Structure and Evolution of Developing and Non-developing African Easterly Waves during NAMMA

Nelsie A. Ramos, M.S.
PhD Student, Howard University[1]
Meteorologist Trainee, NOAA NHC[3]
Dr. Sim D. Aberson, NOAA AOML/HRD[2]
Dr. Vernon R. Morris[1]
HRD Research Update October, 2011

Overview … Objectives and Motivation

Overview:

- ✓ A modeling and data impact study is being conducted in order to find distinguishing factors to better discriminate between possible developing and non-developing AEWs into TCs

Objectives:

- ✓ Study the dynamic-thermodynamic evolution of the environment and structure of a developing and a non-developing AEW
- ✓ Assess the regional and high resolution HWRF model for the study of weak tropical disturbances (i.e. AEWs) as well as the TD, TS and hurricane stages (as opposed to its use only for mature TCs)

Motivation:

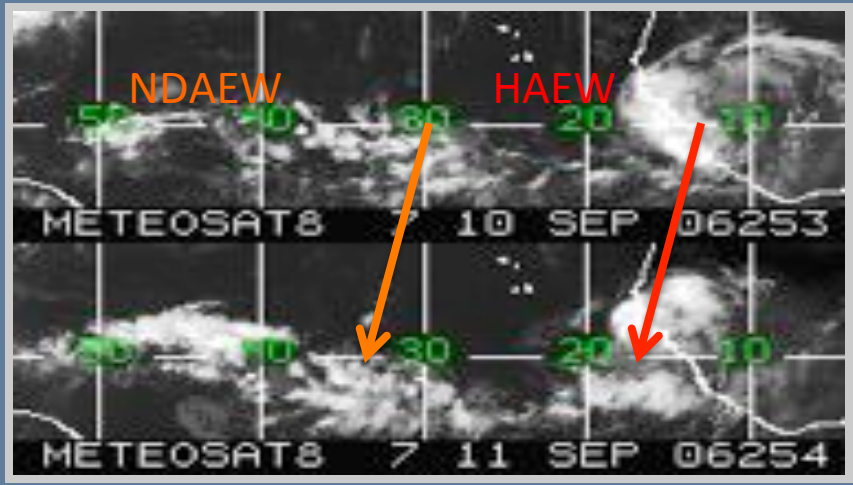
- ✓ Insufficient understanding about how Tropical Cyclones form
  - Difficulty in forecasting time and location
  - Understanding of the physics behind their initiation
- ✓ Improvement of TC genesis forecast is critical, especially if development represent a potential threat for landfall in a short period of time

Scope of the Problem and Cases Selection

- ✓ Factors limiting the cyclogenesis prediction:
  - Lack of an accurate description of the initial conditions in numerical prediction
  - Scarce observations of both AEWs as the precursors and subsequent TC genesis process itself
- ✓ Factors that may contribute to increased model accuracy and reliability:
  - Better observing network over the tropical oceans
  - Development of new and improved DA techniques
  - Improvement of model resolution and physics (e.g., Aberson and DeMaria 1994)

Reasons for 2006 cases selection:

- ✓ Unique NAMMA dataset which sampled major AEWs over the E Atlantic



- ✓ Data were not assimilated into NOAA/NCEP models in real time (opportunity to evaluate impact of additional data)
- ✓ Cyclogenesis of Helene – only existing case sampled off the coast of Africa and after genesis
- ✓ Helene genesis was predicted ~24 hr in advance by many global models which may provide insight on less predictable cases
- ✓ AEWs prior and subsequent to the NDAEW developed into TCs

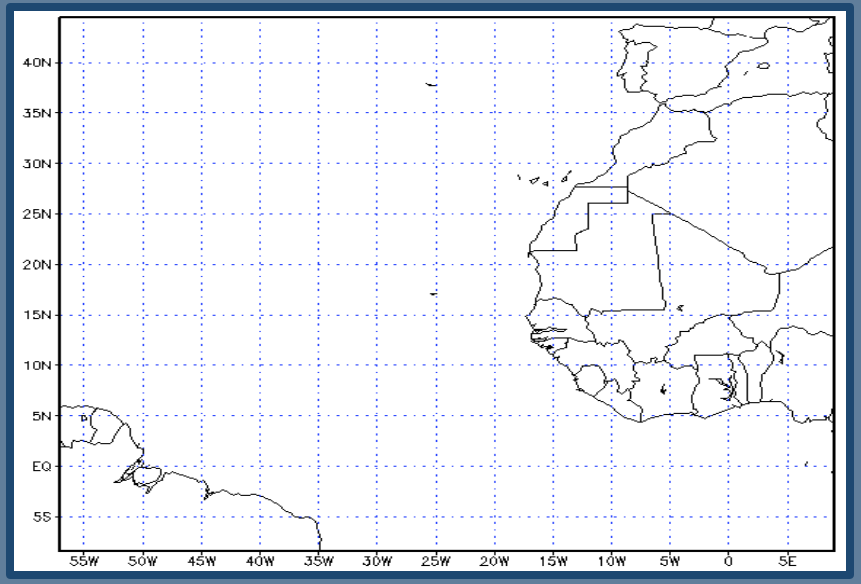
Methodology and Experimental Design

Methodology:

- ✓ HWRF CNTRL (NDA) simulations w/wo CU (for d01; d02 always off)
- ✓ HWRF DA simulations using HEDAS w/wo CU
  - – U, V, T & RH dropsonde data
- ✓ HWRF validation through dropsonde data and NHC best track analyses

Experimental Design:

- ✓ HRD HWRF at 9 : 3 km grid resolution (parent : nest)
- ✓ 42 vertical levels
- ✓ IC/BC from GFS FNL analyses (GEFS for d02 when DA; HEDAS+HWRF IC when DA)
- ✓ Semi-Operational physical parameterizations:
  - – Ferrier Microphysics
  - – GFDL Radiation and Land Surface Physics
  - – NCEP GFS *Surface Layer* and PBL
  - – Simplified Arakawa Schubert (SAS) Cumulus Parameterization

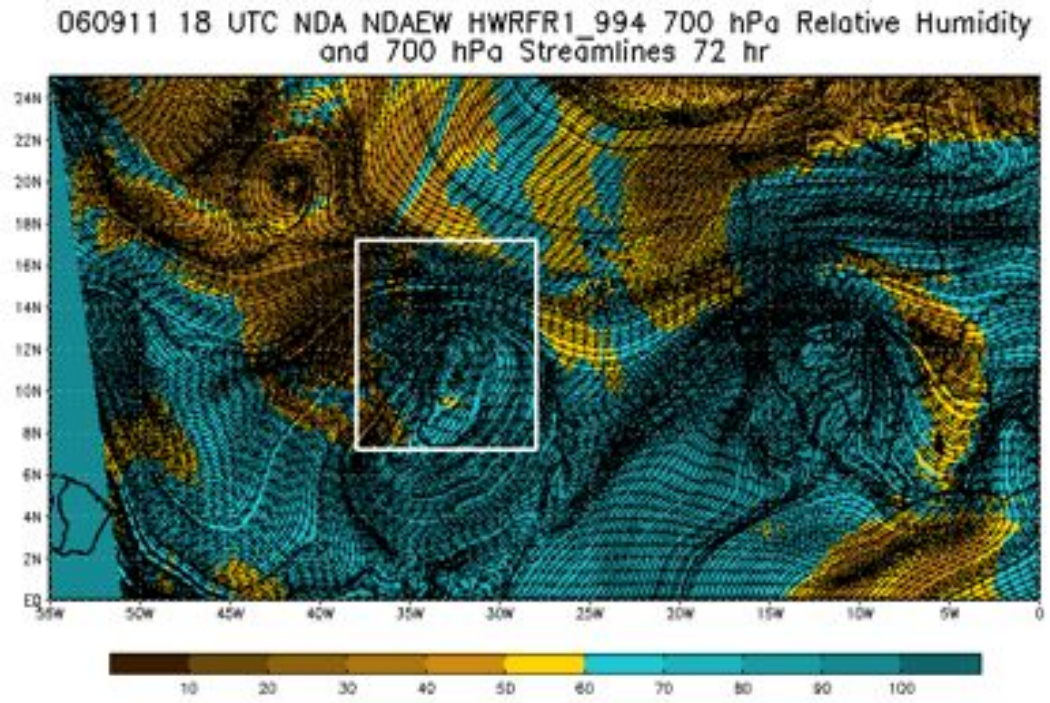


NDA/DA CU/NCU	Start Date	End Date	Run Length
R1 NDAEW	Sep 8/18	Sep 13/18	120 hr
R2 NDAEW	Sep 9/18	Sep 14/18	120 hr
R3 HAEW	Sep 12/18	Sep 17/18	120 hr

NDA HWRF Results

NDAEW R1: CU vs NCU

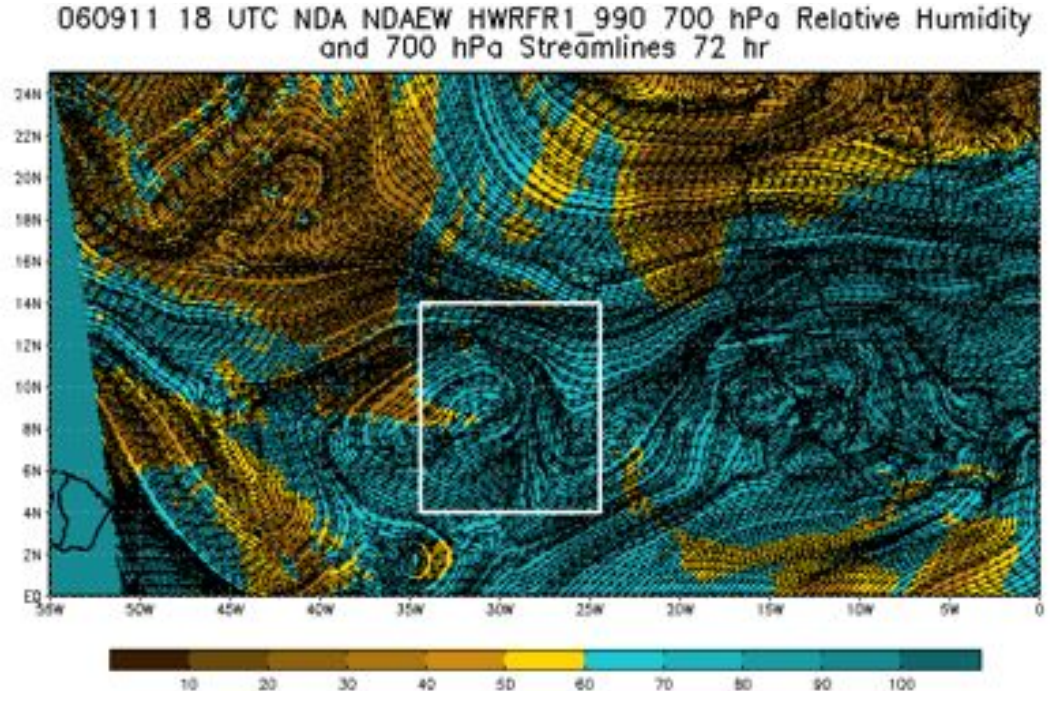
R1 NDAEW CU



MSW= 3 kt
MSLP= 1009 hPa

Stronger synoptic features

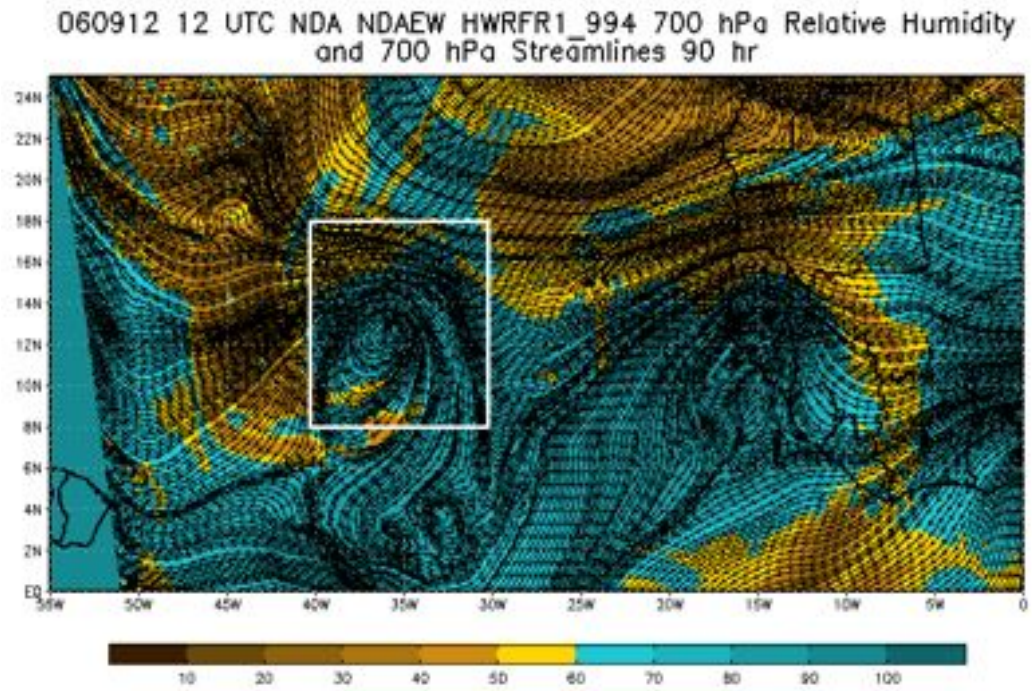
R1 NDAEW NCU



MSW= 15 kt
MSLP= 1010 hPa

- Weaker synoptic features
- Dry air entrainment to the core

R1 NDAEW CU

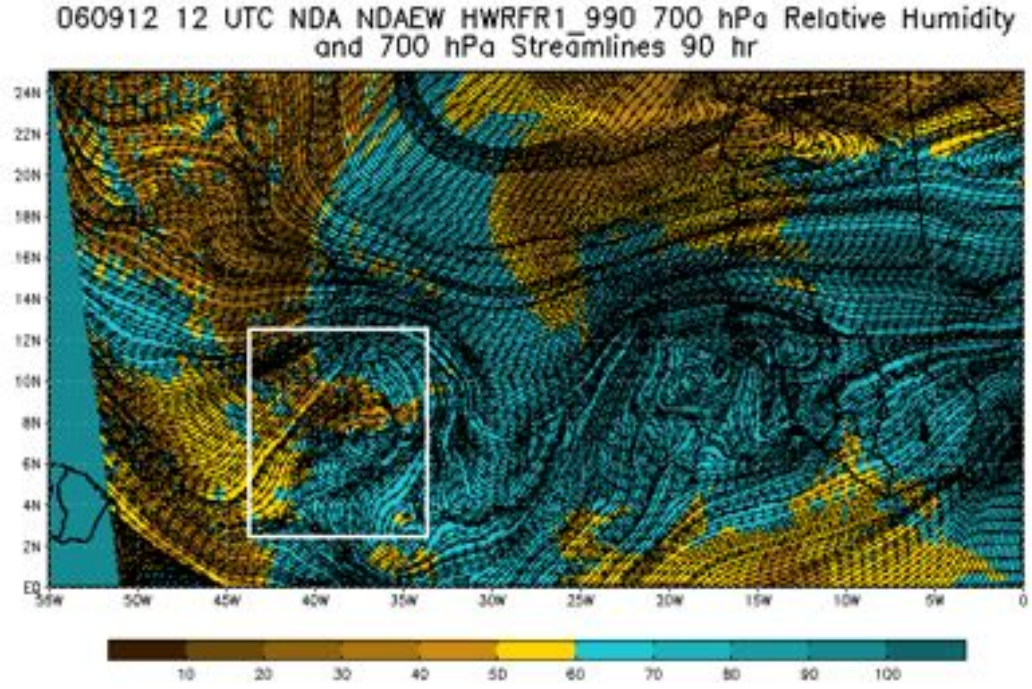


MSW= 37 kt
MSLP= 1004hPa

TS

- Stronger system
- No dry air entrainment at the core

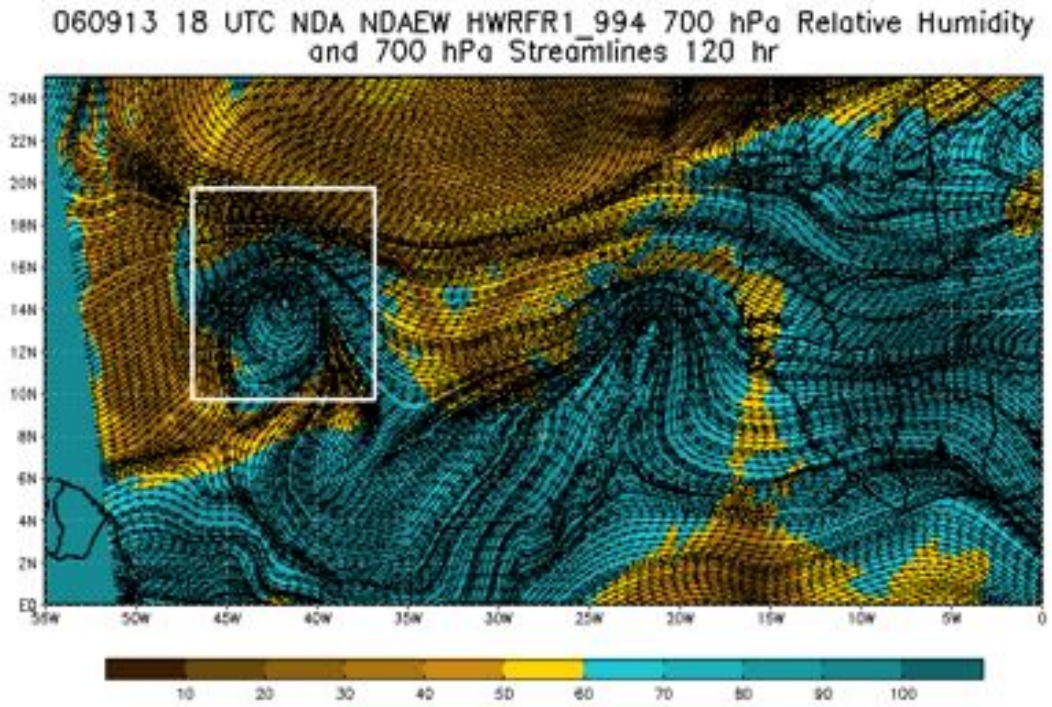
R1 NDAEW NCU



MSW= 9 kt
MSLP= 1012 hPa

- Dry air entrainment at the core continues 18h later

R1 NDAEW CU

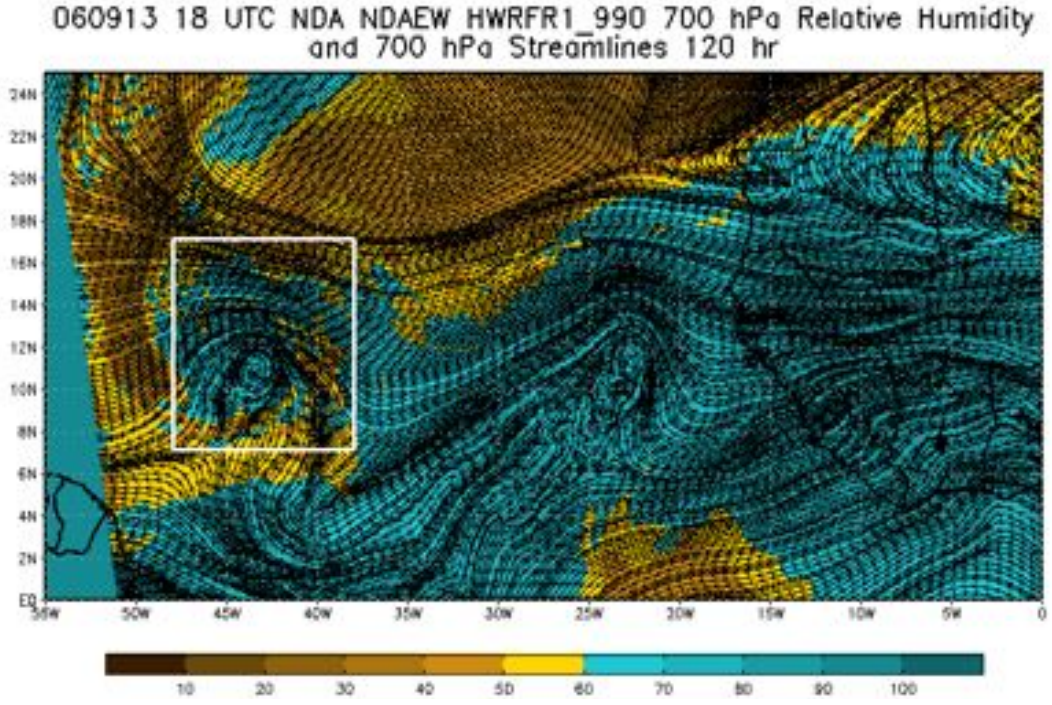


MSW= 45 kt
MSLP= 995 hPa

Stronger TS at the end of run

TS

R1 NDAEW NCU



MSW= 30 kt
MSLP= 1008 hPa

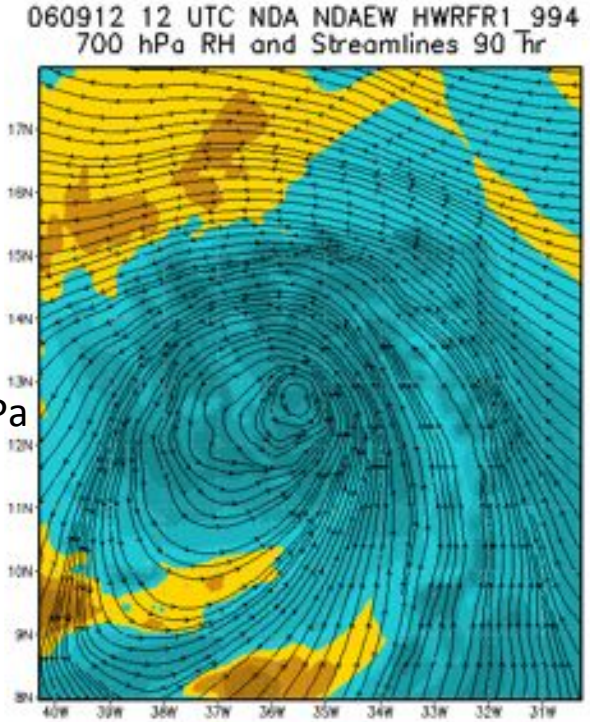
AEW could escape from the dry zone and intensify into a TD

TD

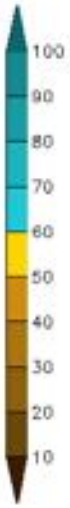
R1 NDAEW CU

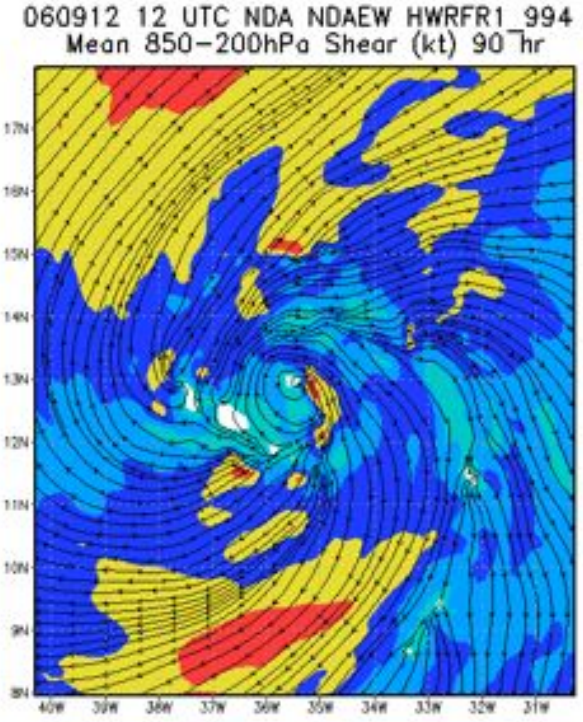
MSW=37 kt

MSLP=1004 hPa

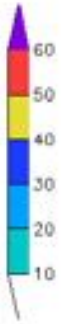


TS



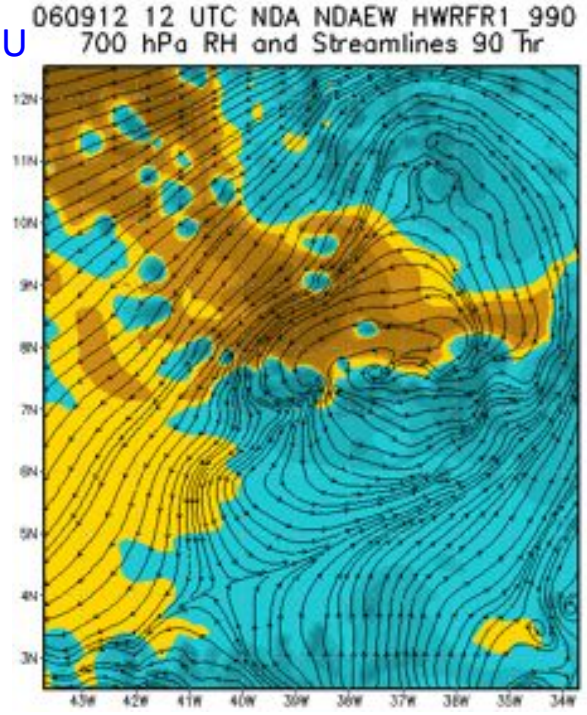


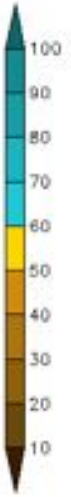
Anticyclonic with height

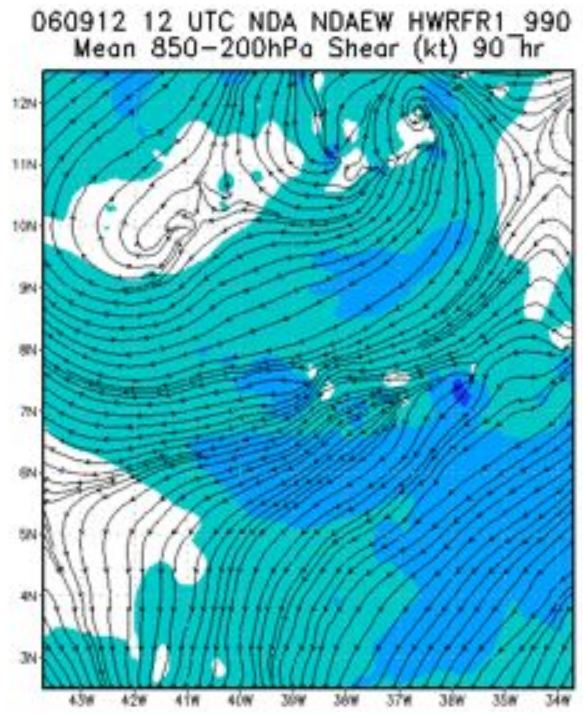


R1 NDAEW NCU

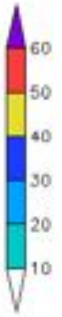
Major dry air entrmnt. produces 2 centers of circulation within the AEW (N & S)







No change of direction with height

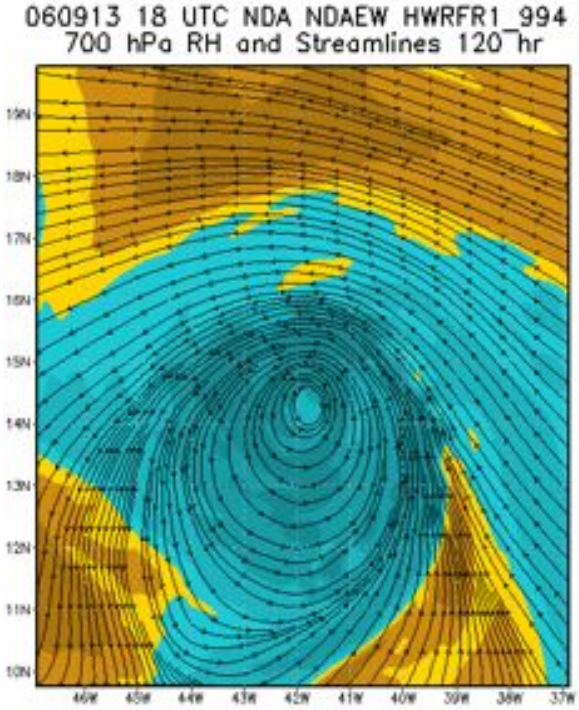


E-NERLY Shear S ctr.

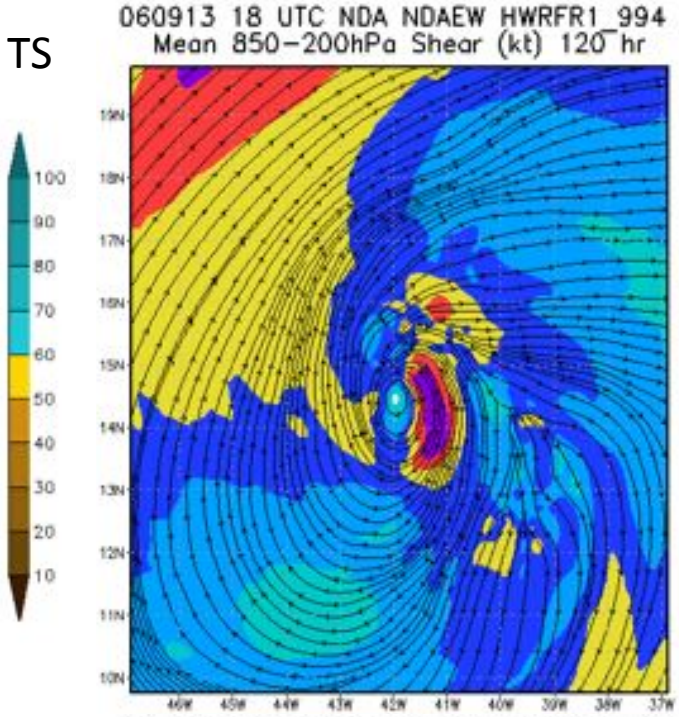
R1 NDAEW CU

MSW= 45 kt

MSLP= 995 hPa



TS



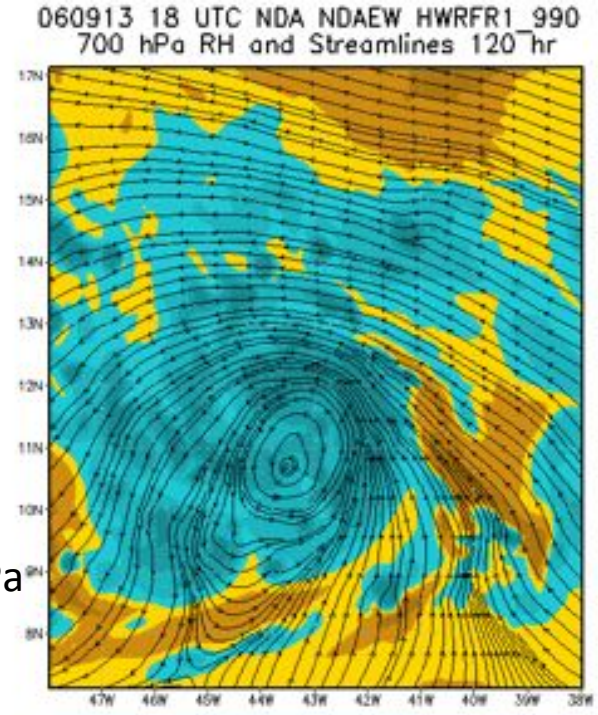
Stronger anticyclonic flow

R1 NDAEW NCU

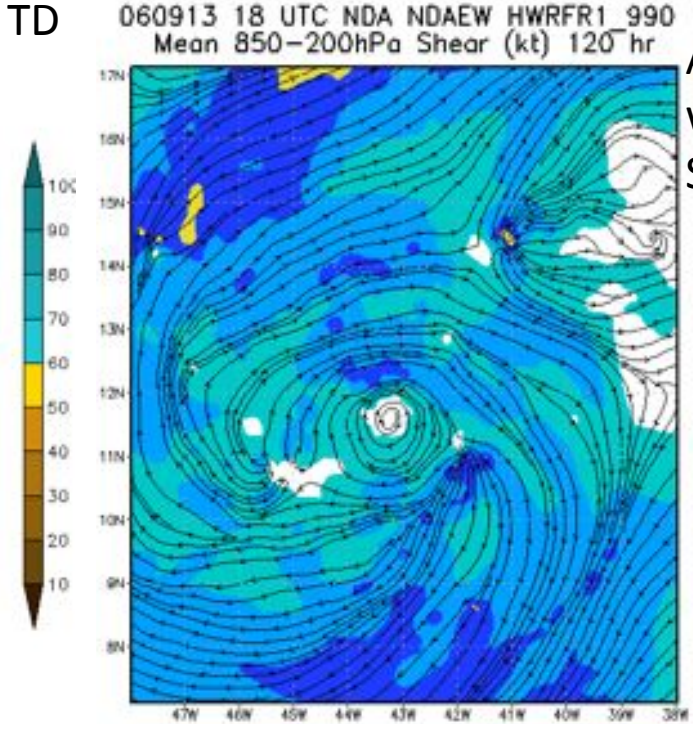
N core escape dry air and intensify into a TD

MSW= 30 kt

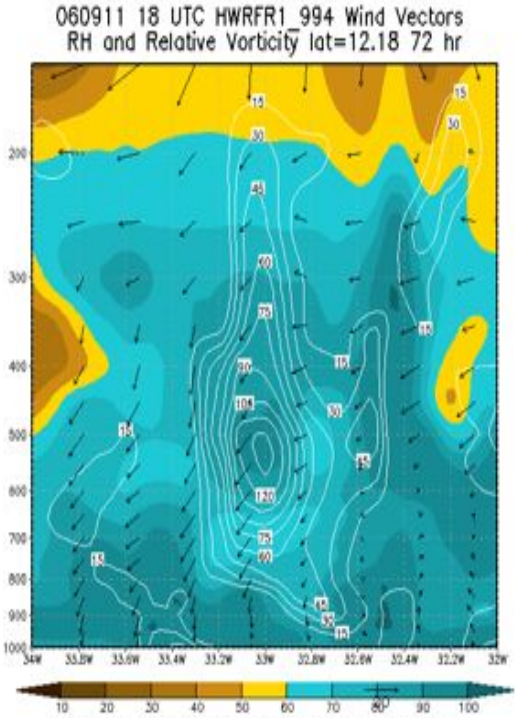
MSLP= 1008 hPa



TD



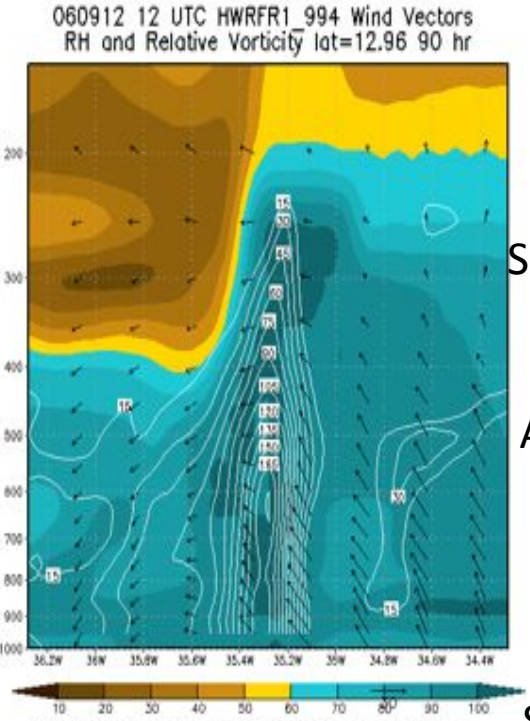
Anticyclonic with height Sign of Strgn.



R1
NDAEW
CU

<-NERLY
Shear

Dryer Env

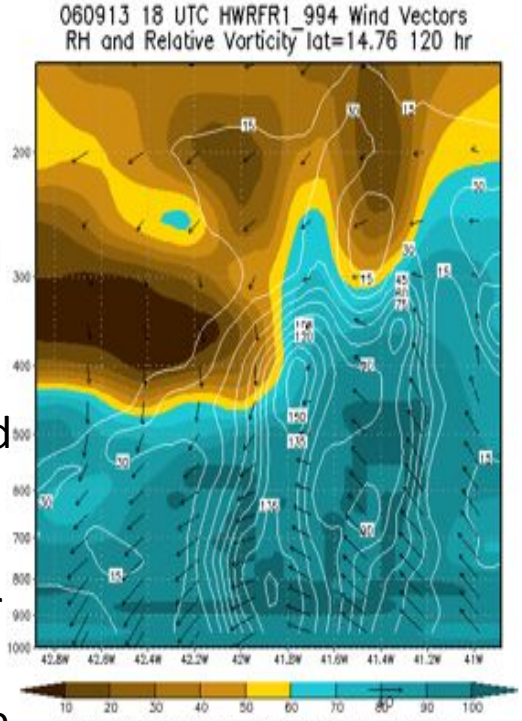


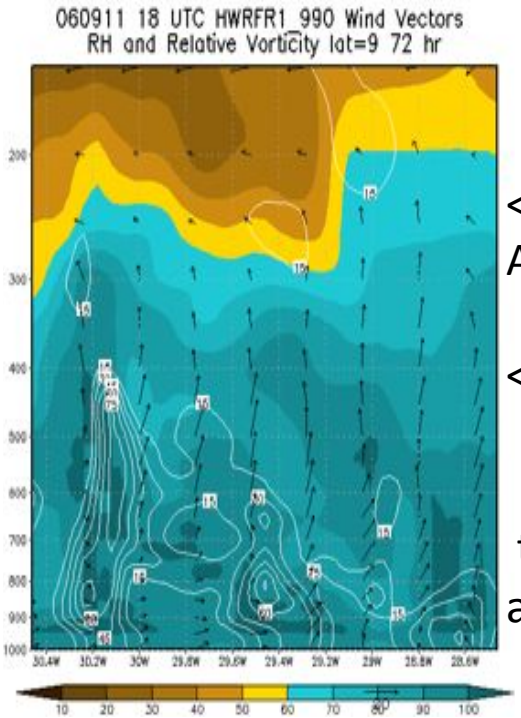
<- **TS** ->

Saturated
Column

Amplified
RVORT

Stronger
Conv.
Structure



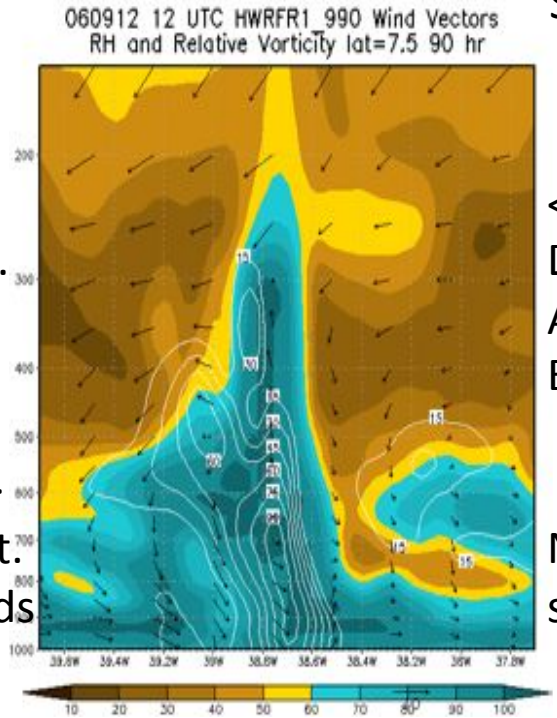


R1
NDAEW
NCU

<-Dry
Air Entrn.

<- N core

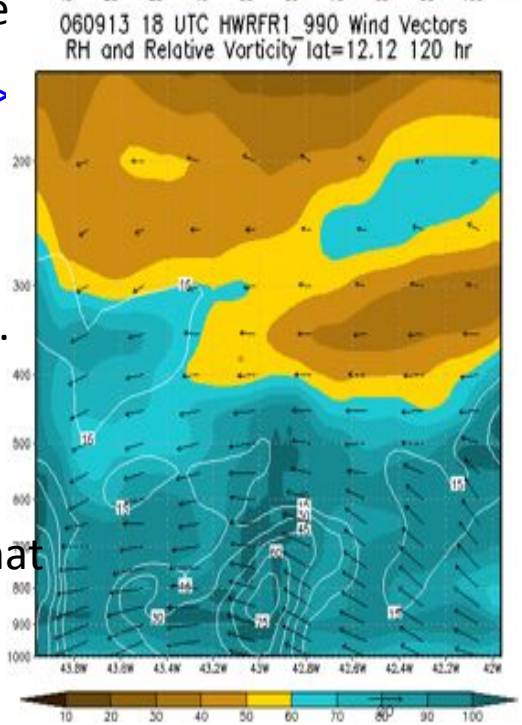
S core->
that dspt.
afterwards

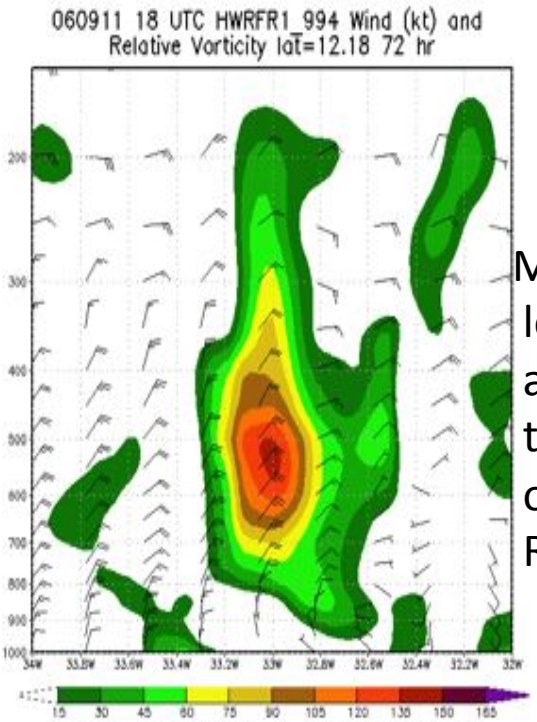


TD ->

<- Major
Dry
Air Entrn.
Event

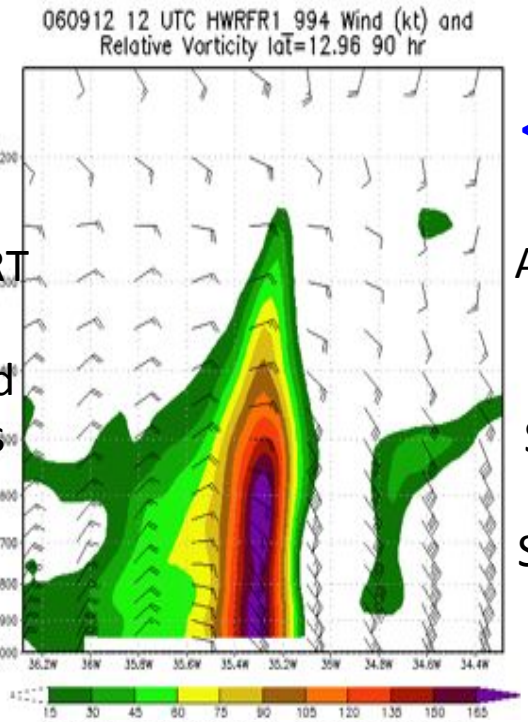
->
N core that
survive





R1
NDAEW
CU

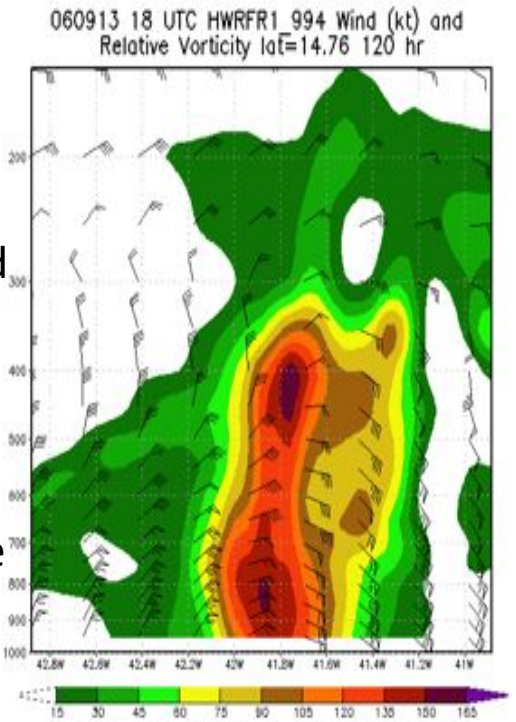
Max RVORT location associated to regions of higher RH

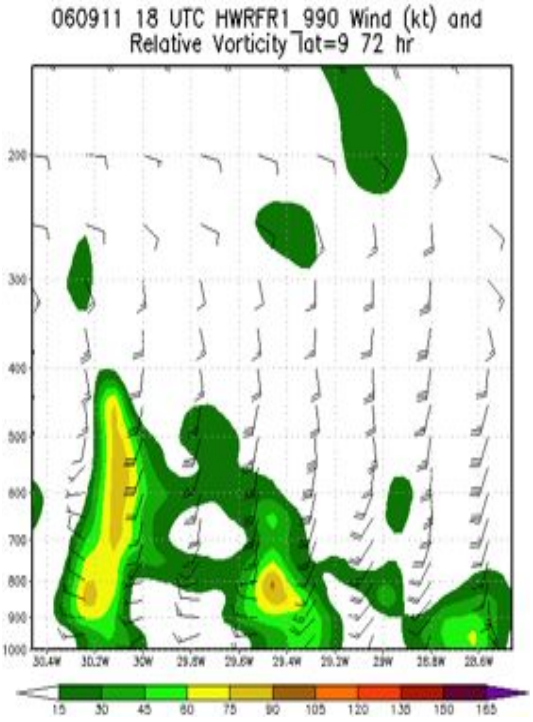


<- TS - >

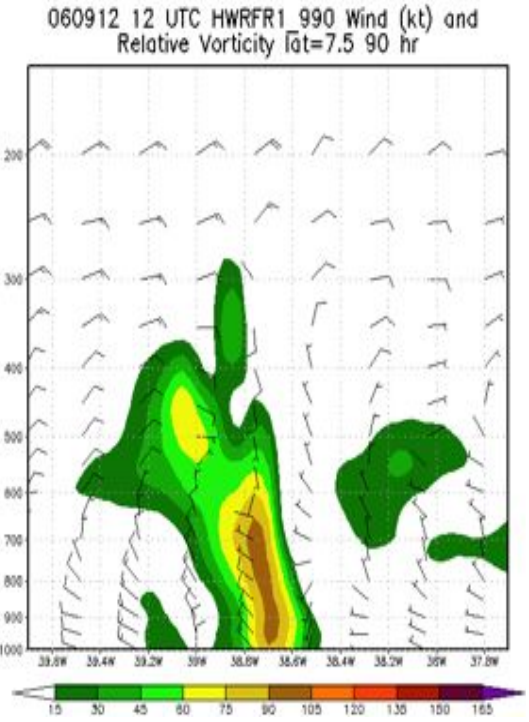
Amplified RVORT

Stronger Conv. Structure



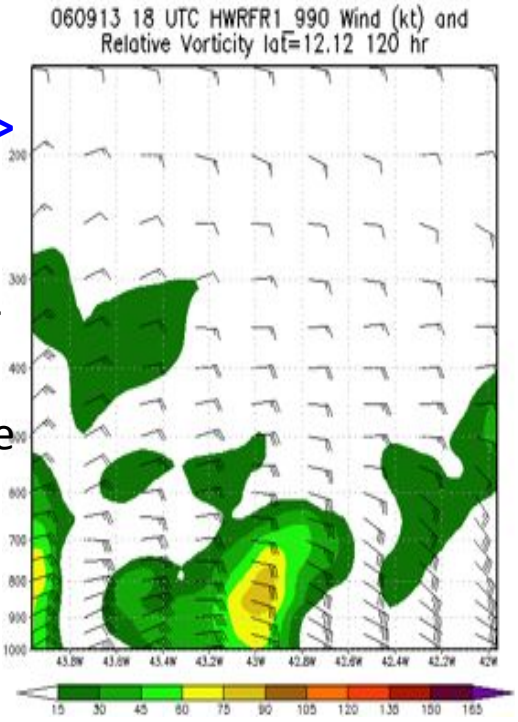


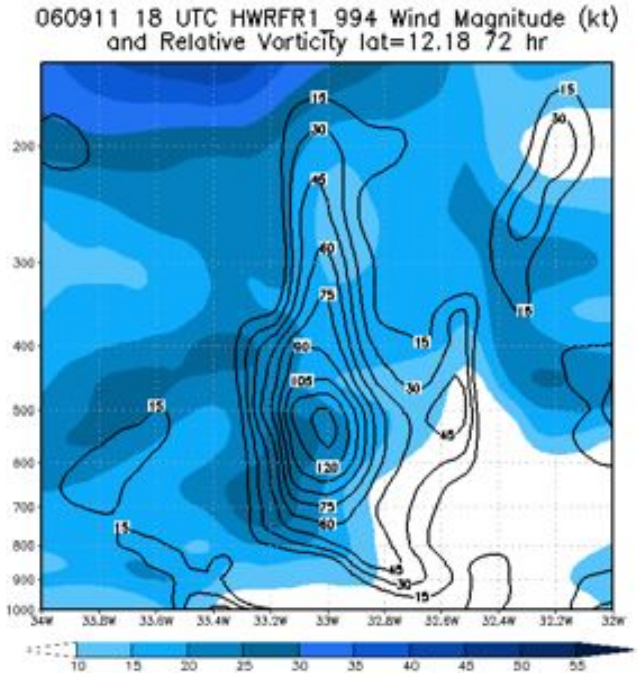
R1
NDAEW
NCU

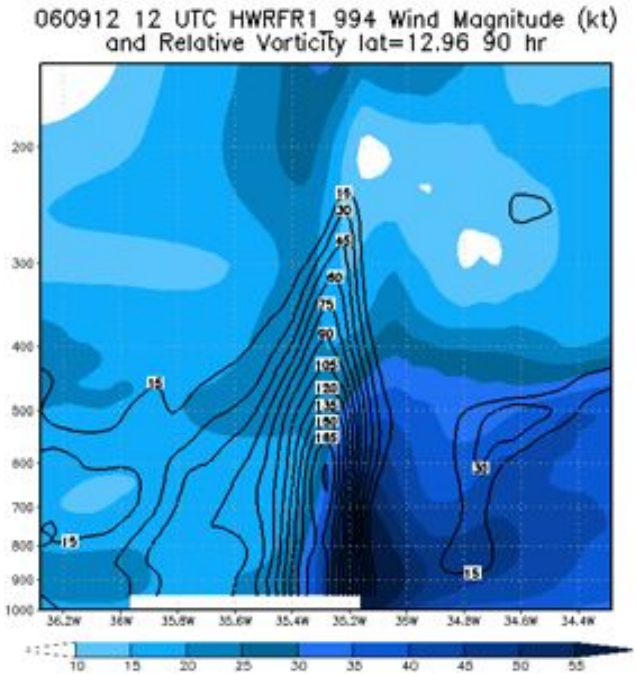


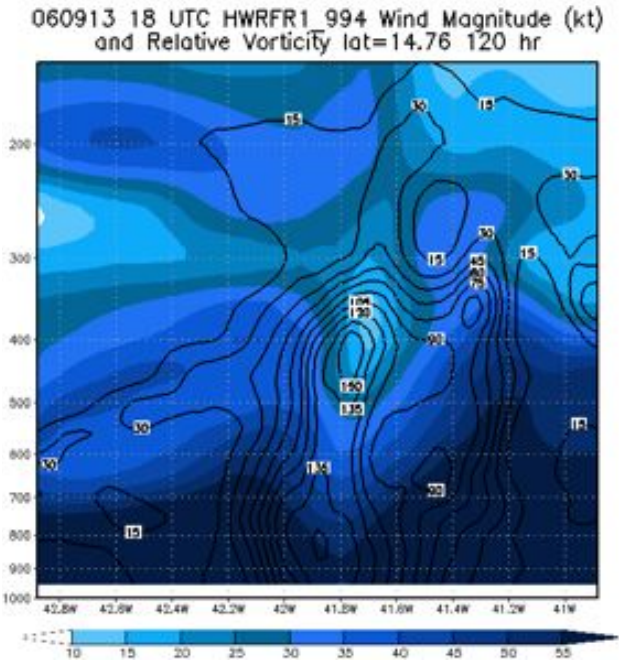
TD ->

Broader and stronger wind structure

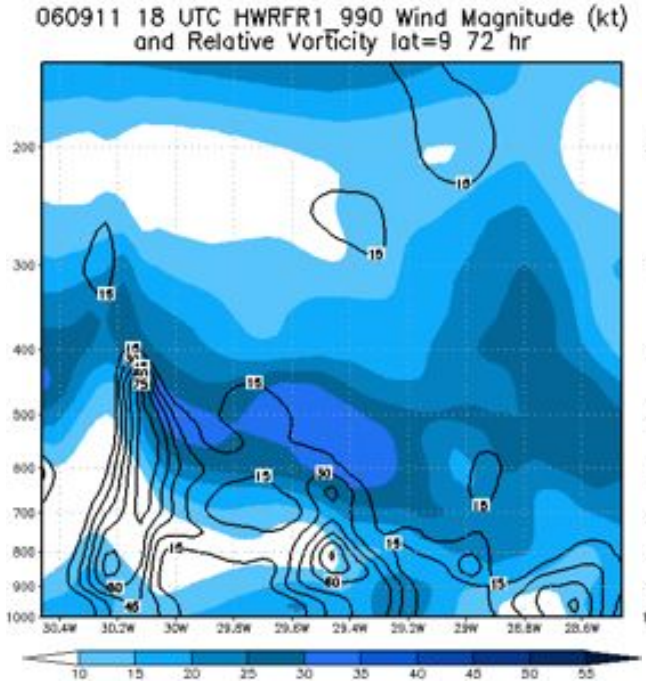


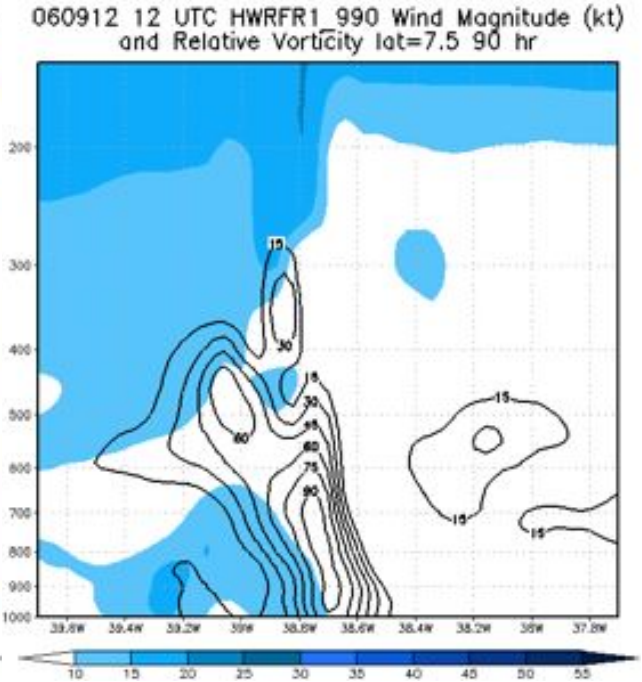

060911 18 UTC HWRFR1_994 Wind Magnitude (kt)
and Relative Vorticity lat=12.18 72 hr

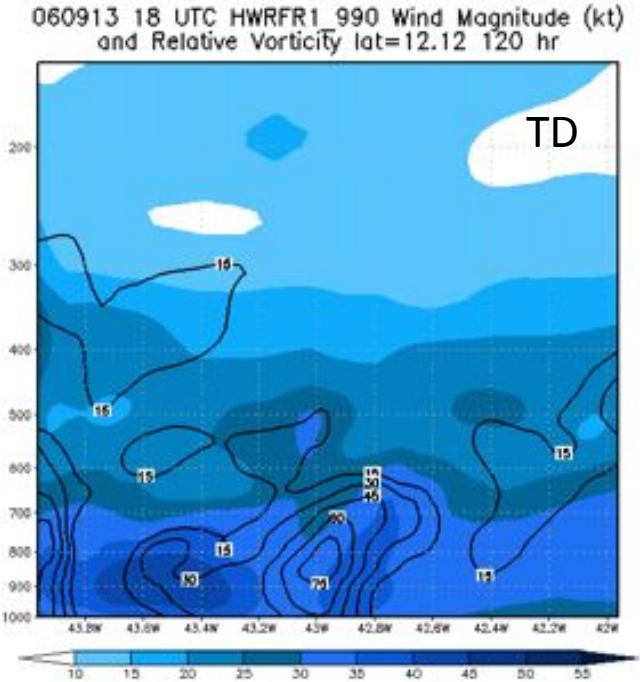

060912 12 UTC HWRFR1_994 Wind Magnitude (kt)
and Relative Vorticity lat=12.96 90 hr

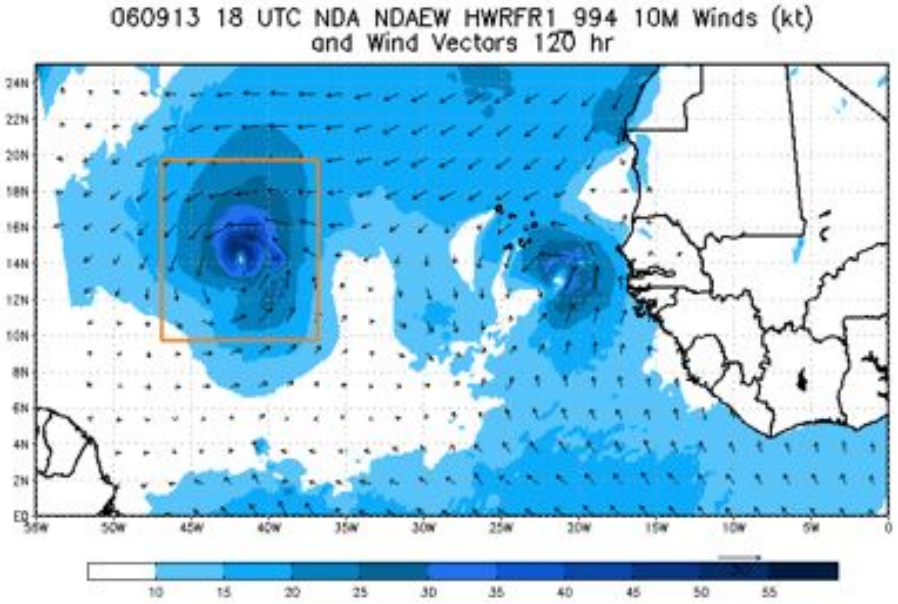

060913 18 UTC HWRFR1_994 Wind Magnitude (kt)
and Relative Vorticity lat=14.76 120 hr

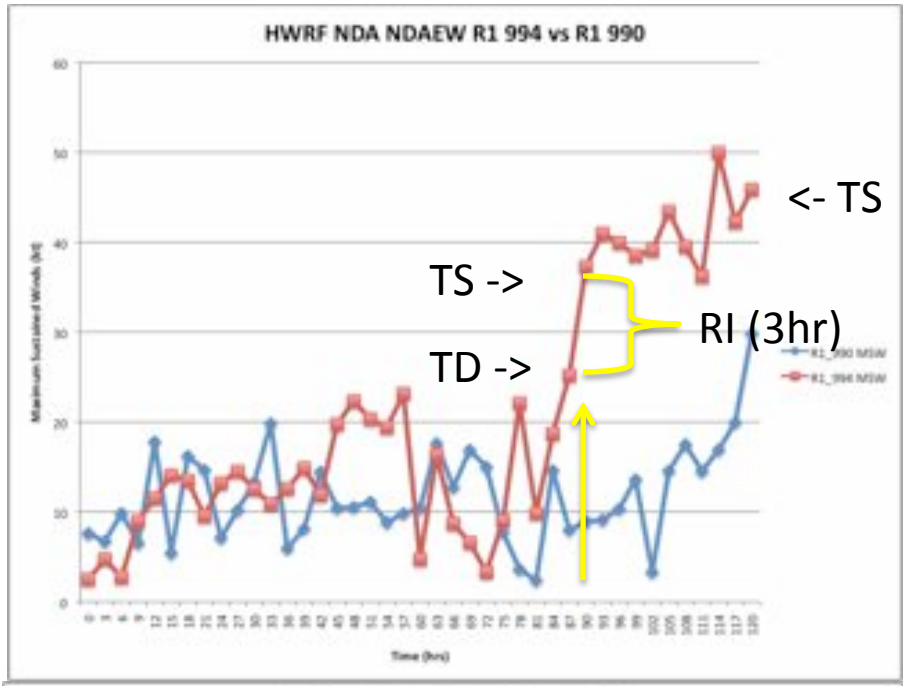
^ TS ^


060911 18 UTC HWRFR1_990 Wind Magnitude (kt)
and Relative Vorticity lat=9 72 hr

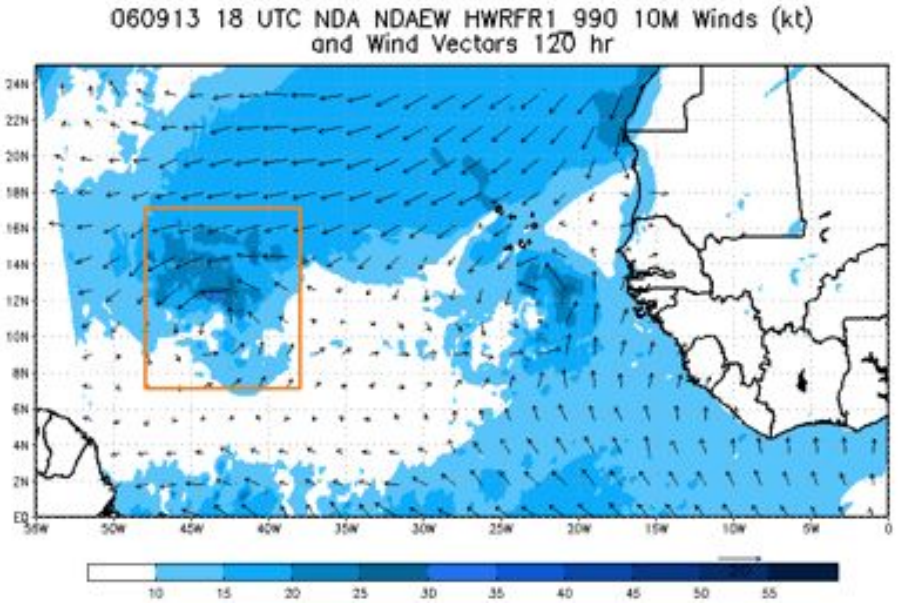

060912 12 UTC HWRFR1_990 Wind Magnitude (kt)
and Relative Vorticity lat=7.5 90 hr

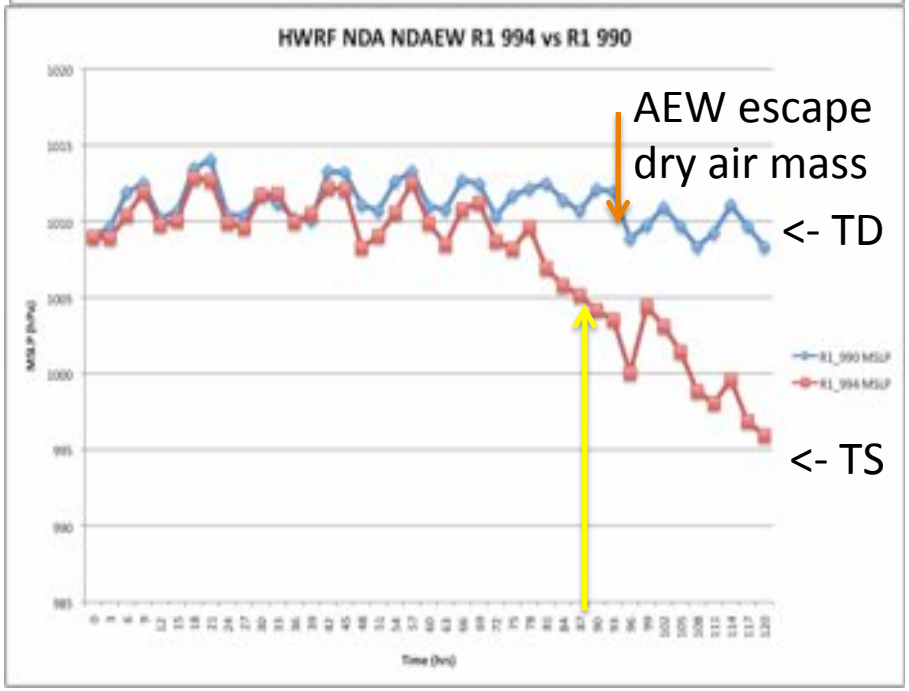

060913 18 UTC HWRFR1_990 Wind Magnitude (kt)
and Relative Vorticity lat=12.12 120 hr
TD





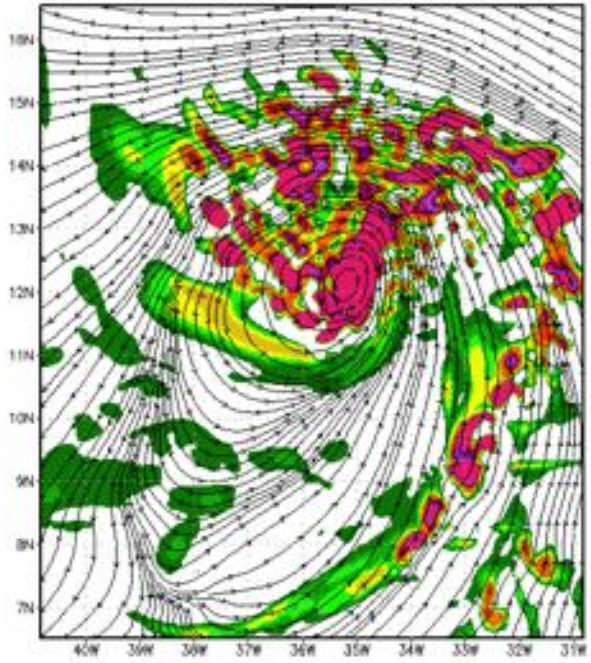
R1 990 shows a more representative structure of a NDAEW





Cyclogenesis of NDAEW in R1 994 (CU)

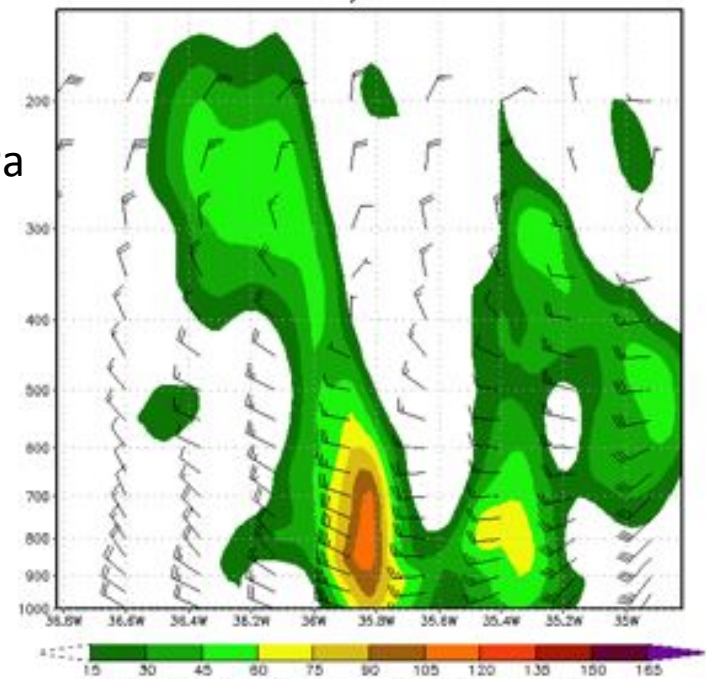
060912 09 UTC NDA NDAEW HWRFR1_994 850 hPa
Relative Vorticity and 700 hPa Streamlines 87 hr



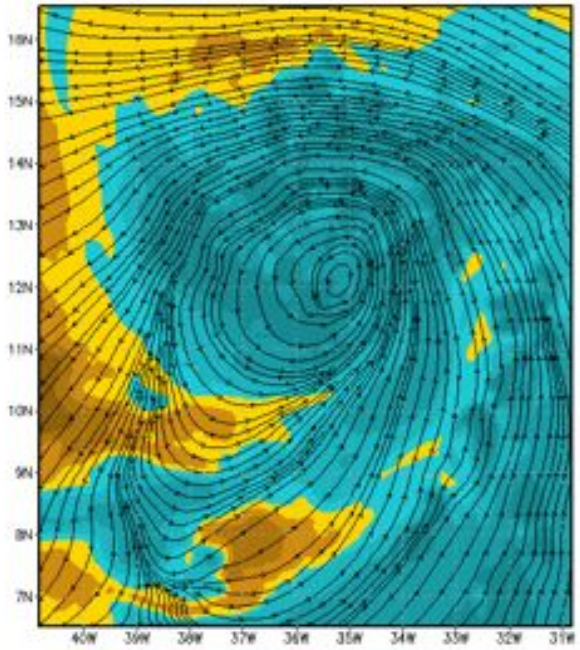
MSW= 25 kt

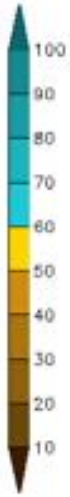
MSLP= 1005 hPa

060912 09 UTC HWRFR1_994 Wind (kt) and
Relative Vorticity lat=11.52 87 hr

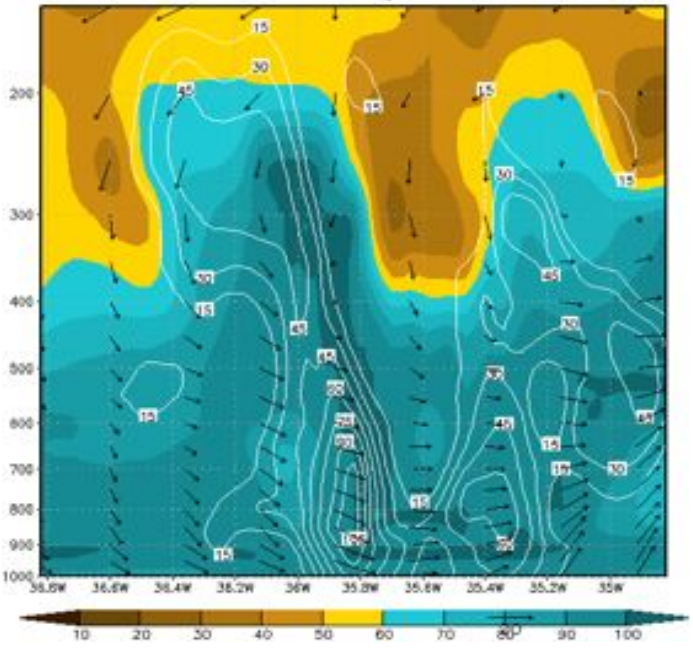


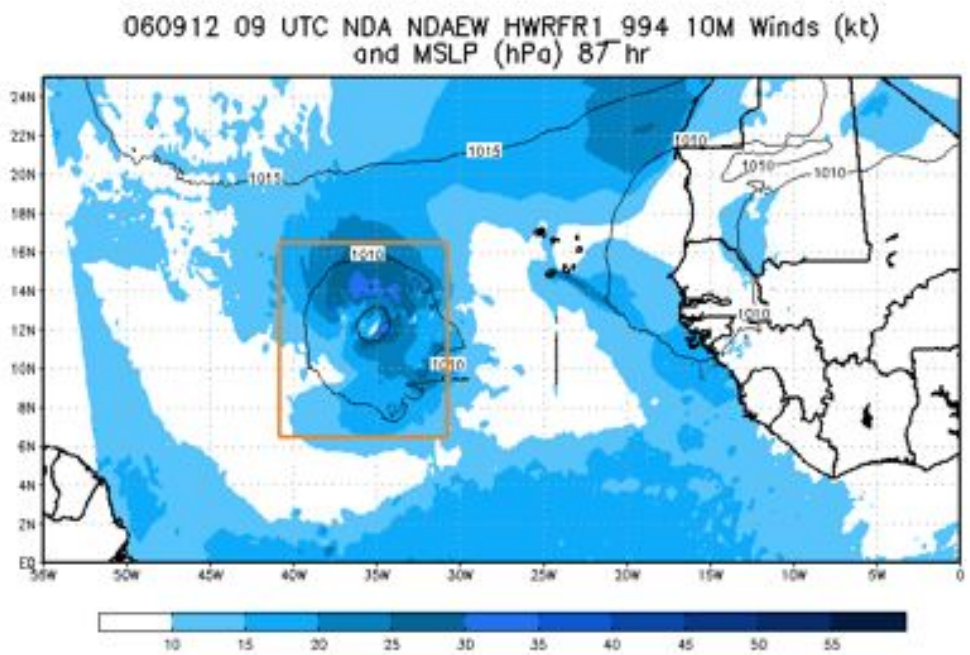
060912 09 UTC NDA NDAEW HWRFR1_994
700 hPa RH and Streamlines 87 hr

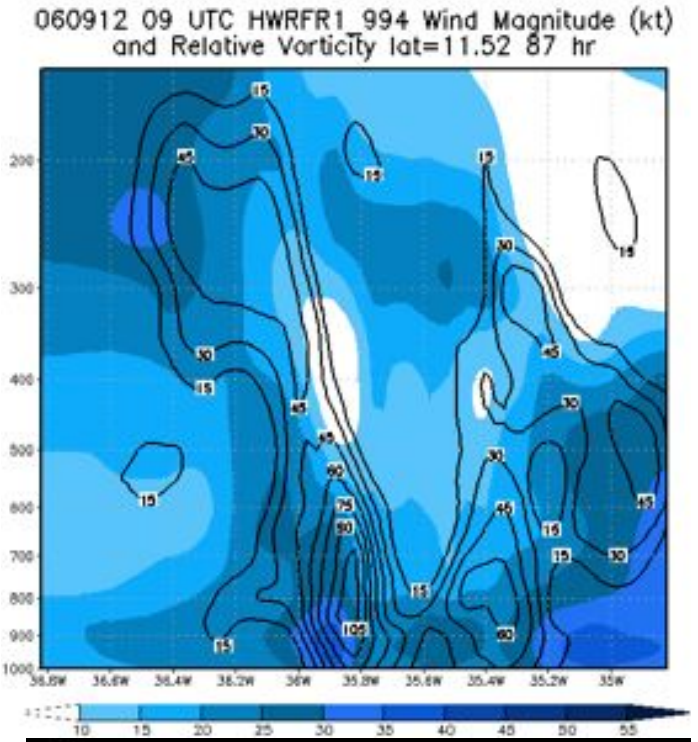


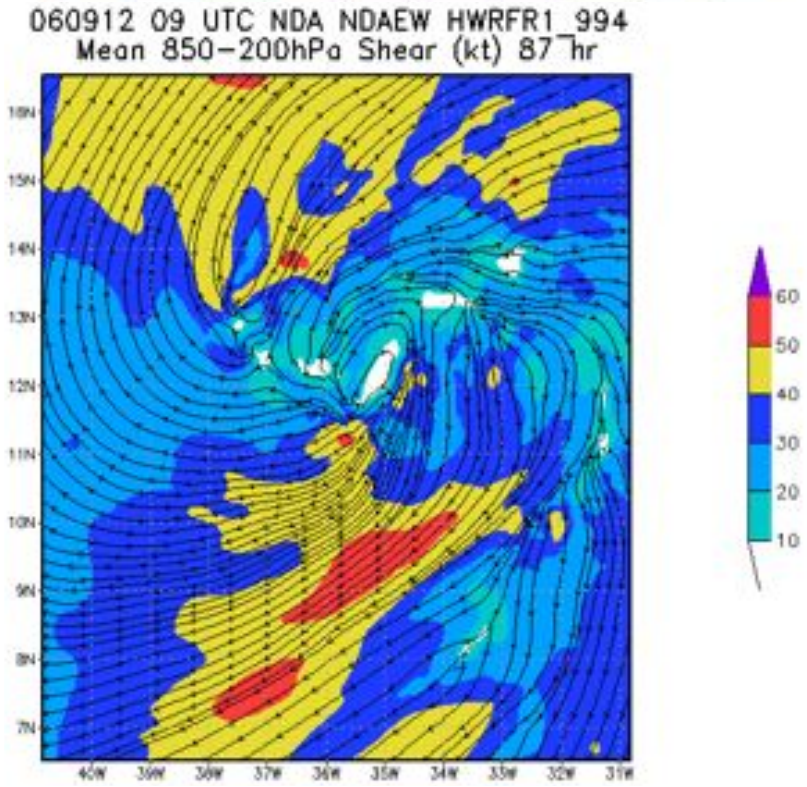


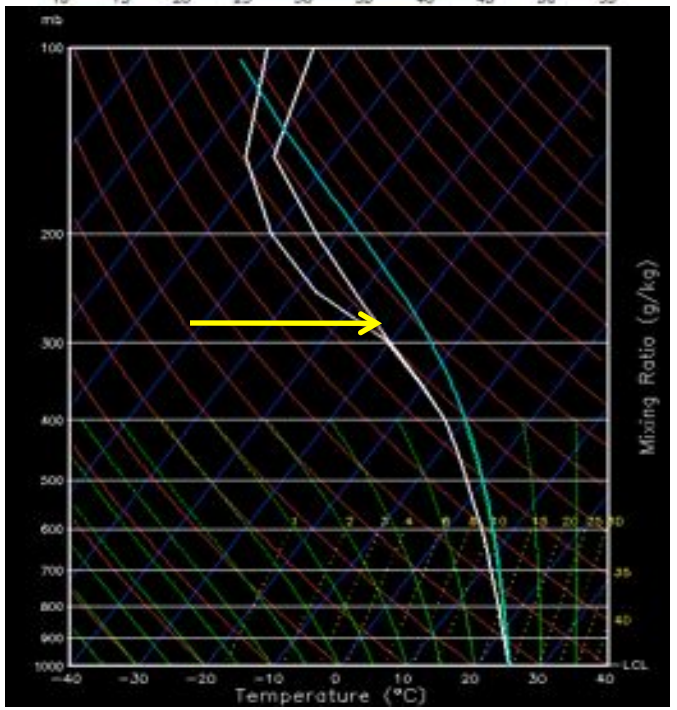
060912 09 UTC HWRFR1_994 Wind Vectors
RH and Relative Vorticity lat=11.52 87 hr



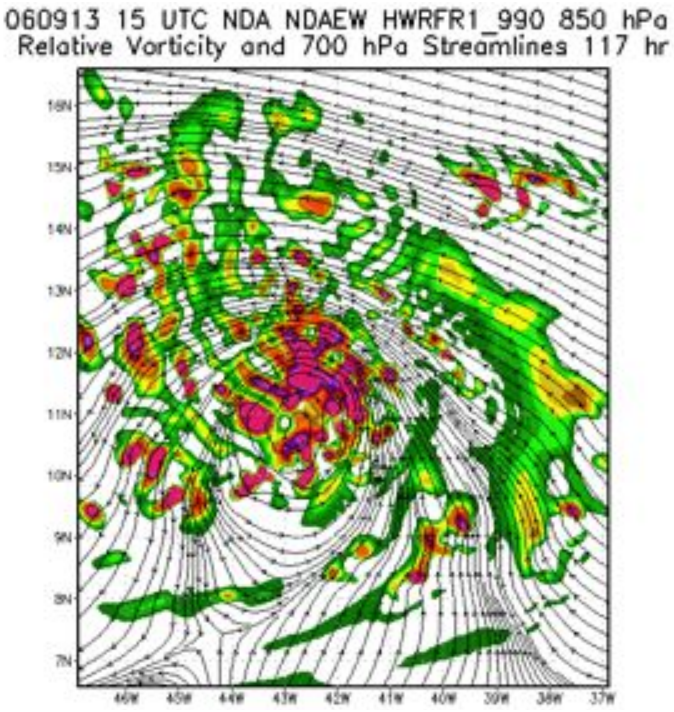

060912 09 UTC NDA NDAEW HWRFR1_994 10M Winds (kt)
and MSLP (hPa) 87 hr


060912 09 UTC HWRFR1_994 Wind Magnitude (kt)
and Relative Vorticity lat=11.52 87 hr

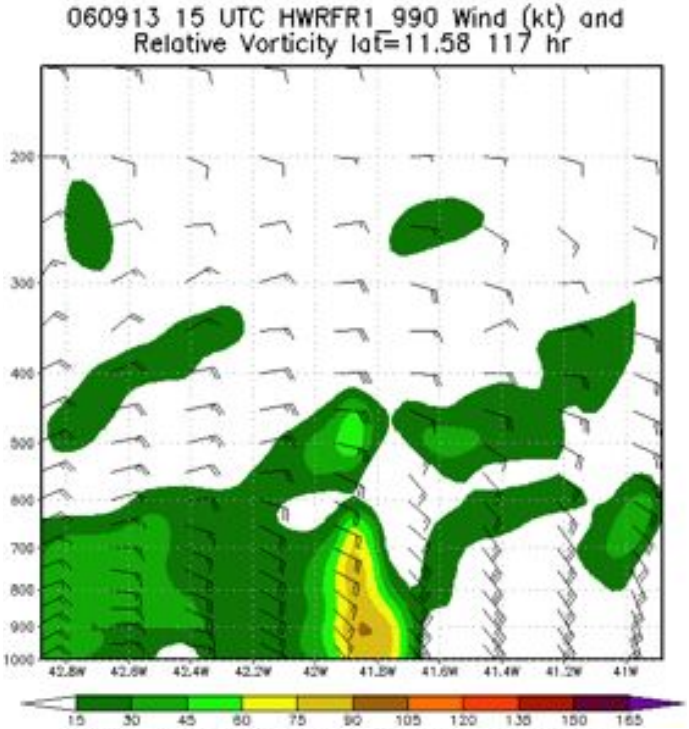

060912 09 UTC NDA NDAEW HWRFR1_994
Mean 850-200hPa Shear (kt) 87 hr

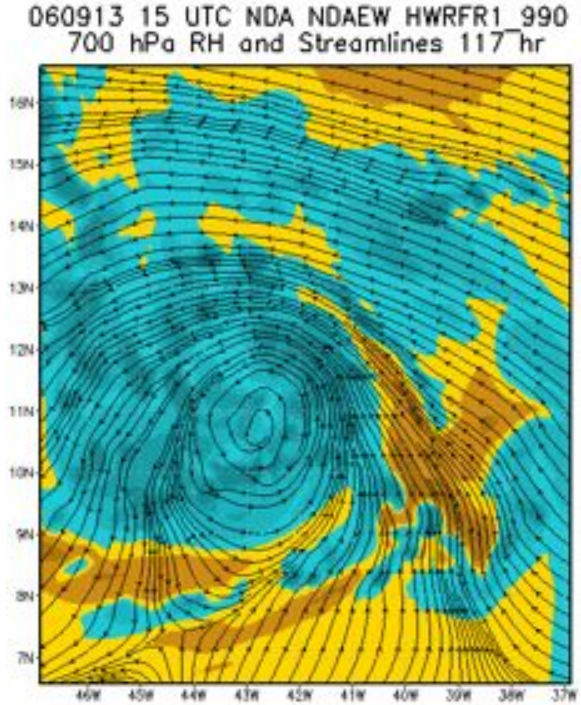

Mixing Ratio (g/kg)
Temperature (°C)

Cyclogenesis of NDAEW in R1 990 (NCU)

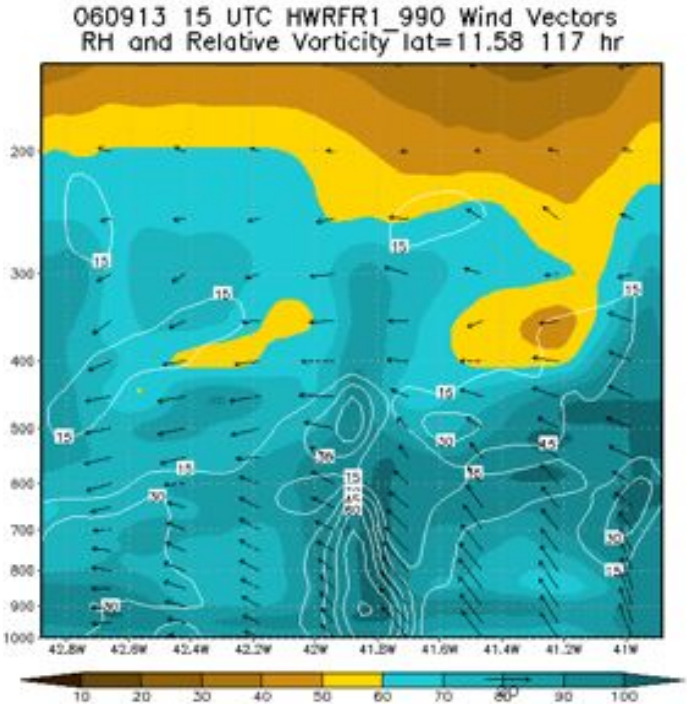


MSW= 20 kt
MSLP= 1009 hPa

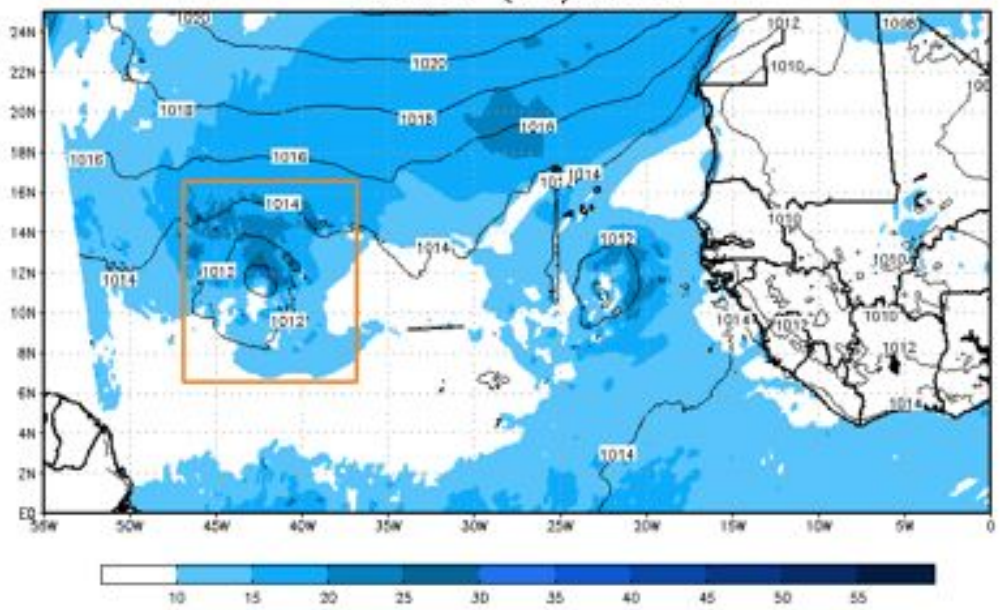




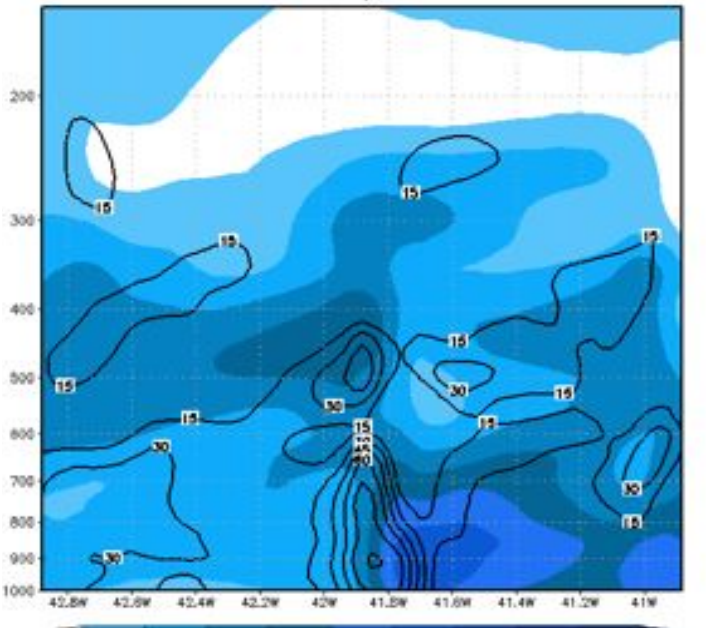
Overall dryer environment than R1 CU



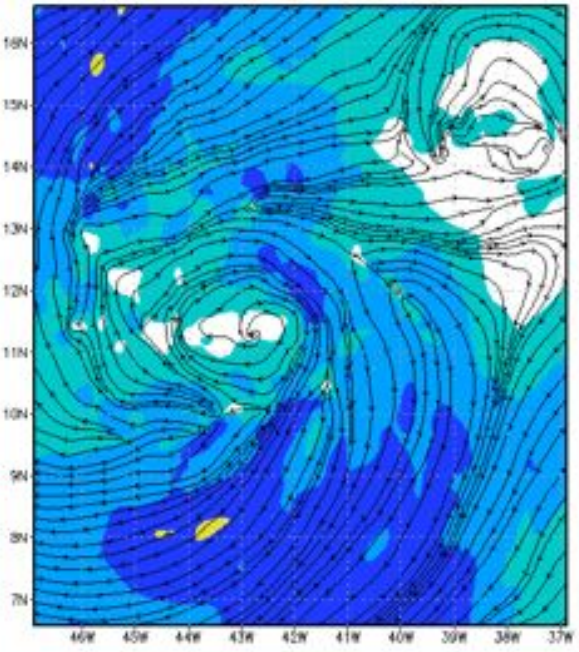
060913 15 UTC NDA NDAEW HWRFR1_990 10M Winds (kt)
and MSLP (hPa) 117 hr

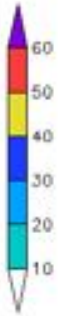


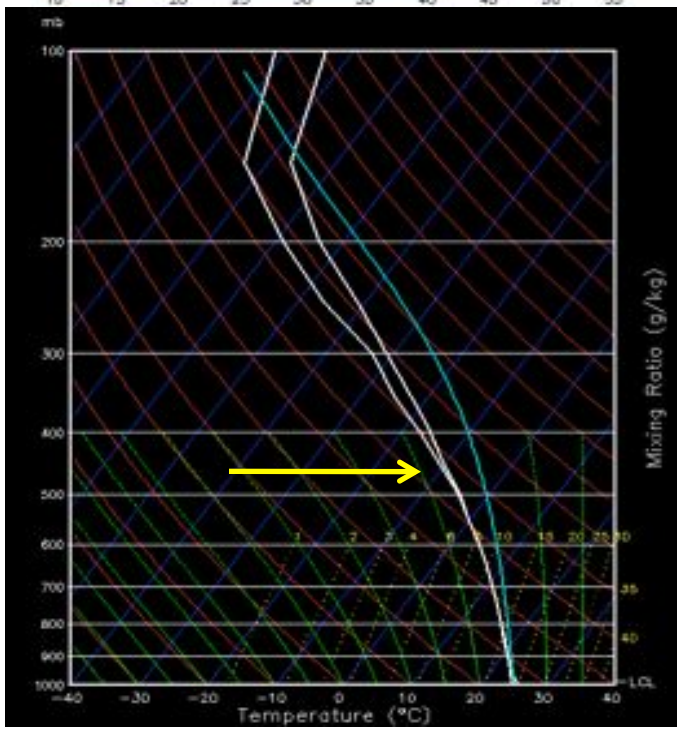
060913 15 UTC HWRFR1_990 Wind Magnitude (kt)
and Relative Vorticity lat=11.58 117 hr

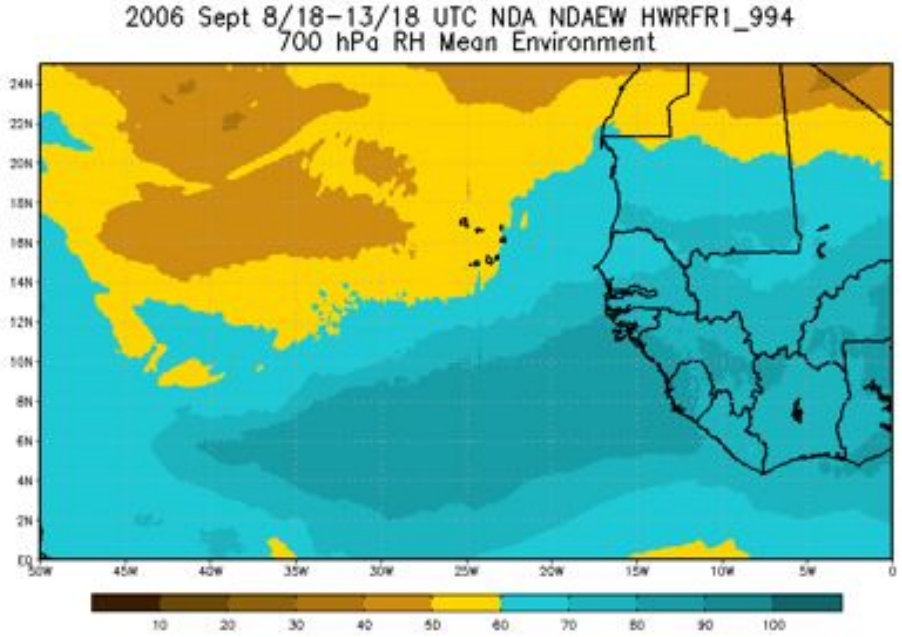


060913 15 UTC NDA NDAEW HWRFR1_990
Mean 850-200hPa Shear (kt) 117 hr

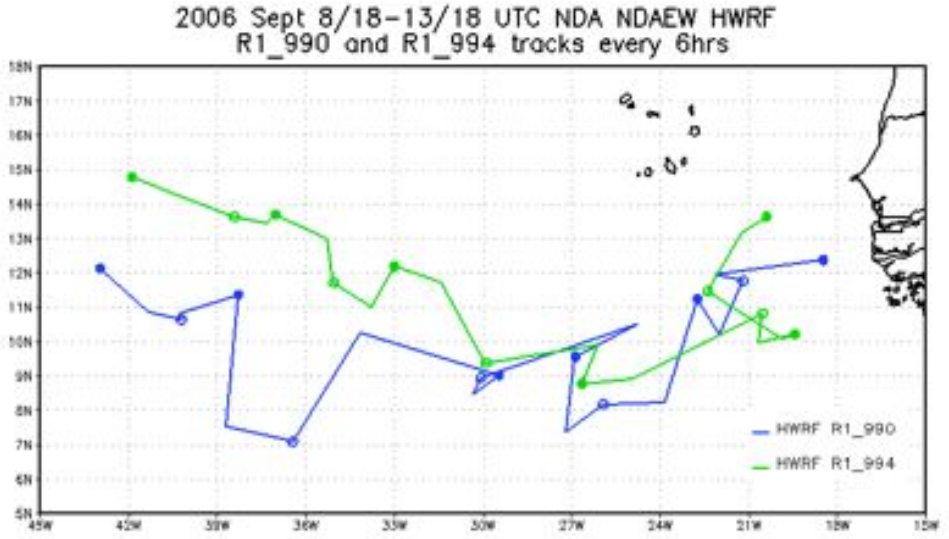


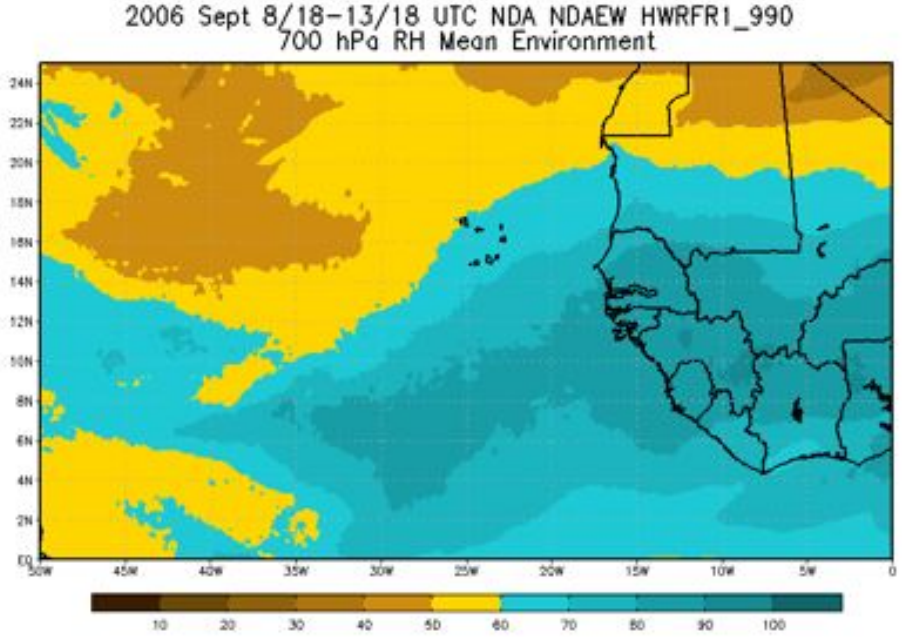






More humid environment





Track

A broader (latitudinal) mid-level anticylone produced by R1 990 (NCU) caused a southern track for this run

Dryer environment

Summary of Observations: NDAEW CU vs NCU

CU

- Stronger synoptic features including the NDAEW
- No dry air intrusion occurs at the core of the system

Pre-cyclogenesis

- A low level circulation (1000 hPa) always existed
- No constancy of a closed MSLP (isobar) through time
- Lack of constancy in an intensification trend during the first 81 hrs as shown in the MSW and MSLP graphs
  - Periods of weakening linked to wind shear and dry air intrusion to the mid and upper levels environment, which limited the growth of the AEW
  - Periods of intensification were associated to the growth of a saturated column of air at the AEW axis up to the mid and upper levels, which was also linked to the enhancement of the RVORT
  - Also intensification was observed through merger between centers of RVORT
- Cyclonic wind >= 10 kt along the vertical structure was necessary to support the column of RH and RVORT

Summary of Observations: NDAEW CU vs NCU

- ***Cyclogenesis***:
  - A second closed MSLP (isobar) developed
  - A consolidated core of maximum RVORT formed at the 850 hPa level
  - A saturated column of air is at the core of the system and extending beyond 300 hPa enhancing the RVORT at the upper levels
  - Merging with another high moist column of air and RVORT is happening
  - Wide vertical column of cyclonic wind >= 10 kt supporting the core of the system
  - Mean Shear started turning clockwise with height
  - MSW= 25 kt ; MSLP= 1005 hPa
- ***RI:***
  - 3 hrs after cyclogenesis TS stage occurred (MSW= 37 kt ; MSLP= 1004 hPa)
  - Strengthening might be associated to the complete merger of the RVORT columns seen during the TD stage
  - VCS of RVORT, WNDS and RH depict better the strengthening of the TC
  - Intensification also could be determined by a tighter low level wind circulation and a better defined anticyclonic mean wind shear flow
    - Area of stronger shear (50 kt) coincides with the location of the strongest wind (55 kt) in the VCS to the E of the TC
- During the rest of the simulation, the NDAEW continues intensifying into a stronger TS

Summary of Observations: NDAEW CU vs NCU

NCU

- Weaker synoptic features
- Massive and continuous dry air entrainment occurs at the core of the system at 700 hPa from 63 hrs -> 93 hrs (~30 hr period; HCSs)

Pre-cyclogenesis

- Weak and intermittent low level circulation (1000 hPa) during 0 -> 60 hrs
- No constancy of a closed MSLP (isobar) through time (0->84 hrs)
- VCSs of RH, RVORT and Wind show that:
  - Periods of weakening were linked to wind shear and dry air intrusion to the mid and upper levels limiting the growth of the AEW
  - Periods of intensification were associated to the enhancement of RVORT in the presence of a highly moisturized or saturated column of air at the AEW axis; also through merger between centers of RVORT
- From 96 hr -> 114 hr intensification is observed at the surface level and is suggested by the start of an anticyclonic mean wind shear pattern when the AEW start moving N away from the extensive mass of dry air

Summary of Observations: NDAEW CU vs NCU

Cyclogenesis:

- Occurs 30 hr after when compared to R1 994 (CU) and in a dryer environment
- Besides the MSW and MSLP plots that show the strengthening, the definition of an anticyclonic center in the mean shear field helped in determining the intensification (i.e. HCS)
  - A RVORT consolidated core is not observed like in R1 994 (CU)
  - A second closed isobar of MSLP appears but it fades at the end of the simulation
- VCS fields show broader and stronger convective winds structure at this time

Mean RH Environment:

- A moister environment is likely to have contributed to the development/early development of the NDAEW
- CU parameterization in a high resolution domain (i.e. < 10 km) must be turned off because convection is explicit

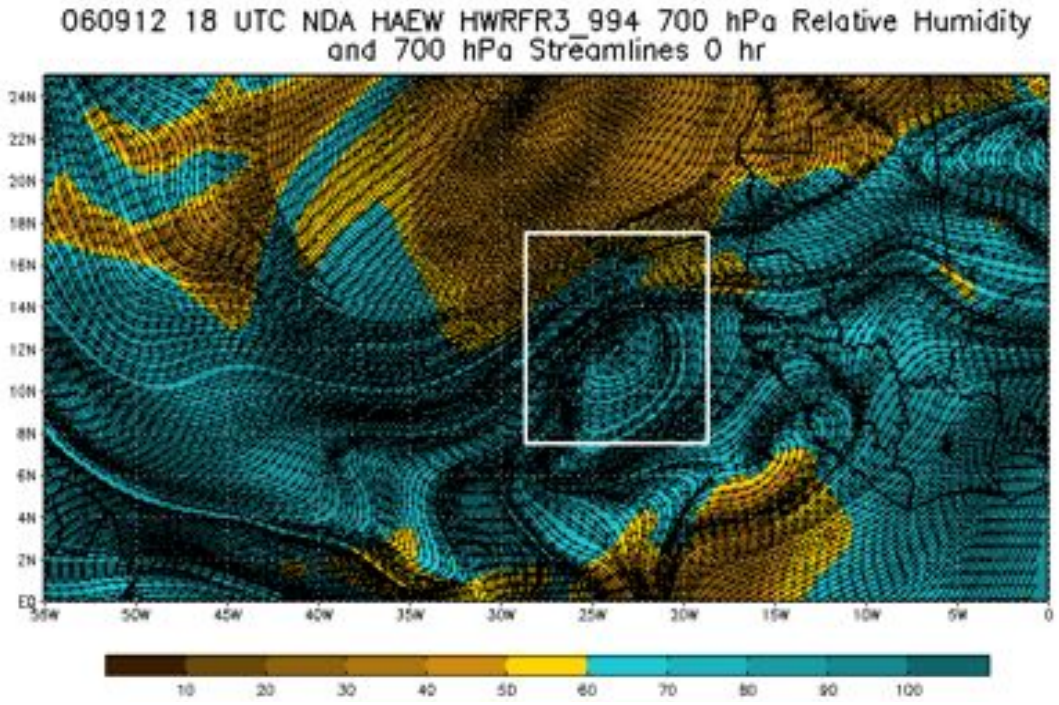
HAEW R3: CU vs NCU

Init

Same initial conditions observed due to ***a cold start*** of the model

Helene Intensification Stages: TD (NHC)
MSW= 30 kt
MSLP=1007 hPa

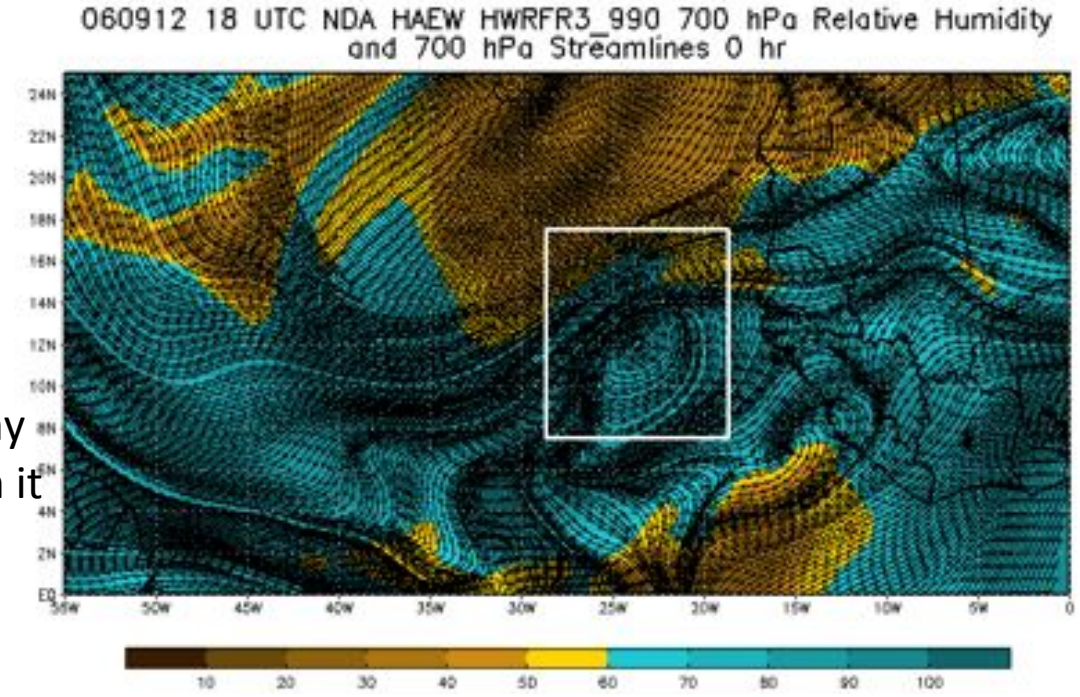
This means that the model can not draw any difference about which it has not yet gathered sufficient information



CU

MSLP=1008 hPa

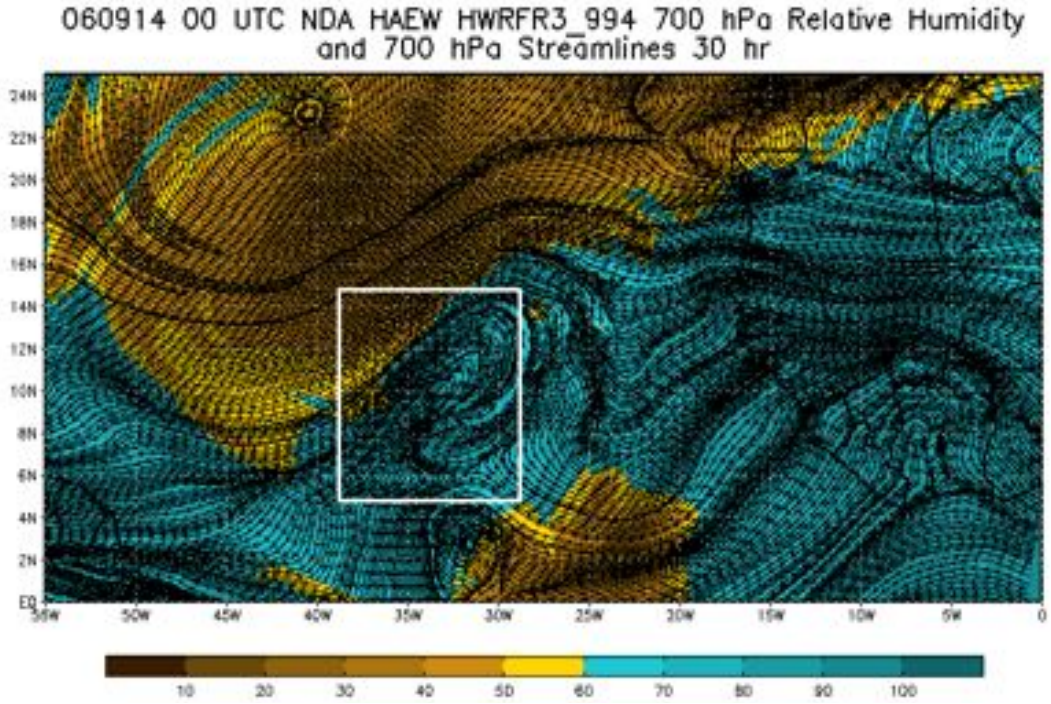
Well-defined and broad circulation at 700 hPa distant from dry air at that level



NCU

MSW=13 kt

Weaker AEW



CU

MSW= 8 kt

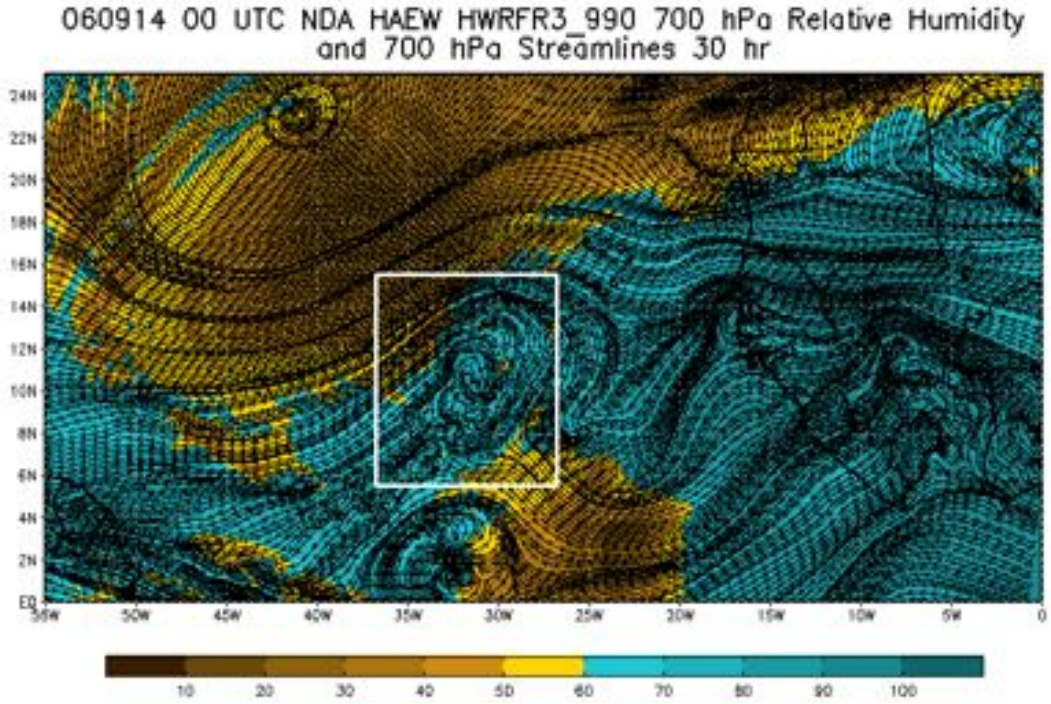
MSLP= 1009 hPa

Helene Intensification Stages: TS (NHC)

MSW= 35 kt

MSLP= 1005 hPa

Nor representative of a TS stage



NCU

MSW= 10 kt

MSLP= 1009 hPa

Dryer environment but overall stronger Features at this time

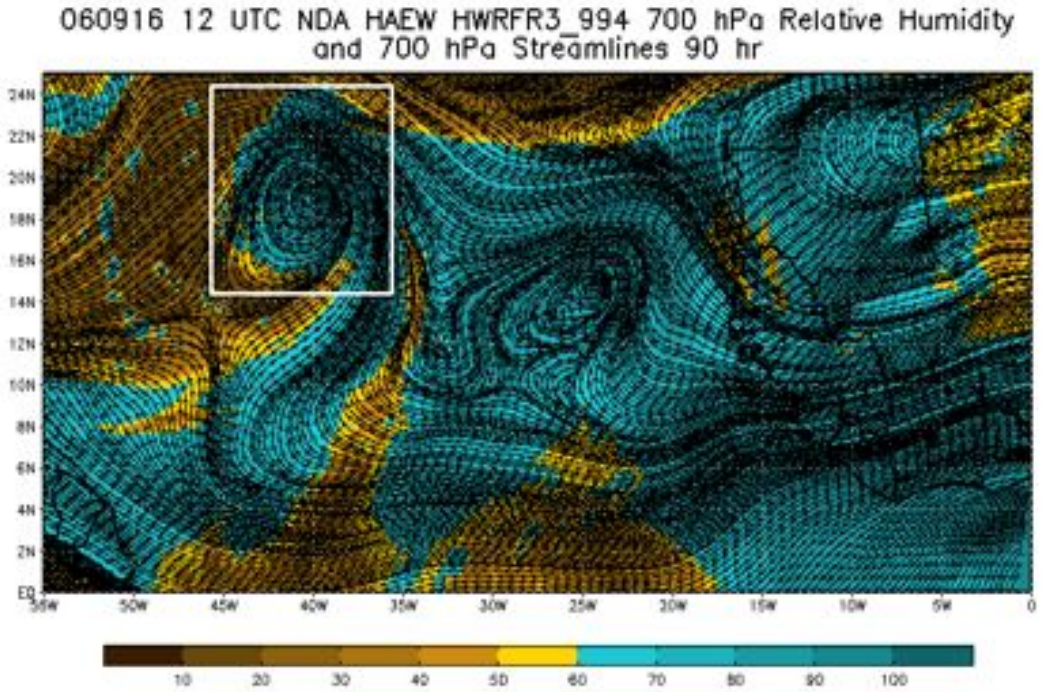
Broader but more remarkable synoptic features

Helene Intensification Stages: H1 (NHC)

MSW= 65 kt

MSLP= 987 hPa

Dryer environment

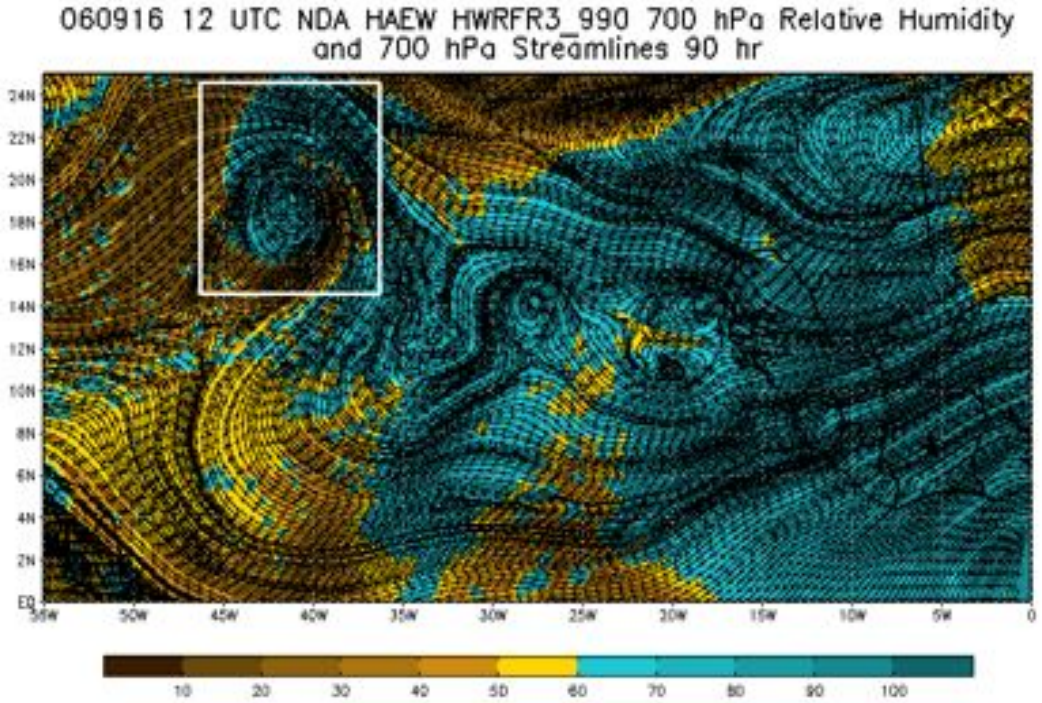


CU

MSW= 48 kt

MSLP= 997 hPa

TS intensity

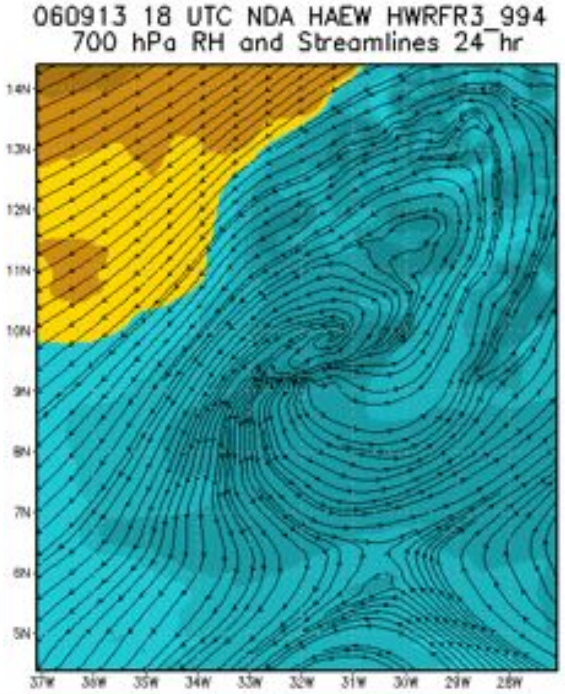


NCU

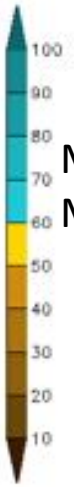
MSW= 26 kt

MSLP= 1003 hPa

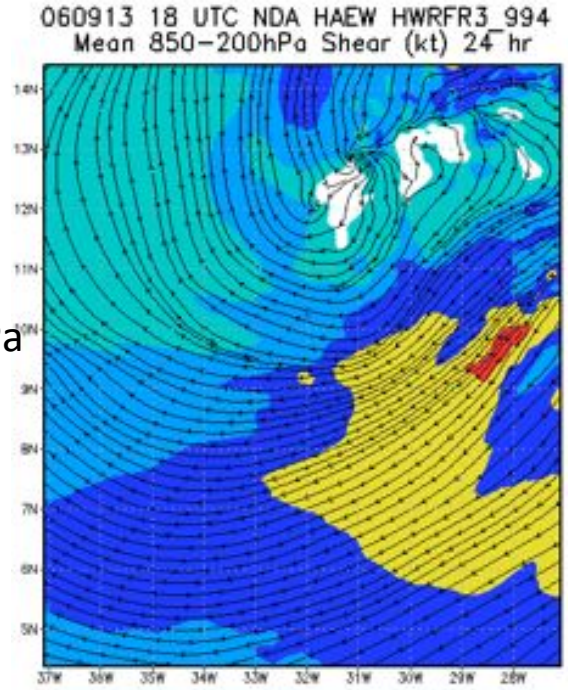
TD intensity



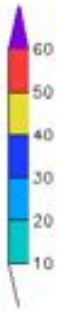
TD (NHC)

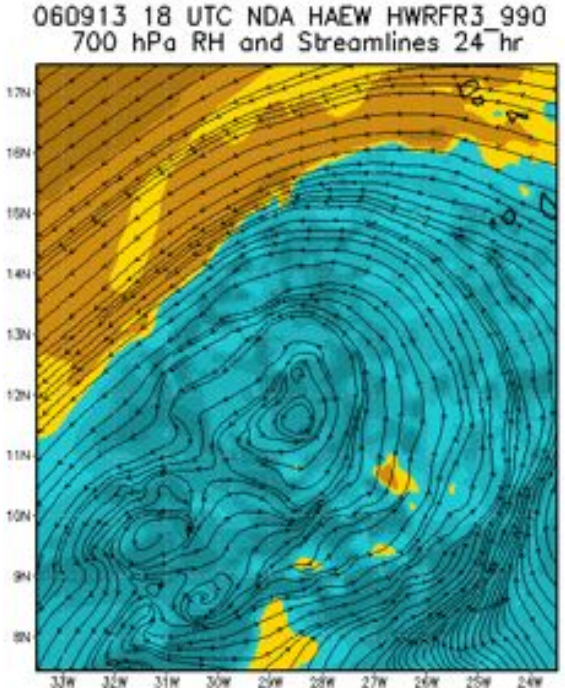


MSW=12 kt
MSLP=1009 hPa

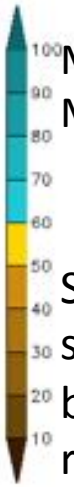


No vertical alignment with surf.



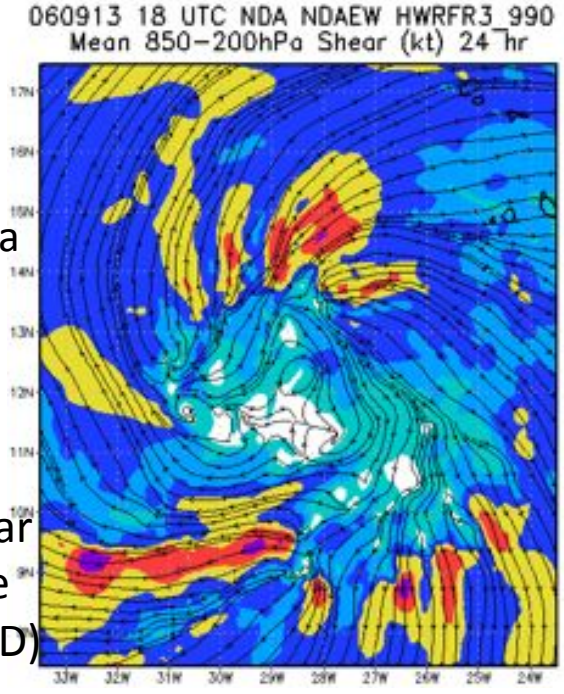


Dryer environment but better defined AEW

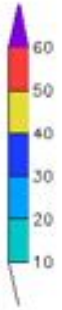


MSW=19 kt
MSLP=1006 hPa

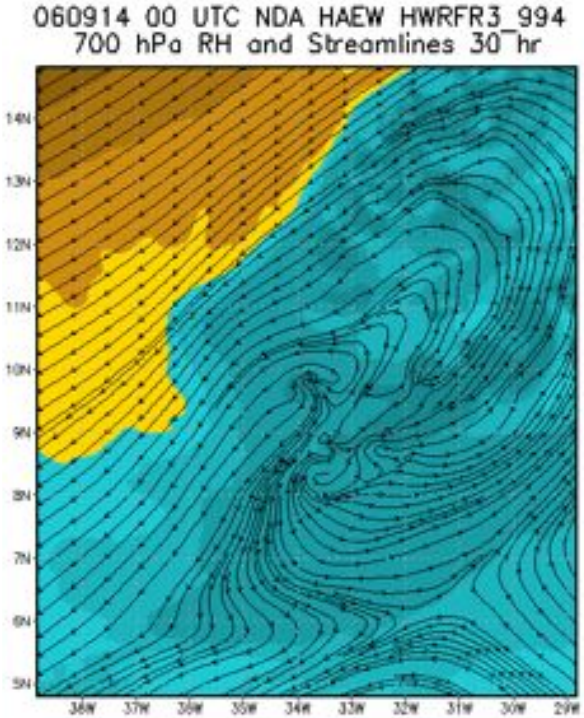
Stronger system det. by anticy. Shear representative of a "TD" (Q-TD)



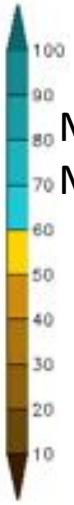
Better vert. structure alignment



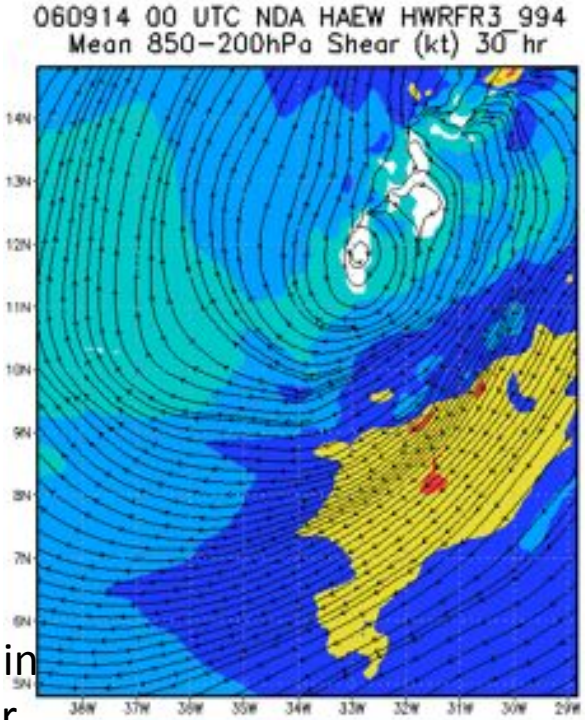
Not well-d anticl. ctr.



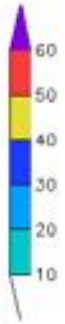
TS (NHC)



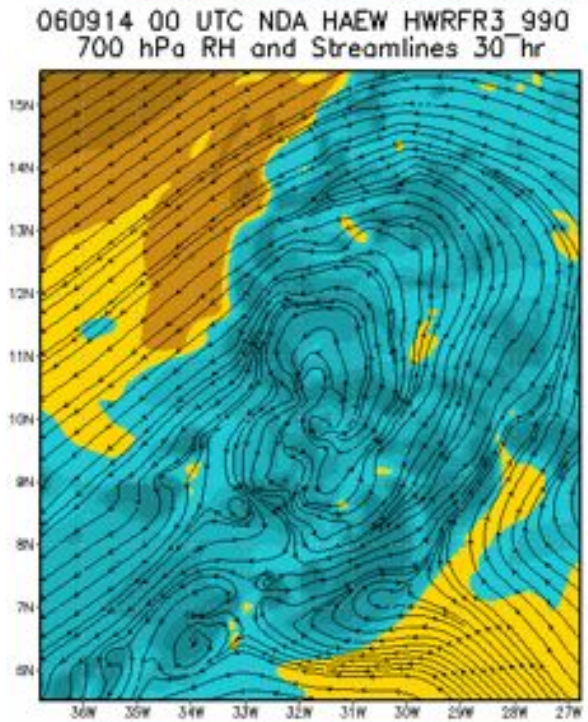
MSW= 8 kt
MSLP= 1009

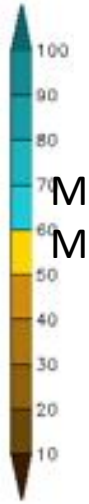


Unaligned

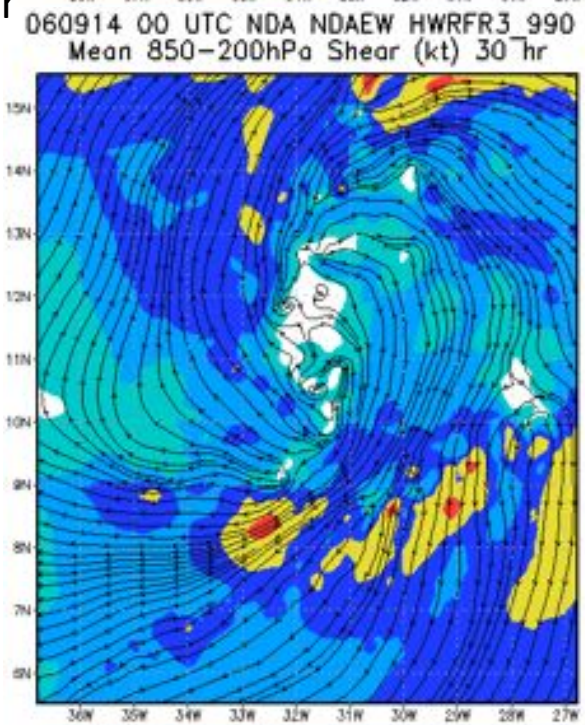


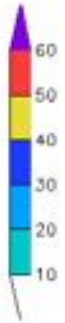
Weakening occurs in both runs, however 990 AEW continue better defined

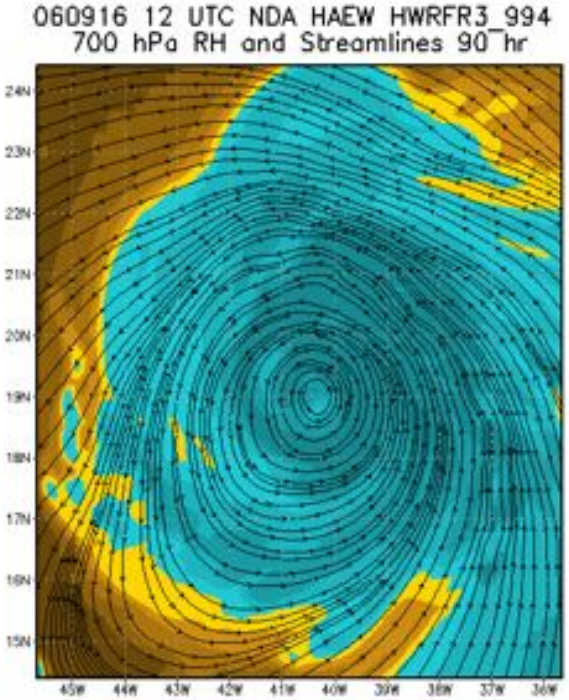


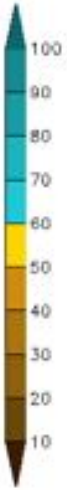


MSW= 10 kt
MSLP= 1009







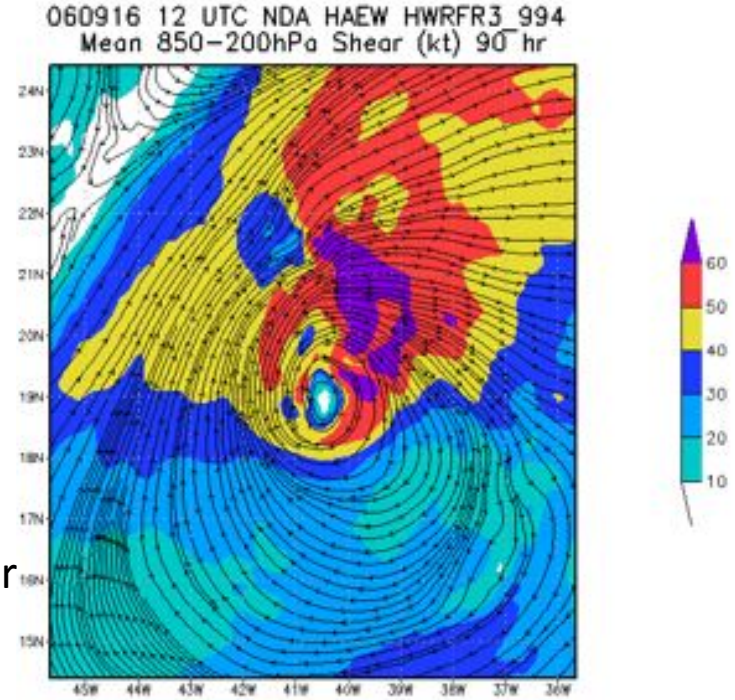


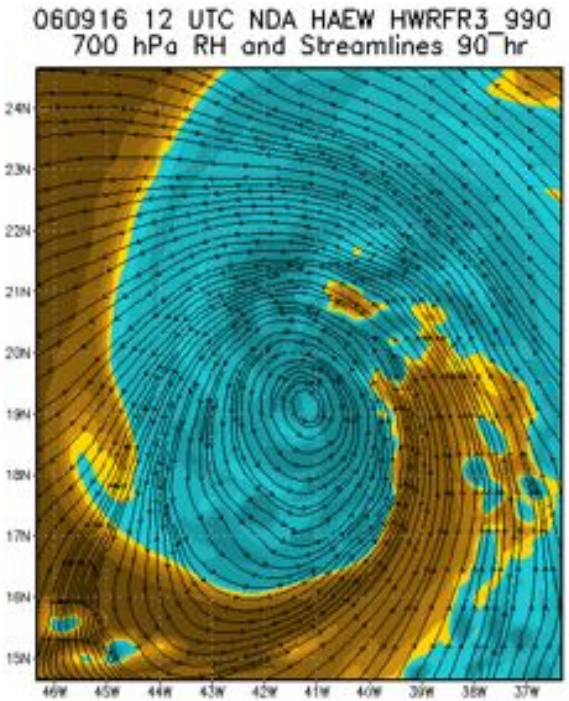
H-C1 (NHC)

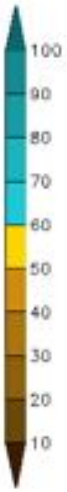
MSW= 48 kt
MSLP= 997 hPa

TS intensity

Stronger mean anticyclonic shear suggesting a stronger TC

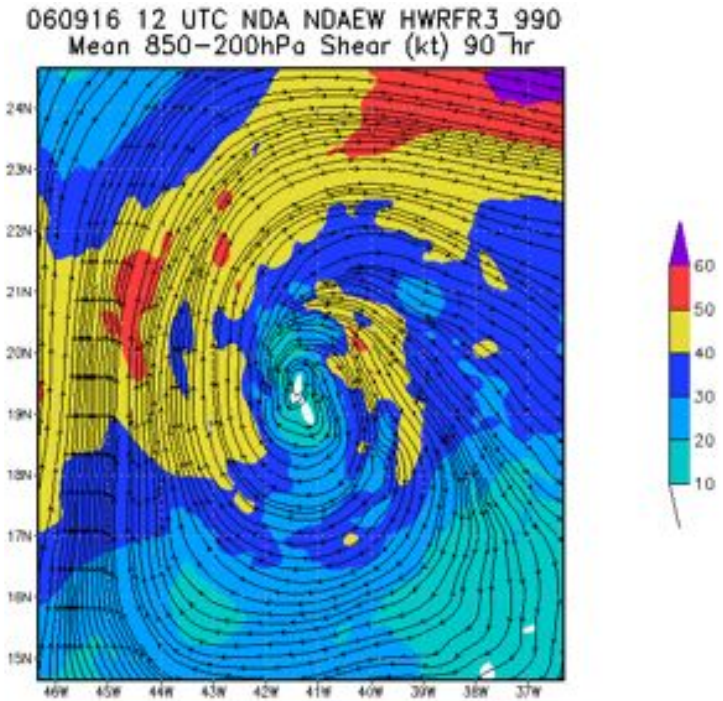




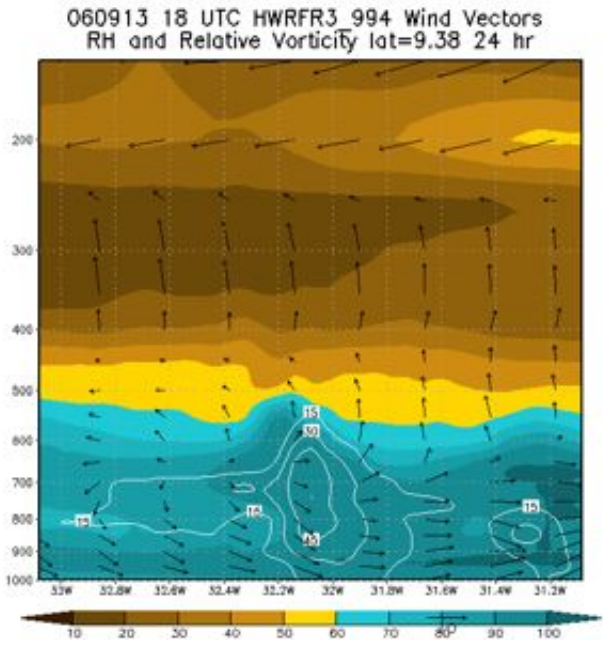


MSW= 26 kt
MSLP= 1003 hPa

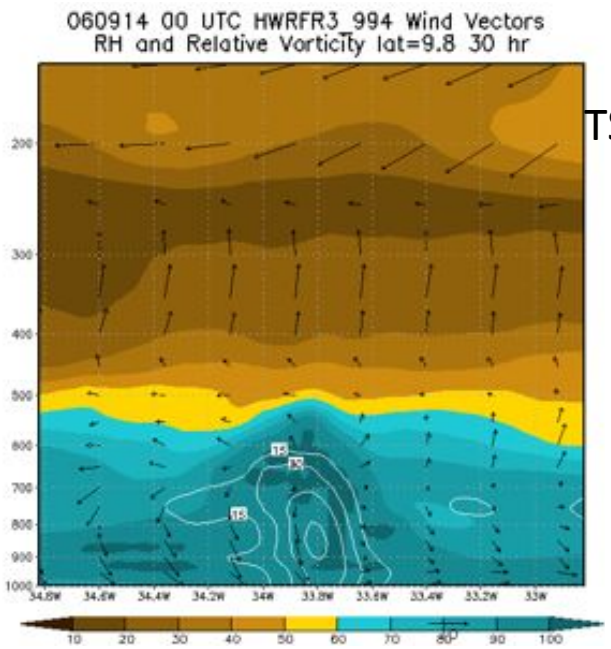
TD intensity



TD (NHC)

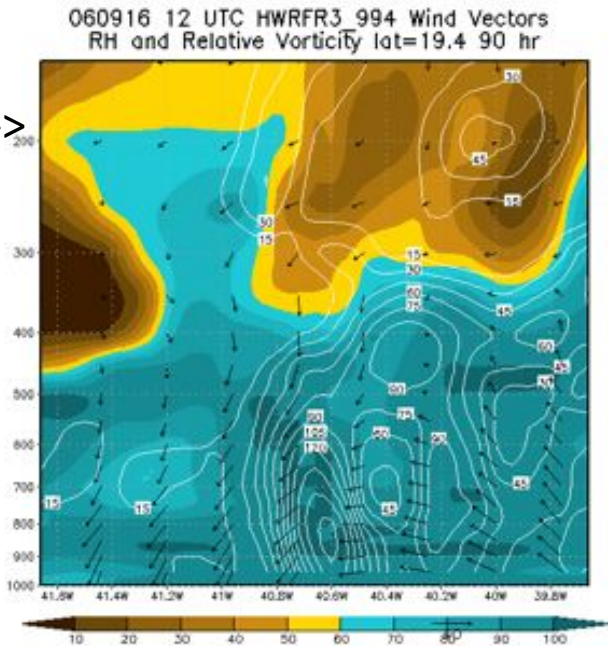


TS (NHC)



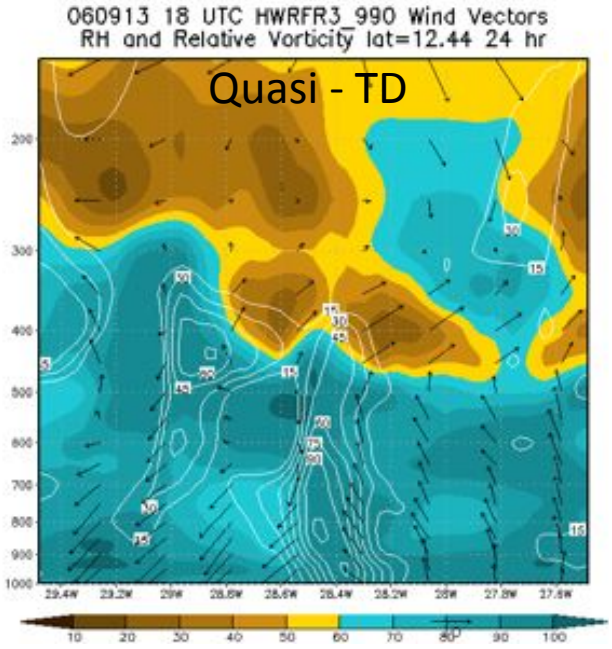
TS->

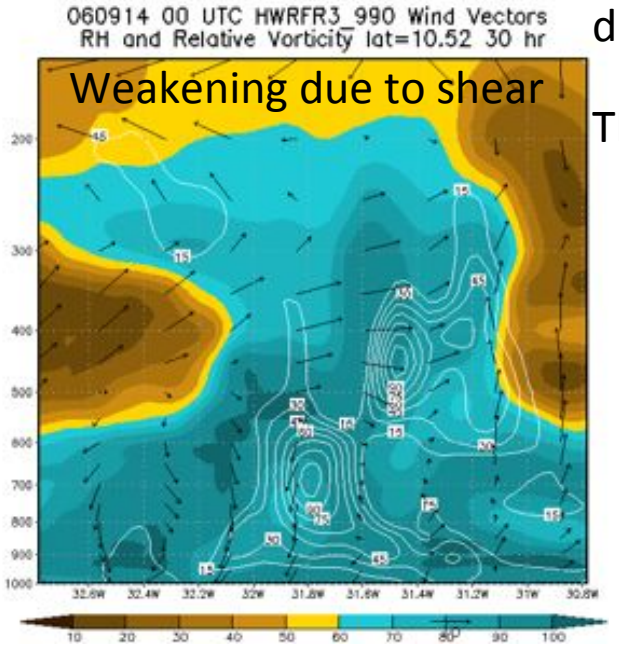
H1 (NHC)



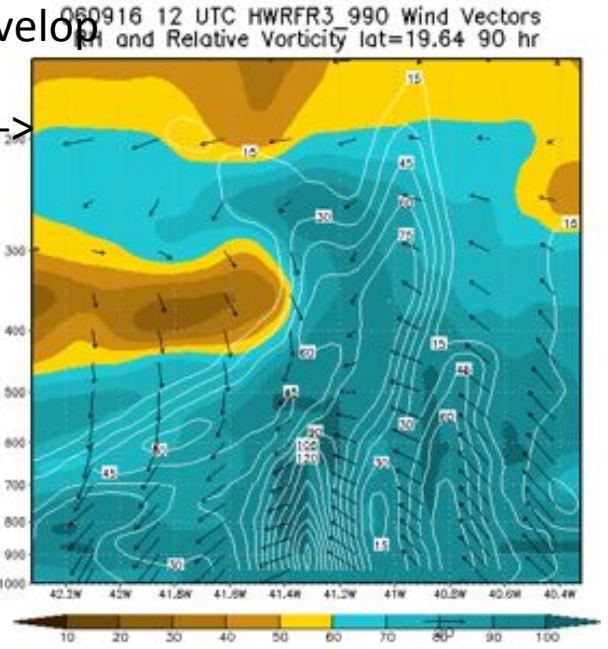
^ Weaker AEW due to dry entrainment at upper levels ^

Broader conv. winds develop

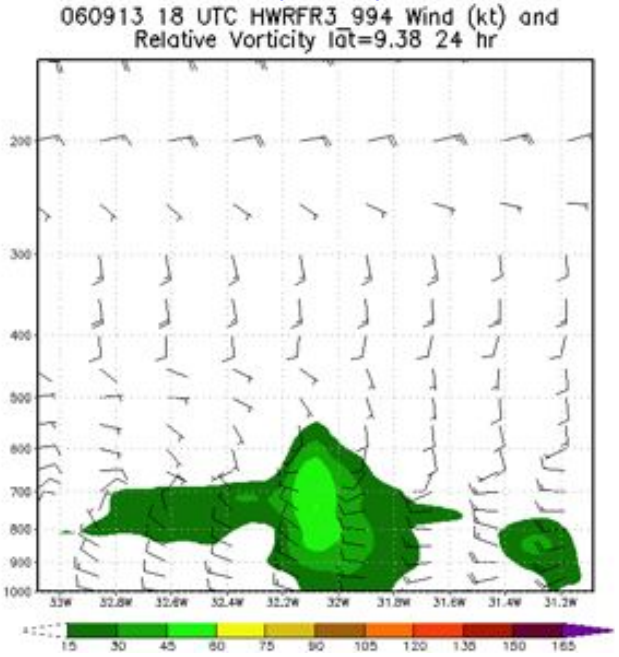




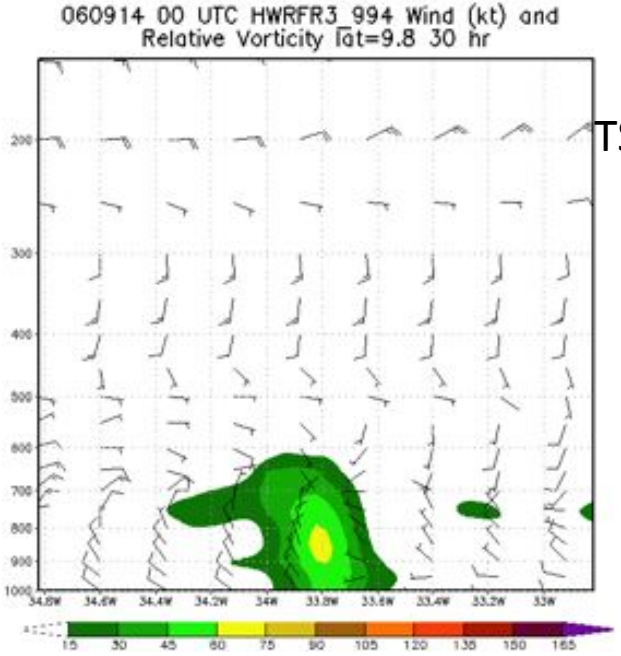
TD->



TD (NHC)

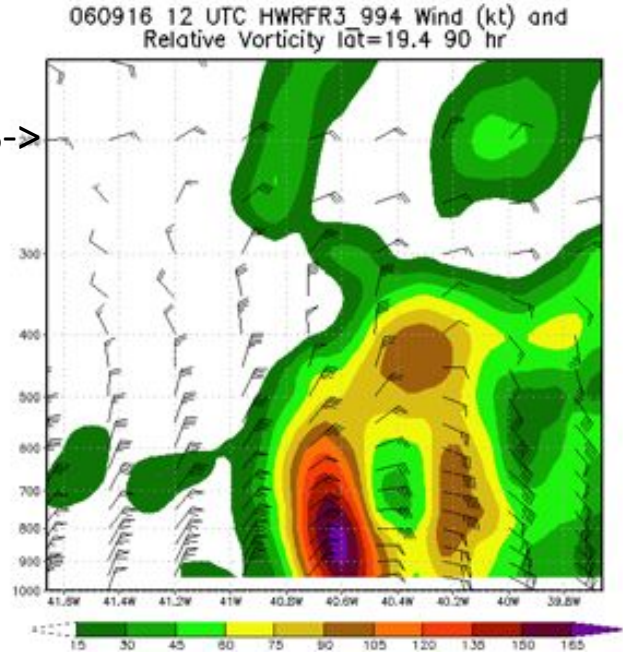


TS (NHC)

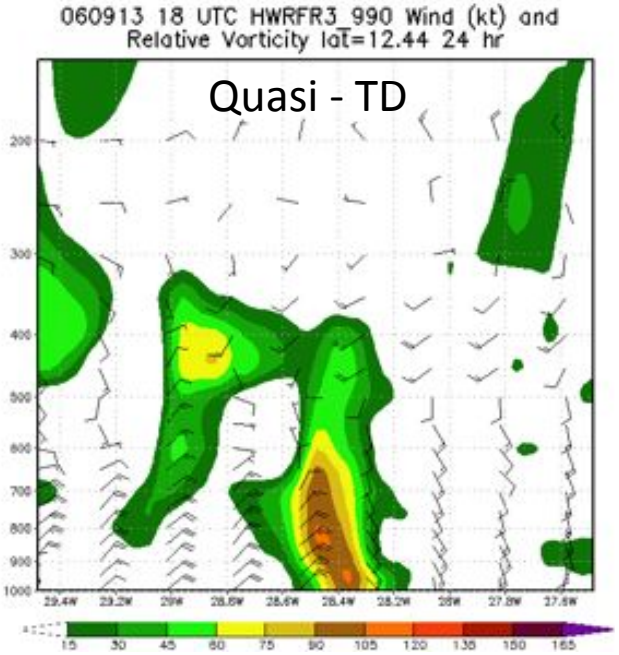


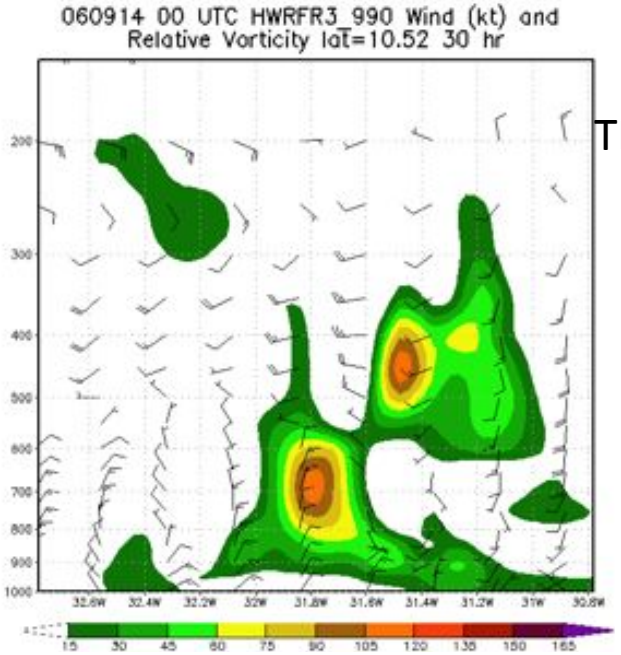
H1 (NHC)

TS->

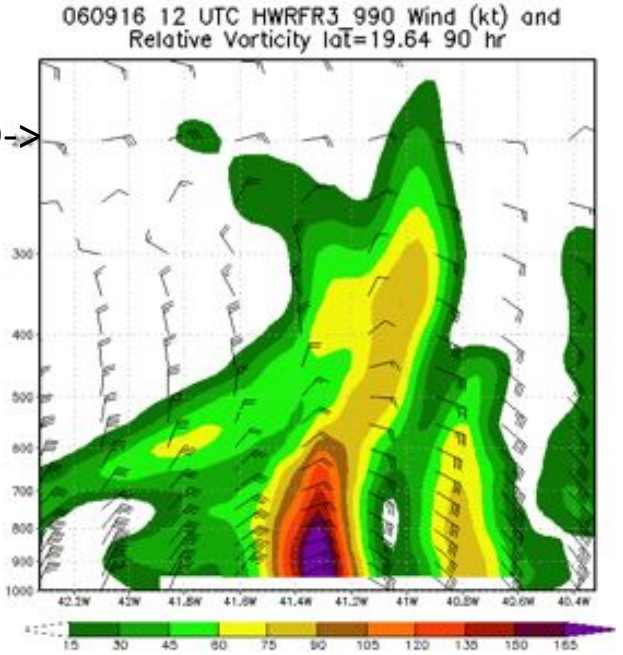


RVORT amplify (H&V) through merger

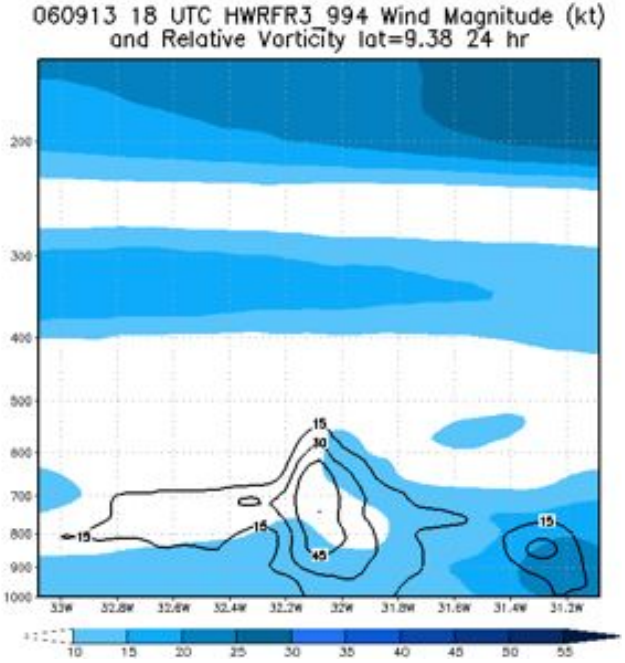




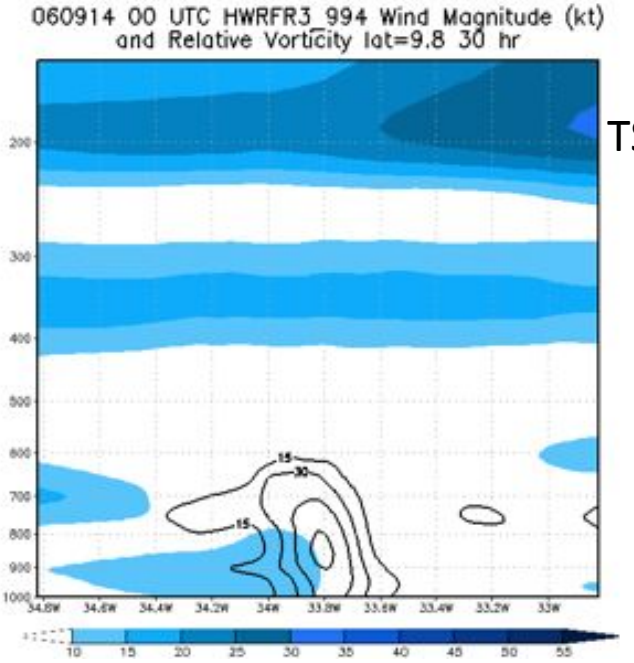
TD->



TD (NHC)

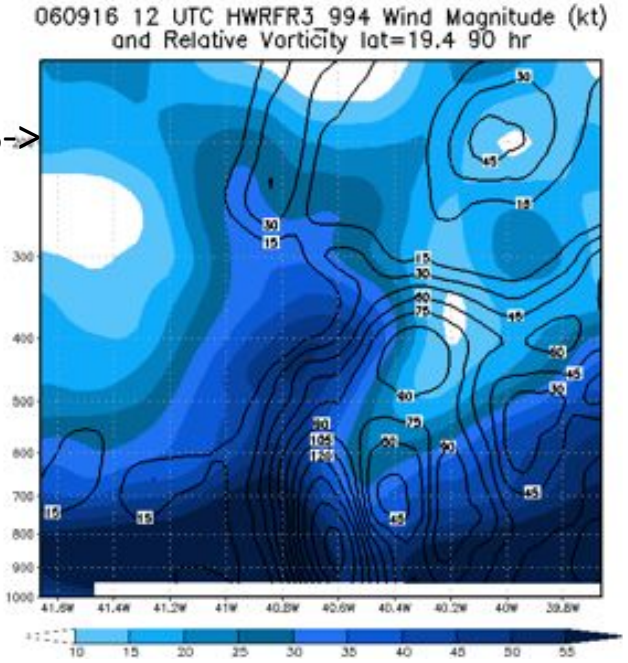


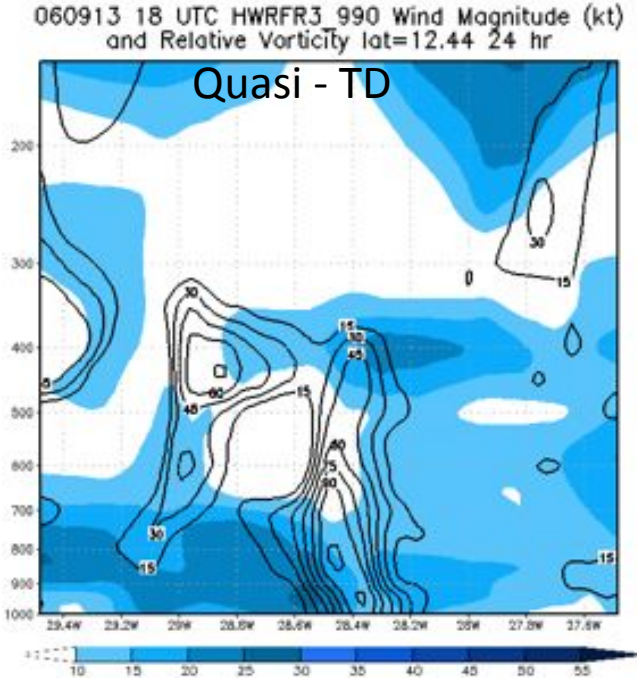
TS (NHC)

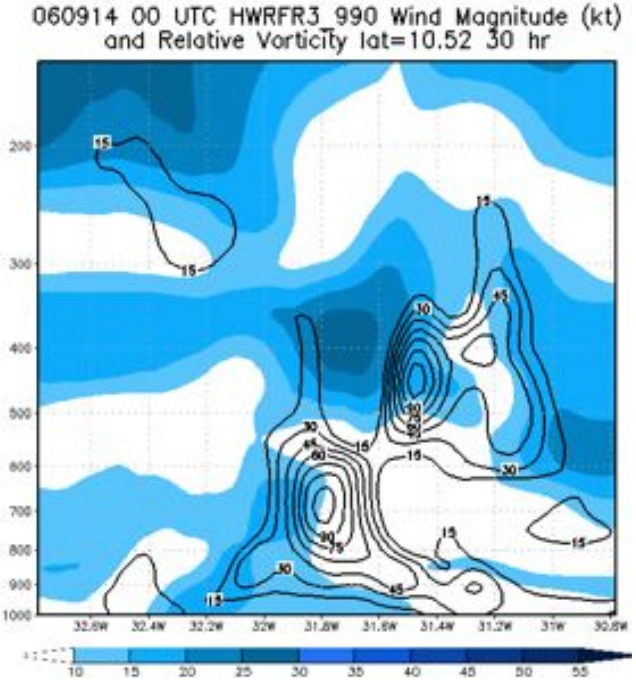


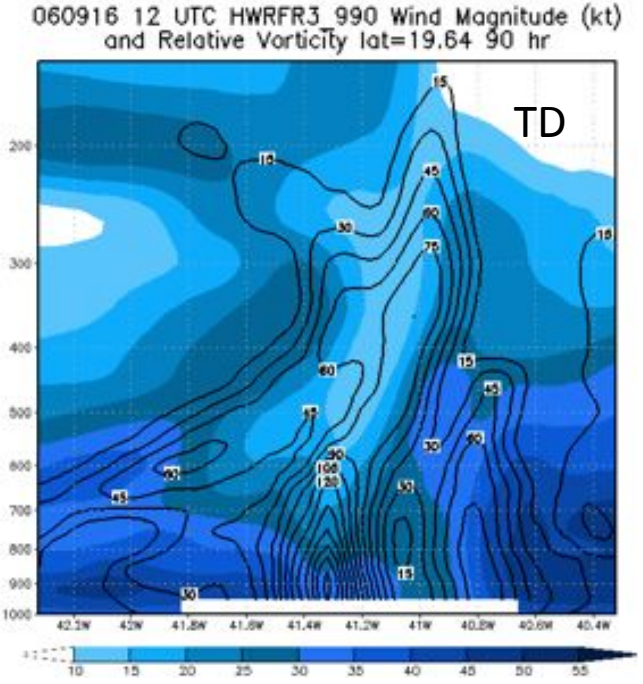
TS->

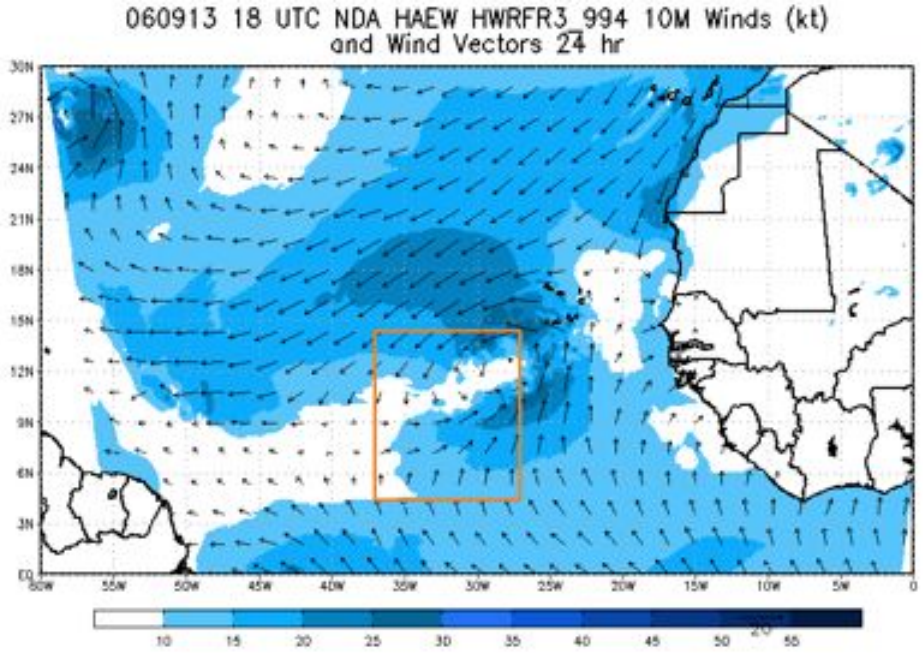
H1 (NHC)



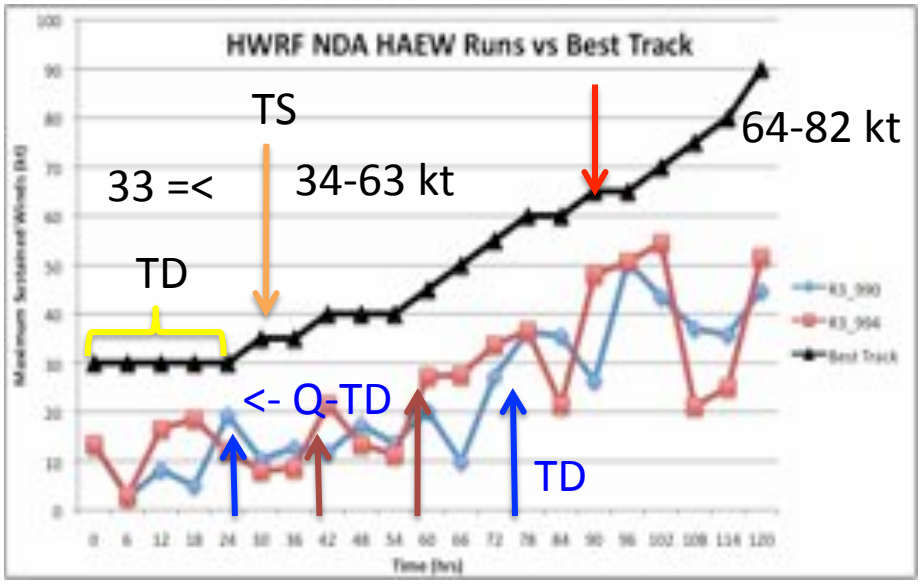




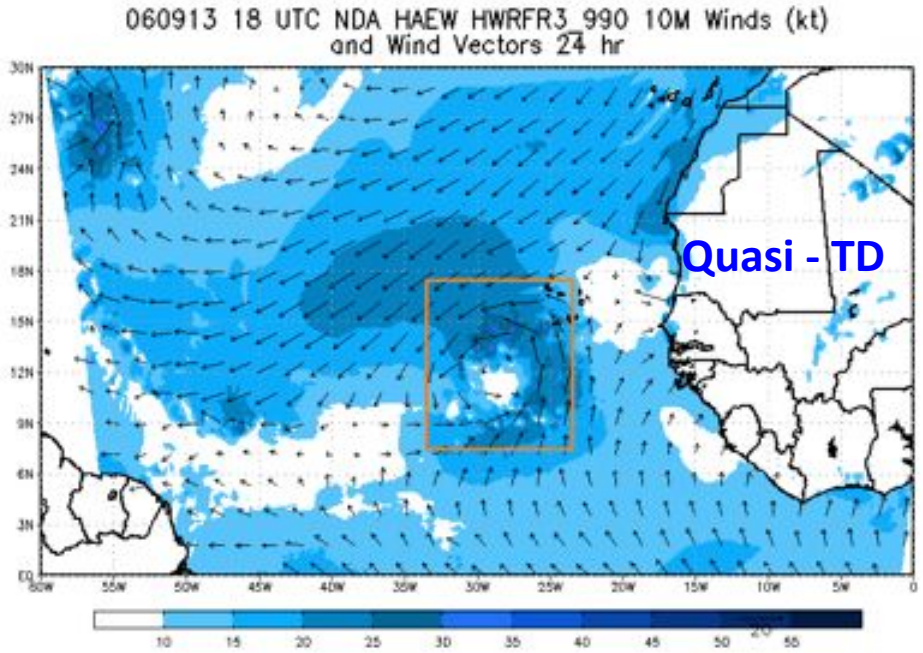


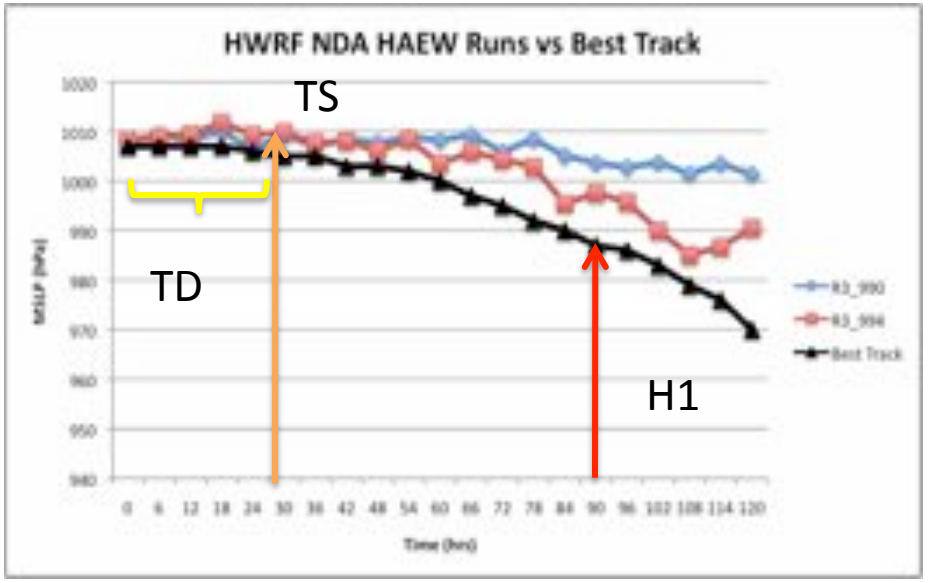


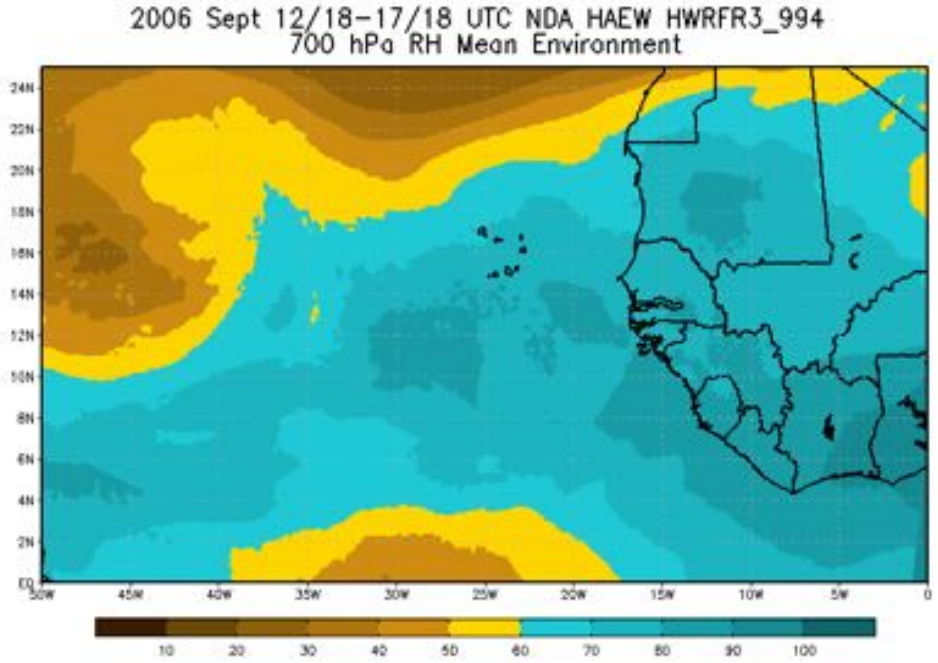
R3 990 better structure that represents better the intensification stages

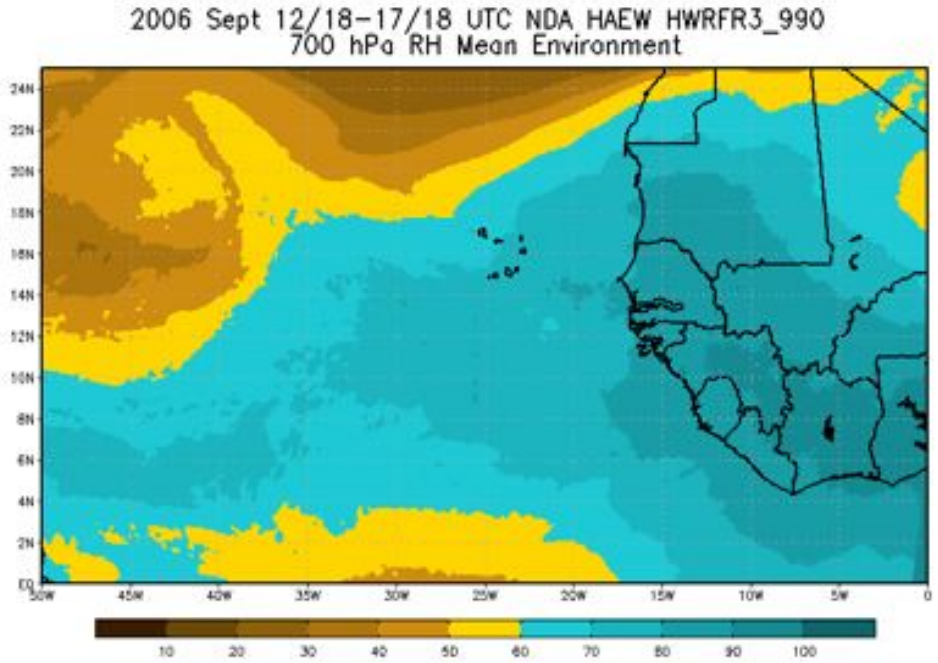


R3 994 overall stronger MSW and MSLP

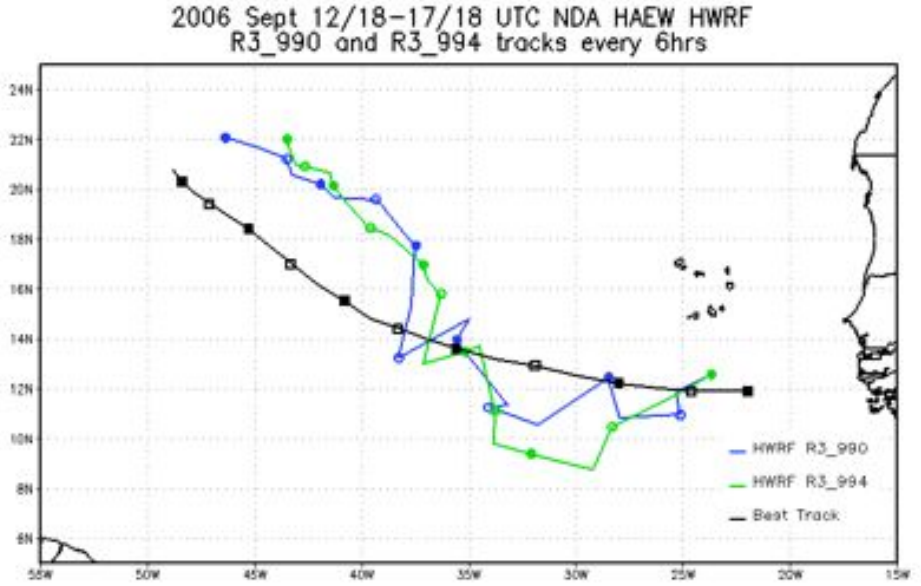








Overall dryer environment inland



Track

Both follow a similar track:

Southward from BT from ~ 0 -> 60 hrs

Northward from BT from ~ 66 -> 120 hrs

Dryer environment off the African coast

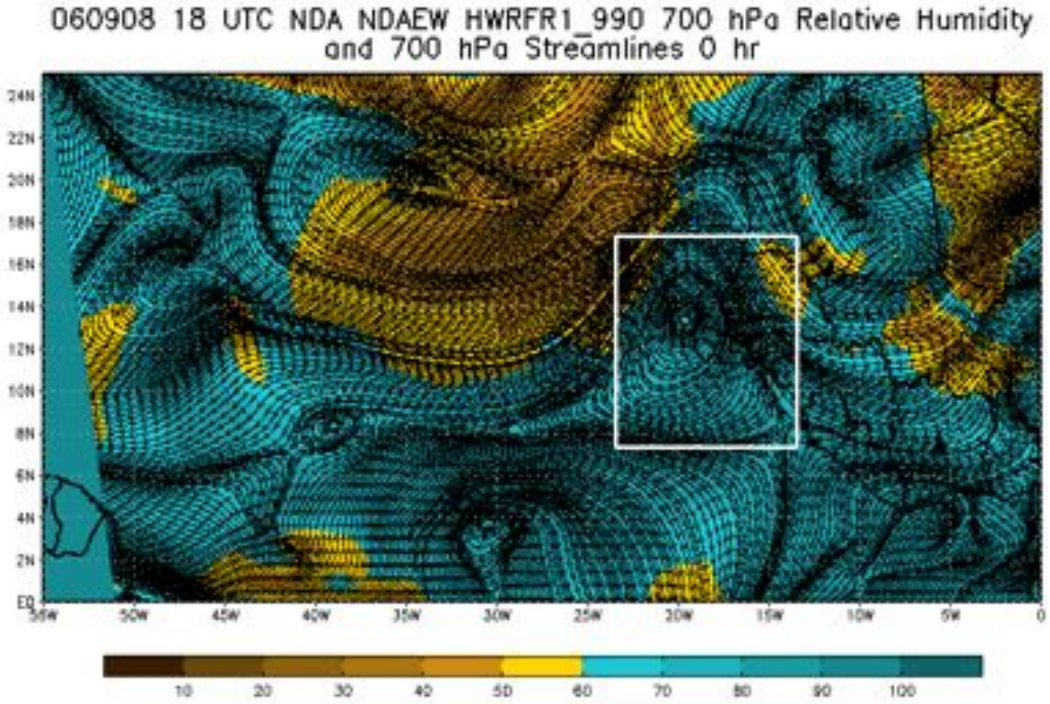
Summary of Observations: HAEW CU vs NCU

- R3 994 overall stronger MSW and MSLP than R3 990
- Both runs underestimate the timing of the intensity stages when compared to the NHC Best Track data
- According to the MSW, the strongest TC stage reached in both runs is: TS
- For both runs, there is a general intensification trend in the MSW, but not constant
- VCSs of RH, RVORT and WND indicate that this inconstancy is due to periods of:
  - Weakening related to wind shear and dry air entrainment to mid and upper levels
  - Intensification associated to formation of a broader wind convective structure and RVORT merger in a moist environment
- Even with a dryer environment, R3 990 showed to have a structure more representative of the intensification stages at all levels (HCSs & VCSs)
- VCSs of WND magnitude and RVORT aid in determining/confirming the strength of a TC in its early development when systems are embedded in similar moist environments and with a broad convective wind structure (i.e. t=90 hr)
  - A reduction in MSW was observed in a less moist environment at the AEW axis (i.e. sharp weakening periods of R3 994 & R3 990)

NCU: NDAEW (R1) & HAEW (R3) Evolution and Structure Analyses

Init

MSW= 7 kt
MSLP= 1009 hPa

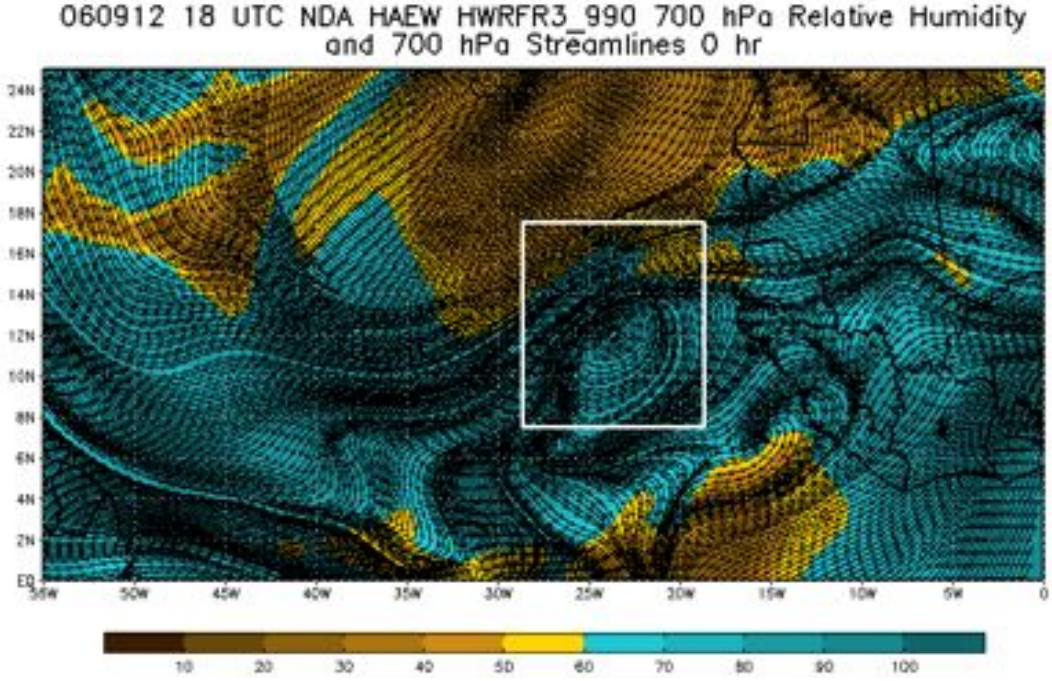


NDAEW

<- Dryer easterly wind flow

Elongated AEW

MSW= 13 kt
MSLP= 1008 hPa



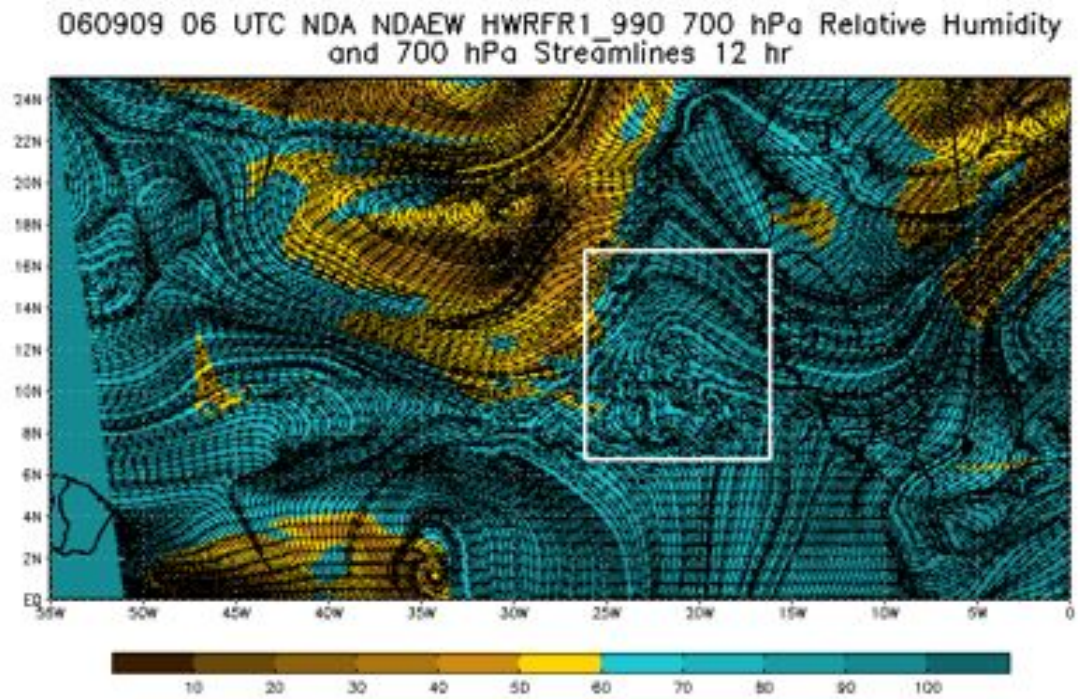
HAEW

Strong circulation already formed off the African coast

Mostly influenced by southerly flow

12 h

MSW= 18 kt
MSLP= 1010 hPa



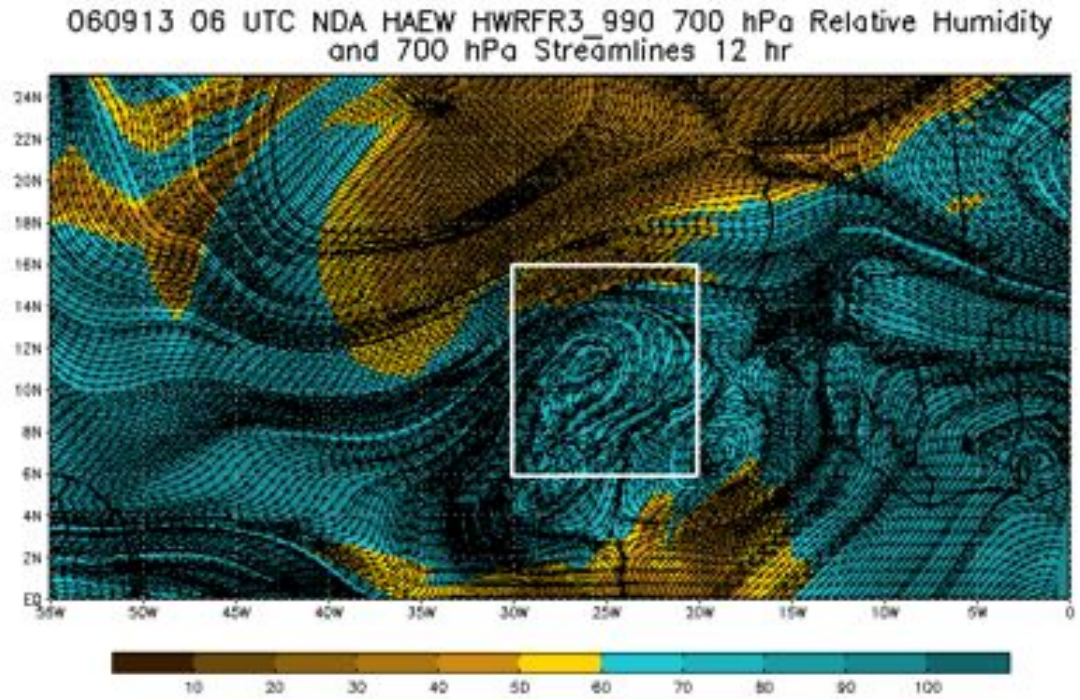
NDAEW

<- Continuous dryer easterly air flow

Open wave extending N

MSW= 8 kt
MSLP= 1008 hPa

10 m winds (MSW) not enough to determine intensification of a tropical disturbance

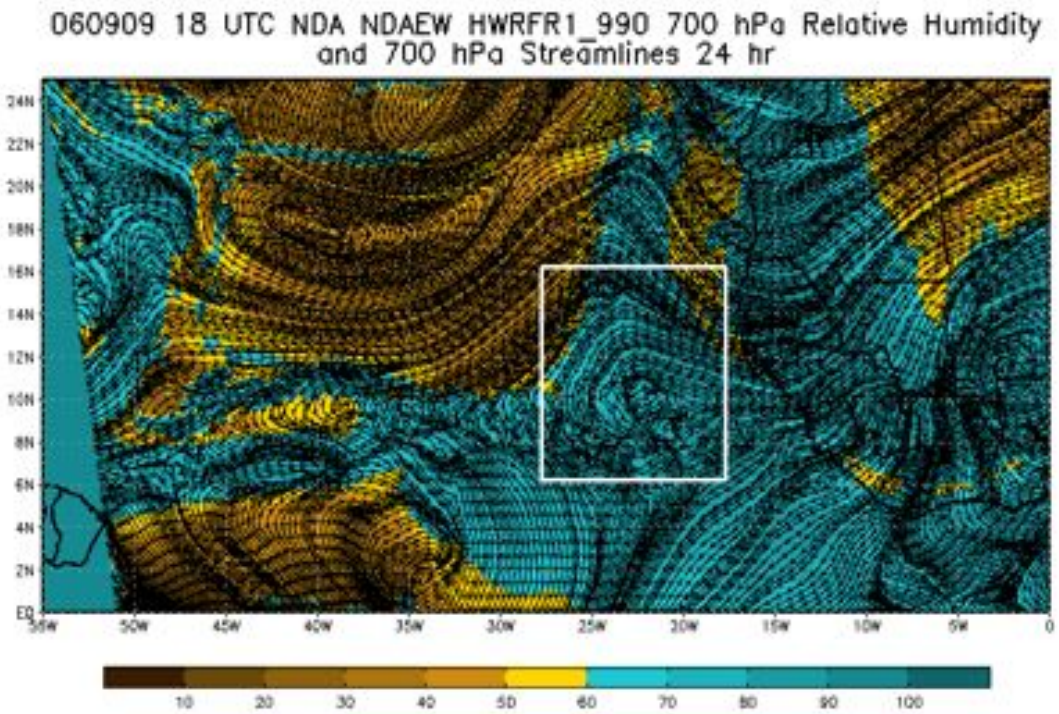


HAEW

Weaker AEW at this time at this level, but stronger structure than R1

24 h

MSW= 7 kt
MSLP= 1010 hPa

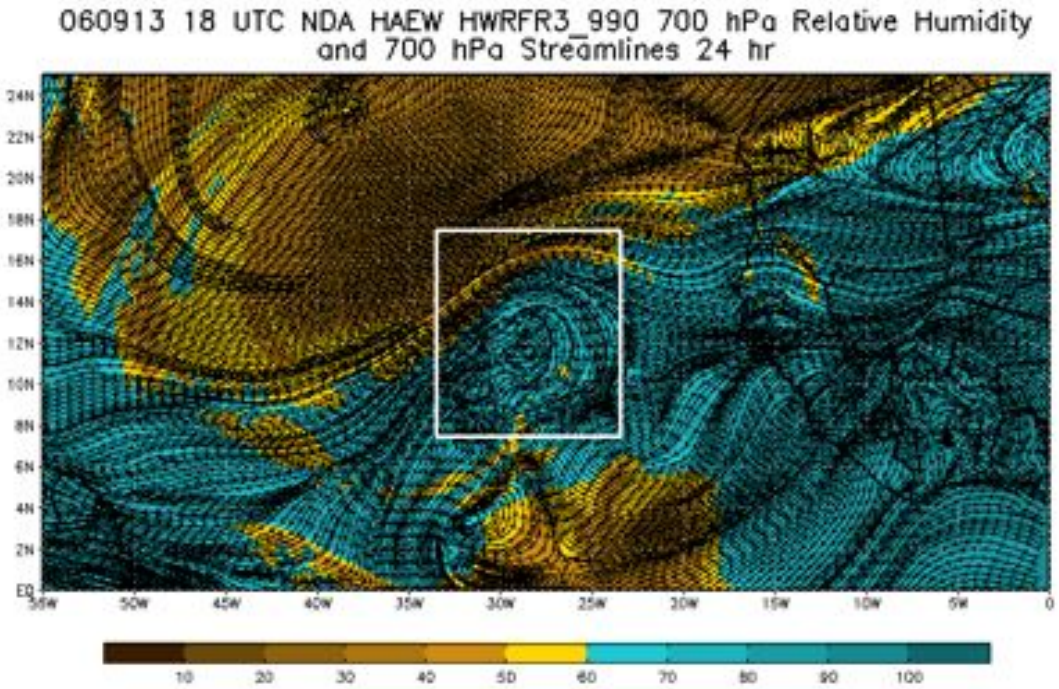


NDAEW

<- Continuous dryer easterly flow

Weaker open wave extending N

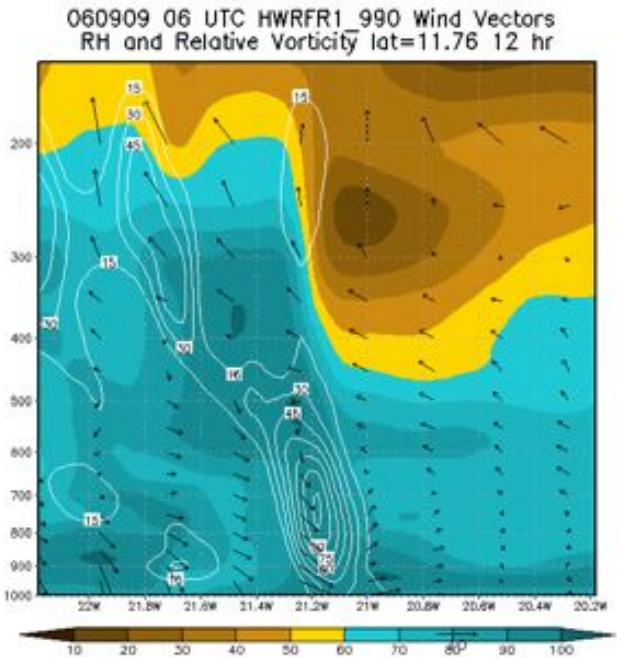
Quasi - TD
MSW= 19 kt
MSLP= 1006 hPa

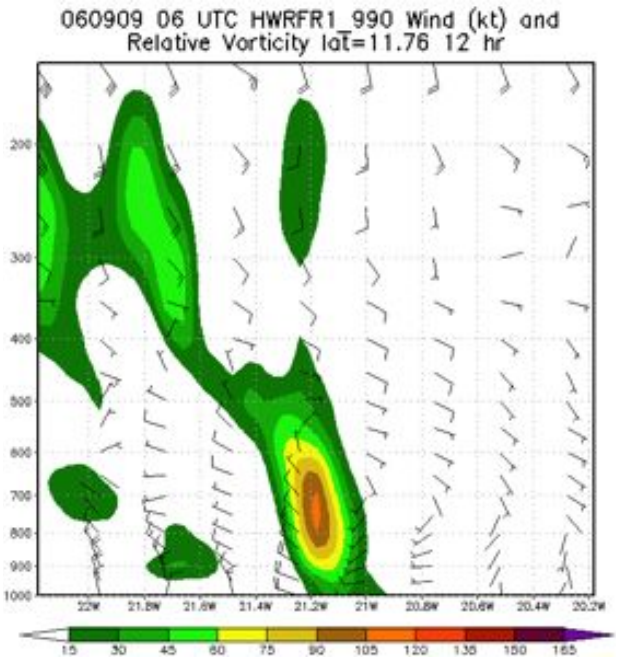


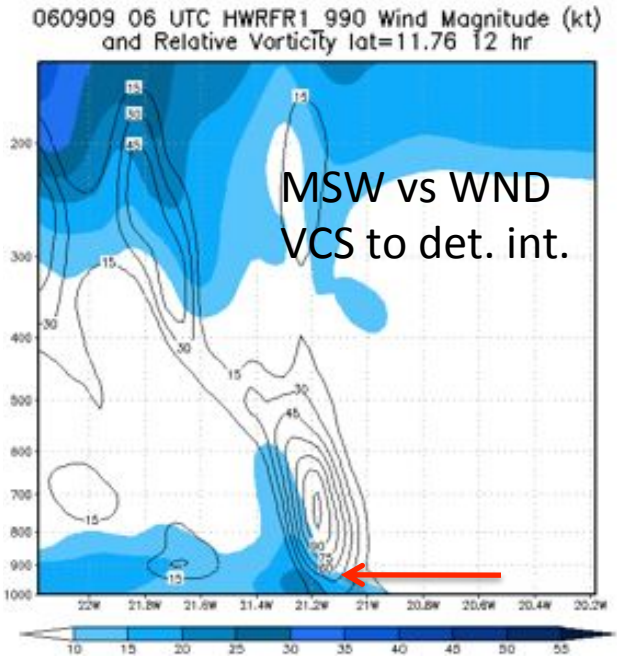
HAEW

TD intensification 24 hr after NHC

NHC:
TD
MSW= 30 kt
MSLP= 1006 hPa

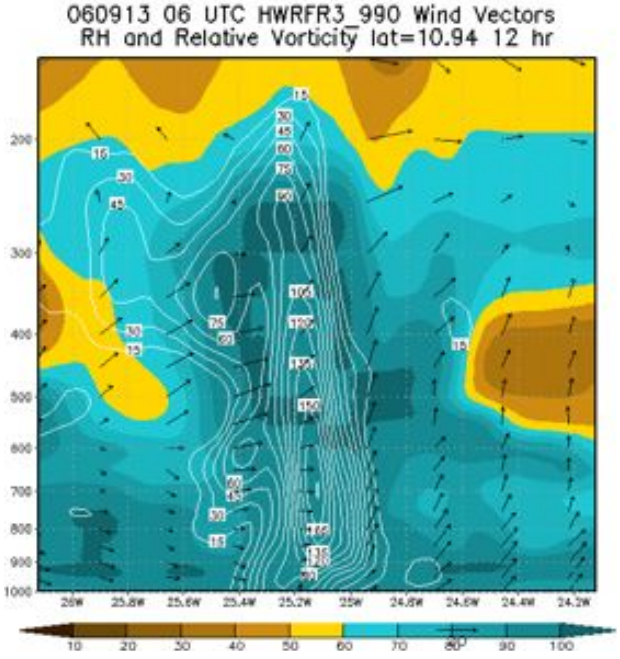


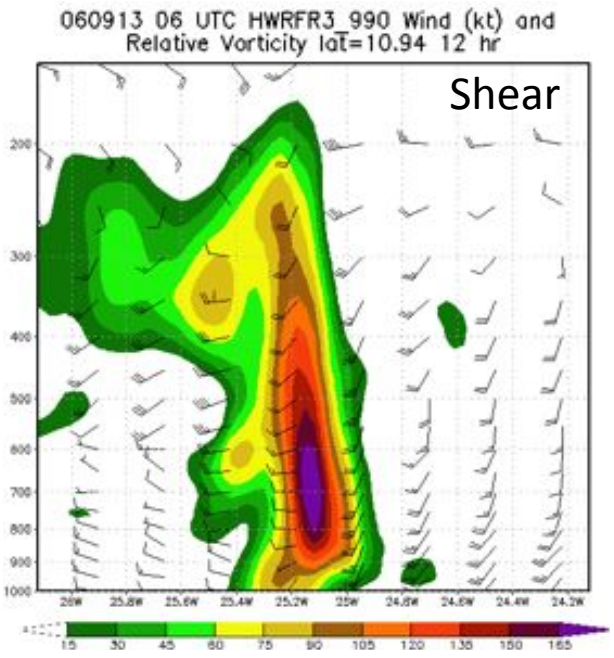


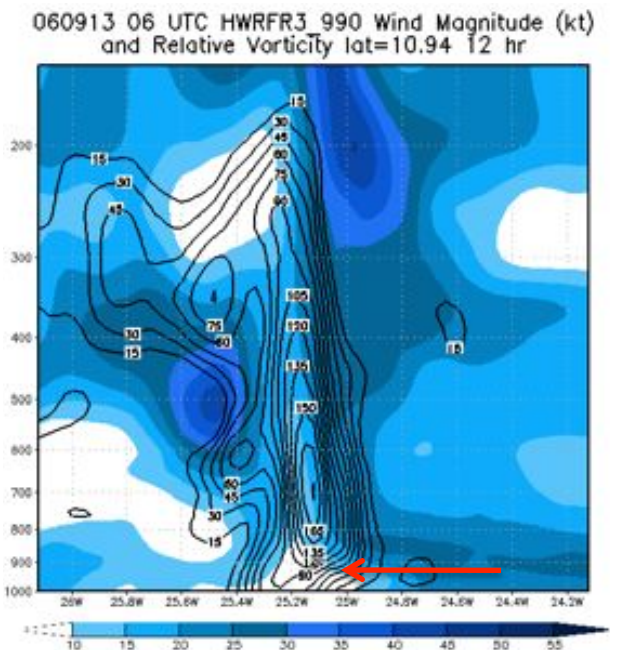


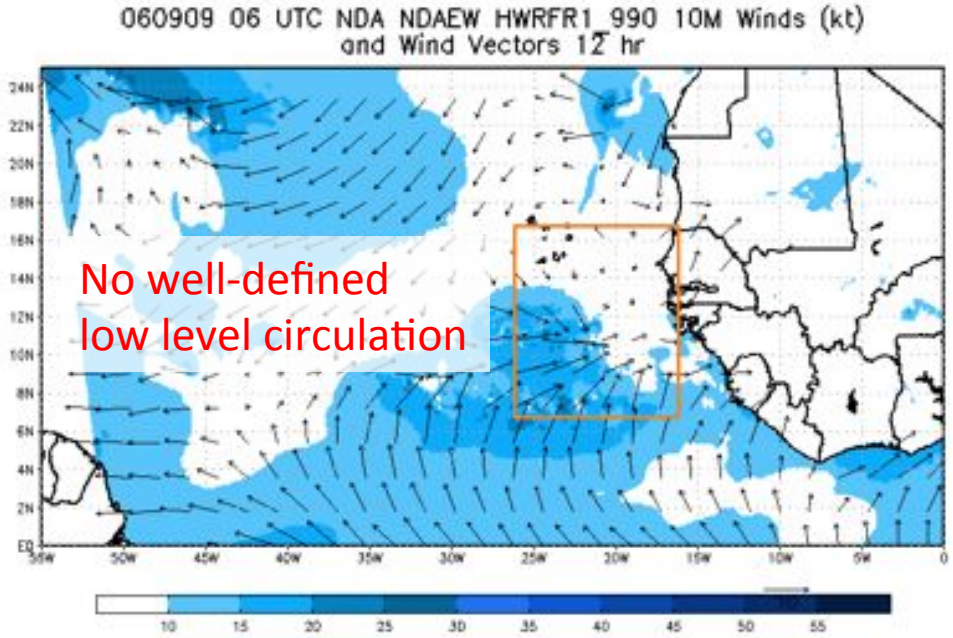
^ SERLY shear limiting growth (hindering RVORT merger); dryer env.

^ Weaker wind convective structure supporting ^ the AEW axis RH/RVORT column

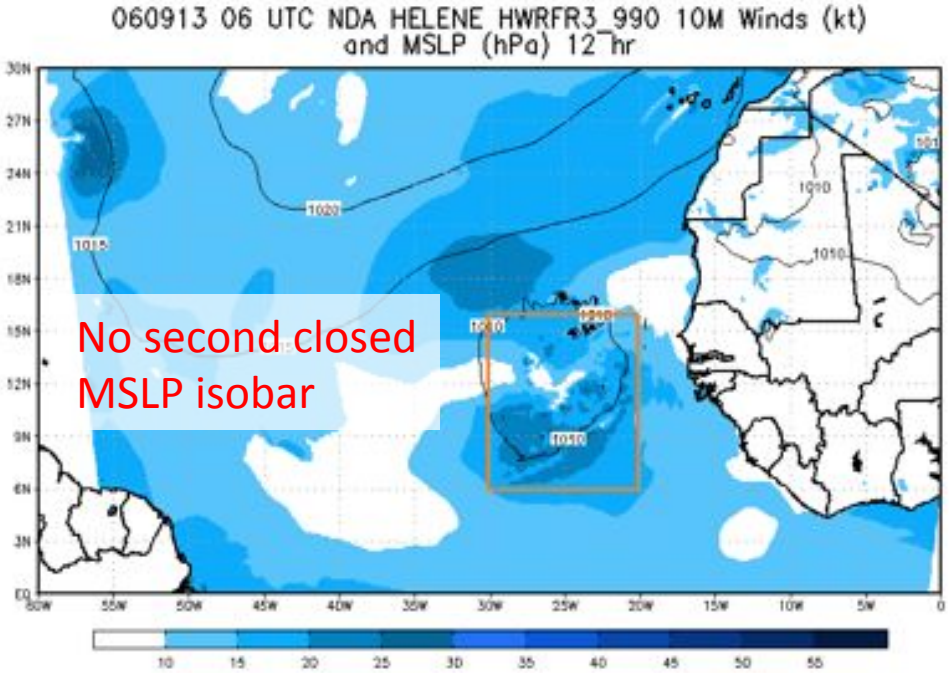


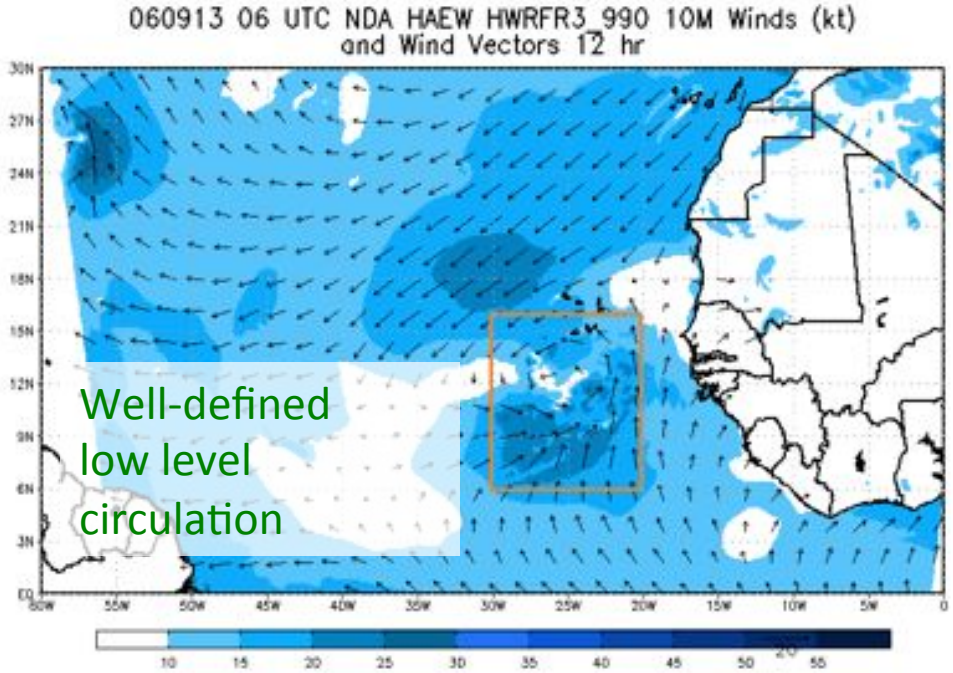






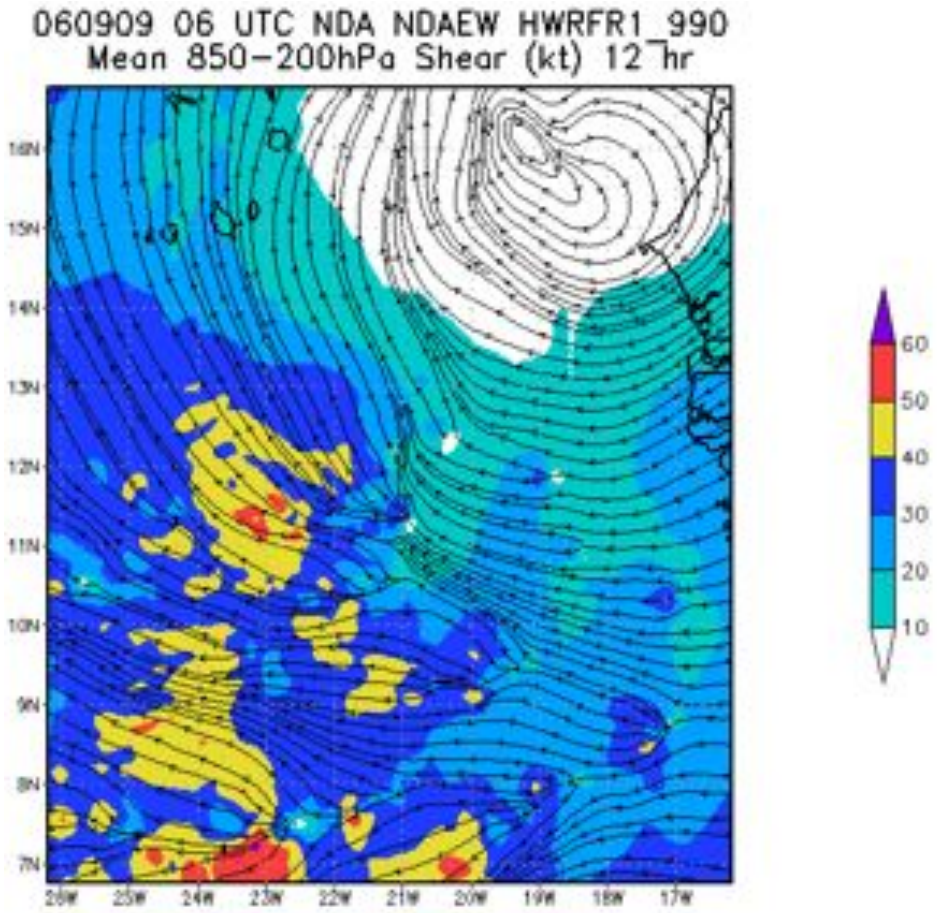
Missing Ingredients for Cyclogenesis to be happening: 12 h

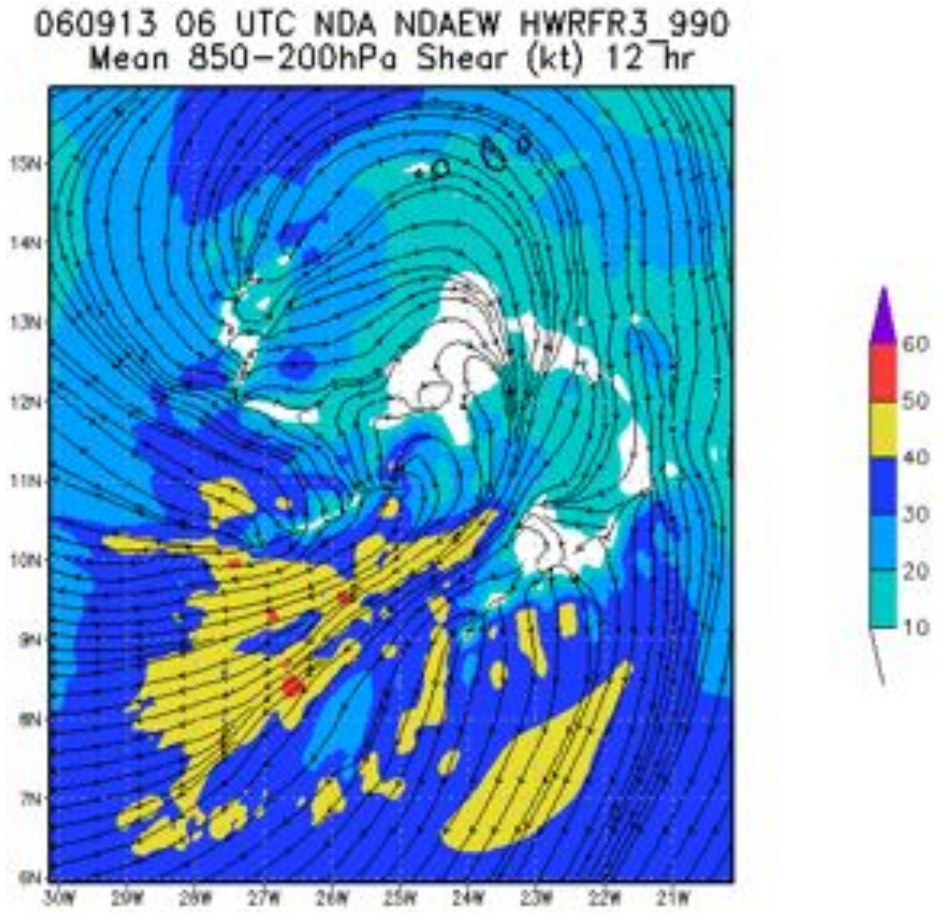


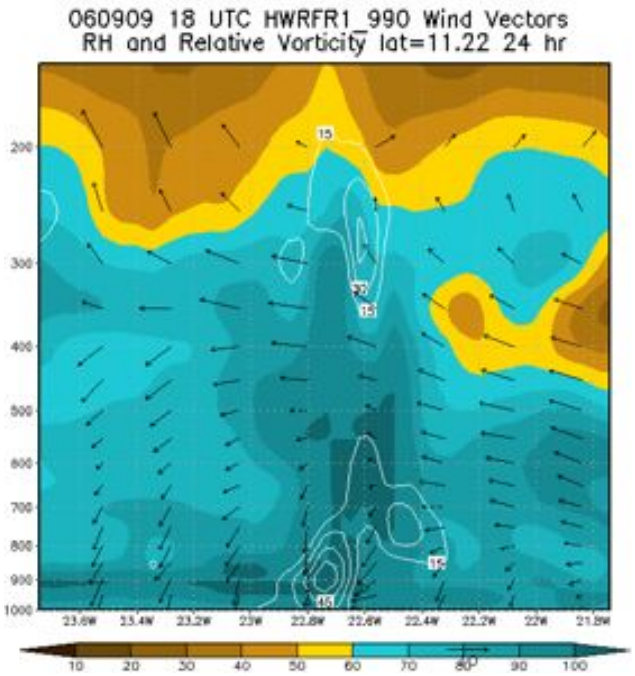


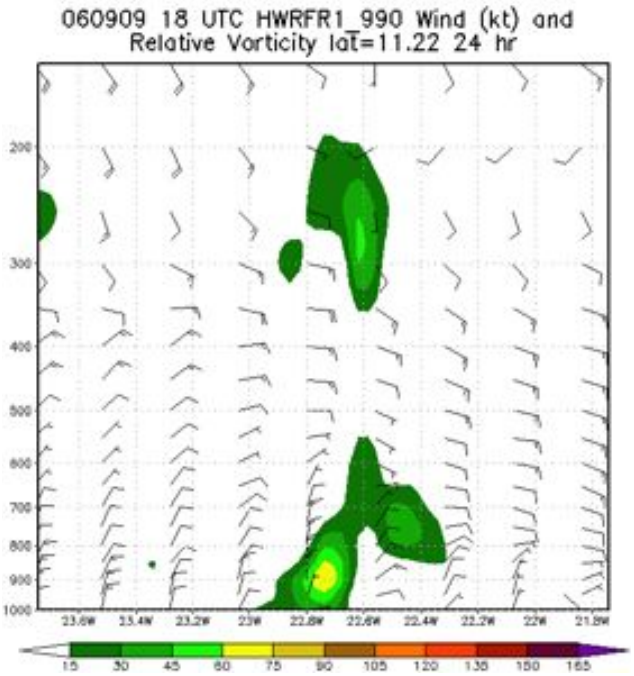
Missing Ingredients for Cyclogenesis: 12 h

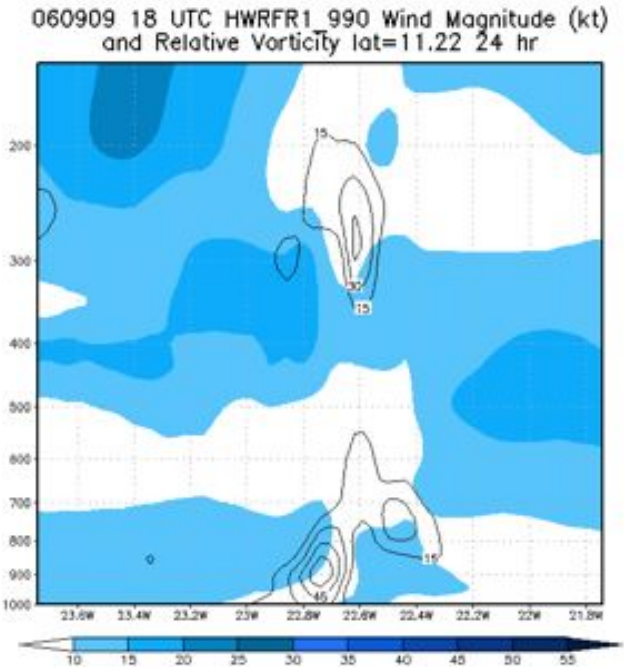
- No anticyclonic mean horizontal shear aligned to the AEW axis (R1)
- No well-defined anticyclonic shear/& center (R3)



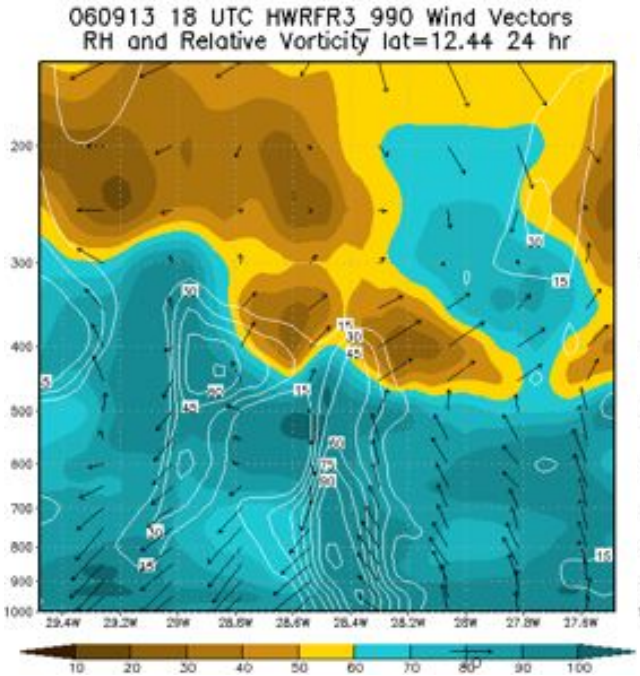


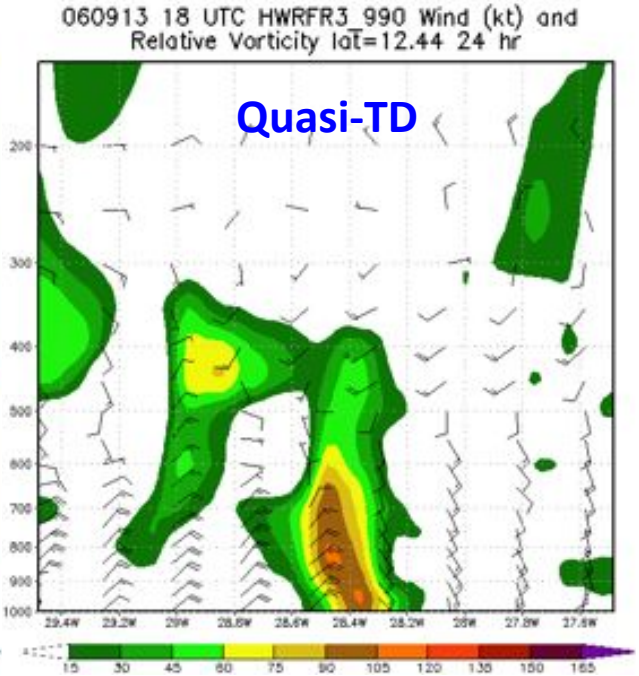


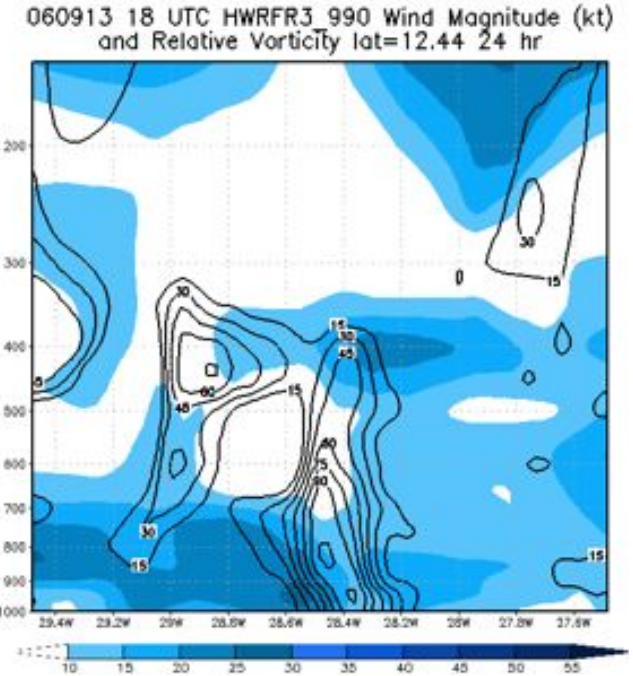


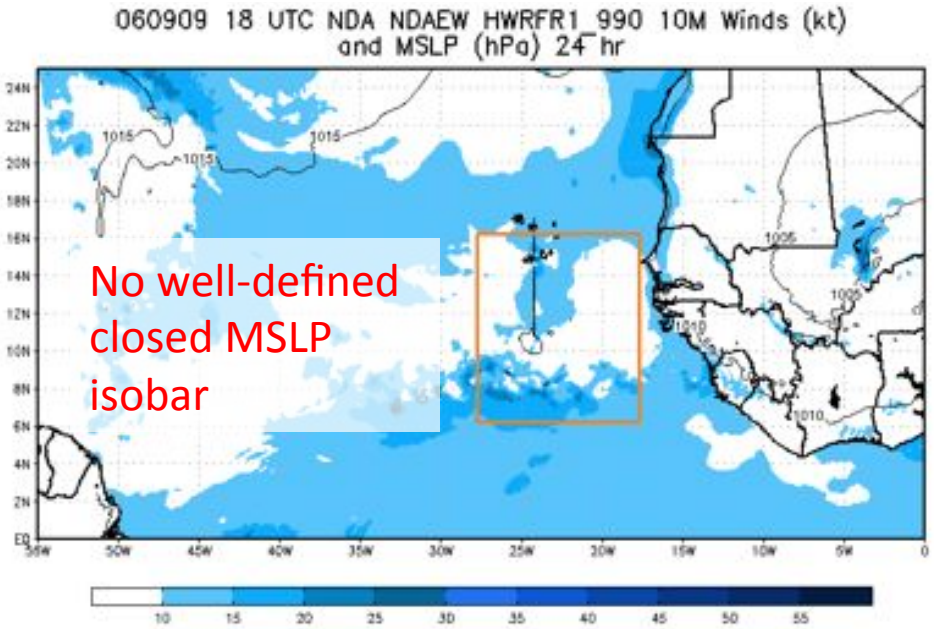


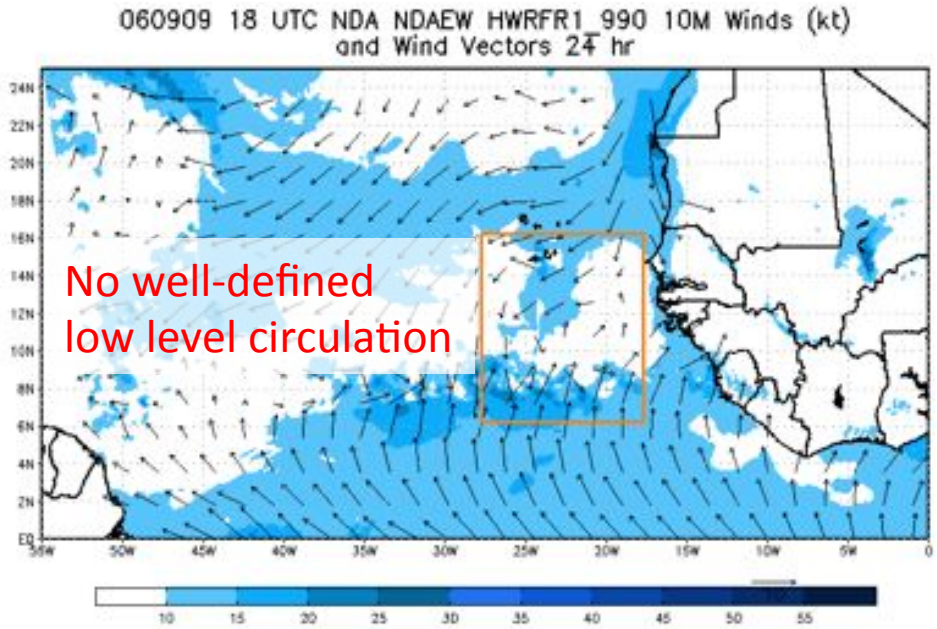
^ Broad wind convective structure ^ Weak RVORT below 600-500 hPa ^ Weak WND < 20-35 kt



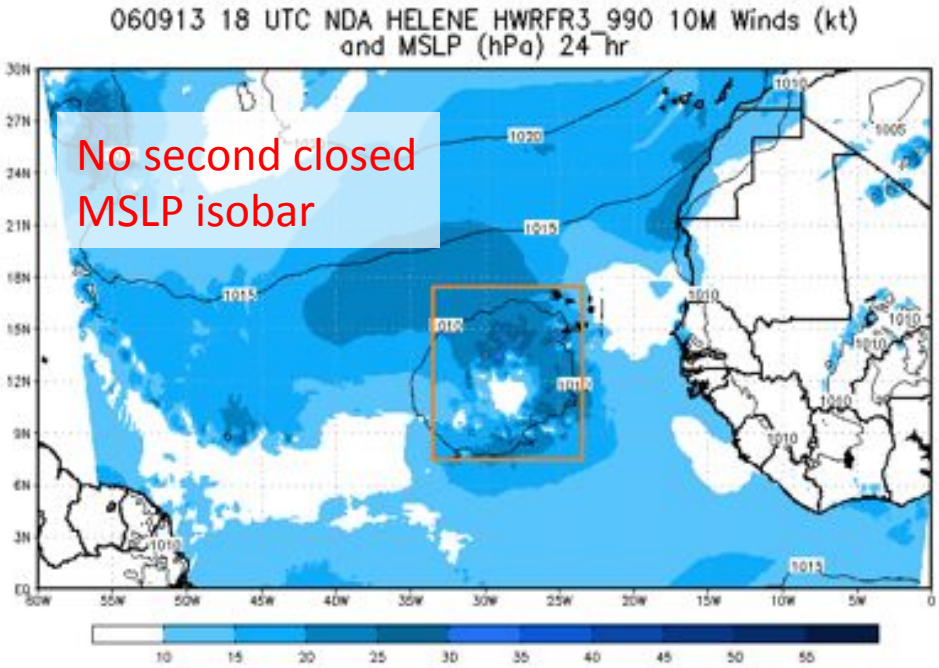


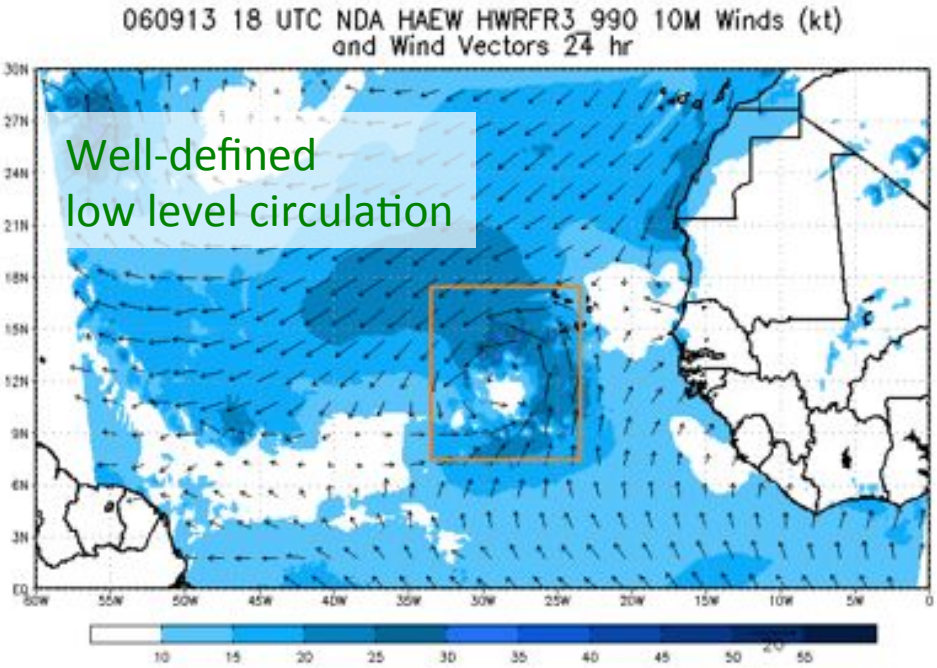






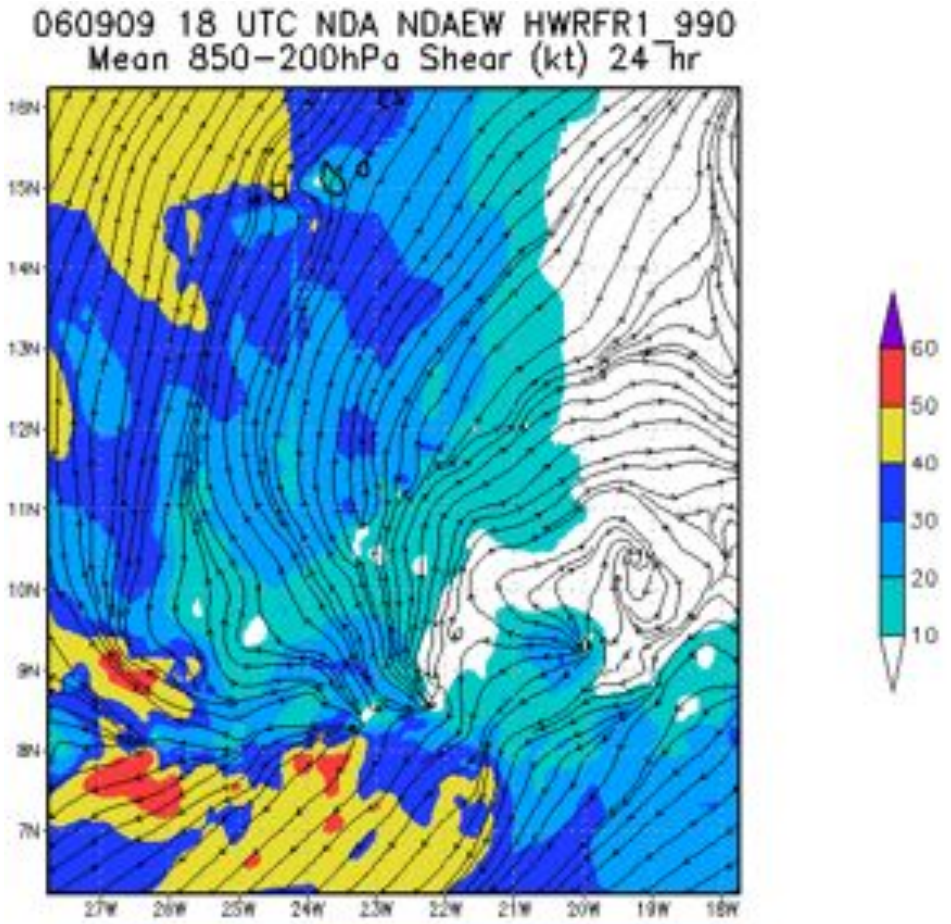
Missing Ingredients for Cyclogenesis to be happening: 24 h

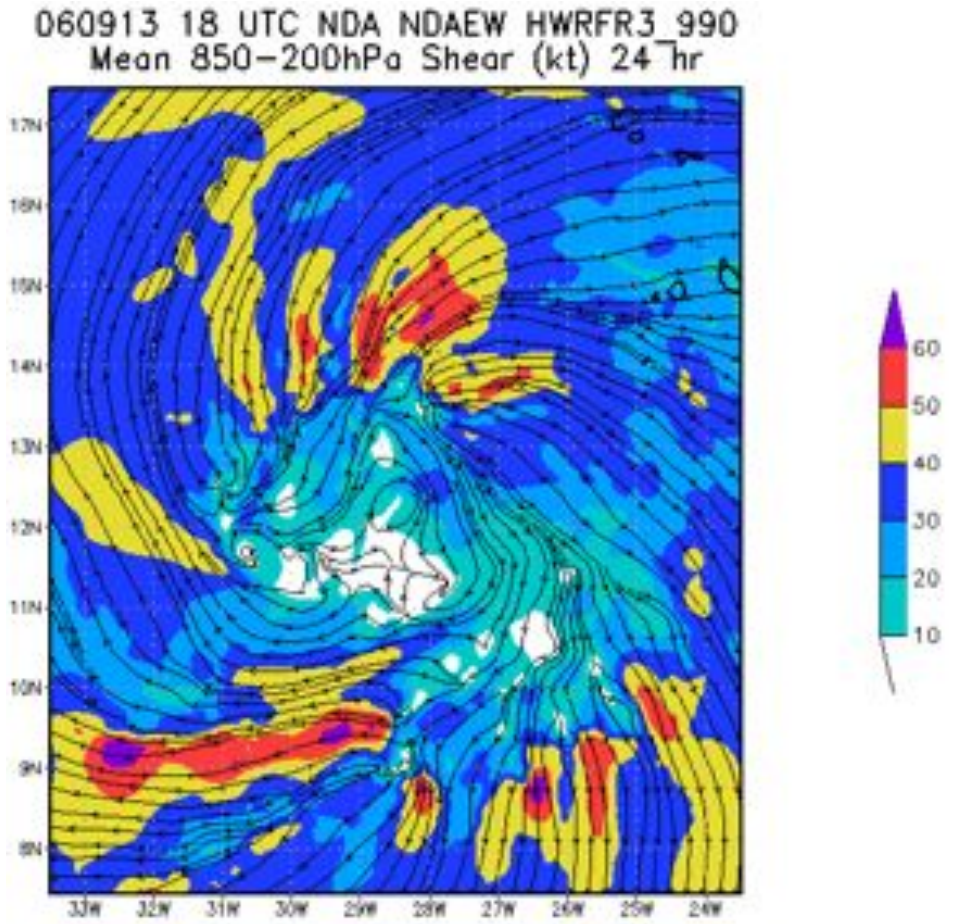


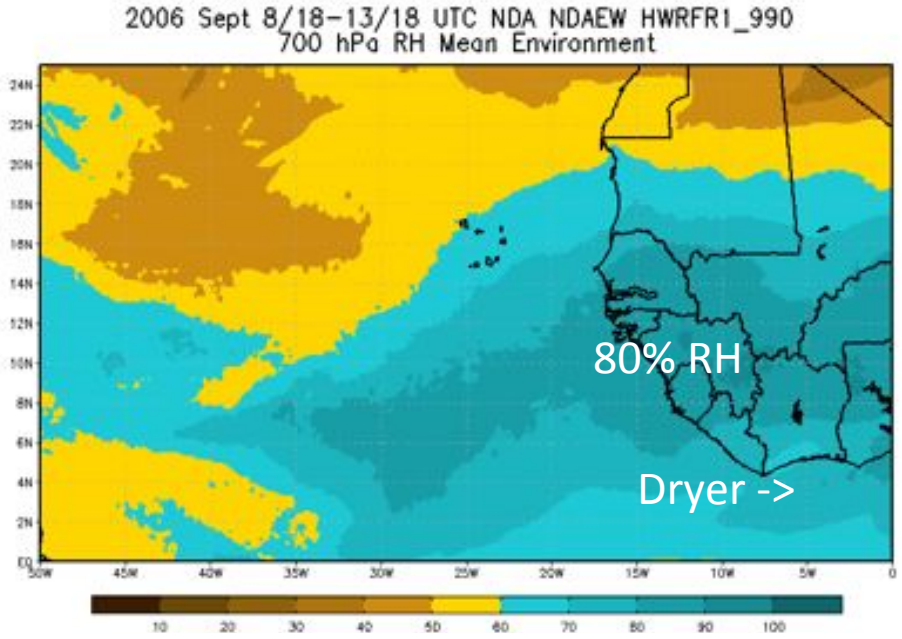


Missing Ingredients for Cyclogenesis: 24 h

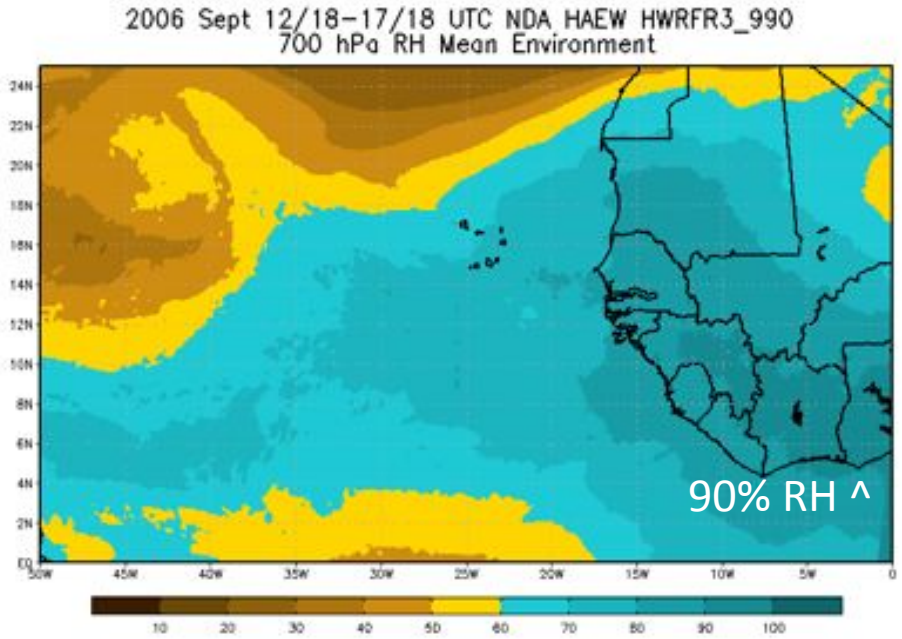
- No well-defined anticyclonic:
  - mean shear/& center aligned to the AEW axis (R1)
  - center in the mean horizontal shear (R3)







HAEW maintains a better constancy of the already well-built structure formed over Africa



<- More humid environment in the E Atlantic: 60-**80**% RH

- Both needed from a continuous/ prolonged moist environment to develop/intensify
- Closeness and massive entrainment of dry air masses likely acted to disrupt the disturbance convective wind flow by enhancing the wind shear, which delayed the development of R1 990 NDAEW to 117 hr of the simulation
- This show importance in analyzing VCS of RH, RVORT and WND, which is an aid for determining how the overall dynamic environment is affecting the intensification of the AEW
- The wind flow in which the AEW is embedded seem to be relevant as well (GFS diagnostic study): HAEW developed within a southerly and moist wind flow from Gulf of Guinea; NDAEW within a dryer ERLY flow

<- Dryer environment off the African coast: 60-**70**% RH

Concluding Remarks on Cyclogenesis

- ✓ For cyclogenesis to occur all these must exist and be vertically aligned:

VCS:

- Broad wind convective structure reaching at least 500 hPa
- 90-100 % RH column of air at the AEW axis
- RVORT column (Max => 75 s^{-1}) aligned with the RH column from surface up to 600 -> 500 hPa
- Cyclonic wind column with magnitude ranging from 20->35 kt supporting the AEW vertical structure

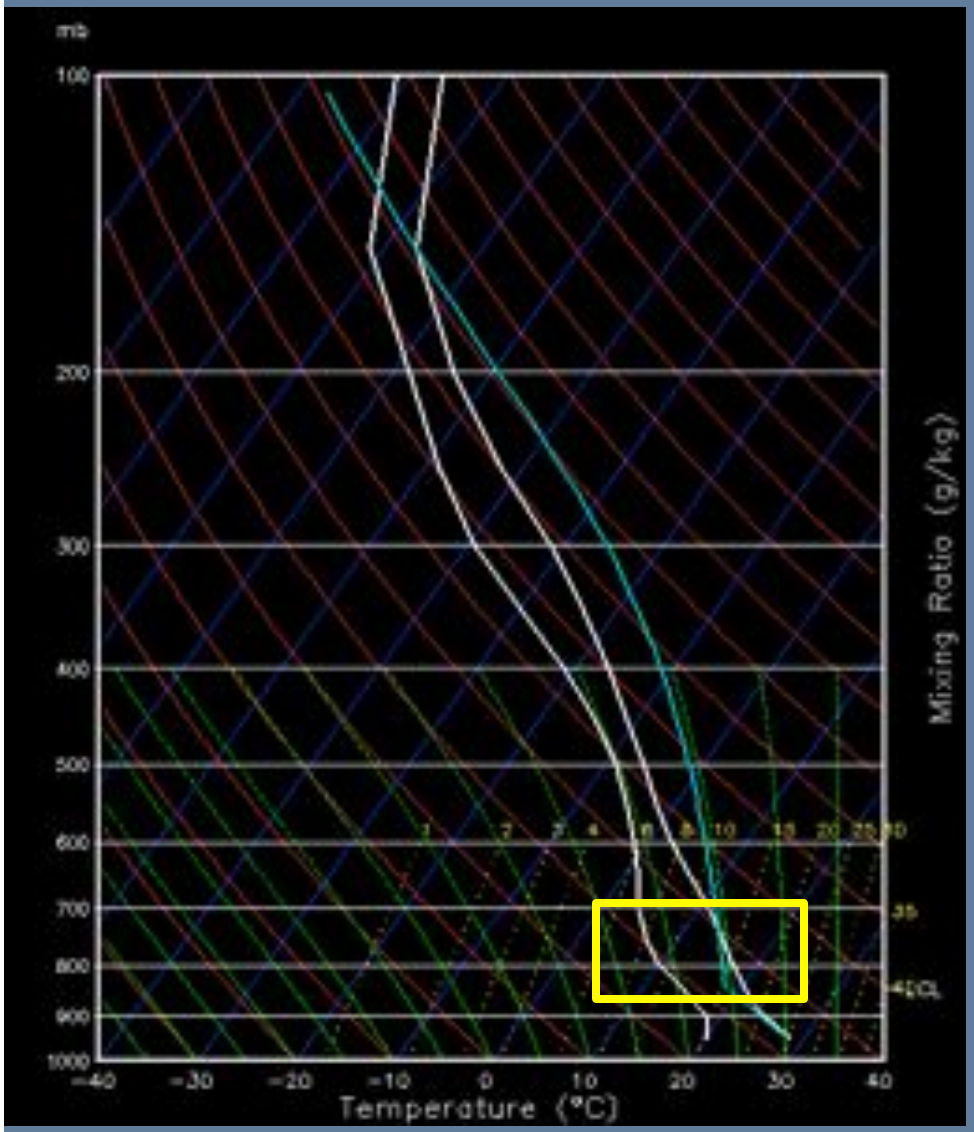
HCS:

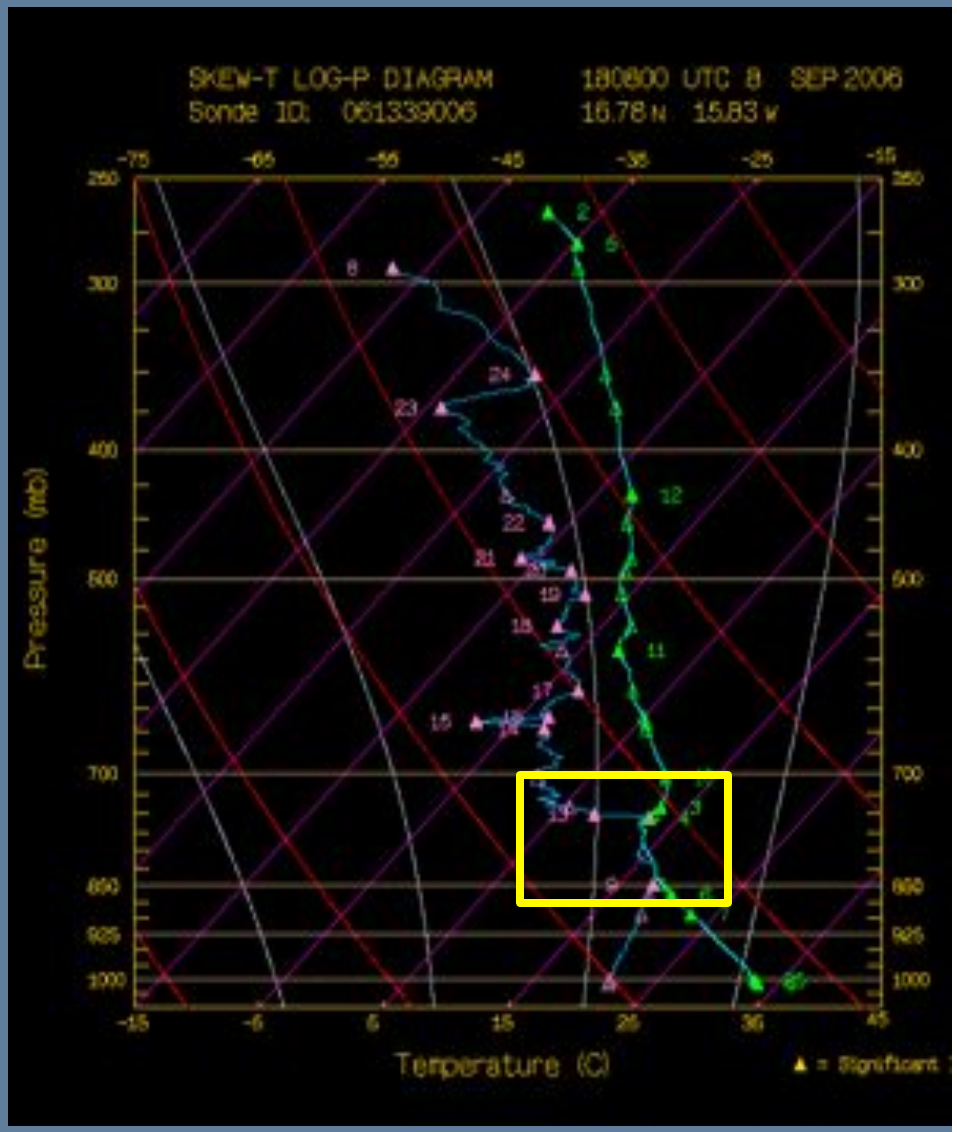
- Well-defined surface cyclonic wind structure (1000 hPa)
- Second closed MSLP isobar (Min <= 1010 hPa)
- Maximum sustained (10 m) winds ranging from 20-33 kt
- Anticyclonic center and wind flow in the mean horizontal shear environment with values ranging from 10 -> 30 kt

- ✓ A constancy in keeping these conditions (i.e. MSW & MSLP graphs intensity trend) along with other favorable environmental factors (i.e. SST) might suggest that further intensification is likely

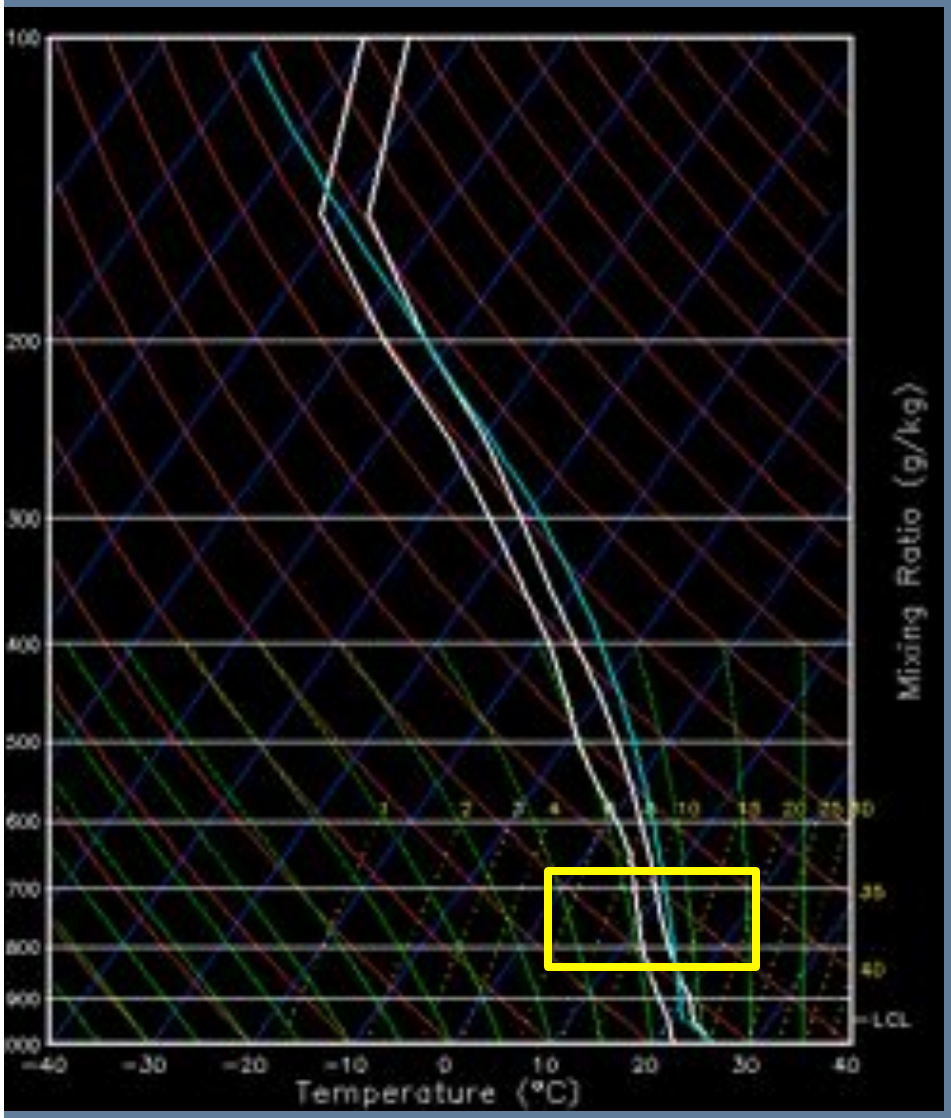
Initial Conditions

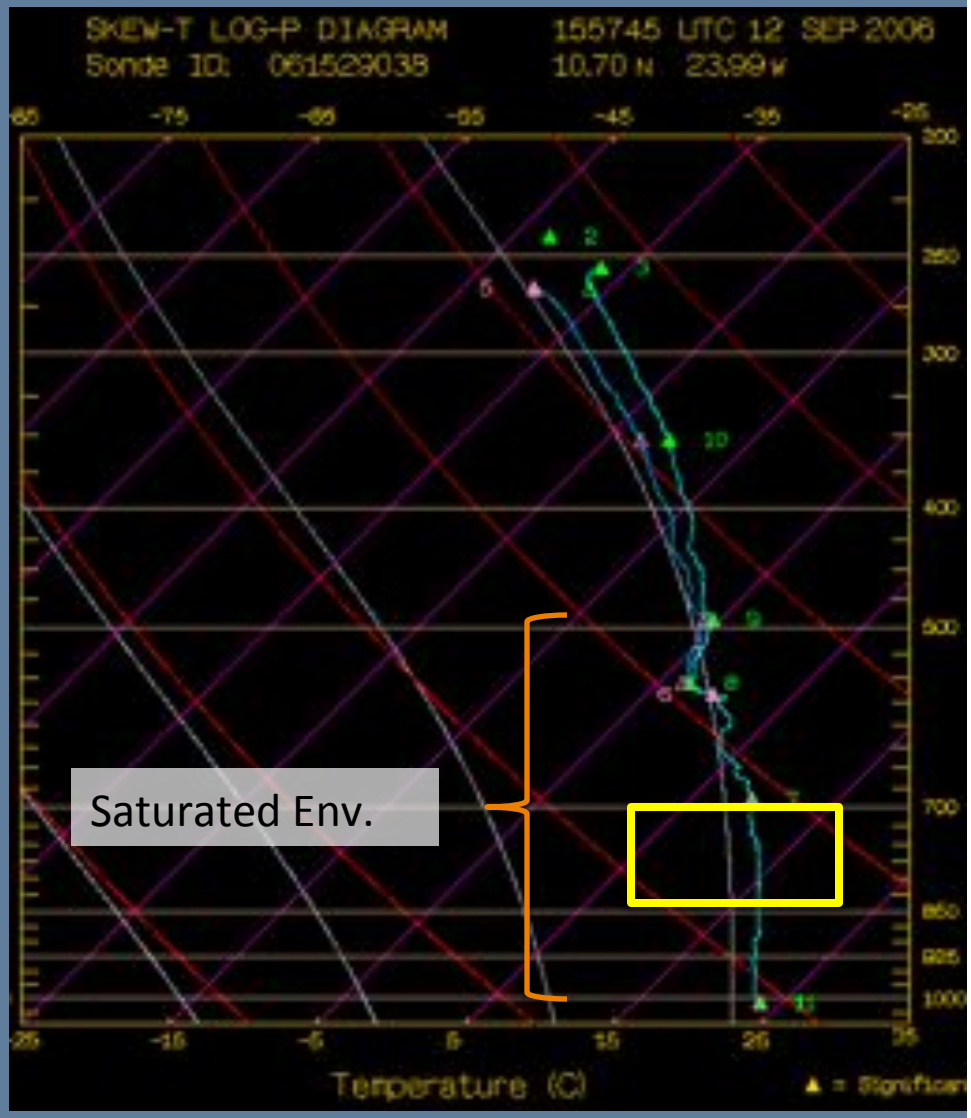
HWRF and Dropsonde soundings: NCU NDAEW R1 Init. Time





HWRF and Dropsonde soundings: NCU HAEW R3 Init. time





Concluding Remarks on Initial Conditions

NDAEW: R1 NCU:

- Dropsonde sounding shows dryer initial conditions below 850 hPa and above 750 hPa
- However, it shows a more moist environment between 850->750 hPa when compared to the model

HAEW: R3 NCU:

- Dropsonde sounding shows an overall more moist environment than the model
- Particularly at this time, a saturated environment is shown by the dropsonde from surface -> ~ 500 hPa

✓ It is expected, that the assimilation of the additional NAMMA dropsonde data have a positive impact:

- Hindering the intensification of the NDAEW (i.e. later in the model run)
- Improving the track and intensity predictions of the HAEW and intensification stages

Acknowledgements


Questions?