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Climatological Patterns of the Americas

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Axiom for WPC International Desks/NWS/NOAA

Overview

01 Importance, Applications and Bases of Climatology

02 Surface Features: Terrain, oceans and impacts in the atmosphere

03 Upper, Mid and LowTroposphere: Flow Climatology and Systems of Interest

04 Impactful Climatological Features and Patterns

05 Impacts of ENSO, MJO and other Climate Oscillations

01

Importance, Applications and Bases of Climatology

Importance and Applications of Climatology

Climatology is the base to understand current processes in the earth-atmosphere system and to be able to interpret Numerical Models:

- Is the best tool available to us to understand if models are not representing reality properly and should not be trusted.
- Climatology allows us to recognize upcoming events that might be unusual or out of season, therefore, potentially more impactful.

Importance and Applications of Climatology

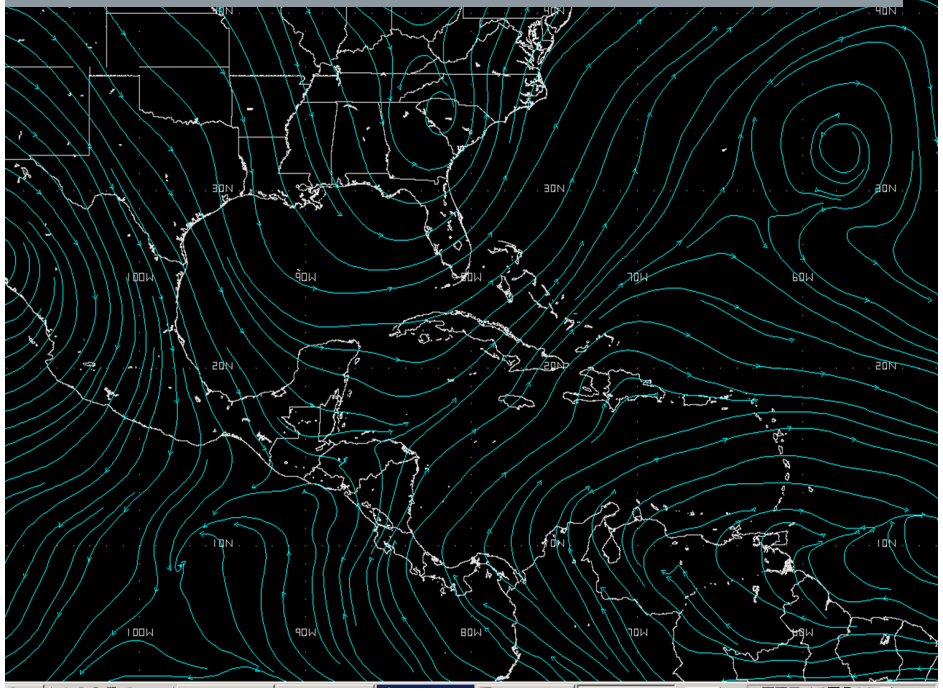
Is this a typical or atypical pattern for March?

- If typical or recurrent for March, it will be useful to know the type of phenomena this produces and use this to make forecast decisions.
- If atypical:

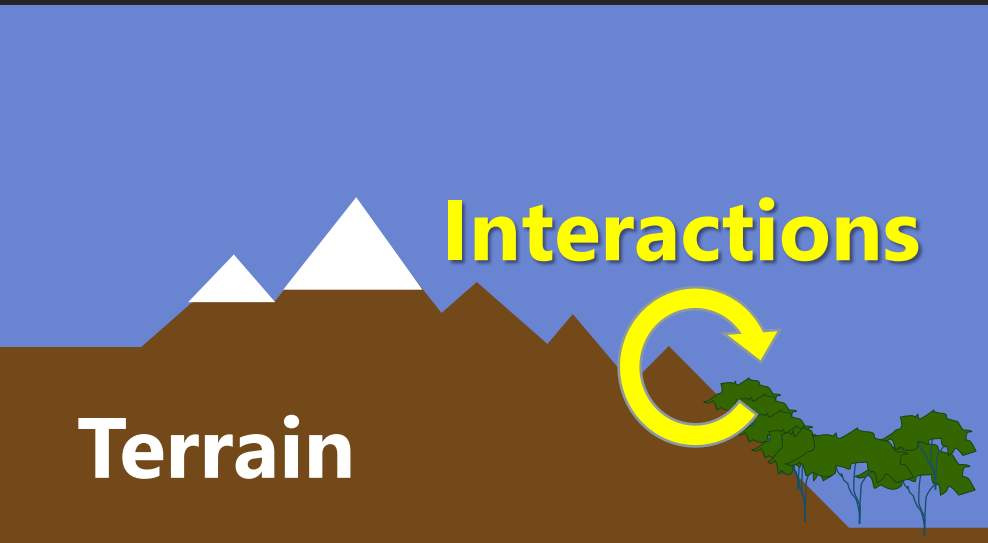
a) Models might be exaggerating and solutions should be considered with caution.

b) But if confidence is gained, this means the impacts might be extraordinary and warnings might be needed.

500 hPa flow pattern forecast during March



Bases for Prediction



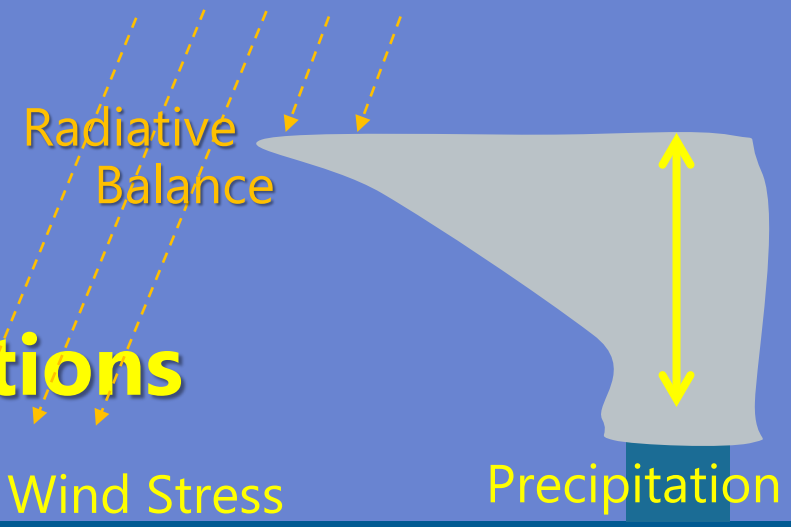
Terrain

-Morphology
- → Elevation
- → Orientation and shape
- → Slope

-Coverage
- → Vegetation, soil moisture, albedo and other radiative properties regulate the exchange of heat and moisture with the atmosphere via surface fluxes.

Interactions

Atmosphere



Heat and Moisture Fluxes

Interactions

Wind Stress
SST

Oceans

- → The atmosphere reads surface temperatures and communicates via fluxes, radiation and precipitation.
- → The ocean reads wind stress and effects of the fluxes of heat and moisture and precipitation.
- → Subsuperficial temperatures impact medium range and climate scales.

02

Surface Features: Terrain, oceans and impacts in the atmosphere

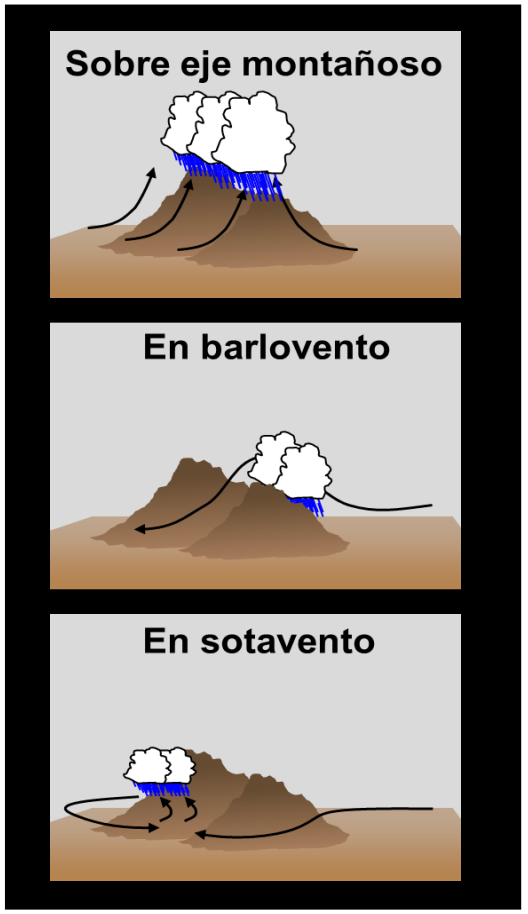
Effects of Terrain in Forecasting

Dynamical:

- Air is forced to ascend, descend or deviate upon stability. The more stable, the more the struggle to ascend.
- It can trigger deep convection, altering the entire column.

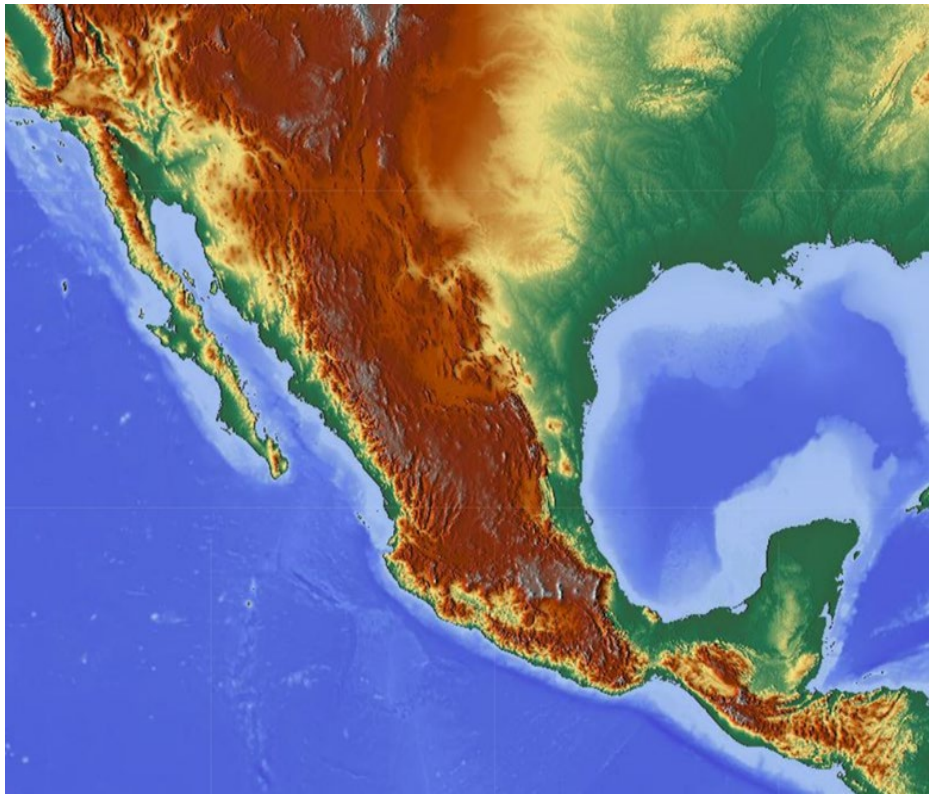
Thermodynamical:

- Differential heating generates pressure/geopotential changes and deviation of the flow.
- This affects regions of convergence and divergence, impacting precipitation.



Terrain in Mexico

- **Different “sierras” or mountain ranges.**
- **They enhance diurnal convection.**
- **The mean flow over the range (850 – 500 hPa) pushes the region of diurnal genesis downstream**
- **The southern Sierra Madre Oriental mountains can generate extreme rainfall during fronts and wind events from N, NE and E.**
- **The Tehuantepec Gap funnels winds, most frequently from the north, when polar highs develop in the US or Gulf of Mexico.**
- **Sierras block moisture inflow into the Central Mexican Plateau and Tierra Calida, favoring drier climates.**

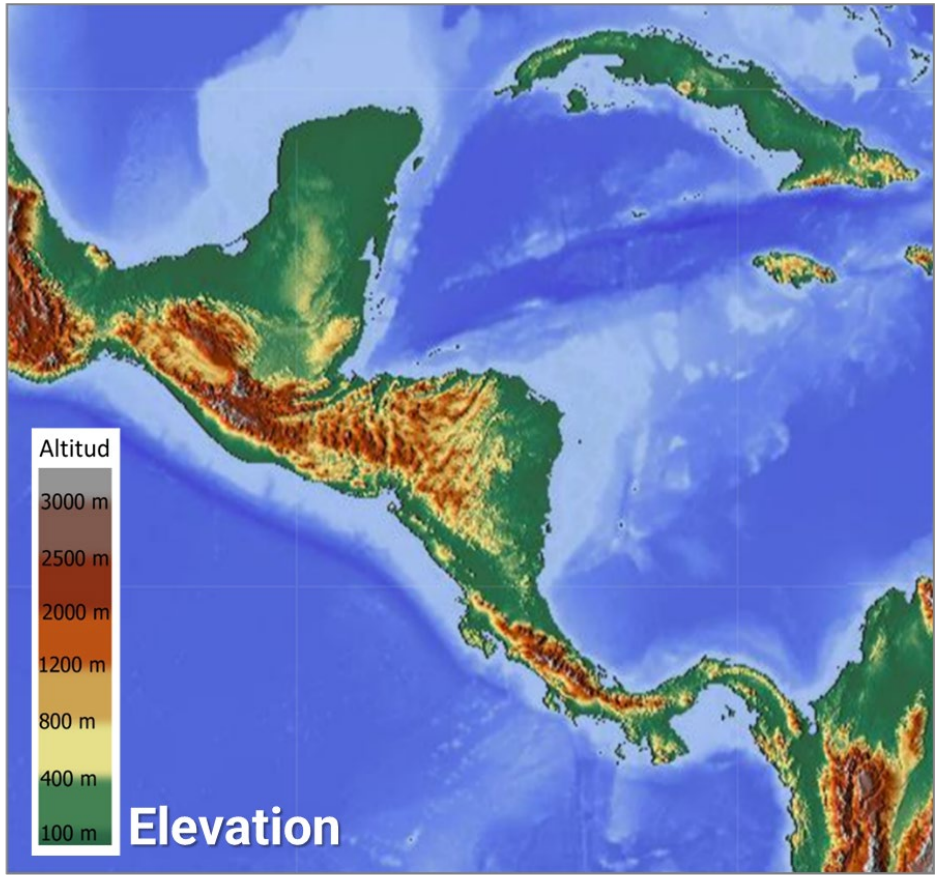


Example, terrain favors specific regions for development of thunderstorms and other types of precipitating clouds.

Promedio de imágenes visibles de MODIS durante la época de lluvias (MAY-OCT). Se ve como la orografía modula las regiones de desarrollo de nubosidad. Fuente: NSSL

Terrain in Central America

- **Tallest in Costa Rica and Guatemala/Chiapas.**
- **Rugged in Honduras and El Salvador.**
- **Mountains enhance diurnal convection when flow is weak.**
- **Predominant easterlies favor ascent (wet) in the Caribbean basin and descent (dry) in the Pacific.**
- **Yet, periods of westerlies in the Pacific can produce heavy thunderstorms.**
- **Some regions favor extreme rainfall when moist perpendicular flows develop (e.g. N Honduras, Central Guatemala, Bocas del Toro/Eastern Costa Rica, S Costa Rica/W Panama, S Guatemala and el Salvador.**
- **Gap flows produce important wind shear, wind gusts and turbulence.**



Low-Level Jets funneled by gaps

February 925 hPa averaged winds

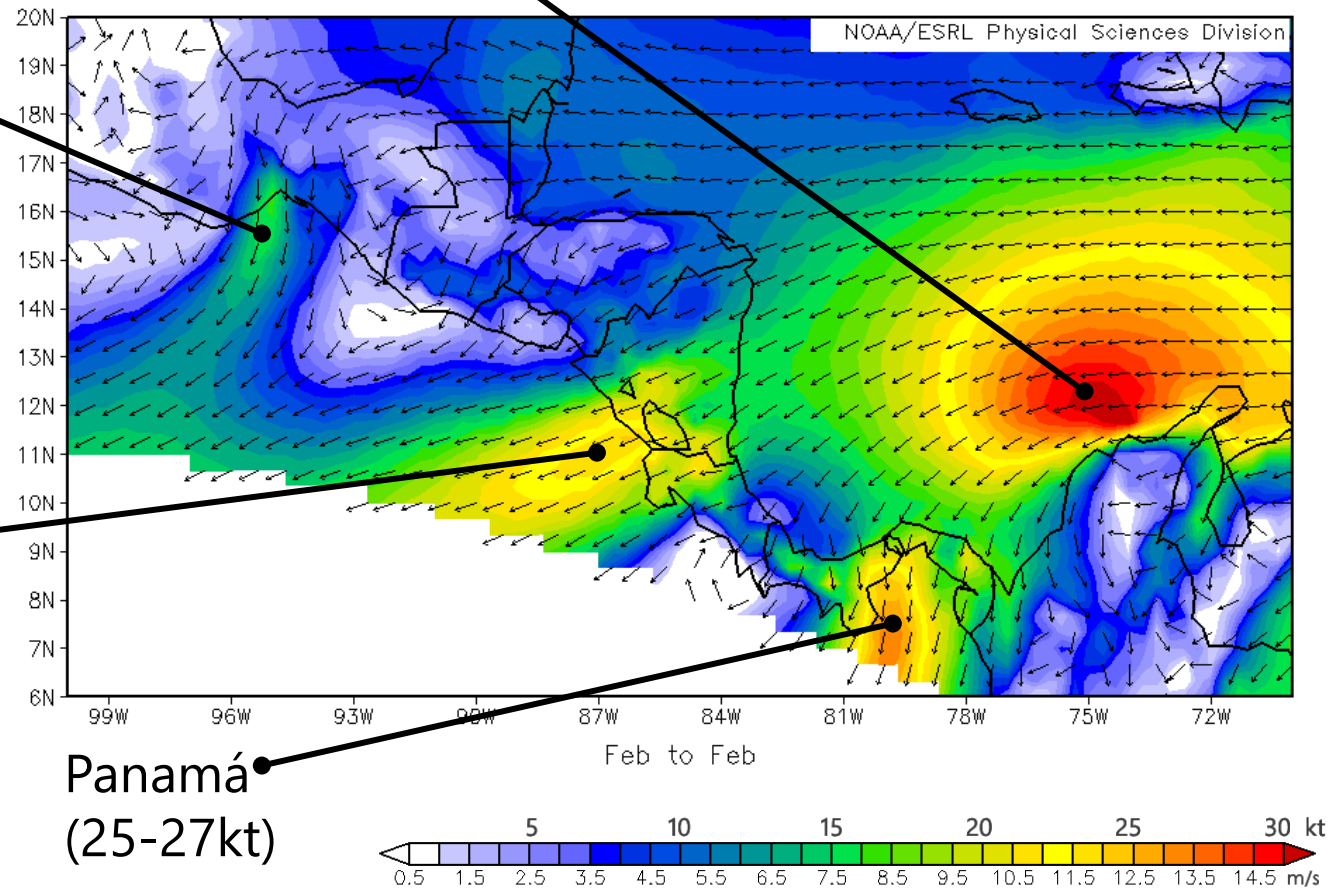
Sur del Caribe (>30kt)

Tehuantepec (15-17kt)

Peaks earlier (October-December) and winds can reach 70kt

Nicaragua/ Papagayo (22-24kt)

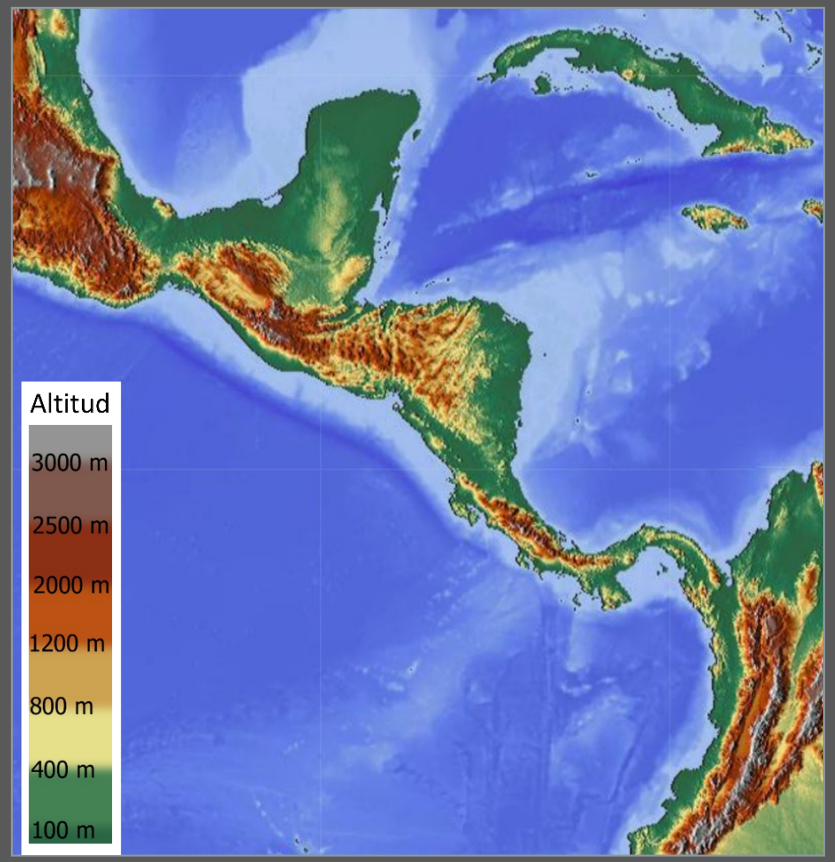
Panamá (25-27kt)



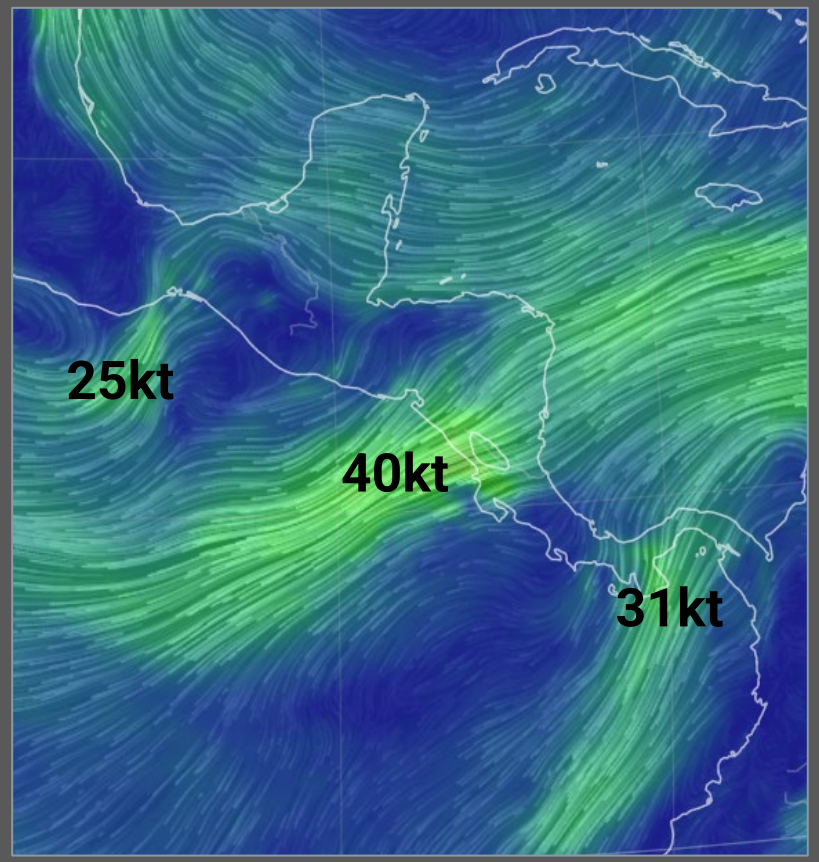
Fuente: NARR (https://www.esrl.noaa.gov) – Climo 1981-2010

Central American Gap Flows

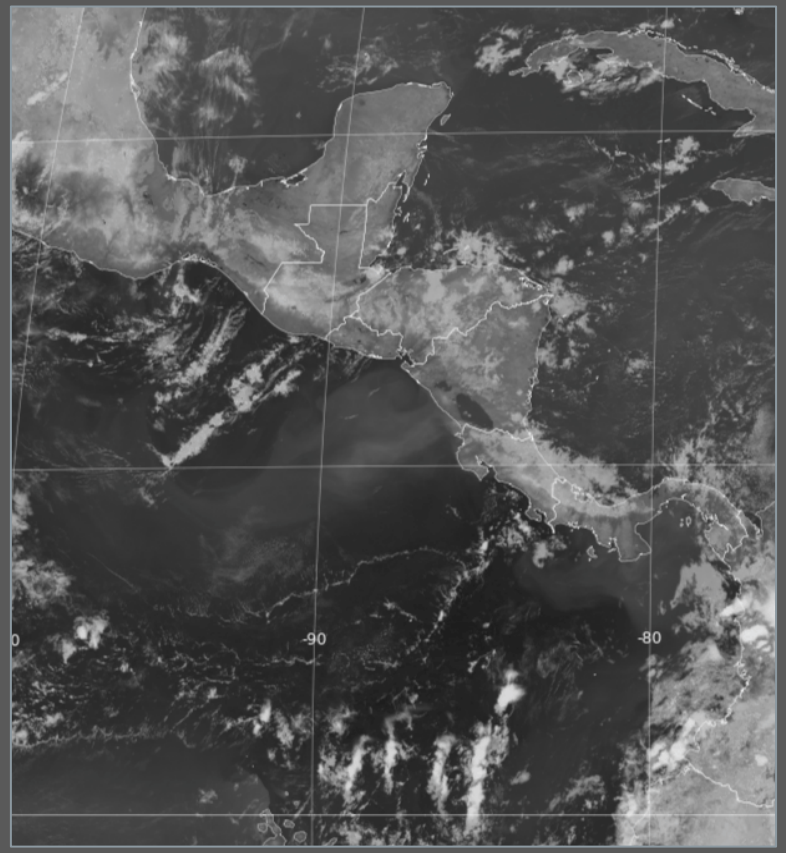
Elevation



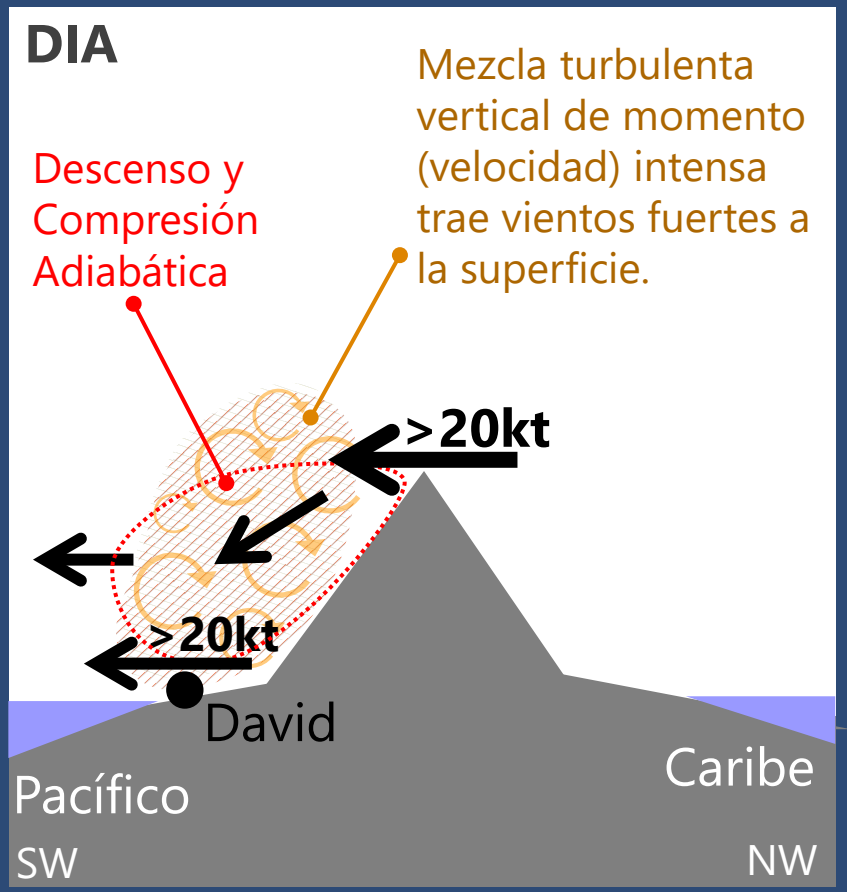
850 hPa Winds

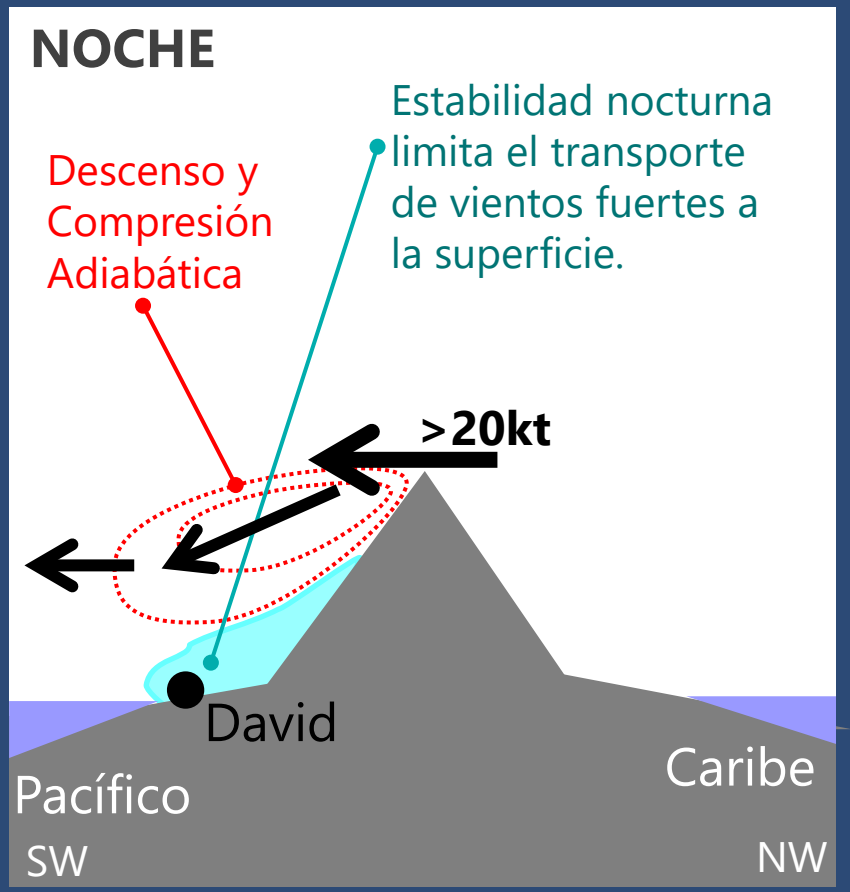


Proxy Vis



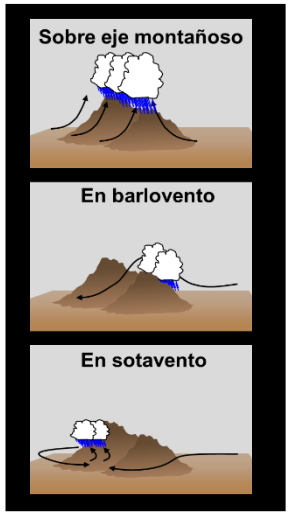
The terrain in Central America can favor strong winds in populated areas, such as David, Panama

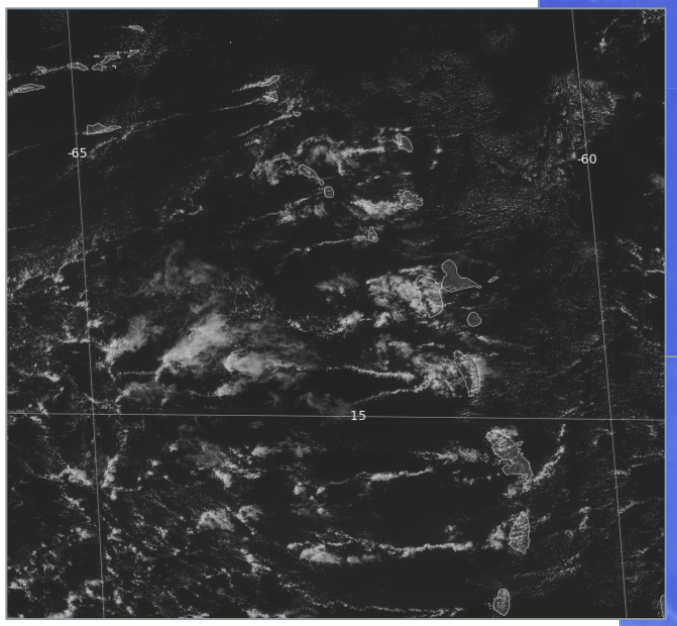




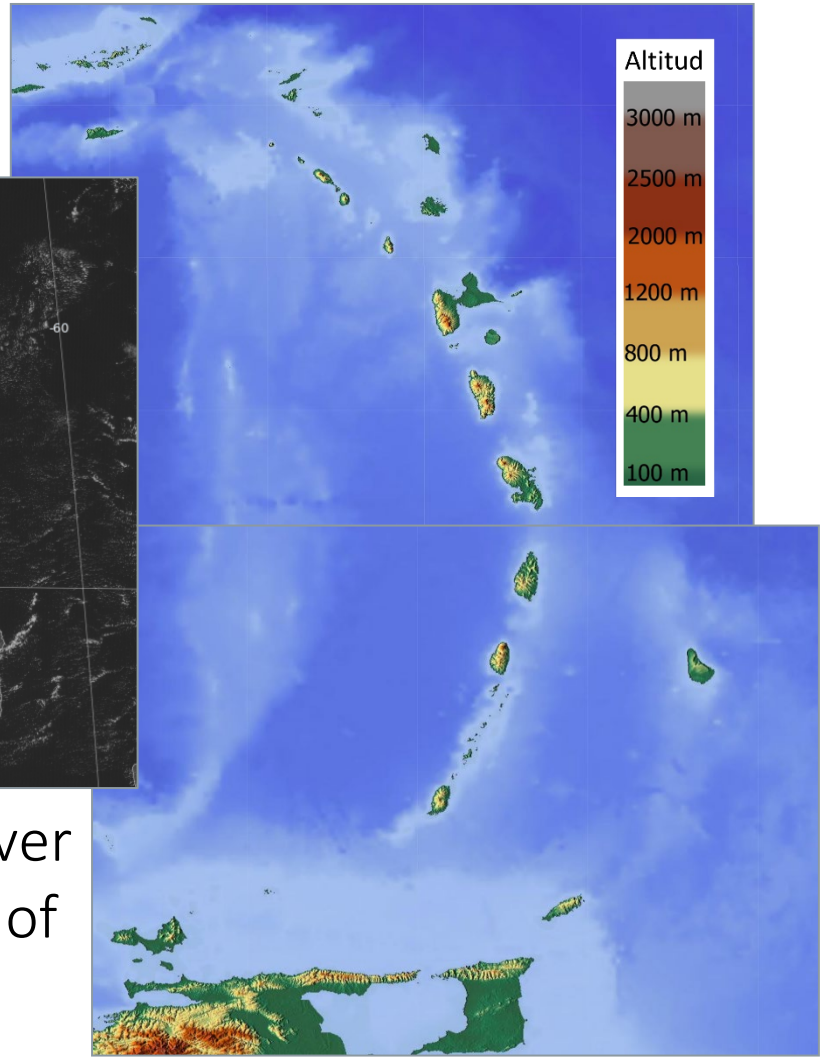
Terrain in the Lesser Antilles

- **Volcanic: sharp elevation.**
- **Global models cannot resolve terrain appropriately, which causes generally underestimation of rainfall and impacts in other weather.**
- **They produce streamers**



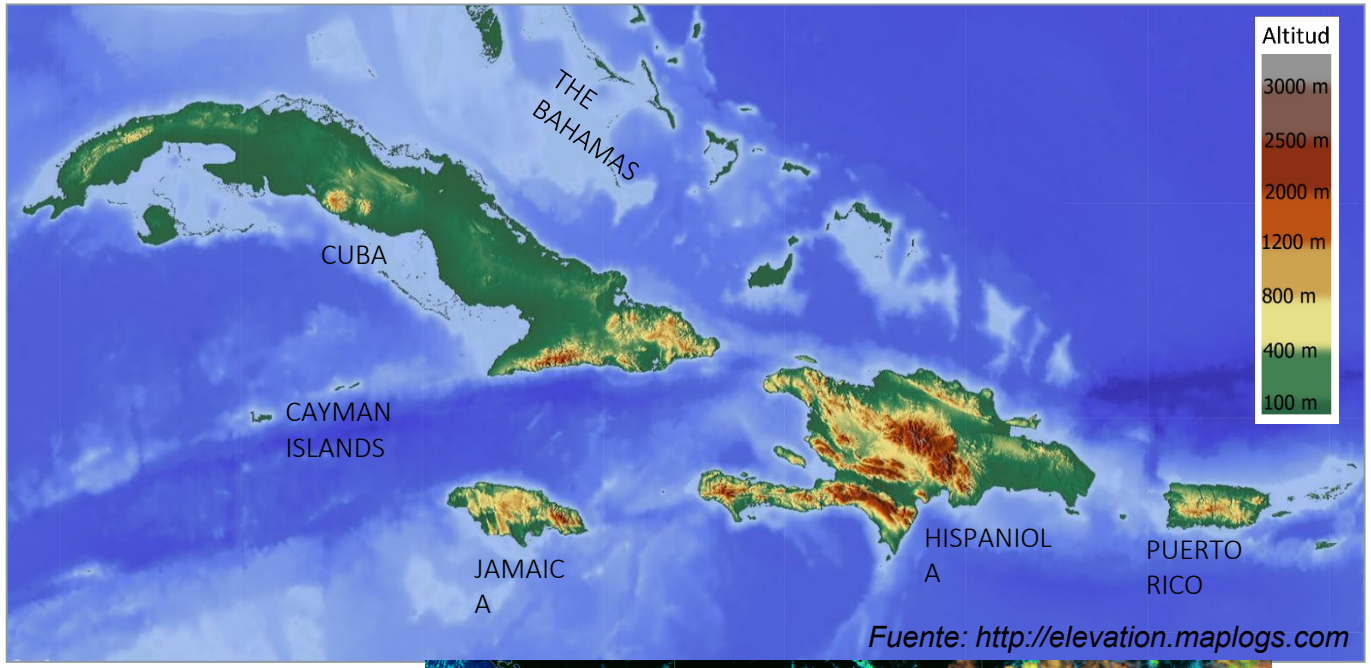


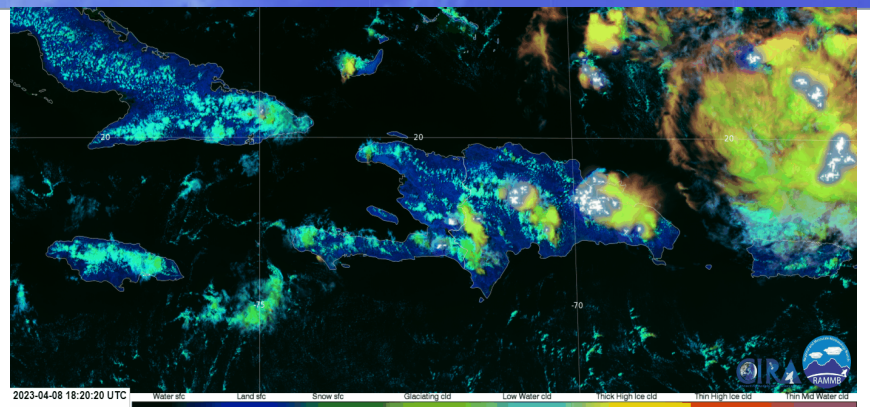
Wake clouds form over and/or downstream of the Lesser Antilles



Terrain in the Greater Antilles

- **Hispaniola has the tallest terrain.**
- **Puerto Rico, Jamaica and southeast Cuba follow.**
- **Stimulates afternoon convection, which flares up downstream following low-mid tropospheric winds.**
- **Enhanced ascent upstream of a mountain range favors heavy rainfall, especially at night/early morning.**
- **Favors regions of descent and drying downstream.**





Terrain in Tropical (Northern) South America

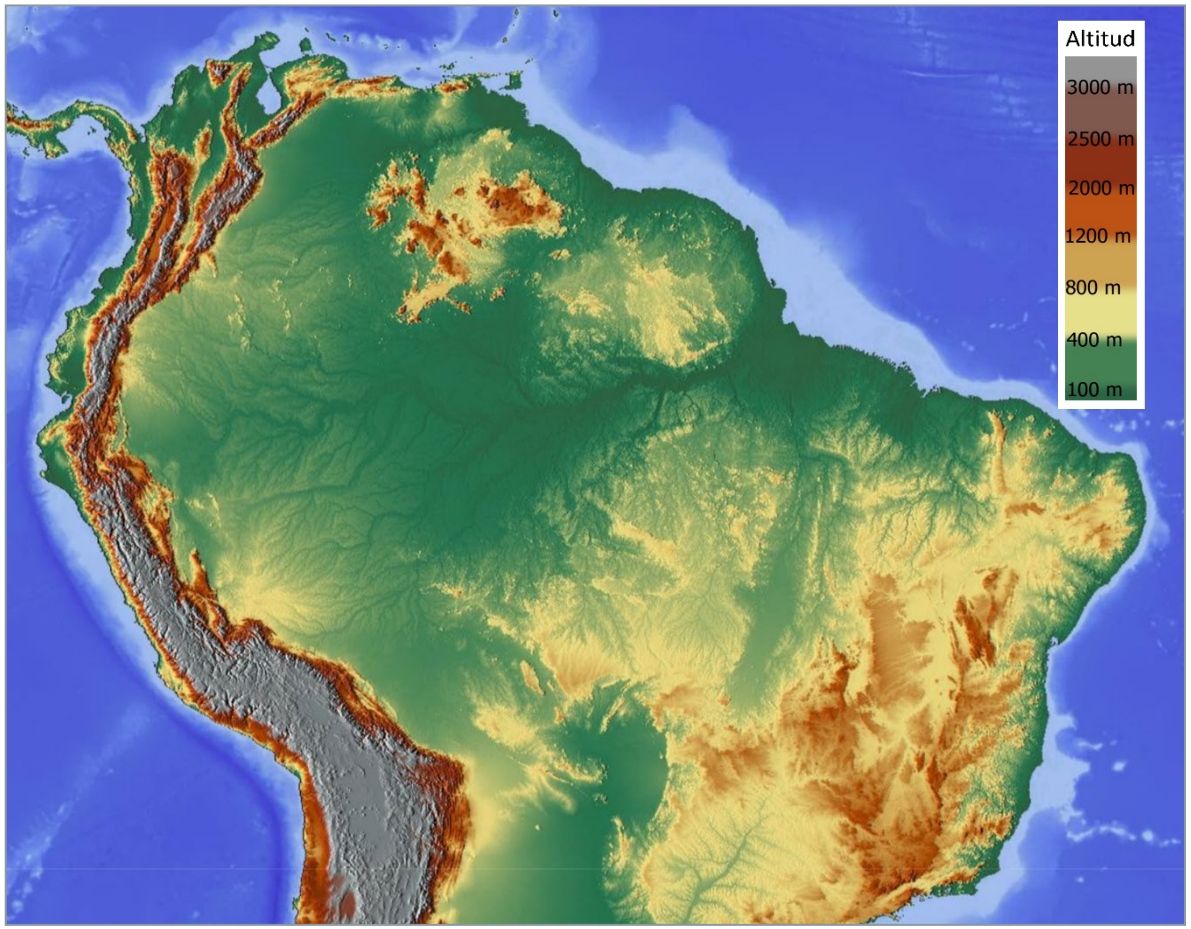
- **The Andes are the most prominent.**
- **Roraima/Canaima/Guyanas shield, and Eastern Brasil are elevated.**
- **The Andes:**

a) **Divide Pacific and Amazon air masses, especially below 10000 ft.**

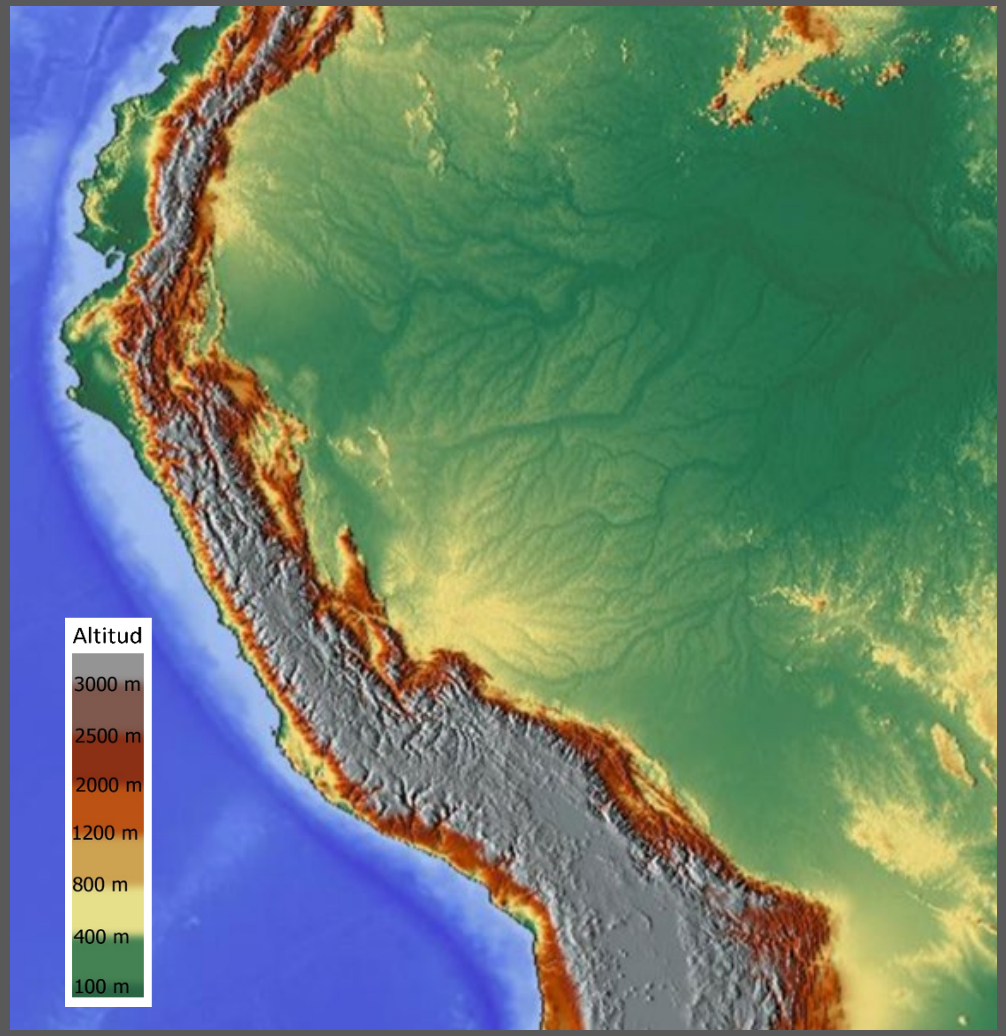
b) **Funnel the flow in regions developing low- and mid-level jets.**

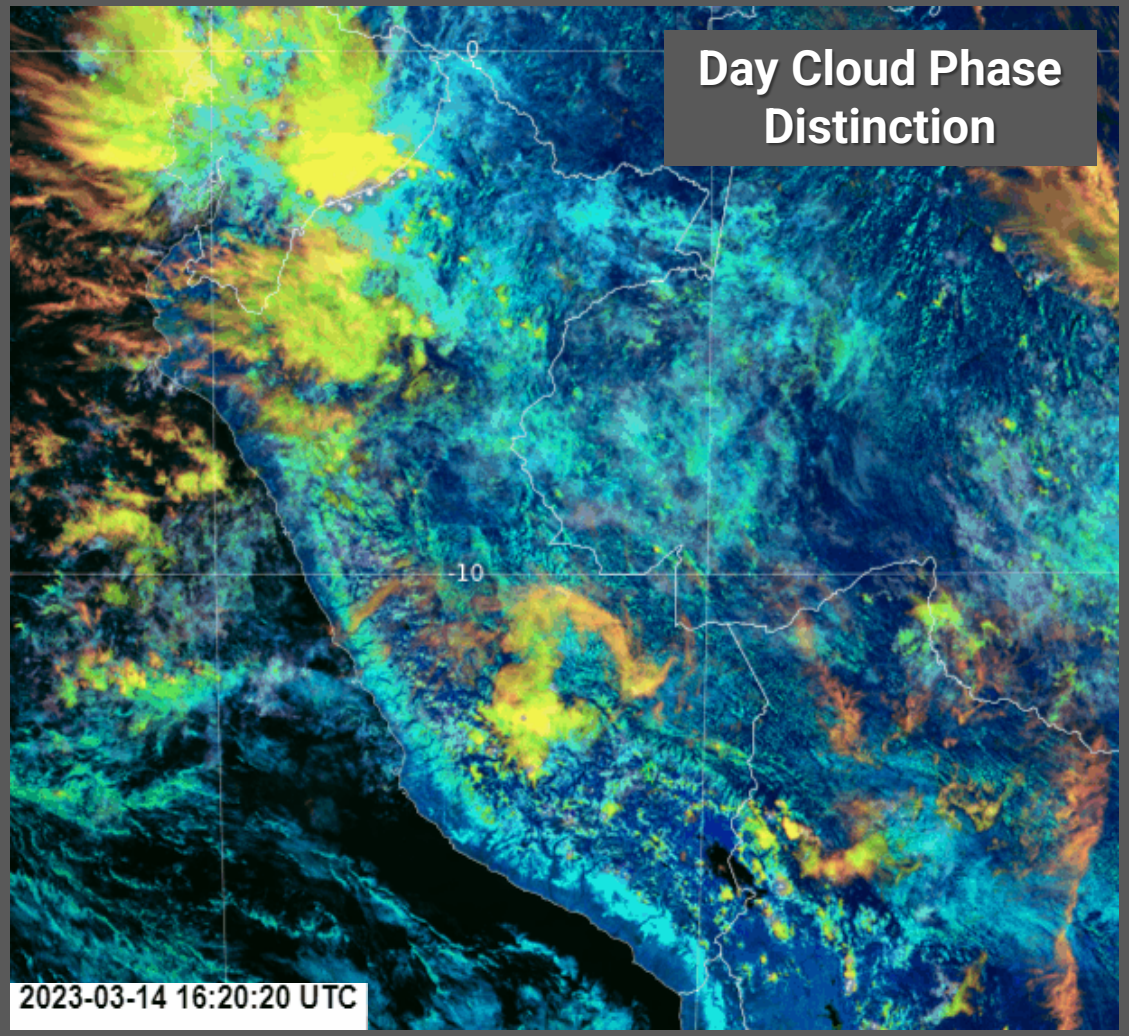
c) **Favor extreme rainfall from perpendicular moist winds.**

d) **Favor afternoon convection, especially when mid-level flow is weak and moisture is available.**



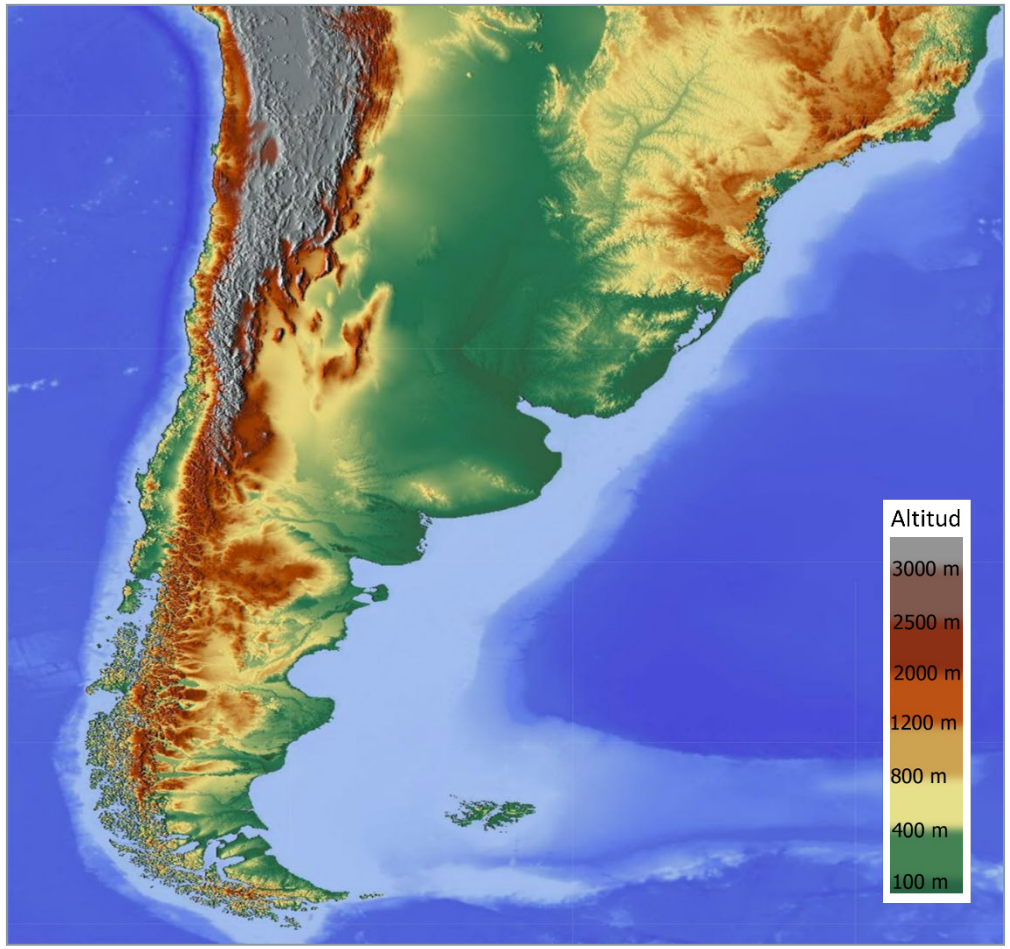
Effects of the Andes on Convection





Terrain in Southern South America

- **The Andes are very tall (>600 hPa) north of 40°S and up to 900-800 hPa to the south.**
- **Frequent strong winds favor strong adiabatic compression and turbulence in Patagonia, when descending in the lee of the Andes.**
- **Upper troughs and jet streams can also favor strong turbulence when crossing the Andes further north, with strong winds.**
- **The Serra do Mar (SE Brasil) can produce extreme rainfall with S, SE and E moist flow.**
- **The flat corridor in the middle favors moisture transport from the Amazon to Patagonia.**



Struggles of NWP with Terrain

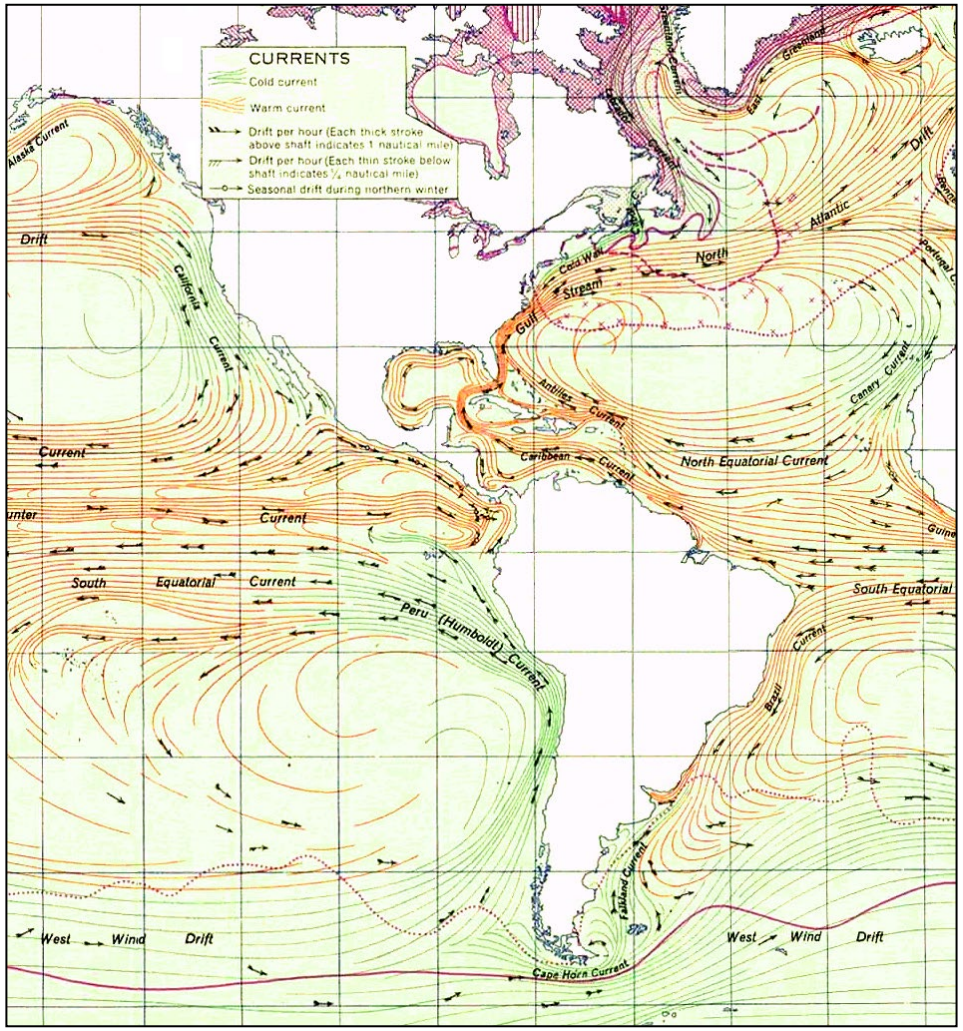
- **Relatively low resolution of global models limits their ability to "see" or resolve the real terrain and its effects. Examples:**
  - Some Caribbean islands are too small (wake clouds effects are not resolved properly)
  - The Andes are too narrow and tall in parts of South America (models make them smoother).
- **Due to examples like these, diurnal circulations and their impact on precipitation are not appropriately resolved.**

02a

Oceans and Impacts in the Atmosphere

Ocean Currents

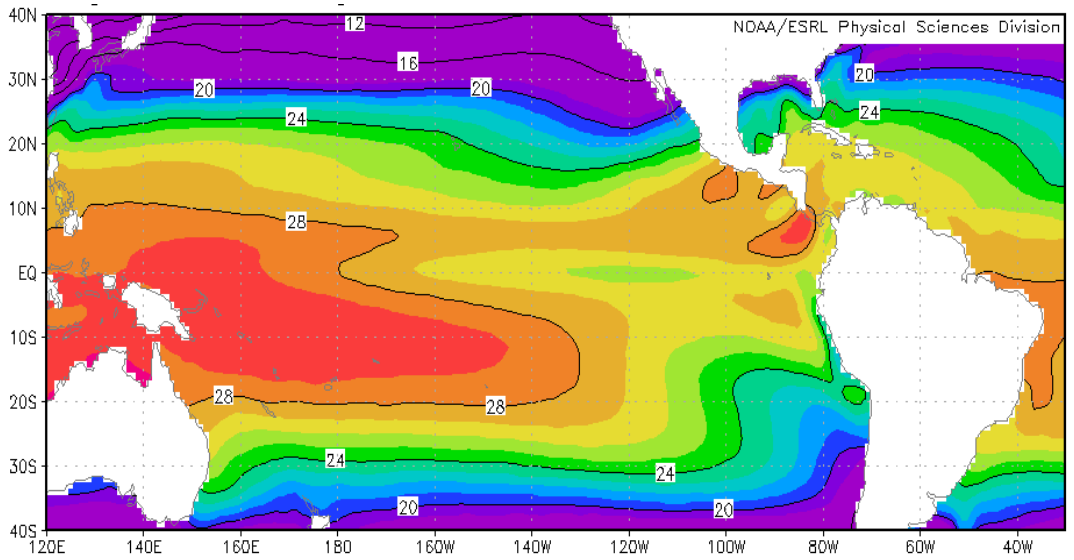
- **Stirred primarily by the surface winds, to a lesser extent by subsuperficial processes.**
- **Cold currents along west coasts.**
- **Warm currents along east coasts.**
- **Sharp gradients in extratropical east coasts where the Gulf Stream meets the Labrador Current and where the Brazil meets the Malvinas current. These favor cyclogenesis.**
- **Currents modulate Sea Surface Temperatures.**



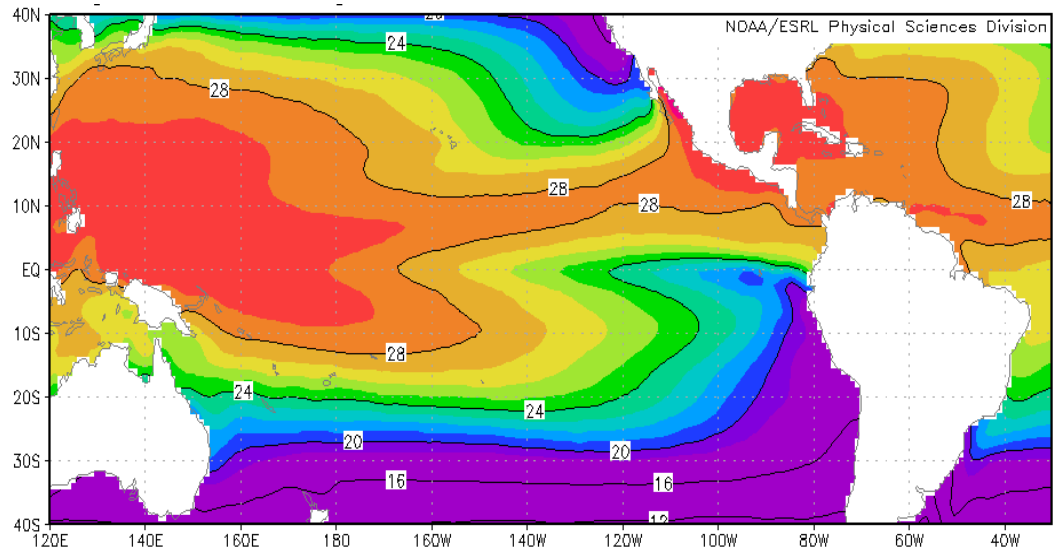
Map collection of the Perry-Castañeda Library (PCL) of the University of Texas at Austin.

Sea Surface Temperatures

FEB-MAR



AGO-SET



Peak of South Hemisphere Warm Season

Peak of North Hemisphere Warm Season

Fuente: OISST (NOAA/ESRL) – Climatología 1981-2010

SST are key drivers of the climate

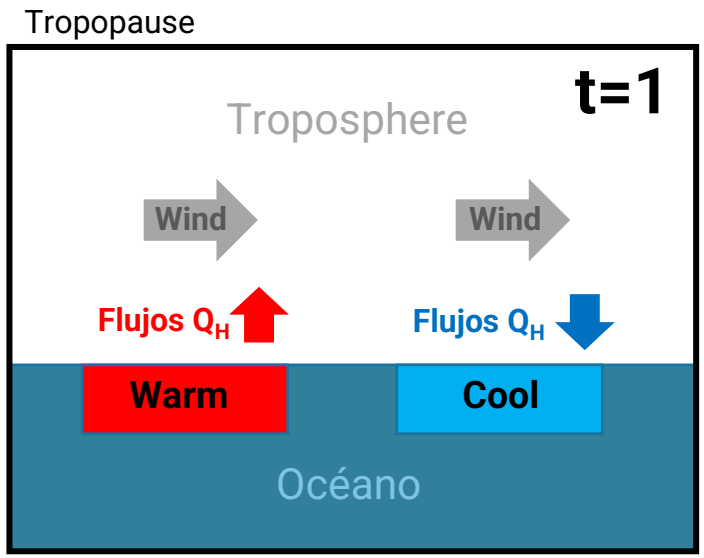
- Oceans cover most of the world.
- They are stable sources of heat and moisture, as their temperature varies slowly. [The high specific heat of water C_P stabilizes temperature variations].
- The atmosphere only “sees” or “reads” temperatures in the sea surface (SST), but top layer lingering temperature anomalies can affect SST in weeks and months
- Rainfall and convection also react to SST and anomalies, generally enhanced (inhibited) downstream from warm (cool) anomalies.

Takeaway: Slow-changing ocean temperatures are very useful for sub-seasonal and climate forecasting.

How do SST modulate atmospheric circulations?

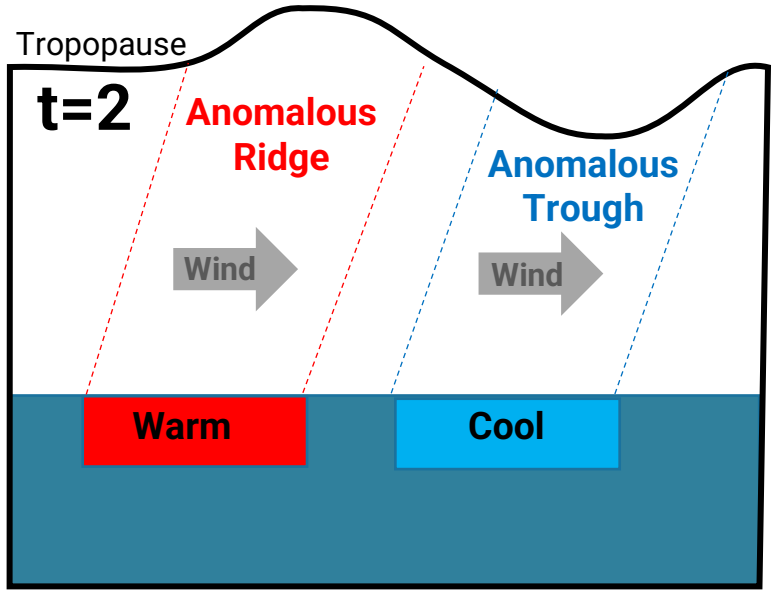
SST affect atmospheric thermodynamics and the flow reacts

Differential heating favors anomalous ridges and troughs



Warm and cool SST anomalies communicate with the overlying atmosphere by fluxes, controlled by the wind and temperature gradients.

This then communicates with the rest of the troposphere via turbulent mixing, favoring anomalous ridges and troughs downstream from the initial anomalies

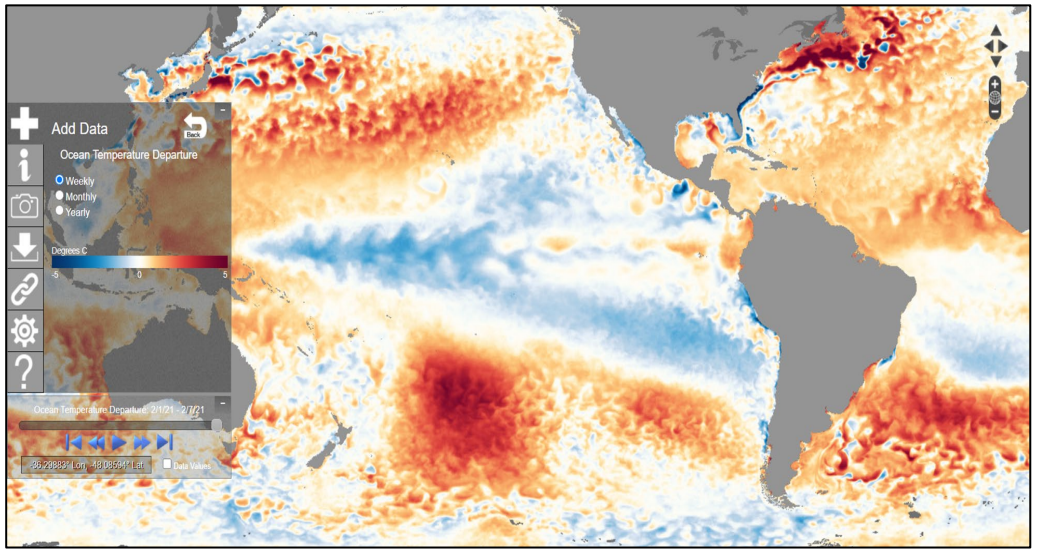


The resulting anomalous ridges and troughs develop anomalous circulations.

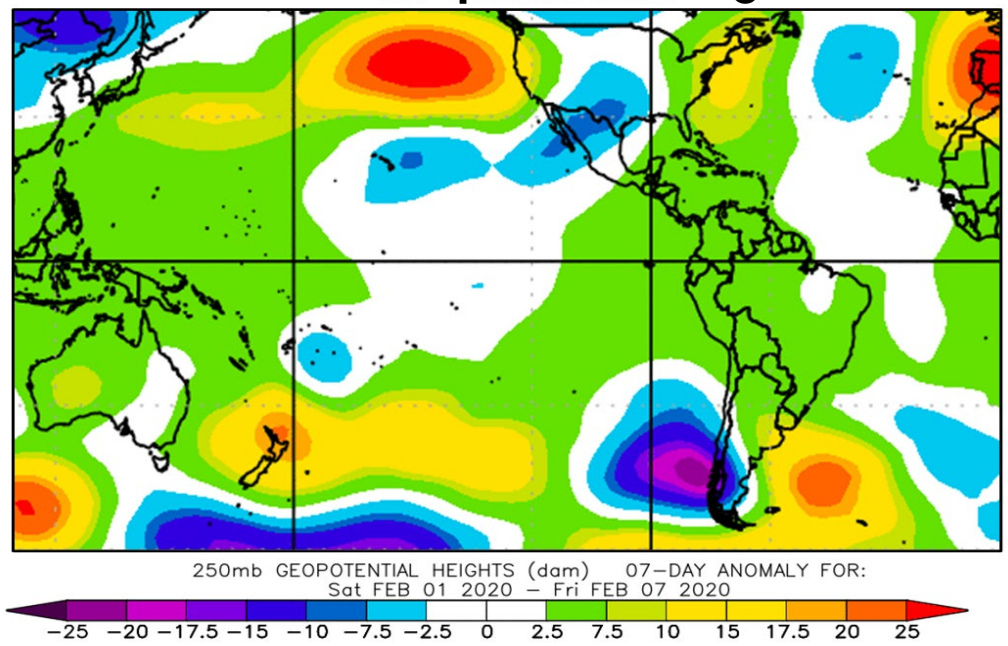
SST affect atmospheric thermodynamics and the flow reacts

- Troughs and ridges are favored over/downstream from SST anomalies.
- Still, synoptic variability in the extra tropics will sometimes overwhelm the influence of SST and anomalies.

SST Anomaly

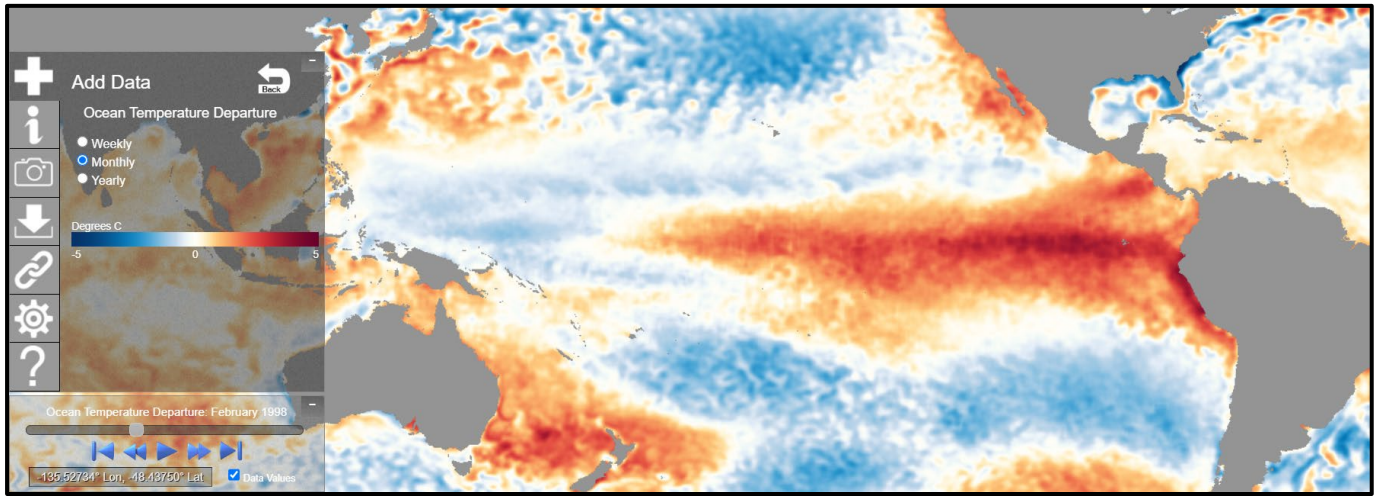


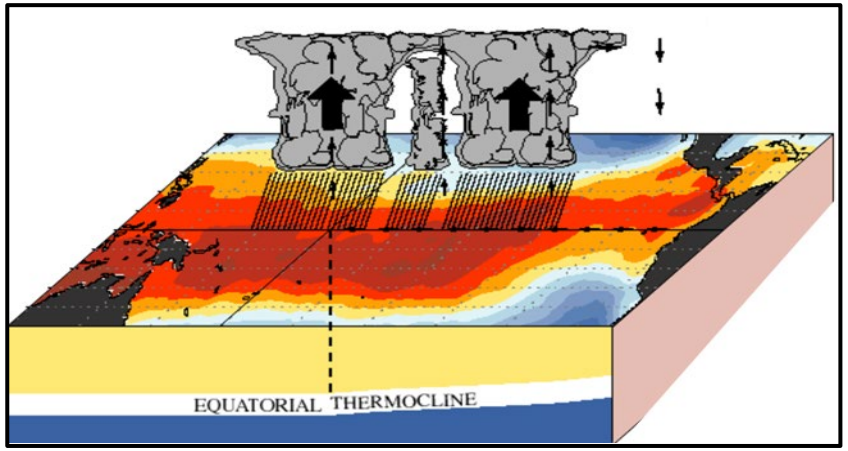
250 hPa Geopotential Height



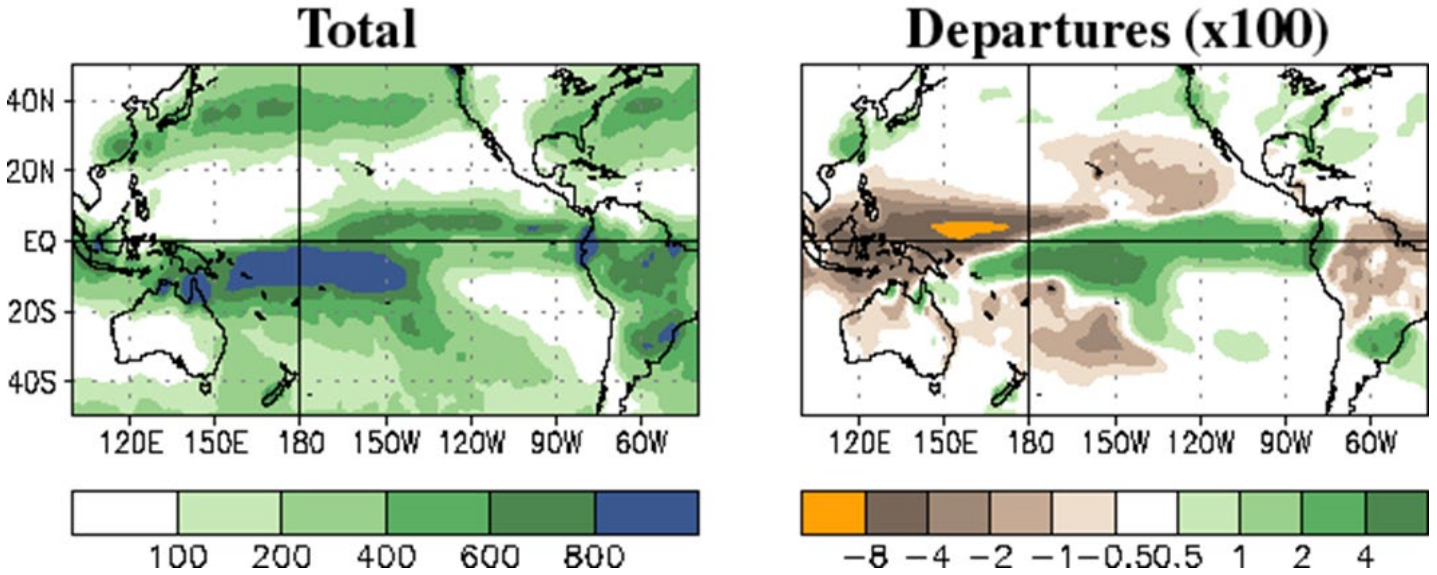
1998 El Niño

Feb 1998 SST Anomalies



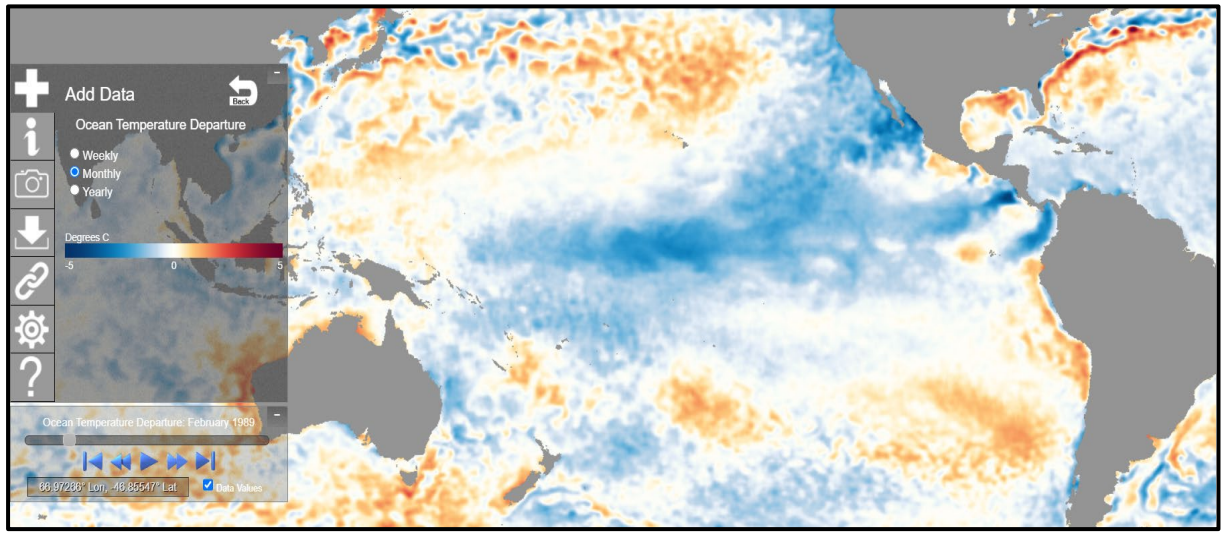


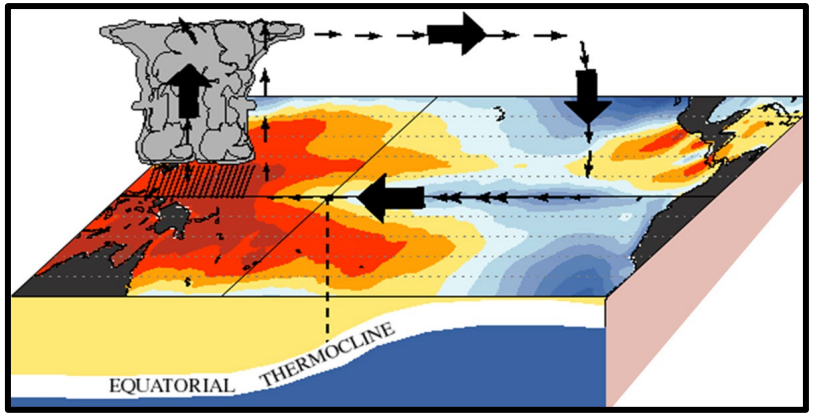
Jan-Mar 1998 Precipitation (mm)



1989 La Niña

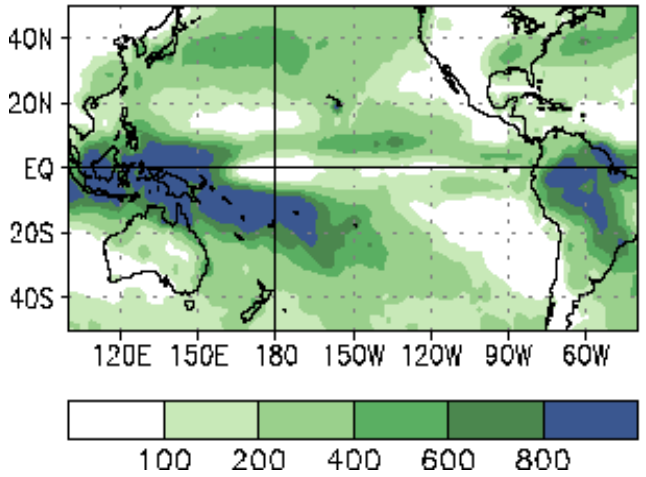
Feb 1989 SST Anomalies



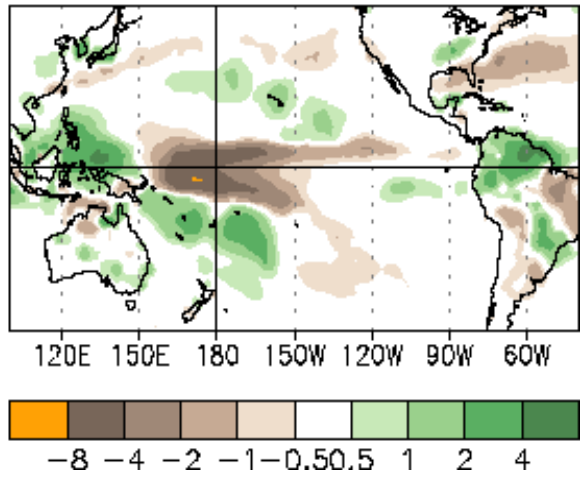


Jan-Mar 1989 Precipitation (mm)

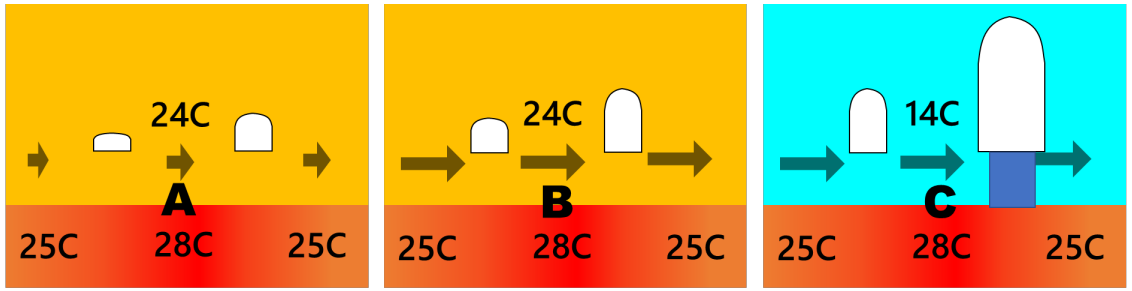
Total



Departures (x100)

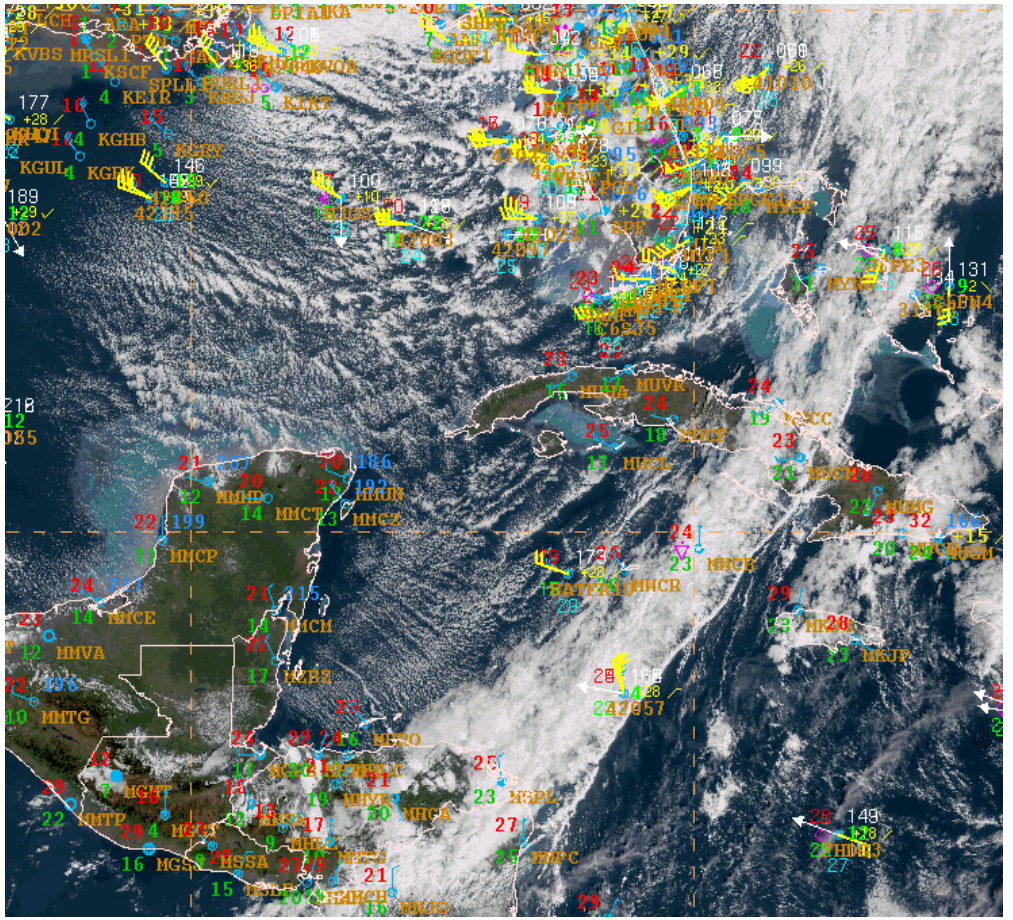


Cold air intrusions generate convection (Cold air Cu)



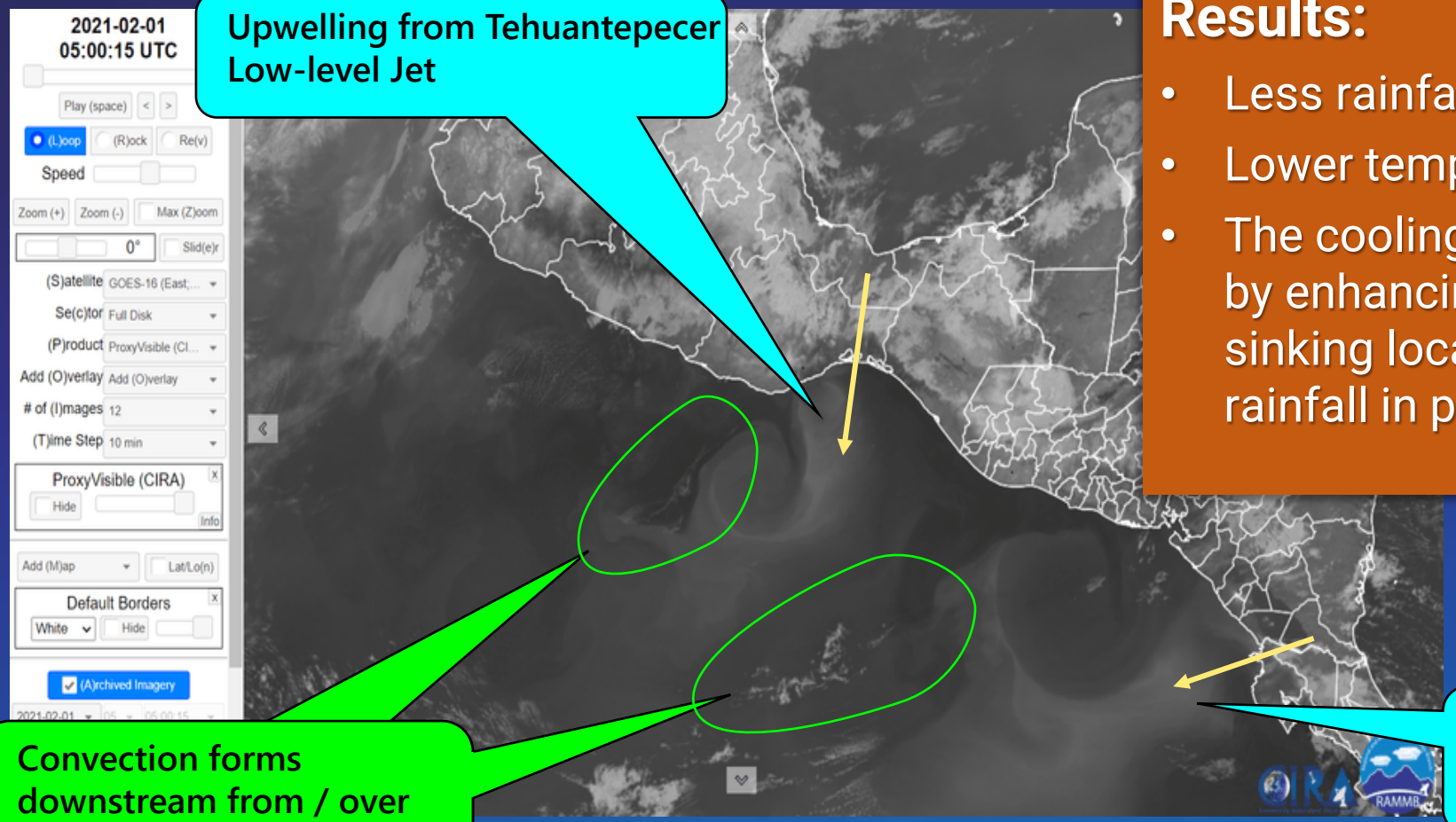
Following frontal passage or during a shift of winds to northerlies (in the Caribbean), cold air advection over warmer waters:

1) Extracts heat and moisture from the ocean
2) This destabilizes the lower troposphere.
3) "cold air cumulus" form (Moderate Cu and Cu Congestus)



Aviation Implications: Convection and turbulence in the lower troposphere.

Cooler SST tend to inhibit convection



Upwelling from Tehuantepecer Low-level Jet

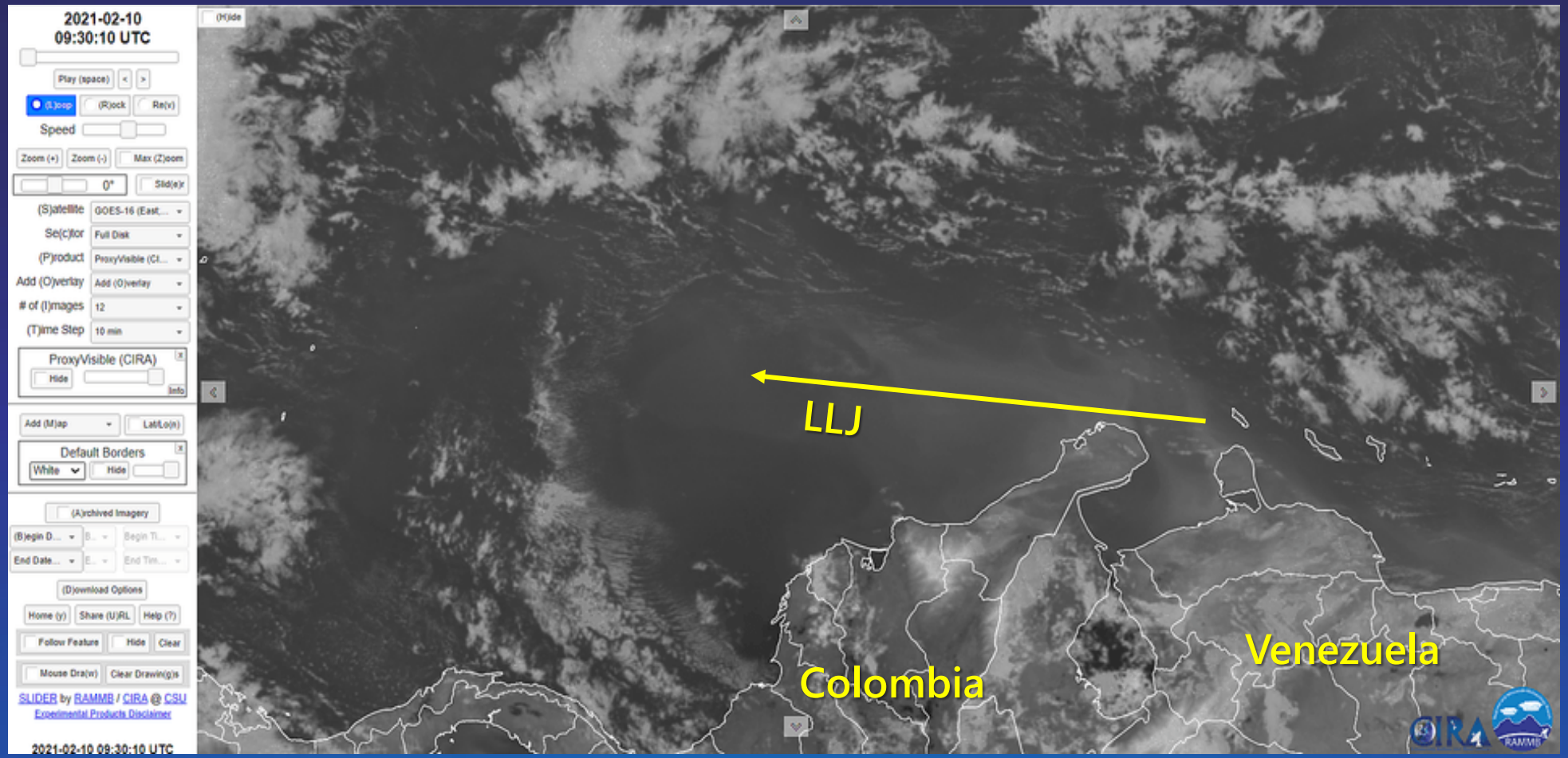
Results:

- Less rainfall than envisioned.
- Lower temperatures.
- The cooling can also modify circulations by enhancing low-level divergence and sinking locally. This can stimulate rainfall in peripheral areas.

Convection forms downstream from / over warmer SSTs

Upwelling from Papagayo Low-level Jet

SST: Upwelling inhibits convection



03

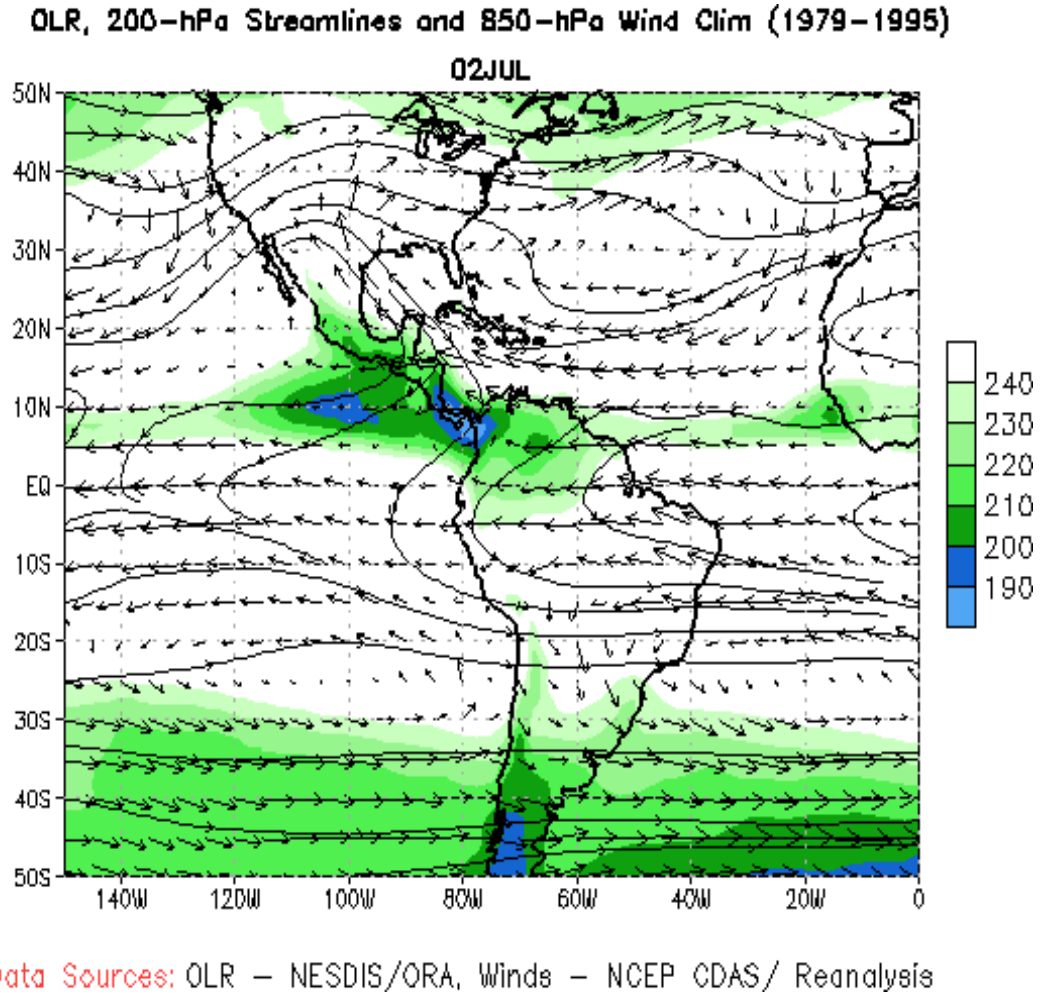
Upper, Mid and LowTroposphere: Flow Climatology and Systems of Interest

03a

Upper Flow and Systems of Interest

Annual Cycle of 200 hPa Flow

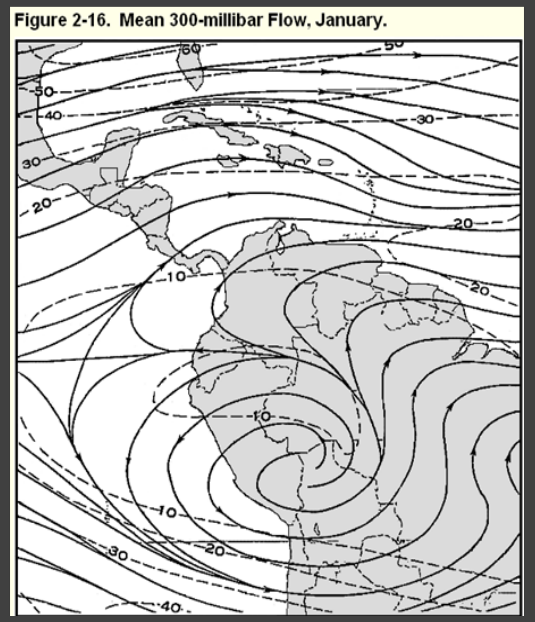
- **Upper ridges follow condensational heating from deep convection.**
- **Lower OLR (greens and blues) represents colder cloud tops, which often associate with more thunderstorms.**
- **Note how upper ridges (in streamlines) follows low OLR (deep convection).**
- **Subtropical ridges form over wider continental regions during the summer time.**
- **Over the Tropical Atlantic, Caribbean and northern South America, the "Subequatorial" ridge is dominant.**



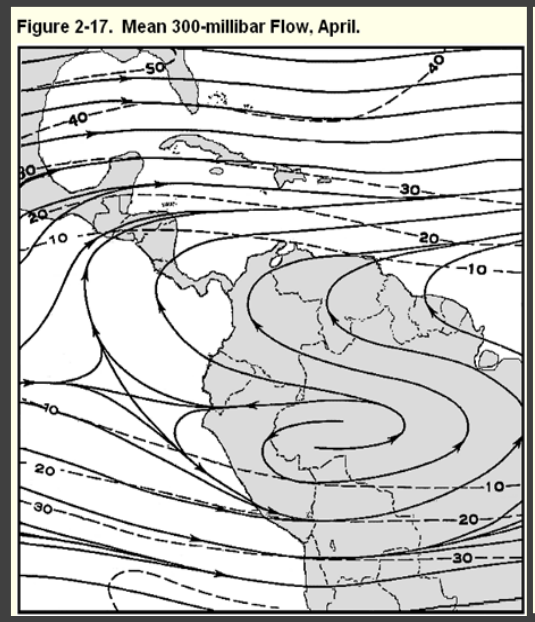
300 hPa Flow

- Upper ridges develop in the subtropics during their warm season. Example: Bolivian High in South America during January and the subtropical ridge over southern Mexico in October.
- The subequatorial ridge also meanders from northern South America and southern Central America in April towards the north Atlantic by July following hearing.
- TUTTs are favored between June and November, in the northern Caribbean.

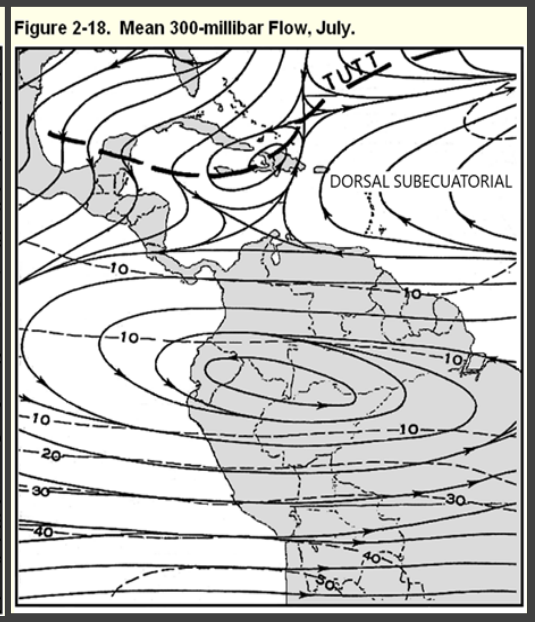
January



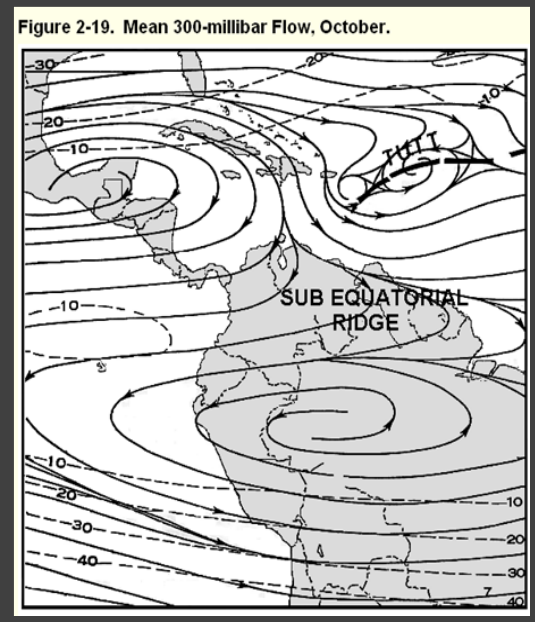
April



July

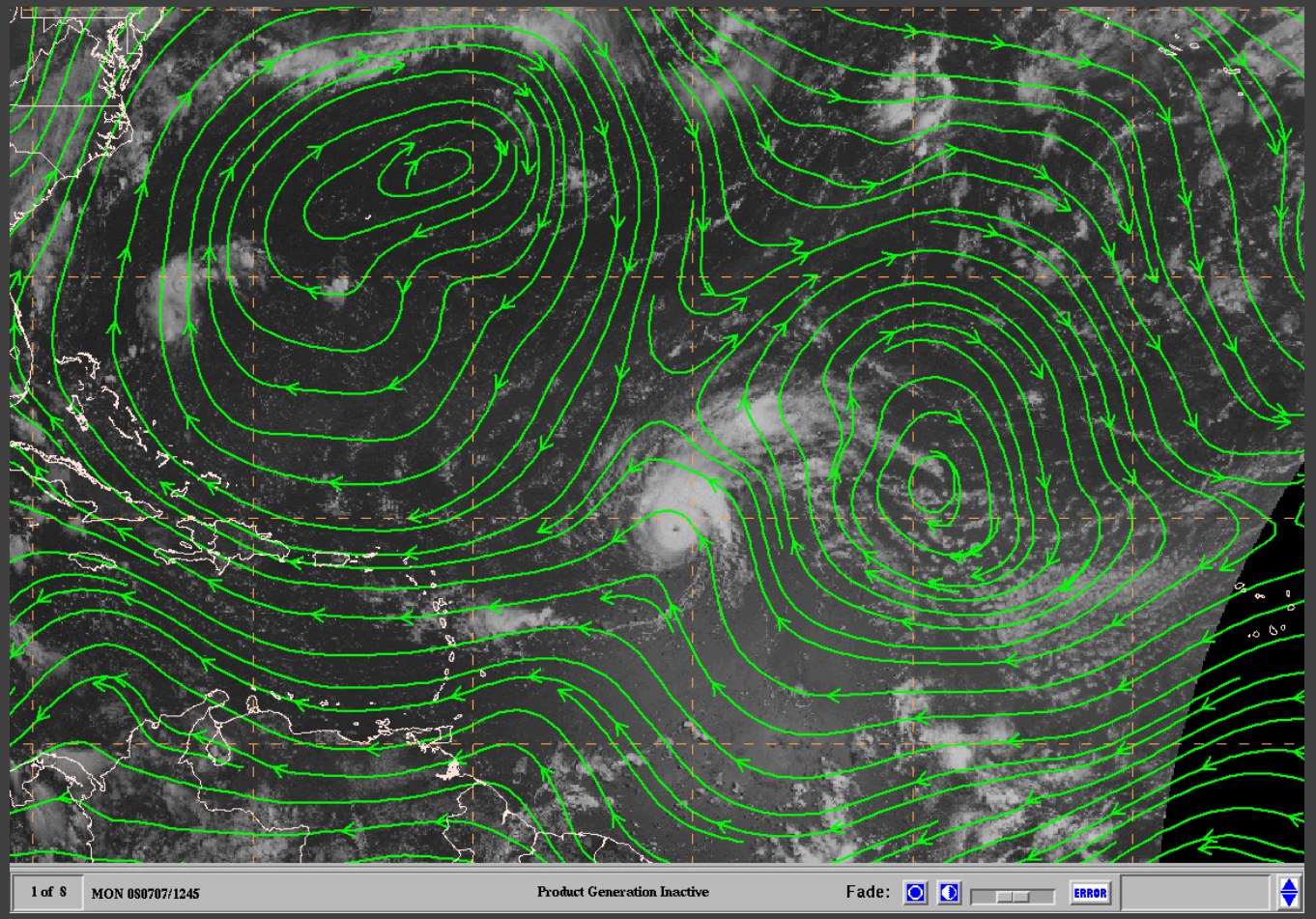


October



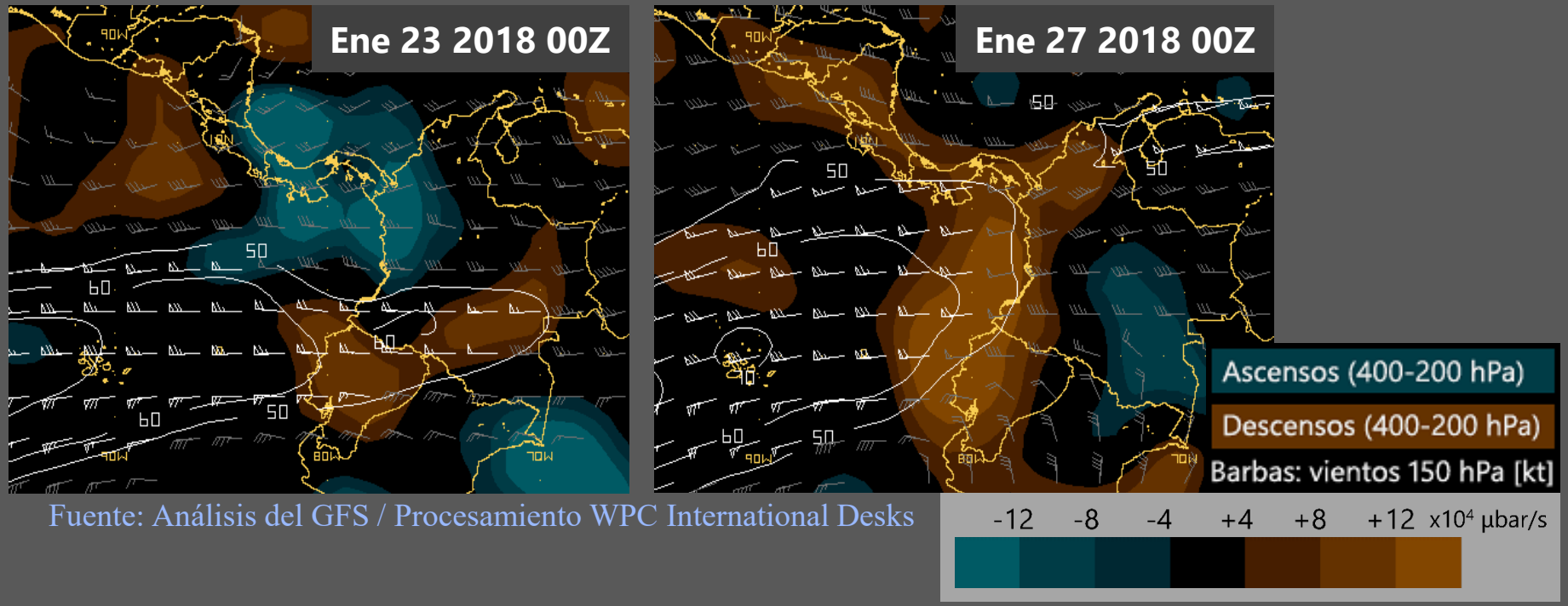
Upper ridges steer Tropical Cyclones

Example of Hurricane Bertha (2008) turning northward due to a weakness of the ridges



Subequatorial Jet

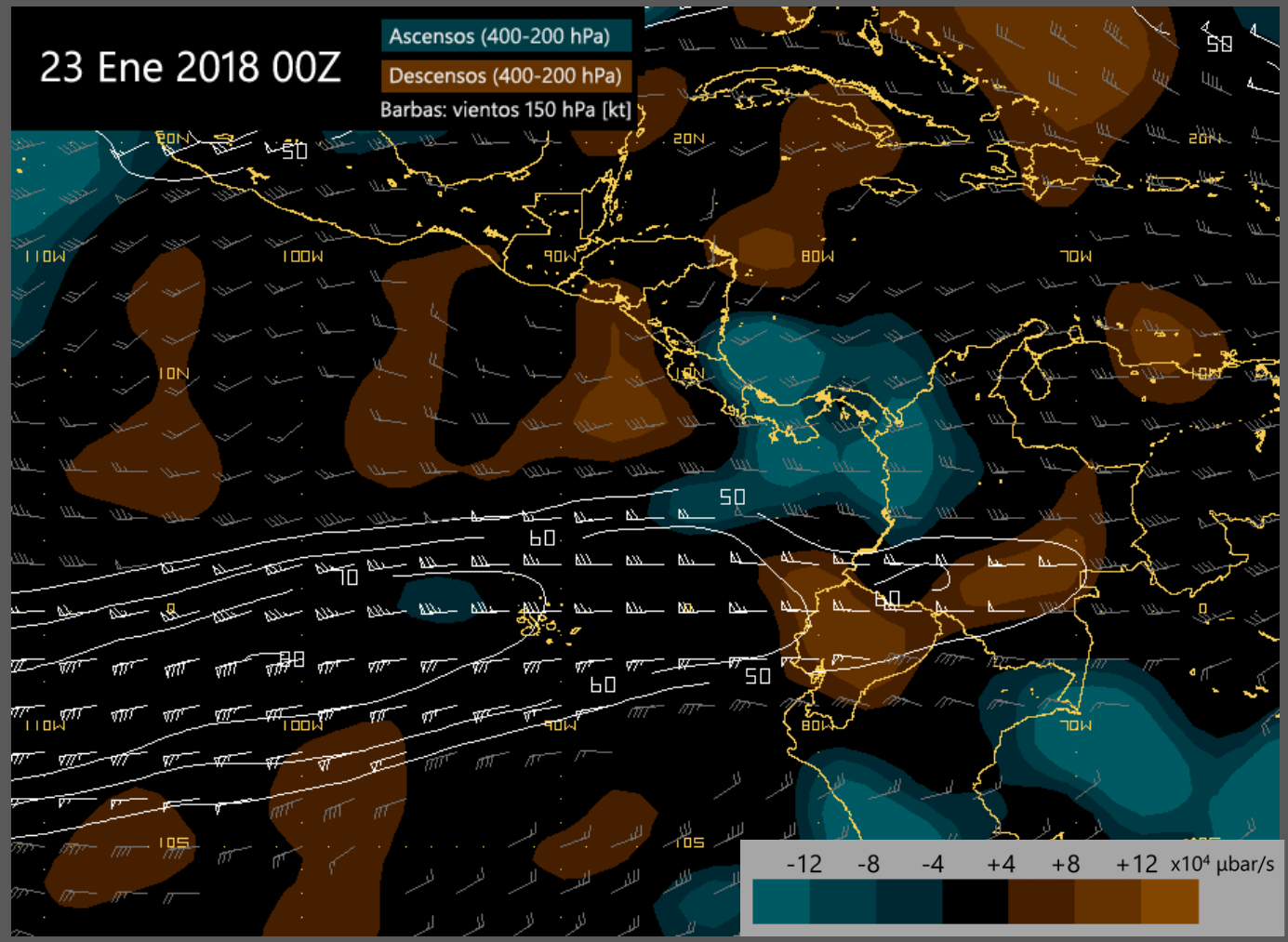
- Over the Eastern Pacific, intermittent between December and February.
- Best defined between 200 and 150 hPa.
- Descends isentropically from the Tropical Pacific to the South American Coast. Enhanced convergence in its mouth stimulated descent in the 200-400 hPa layer, limiting the development of deep Convection (drier conditions).



Fuente: Análisis del GFS / Procesamiento WPC International Desks

Subequatorial Jet

Animación: Evento de fines de enero de 2018



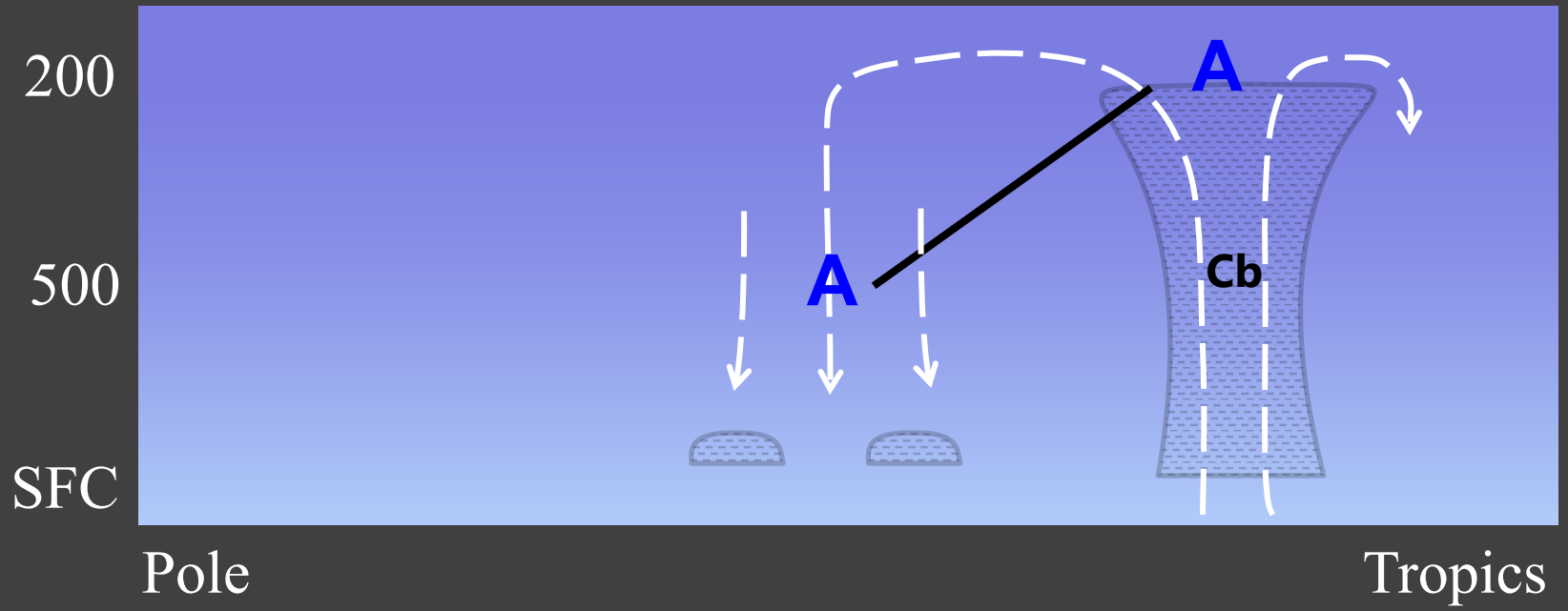
Fuente: Análisis del GFS / Procesamiento WPC International Desks

03b

Mid Flow and Systems of Interest

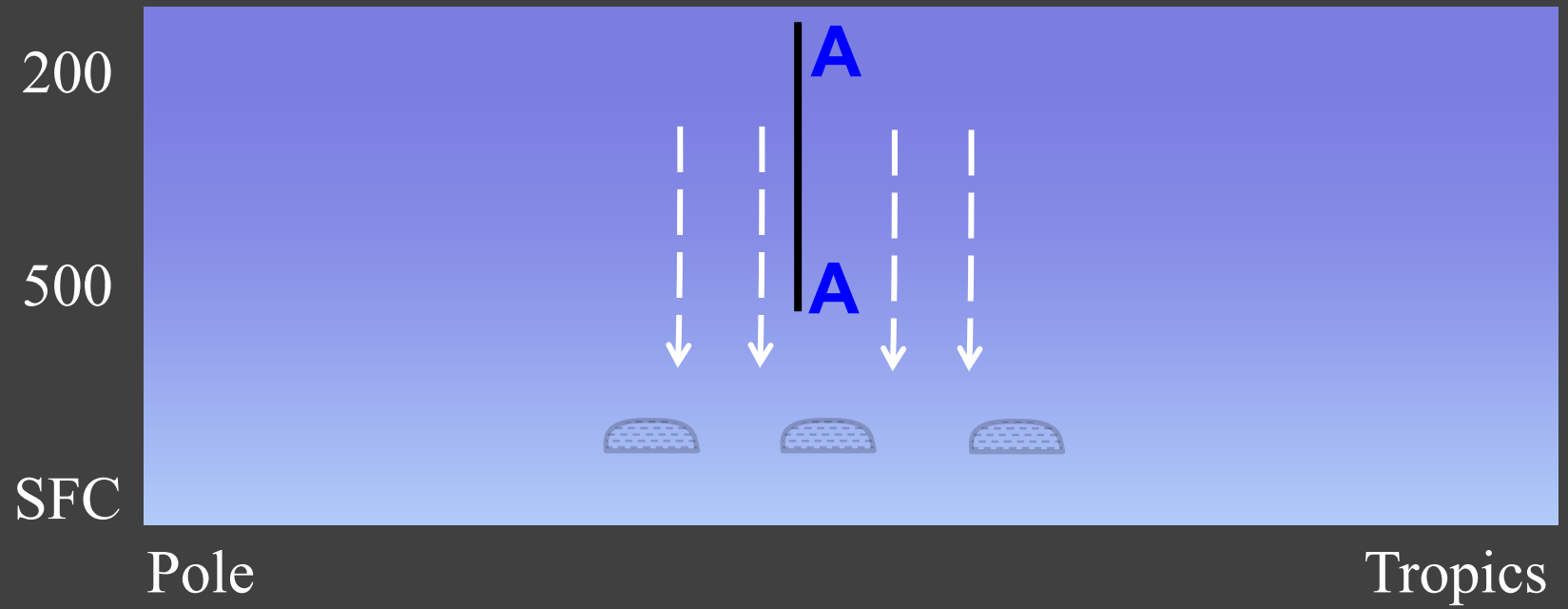
Upper and Mid-Level Ridges

- Mid-Upper ridges slant towards the Tropics with height
  - 500 hPa high is closer to the poles (~35N) tan the 200 hPa High
  - The 500 hPa ridge favors subsidence and fair weather. The 200 hPa ridge favors ventilation (enhanced Upper divergence), which stimulates Tstorms.

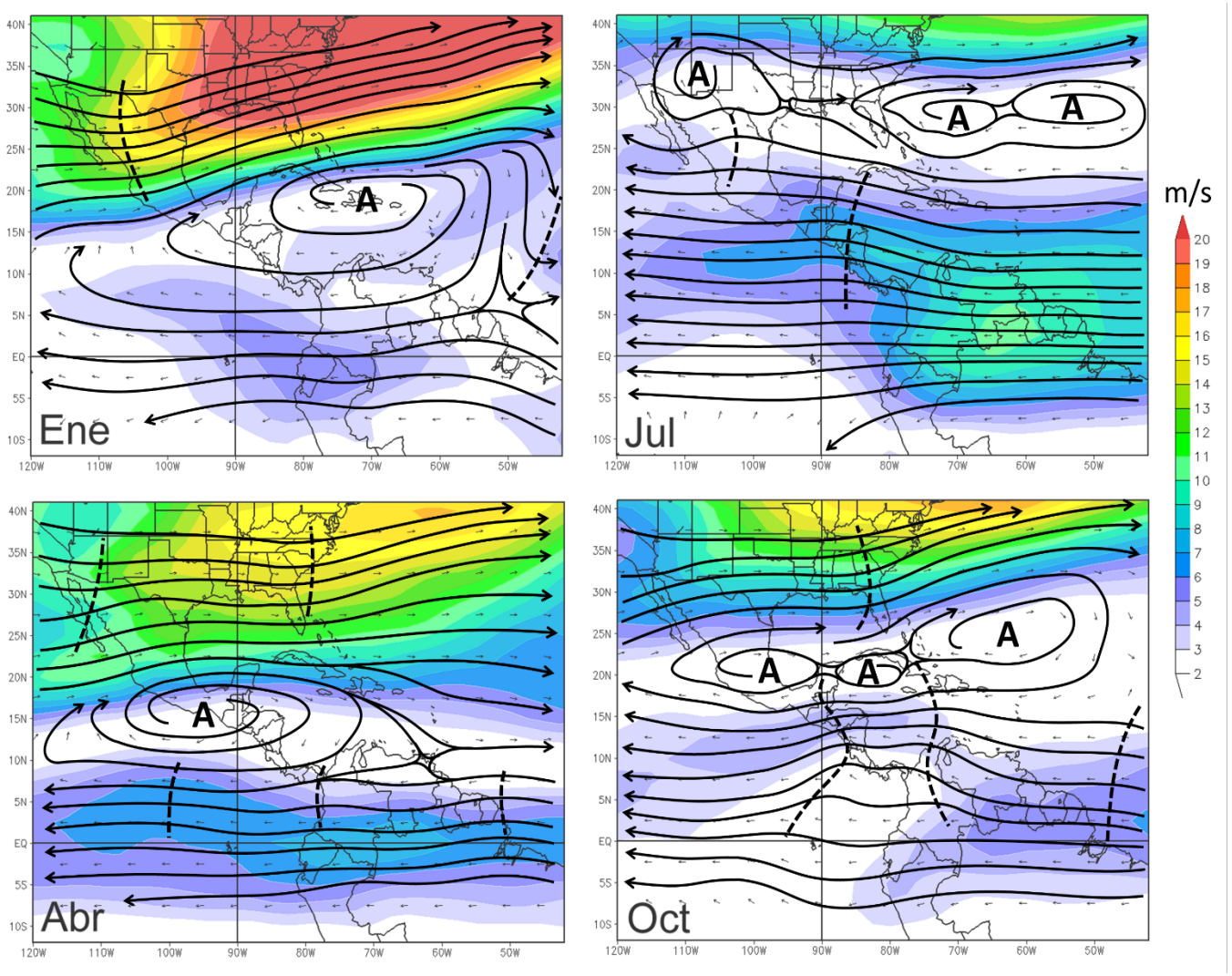


Vertically Stacked Subtropical Ridges

- When both 500 and 200 hPa ridges become vertically stacked, the mid-level feature dominates by stimulating subsidence.
- This strenghthens a temperature inversion in the lower troposphere, disconnecting low-level processes from the Upper troposphere.



500 hPa: Mid-Levels



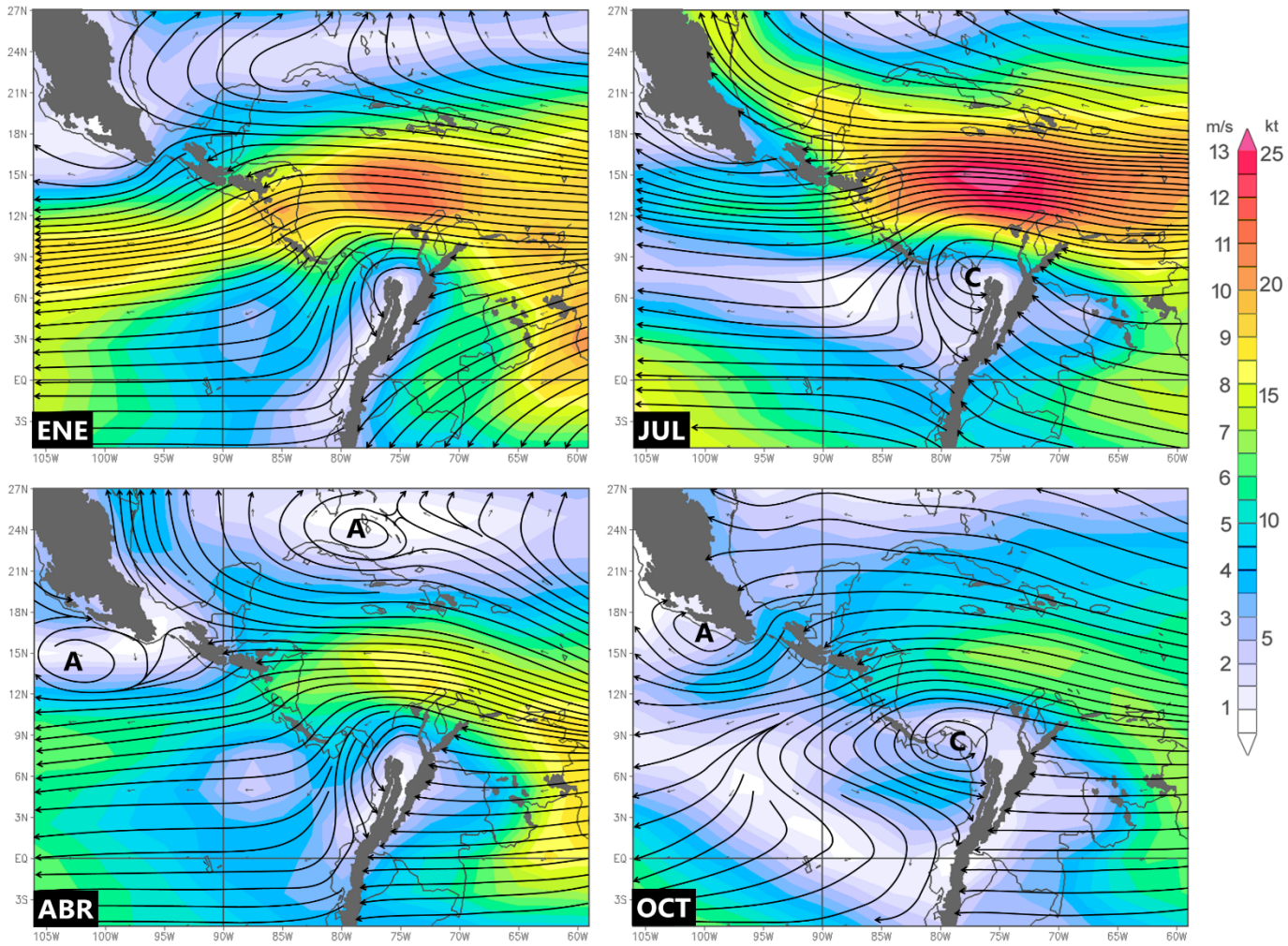
Aviation Implications: Mid-level Ridges favor smooth flights. Poleward peripheries favor wind shear and turbulence.

Fuente: Climatologías de 1981-2010 - NCEP/NCAR Reanalysis, procesamiento por WPC International Desks

03c

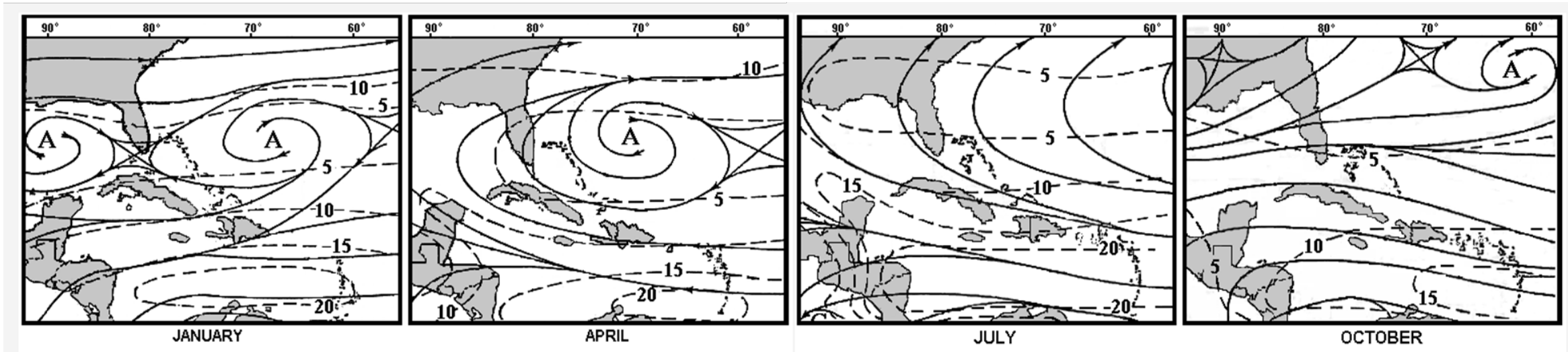
Lower Flow and Systems of Interest

850 hPa Flow Climatology

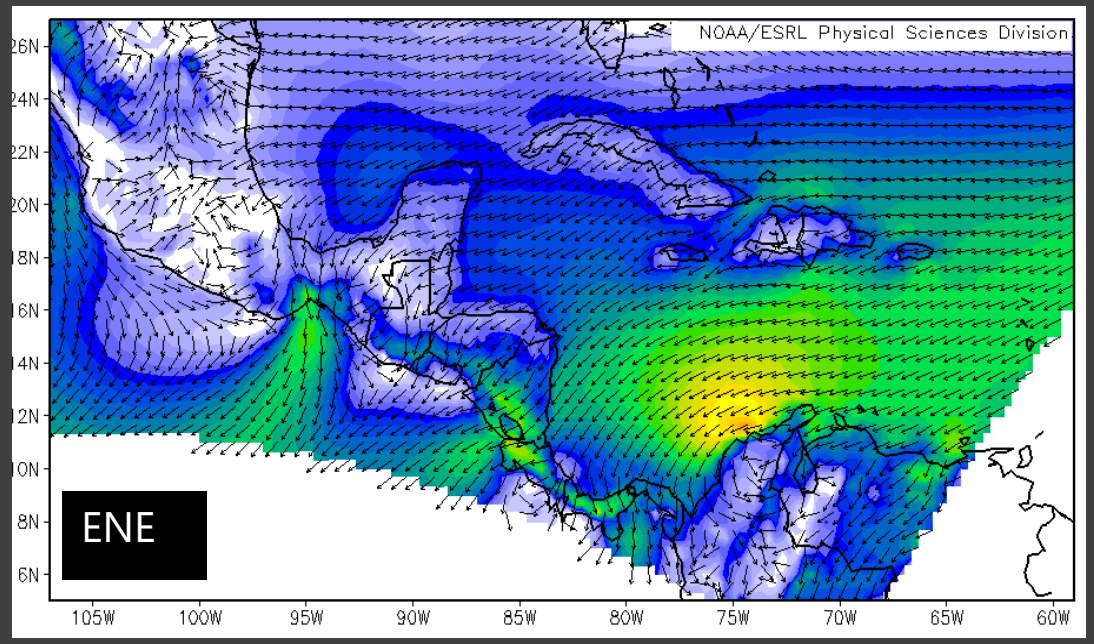


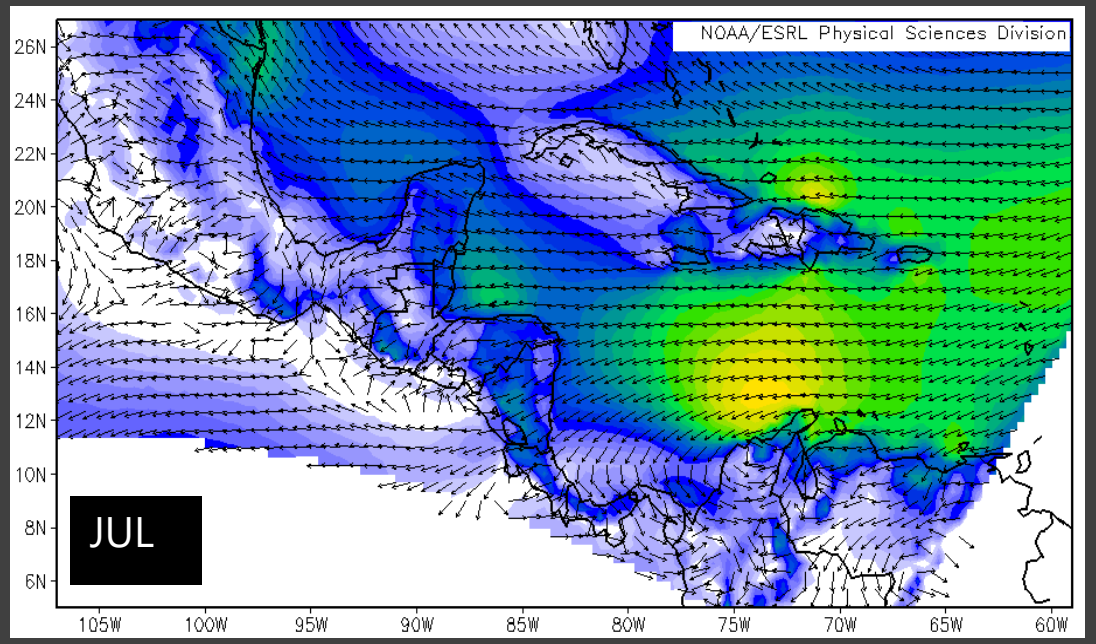
Fuente: Reanálisis de NCEP, Climatología de 1981-2010. Procesamiento WPC International Desks

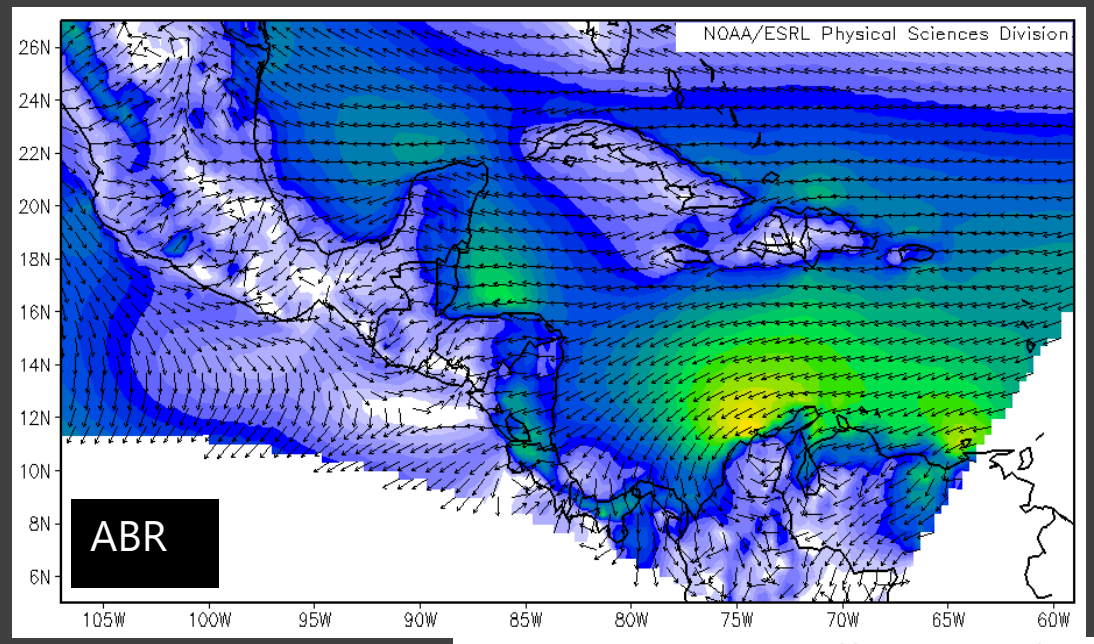
1000 hPa Flow Climatology

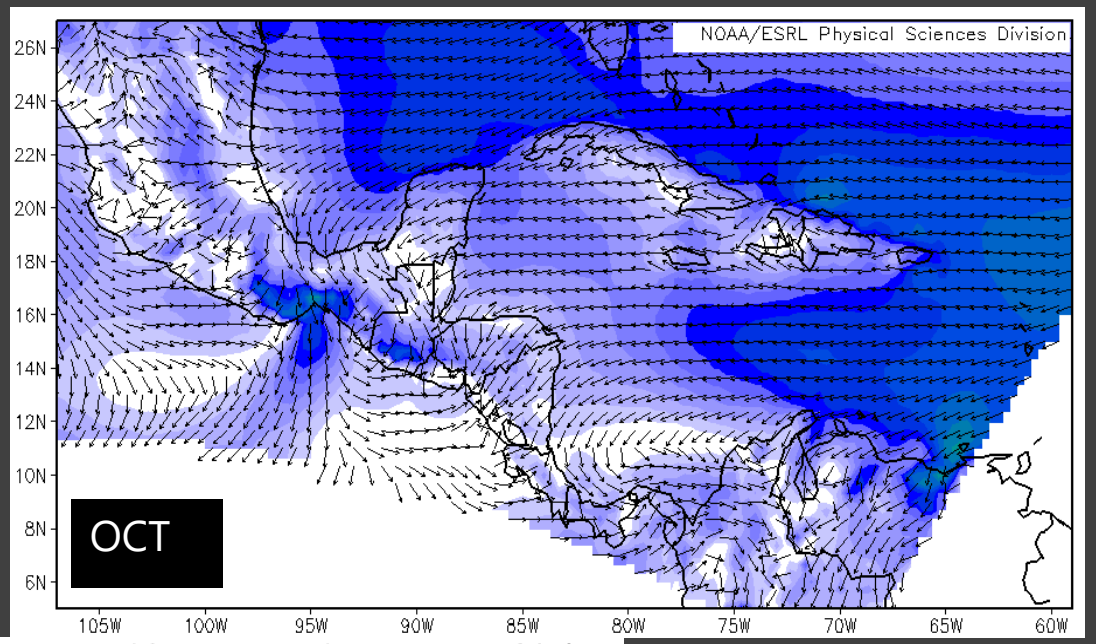


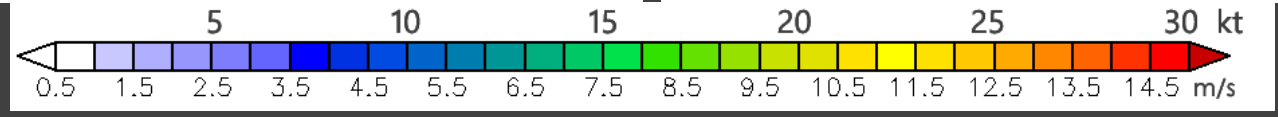
1000 hPa Winds





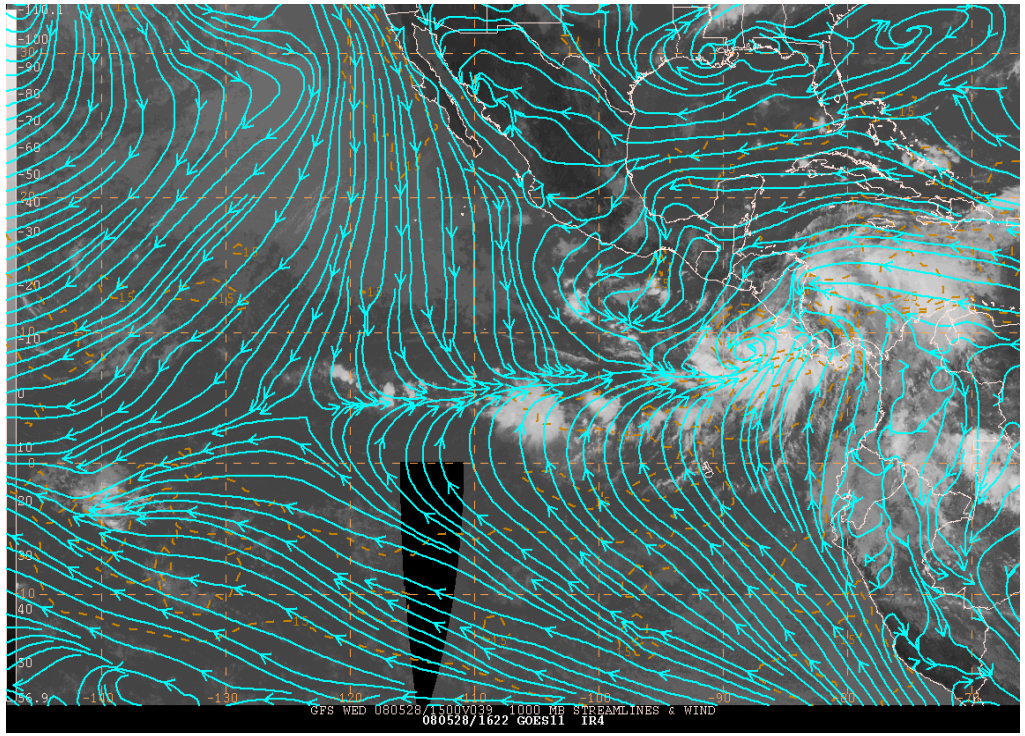






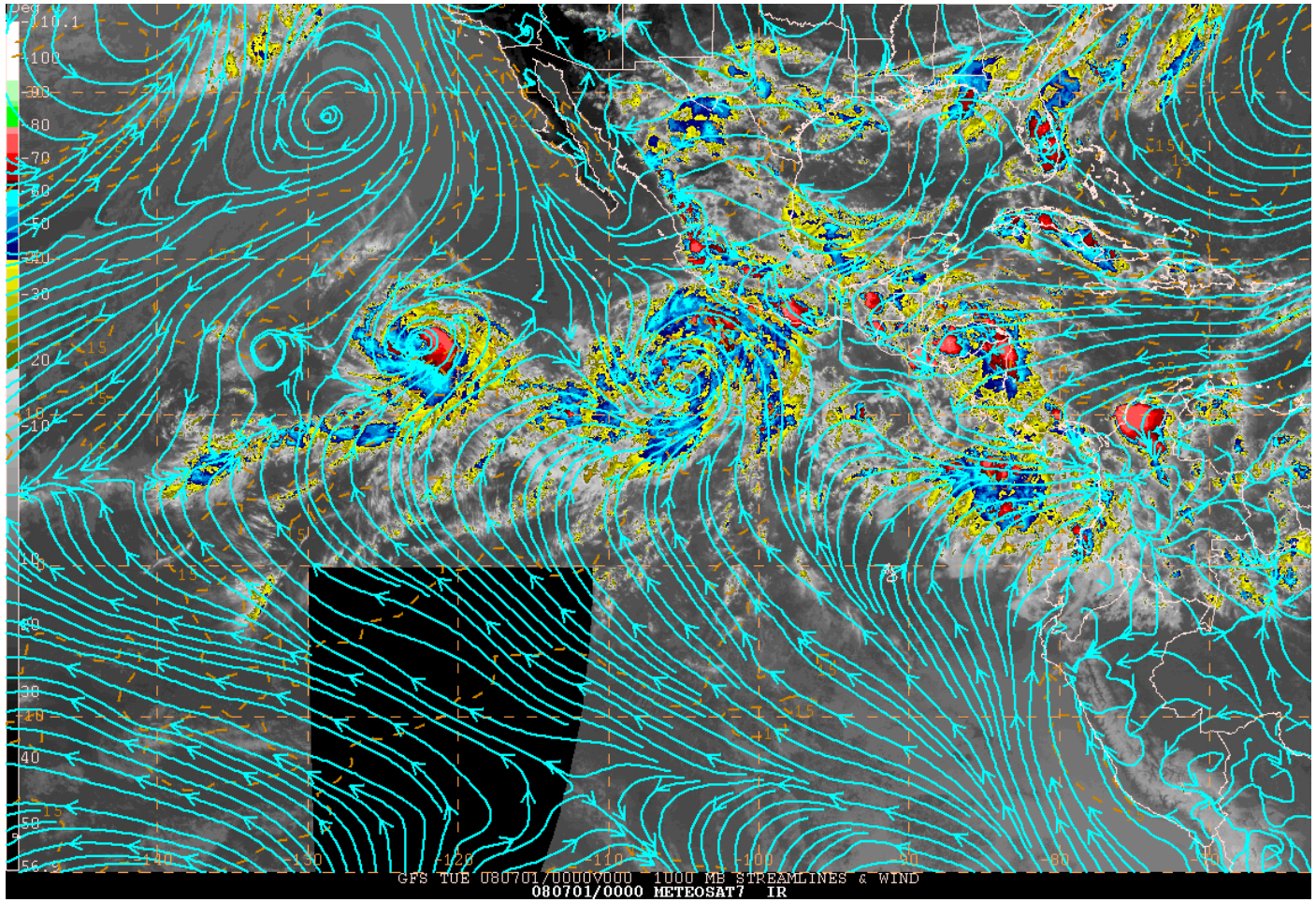
Intertropical Convergence Zone (ITCZ)

- Zone where north and south hemisphere winds converge. Follows warmer SST where lower SFC pressures are favored.
- Over the ocean, 1000 and 925 hPa winds tend to converge. Over land forms an ill-defined trough, the Near Equatorial Trough (NET).
- Cloud maxima are often present, but convection coverage and depth is very variable.
- Importance: Favors thunderstorms and turbulence from them. Also: heavy rainfall and can spawn tropical cyclones.



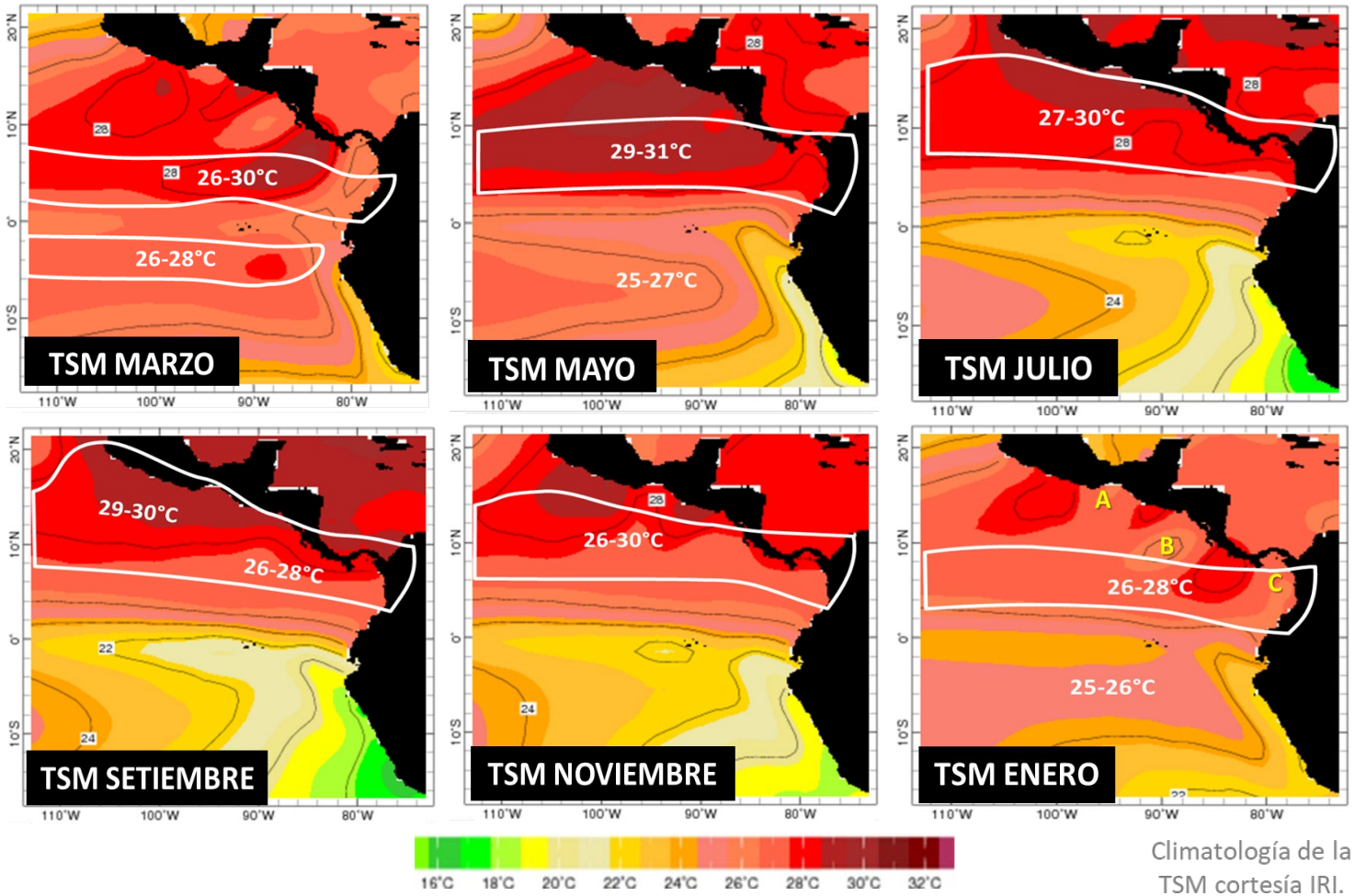
The ITCZ can be a source of tropical cyclones

- June-October
- ITCZ lows can become tropical cyclones.
- Favored by the upper divergent MJO (Phases 7, 8 and 1).



Migration: The ITCZ follows warm SST

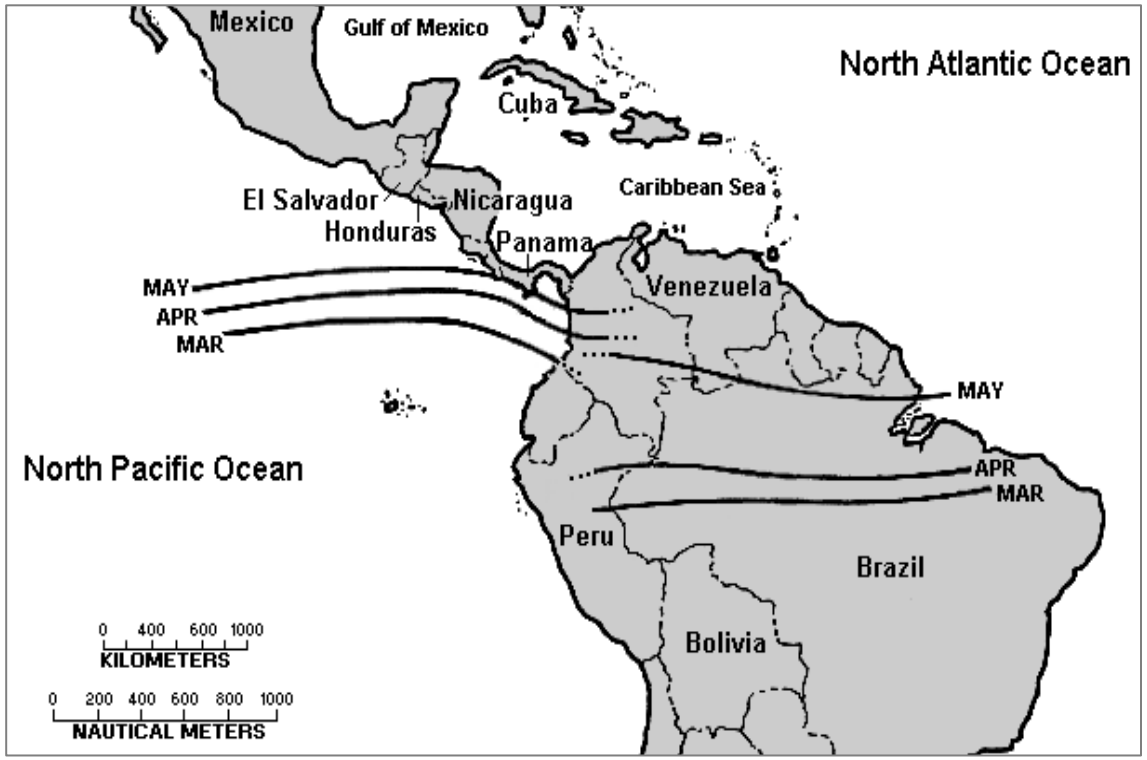
- Follows lower pressures that form over warmer SST.
- Strong trades equatorward from subtropical ridges and fronts and shear lines can push it as well.



Climatología de la TSM cortesía IRI.

ITCZ, North Hemisphere Winter/Spring

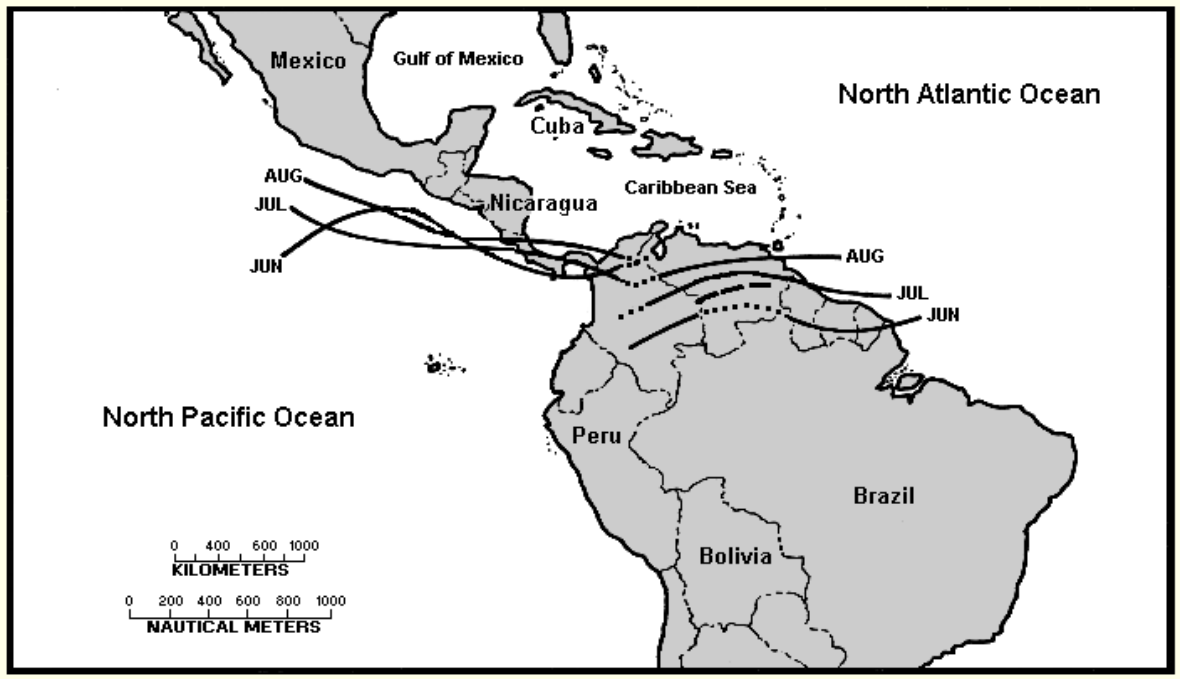
Cooler SSTs (NH)



ITCZ, North Hemisphere Summer/Fall

- Occasionally behaves as a monsoon trough.

Warm SSTs



Trough Position, June-July-August.

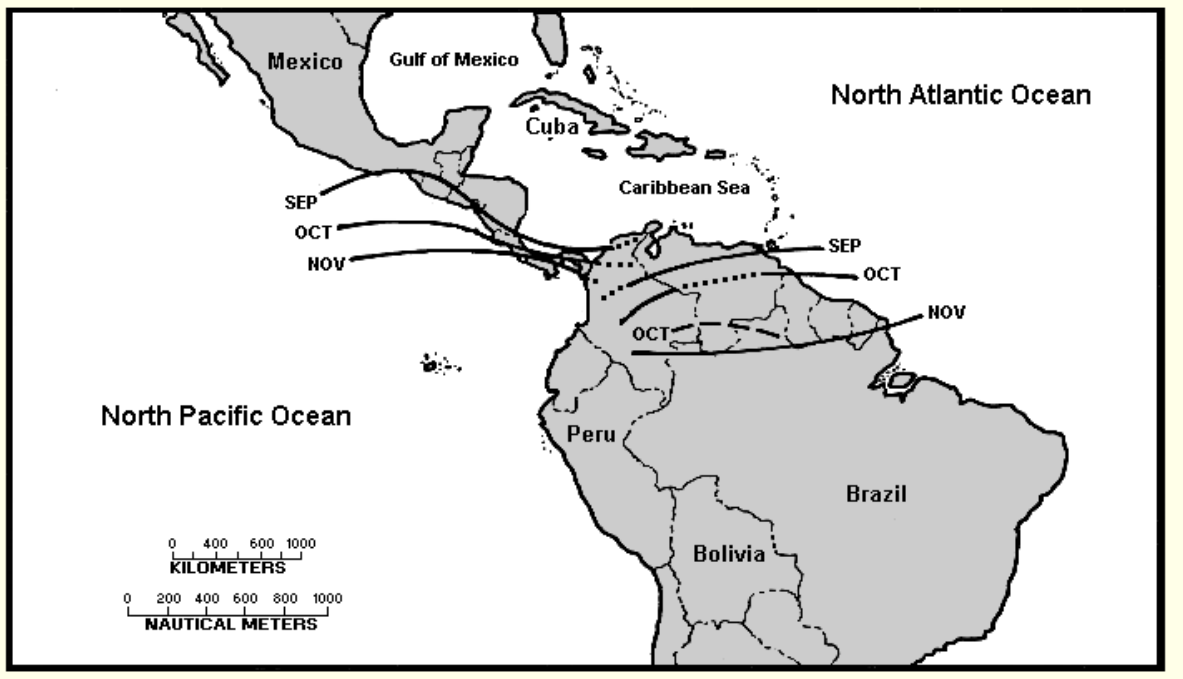
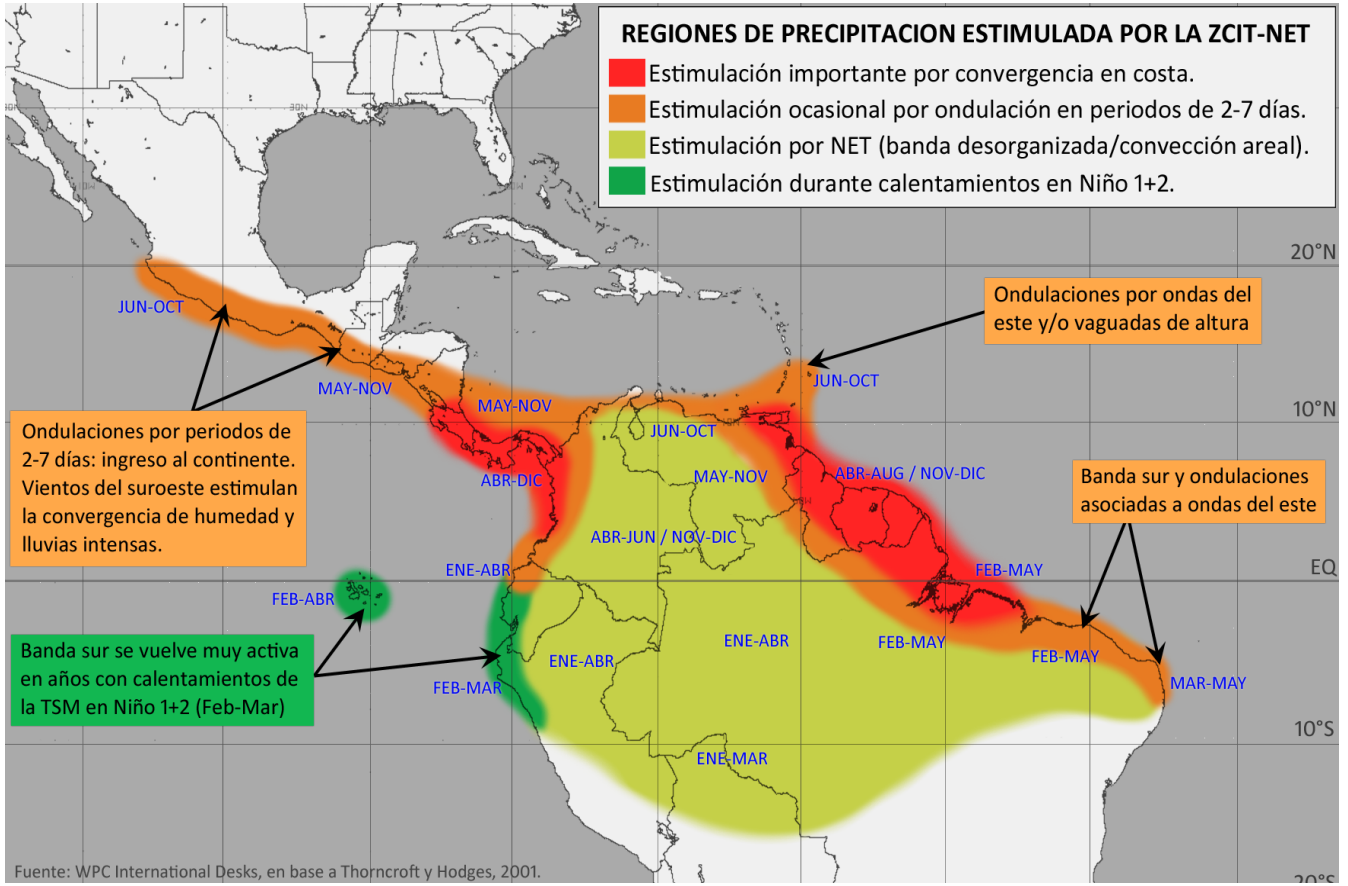


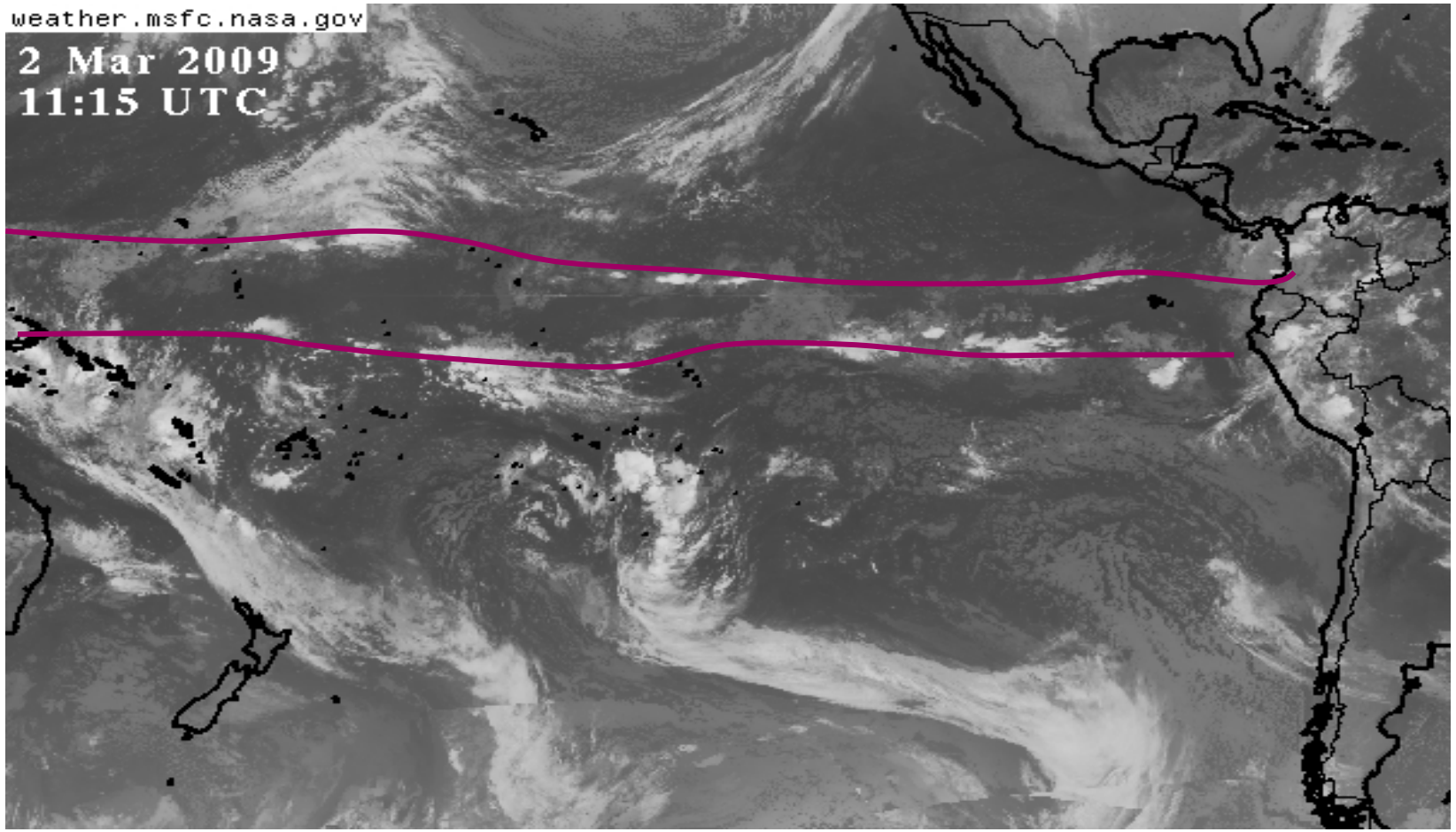
Figure 2-4. Monsoon Trough Position, September thru November.

Regions where rainfall and Thunderstorms are largely sensitive to the ITCZ

- Most frequent in equatorial latitudes of the north Hemisphere, up to 10°N.
- Ocasionally undulates north into Southern Mexico, behaving as a temporary monsoonal trough.
- Rarely north of Nicaragua or central Lesser Antilles.
- In Peru and Ecuador during El Niño-type warmings.



Dual ITCZ



04

Impactful Climatological Features and Patterns

Goals:

- Recognizing features and specific patterns that can lead to impactful weather.
- For aviation: More and/or stronger thunderstorms and wind shear/turbulence.

04a

The Central American Gyre

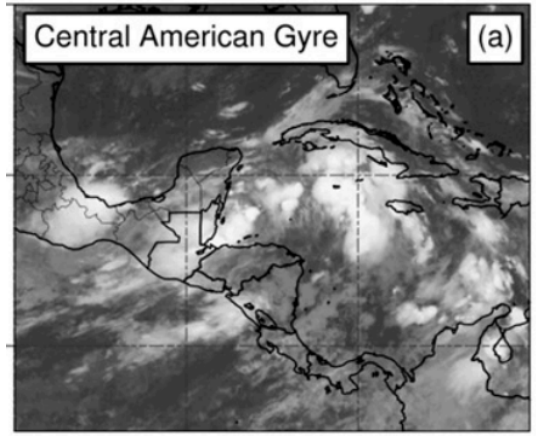
Central American Gyre (CAG)

Definition

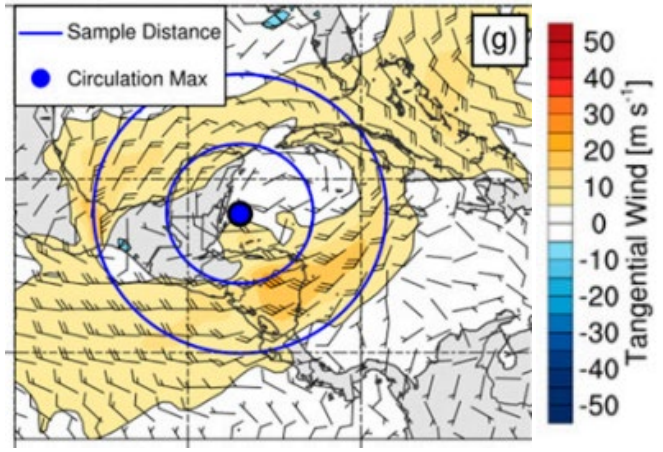
Large, closed, cyclonic circulation that develops near Central America during the rainy season (May–November), similar to broad monsoonal low pressure systems (ML) in other basins.

ML are characterized by loosely organized deep convection while maintaining a circular, closed, vortex characterized by a broad low-level radius of maximum winds (RMW), 500-1000km wide.

It can yield exceptional rainfall, catastrophic flooding and large societal impacts.



Infrared satellite imagery depicting brightness temperature (8C, shaded)



850-hPa winds and isotachs of the tangential wind. Blue circles indicate 500km and 1000km radius from the center of circulation.

Reference: Papin et al, 2017

Criteria for the Identification of a CAG

Criteria is somewhat loose. Papin et al. (2017) developed an algorithm for classification of CAG, and used some of the following criteria for detection of CAG situations:

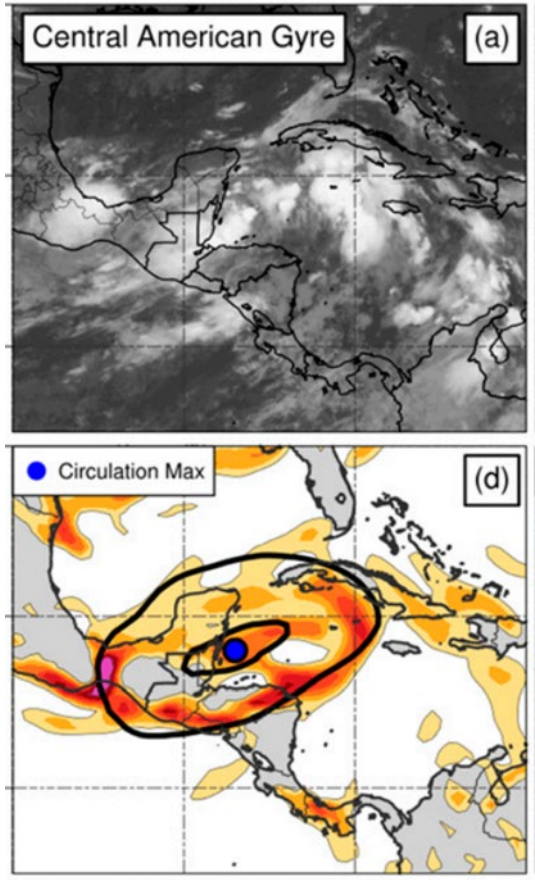
1) A broad radius of winds rotating cyclonically

- Radius of 500-1000km (~5°-10°)
- Best defined at 850 hPa

2) Enhanced relative vorticity averaged over the circulation area (AVORT) exceeding a threshold

- AVORT > 1 x 10^{-5} s^{-1} over

3) Persistence of at least 48 hours.



850-hPa cyclonic relative vorticity (shaded) and AVORT (black contours)

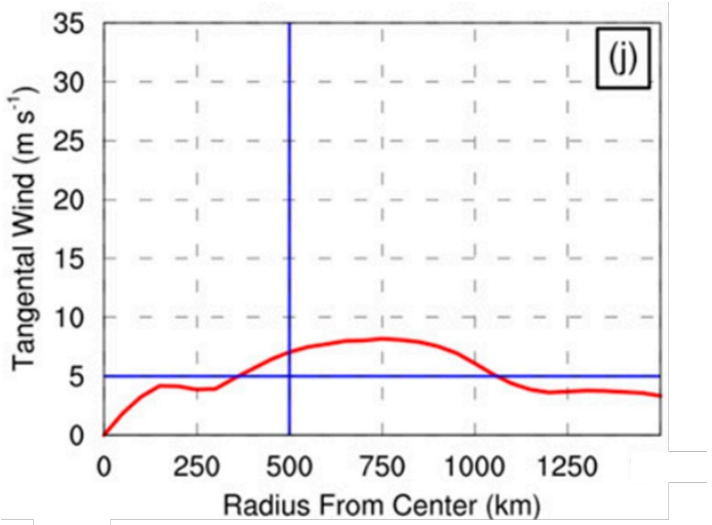
Reference: Papin et al, 2017

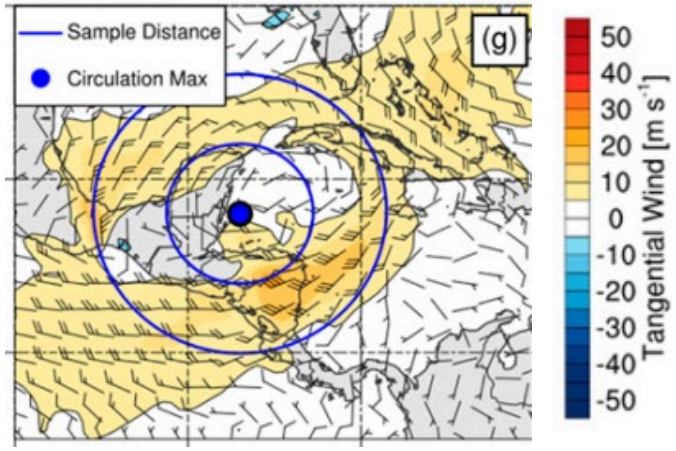
Criteria for the Identification of a CAG

The strongest winds generally develop in the edges of the circulation.

This example shows the strongest averaged winds between 500 and 1000km away from the circulation center, averaging 6-8 m/s or 12-16kt.

Note that the winds are not perfectly symmetric, as it would be expected. Regions of 20-35kt are possible, which occurred over Nicaragua in this example.





Reference: Papin et al, 2017

Non Baroclinic vs Baroclinic CAG

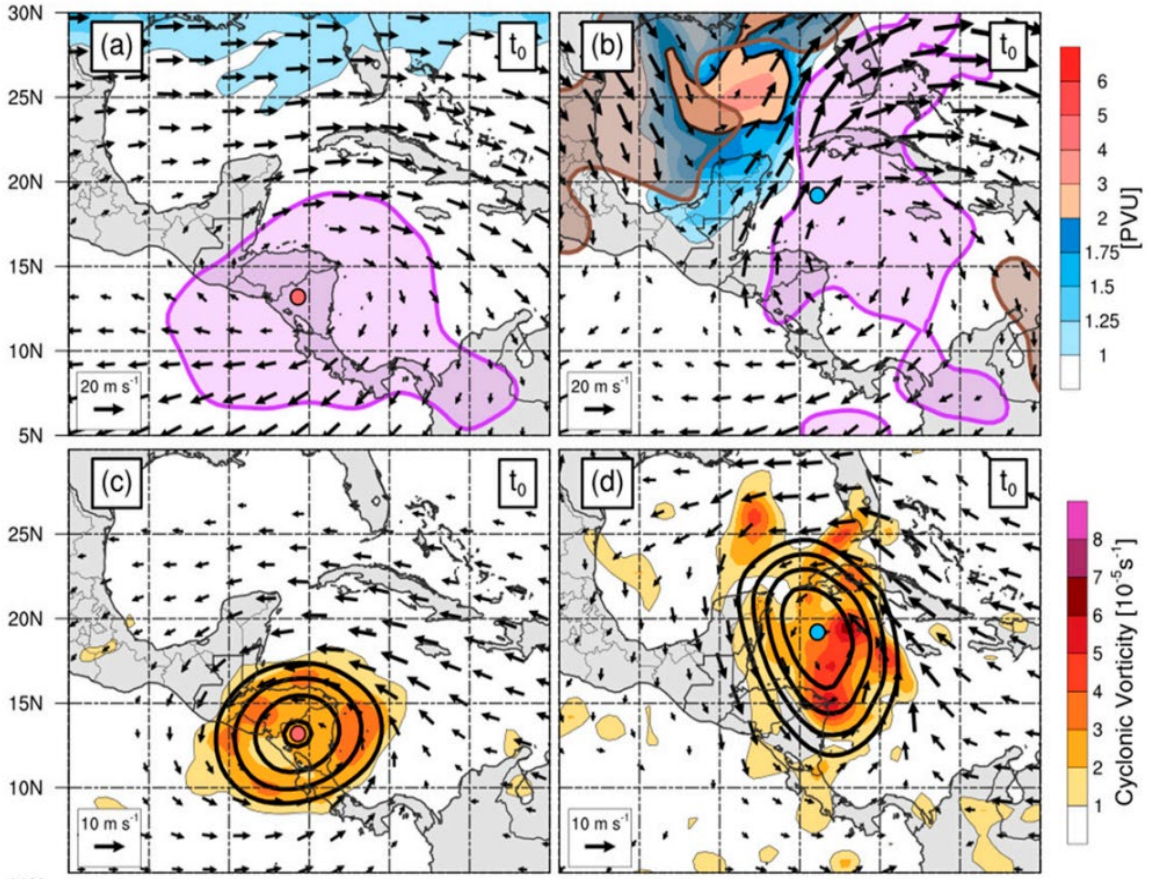
CAG can be classified into two types: Non-Baroclinic and Baroclinic.

Non Baroclinic

They comprise about 85% of all CAG.

They associate with a ridge aloft.

The convection of the CAG helps to build an upper ridge almost perfectly centered over them.



Baroclinic

They comprise about 15% of all CAG.

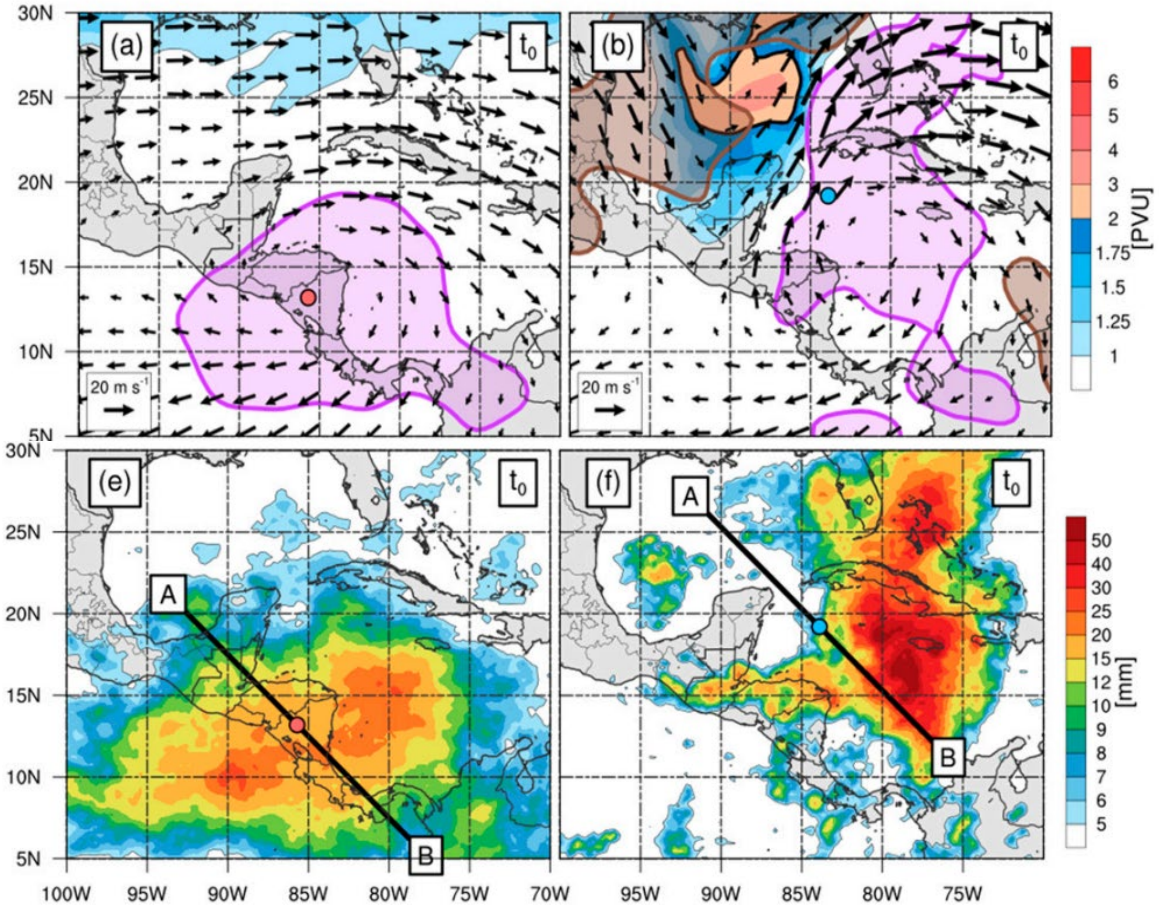
They associate with an upper trough to the northwest.

Sinking motion and large values of potential vorticity occur with the upper trough, northwest of the CAG.

Non Baroclinic vs Baroclinic CAG

Non Baroclinic

Precipitation tends to be symmetric with respect to the center.



Baroclinic

Precipitation is located to the right of the center. Enhanced dry air entrainment from the north and northwest favor a dry slot to the northwest and west of the center.

Rainfall can be extreme east of the center and expand north.

CAG Rainfall

- CAG produce excessive rainfall primarily across Central America and the western Caribbean, including the Cayman Islands, Cuba and sometimes Jamaica.

- Extreme rainfall tends to cluster in the Pacific basin of Central America, from southern Costa Rica into southern Guatemala, due to enhanced onshore flow. This produces extreme impacts due to the distribution of population and enhanced risk for mudslides.

- Northern Honduras and Belize can receive extreme rainfall from enhanced moist onshore winds as well.

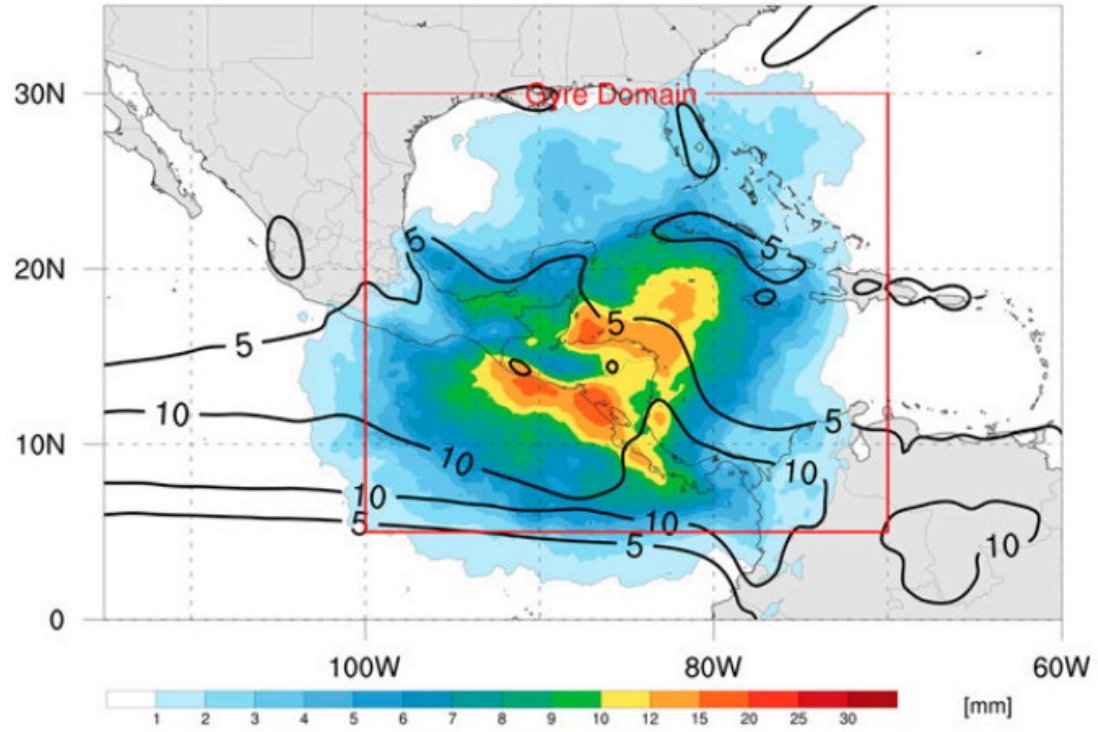


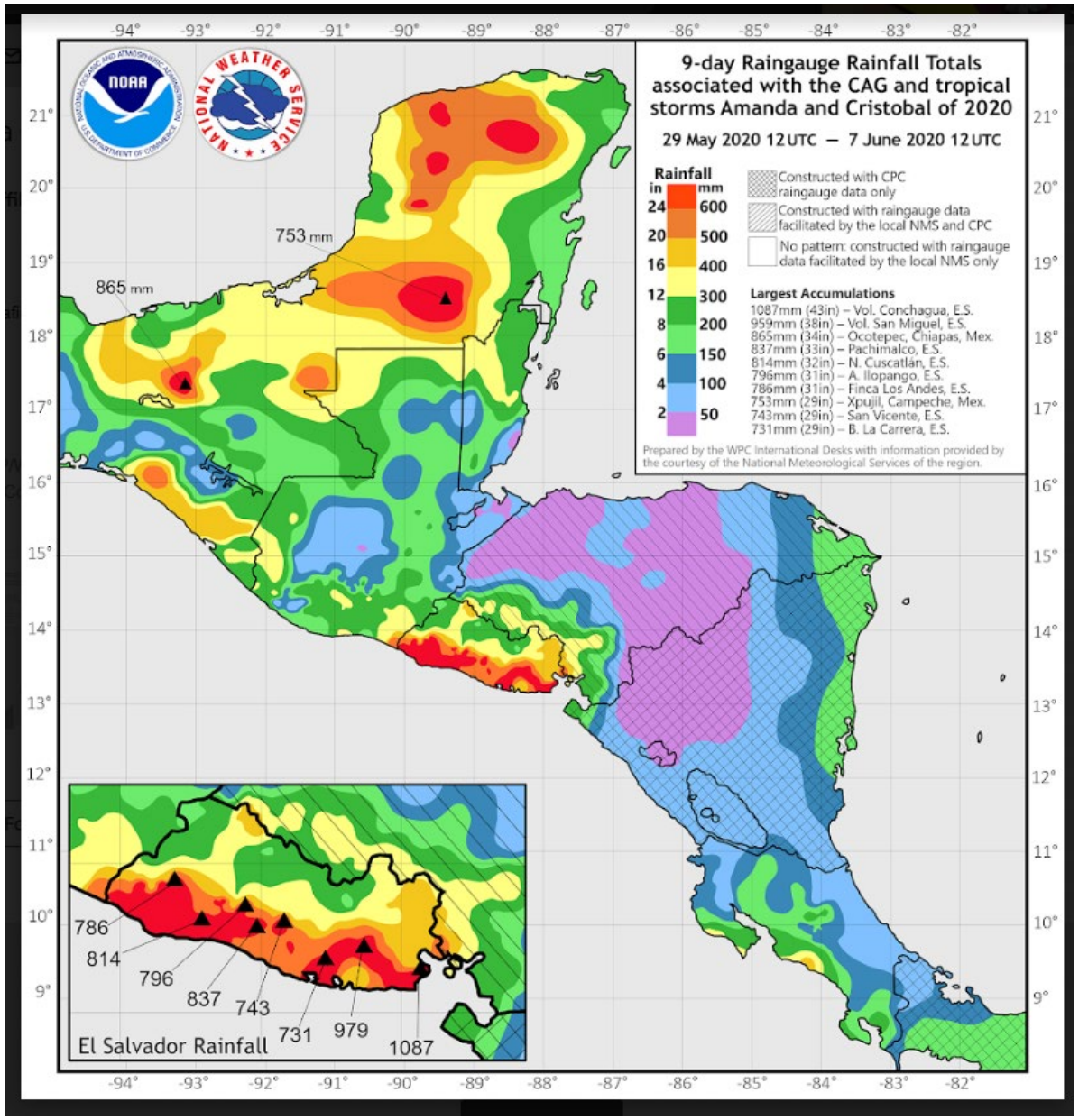
FIG. 8. Average daily rainfall rate composite for CAGs (shaded, mm day^{-1}) using rainfall observed within 10° of a CAG center compared to climatological rainfall rate during 1 May–30 Nov (black contours, every 5 mm day^{-1}).

May-June 2020 CAG

- A potent and long-lasting CAG formed on 29 May 2020 and dissipated on 7 June 2020 producing excessive rainfall in Central America during 9 days.

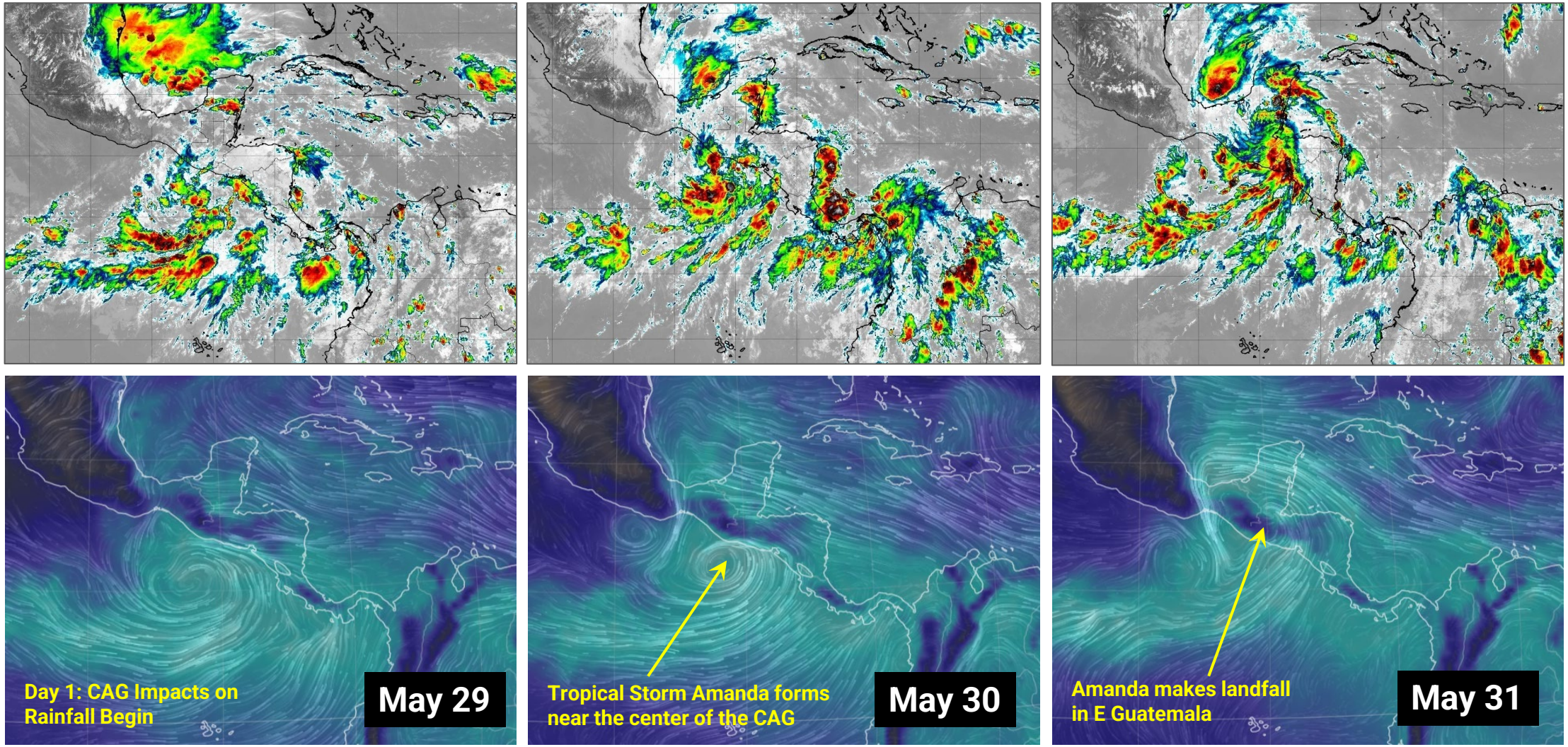
- Rainfall totals in 9 days:
  - The southern half of Salvador received 400-1000mm, and the rest 200-400mm.
  - 80% of the Yucatan Peninsula received 200-750mm.
  - Western Costa Rica and other portions of northern Central America received 200-500mm and locally higher amounts.

- This event was well forecasted by the WPC International Desks, who warned days in advance about the potential.



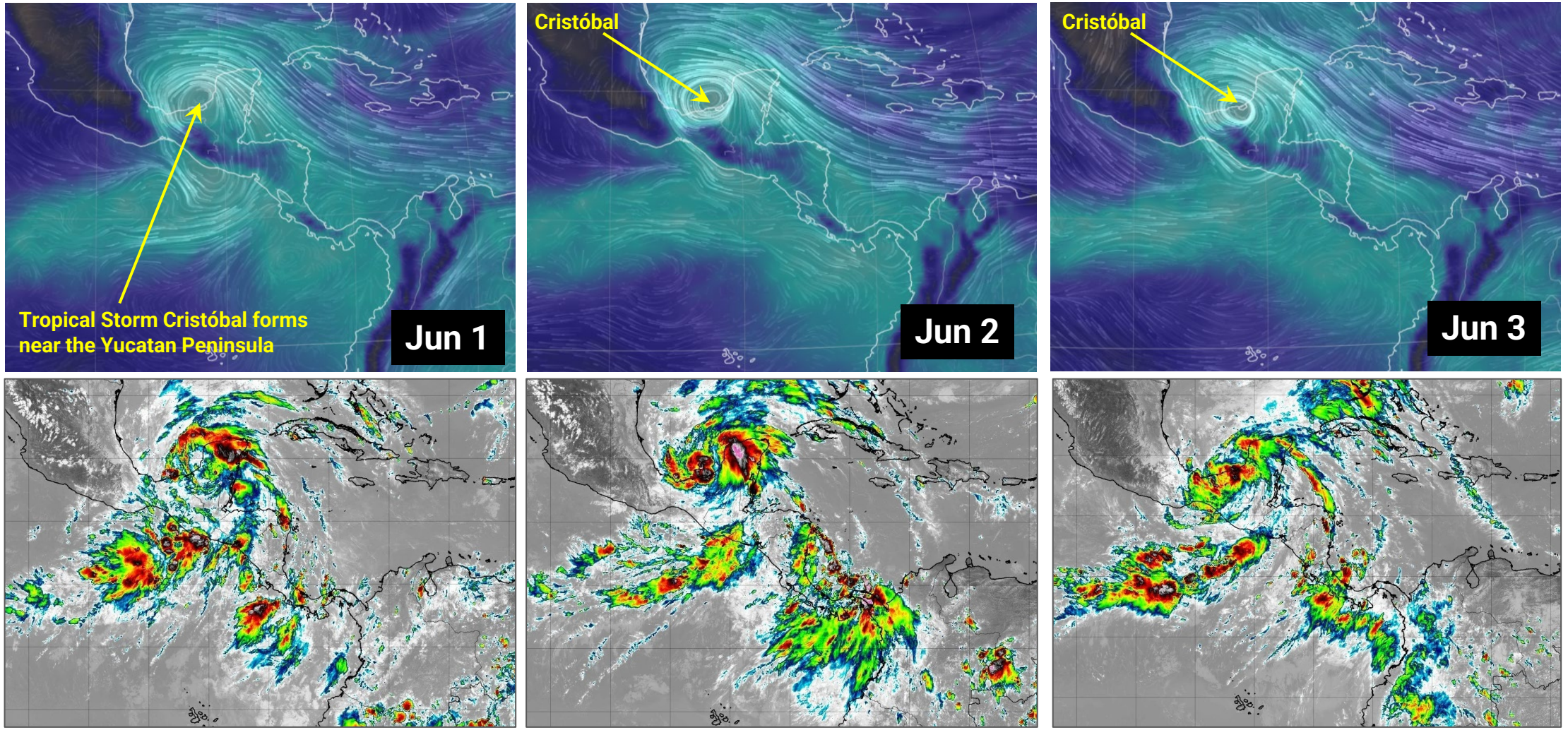
May-June 2020 CAG

Daily 850 hPa Winds and TPW at 18 UTC



May-June 2020 CAG

Daily 850 hPa Winds and TPW at 18 UTC



CAG and the MJO

- Favored in phases 8, 2 and 1.
- These are characterized by enhanced upper divergence and low-level westerlies in the basin.
- Panel b shows composite anomalies of winds and standardized geopotential height anomalies at 850 hPa during phases 8, 1 and 2

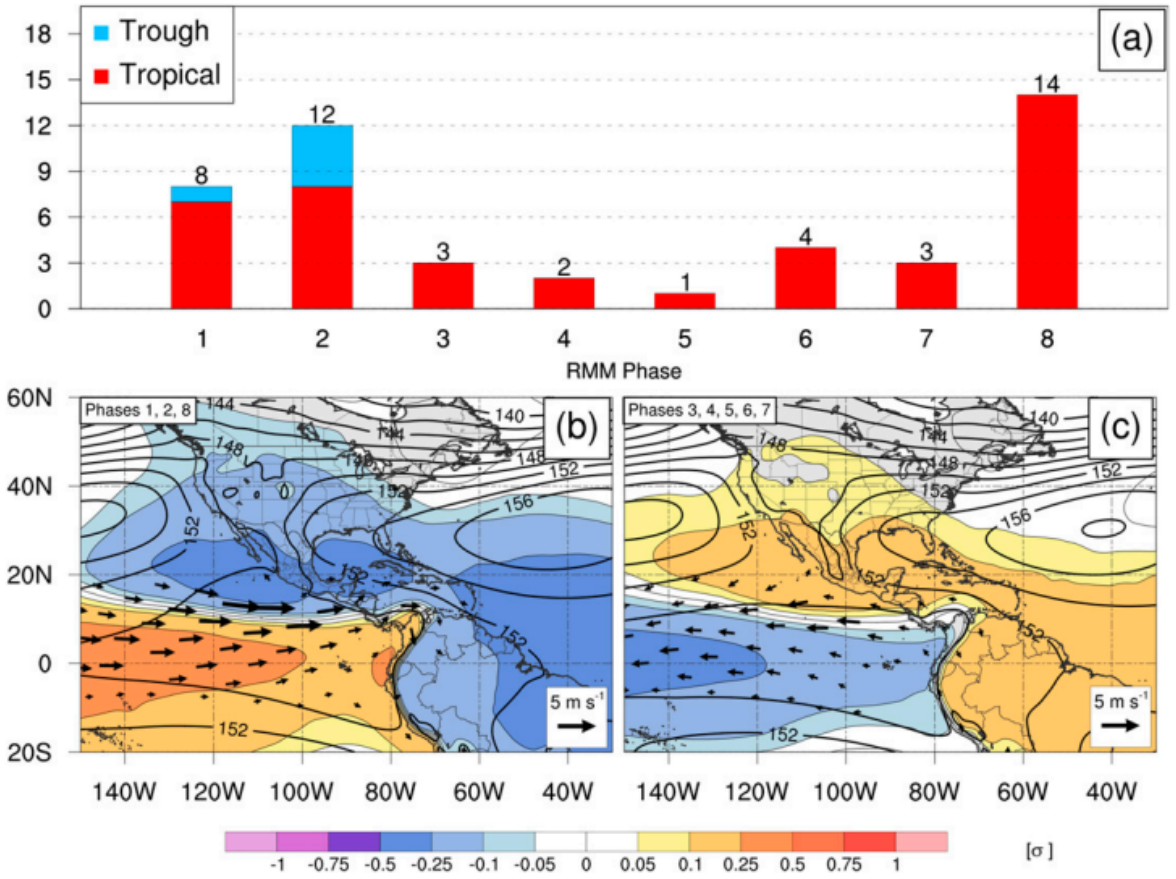


FIG. 11. (a) Bar graph of the number of CAG events in each RMM phase, where nonbaroclinic and baroclinic CAGs denoted by red and blue, respectively. (b),(c) Composite 850-hPa geopotential height (black contours, dam), standardized geopotential height anomaly (shaded, σ), and anomalous winds (vectors, m s^{-1}) for (b) MJO RMM phases 8, 1, and 2 (N = 3041 days) and (c) MJO RMM phases 3–7 (N = 4365 days) occurring during 1 May–30 Nov.

04b

Upper troughs with jets and severe thunderstorms

Apr 28 2019 Case: Severe Weather in Cuba

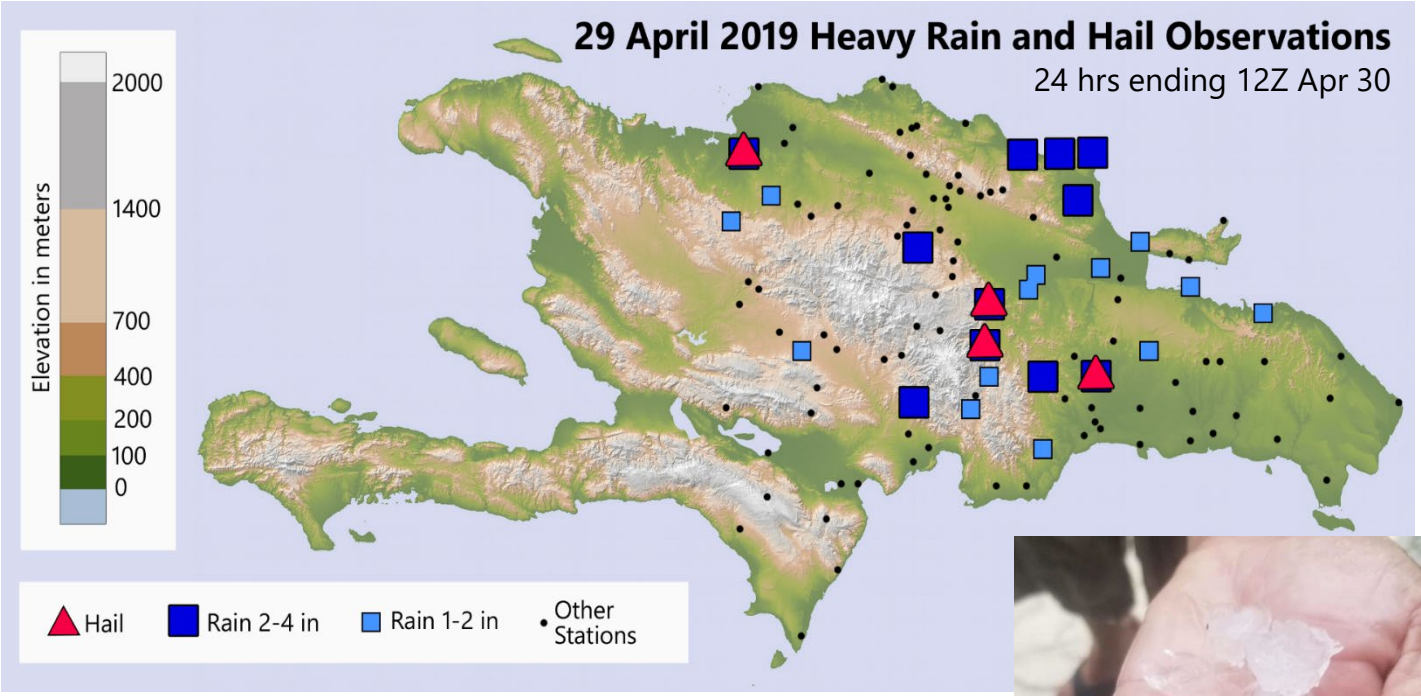
Santa Clara, Cuba - Severe Thunderstorm

- Winds topped near 100 kph
- Nickel-size hail
- Airport and 60 houses affected

Damage in Santa Clara Airport

Observations and Impacts

Apr 29: Local Flooding and hail in Hispaniola



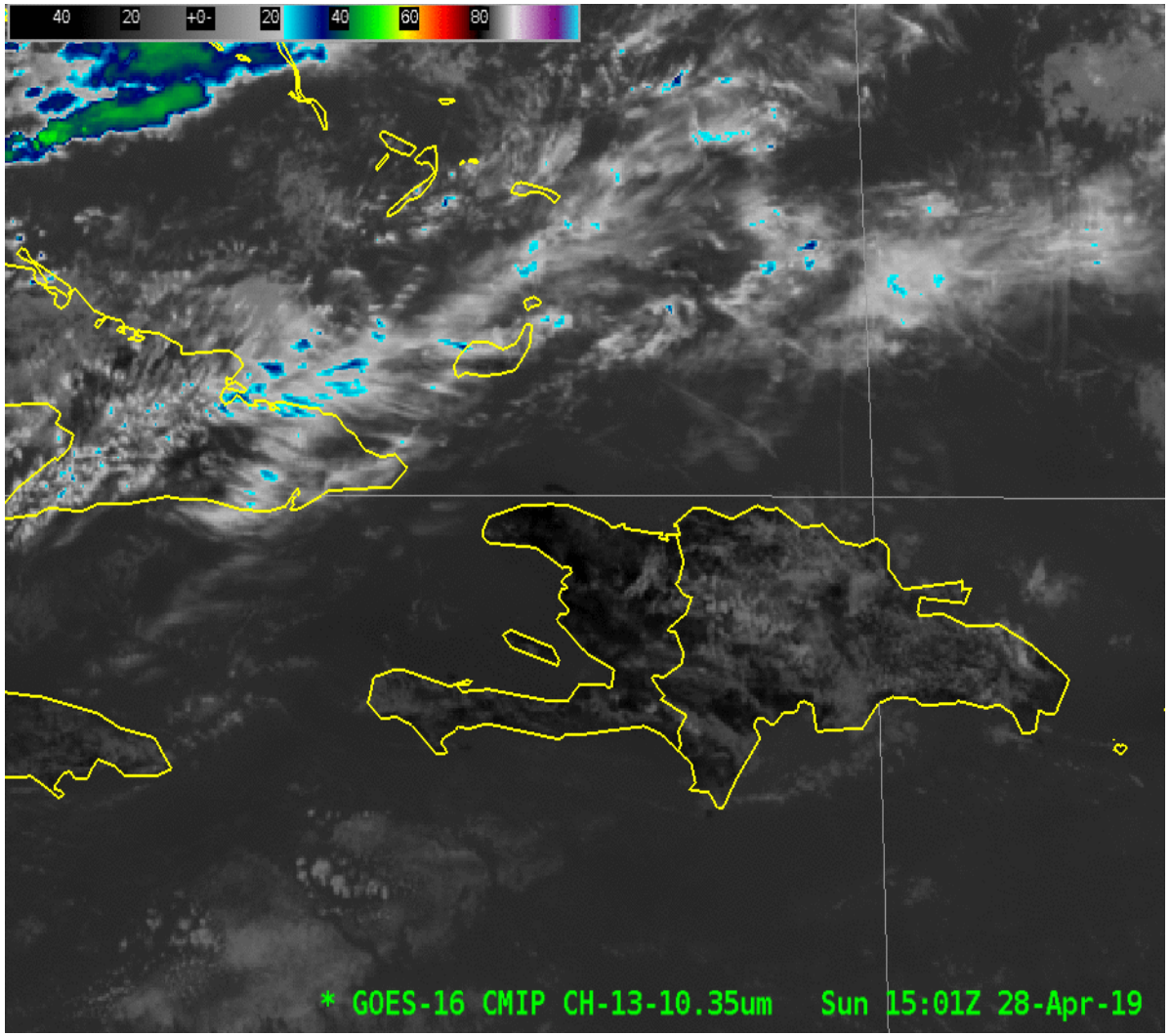
HAIL
5% of stations

Heavy rain (>2in)
11% of stations

Moderate rain (1-2in)
13% of stations

Note: Hail reported in lower elevations

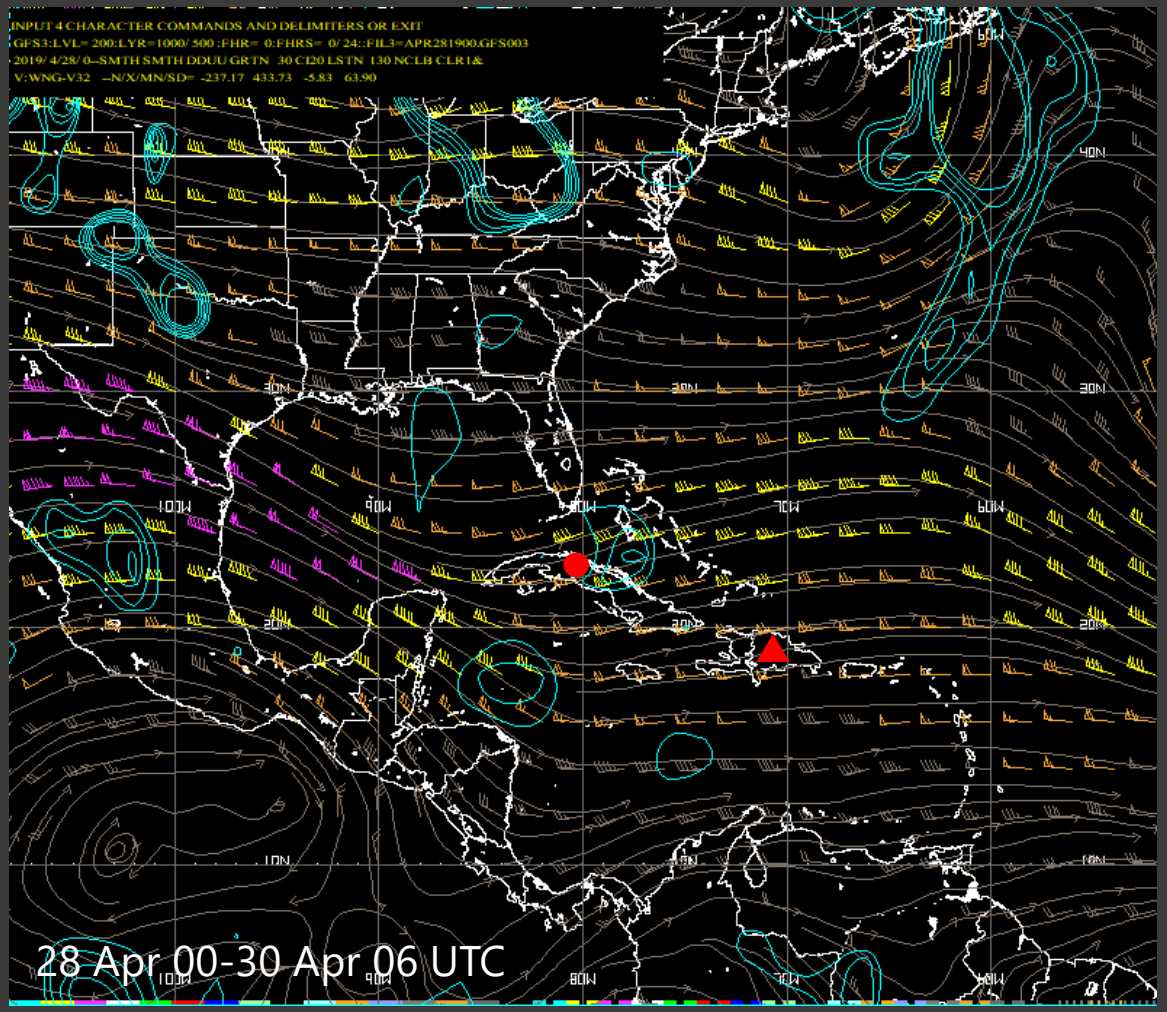
Satellite Loop over Hispaniola/Cuba on April 28



- April 28: Day of the Cuba event, one day before the Hispaniola event.
- Does not capture Santa Clara in Cuba, but clearly shows
  - Severe convection signatures in Cuba:
    - Long lasting cells
    - Cell propagation in different directions
    - Overshooting tops
    - V-shapes
  - Trough pattern to the west
  - Upper jet (transversal bands)
  - Vertical wind shear.

Upper Flow Pattern Evolution

Animation: 200 hPa Flow (kt) and 200-400 hPa Divergence



The dynamics were favorable for strong ascent.

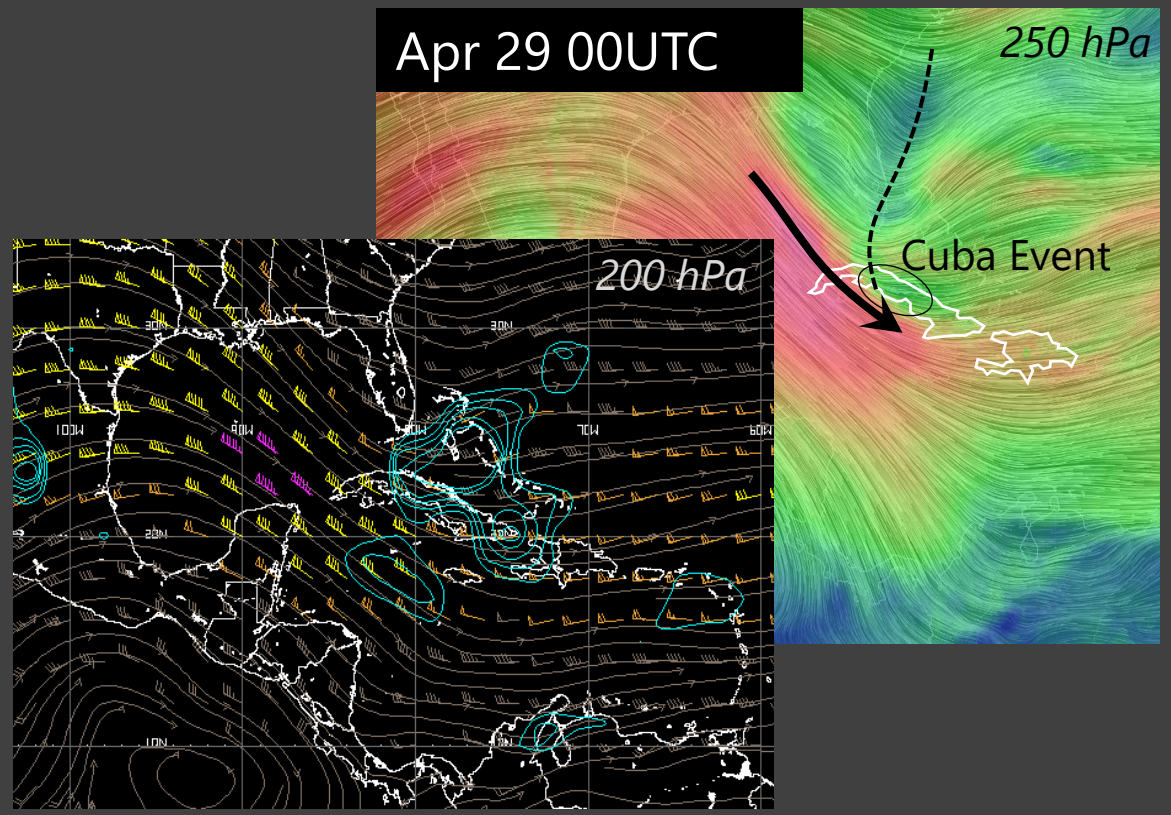
Factors in place:

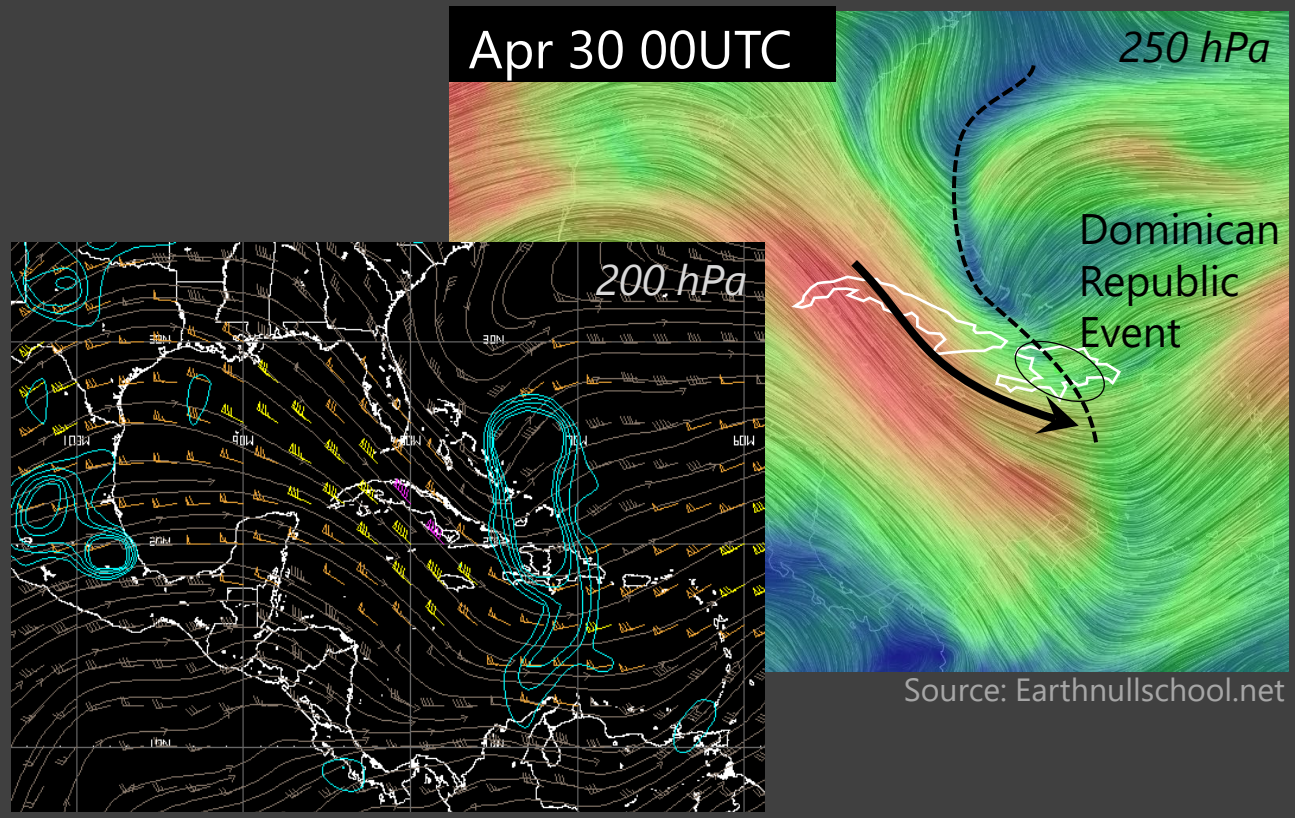
- Upper trough developing negative tilt.
- Upper Jet
- Divergent left exit of upper jet

Hail/wind damage in Cuba, Apr 28th 21UTC

Hail damage in Hispaniola, Apr 29th 21UTC

Upper Flow Pattern





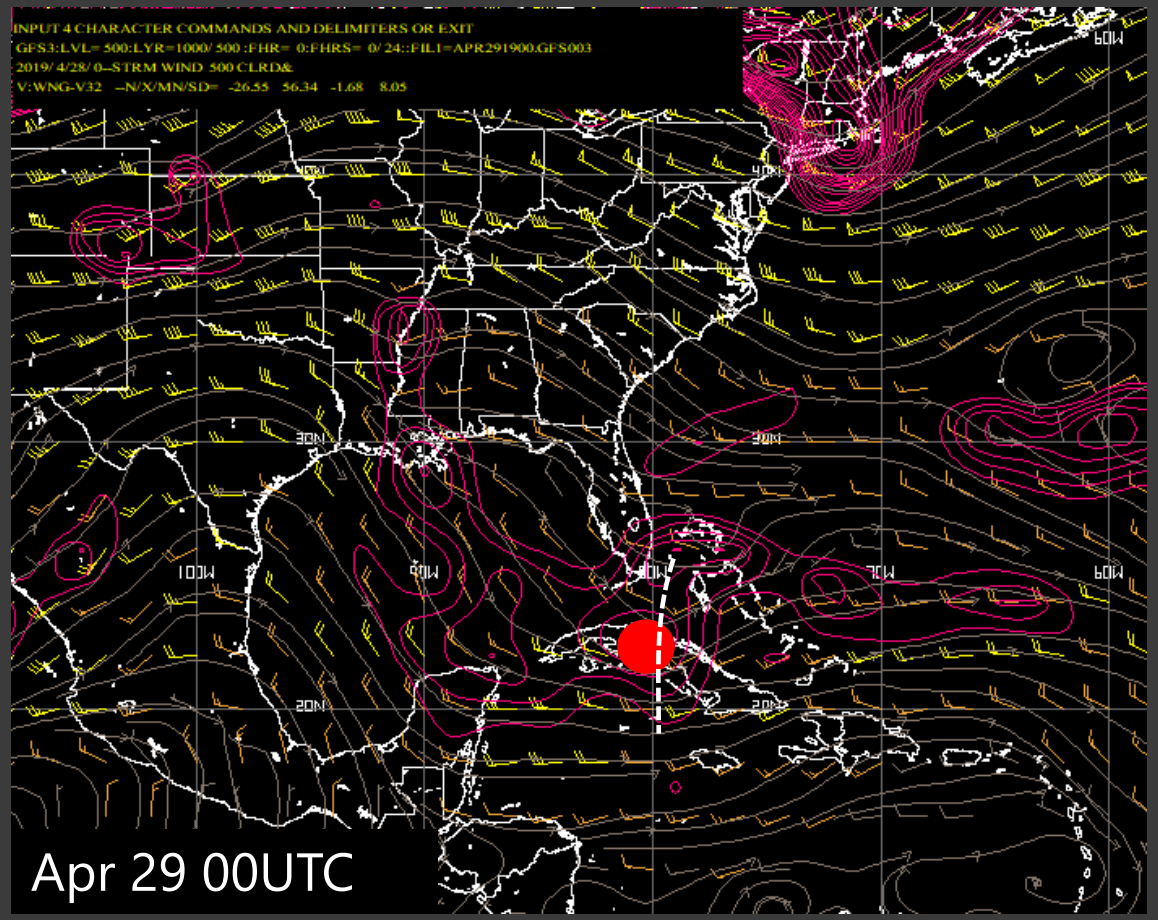
Source: Earthnullschool.net

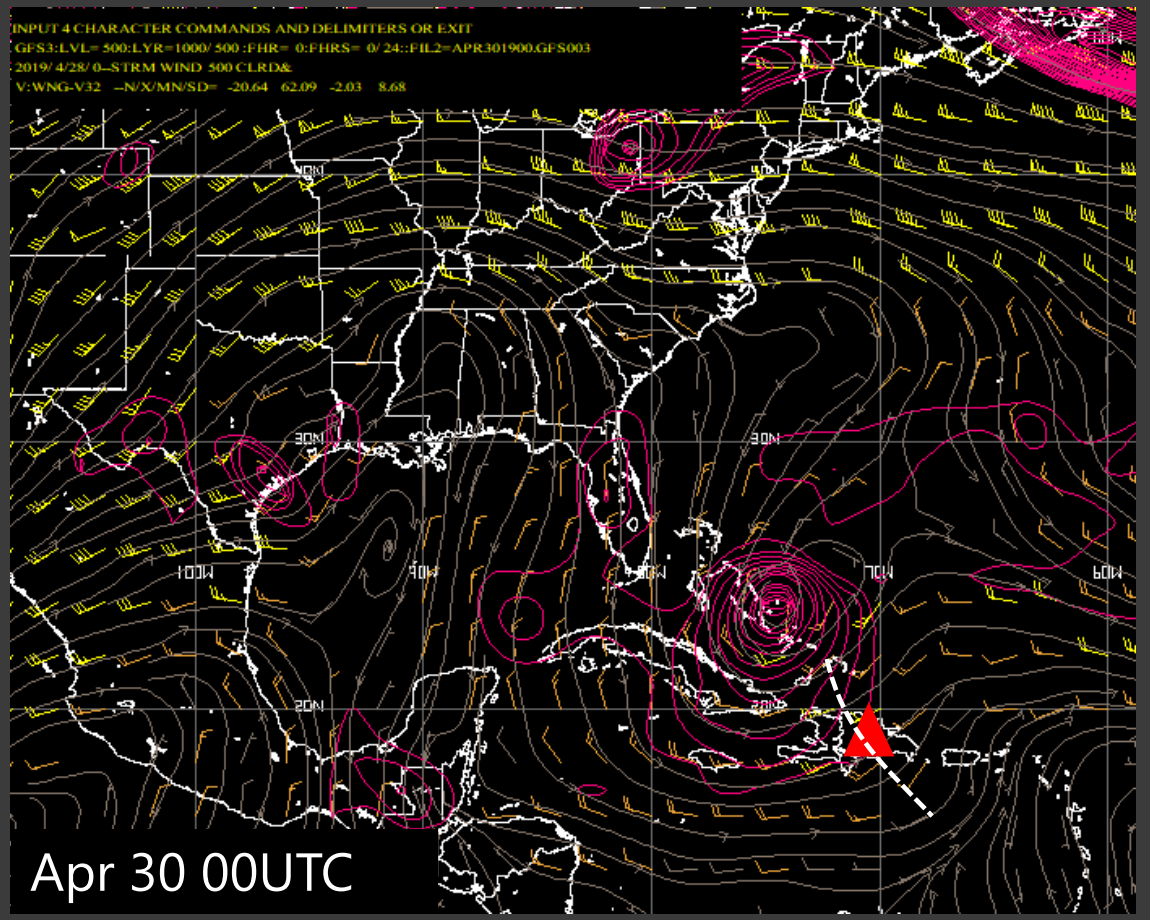
Upper trough and jet dynamics were favorable for ascent:

- Divergent exit region of jet streak
- Divergence, vorticity advection and height falls ahead of upper trough
- Jet dynamics were stronger in Cuba, trough dynamics in Hispaniola.

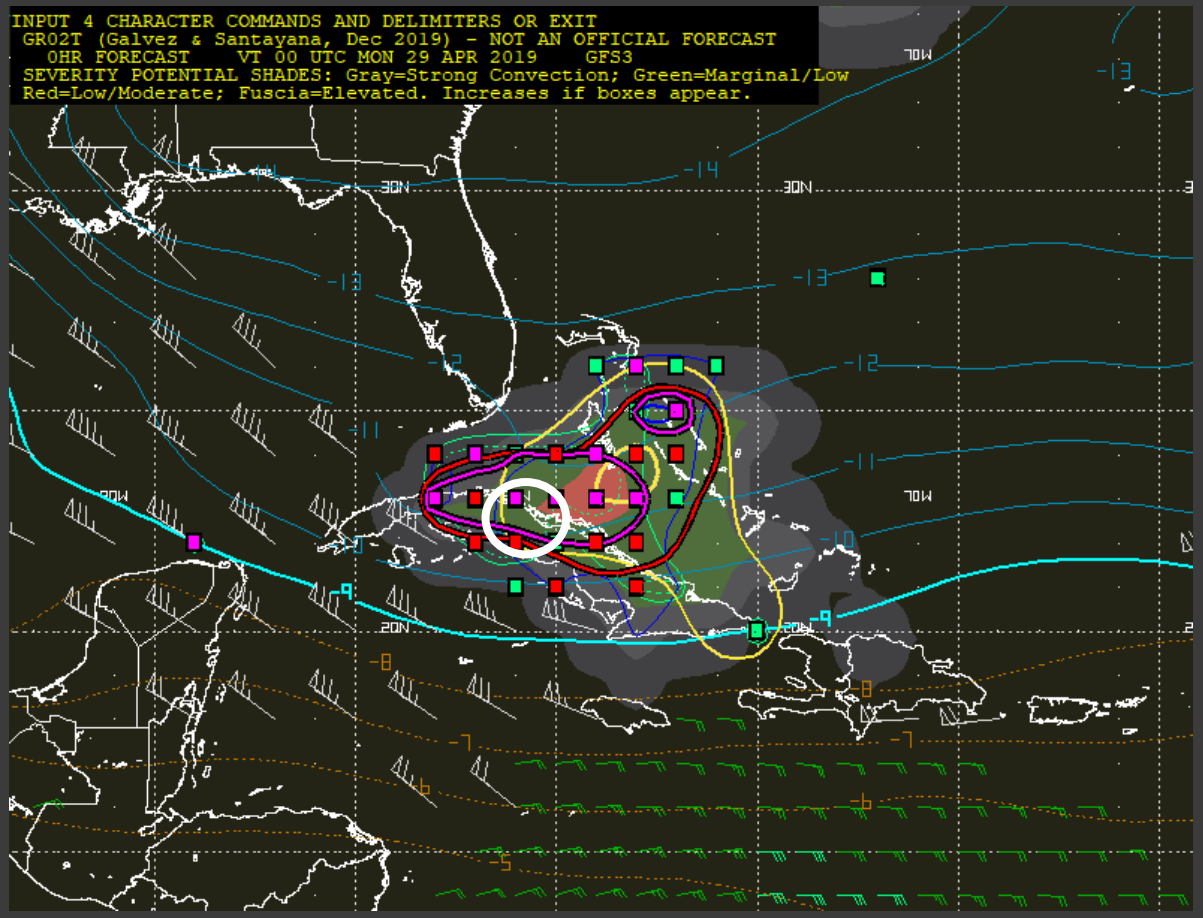
Mid-level Flow Pattern Evolution

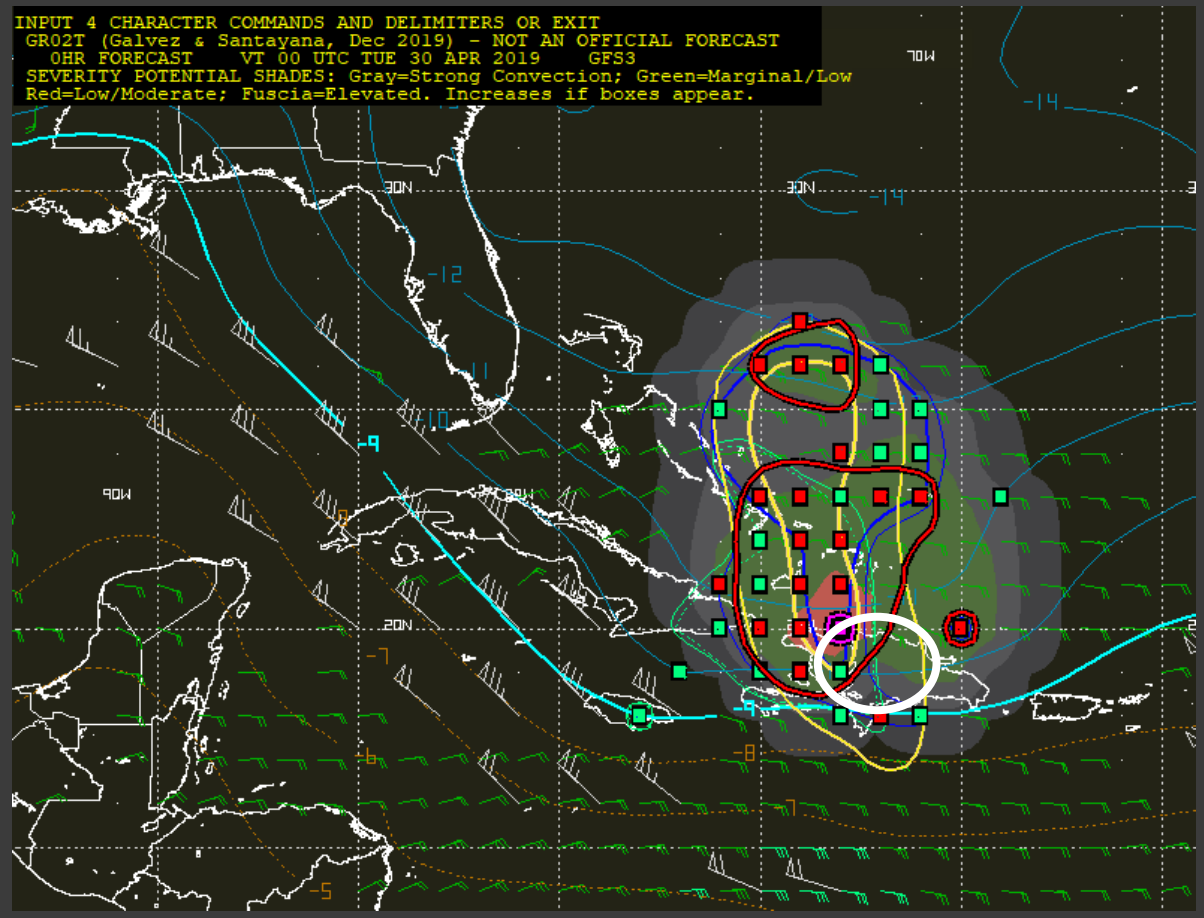
500 hPa Flow (kt) and 600-400 hPa Vorticity





Potential for Severity: GR02T

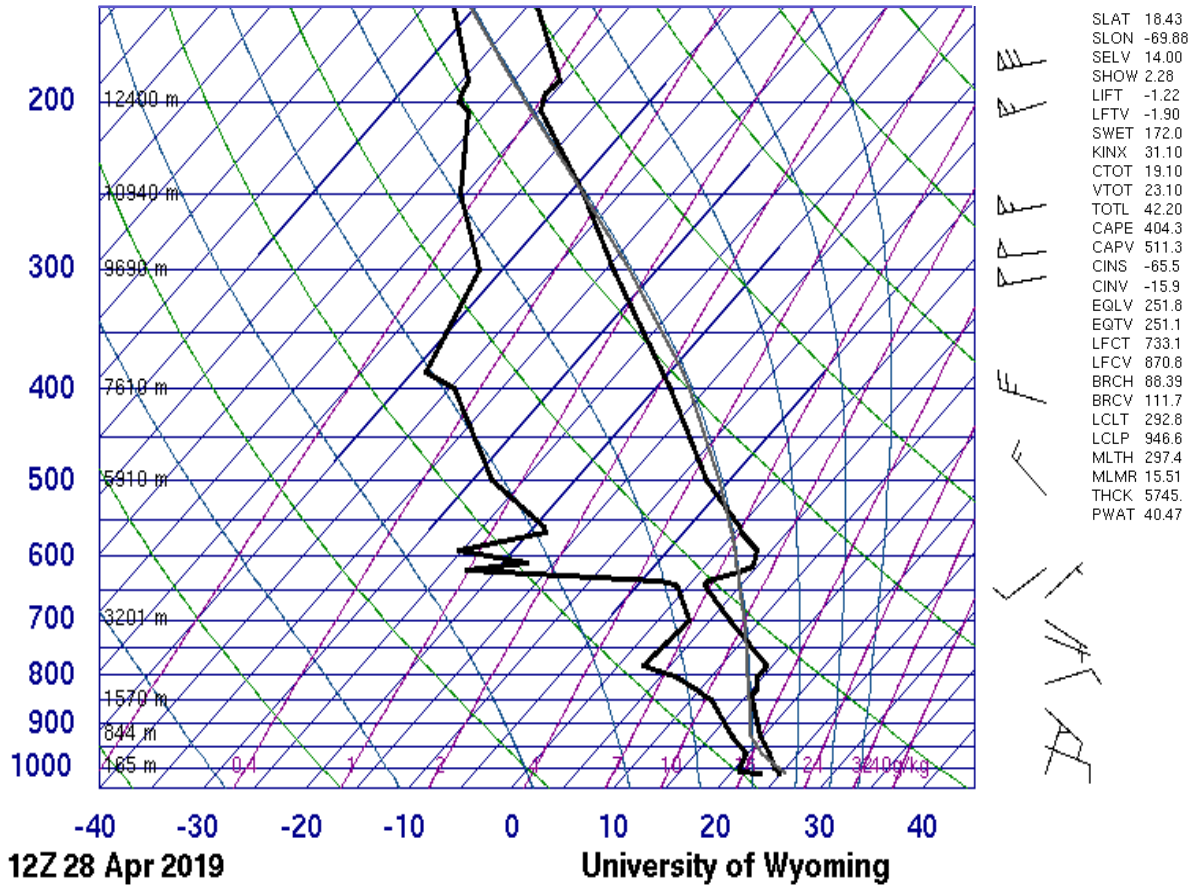




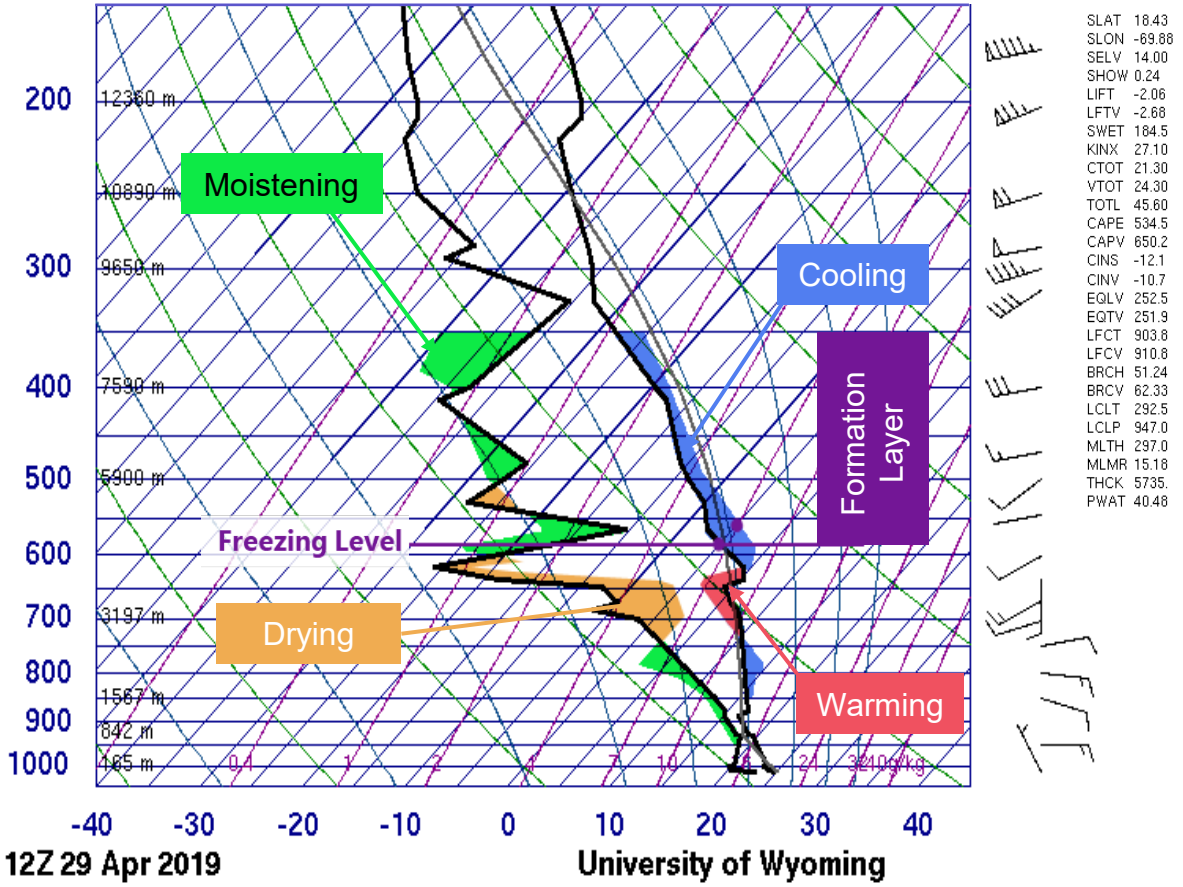
12Z MDSD Sounding Evolution

- Destabilization
- Moistening in hail formation layer
- Lowering of freezing level
- Drying below freezing level

Day -1



Day 0: Heavy Rain and Hail



05

Impacts of ENSO, MJO and other Climate Oscillations

Aviation in the Americas is affected by ENSO and the MJO

They modulate preferred regions for thunderstorms and wind shear/turbulence.

ENSO examples

- El Niño = stronger subtropical jets in winter and associated storms, fronts and wind shear. Active winters in the northern Caribbean and subtropical South America.
- El Niño = stronger Central America low-level jets and associated shear. But less Tstorms. More Tstorms in Ecuador and Peru, and central South America in the spring.
- La Niña = More Tstorms in northern South America, Central America and the Caribbean; and more cyclones and CAG.

MJO examples

- Upper divergent (Phases 7, 8 and 1) = more Tstorms in the tropical Americas.
- Phases 8, 1, 2 = Favors Tropical cyclogenesis if perturbations are in place
- Upper convergent (Phases 3, 4 and 5) = stronger easterly trades and more low-level wind shear.

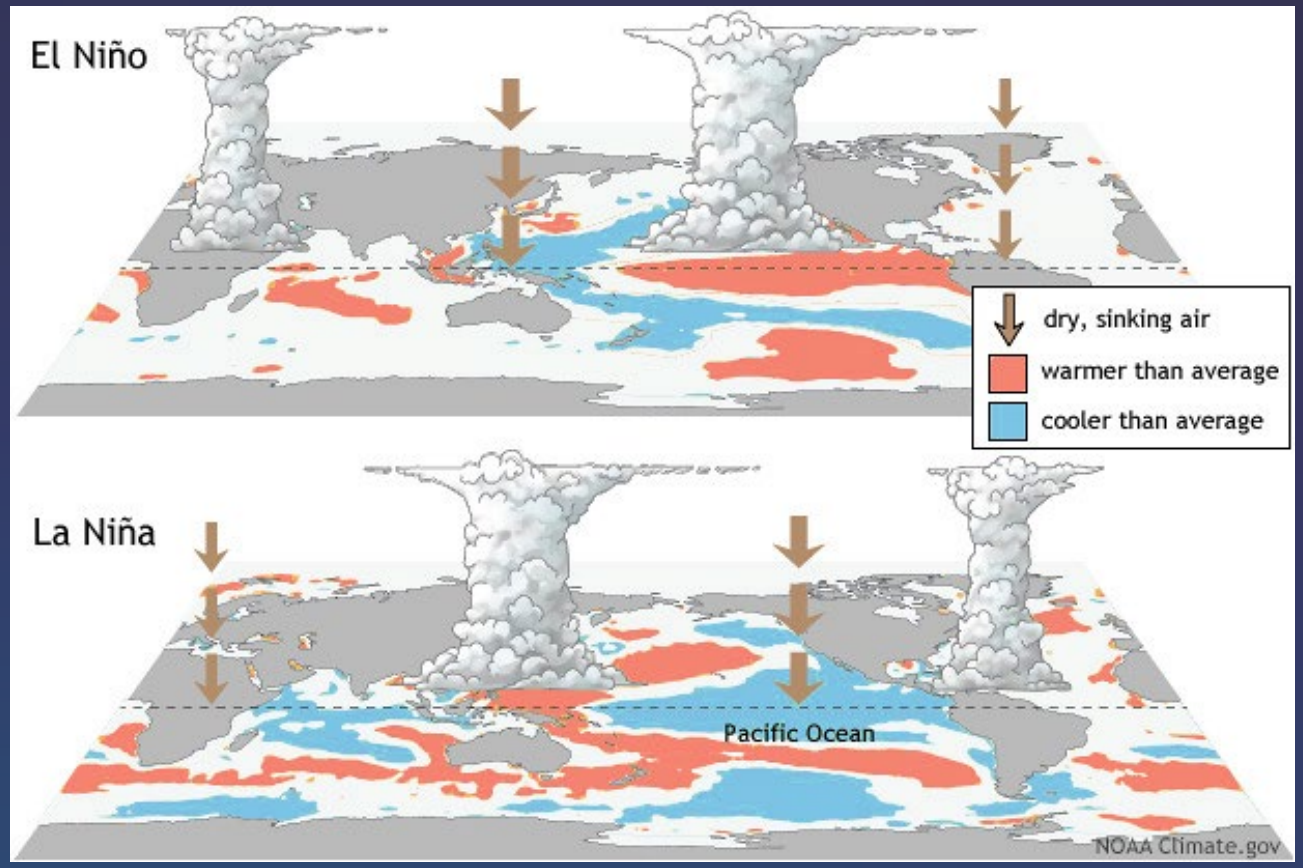
05a

El Niño-Southern Oscillation (ENSO)

El Niño-Southern Oscillation (ENSO)

Definition

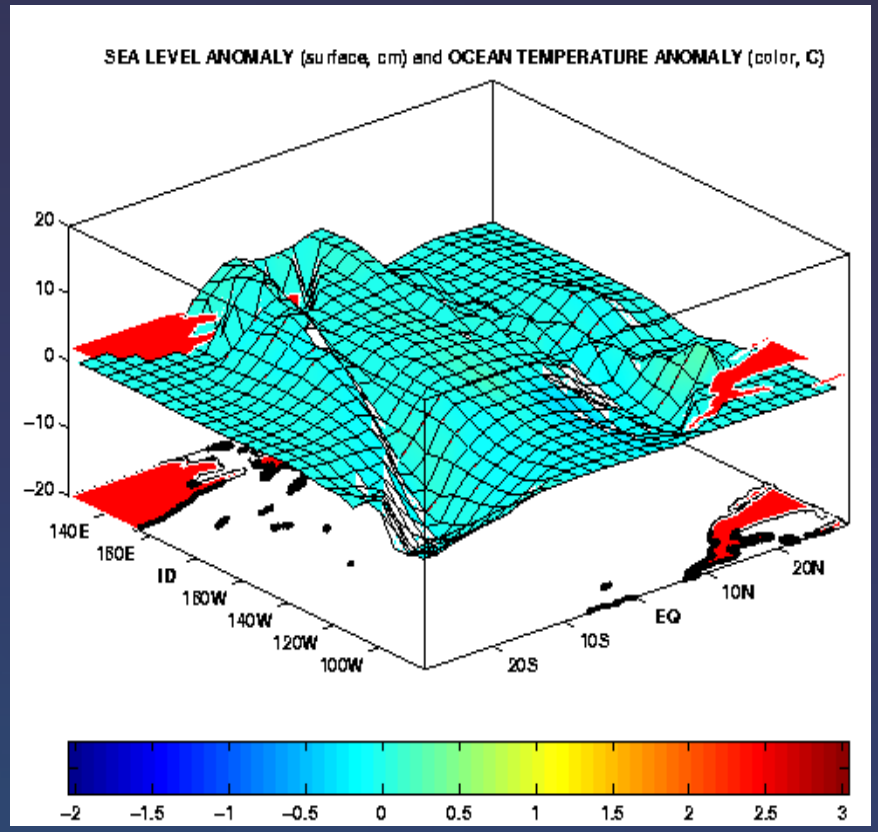
- A recurring climate pattern in the tropical Pacific.
- Consists of changes in oceanic and atmospheric variables that persist for many months.
- Has 3 phases: El Niño (warm), La Niña (cold) and neutral.
- El Niño and La Niña return in intervals of 2-7 years, non periodic.



Source: Climate.gov

How does ENSO operate?

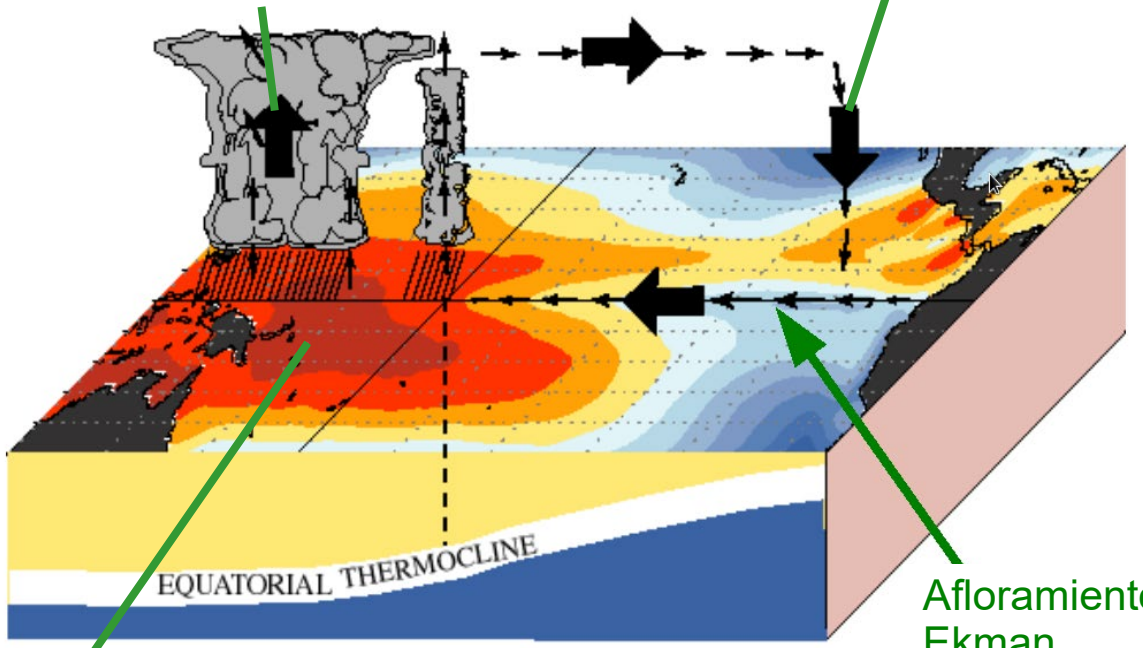
- Consists of changes in the distribution of temperature and sea level in the equatorial Pacific, which induce changes in atmospheric circulations and global impacts.
- Aviation Impacts: Modifies locations prone to Tstorm development and wind shear.
- Some of these modified circulations exacerbate the phase of ENSO (e.g. ocean warming favors more westerly wind bursts, which strengthen the warming), so it is largely reliant on ocean-atmospheric interactions.



Normal Conditions

ASCENDING BRANCH OF THE WALKER CIRCULATION
Ascending and convective branch over the warm pool to the west

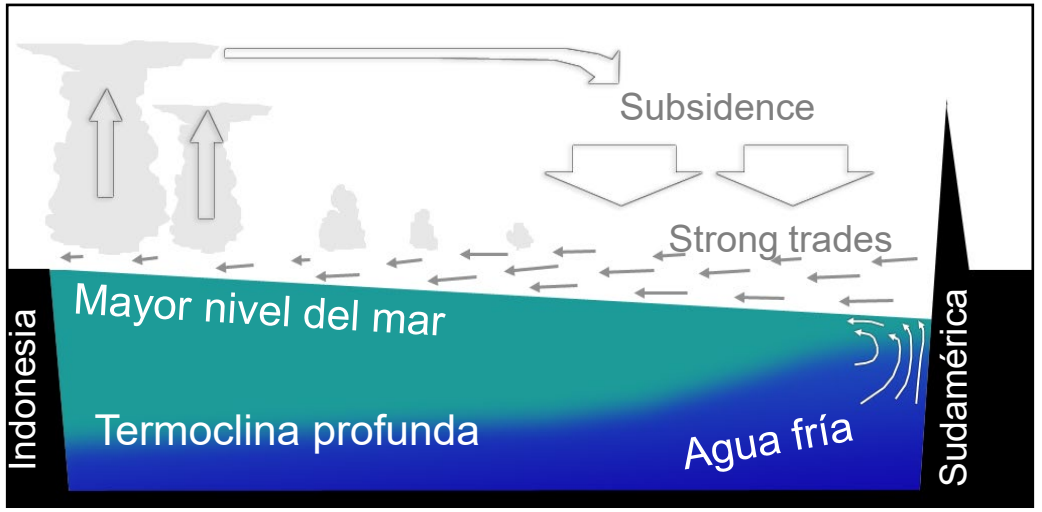
DESCENDING BRANCH OF THE WALKER
The subsiding branch of the Walker Circulation brings stable conditions to the Eastern Pacific



WARM WATER TO THE WEST
Trade winds from the east push warm water in the Western Pacific

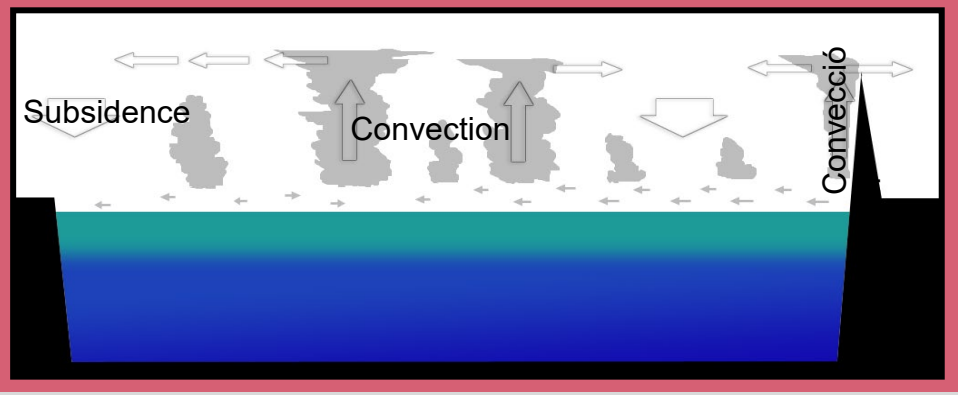
COLD WATER TO THE EAST
Southern transport (Humboldt), coastal and equatorial upwelling (Ekman).

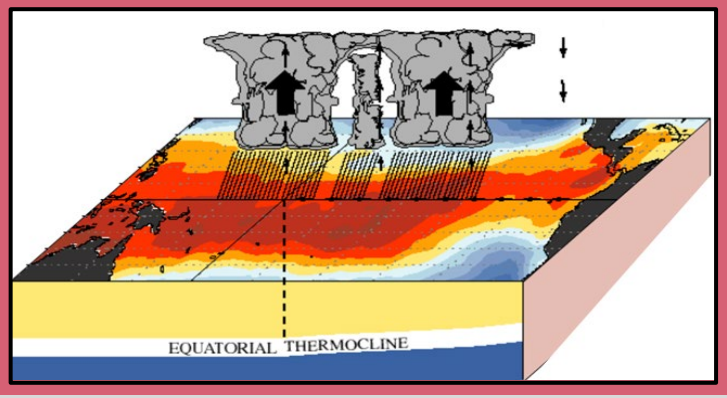
SEA LEVEL AND THE THERMOCLINE



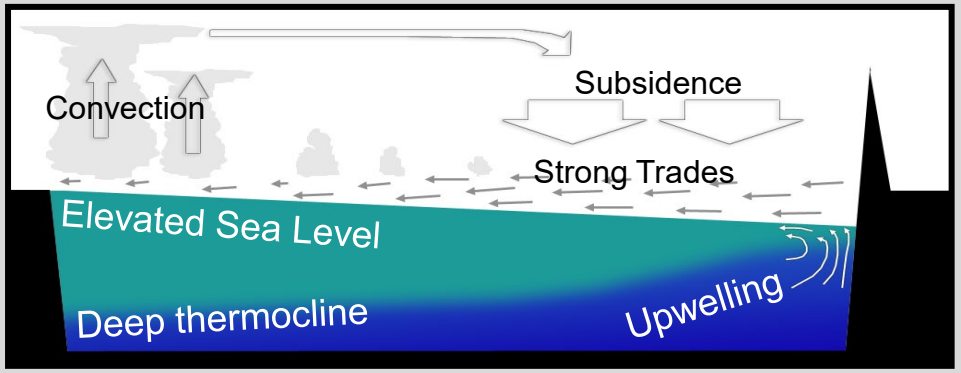
Phases of ENSO

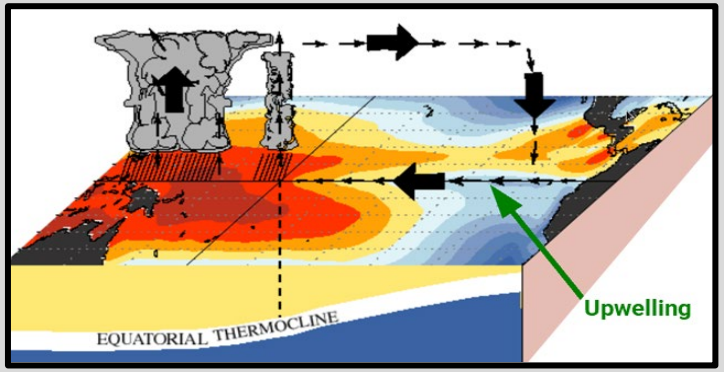
El Niño





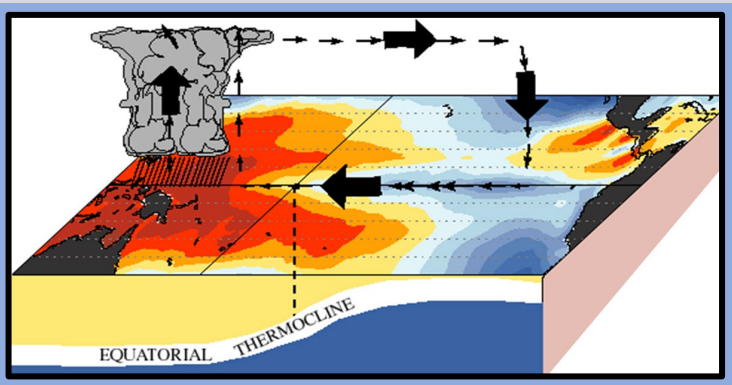
Normal or Neutral





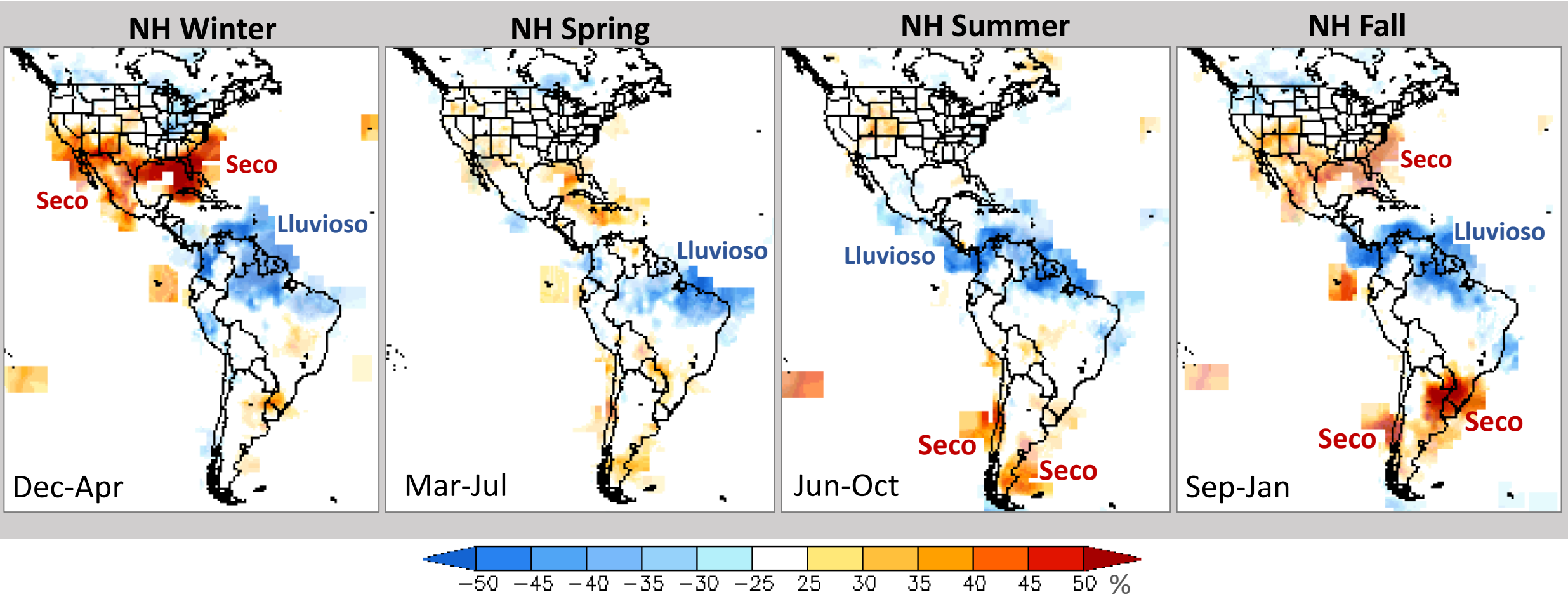
La Niña

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



Seasonability of Anomalous Precipitation

Correlations with Precipitation



https://www.cpc.ncep.noaa.gov/products/precip/CWlink/ENSO/regressions/geplr.shtml

each El Niño is different

- SST Anomaly distributions differ due to interaction with Other earth-ocean-atmosphere systems.

- Impacts are different because:

(1) SST Anomaly distribution

(2) Seasonality

(3) Interactions with other processes and atmospheric oscillations (e.g. MJO, PDO, AMO, NAO, etc).

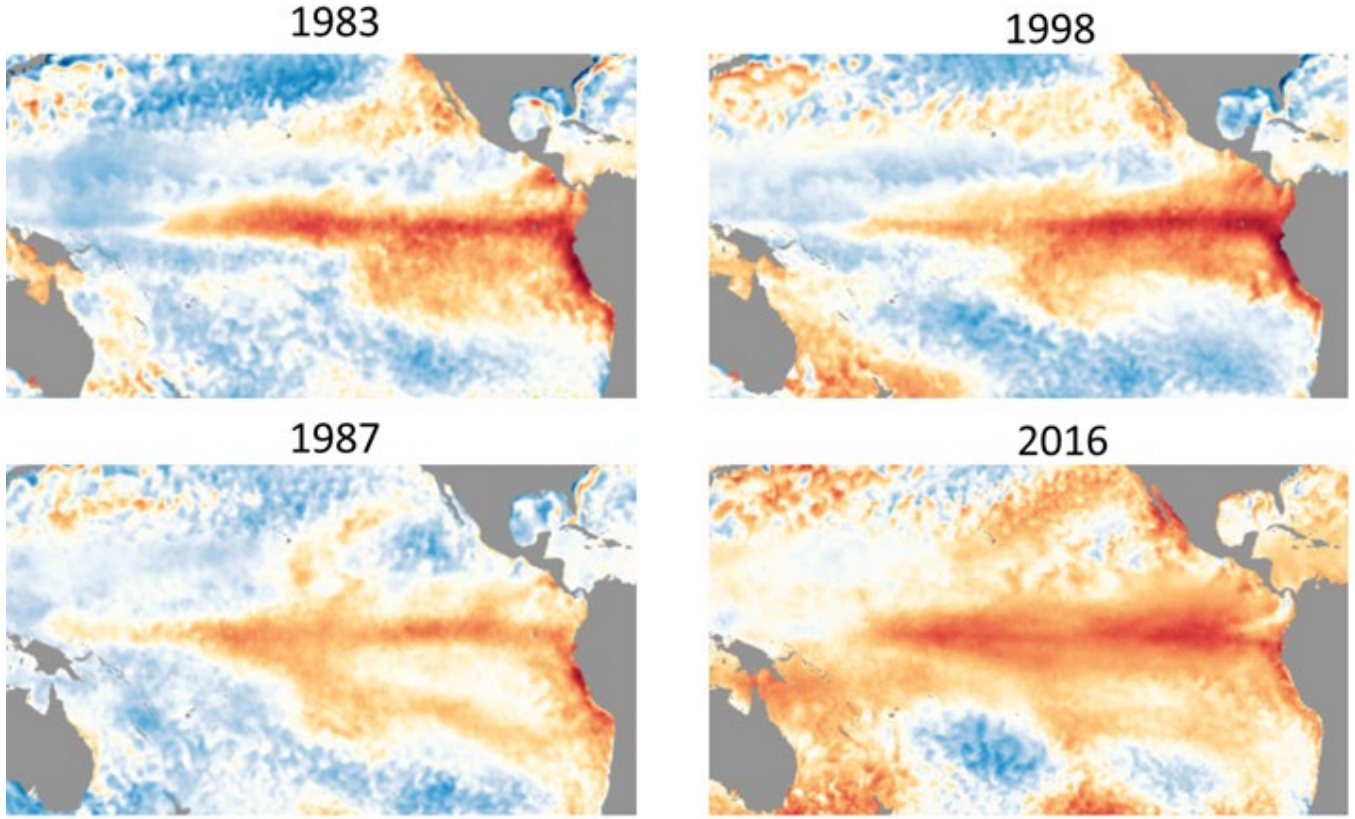


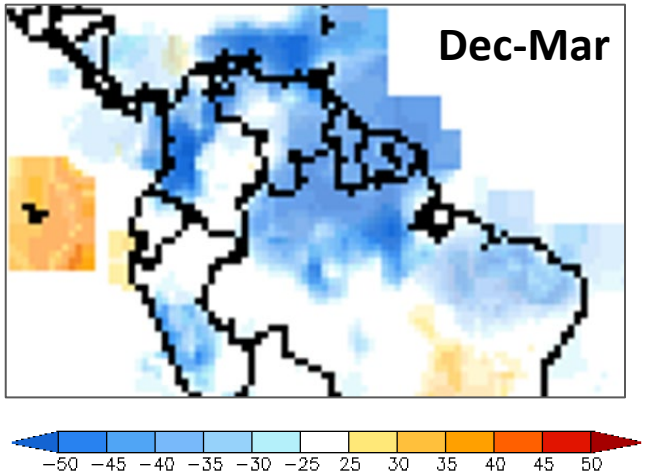
Figura. Promedios mensuales de anomalías de TSM, base de datos de OISST, durante las fases cálidas del ENSO en cuatro meses de marzo distintos. Fuente: NVVL/NOAA.

La Niña Dry Season in the Southern Caribbean: More precipitation due to fronts and shear lines

October to March

- Very rainy except in north Peru and Ecuador.
- Ascendant cell of the Walker Circulation over South America.

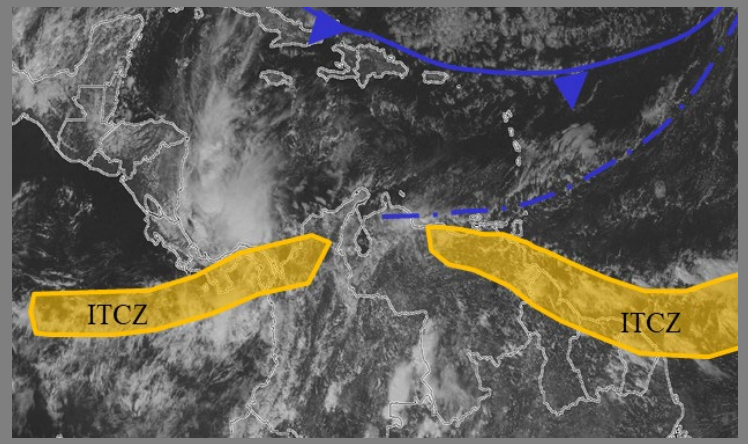
SST Correlation Niño 3.4 - Precipitation



Vargas Tragedy in Venezuela

Dec 1999

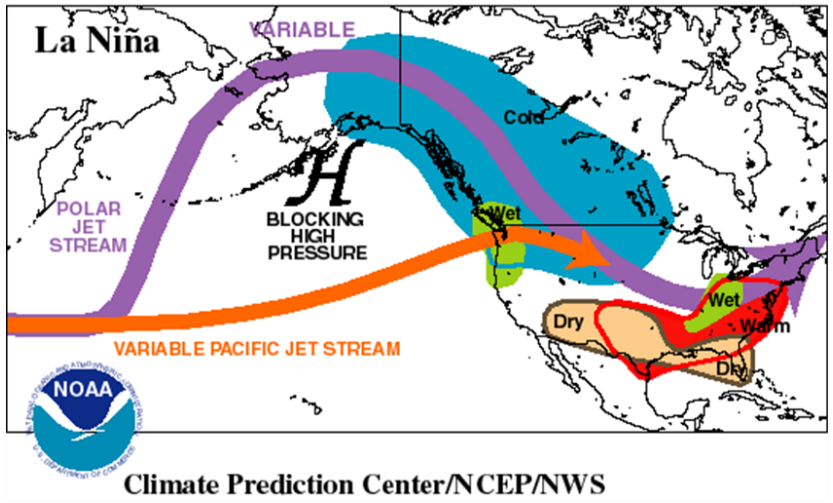
- ITCZ and shear lines
- Precipitation: 1-13 Dec: 293mm, 14-16 Dec: 911mm
- Impact: 30-50K deaths, $1.79 Billion in loses, 8000 homes and 700 building damaged.

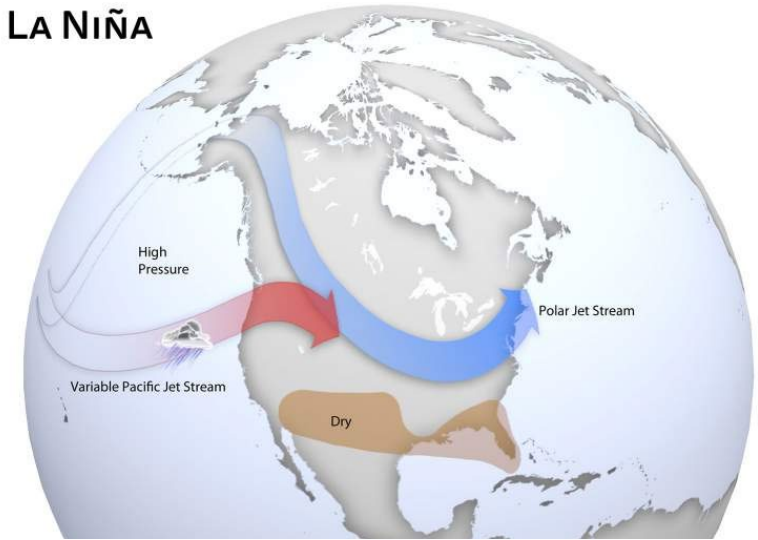


Mexico: La Niña Winter/Dry Season

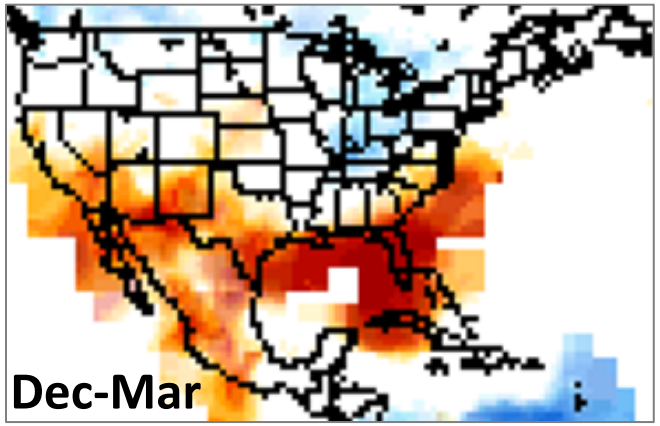
October to May

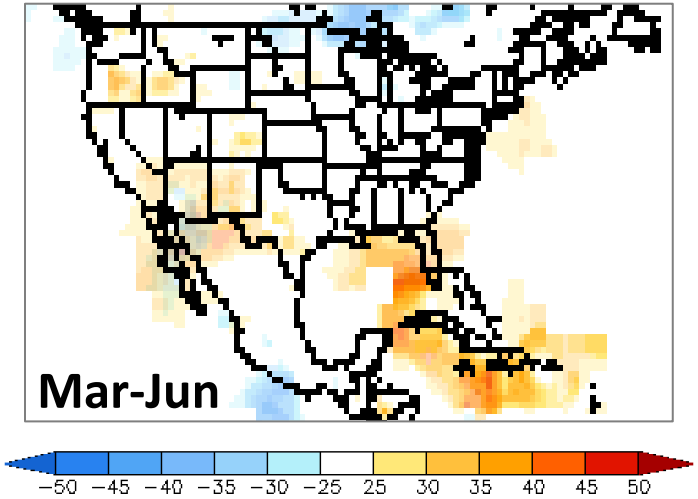
- The jet streams in the upper levels migrate further north than normal, making the passage for extratropical cyclones further north, generating dry spells in Mexico and Southern USA.
- The north Caribbean dries up, especially during the Spring season, during April and May (due to the absence of jets and troughs aloft)





SST Correlation Niño 3.4 - Precipitation



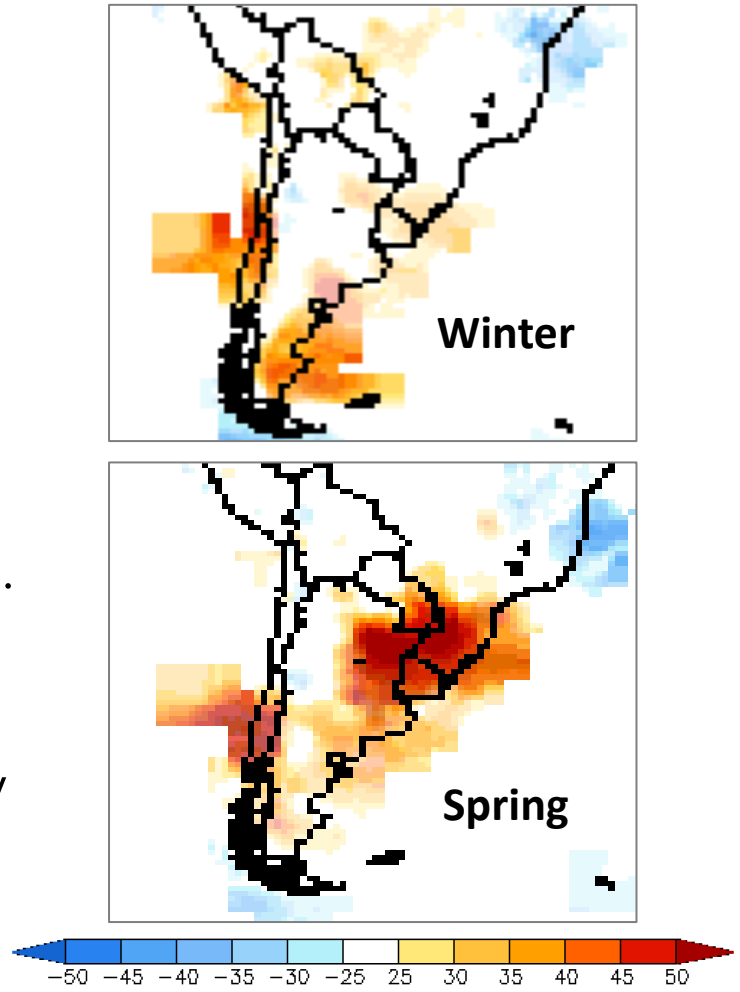


Argentina, Paraguay, Uruguay and Southern Brazil are Dry in the Spring

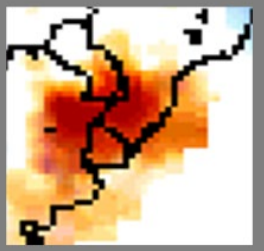
June to September

- The subtropical jet stream weakens and displaces the trajectory of the extratropical cyclones further south.
- This weakens the South American Low Level Jet (SALJJ) limiting a strong humidity source.
- Storms pass further south and produce less precipitation in central Chile and a mayor part of Argentina.
- Spring: Extreme droughts in Argentina/southern Brazil/Uruguay, where they usually experience many convective systems with intense precipitation.

SST Correlation Niño 3.4 - Precipitation



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



Central Chile: Dry During La Niña

May to October

- During La Niña, it dries up in central and south-central Chile (and it becomes wet during El Niño).
- Dry: Primarily through the southern displacement of storm tracks and the absence of robust atmospheric rivers from Polynesia during the winter months.

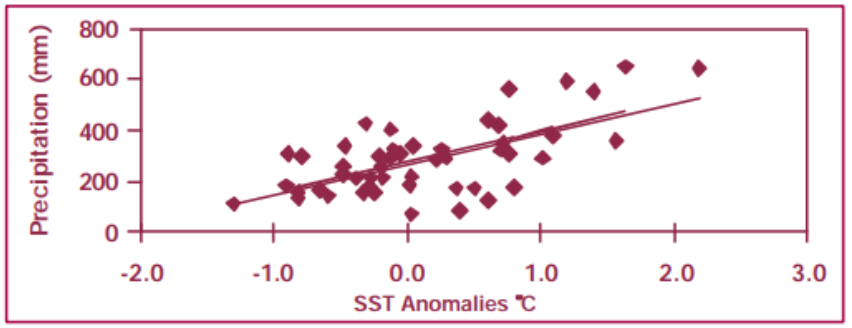


Figure 2. Precipitation for Santiago correlated with anomalies of the SST (Niño 3), April–September 1950–98.

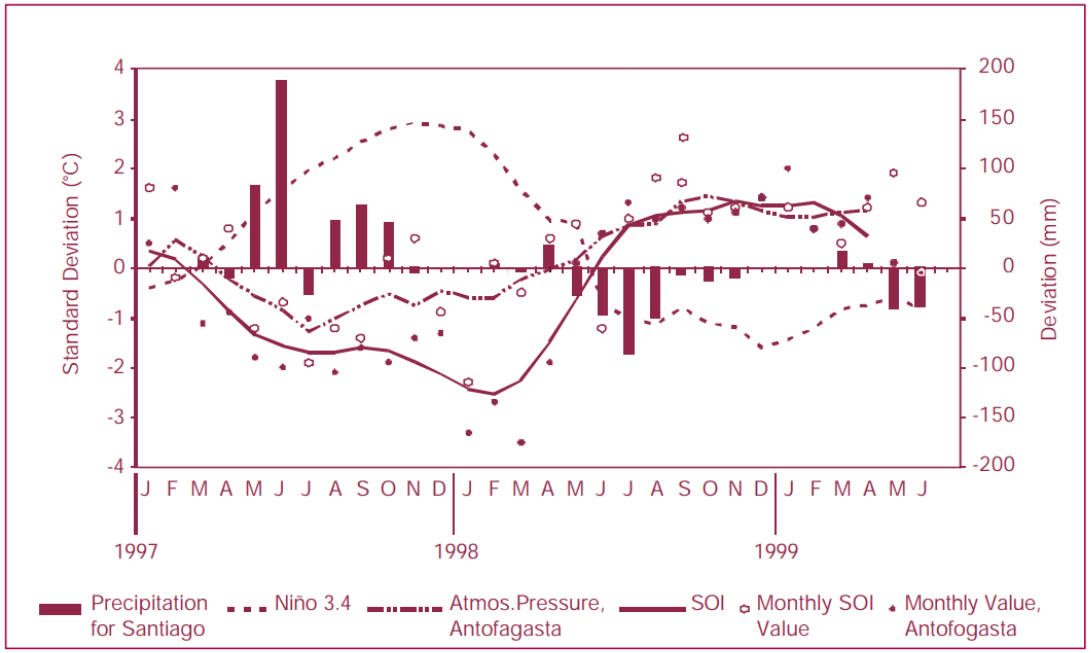
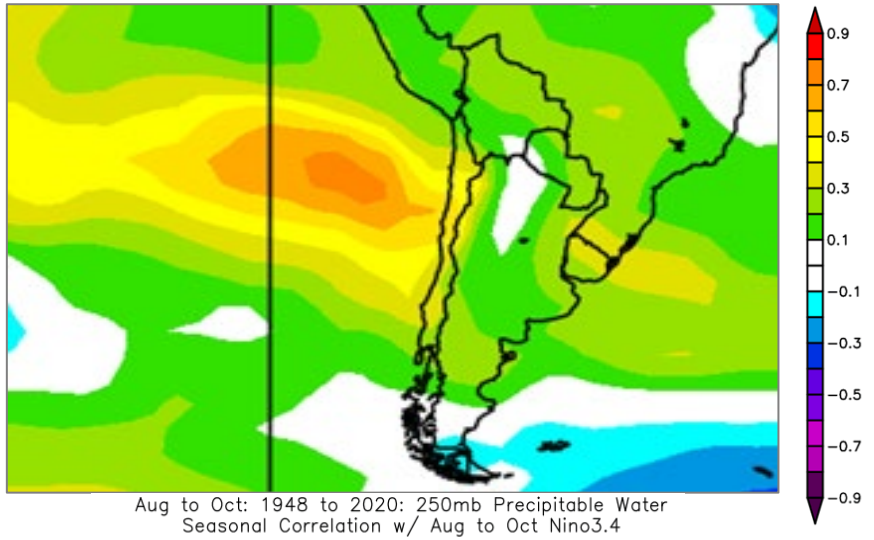


Figure 4. Sea surface temperature in the central equatorial Pacific, atmospheric pressure in Antofagasta, and precipitation in Santiago, January 1997–July 1999.

Correlación TSM Niño 3.4 – Agua Precipitable



Aug to Oct: 1948 to 2020: 250mb Precipitable Water
Seasonal Correlation w/ Aug to Oct Nino3.4

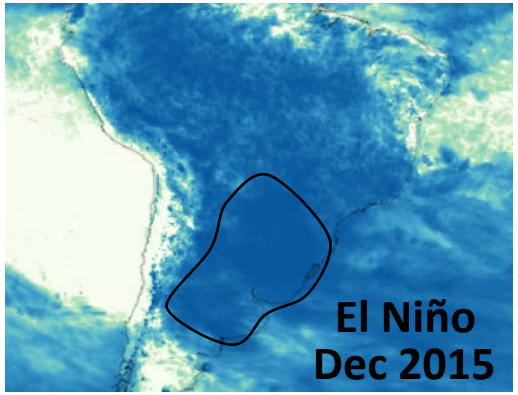
NCEP/NCAR Reanalysis

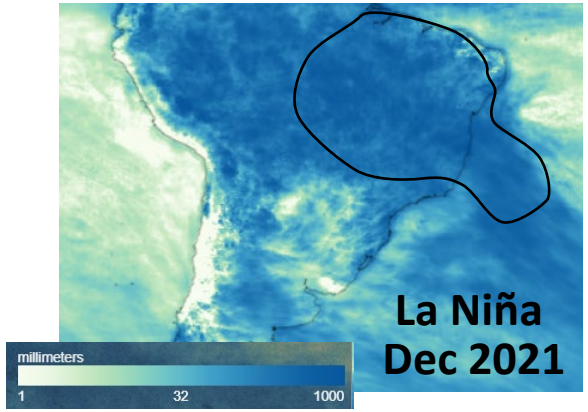
Summer in Brazil: Wet to the North and East

November to March

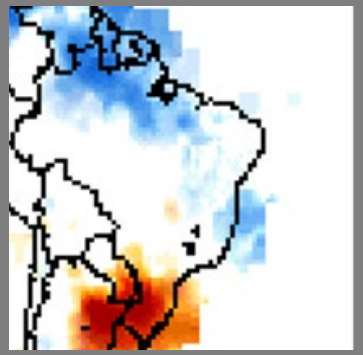
SACZ and ascent from the active Walker Circulation

- A strong ascending branch of the Walker Circulation favors more rain in the Amazon and extends to eastern Brazil.
- The descents and dry spells in southern Brazil/Argentina make up for the strong ascents in the north.
- The South Atlantic Convergence Zone (SACZ) becomes more prominent and recurrent, generating extreme events that may sometimes affects the Andes and jungles of Peru and Bolivia.



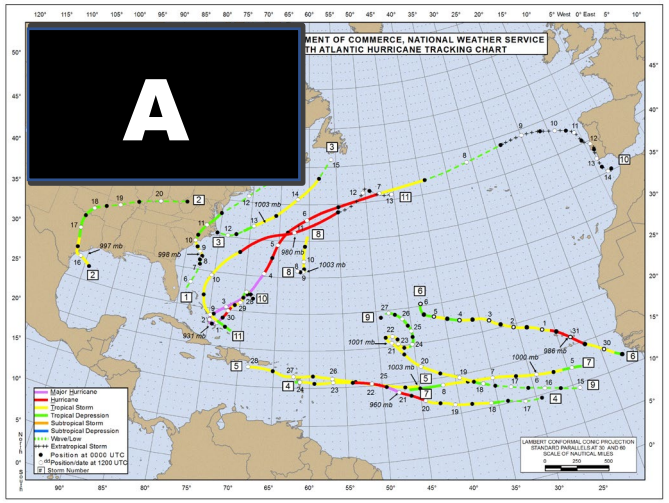


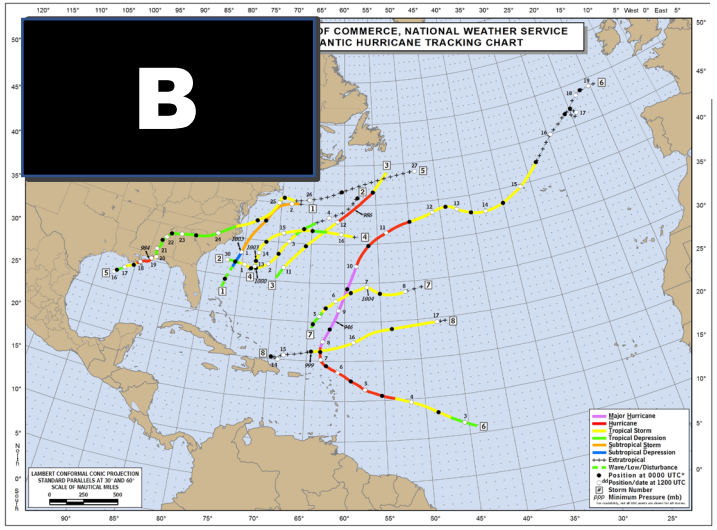
Flooding becomes more frequent in eastern and northern Brazil during La Niña due to the intensification and displacement to the north of the SACZ.

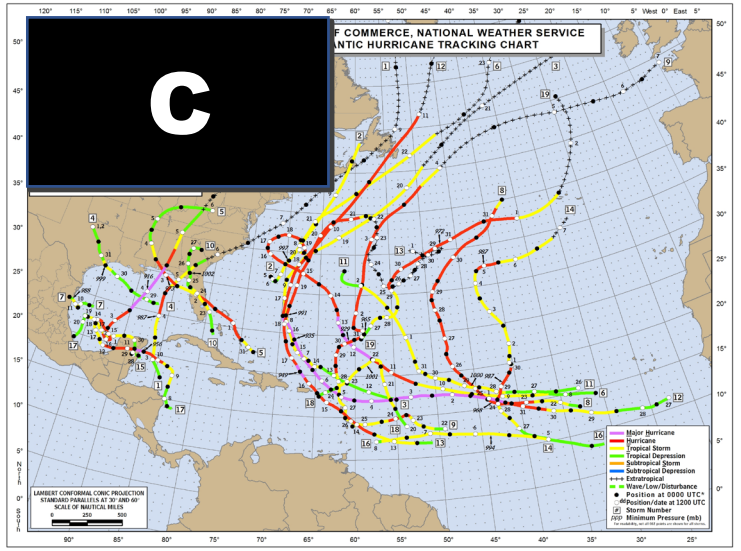


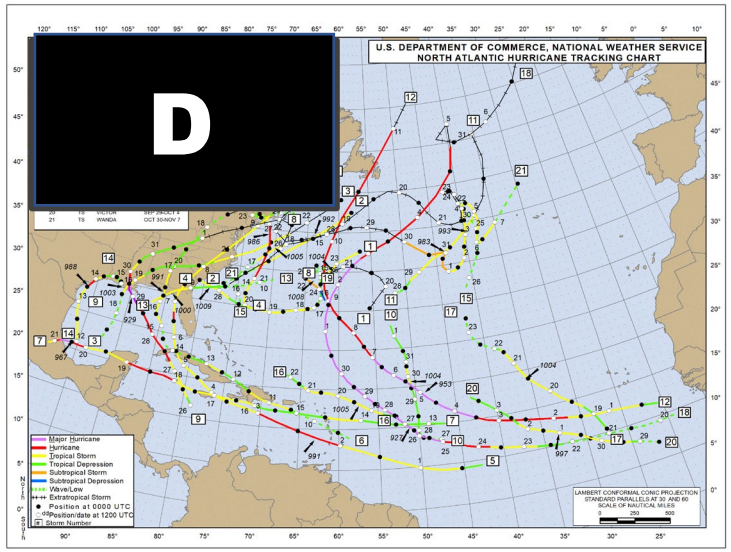
Hurricane Season in the Caribbean

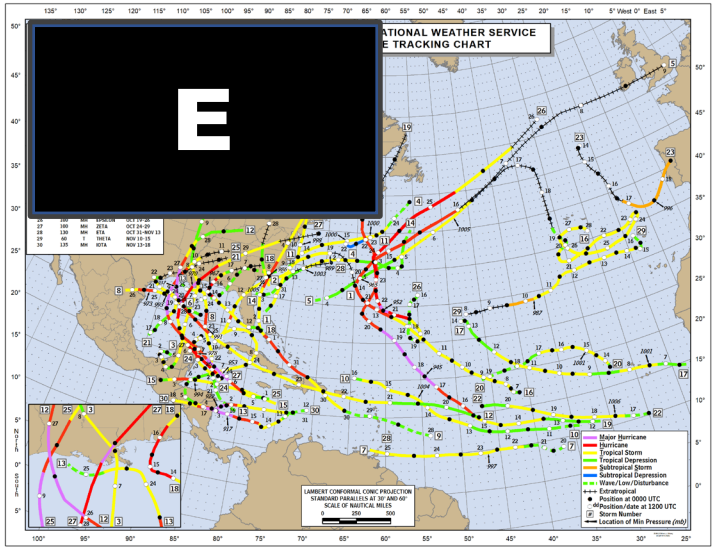
Which correspond to La Niña years and El Niño years?





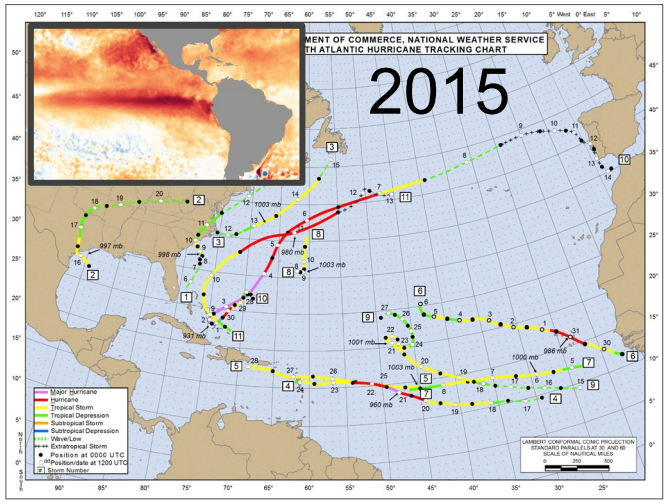


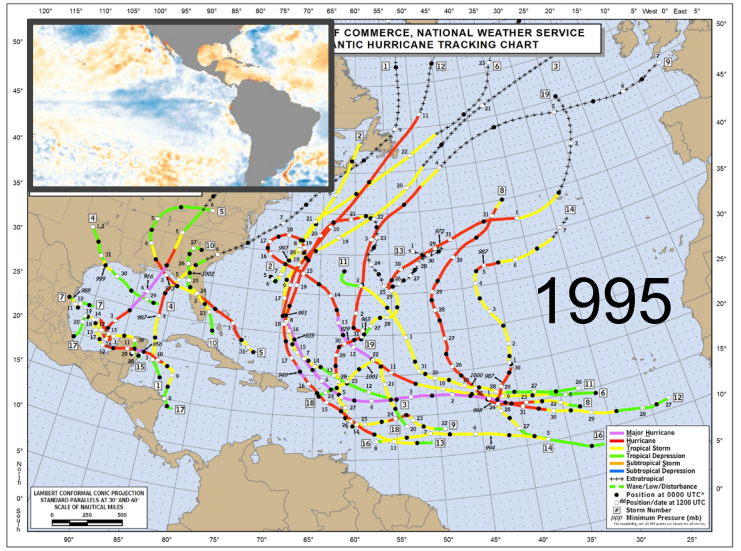


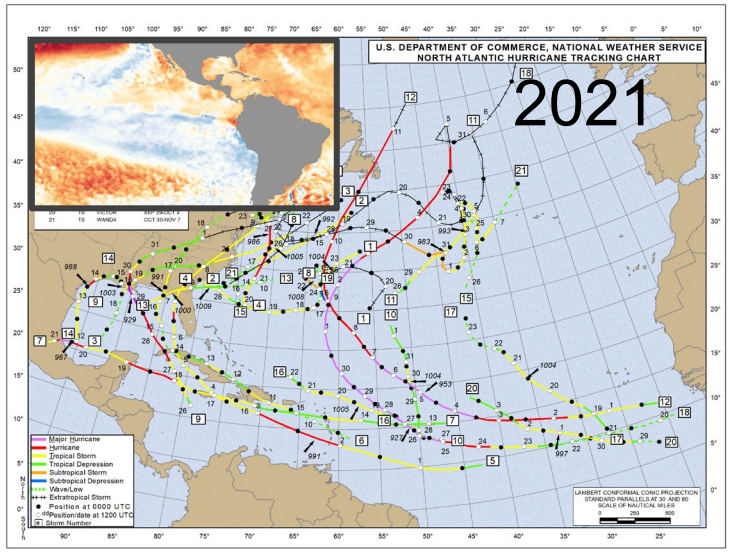


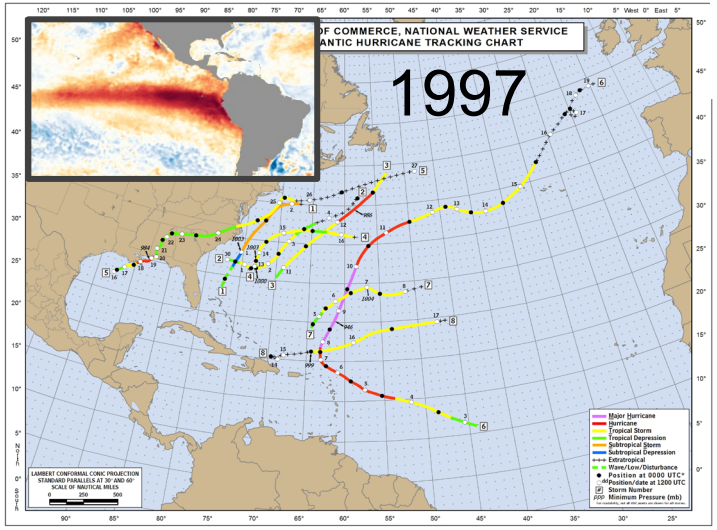
Hurricane Season in the Caribbean

Which correspond to La Niña years and El Niño years?

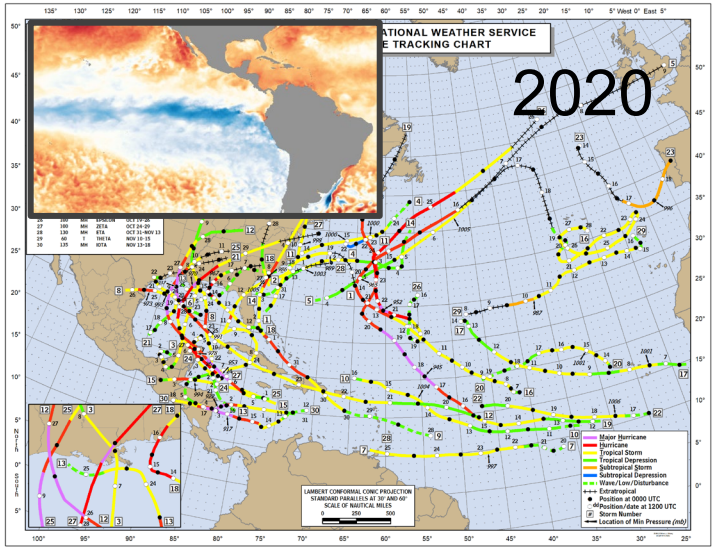




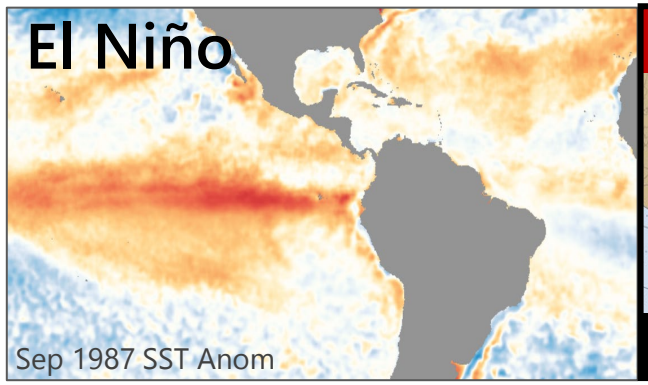


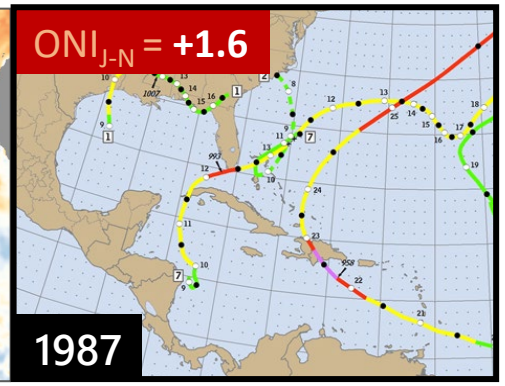


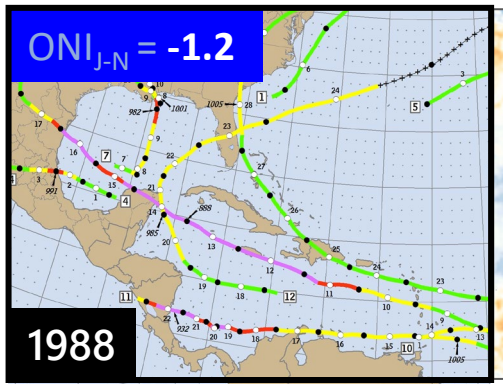
The Atlantic is more active during La Niña

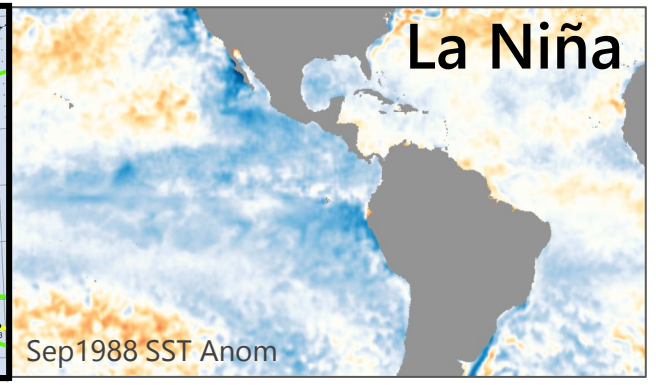


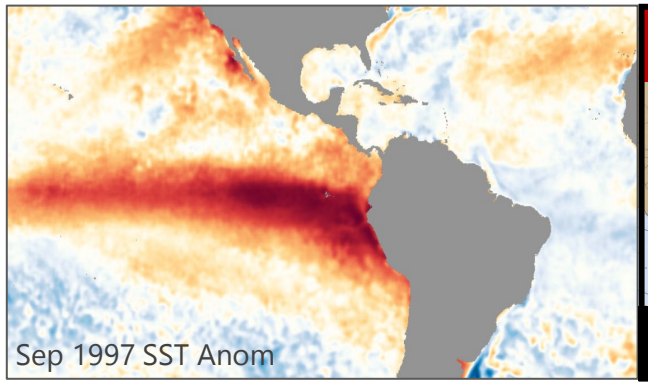
El Niño = Less hurricanes in the Caribbean(Jun-Nov)

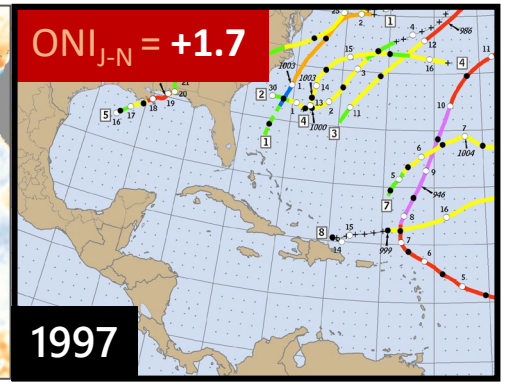


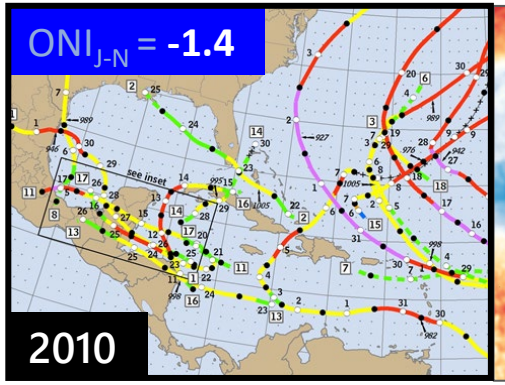


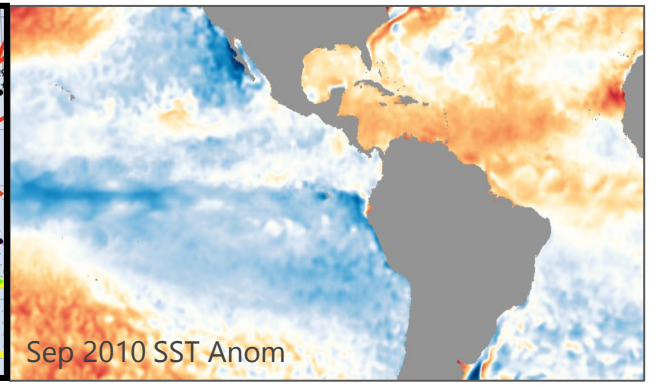


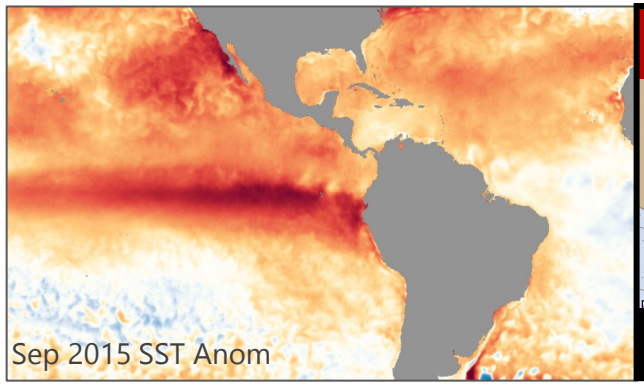


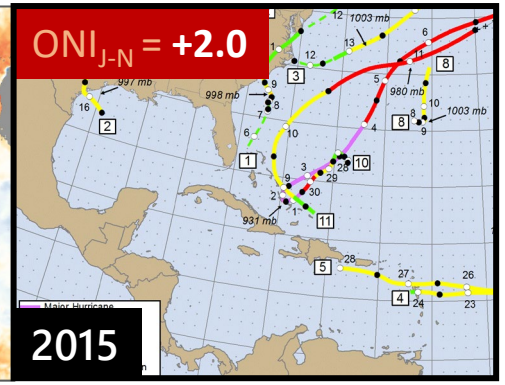


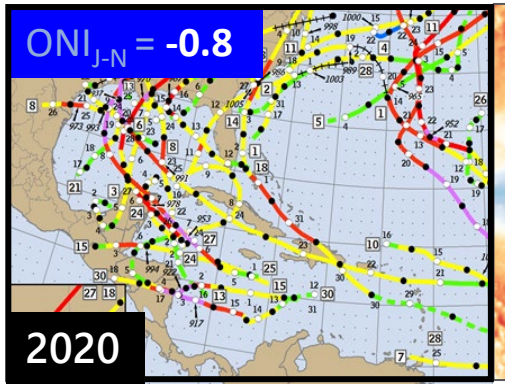


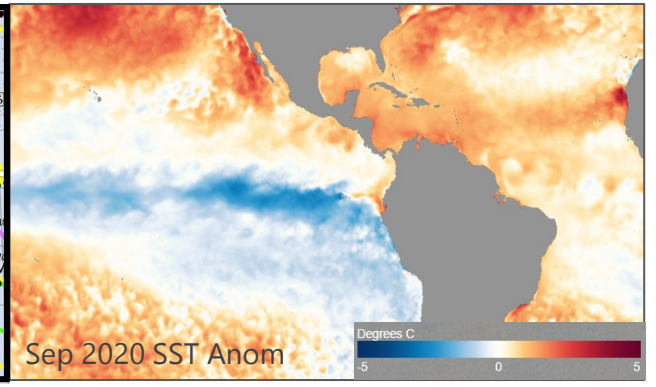




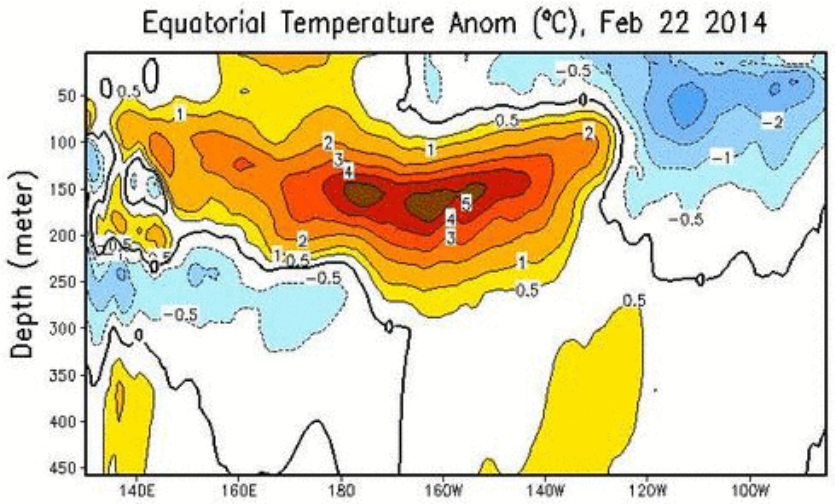


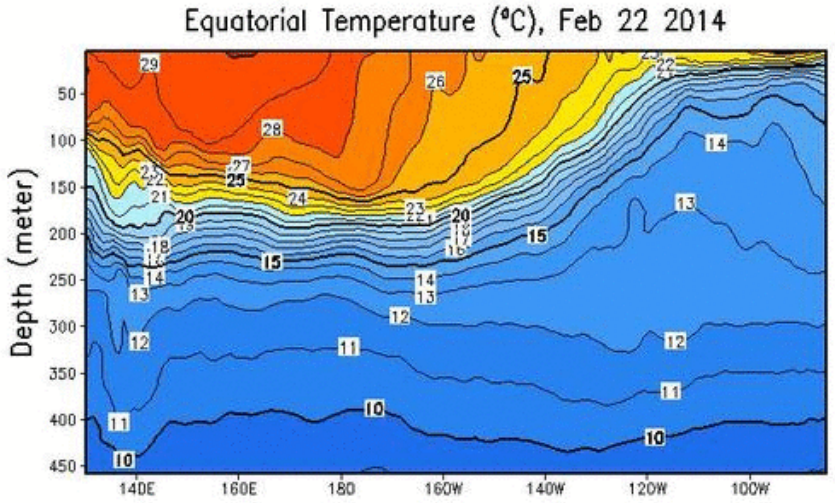




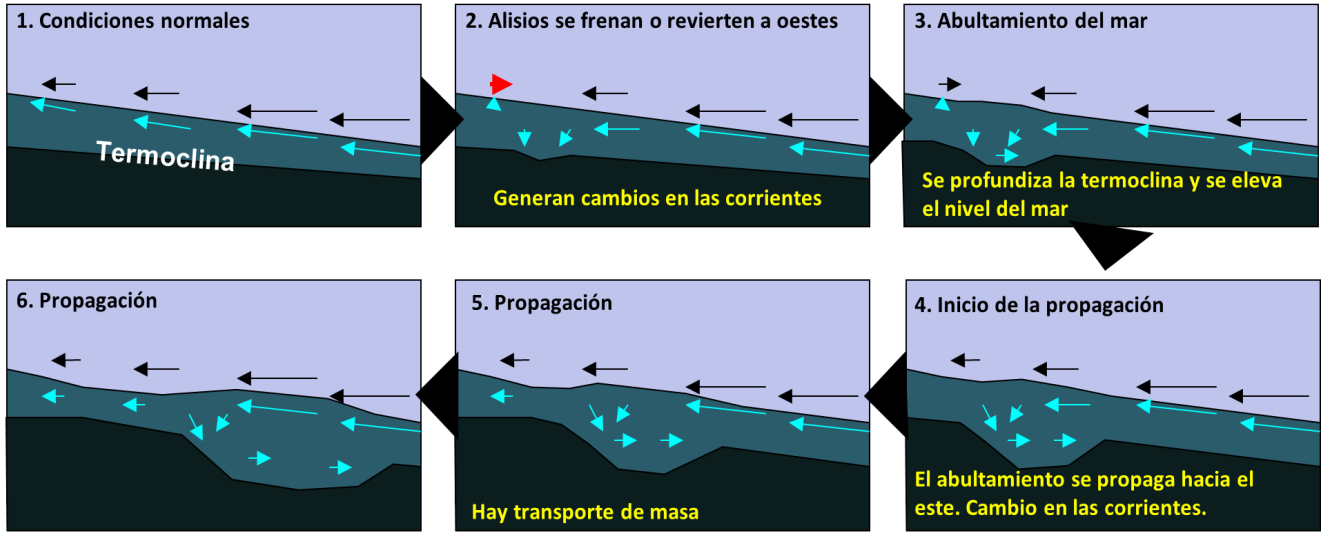


Oceanic Kelvin Wave Mechanism





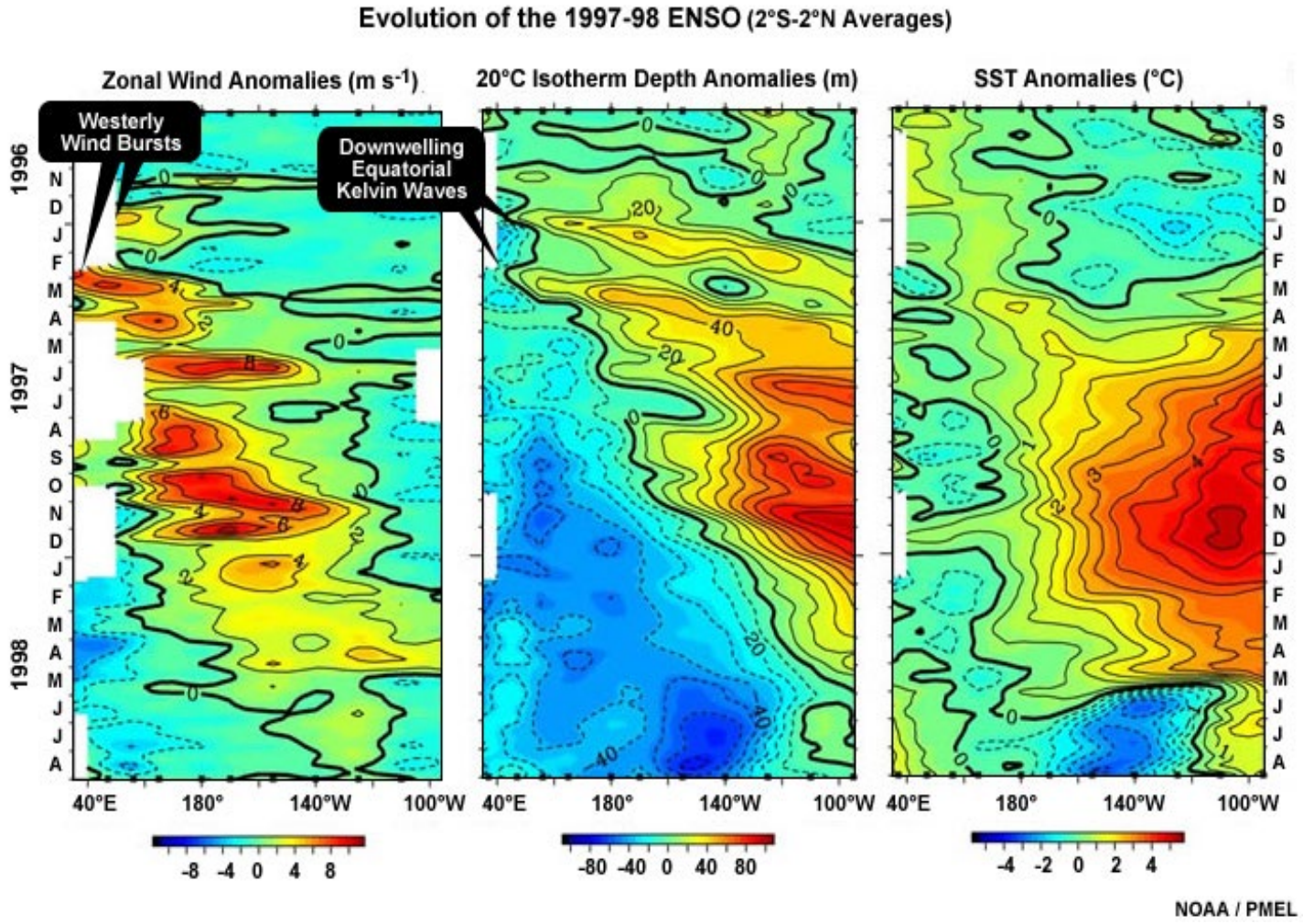
- Winds from the west stimulate convergence, when they clash with trade winds from the east.
- Currents also converge, generating perturbations that propagate to the east. They take 2 to 3 months to travel from the Western Pacific to South America.
- It is reflected on the sea surface and the thermocline.



Evolution of the 1997-8 El Niño

Westerly Wind Bursts and Kelvin Waves

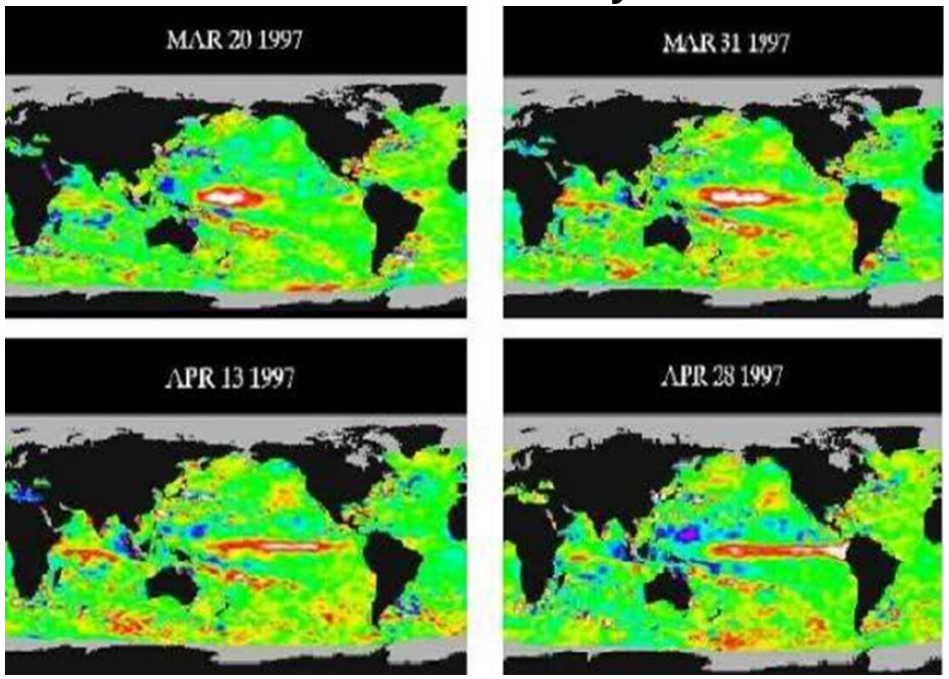
- Westerly wind bursts in the low-levels generate warm Kelvin Waves (subsidence) that arrive to the coast of South America in timeframes of several weeks.
- Superficial currents from the east then redistribute the warm anomalies to the rest of the equatorial Pacific from east to west.
- The new superficial warming lowers the pressures and favors the development of more westerly wind bursts.
- The MJO is often a source of westerly wind busrts



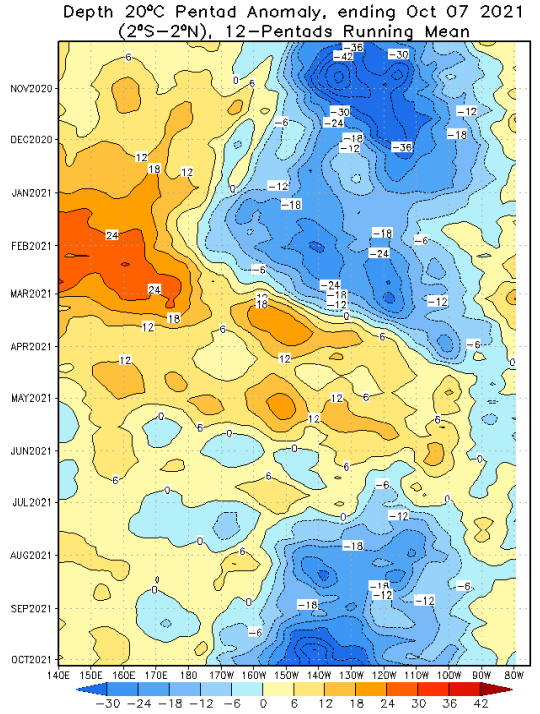
Monitoring Kelvin Waves

Kelvin Waves can be seen at sea level and in variables associated with sea temperatures. Hovmoller diagrams of the depth of the 20°C Isotherm or ocean heat content, are the best tools to evaluate propagation.

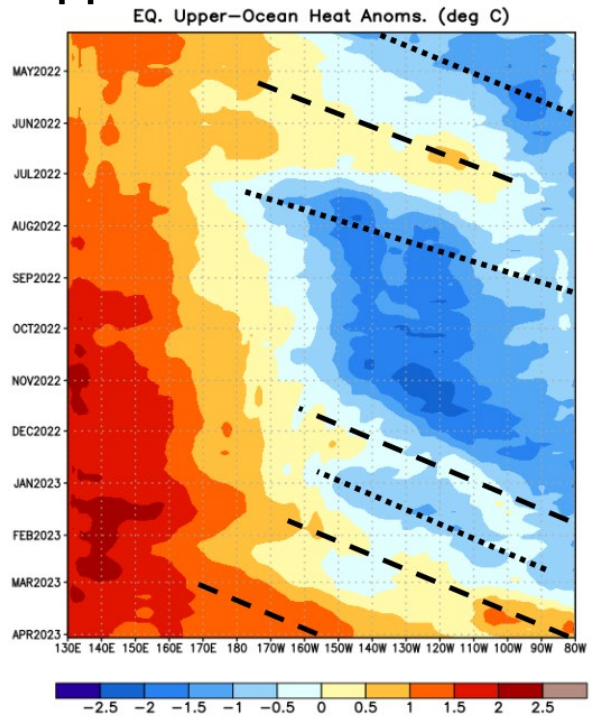
Sea level (Altimetry)



Depth of 20°C Isotherm



Upper Ocean Heat Content

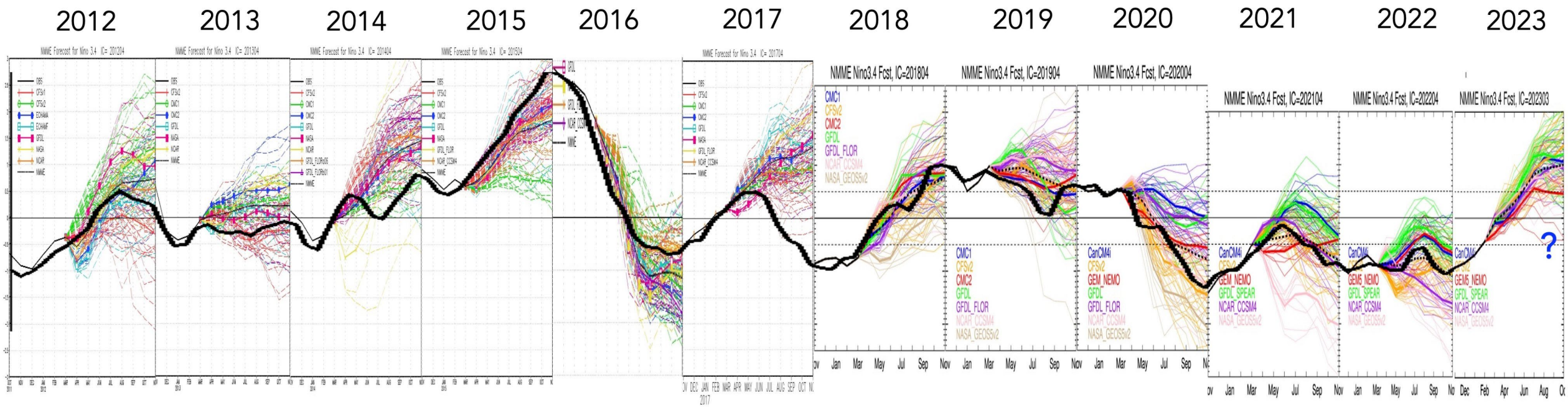


ENSO Predictability

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.

Pronósticos NMME de El Niño/La Niña en el Pacífico central (región Niño 3.4) inicializados en abril*



* inicializado en marzo 2023

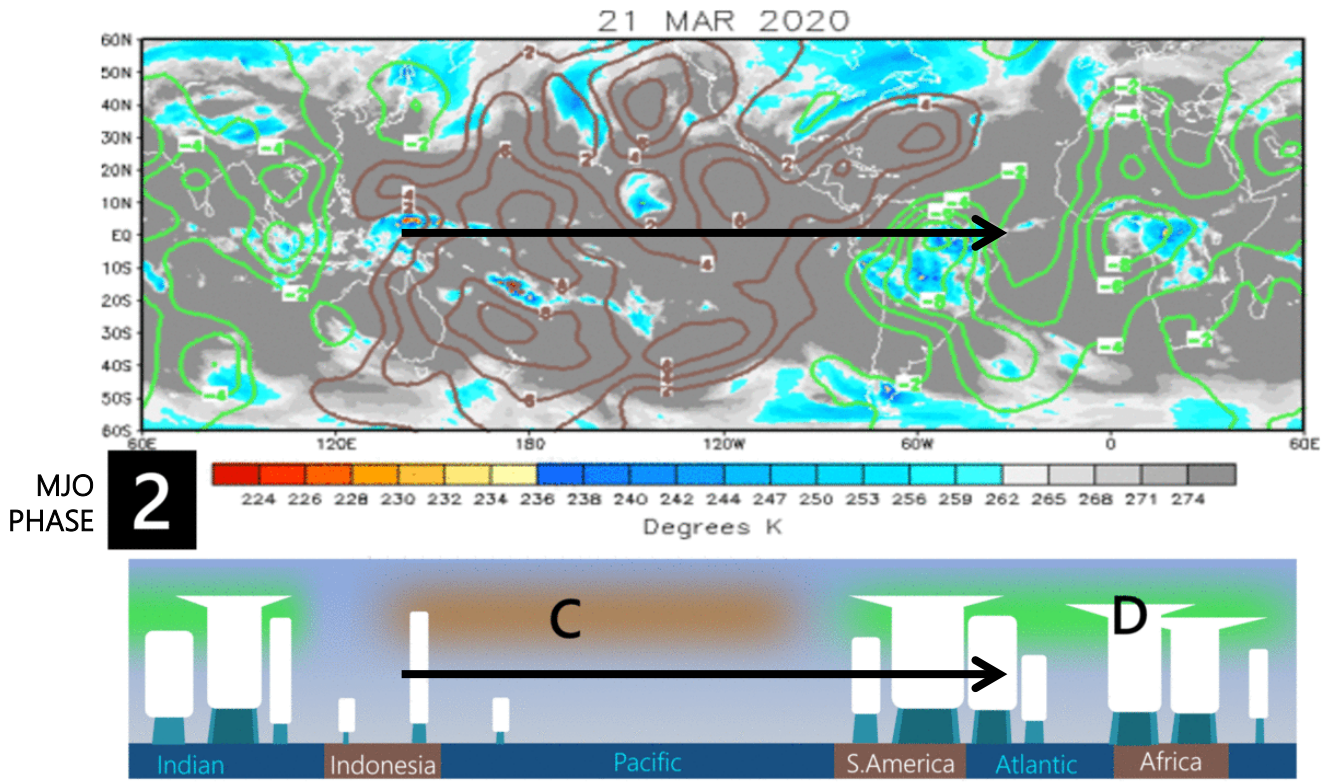
05b

Madden-Julian Oscillation and other Tropospheric Waves

The Madden-Julian Oscillation

- Eastward moving disturbance of clouds, rainfall, winds, and pressure that traverses the planet in the tropics and returns to its initial starting point in ~30 to 60 days.
- Intraseasonal tropical climate variability (i.e. varies on a week-to-week basis).

200 hPa Velocity Potential and Brightness Temperature (convection)

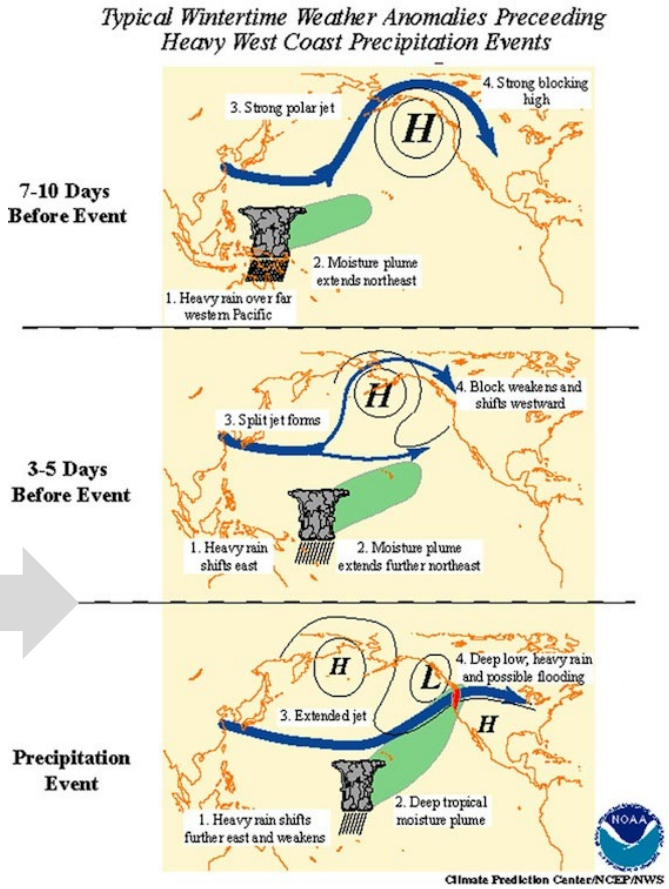


Convergent (C) / Divergent (D) and associated convection

Importance of the MJO

- Key for the variability of precipitation and Tstorm formation in the tropics.
  - Upper divergent phase enhances deep convection and tropical cyclone intensity and formation.
  - Upper convergent phase enhances easterly trades and often vertical wind shear in the Caribbean.
- Affects the extra tropics too, via teleconnections (Rossby Waves and modulation of subtropical jets.

Aviation Implications: Upper Divergent phase enhances the coverage and intensity of Tstorms.



The Madden-Julian Oscillation

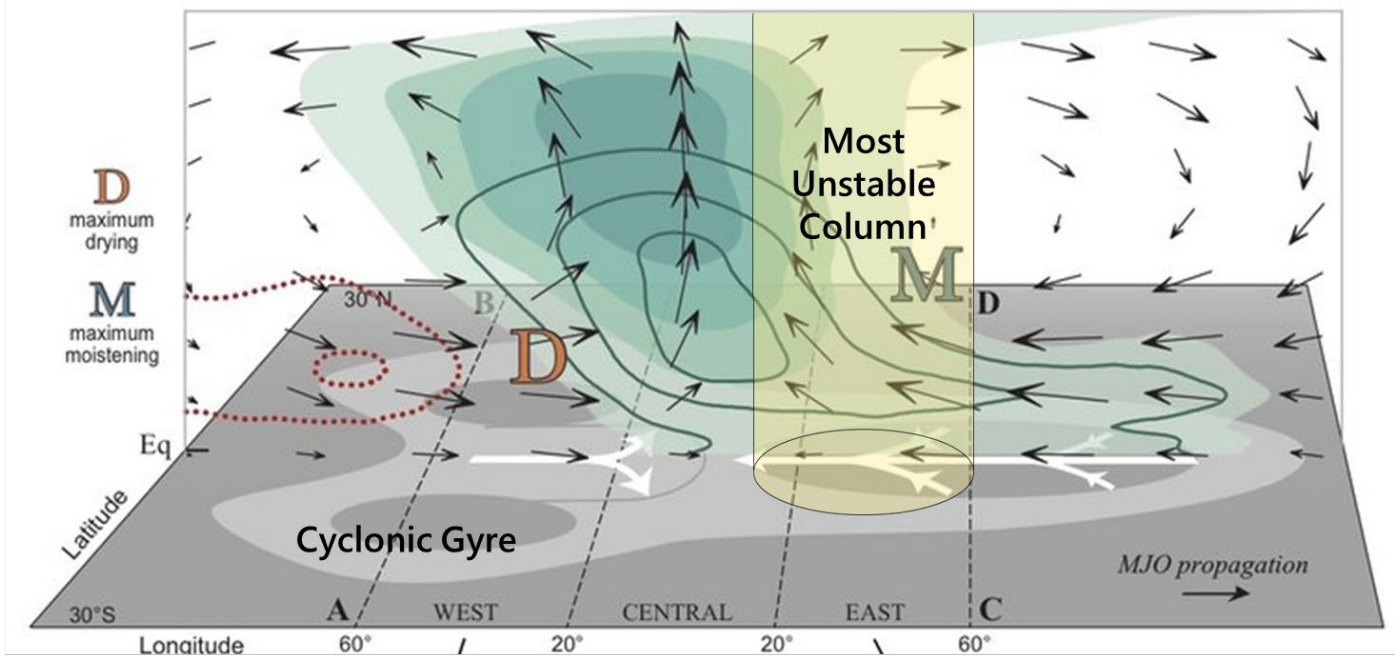
Propagates eastward.

Driven by equatorially trapped waves (Kelvin and Rossby waves) and by atmospheric-ocean coupling (AOC).

AOC: East of the convection…

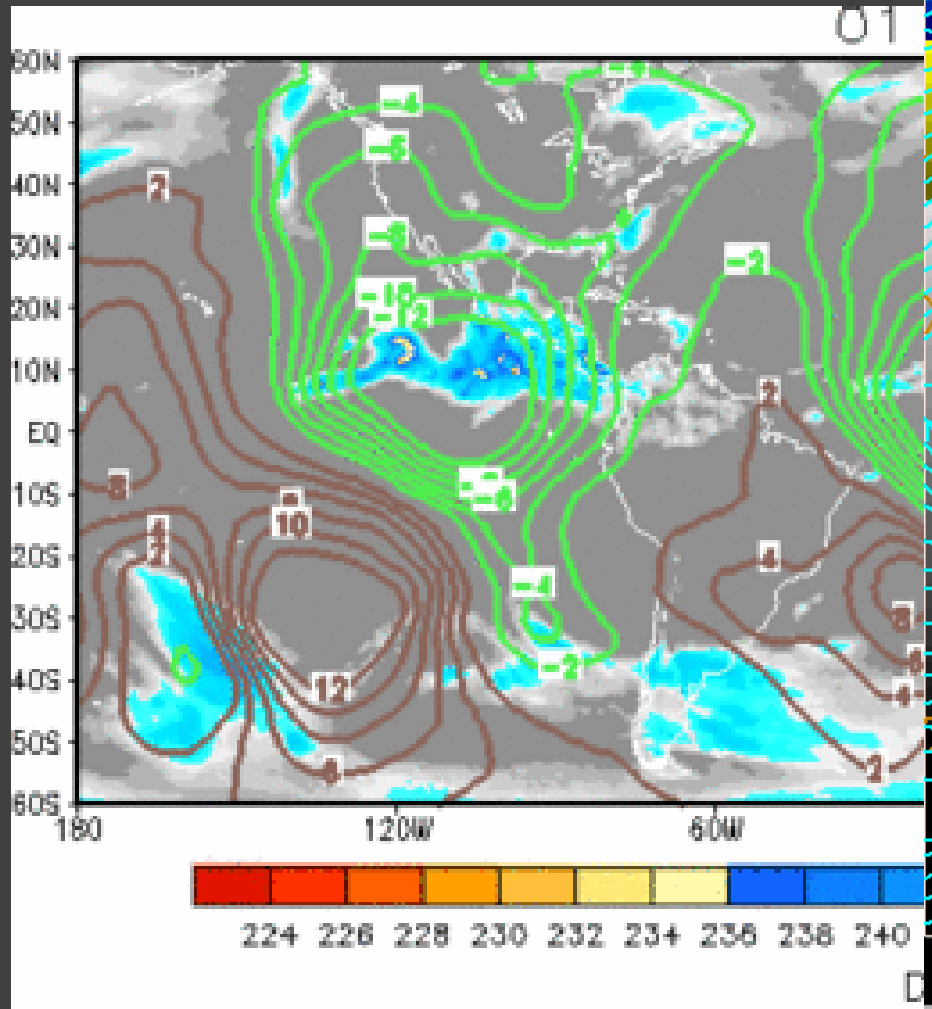
a. Horizontal gyres favor upper divergence and ascent.

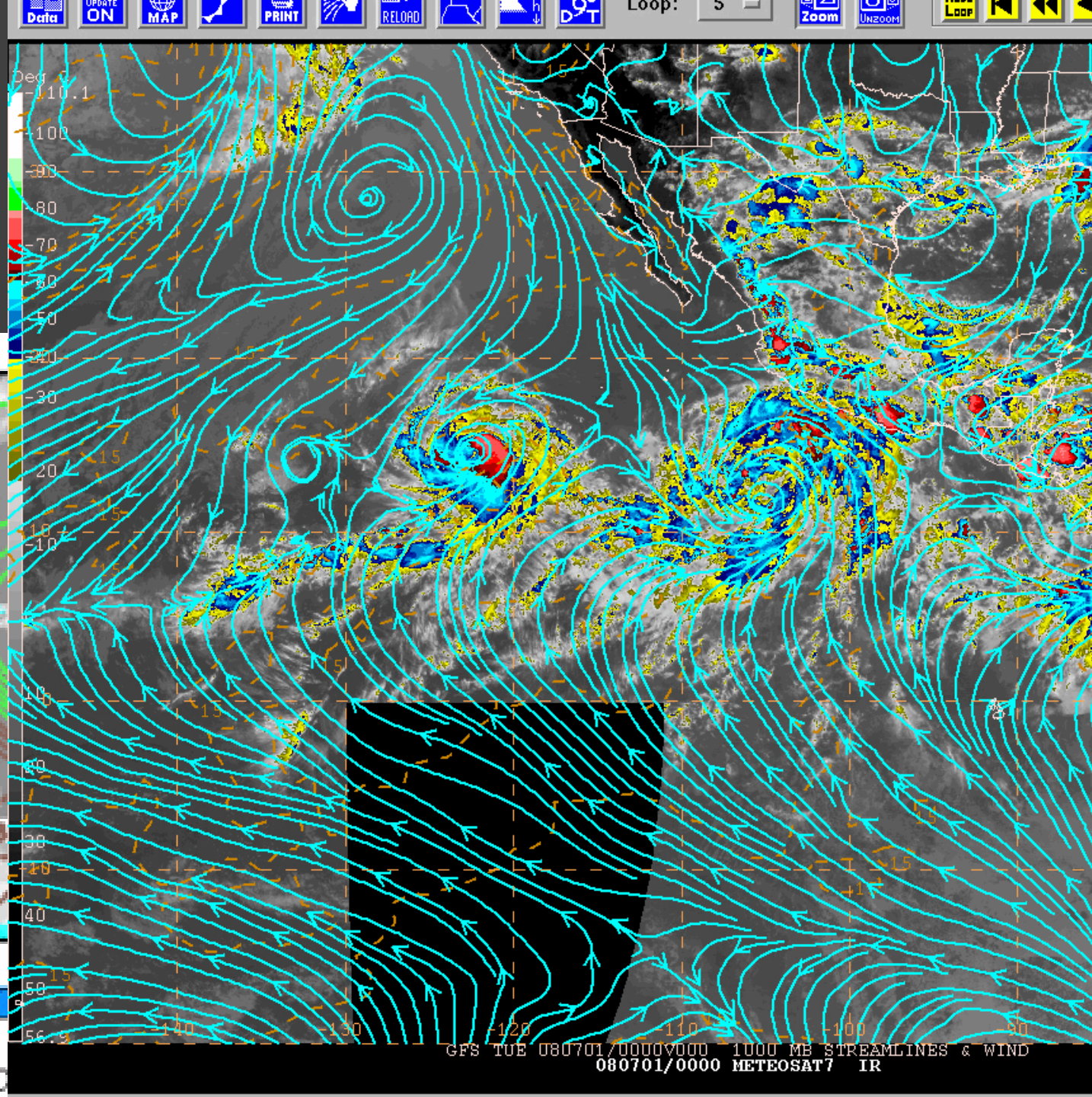
b. Subsidence and solar radiation favor surface warming, thus destabilization.



Source: Adames and Wallace (2015)

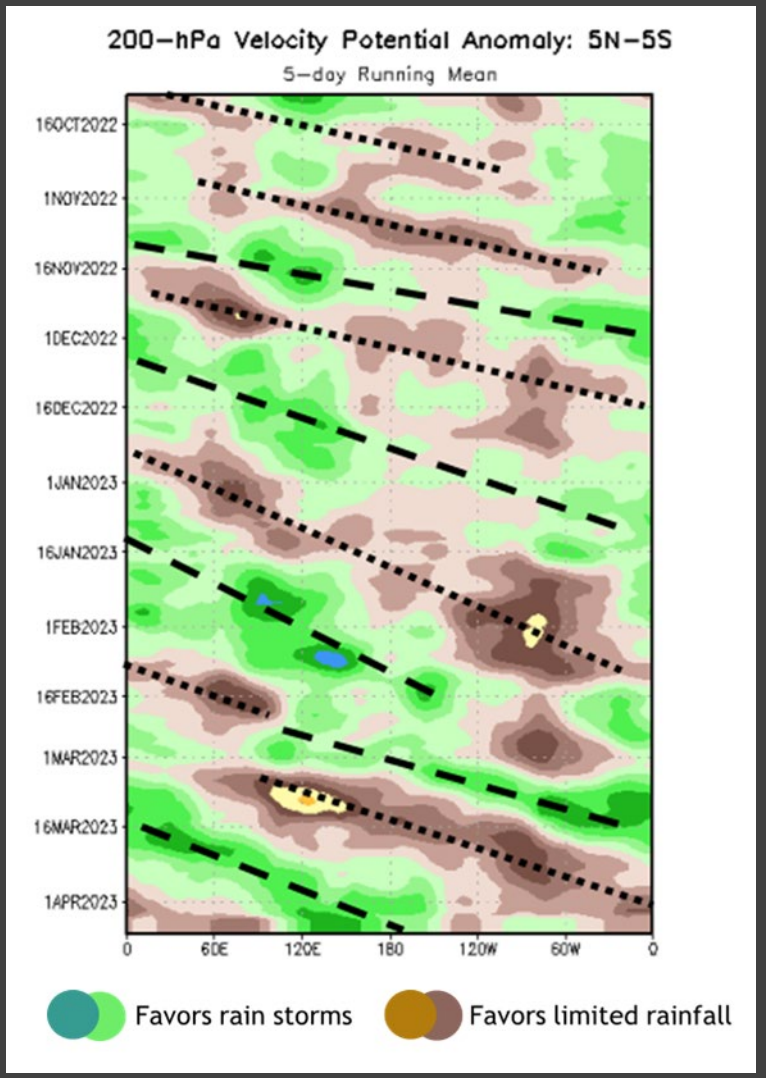
MJO-IR
July 1, 2018





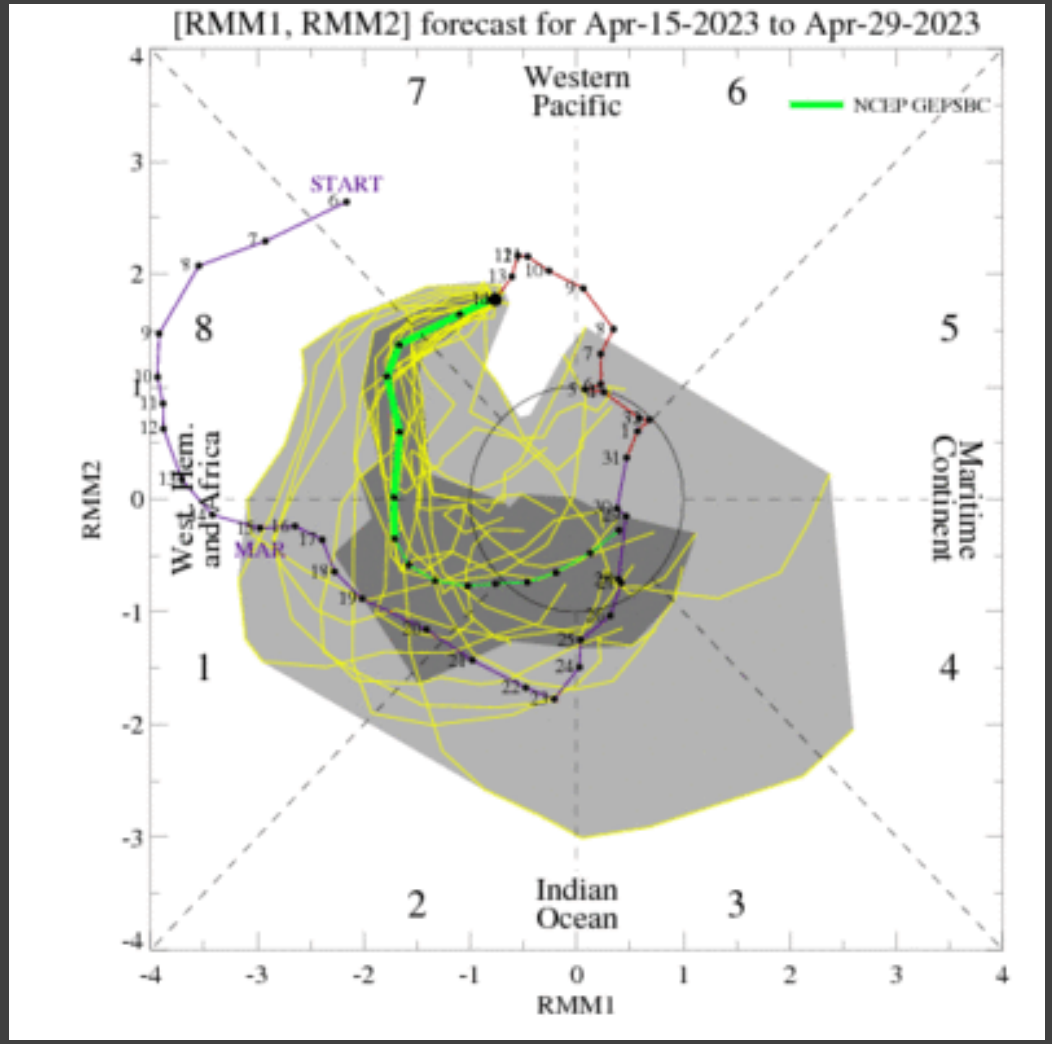
Evaluating Propagation of the MJO

- Hovmoller Diagrams are great tools.
- Variables: Velocity potential (CHI) anomaly in 200 hPa is a great variable. It tends to tie well to the MJO and its smoother than other variables.
- CHI represents if the upper flow is anomalously divergent (green), which favors more deep convection and rainfall, or not.



MJO Phase Diagram

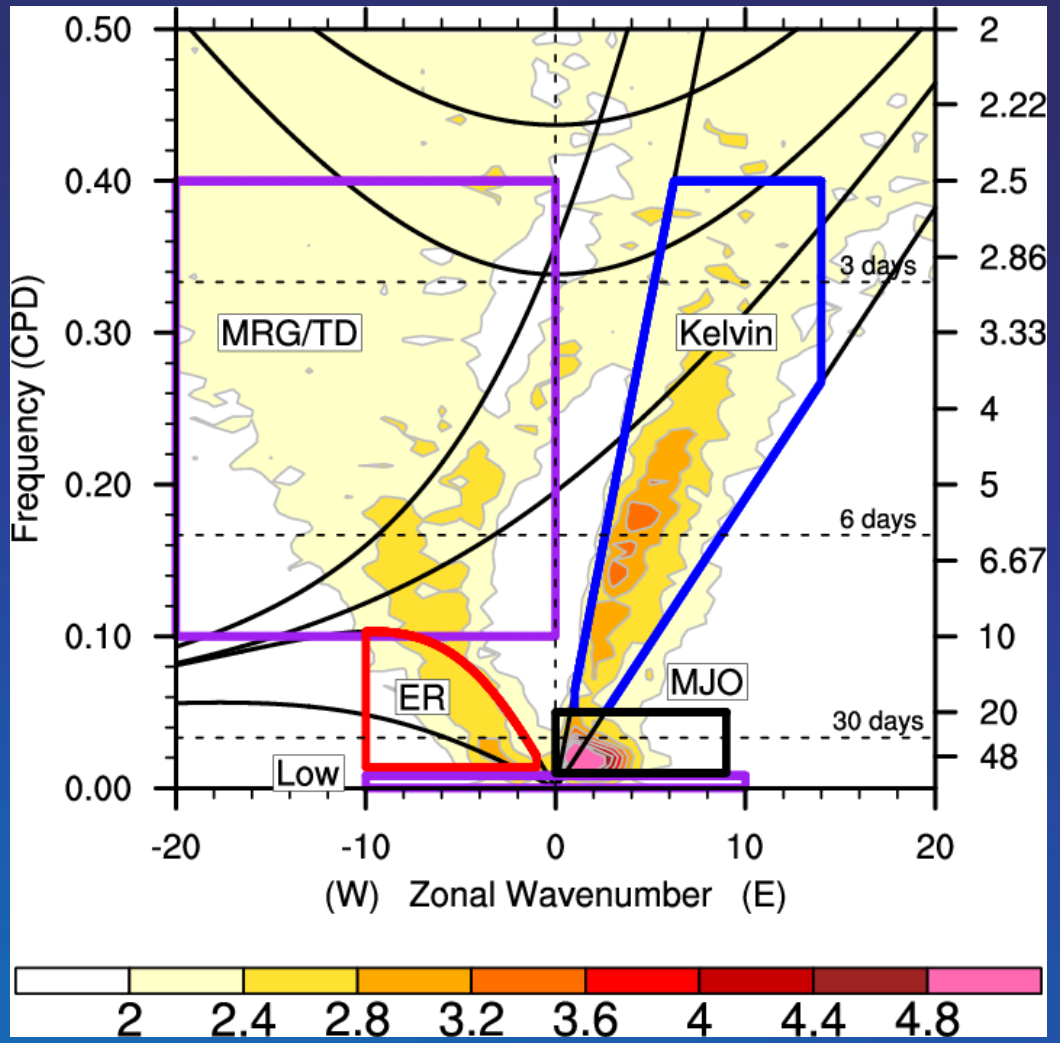
- Constructed using the two main modes of variability of the MJO signal.
- Closeness to the center means a less organized MJO.
- The quadrant or Phase of the MJO, represents the part of the Globe where the wet and dry phases are present.
- Phases 7, 8 and 1 are the wettest for the Americas. During March 2023 a strong (away from the circle) phase 8 produced heavy Rainfall and increased the SST warming off the coasts of Peru and Ecuador.



Equatorial Tropospheric Perturbations

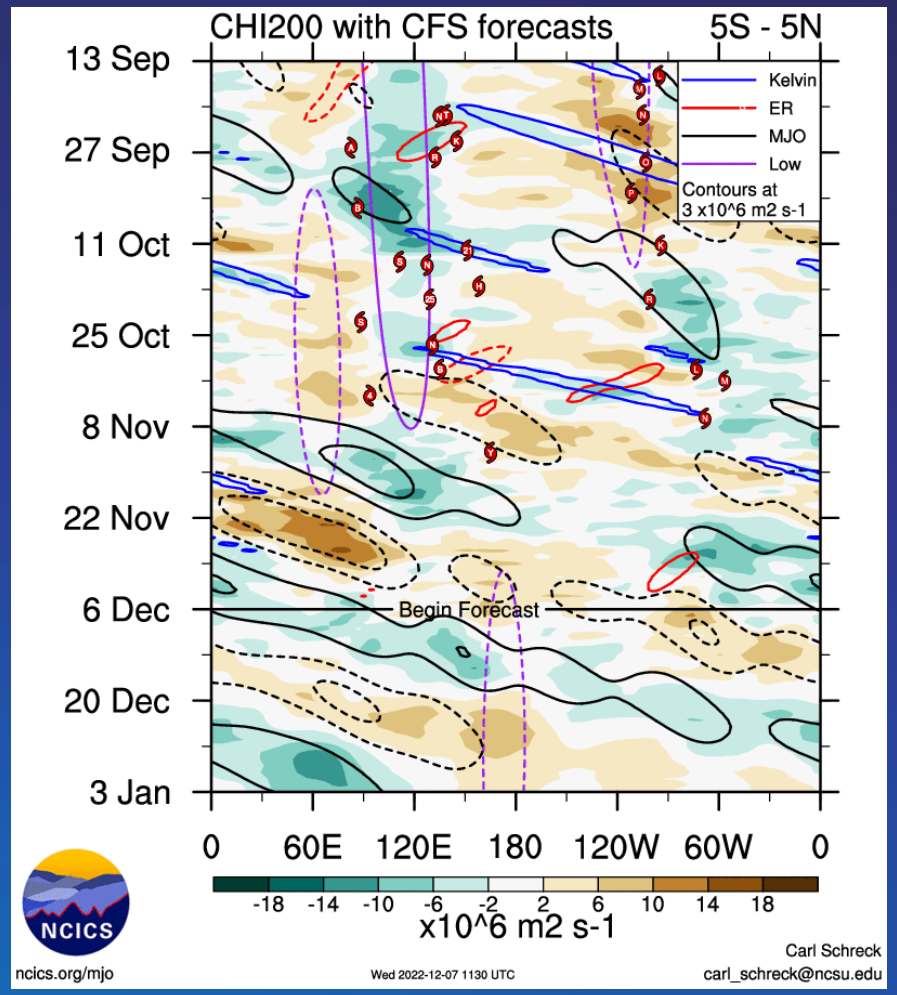
- There are different equatorial waves that propagate mostly using the tropopause as the “surface” (stable layer) for propagation.
- From these, the MJO and Kelvin waves are the most impactful to tropical weather forecasting in the Americas.

Wheeler and Weickmann (2001) developed a method for filtering OLR in real-time to identify, track, and predict the MJO and equatorial waves.



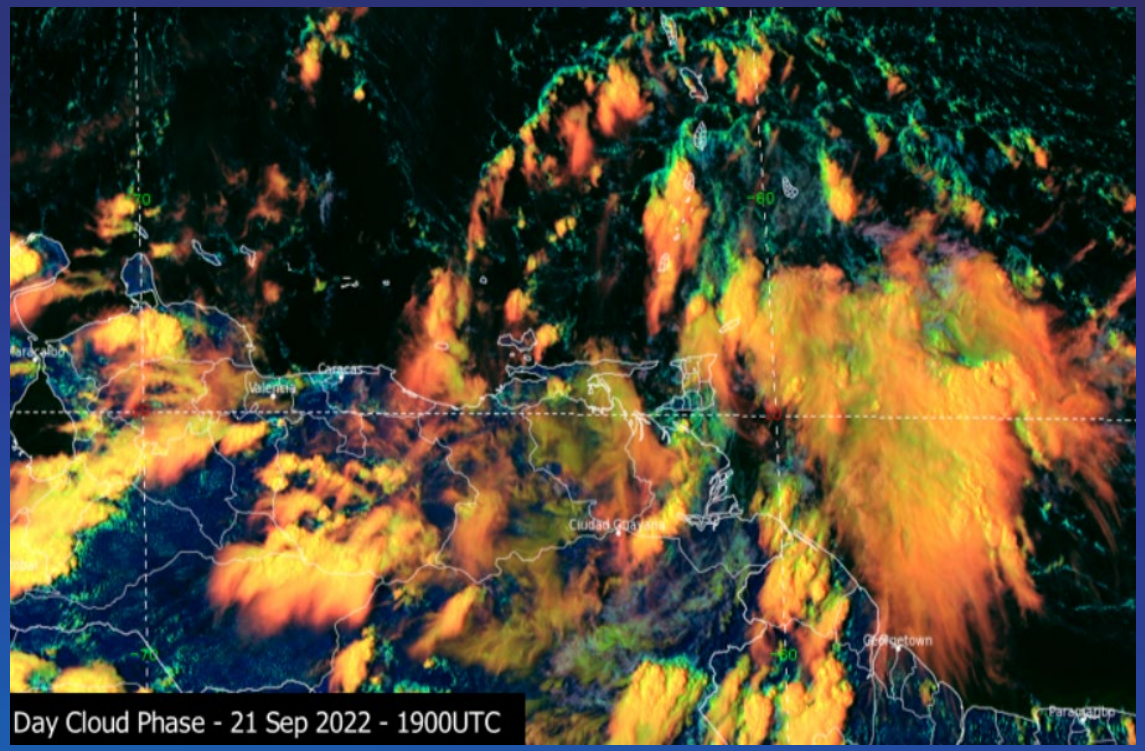
Kelvin Waves move faster than the MJO

- Hovmöller shows propagation.
- The effects of Kelvin waves are similar to those of the MJO, but they move faster.
- Since they propagate faster, they do not rely as much on ocean-atmospheric interactions.
- They can still trigger heavy rainfall and favor tropical cyclone formation.



Signatures of Upper Divergent Kelvins (and MJO)

- They often show up in enhanced outflow: Broad region of opening/diffluent cirrus in tropical regions.
- Enhanced outflow means an enhanced upper divergent pattern that relates to enhanced ascent and enhanced low-level convergence.



Outflow during a Kelvin wave that enhanced precipitation during the passage of Ian through the Windward Islands as a disturbance in 2022.

Thank You!

ICAO