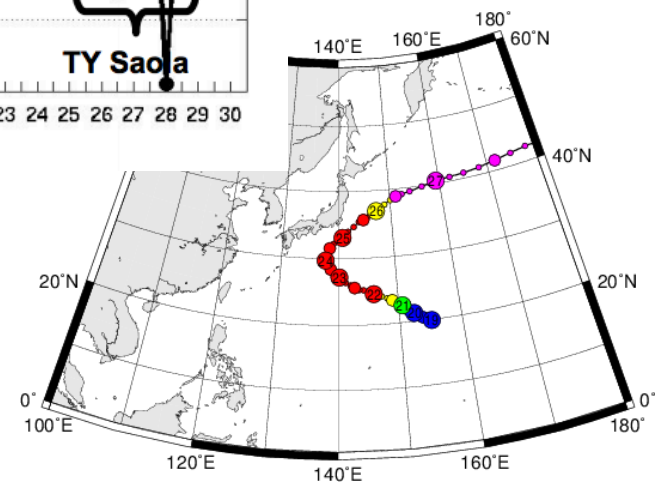
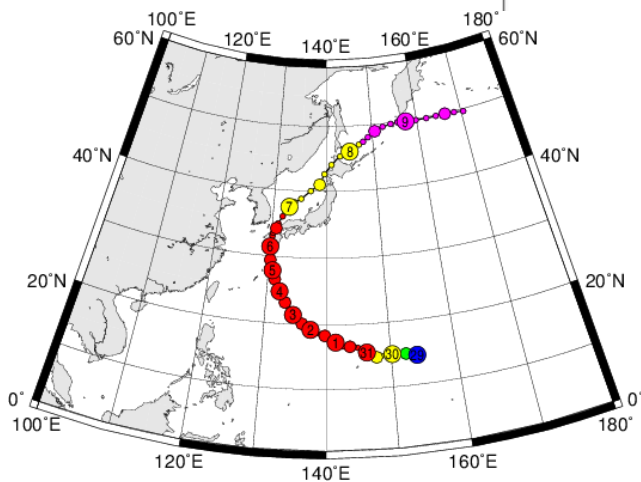
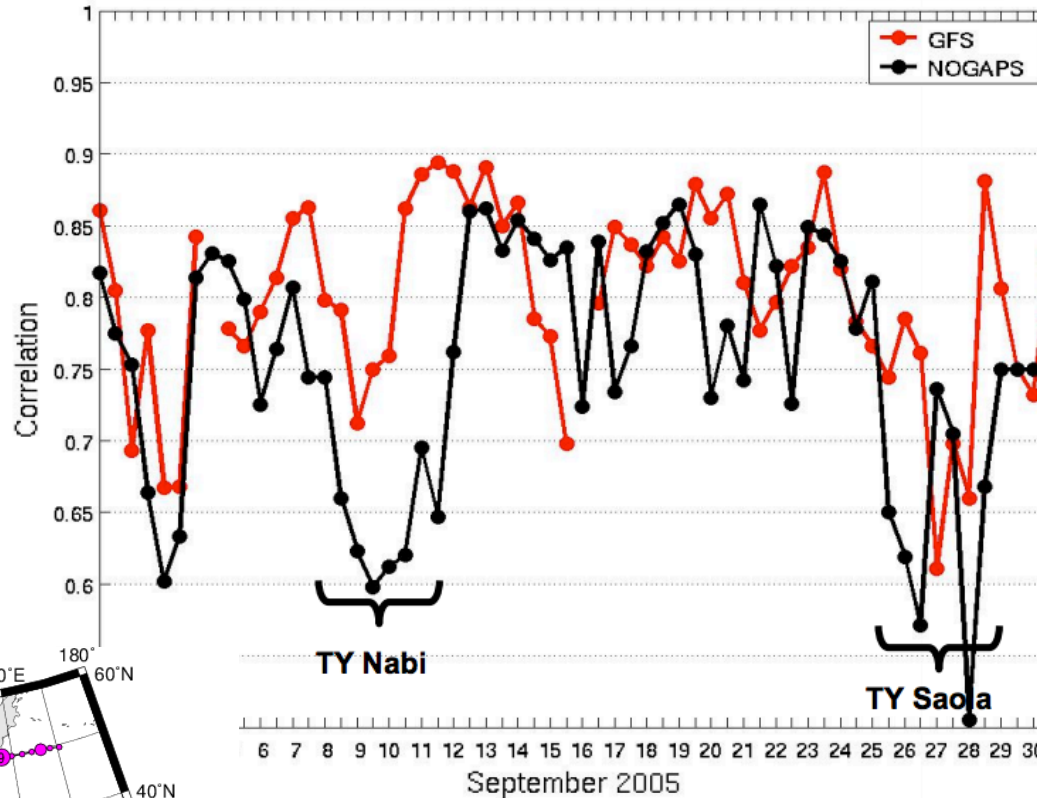


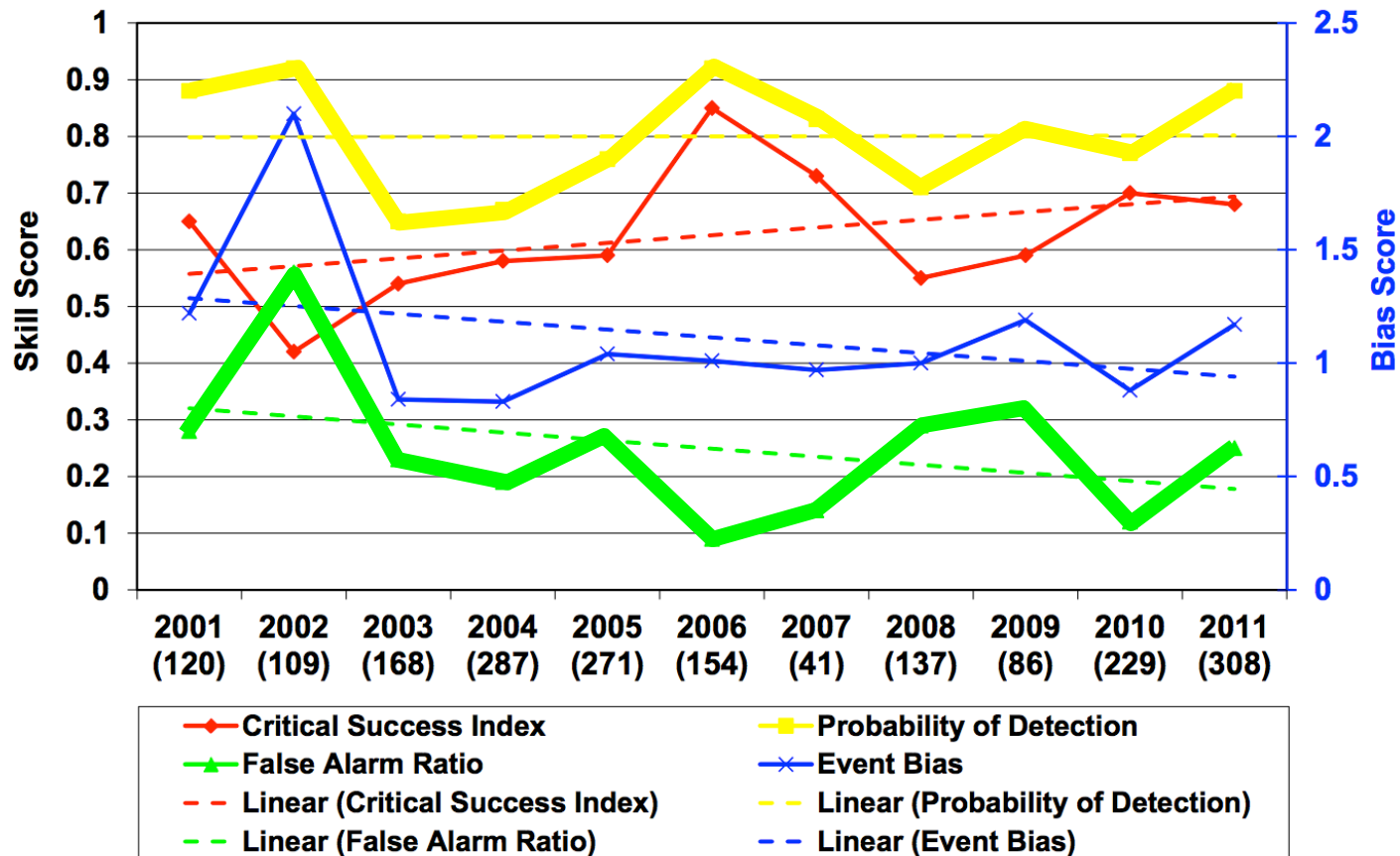
Extratropical transition: Another significant forecast issue

120 h 500 hPa Northern Hemisphere Height Anomaly Correlations



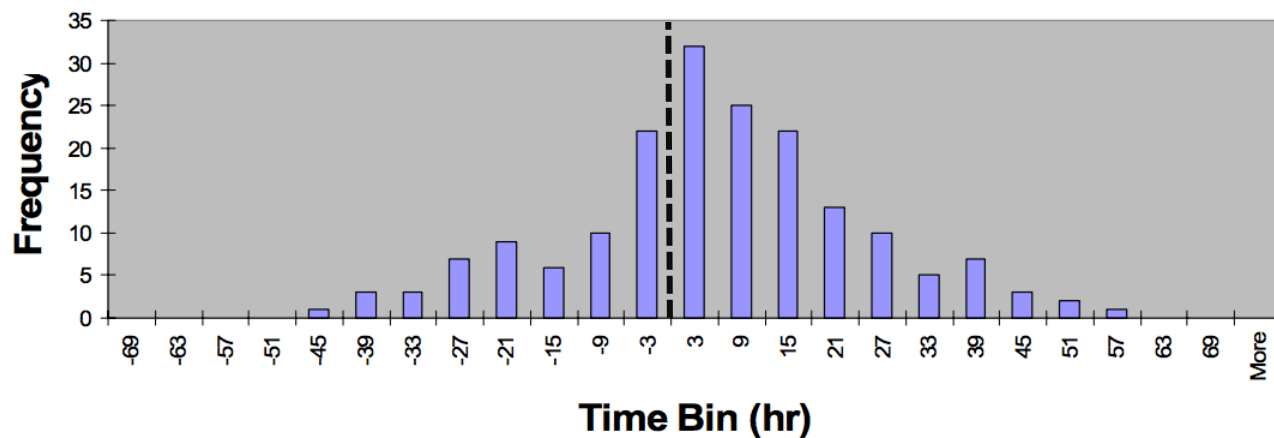
Extratropical transition: Another significant forecast issue

5-Day Potential ET Cases Only



Extratropical transition: Another significant forecast issue

Time Bias Histogram

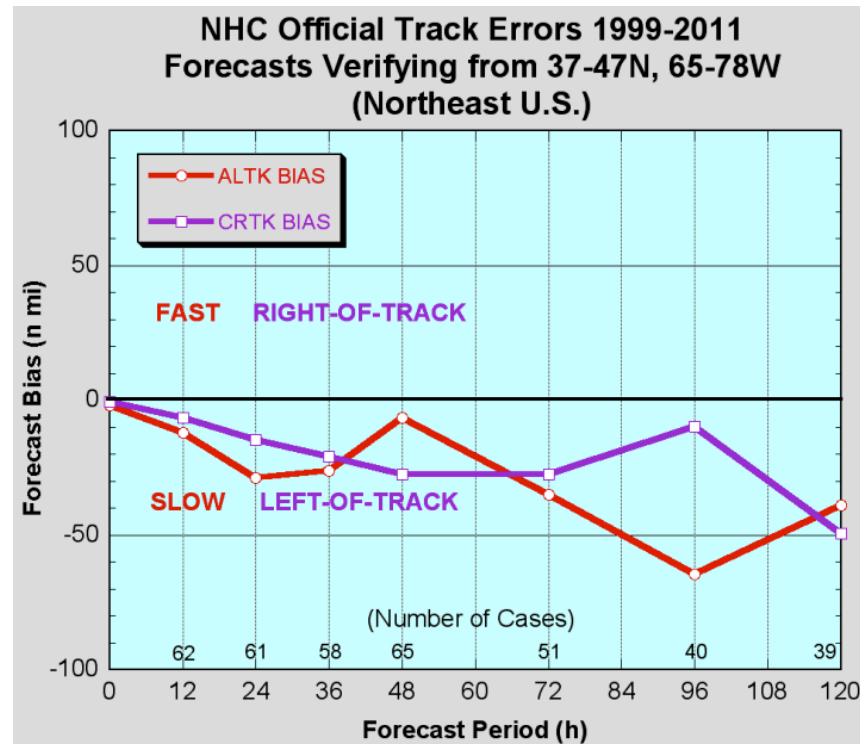
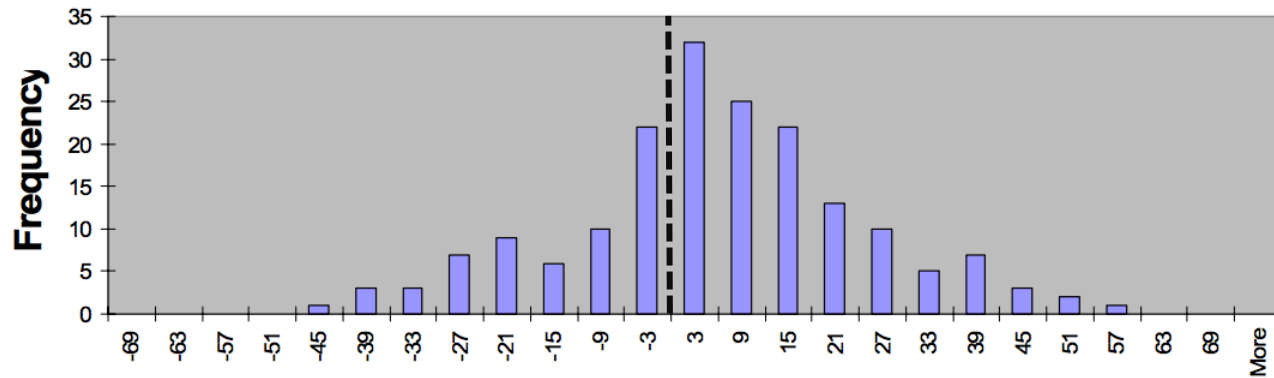


***NHC ET forecasts have a positive time bias:
~14.5 h***

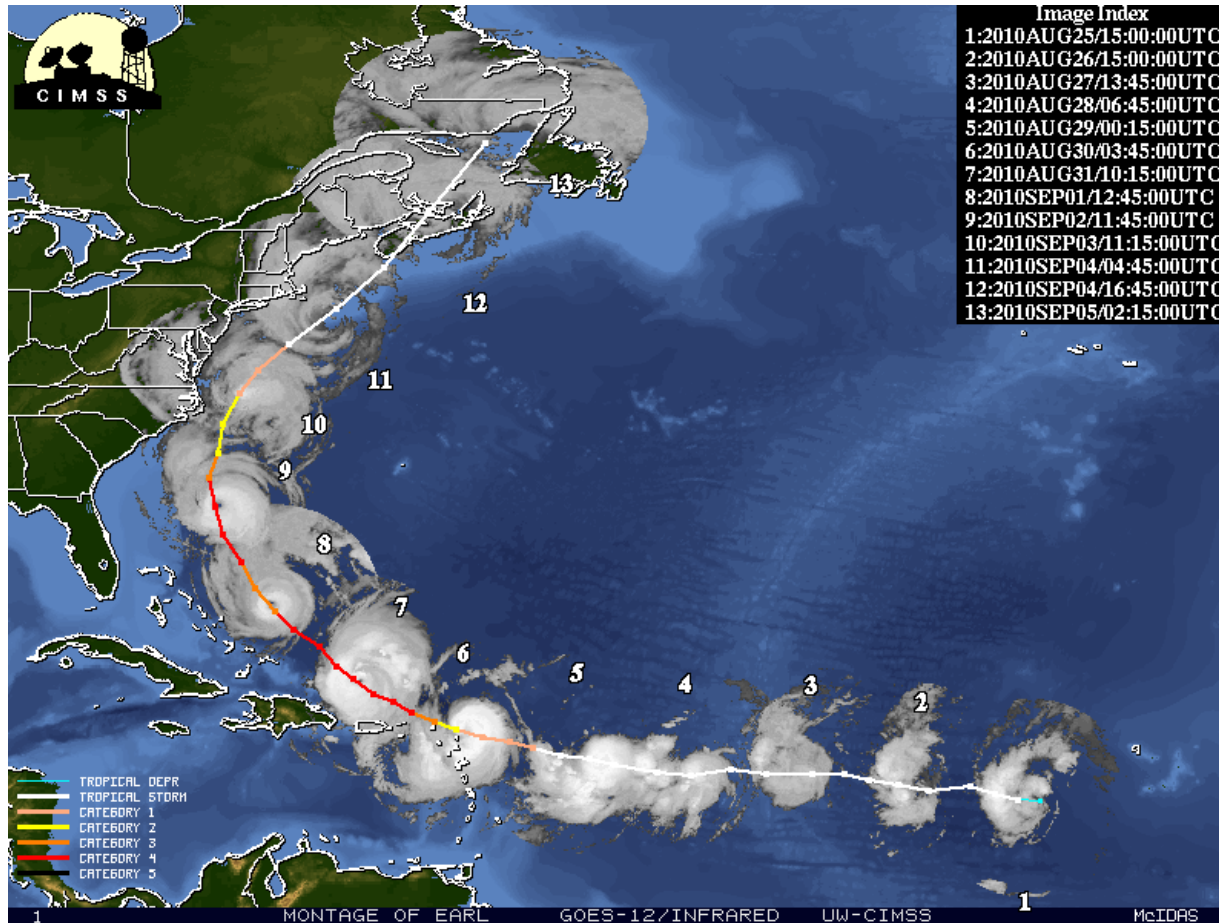
ET occurs earlier than the NHC forecast

WHY?

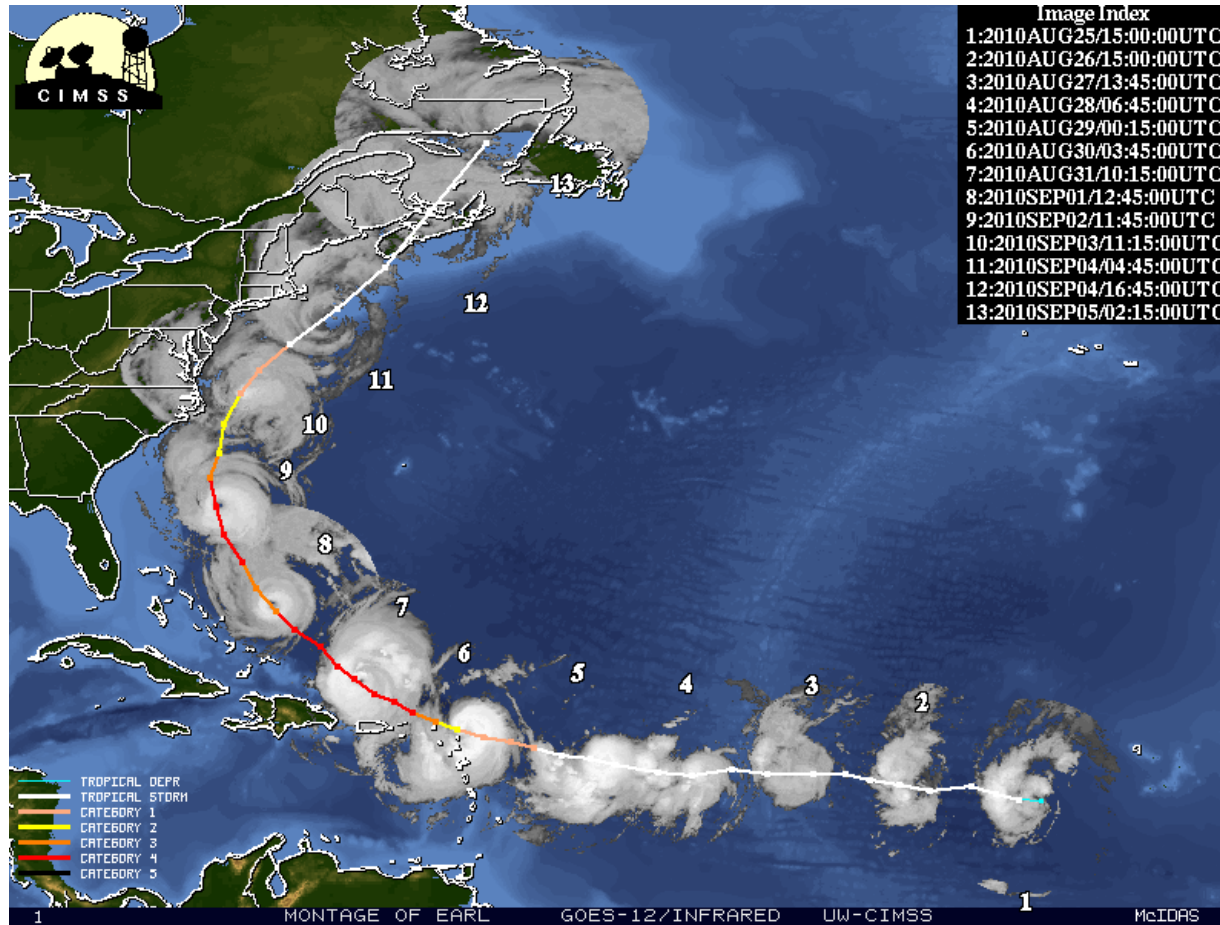
Extratropical transition: Another significant forecast issue



Extratropical transition: What is it?

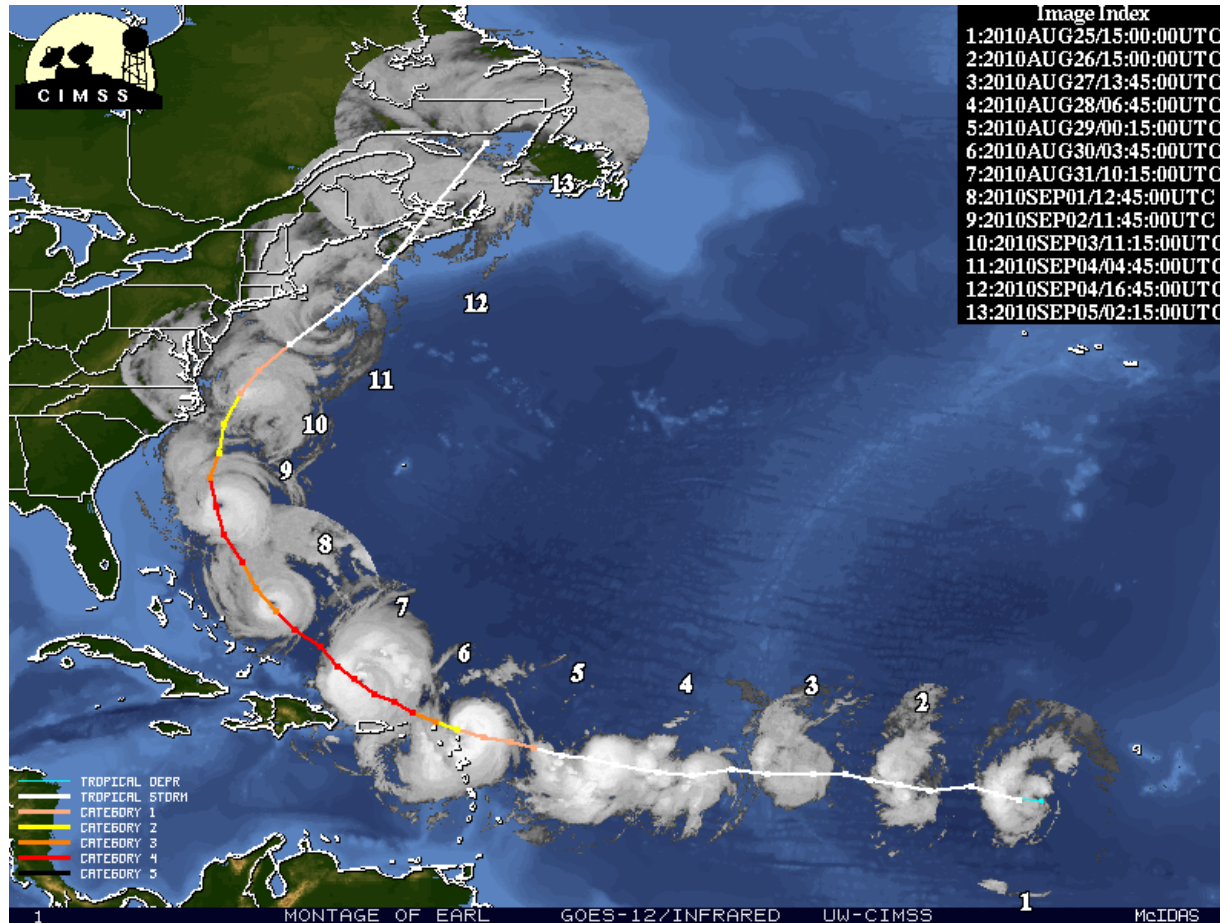


Extratropical transition: What is it?

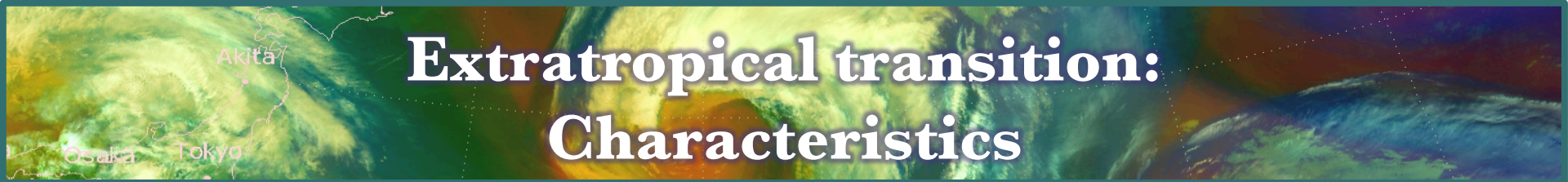


The *AMS Glossary* lacks a definition...

Extratropical transition: What is it?



...as does the *WMO* (*no operational definition*)

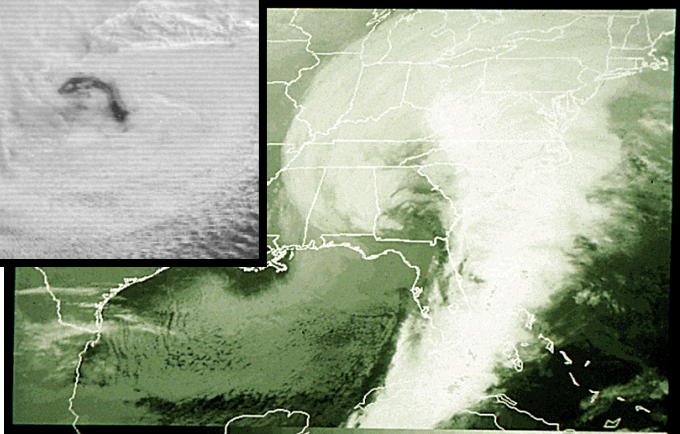
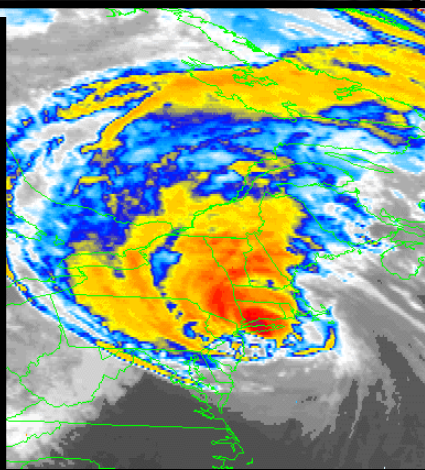
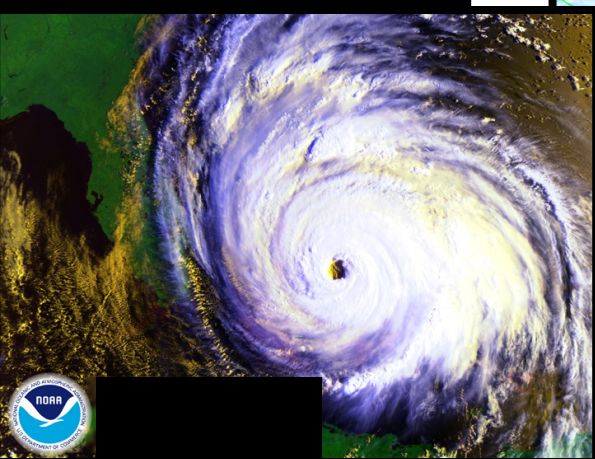
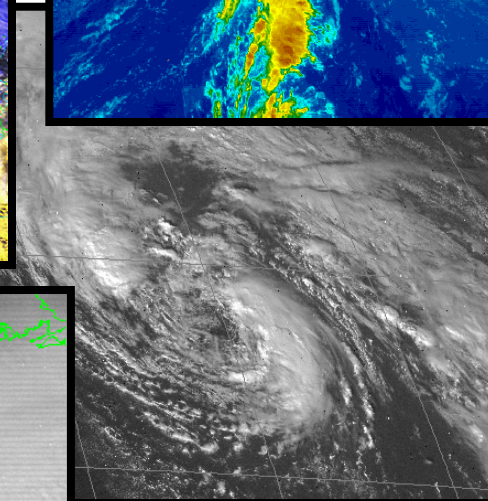
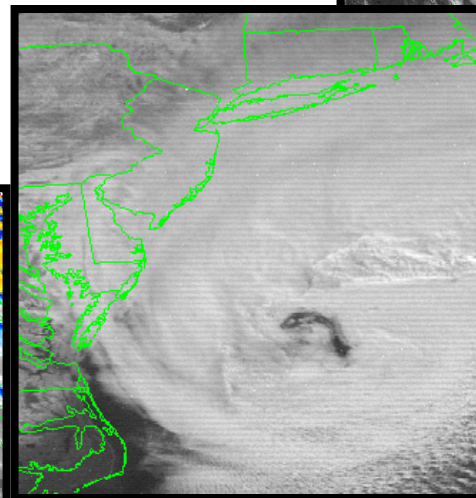
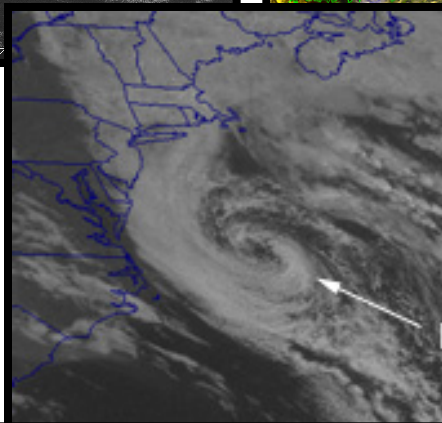
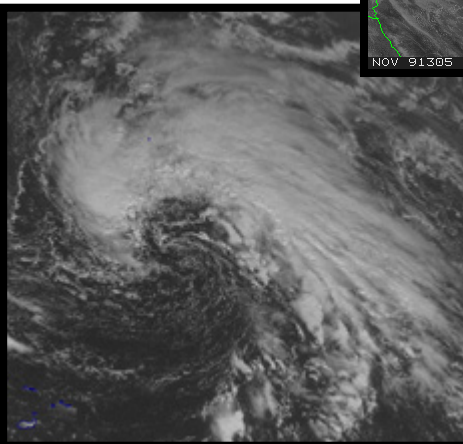
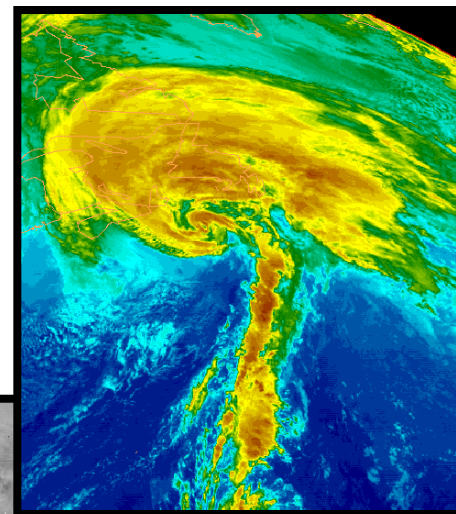
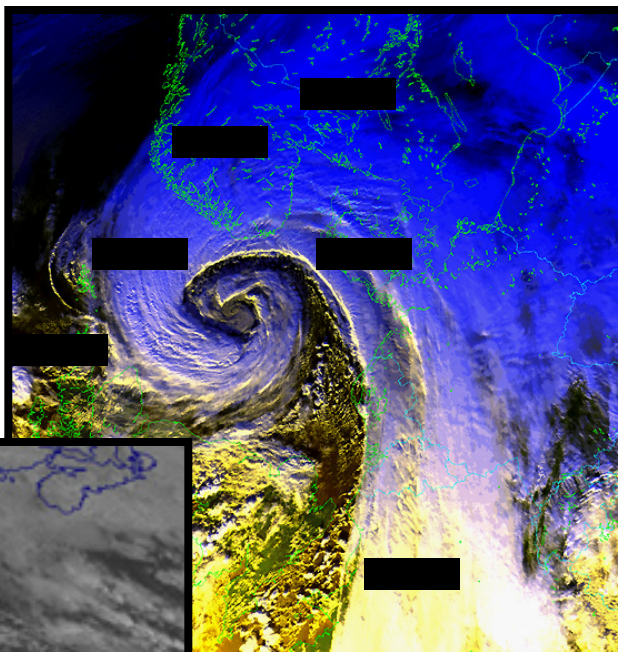
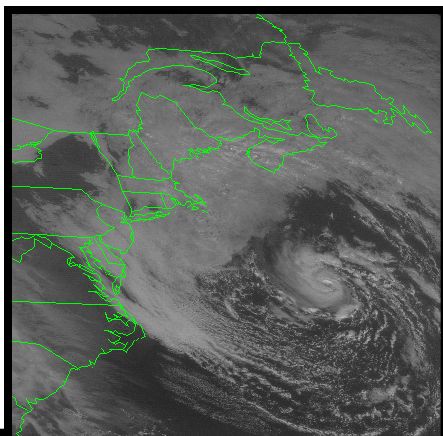


Extratropical transition: Characteristics

<i>Tropical cyclones</i>	<i>Extratropical cyclones</i>
Non-frontal	Frontal
Warm core	Cold core
Driven by latent heat release	Driven by baroclinic instability
Wind maximum close to the center & the ground	Wind maximum removed from the center & aloft
Symmetric precipitation	Precipitation left of track

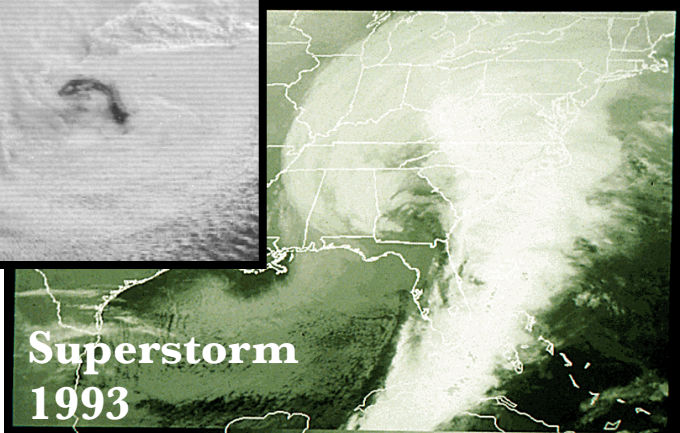
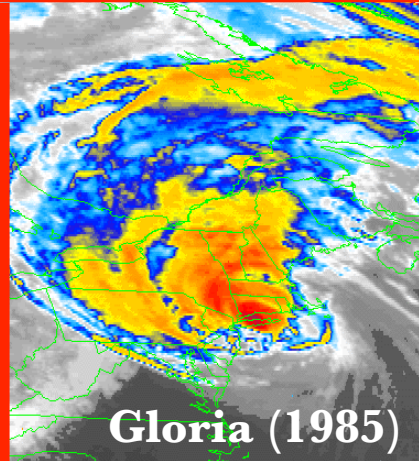
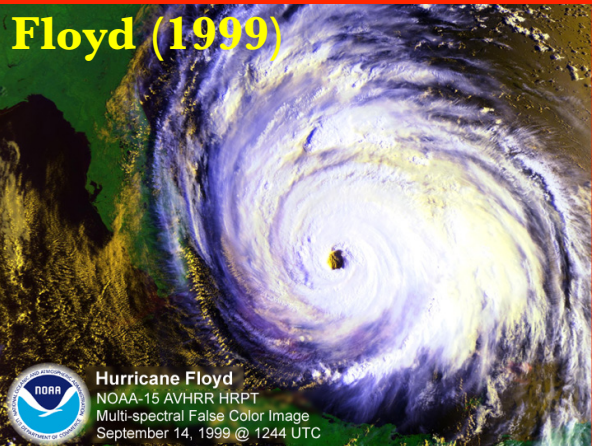
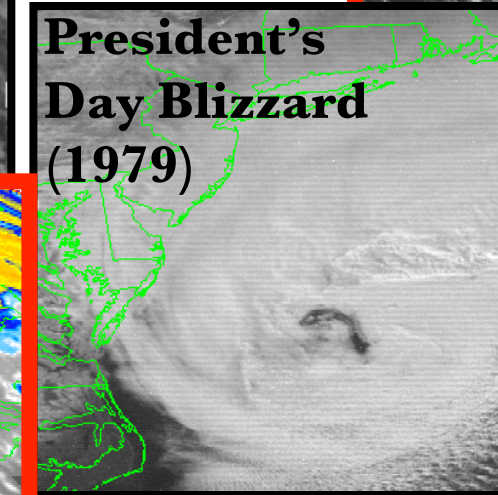
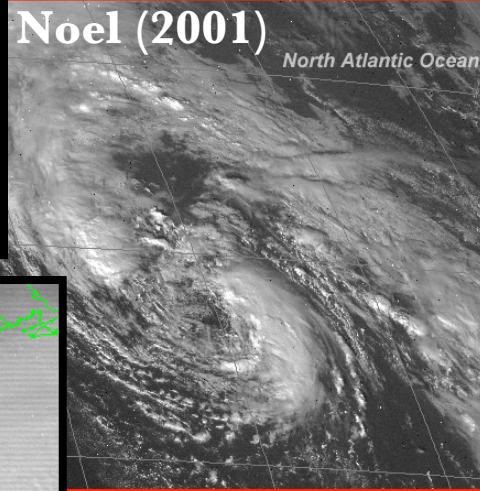
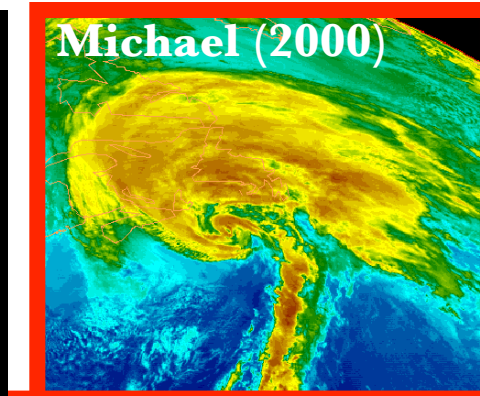
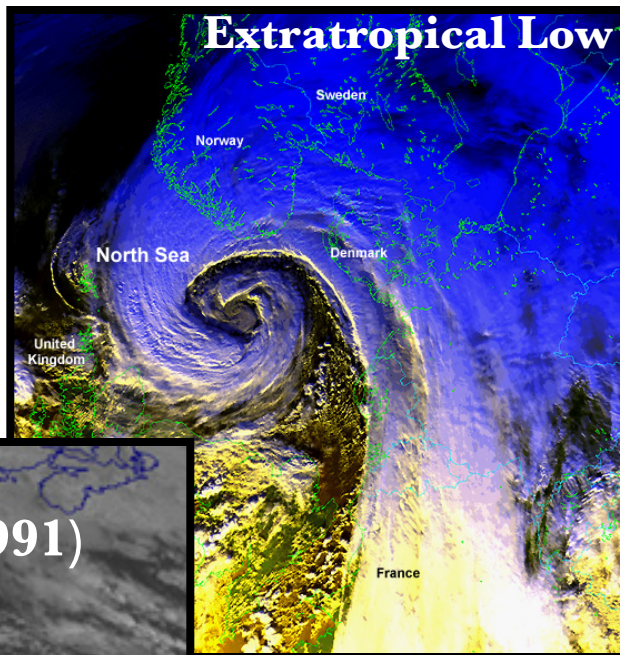
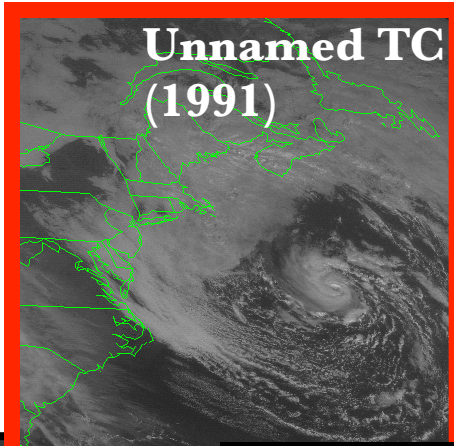
Which five are officially tropical cyclones?

*Images
courtesy
NOAA/
NCDC*



Which five are officially tropical cyclones?

Images
courtesy
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NCDC





Extratropical transition: Characteristics

<i>Tropical cyclones</i>	<i>Extratropical cyclones</i>
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Extratropical transition: A continuum approach

Tropical cyclones

Non-frontal

Warm core

**Driven by
latent heat release**

**Wind maximum close to the
center & the ground**

Symmetric precipitation

Extratropical cyclones

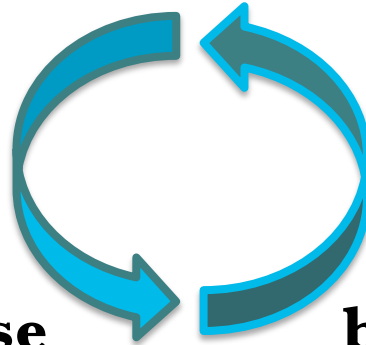
Frontal

Cold core

**Driven by
baroclinic instability**

**Wind maximum removed
from the center & aloft**

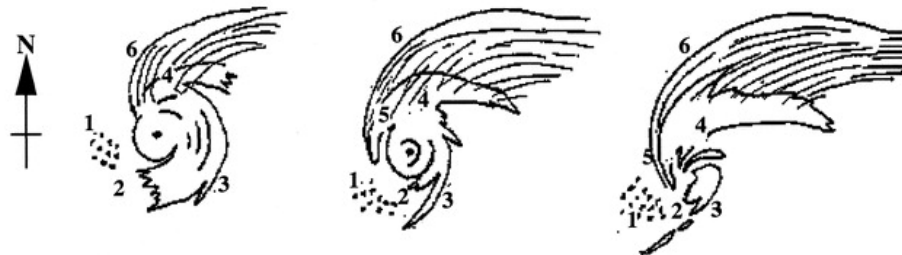
Precipitation left of track



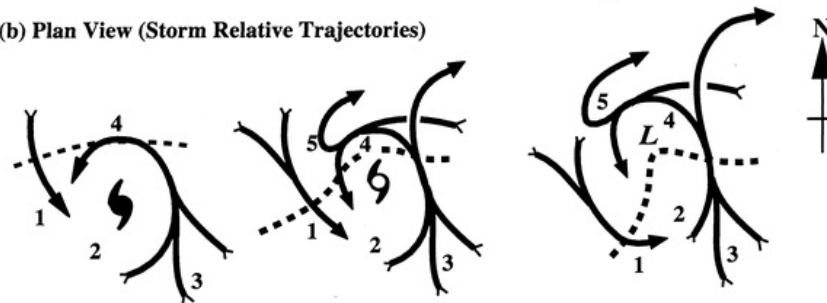
Klein et al. (2000): Conceptual model of West Pac ET

Conceptual Model of Transformation Stage of ET in the Western North Pacific

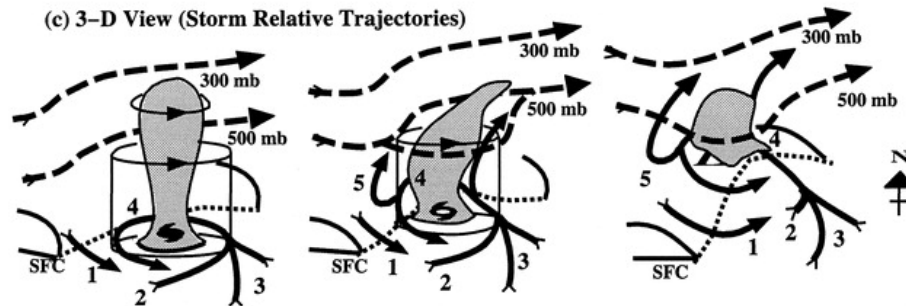
(a) Infrared Imagery



(b) Plan View (Storm Relative Trajectories)



(c) 3-D View (Storm Relative Trajectories)



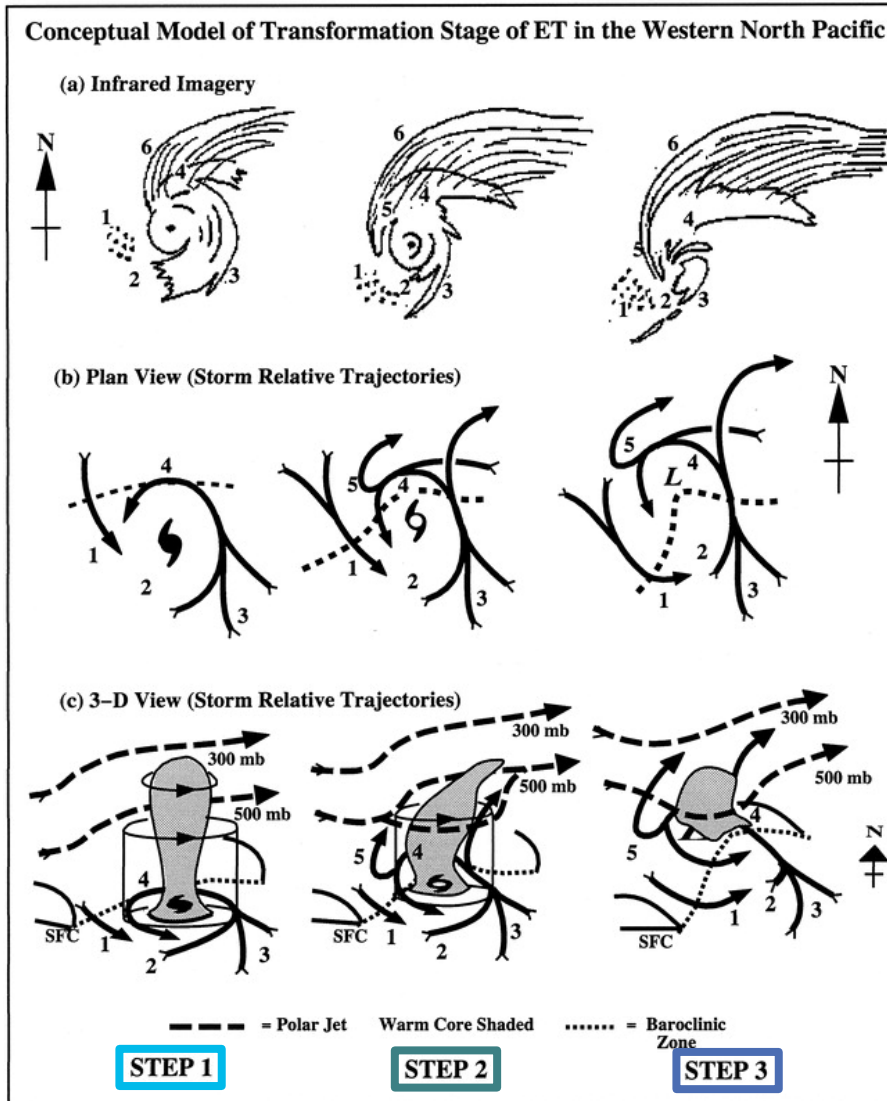
--- = Polar Jet Warm Core Shaded = Baroclinic Zone

STEP 1

STEP 2

STEP 3

Klein et al. (2000): Steps of the transformation stage of ET



Step 1:

**Decreased *SSTs* &
cooler, drier
*environmental air***

Step 2:

**Increased
*vertical wind shear***

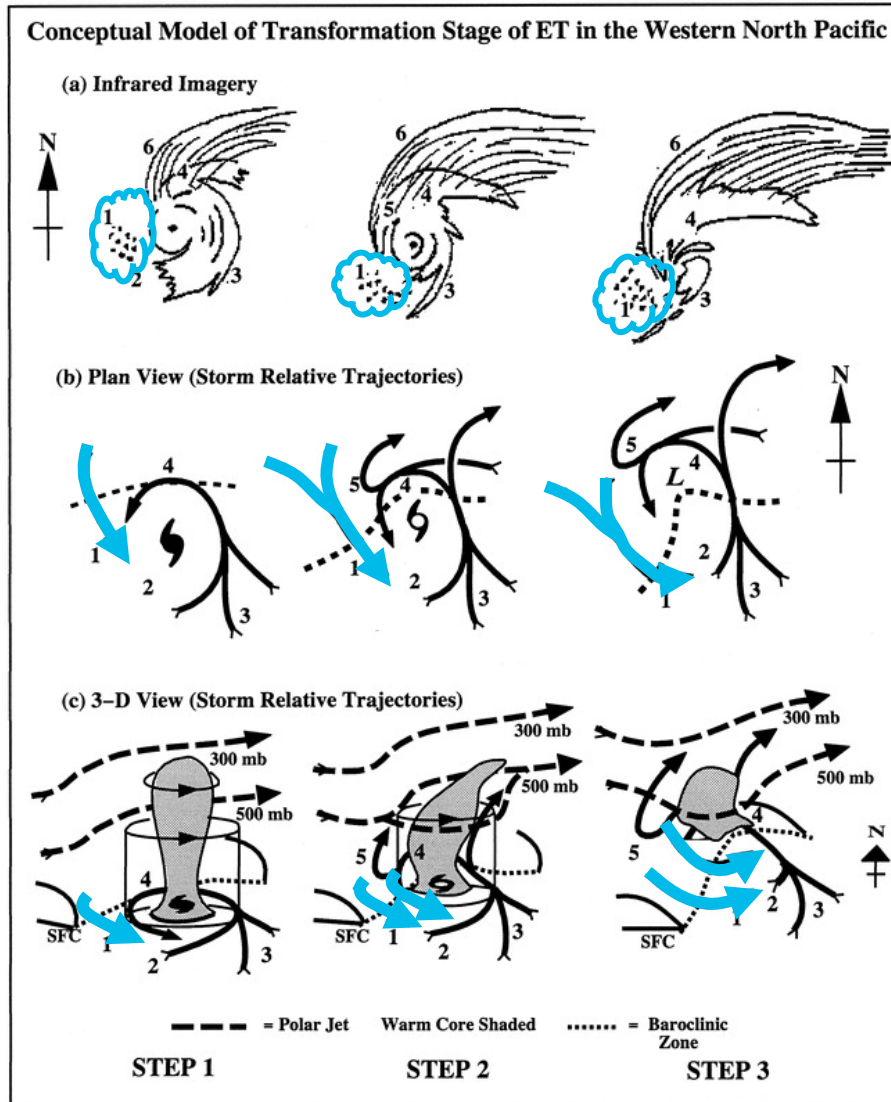
Step 3:

**Interaction with
baroclinic zone &
*frontogenesis***

Akita

Klein et al. (2000):

Main features of the transformation stage of ET



1:

***Equatorward* flow of
cool, dry air
(*open cell cumulus*)**

2:

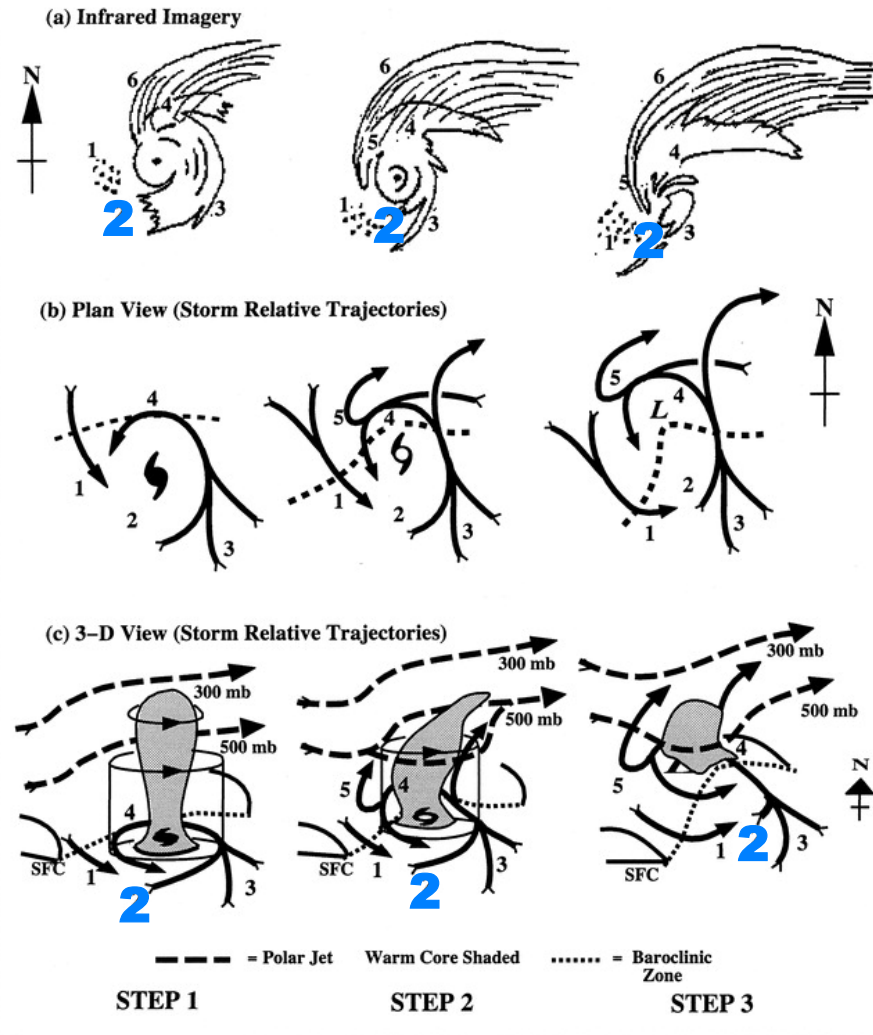
***Decreased convection*
west of TC
(*extends cyclonically*
around the TC in
steps 2 and 3)**

Akita

Klein et al. (2000):

Main features of the transformation stage of ET

Conceptual Model of Transformation Stage of ET in the Western North Pacific



1:

*Equatorward flow of
cool, dry air
(open cell cumulus)*

2:

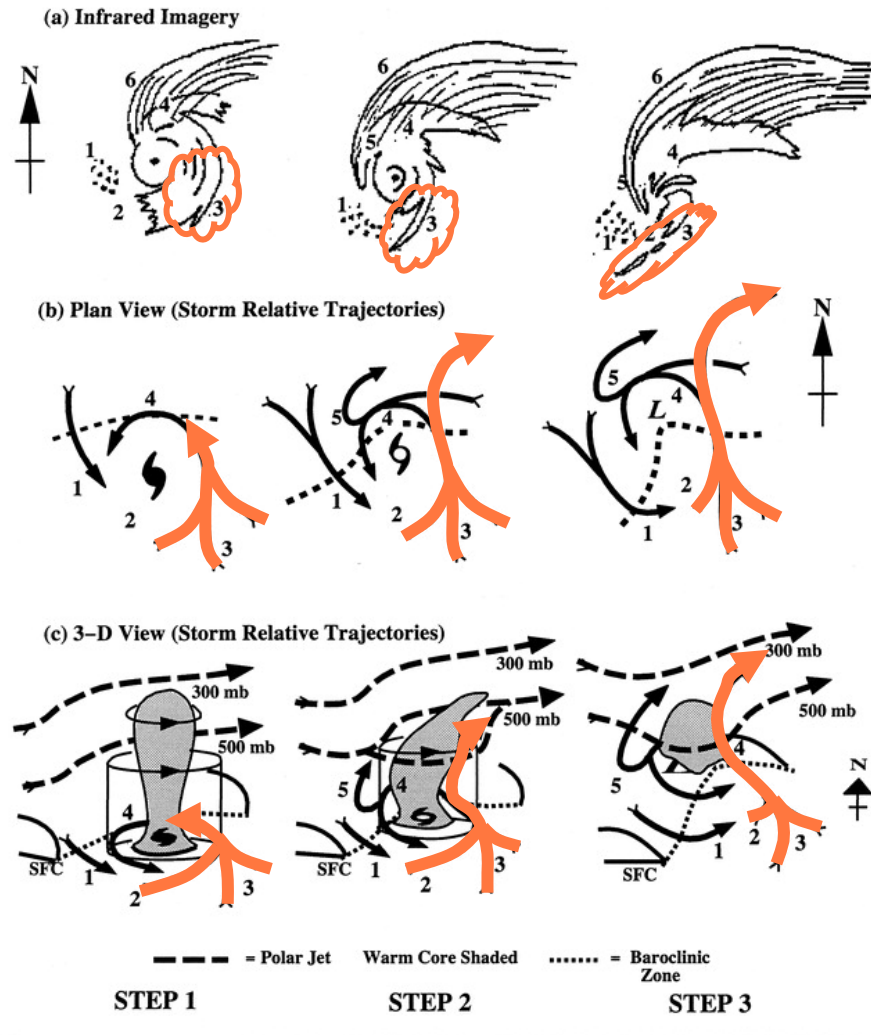
*Decreased convection
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steps 2 and 3)*

Akita

Klein et al. (2000):

Main features of the transformation stage of ET

Conceptual Model of Transformation Stage of ET in the Western North Pacific



3:

Poleward flow of warm, moist air
(*maintains convection; overrunning of θ lines*)

4:

Ascent of warm, moist air over tilted θ lines of baroclinic zone

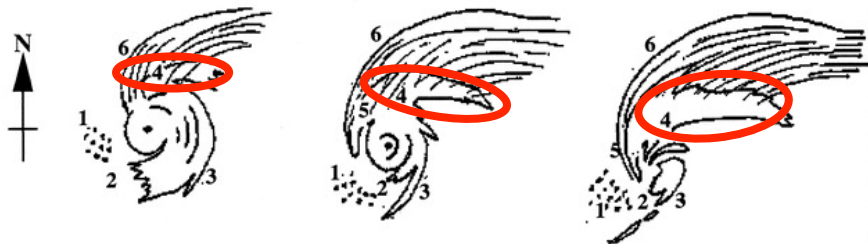
Akita

Klein et al. (2000):

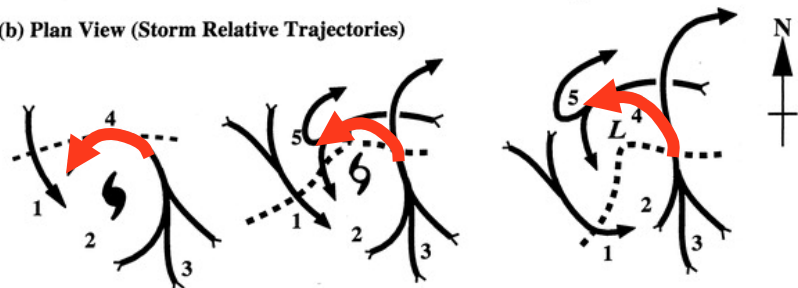
Main features of the transformation stage of ET

Conceptual Model of Transformation Stage of ET in the Western North Pacific

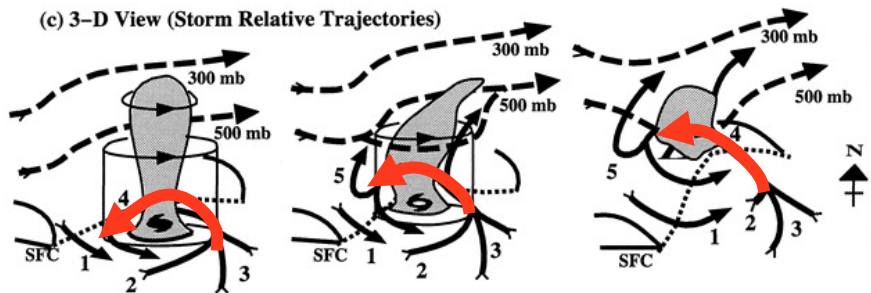
(a) Infrared Imagery



(b) Plan View (Storm Relative Trajectories)



(c) 3-D View (Storm Relative Trajectories)



- - - - = Polar Jet Warm Core Shaded = Baroclinic Zone
 STEP 1 STEP 2 STEP 3

3:

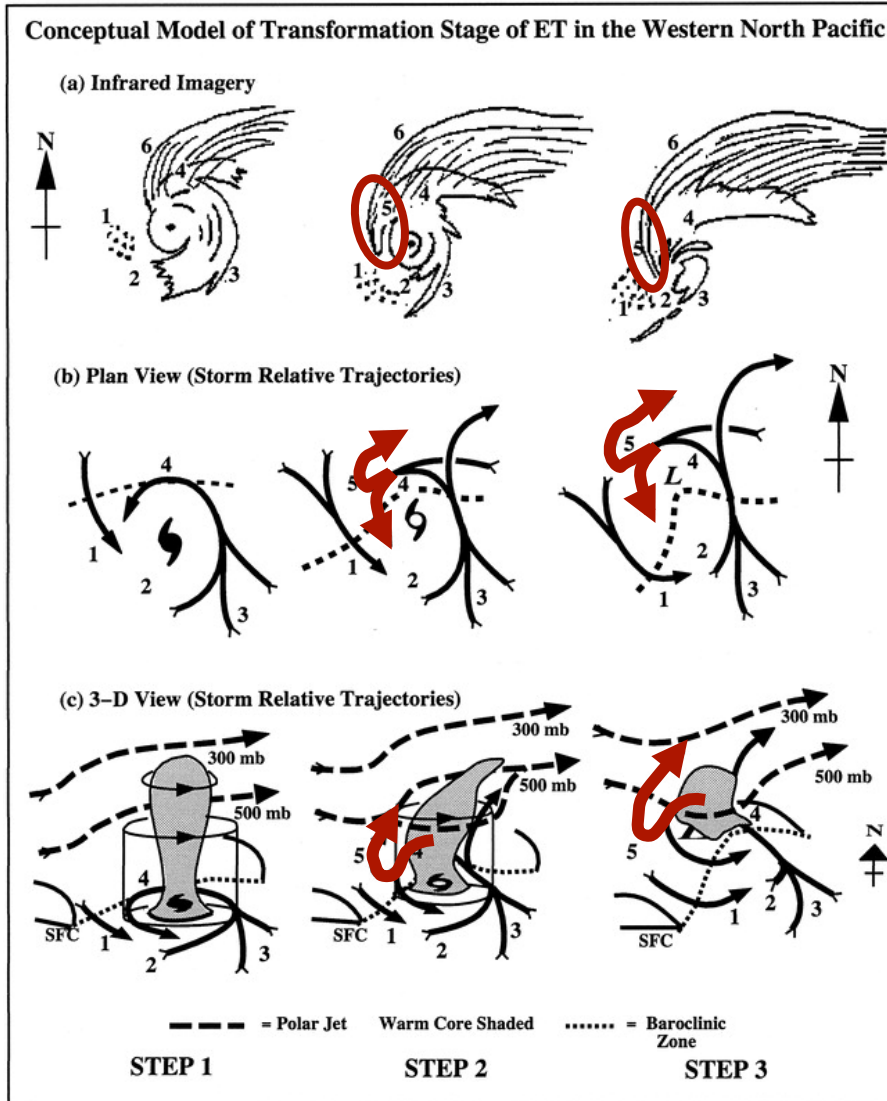
Poleward flow of warm, moist air
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4:

Ascent of warm, moist air over tilted θ lines of baroclinic zone

Akita

Klein et al. (2000): Main features of the transformation stage of ET



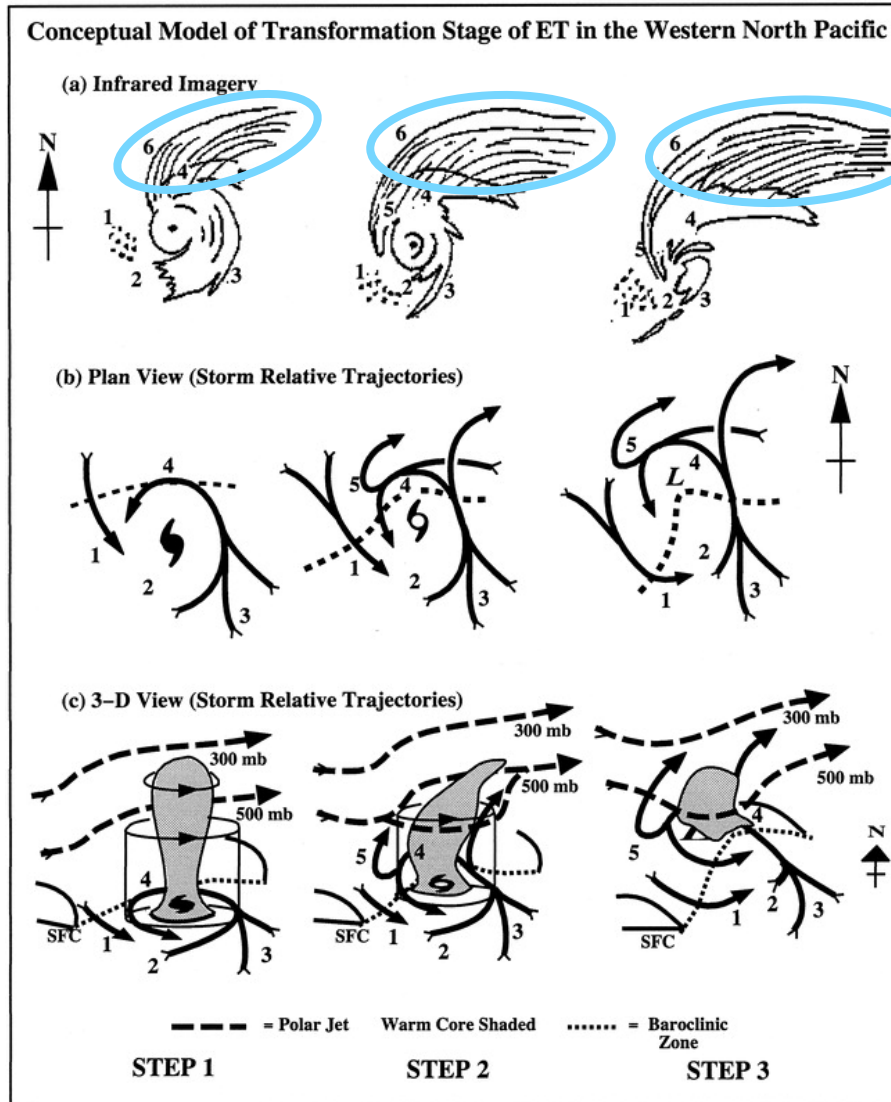
5:
Ascent, producing
cloud bands to the
west of the TC,
undercut by descent

6:
Sharp-edged *cirrus*
shield interacting
with the jet

Akita

Klein et al. (2000):

Main features of the transformation stage of ET



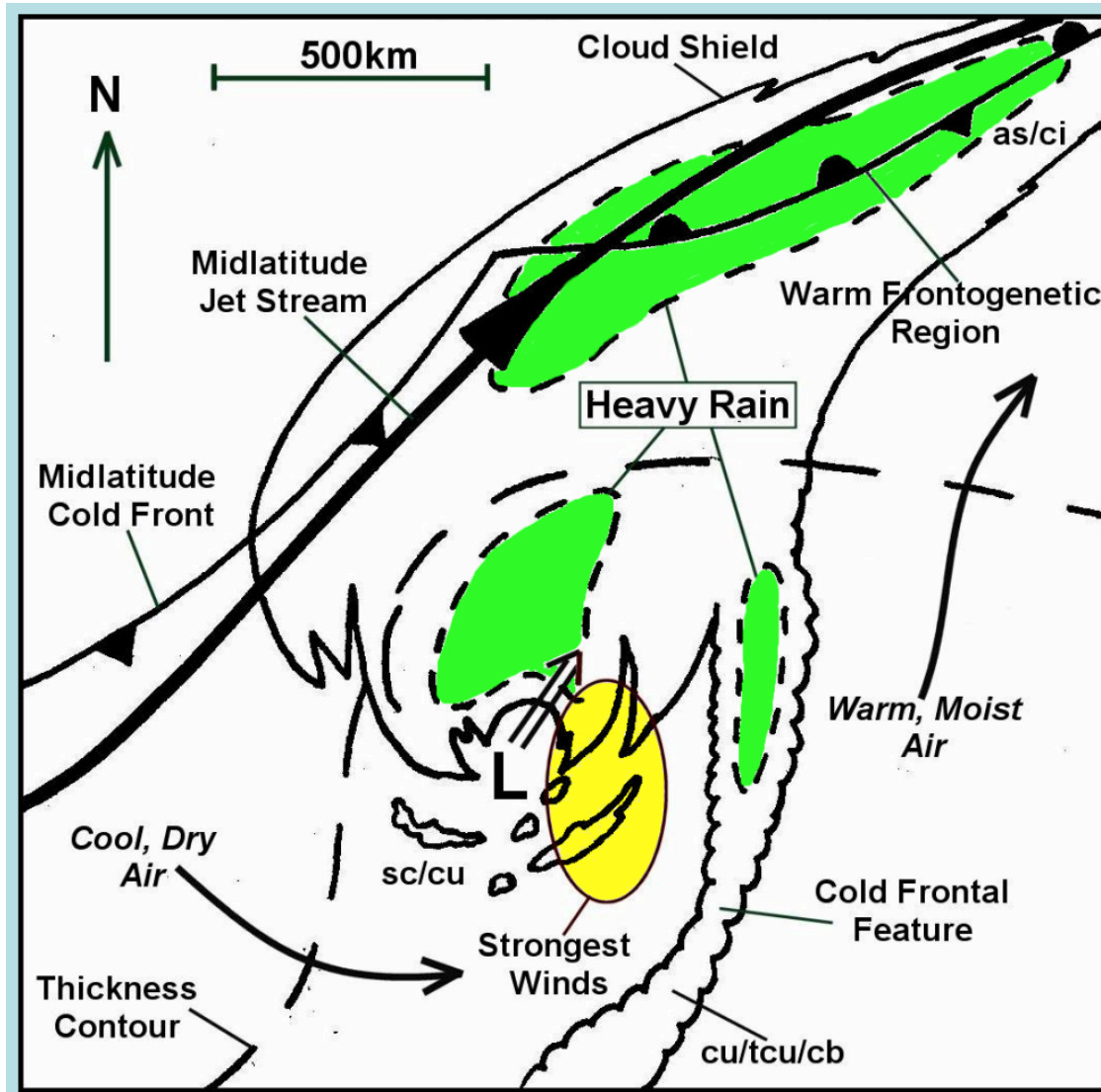
5:

Ascent, producing cloud bands to the west of the TC, undercut by descent

6:

*Sharp-edged **cirrus shield** interacting with the jet*

Klein et al. (2000): Step 3



Extratropical transition: A continuum approach

Tropical cyclones

Non-frontal

Warm core

**Driven by
latent heat release**

**Wind maximum close to the
center & the ground**

Symmetric precipitation

Extratropical cyclones

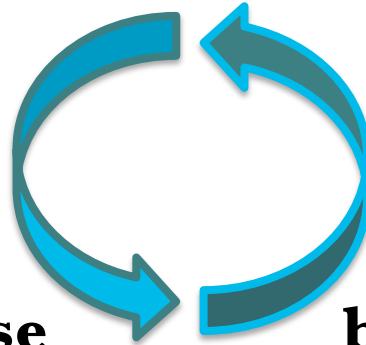
Frontal

Cold core

**Driven by
baroclinic instability**

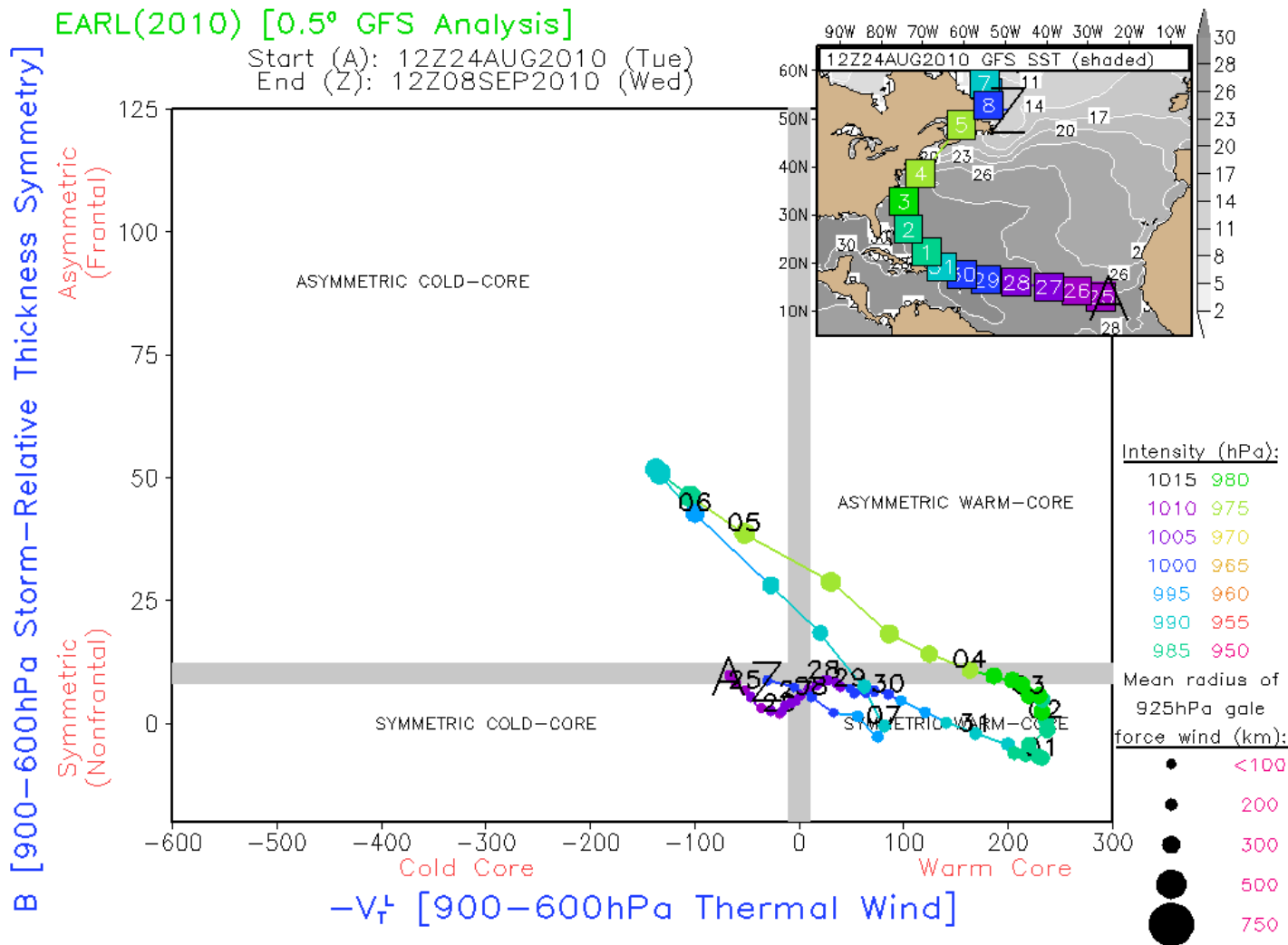
**Wind maximum removed
from the center & aloft**

Precipitation left of track





ET: The phase space diagram

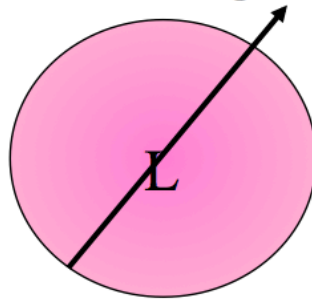


Phase space parameters: Thermal asymmetry

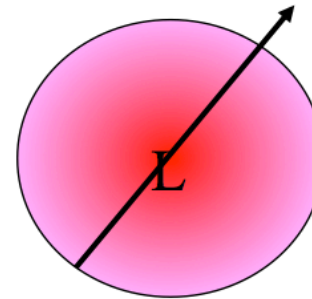
Thermal Asymmetry

*Conventional
Tropical
cyclone:*

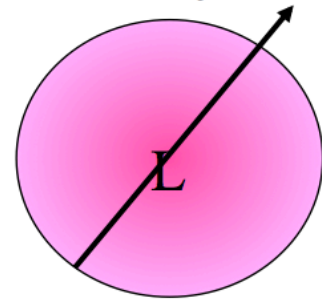
Forming



Mature

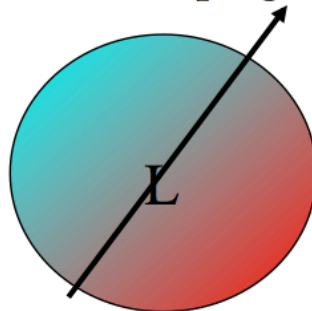


Decay

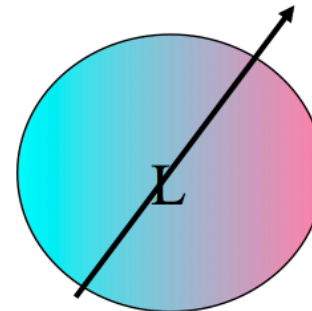


*Conventional
Extratropical
cyclone:*

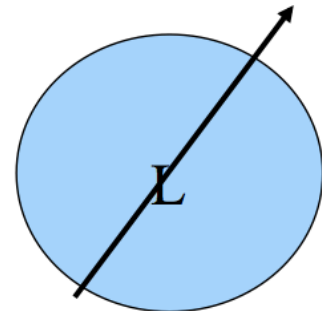
Developing



Mature



Occlusion

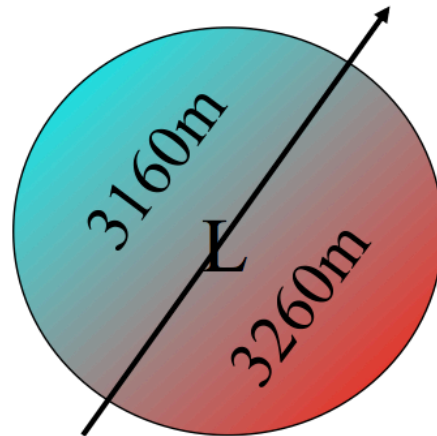


Phase space parameters: Thermal asymmetry

Cyclone Parameter B: Thermal Asymmetry

Storm-relative 900–600-hPa mean thickness field asymmetry within a 500km radius:

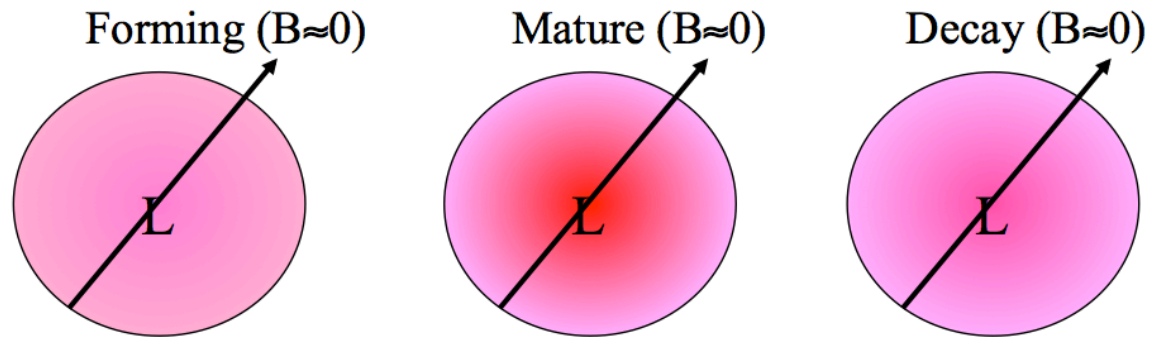
$$B = \overline{Z_{600hPa} - Z_{900hPa}} \Big|_{RIGHT} - \overline{Z_{600hPa} - Z_{900hPa}} \Big|_{LEFT}$$



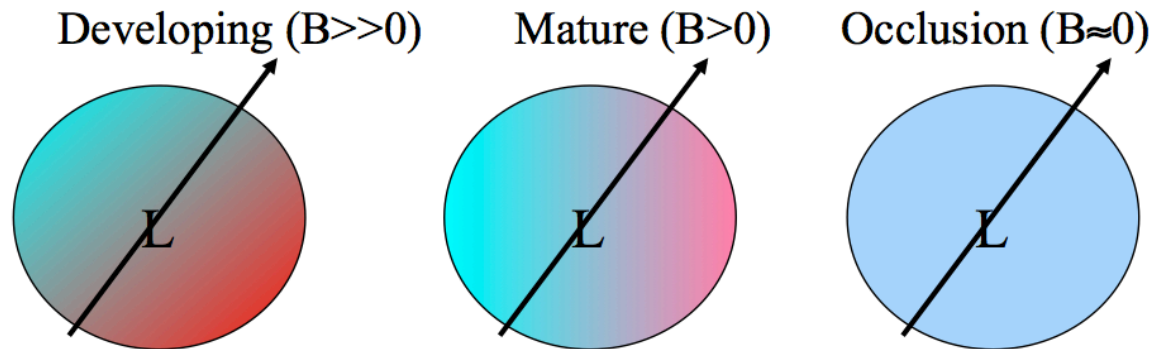
Phase space parameters: Thermal asymmetry

Cyclone Parameter B: Thermal Asymmetry

*Conventional
Tropical
cyclone:
 $B \approx 0$*



*Conventional
Extratropical
cyclone:
 B varies*



Phase space parameters: Thermal wind

Cyclone parameter - V_T : Thermal Wind

$$\Delta Z = Z_{MAX} - Z_{MIN}:$$

Isobaric height difference within 500 km radius

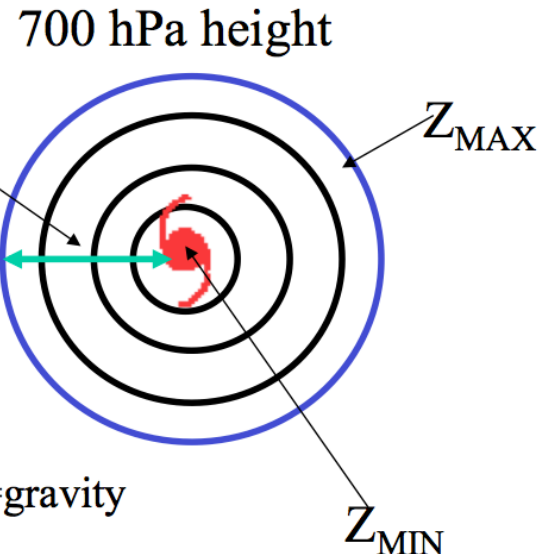
Proportional to geostrophic wind (V_g) magnitude

$$\Delta Z = d f |V_g| / g \quad \text{where}$$

d =distance between height extremes, f =Coriolis, g =gravity

Vertical profile of $Z_{MAX} - Z_{MIN}$ is proportional to thermal wind (V_T) if d is constant:

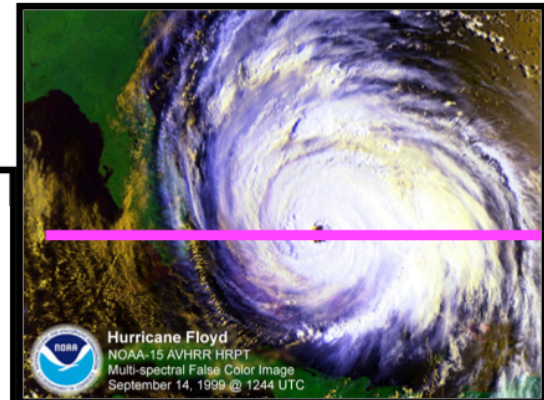
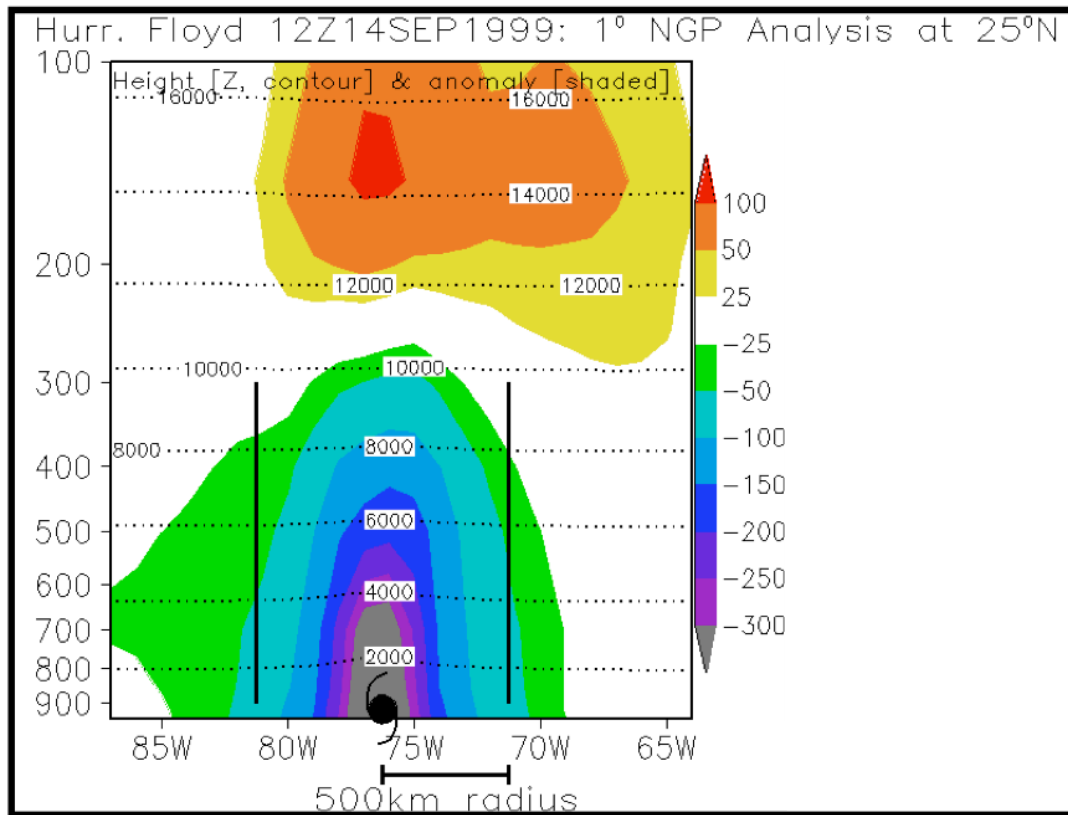
$$\frac{\partial(Z_{MAX} - Z_{MIN})}{\partial \ln p} = -|V_T| \quad \rightarrow \quad \begin{array}{l} 900-600 \text{ hPa: } -V_T^L \\ 600-300 \text{ hPa: } -V_T^U \end{array}$$



Phase space parameters: Thermal wind

Cyclone Parameter - V_T : Thermal Wind

Warm-core example: Floyd 14 Sep 1999

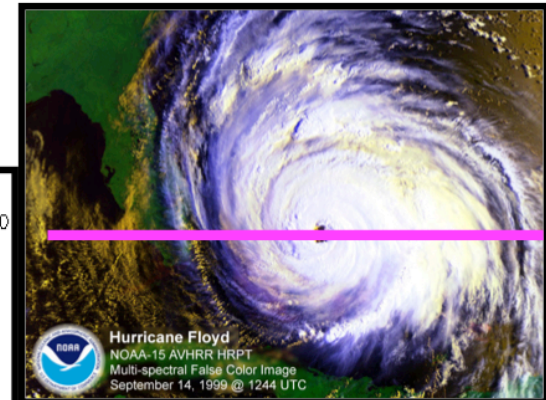
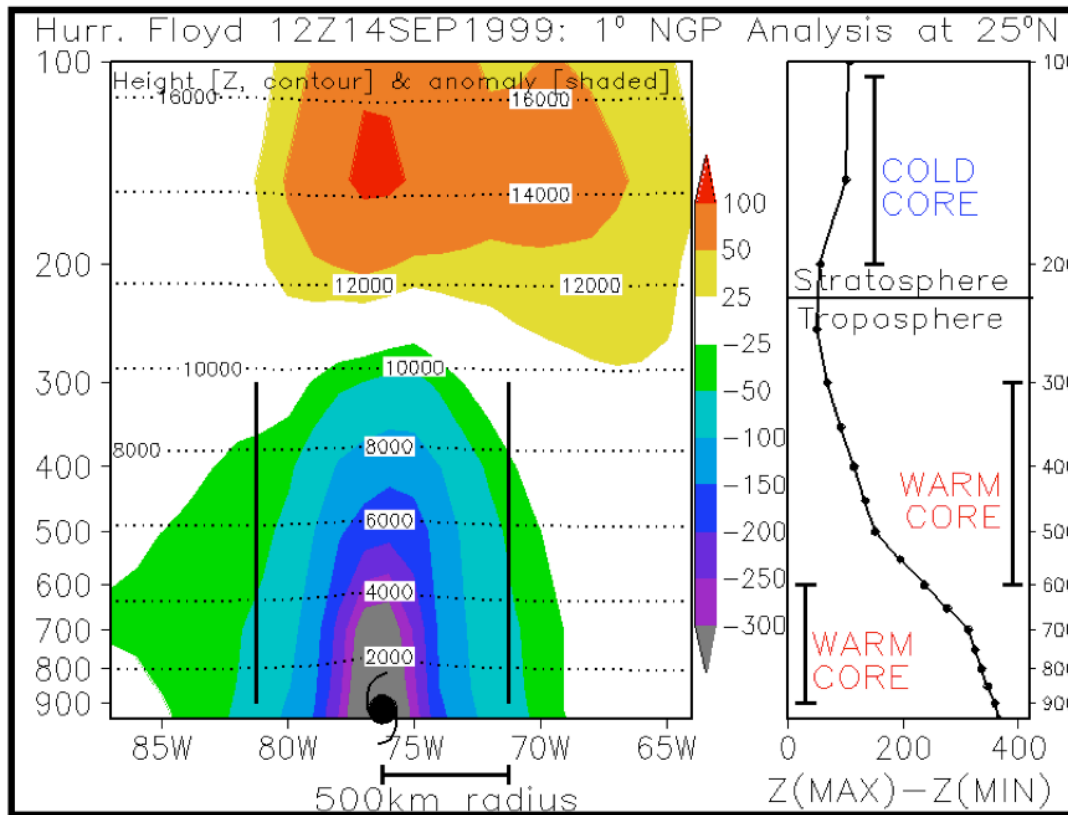


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Phase space parameters: Thermal wind

Cyclone Parameter - V_T : Thermal Wind

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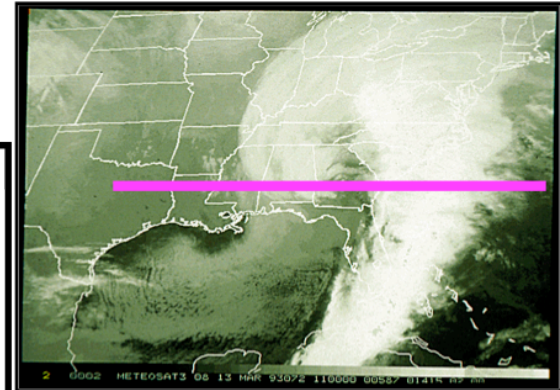
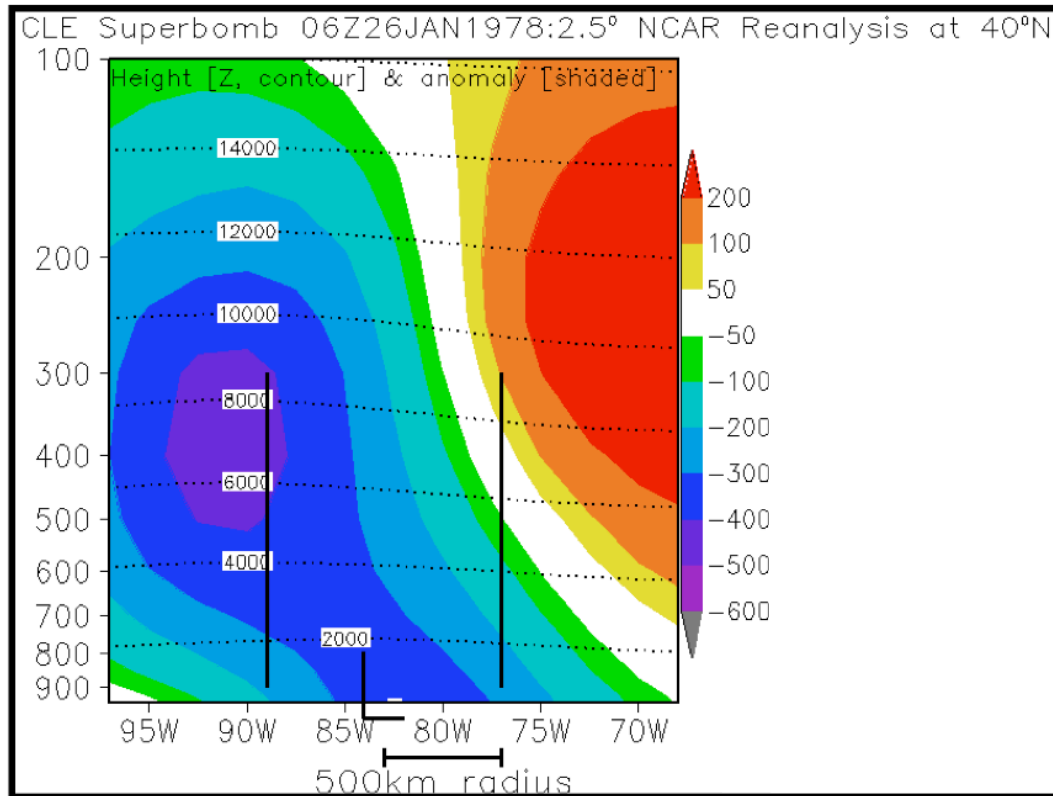


$$\frac{\partial(Z_{MAX} - Z_{MIN})}{\partial \ln p} = -|V_T|$$

Phase space parameters: Thermal wind

Cyclone Parameter - V_T : Thermal Wind

Cold-core example: Cleveland Superbomb 26 Jan 1978

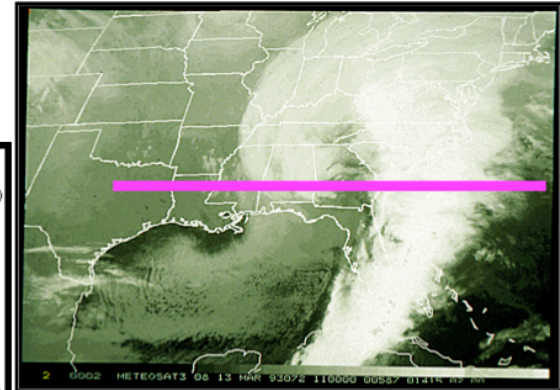
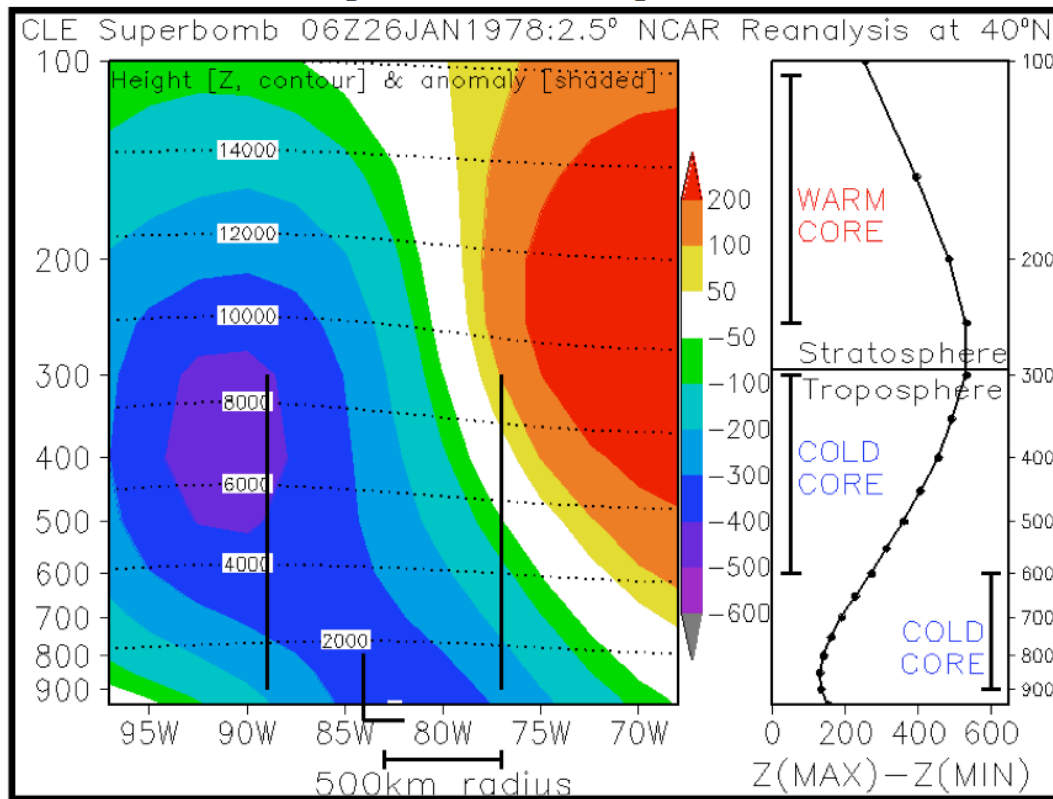


$$\frac{\partial(Z_{MAX} - Z_{MIN})}{\partial \ln p} = - |V_T|$$

Phase space parameters: Thermal wind

Cyclone Parameter - V_T : Thermal Wind

Cold-core example: Cleveland Superbomb 26 Jan 1978



$$\frac{\partial(Z_{MAX} - Z_{MIN})}{\partial \ln p} = - |V_T|$$

Phase space parameters: Thermal wind

Cyclone parameter $-V_T$: Thermal Wind

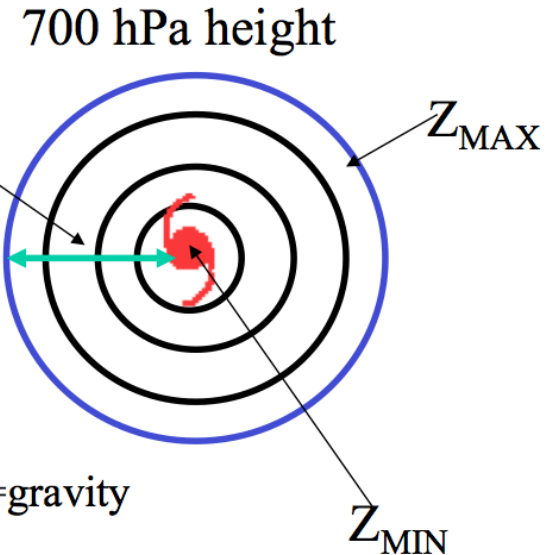
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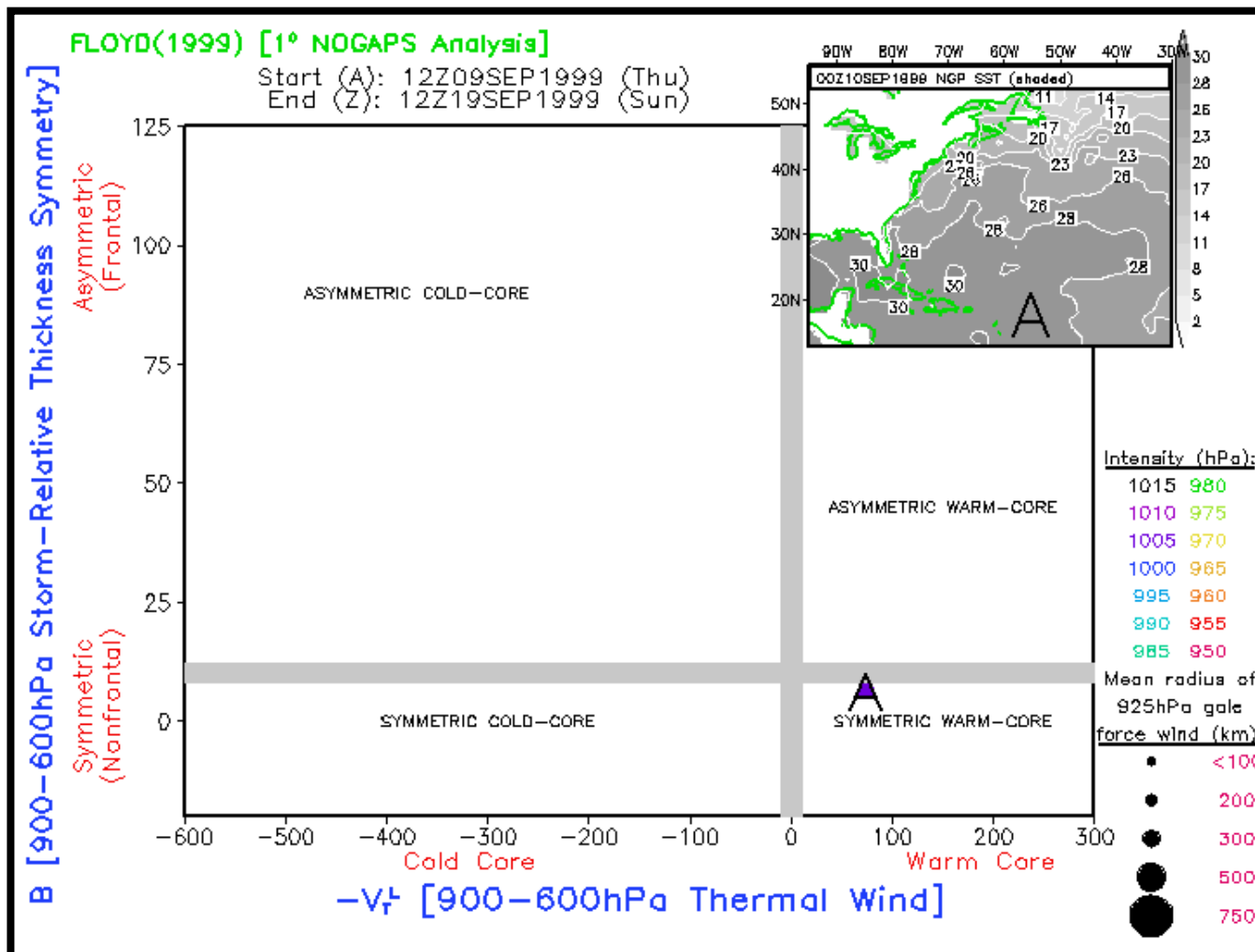


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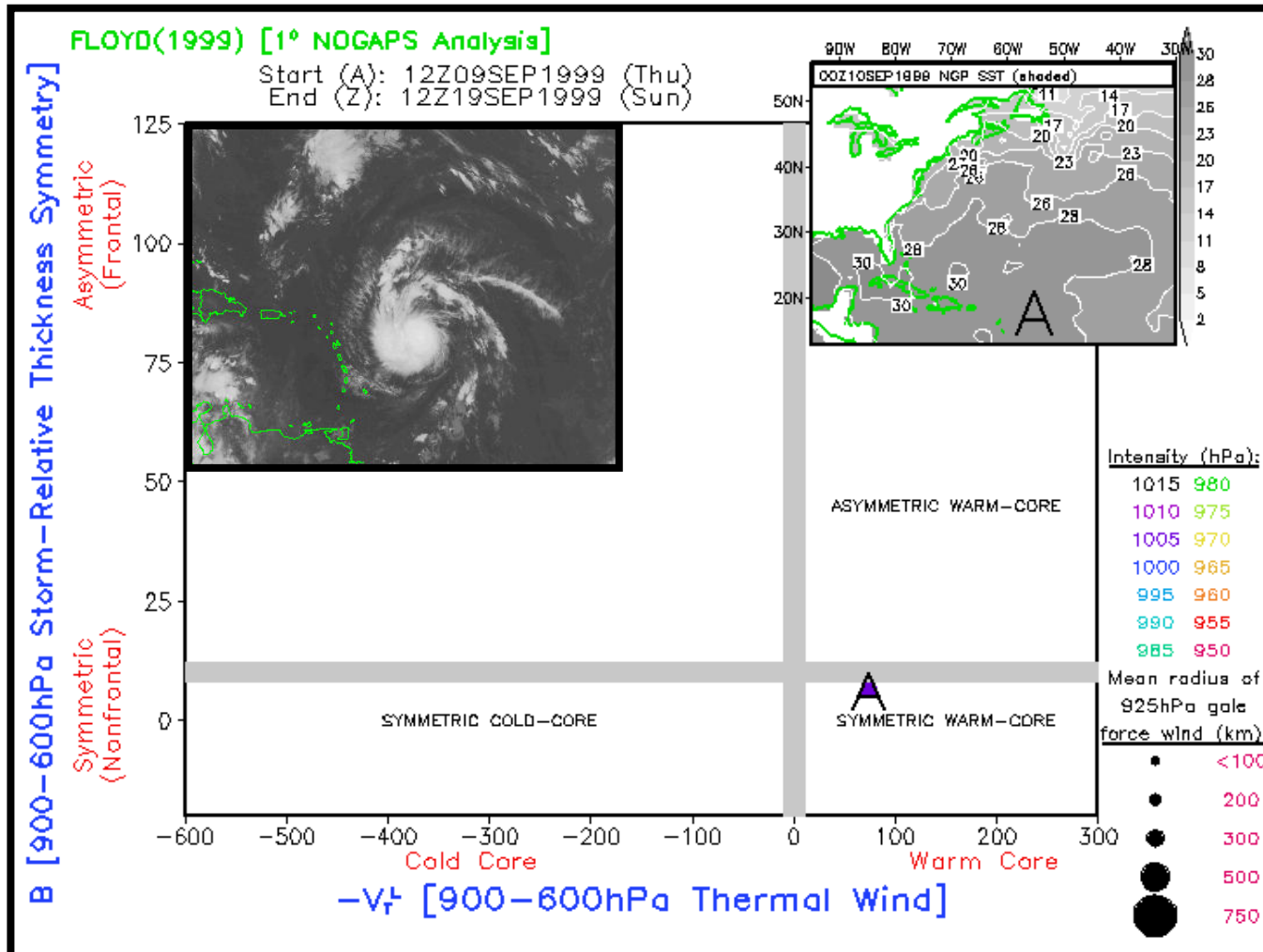
$$\frac{\partial(Z_{MAX} - Z_{MIN})}{\partial \ln p} = -|V_T| \quad \rightarrow \quad \begin{array}{l} 900-600 \text{ hPa: } -V_T^L \\ 600-300 \text{ hPa: } -V_T^U \end{array}$$

$-V_T < 0 = \text{Cold core, } -V_T > 0 = \text{Warm core}$

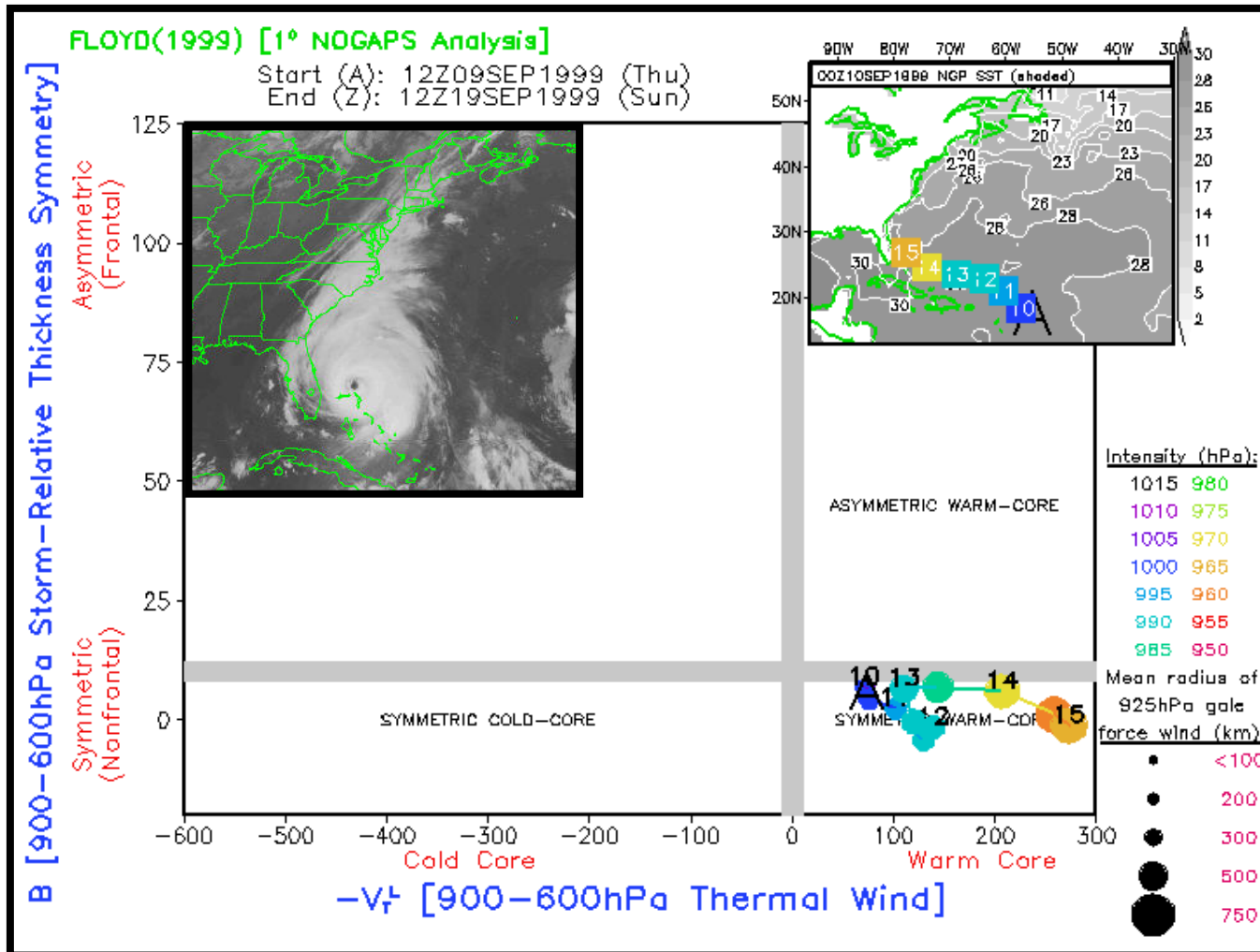
Phase space parameters: The diagram



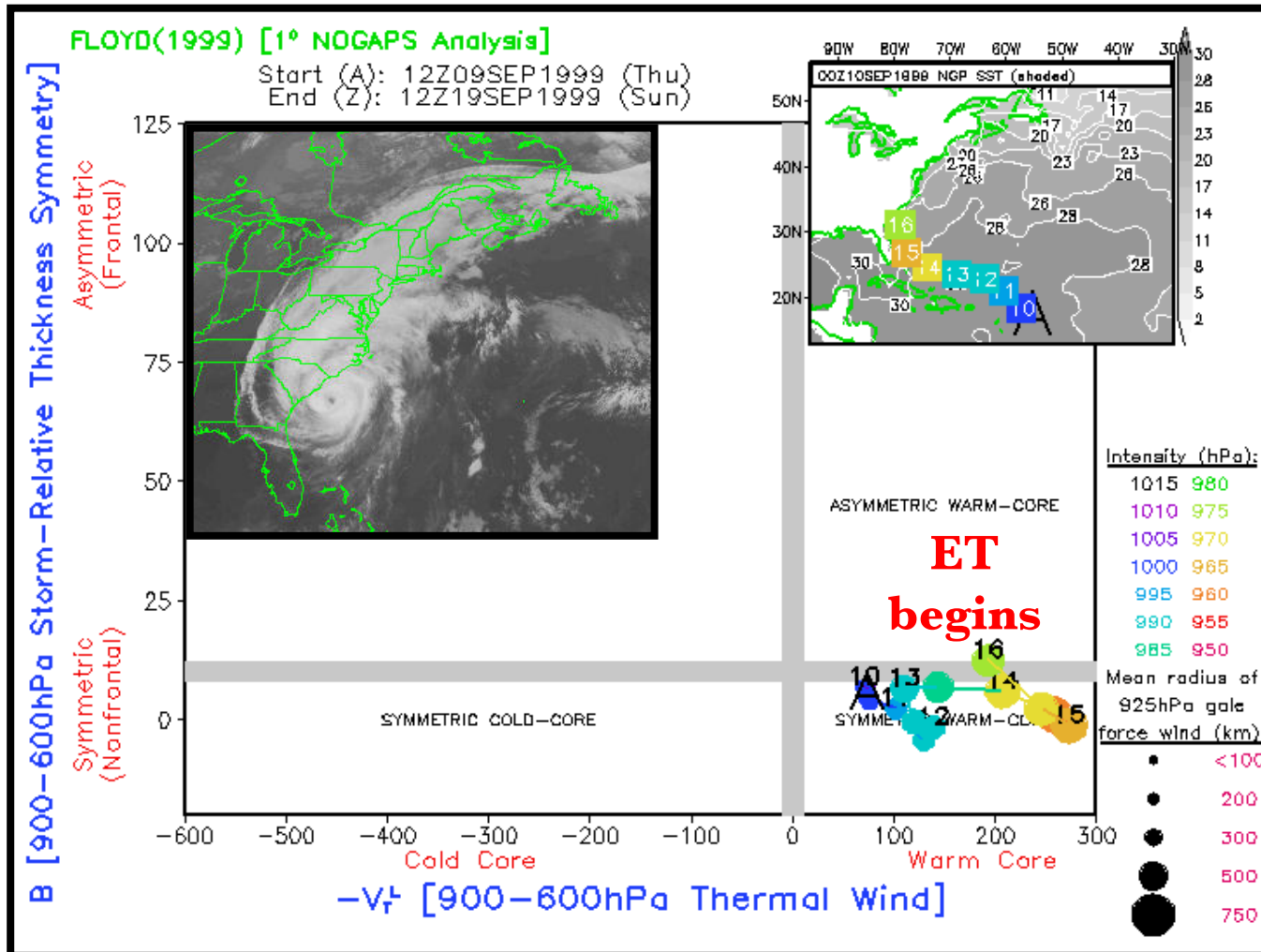
Cyclone phase space: Floyd (1999)



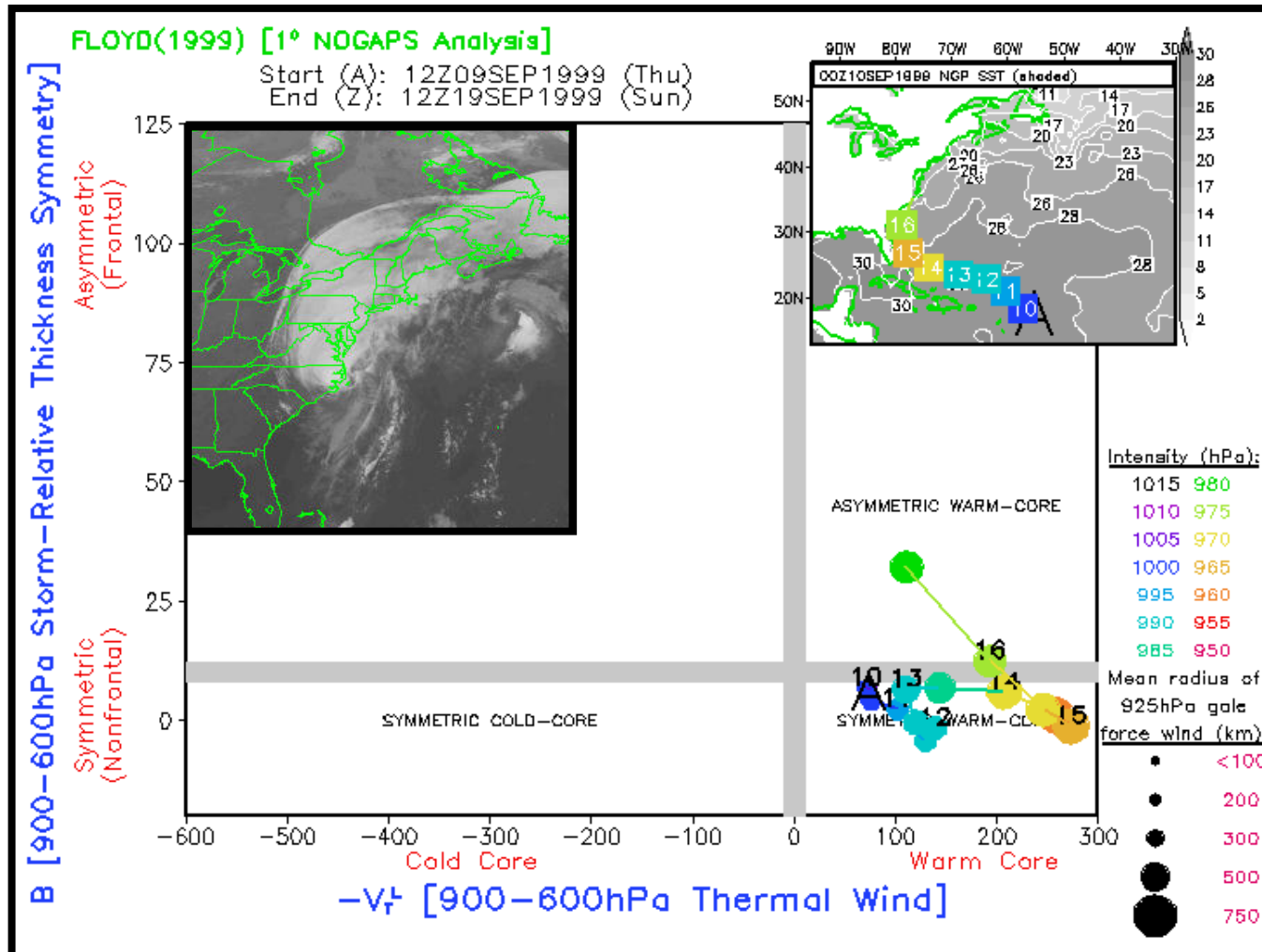
Cyclone phase space: Floyd (1999)



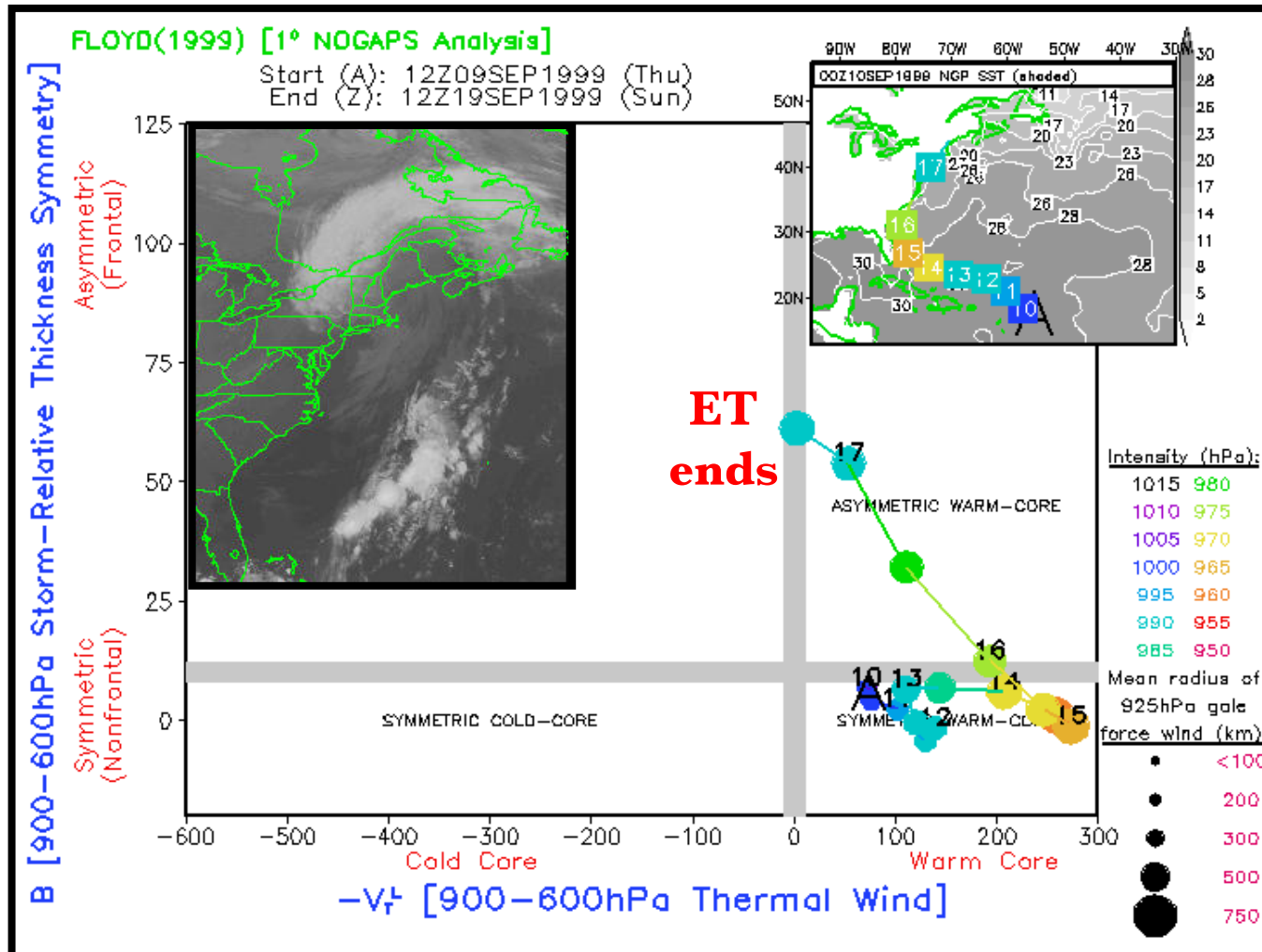
Cyclone phase space: Floyd (1999)



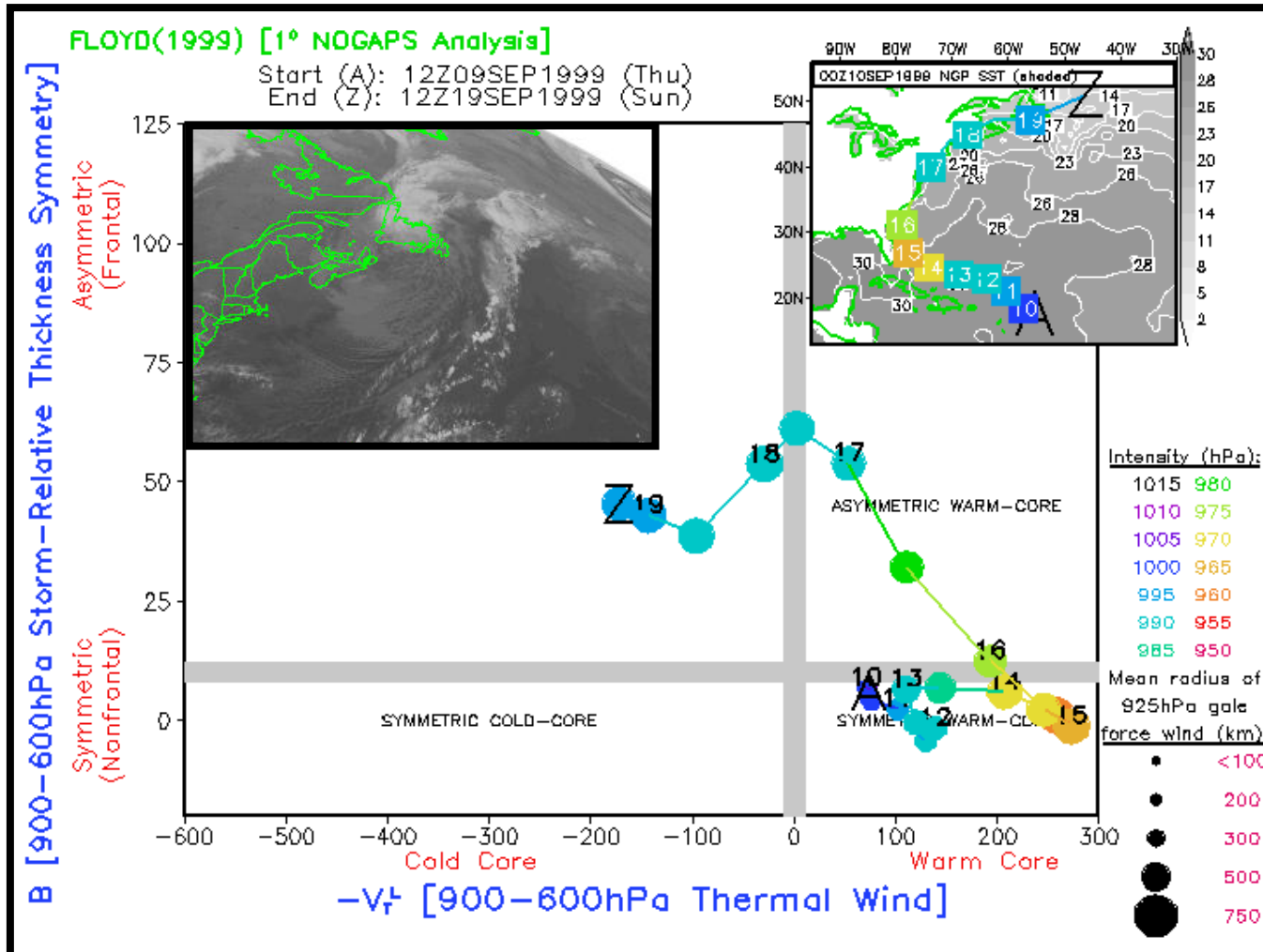
Cyclone phase space: Floyd (1999)



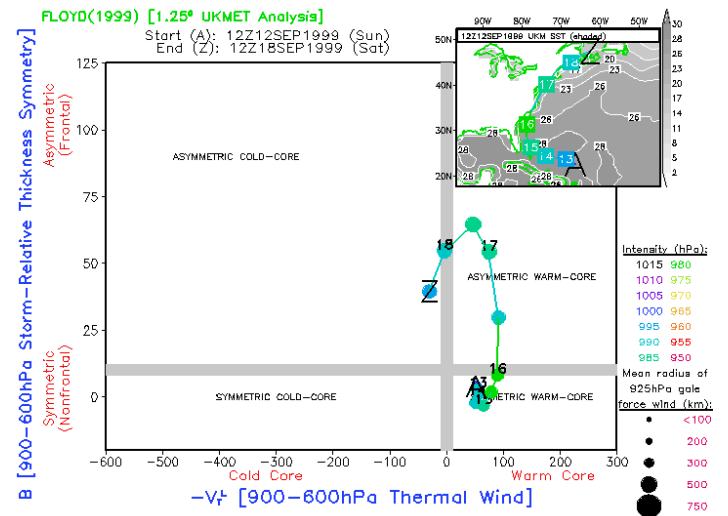
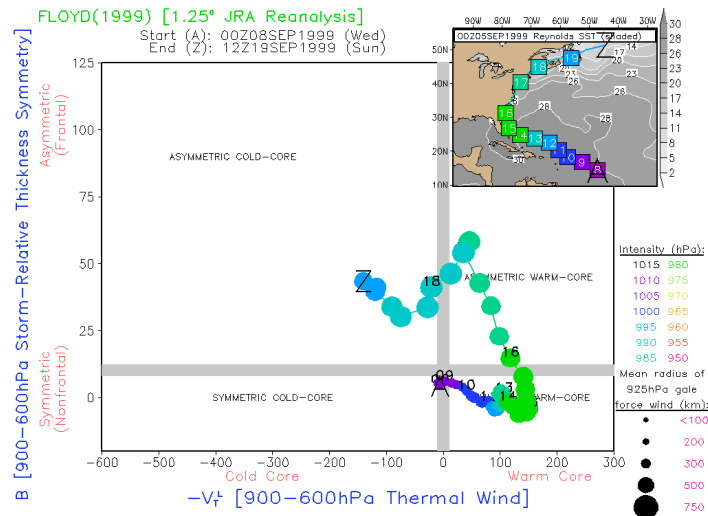
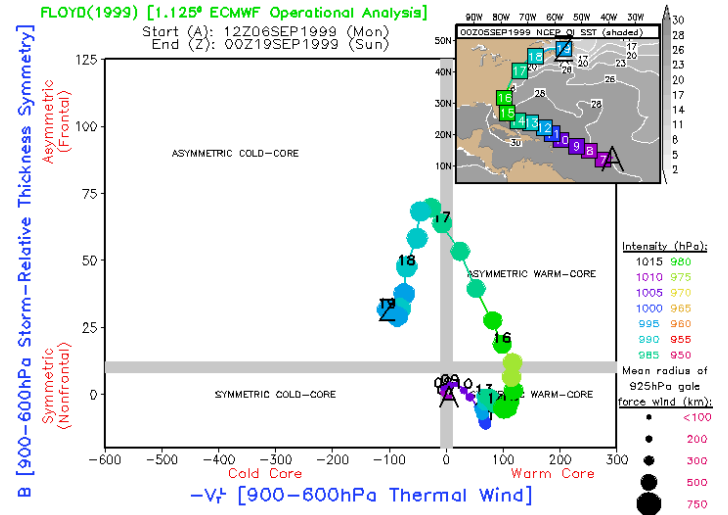
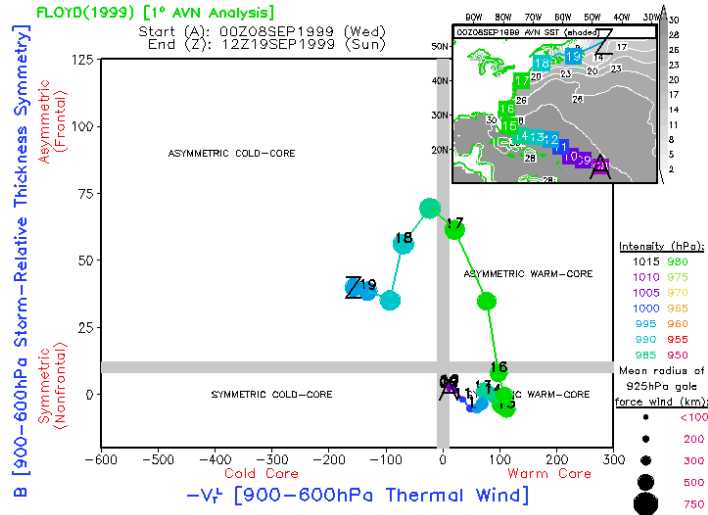
Cyclone phase space: Floyd (1999)



Cyclone phase space: Floyd (1999)



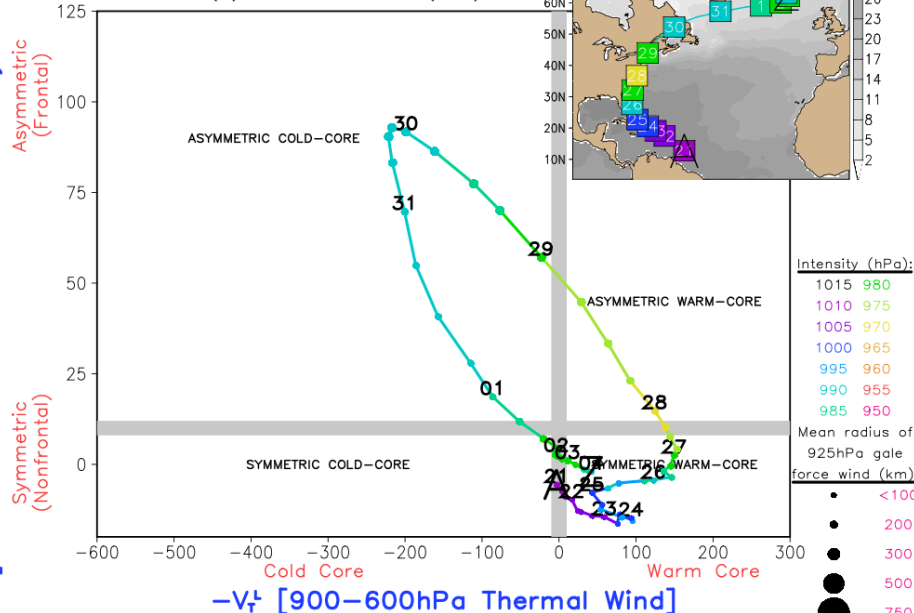
Cyclone phase space: Floyd (1999)



Cyclone phase space: Many flavors of ET

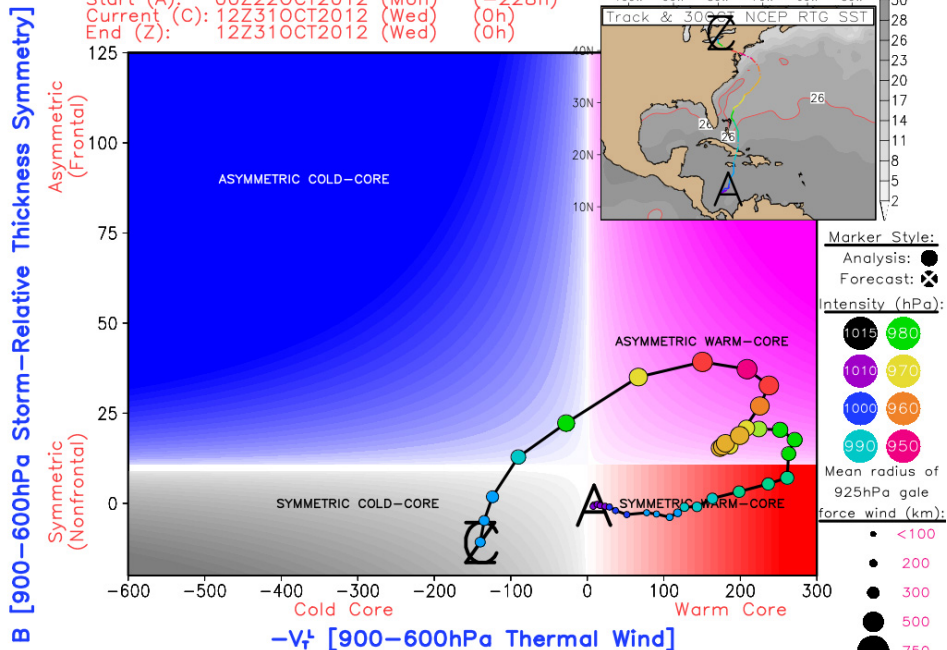
IRENE(2011) [0.7°x0.7° ERAI Reanalysis]

Start (A): 00Z21AUG2011 (Sun)
End (Z): 00Z04SEP2011 (Sun)



0.5° NCEP GFS (12Z31OCT2012 run) Cyclone #1 (Existing cyclone)

Start (A): 00Z22OCT2012 (Mon) (-228h)
Current (C): 12Z31OCT2012 (Wed) (0h)
End (Z): 12Z31OCT2012 (Wed) (0h)



NOTE: A 24hr running mean smoother is applied to the CPS trajectory.

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

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

Cyclone phase space: Forecasting tool

Cold-core phase diagnosis compared to NHC ET declaration
1979–1993 ECMWF 1.125° Reanalysis [60 storms]

