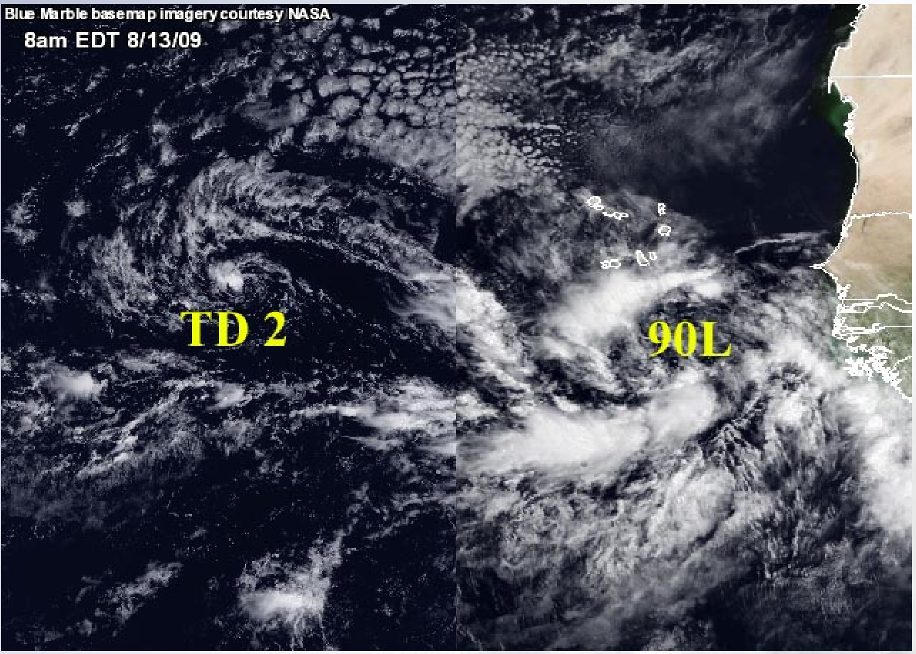
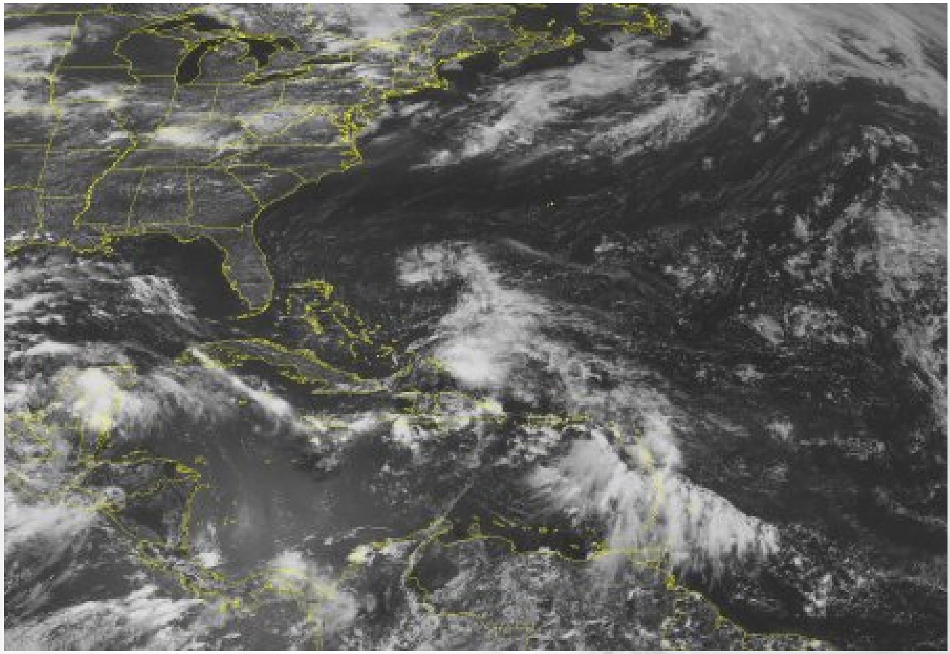
Tropical Waves and Tropical Analysis

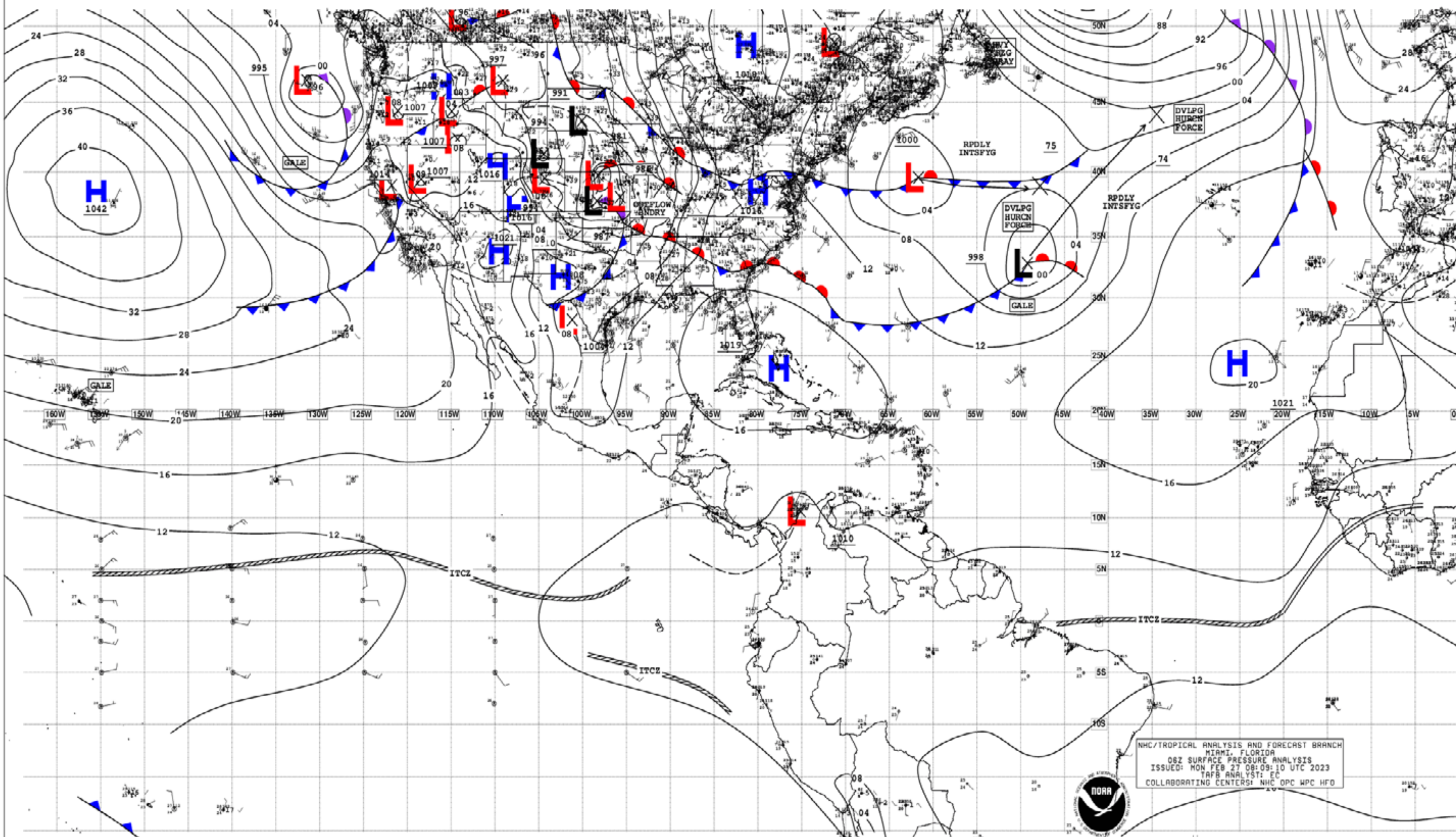




John Cangialosi, Dr. Jiann-Gwo Jiing, and Andrew Levine
National Hurricane Center

WMO Region IV
Tropical Cyclone Workshop

Tropical Analysis Basics


NHC/TROPICAL ANALYSIS AND FORECAST BRANCH
MIAMI, FLORIDA
06Z SURFACE PRESSURE ANALYSIS
ISSUED: MON FEB 27 08:09:10 UTC 2023
TAFB ANALYST: EC
COLLABORATING CENTERS: NHC OPC WPC HFO

Why analyzing the tropics is a challenge?

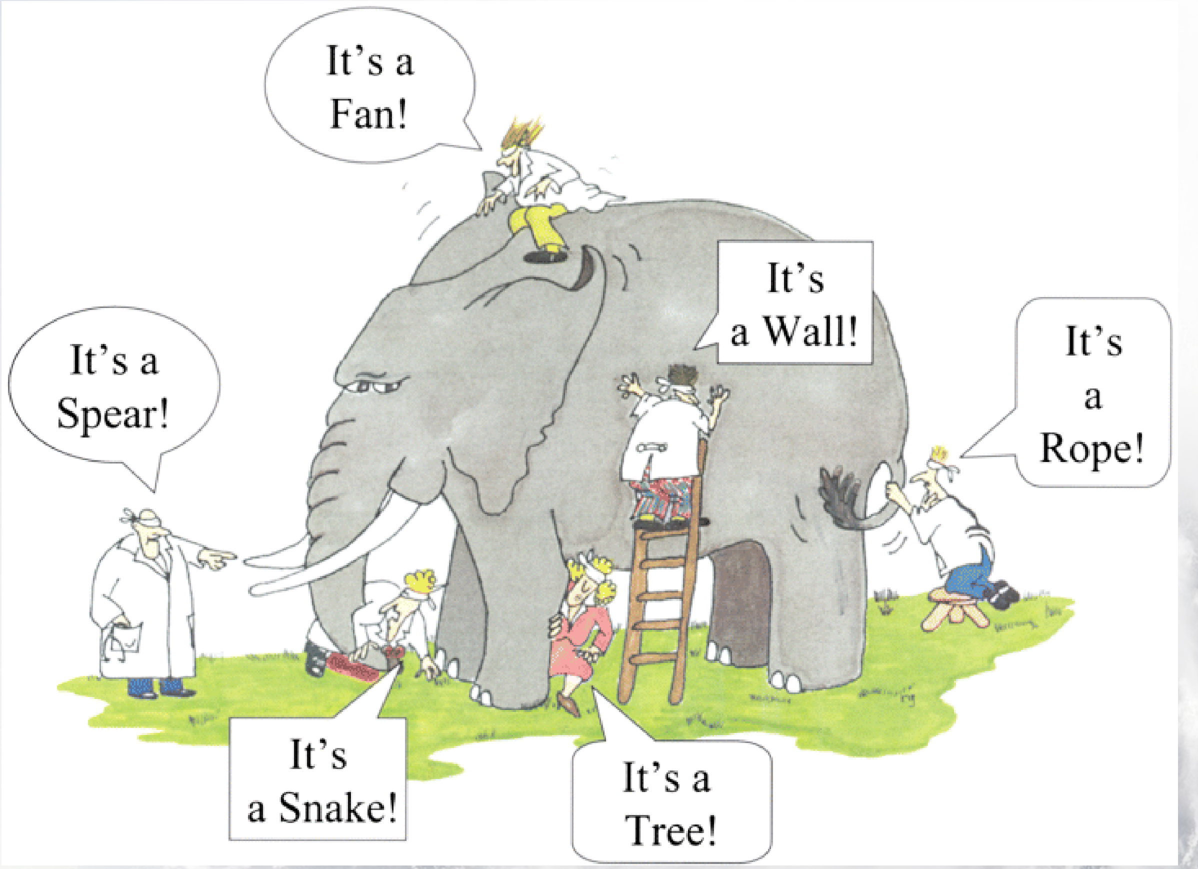
- Poor data coverage
- Lack of understanding of tropical weather systems
- Many tropical weather systems have small amplitude
- Local effects
  - coastal, topographical, diurnal, semi-diurnal,…and they tend to be more noticeable
- Most textbooks teach mid-latitude systems

Why is a good analysis important

- Real-time analysis - May lead to better forecast
- Case studies – Can help understand weather systems better
  - A good knowledge is the basis for a better real-time analysis and forecast

(Don’t believe everything you read. Do your own analysis if possible)

Blind/blindfolded men and an elephant



When the data is very limited, and the knowledge about the subject is almost none, people sometimes come up with all kind of interpretation based on the limited data they'd collected.

Some Useful Analysis Practices

- Check the data/analysis over a longer period of time
- Time series analysis
- Check vertical cross sections
- Space-time analysis
- Use wind analysis when possible

Some Useful Analysis Practices

- Use all observations you have
- Filtering
- If necessary, use continuity – extrapolation

  If necessary, use short term forecast from previous global model run
- When nothing else is available, use climatology

Tropical Waves Basics

What are tropical waves?

* Perturbations / disturbances in the tropical easterlies that typically move from east to west.

* Often seen as inverted troughs of low pressure (inverted-V pattern in satellite imagery). Significant rain producers.

* Convection typically on the east side. Subsidence/clearing on the west side.

* Convection highly modulated by atmospheric moisture, upper level features, topography, etc.

* Develop into tropical cyclones.

* Around 60 tracked per year (little annual variability)

Tropical Wave Research

Tropical wave basics

Significance known as far back as 1930s (Piersig, Regula)

Patterns of rain, cloudiness, and windshifts received increased attention during WWII (Riehl, 1945)

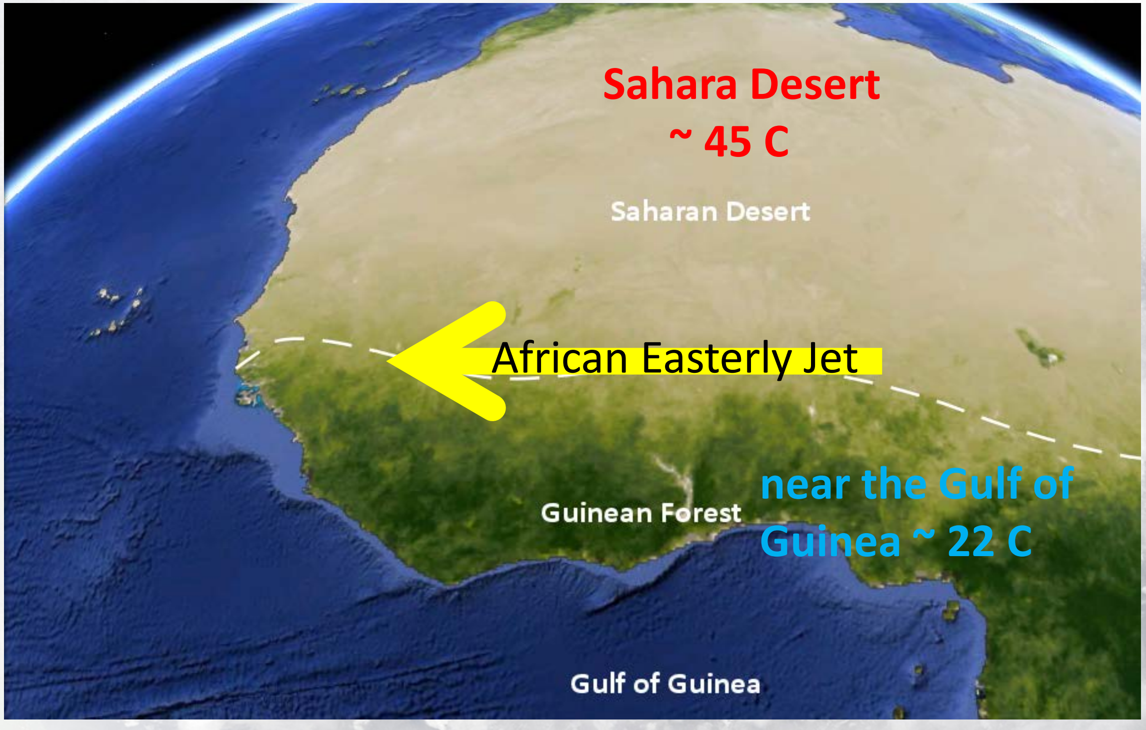
With the growth of rawinsonde networks and better surface synoptic data, easterly waves were studied with 3 approaches:

Synoptic (Carlson, 1969)
Spectral analysis (Burpee, 1972)
Compositing (Reed et al. 1971 (Pacific), 1977, 1979 (Atlantic))

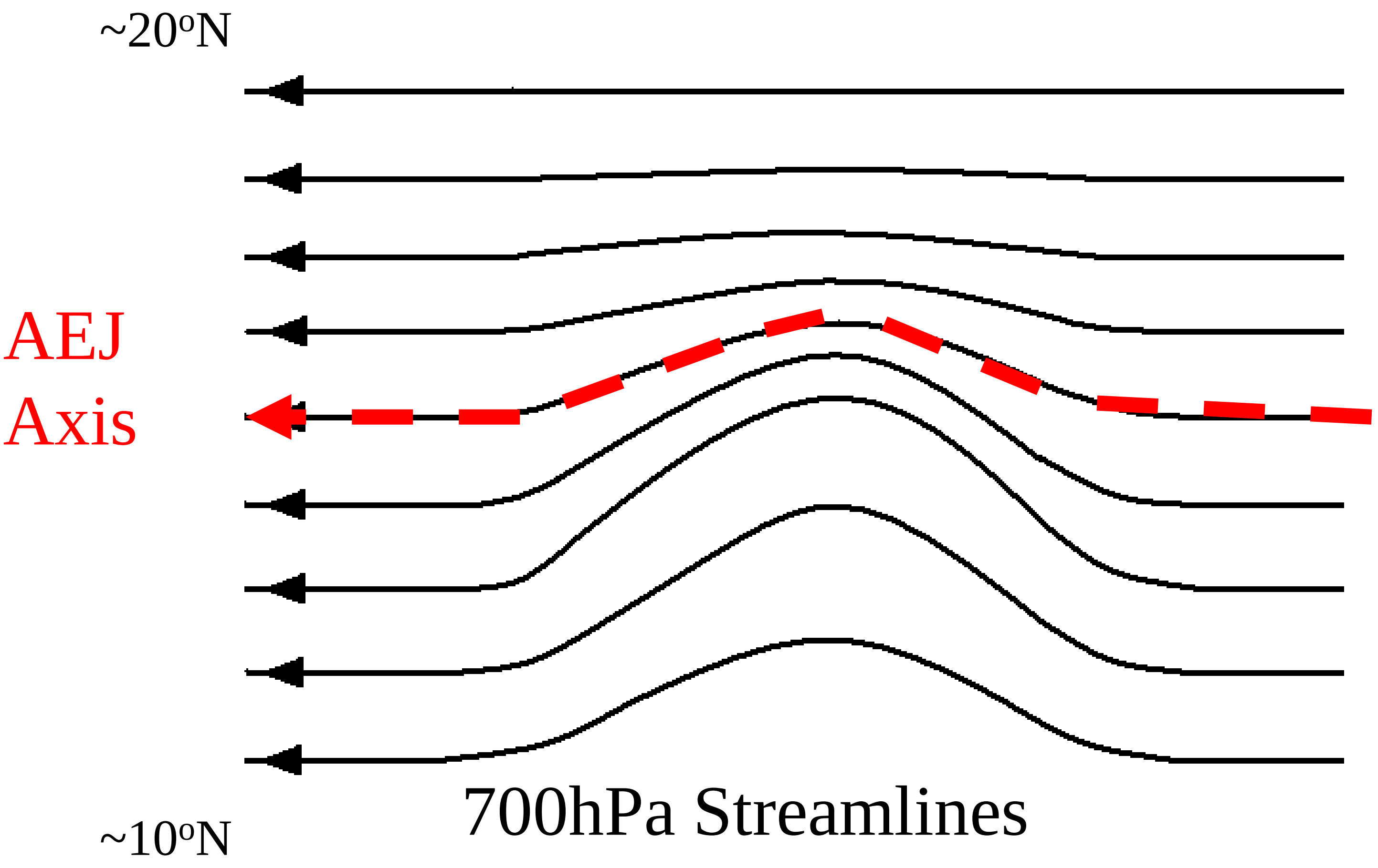
The composite from Reed (1977) still serves as the primary 'text book' description of AEWs.

How/where they form

- Generated by an instability (baroclinic-barotropic)of the African easterly jet
- Jet arises as a result of reversed lower tropospheric temperature gradient over west-central north Africa due to extremely warm temperatures over the Sahara Desert and substantially cooler temperatures along the coast of Guinea.



AEW synoptic structure over West Africa.



Synthesis of Carlson (1969a, b), Burpee (1972,1974), Reed et al (1977)

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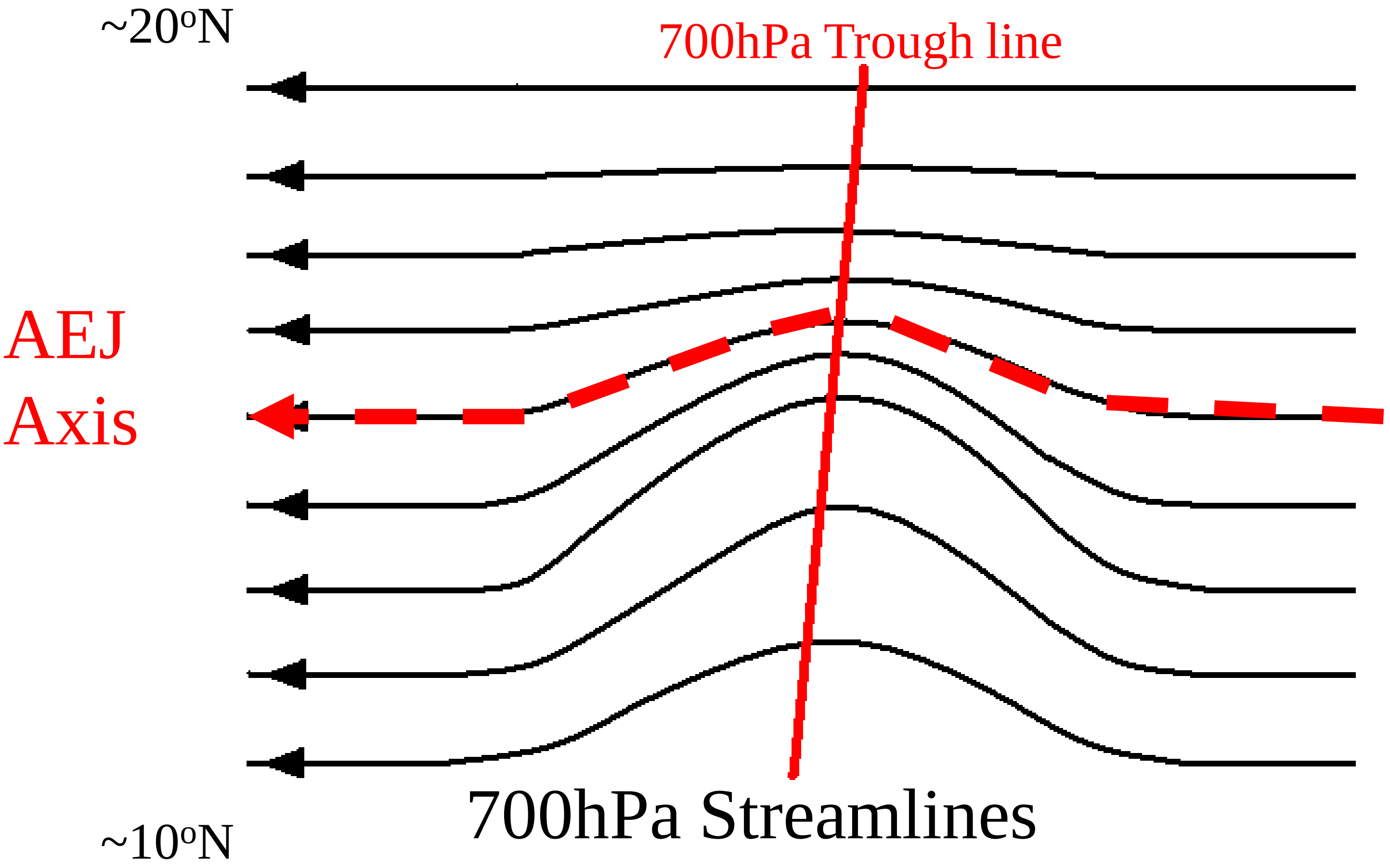

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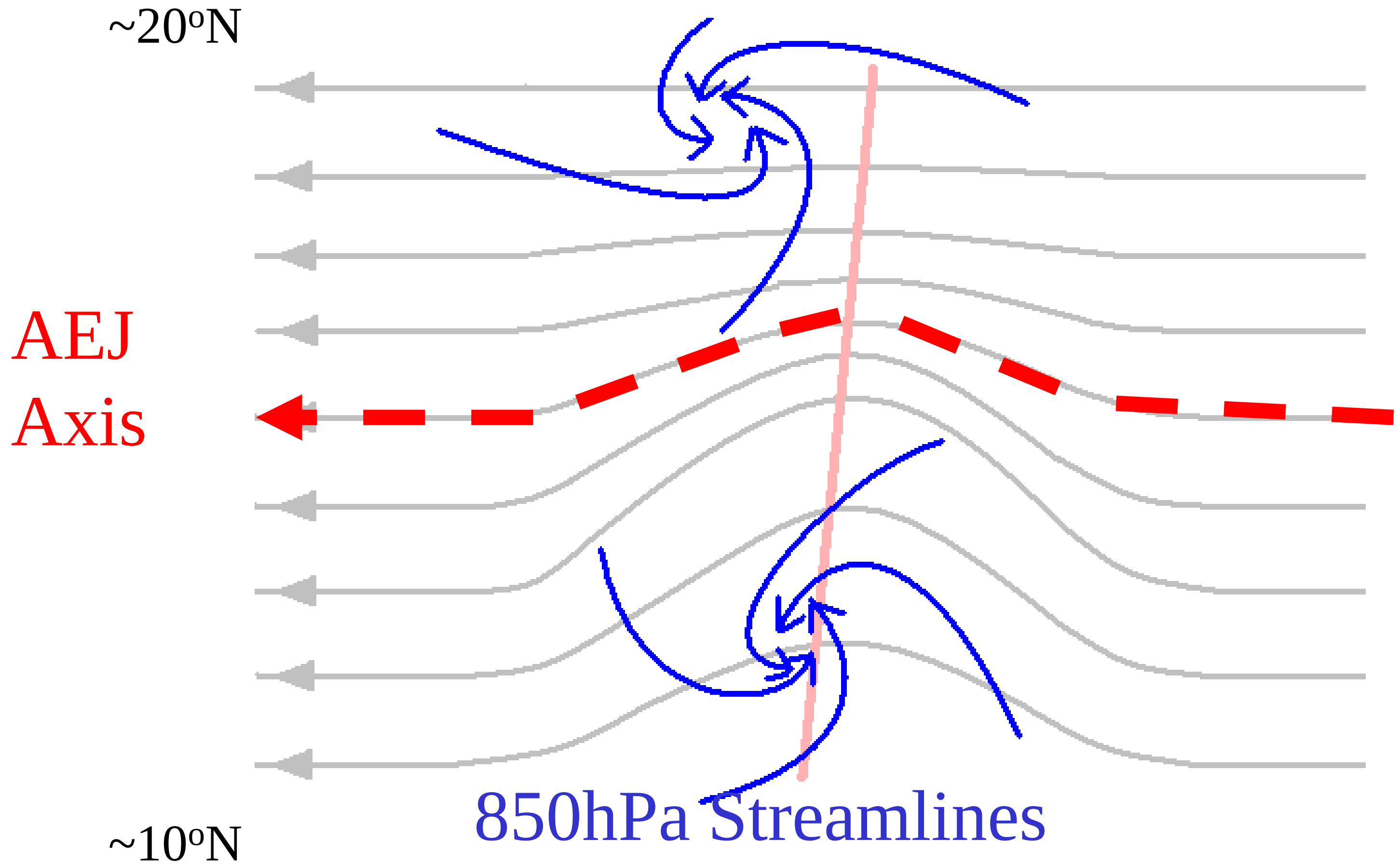

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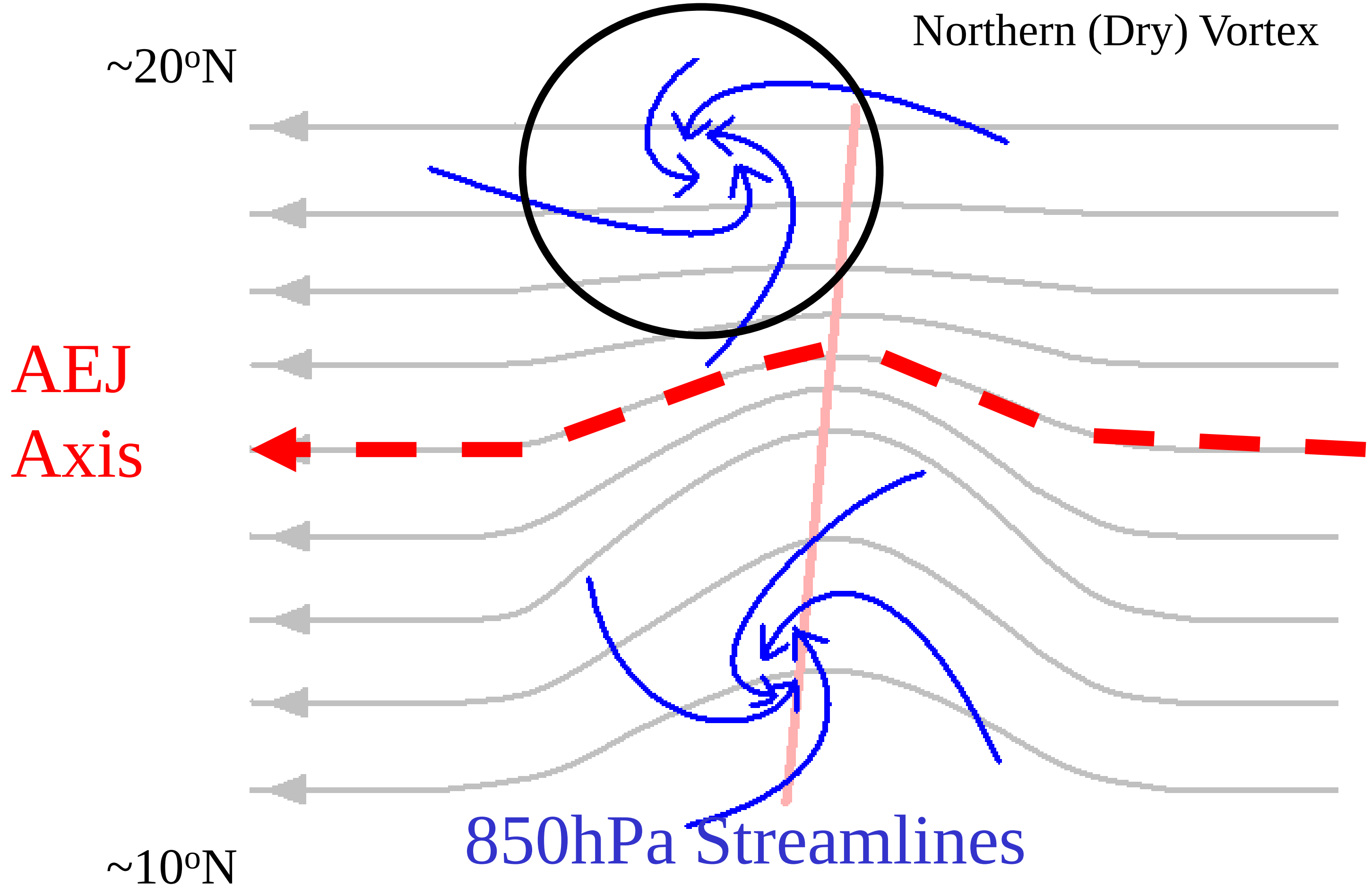

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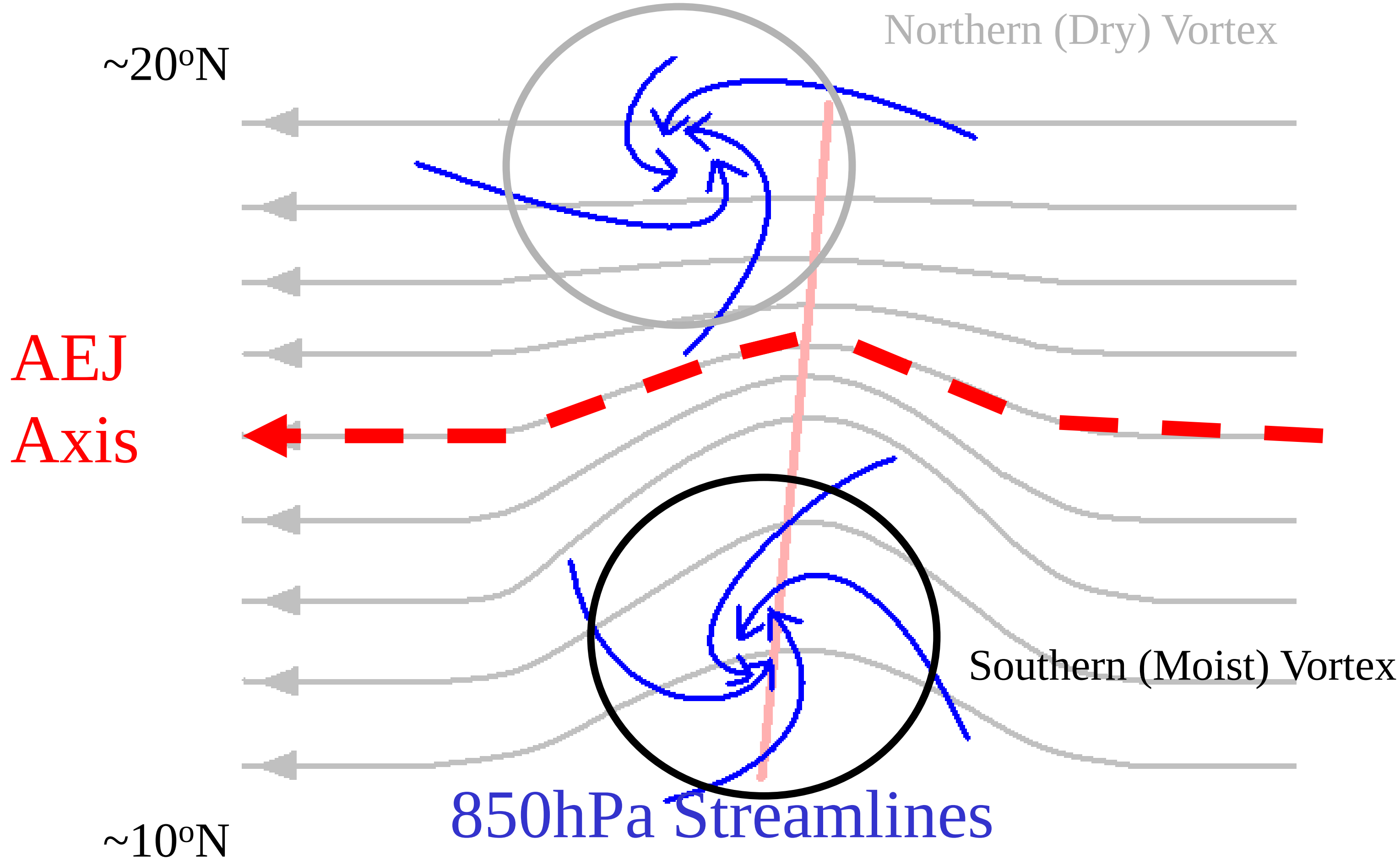

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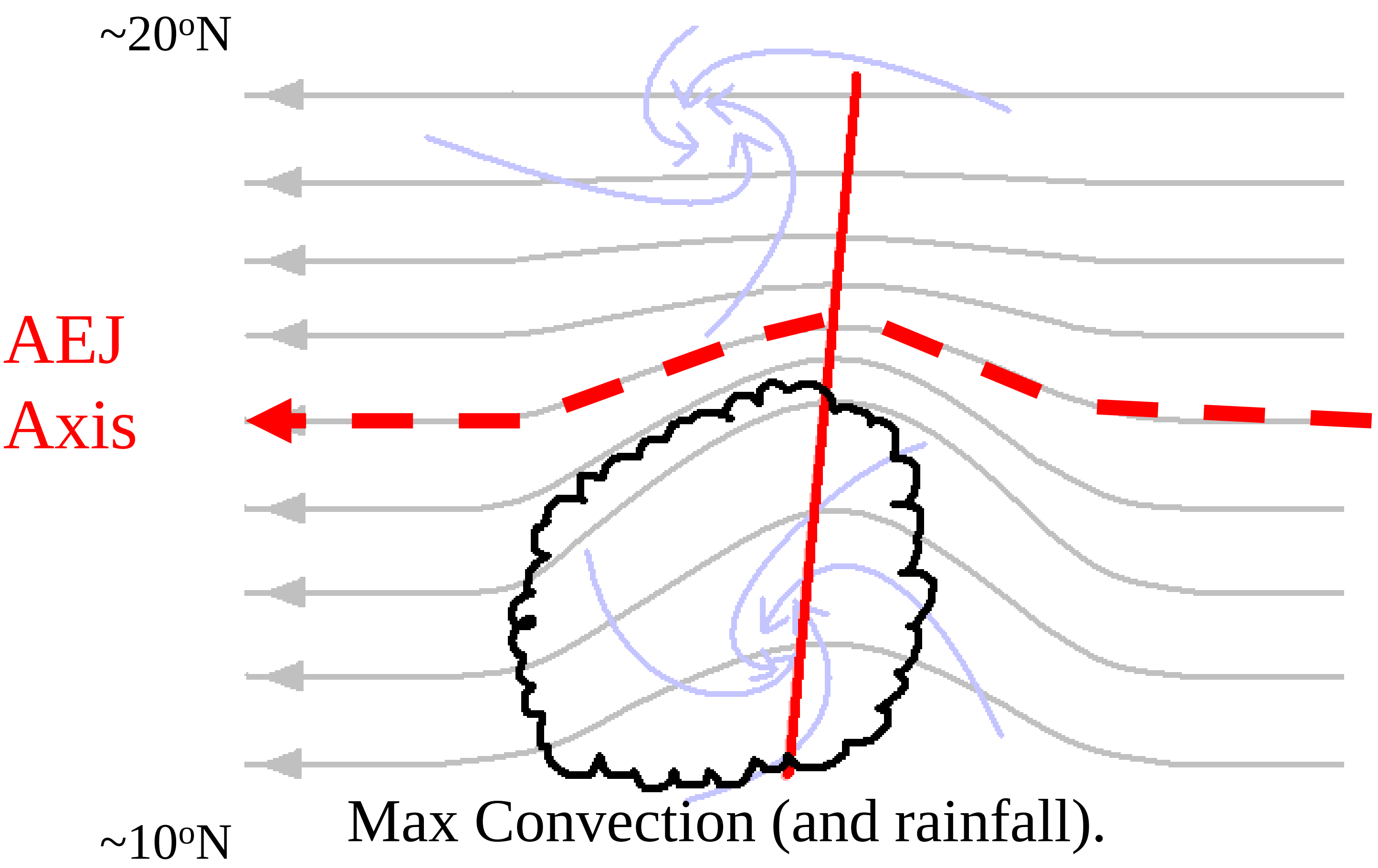
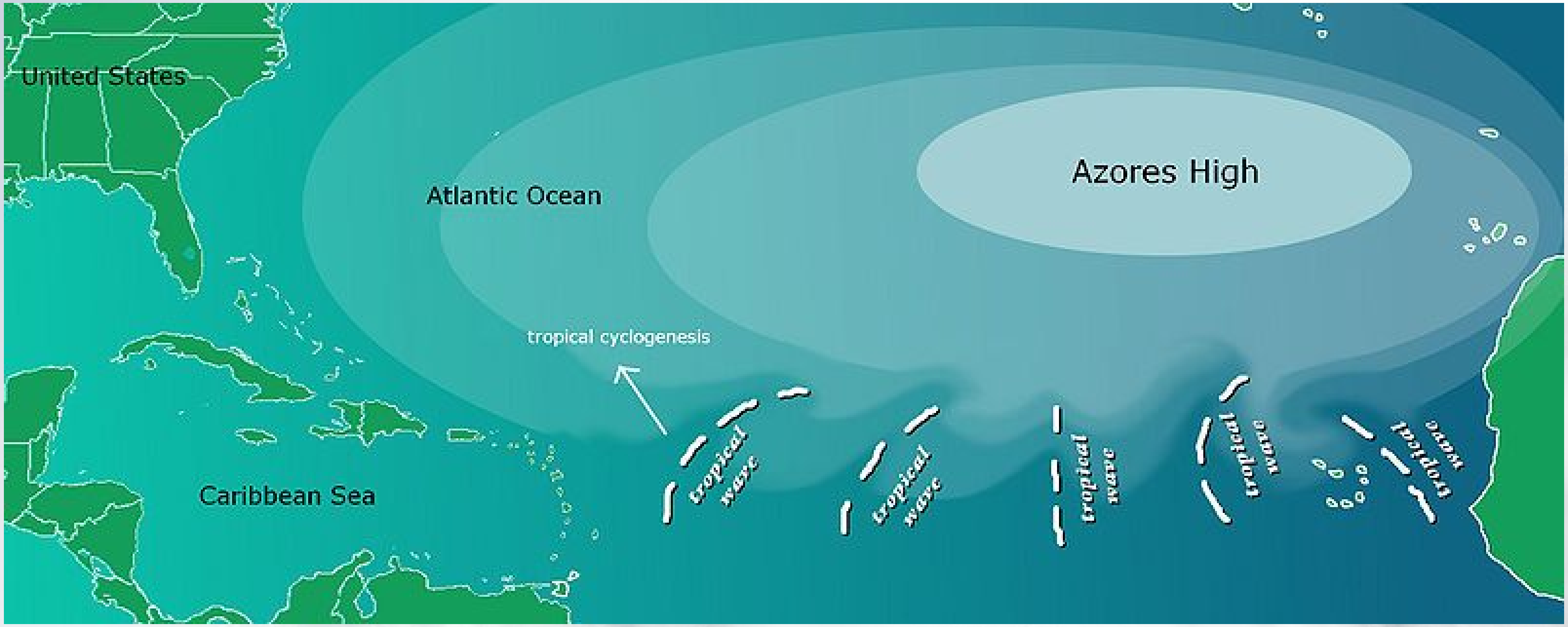


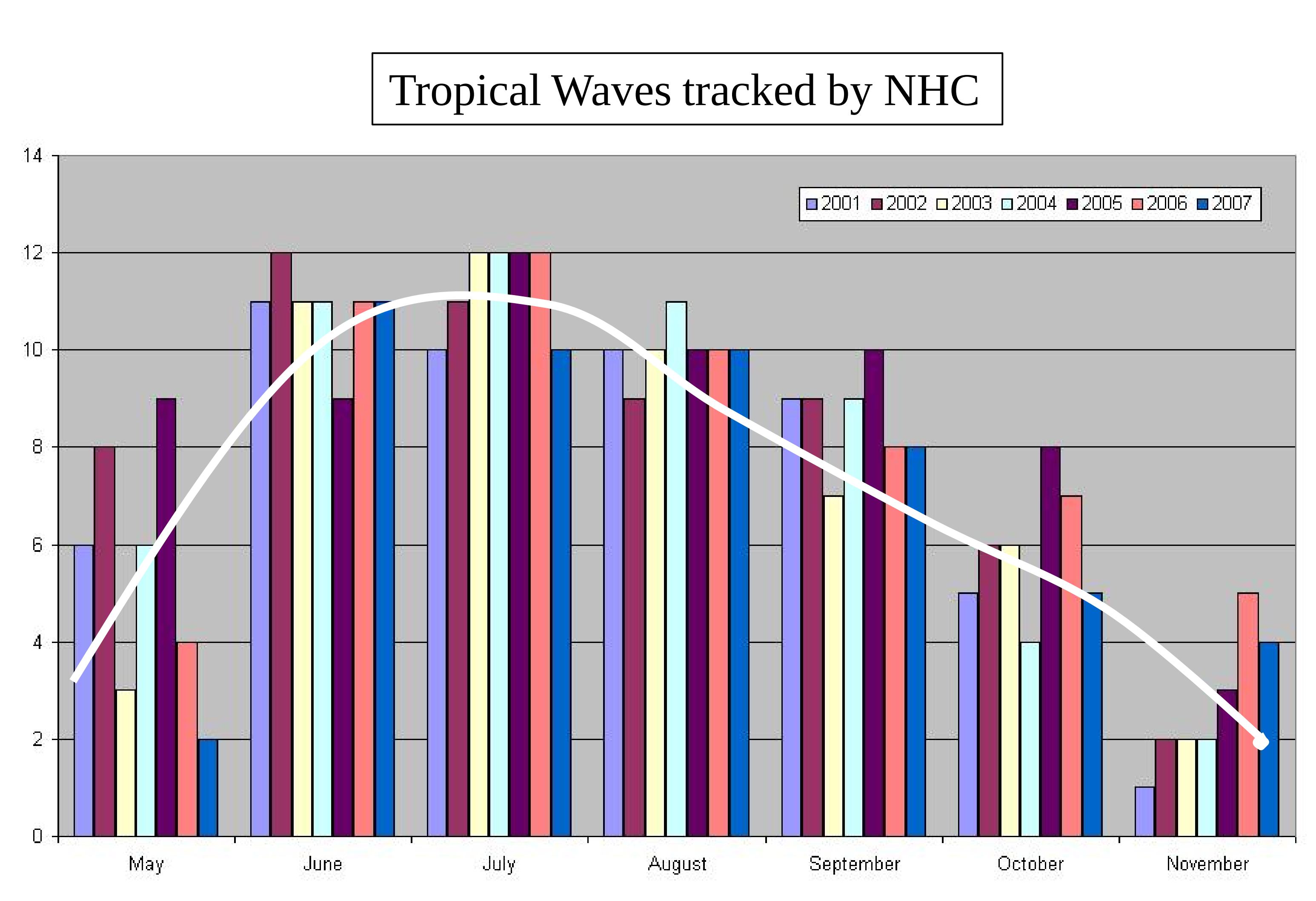
Synthesis of Carlson (1969a, b), Burpee (1972,1974), Reed et al (1977)

Typical Synoptic Setup



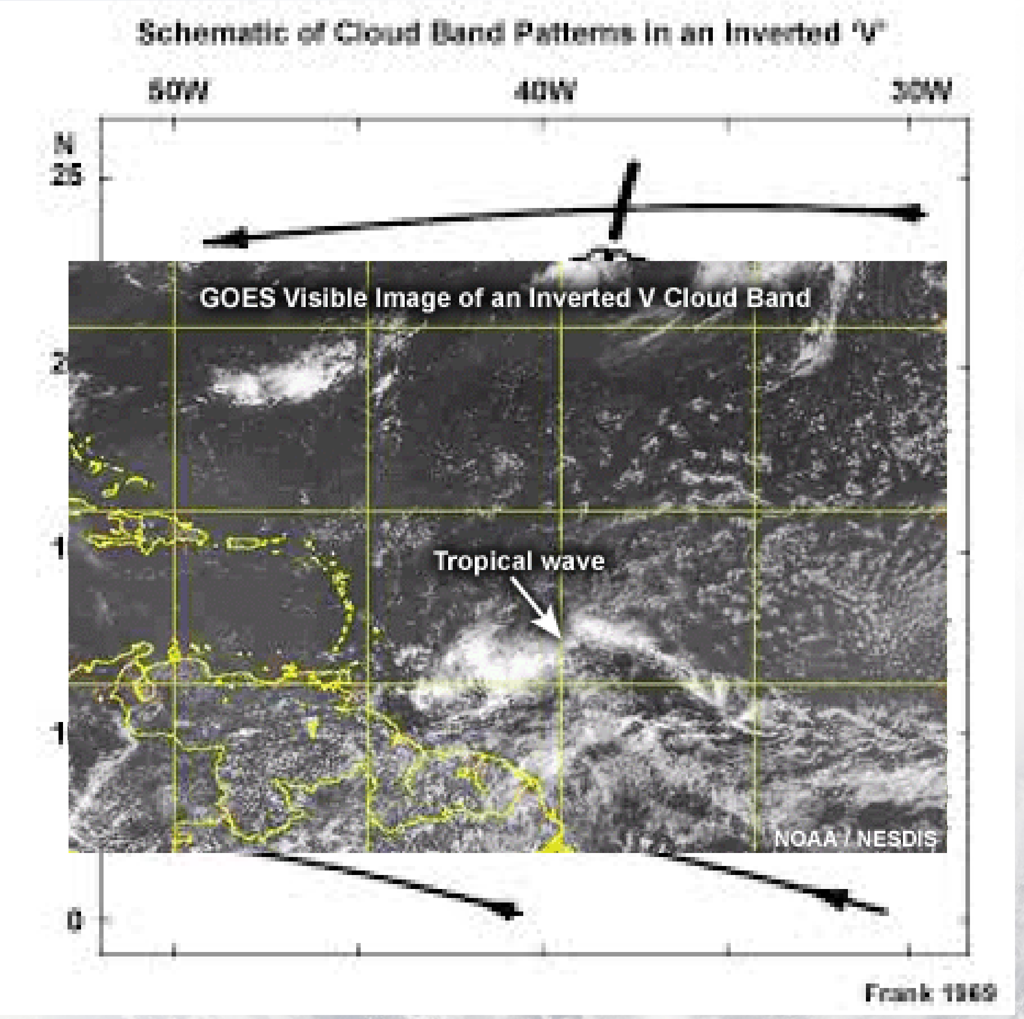
Tropical waves/African easterly waves move westward within the trade wind flow south of the Bermuda-Azores high

Frequency by month



Tropical wave activity in terms of numbers is highest June-August

Schematic diagrams

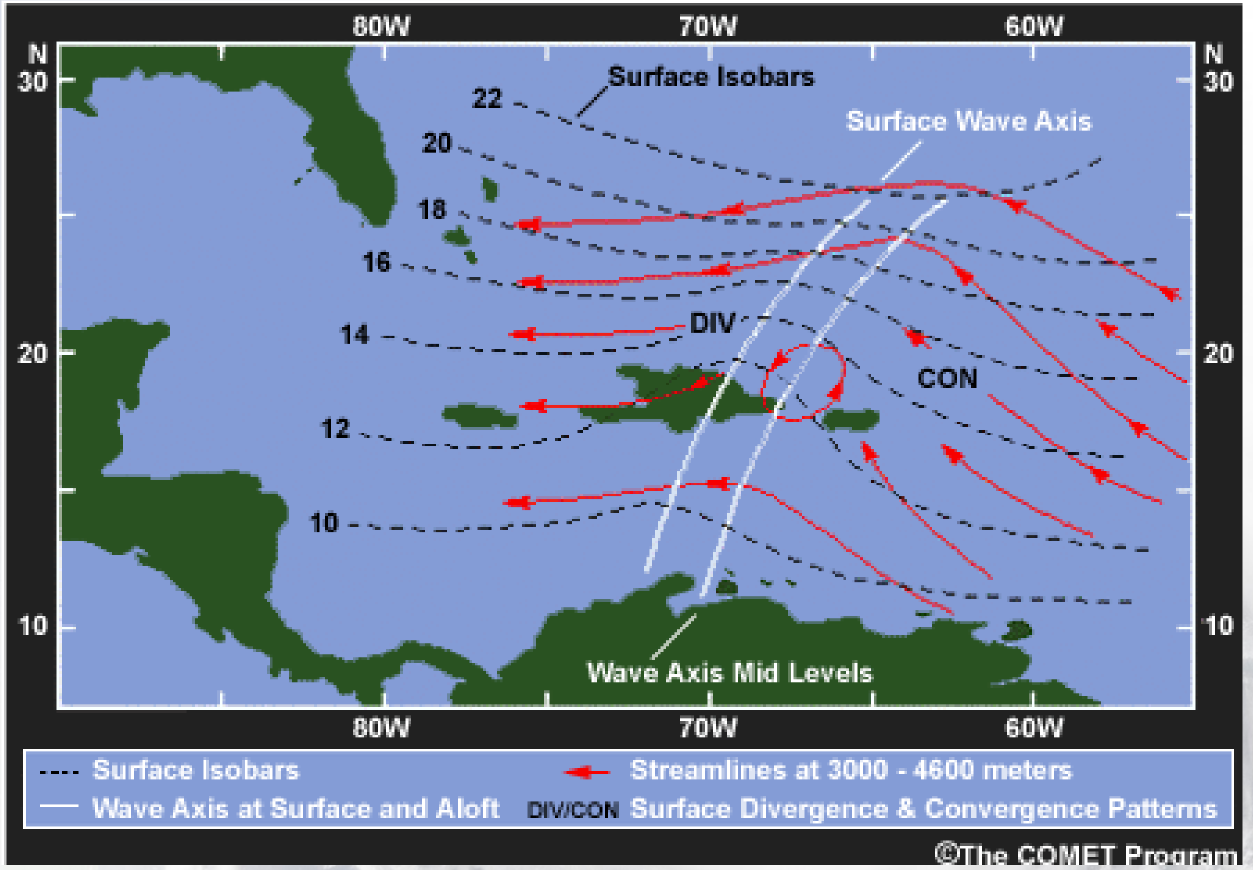


Classic inverted V-shape near the eastern Caribbean

At what pressure level is the maximum amplitude?

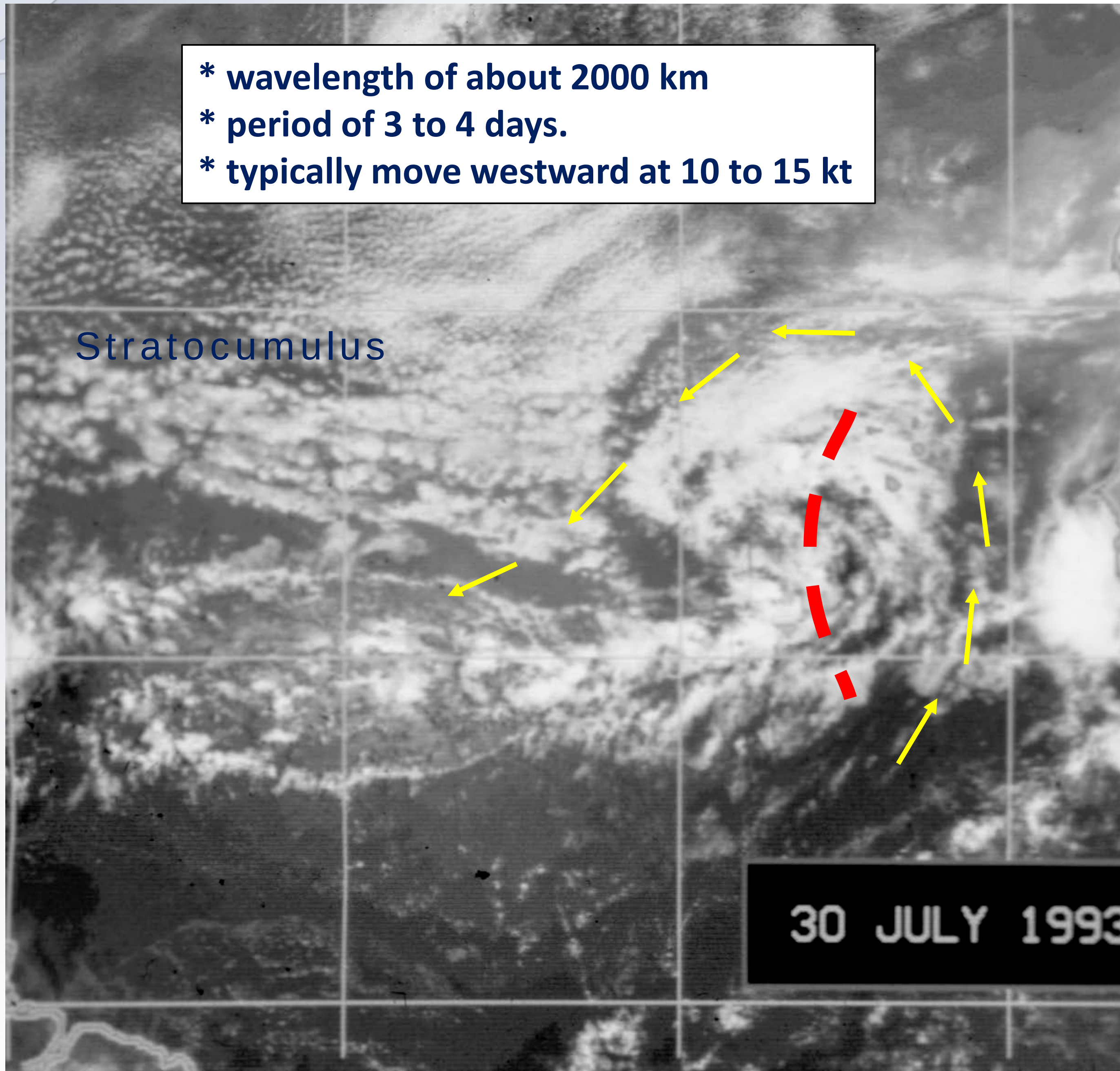
(a) 700 mb
(b) 500 mb
(c) 200 mb
(d) surface

Schematic diagram



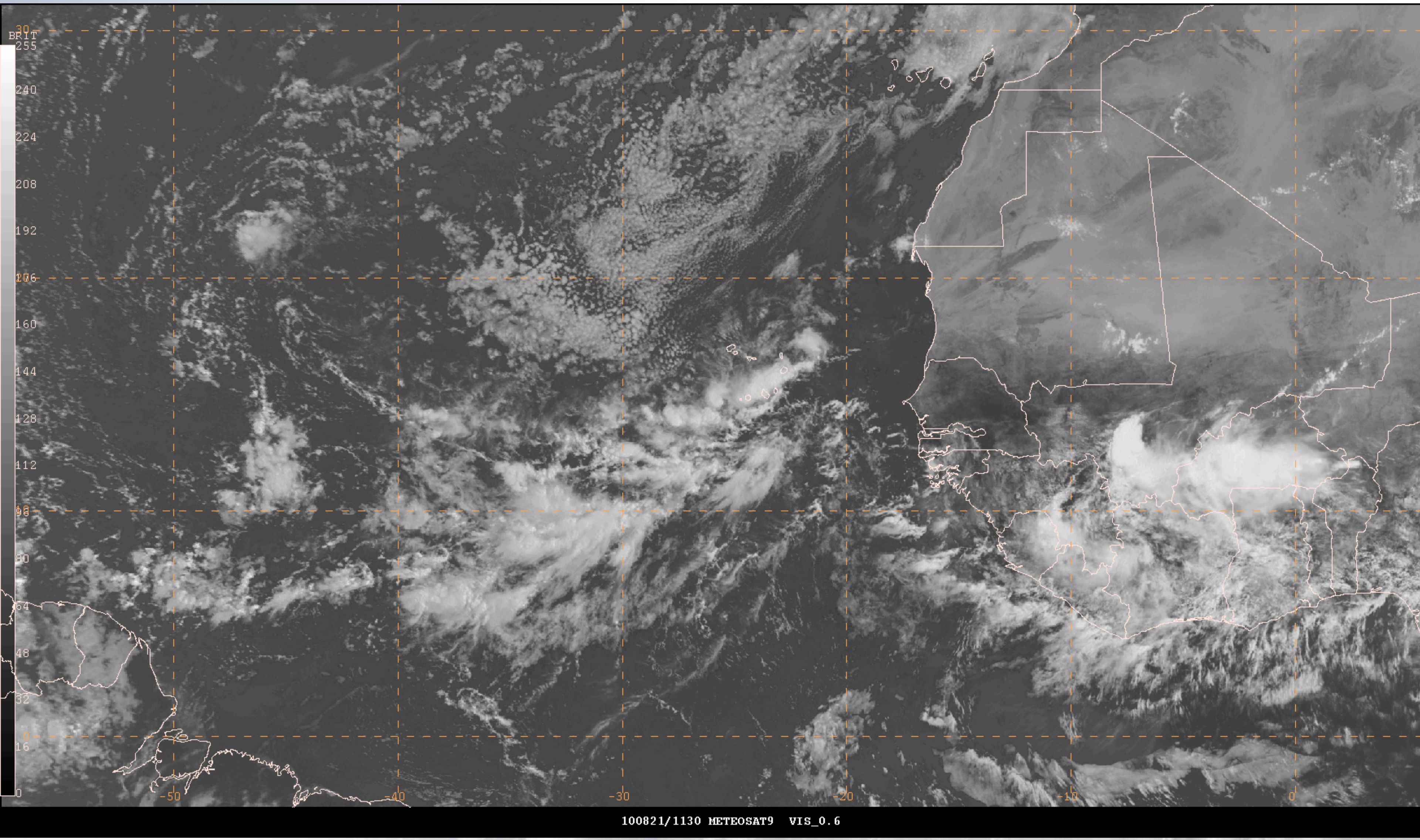
- Notice eastward slope will height
- Maximum amplitude is around 700 mb

* wavelength of about 2000 km
* period of 3 to 4 days.
* typically move westward at 10 to 15 kt



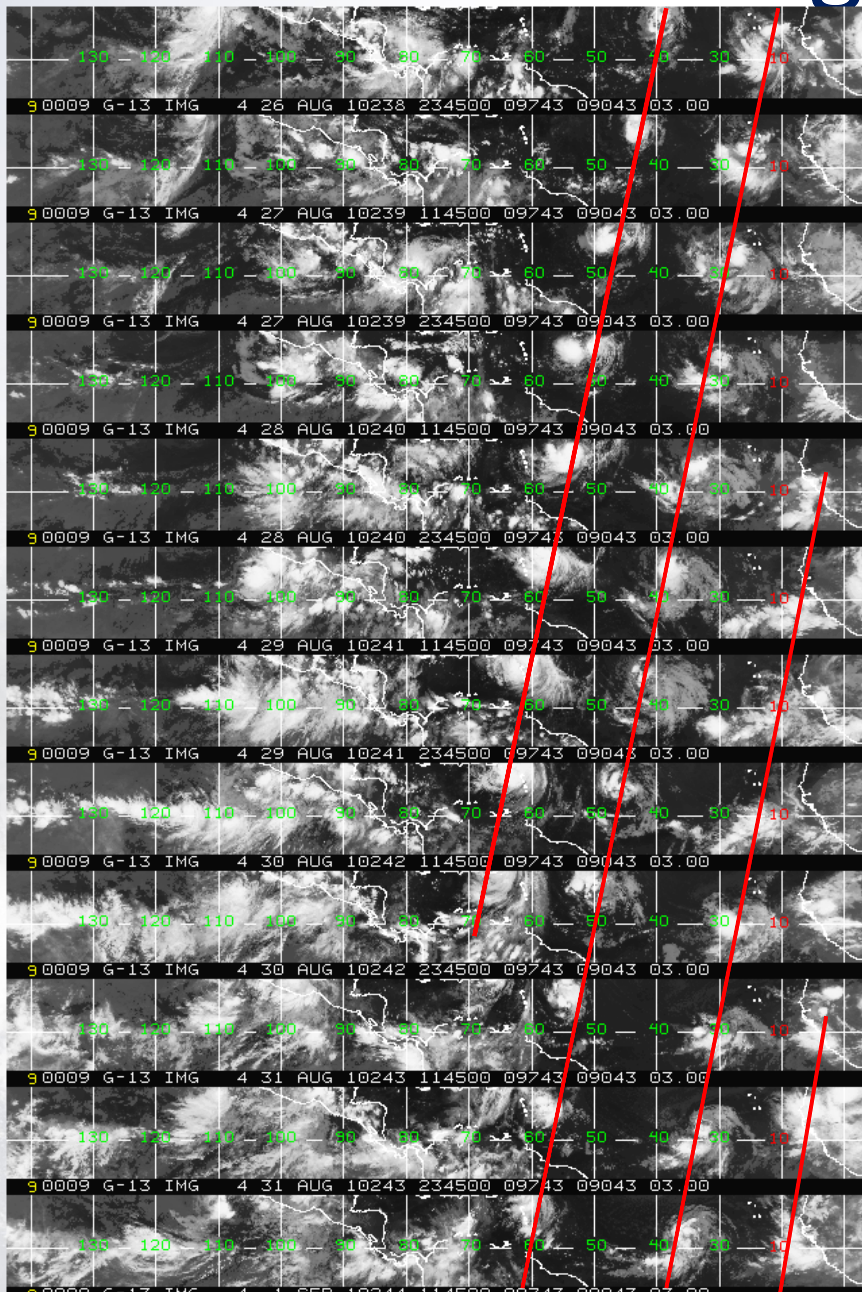
Tools to track tropical waves

Satellite Imagery



Satellite Hovmoller Diagrams

Time



Aug 26

Aug 27

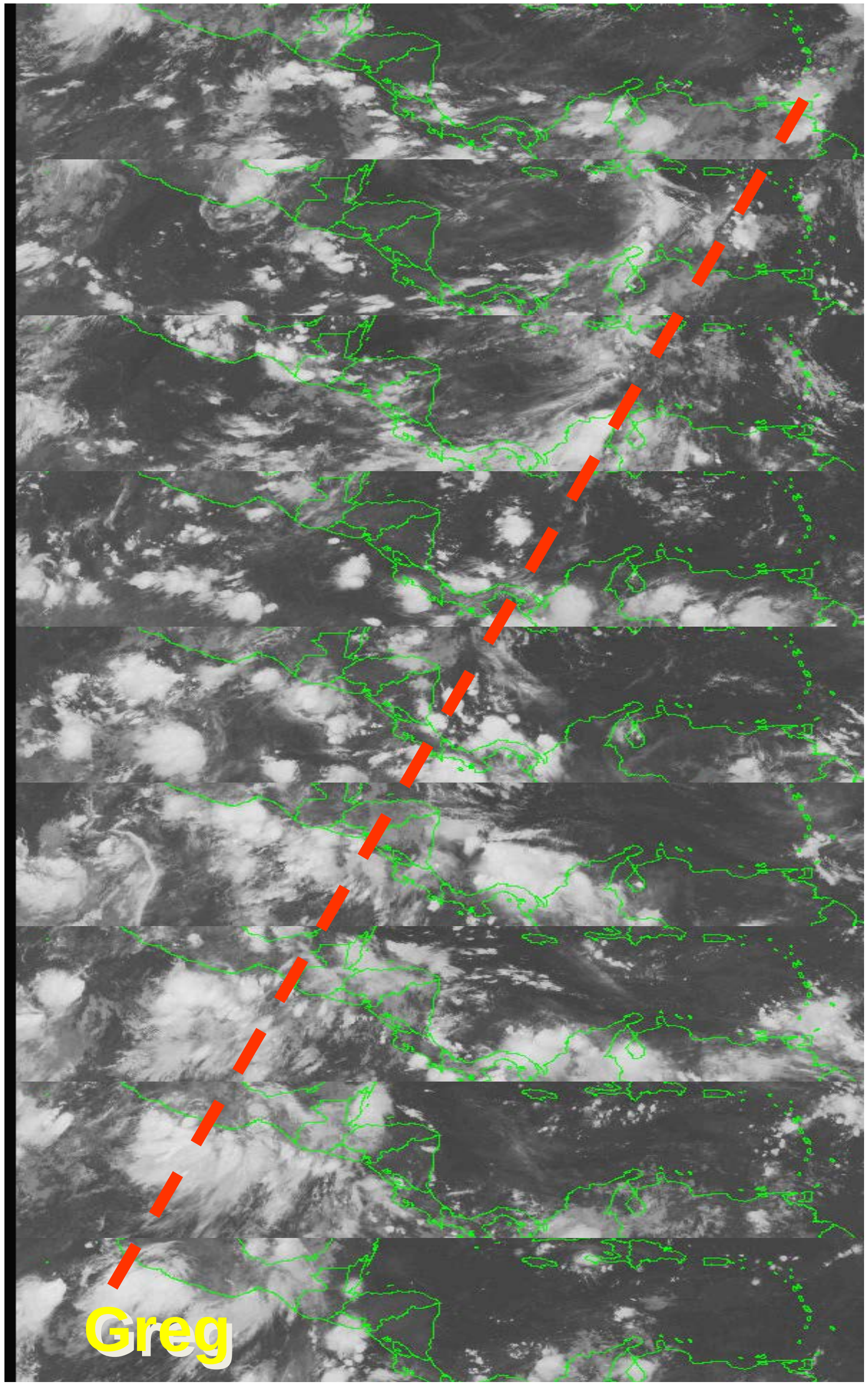
Aug 28

Aug 29

Aug 30

Aug 31

Sep 1



27

28

29

30

31

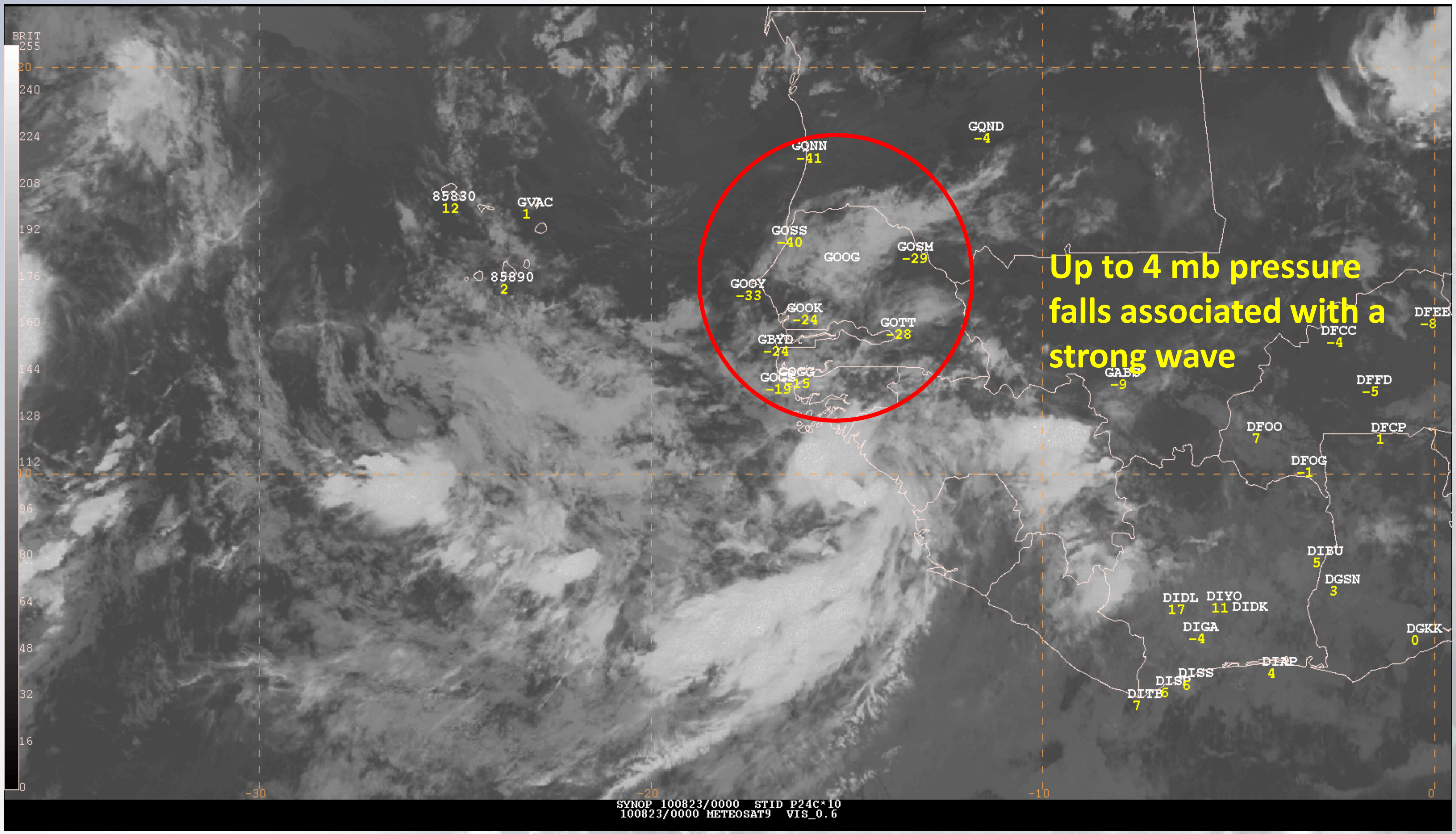
1

2

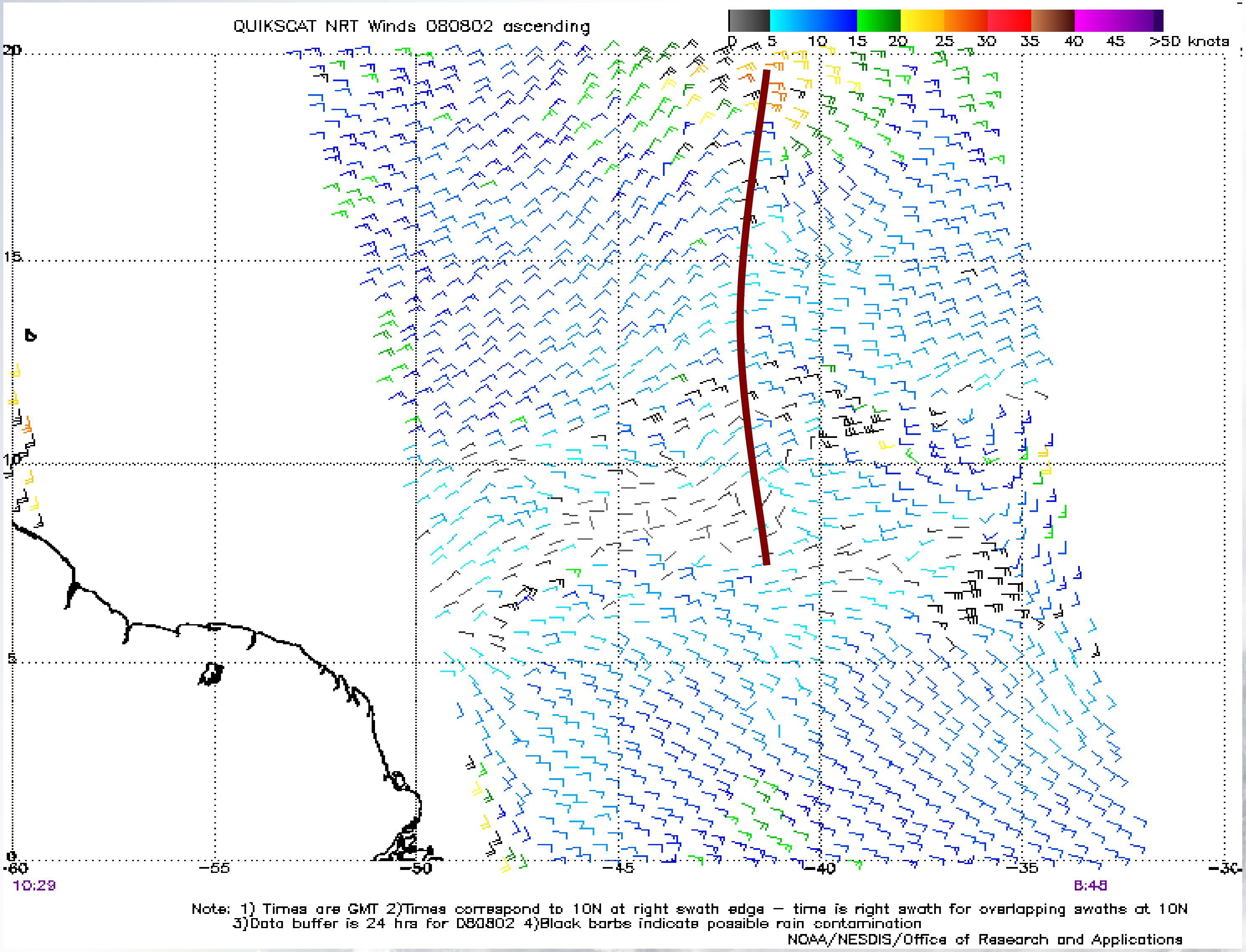
3

4

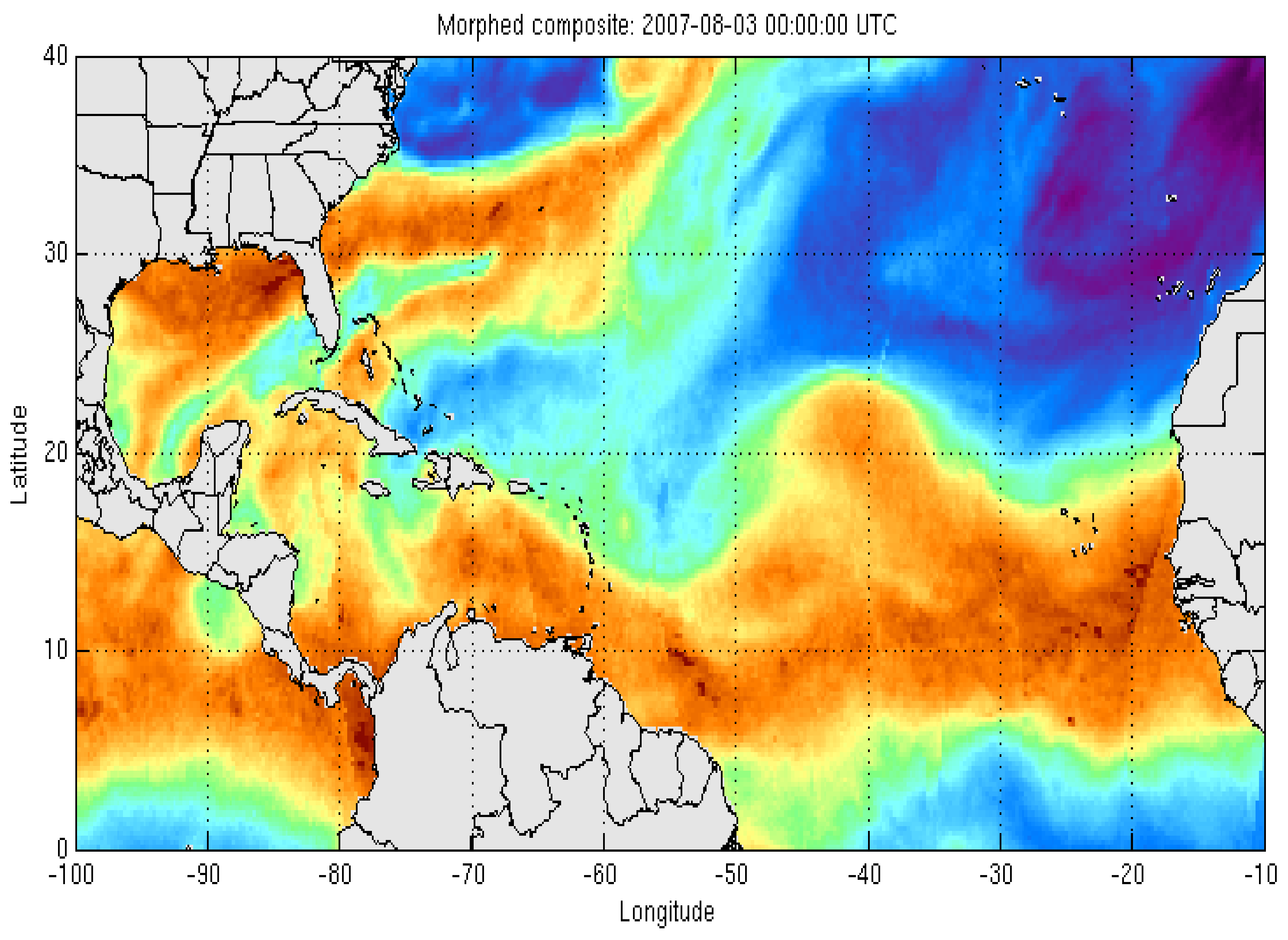
Surface Observations



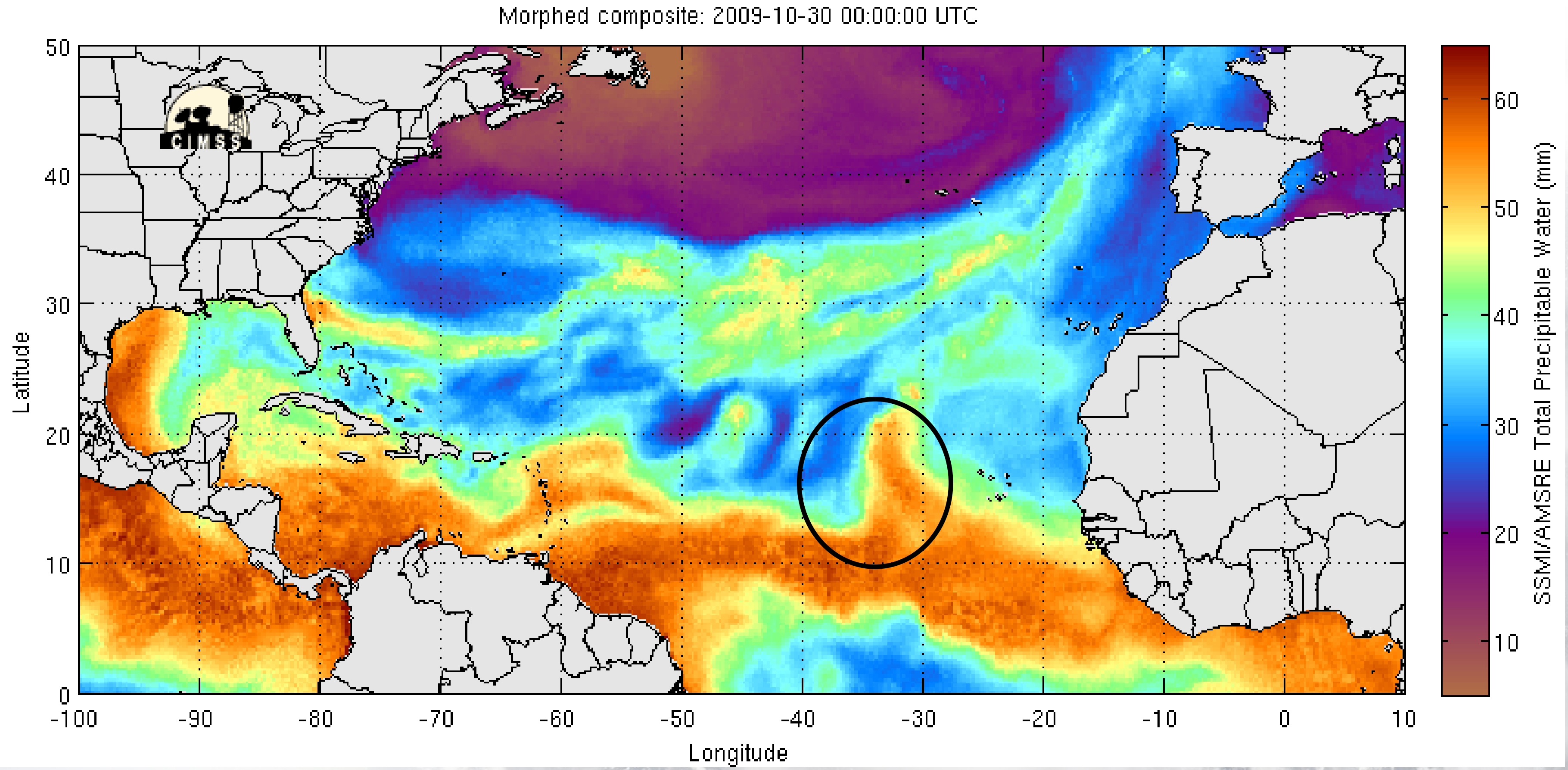
Scatterometer



Total Precipitable Water



Wave Splitting

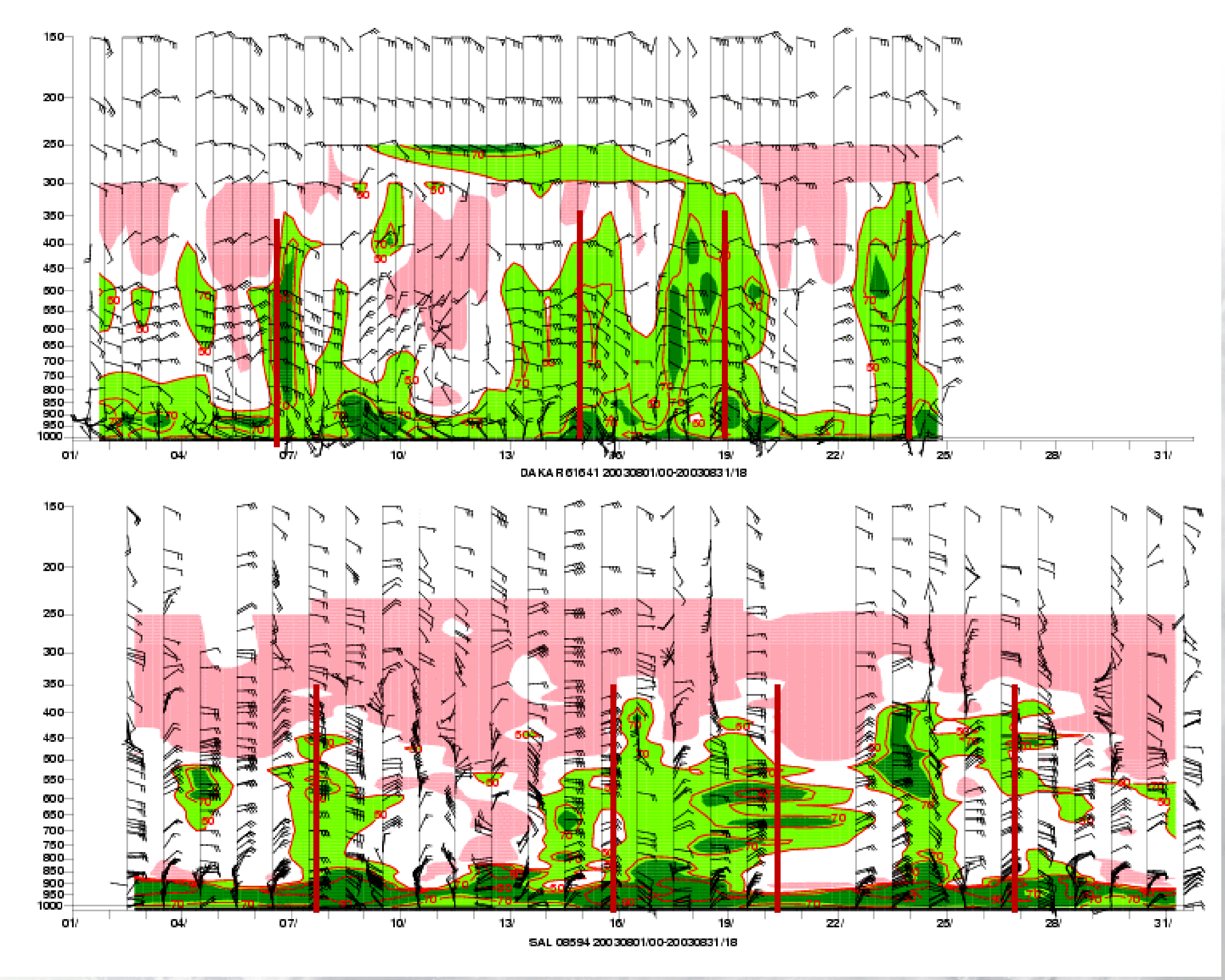


The northern portion of the wave often fractures but the southern extension continues moving westward

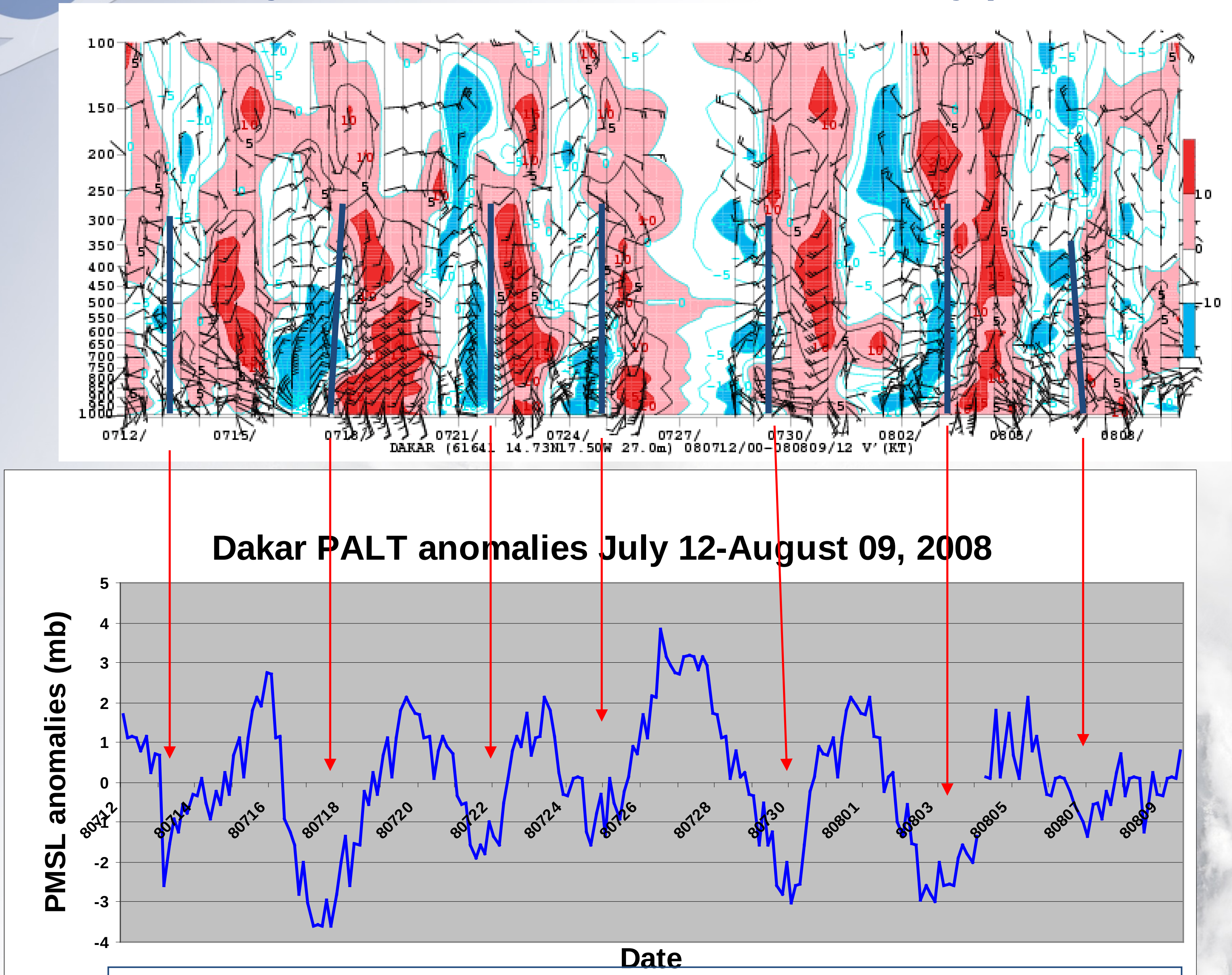
Upper-Air Time Sections

Dakar

Sal

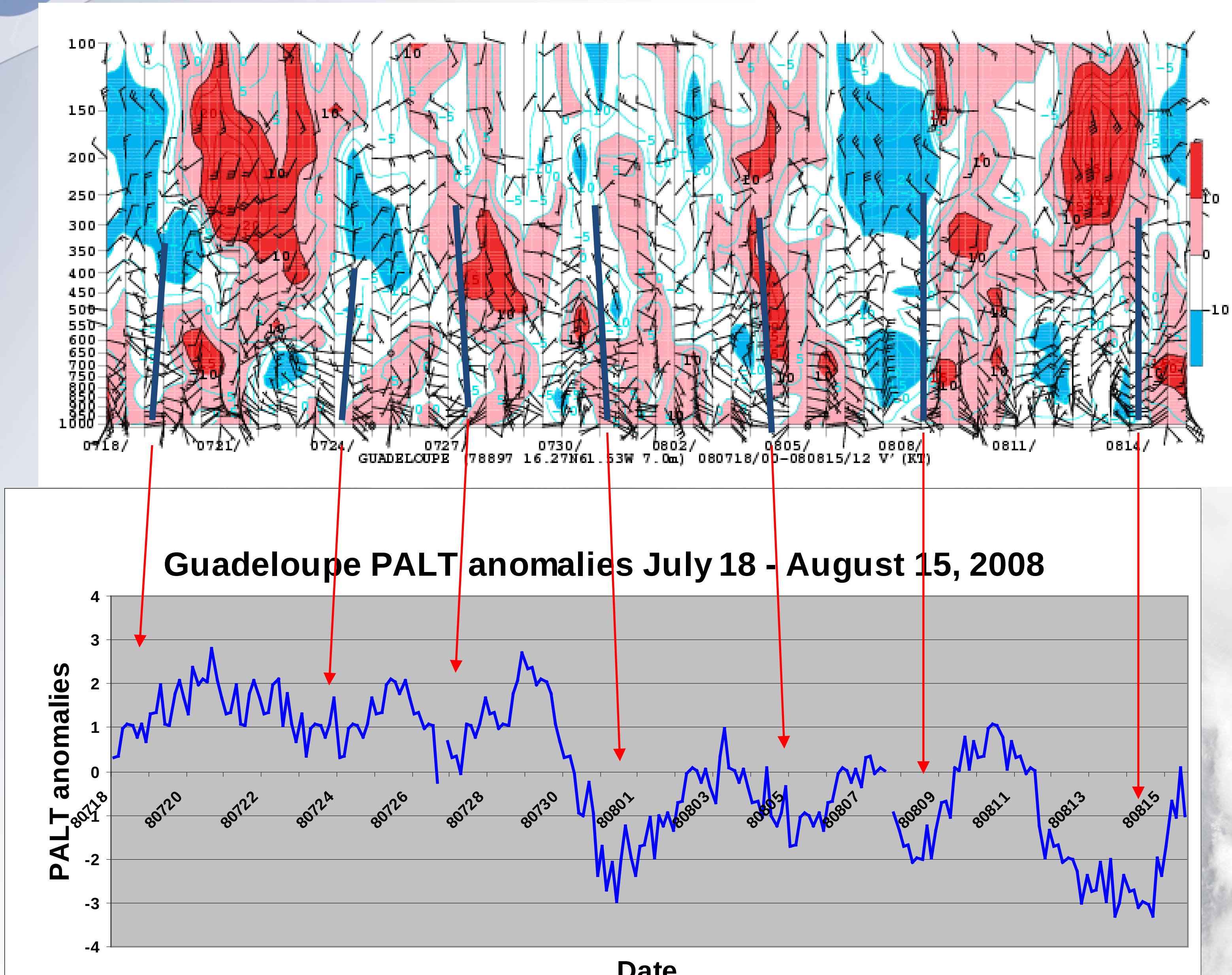


Can we identify these waves at the surface as they passed Dakar?



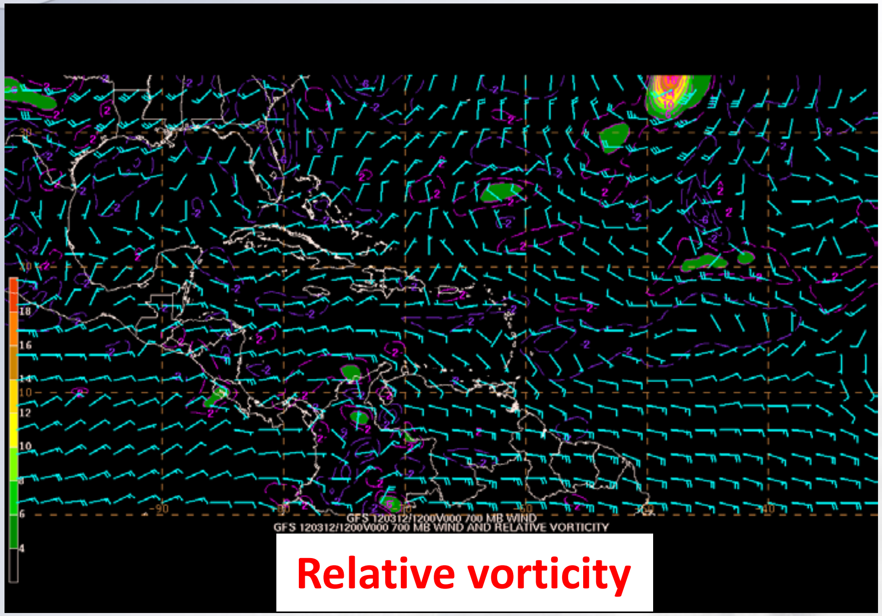
Surface pressure with mean and diurnal and semi-diurnal tide removed

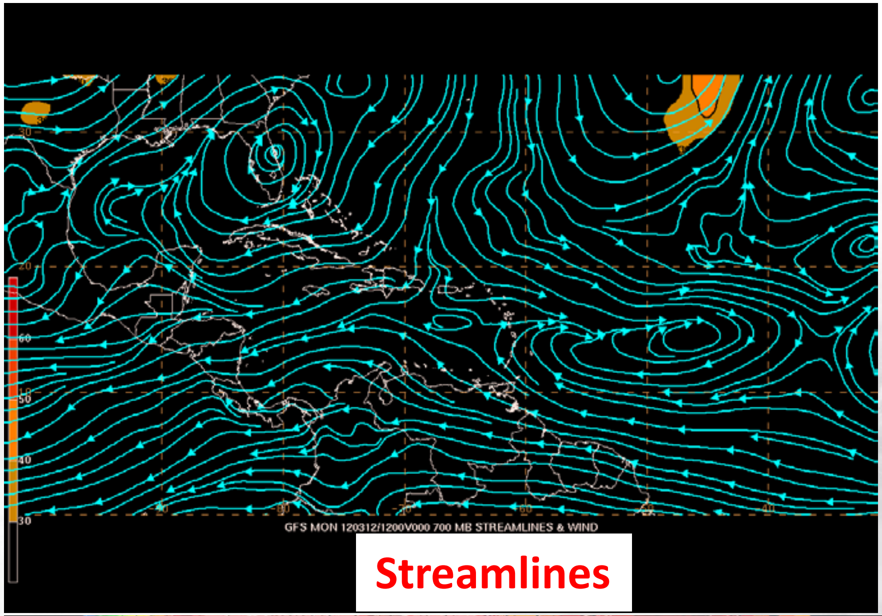
Can we identify these waves at the surface as they passed Guadeloupe

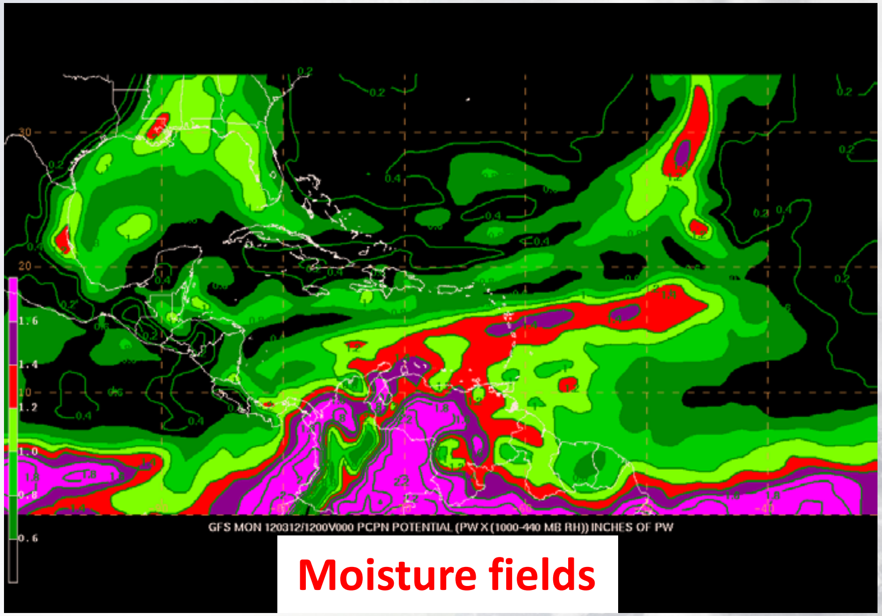


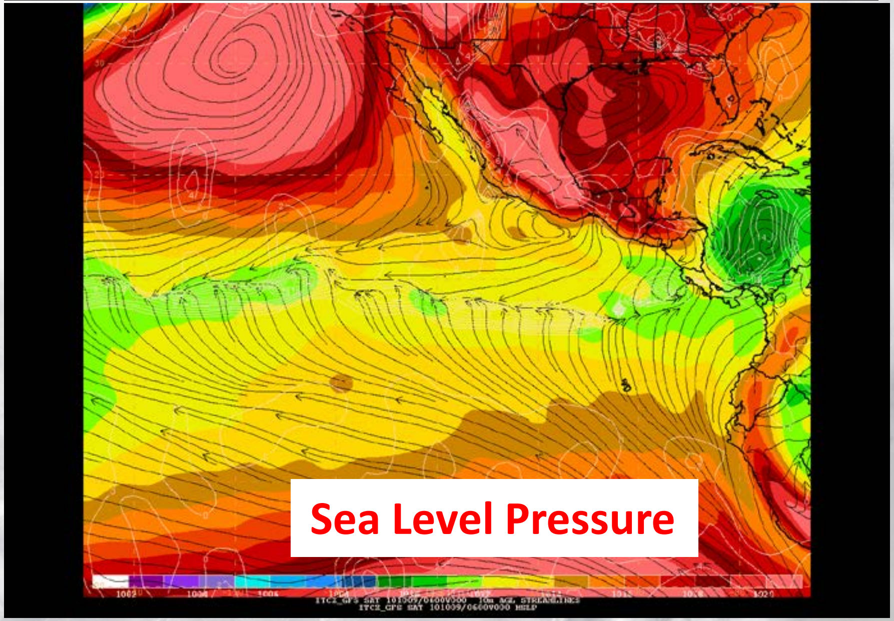
Surface pressure with mean and diurnal and semi-diurnal tide removed

Models

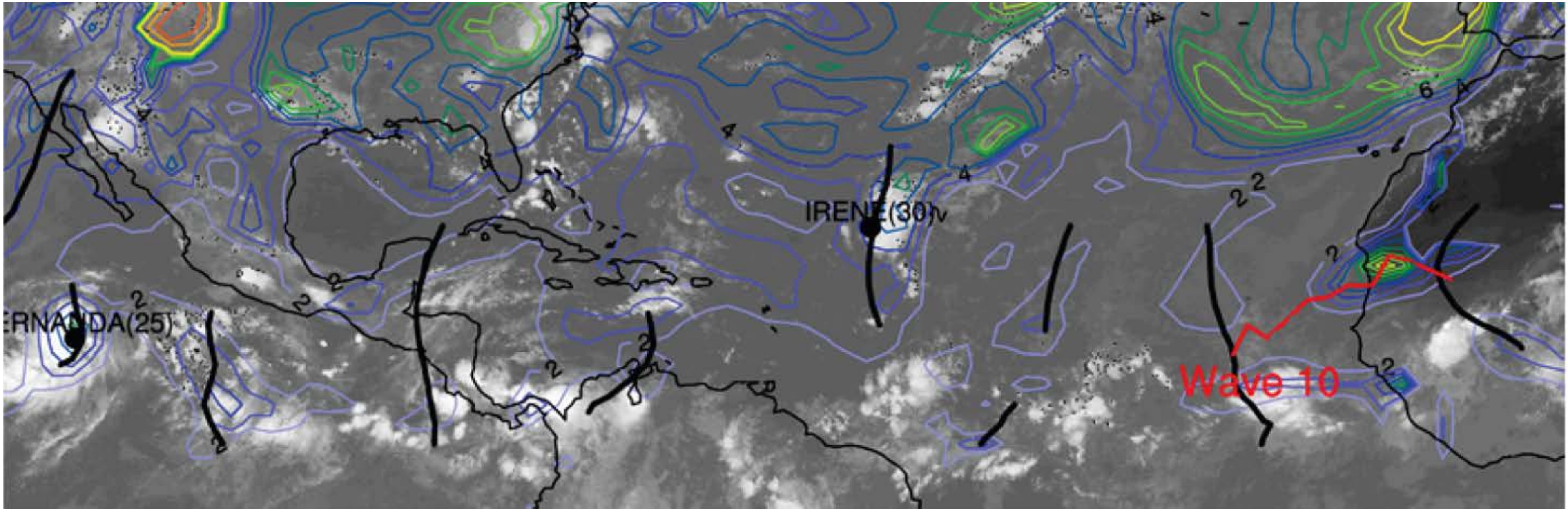

GFS 120312/1200V000 700 MB WIND AND RELATIVE VORTICITY
Relative vorticity

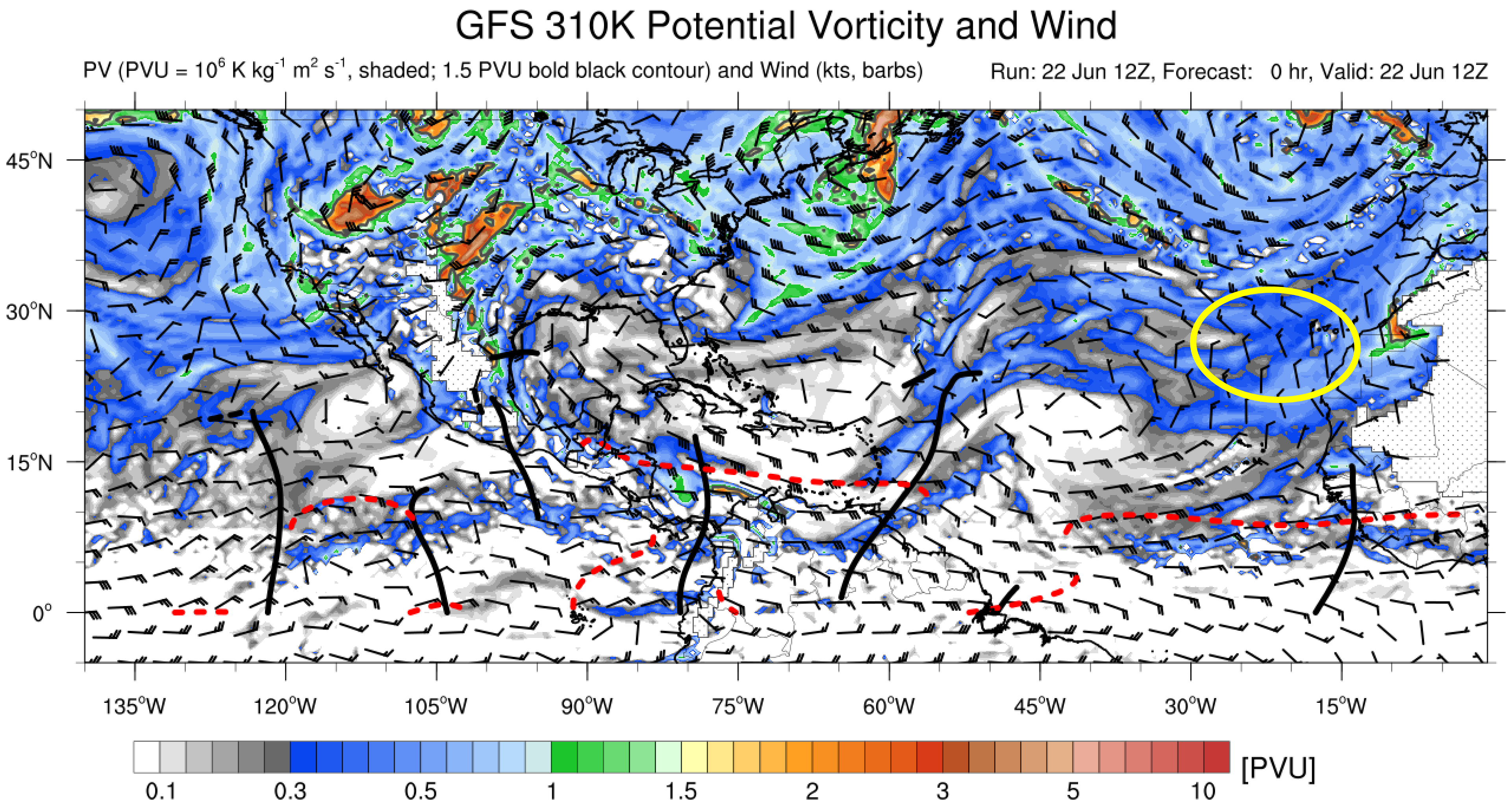

GFS MON 120312/1200V000 700 MB STREAMLINES & WIND
Streamlines


GFS MON 120312/1200V000 PCPN POTENTIAL (PW X (1000-440 MB RH)) INCHES OF PW
Moisture fields


Sea Level Pressure

Tools to track easterly waves: Tropical Wave Diagnostics





GFS 310K Potential Vorticity and Wind
PV (PVU = 10^6 K kg^{-1} m^2 s^{-1}, shaded; 1.5 PVU bold black contour) and Wind (kts, barbs)
Run: 22 Jun 12Z, Forecast: 0 hr, Valid: 22 Jun 12Z
45°N
30°N
15°N
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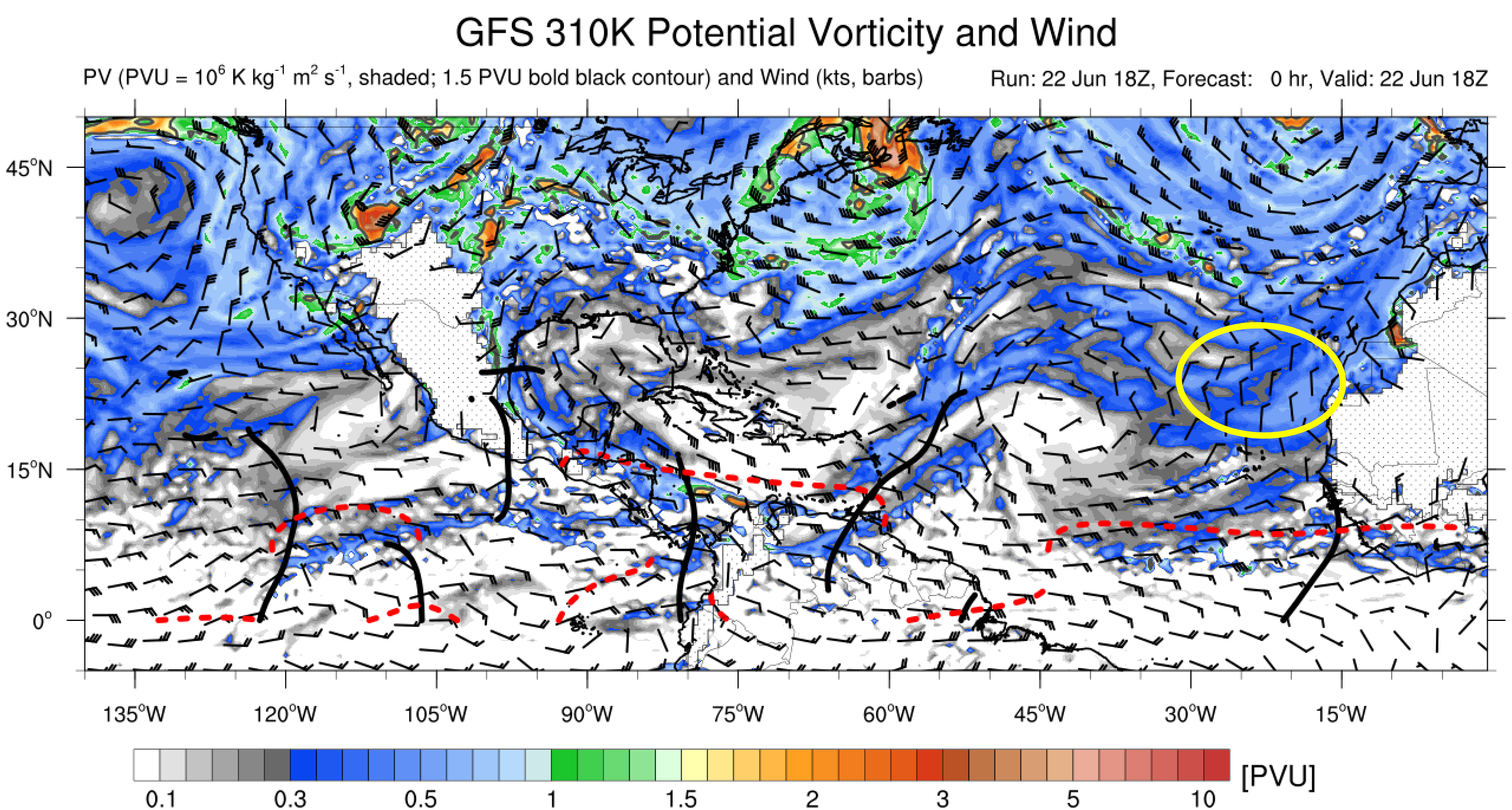
[PVU]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Run: 22 Jun 18Z, Forecast: 0 hr, Valid: 22 Jun 18Z
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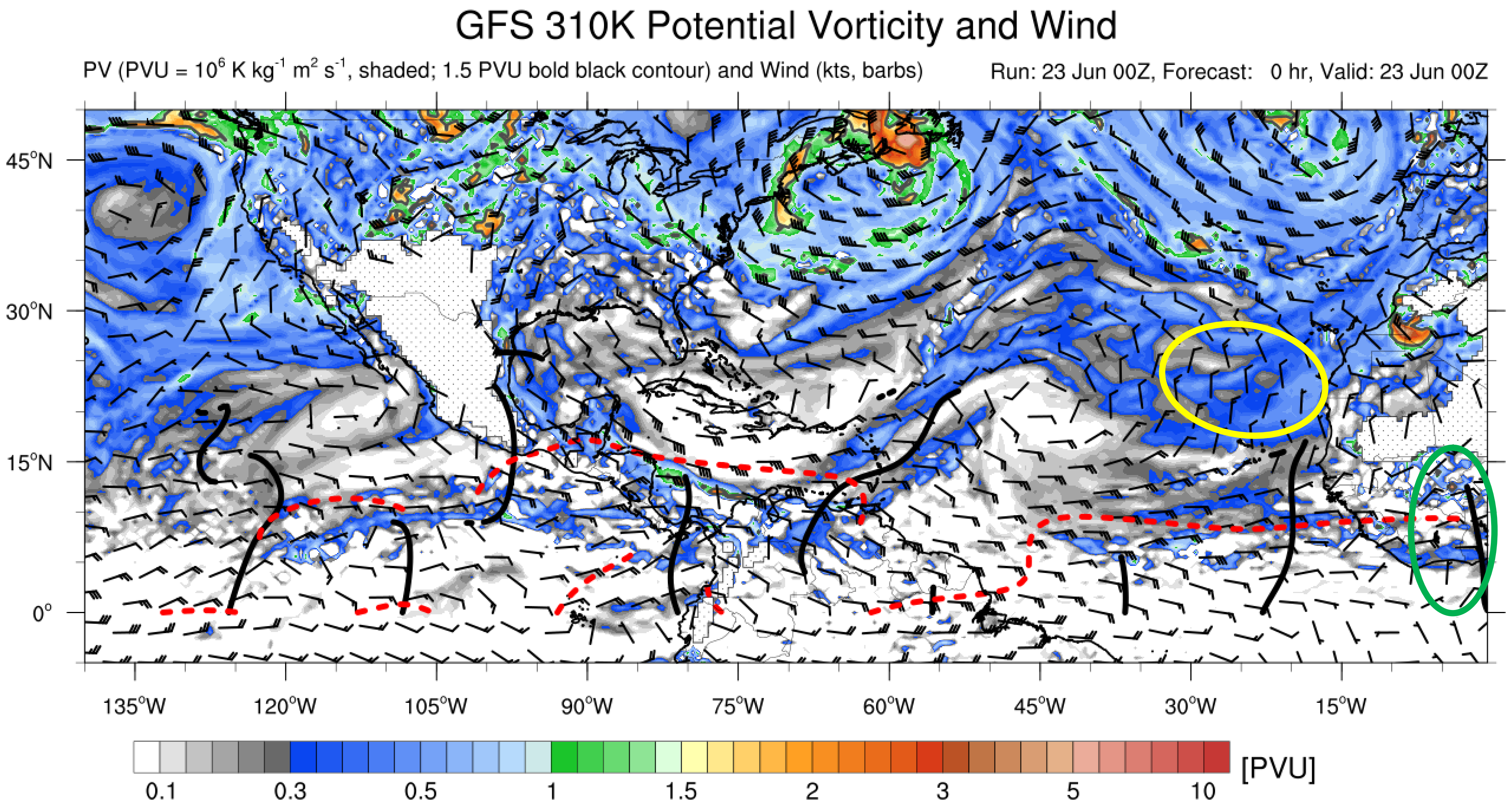
GFS 310K Potential Vorticity and Wind
PV (PVU = 10^{6} K kg^{-1} m^{2} s^{-1}, shaded; 1.5 PVU bold black contour) and Wind (kts, barbs)
Run: 23 Jun 00Z, Forecast: 0 hr, Valid: 23 Jun 00Z
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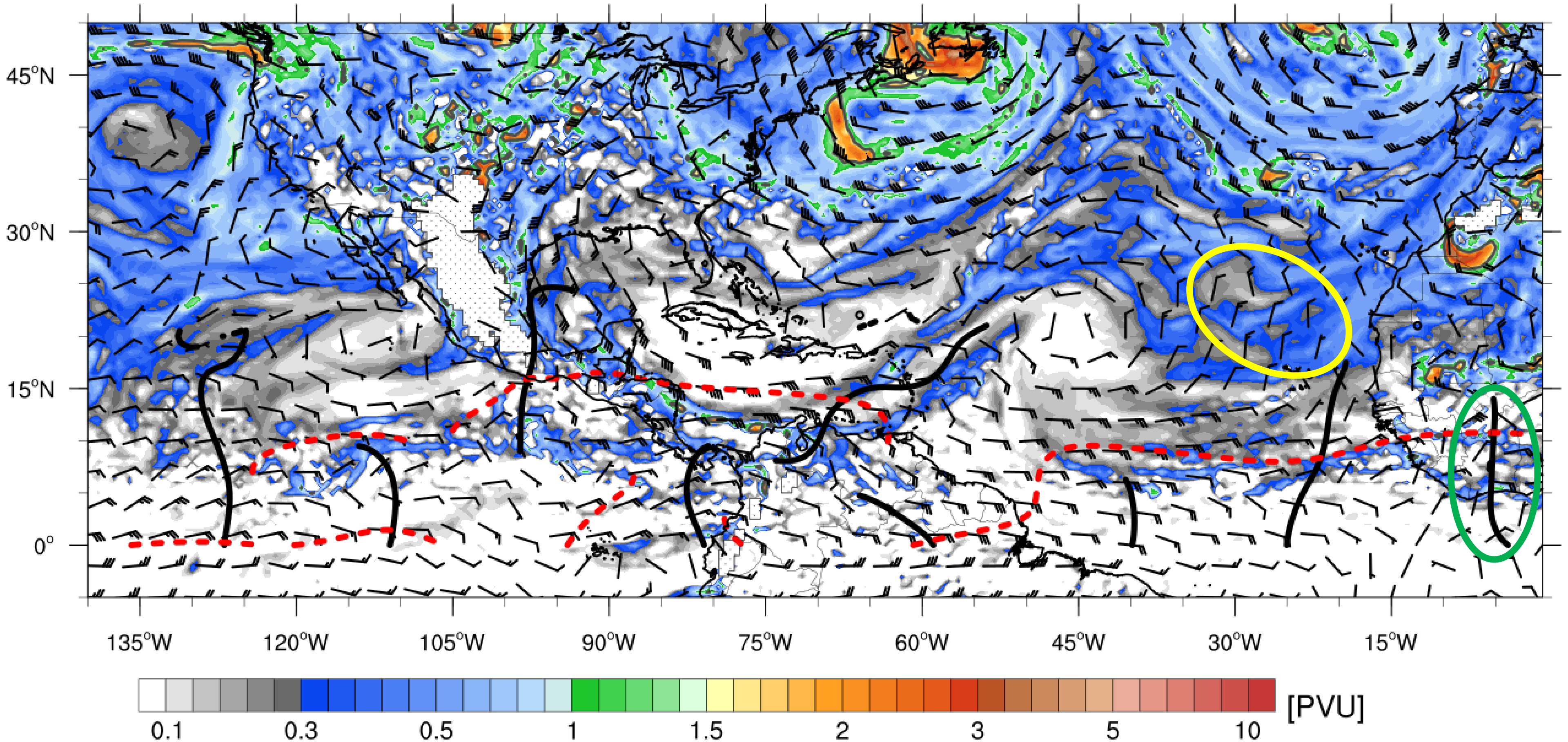
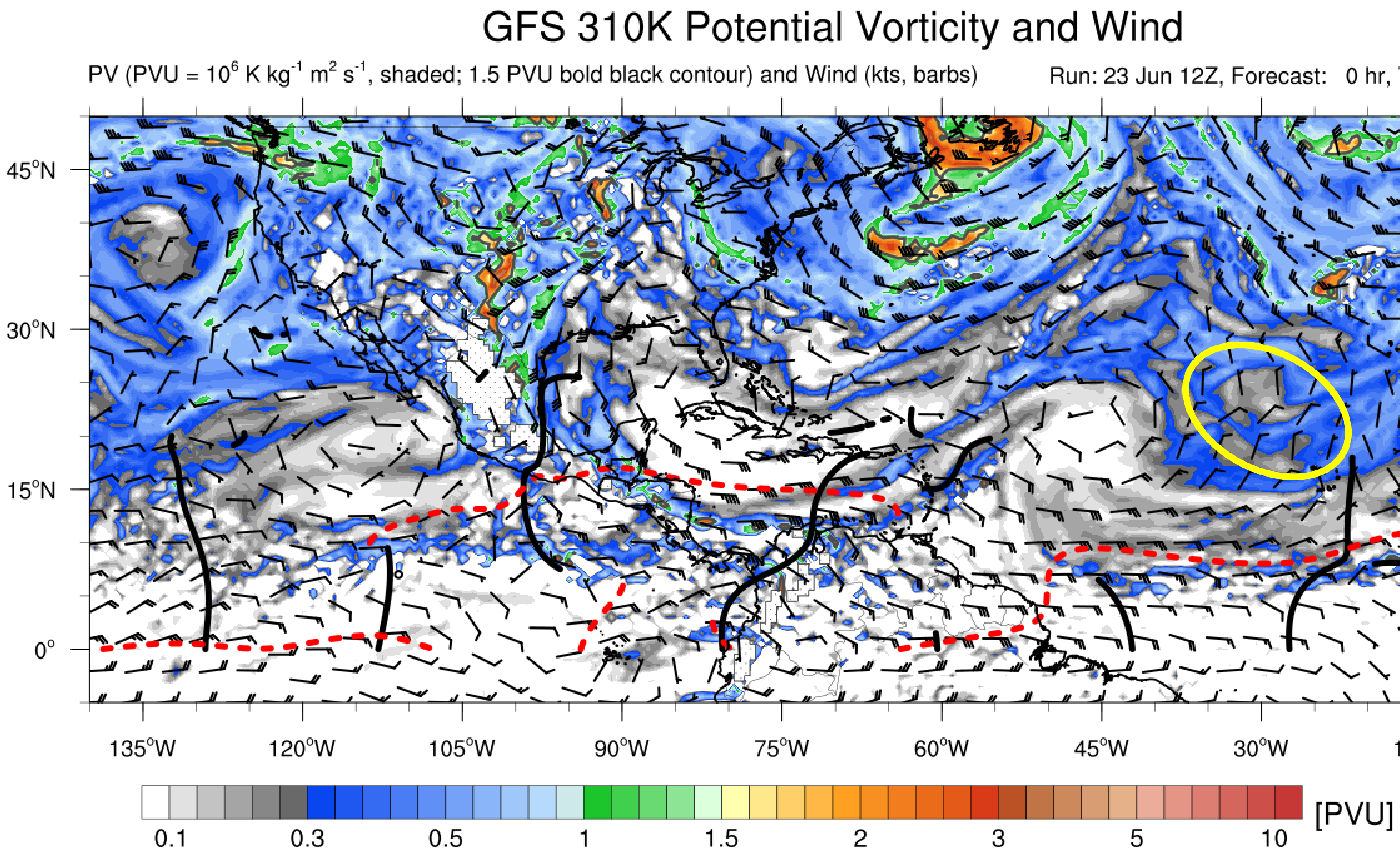
[PVU]

GFS 310K Potential Vorticity and Wind

PV (PVU = 10^6 K kg^{-1} m^2 s^{-1}, shaded; 1.5 PVU bold black contour) and Wind (kts, barbs) Run: 23 Jun 06Z, Forecast: 0 hr, Valid: 23 Jun 06Z

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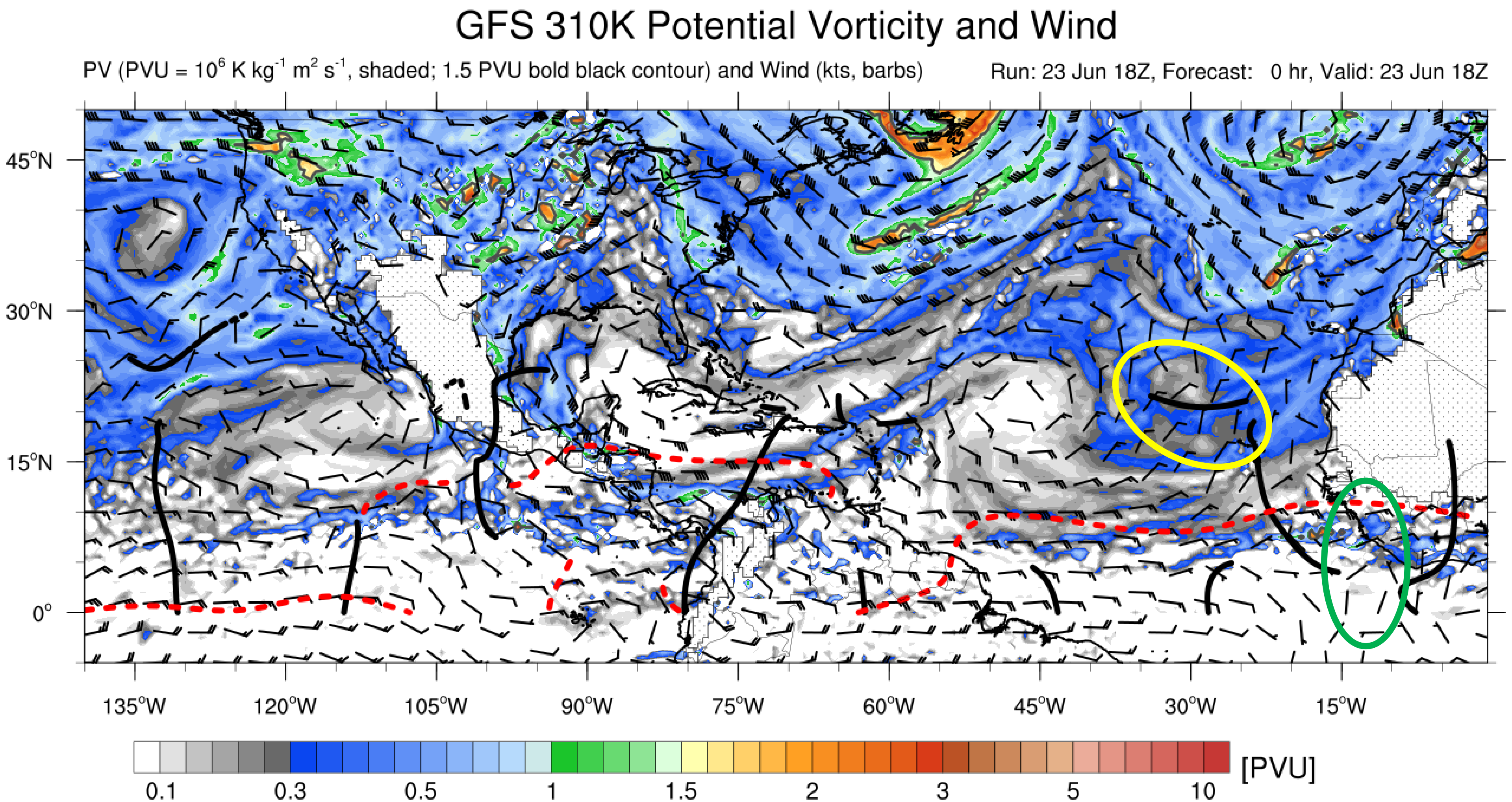
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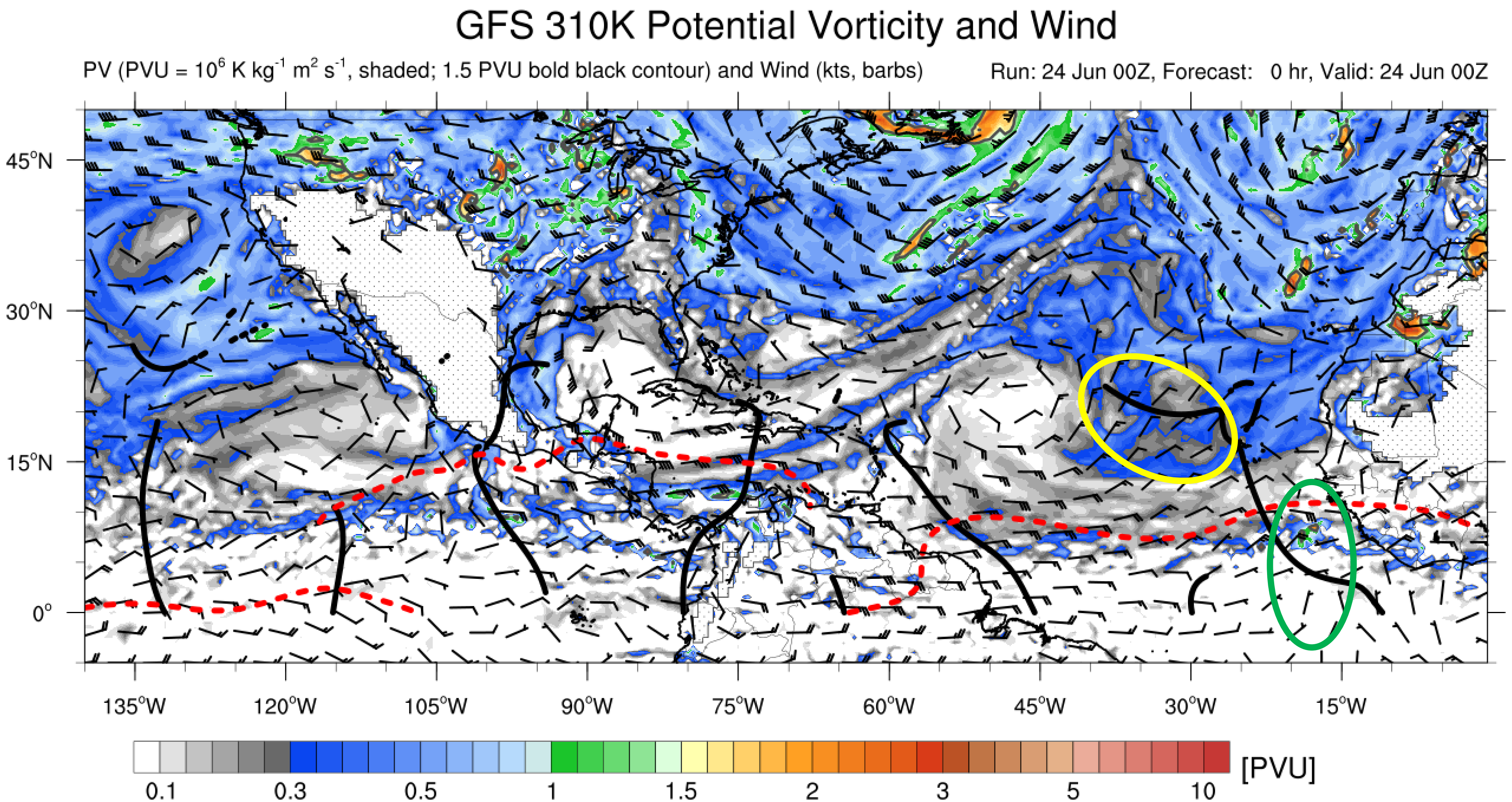

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Run: 24 Jun 00Z, Forecast: 0 hr, Valid: 24 Jun 00Z
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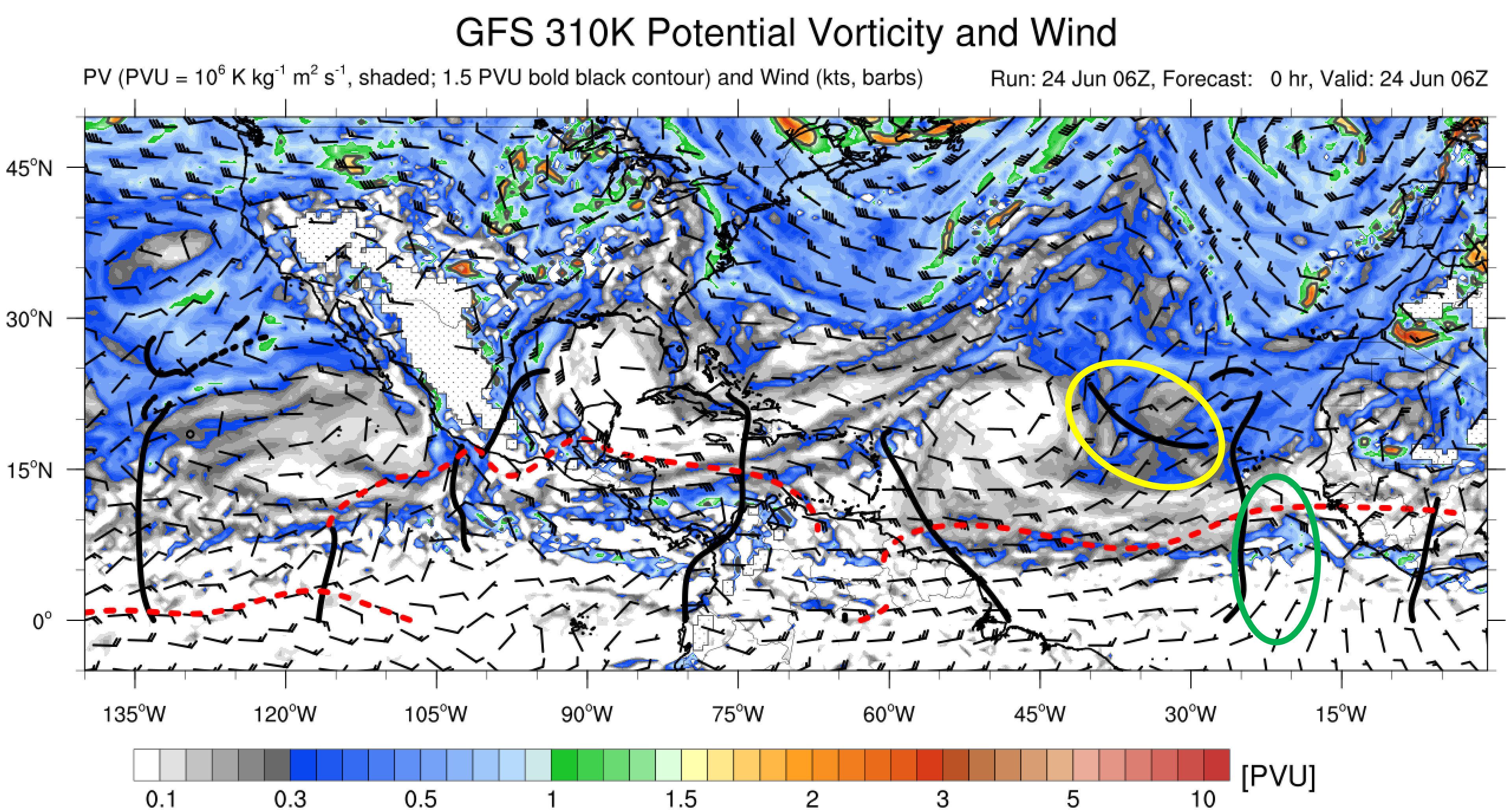
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Run: 24 Jun 06Z, Forecast: 0 hr, Valid: 24 Jun 06Z
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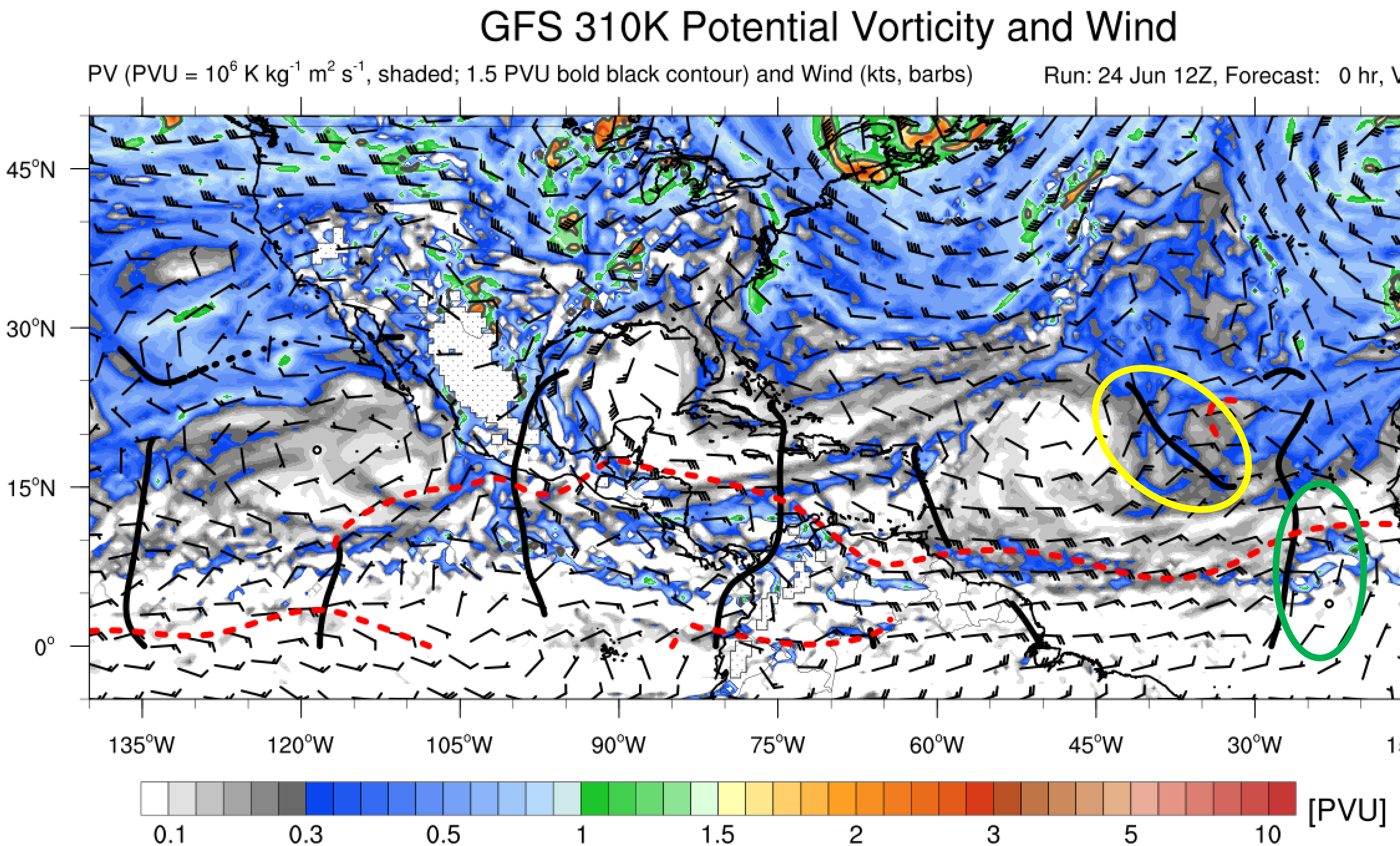
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PV (PVU = 10^6 K kg^-1 m^2 s^-1, shaded; 1.5 PVU bold black contour) and Wind (kts, barbs)
Run: 24 Jun 12Z, Forecast: 0 hr, Valid: 24 Jun 12Z
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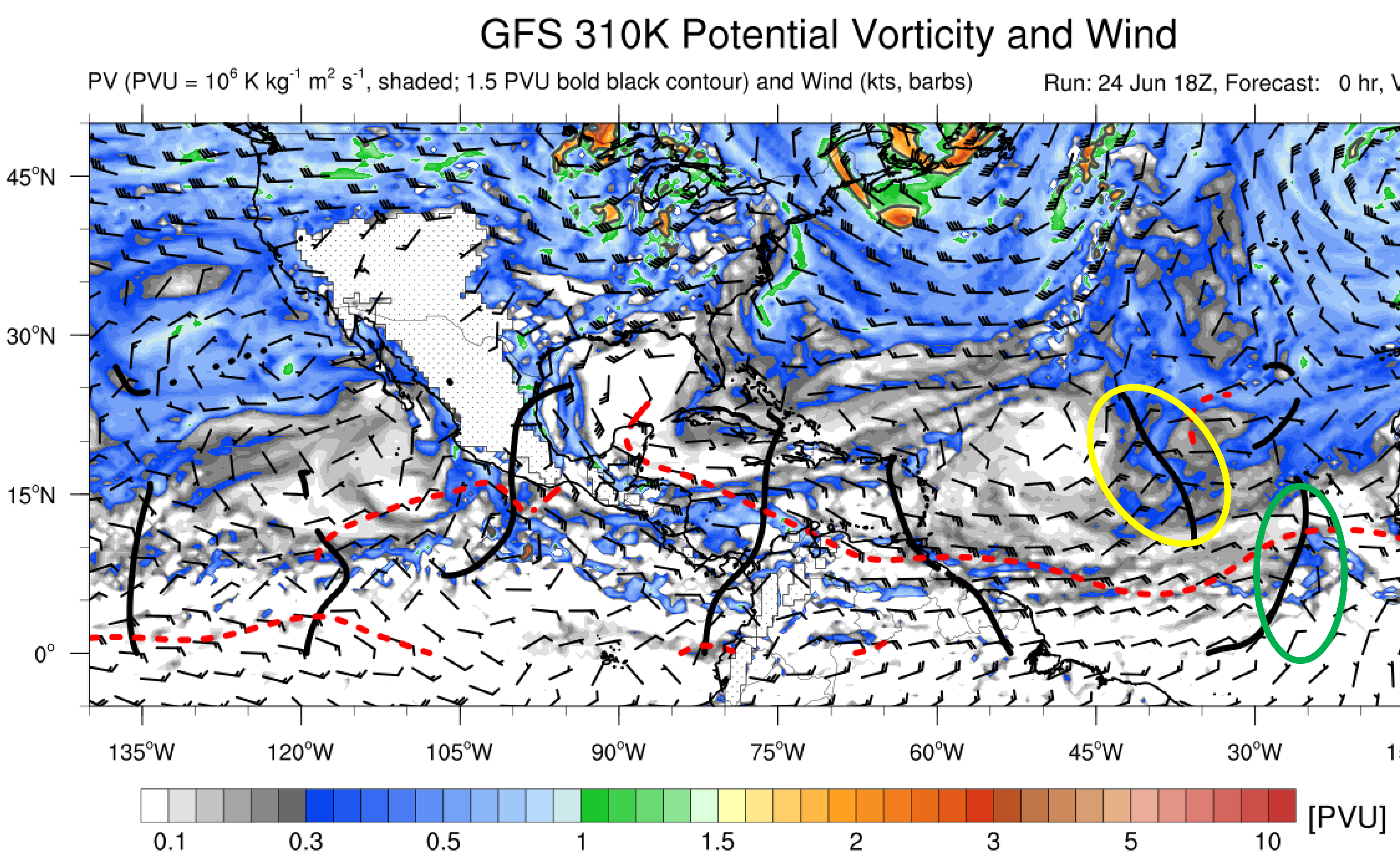
GFS 310K Potential Vorticity and Wind
PV (PVU = 10⁶ K kg⁻¹ m² s⁻¹, shaded; 1.5 PVU bold black contour) and Wind (kts, barbs)
Run: 24 Jun 18Z, Forecast: 0 hr, Valid: 24 Jun 18Z
45°N
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135°W
120°W
105°W
90°W
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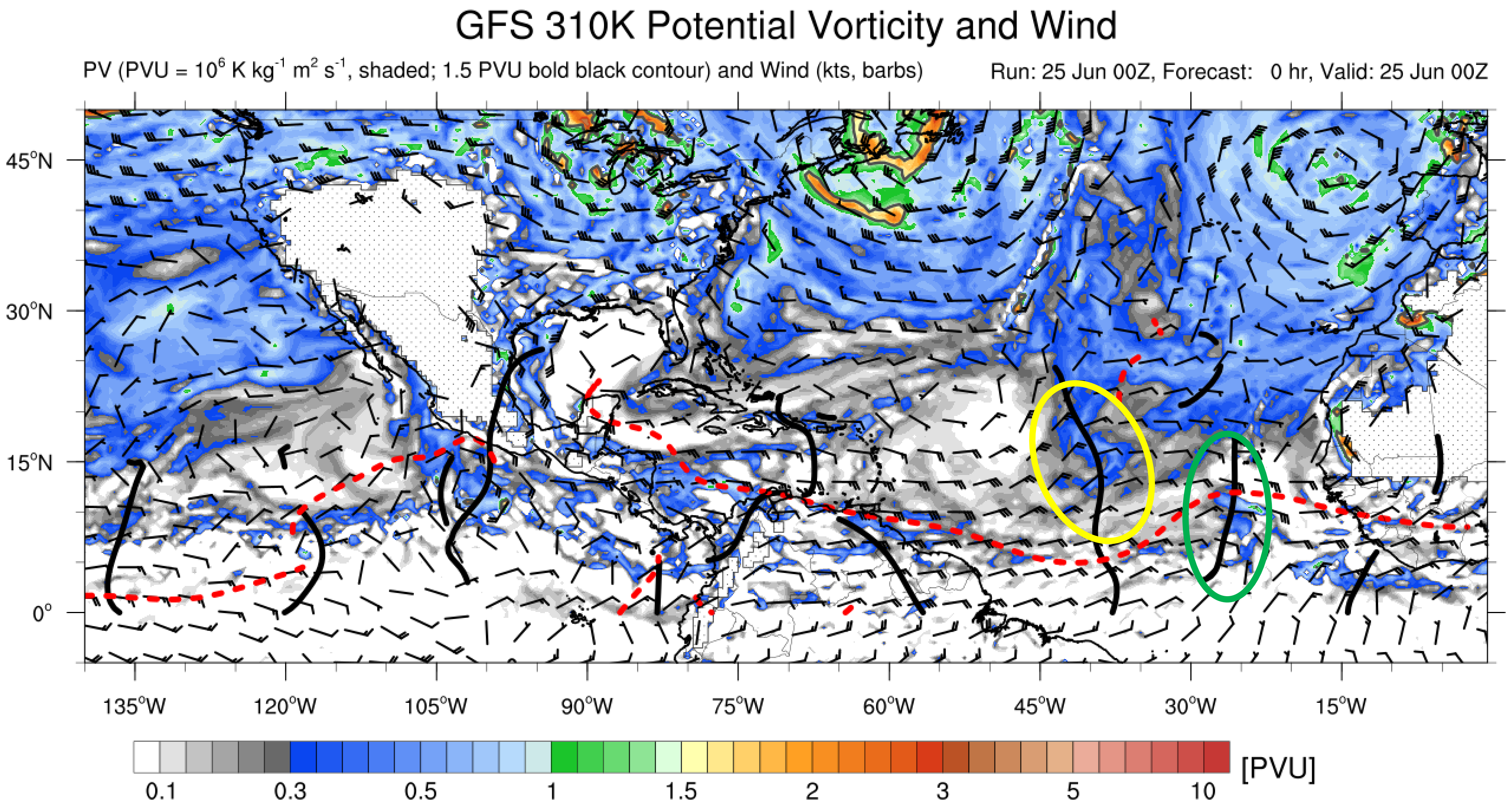
[PVU]



GFS 310K Potential Vorticity and Wind
PV (PVU = 10^6 K kg^-1 m^2 s^-1, shaded; 1.5 PVU bold black contour) and Wind (kts, barbs)
Run: 25 Jun 00Z, Forecast: 0 hr, Valid: 25 Jun 00Z
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0°
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120°W
105°W
90°W
75°W
60°W
45°W
30°W
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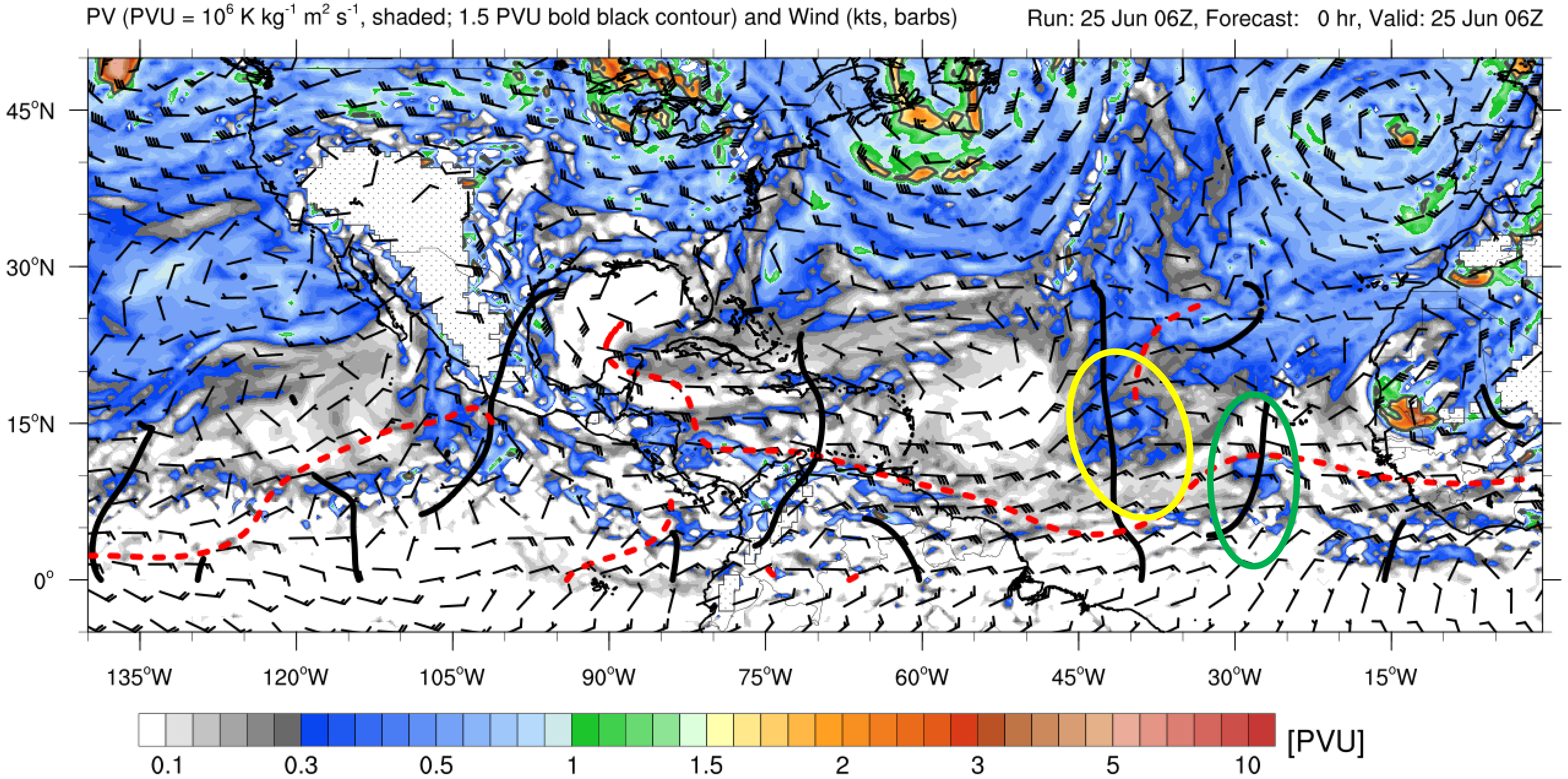
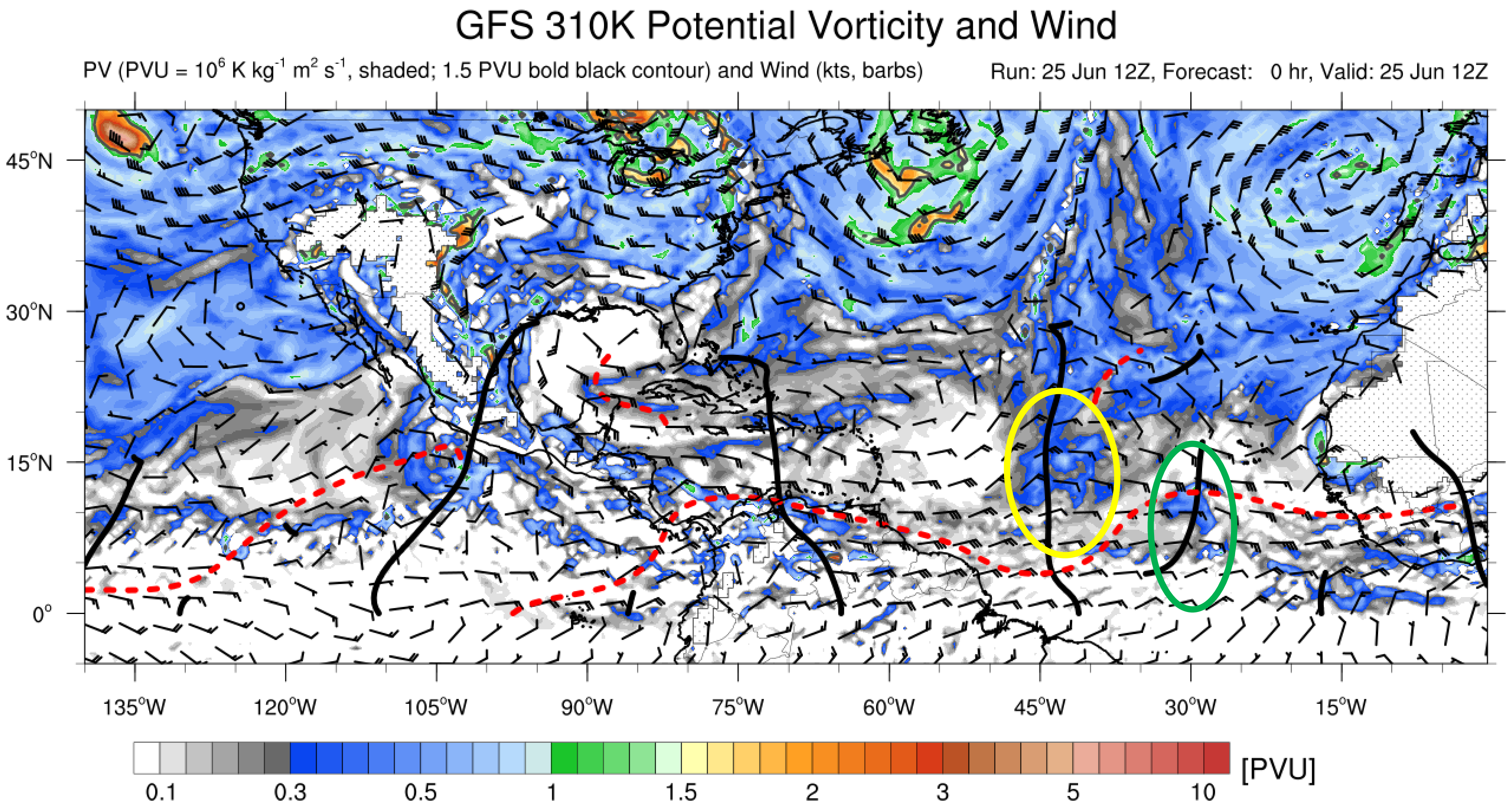
[PVU]

GFS 310K Potential Vorticity and Wind




GFS 310K Potential Vorticity and Wind
PV (PVU = 10^6 K kg^-1 m^2 s^-1, shaded; 1.5 PVU bold black contour) and Wind (kts, barbs)
Run: 25 Jun 12Z, Forecast: 0 hr, Valid: 25 Jun 12Z
45°N
30°N
15°N
0°
135°W
120°W
105°W
90°W
75°W
60°W
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30°W
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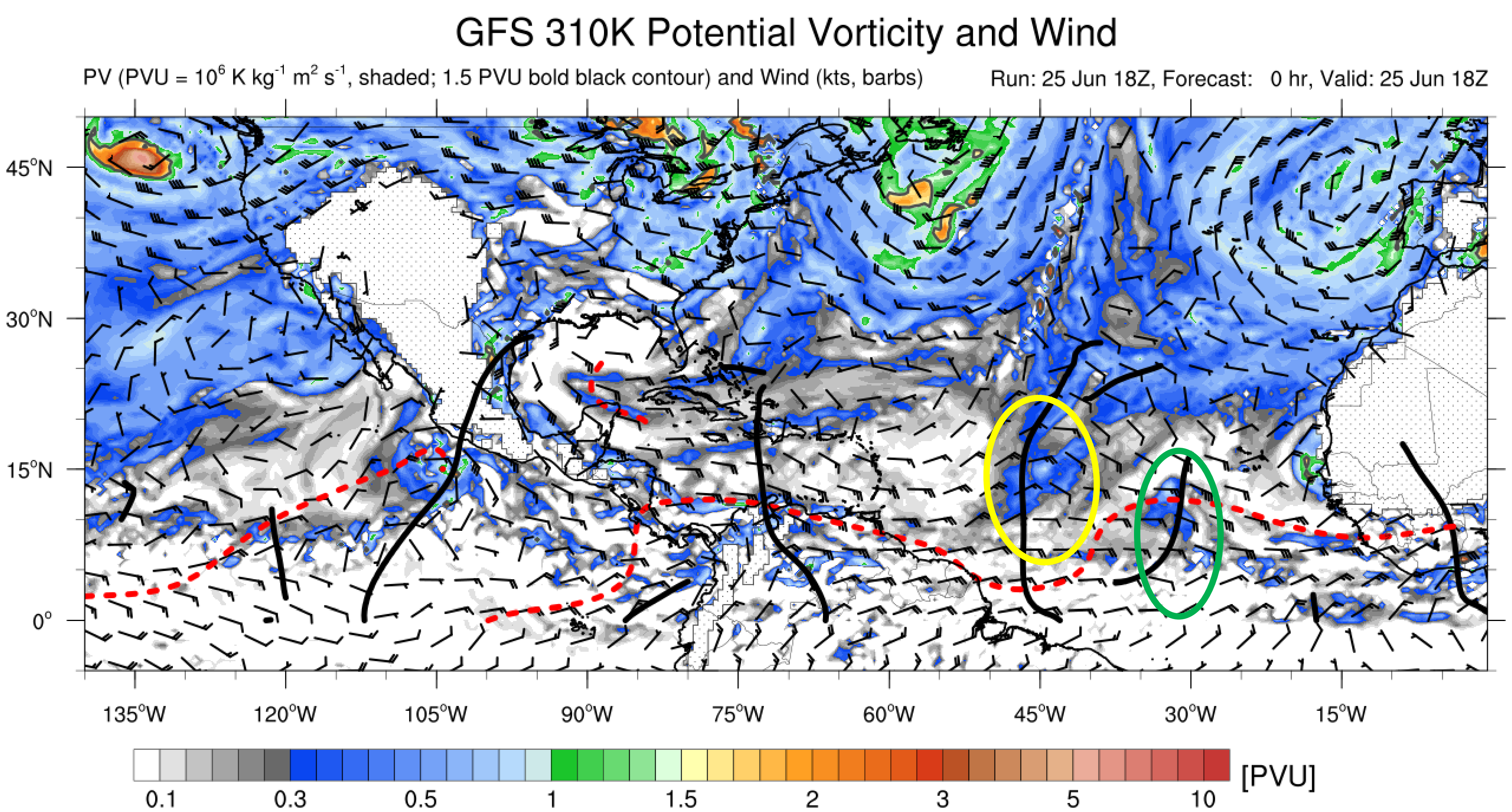
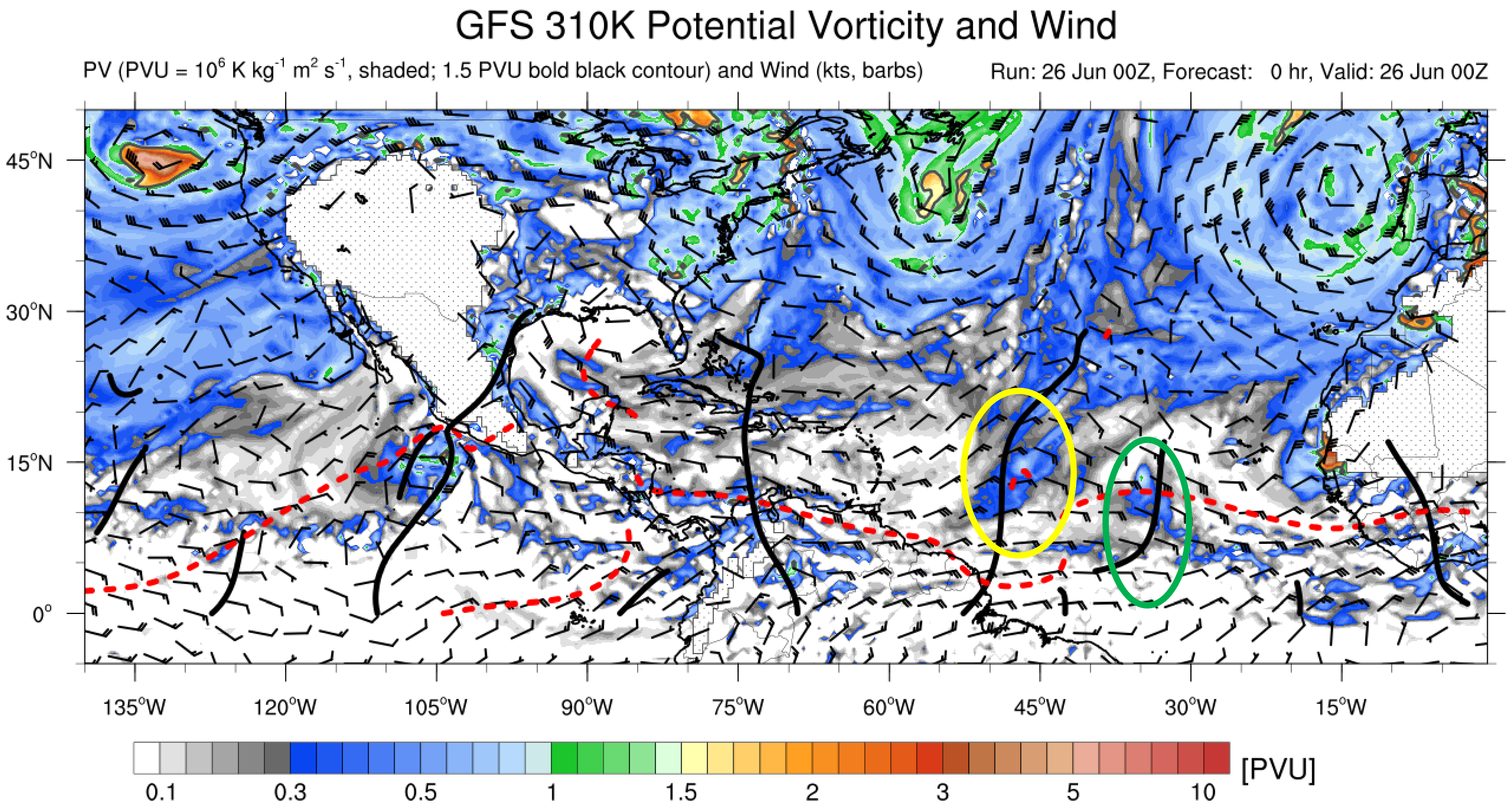
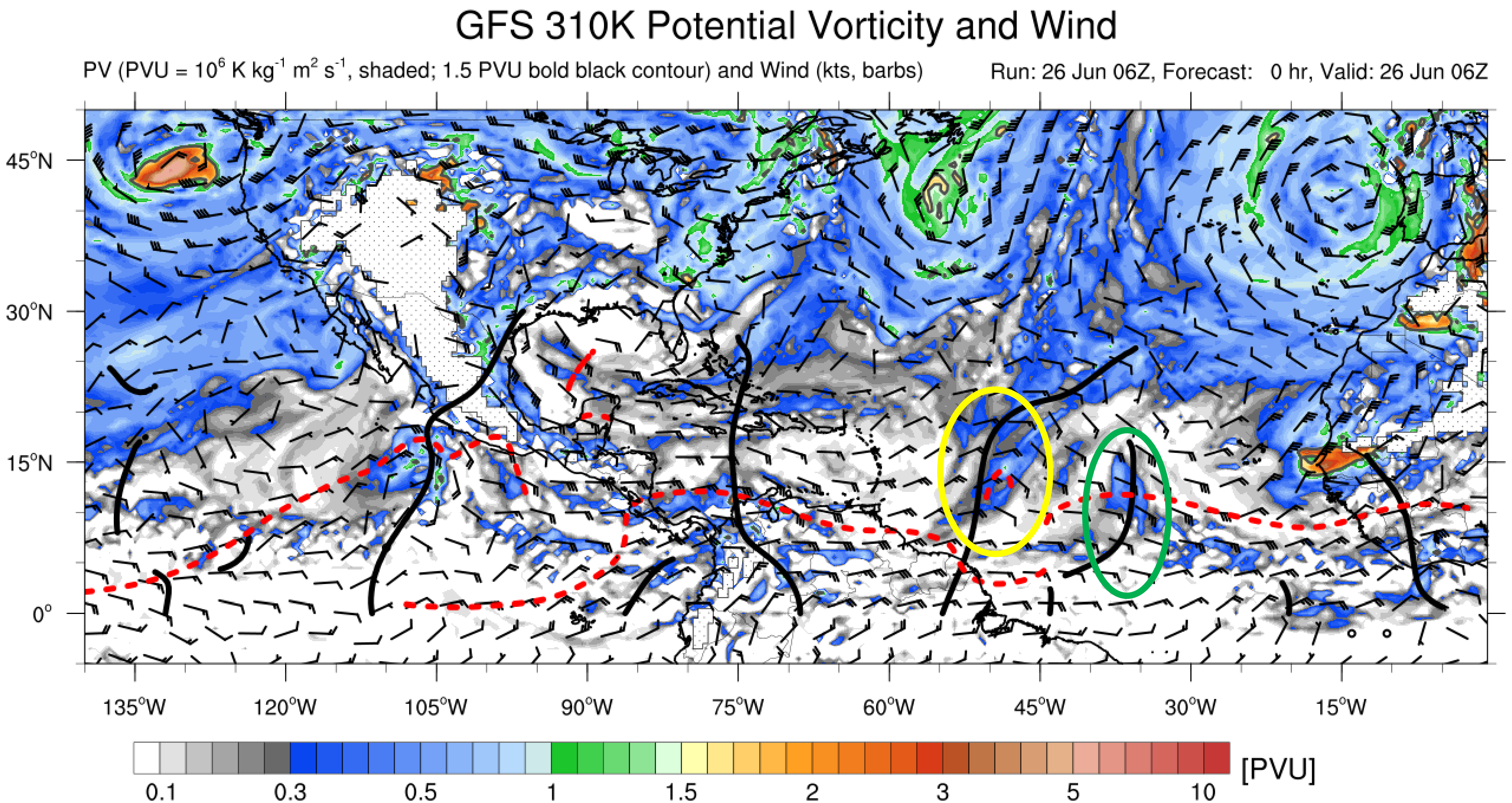
10
[PVU]



GFS 310K Potential Vorticity and Wind
PV (PVU = 10^6 K kg^-1 m^2 s^-1, shaded; 1.5 PVU bold black contour) and Wind (kts, barbs)
Run: 25 Jun 18Z, Forecast: 0 hr, Valid: 25 Jun 18Z
45°N
30°N
15°N
0°
135°W
120°W
105°W
90°W
75°W
60°W
45°W
30°W
15°W
0.1
0.3
0.5
1
1.5
2
3
5
10
[PVU]



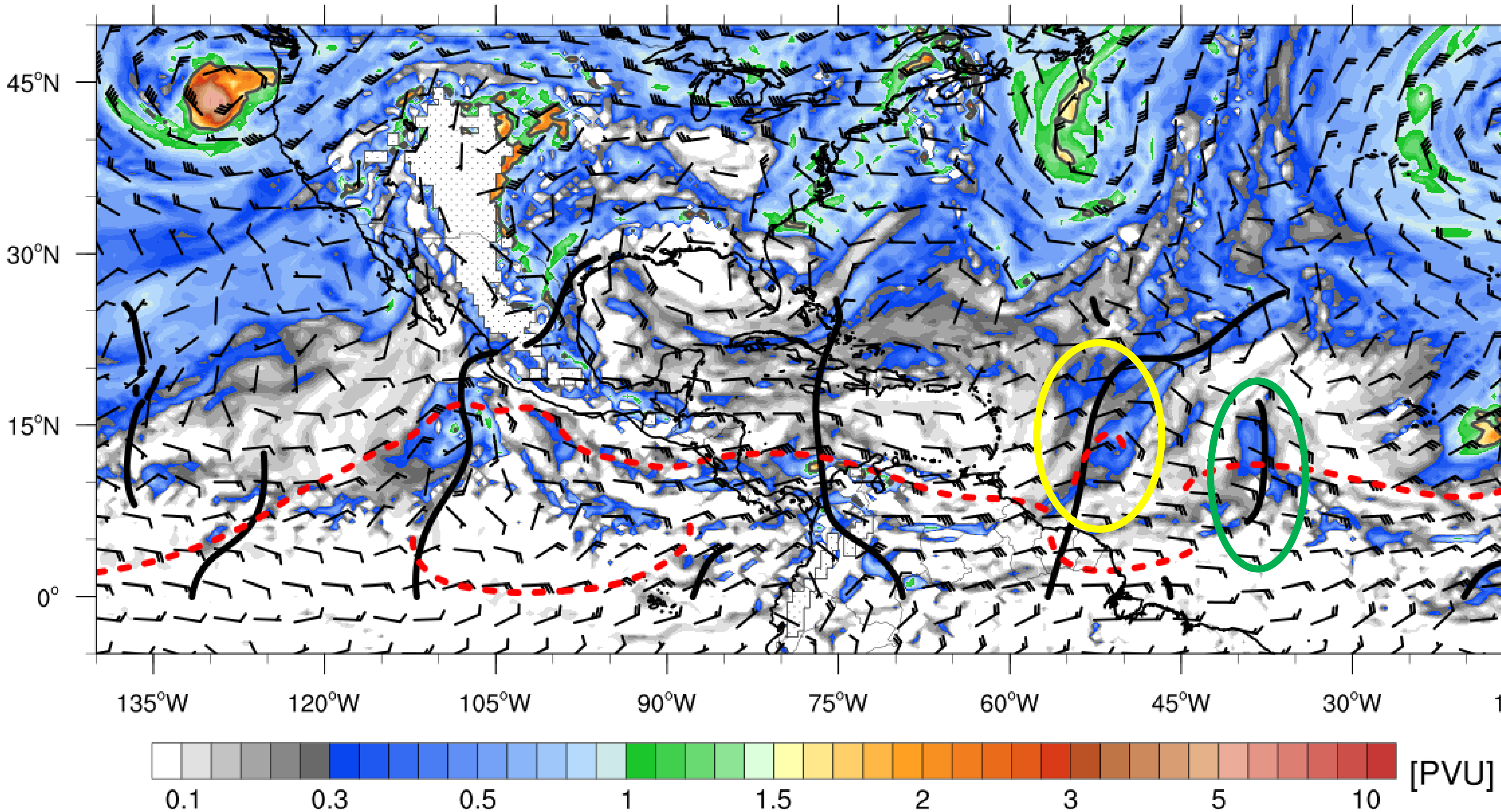
GFS 310K Potential Vorticity and Wind
PV (PVU = 10⁶ K kg⁻¹ m² s⁻¹, shaded; 1.5 PVU bold black contour) and Wind (kts, barbs)
Run: 26 Jun 00Z, Forecast: 0 hr, Valid: 26 Jun 00Z
45°N
30°N
15°N
0°
135°W
120°W
105°W
90°W
75°W
60°W
45°W
30°W
15°W
0.1
0.3
0.5
1
1.5
2
3
5
10
[PVU]

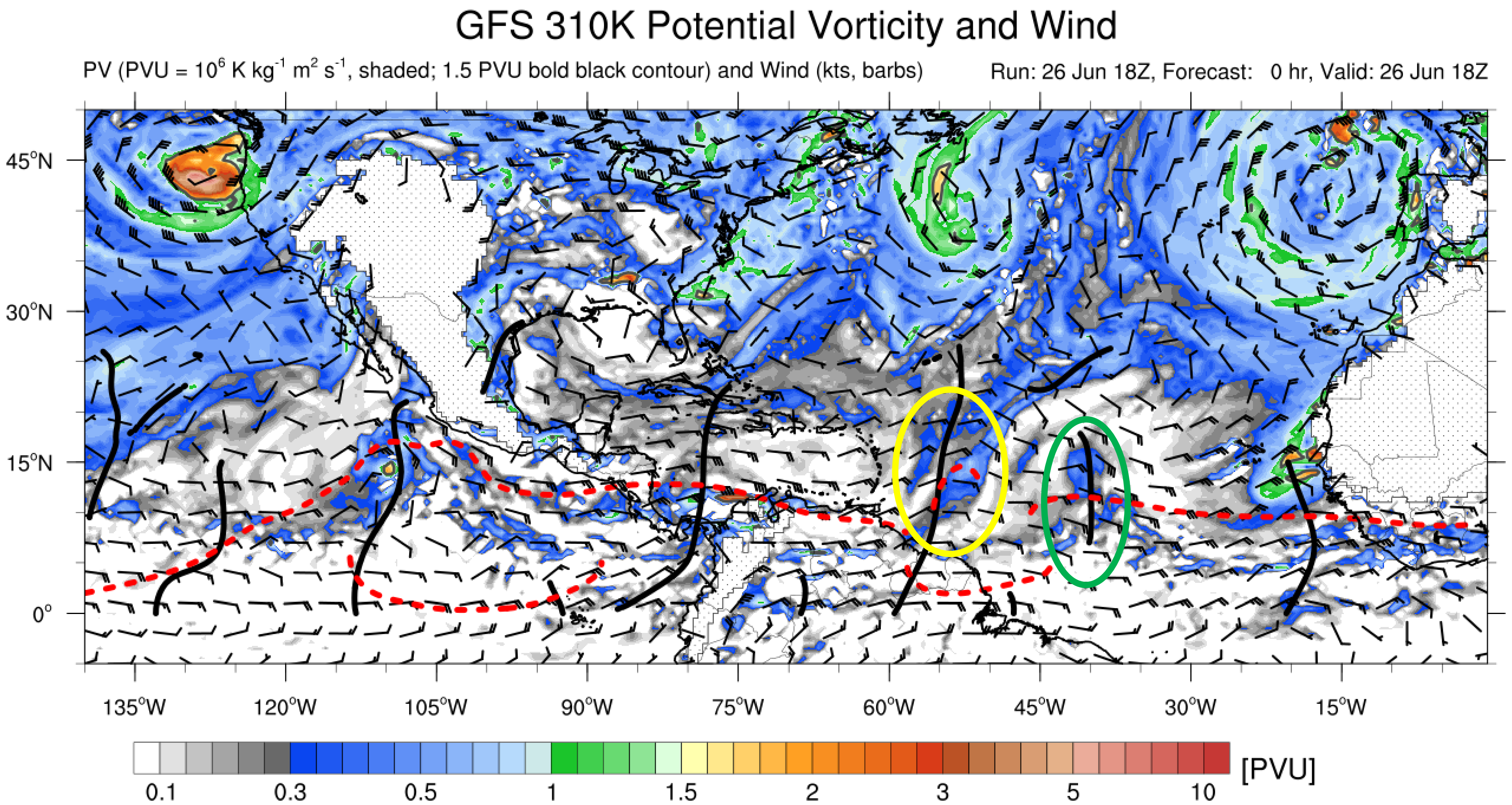


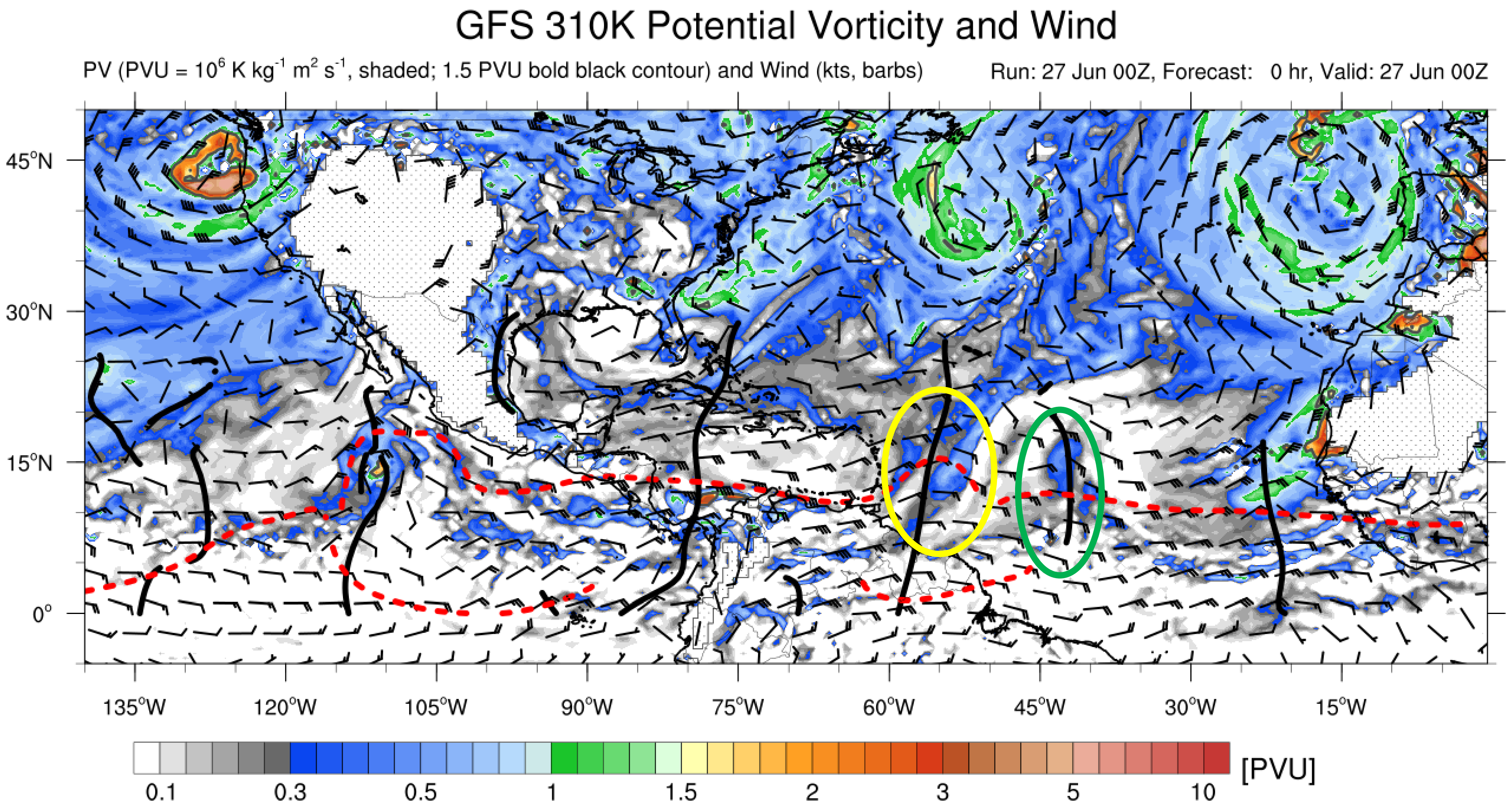
GFS 310K Potential Vorticity and Wind
PV (PVU = 10^6 K kg^{-1} m^2 s^{-1}, shaded; 1.5 PVU bold black contour) and Wind (kts, barbs)
Run: 26 Jun 06Z, Forecast: 0 hr, Valid: 26 Jun 06Z
45°N
30°N
15°N
0°
135°W
120°W
105°W
90°W
75°W
60°W
45°W
30°W
15°W
0.1
0.3
0.5
1
1.5
2
3
5
10
[PVU]

GFS 310K Potential Vorticity and Wind

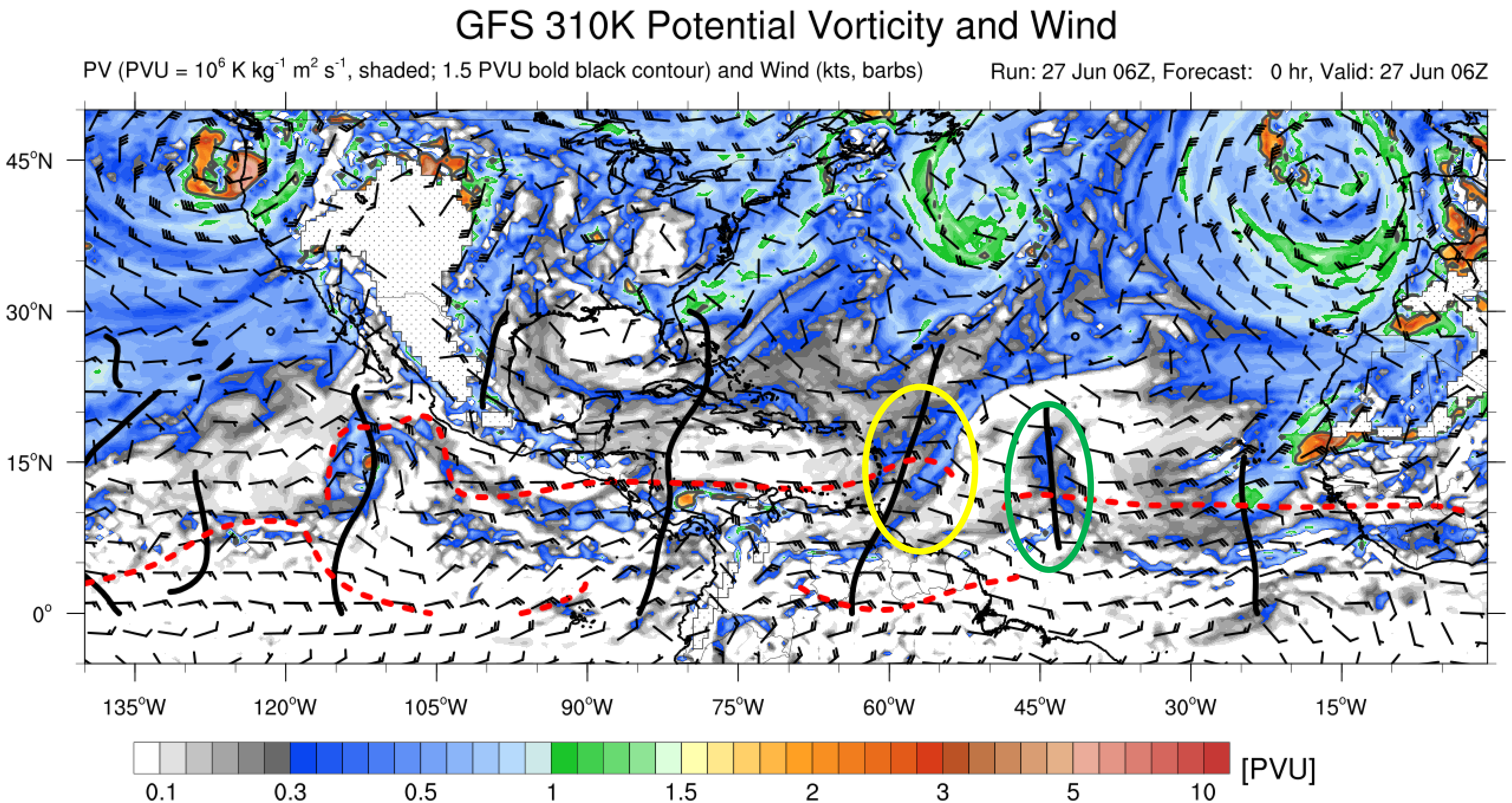
PV (PVU = 10^{6} K kg^{-1} m^{2} s^{-1}, shaded; 1.5 PVU bold black contour) and Wind (kts, barbs) Run: 26 Jun 12Z, Forecast: 0 hr, Valid: 26 Jun 12Z



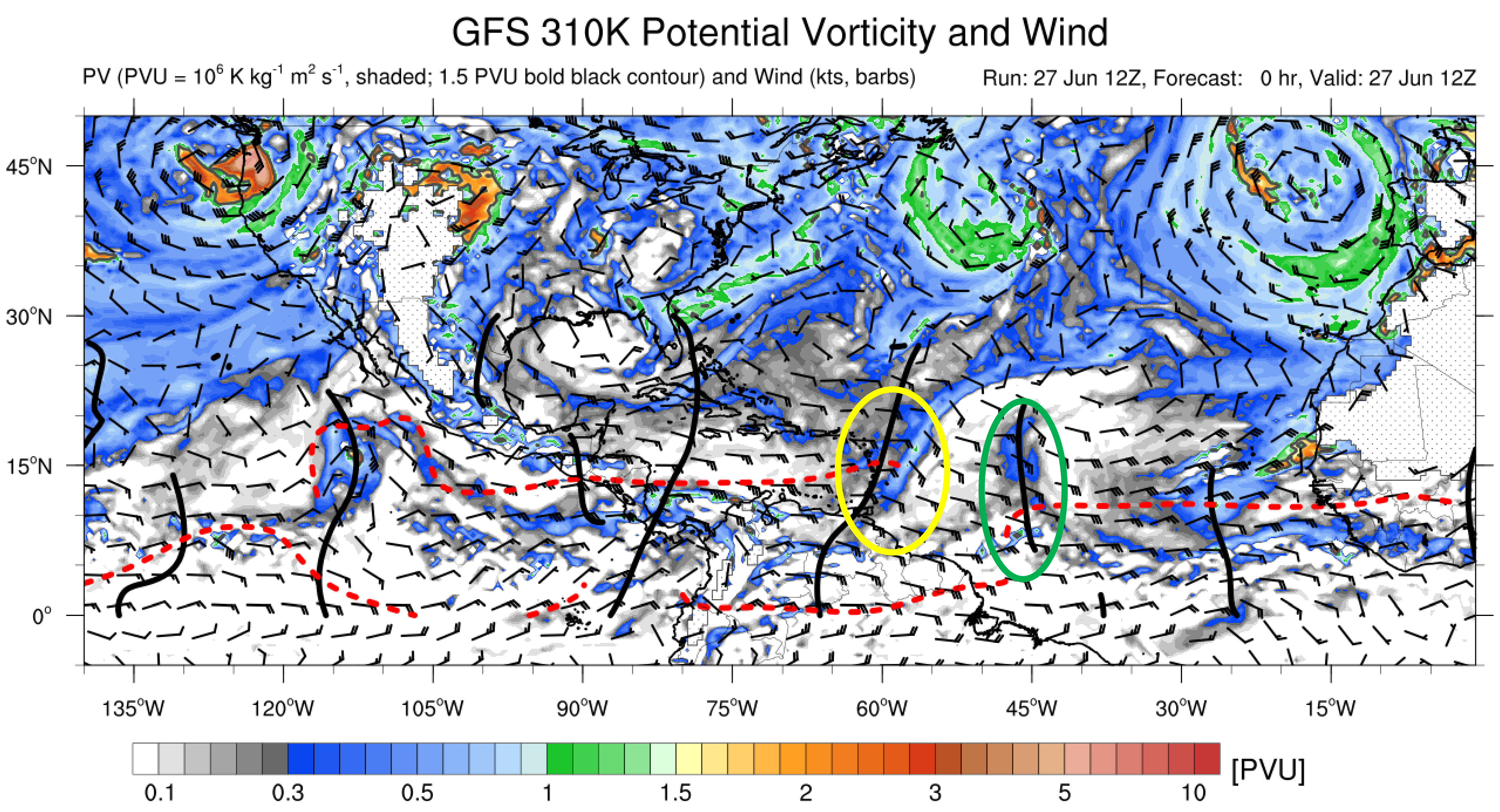

GFS 310K Potential Vorticity and Wind
PV (PVU = 10^6 K kg^-1 m^2 s^-1, shaded; 1.5 PVU bold black contour) and Wind (kts, barbs)
Run: 26 Jun 18Z, Forecast: 0 hr, Valid: 26 Jun 18Z
45°N
30°N
15°N
0°
135°W
120°W
105°W
90°W
75°W
60°W
45°W
30°W
15°W
0.1
0.3
0.5
1
1.5
2
3
5
10
[PVU]



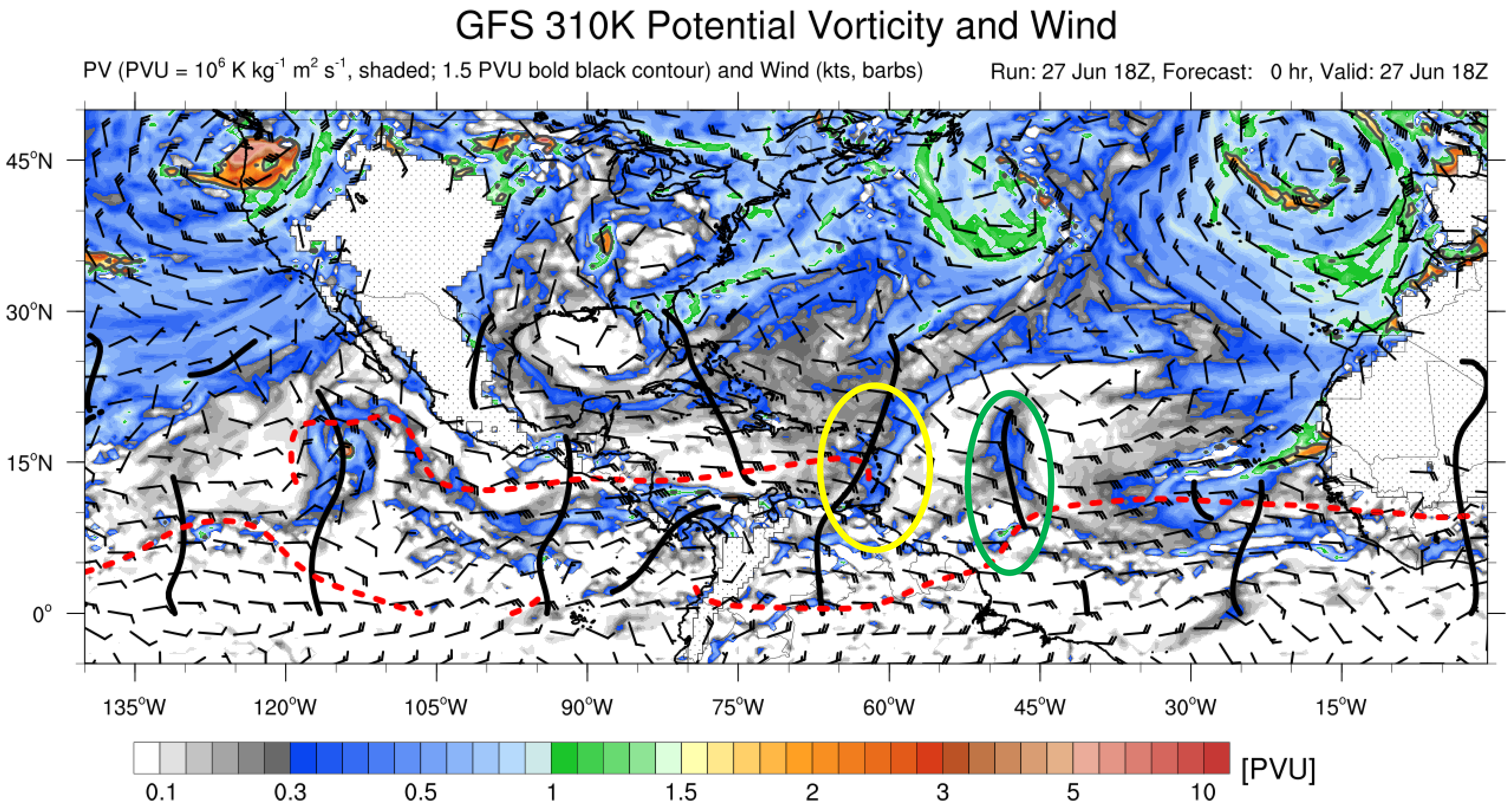
GFS 310K Potential Vorticity and Wind
PV (PVU = 10^{6} K kg^{-1} m^{2} s^{-1}, shaded; 1.5 PVU bold black contour) and Wind (kts, barbs)
Run: 27 Jun 00Z, Forecast: 0 hr, Valid: 27 Jun 00Z
45°N
30°N
15°N
0°
135°W
120°W
105°W
90°W
75°W
60°W
45°W
30°W
15°W
0.1
0.3
0.5
1
1.5
2
3
5
10
[PVU]

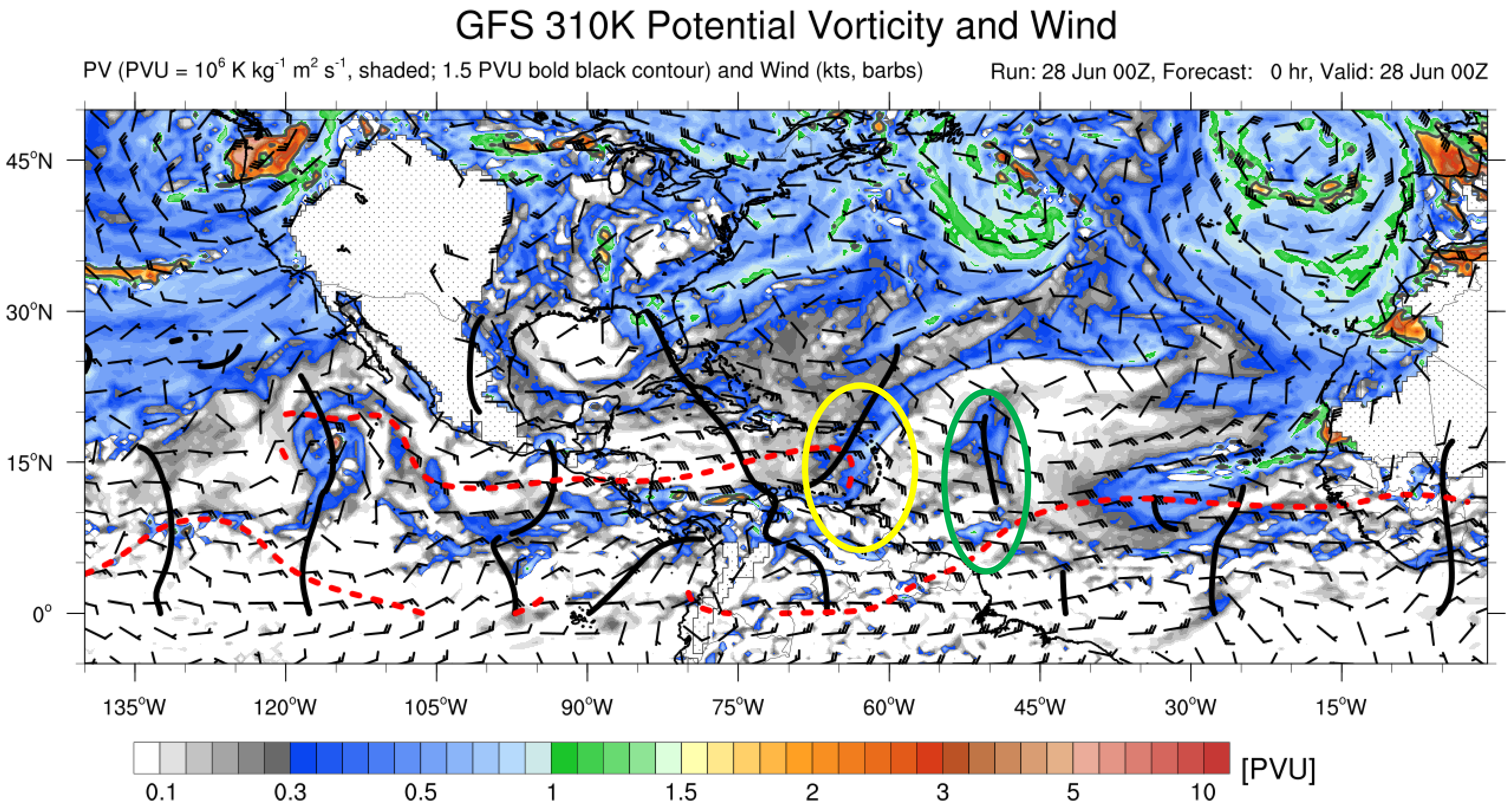


GFS 310K Potential Vorticity and Wind
PV (PVU = 10^6 K kg^-1 m^2 s^-1, shaded; 1.5 PVU bold black contour) and Wind (kts, barbs)
Run: 27 Jun 06Z, Forecast: 0 hr, Valid: 27 Jun 06Z
45°N
30°N
15°N
0°
135°W
120°W
105°W
90°W
75°W
60°W
45°W
30°W
15°W
0.1
0.3
0.5
1
1.5
2
3
5
10
[PVU]

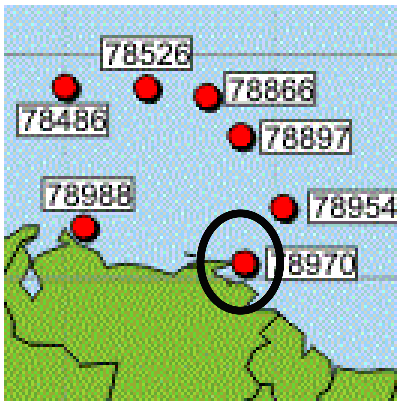


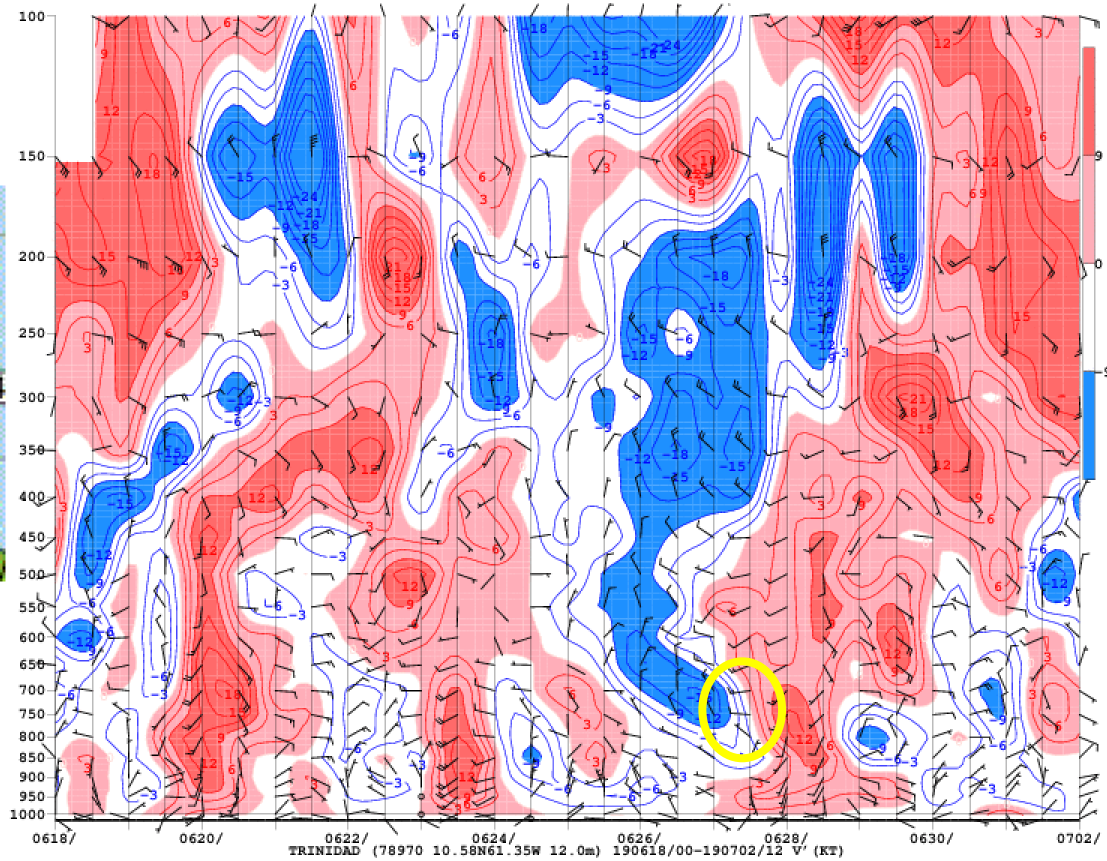
GFS 310K Potential Vorticity and Wind
PV (PVU = 10^6 K kg^-1 m^2 s^-1, shaded; 1.5 PVU bold black contour) and Wind (kts, barbs)
Run: 27 Jun 12Z, Forecast: 0 hr, Valid: 27 Jun 12Z
45°N
30°N
15°N
0°
135°W
120°W
105°W
90°W
75°W
60°W
45°W
30°W
15°W
0.1
0.3
0.5
1
1.5
2
3
5
10
[PVU]


GFS 310K Potential Vorticity and Wind
PV (PVU = 10^6 K kg^-1 m^2 s^-1, shaded; 1.5 PVU bold black contour) and Wind (kts, barbs)
Run: 27 Jun 18Z, Forecast: 0 hr, Valid: 27 Jun 18Z
45°N
30°N
15°N
0°
135°W
120°W
105°W
90°W
75°W
60°W
45°W
30°W
15°W
0.1
0.3
0.5
1
1.5
2
3
5
10
[PVU]



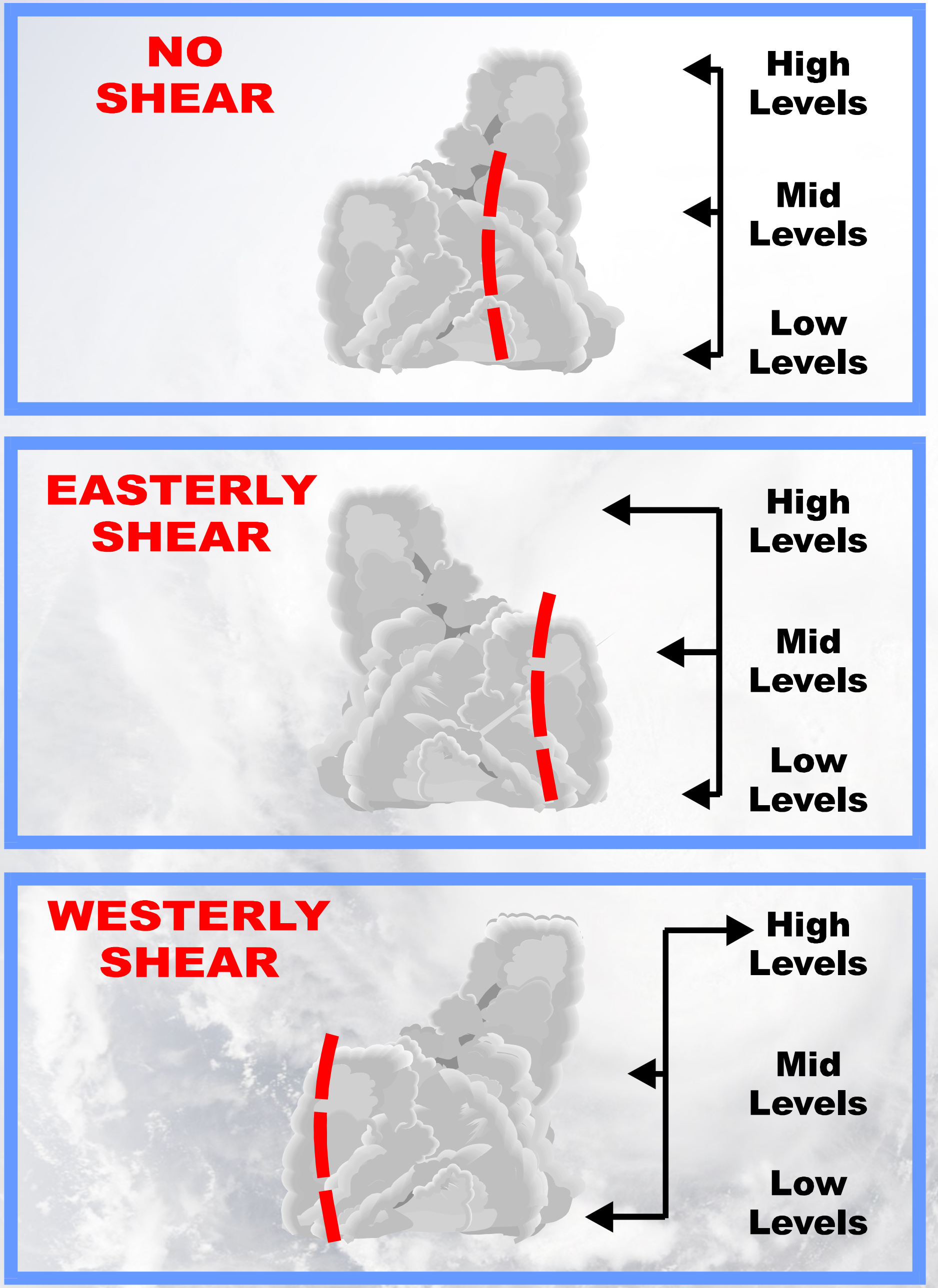
GFS 310K Potential Vorticity and Wind
PV (PVU = 10^6 K kg^-1 m^2 s^-1, shaded; 1.5 PVU bold black contour) and Wind (kts, barbs)
Run: 28 Jun 00Z, Forecast: 0 hr, Valid: 28 Jun 00Z
45°N
30°N
15°N
0°
135°W
120°W
105°W
90°W
75°W
60°W
45°W
30°W
15°W
0.1
0.3
0.5
1
1.5
2
3
5
10
[PVU]



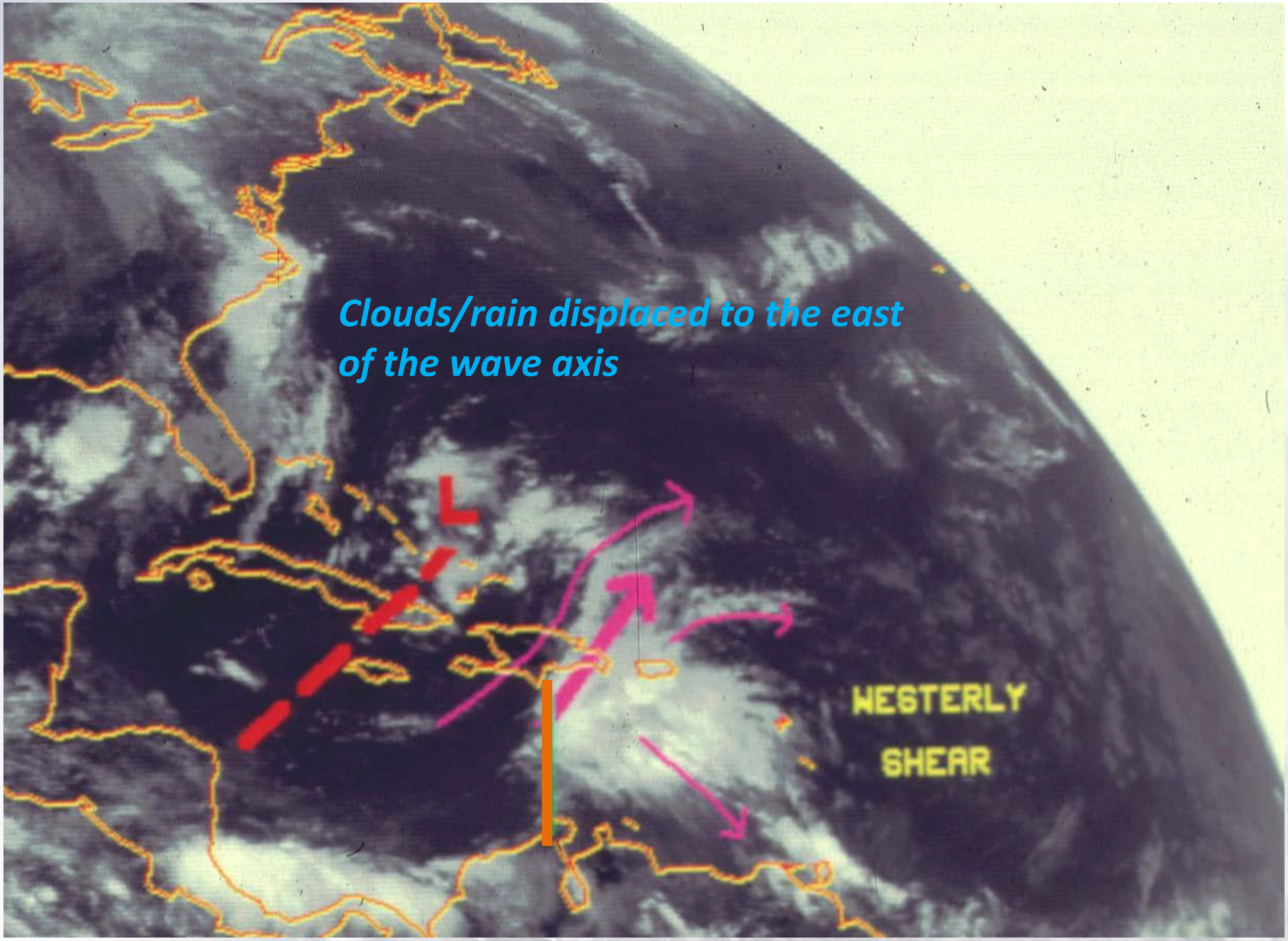


Trinidad upper air sounding v anomaly. The PV streamer passed Trinidad June 27 (yellow oval).

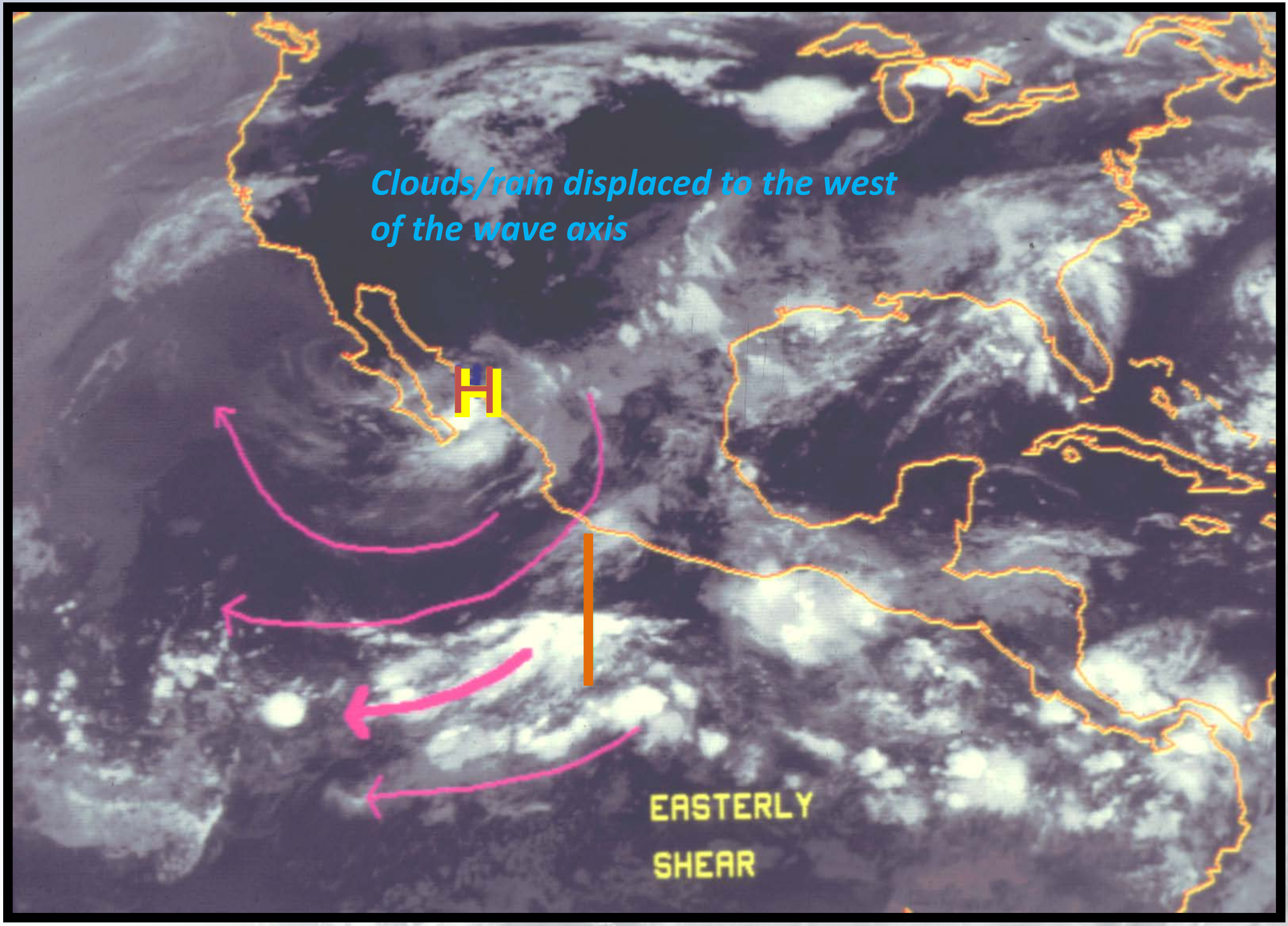
Tropical Wave Interactions


NO
SHEAR
High
Levels
Mid
Levels
Low
Levels
EASTERLY
SHEAR
High
Levels
Mid
Levels
Low
Levels
WESTERLY
SHEAR
High
Levels
Mid
Levels
Low
Levels

Waves in Westerly Shear

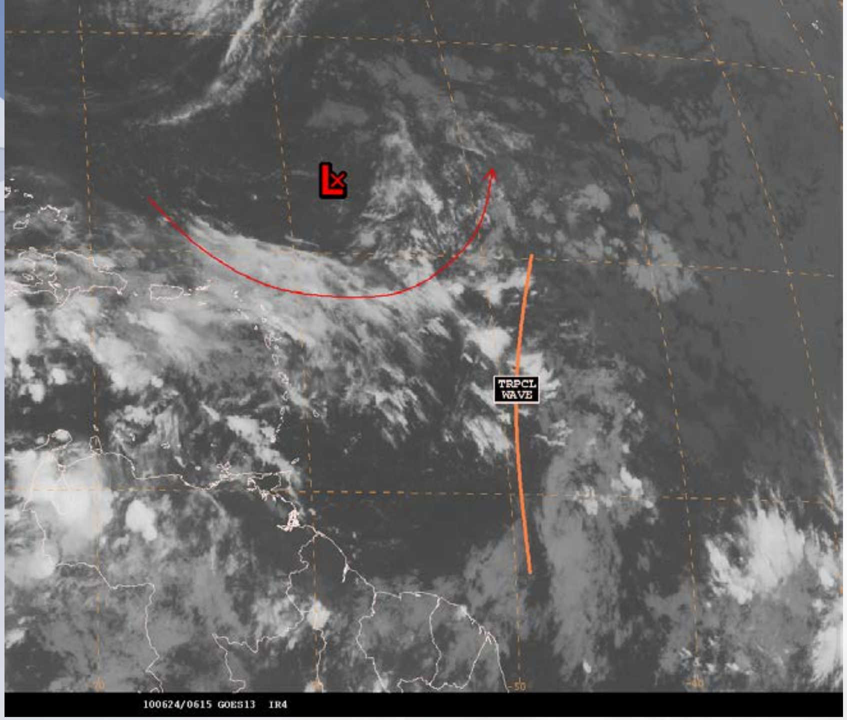


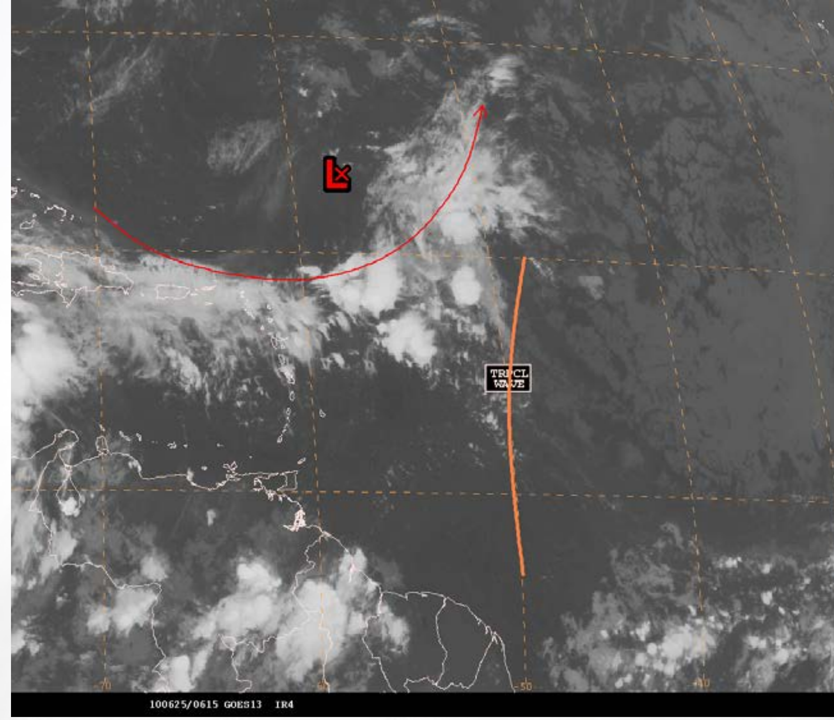
Waves in Easterly Shear

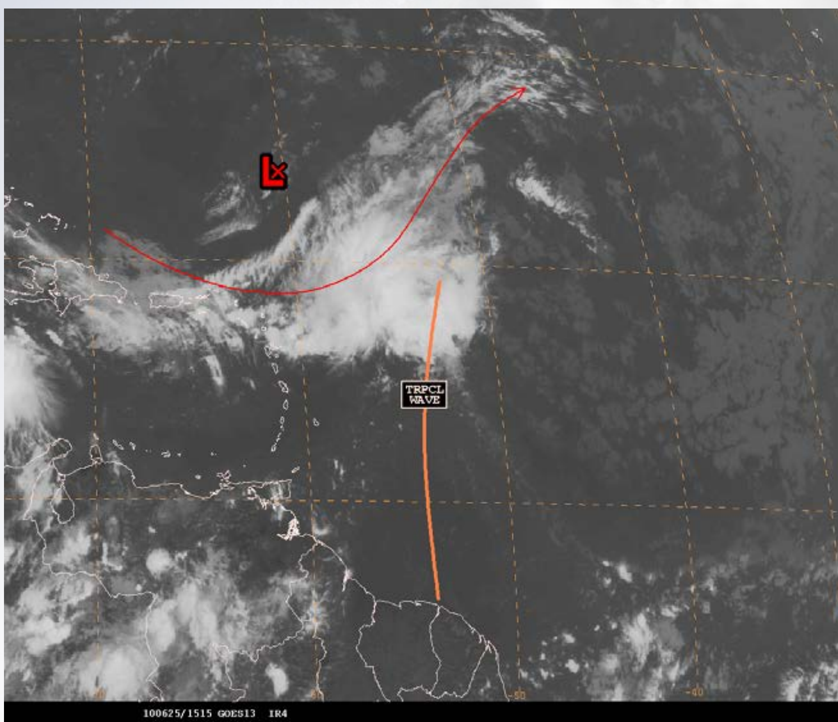


What happens when tropical waves interact with upper-level lows and troughs?

(a) Convection decreases
(b) Convection increases
(c) A tropical cyclone forms





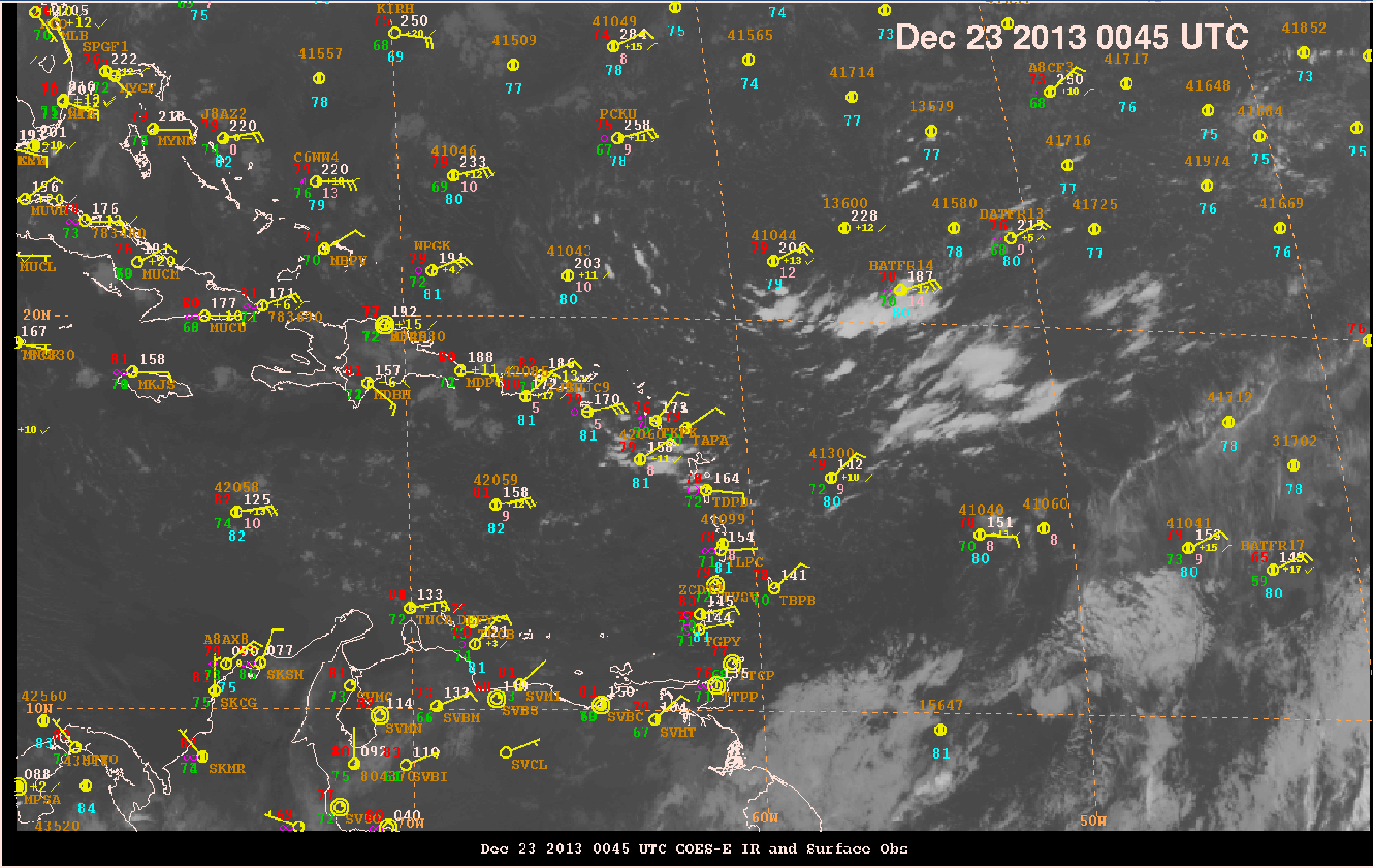


Although interaction with upper-level lows are unfavorable for tropical cyclogenesis, it can often induce heavy rainfall.

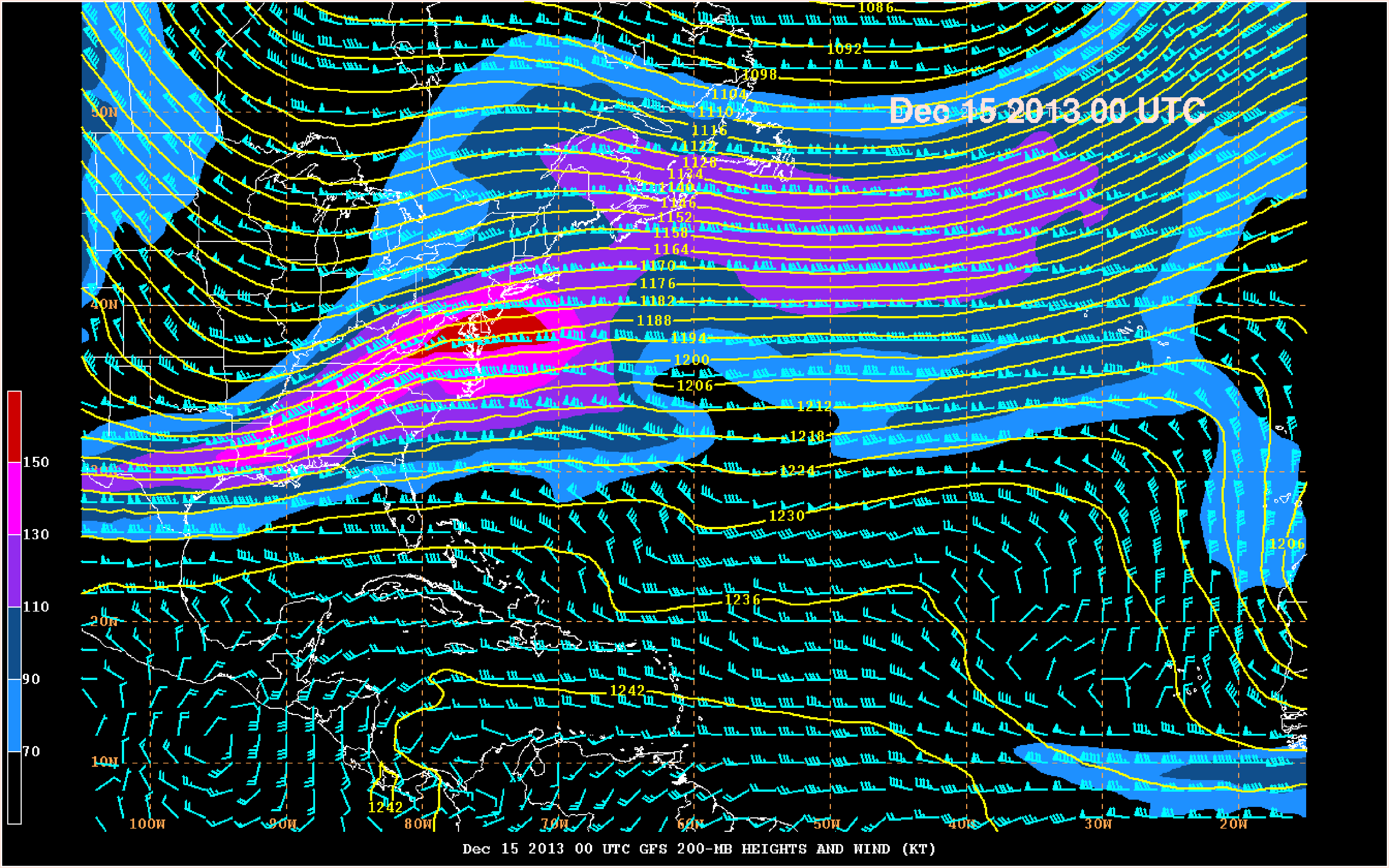
Eastern Caribbean: Floods and Landslides - Dec 2013

- Severe rains and high winds **due to a low level trough** caused floods and landslides in St. Vincent and the Grenadines, Saint Lucia and Dominica from 23-25 Dec 2013
- Torrential rains on Christmas Eve, with **15 inches falling in 24 hours**, led to dramatic floods and landslides

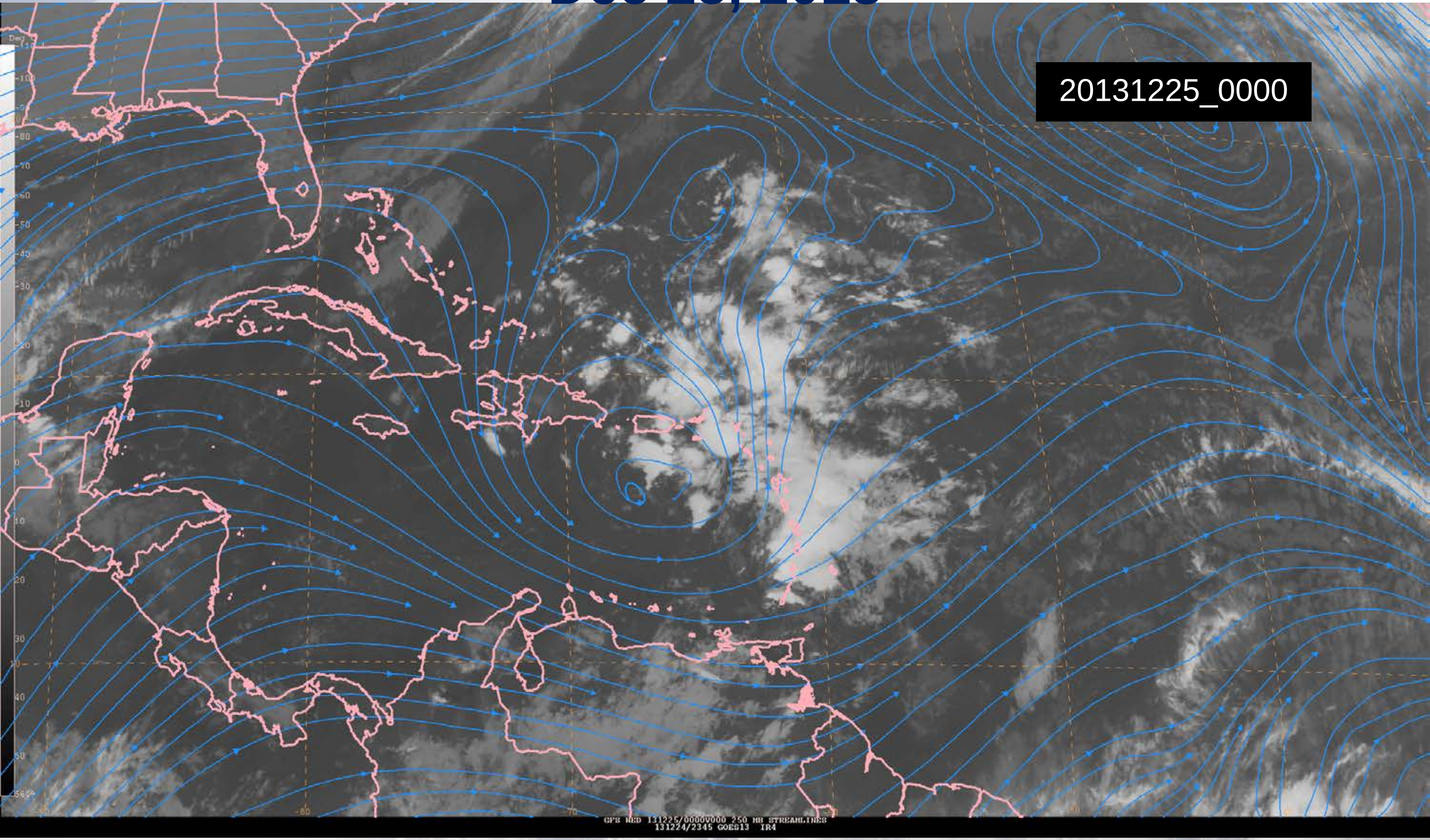
A quick view using GOES-E imagery



200 mb heights and wind
00Z Dec 15 – 18Z Dec 27

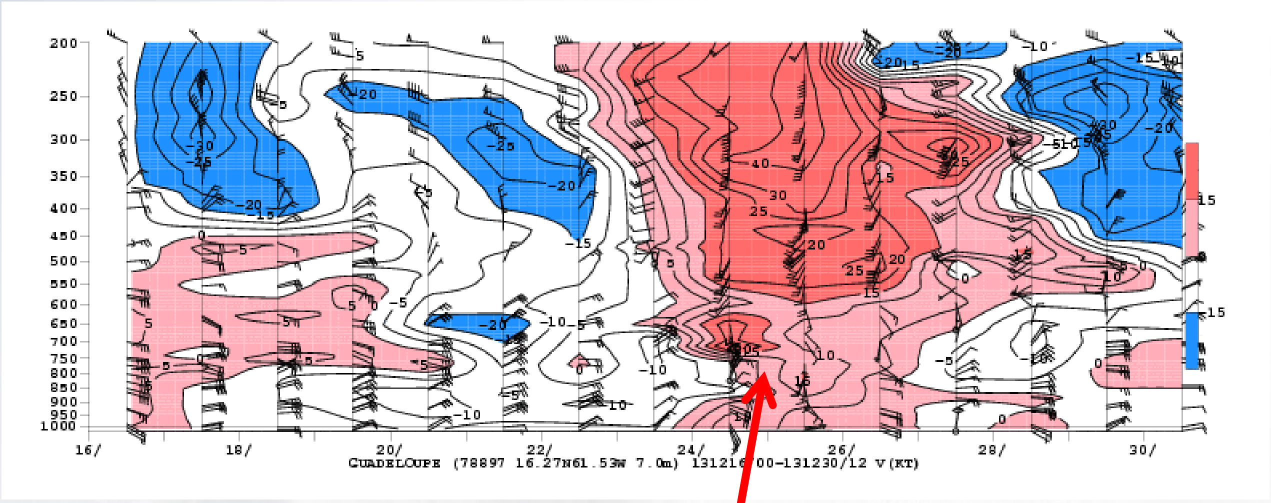


IR image and 250 mb streamlines at 0000 UTC Dec 25, 2013

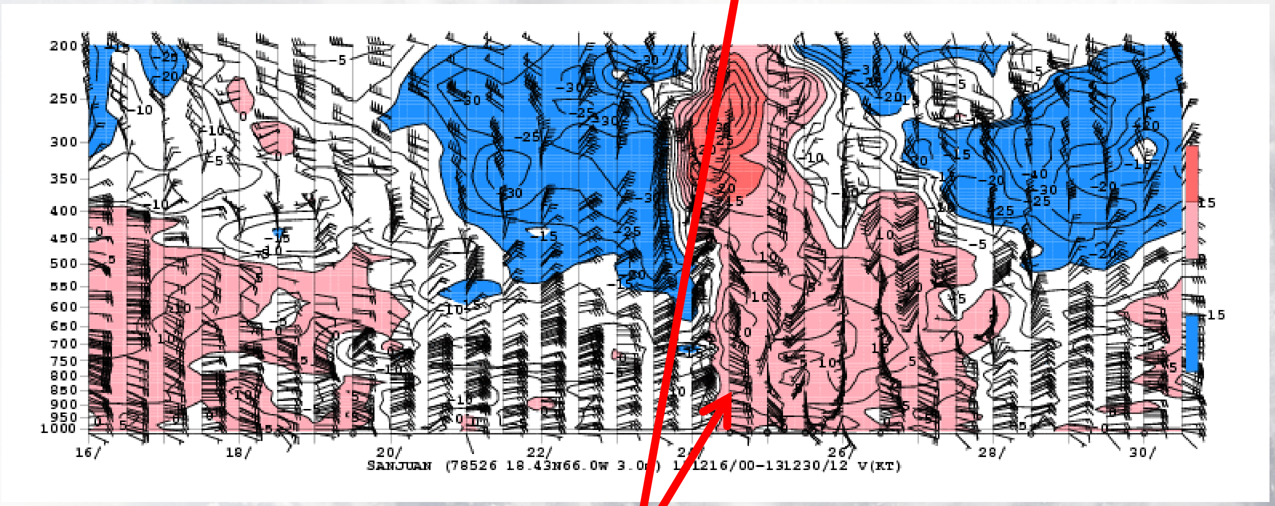


Sounding winds Dec 16 – Dec 30

Guadeloupe



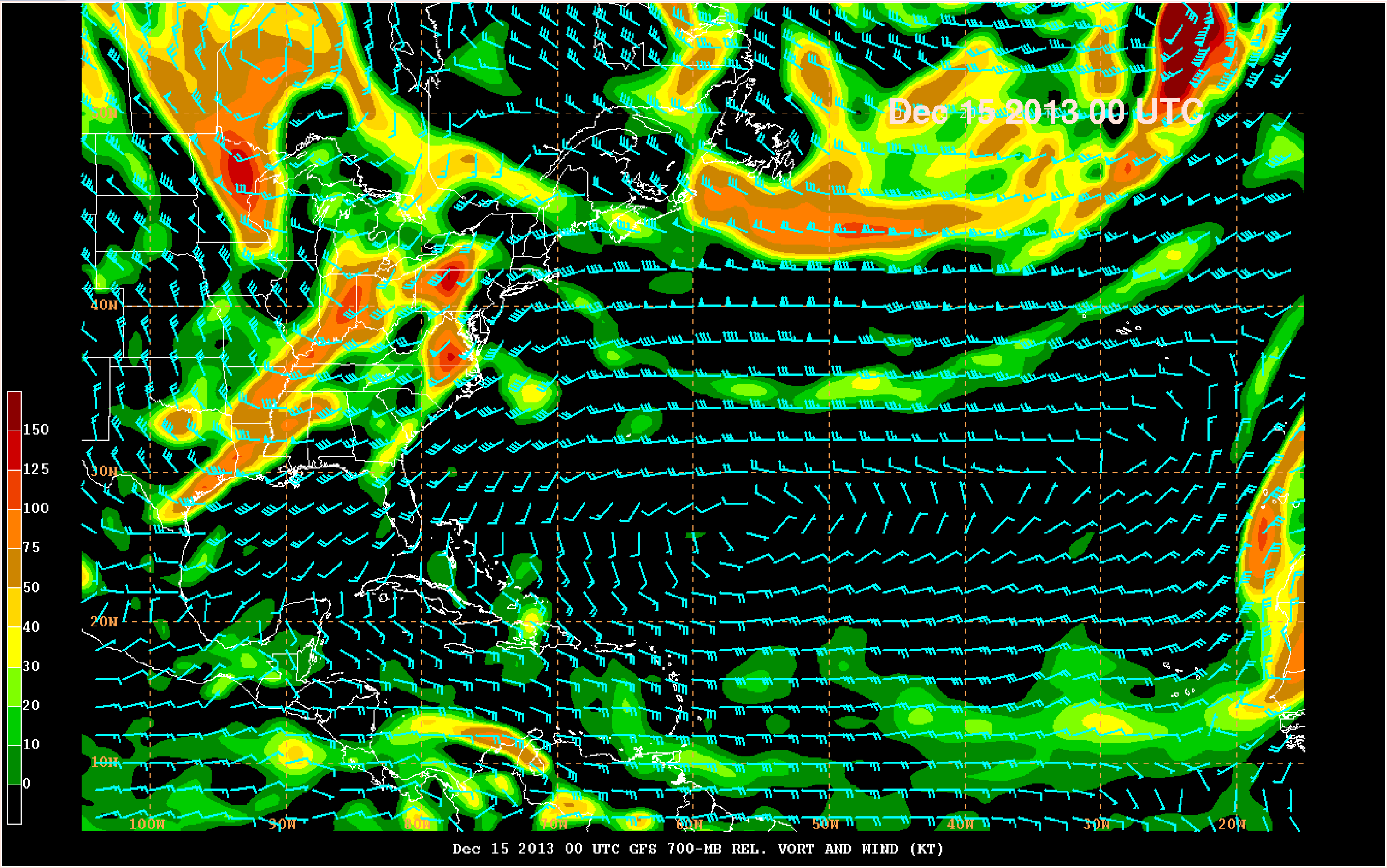
San Juan



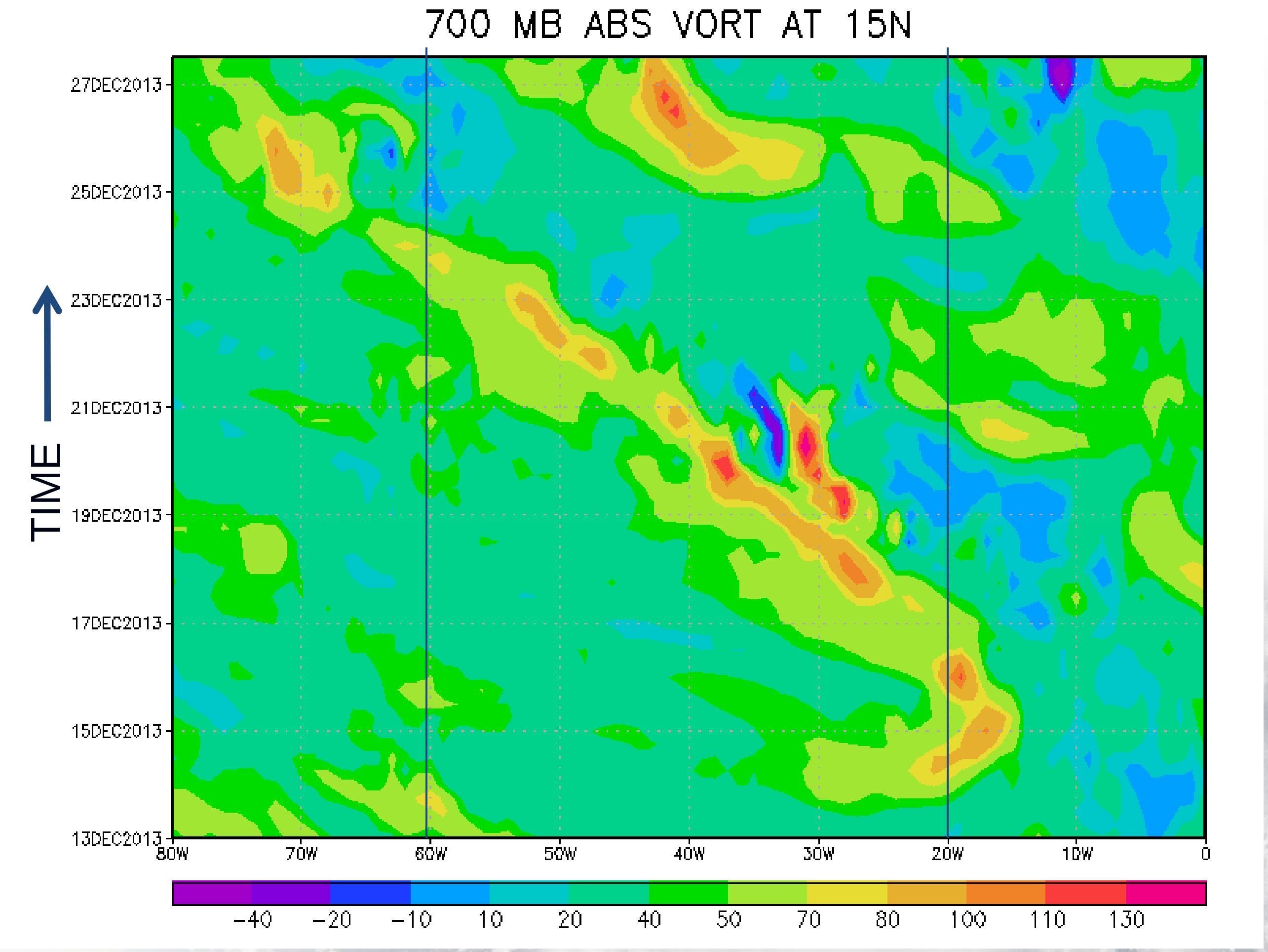
Was the low level southerly winds related to the upper level low only?

Was the heavy rainfall over the Windward Islands caused by the upper level low and a shortwave, or by the low level trough, or both?

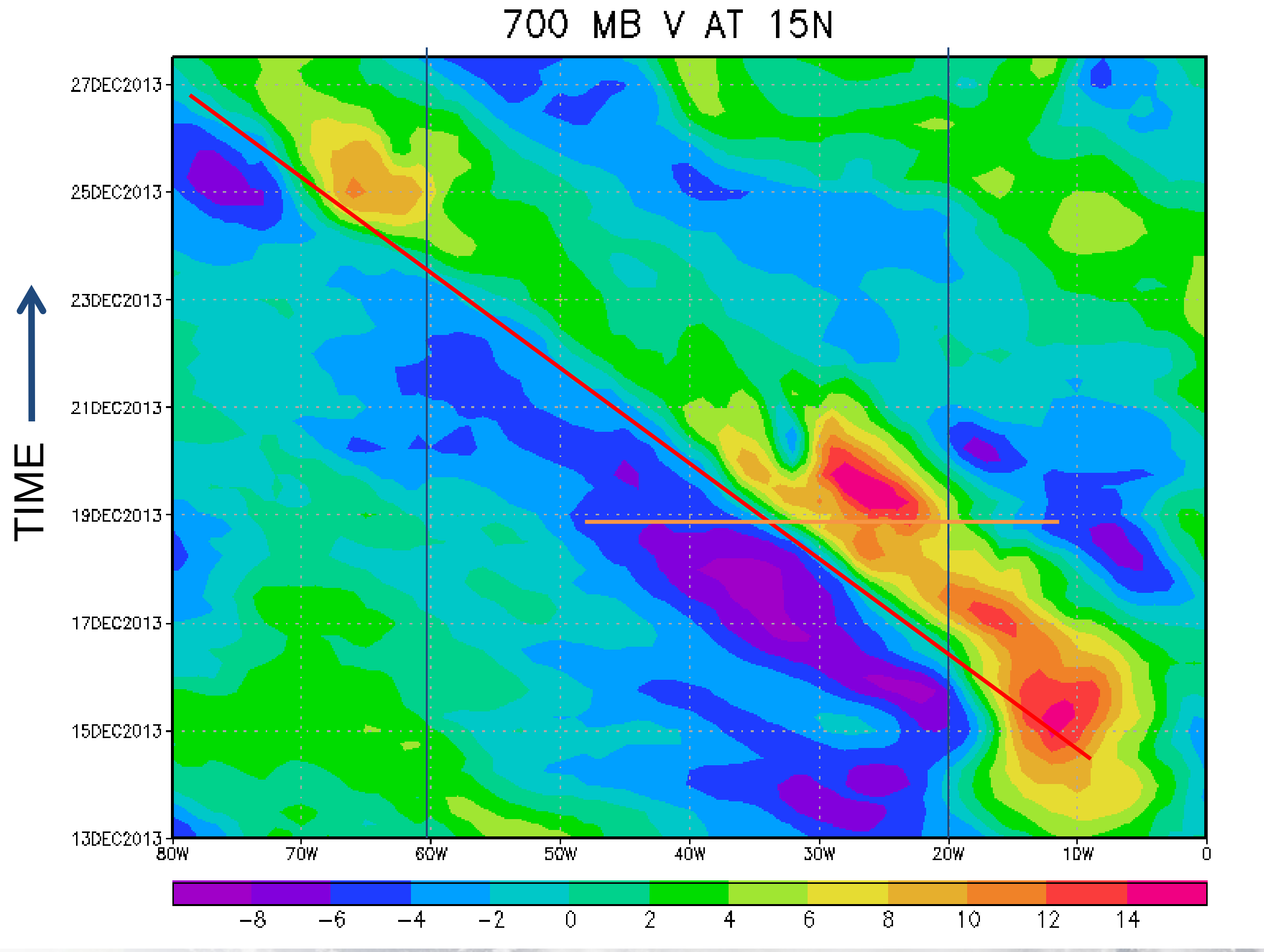
700 mb relative vorticity and wind
00 Z Dec 15 – 18Z Dec 27



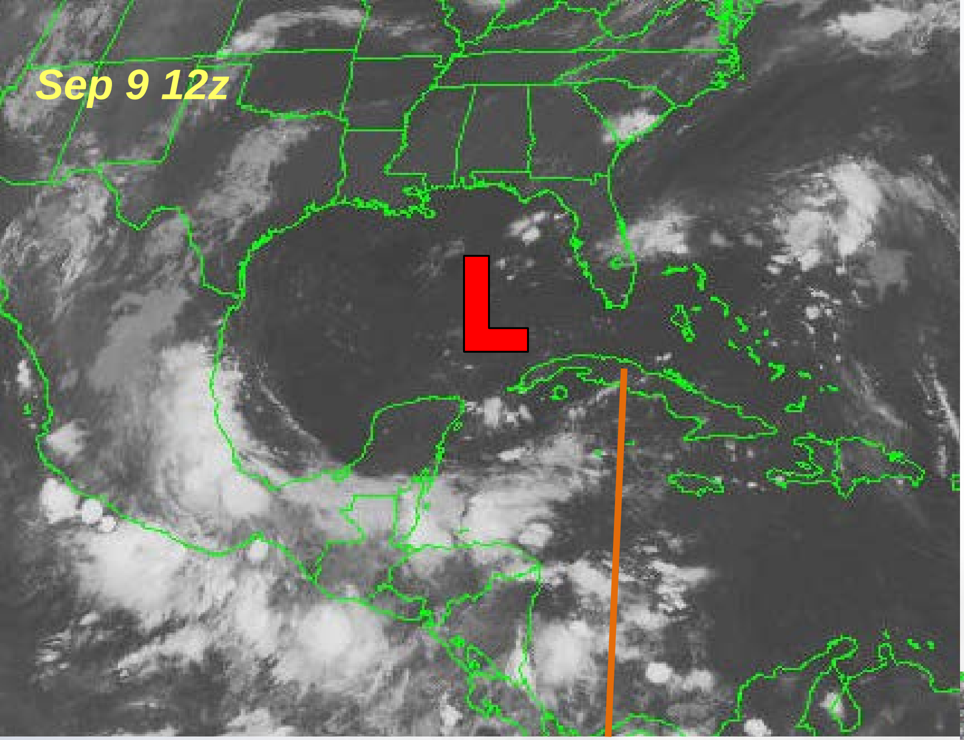
GFS analysis



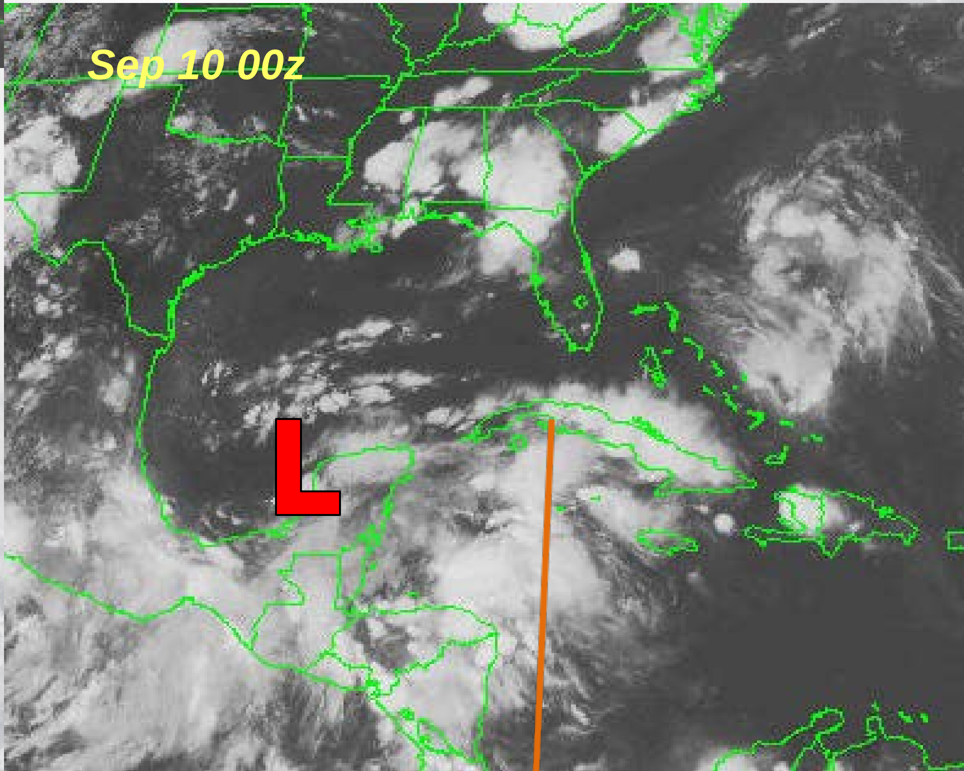
GFS analysis



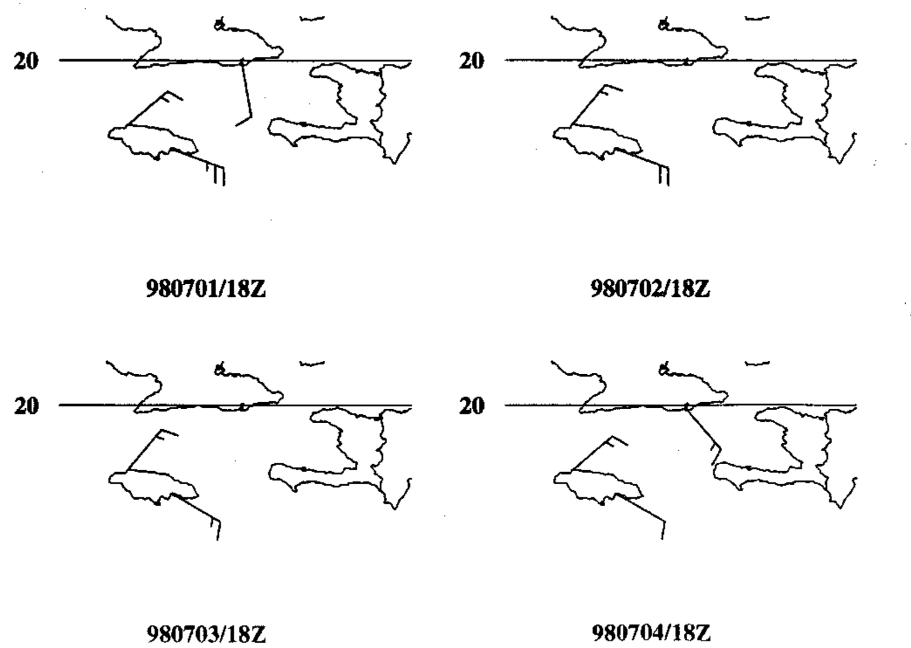
Local Effects



Sea-breeze convergence, upslope flows, and afternoon heating can cause convection to become chaotic and difficult to predict.

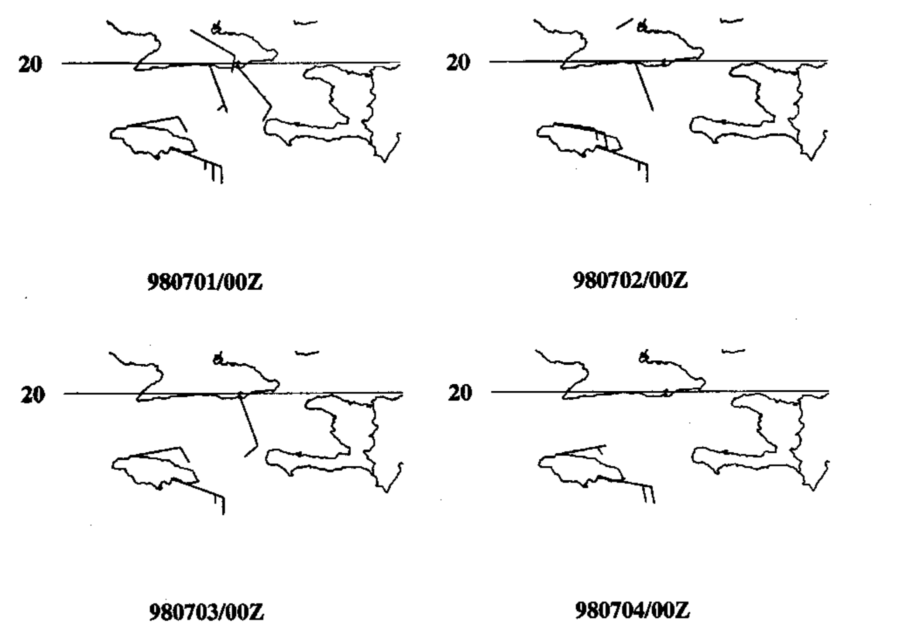


Wind shift between Kingston and Montego Bay at 18Z on those days, suggesting a trough over the island

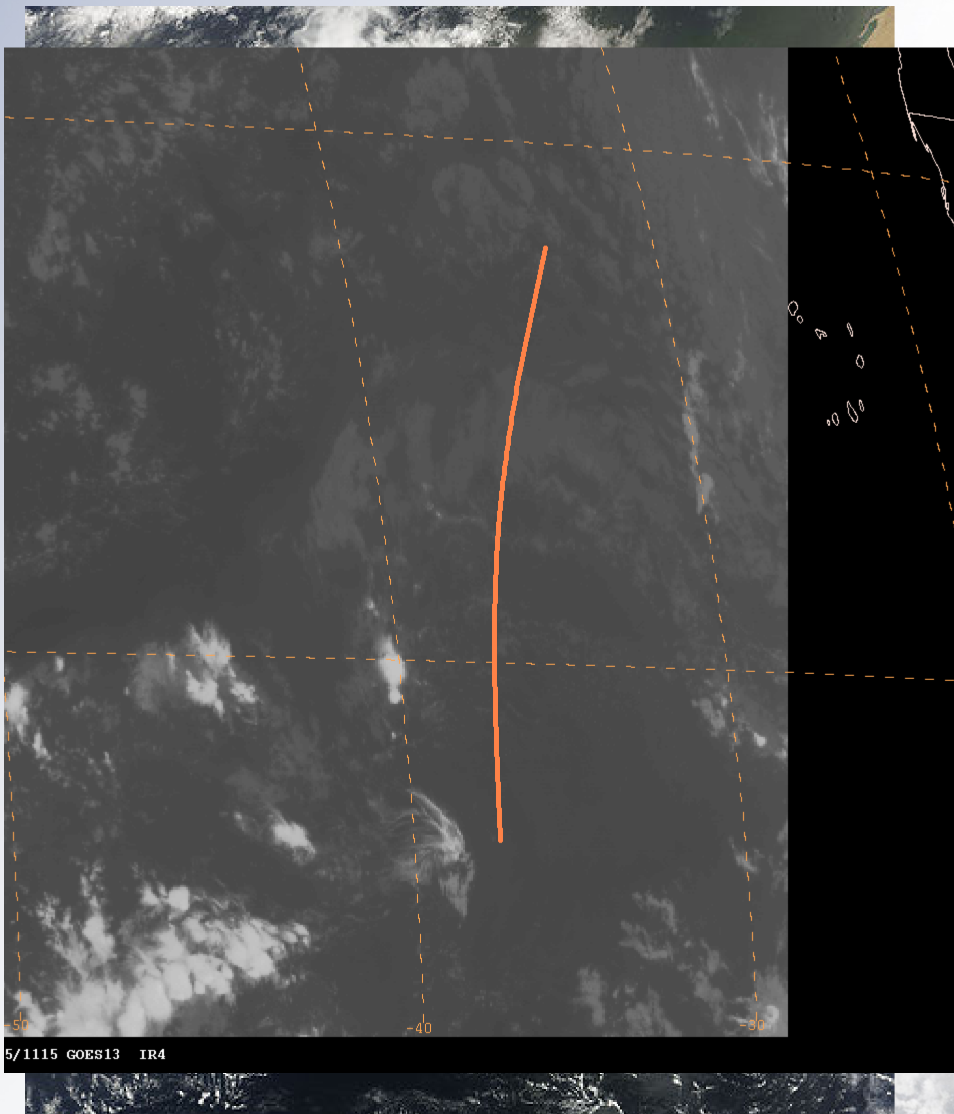


Heated island

But the wind shift was mostly gone by 00Z



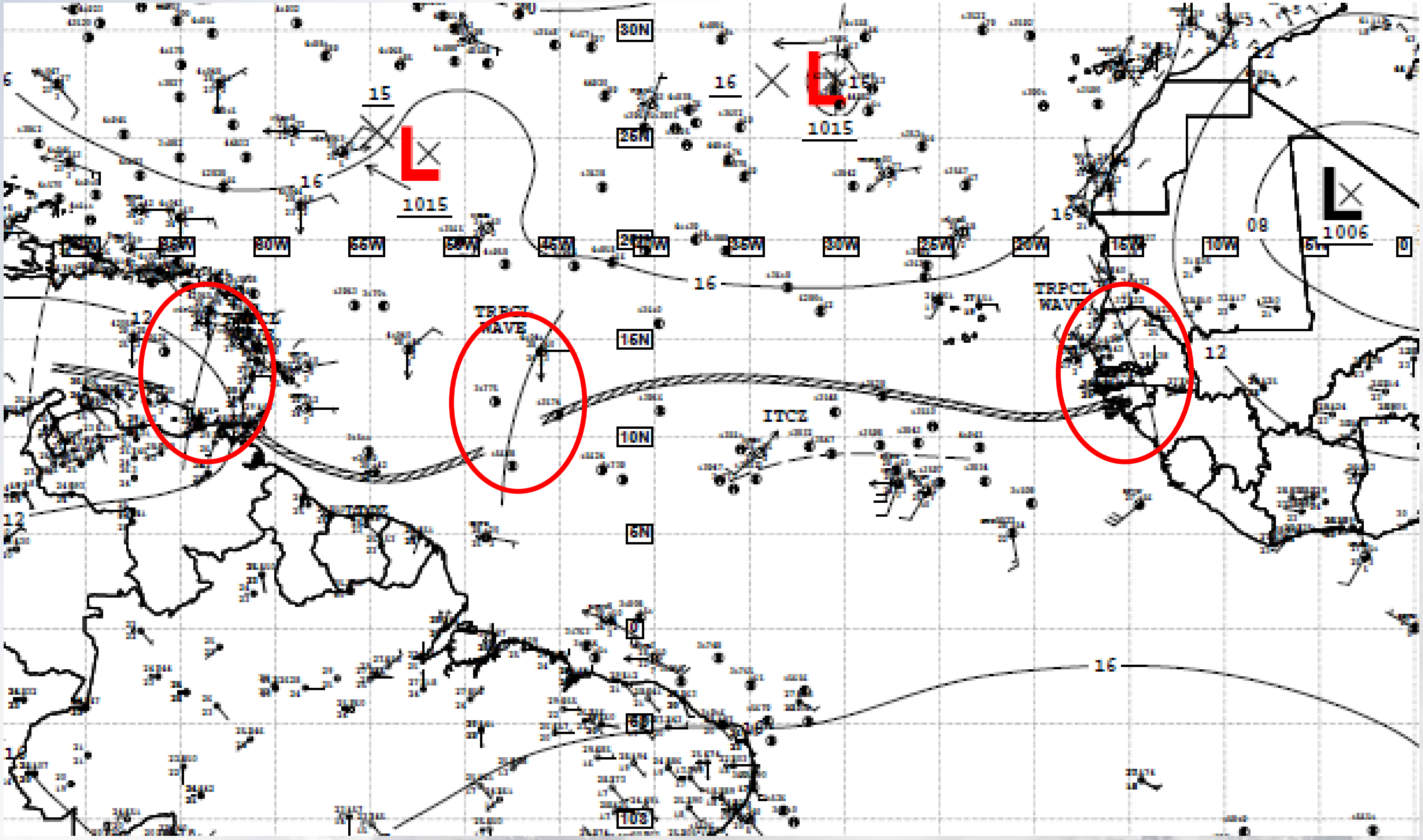
Saharan Air Layer



Very dry/warm air in the low-mid levels of the atmosphere limits convection.

NHC Products

TAFB products: Surface Analysis



Analyze current positions every 6 h

TAFB products: Tropical Weather Discussion

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TROPICAL WEATHER DISCUSSION FOR NORTH AMERICA...CENTRAL
AMERICA...GULF OF MEXICO...CARIBBEAN SEA...NORTHERN SECTIONS
OF SOUTH AMERICA...AND ATLANTIC OCEAN TO THE AFRICAN COAST
FROM THE EQUATOR TO 32N. THE FOLLOWING INFORMATION IS BASED
ON SATELLITE IMAGERY...METEOROLOGICAL ANALYSIS...WEATHER
OBSERVATIONS...AND RADAR.

BASED ON 1800 UTC SURFACE ANALYSIS AND SATELLITE IMAGERY THROUGH
2315 UTC.

...TROPICAL WAVES...

A TROPICAL WAVE IS ALONG 32W S OF 17N MOVING W NEAR 13 KT. THIS
WAVE COINCIDES WITH A DEEP LAYER MOISTURE MAXIMUM OBSERVED IN
TOTAL PRECIPITABLE WATER IMAGERY. ISOLATED MODERATE CONVECTION
IS FROM 13N-15N BETWEEN 30W-34W.

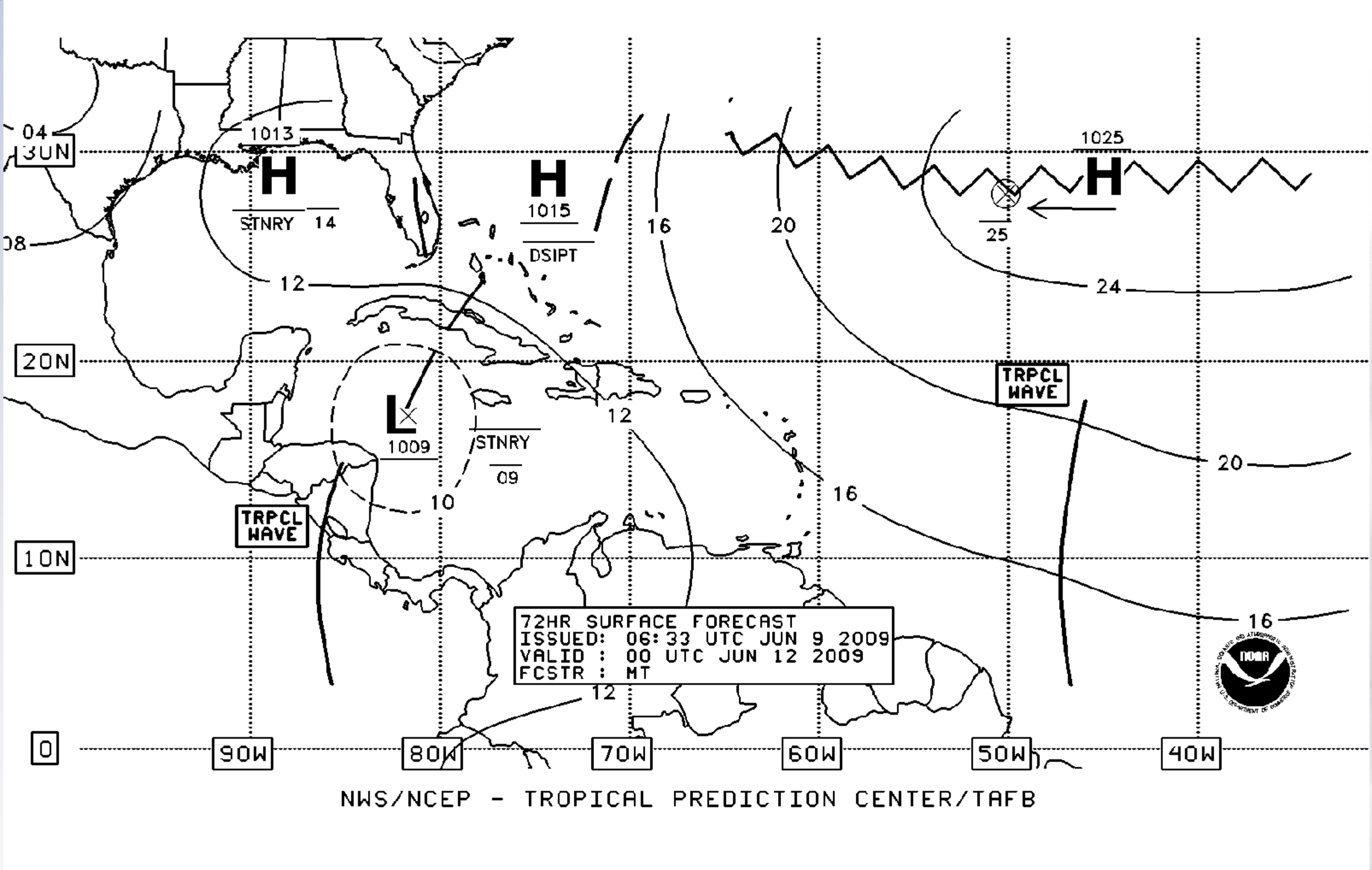
A TROPICAL WAVE IS ALONG 49W S OF 14N MOVING W NEAR 18 KT. THIS
WAVE REMAINS ON THE LEADING EDGE OF DRY SAHARAN AIR AND DUST
INHIBITING DEEP CONVECTION ALONG THE WAVE AXIS. HOWEVER...
SCATTERED SHOWERS ARE FROM 10N-12N BETWEEN 46W-50W.

A TROPICAL WAVE IS ALONG 66W S OF 18N MOVING W NEAR 15 KT. THIS
WAVE COINCIDES WITH A DEEP LAYER MOISTURE MAXIMUM THAT STRETCHES
NWD INTO THE SW NORTH ATLC DUE TO AN UPPER LEVEL LOW CENTERED
NEAR 23N67W. INTERACTIONS BETWEEN THE TROPICAL WAVE AND UPPER
LEVEL LOW ARE PRODUCING SCATTERED SHOWERS AND ISOLATED MODERATE
CONVECTION FROM 10N-19N BETWEEN 60W-70W.

A TROPICAL WAVE IS ALONG 82W S OF 21N MOVING W NEAR 15 KT. THIS
WAVE LIES IN A BROAD AREA OF DEEP LAYER MOISTURE OBSERVED IN
TOTAL PRECIPITABLE WATER IMAGERY. THIS WAVE CONTINUES MOVING
BENEATH A DIFFLUENT PATTERN ALOFT ENHANCING SCATTERED MODERATE
CONVECTION OVER THE SW CARIBBEAN S OF 12N AND ACROSS PANAMA AND
COSTA RICA. ALSO SCATTERED MODERATE/ISOLATED STRONG CONVECTION
IS OVER THE NW CARIBBEAN N OF 18N BETWEEN 80W-89W...INCLUDING
PORTIONS OF WRN CUBA AND THE YUCATAN PENINSULA.
```

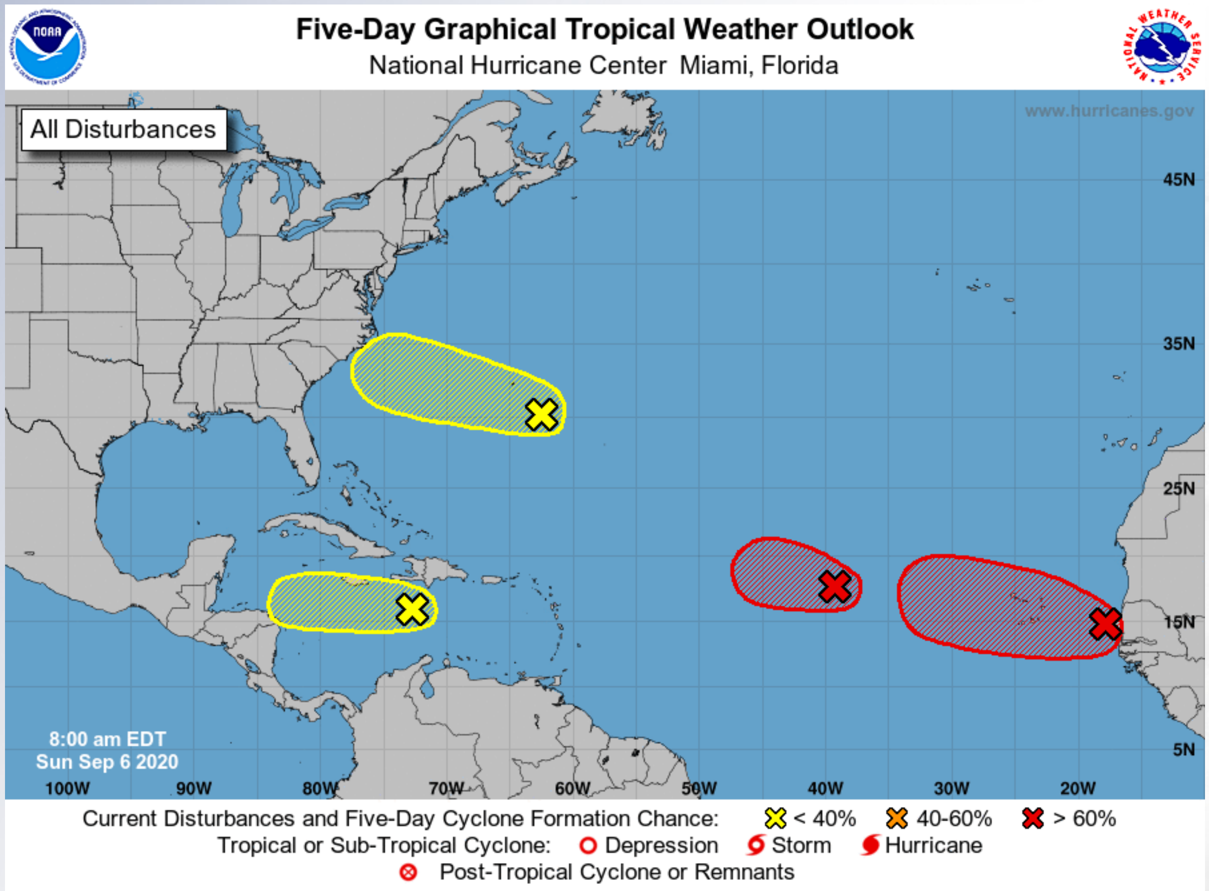
Discussion of tropical waves

TAFB products: graphical forecast



Predict future positions: 24h, 48h, and 72h

Tropical Weather Outlook



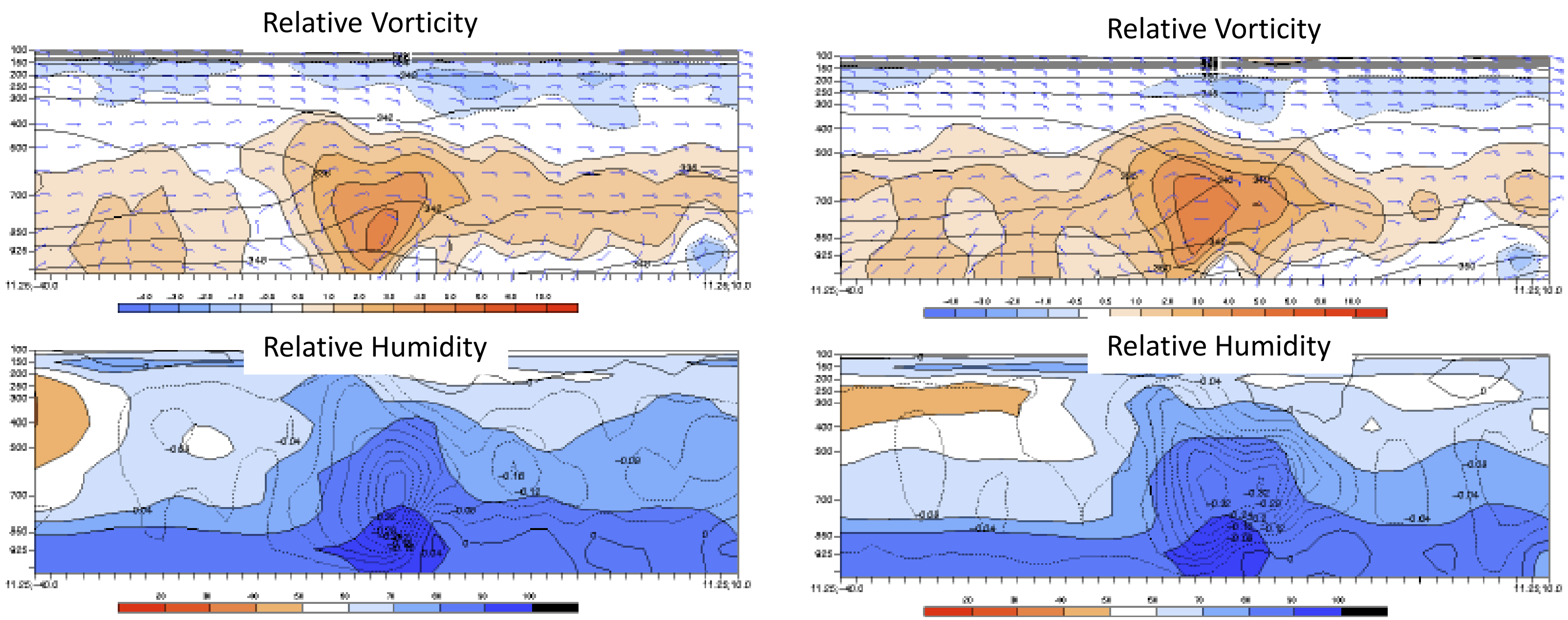
Approximately 60 % of Atlantic tropical cyclones and 85 % of major hurricanes originate from tropical waves

What is more important for tropical cyclogenesis?

(a) the wave structure
(b) the environment

Developing vs. Non-developing

Developing (33) | Non-Developing (33 most intense)

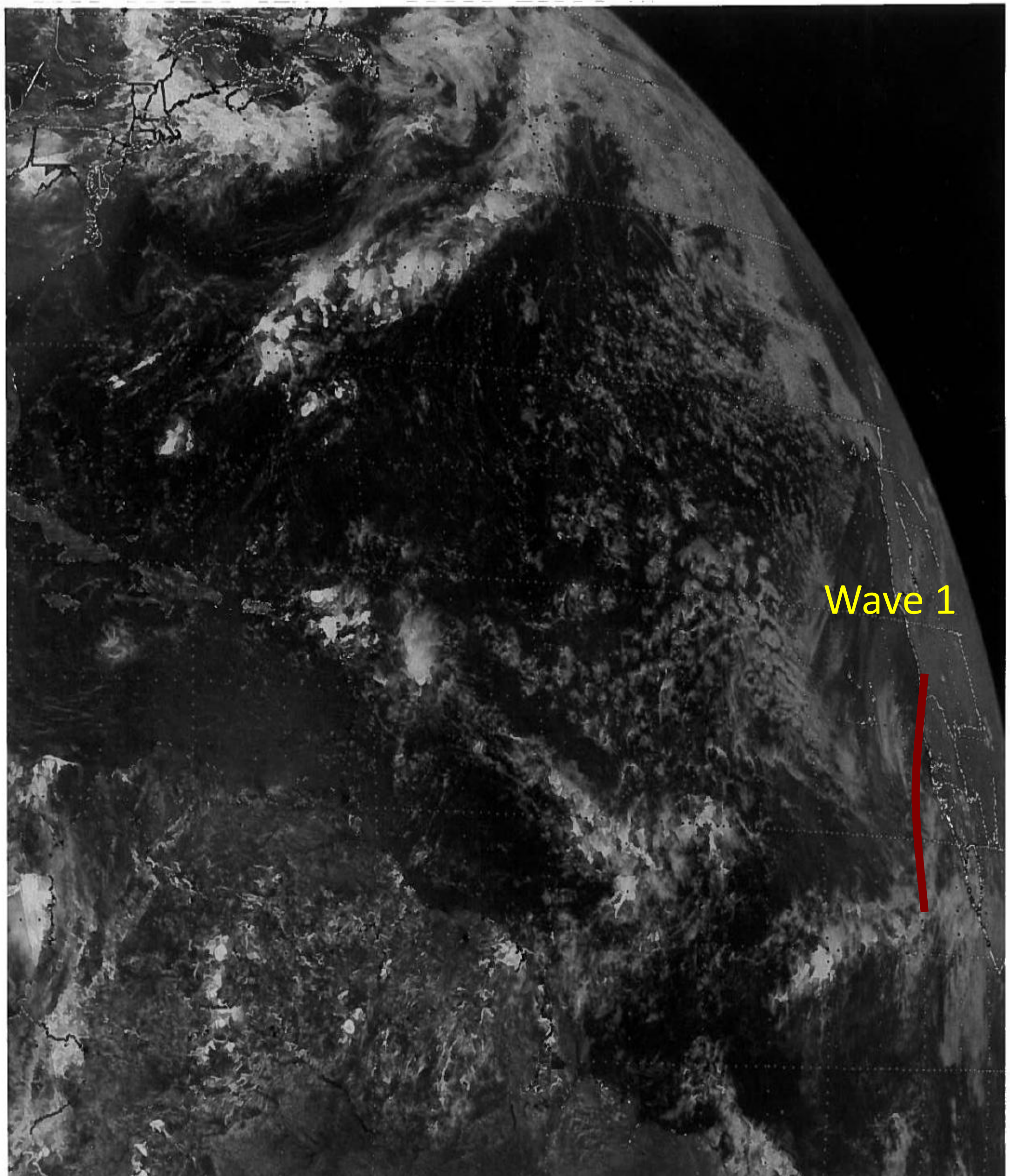


Hopsch, Thorncroft, and Tyle (2009)

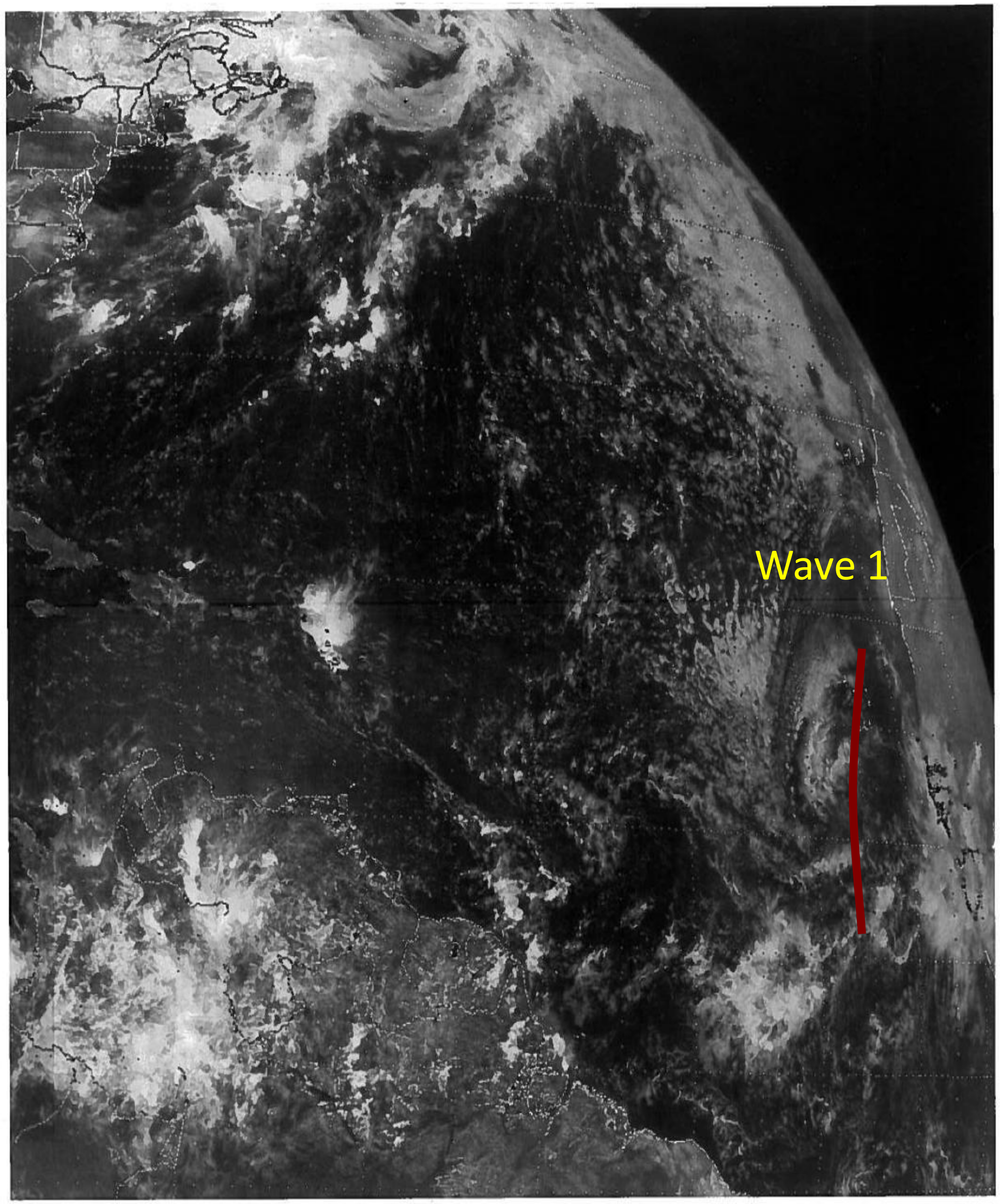
Very little different in structure between developing and non-developing waves

EXERCISE

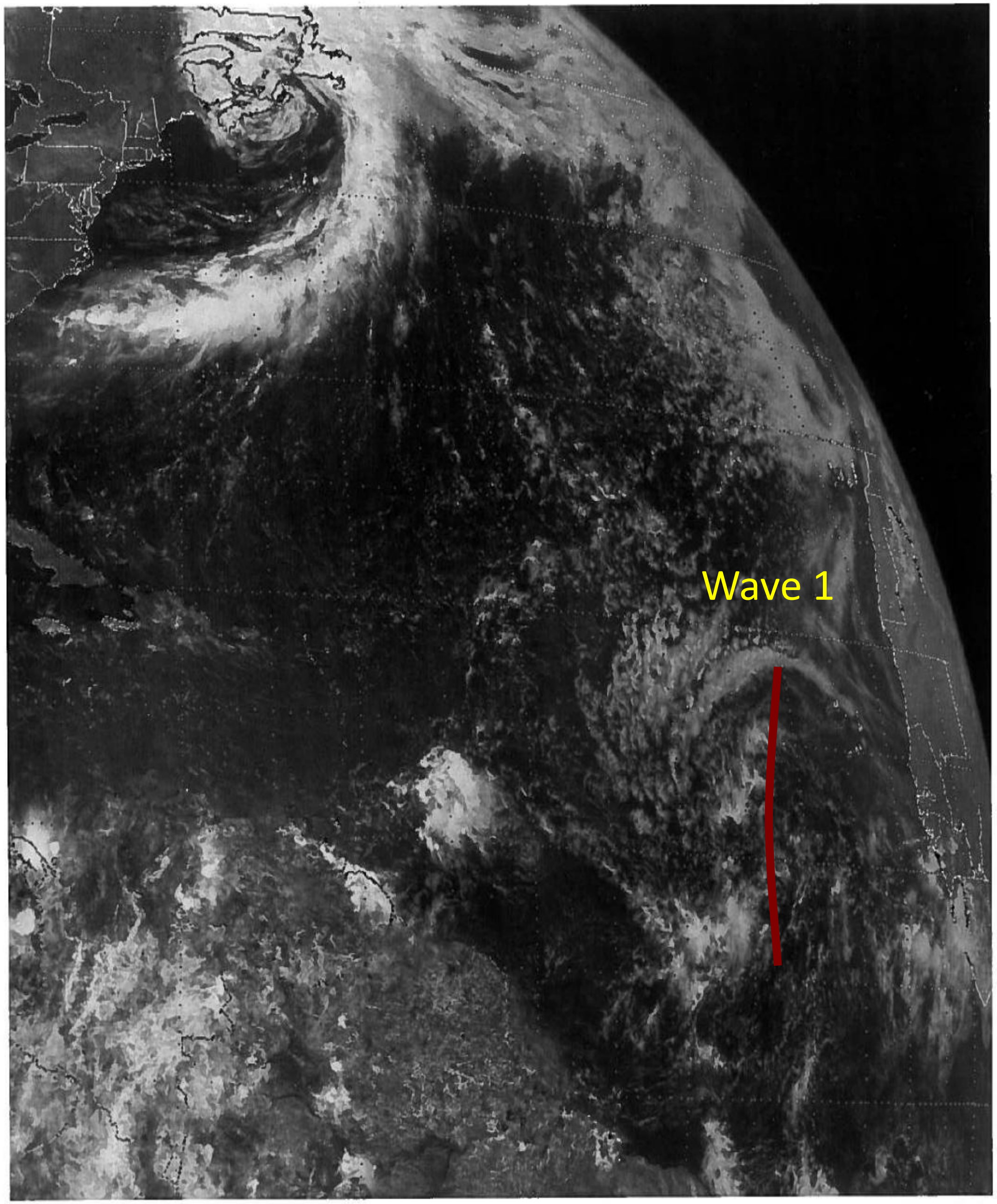
July 13



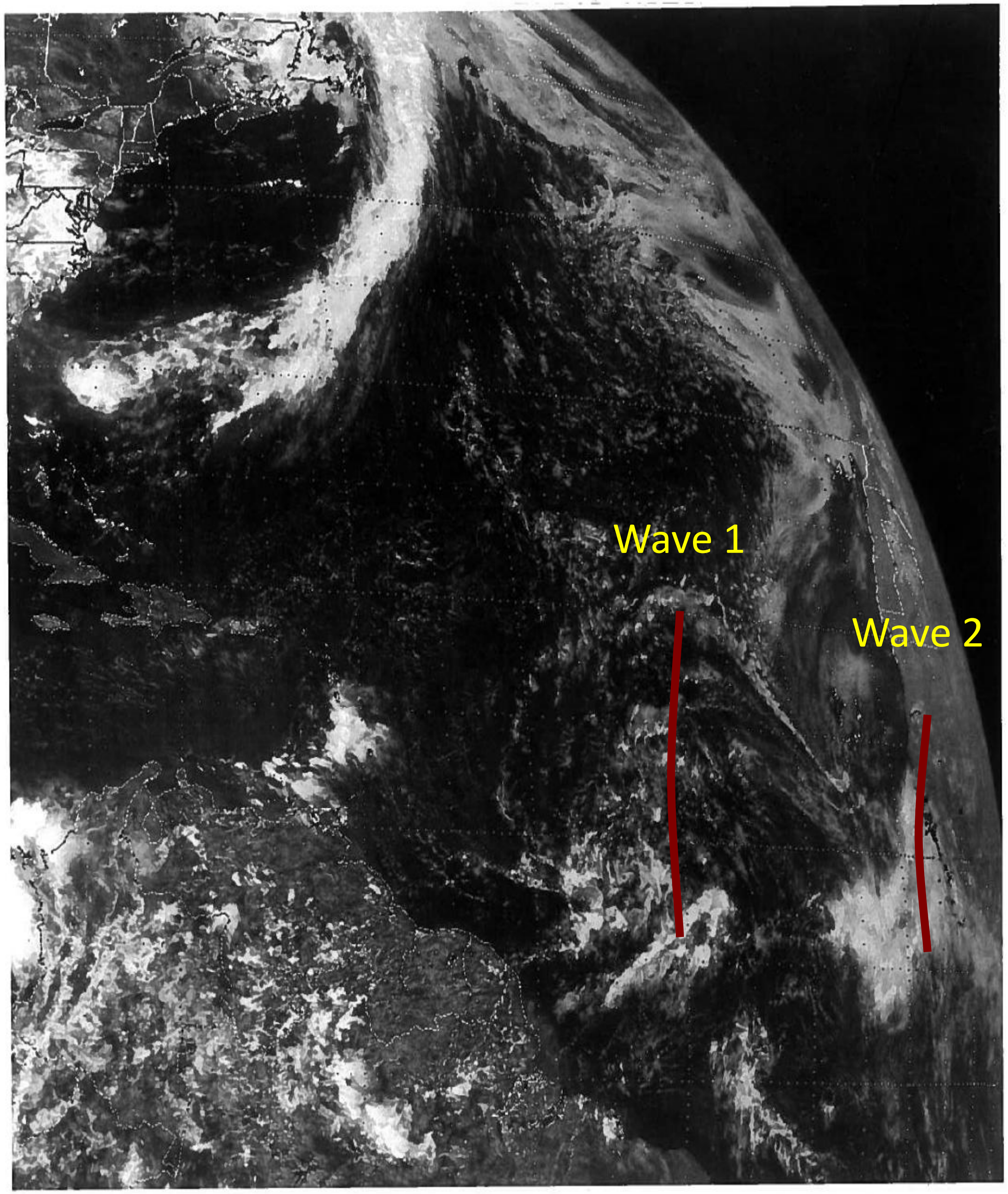
July 14



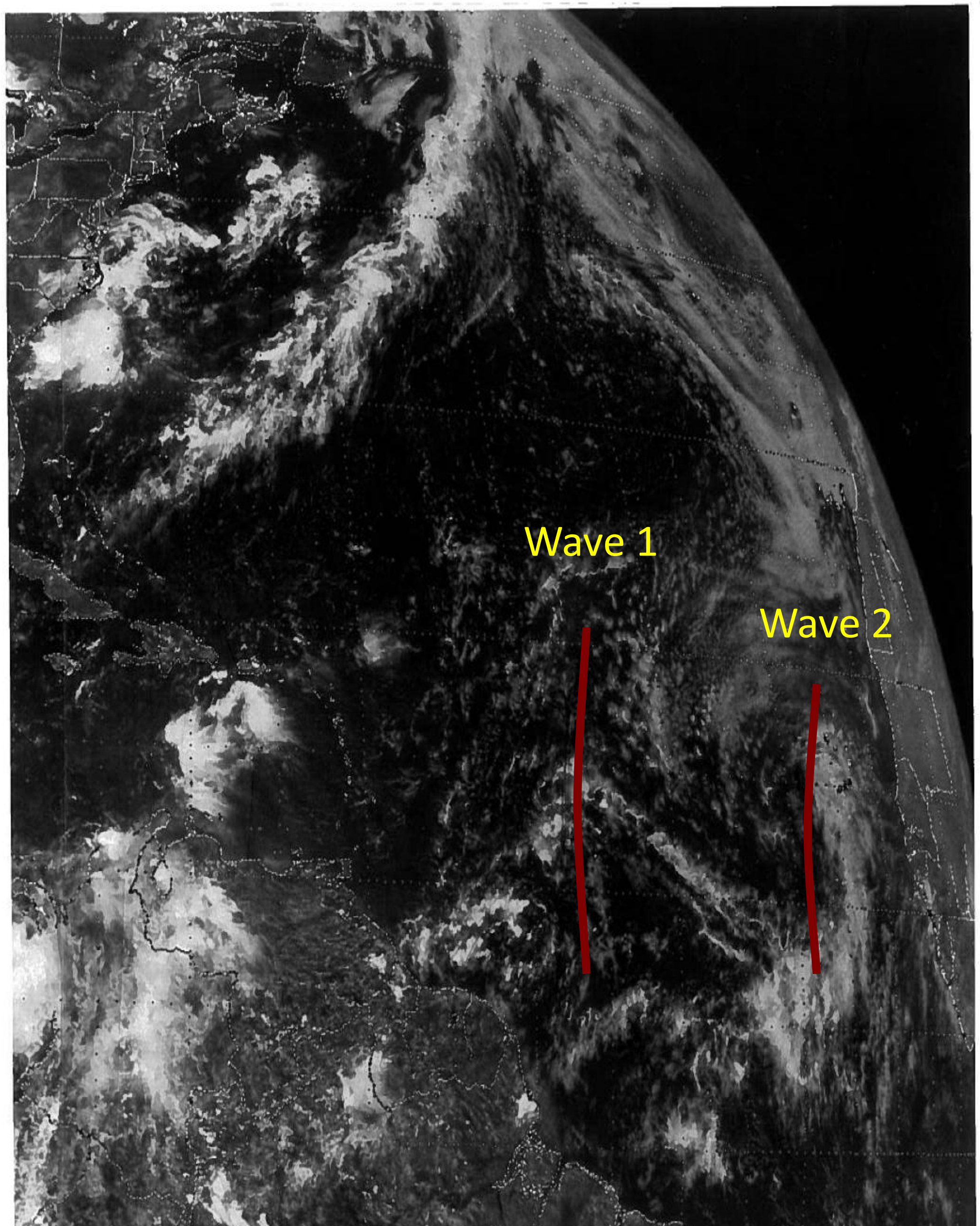
July 15



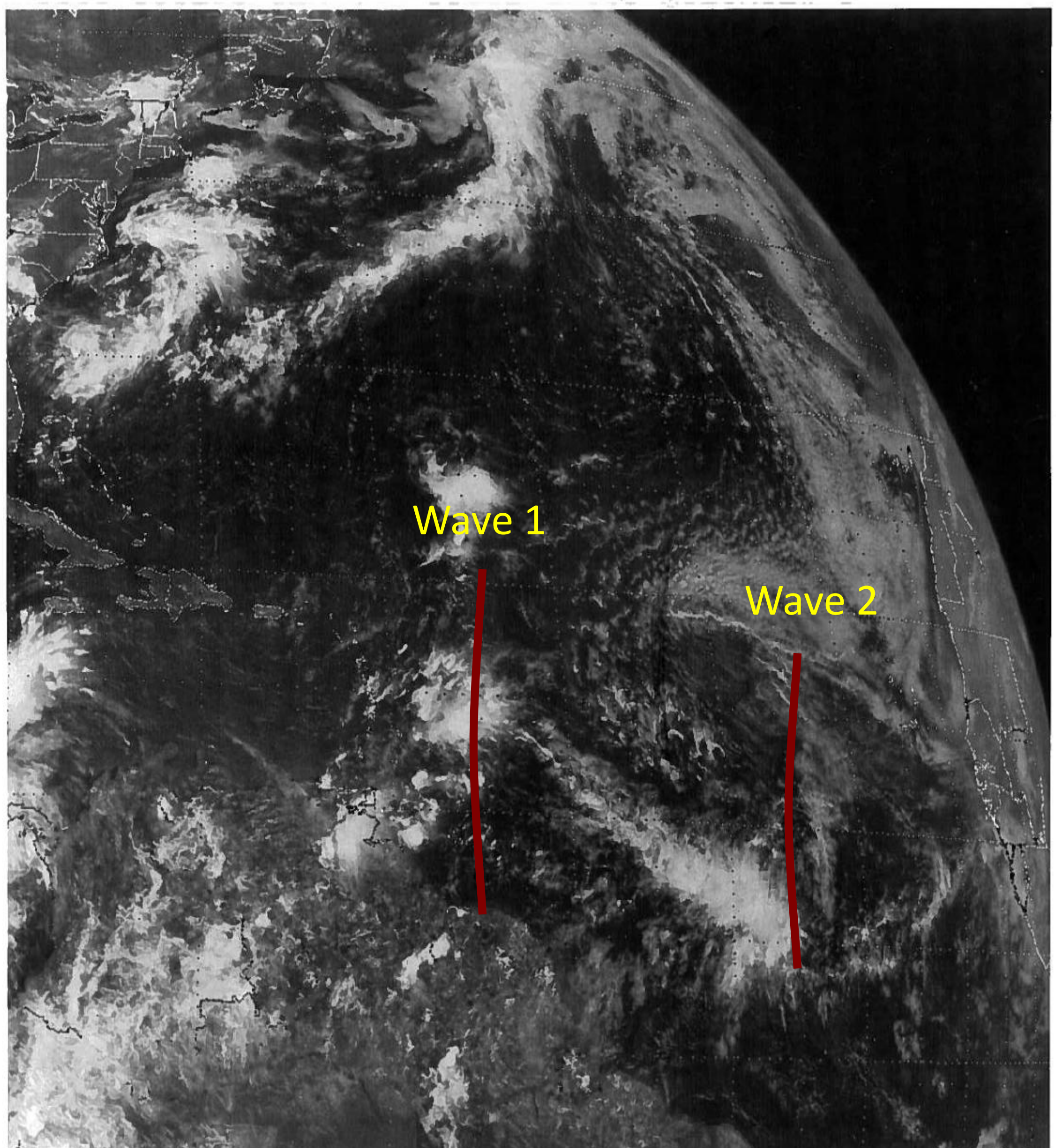
July 16



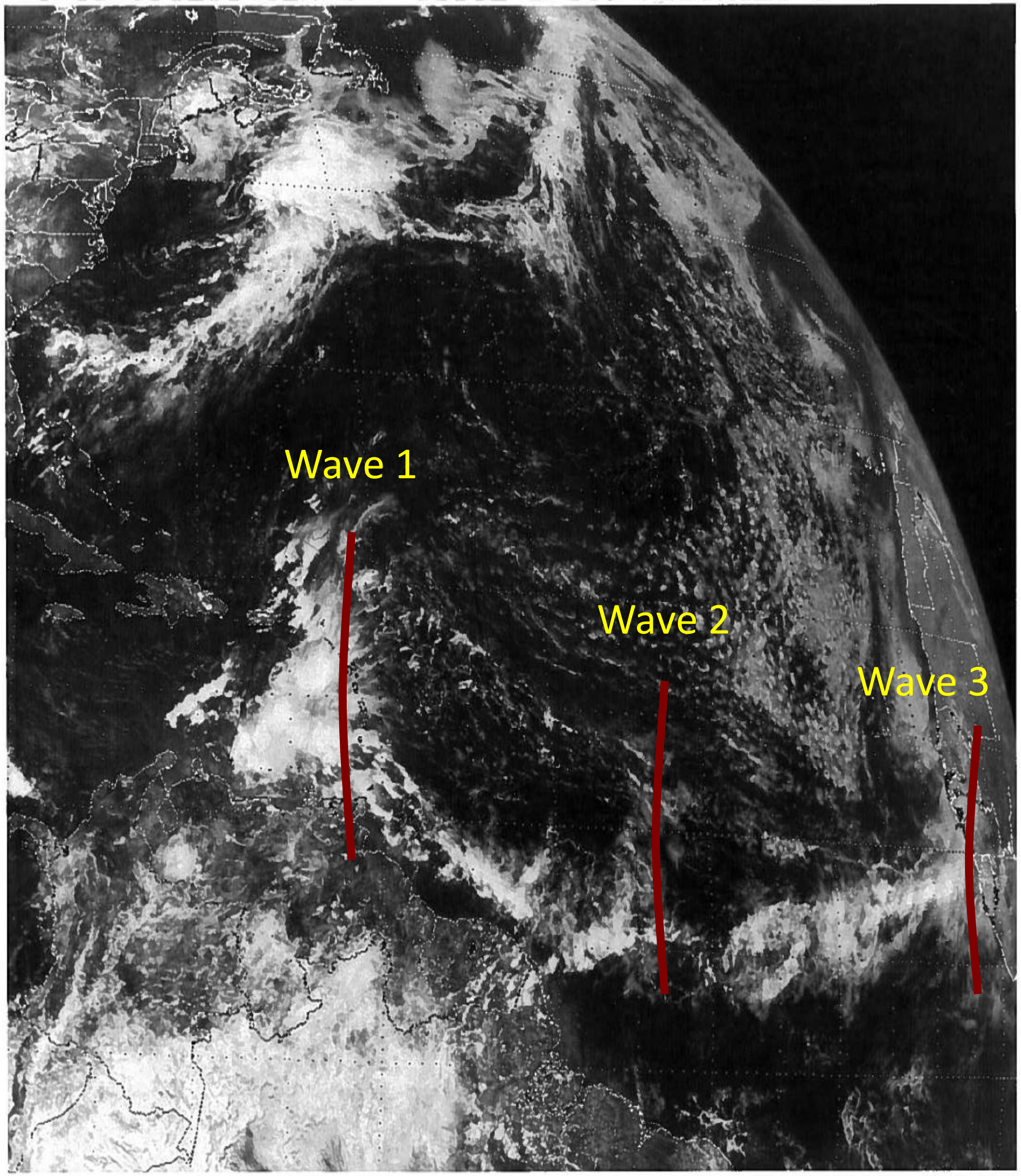
July 17



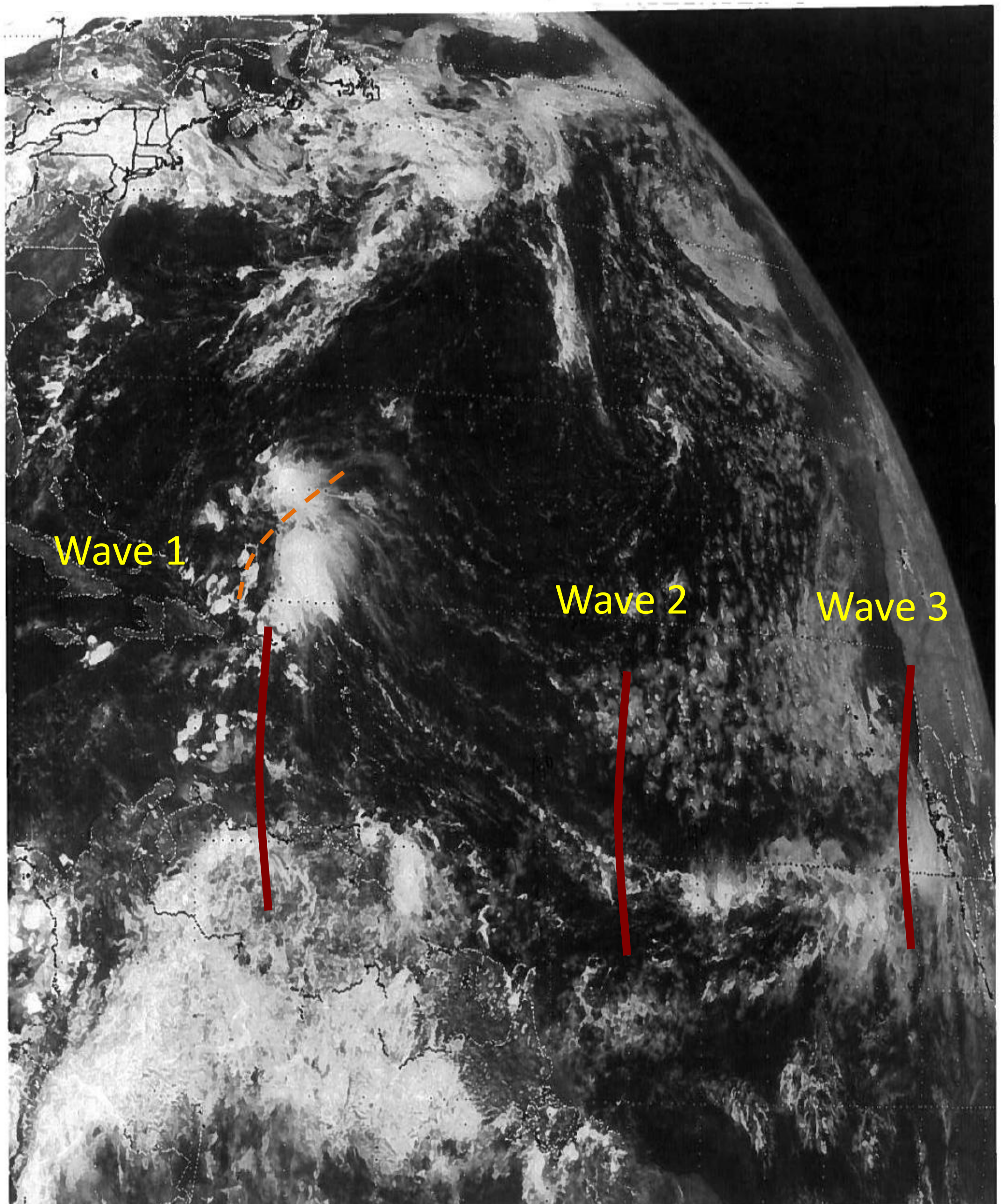
July 18



July 19



July 20



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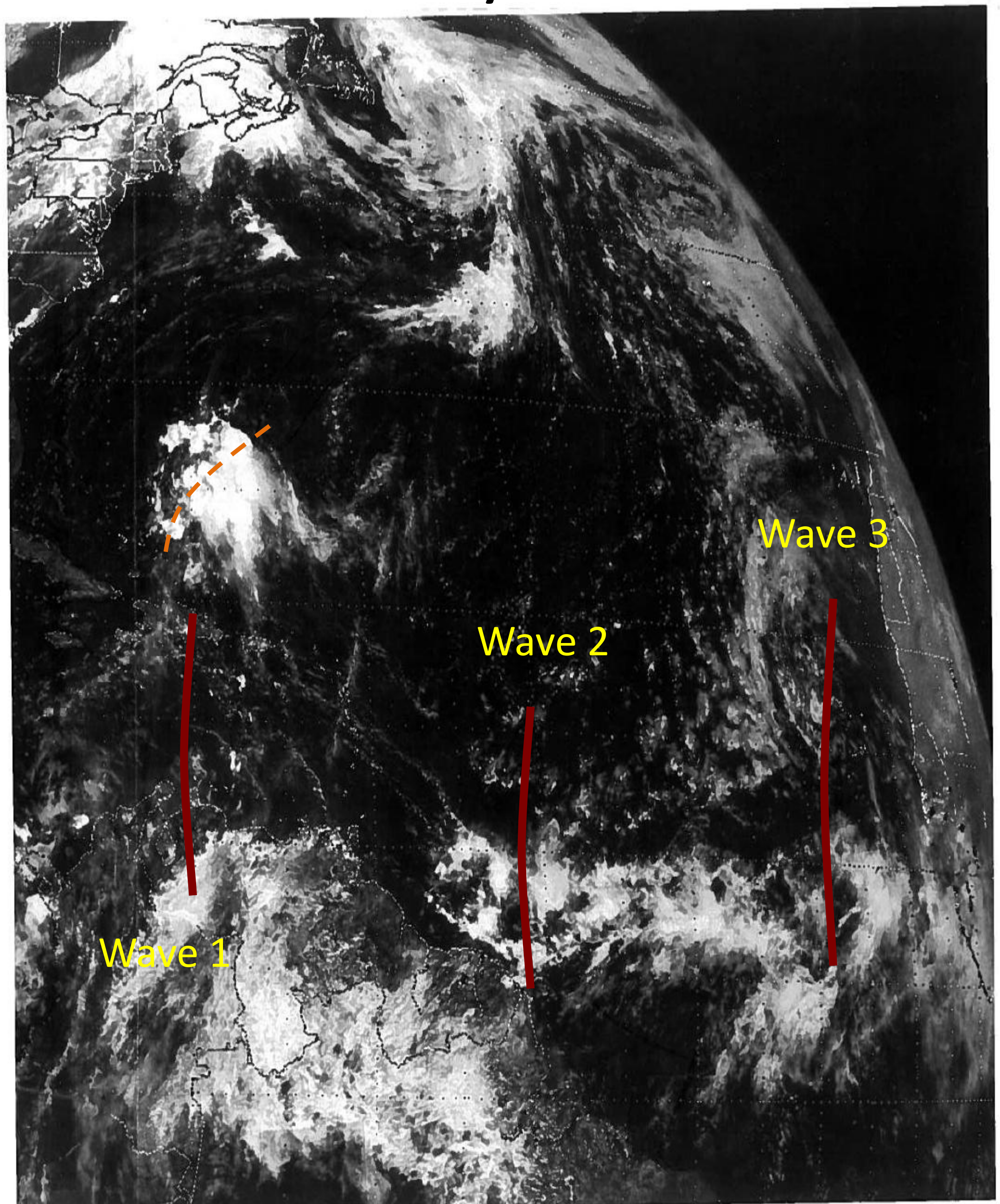
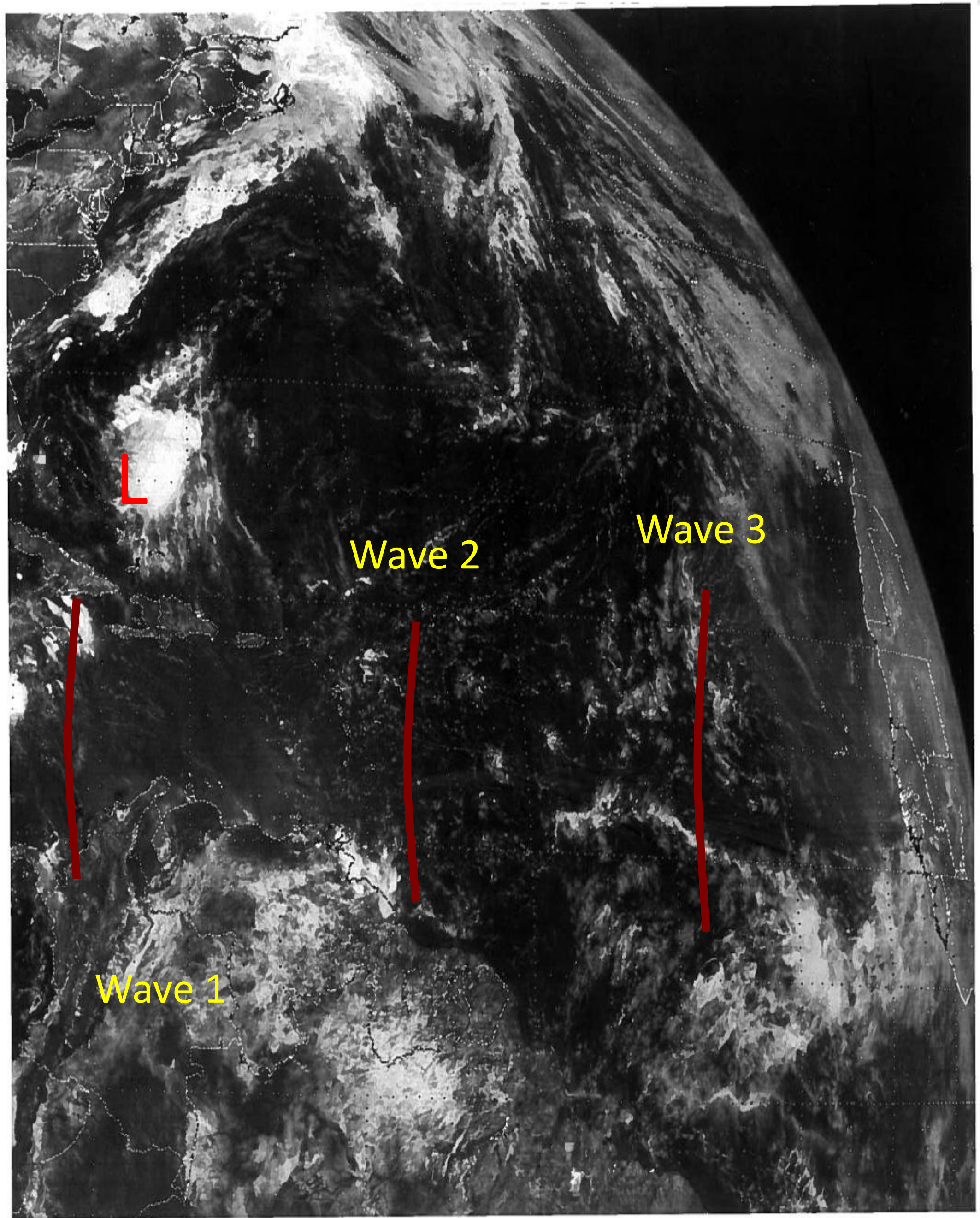


July 22



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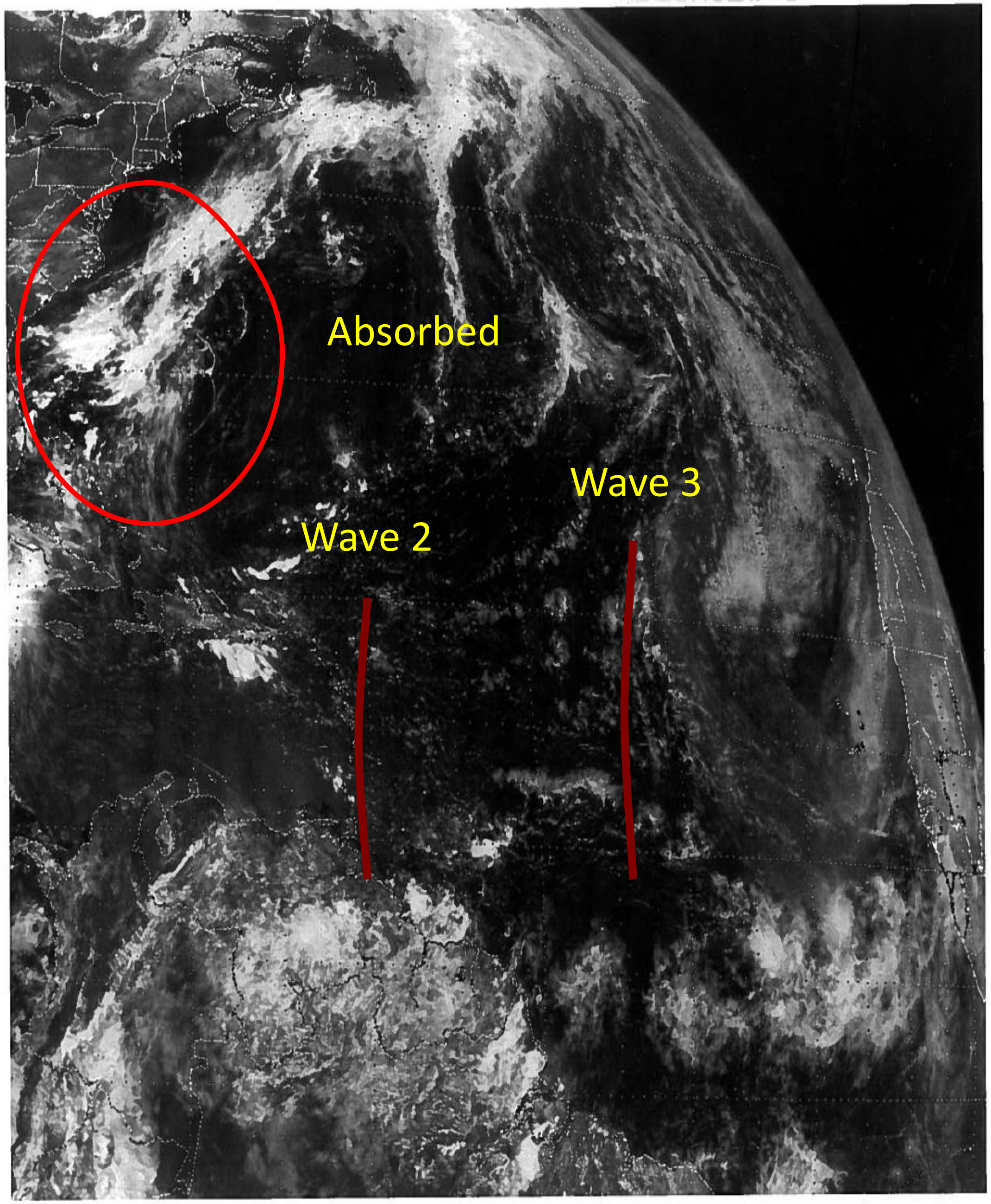

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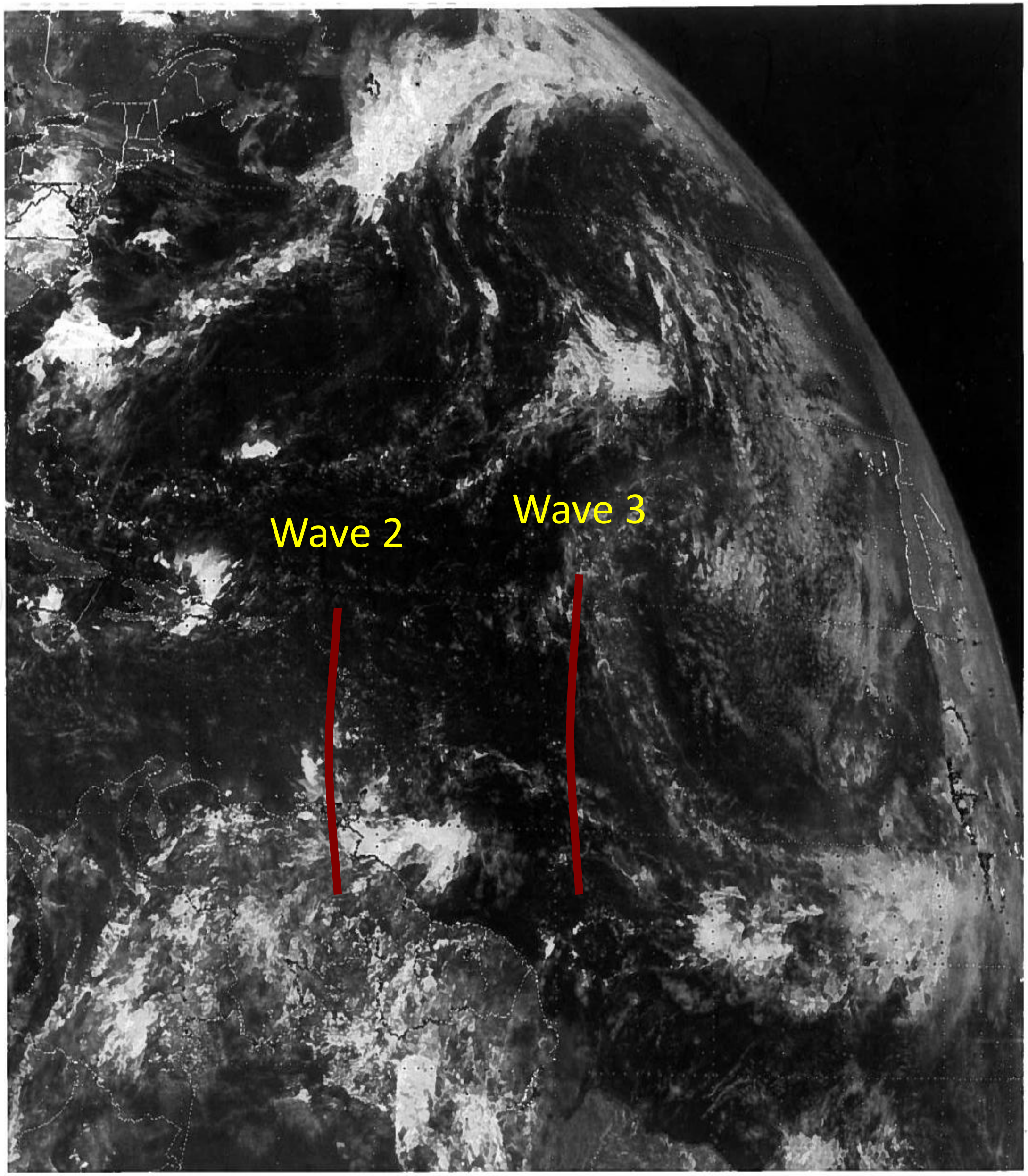
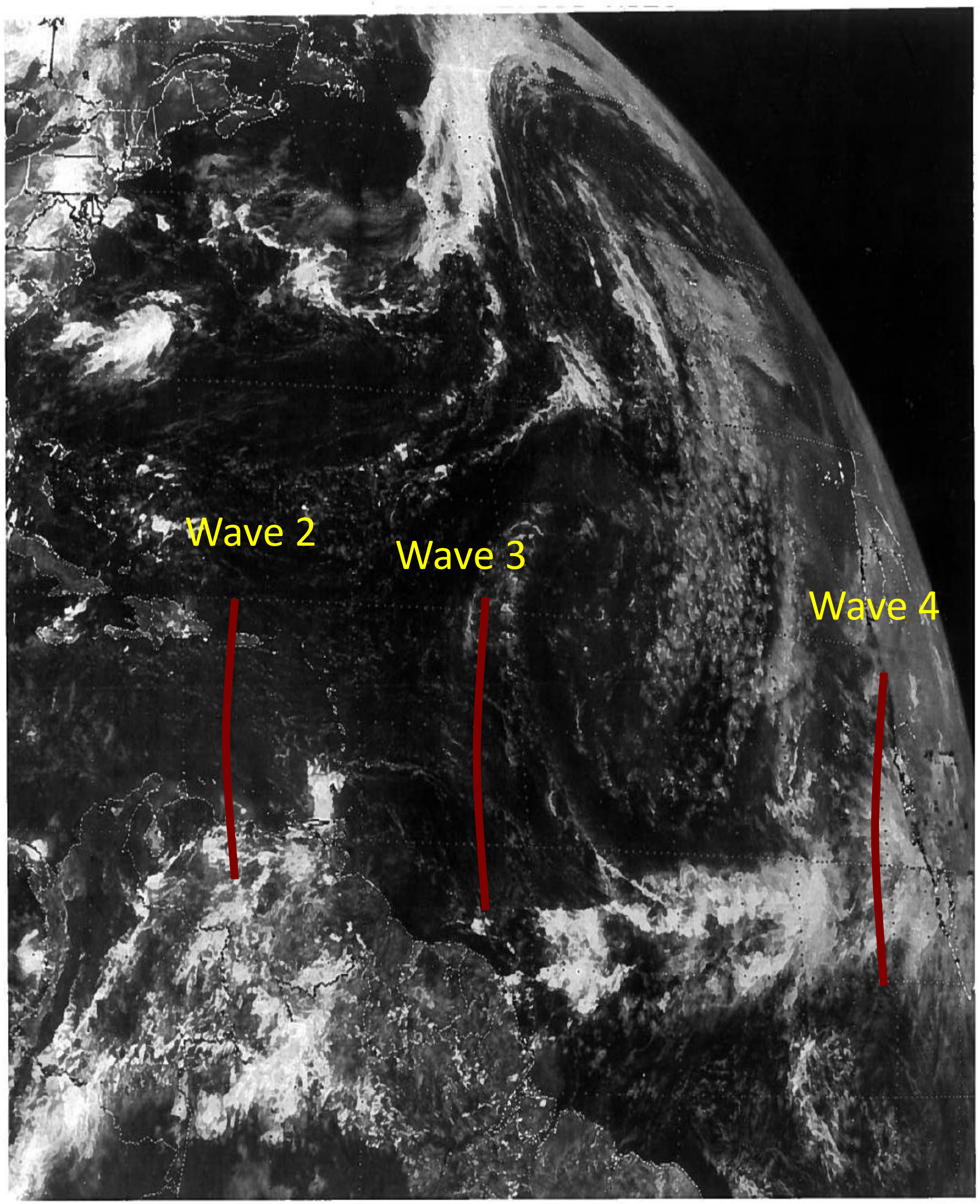
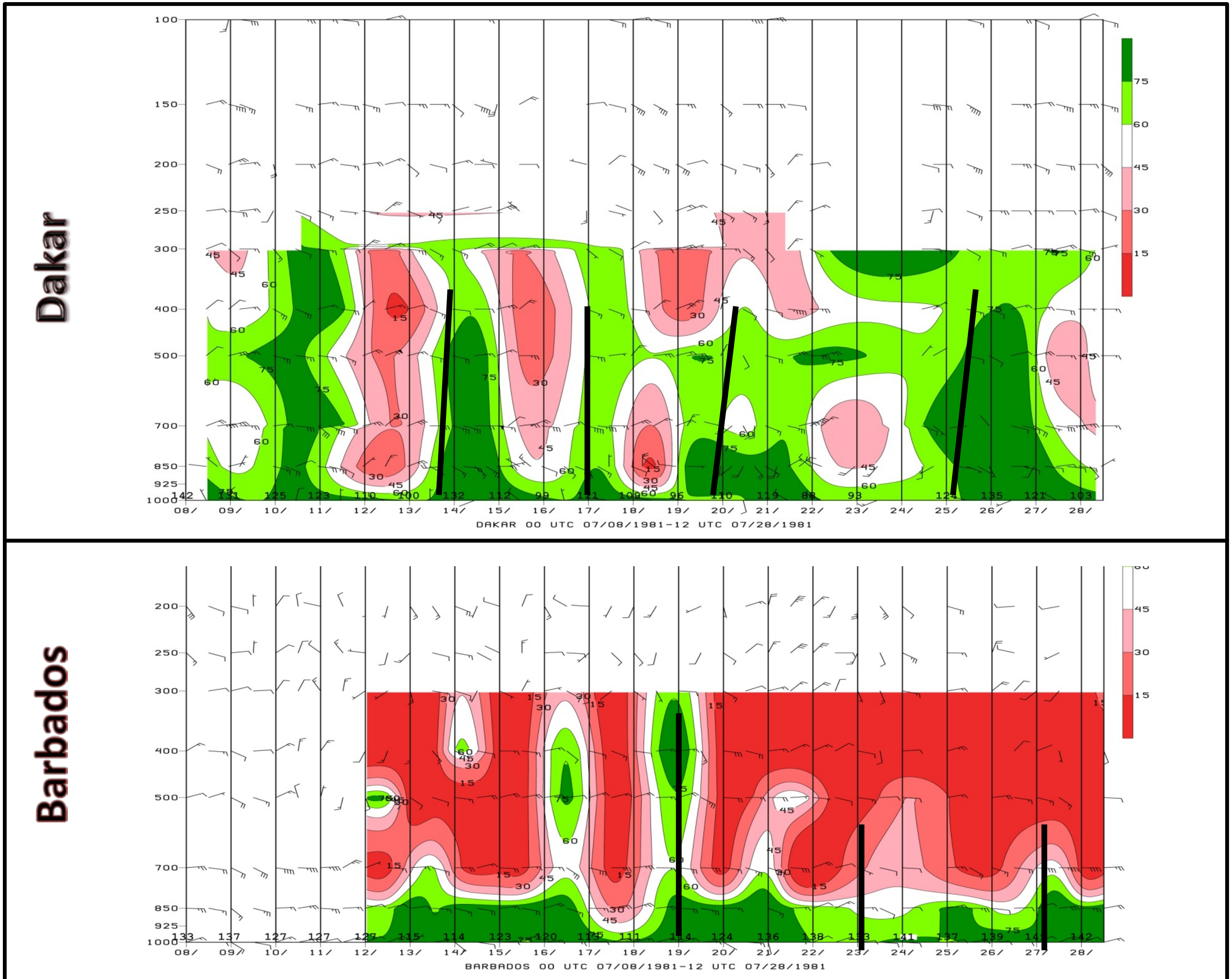
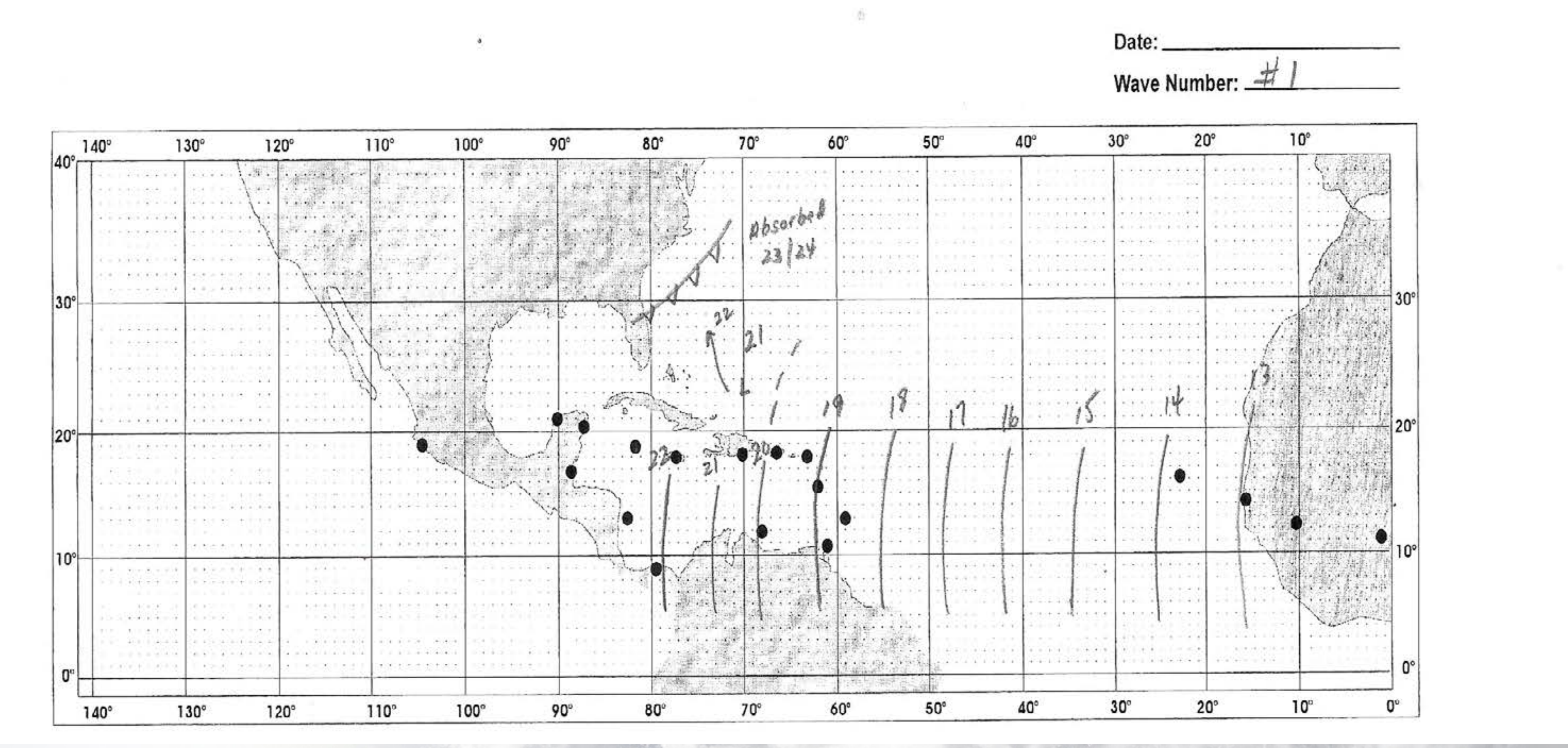


July 25

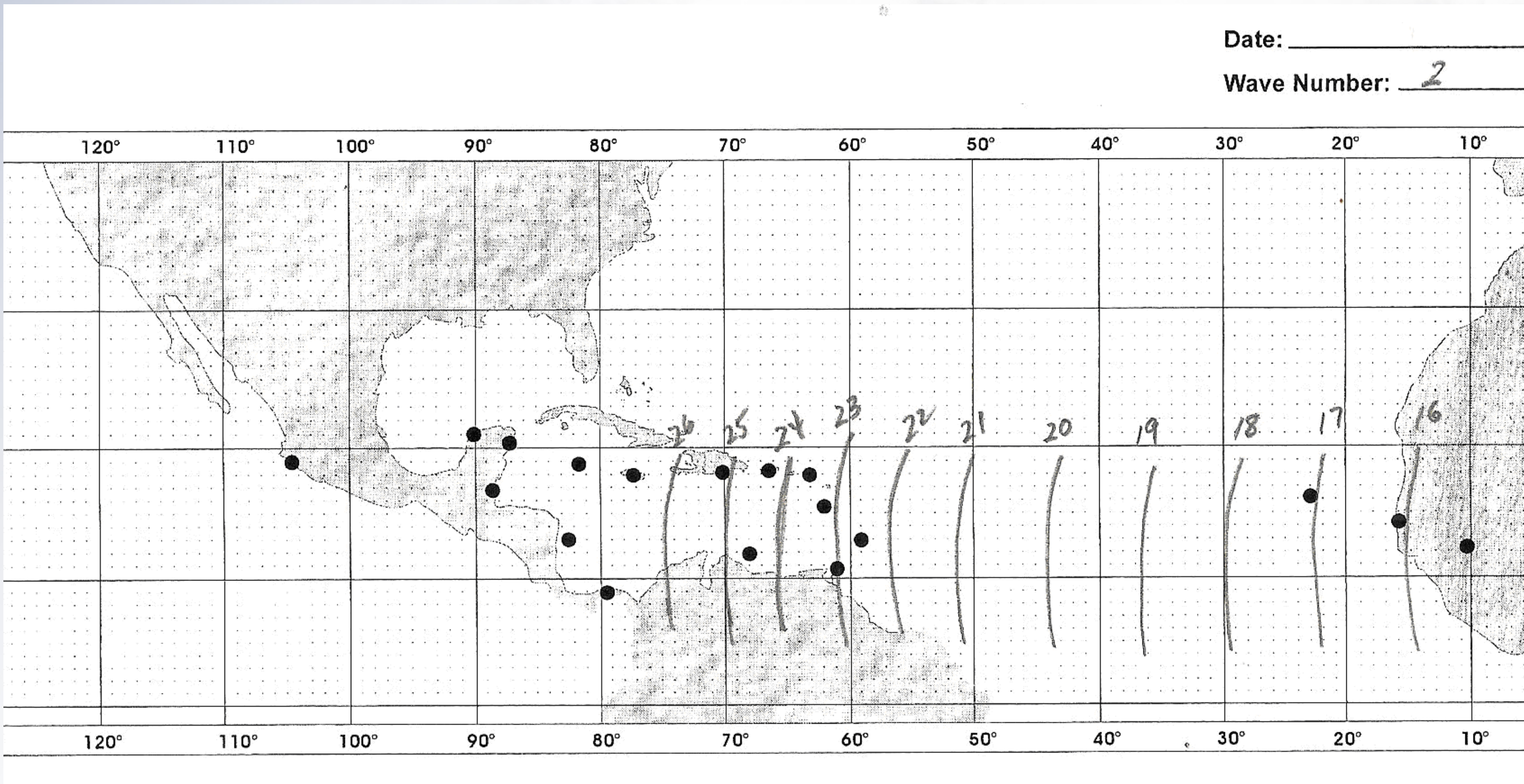



Dakar
DAKAR 00 UTC 07/08/1981-12 UTC 07/28/1981
Barbados
BARBADOS 00 UTC 07/08/1981-12 UTC 07/28/1981

Tropical Wave 1



Tropical Wave 2



Tropical Wave 3