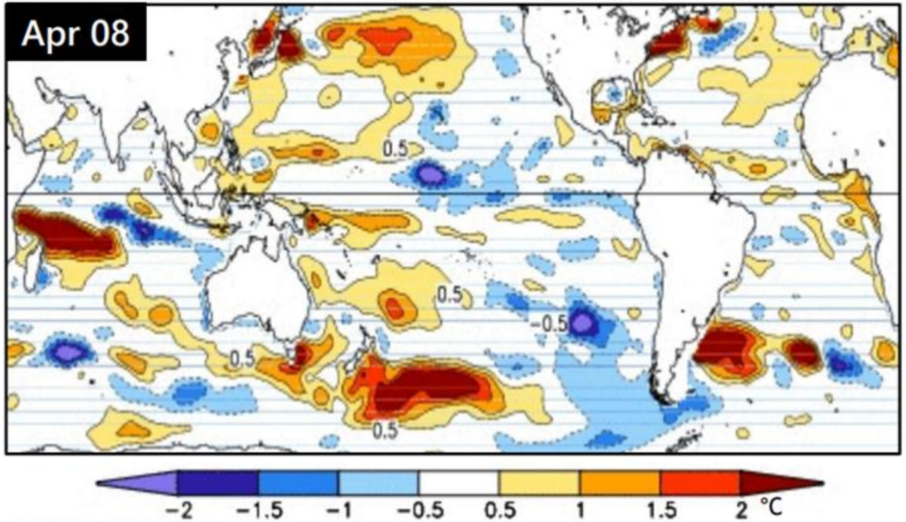
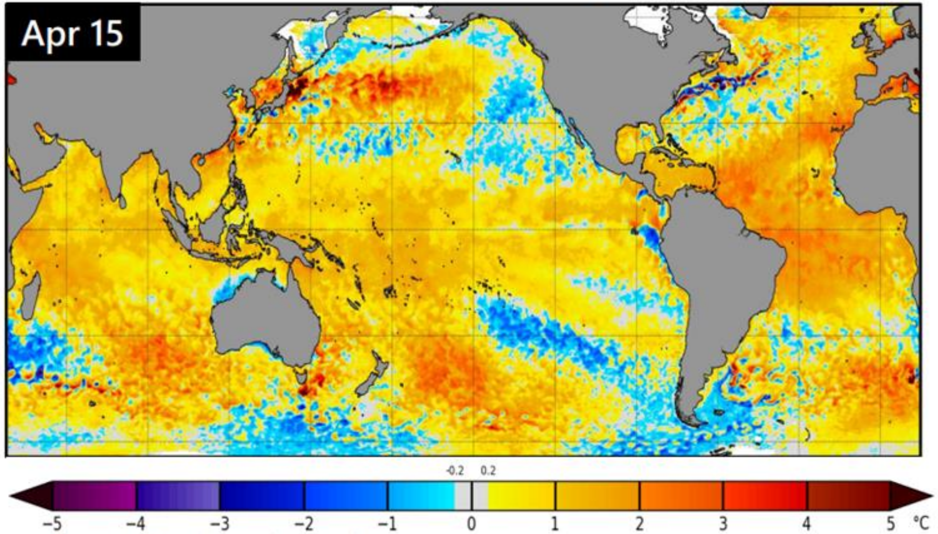
Top 300m-Layer Anomaly



NOAA CPC
Source: CPC GODAS, https://www.cpc.ncep.noaa.gov/products/GODAS/

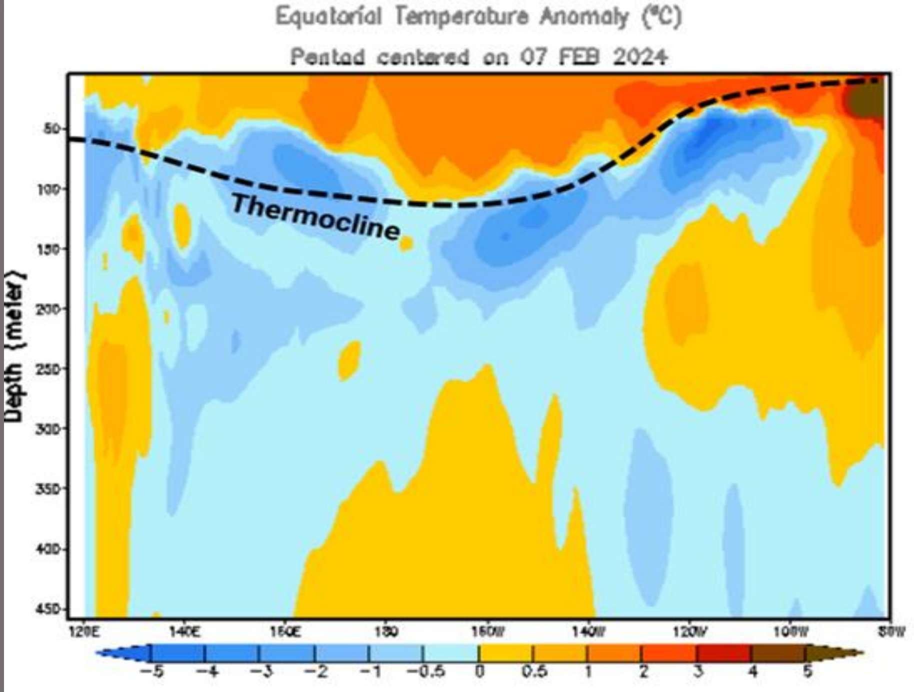
Surface Anomaly



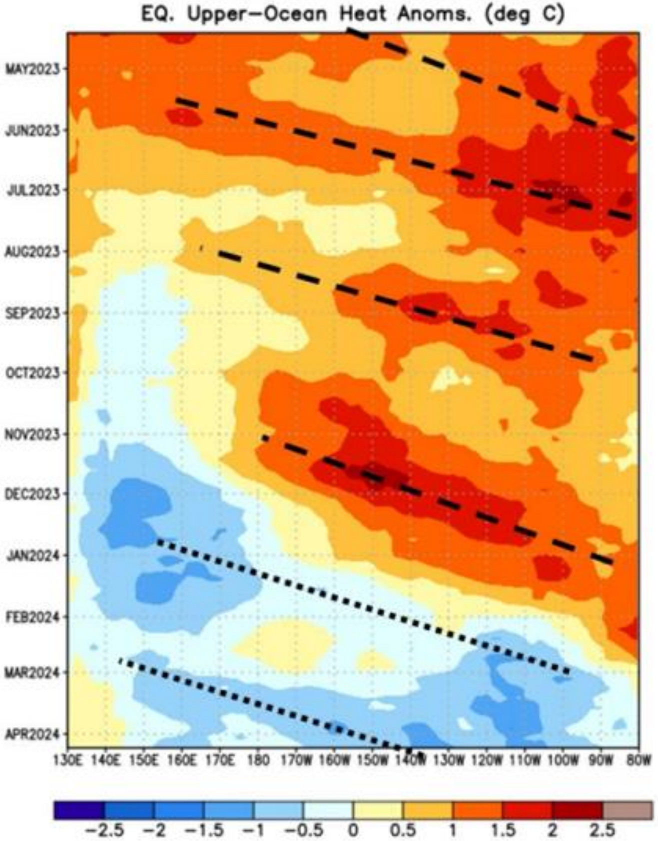
NOAA Coral Reef Watch
https://coralreefwatch.noaa.gov/product/5km/index_5km_ssta.php

ENSO: Oceanic Kelvin Waves

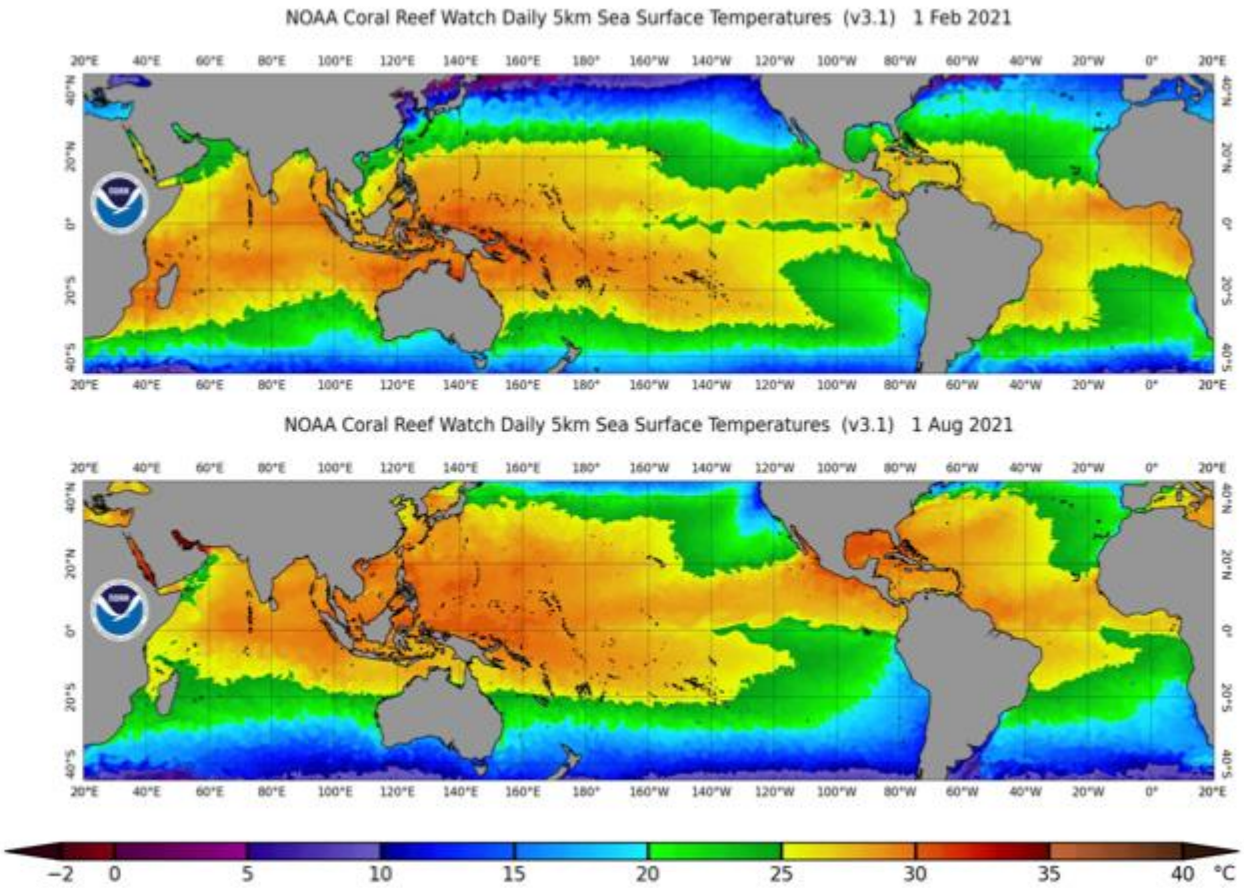
Equatorial Pacific Temperature Anomaly Cross Section

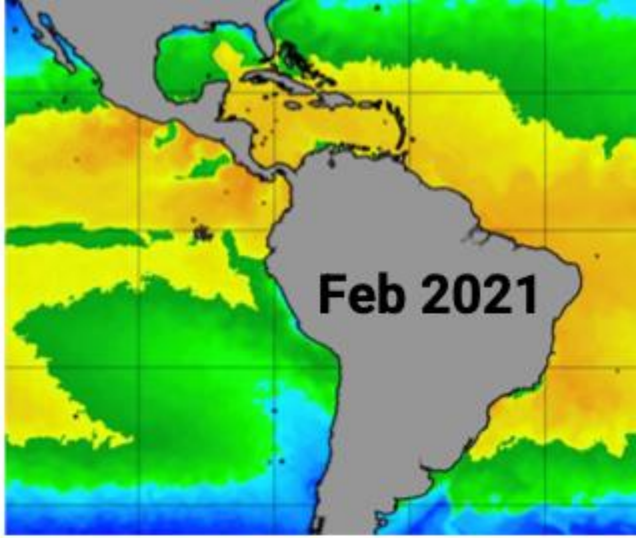


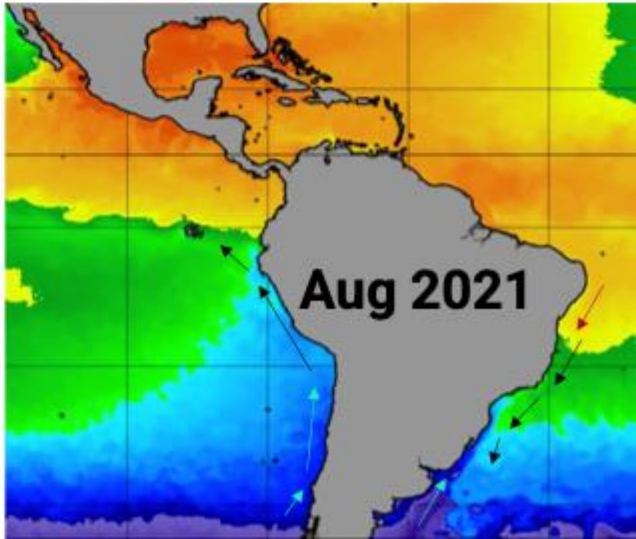
Source: CPC



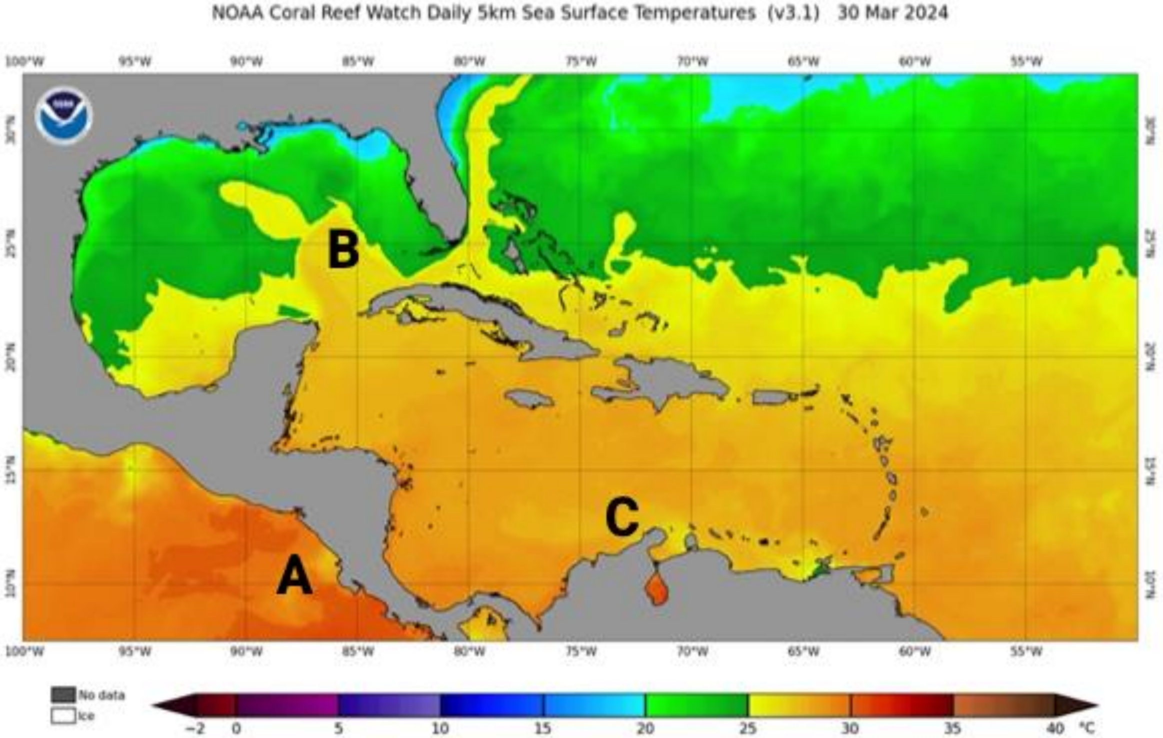
Sea Surface Temperatures (°C)

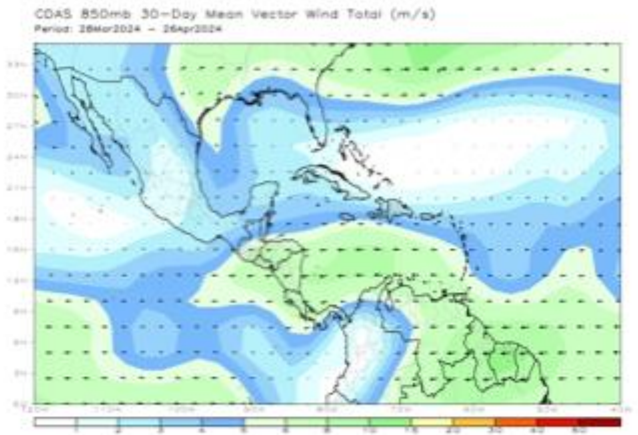


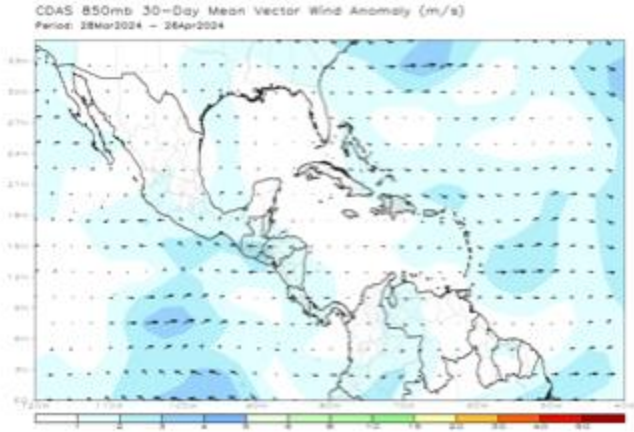


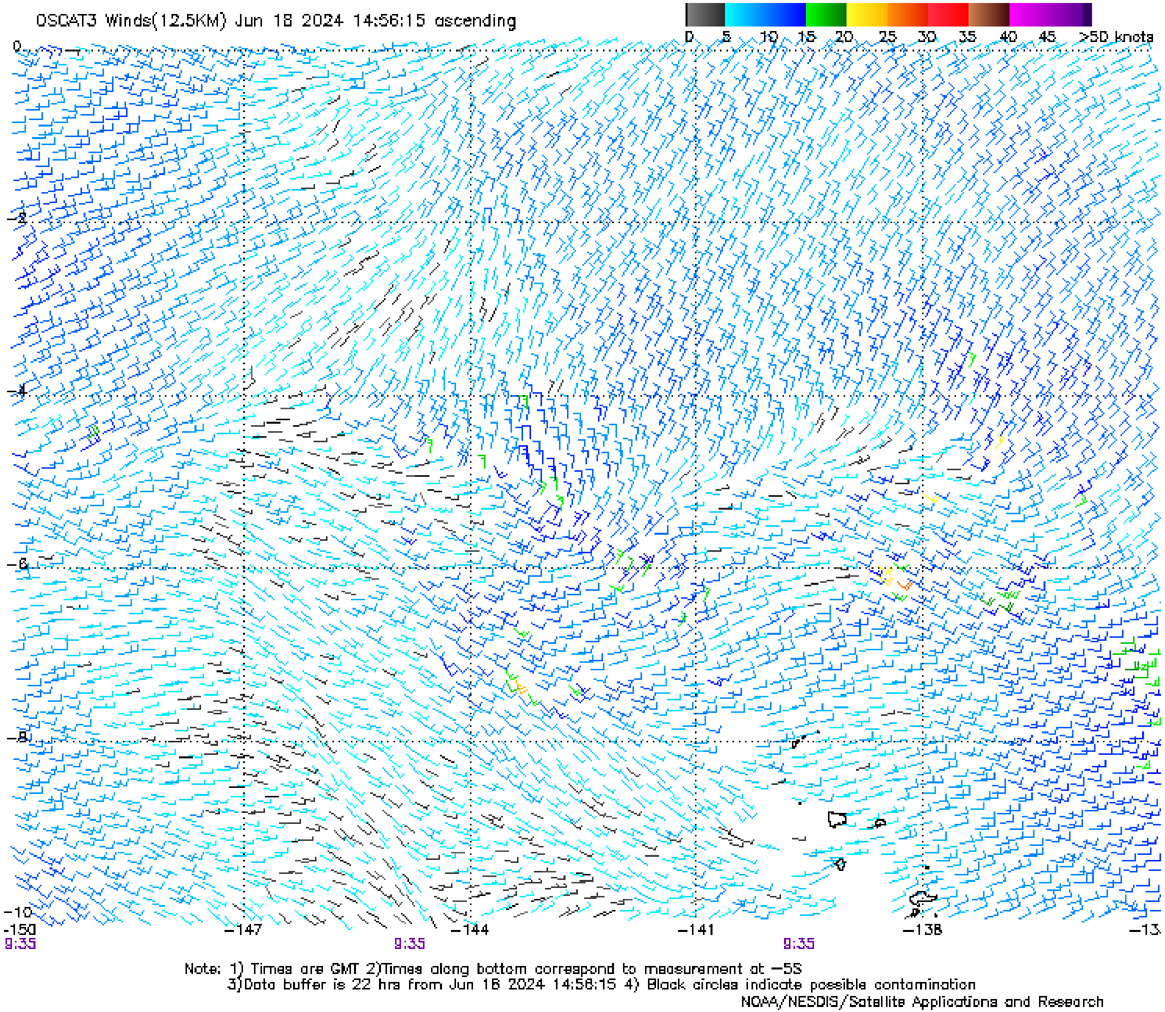


What is happening in the different points?

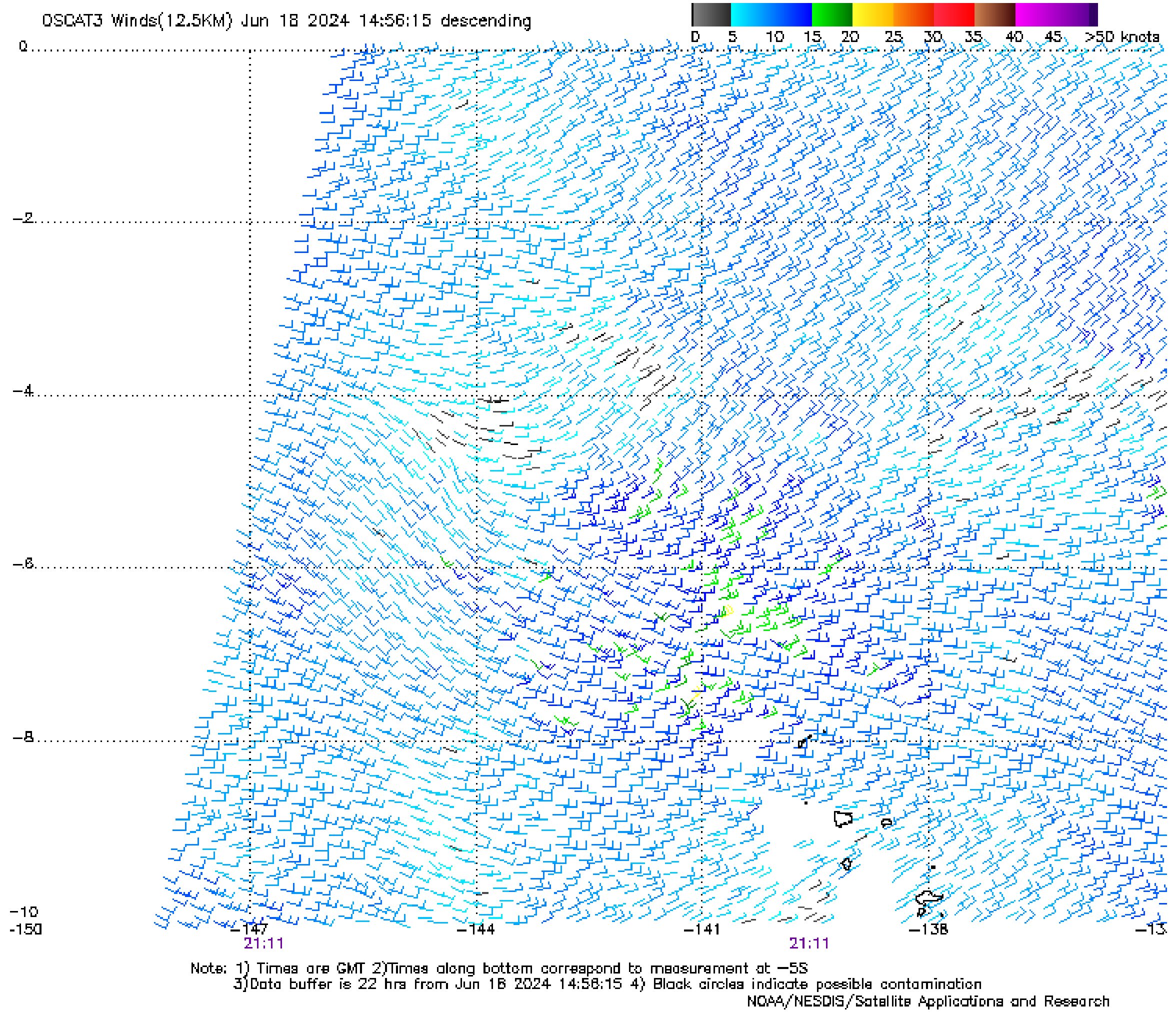




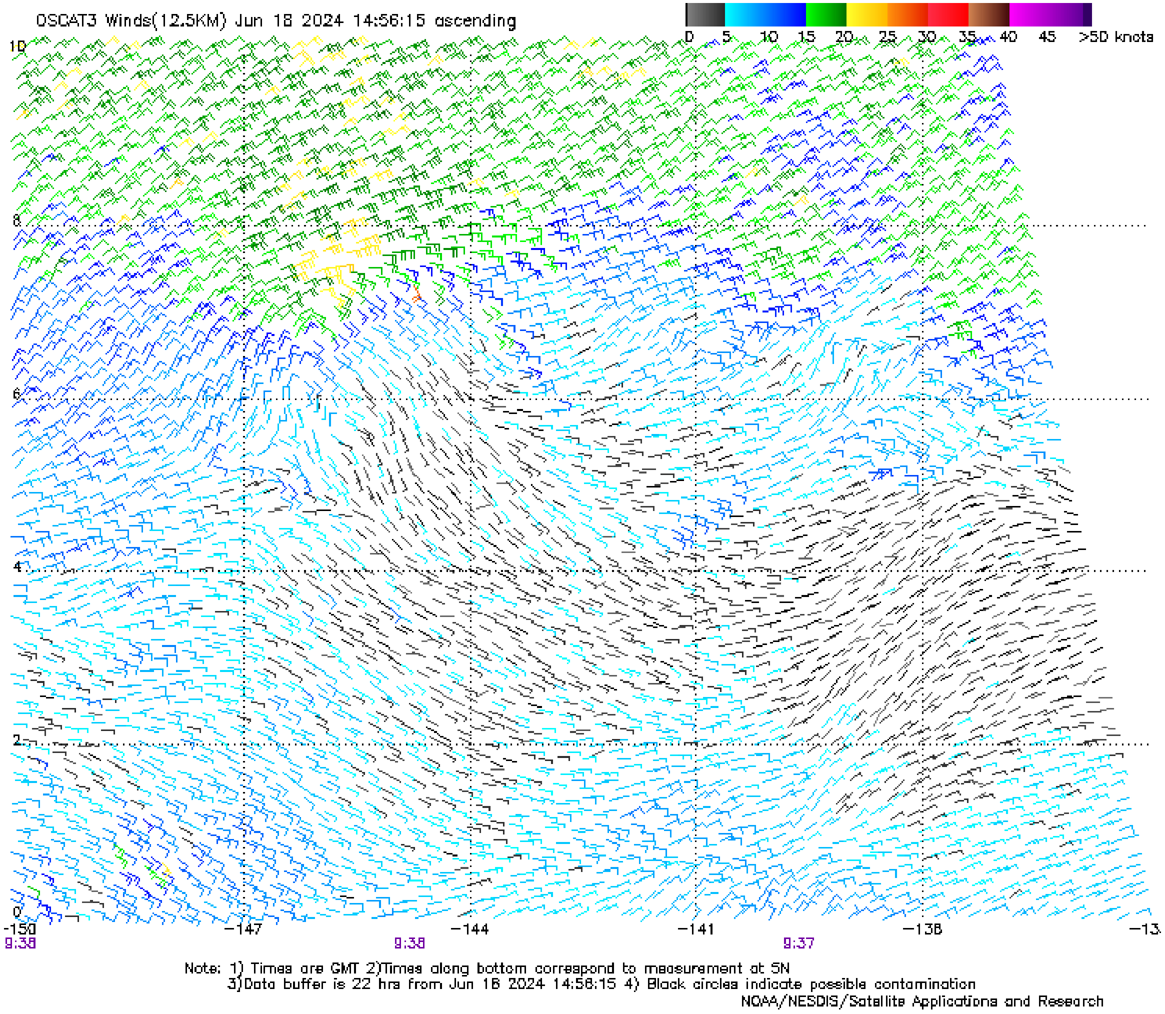




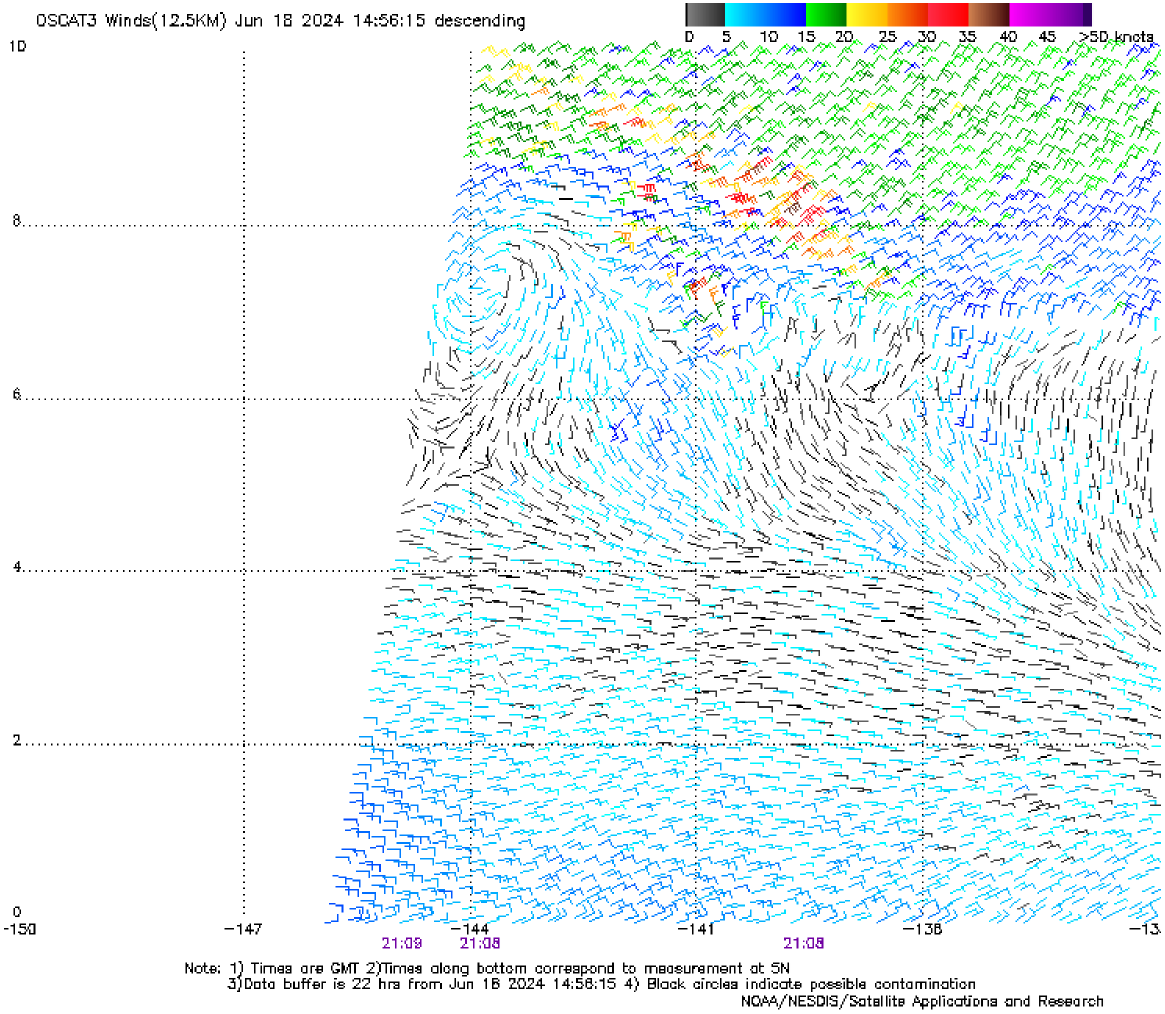
June 18, 2024
Ascending
OSCAT3
From 0 to 10S
From 150W to 135W



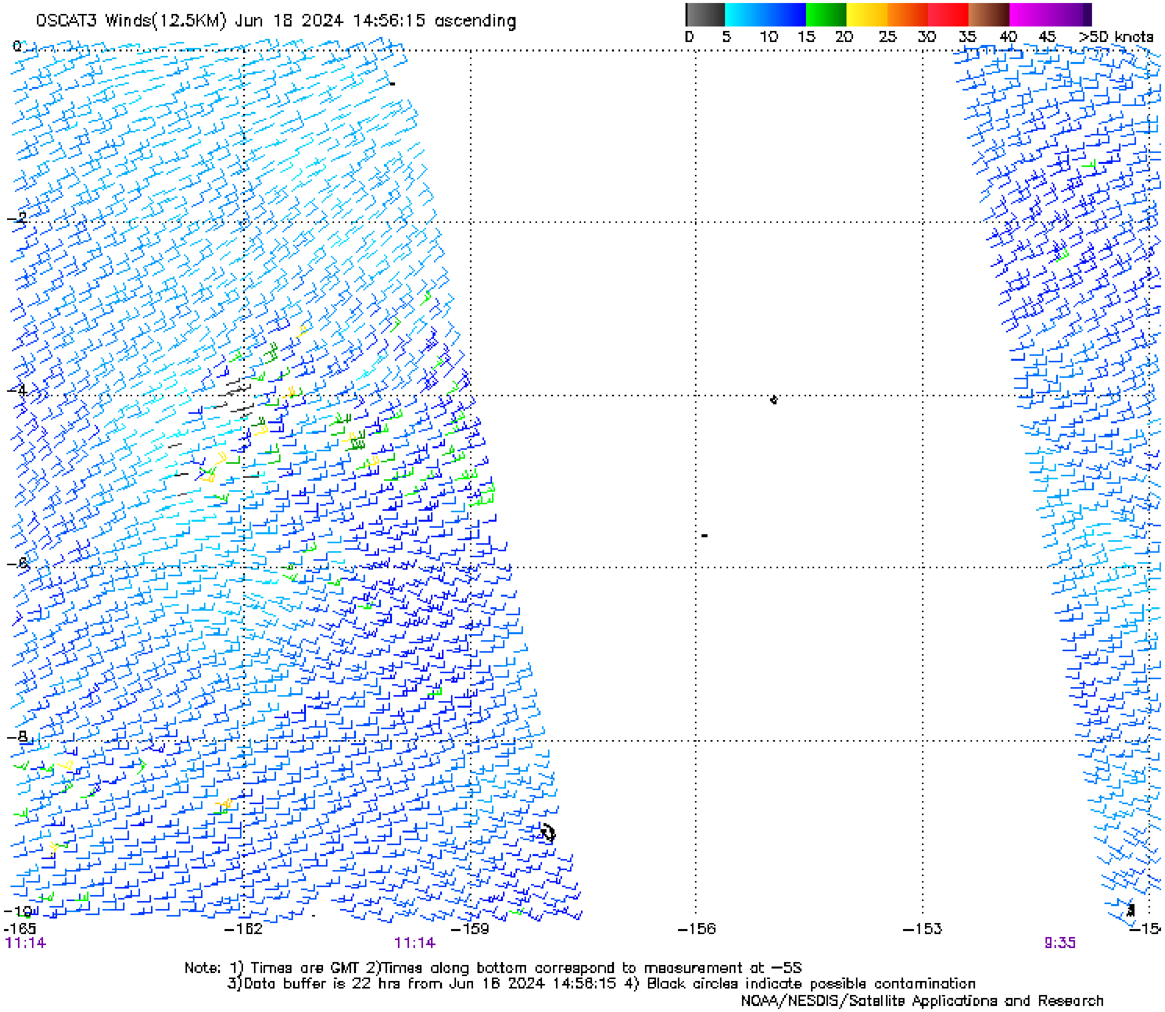
June 18, 2024
Descending
OSCAT3
From 0 to 10S
From 150W to 135W



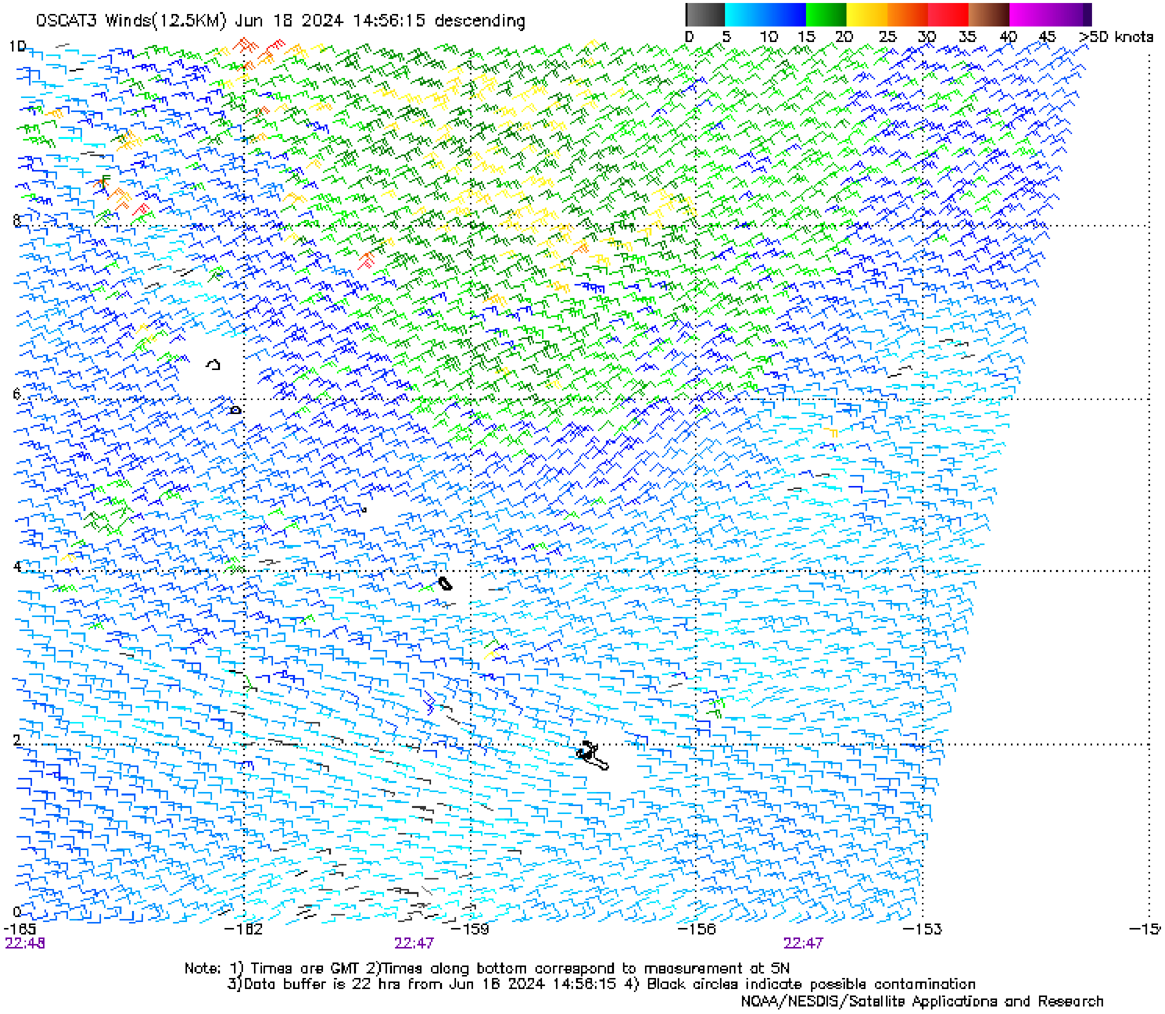
June 18, 2024
Ascending
OSCAT3
From 10N to 0
From 150W to 135W



June 18, 2024
Descending
OSCAT3
From 10N to 0
From 150W to 135W



June 18, 2024
Ascending
OSCAT3
From 0 to 10S
From 165W to 150W



June 18, 2024
Descending
OSCAT3
From 10N to 0
From 165W to 150W