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Easterly Waves and the Tropical Upper Tropospheric Trough (TUTT)

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Overview

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02 Easterly Waves

03 Tropical Upper Tropospheric Trough (TUTT)

04 Identification Exercises

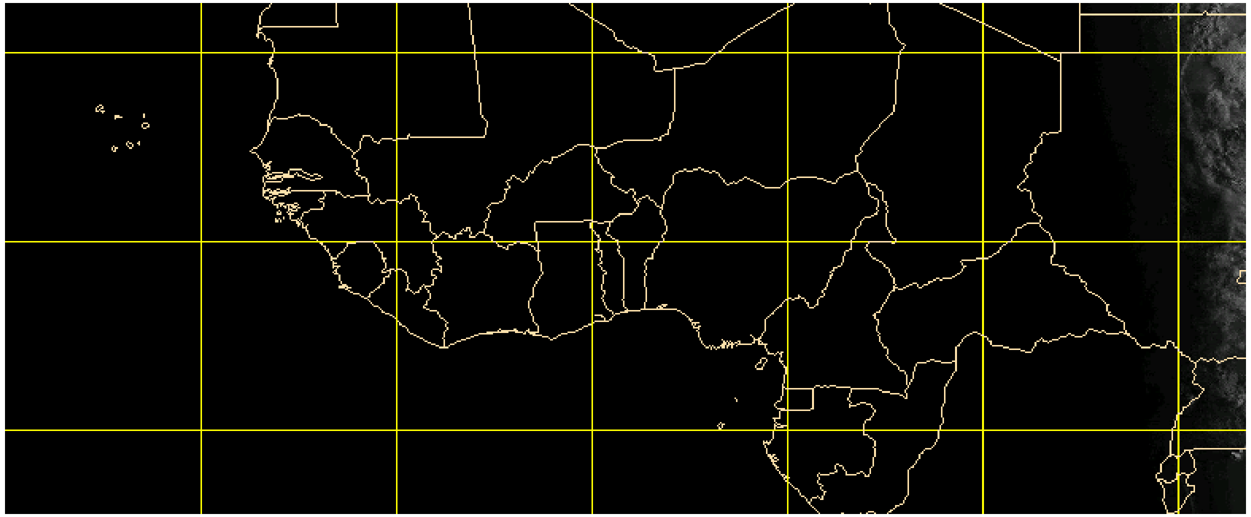
01

Easterly waves vs Induced troughs and why differentiate them

Easterly Waves vs Induced Troughs

Both are troughs that manifest in the low-level flow, especially 850 and 700 hPa (1.5 – 3km AGL).

The main difference is that an easterly wave propagates in the easterly trades, but an induced trough follows the inductor system, generally an upper level trough. This means that their impacts can be different.

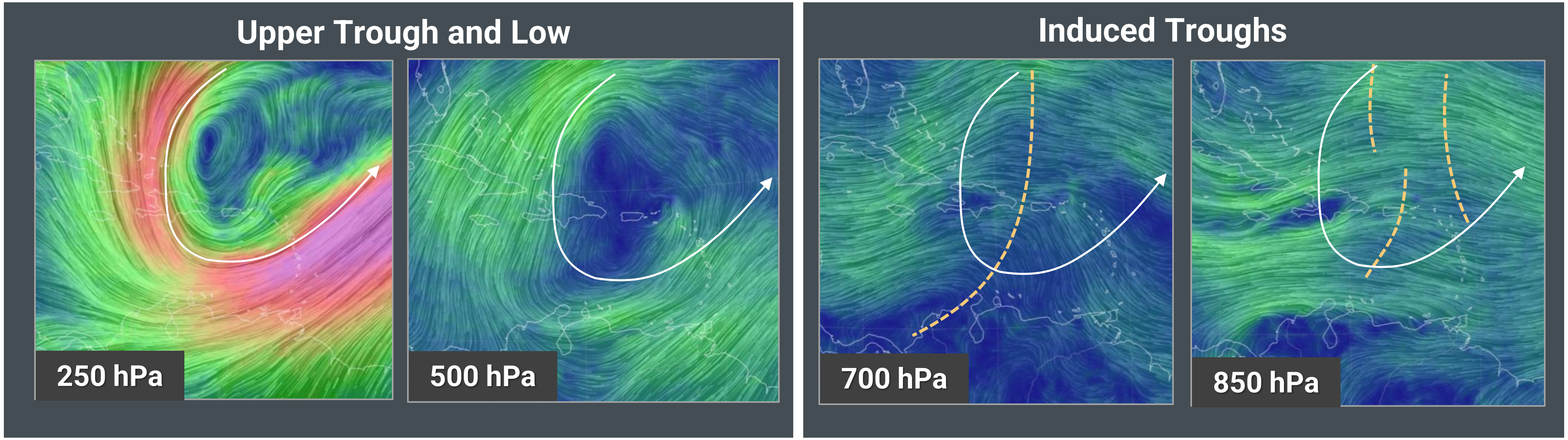


Easterly Waves propagating across North Africa in a visible satellite animation.

Example of an Induced Trough

On April 6th 2023, a large and robust upper trough centering north of the Dominican Republic, induced trough in the easterly trades, visible at 700 and 850 hPa.

The broad induced trough organizes in several smaller troughs (850 hPa).



Commonalities of Easterly Waves and Induced Troughs

- Both can produce significant persistent precipitation (rain/rain showers and deep convection).
- Both can produce severity, especially in the form of wind gusts.
- Both can develop into Tropical Cyclones.

So, why differentiate them?

Why differentiate an easterly wave from an induced wave?

1) Induced waves can remain stationary = persistent Tstorms and rain

- Higher potential to produce flash flooding, generally soon. Colder upper troughs in the mid-levels, could favor severe weather including hail in some locations and aviation hazards.

2) Easterly Waves can interact with other features

- They **move**. Then they might encounter upper systems and interact positively (more convection), resulting in areas of heavy/potentially severe convection (aviation hazards). But they can also interact negatively, transitioning to fair weather.

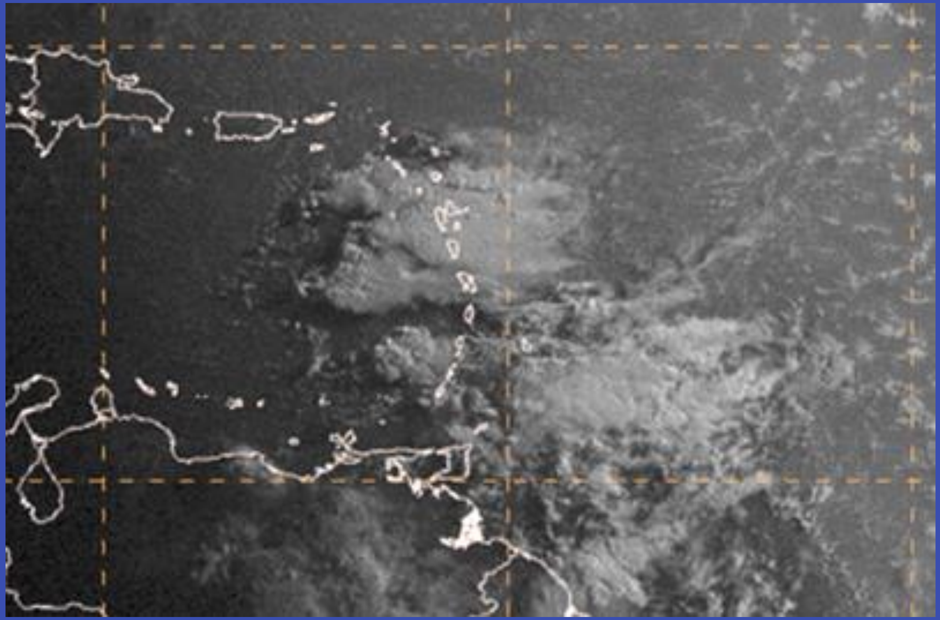
02

Easterly Waves

What is an Easterly Wave (EW)?

- Perturbation that propagates westward in the easterly trades. It tends to reflect as a trough (band of enhanced cyclonic vorticity) in 850 and 700 hPa and tends to associate with enhanced convection and rainfall.

- African Easterly Waves (AEW), referred to as "Tropical Waves" (TW) in some instances, are a sub-type of easterly wave. The only difference is that they originate in Africa (Riehl, 1945 and Burpee, 1972).



… AEW tend to be more robust than other EW, but this is not always the case.

African Easterly Waves (AEW)
also called Tropical Waves (TW)

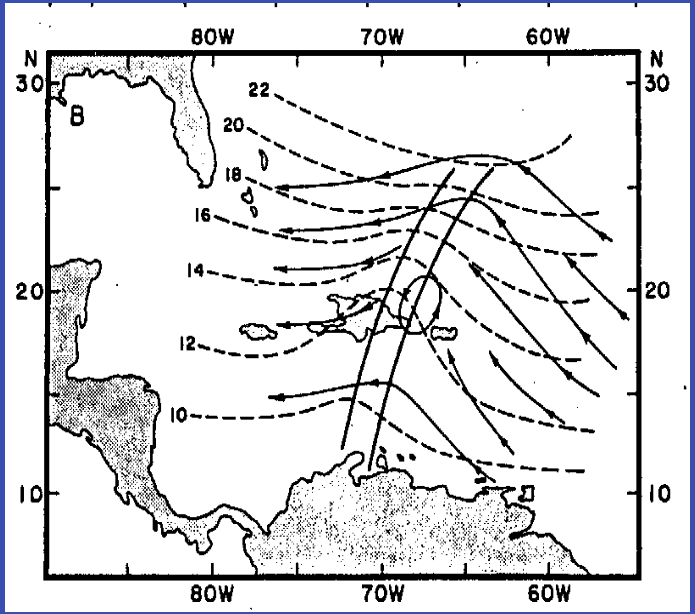
- Subtype of Easterly Waves.

- They tend to be more robust, larger in scale (1500-2500km) and produce stronger impacts in the flow and precipitation than non-African EW. They tend to have more rotation are the most common source of tropical cyclones.

- This prompted their study and description since the 1940’s (Riehl, 1945). This we will study these ones first.

African Easterly Wave (AEW or TW)

- **Conceptual Model**
  - Riehl (1945) : Inverted “V”
  - Burpee (1972):
    - -Origin in North Equatorial Africa
    - -Instability on Easterly Mid-Level African Jet.
    - -Easterly waves that form in-situ are not classified as Tropical Waves.



- **Characteristics**
  - Meso-synoptic scale trough in the lower troposphere.
  - Typically from the surface up to 850-700 hPa (1.5 - 3 km)
  - Rotation best defined at 850 and 700 hPa.
  - Strong waves can reflect at 600 hPa.

Origin of African Easterly Waves

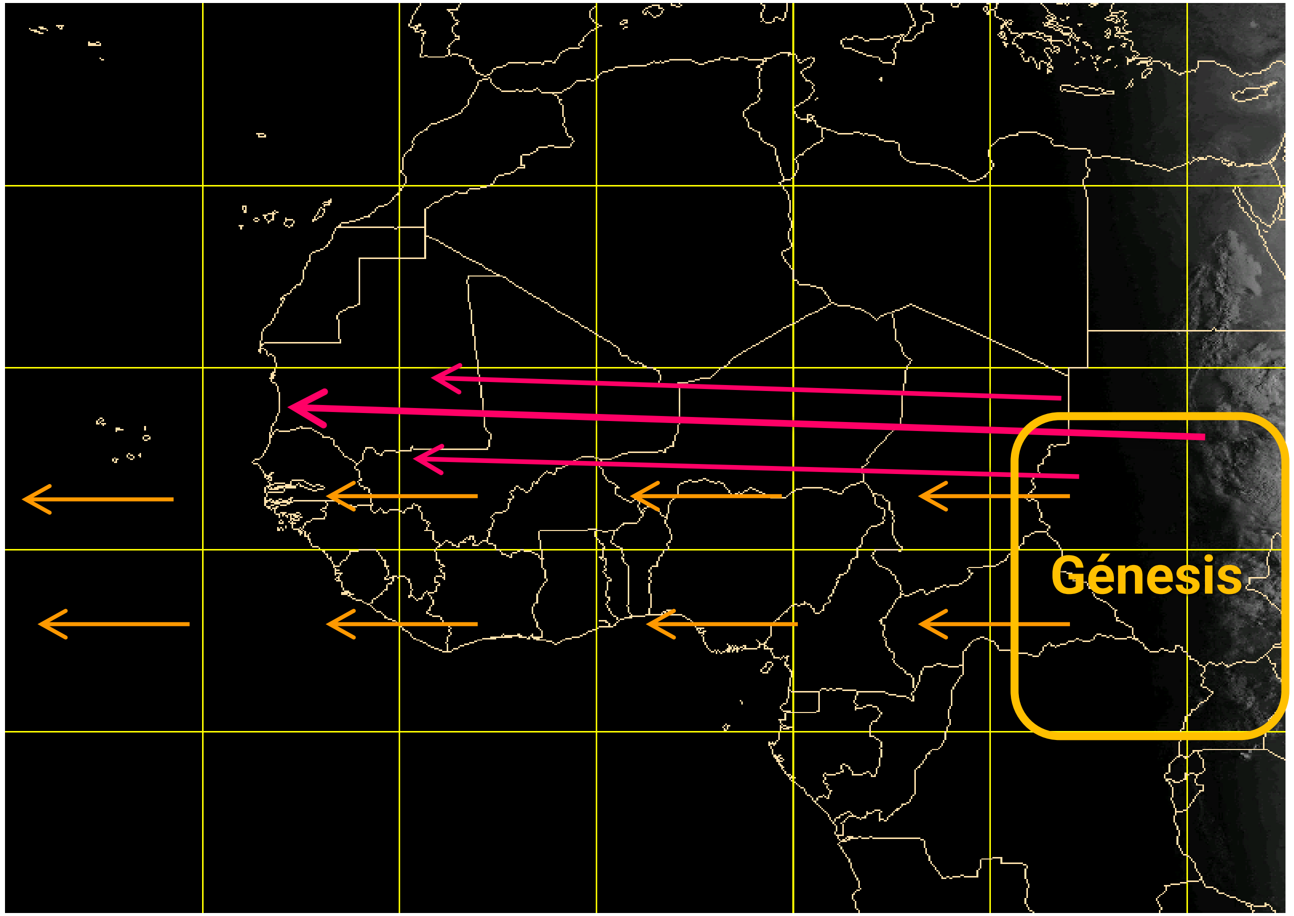
They originate from strong convection in Tropical North Africa (Ethiopia, Kenya and South Sudan)

They propagate westward following low and mid-level easterly Flow.

Then acquire vorticity (rotation) from:

1. Cyclonic vorticity from the mid-level African Easterly Jet located between the North Sahel and southern Saharan Desert (red arrows).
2. Organized convection enhances cyclonic vorticity in the system.

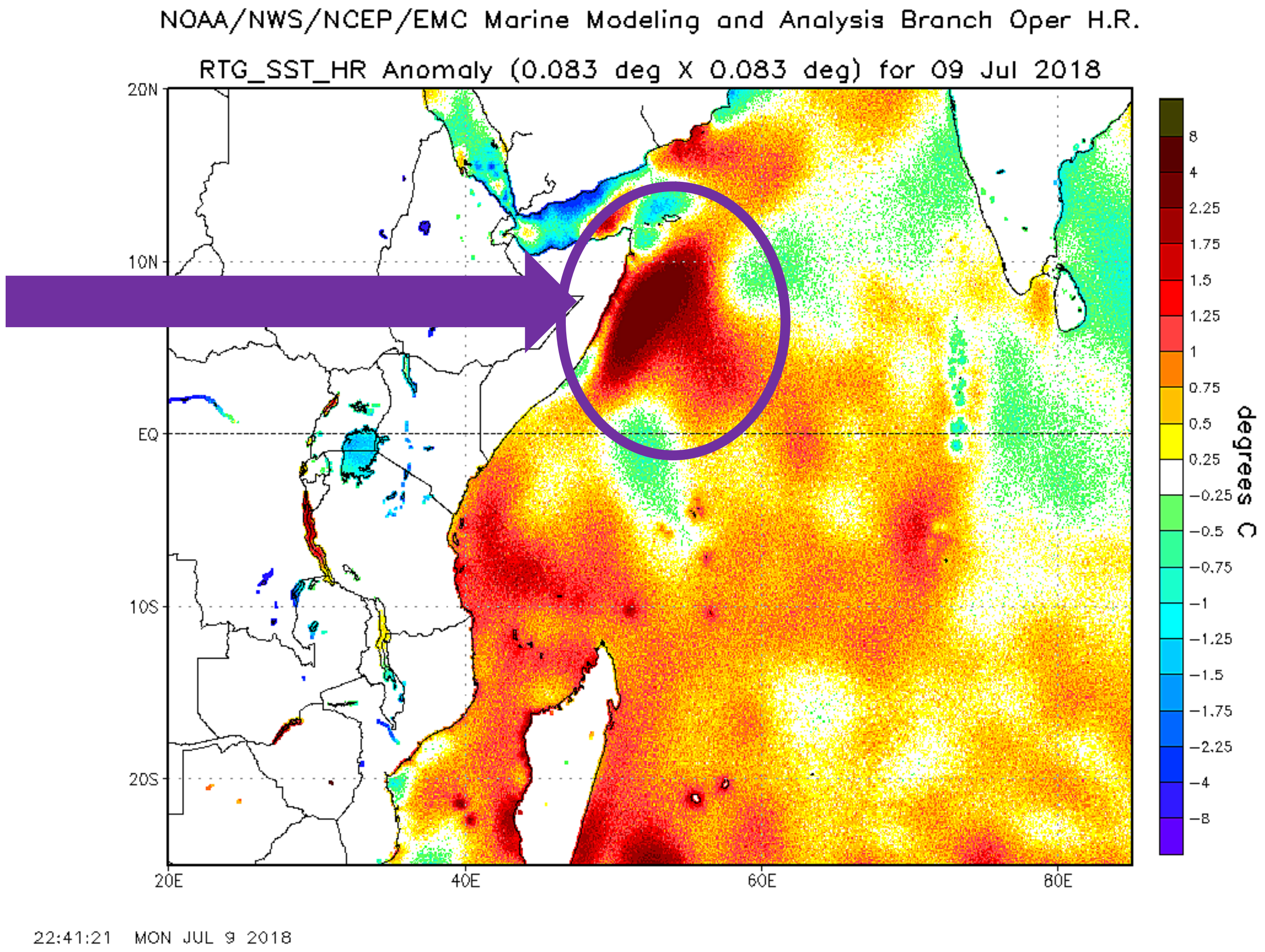
Tropical North Africa, Satellite Visible Loop



Warm SST Anomalies off the Horn of Africa Stimulate AEW Formation

- Warm SST anomalies highlight the availability of heat and moisture in air downstream.

- When they develop off the Horn of Africa, they favor stronger Convection in Ethiopia/Kenya, which produces stronger rotation and stimulates the strength and formation of AEW.



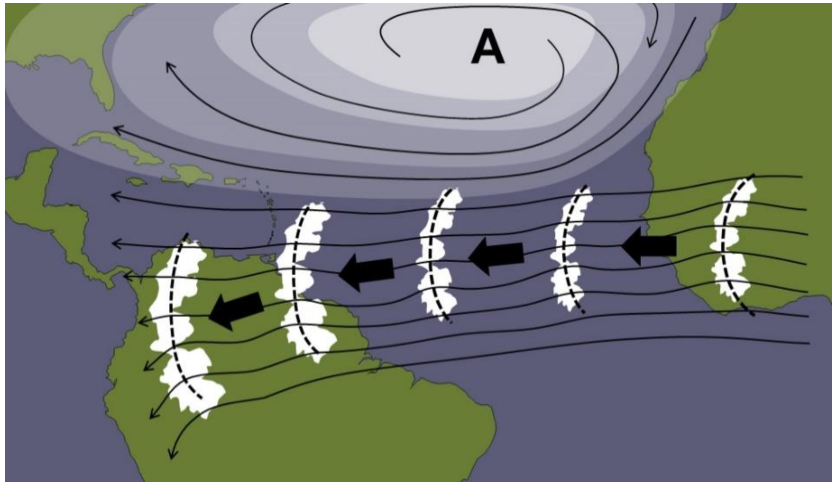
African Easterly Wave Characteristics

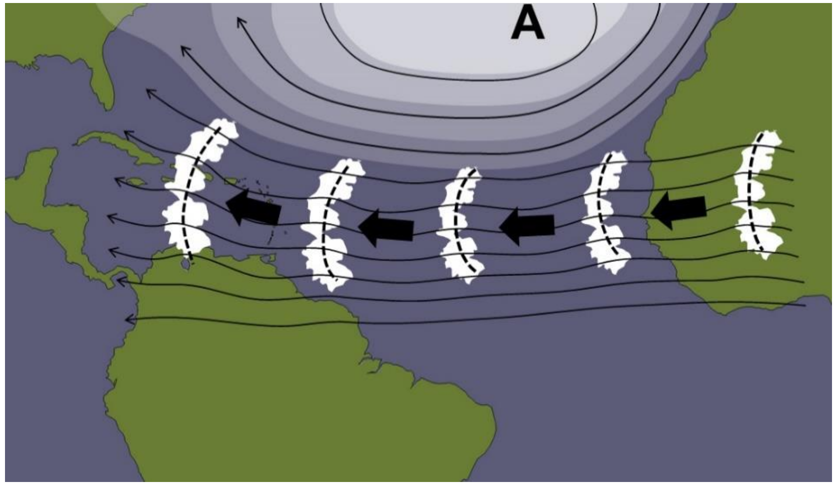
- **Propagation**
  - Westward or from the east (type of "Easterly Wave")
  - Propagation speed → 10-15 kt
  - Horizontal wave amplitude → 1,500-2,500 km
- **Frequency:** Period of 3-4 days between waves.
- **Seasonality**: April through November

More pronounced from June through September when Ethiopian convection and the African Jet peak.

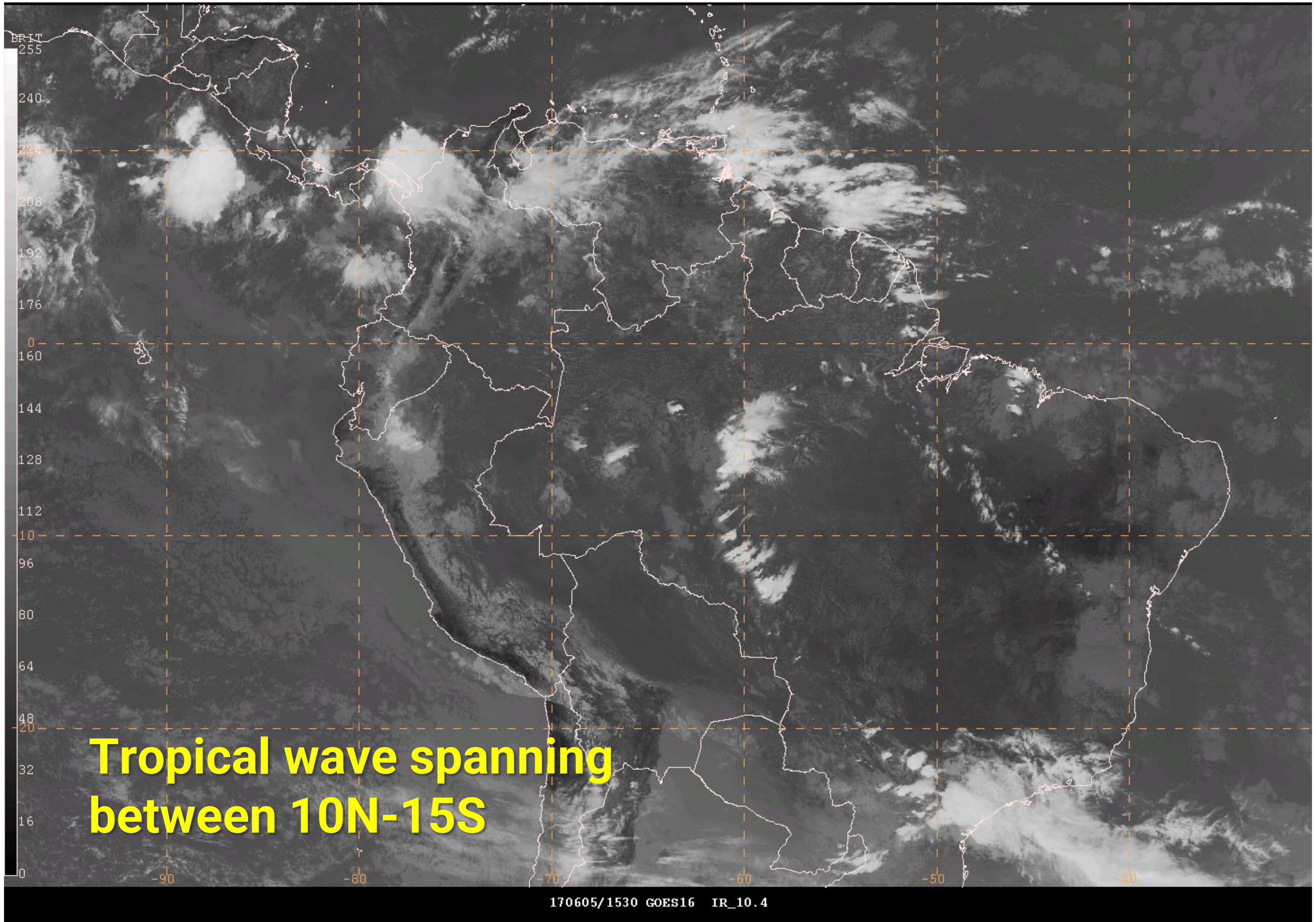
Seasonality of Propagation

- Depends on how strong and far north the subtropical ridge is.
- April-June: Stronger ridge further south favors propagation into South America.
- July-October: Ridge displaced northward favors waves entering the Caribbean.
- ITCZ convection and perturbations fuel the waves.



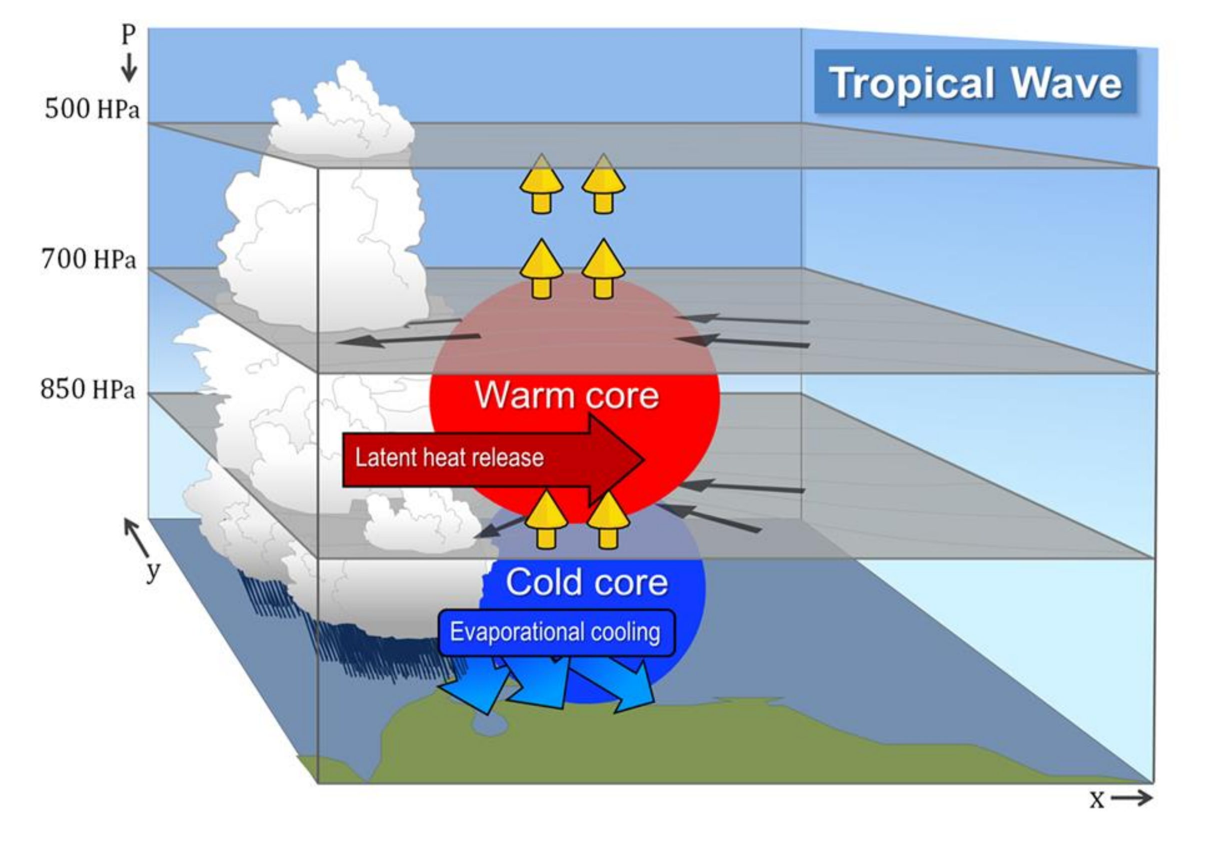


Early Season Tropical Wave (June)



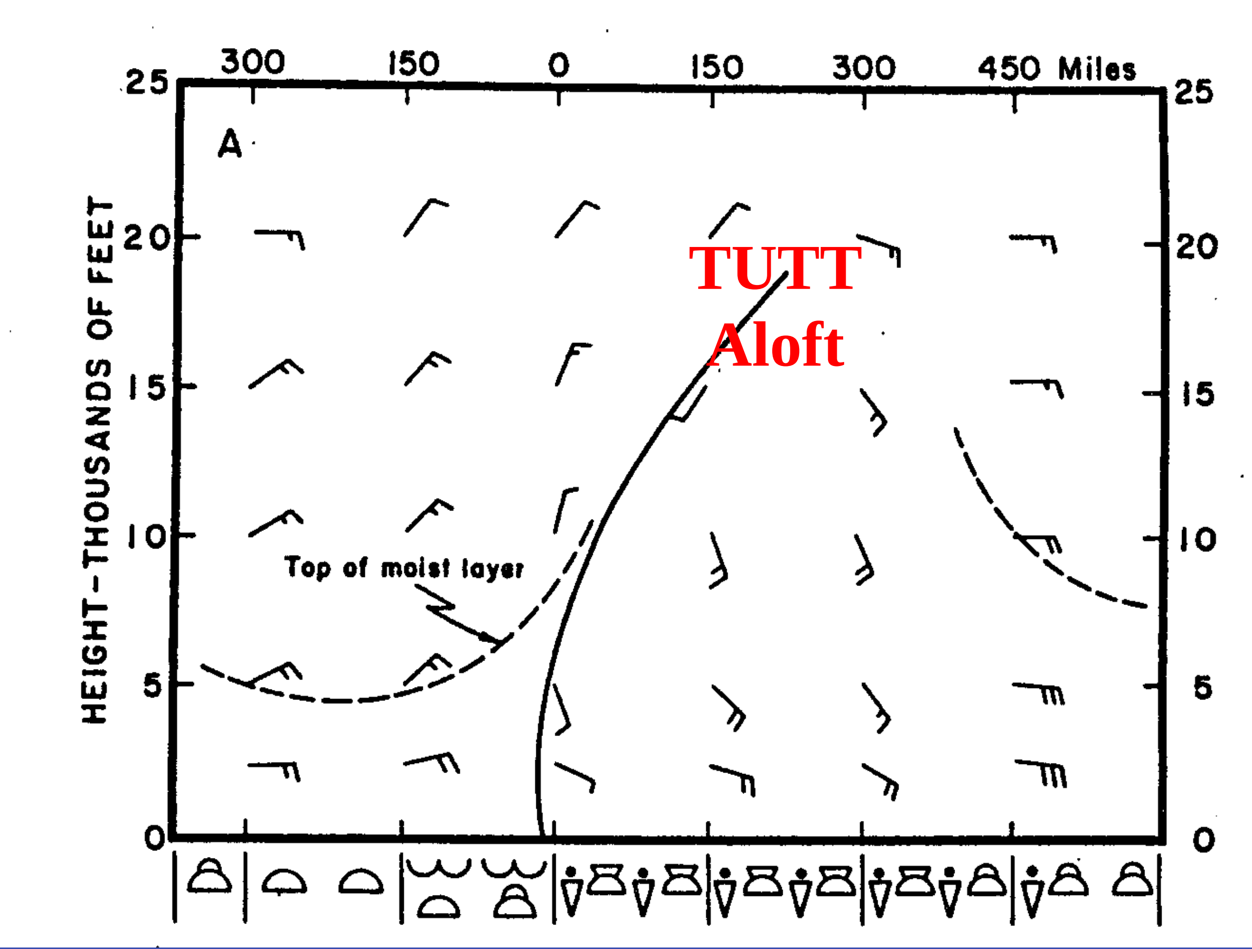
African Easterly Wave Characteristics

- **Core: Cold at low levels/warm above.**
- **Sustained by latent heat released by condensation.**
- **Vorticity:** Due to low level cold core and upper warm core, the cyclonic vorticity increases from surface to 850/800 hPa, then decreases with height.
- **Effects of Vertical Wind Shear on convection**
  - **Weak: Enhances convection.**
  - **Strong: Inhibits convection.**



Riehl's Conceptual Model

- Riehl's conceptual model showed a deep layer trough extending from the surface to 500 hPa, in this vertical cross section.
- It is an ideal wave, but this model shows the influence of a TUTT, as the rotation is more pronounced in the mid-upper troposphere.

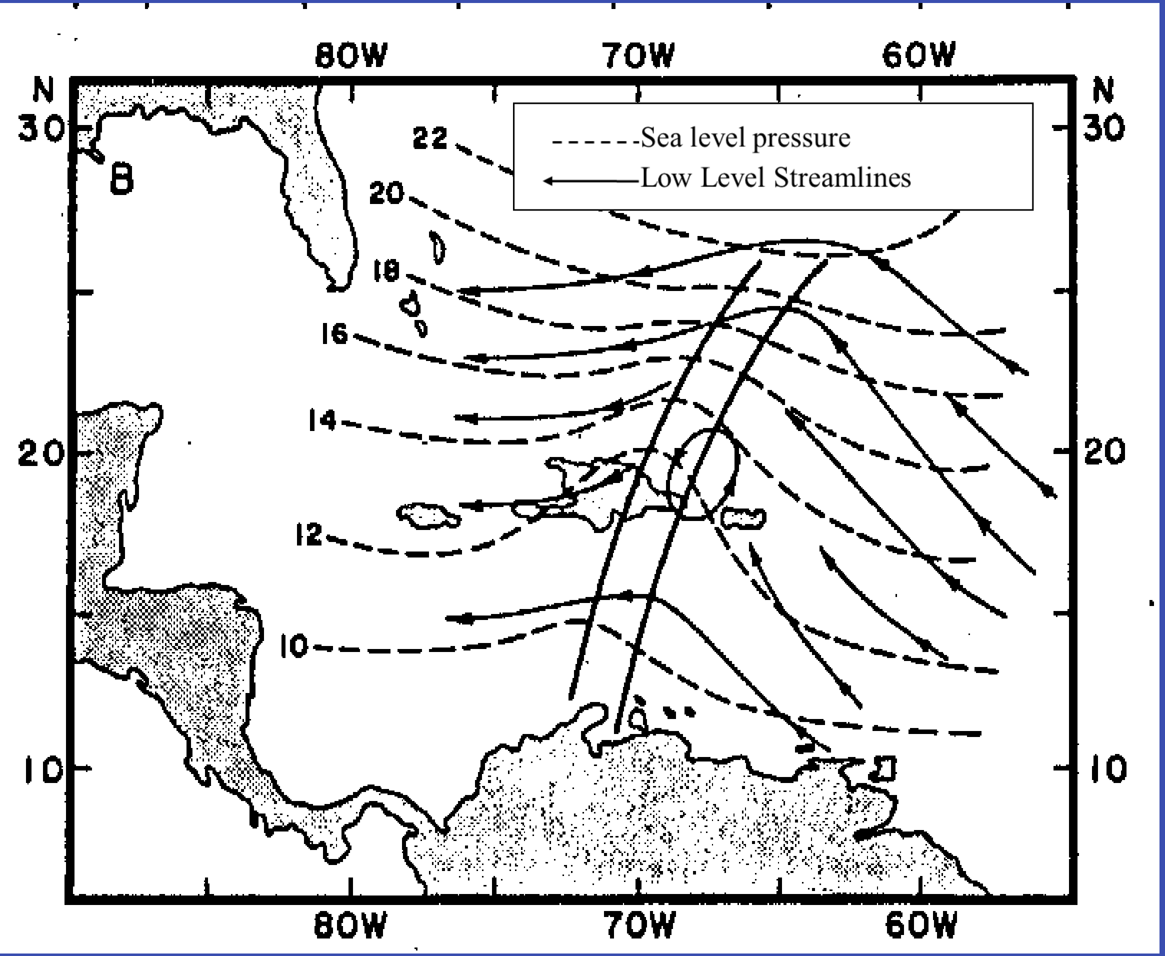


Riehl's Conceptual Model

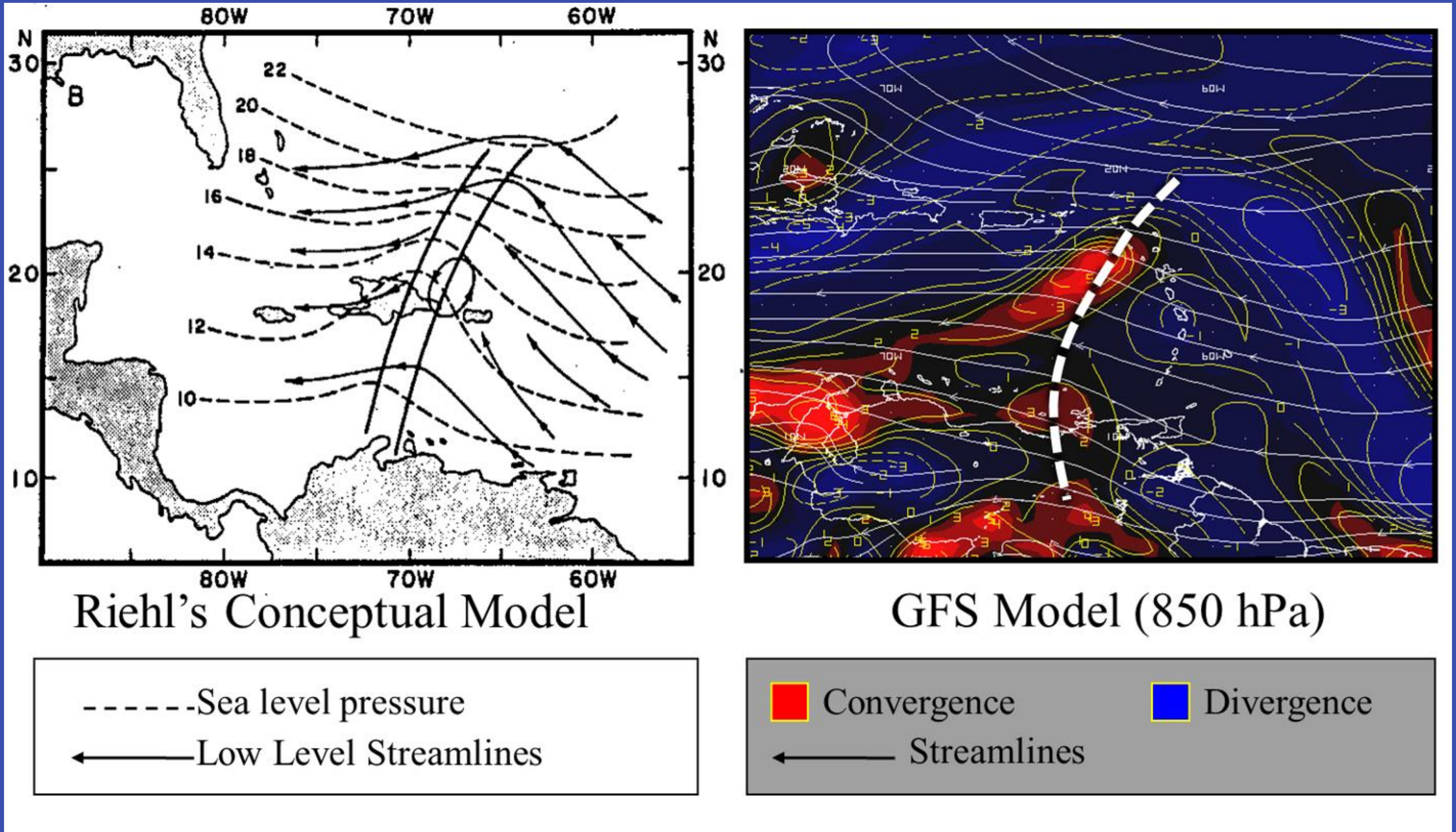
- In the horizontal, Riehl's Model does represent fairly well the structure of strong AEW.

- The example shows a conceptual model for the Caribbean, showing a strong signal in the low-level stream lines and a weaker signal in the surface pressure field.

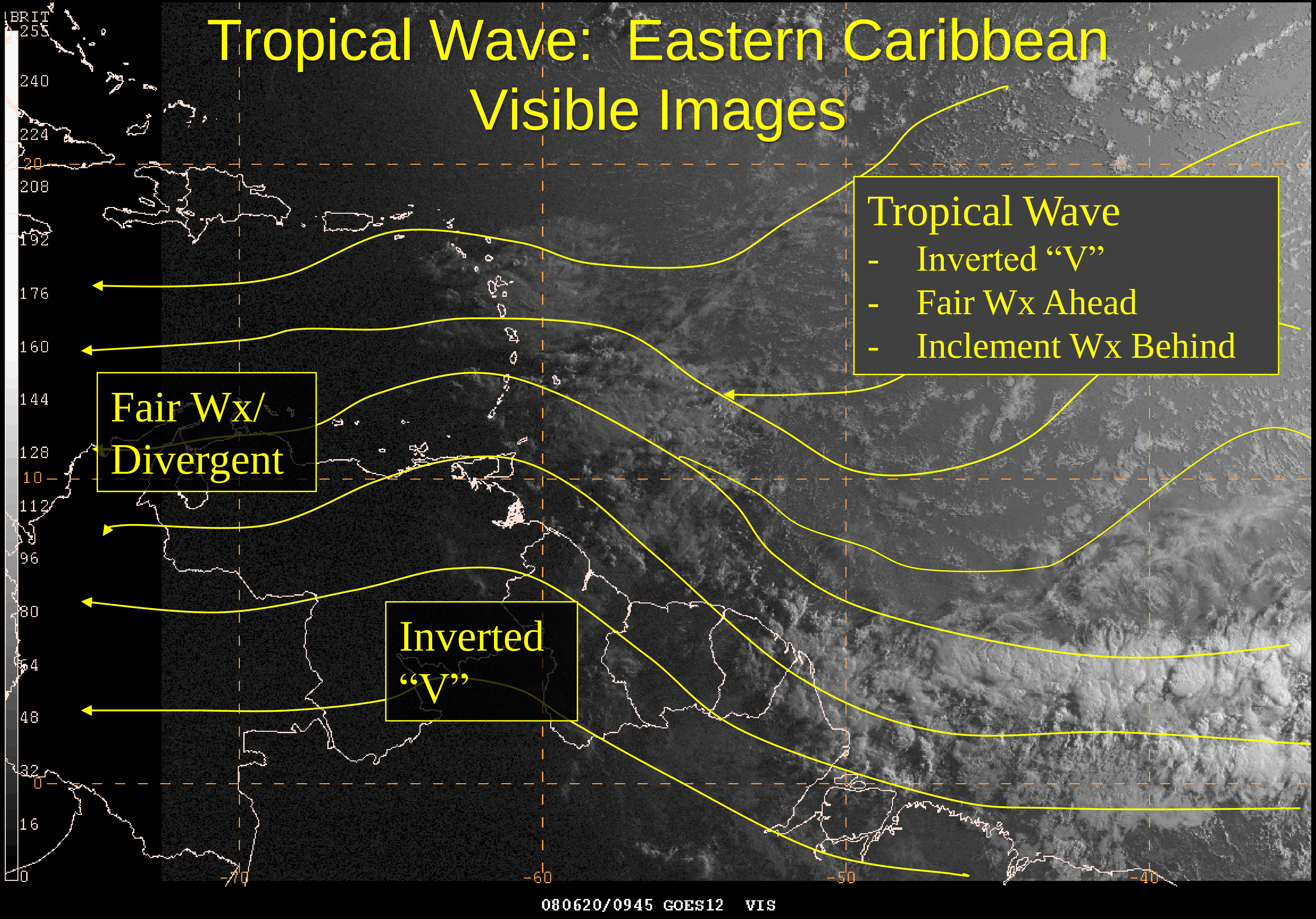
- The structure has an inverted "V" shape.



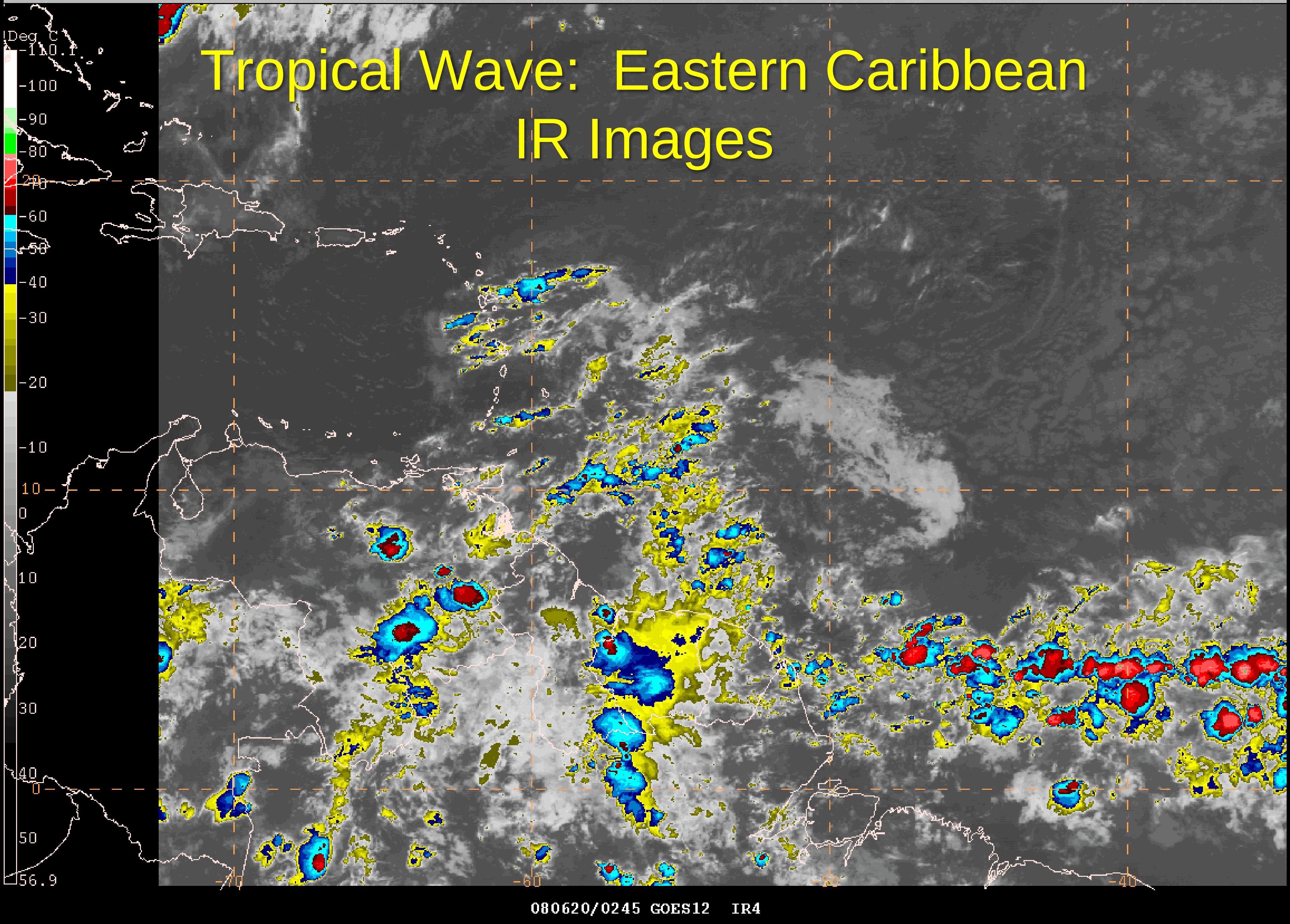
Riehl's Conceptual Model vs GFS

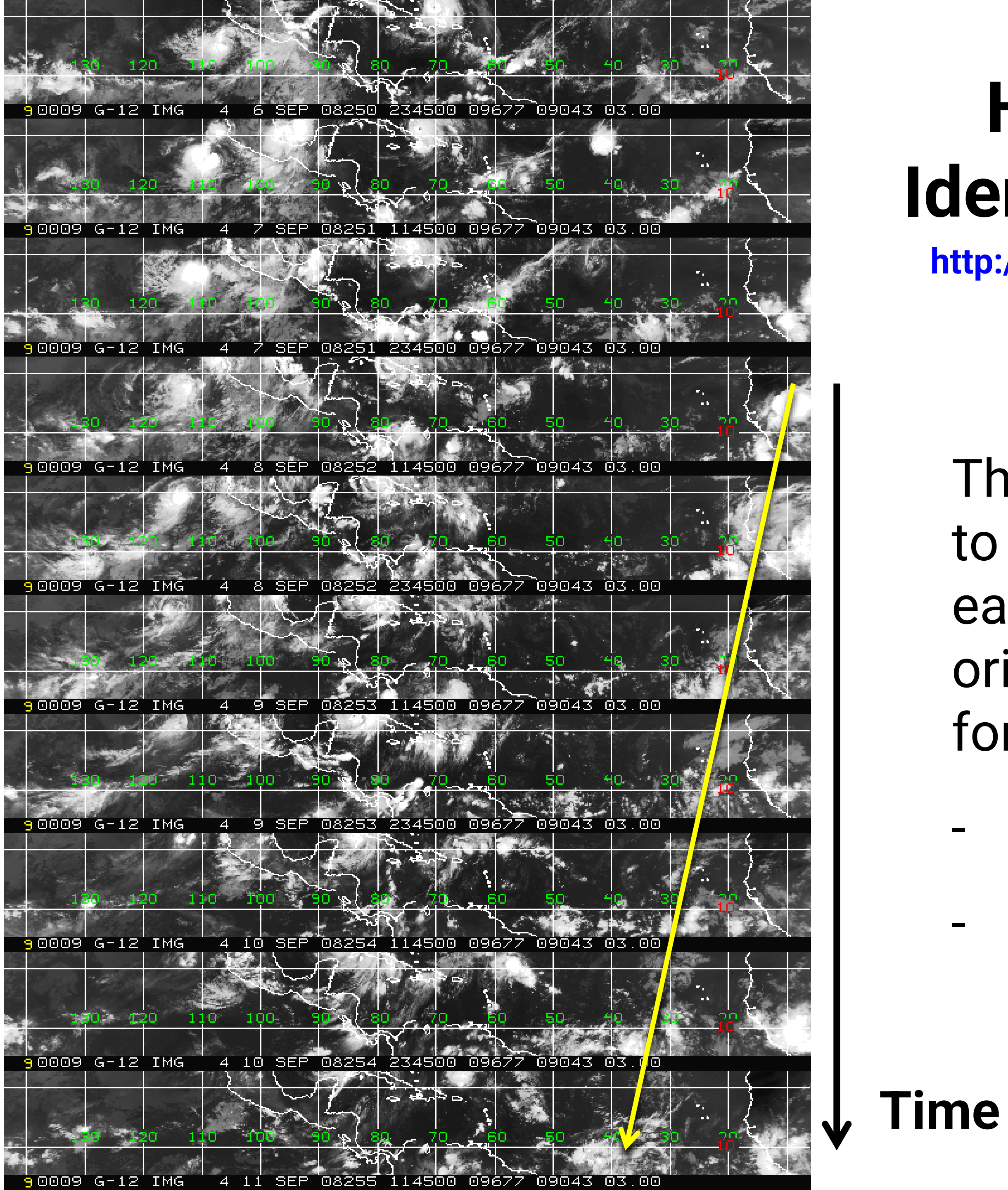


Tropical Wave: Eastern Caribbean
Visible Images



Tropical Wave: Eastern Caribbean IR Images





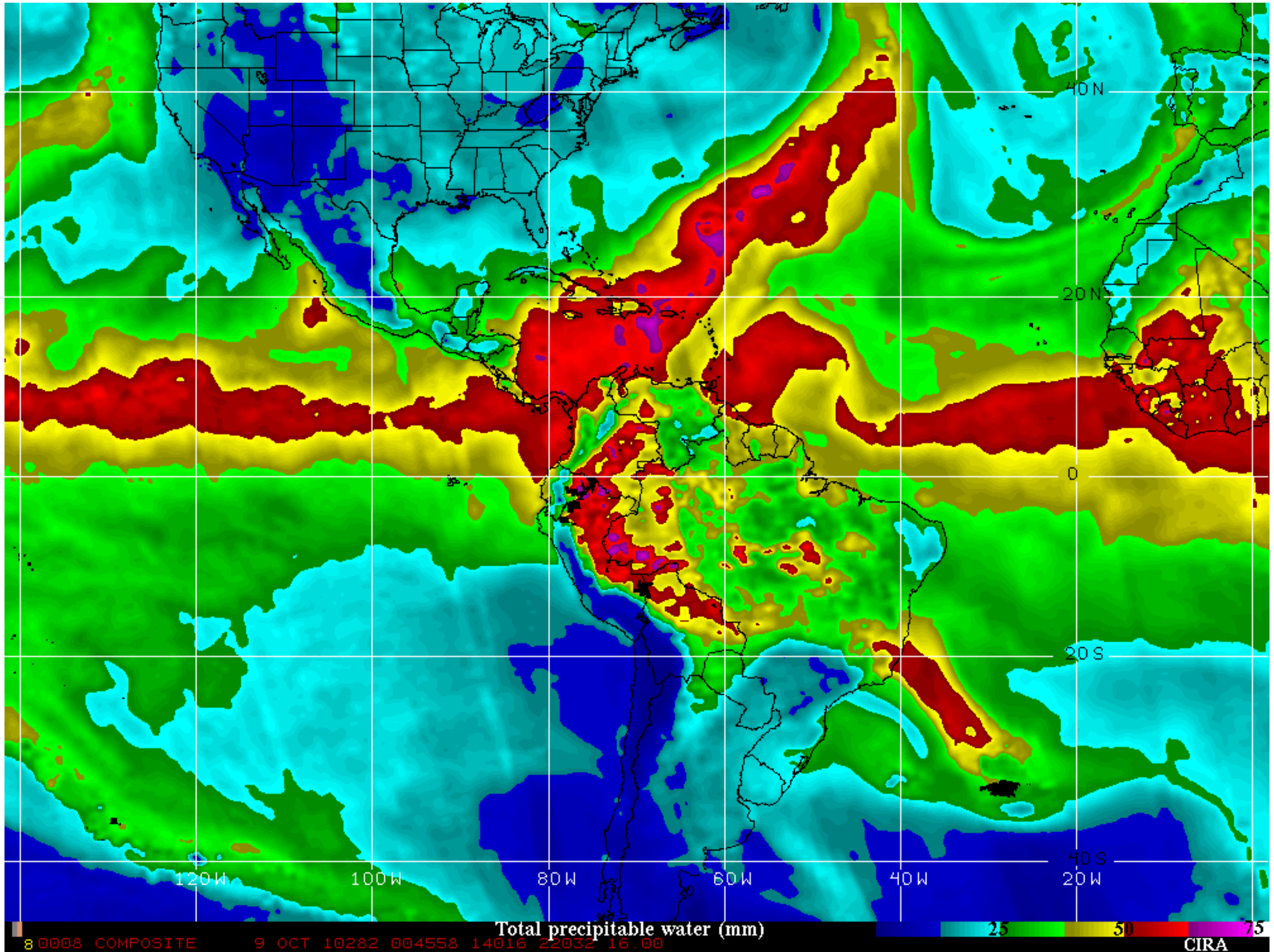
Hovmöller Diagram: Identifying African Origin

http://www.nhc.noaa.gov/analysis_tools.shtml

The Hovmöller Diagram allows us to determine the origin of an easterly wave, and whether it originated over Africa or if it formed in-situ.

- African Origin: Tropical Wave
- Other Origin: Easterly Wave

Satellite Derived TPW Analysis



The TPW analysis is another tool we can use to monitor easterly waves, and where they originated.

- In this example you can see one exiting Africa as another enters the eastern Caribbean.
- A third wave seems to be entering Central America

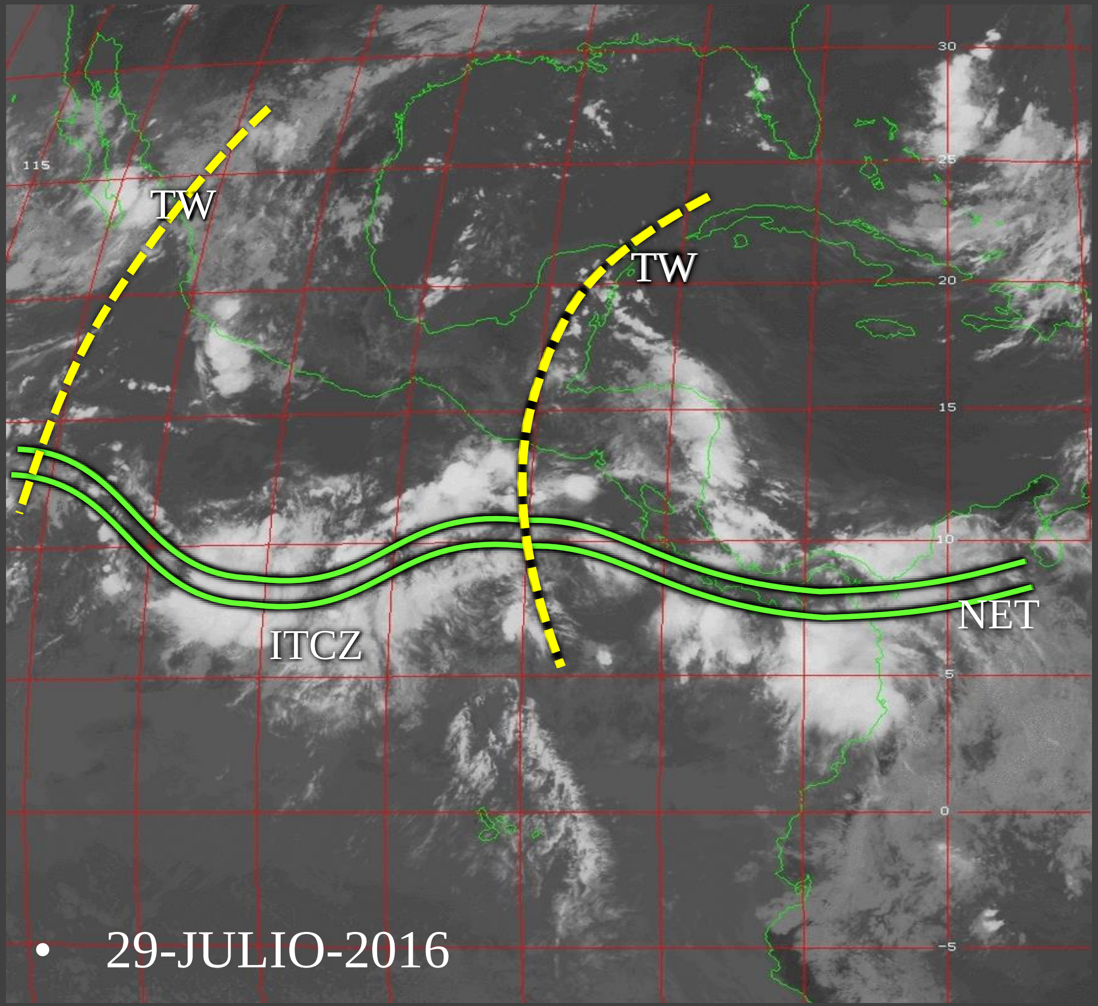
Tropical Waves and the ITCZ

They interact positively with the near equatorial trough/ITCZ

- Enhancement of convection, especially across:
  - Lake Maracaibo
  - Gulf of Urabá
  - Gulf of Honduras
  - Gulf of Fonseca
  - Gulf of Tehuantepec
- Enhancement of the Panamanian Low
  - Gulf of Panama
- Modulation of the ITCZ
  - Strong wave can modulate the ITCZ to the north/south
    - The ITCZ could migrate as much as 3-5 degrees to the north/south of its climatological position following wave passage
    - It can take the ITCZ 2-3 days to return to its climatological position.

Easterly Waves Interact with the ITCZ, modulating it

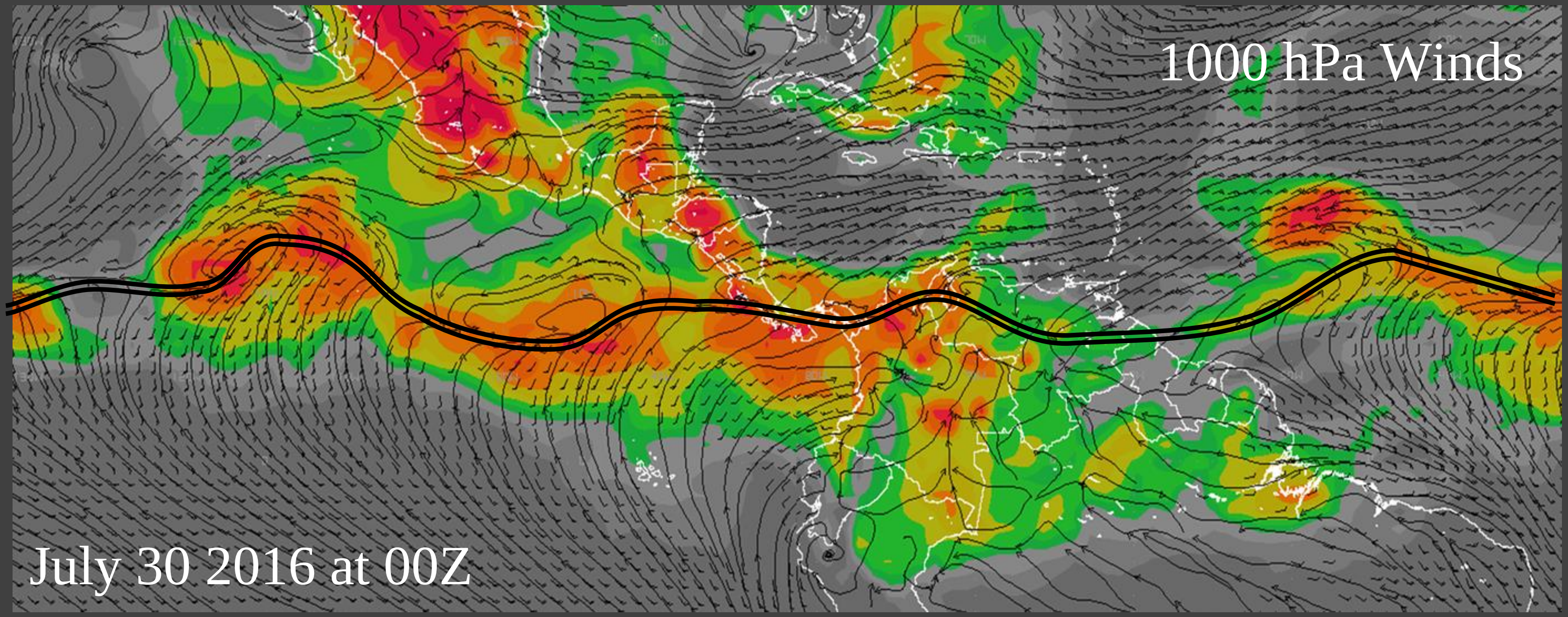
- The ITCZ undulates northward with the Waves.
- In this case there are two robust African Easterly Waves (AEW), also called Tropical Waves (TW).
- Can you spot the TUTT?



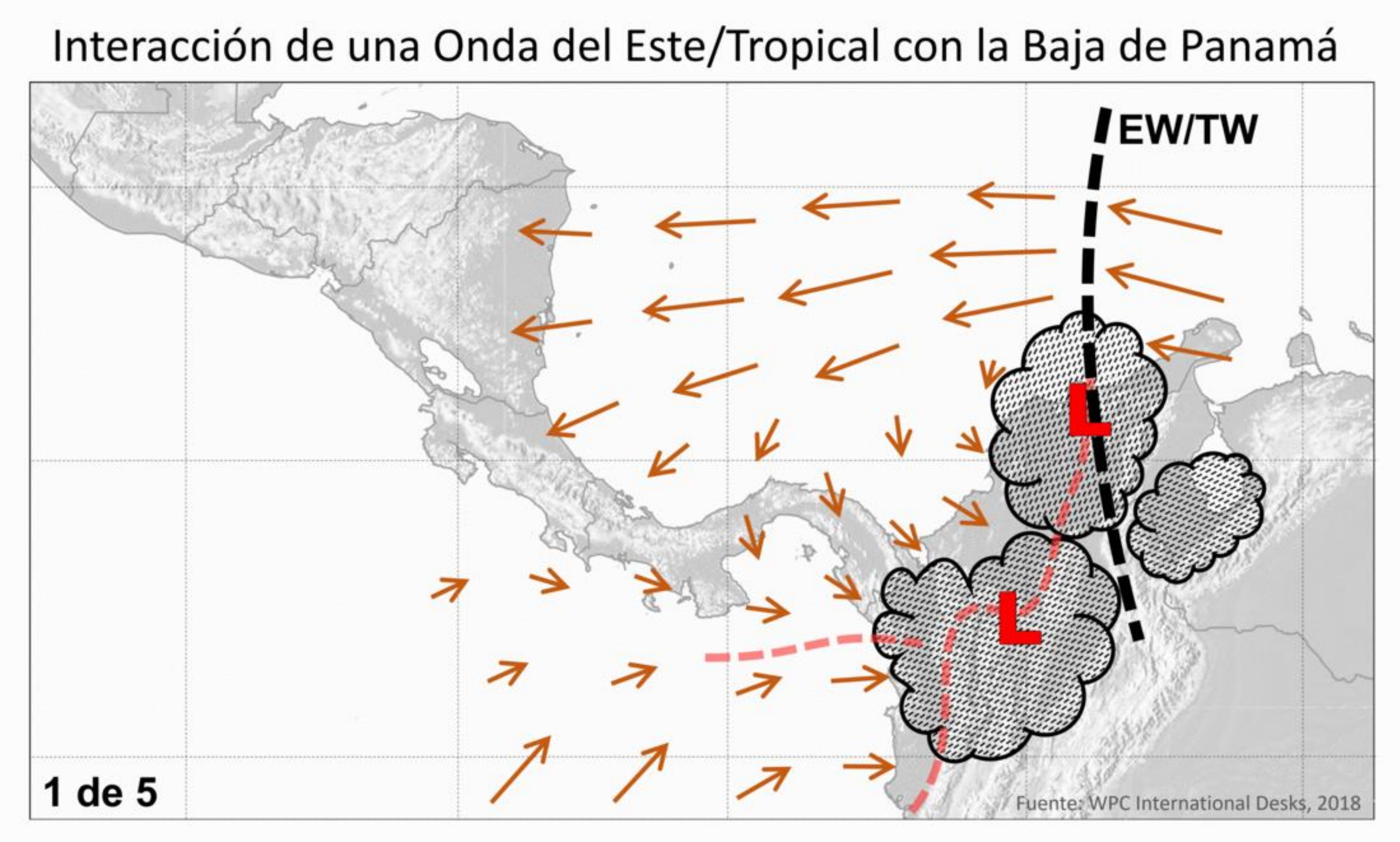
- 29-JULIO-2016

Easterly Waves and the ITCZ are often well represented by the GDI

- The GDI captures the band of enhanced moisture and instability, which results from large values of equivalent potential temperature.
- 1000 hPa winds help to find the ITCZ. For Easterly Waves, 925 to 700 hPa are often good levels.



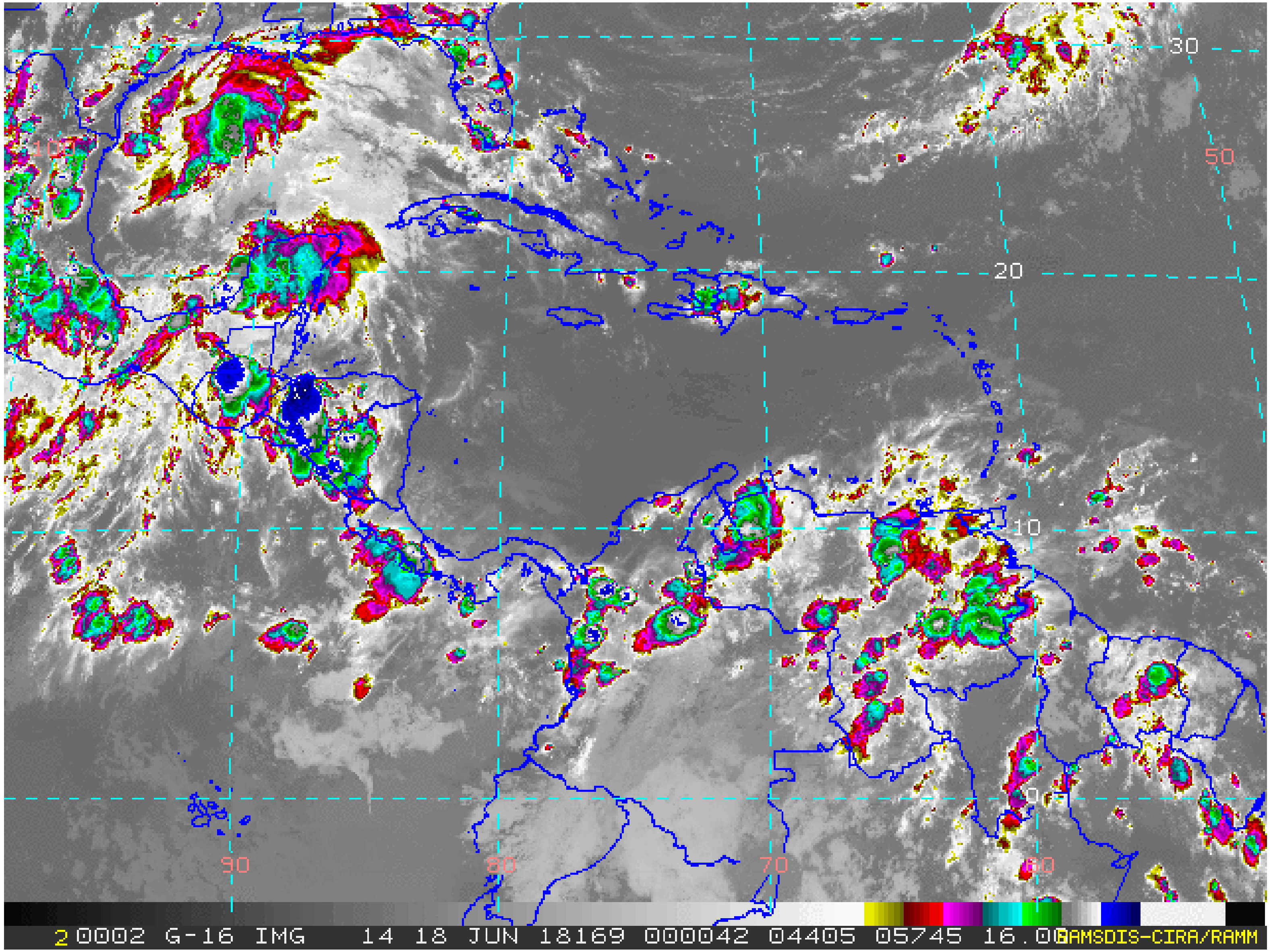
Wave Interaction with Panamanian Low/Trough



As the wave approaches, the Panamanian low deepens and the convection intensifies.

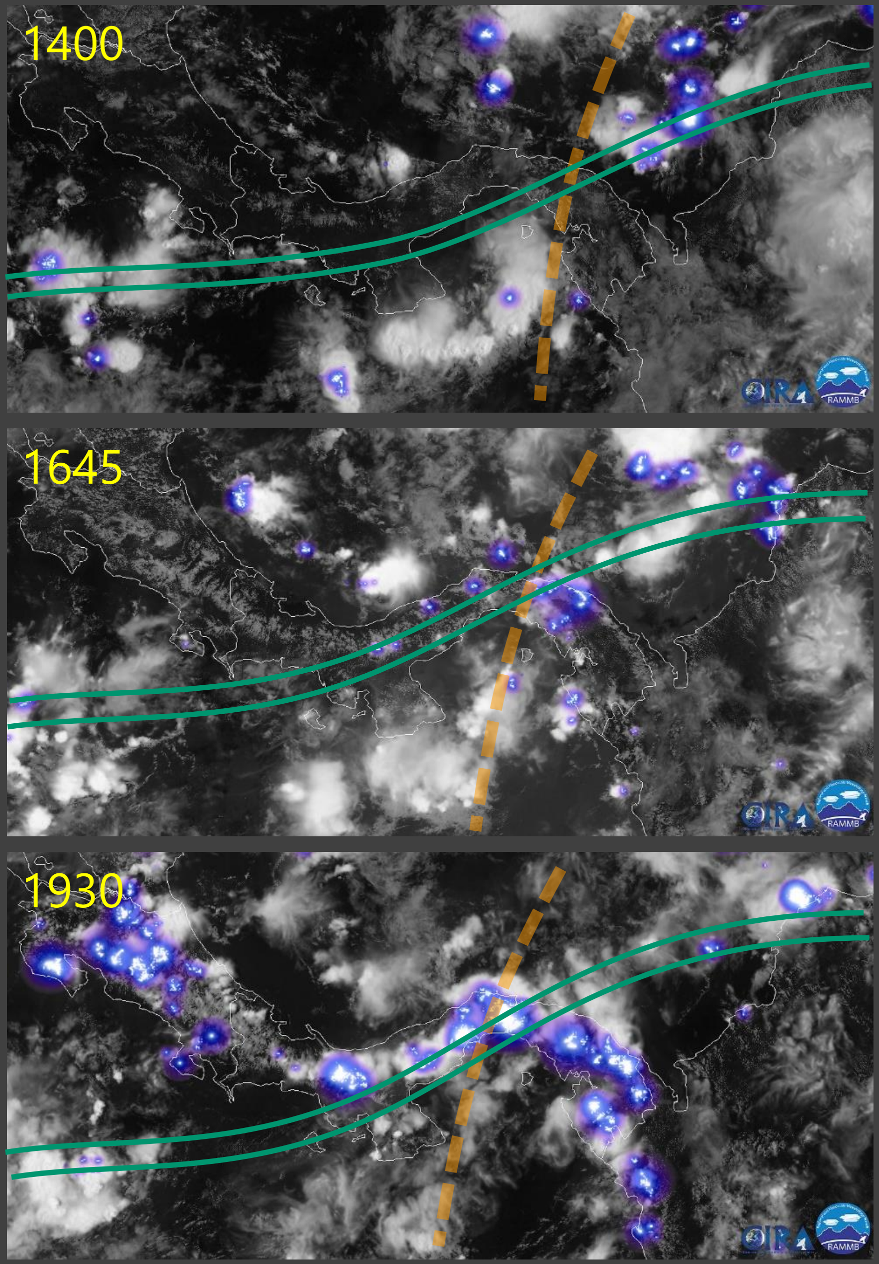
IR (10.3um): 18-20 June, 2018

Two Waves: One crossing Colombia and the other entering the Eastern Caribbean.

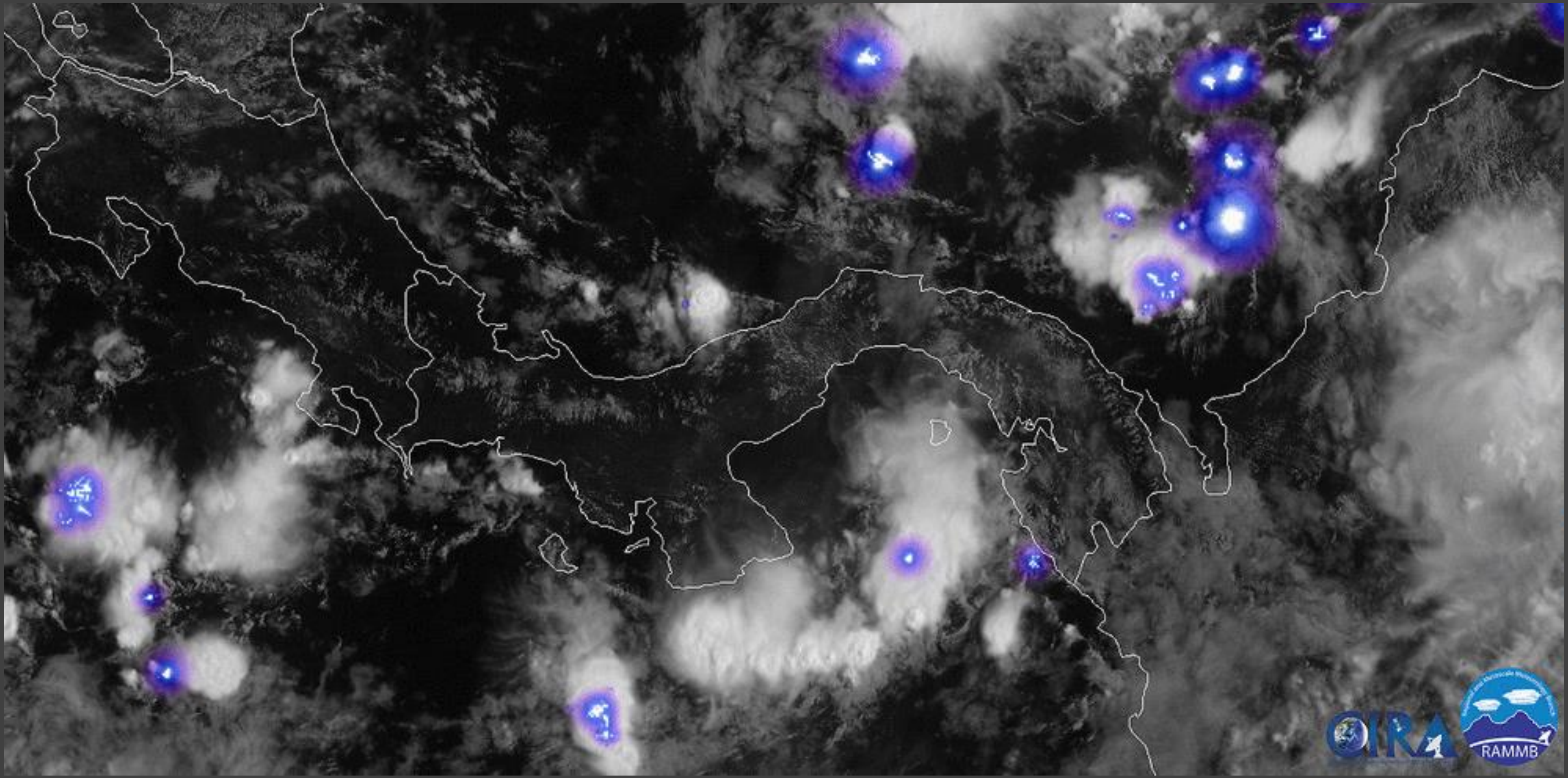


An Easterly Wave intercepting the ITCZ and entering in the early afternoon can trigger heavy Rainfall in Panama

- Weak winds in the low-level enhance convection.
- This allows diurnal breezes to trigger convection, while the ITCZ and wave favor a moister environment and enhance low-level convergence, as well as some rotation and ascent.



Easterly Wave and Convection in Panama



Canal visible, cirrus y GLM –
6/SET/2018 1400-1930 UTC

03

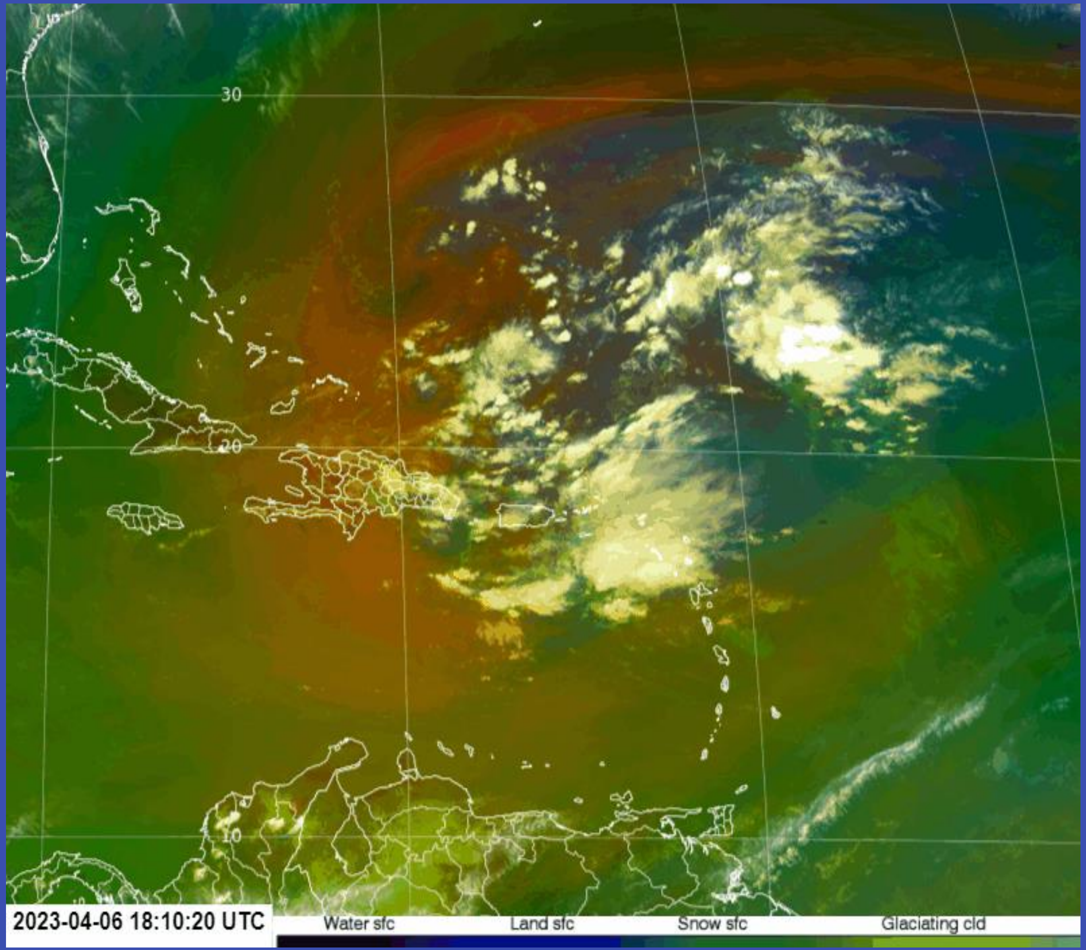
Tropical Upper Tropospheric Trough (TUTT)

TUTT

Mid-Upper atmospheric feature that separates the subtropical ridge from the subequatorial ridge.

600/500 hPa and above. They can retrogress, move westward, along the periphery of the subtropical ridge as it lies to the west and north.

Seasonality: most frequent from **May-September**.



TUTT Characteristics

Cold core system (center is colder than surroundings).

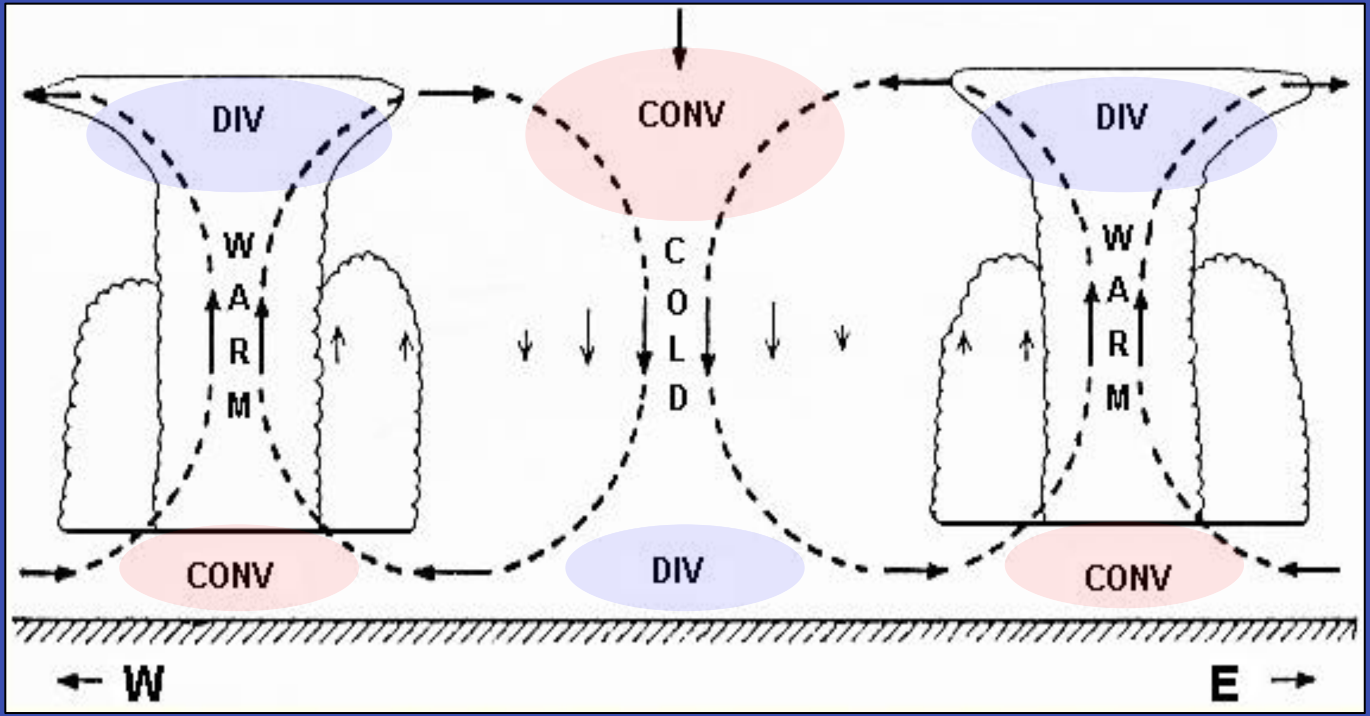
Circulation: cyclonic vorticity strengthens with height.

Maximum cyclonic rotation near the tropopause.

Source of Energy: potential energy.

Potential to kinetic energy.

Requires source of cold air, if not it tends to dissipate.

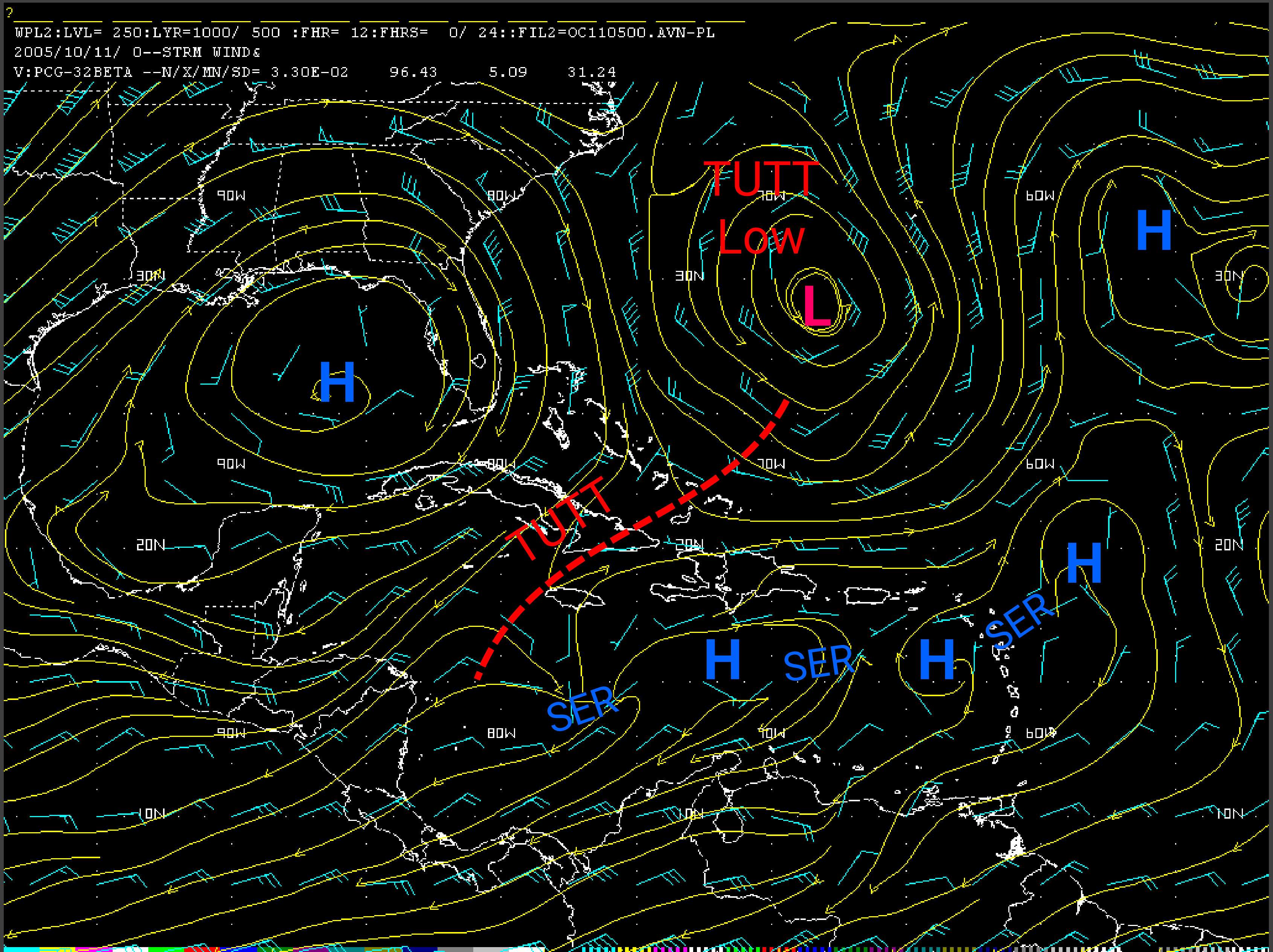


TUTT Cross Section

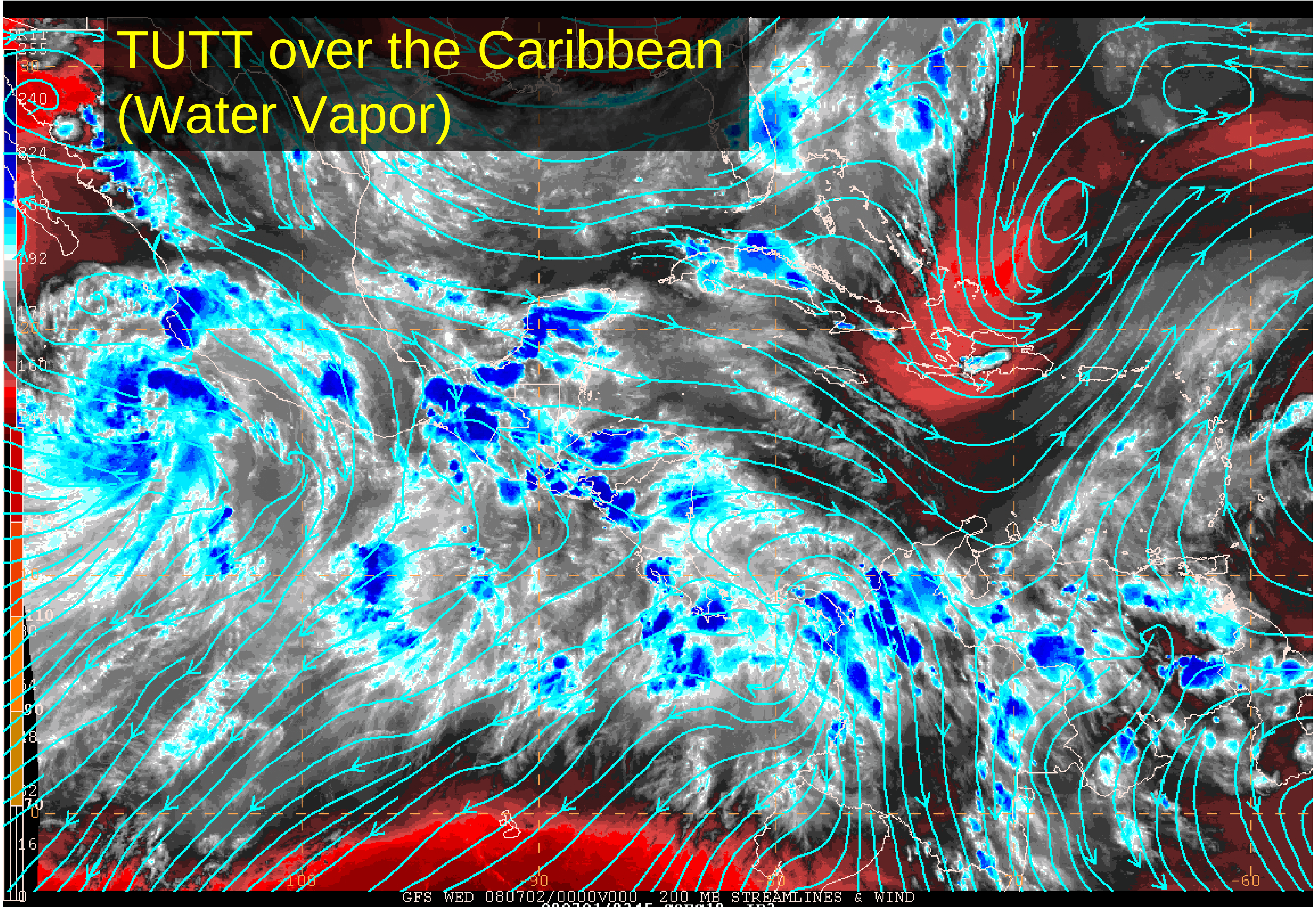
TUTT Impacts

- Formation of cloud complexes depends on heat and moisture available:
  - Most significant systems tend to form to the south of trough axis.
- Main function: supply outflow channels while venting deep convection.
- TUTT location/orientation has an important role on the secondary formation of tropical cyclones over the Caribbean/Atlantic, starting as subtropical cyclones
- Interaction with the ITCZ
  - Can induce the northward modulation
  - Can induce perturbations/inverted trough along the convergence zone
- Trigger Severe Weather and Flooding

GFS Analysis of a TUTT

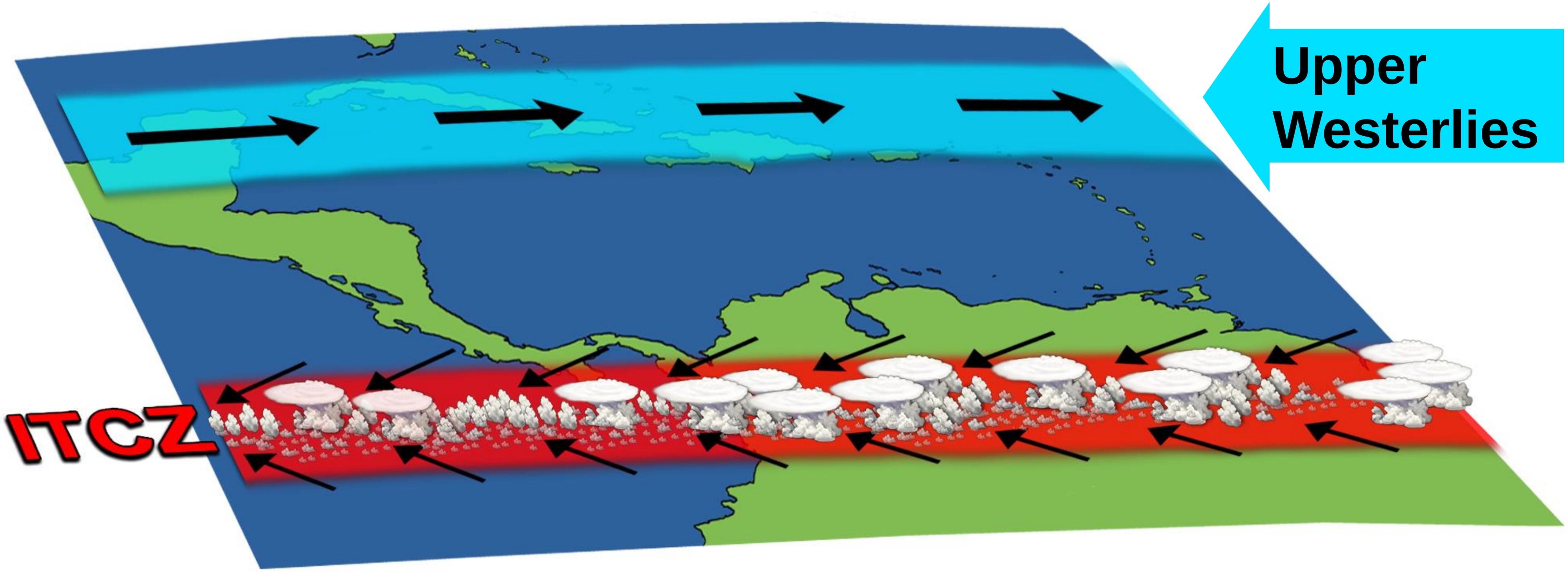


TUTT over the Caribbean (Water Vapor)



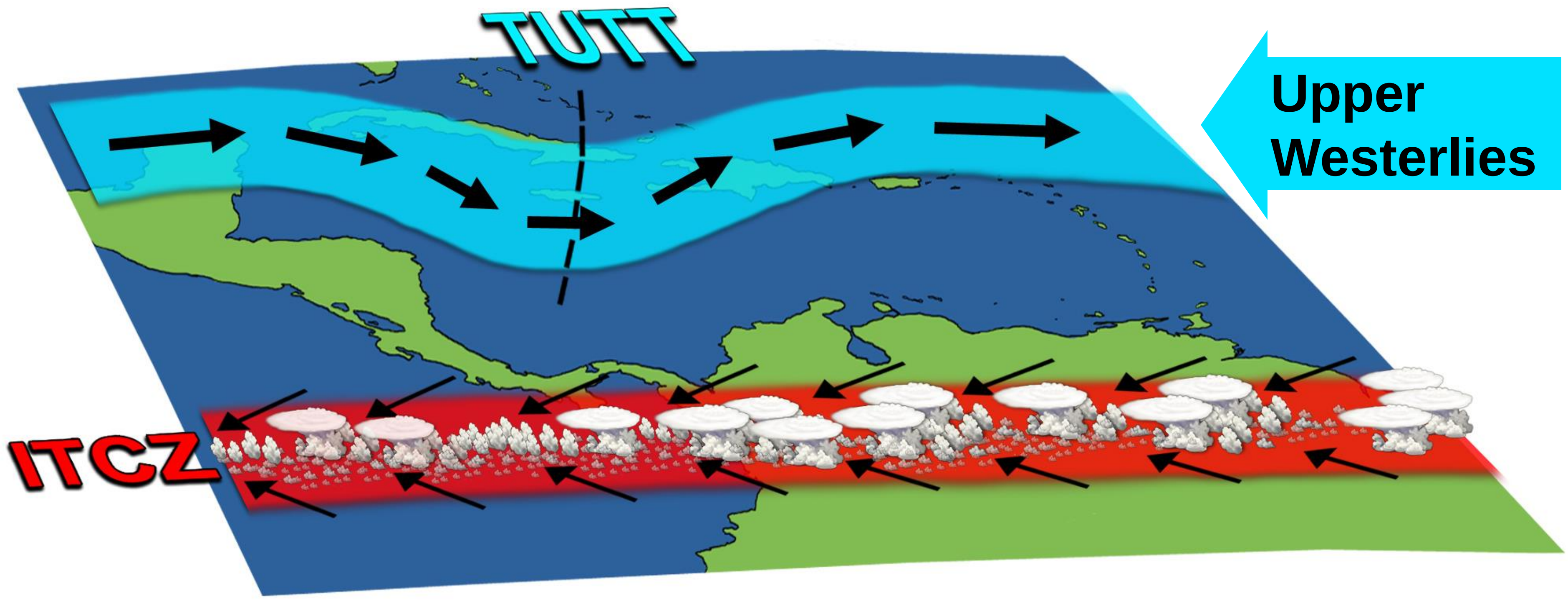
Genesis of a TUTT-Induced Trough

(1) Starts with zonal flow



Genesis of a TUTT-Induced Trough

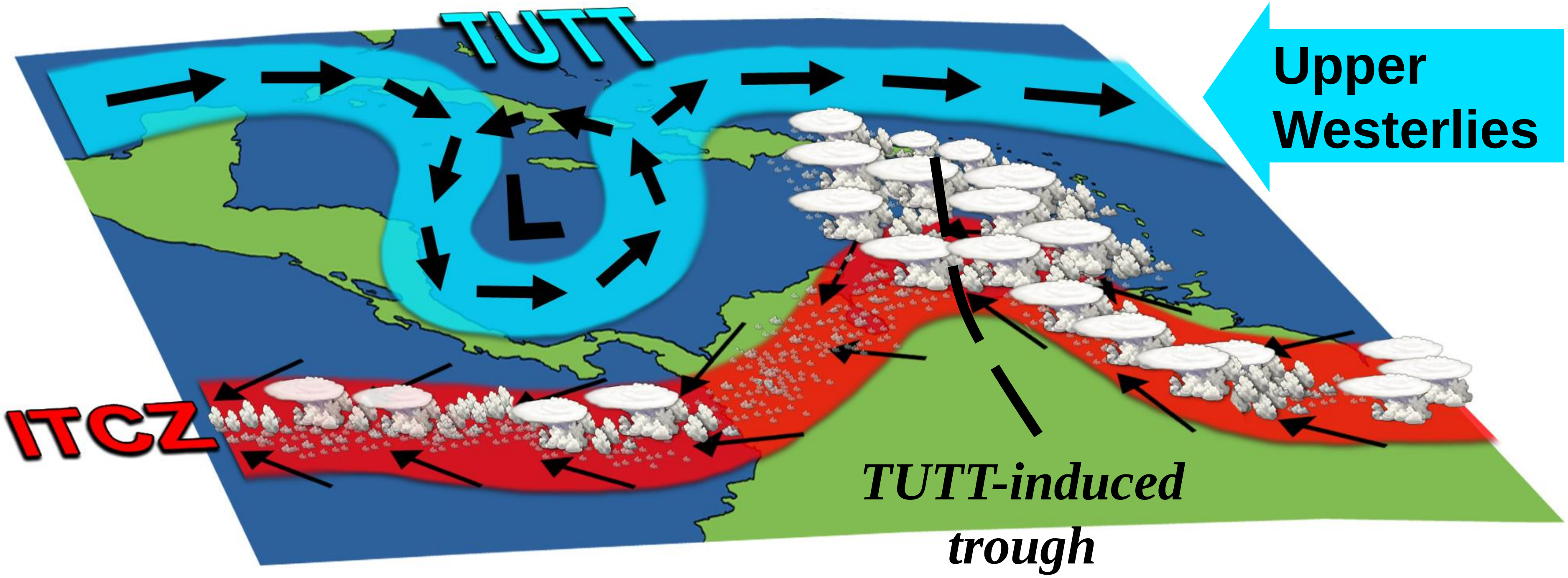
(2) Perturbation in upper westerlies forms



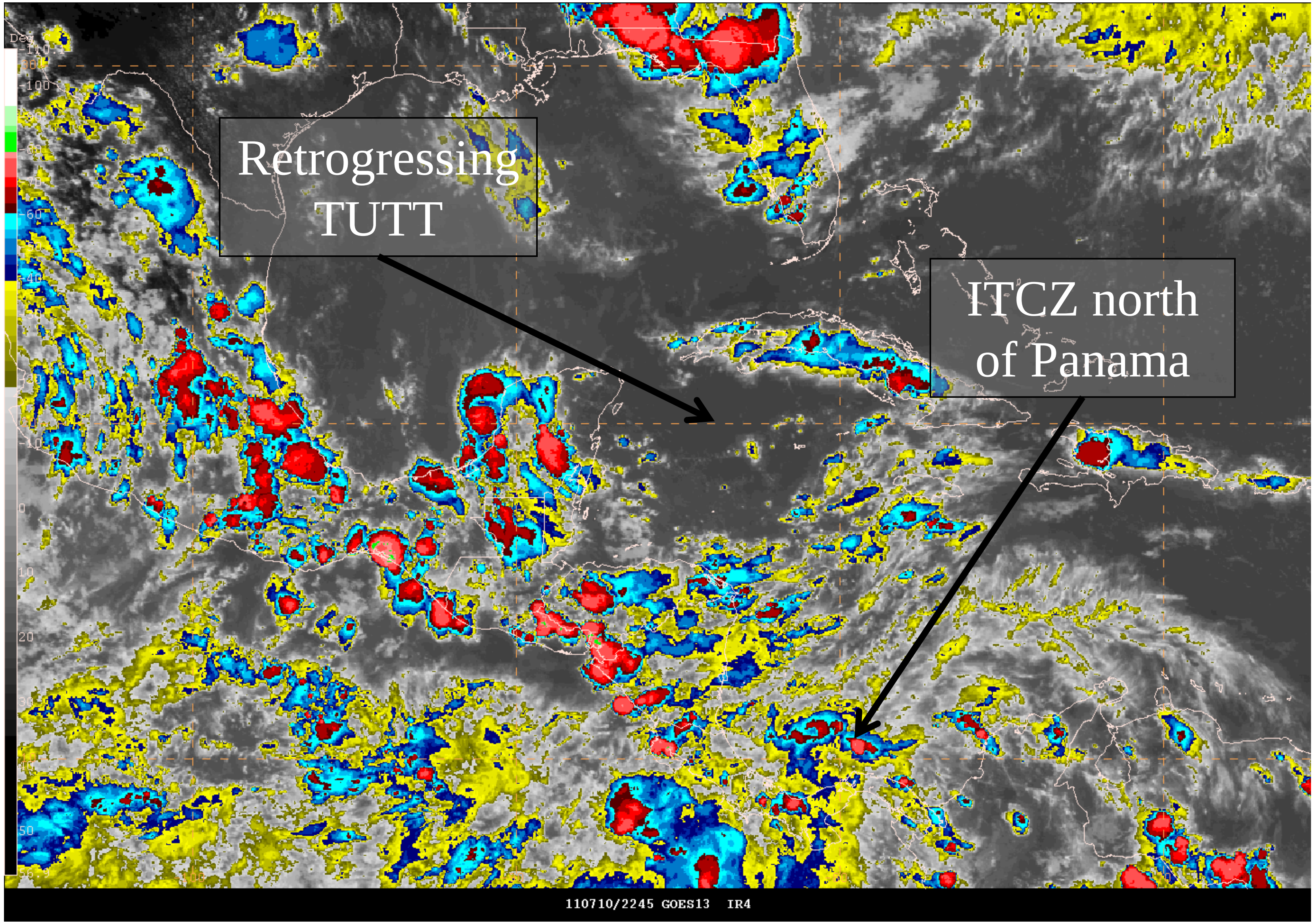
Genesis of a TUTT-Induced Trough

(3) Lower flow responds to upper forcing.

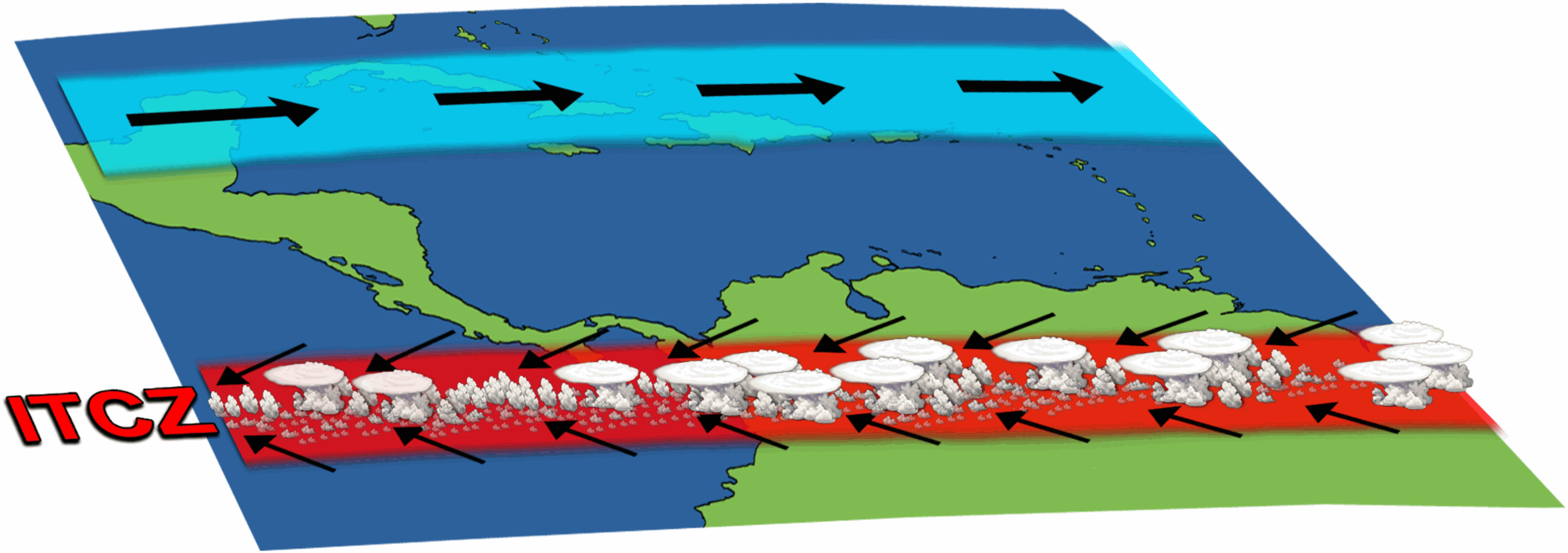
- TUTT induces height falls at lower levels.
- This induces the northward modulation of the ITCZ
- Inverted “V” forms, flow similar to that of a Tropical Wave.



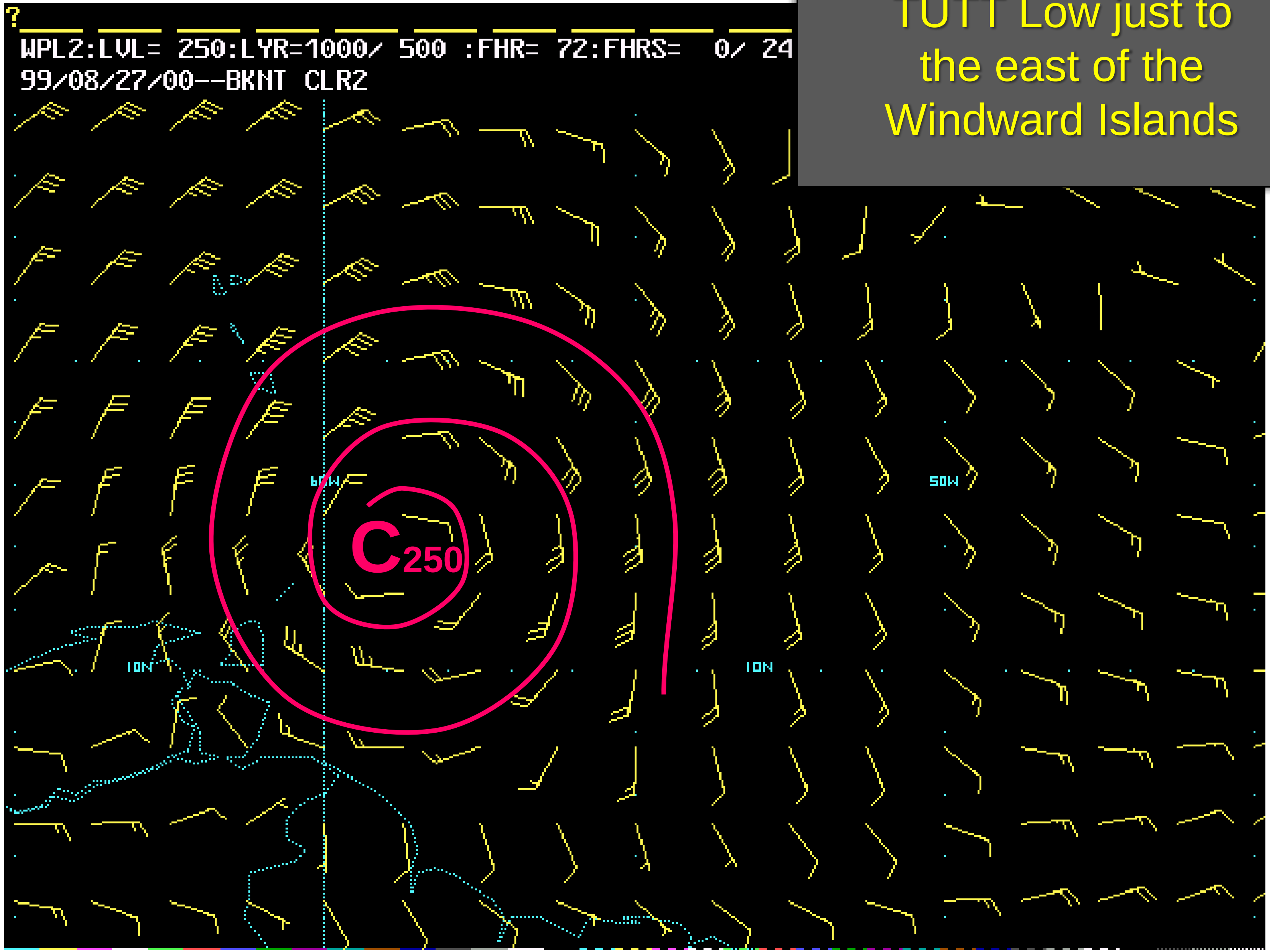
Modulation of the ITCZ by a TUTT



Animation: Induced Trough and Modulation of the ITCZ

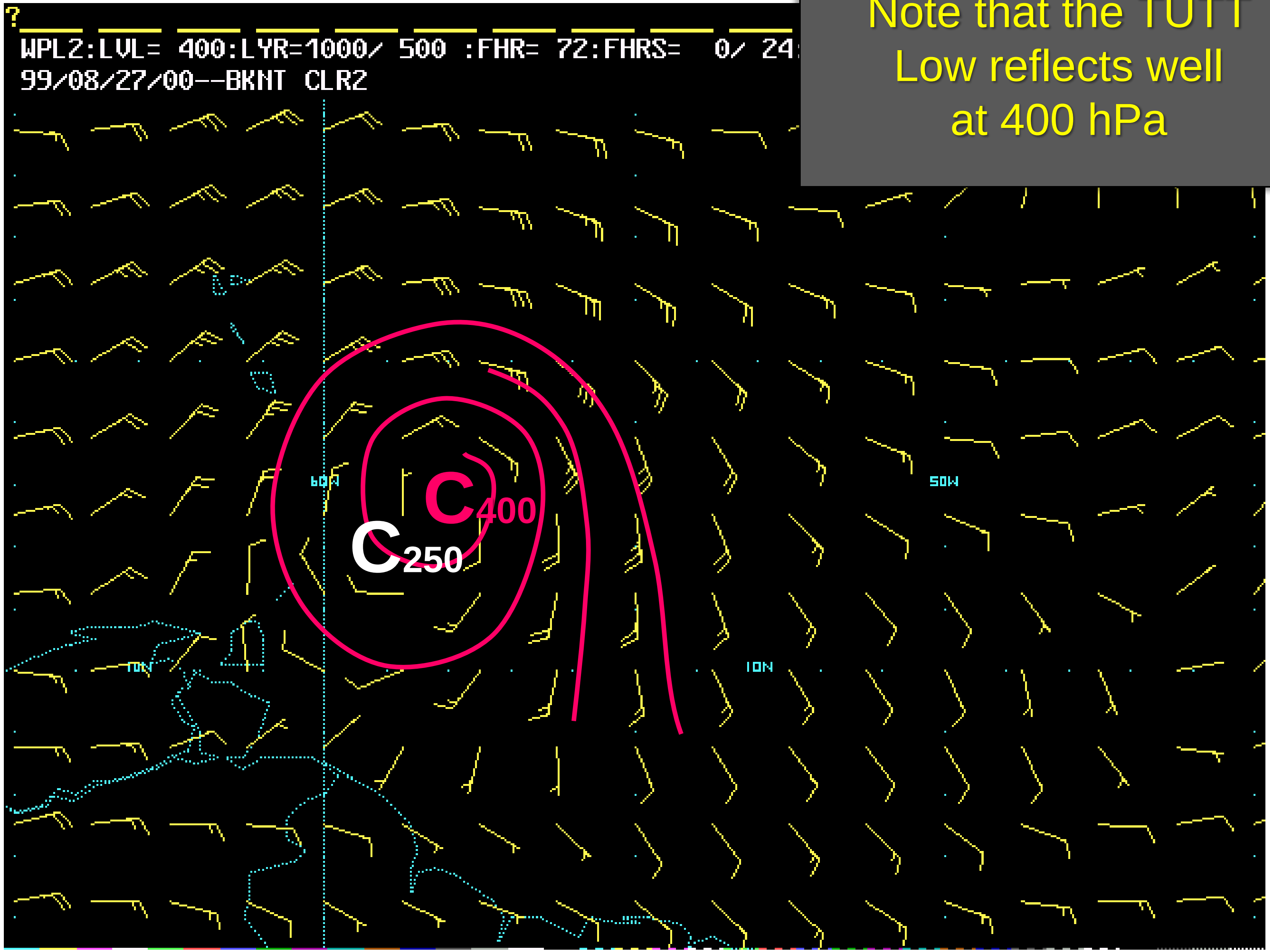


250 hPa TUTT Low



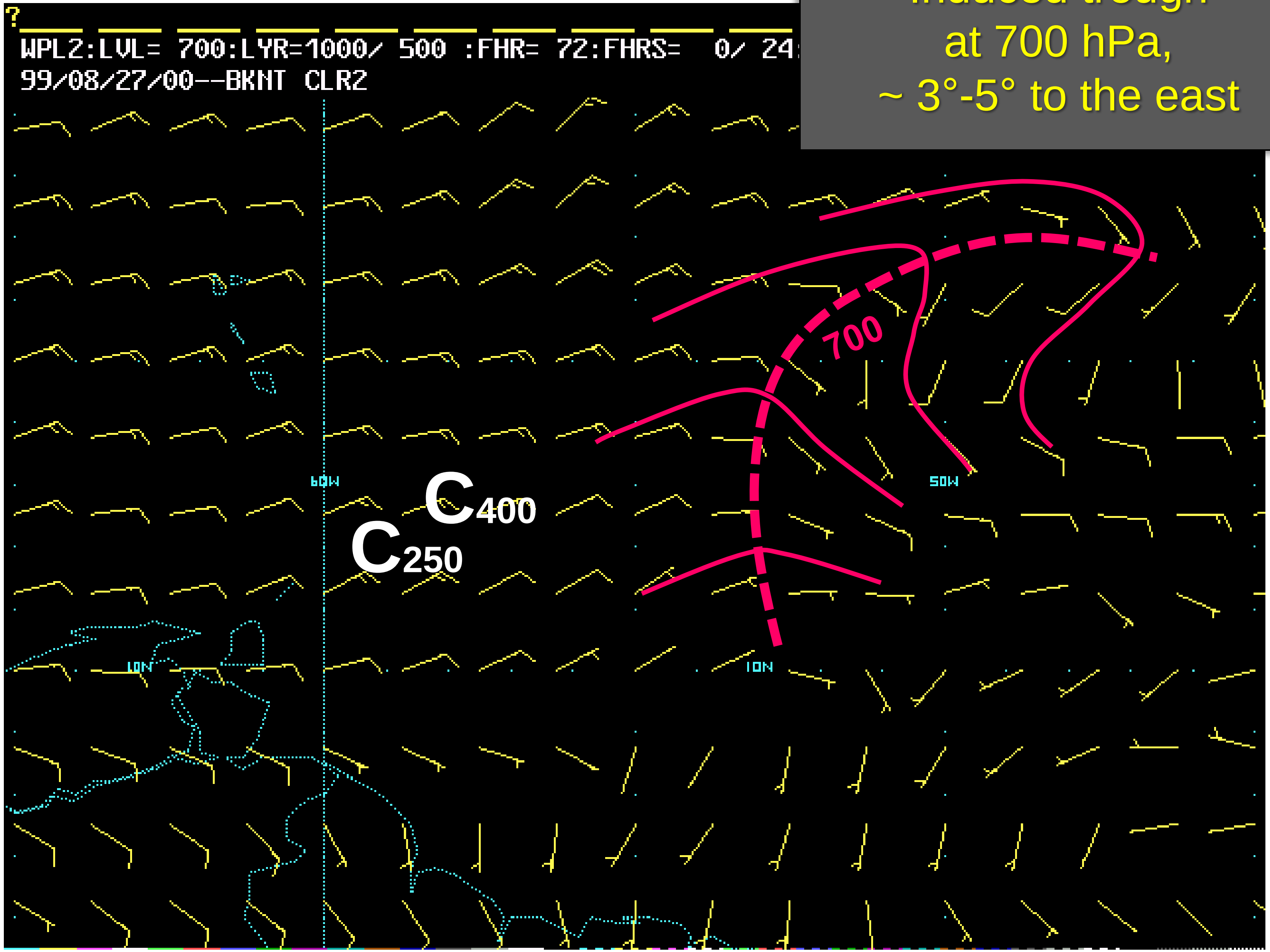
TUTT Low just to the east of the Windward Islands

TUTT Low at 400 hPa



Note that the TUTT Low reflects well at 400 hPa

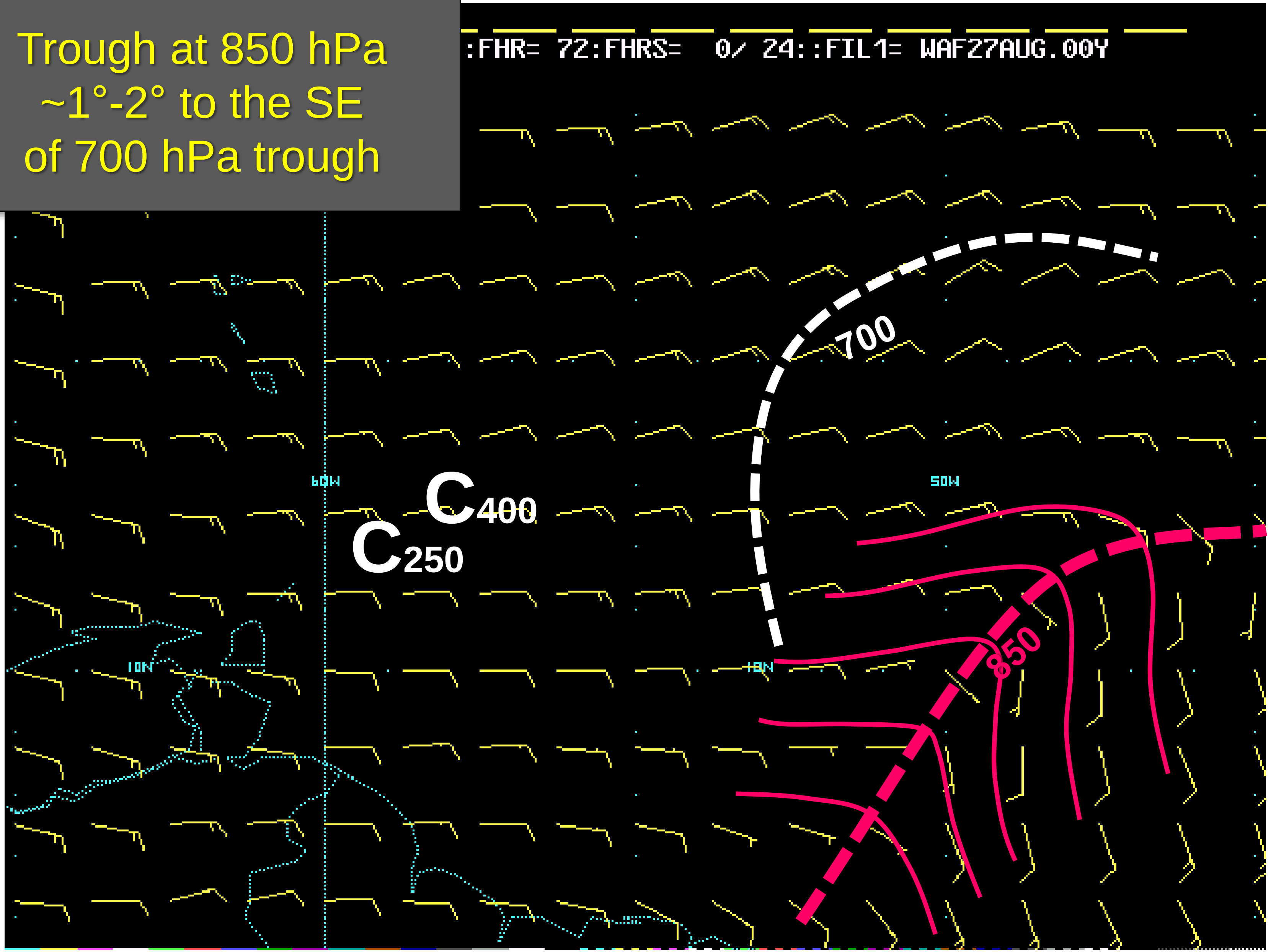
Open Trough at 700 hPa



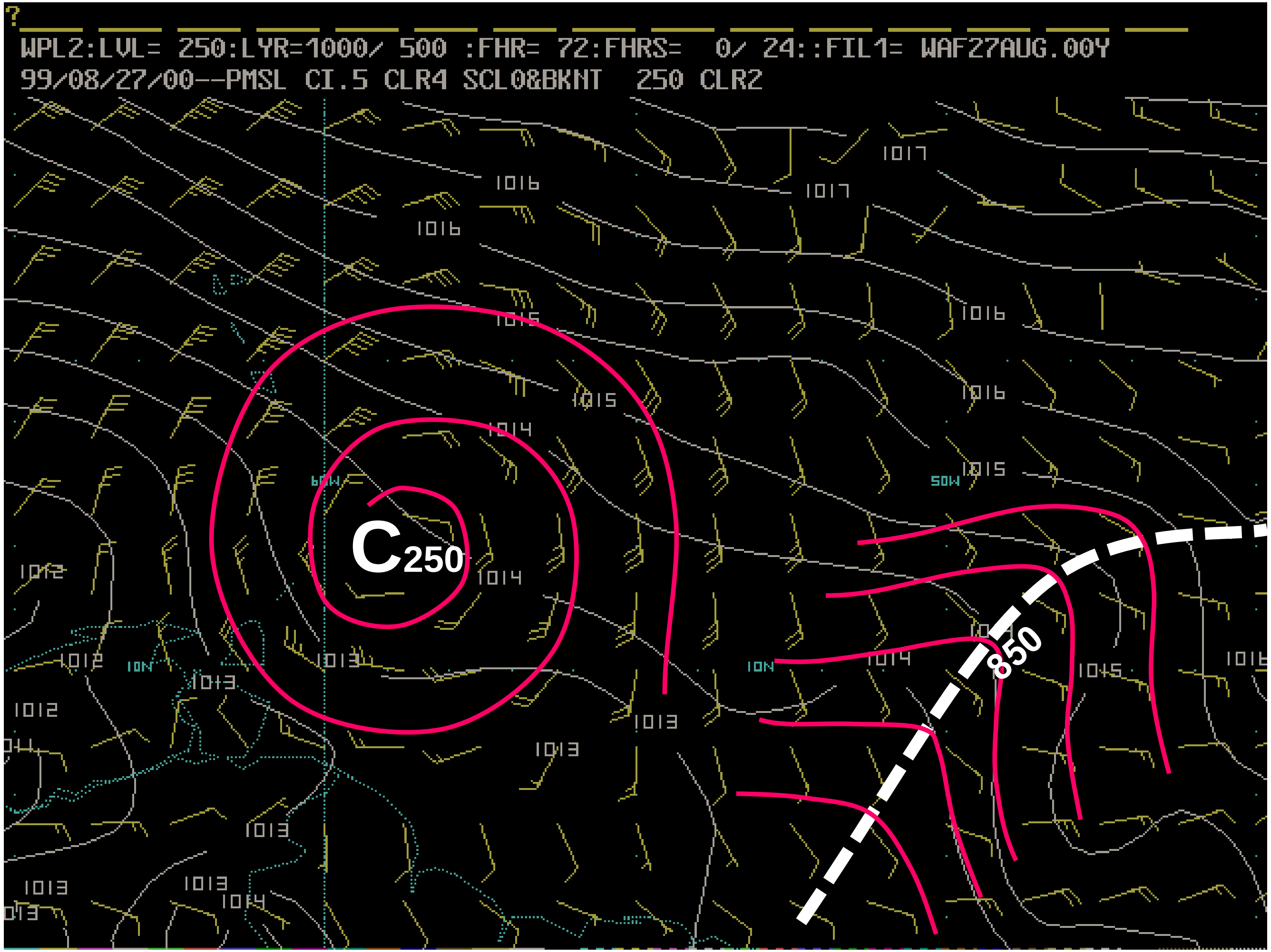
Induced trough at 700 hPa, ~ 3°-5° to the east

Induced Inverted Trough at 850 hPa

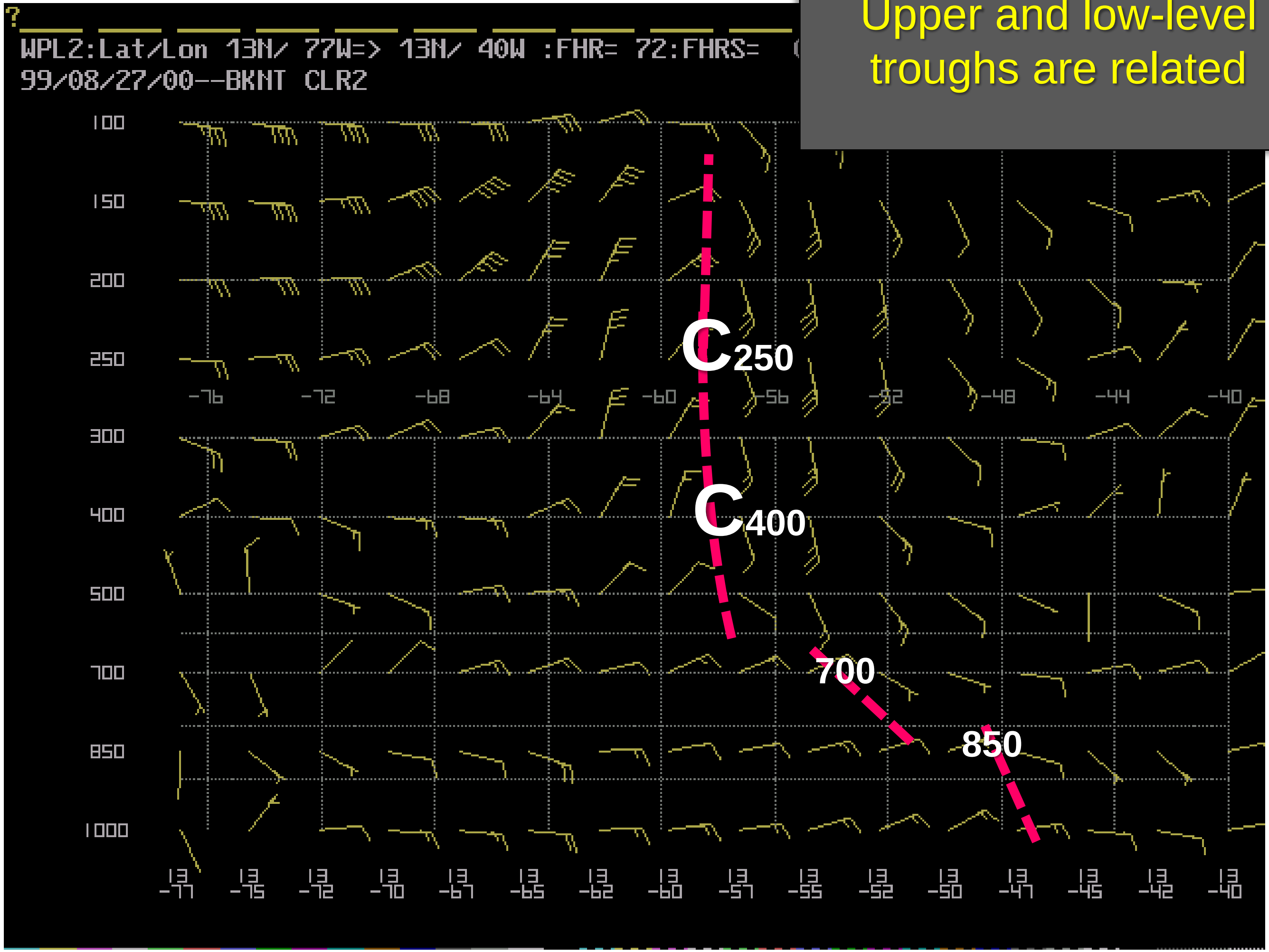
Trough at 850 hPa
~1°-2° to the SE
of 700 hPa trough



TUTT at 250 hPa and Low-Level Induced Trough



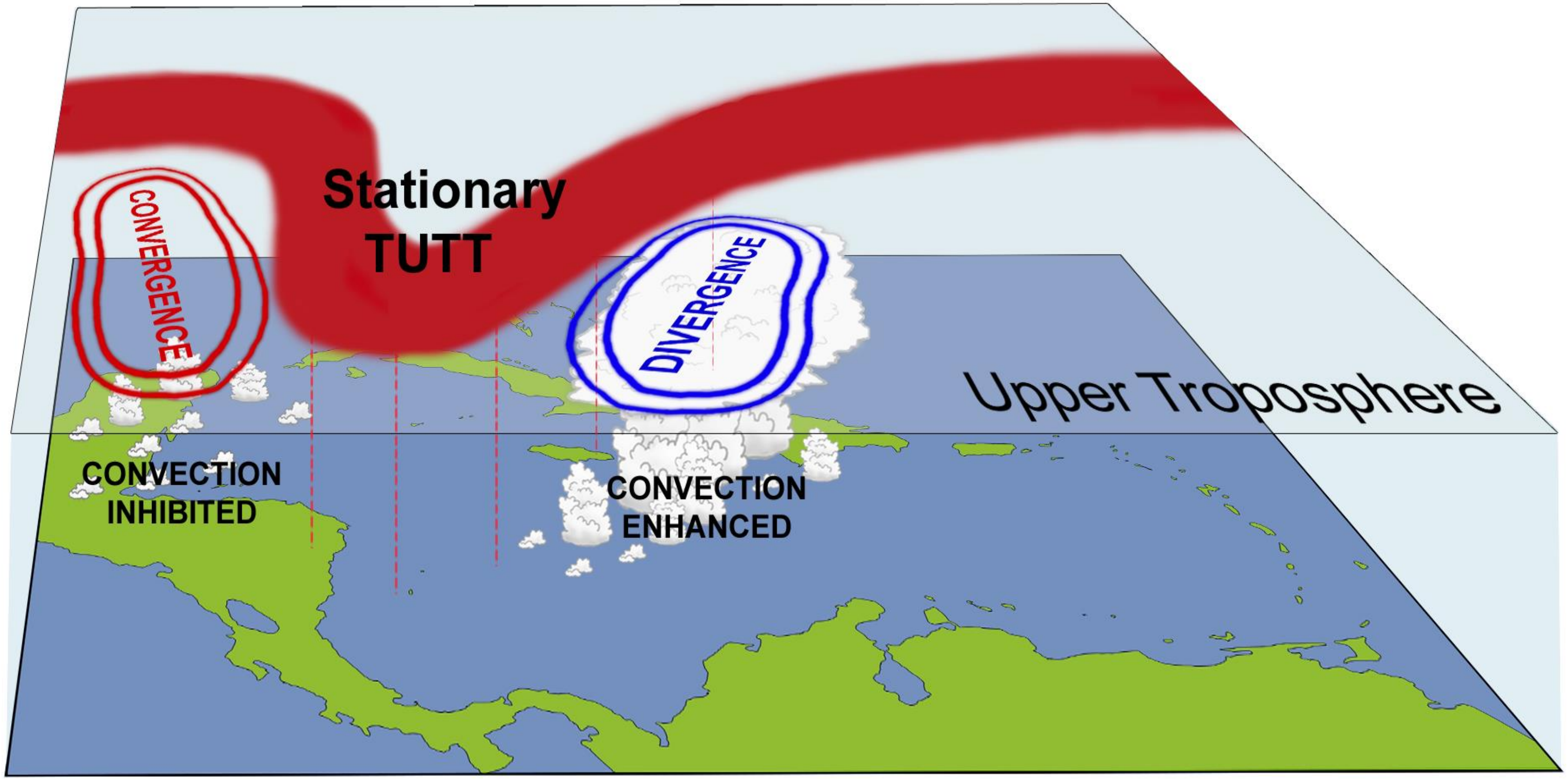
Vertical Cross Section



Upper and low-level troughs are related

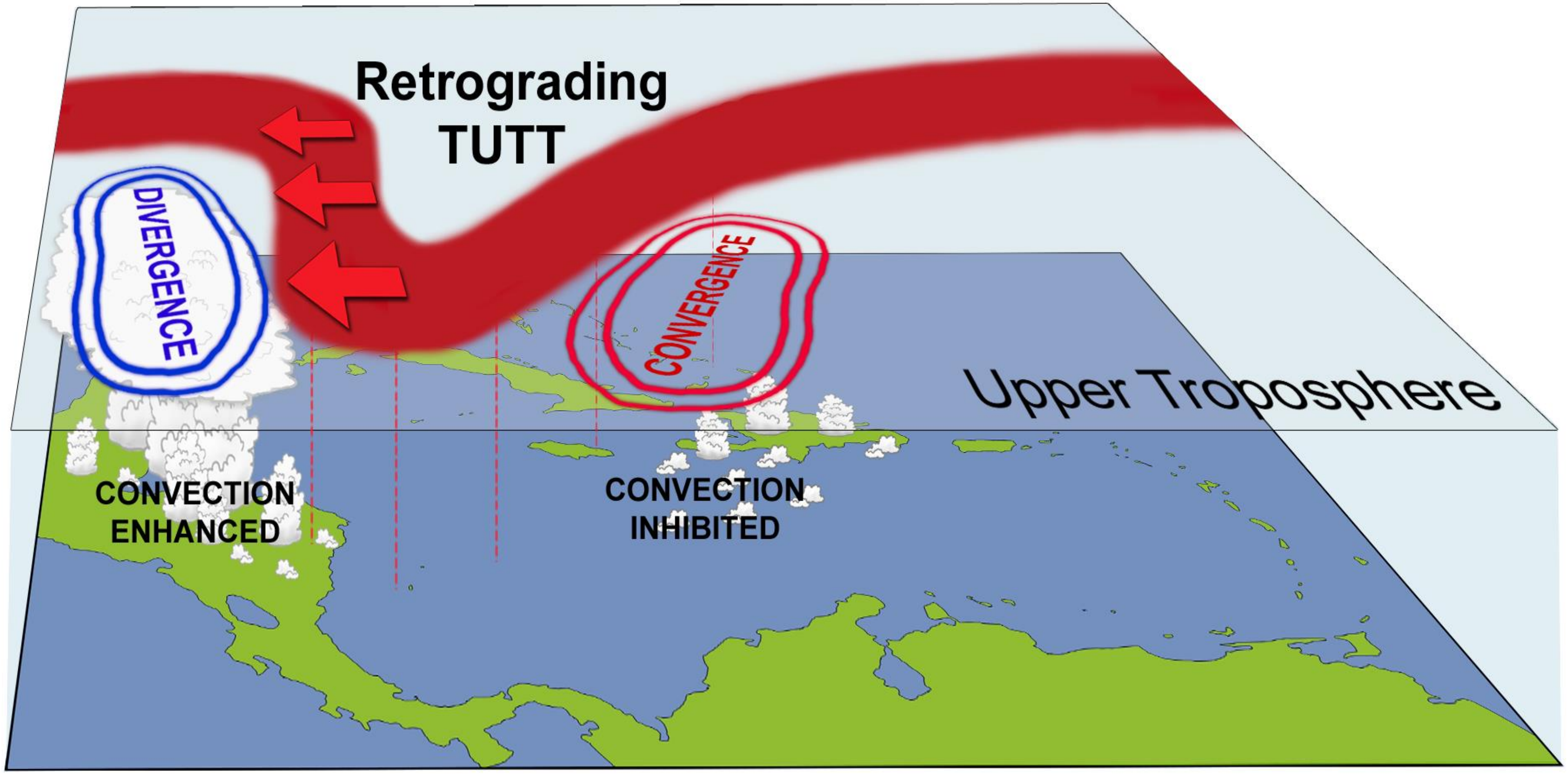
Stationary TUTT

-In a neutral to positively tilted trough axis with height, the best upper divergence lies east of the trough axis.
-Upper convergence west of axis.
-Some upper convergence also along the trough axis.



Retrograding TUTT

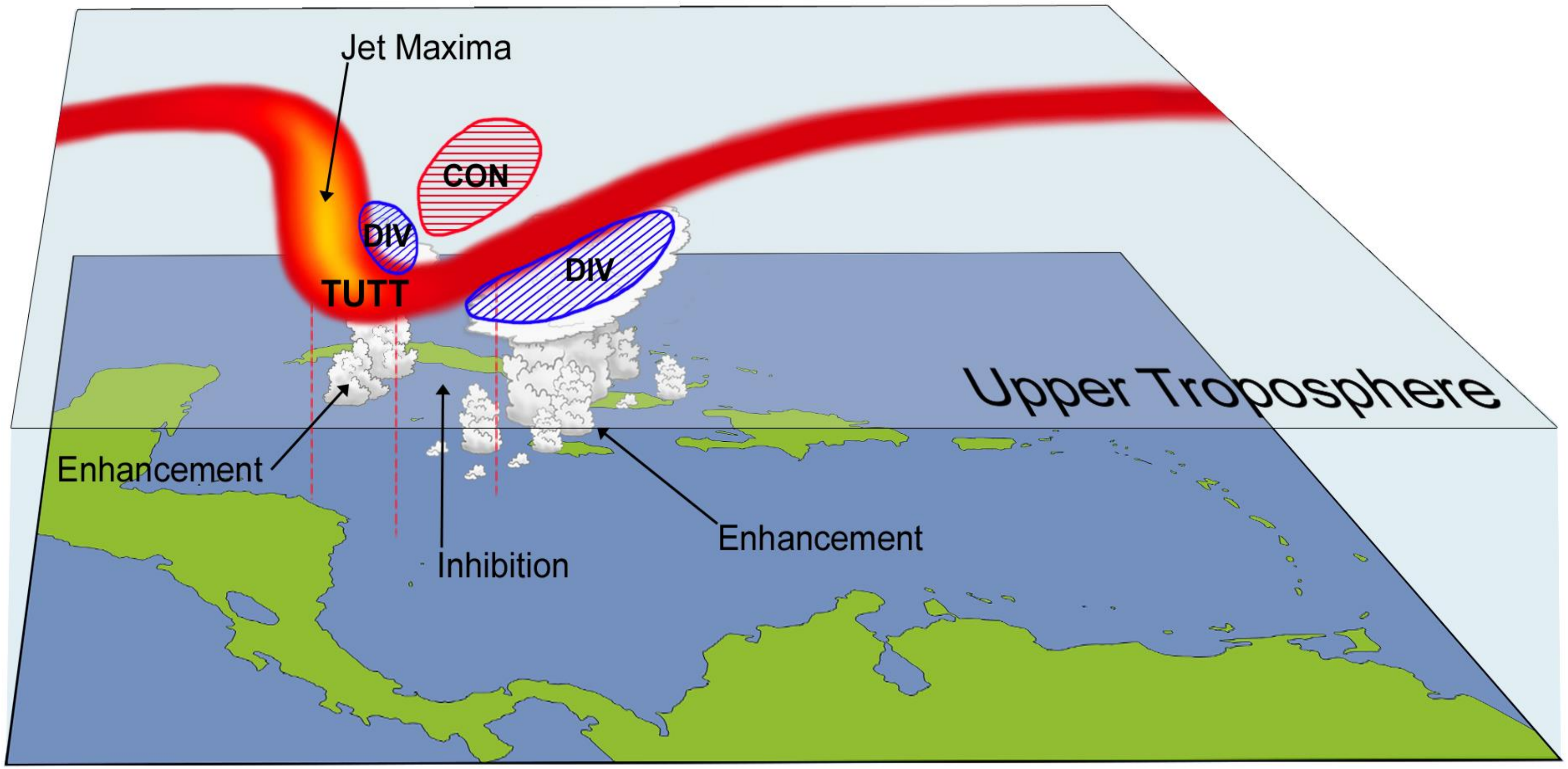
-In a negatively tilted trough axis with height, best upper divergence lies to the west of main axis.
-Upper convergence to the east of main axis.
-Some areas of upper convergence along its axis.



Jet Rounding a TUTT

Jet Maxima Upstream (to the west)

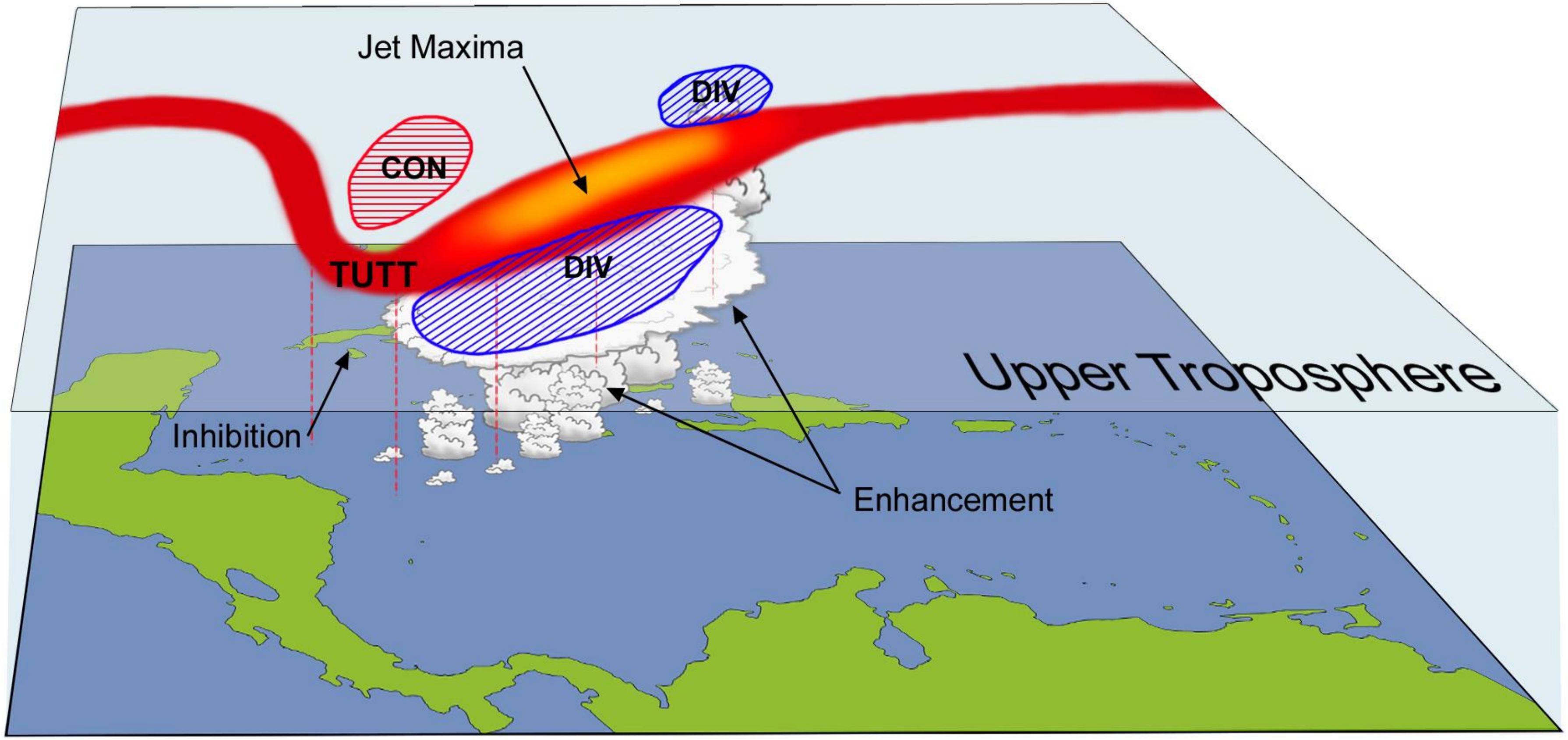
-Best upper divergence to the southeast of TUTT.
-Some upper divergence on upper jet's left exit.
-Upper convergence along TUTT's axis.



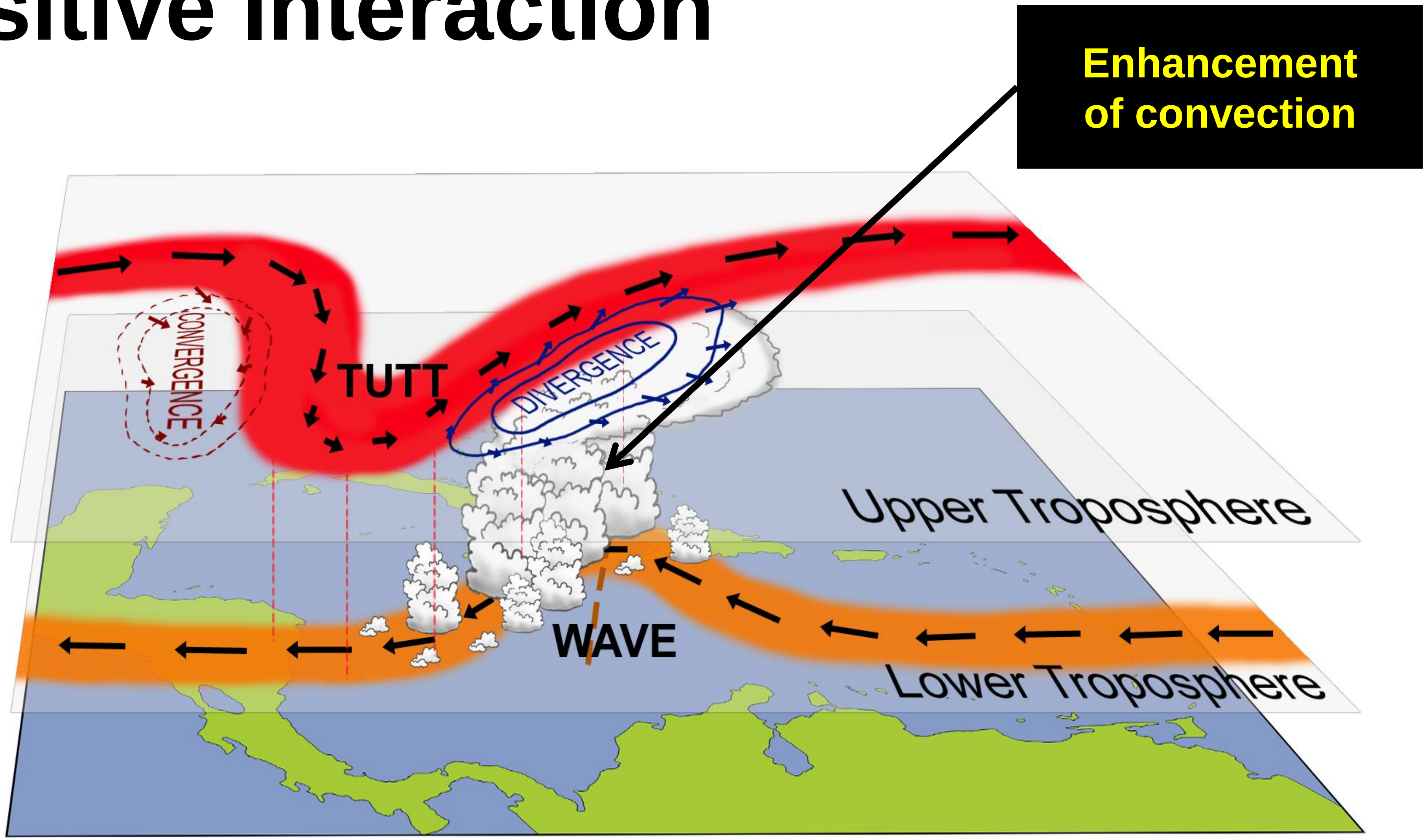
Jet Rounding Base of the TUTT

Jet Maxima Downstream (to the east)

-Upper divergence **boosted** to the southeast of TUTT.
-Some upper divergence on upper jet's left exit.
-Upper convergence along TUTT's axis.

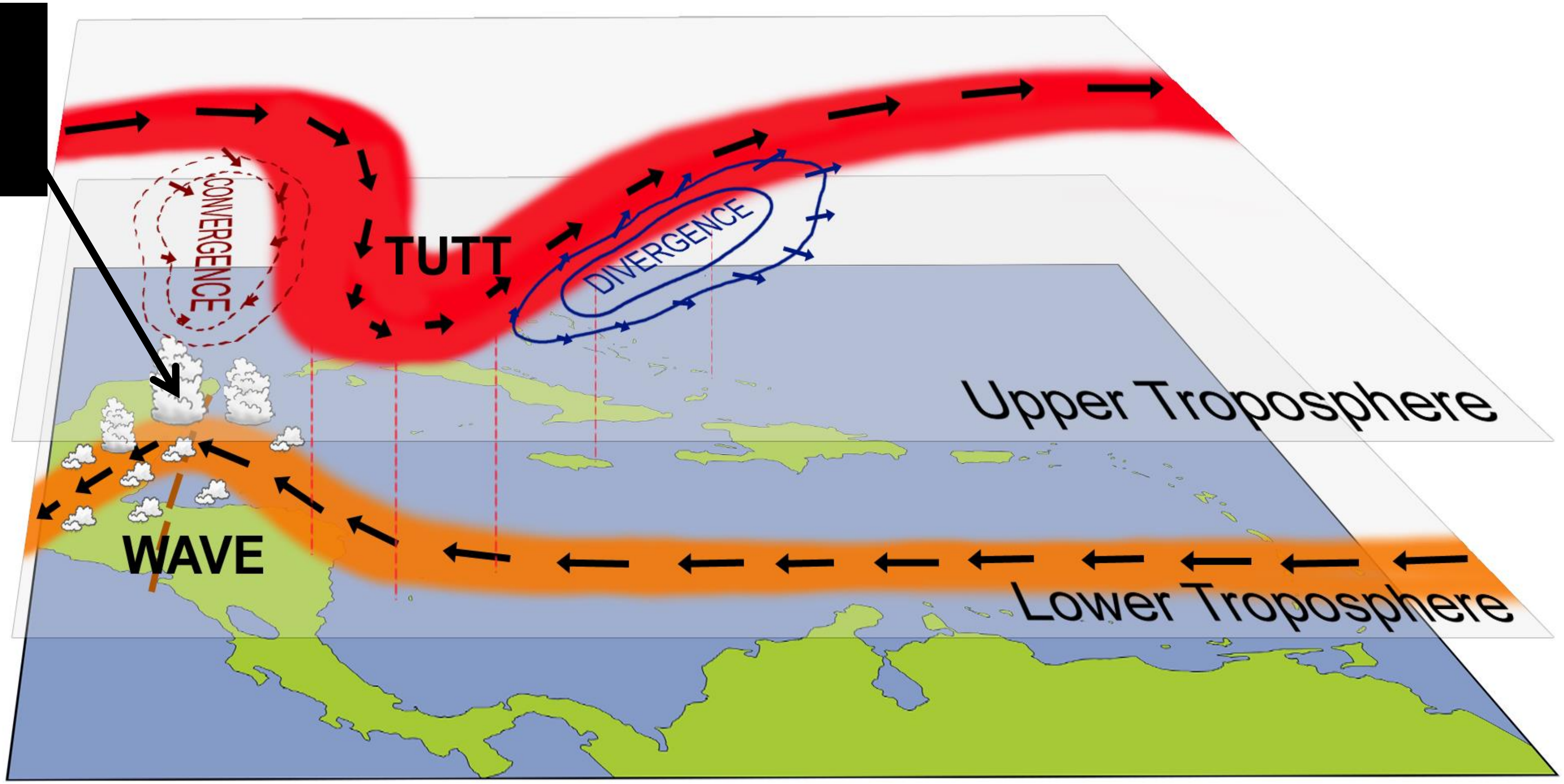


Positive Interaction



Negative Interaction

Inhibits convection



How to differentiate between an induced trough from a tropical wave?

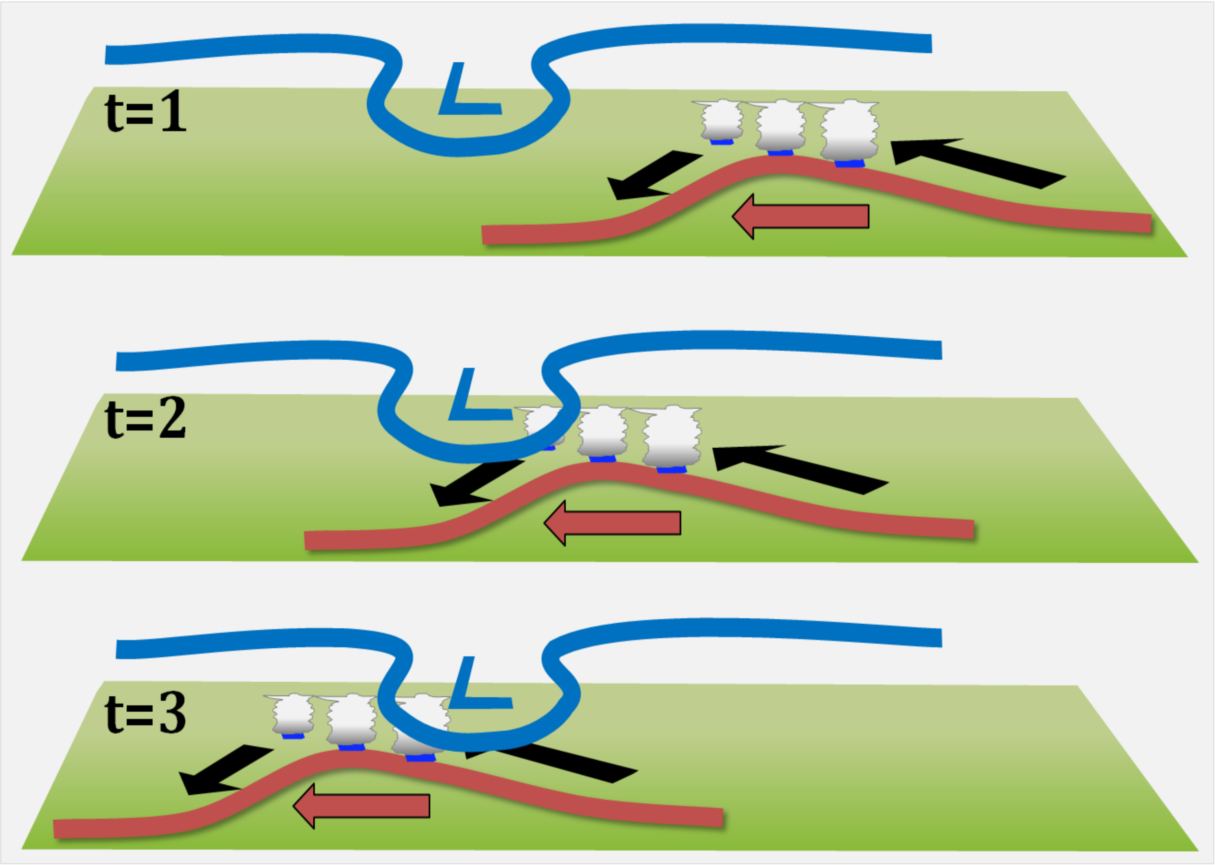
By analyzing the movement and origin of the system!

- If a trough in the low-level easterlies is **moving independently from mid/upper tropospheric systems**, it is an easterly wave (EW).

- If a trough in the low-level easterlies **moves in-tandem** with a TUTT it is likely that it is an induced trough.
  - If it decouples from upper trough, it becomes an easterly wave.

- Occasionally an EW and a TUTT can enter in phase and will appear to move in unison.

Tropical Wave: Moving Independently

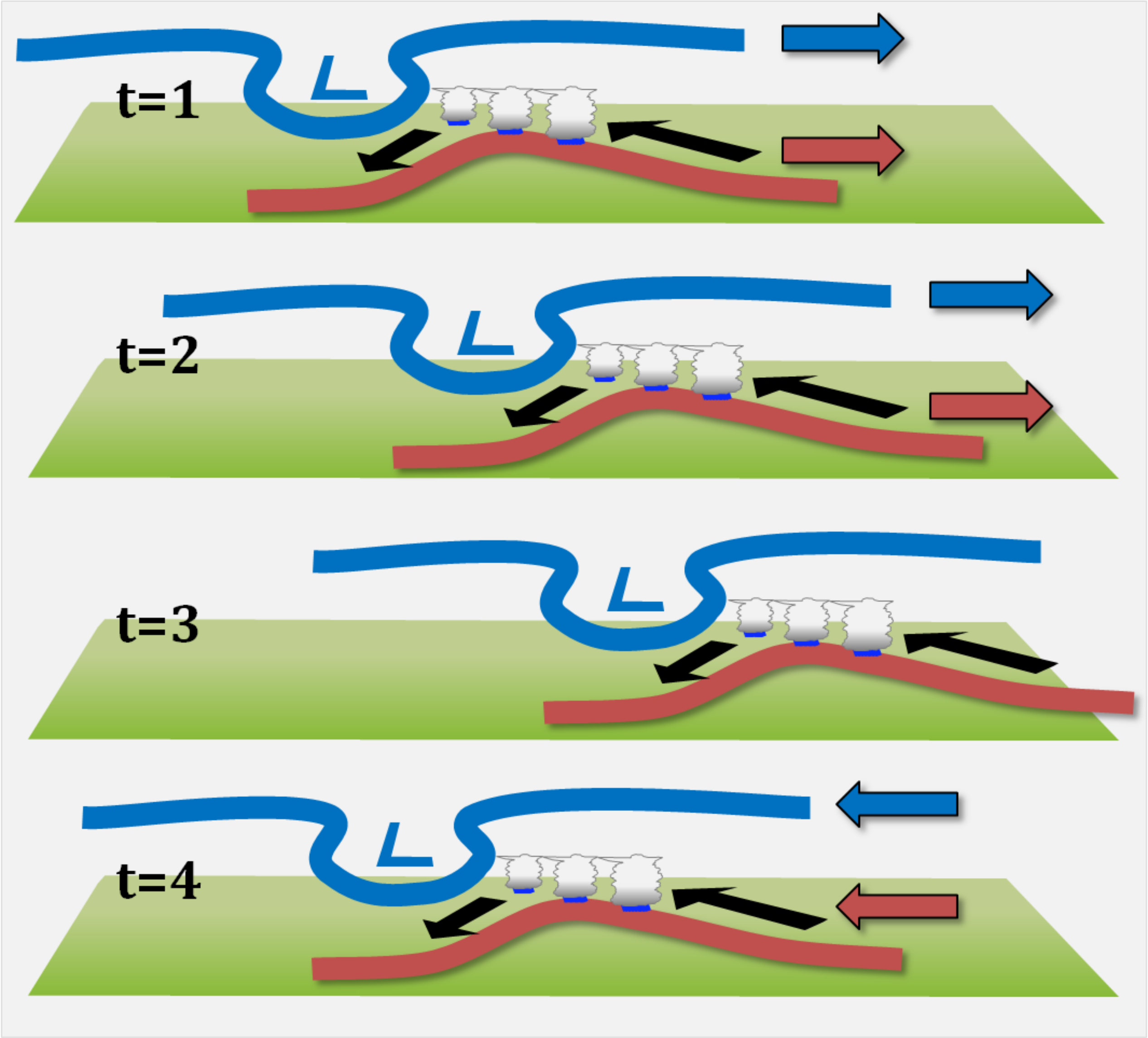


The TUTT aloft is stationary, wave in the trades is moving west

Induced Trough: In-Tandem with TUTT

TUTT moving to the East

TUTT retrogressing to the West



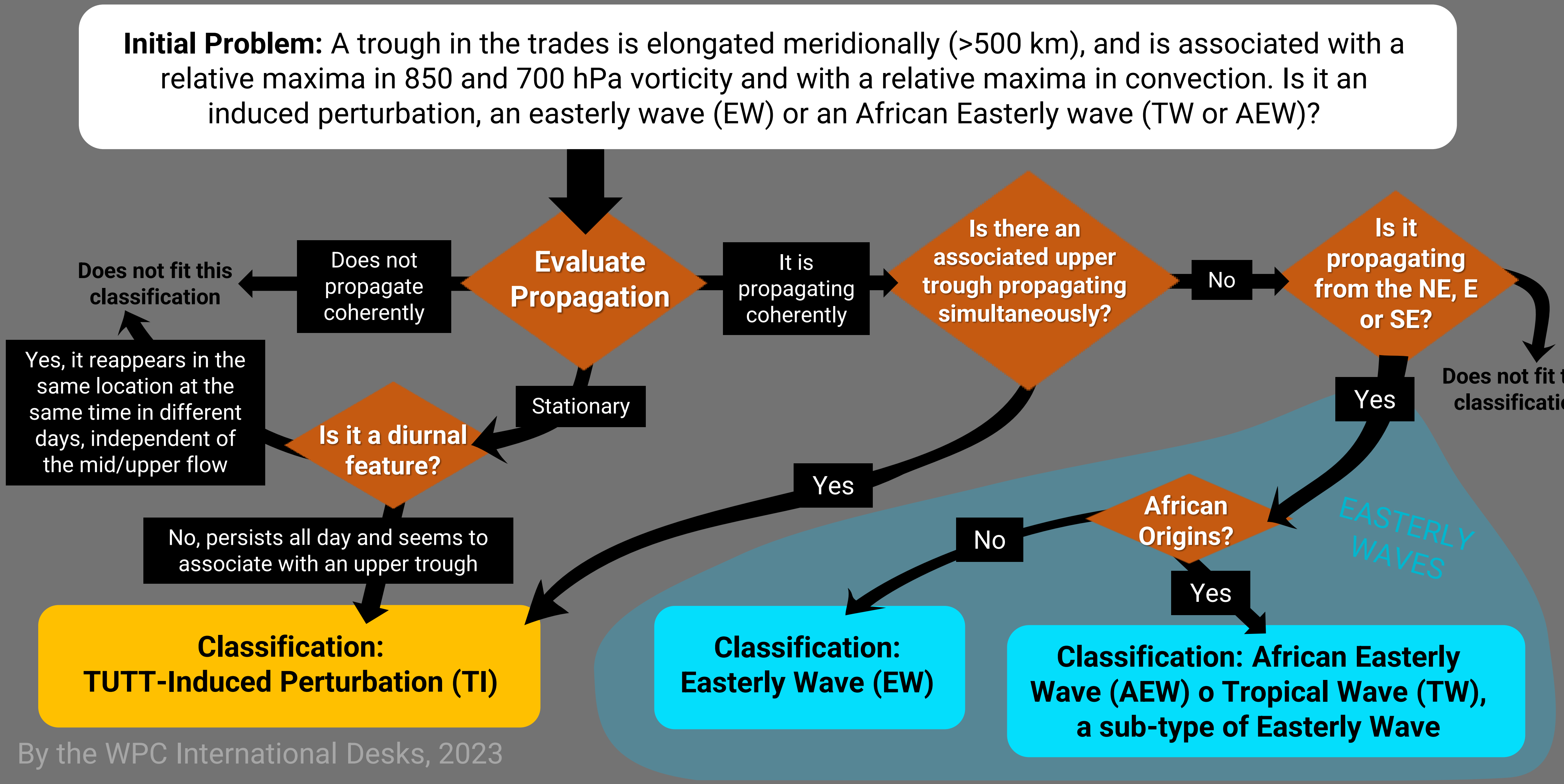
Summary of Characteristics

TUTT Induced Trough	Easterly Wave
• Cold core dominates – Cannot evolve directly into a Tropical cyclone (warm core system). – Could first evolve into a subtropical cyclone (hybrid system)	• Combination of warm/cold core. – Could directly evolve into a tropical cyclone (is the seed).
• Movement: Controlled by upper flow.	• Movement: controlled by the lower troposphere.
• Origin: Induced by a trough generally to its northwest.	• Origin: Along monsoon trough of Tropical North Africa.

Tools to differentiate wave type

	Induced Trough	**Tropical Wave**
Water Vapor Image	Best tool to assess the presence and depth of an upper cyclone (TUTT).	Determine sources of upper level ventilation, or the lack of.
IR and Visible Images	• Good to find inverted "V" troughs in low-level cloud fields. • Ci/Cs might hint presence of upper trough..	Good to find inverted "V" troughs in low-level cloud fields.
Flow analysis	500-200 hPa for upper trough, 850-700 hPa for low level trof.	850-700 hPa
Movement of low-level trough	• It moves **in-tandem** with upper trough. • Could remain stationary or , if the TUTT is retrogressing, progress at 05-15 kt.	• Low-level trough moves **independent** from upper systems. • They move at 10-20 kt. •Negatively tilted tend to be faster.

Decision Tree to characterize a Wave in the Trades

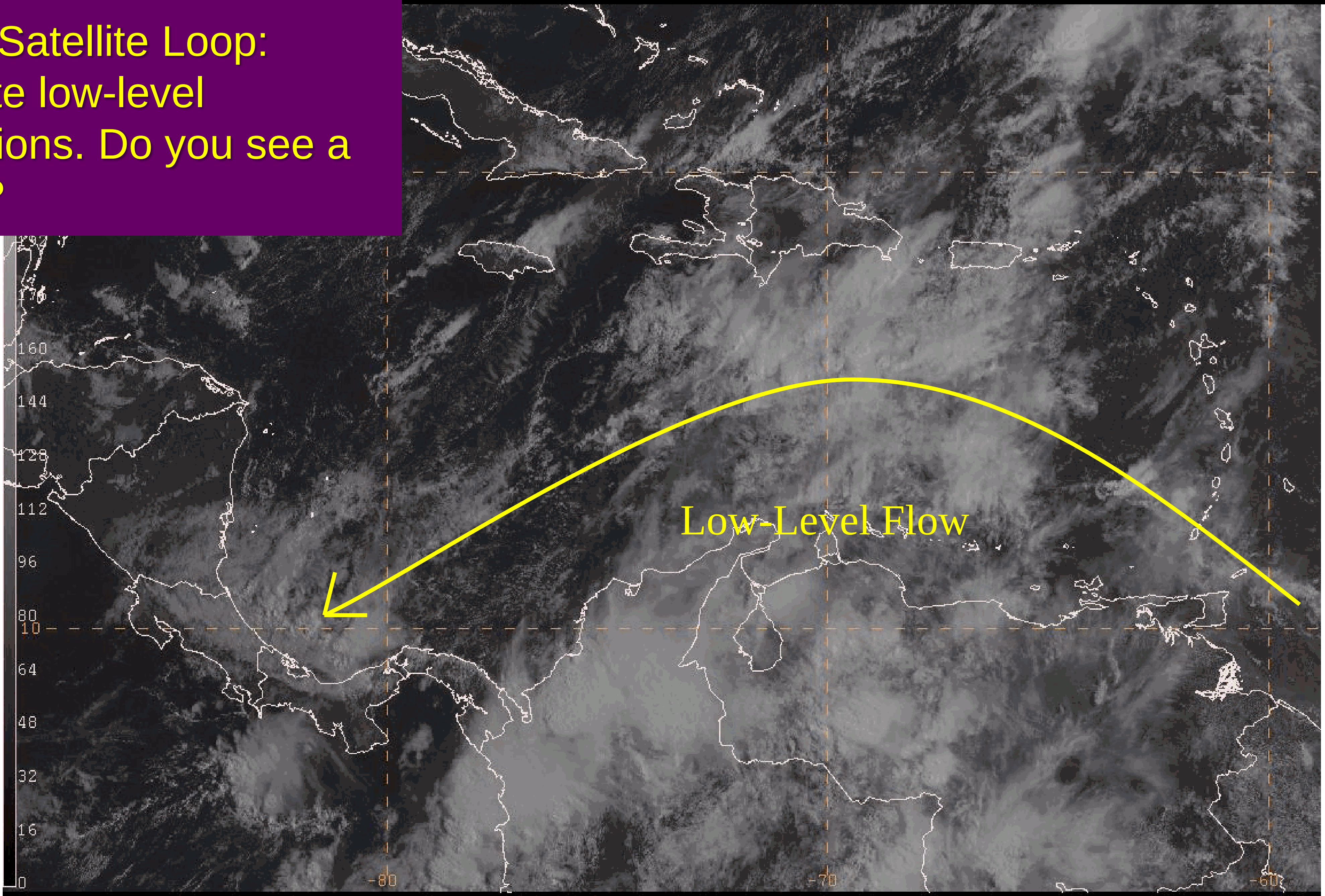


By the WPC International Desks, 2023

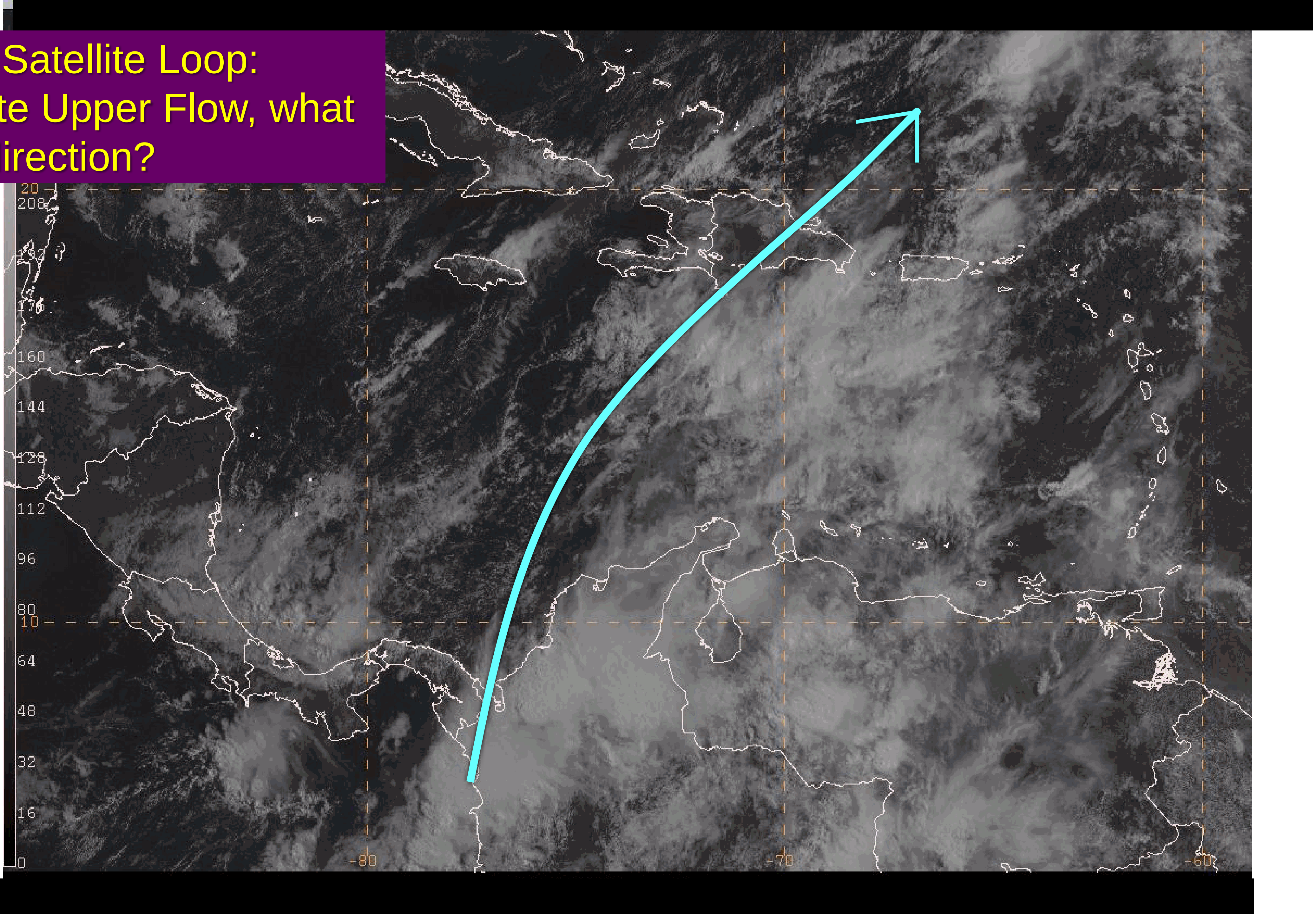
Exercise:

20 April 2004

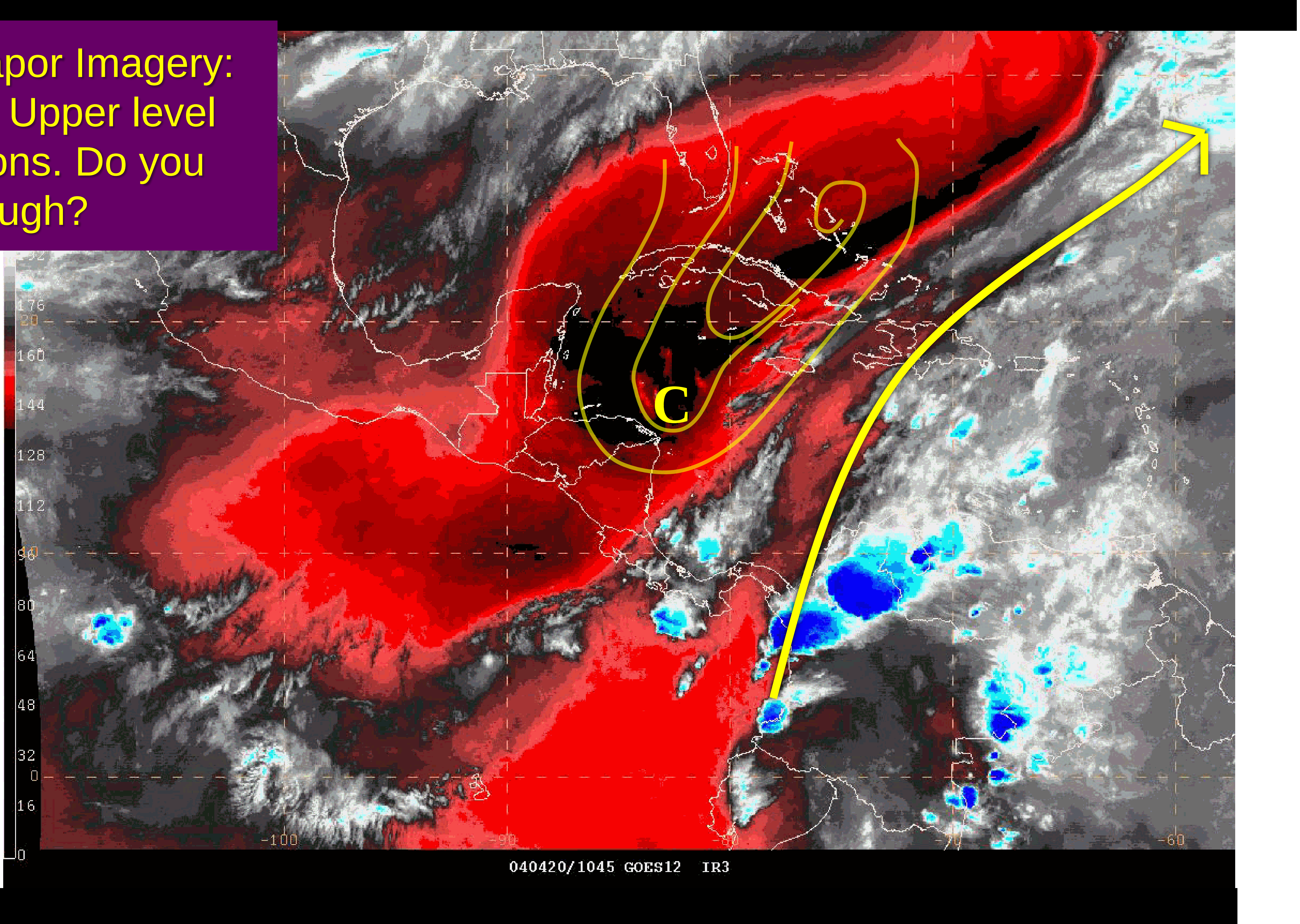
Visible Satellite Loop: Evaluate low-level circulations. Do you see a trough?



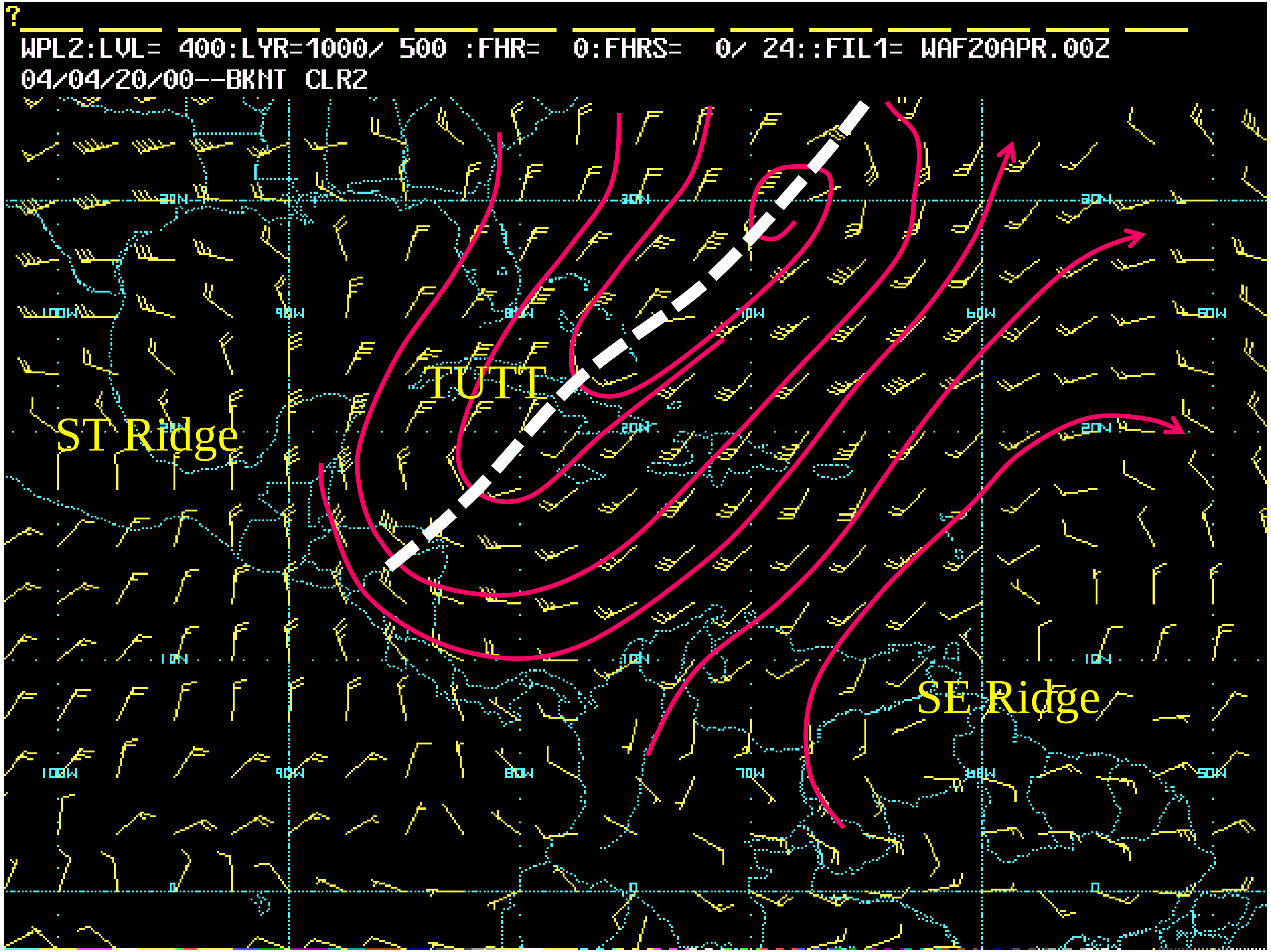
Visible Satellite Loop: Evaluate Upper Flow, what is the direction?



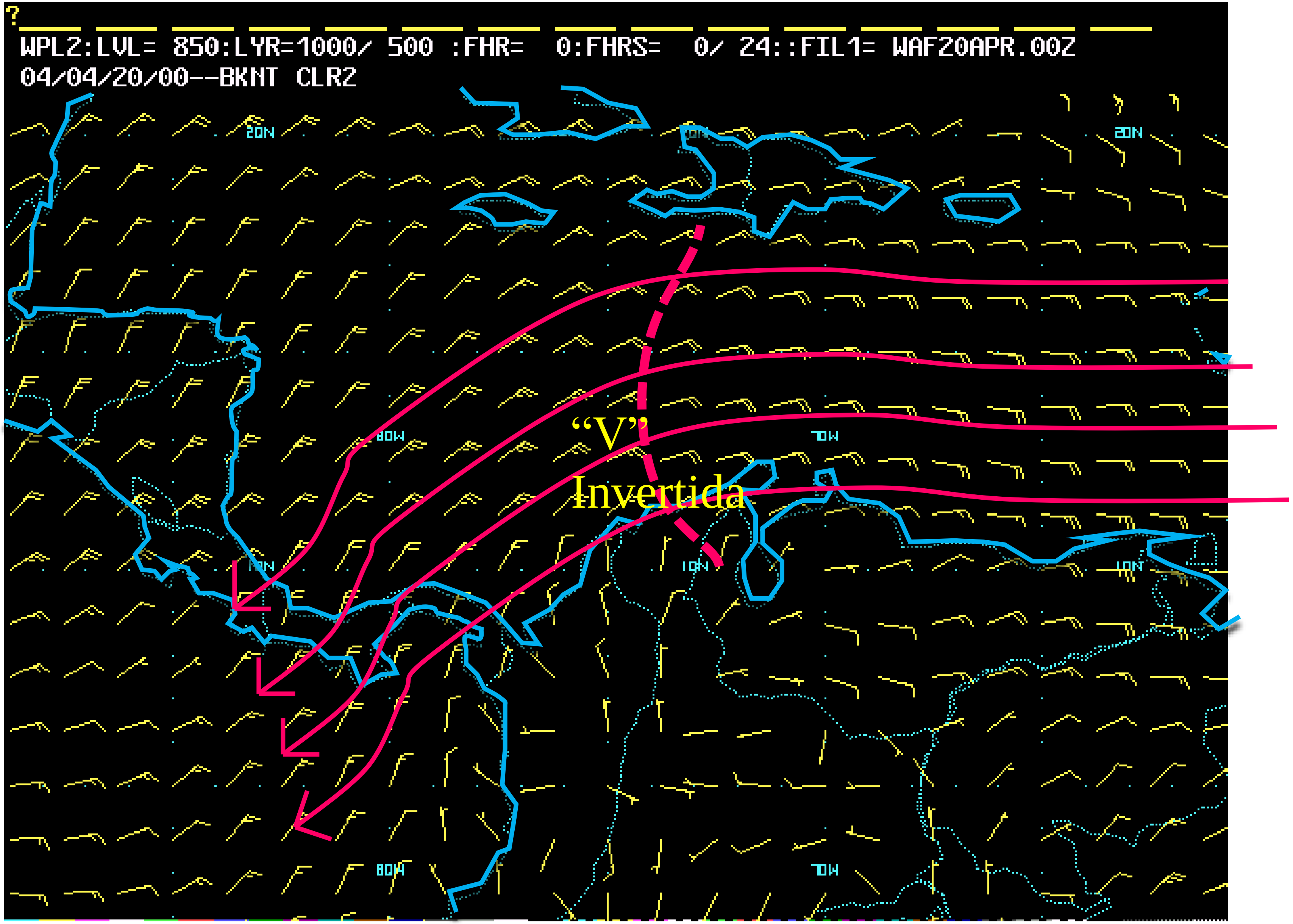
Water Vapor Imagery: Evaluate Upper level Circulations. Do you see a trough?



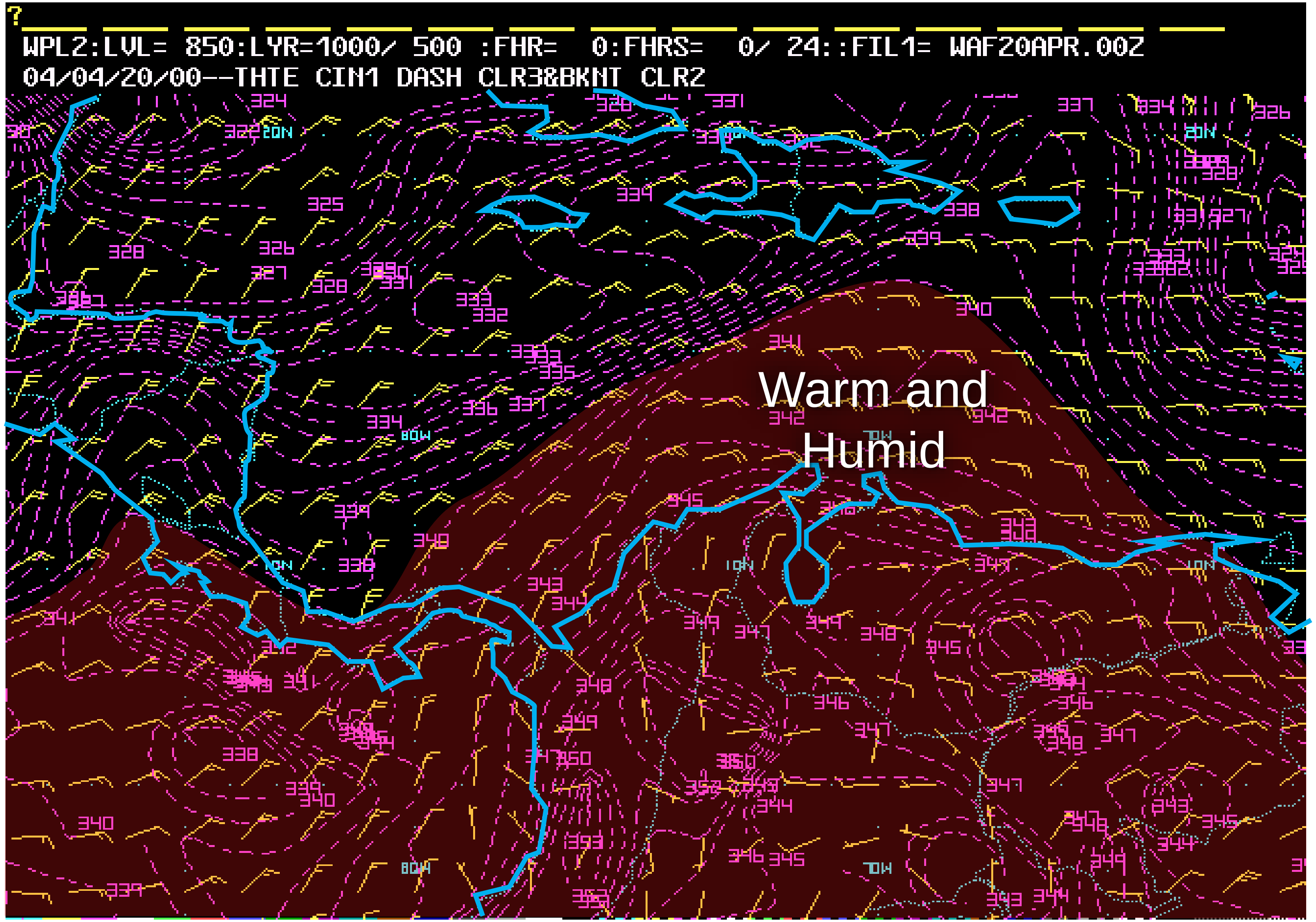
GFS Analysis 400 hPa: Upper Flow



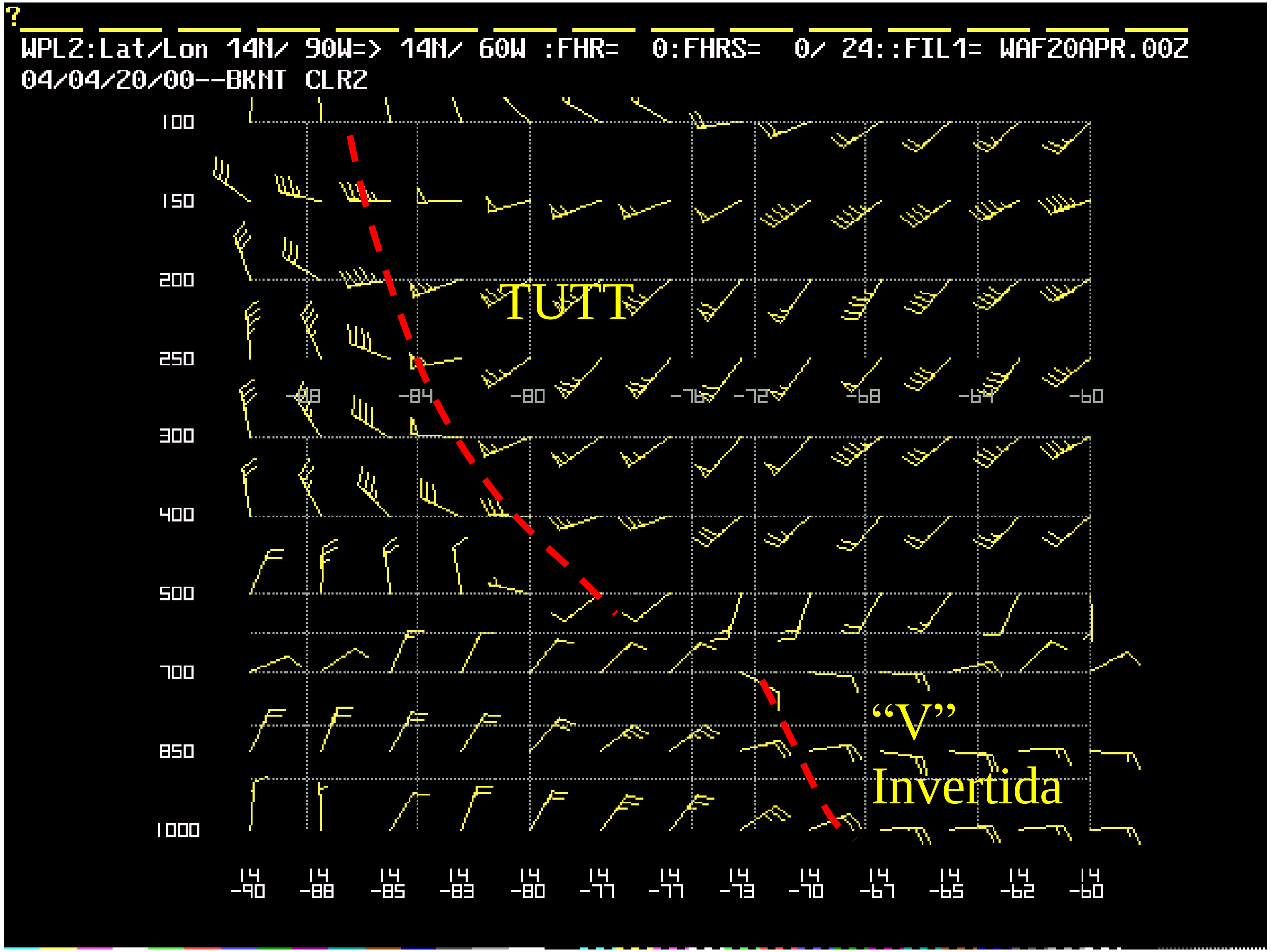
GFS Analysis 850 hPa: Inverted V



Winds and Equivalent Potential Temperature (θe) in 850 hPa



Winds in Vertical Cross Section



Observations

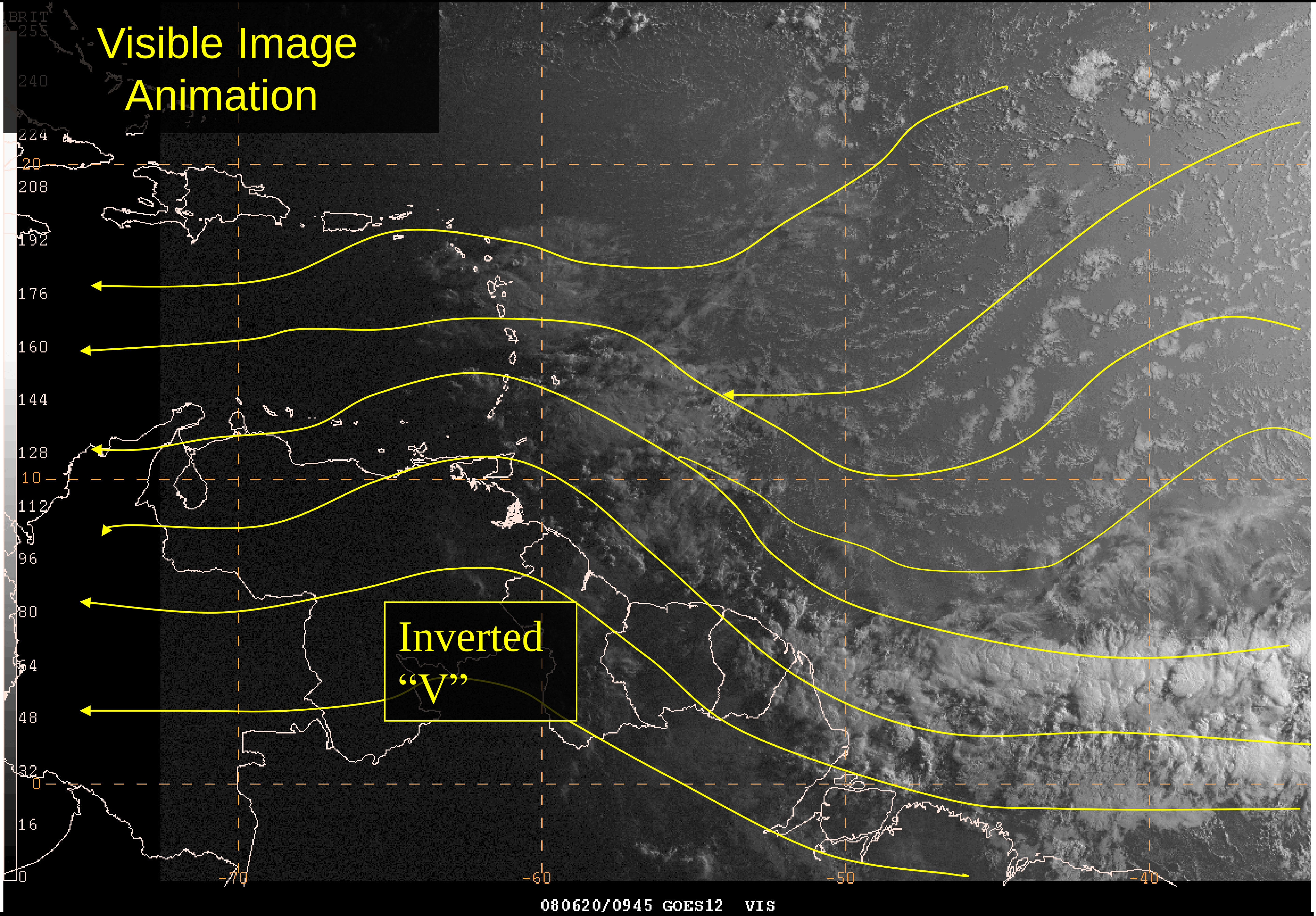
- Visible imagery shows an inverted trough in the low-levels.
  - Visible imagery, however, does not always confirm the presence of an upper system. The wave could be analyzed as an easterly wave.
  - Best to consider other backup tools.
- Water vapor imagery combined with visible imagery, clearly shows the upper trough to the northwest of the low-level feature.
  - This suggests that both features are interacting. Longer loops will help to determine clear interactions between the systems.
  - If there are additional doubts, model cross sections could help to clarify the situation.

04

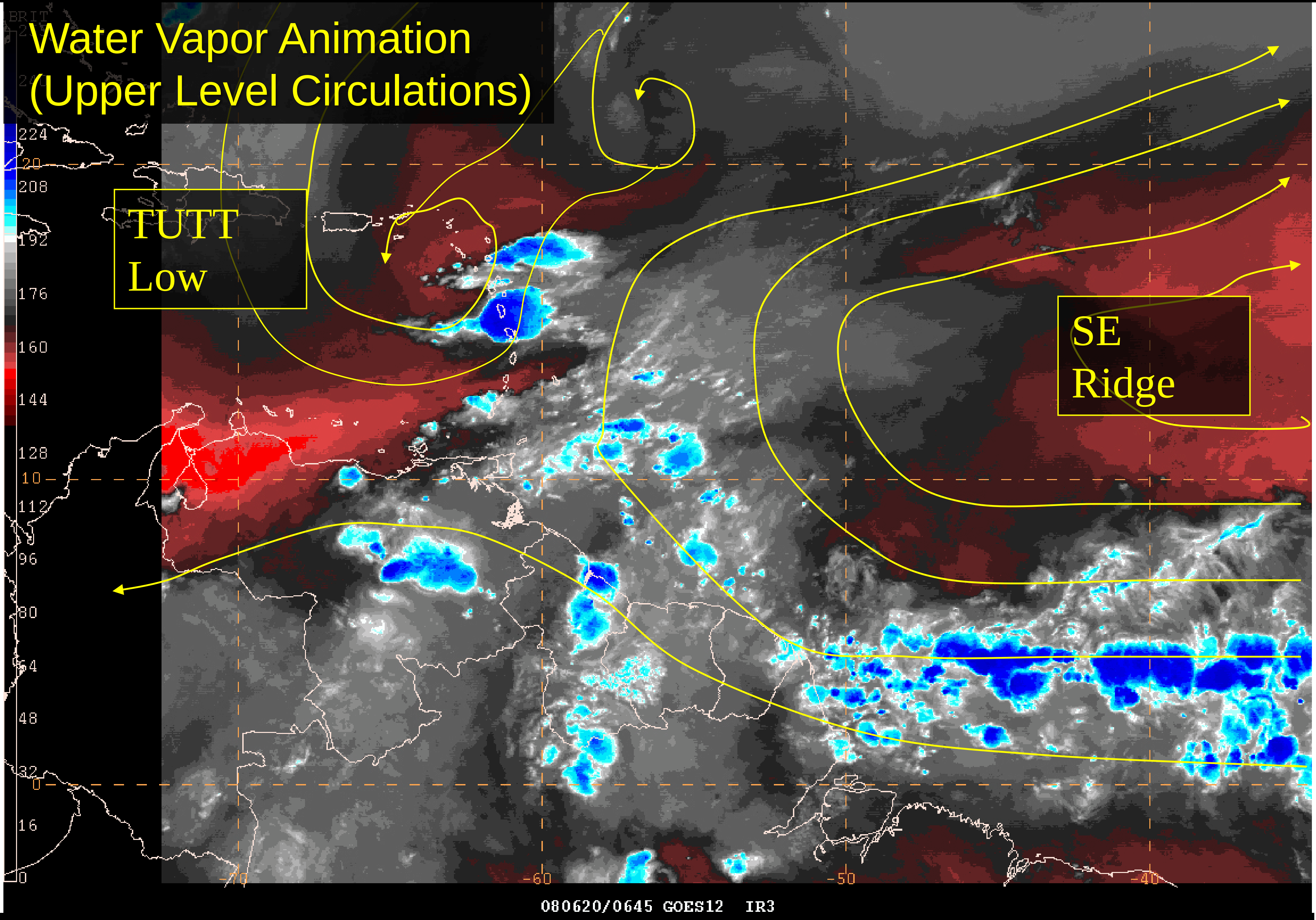
Identification Exercises

Exercise:

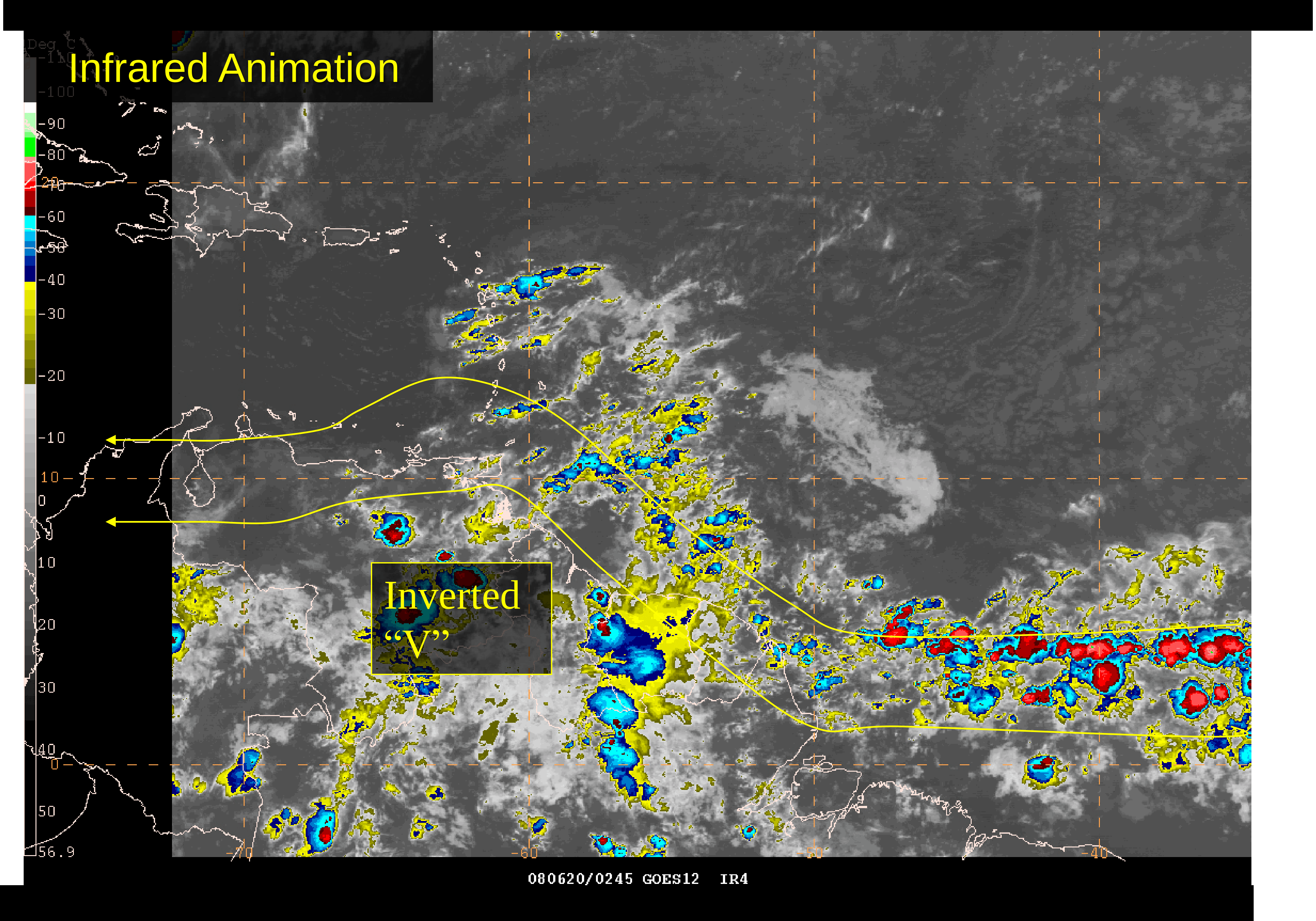
Event from June 20, 2008



Visible Image
Animation
Inverted
“V”
080620/0945 GOES12 VIS

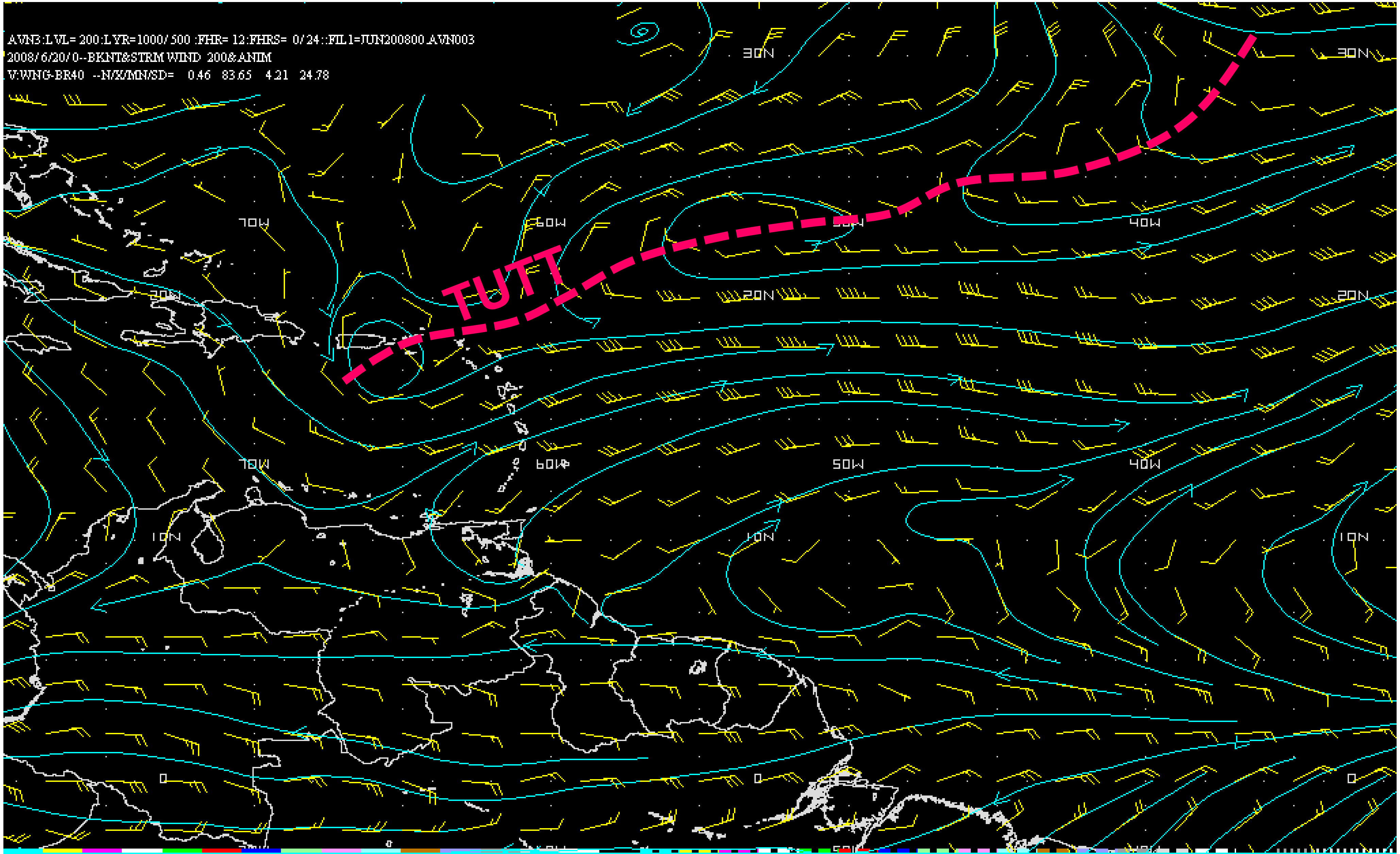


Water Vapor Animation
(Upper Level Circulations)
TUTT
Low
SE
Ridge
224
208
192
176
160
144
128
112
96
80
64
48
32
16
0
20
10
0
70
-60
-50
-40
080620/0645 GOES12 IR3

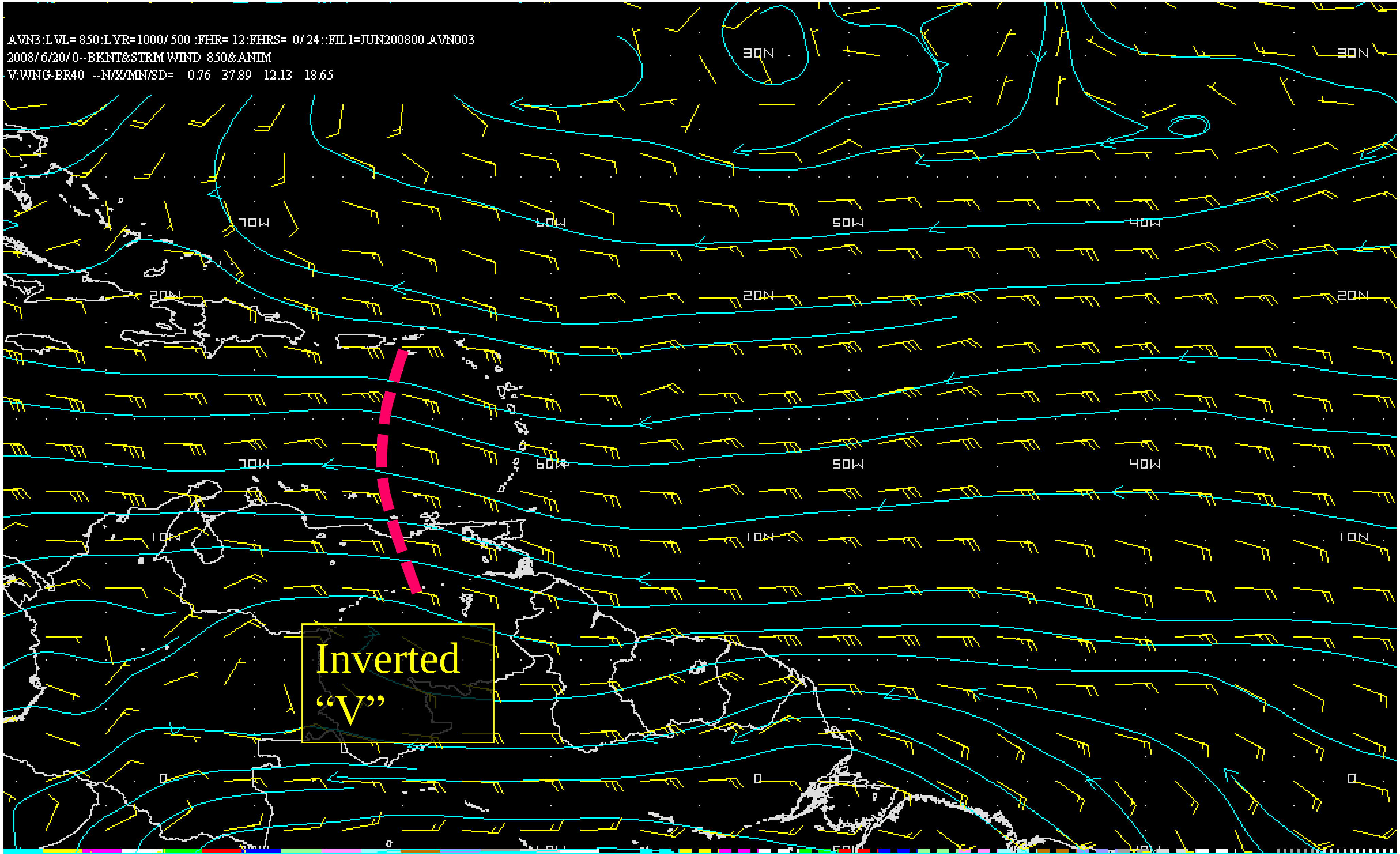


Infrared Animation
Inverted "V"
080620/0245 GOES12 IR4

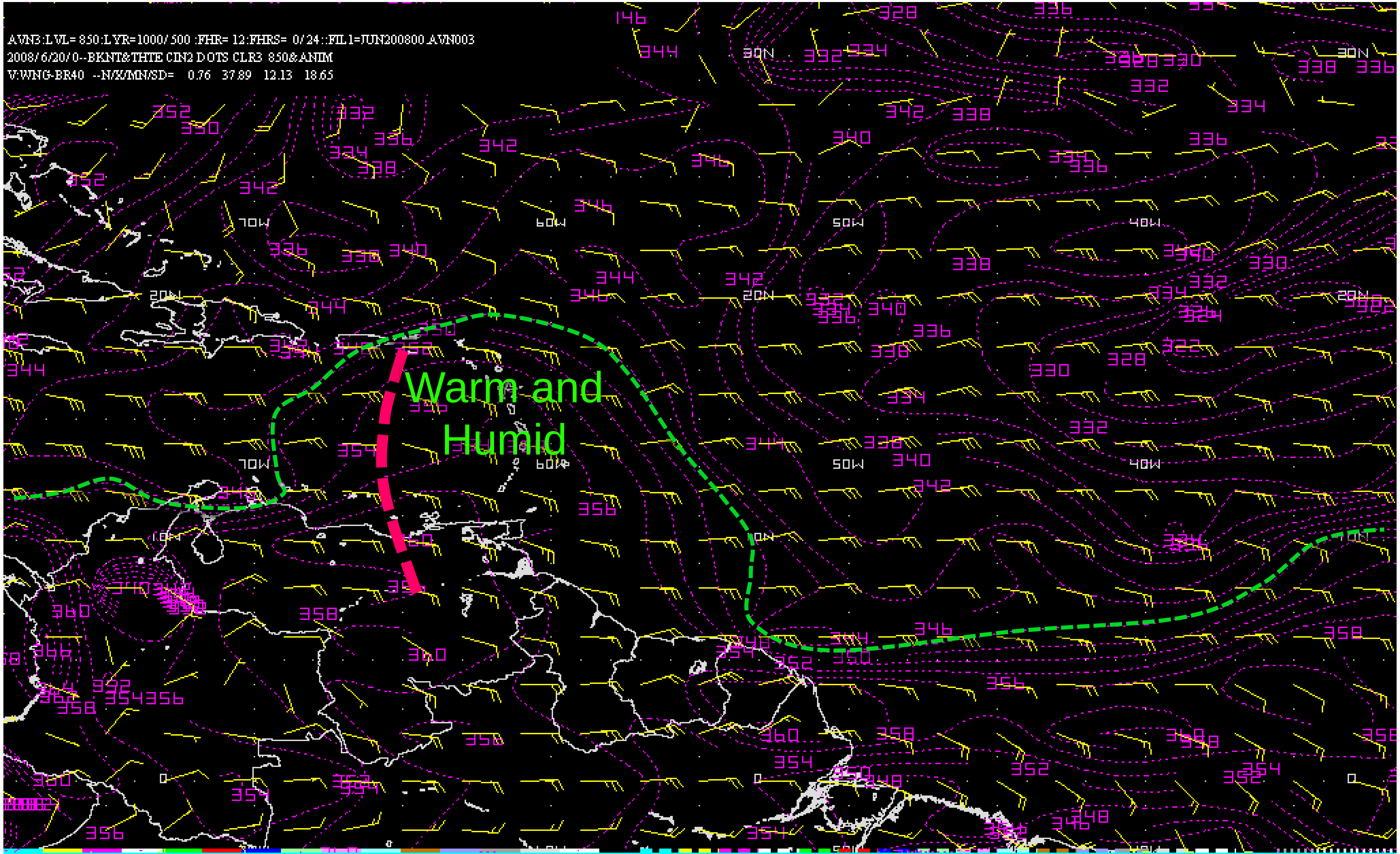
GFS Analysis: Winds at 200 hPa



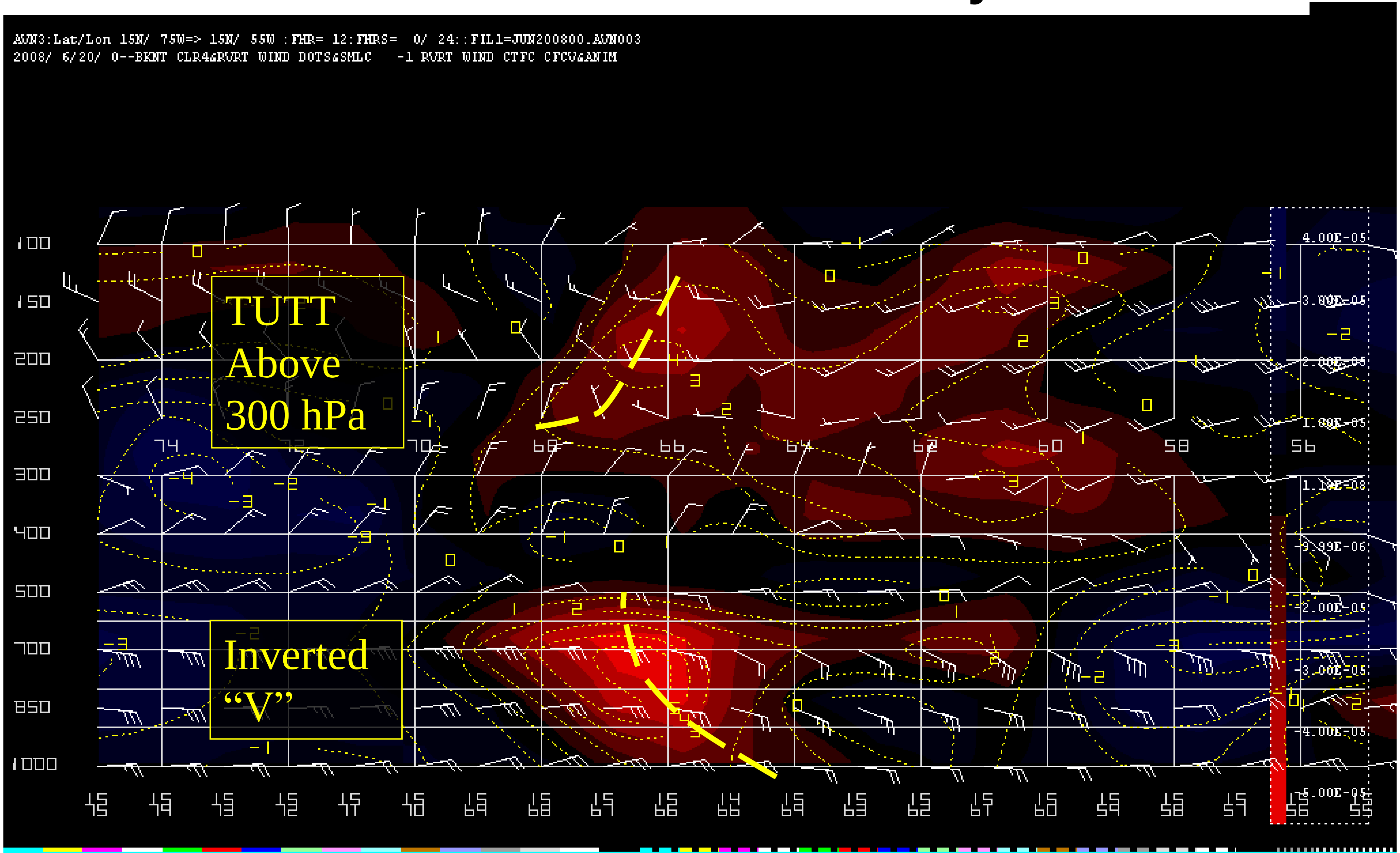
GFS Analysis: Winds at 850 hPa



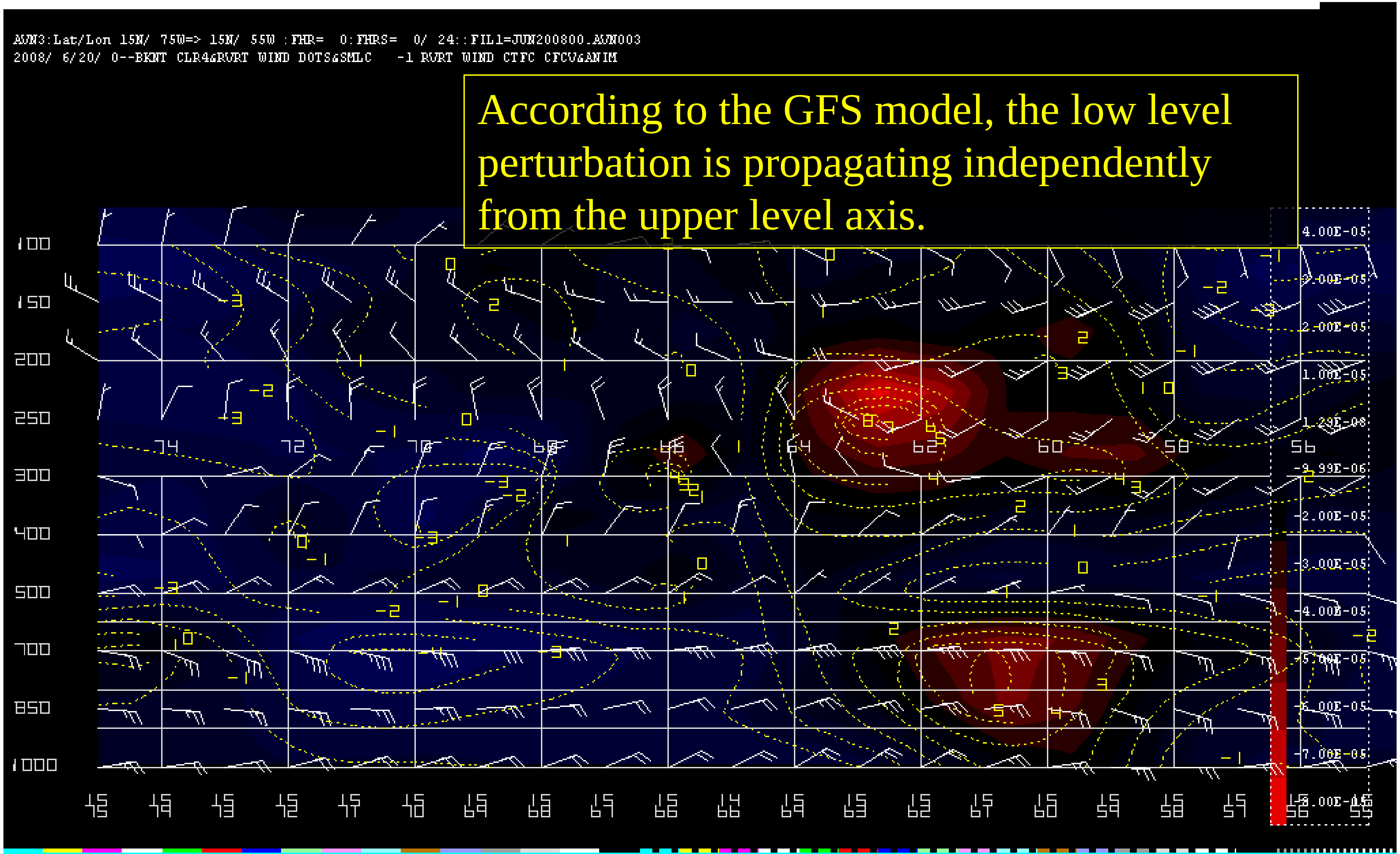
Winds and EPT (θe) at 850 hPa



Cross Section:
Winds and Relative Vorticity



Animation:
Winds and Relative Vorticity



Observations

- The Visible image and the IR are showing an inverted trough in the easterlies in the lower levels.
- The water vapor image shows a TUTT low.
- The animation of the satellite images and the forecasting models are indicating that the perturbation in the easterlies is propagating **independently** of that in the upper levels.
  - **But there is positive interaction between the two systems in different scales, with strong convection in the Leeward Islands.**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Lima

Thank You!