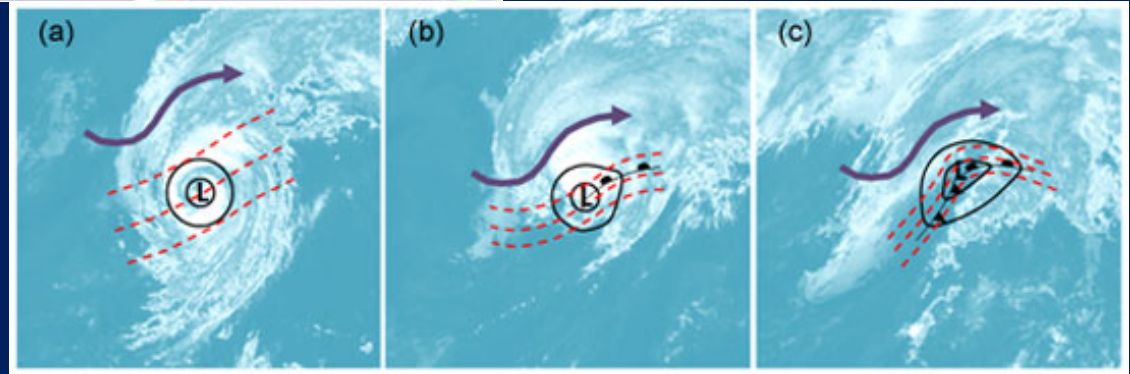
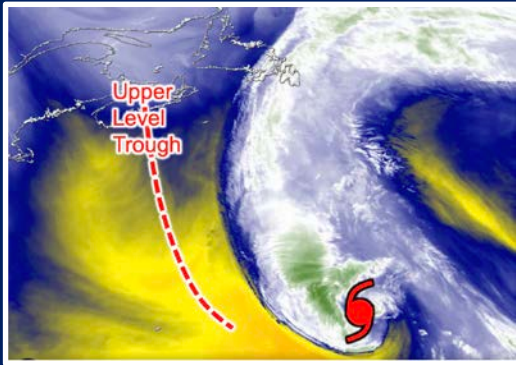
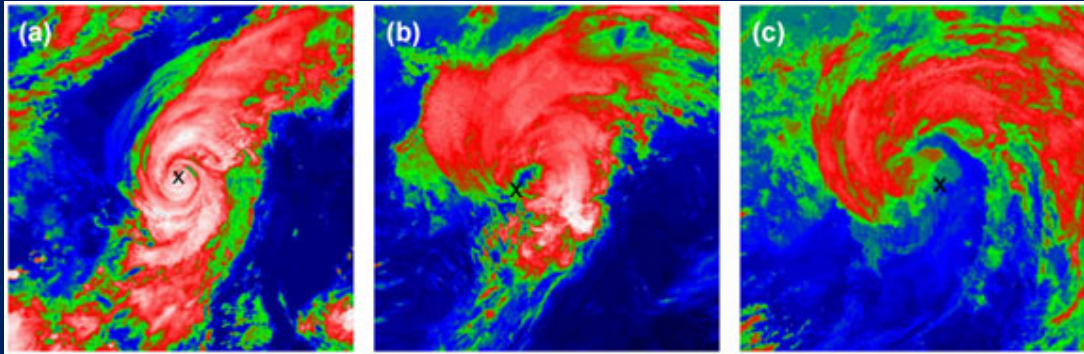


Extratropical Transition



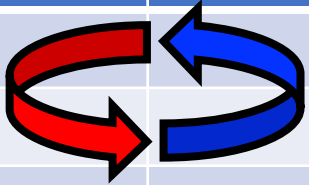
Philippe Papin
National Hurricane Center
World Meteorological Organization Workshop



What is Extratropical Transition

- Process by which tropical cyclones (TCs) transition from a symmetric warm-core vortex into an asymmetric, cold-core baroclinic cyclone as they recurve into the mid-latitudes
- Initiated when a TC moves into higher latitudes with baroclinic westerly flow and interacts with Rossby waves along the midlatitude jet
- Can be a major forecast challenge given rapid structural and track changes that occur at this stage of the storm lifecycle

Tropical Cyclones	Extratropical Cyclones
Non-frontal	Frontal
Warm core	Cold Core
Driven by latent heat release	Driven by baroclinic instability
Wind max close to center & near the ground	Wind max removed from center & aloft
Symmetric precipitation	Precipitation left of track



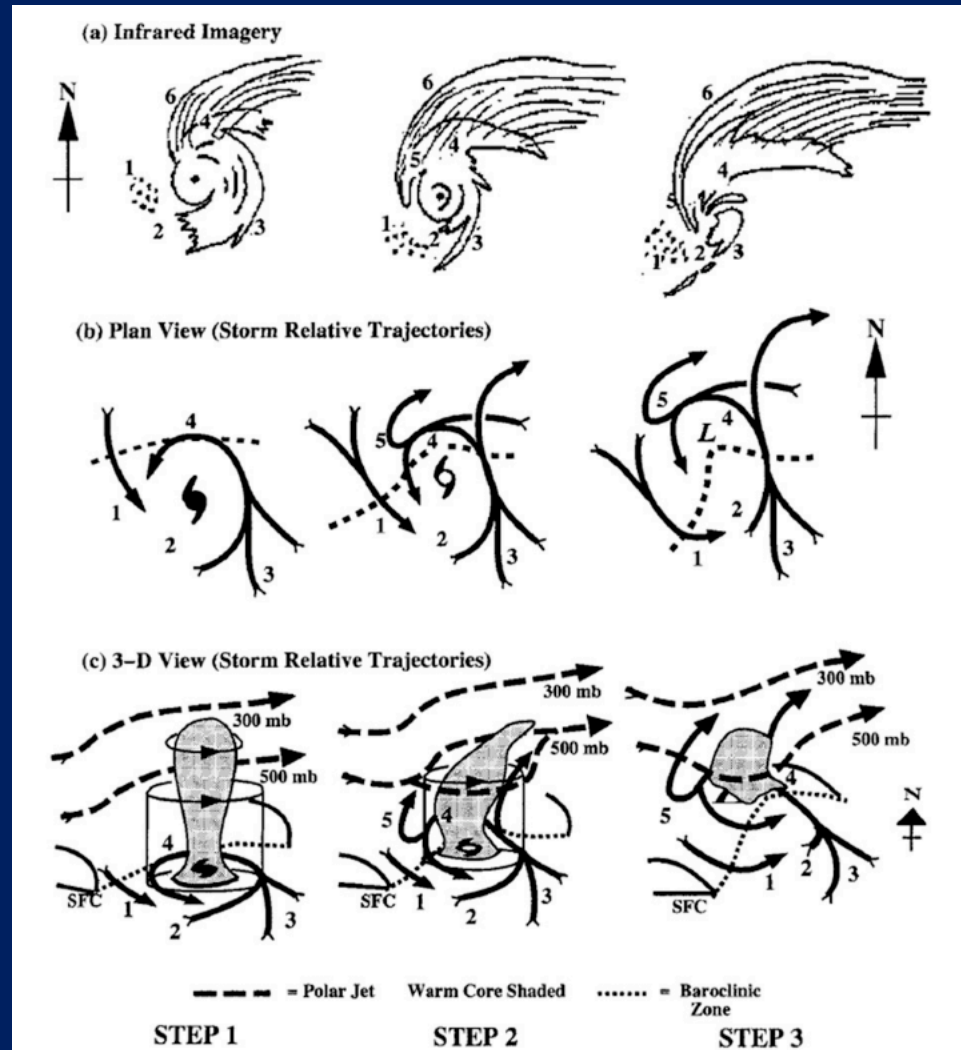
What is Extratropical Transition

- Process can generally be broken down into three general steps

Step 1: Decreasing SSTs & cooler, drier environmental air

Step 2: Increased vertical wind shear (i.e., Thermal Wind)

Step 3: Interaction with baroclinic zone & frontogenesis (front development)



Klein et al. (2000)

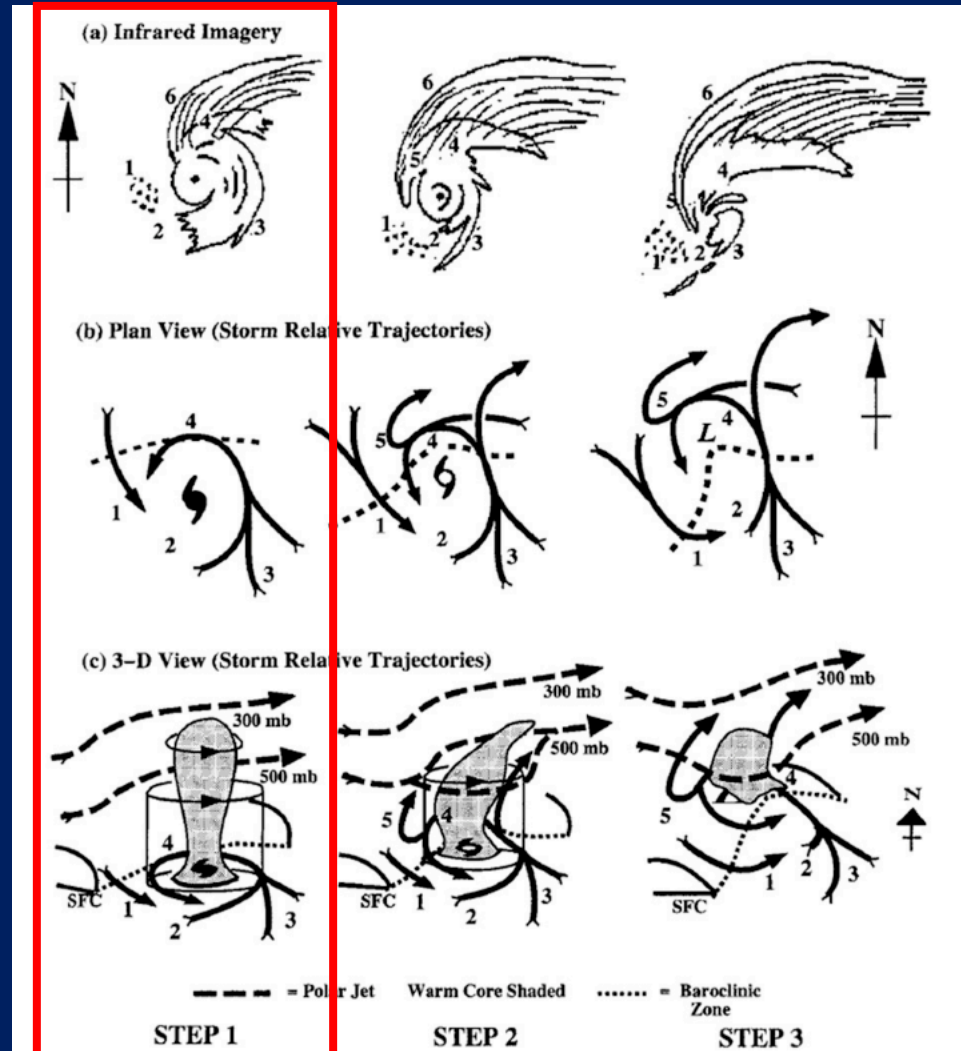
What is Extratropical Transition

- Process can generally be broken down into three general steps

Step 1: Decreasing SSTs & cooler, drier environmental air

Step 2: Increased vertical wind shear (i.e., Thermal Wind)

Step 3: Interaction with baroclinic zone & frontogenesis (front development)



Klein et al. (2000)

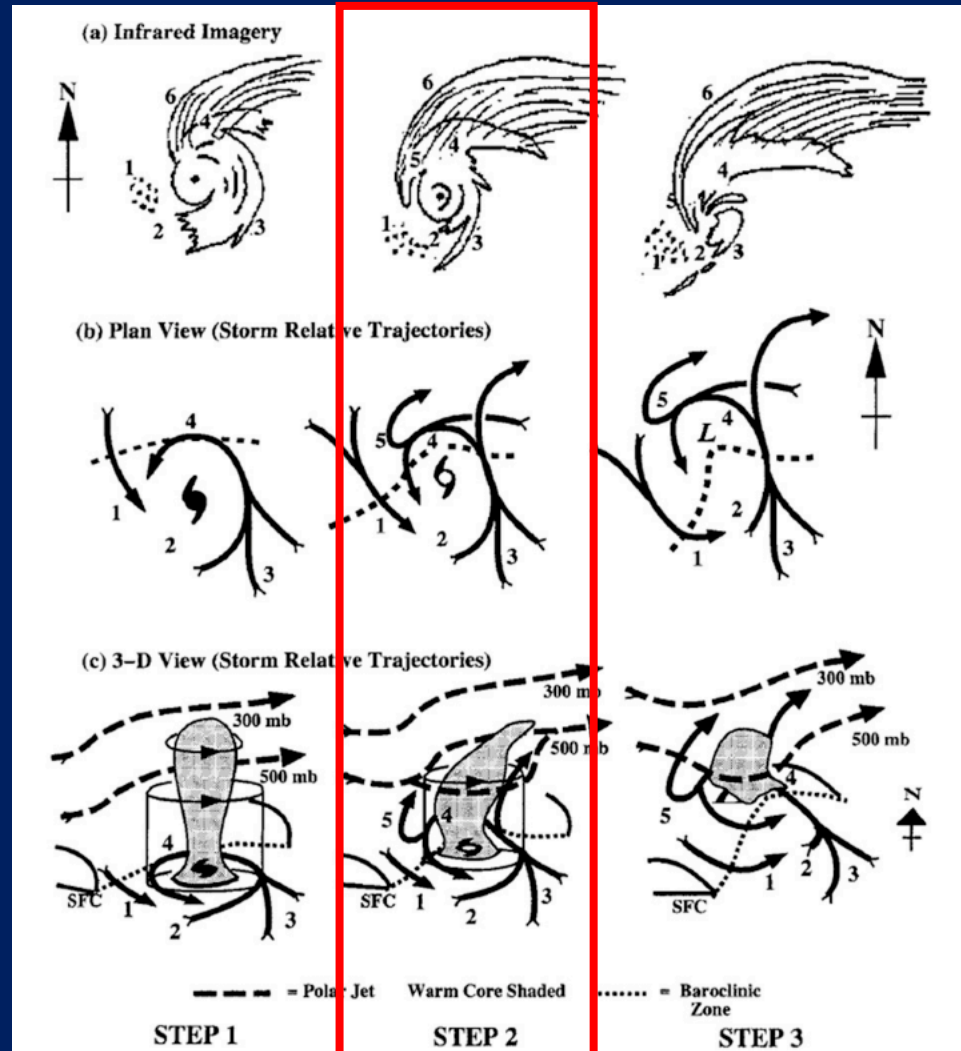
What is Extratropical Transition

- Process can generally be broken down into three general steps

Step 1: Decreasing SSTs & cooler, drier environmental air

Step 2: Increased vertical wind shear (i.e., Thermal Wind)

Step 3: Interaction with baroclinic zone & frontogenesis (front development)



Klein et al. (2000)

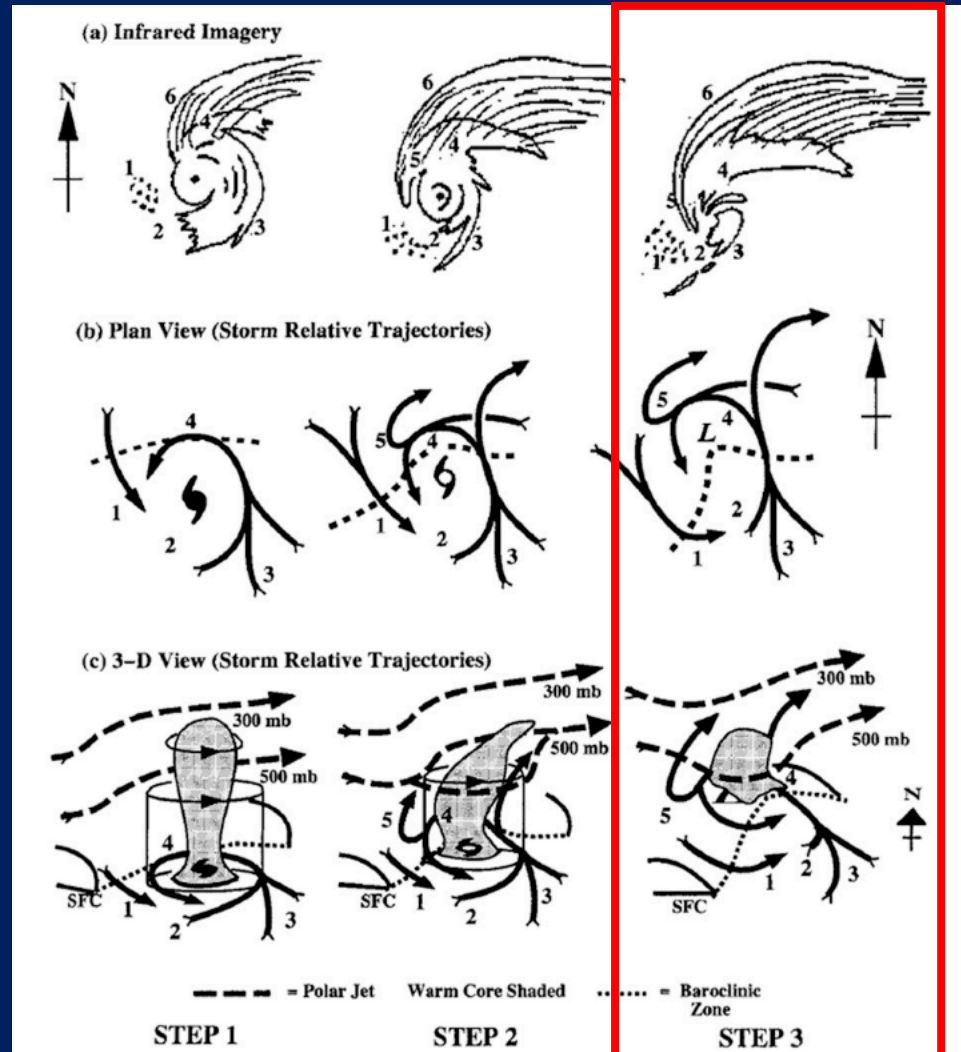
What is Extratropical Transition

- Process can generally be broken down into three general steps

Step 1: Decreasing SSTs & cooler, drier environmental air

Step 2: Increased vertical wind shear (i.e., Thermal Wind)

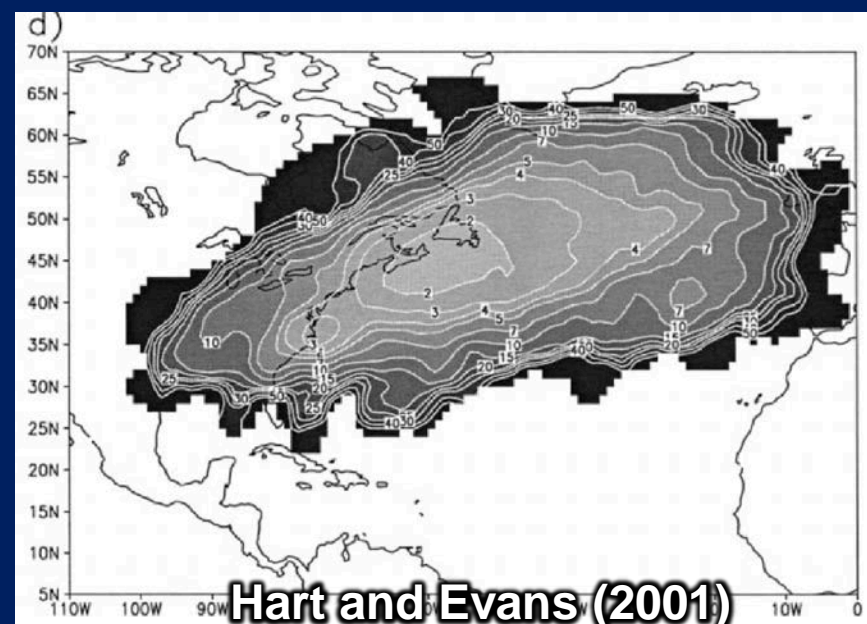
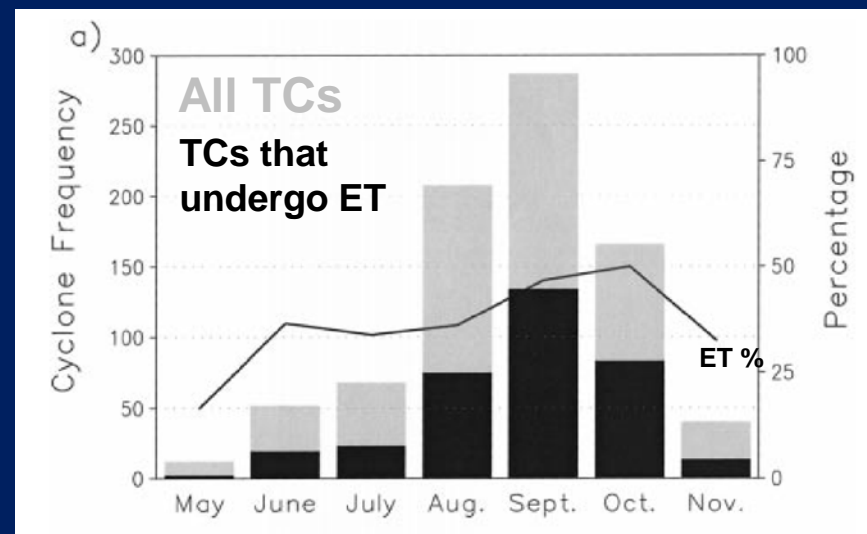
Step 3: Interaction with baroclinic zone & frontogenesis (front development)



Klein et al. (2000)

NATL Climatology of ET

- TCs that undergo extratropical transition can occur throughout the season, with most cases in the mid to late season
 - September/October
- Fraction of TCs that undergo ET also increases later in the season (up to 50% in October)
- ET is rare equatorward of 30°N and maximizes off the eastern North America near Nova Scotia & Newfoundland



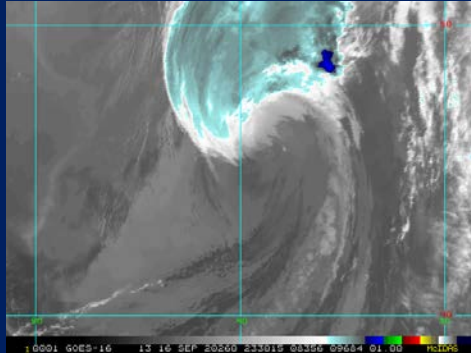
Recent Illustrative Example of ET

- Hurricane Paulette (14–17 September)

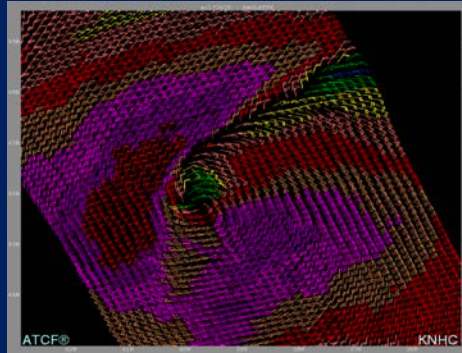


Different Tools Used to Diagnose ET

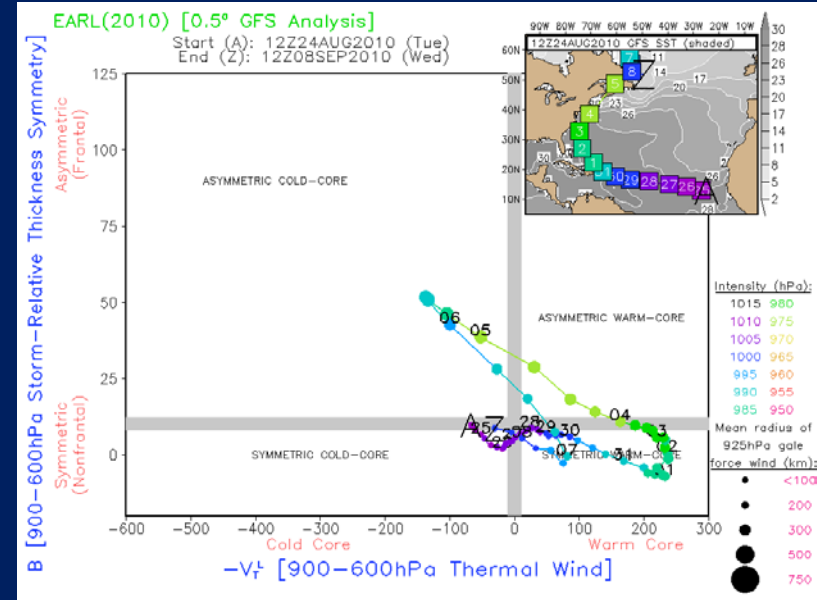
- Geostationary Satellite (IR)



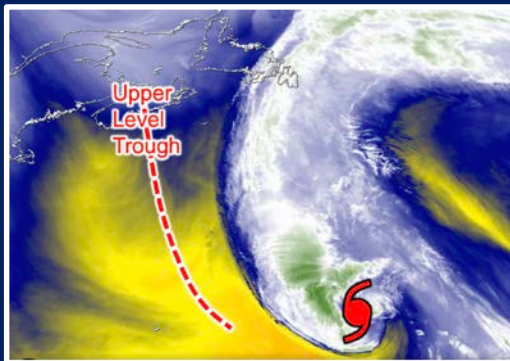
- Scatterometer (ASCAT)



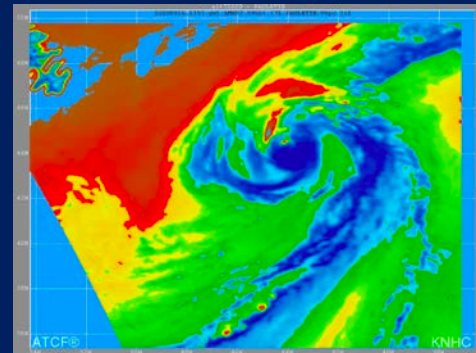
- Model Output (FSU Cyclone Phase Space)



- Geostationary Satellite (WV)



- Microwave Imagery



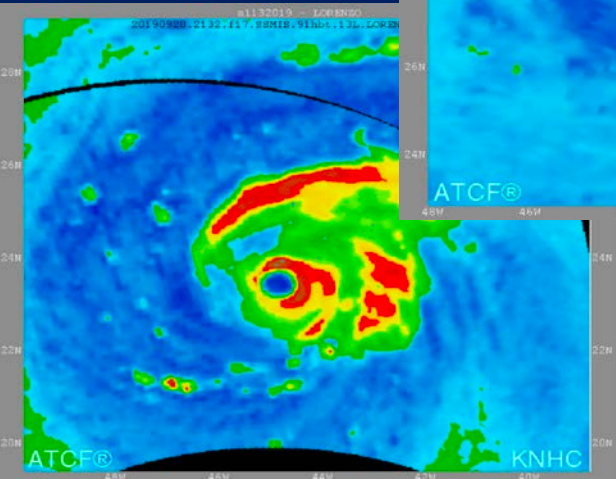
- In-situ observations when available
 - Buoys, Ships, Recon

Different Tools Used to Diagnose ET

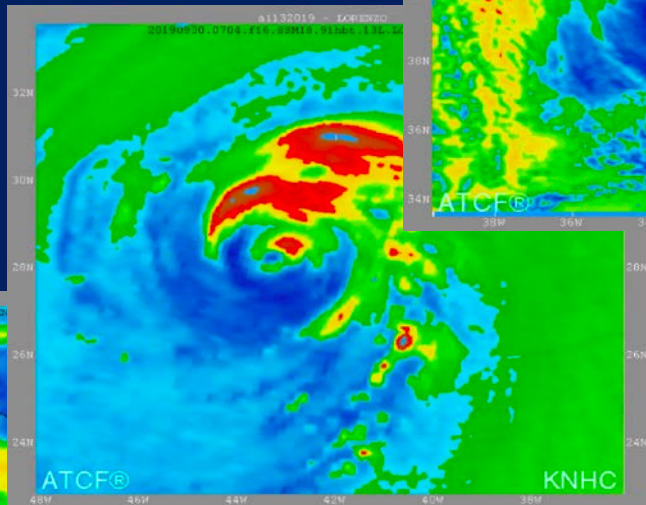
- **Microwave Imagery**

Evolution of 89-91 GHz
Microwave Channel

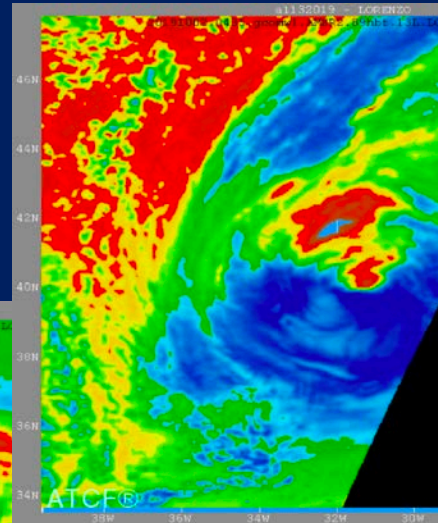
**2132 UTC
28 Sep 2019**



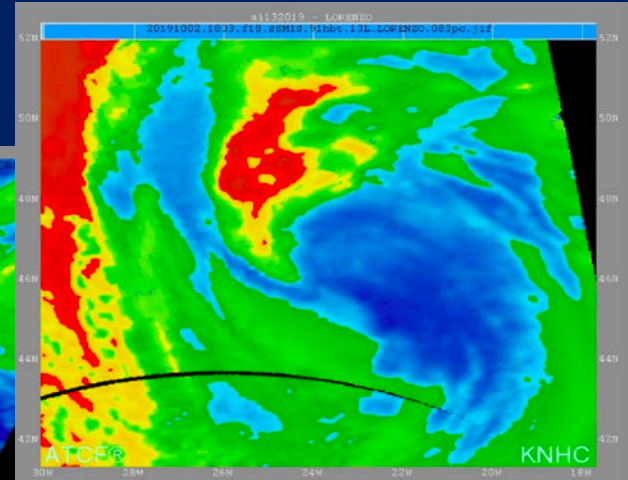
**0704 UTC
30 Sep 2019**



**0435 UTC
2 Oct 2019**



**1833 UTC
2 Oct 2019**



**Hurricane
Lorenzo (2019)**

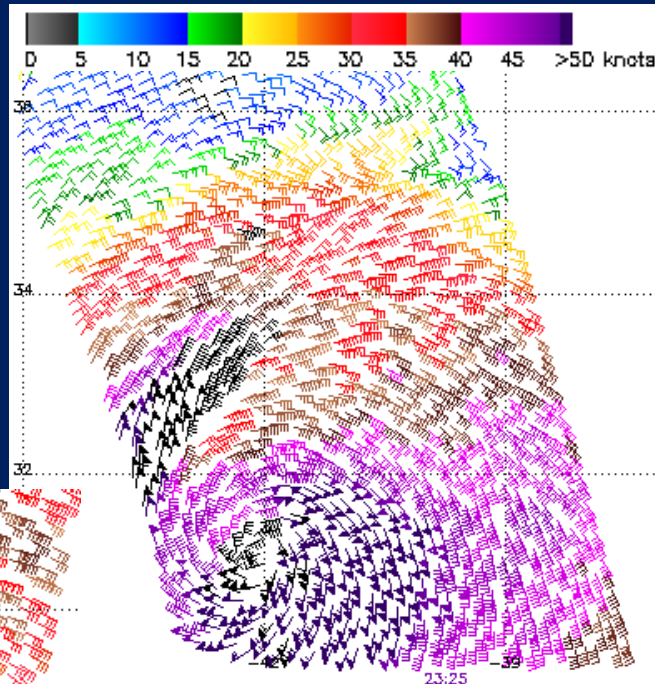
URL: <https://www.nrlmry.navy.mil/TC.html>

Different Tools Used to Diagnose ET

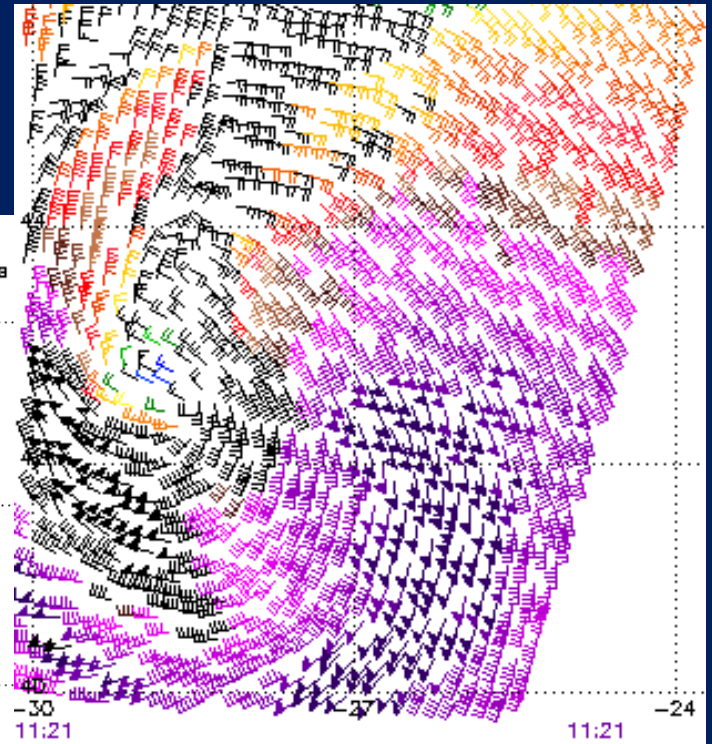
- Scatterometer

Evolution of
ASCAT Passes

26 Sep 2019



30 Sep 2019



2 Oct 2019

**Hurricane
Lorenzo (2019)**

URL: <https://manati.star.nesdis.noaa.gov/datasets/ASCATData.php>

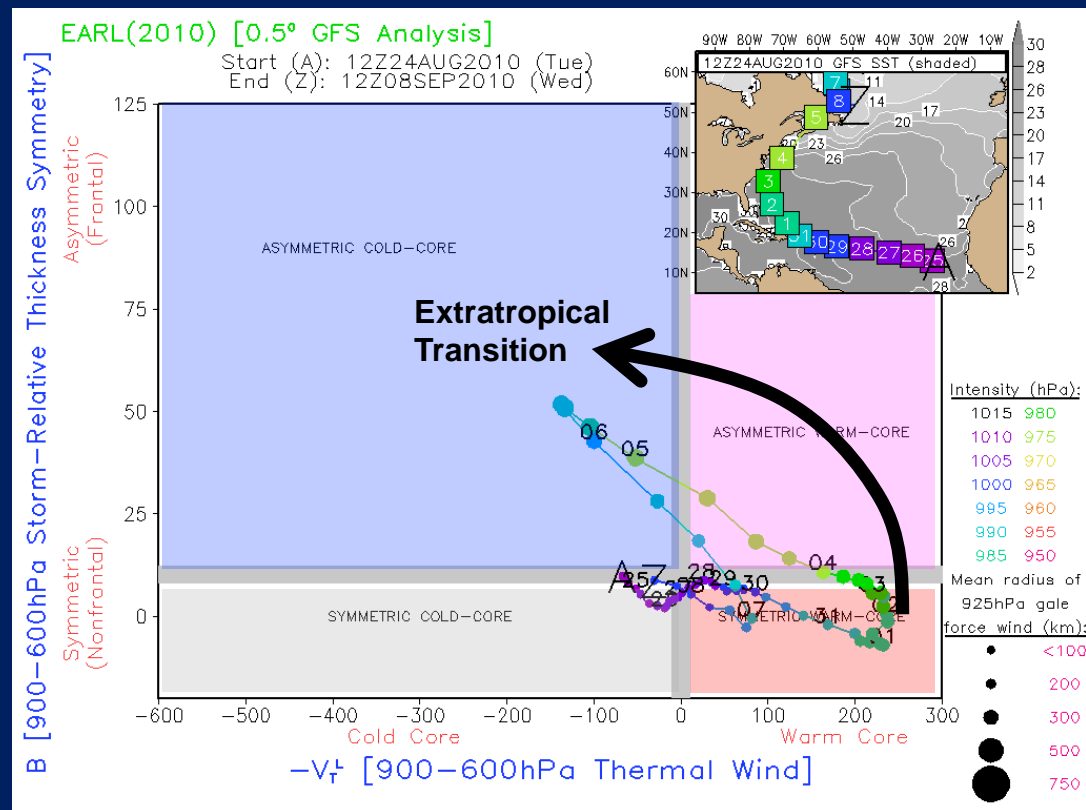
Different Tools Used to Diagnose ET

- **Cyclone Phase Space** URL: <http://moe.met.fsu.edu/cyclonephase/>
 - 2 – 3 dimensional space to indicate thermal characteristics of a cyclone

- **Thermal Wind**
 - 900–600 hPa – V_{TL}
 - 600–300 hPa – V_{TU}
- **Thickness Asymmetry**
 - $Z_{600\text{-hPa}} - Z_{900\text{-hPa}}$
LEFT minus RIGHT
- **Evolution TC → ET**

Thickness Asymmetry
Near 0 to greater than 0

Thermal Wind
Greater than 0 to less than 0



Hart and Evans (2002)

Cyclone Phase Space Examples

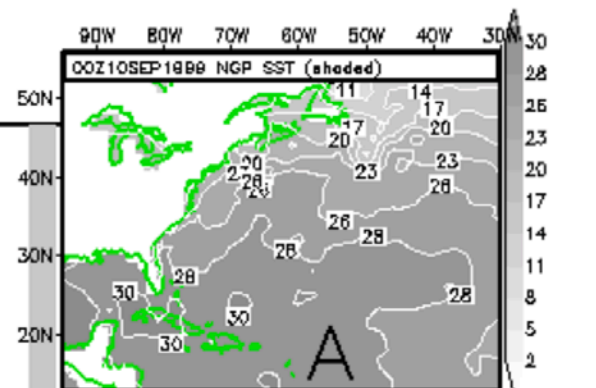
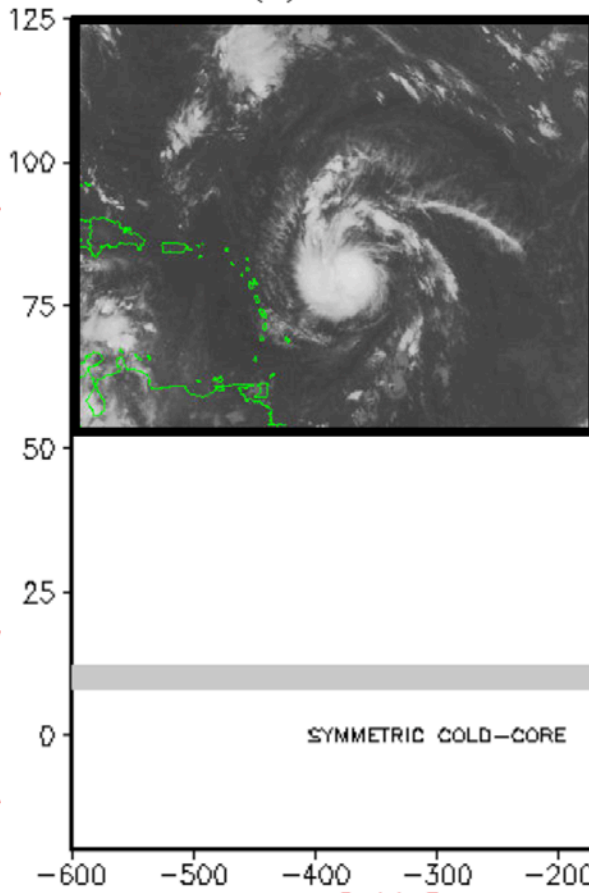
FLOYD(1999) [1° NOGAPS Analysis]

Start (A): 12Z09SEP1999 (Thu)
End (Z): 12Z19SEP1999 (Sun)

B [900–600hPa Storm–Relative Thickness Symmetry]

Asymmetric
(Frontal)

Symmetric
(Nonfrontal)



Intensity (hPa):

1015	980
1010	975
1005	970
1000	965
995	960
990	955
985	950

Mean radius of
925hPa gale
force wind (km):

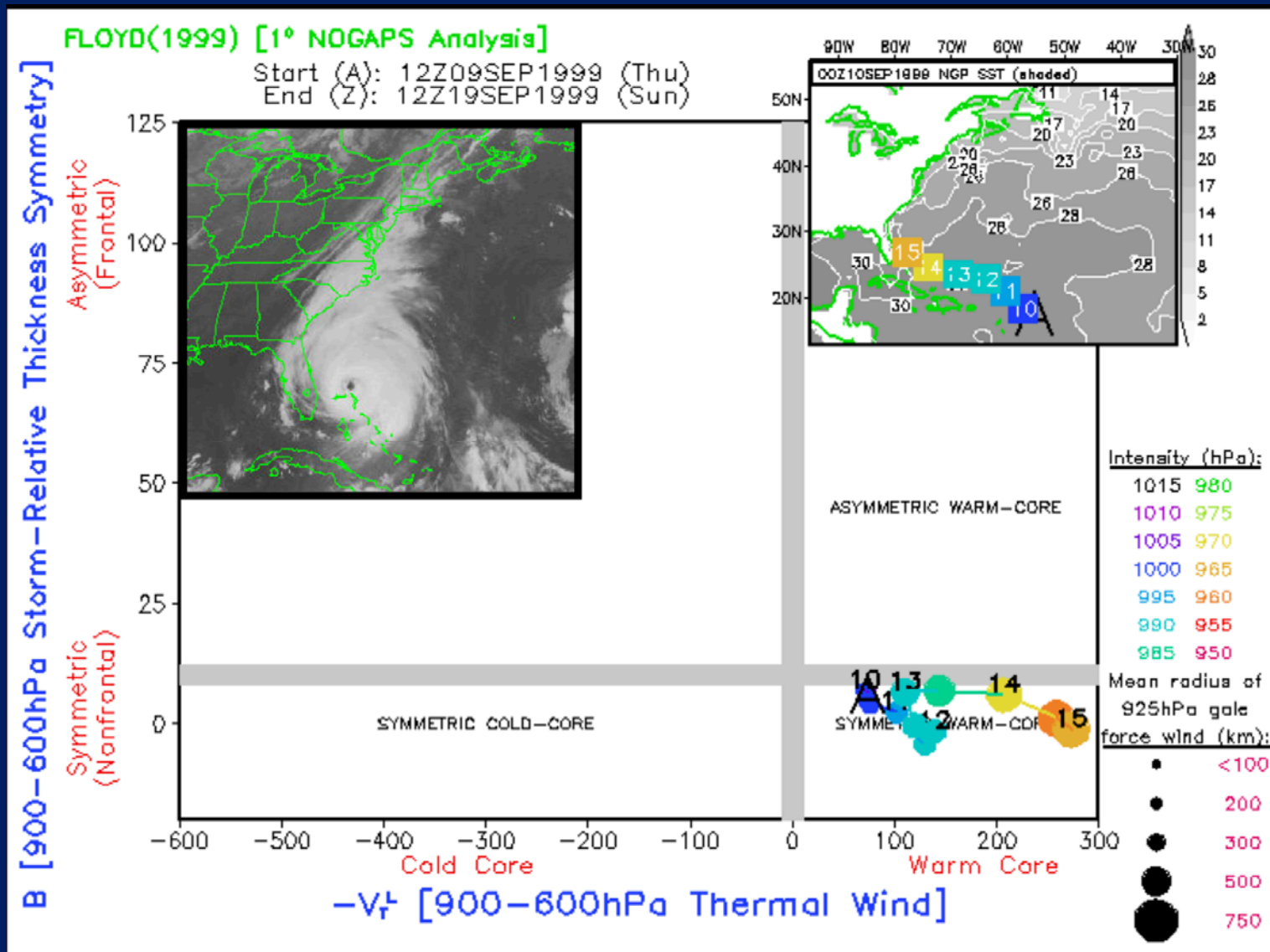
•	<100
•	200
•	300
•	500
•	750

$-V_T^2$ [900–600hPa Thermal Wind]

Cold Core

Warm Core

Cyclone Phase Space Examples



Cyclone Phase Space Examples

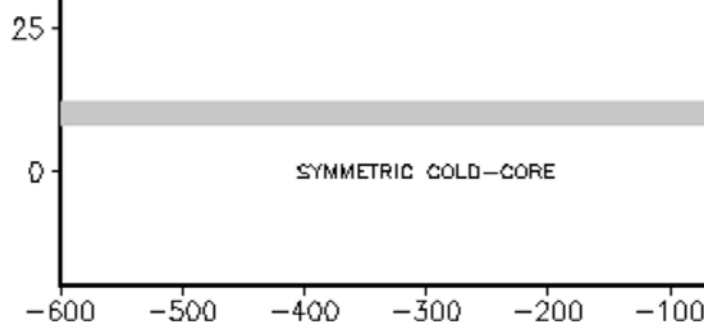
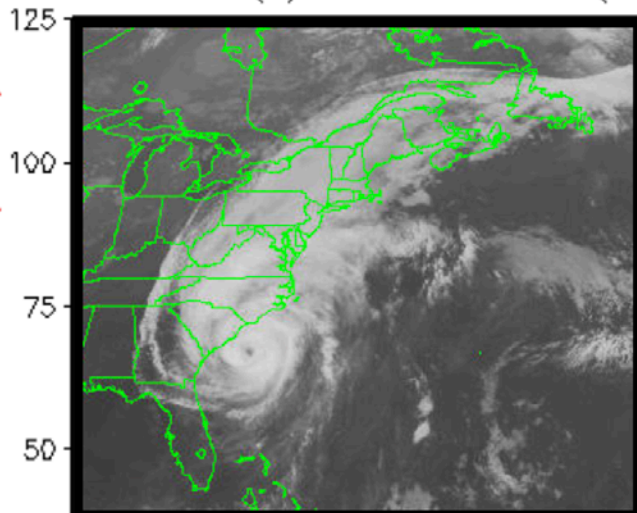
FLOYD(1999) [1° NOGAPS Analysis]

Start (A): 12Z09SEP1999 (Thu)
End (Z): 12Z19SEP1999 (Sun)

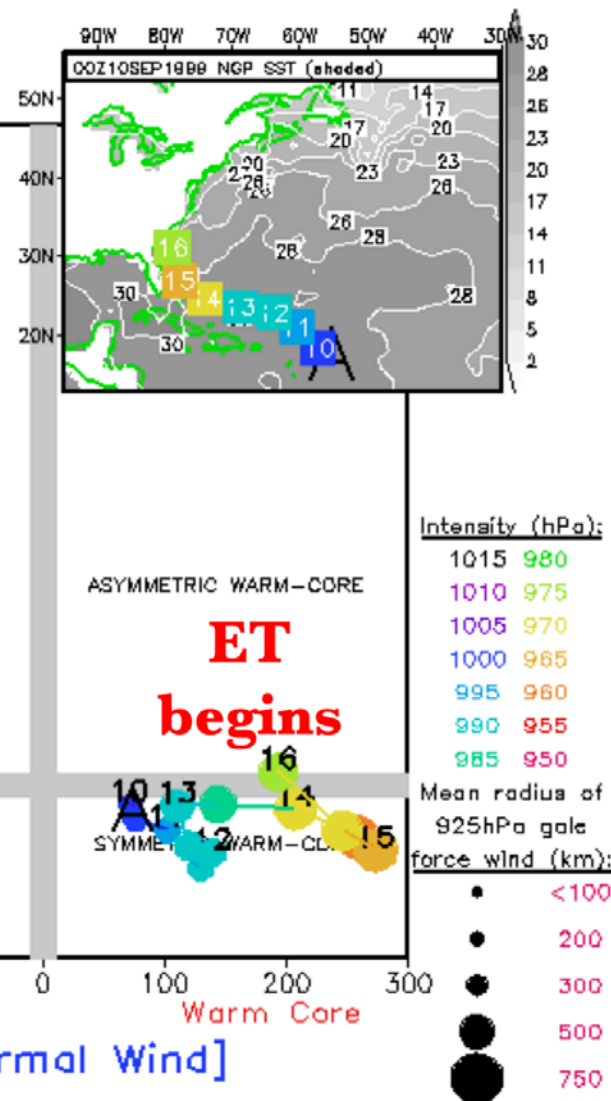
B [900–600hPa Storm–Relative Thickness Symmetry]

Asymmetric
(Frontal)

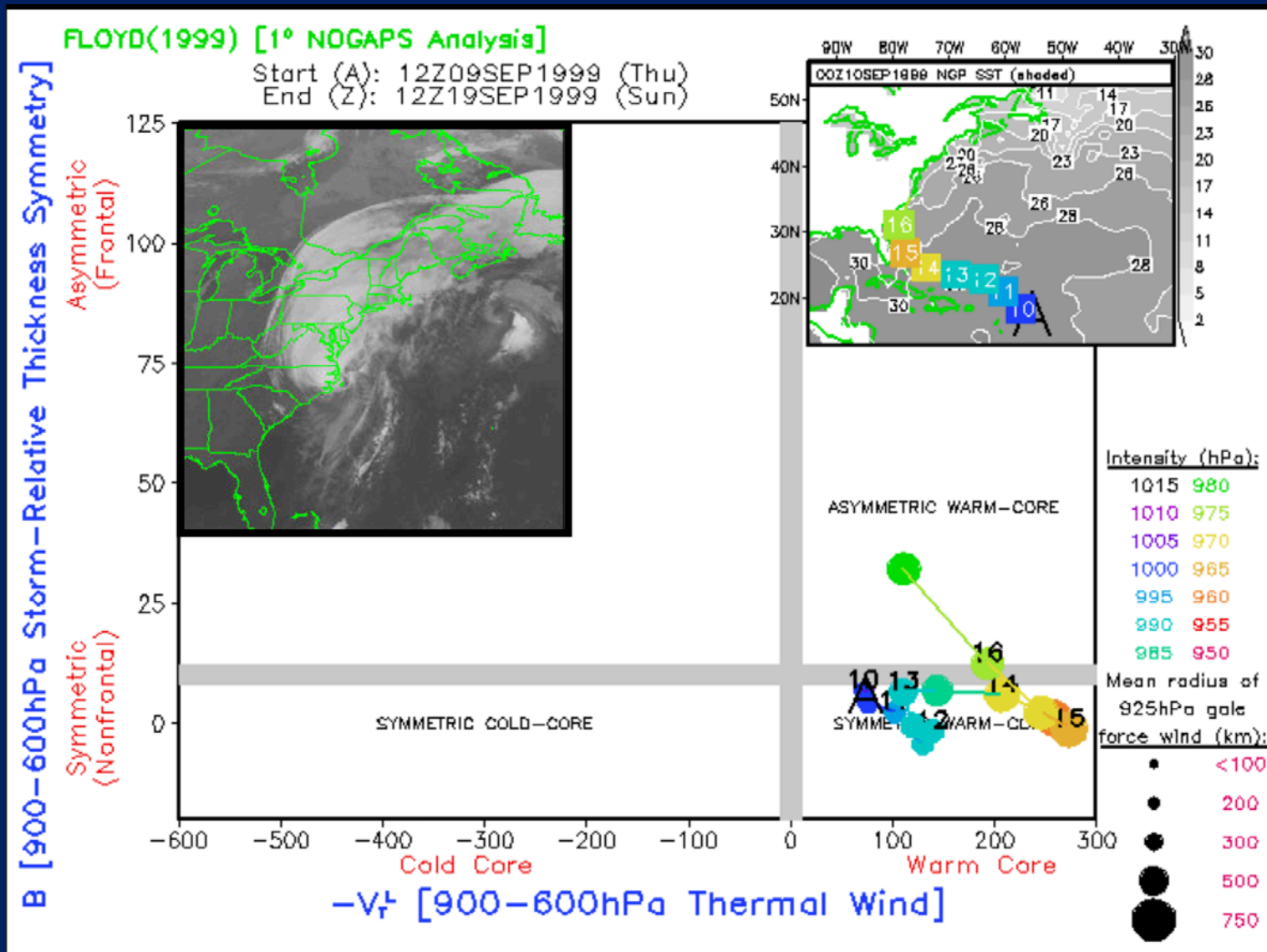
Symmetric
(Nonfrontal)



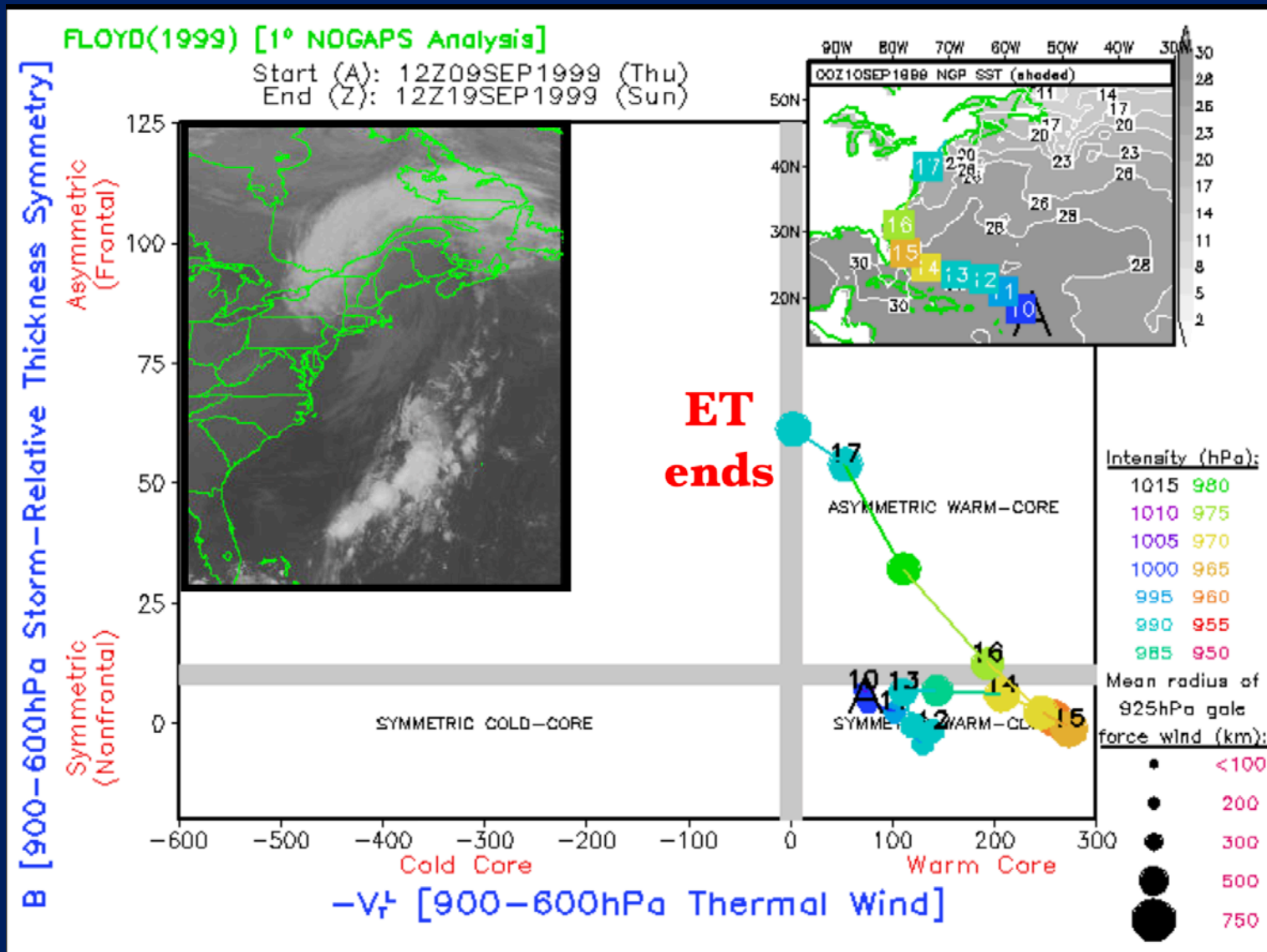
$-V_T$ [900–600hPa Thermal Wind]



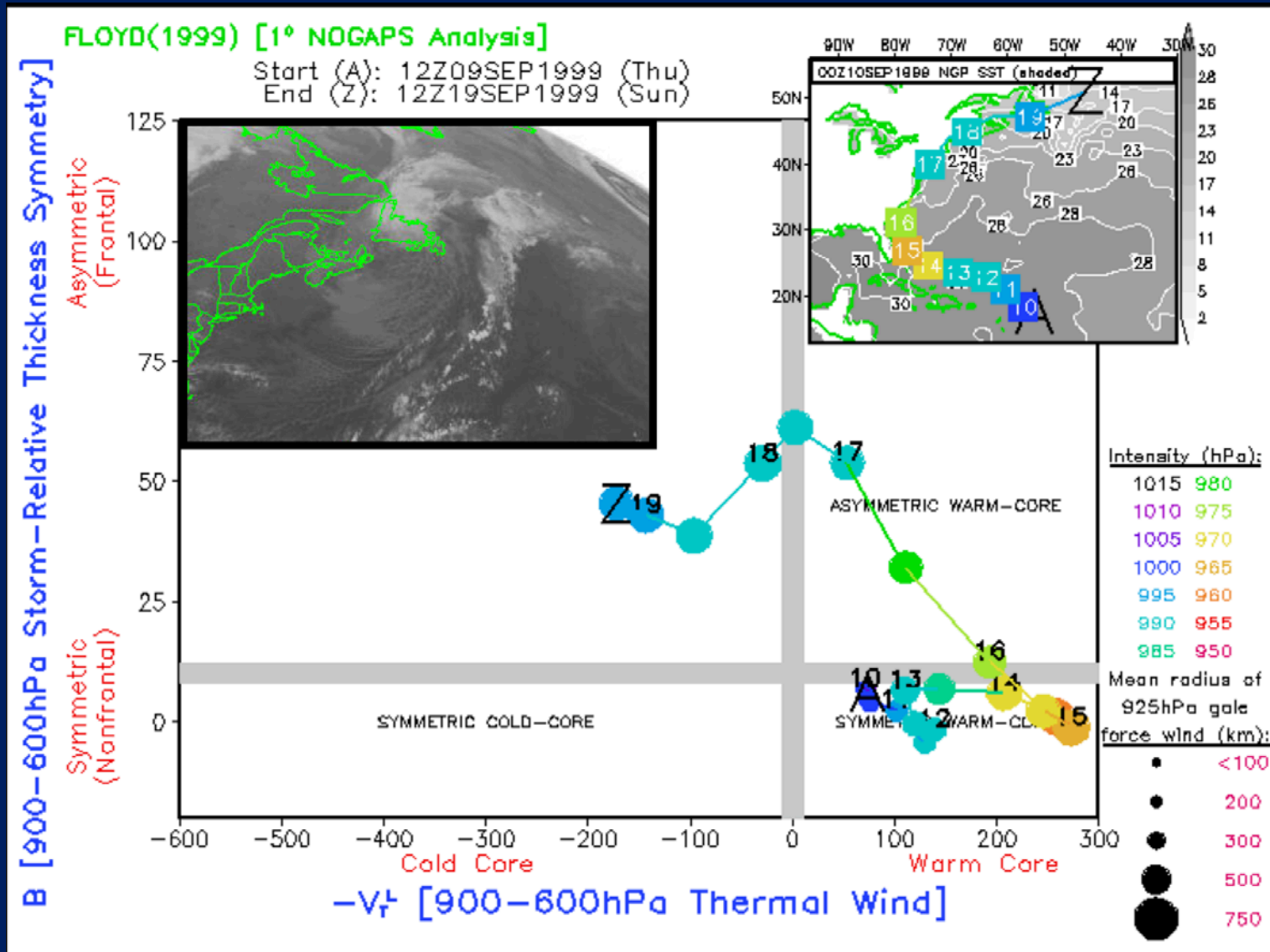
Cyclone Phase Space Examples



Cyclone Phase Space Examples

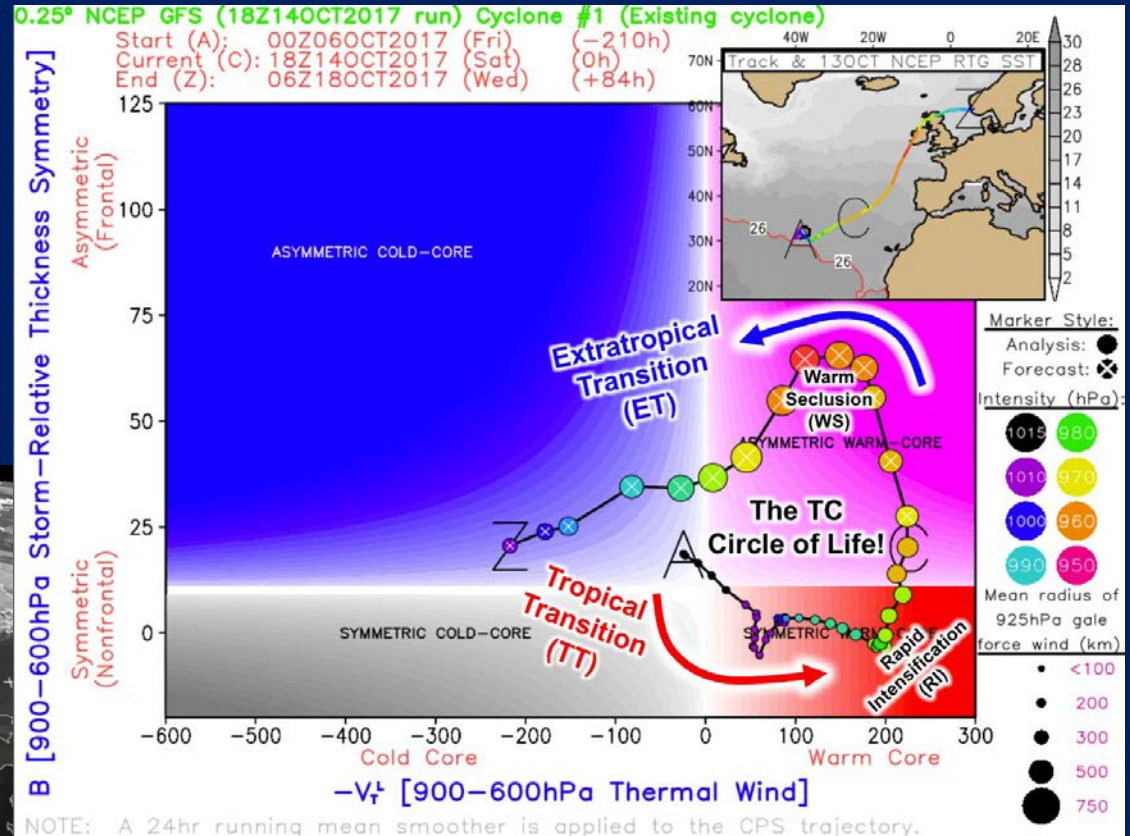
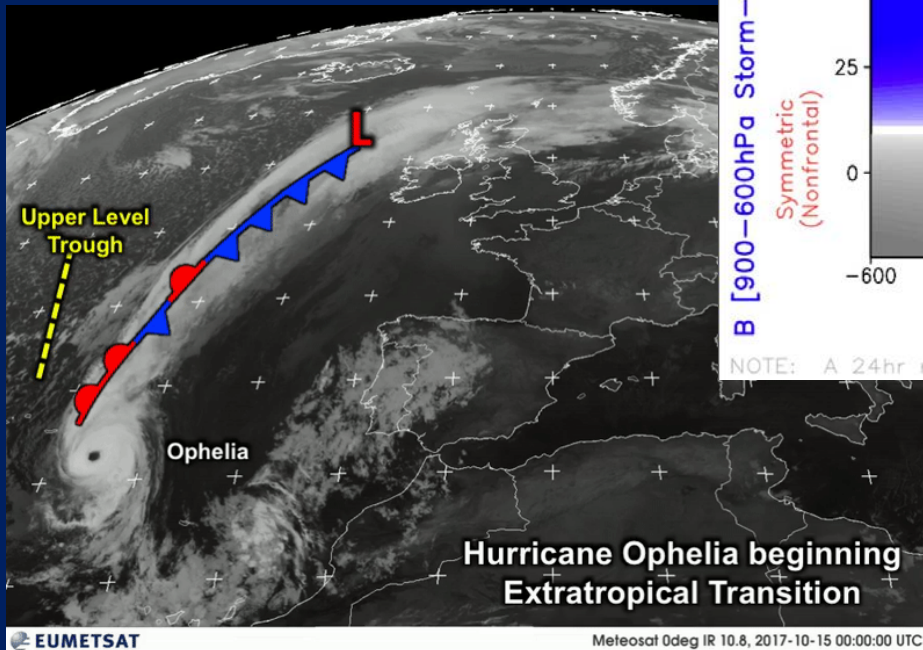


Cyclone Phase Space Examples



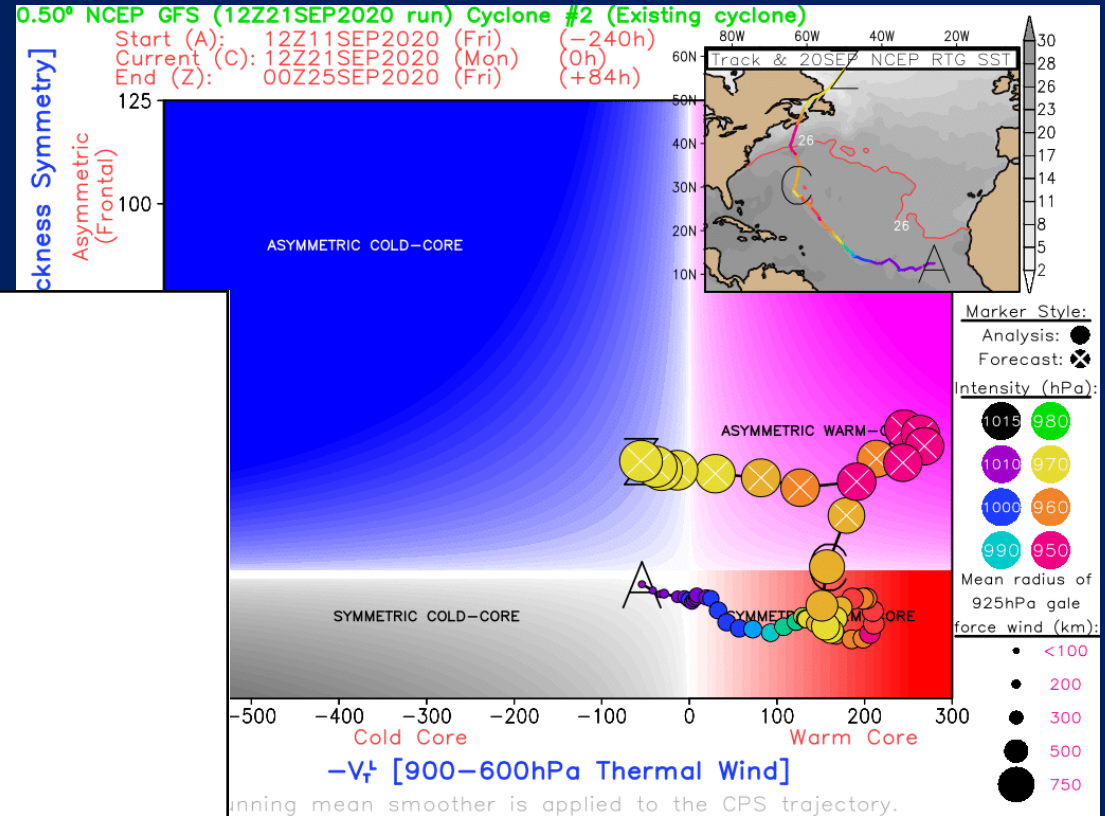
Cyclone Phase Space Example

- Hurricane Ophelia (2017)



Cyclone Phase Space Example

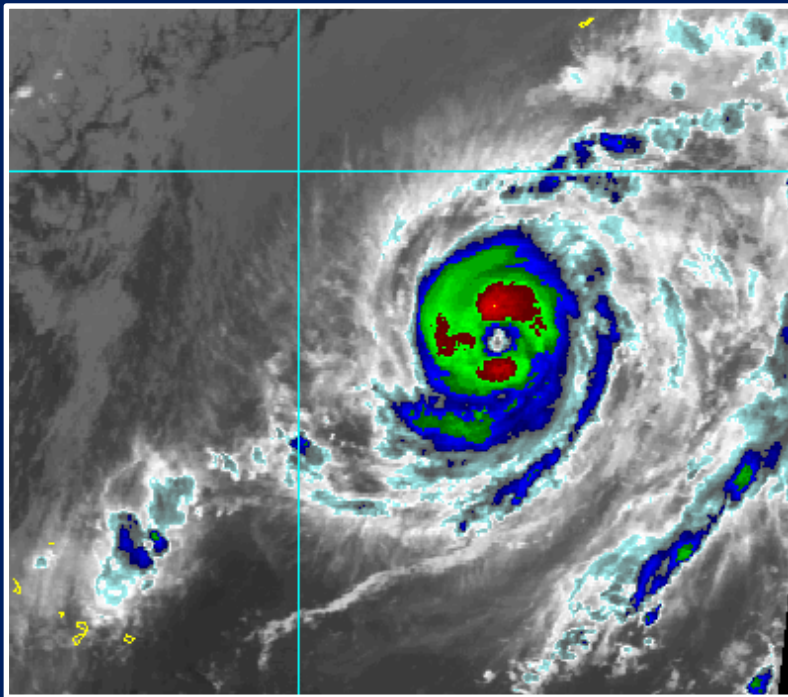
- Hurricane Teddy (2020)



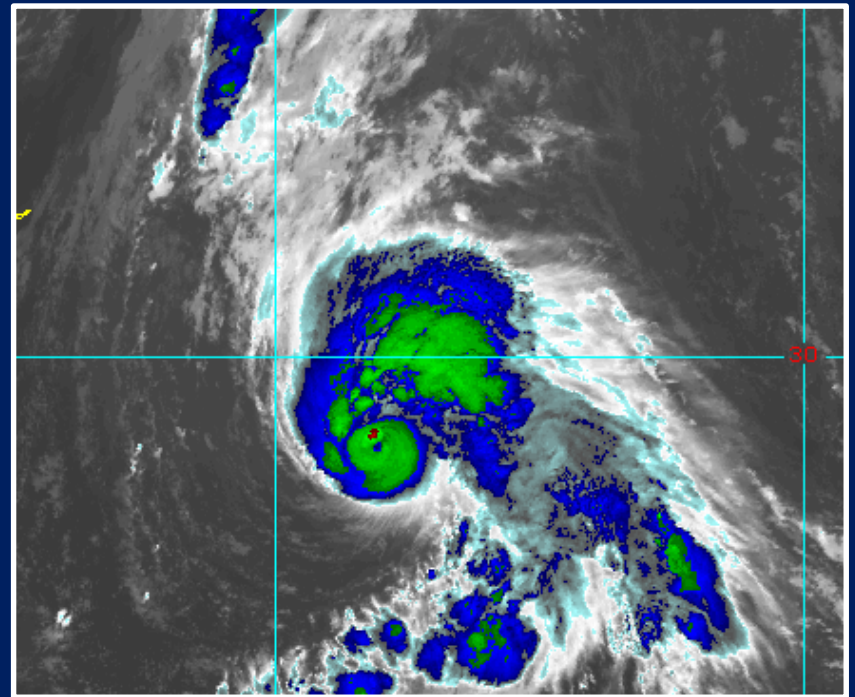
“Warm Seclusion”

Quiz Time

- Which of these two TCs underwent extratropical transition within 24 hours?



(A)

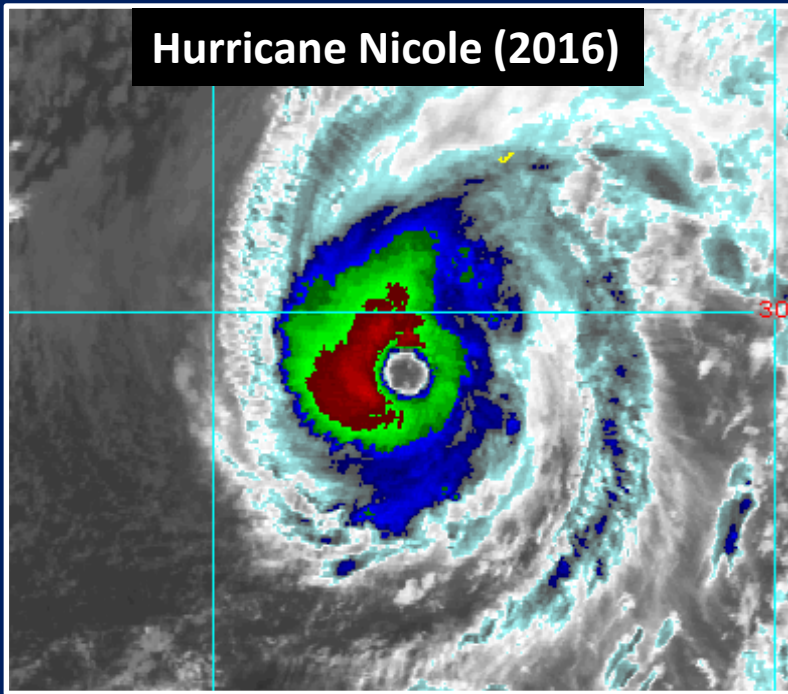


(B)

Quiz Time

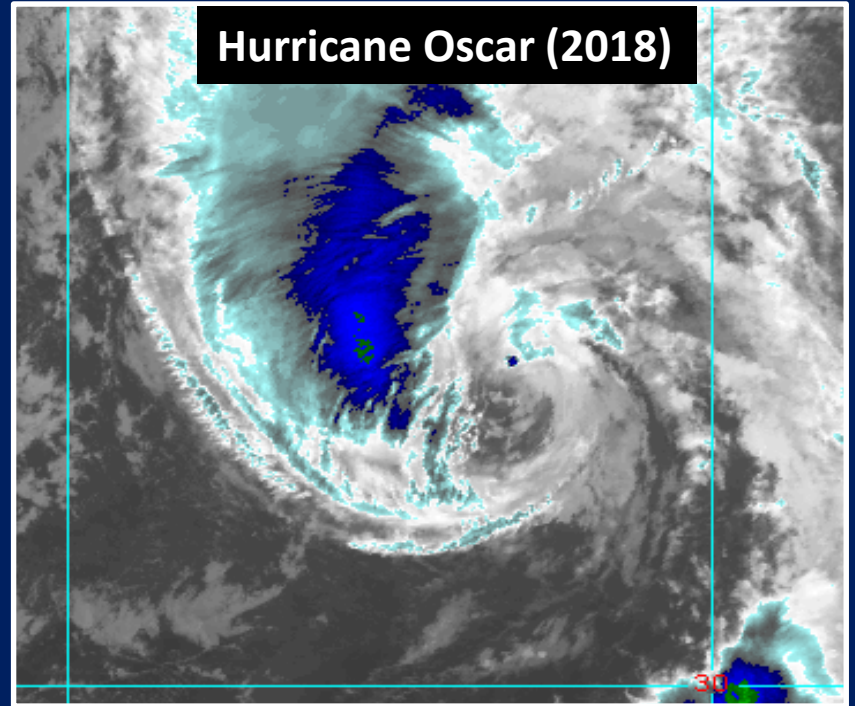
- Which of these two TCs underwent extratropical transition within 24 hours?

Hurricane Nicole (2016)



(A)

Hurricane Oscar (2018)



(B)

Questions?

Recent Illustrative Examples of ET

- Hurricane Teddy (20–24 September)

- Good Example of a Warm Seclusion ET



Illustrative Examples of ET

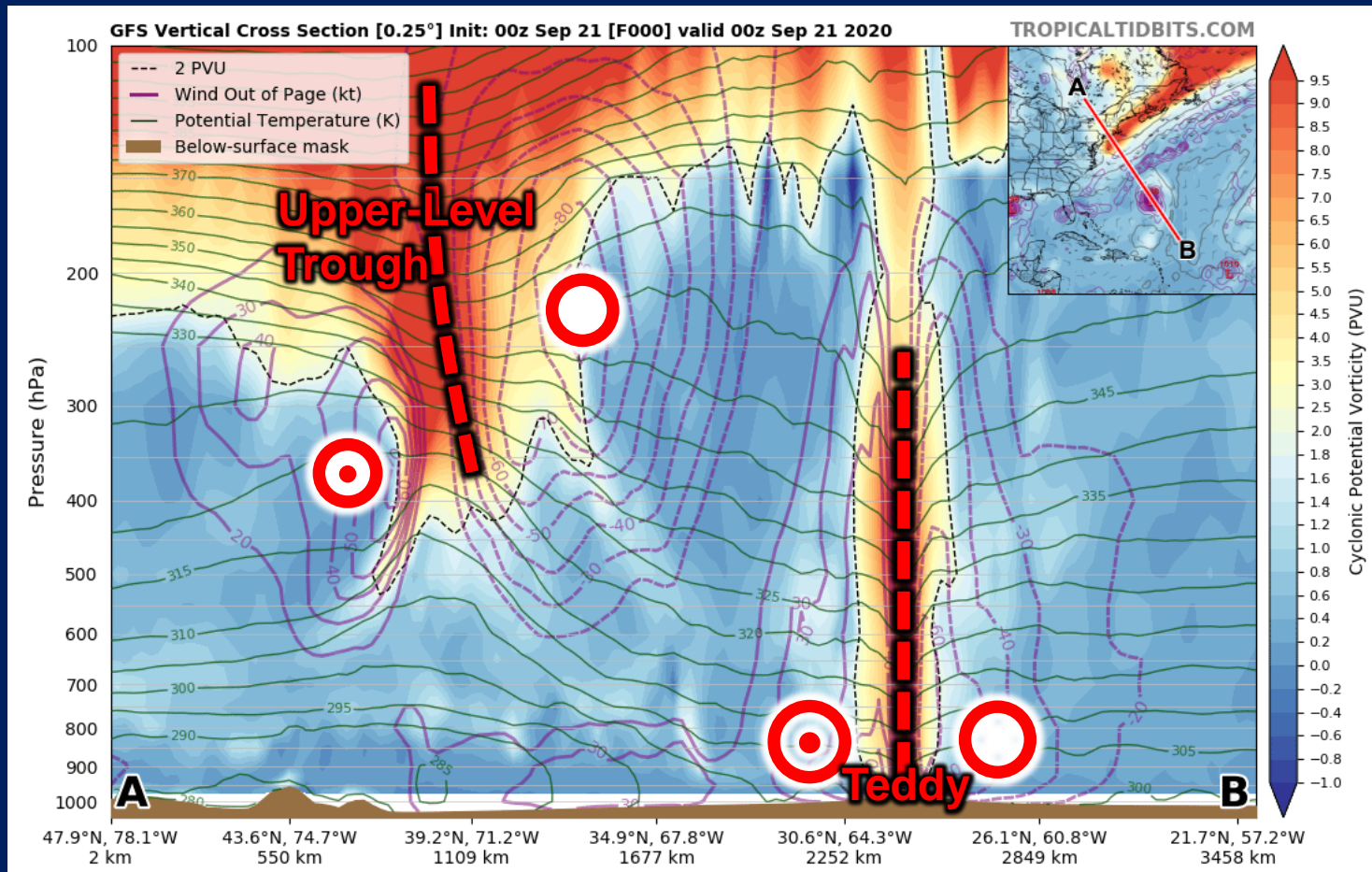
- Hurricane Teddy (14–17 September)

Vertical Cross-Section Evolution

Out



In



Illustrative Examples of ET

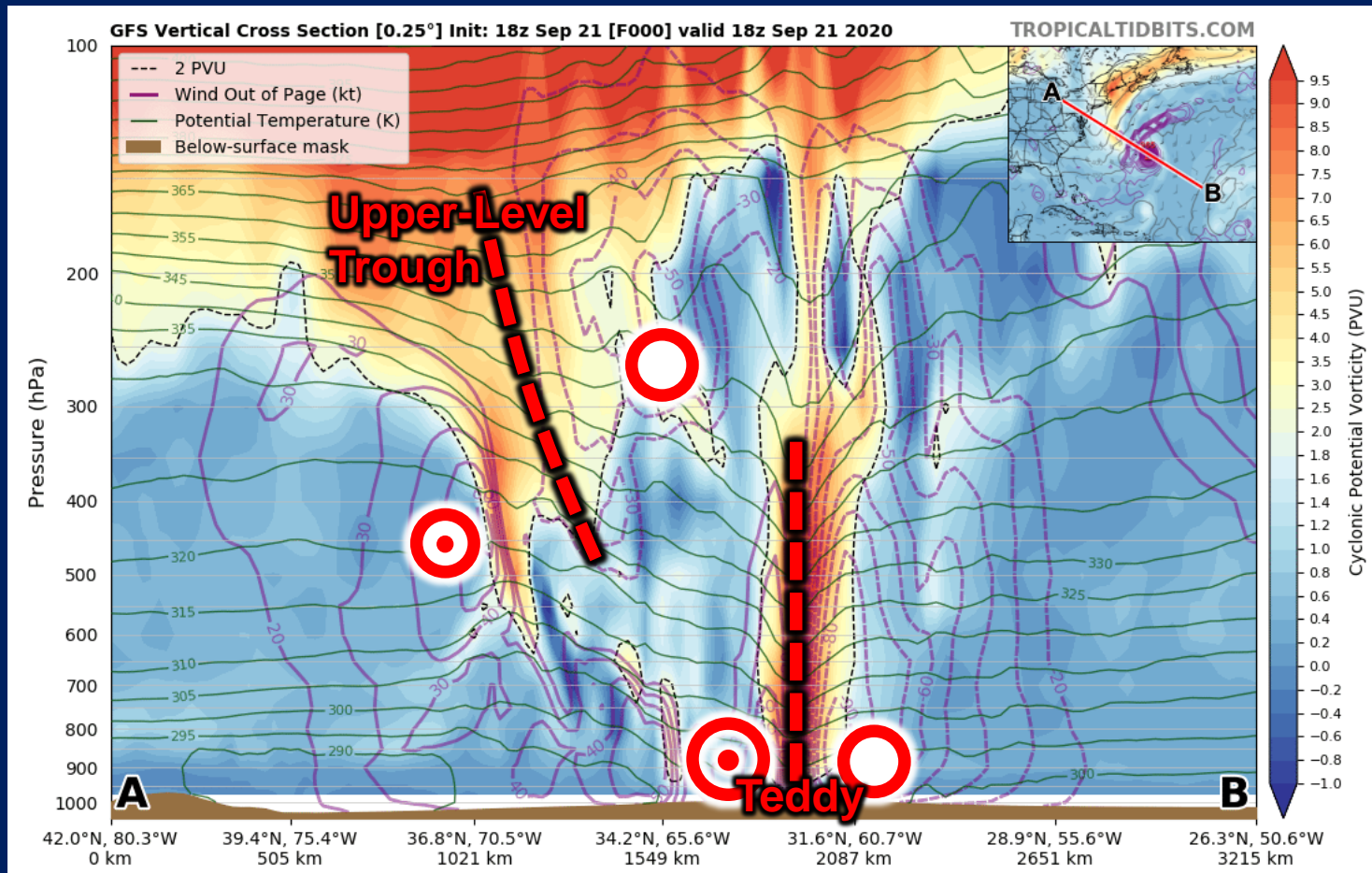
- Hurricane Teddy (14–17 September)

Vertical Cross-Section Evolution

Out



In



Illustrative Examples of ET

- Hurricane Teddy (14–17 September)

Vertical Cross-Section Evolution

Out



In

