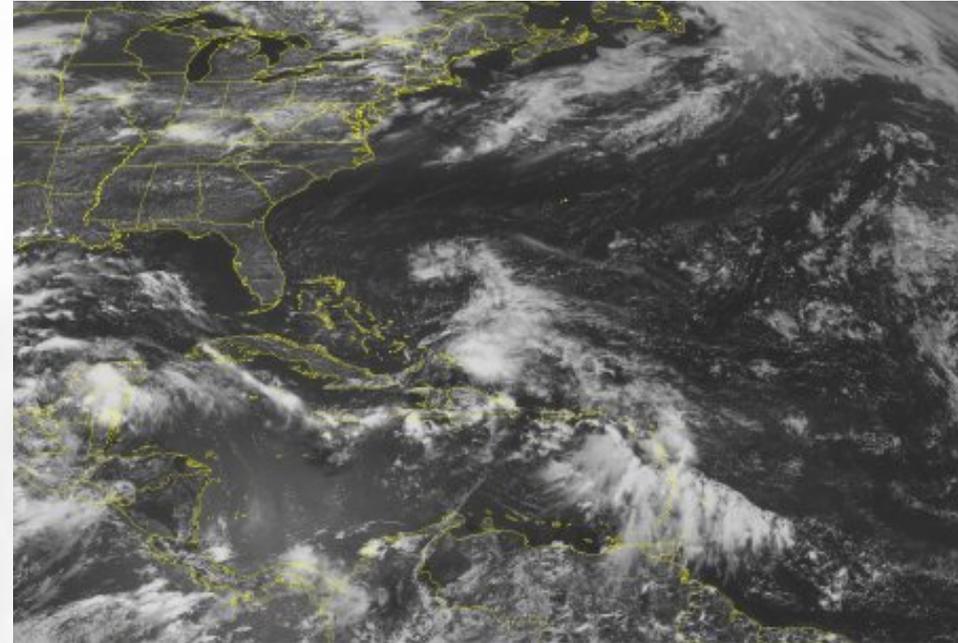
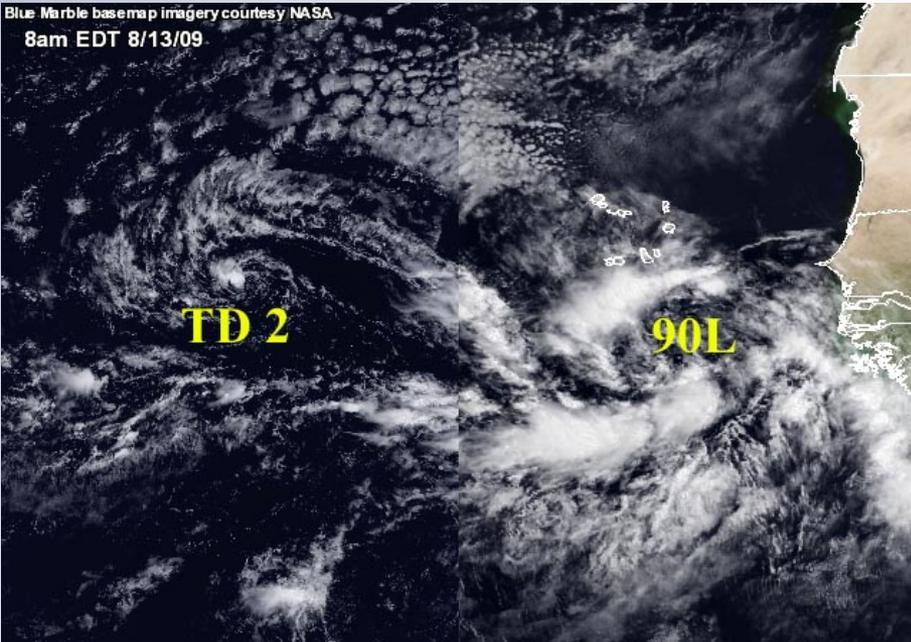




Tropical Waves



John Cangialosi and Andrew Levine
National Hurricane Center

WMO Region IV
Tropical Cyclone Workshop



Outline

- Basic definition/research
- Schematic diagrams/Interactions
- Operational products/forecasts
- Tools for tracking
- Exercise



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))

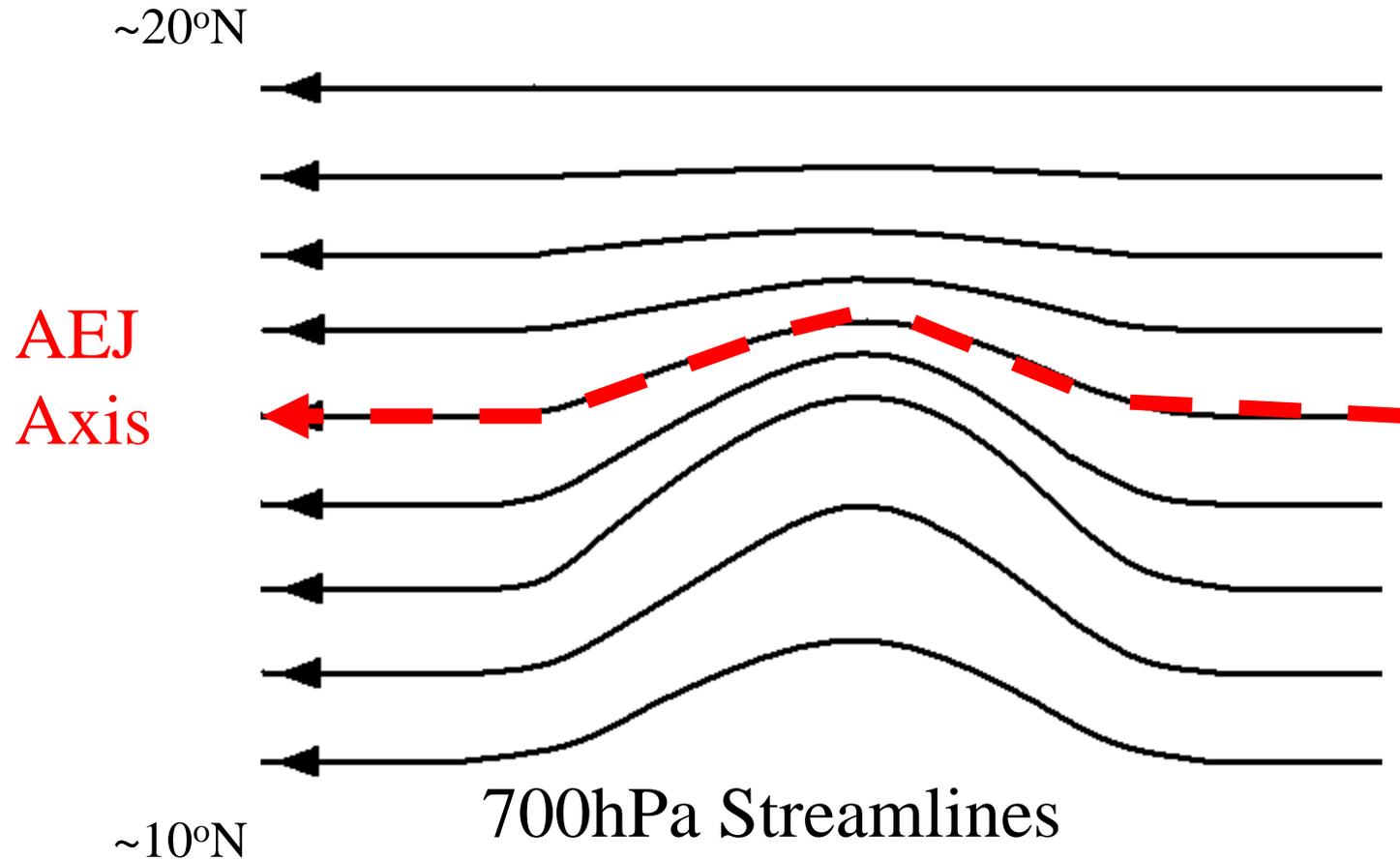
The composite from Reed (1977) still serves as the primary 'text book' description of AEWs.

How/where they form

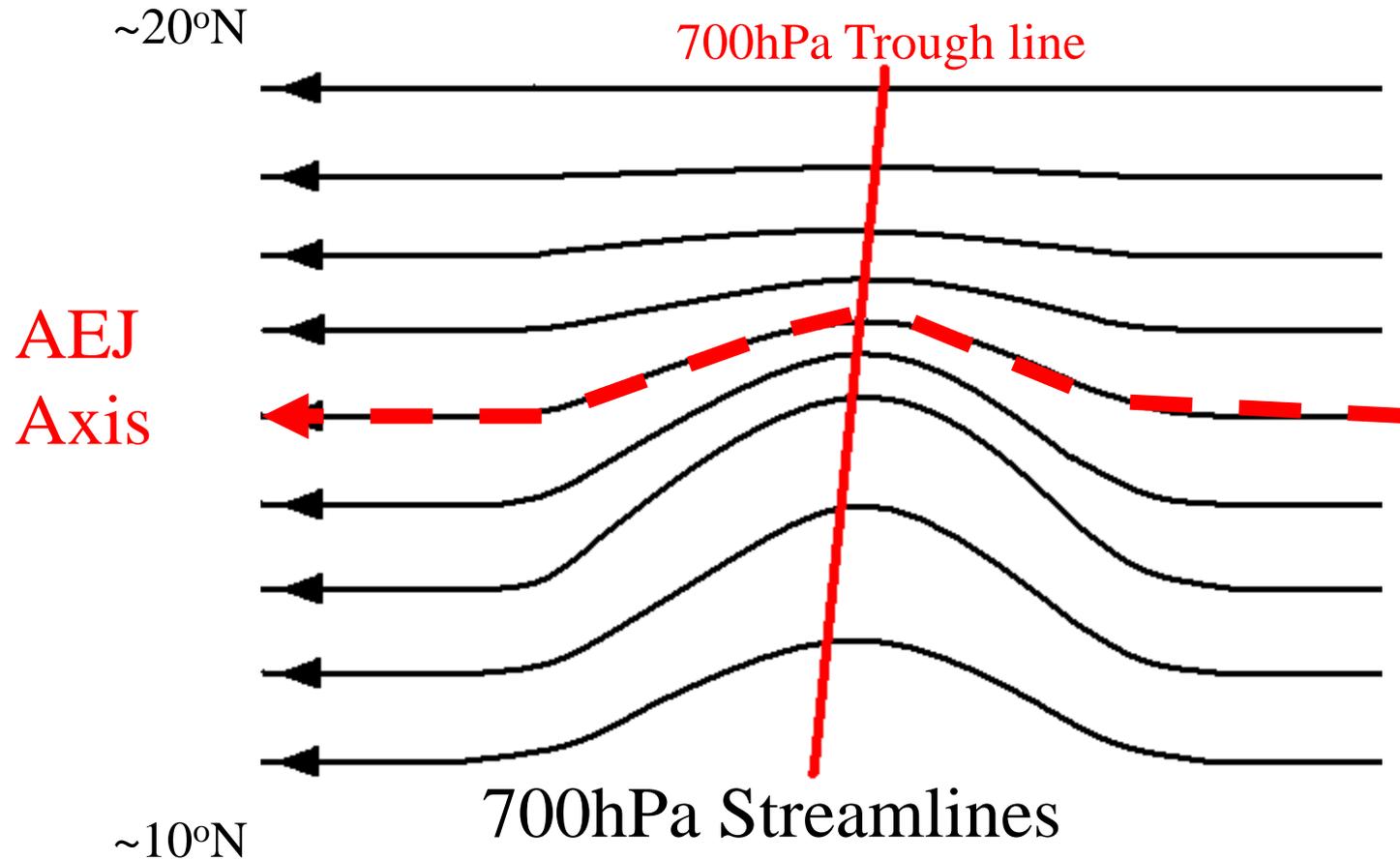
- Generated by an instability (baroclinic-barotropic) of the African easterly jet
- Jet arises as a result of reversed lower tropospheric temperature gradient over west-central north Africa due to extremely warm temperatures over the Sahara Desert and substantially cooler temperatures along the coast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



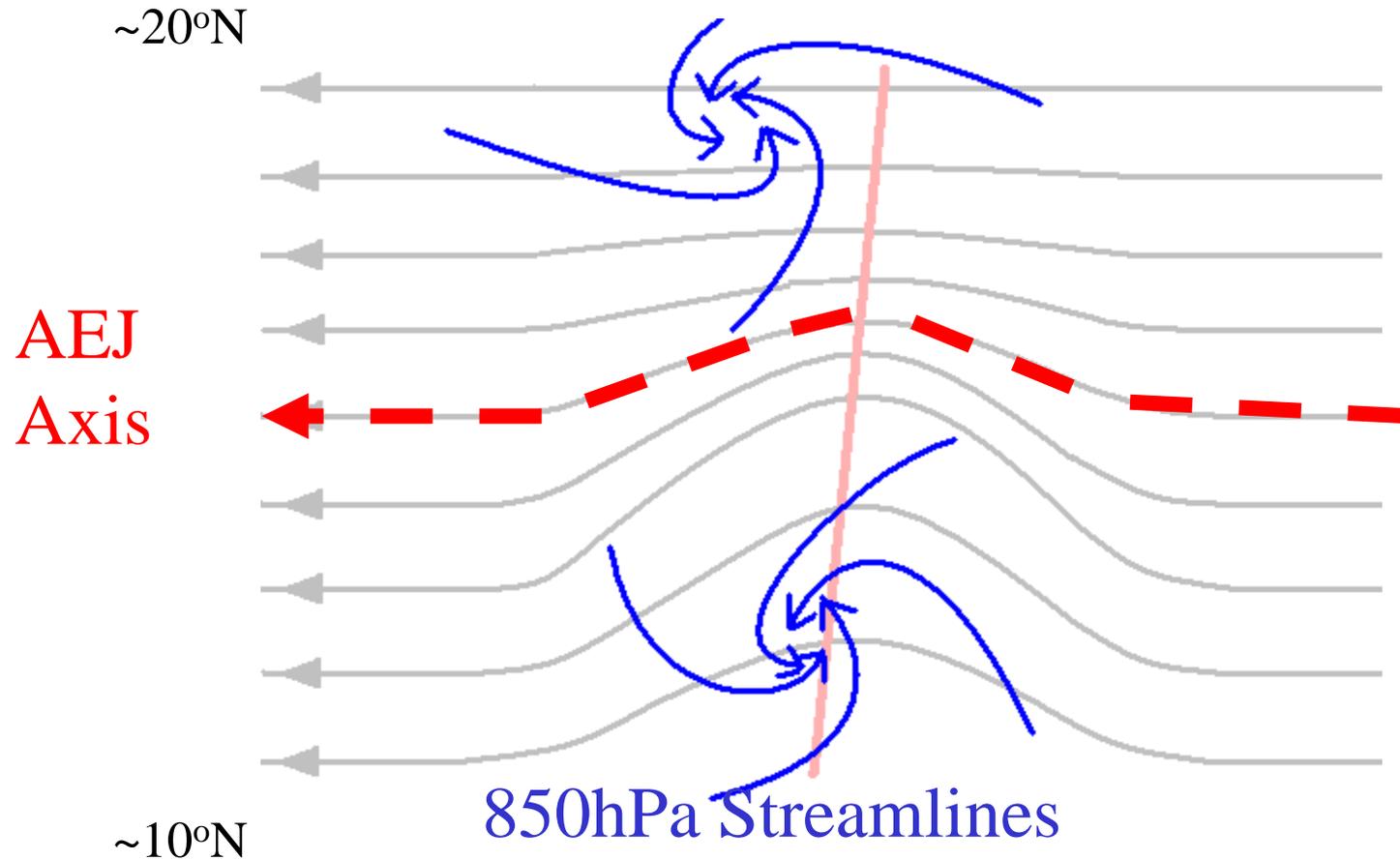
AEW synoptic structure over West Africa.



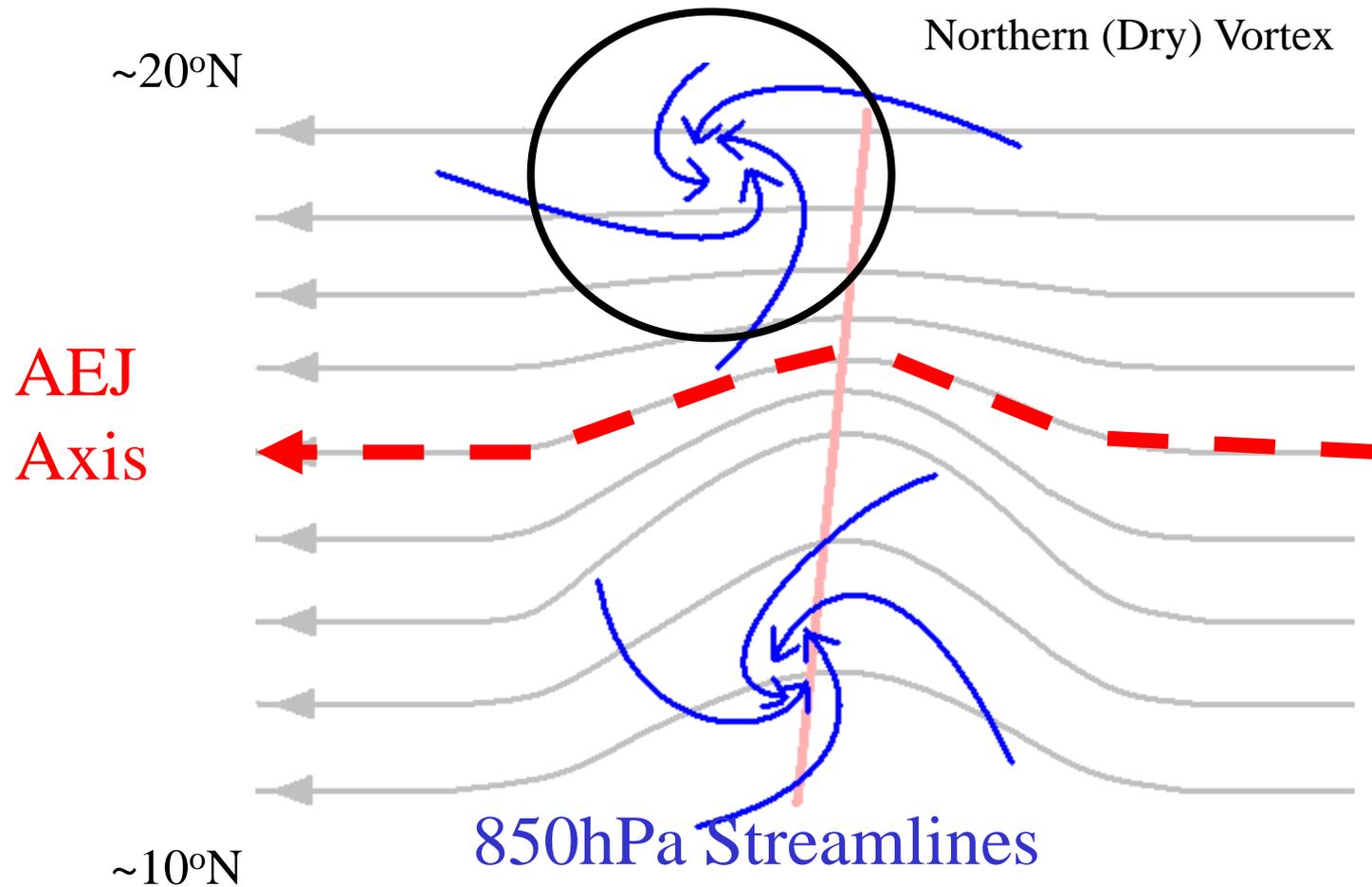
AEW synoptic structure over West Africa.



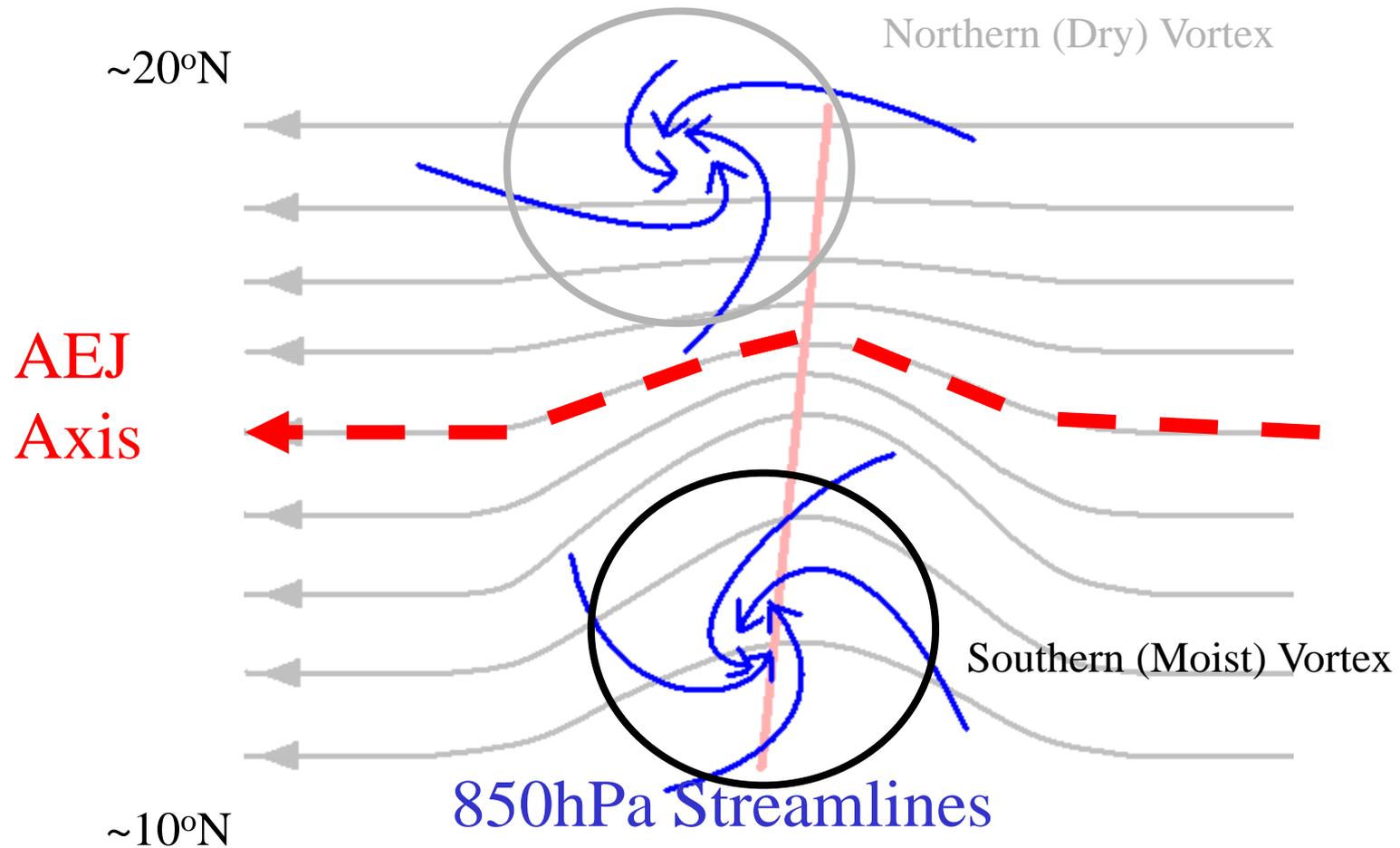
AEW synoptic structure over West Africa.



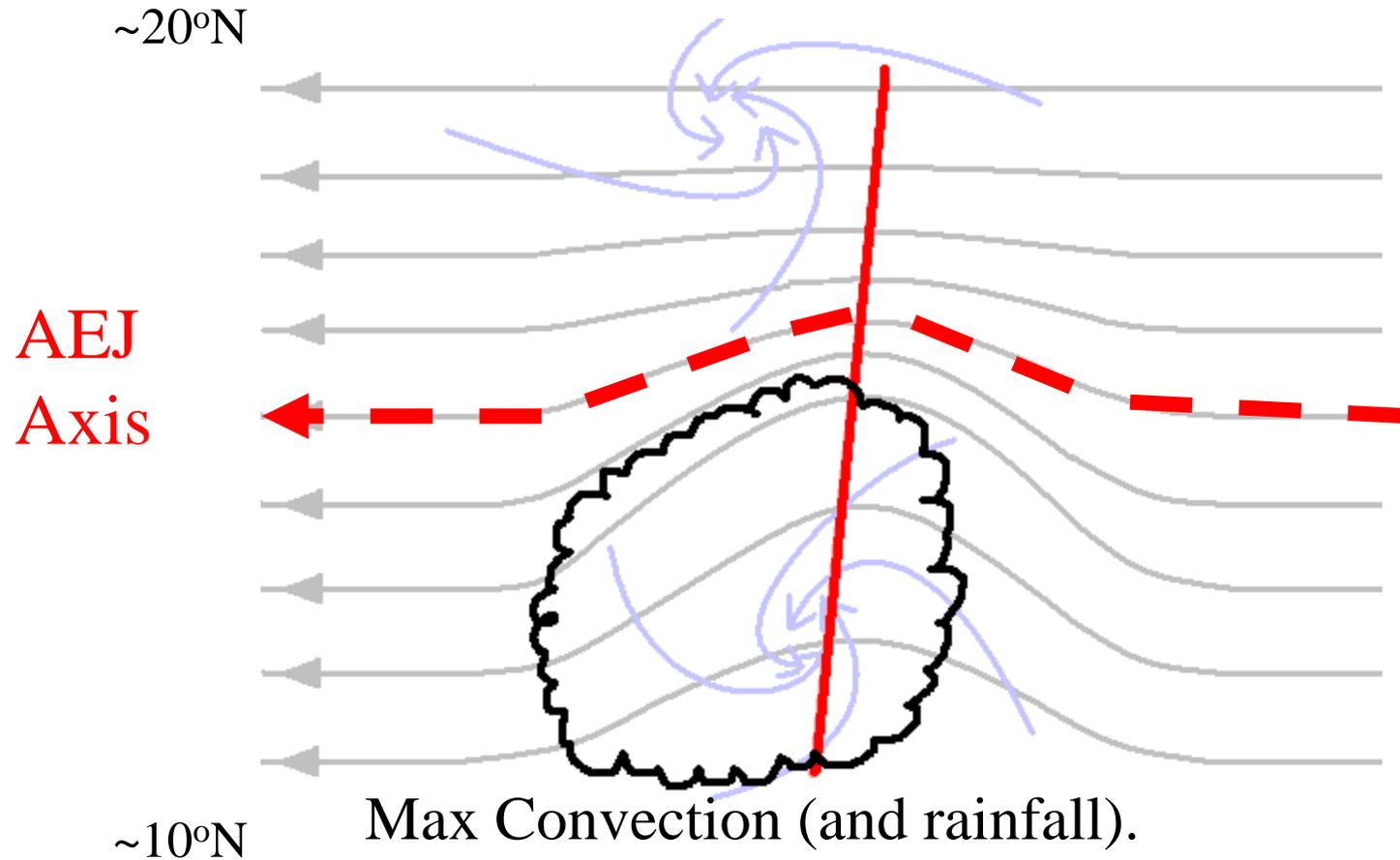
AEW synoptic structure over West Africa.



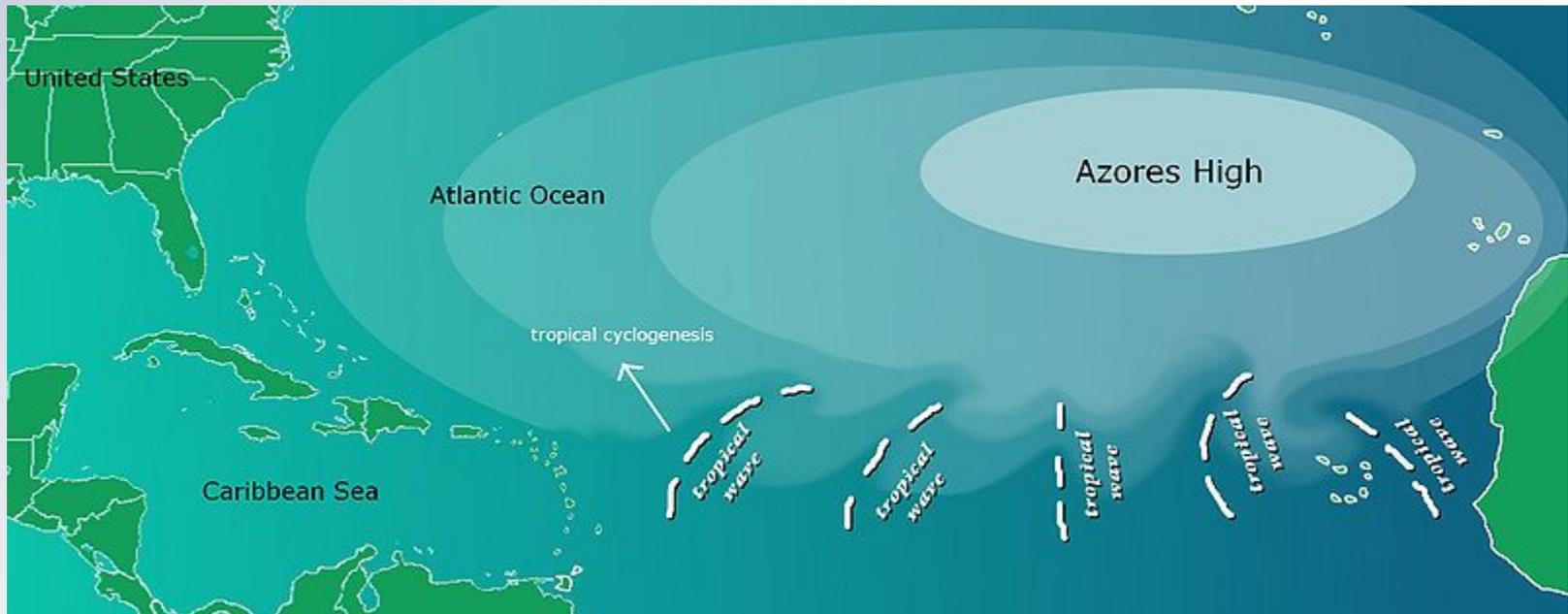
AEW synoptic structure over West Africa.



AEW synoptic structure over West Africa.



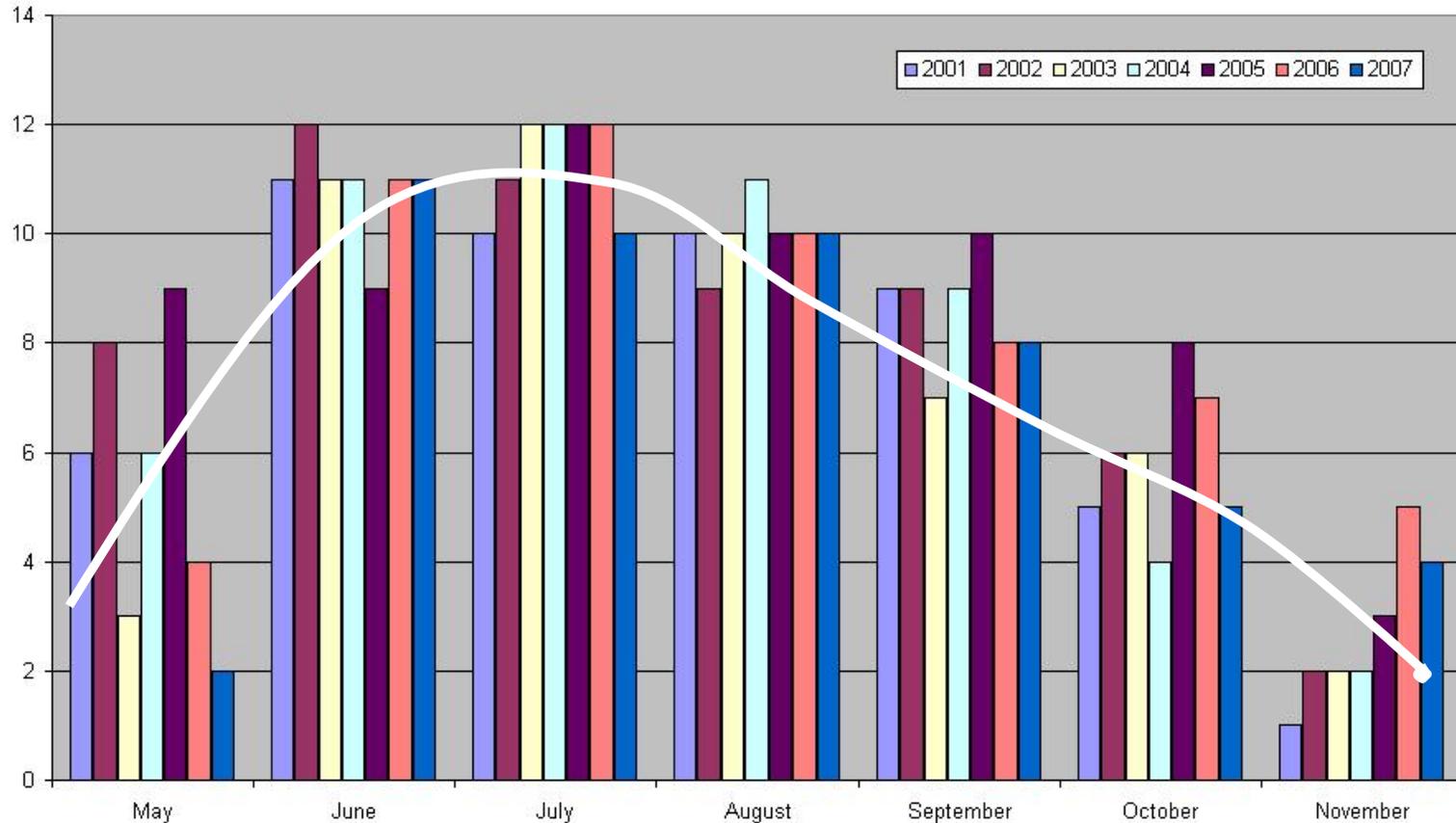
Typical Synoptic Setup



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

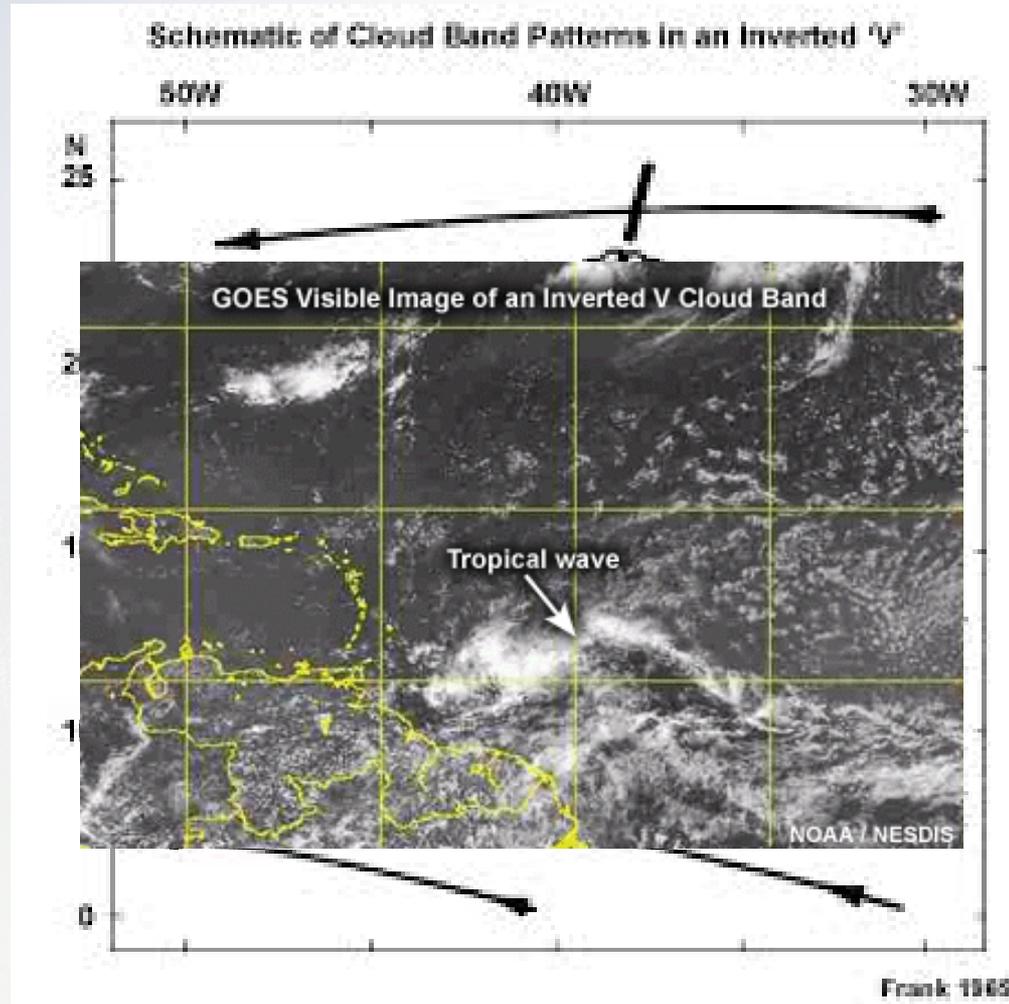
Frequency by month

Tropical Waves tracked by NHC



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

Schematic diagrams

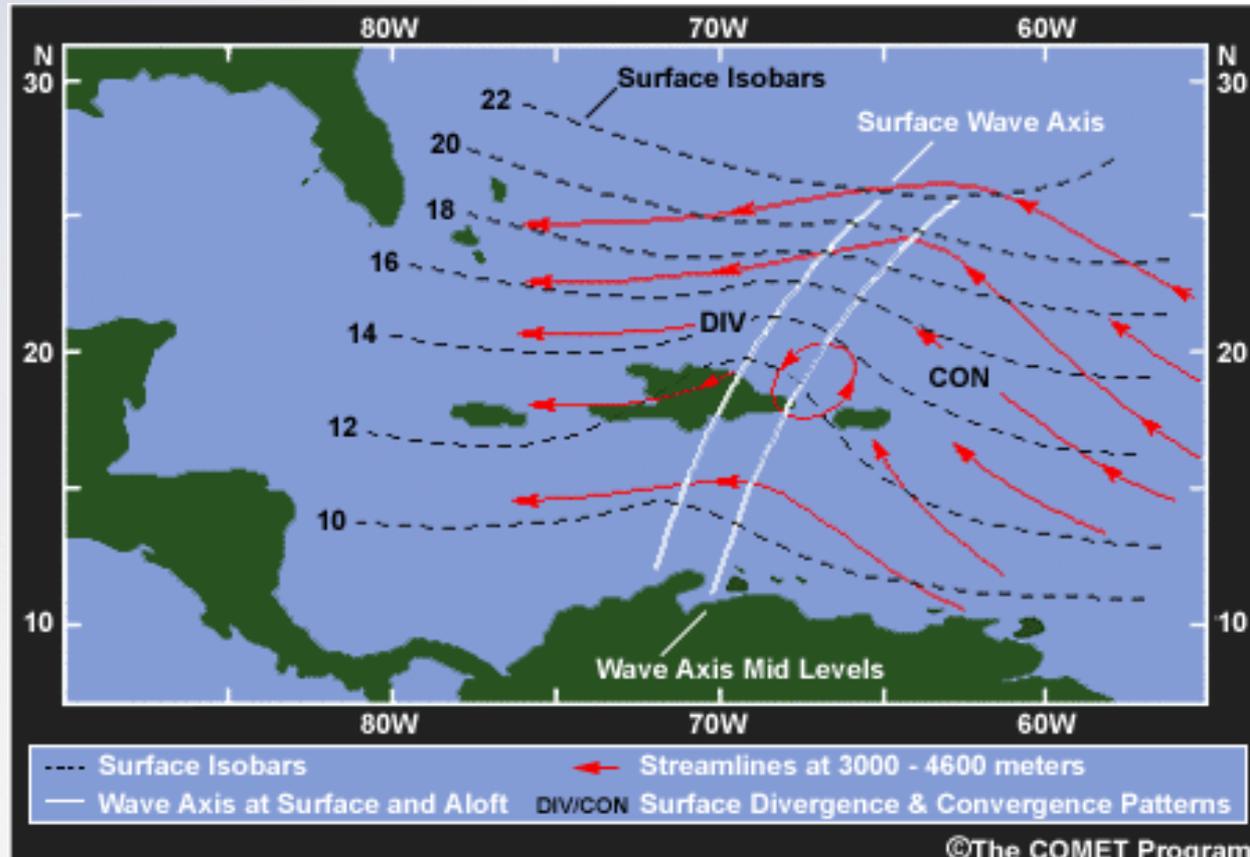


Classic inverted V-shape near the eastern Caribbean

At what pressure level is the maximum amplitude?

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

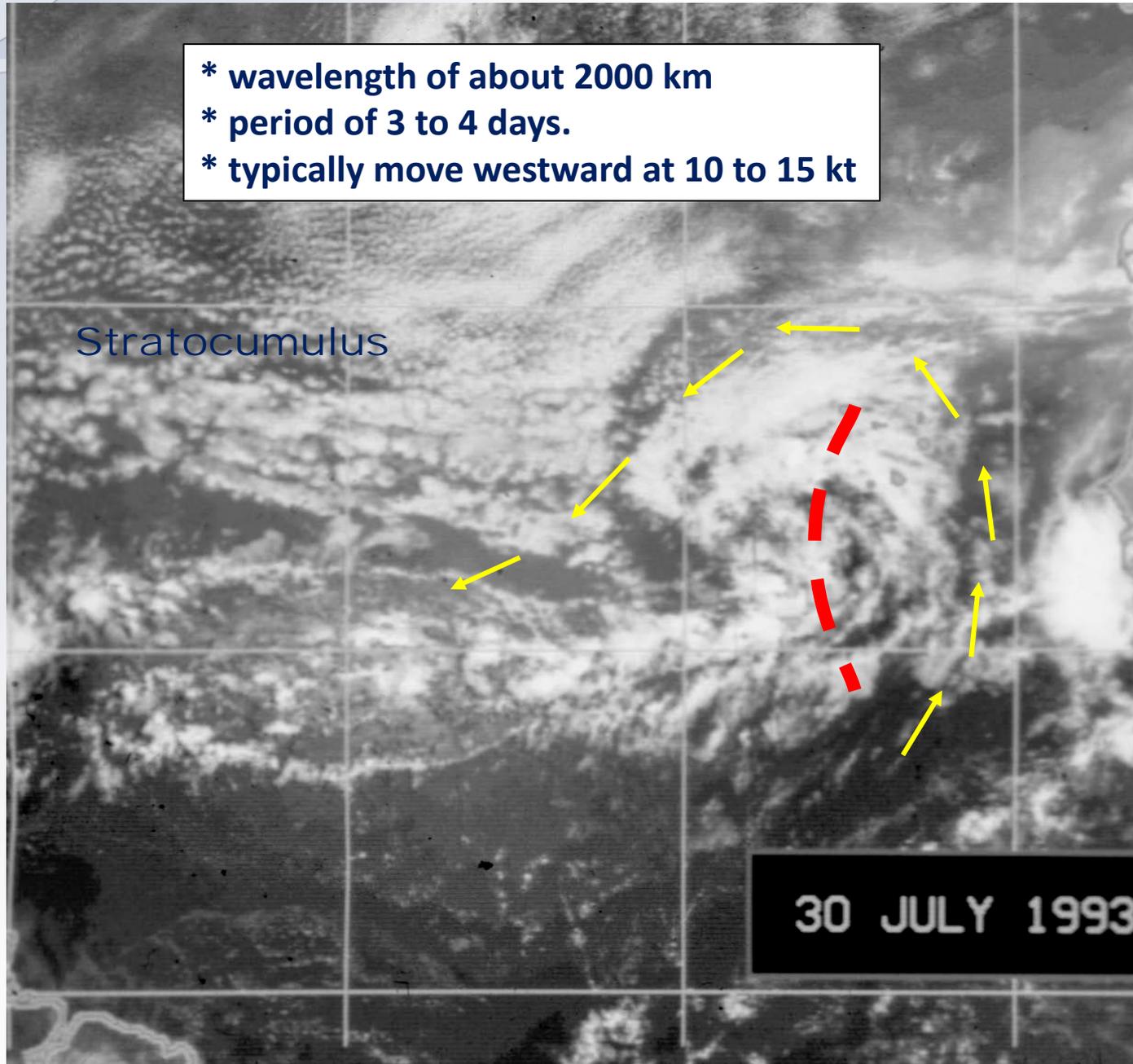
Schematic diagram



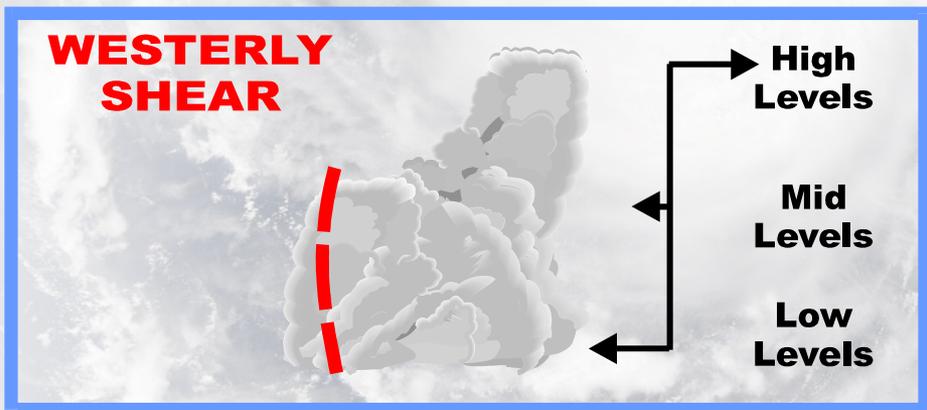
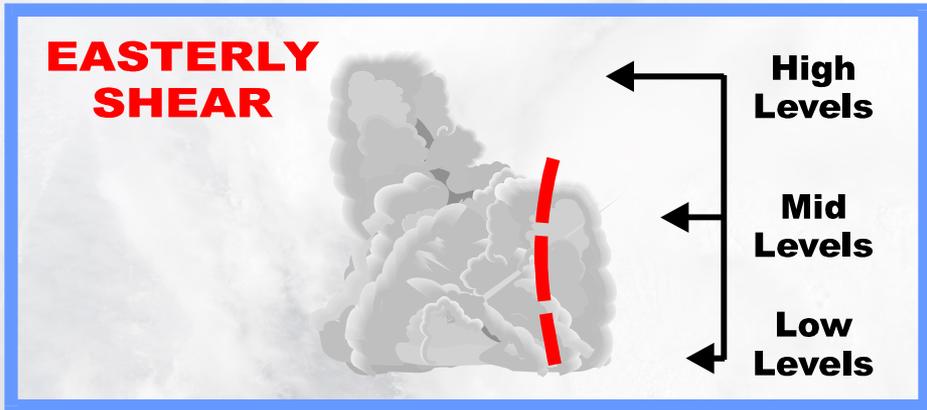
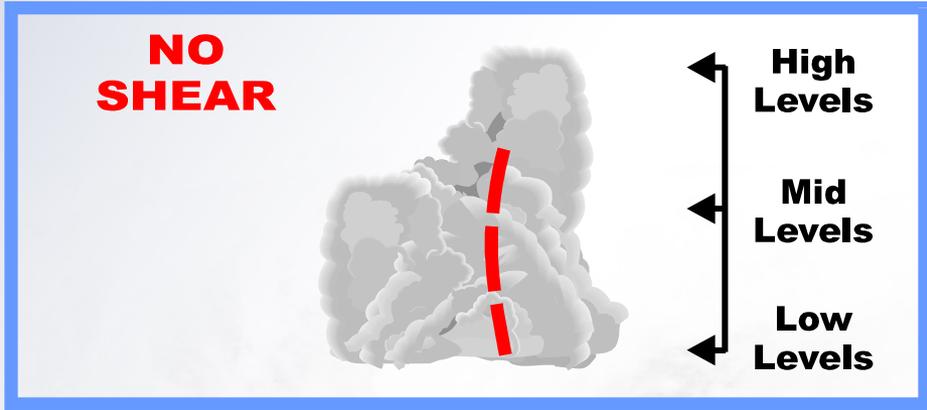
- Notice eastward slope will height
- Maximum amplitude is around 700 mb

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

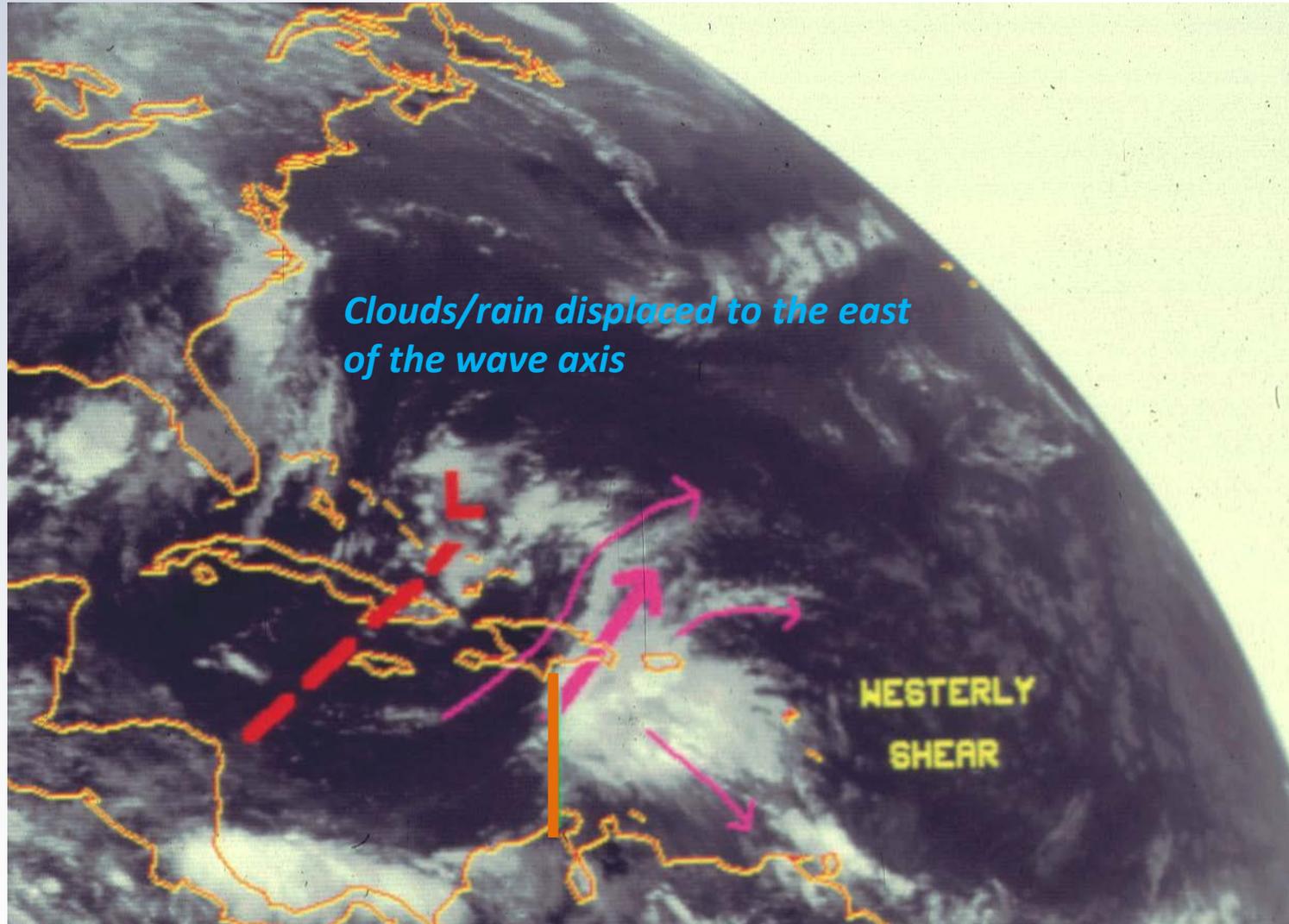
Stratocumulus



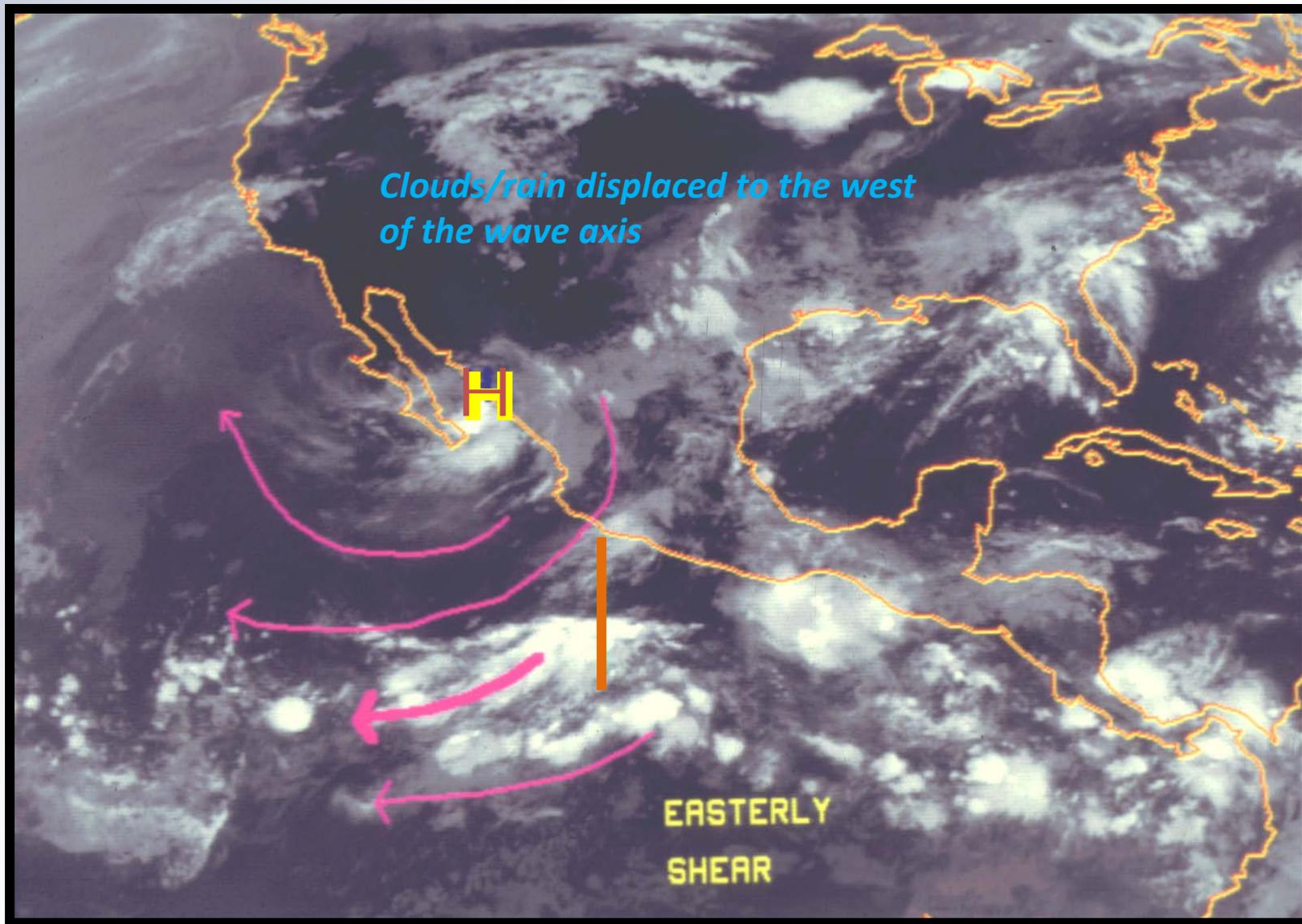
30 JULY 1993



Waves in Westerly Shear



Waves in Easterly Shear

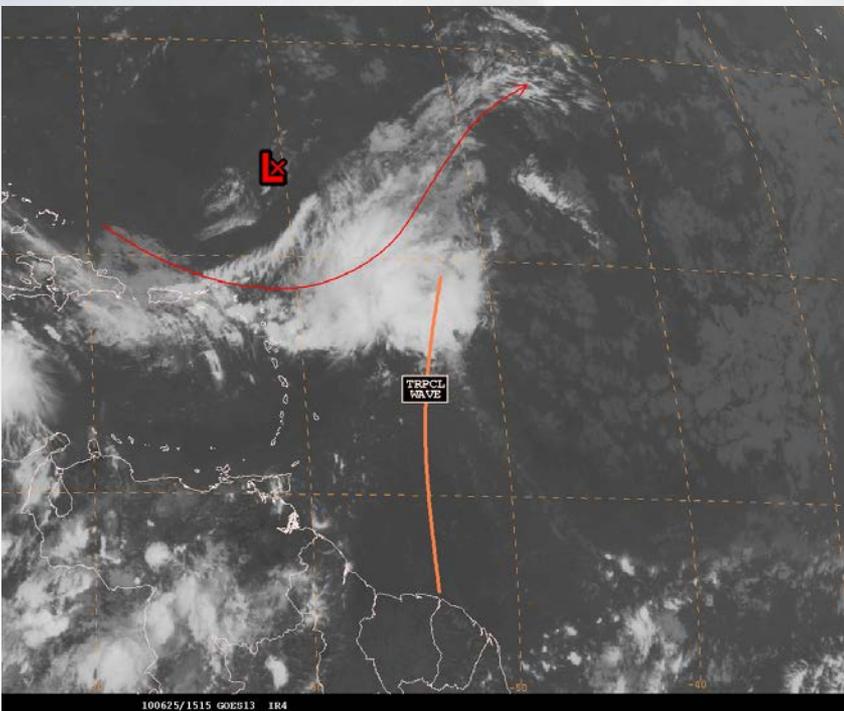
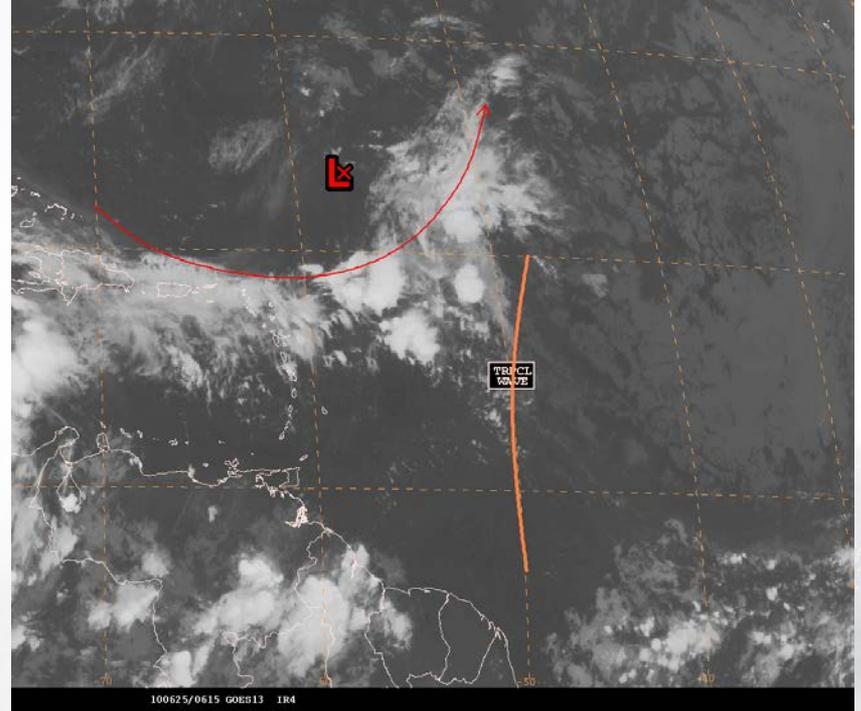
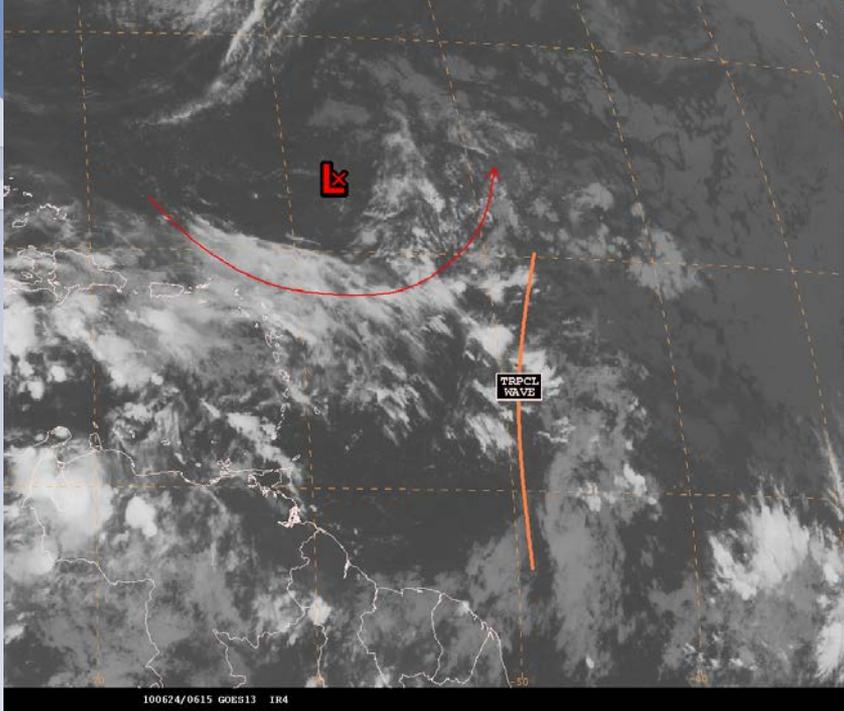


What happens when tropical waves interact with upper-level lows and troughs?

(a) Convection decreases

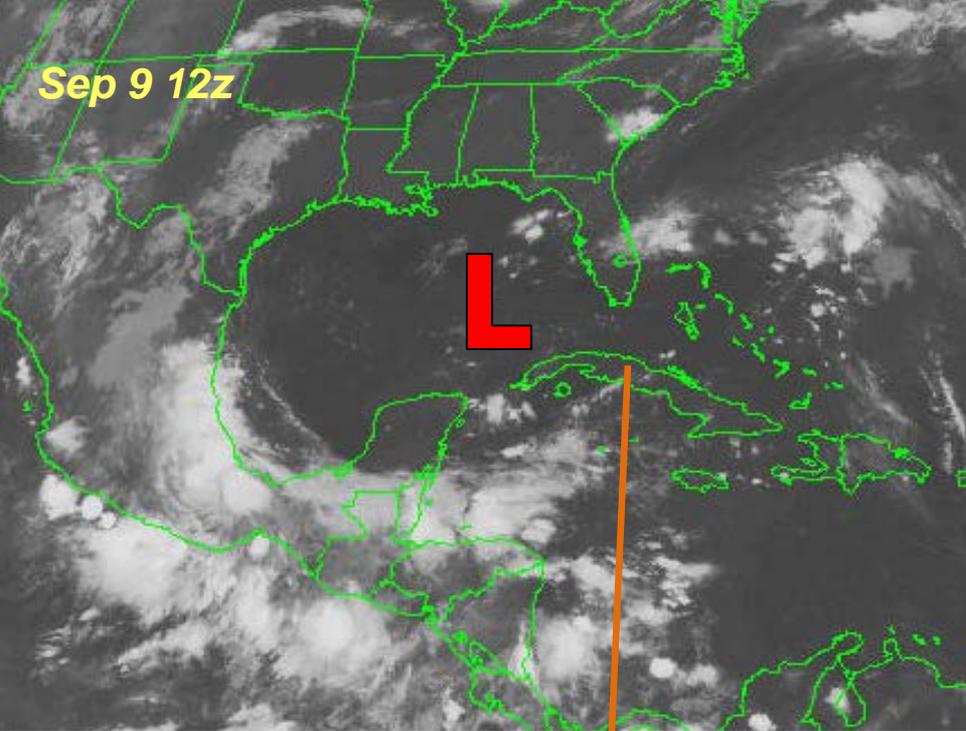
(b) Convection increases

(c) A tropical cyclone forms



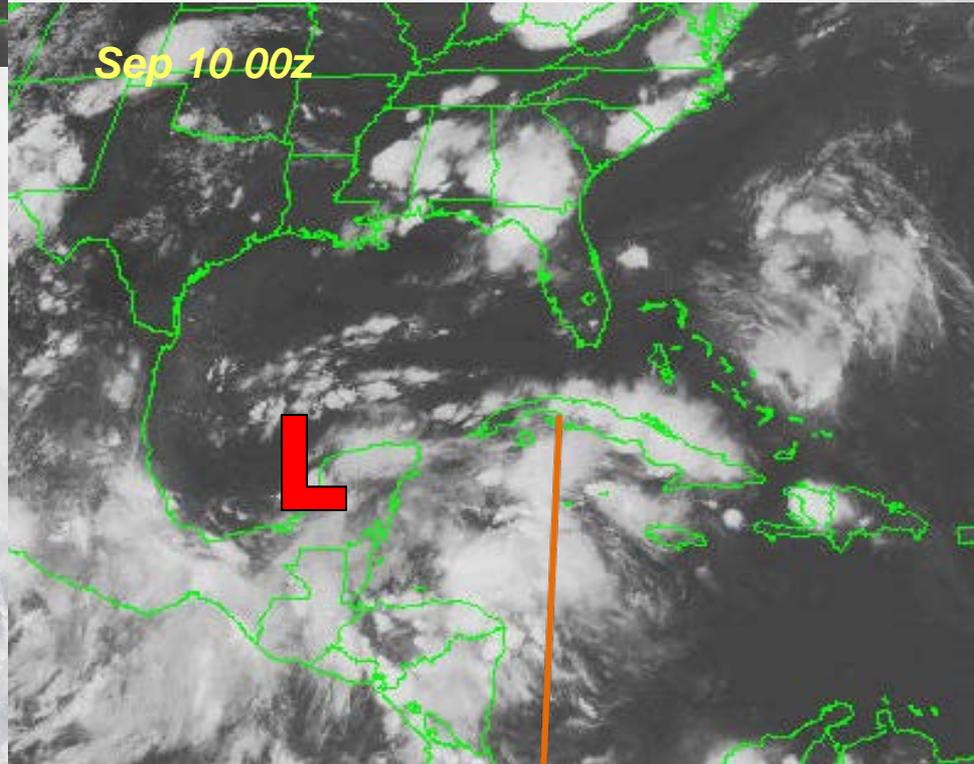
Although interaction with upper-level lows are unfavorable for tropical cyclogenesis, it can often induce heavy rainfall.

Sep 9 12z

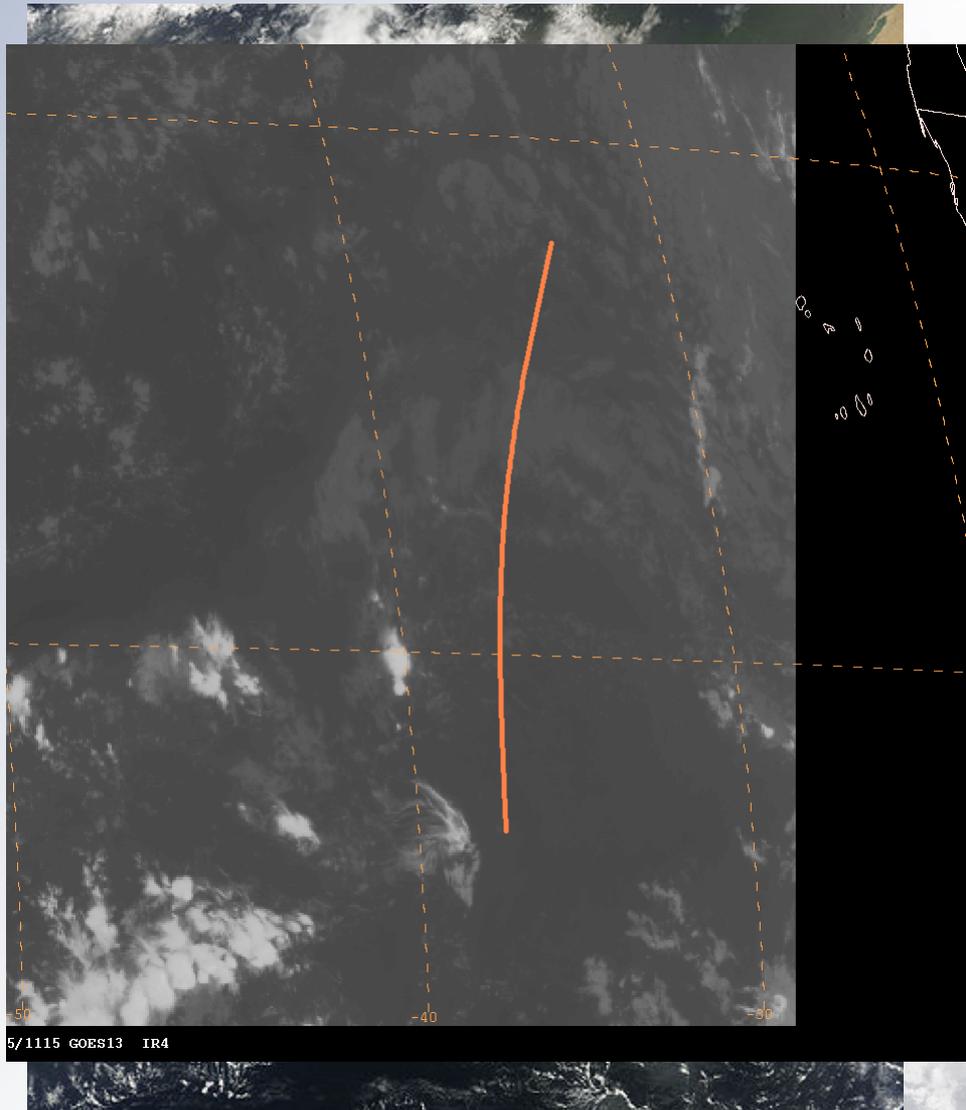


Sea-breeze convergence, upslope flows, and afternoon heating can cause convection to become chaotic and difficult to predict.

Sep 10 00z

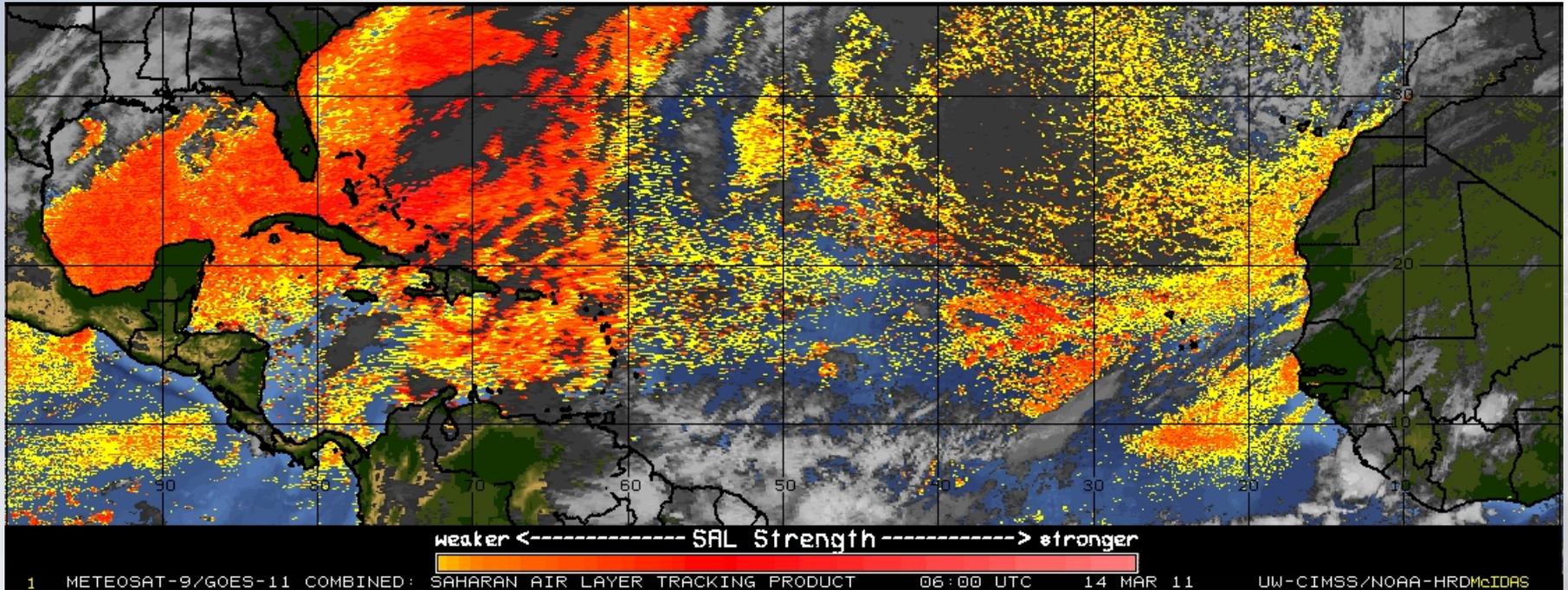


Saharan Air Layer



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

Saharan Air Layer

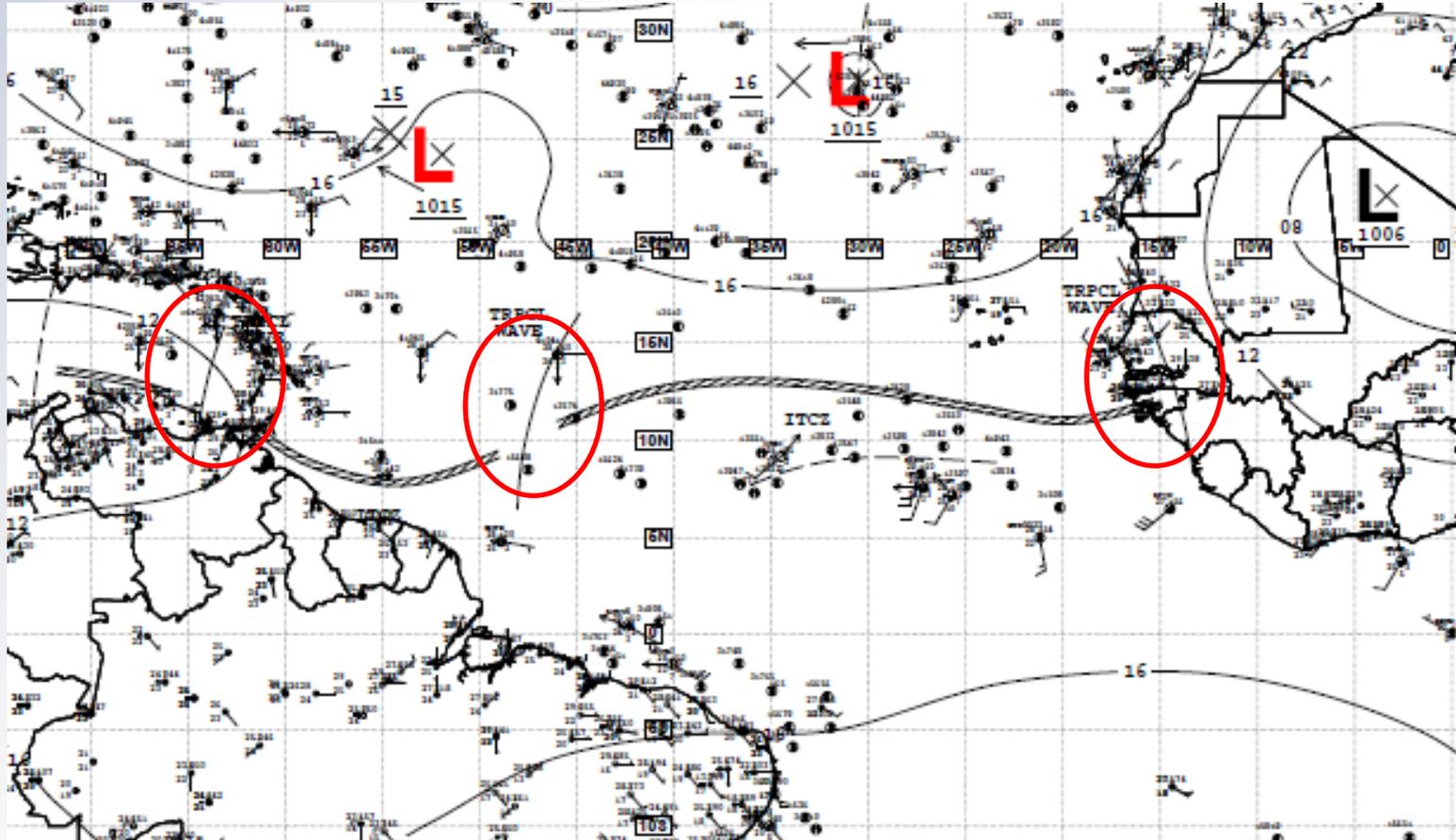


Tool to help track the strength and position of the SAL



NHC Products

TAFB products: Surface Analysis



Analyze current positions every 6 h



TAFB products: Tropical Weather Discussion



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...

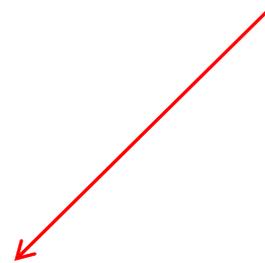
A TROPICAL WAVE IS ALONG 32W S OF 17N MOVING W NEAR 13 KT. THIS WAVE COINCIDES WITH A DEEP LAYER MOISTURE MAXIMUM OBSERVED IN TOTAL PRECIPITABLE WATER IMAGERY. ISOLATED MODERATE CONVECTION IS FROM 13N-15N BETWEEN 30W-34W.

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.

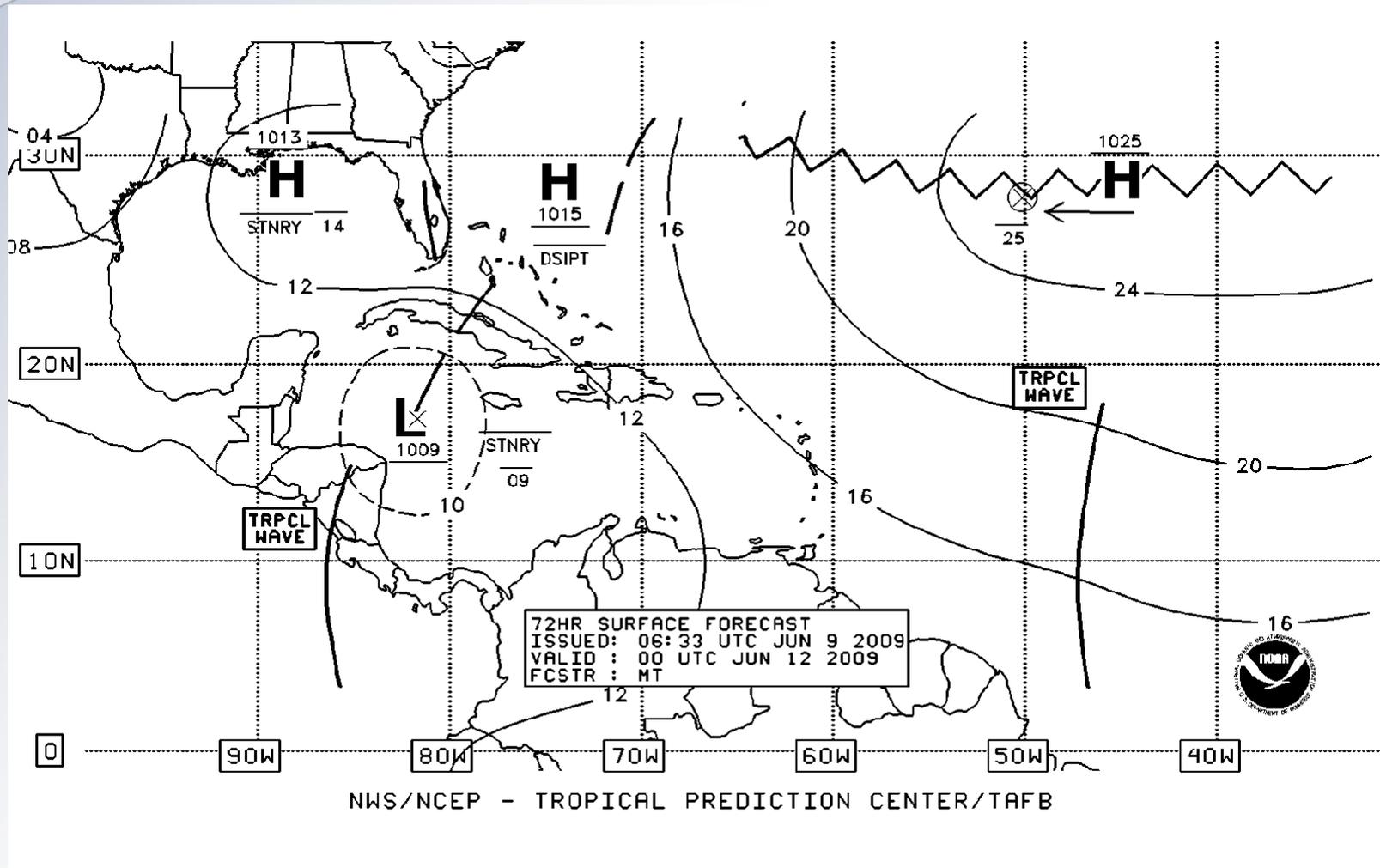
A TROPICAL WAVE IS ALONG 82W S OF 21N MOVING W NEAR 15 KT. THIS WAVE LIES IN A BROAD AREA OF DEEP LAYER MOISTURE OBSERVED IN TOTAL PRECIPITABLE WATER IMAGERY. THIS WAVE CONTINUES MOVING BENEATH A DIFFLUENT PATTERN ALOFT ENHANCING SCATTERED MODERATE CONVECTION OVER THE SW CARIBBEAN S OF 12N AND ACROSS 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

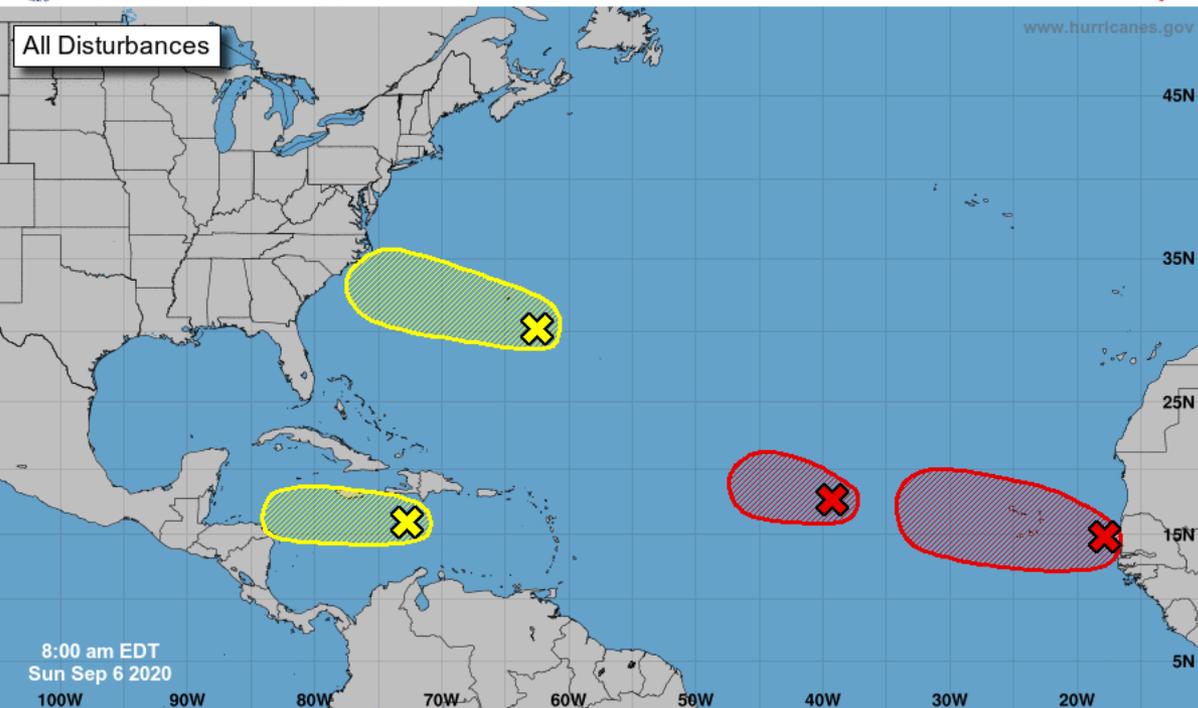


Tropical Weather Outlook



Five-Day Graphical Tropical Weather Outlook

National Hurricane Center Miami, Florida

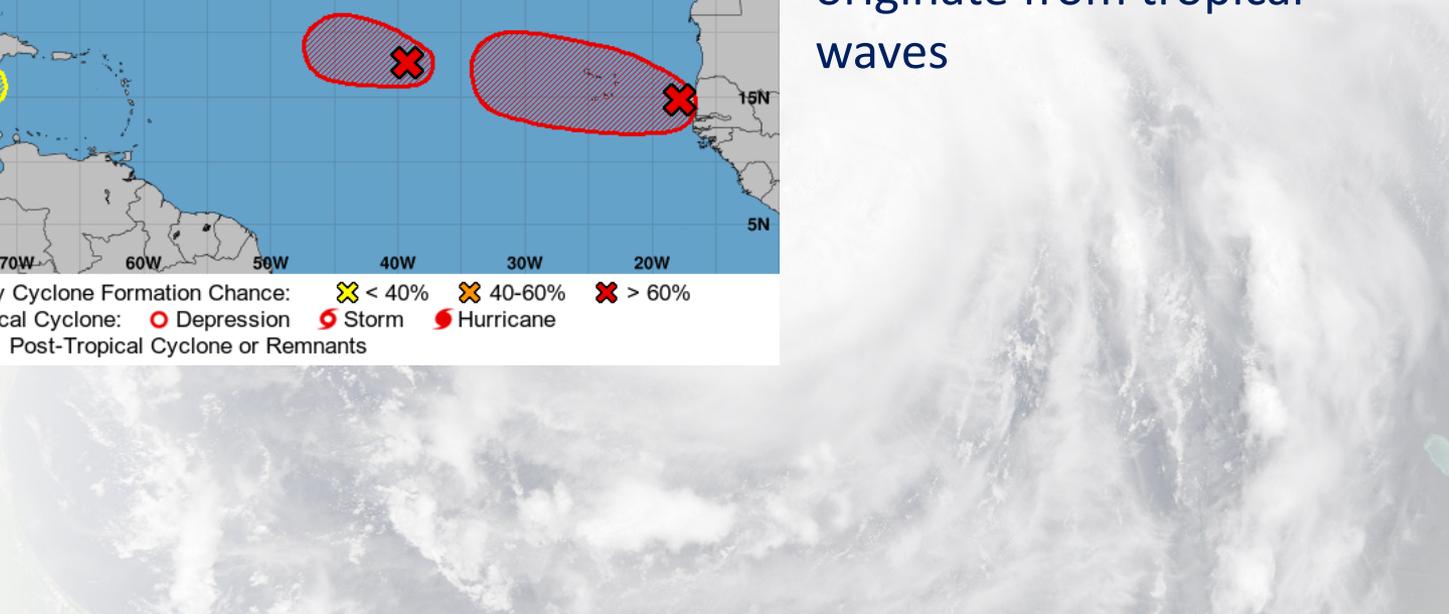


Current Disturbances and Five-Day Cyclone Formation Chance: < 40% 40-60% > 60%

Tropical or Sub-Tropical Cyclone: Depression Storm Hurricane

Post-Tropical Cyclone or Remnants

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



What is more important for tropical
cyclogenesis?

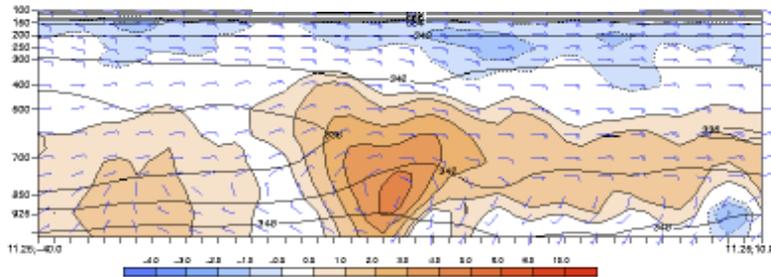
(a) the wave structure

(b) the environment

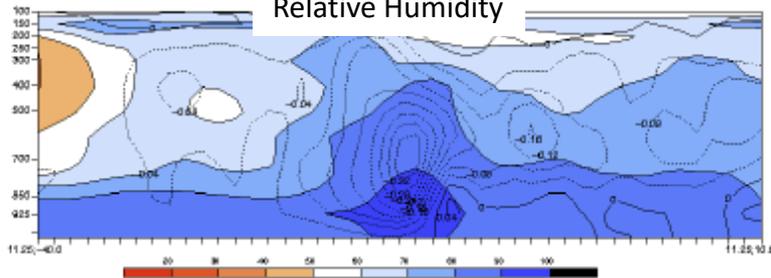
Developing vs. Non-developing

Developing (33)

Relative Vorticity

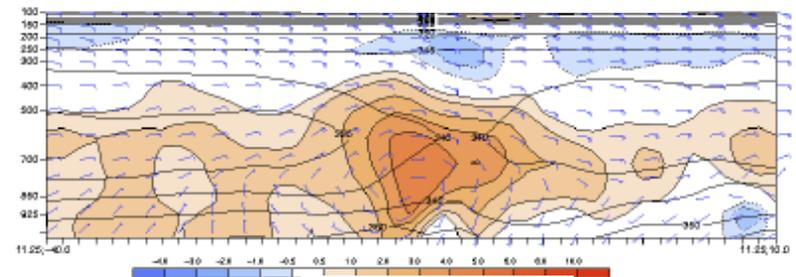


Relative Humidity

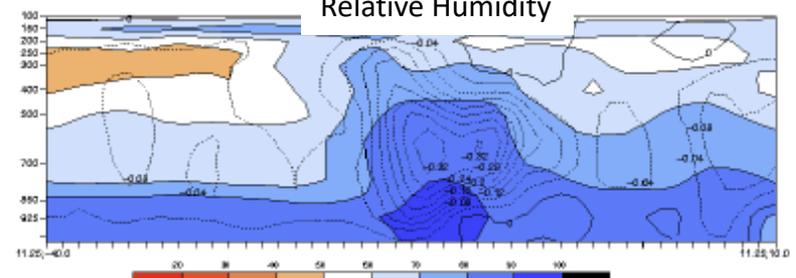


Non-Developing (33 most intense)

Relative Vorticity



Relative Humidity



Hopsch, Thorncroft, and Tyle (2009)

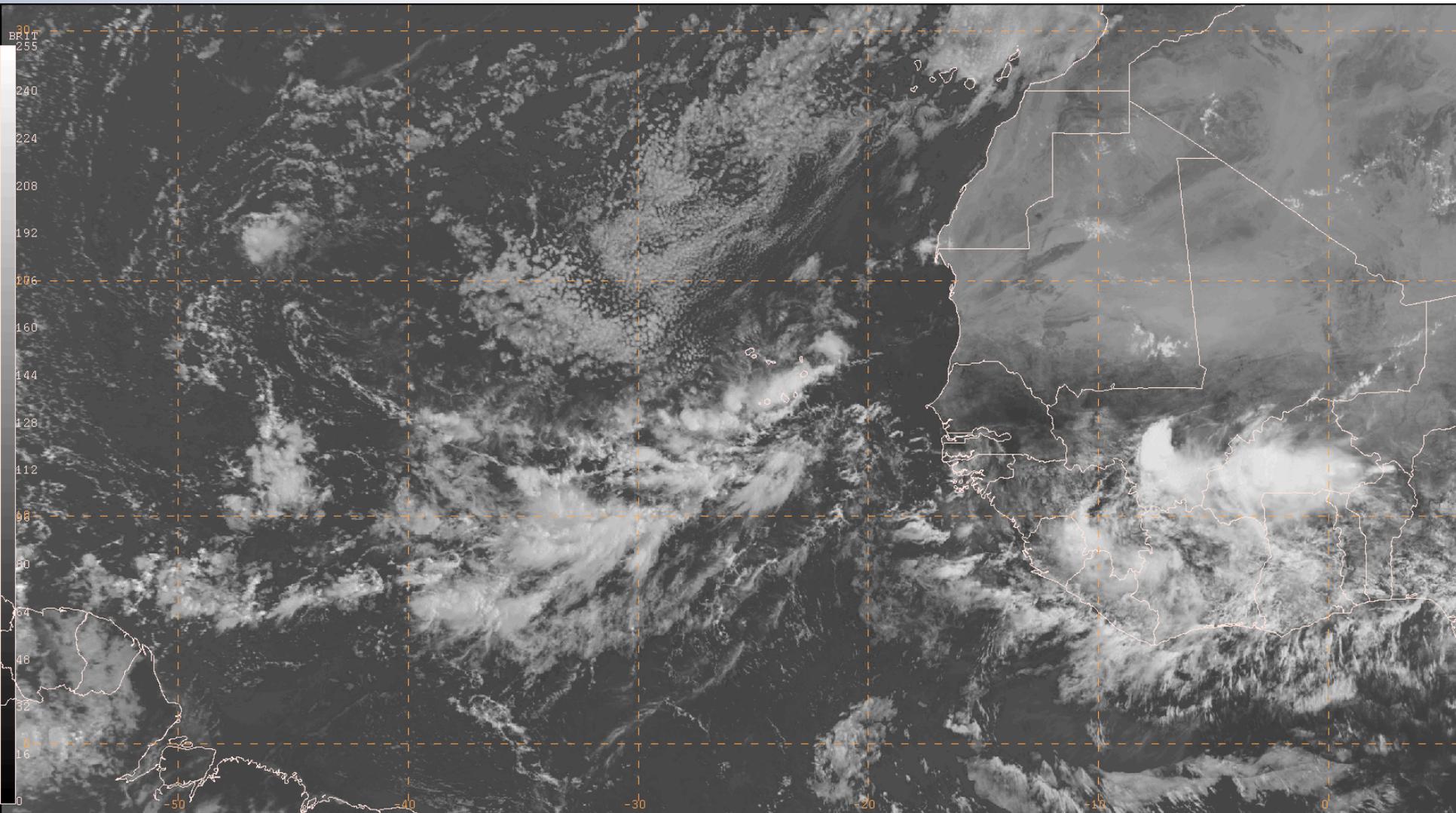
Very little different in structure between developing and non-developing waves



Tools to track tropical waves



Satellite Imagery

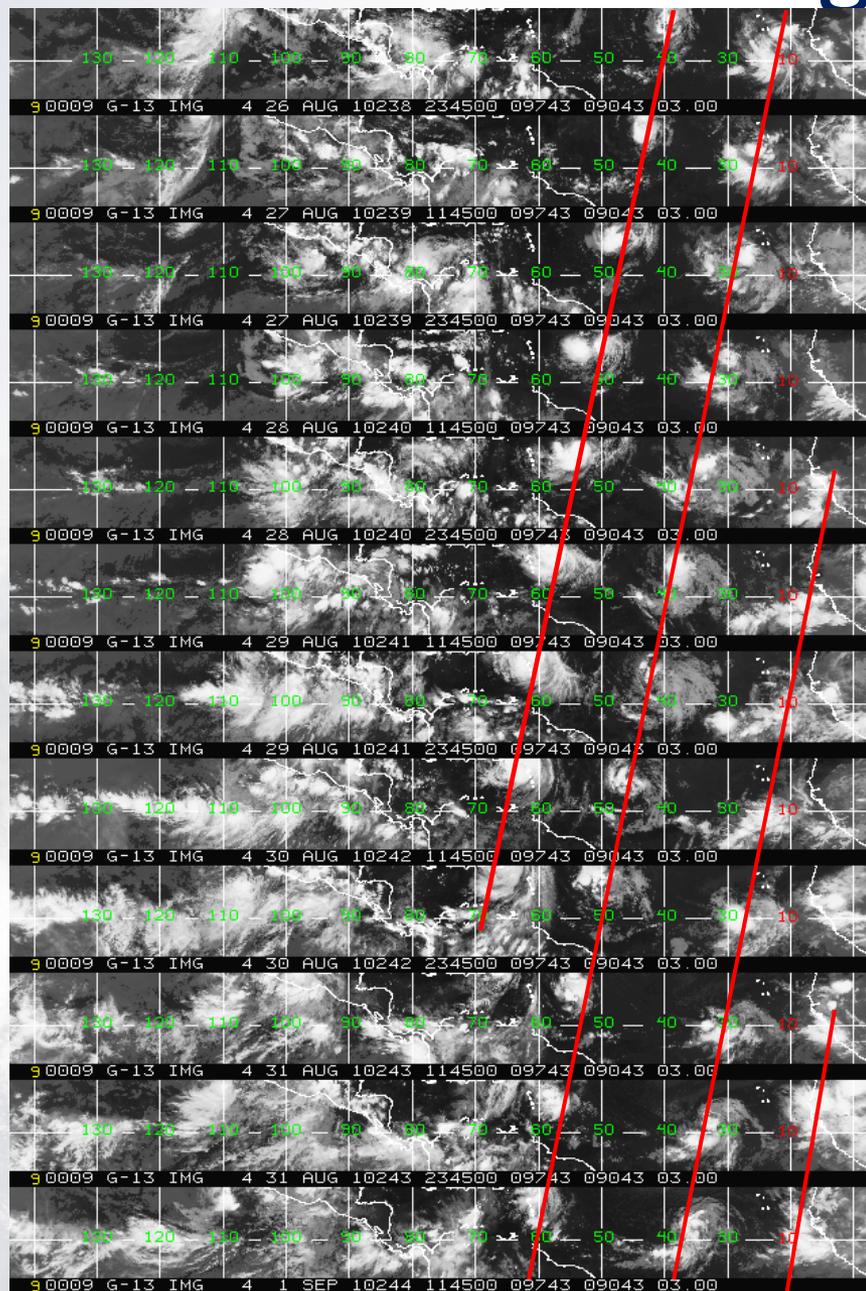




Satellite Hovmoller Diagrams



Time
↓



Aug 26

Aug 27

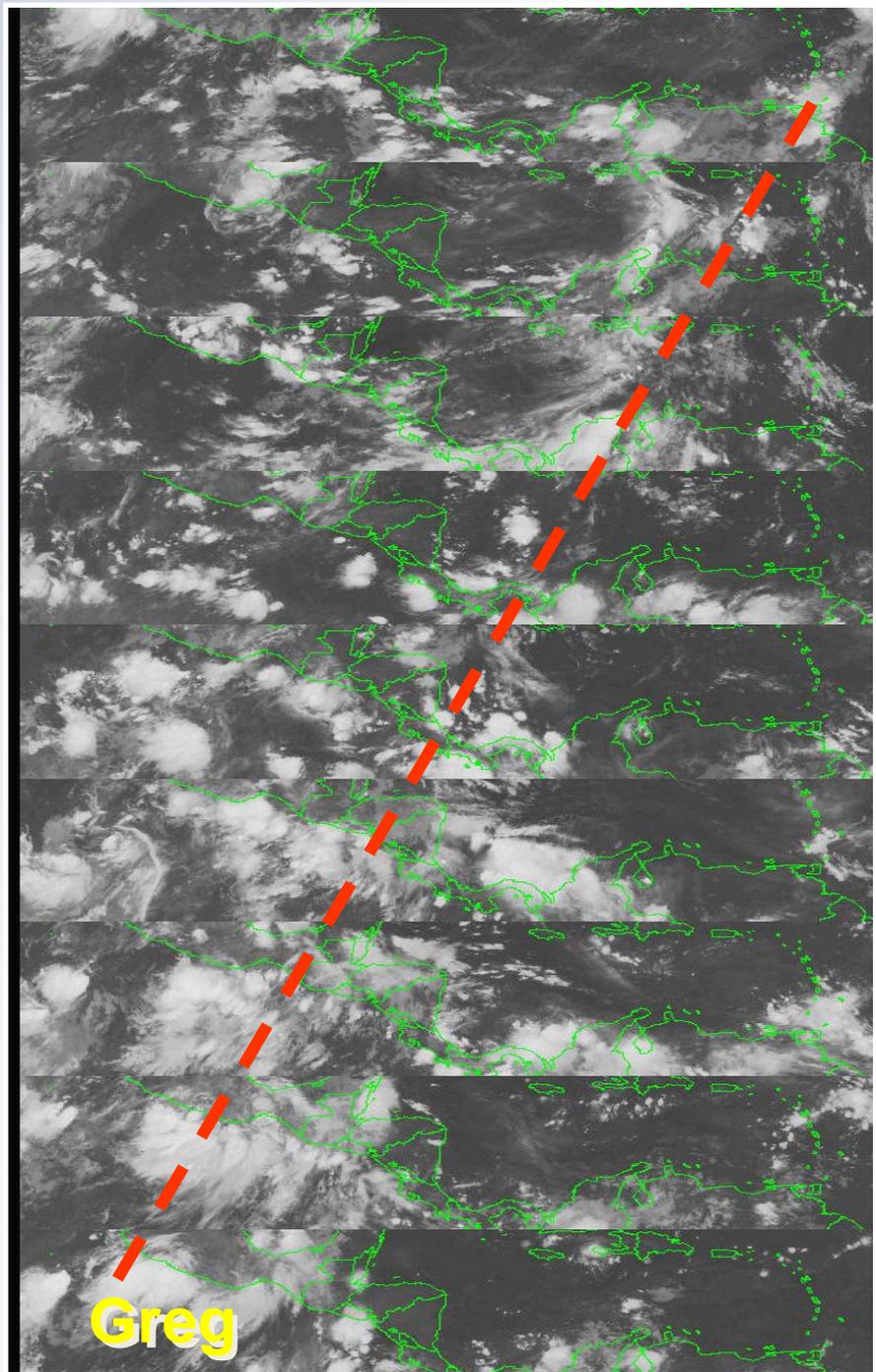
Aug 28

Aug 29

Aug 30

Aug 31

Sep 1



27

28

29

30

31

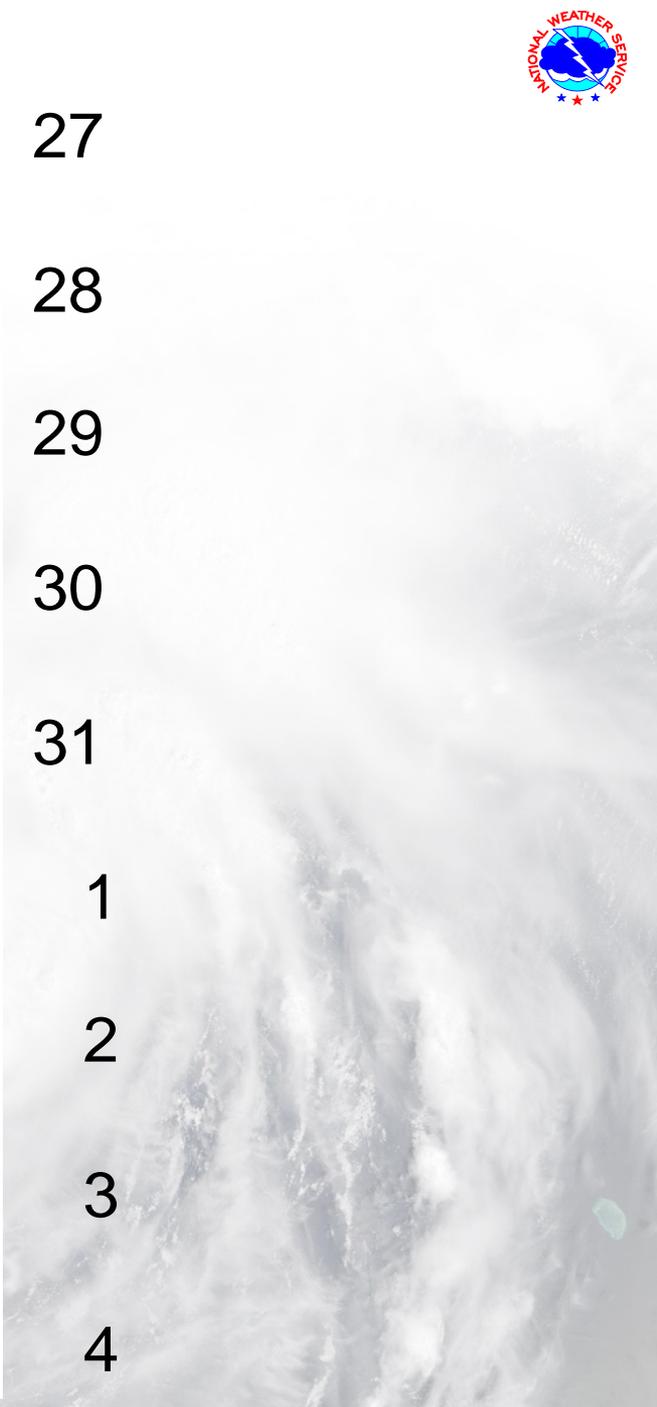
1

2

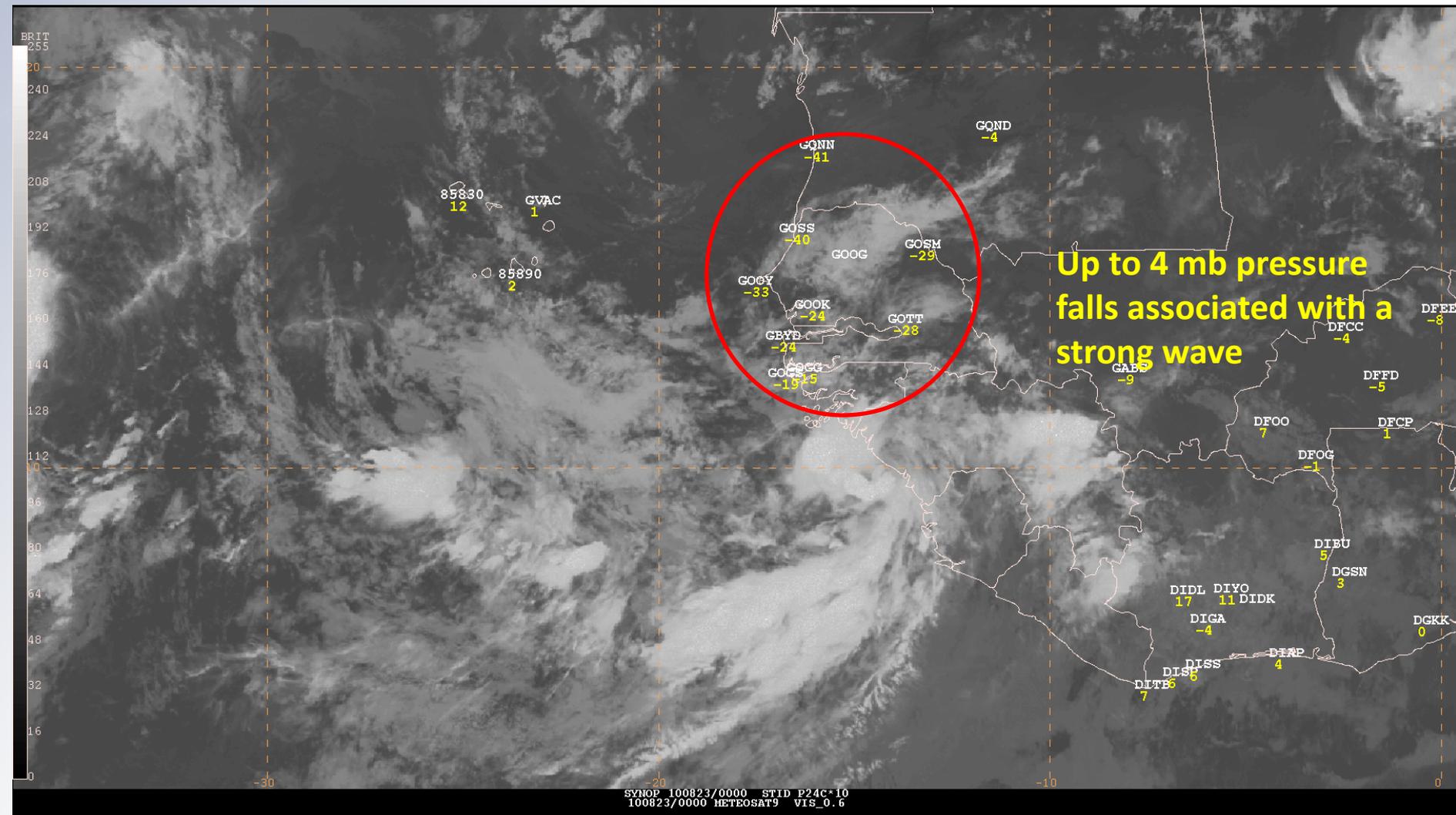
3

4

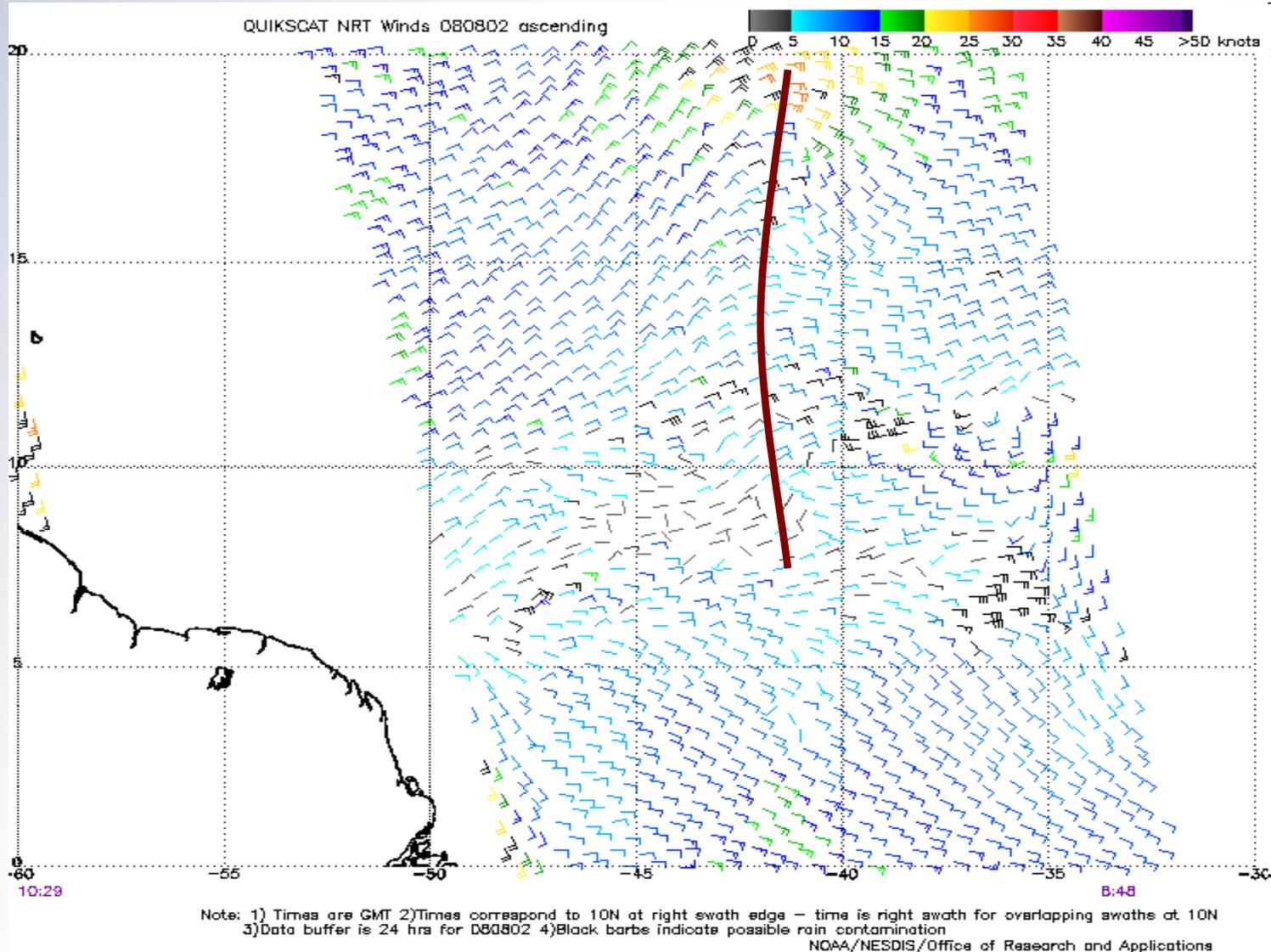
Greg



Surface Observations

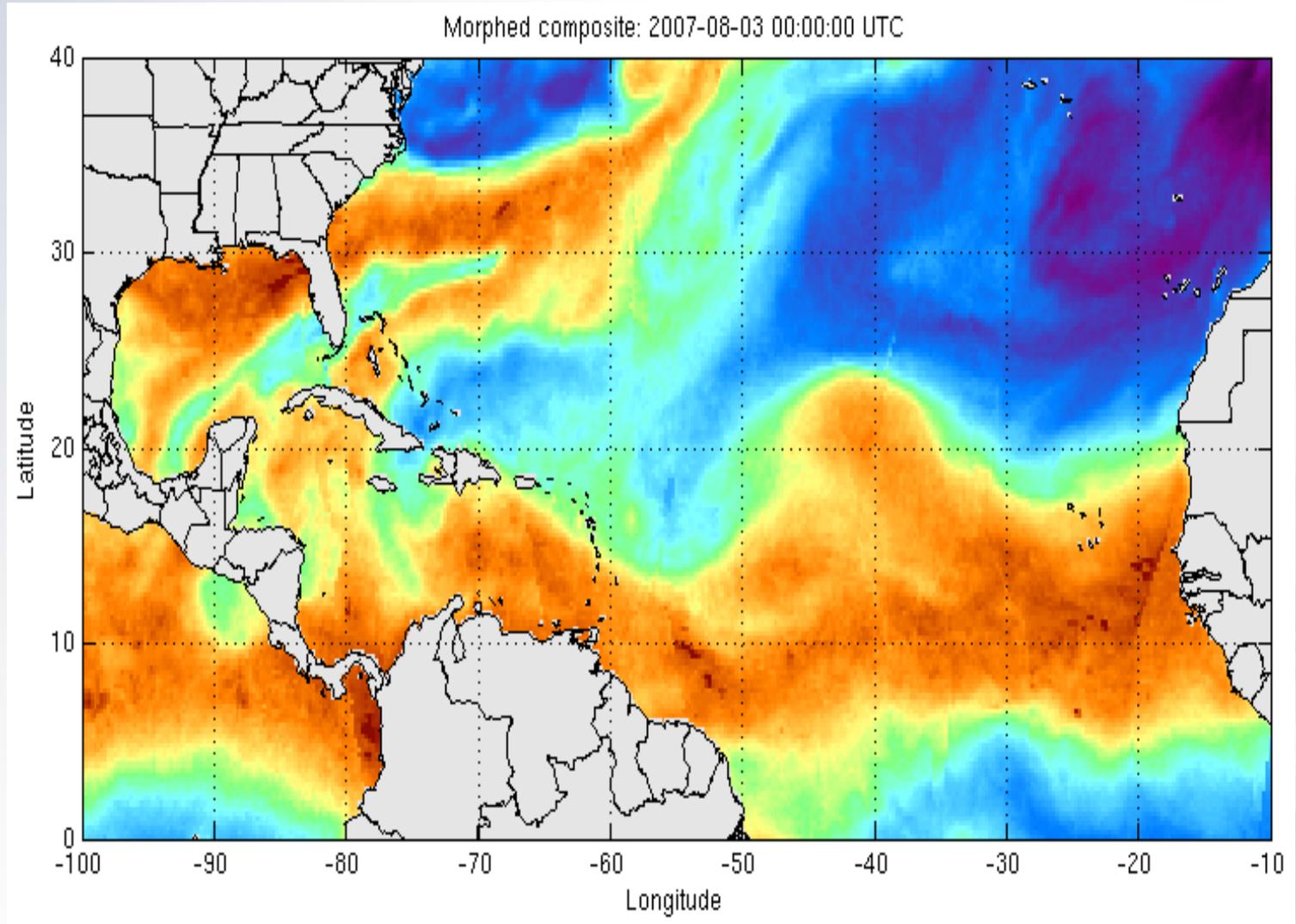


Scatterometer



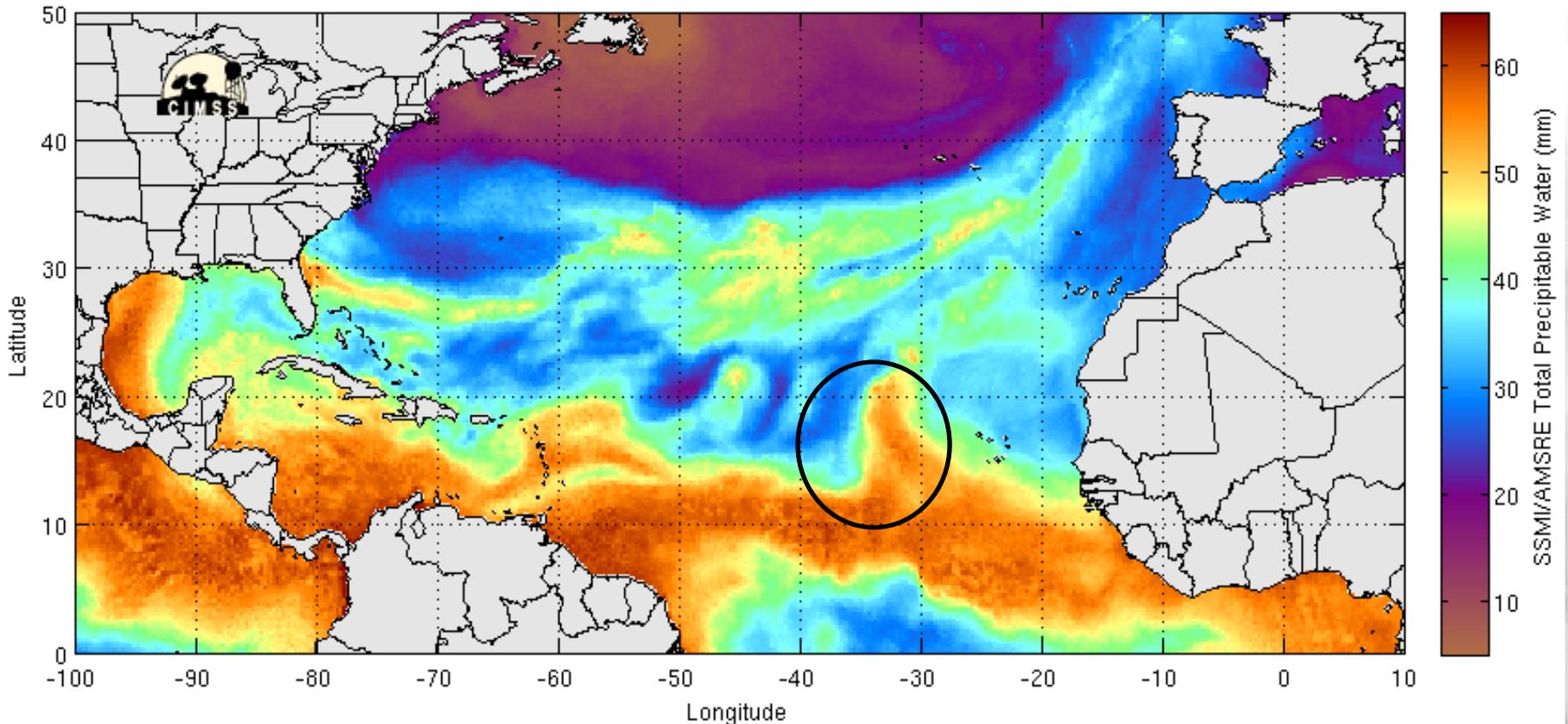


Total Precipitable Water



Wave Splitting

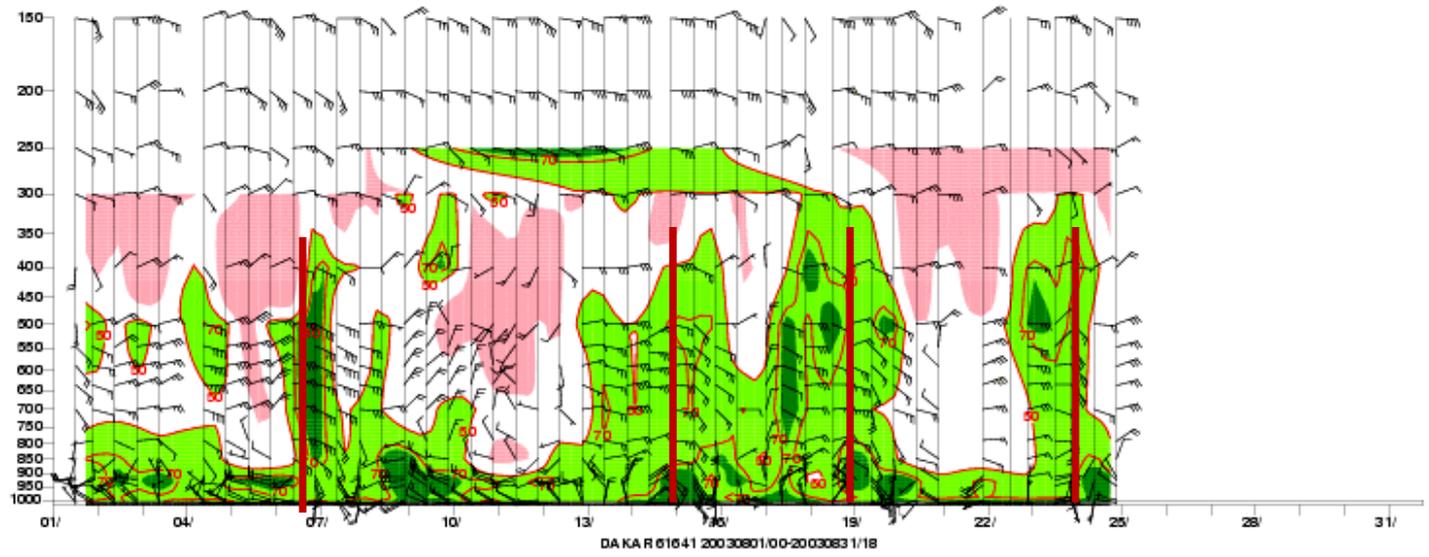
Morphed composite: 2009-10-30 00:00:00 UTC



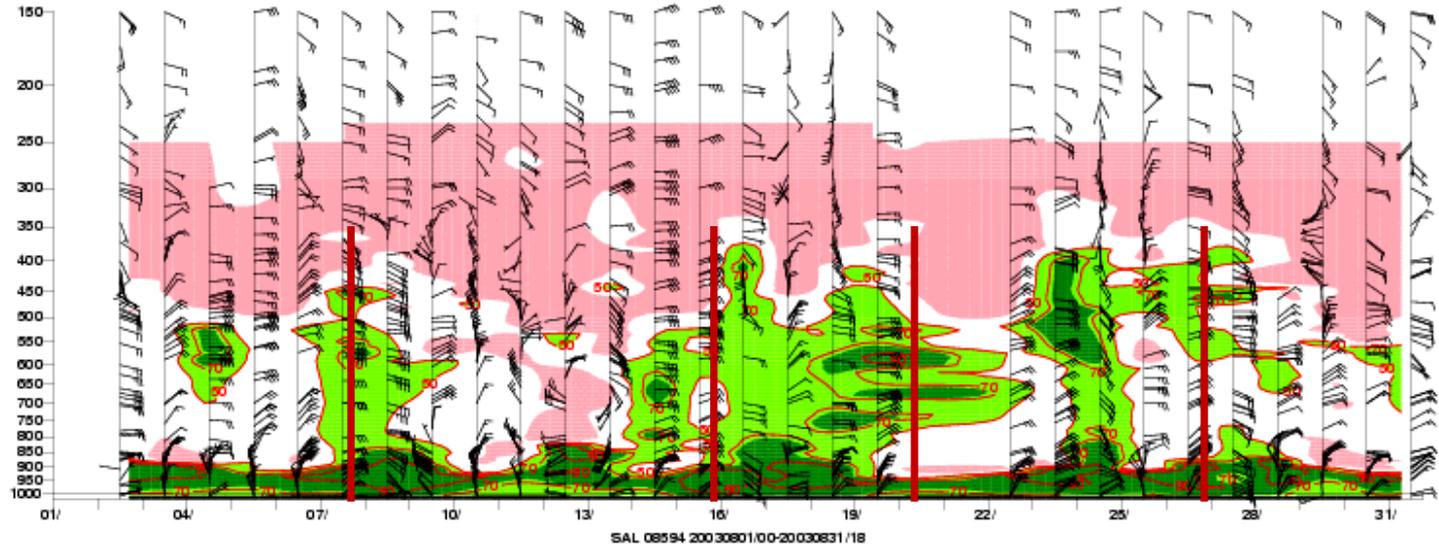
The northern portion of the wave often fractures but the southern extension continues moving westward

Upper-Air Time Sections

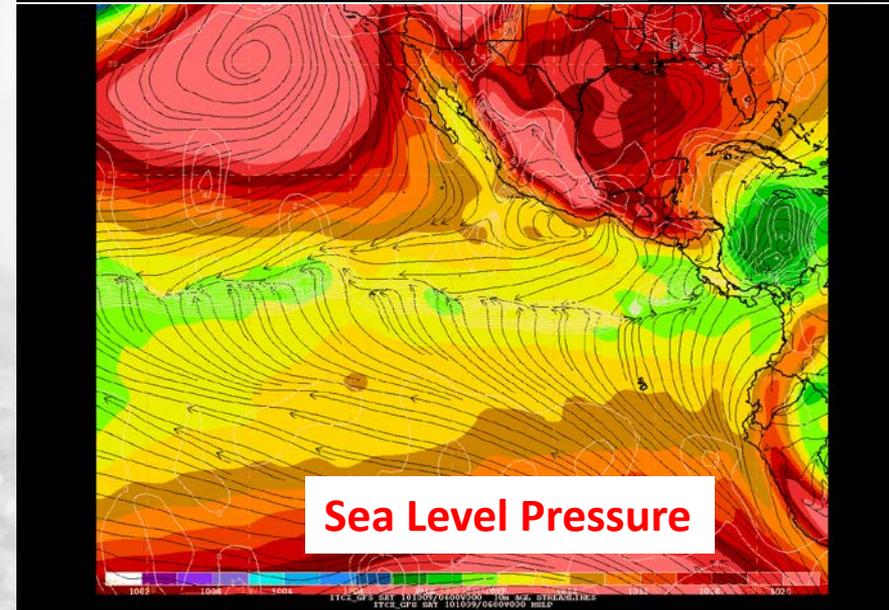
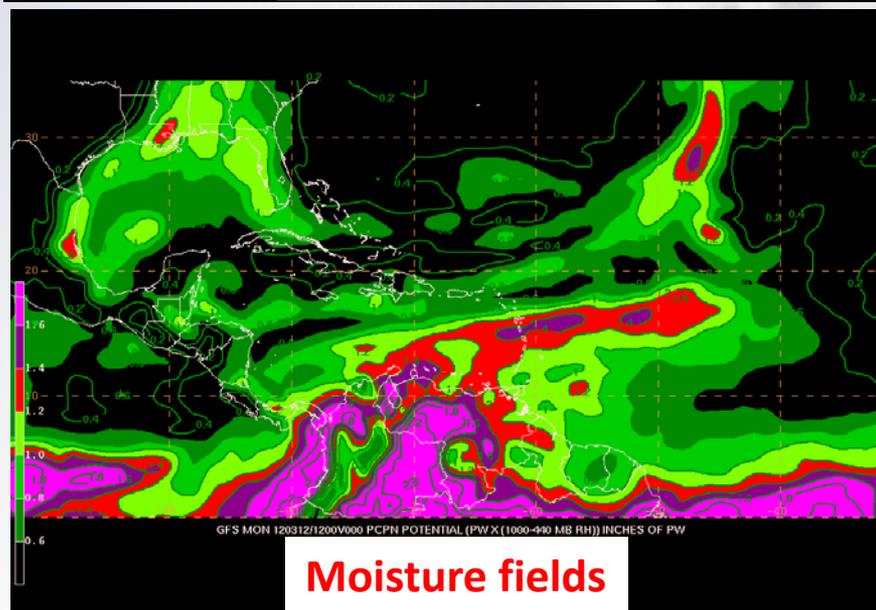
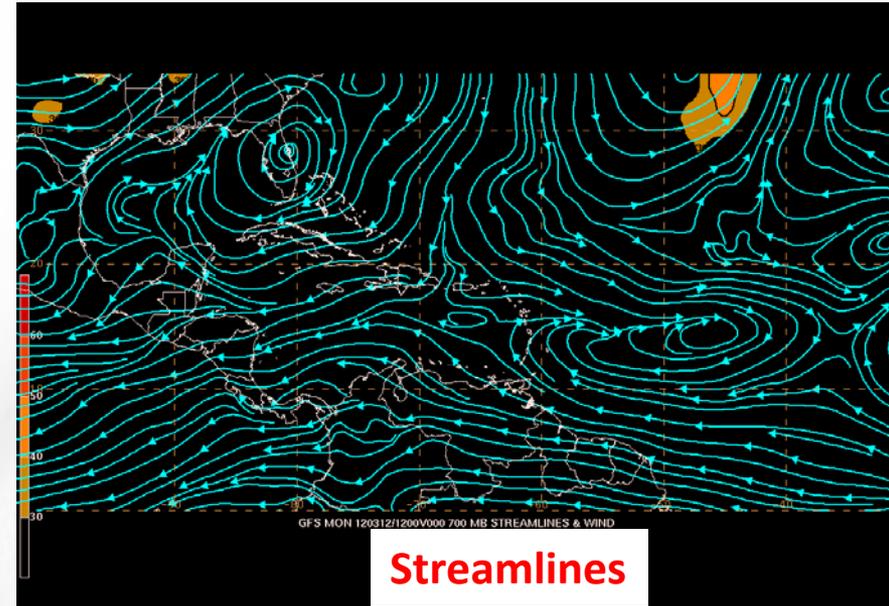
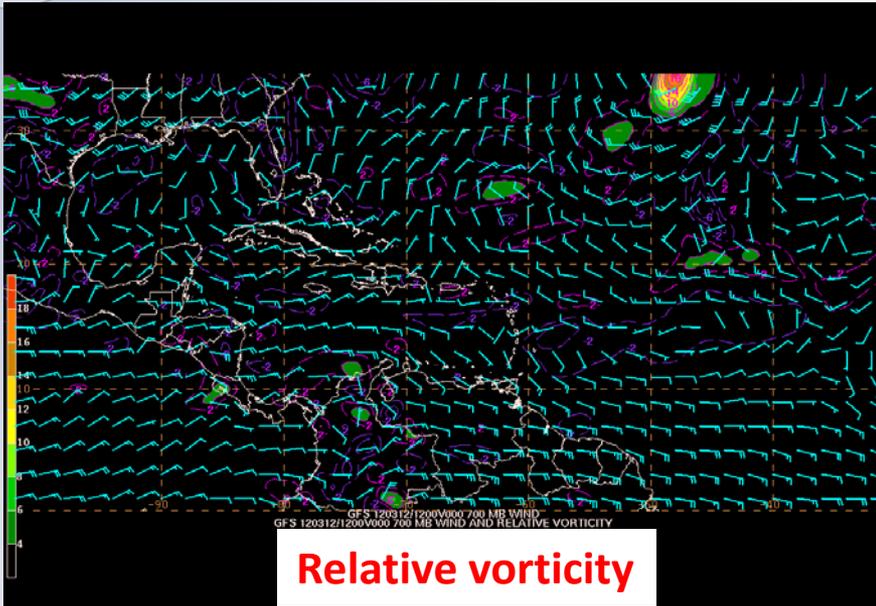
Dakar



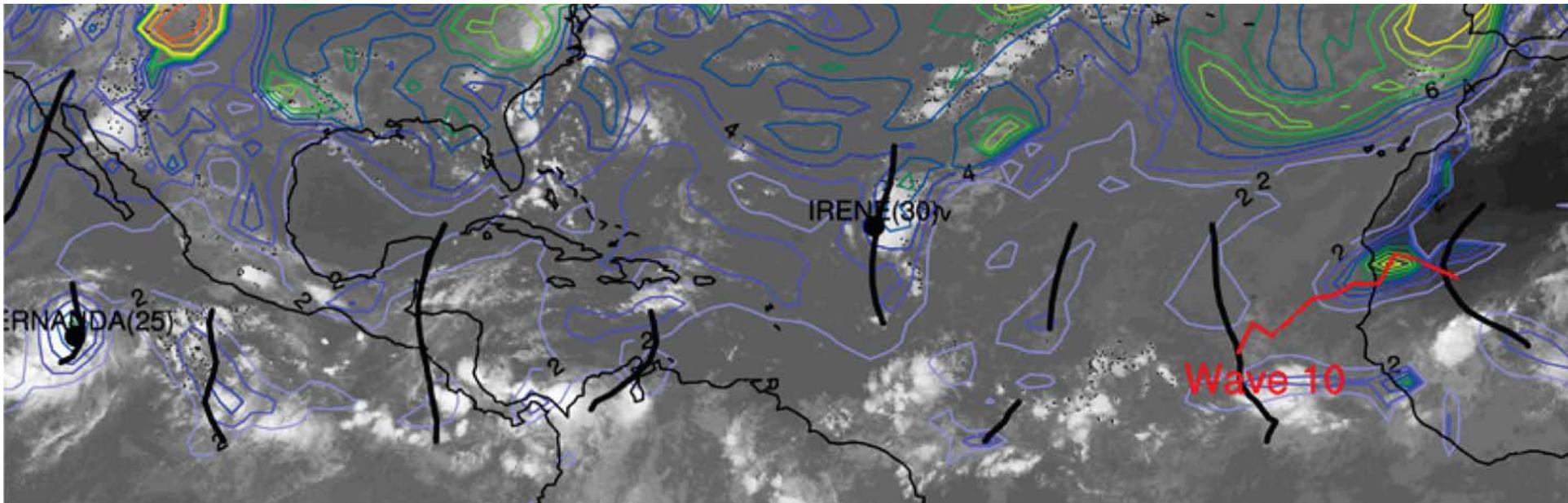
Sal



Models



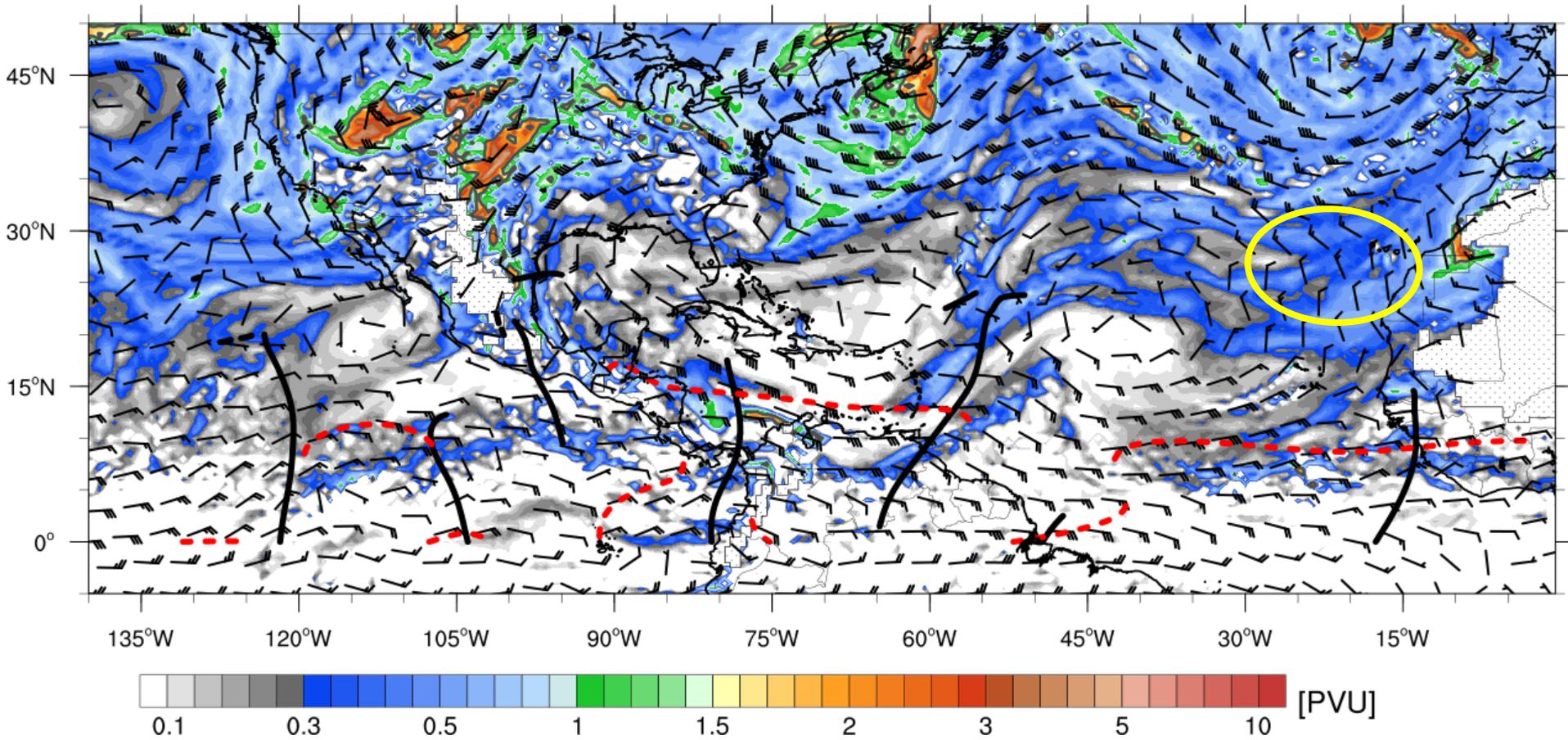
Tools to track easterly waves: Tropical Wave Diagnostics



GFS 310K Potential Vorticity and Wind

PV (PVU = $10^6 \text{ K kg}^{-1} \text{ m}^2 \text{ s}^{-1}$, shaded; 1.5 PVU bold black contour) and Wind (kts, barbs)

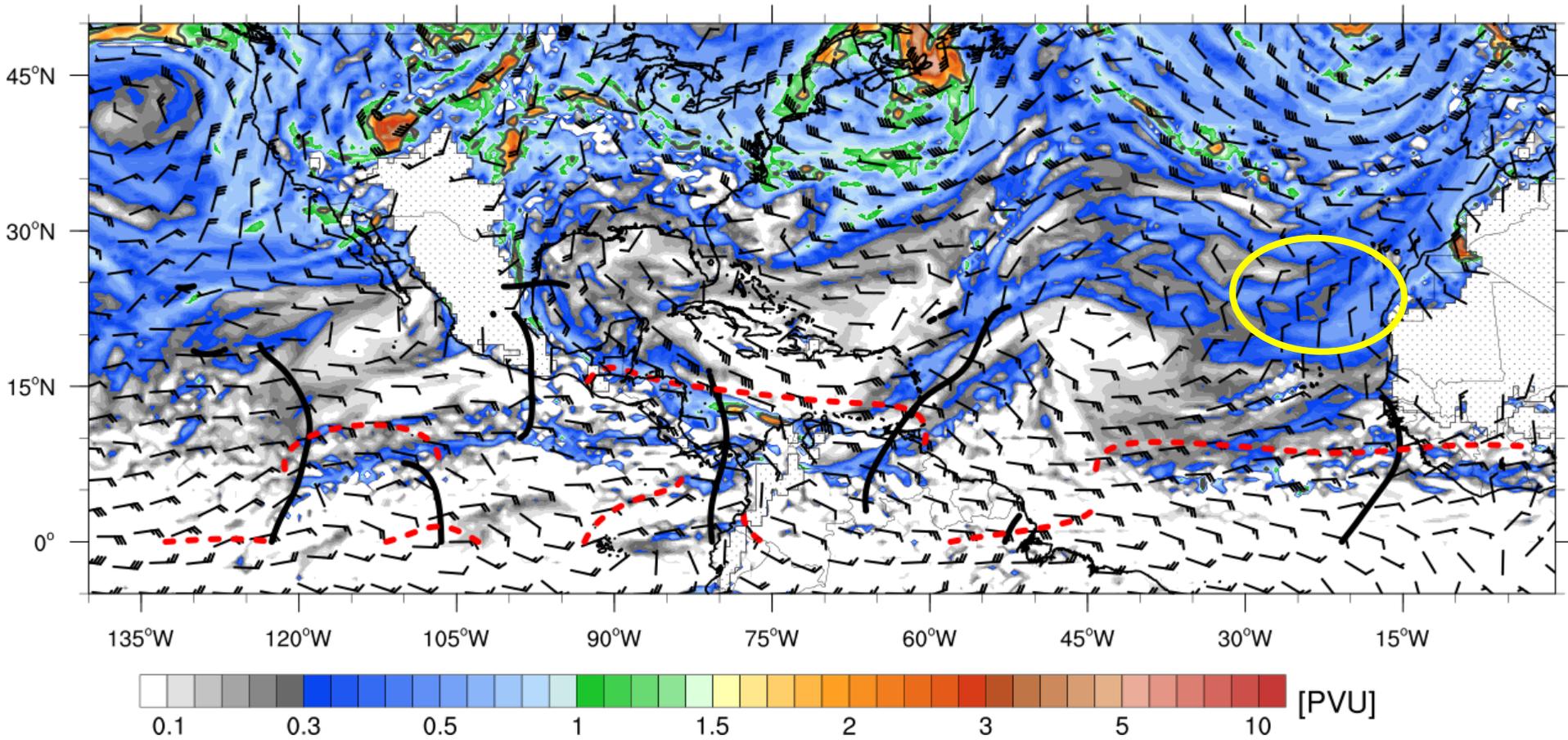
Run: 22 Jun 12Z, Forecast: 0 hr, Valid: 22 Jun 12Z



GFS 310K Potential Vorticity and Wind

PV (PVU = $10^6 \text{ K kg}^{-1} \text{ m}^2 \text{ s}^{-1}$, shaded; 1.5 PVU bold black contour) and Wind (kts, barbs)

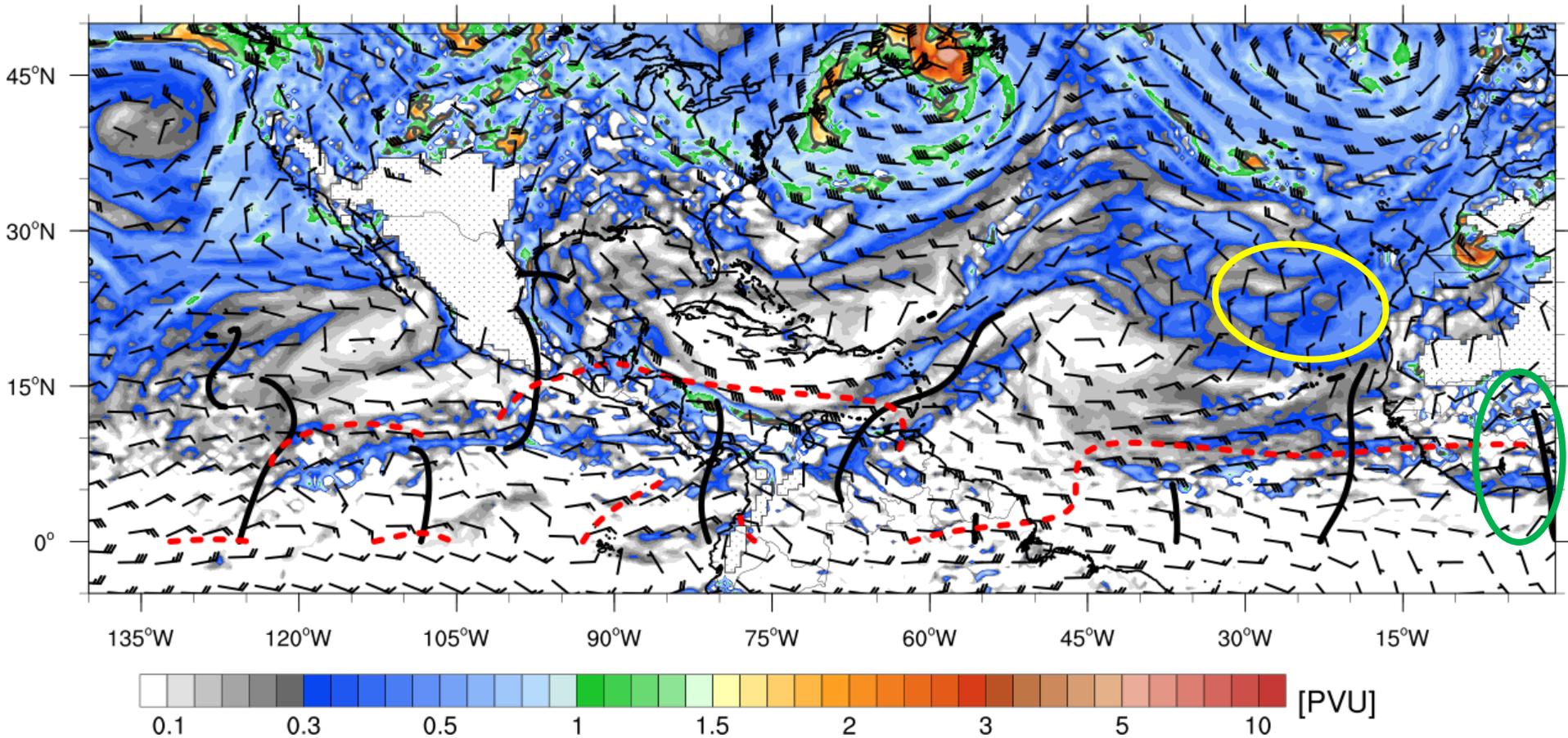
Run: 22 Jun 18Z, Forecast: 0 hr, Valid: 22 Jun 18Z



GFS 310K Potential Vorticity and Wind

PV (PVU = $10^6 \text{ K kg}^{-1} \text{ m}^2 \text{ s}^{-1}$, shaded; 1.5 PVU bold black contour) and Wind (kts, barbs)

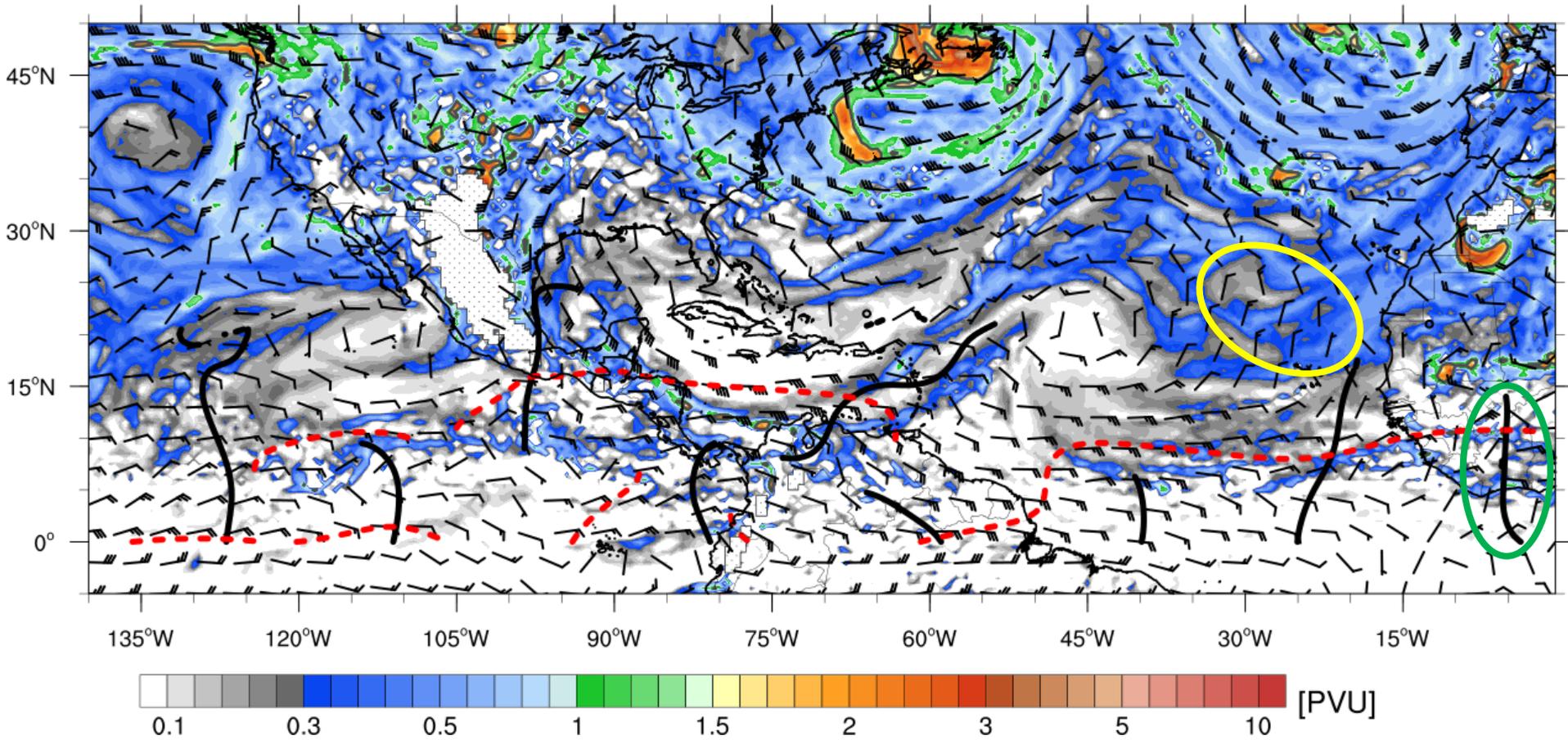
Run: 23 Jun 00Z, Forecast: 0 hr, Valid: 23 Jun 00Z



GFS 310K Potential Vorticity and Wind

PV (PVU = $10^6 \text{ K kg}^{-1} \text{ m}^2 \text{ s}^{-1}$, shaded; 1.5 PVU bold black contour) and Wind (kts, barbs)

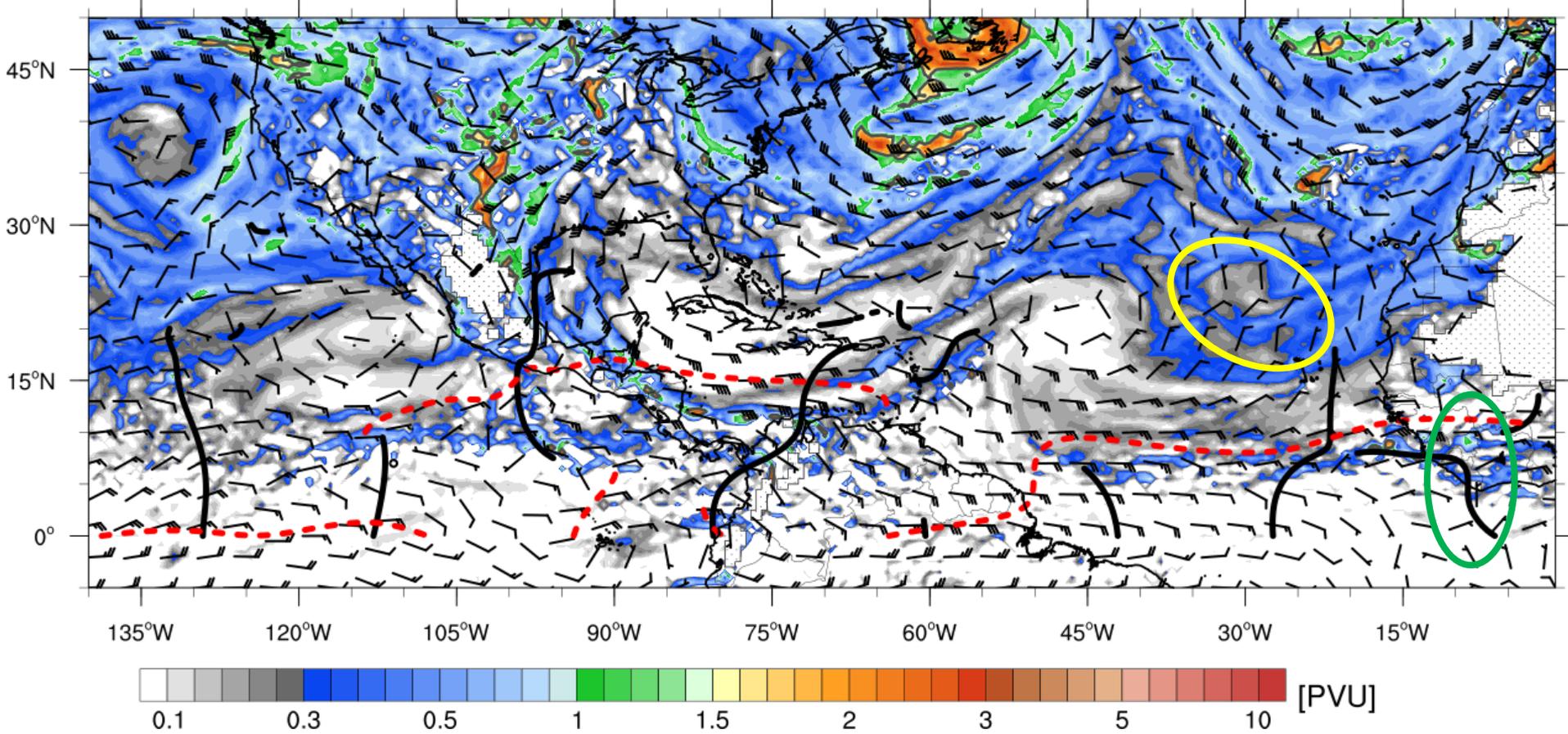
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GFS 310K Potential Vorticity and Wind

PV (PVU = $10^6 \text{ K kg}^{-1} \text{ m}^2 \text{ s}^{-1}$, shaded; 1.5 PVU bold black contour) and Wind (kts, barbs)

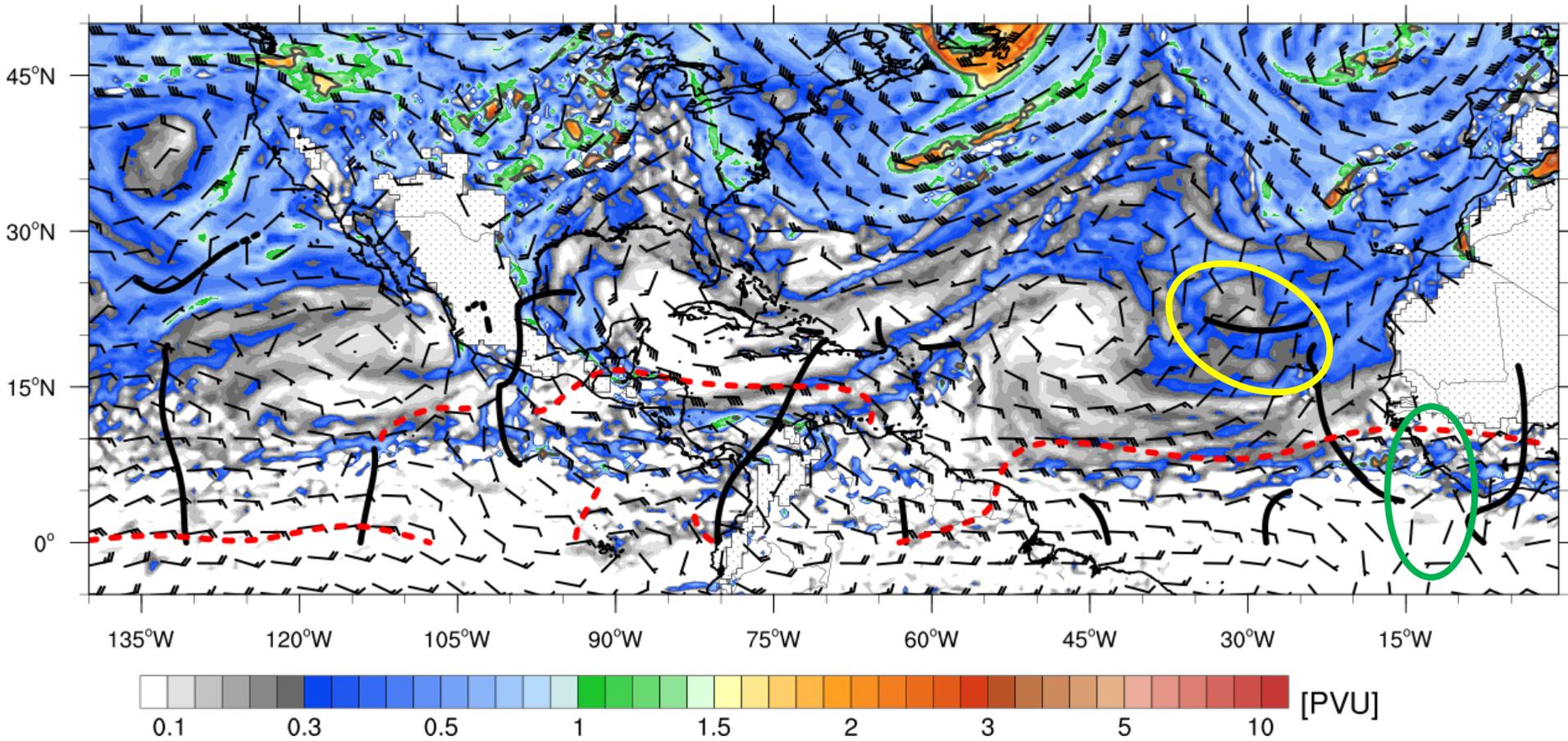
Run: 23 Jun 12Z, Forecast: 0 hr, Valid: 23 Jun 12Z



GFS 310K Potential Vorticity and Wind

PV (PVU = $10^6 \text{ K kg}^{-1} \text{ m}^2 \text{ s}^{-1}$, shaded; 1.5 PVU bold black contour) and Wind (kts, barbs)

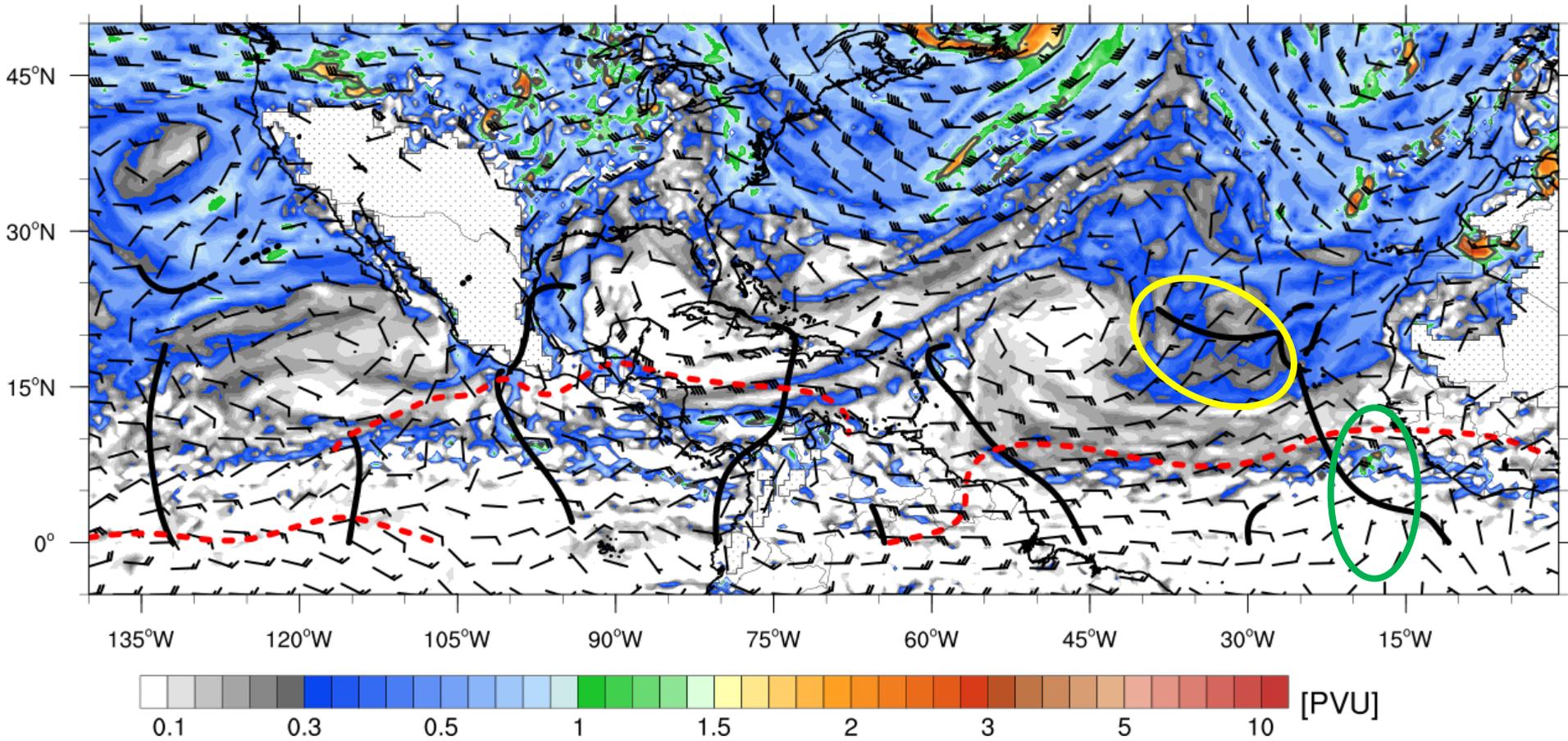
Run: 23 Jun 18Z, Forecast: 0 hr, Valid: 23 Jun 18Z



GFS 310K Potential Vorticity and Wind

PV (PVU = $10^6 \text{ K kg}^{-1} \text{ m}^2 \text{ s}^{-1}$, shaded; 1.5 PVU bold black contour) and Wind (kts, barbs)

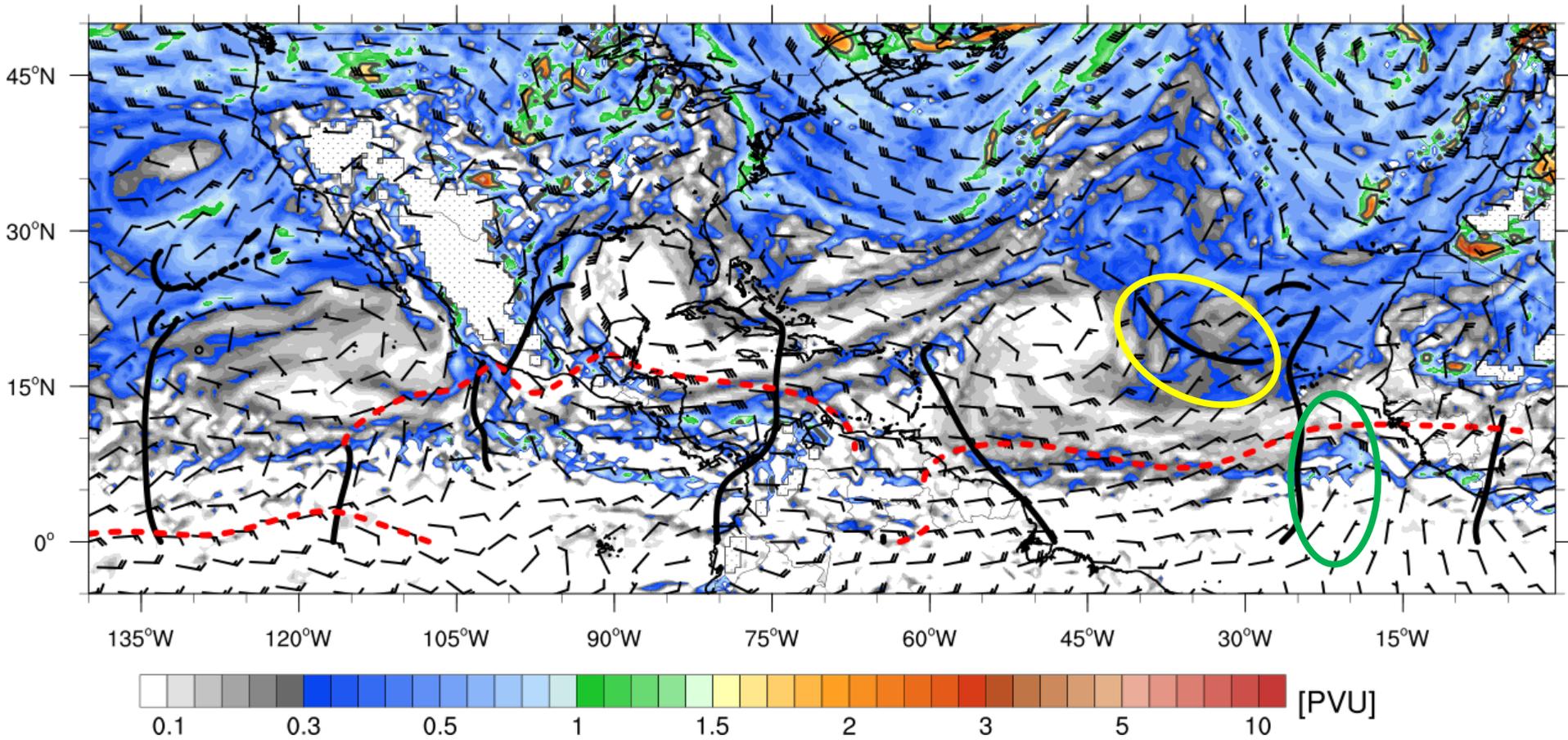
Run: 24 Jun 00Z, Forecast: 0 hr, Valid: 24 Jun 00Z



GFS 310K Potential Vorticity and Wind

PV (PVU = $10^6 \text{ K kg}^{-1} \text{ m}^2 \text{ s}^{-1}$, shaded; 1.5 PVU bold black contour) and Wind (kts, barbs)

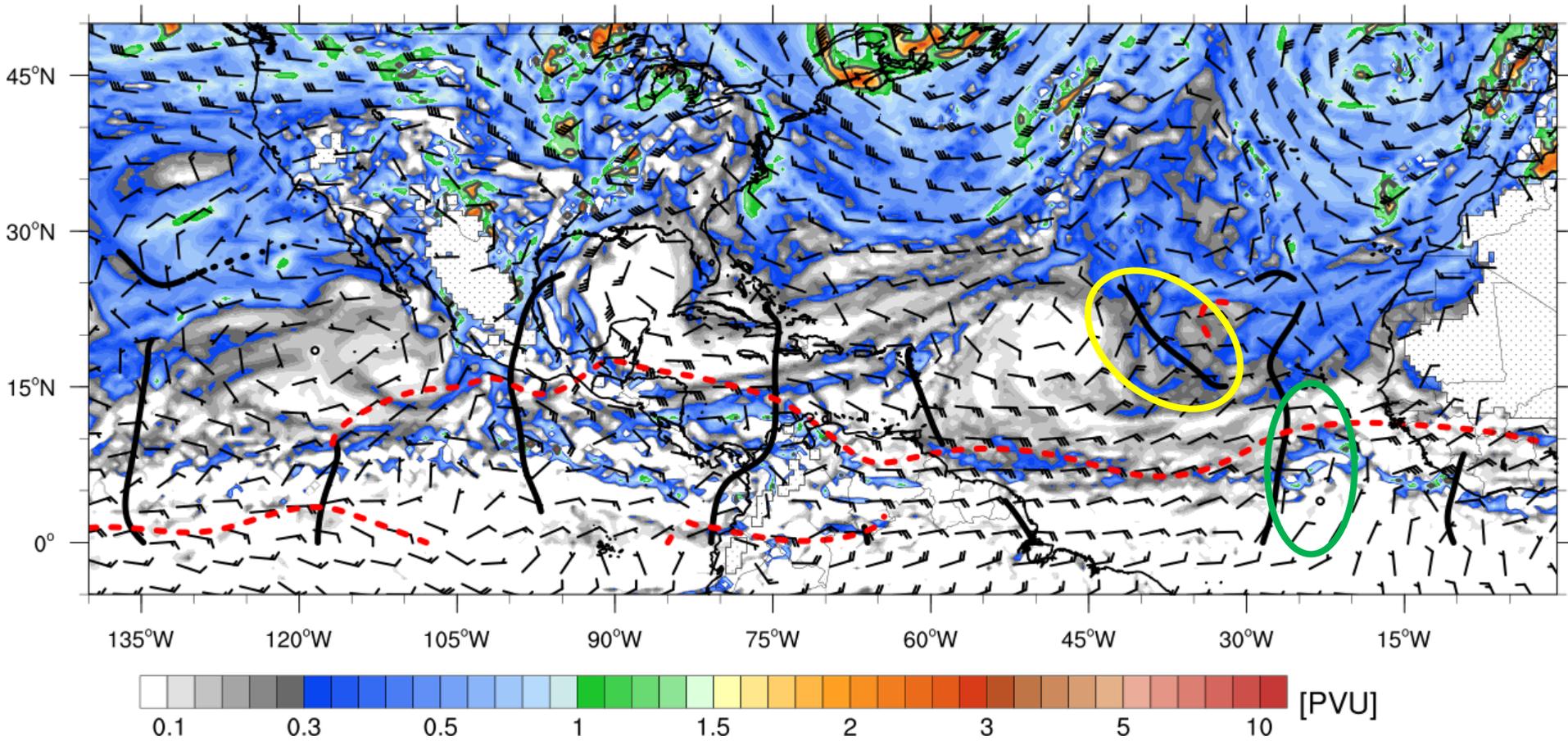
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GFS 310K Potential Vorticity and Wind

PV (PVU = $10^6 \text{ K kg}^{-1} \text{ m}^2 \text{ s}^{-1}$, shaded; 1.5 PVU bold black contour) and Wind (kts, barbs)

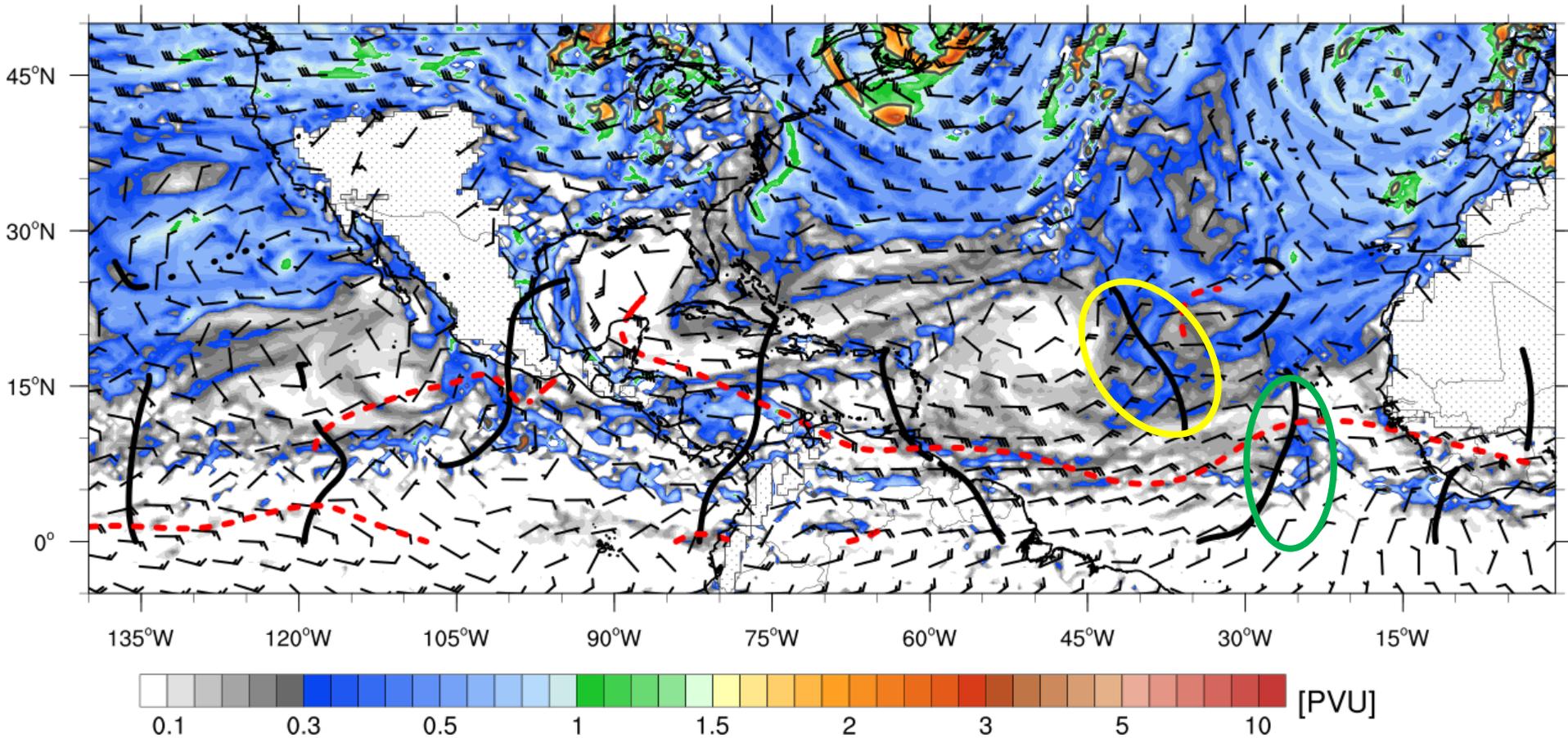
Run: 24 Jun 12Z, Forecast: 0 hr, Valid: 24 Jun 12Z



GFS 310K Potential Vorticity and Wind

PV (PVU = $10^6 \text{ K kg}^{-1} \text{ m}^2 \text{ s}^{-1}$, shaded; 1.5 PVU bold black contour) and Wind (kts, barbs)

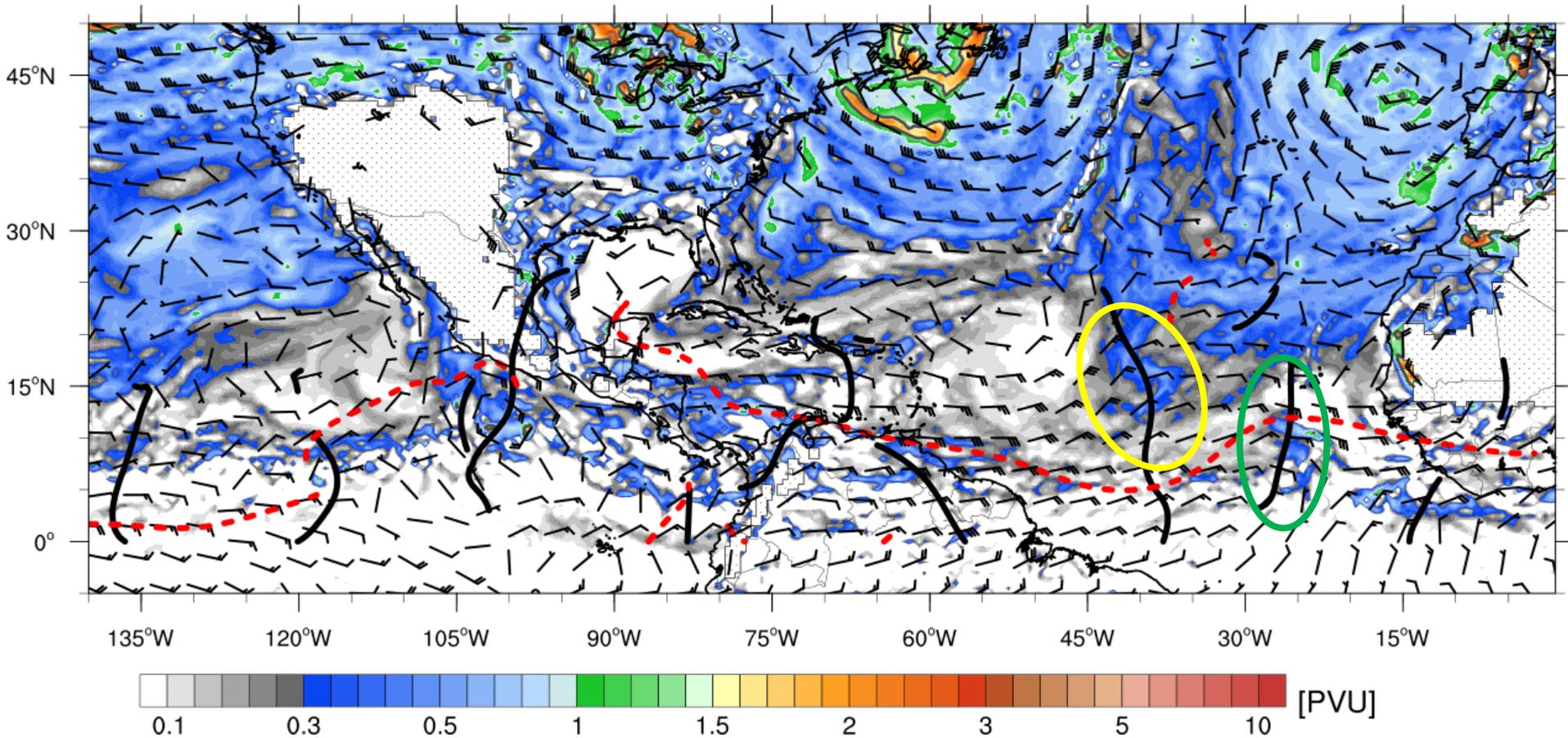
Run: 24 Jun 18Z, Forecast: 0 hr, Valid: 24 Jun 18Z



GFS 310K Potential Vorticity and Wind

PV (PVU = $10^6 \text{ K kg}^{-1} \text{ m}^2 \text{ s}^{-1}$, shaded; 1.5 PVU bold black contour) and Wind (kts, barbs)

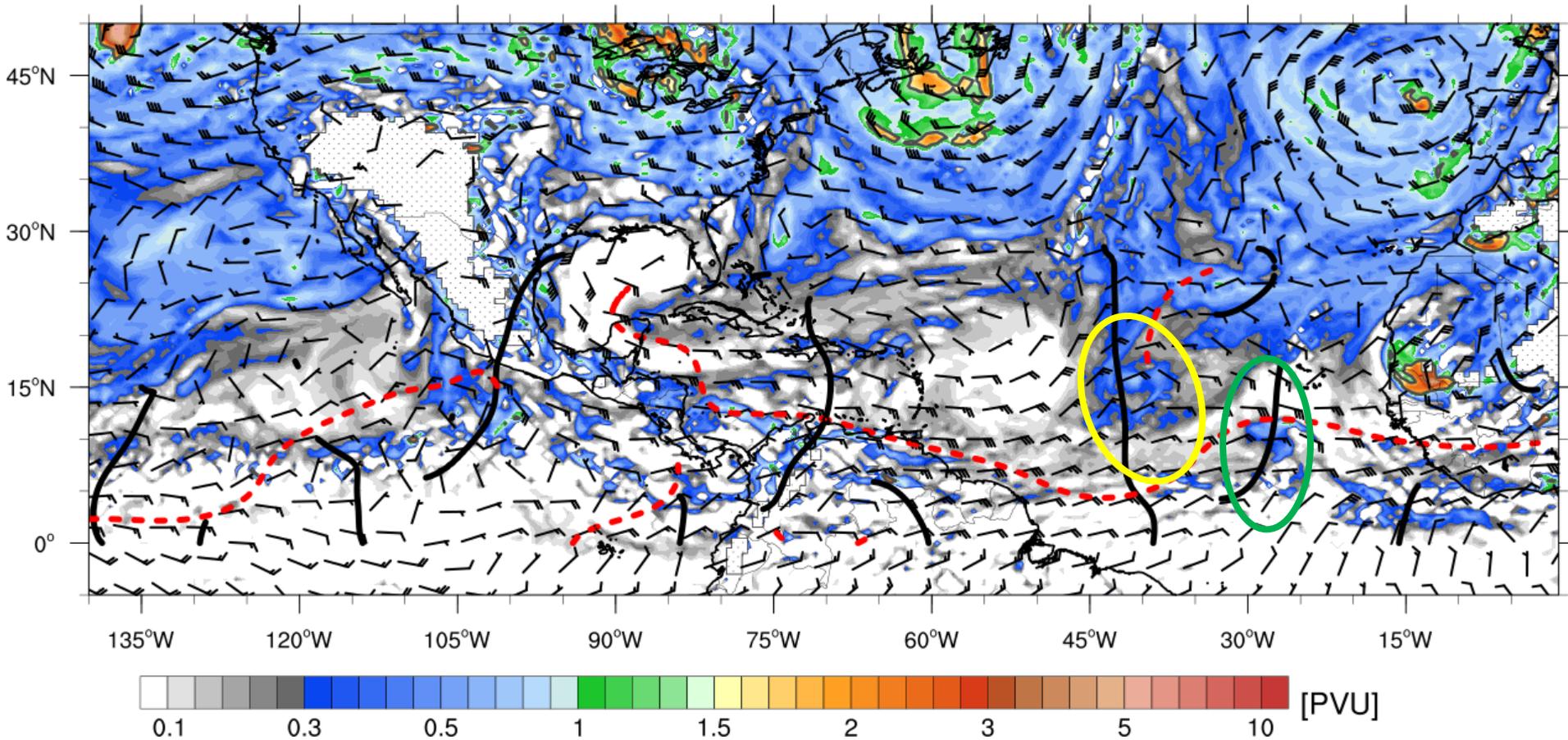
Run: 25 Jun 00Z, Forecast: 0 hr, Valid: 25 Jun 00Z



GFS 310K Potential Vorticity and Wind

PV (PVU = $10^6 \text{ K kg}^{-1} \text{ m}^2 \text{ s}^{-1}$, shaded; 1.5 PVU bold black contour) and Wind (kts, barbs)

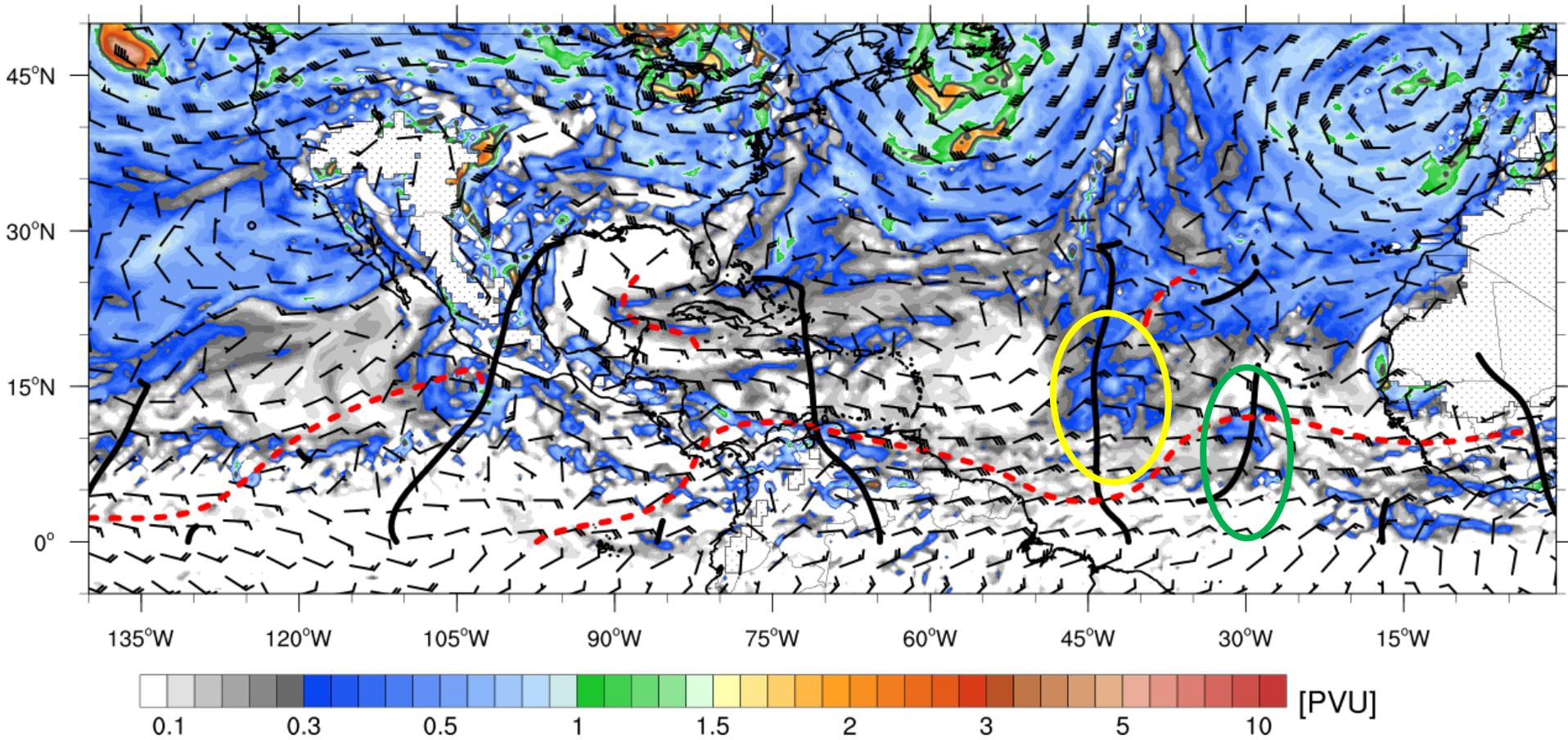
Run: 25 Jun 06Z, Forecast: 0 hr, Valid: 25 Jun 06Z



GFS 310K Potential Vorticity and Wind

PV (PVU = $10^6 \text{ K kg}^{-1} \text{ m}^2 \text{ s}^{-1}$, shaded; 1.5 PVU bold black contour) and Wind (kts, barbs)

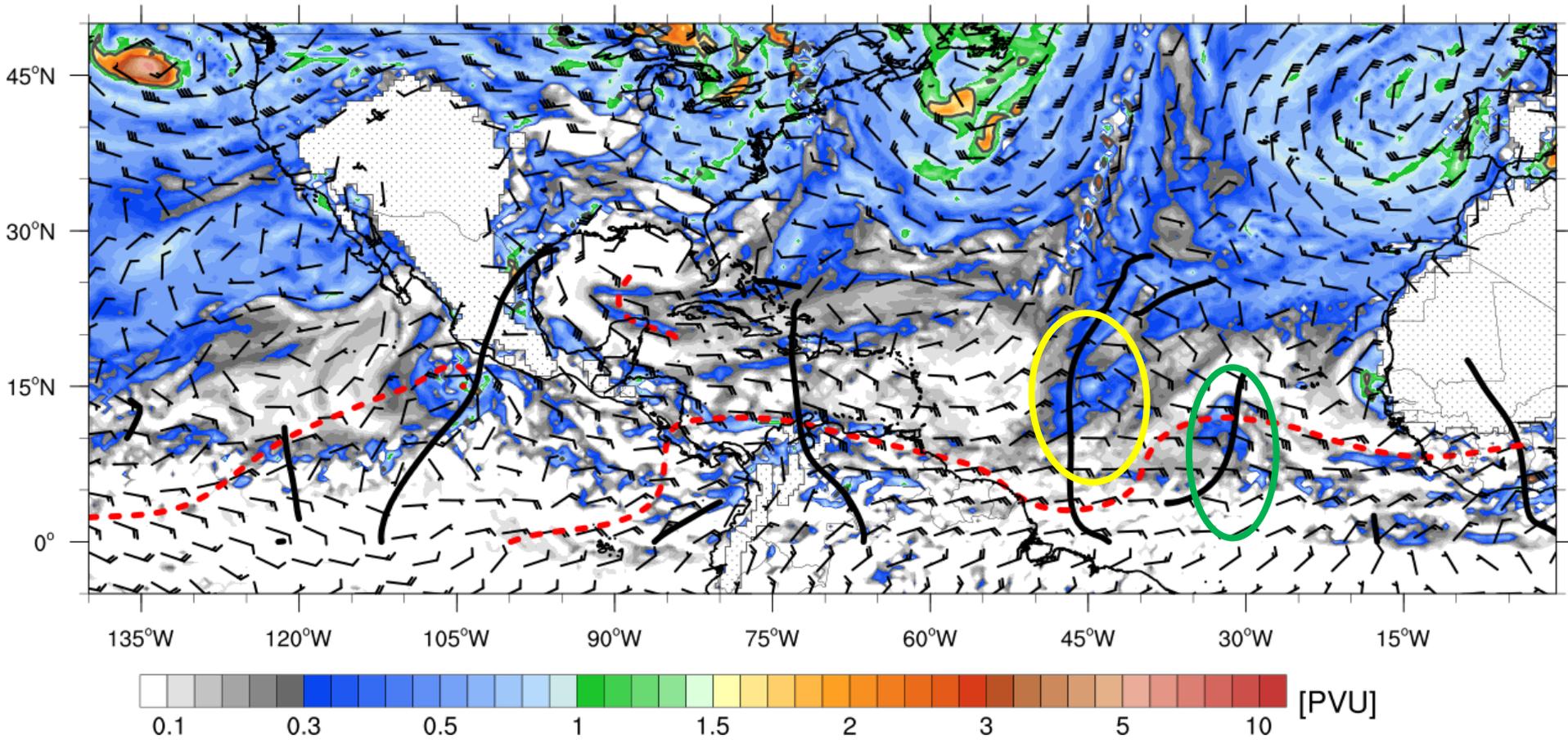
Run: 25 Jun 12Z, Forecast: 0 hr, Valid: 25 Jun 12Z



GFS 310K Potential Vorticity and Wind

PV (PVU = $10^6 \text{ K kg}^{-1} \text{ m}^2 \text{ s}^{-1}$, shaded; 1.5 PVU bold black contour) and Wind (kts, barbs)

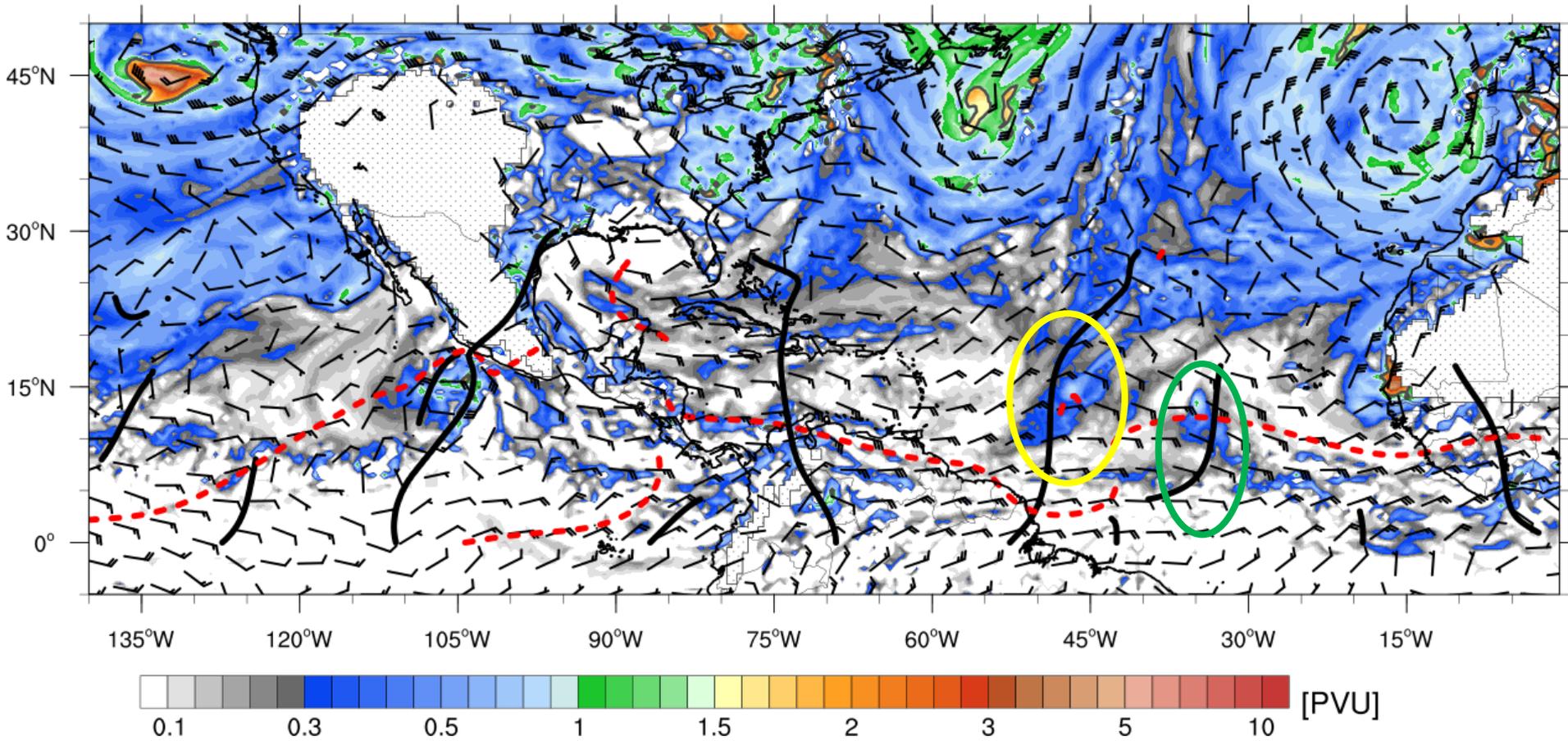
Run: 25 Jun 18Z, Forecast: 0 hr, Valid: 25 Jun 18Z



GFS 310K Potential Vorticity and Wind

PV (PVU = $10^6 \text{ K kg}^{-1} \text{ m}^2 \text{ s}^{-1}$, shaded; 1.5 PVU bold black contour) and Wind (kts, barbs)

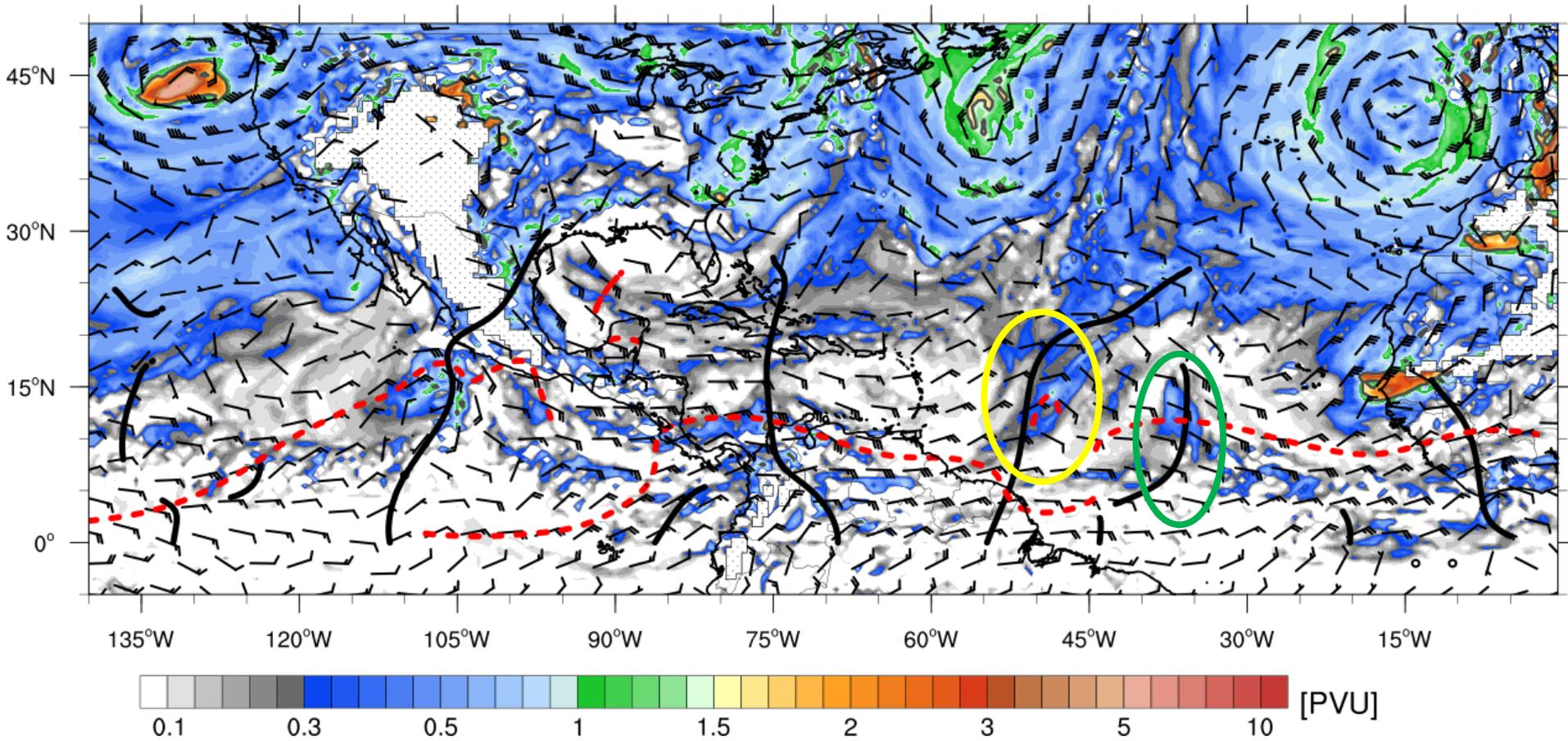
Run: 26 Jun 00Z, Forecast: 0 hr, Valid: 26 Jun 00Z



GFS 310K Potential Vorticity and Wind

PV (PVU = $10^6 \text{ K kg}^{-1} \text{ m}^2 \text{ s}^{-1}$, shaded; 1.5 PVU bold black contour) and Wind (kts, barbs)

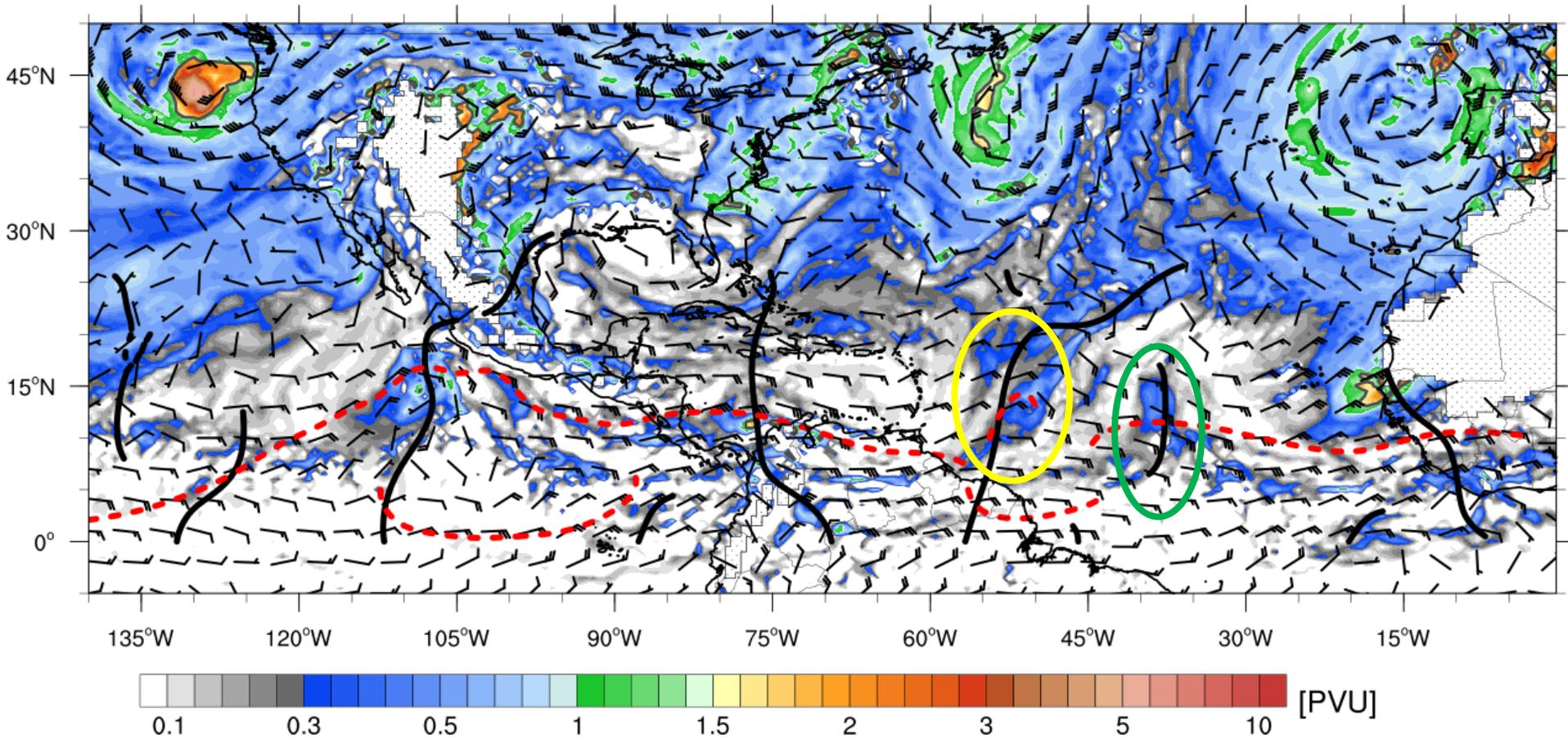
Run: 26 Jun 06Z, Forecast: 0 hr, Valid: 26 Jun 06Z



GFS 310K Potential Vorticity and Wind

PV (PVU = $10^6 \text{ K kg}^{-1} \text{ m}^2 \text{ s}^{-1}$, shaded; 1.5 PVU bold black contour) and Wind (kts, barbs)

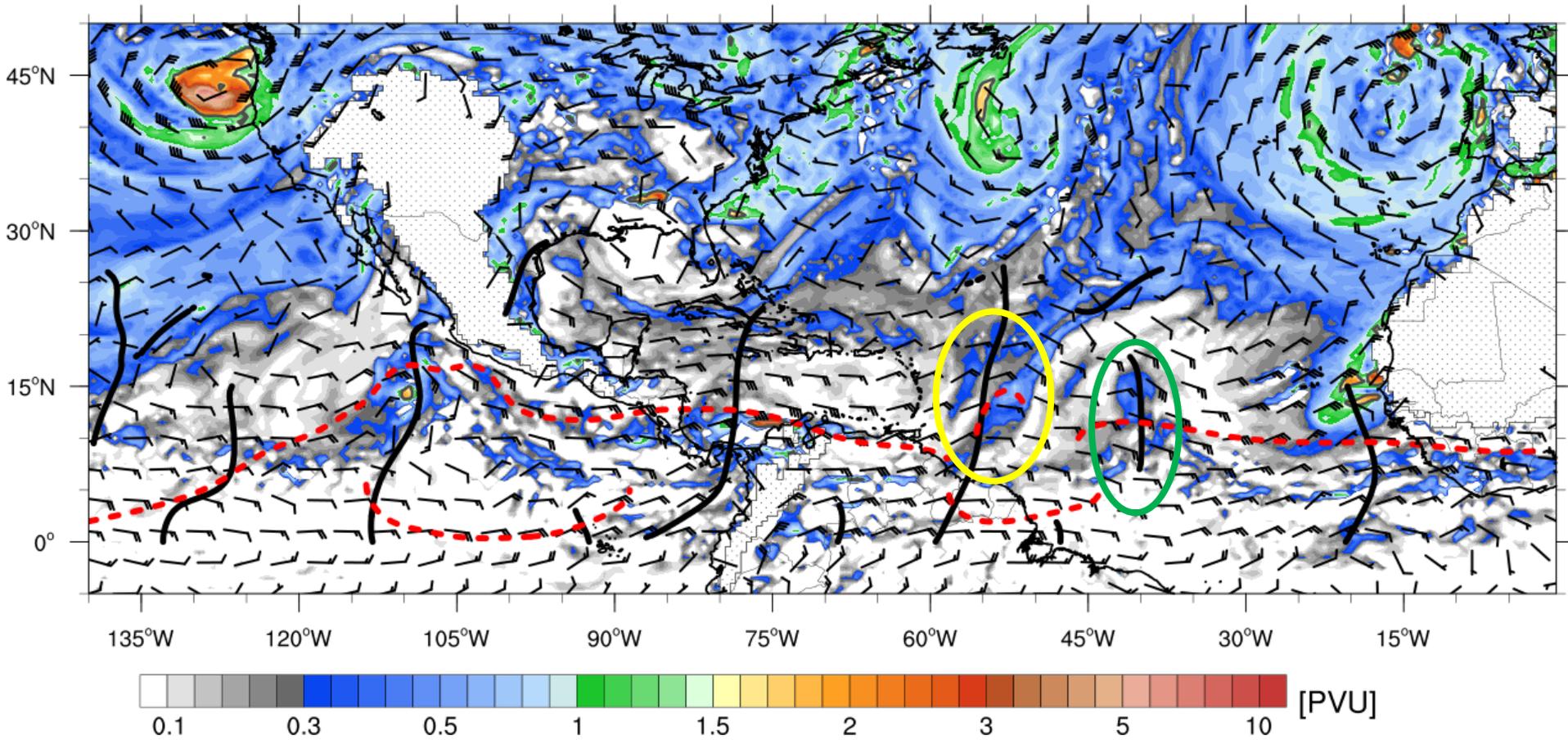
Run: 26 Jun 12Z, Forecast: 0 hr, Valid: 26 Jun 12Z



GFS 310K Potential Vorticity and Wind

PV (PVU = $10^6 \text{ K kg}^{-1} \text{ m}^2 \text{ s}^{-1}$, shaded; 1.5 PVU bold black contour) and Wind (kts, barbs)

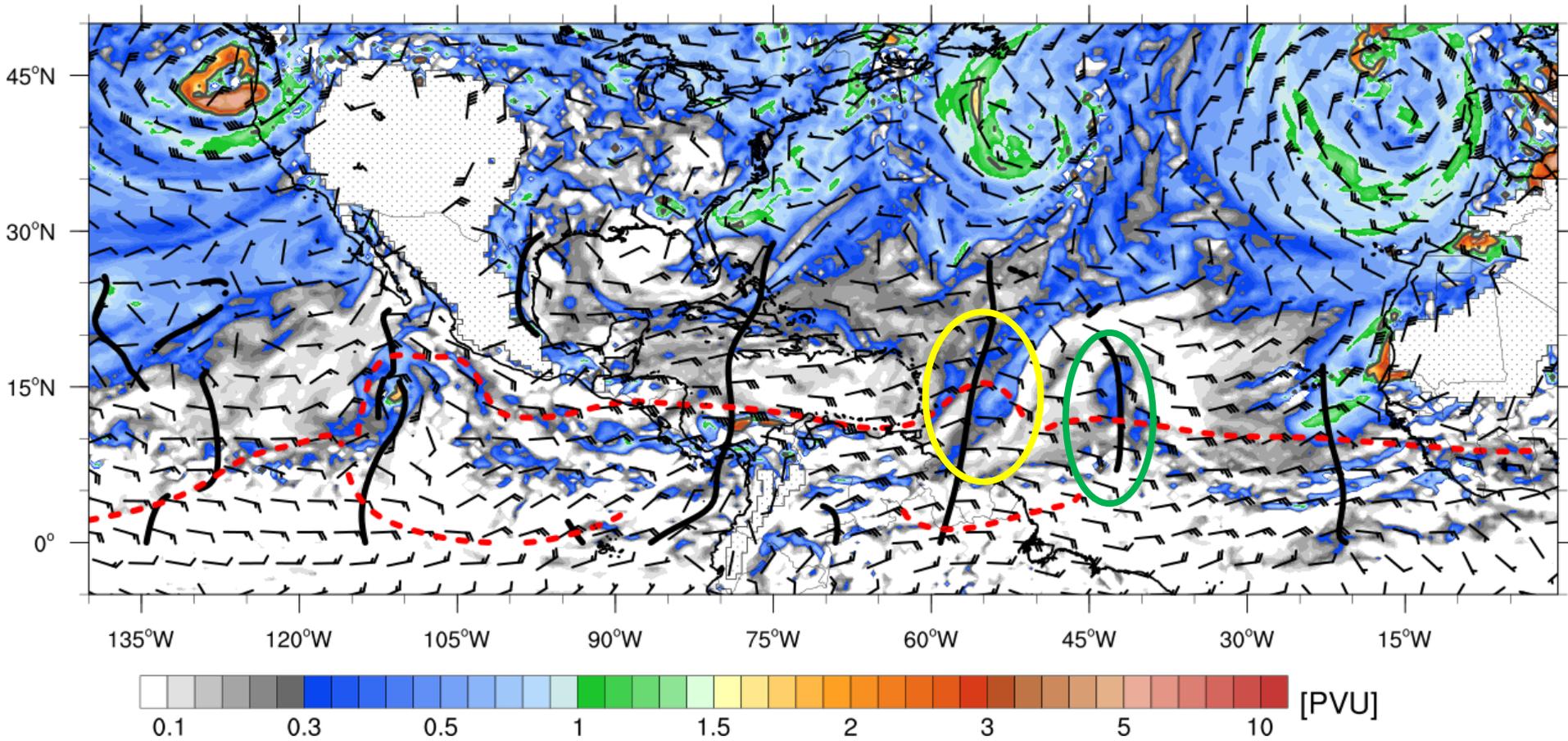
Run: 26 Jun 18Z, Forecast: 0 hr, Valid: 26 Jun 18Z



GFS 310K Potential Vorticity and Wind

PV (PVU = $10^6 \text{ K kg}^{-1} \text{ m}^2 \text{ s}^{-1}$, shaded; 1.5 PVU bold black contour) and Wind (kts, barbs)

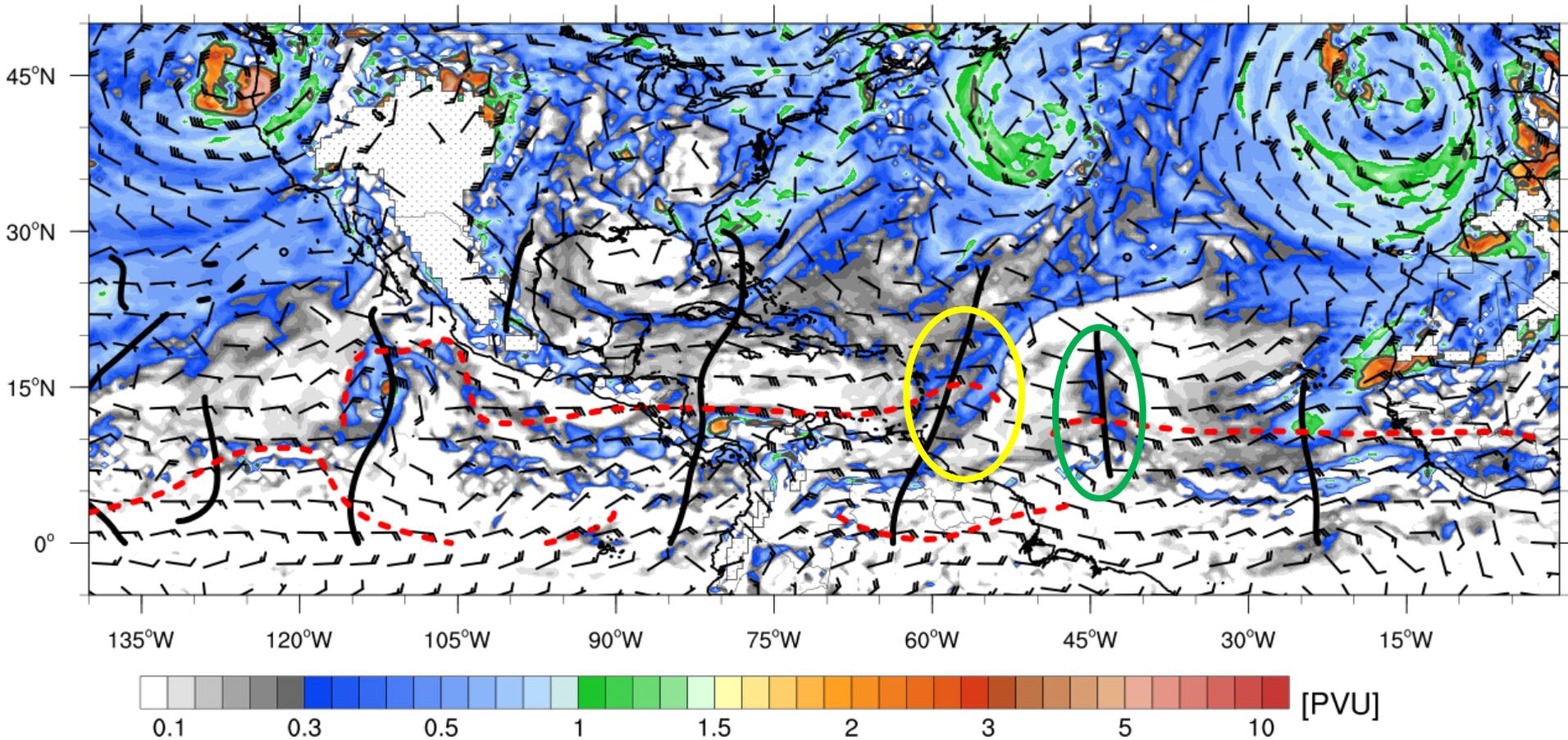
Run: 27 Jun 00Z, Forecast: 0 hr, Valid: 27 Jun 00Z



GFS 310K Potential Vorticity and Wind

PV (PVU = $10^6 \text{ K kg}^{-1} \text{ m}^2 \text{ s}^{-1}$, shaded; 1.5 PVU bold black contour) and Wind (kts, barbs)

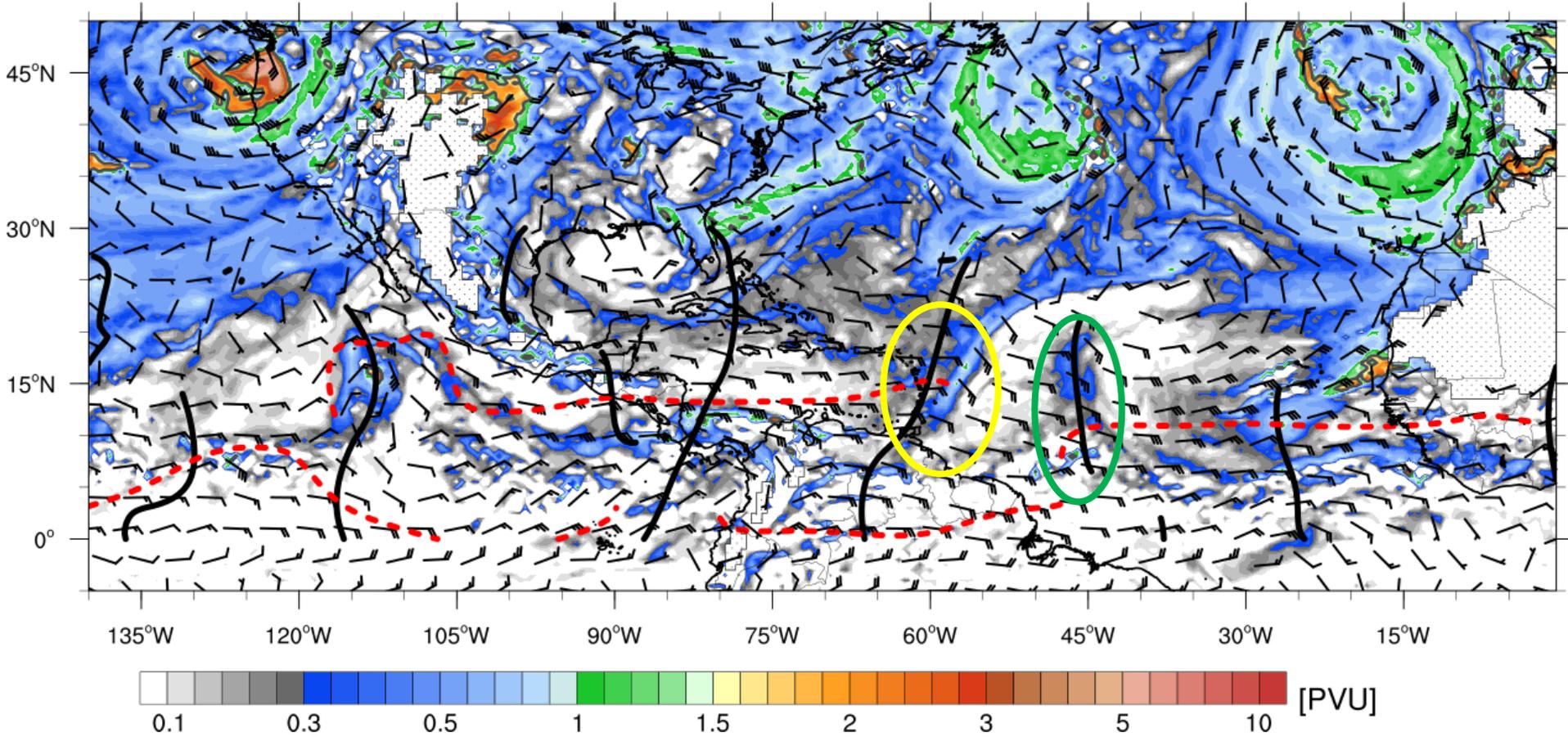
Run: 27 Jun 06Z, Forecast: 0 hr, Valid: 27 Jun 06Z



GFS 310K Potential Vorticity and Wind

PV (PVU = $10^6 \text{ K kg}^{-1} \text{ m}^2 \text{ s}^{-1}$, shaded; 1.5 PVU bold black contour) and Wind (kts, barbs)

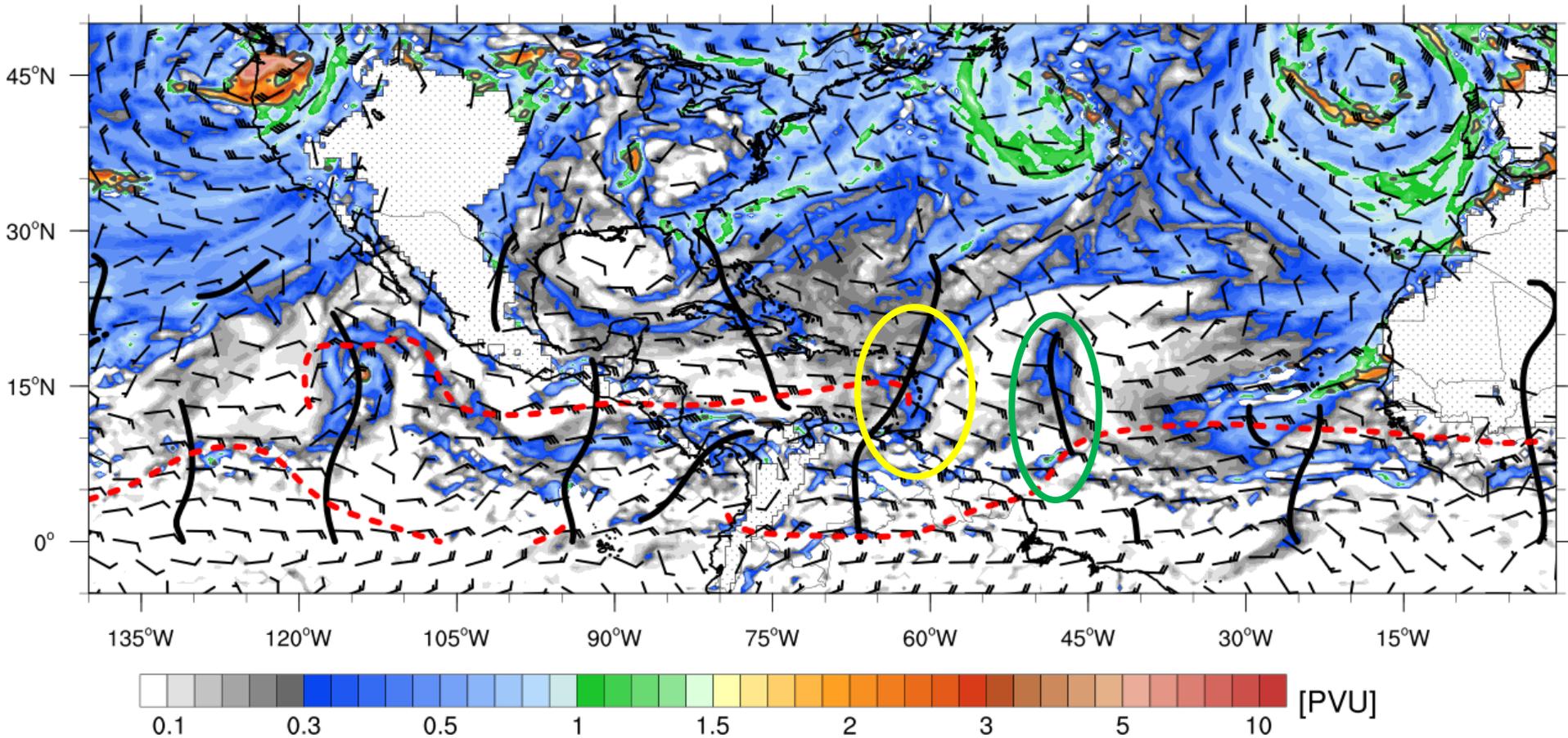
Run: 27 Jun 12Z, Forecast: 0 hr, Valid: 27 Jun 12Z



GFS 310K Potential Vorticity and Wind

PV (PVU = $10^6 \text{ K kg}^{-1} \text{ m}^2 \text{ s}^{-1}$, shaded; 1.5 PVU bold black contour) and Wind (kts, barbs)

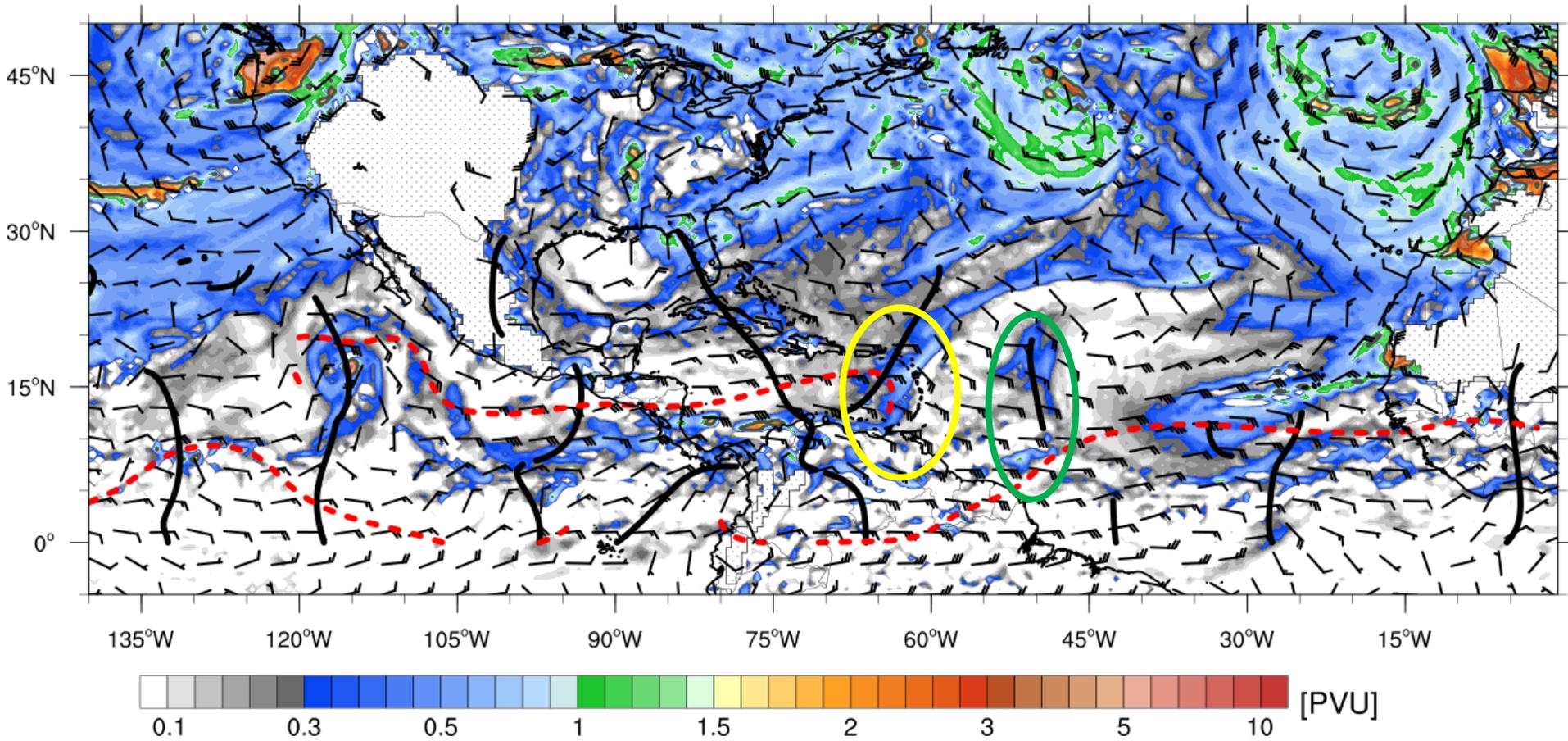
Run: 27 Jun 18Z, Forecast: 0 hr, Valid: 27 Jun 18Z

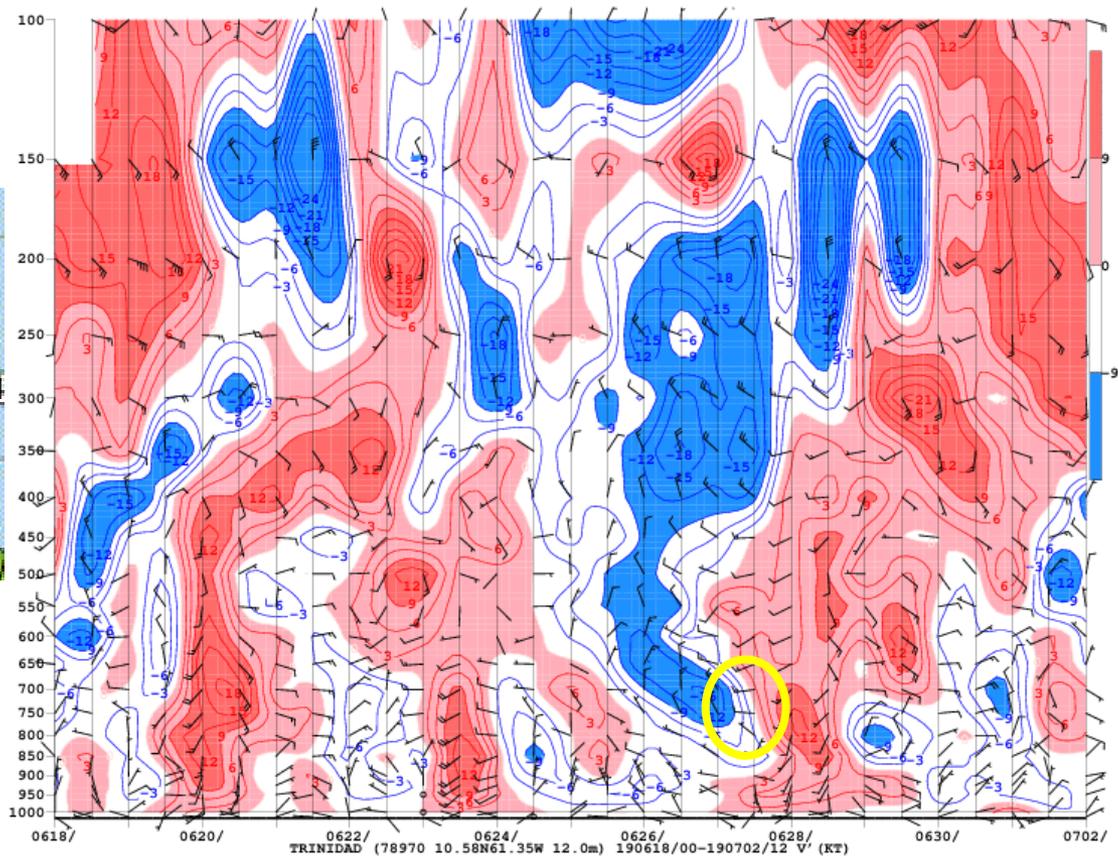
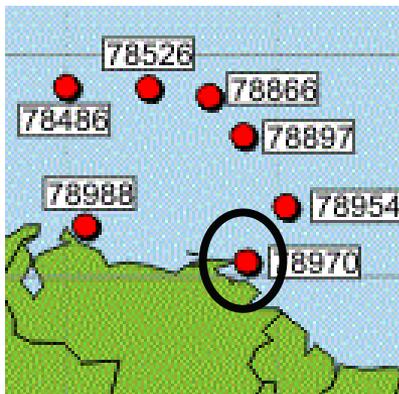


GFS 310K Potential Vorticity and Wind

PV (PVU = $10^6 \text{ K kg}^{-1} \text{ m}^2 \text{ s}^{-1}$, shaded; 1.5 PVU bold black contour) and Wind (kts, barbs)

Run: 28 Jun 00Z, Forecast: 0 hr, Valid: 28 Jun 00Z



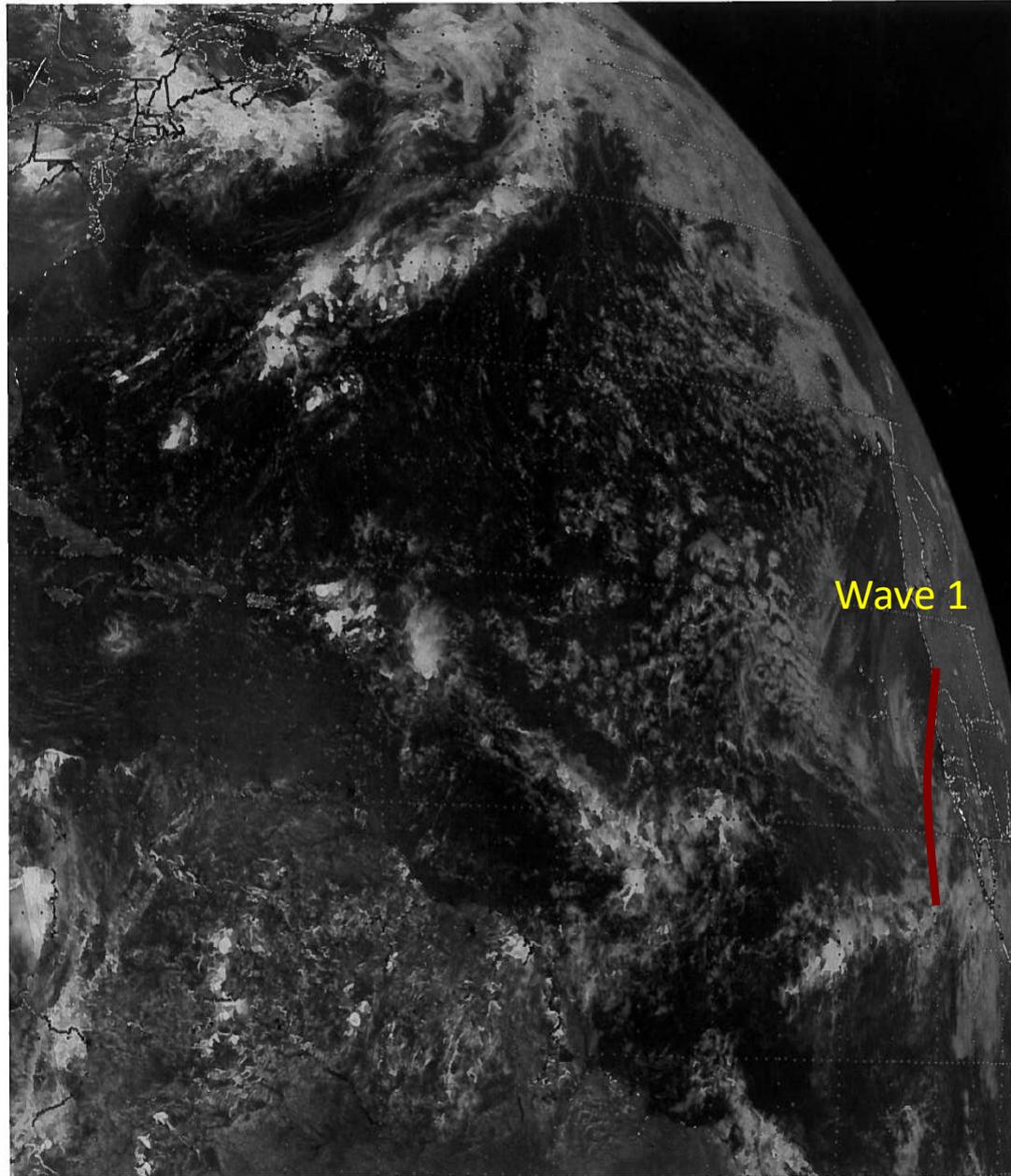


Trinidad upper air sounding v anomaly. The PV streamer passed Trinidad June 27 (yellow oval).

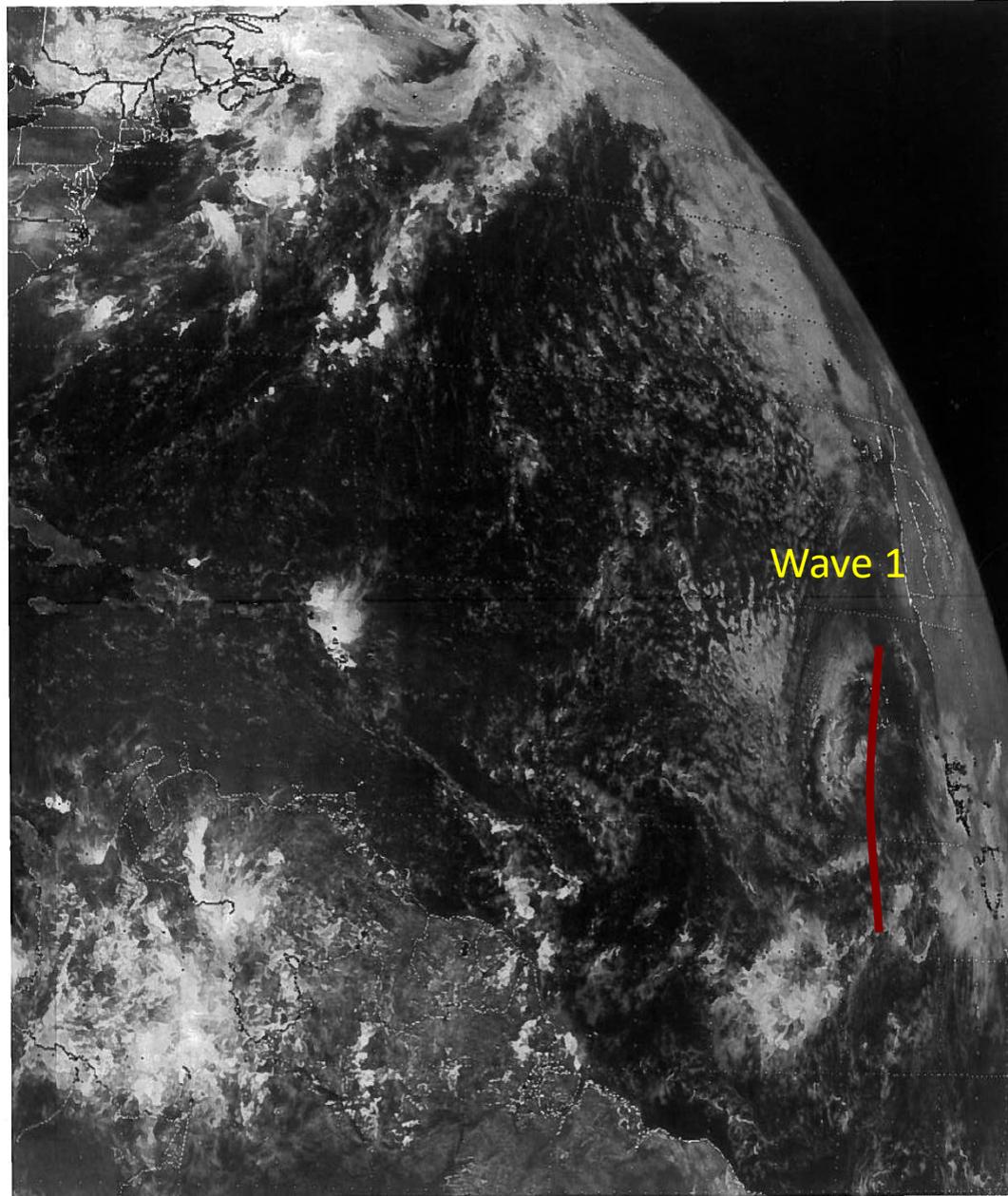


EXERCISE

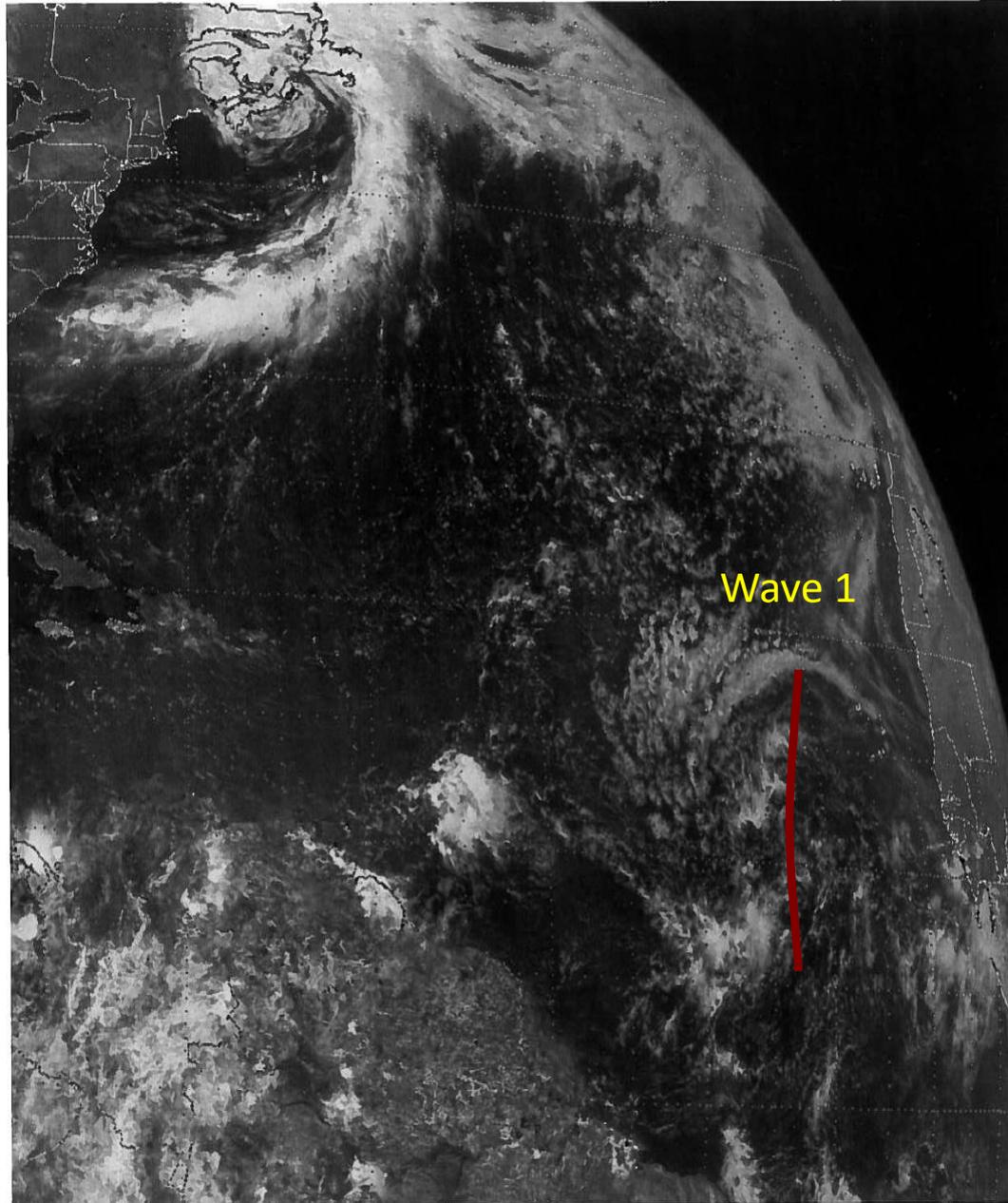
July 13



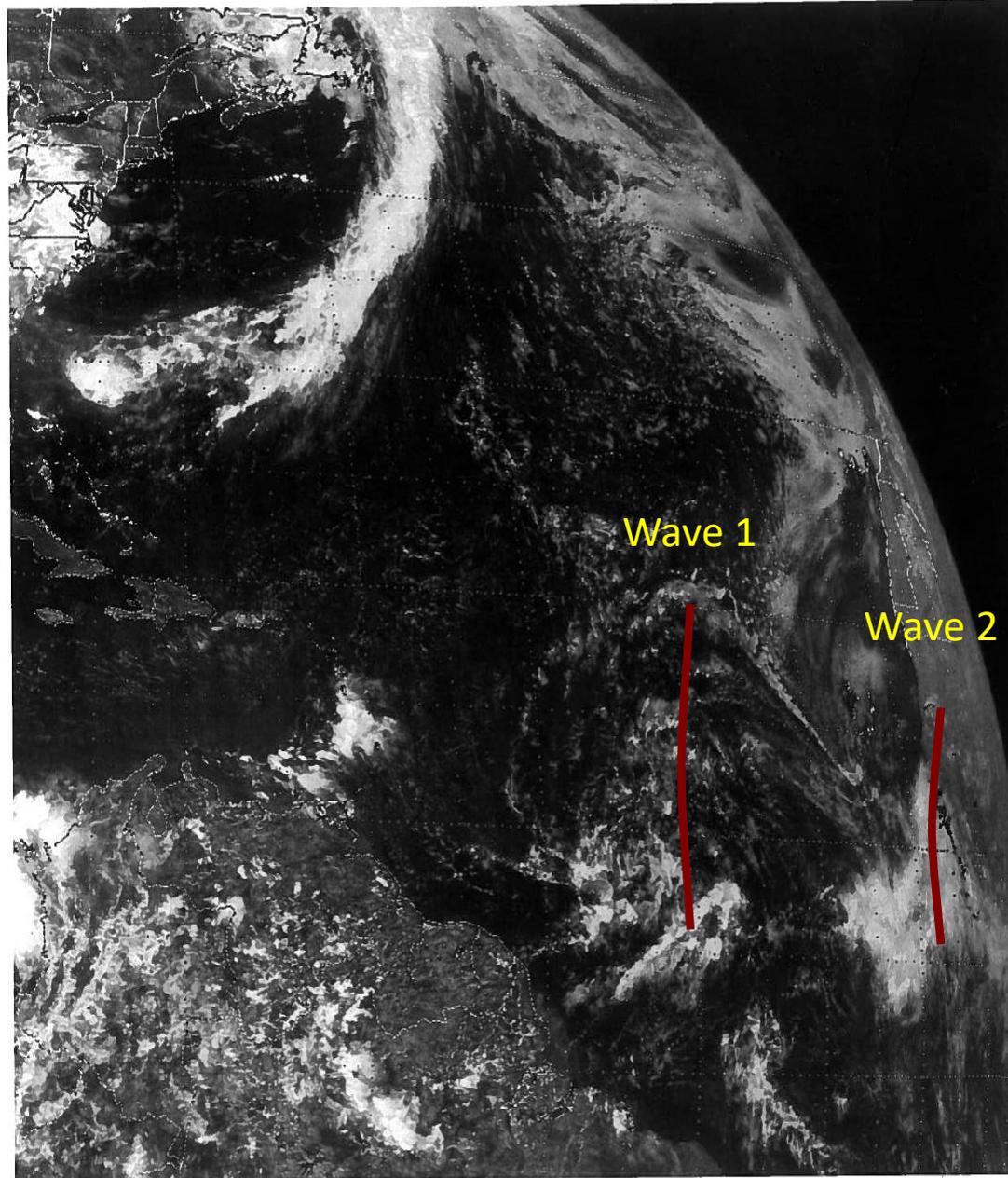
July 14



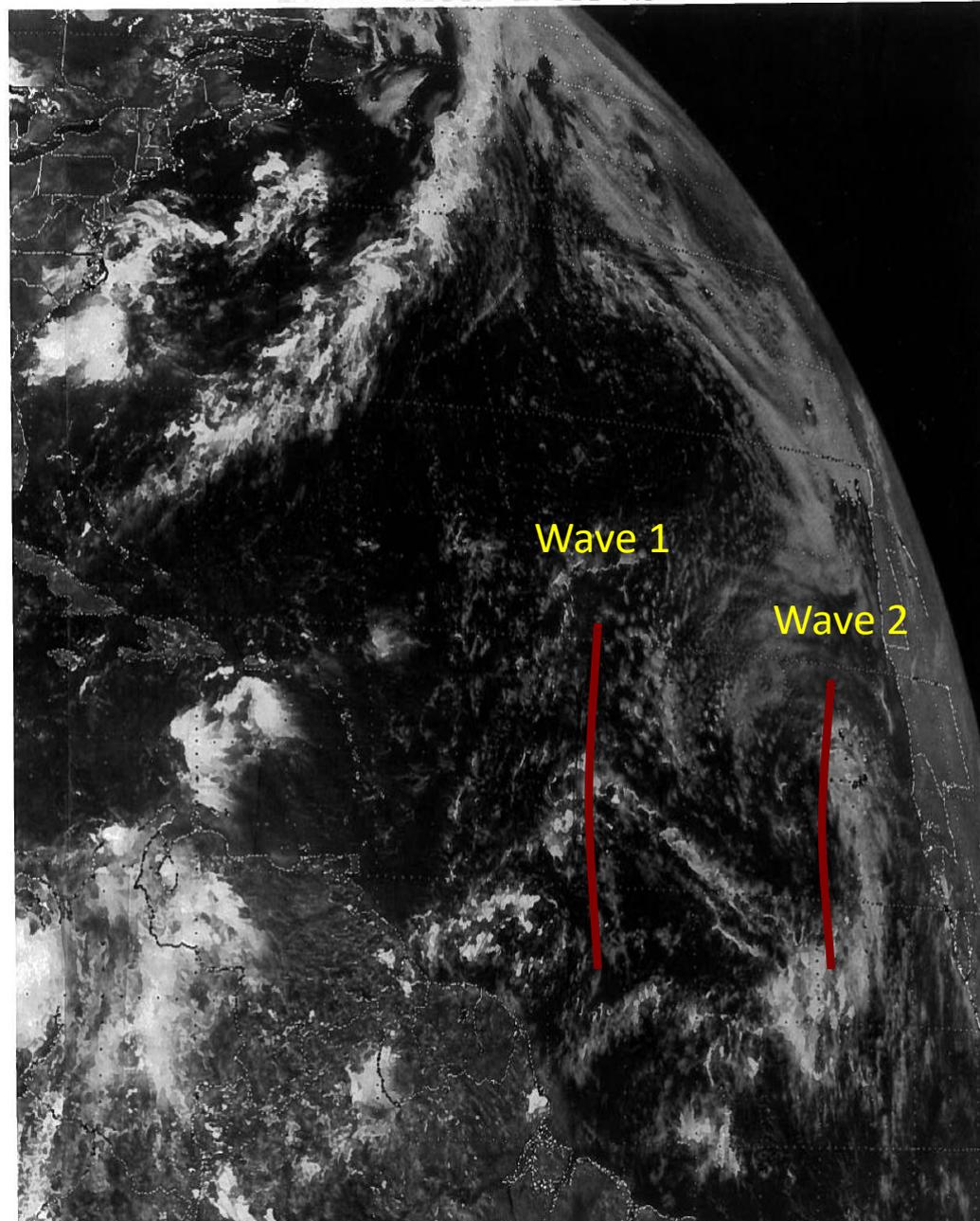
July 15



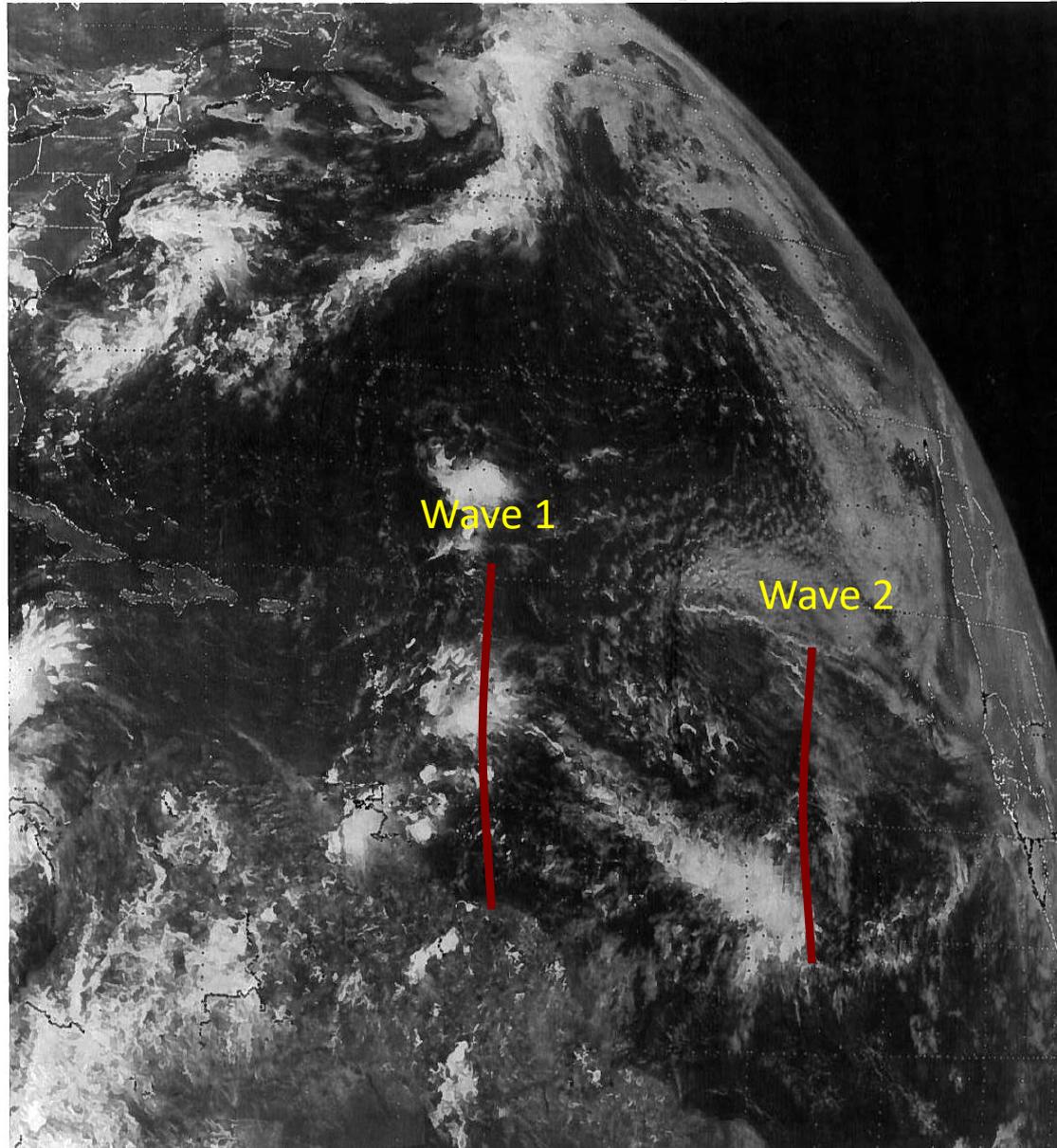
July 16



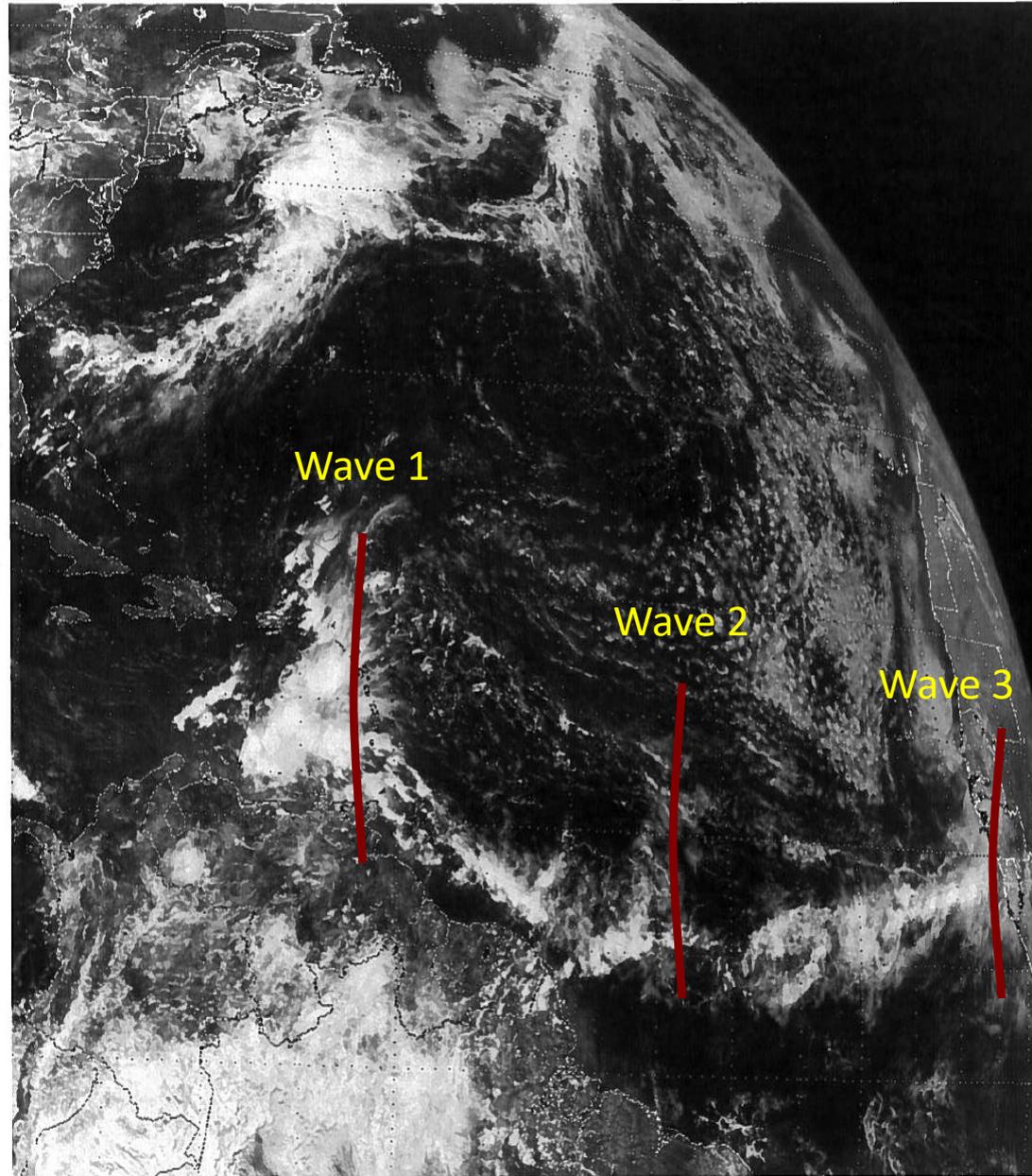
July 17



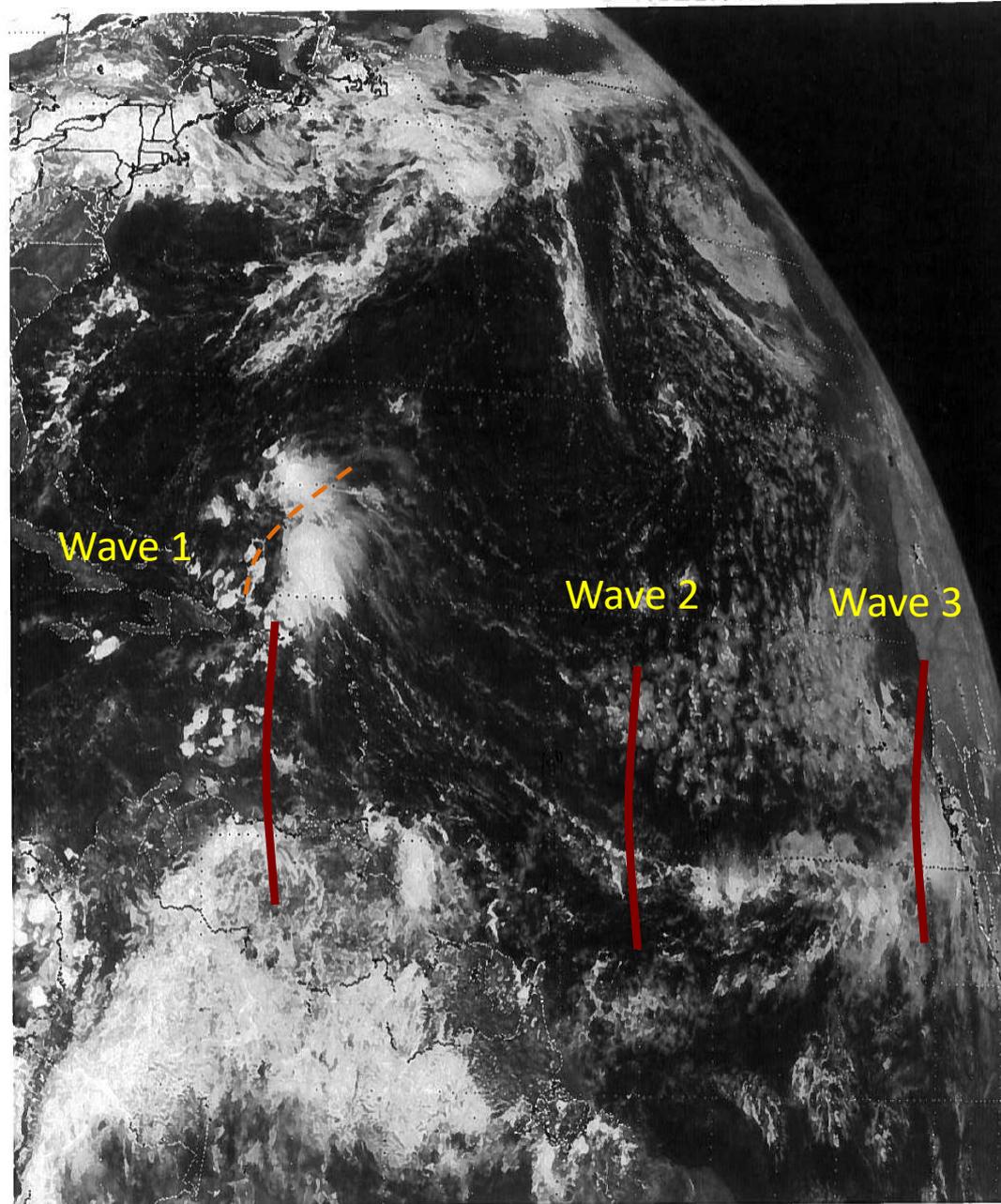
July 18



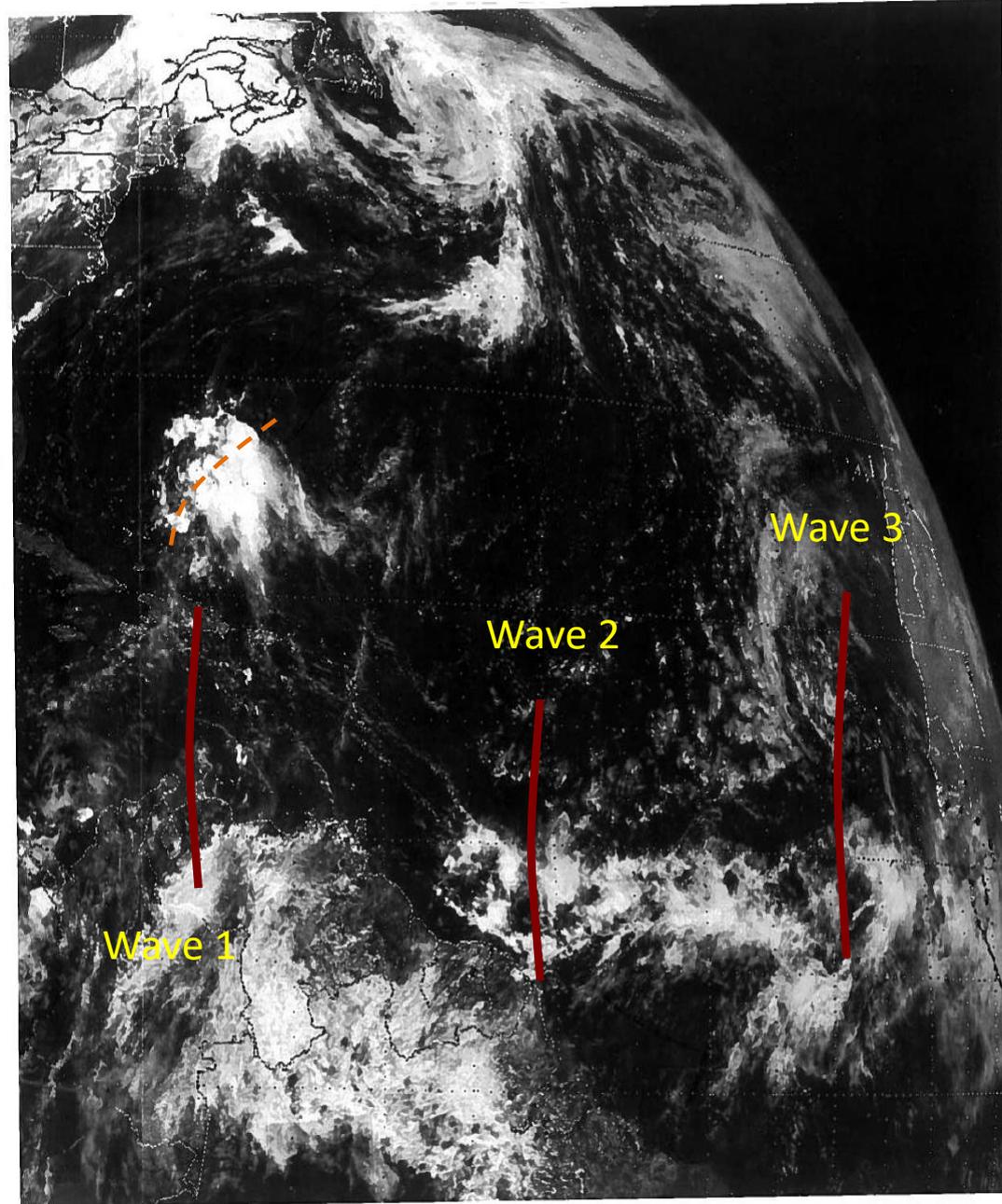
July 19



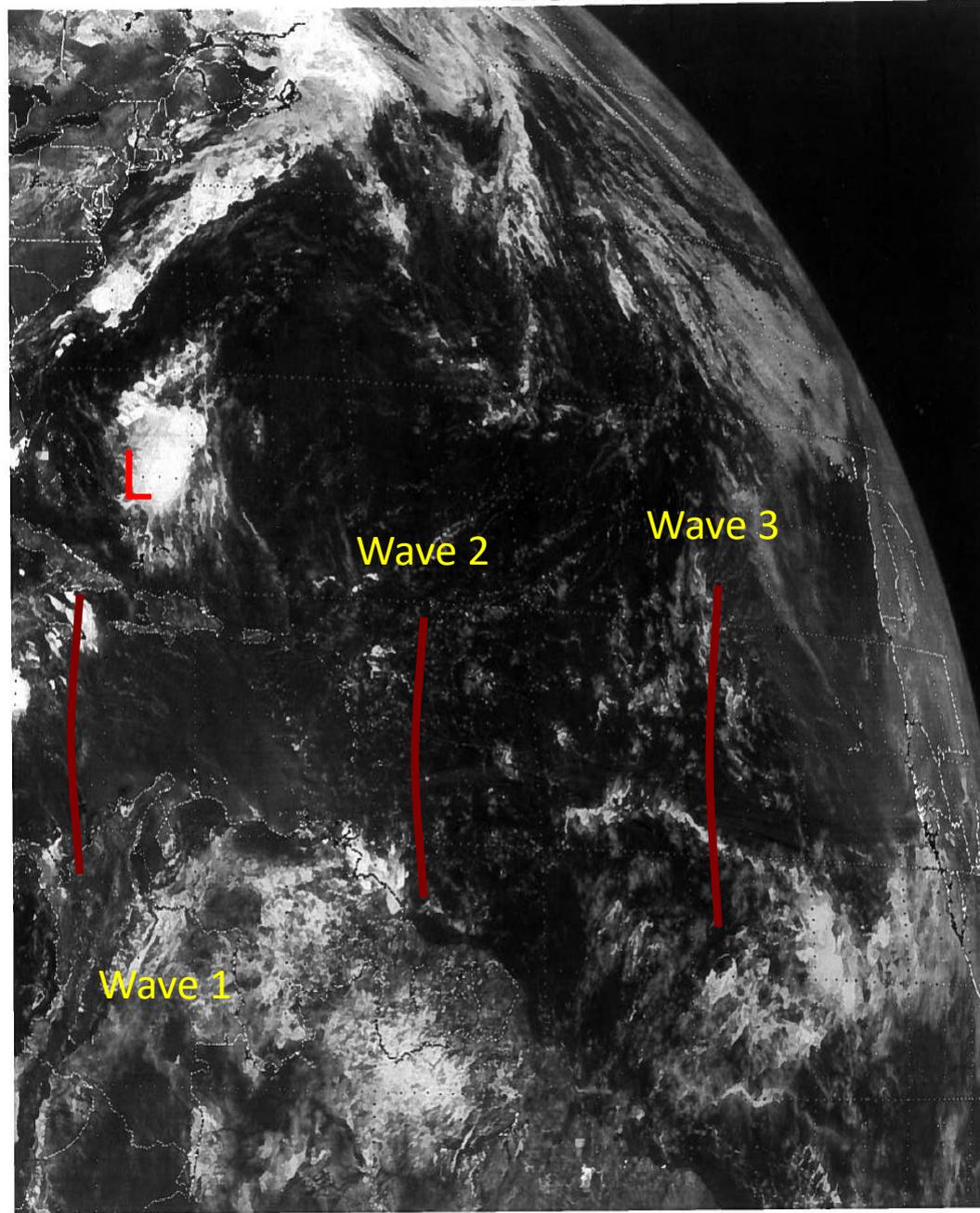
July 20



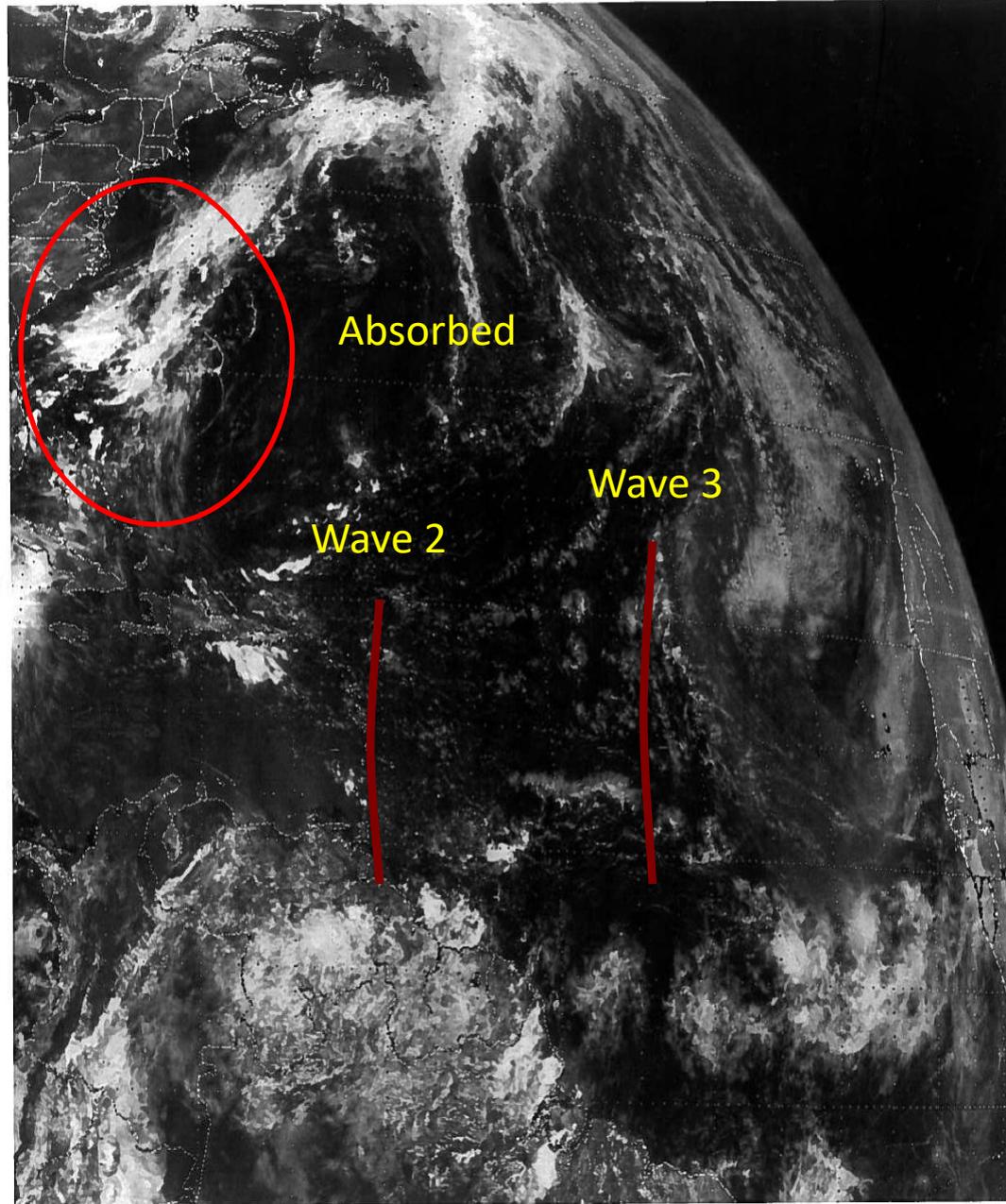
July 21



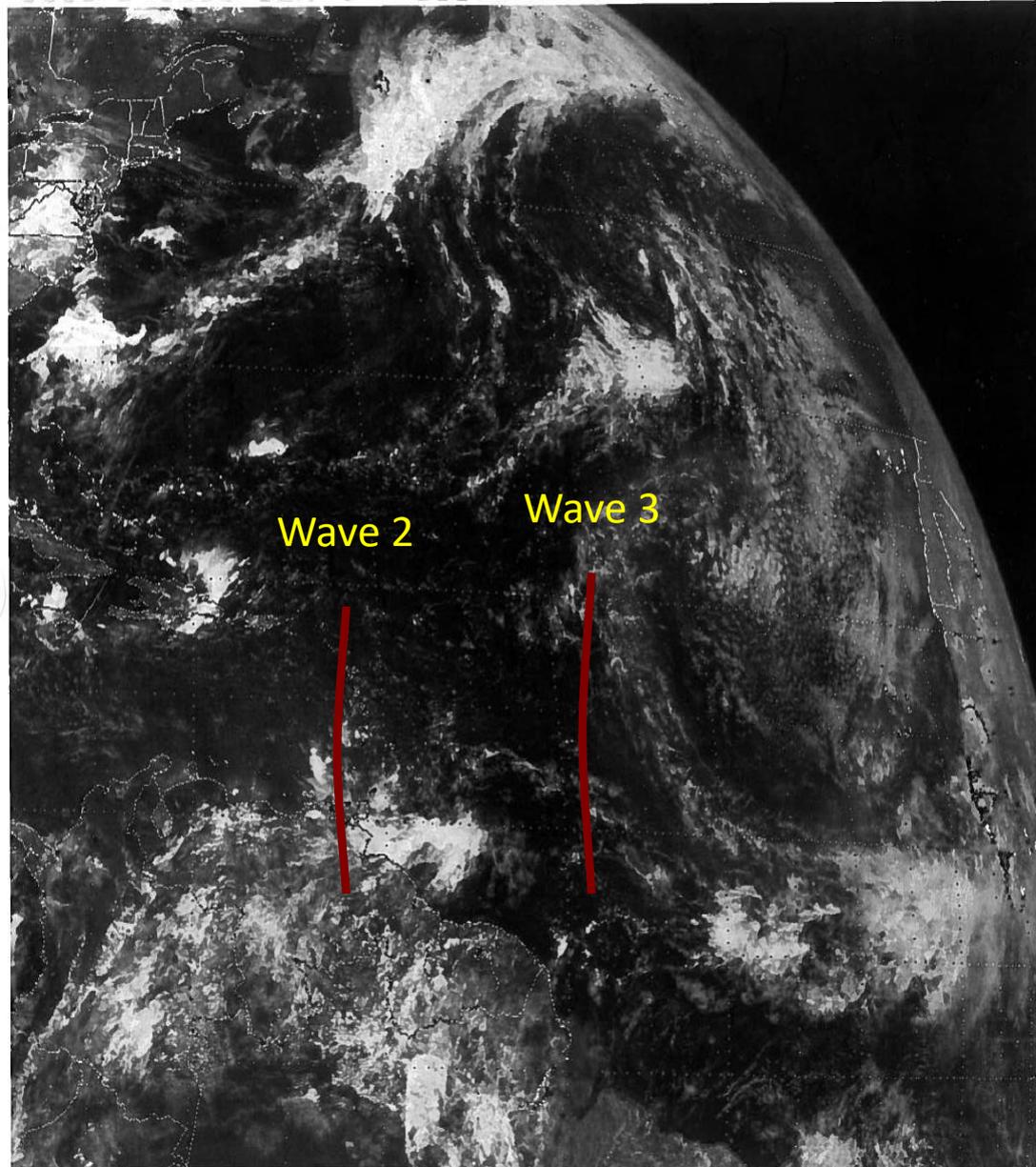
July 22



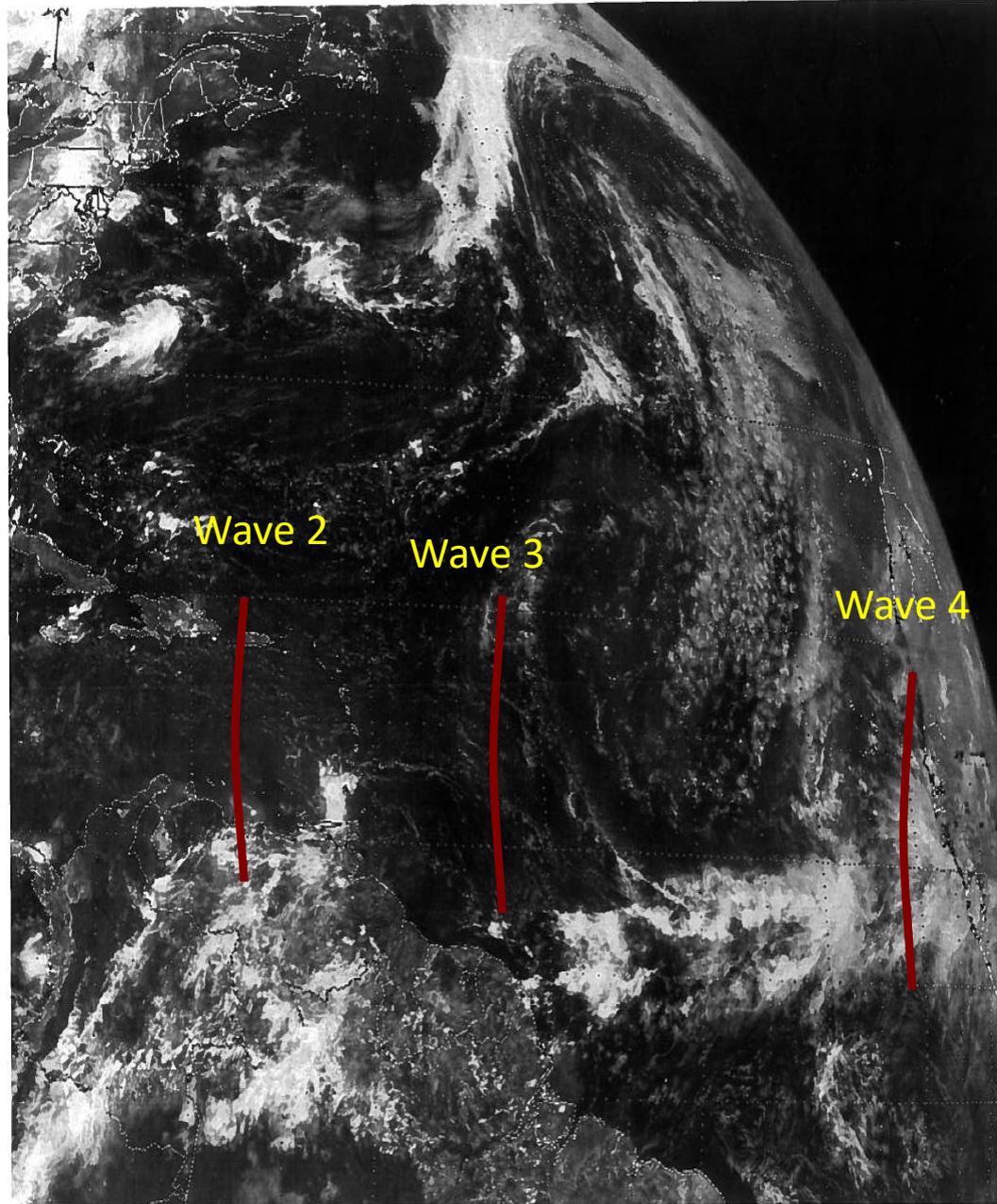
July 23



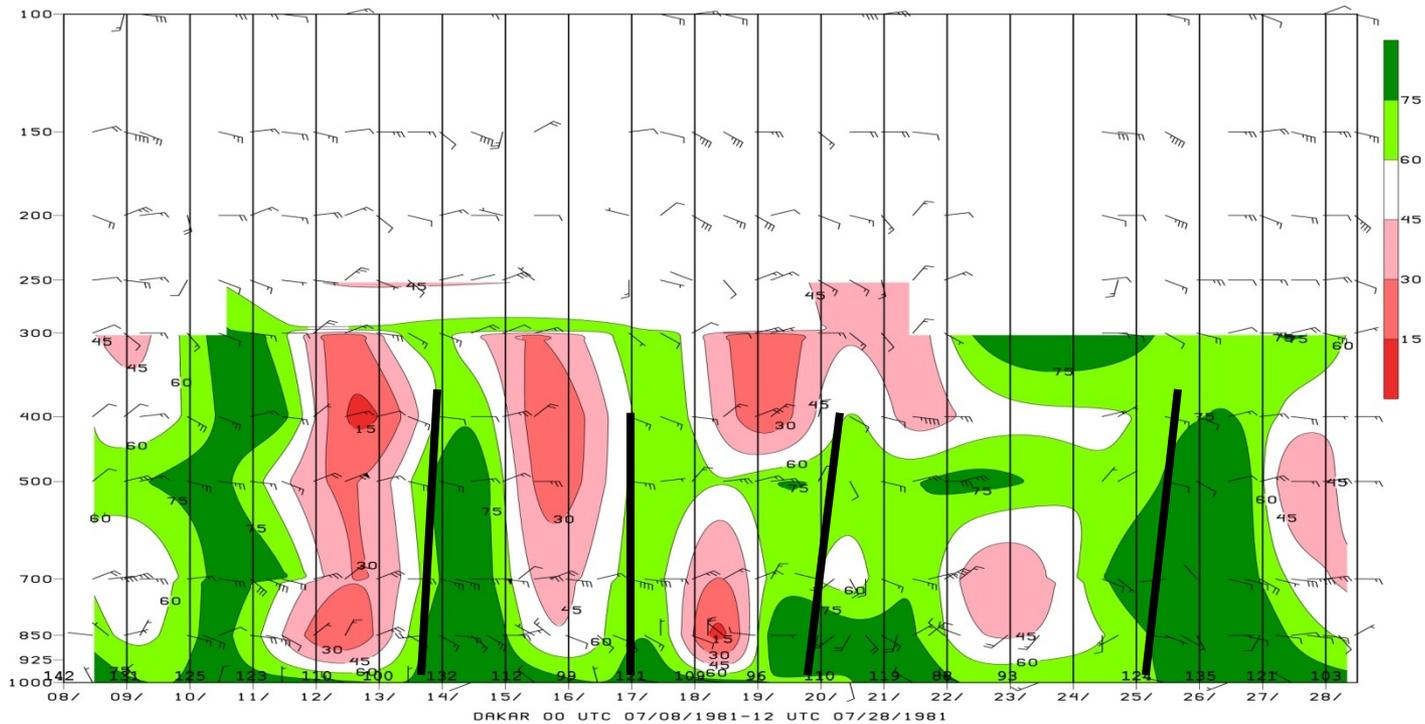
July 24



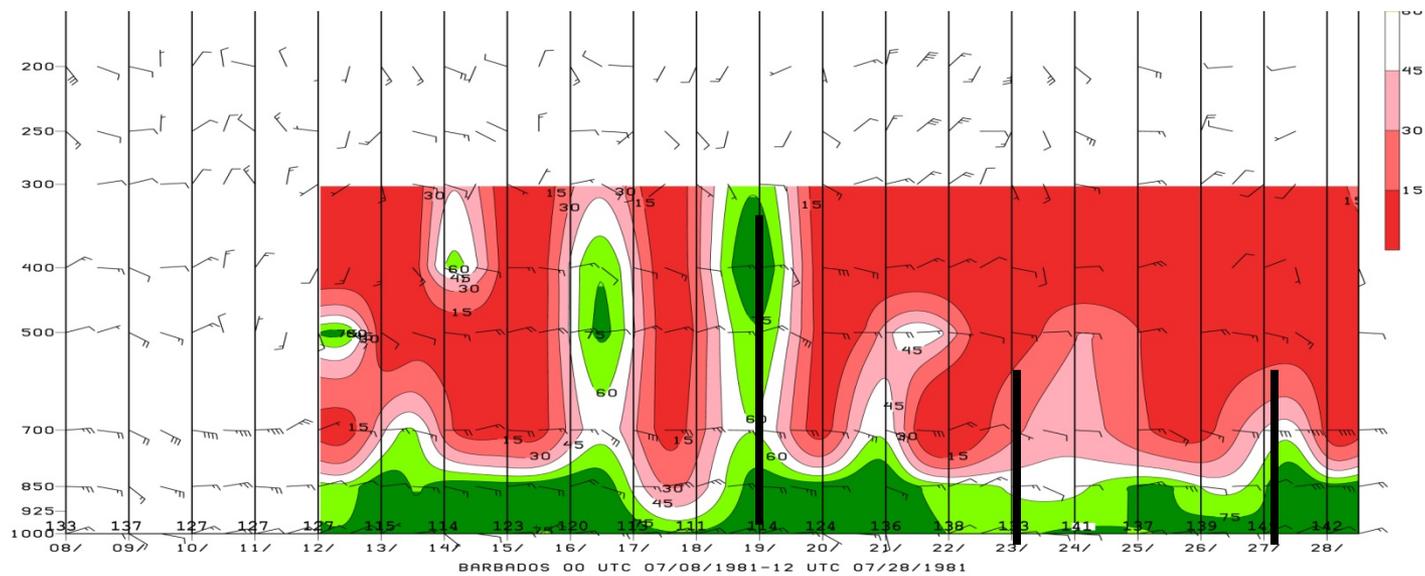
July 25



Dakar



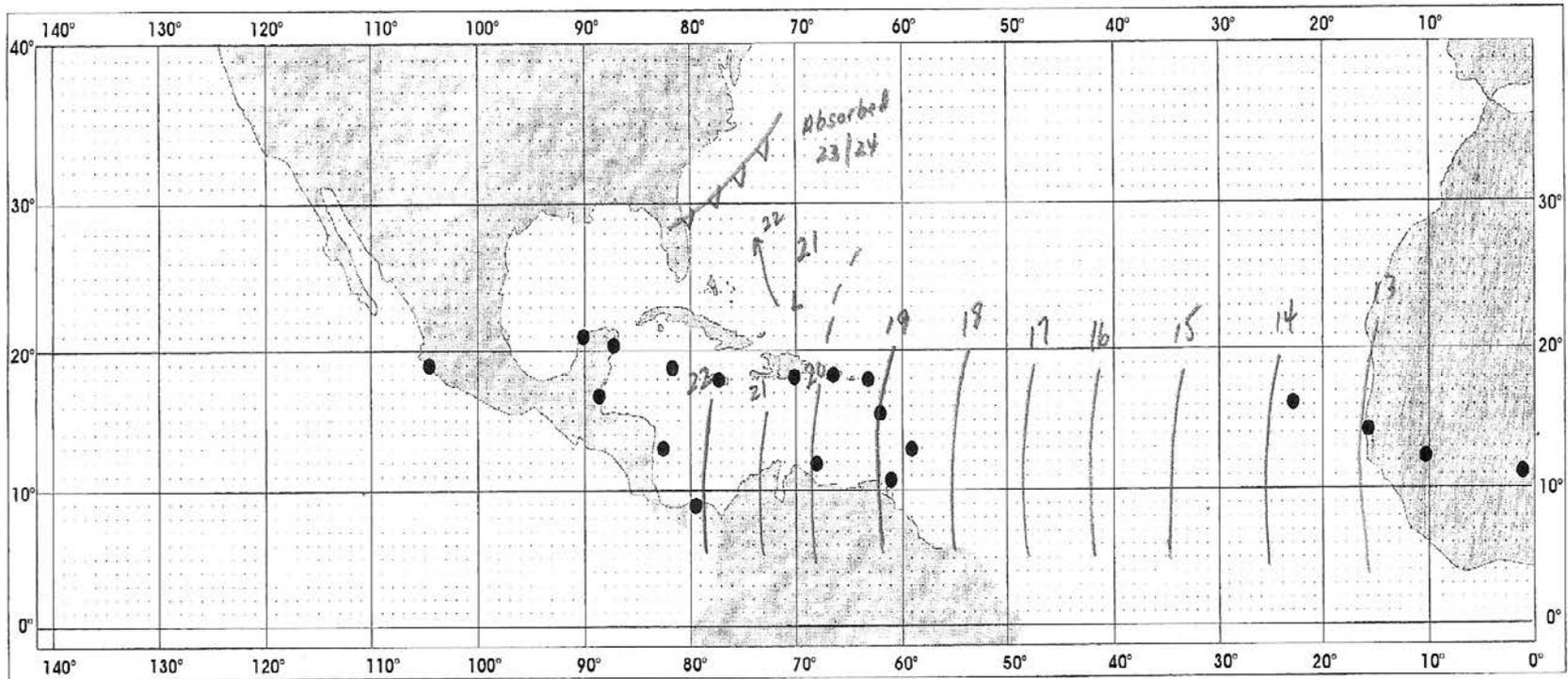
Barbados



Tropical Wave 1

Date: _____

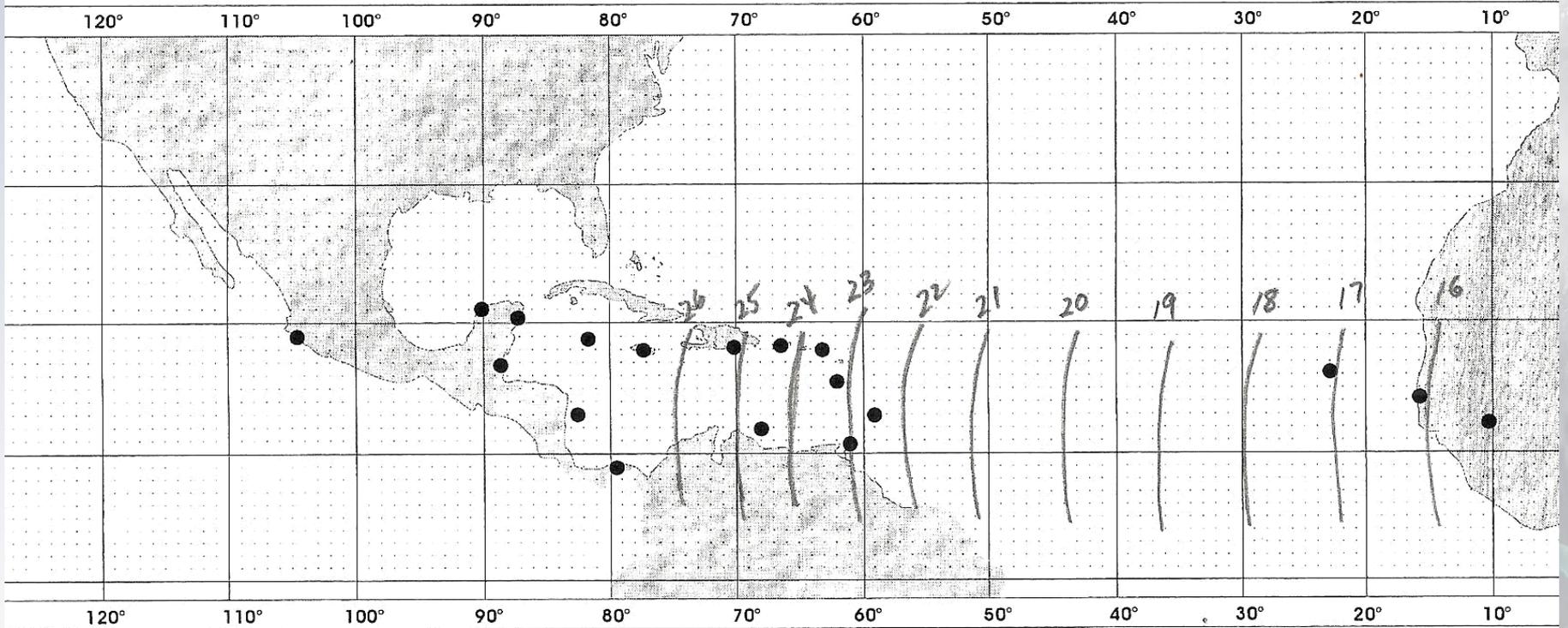
Wave Number: #1



Tropical Wave 2

Date: _____

Wave Number: 2



Tropical Wave 3

Date: _____

Wave Number: 3

