Diagnosing Forecast Errors in Tropical Cyclone Motion

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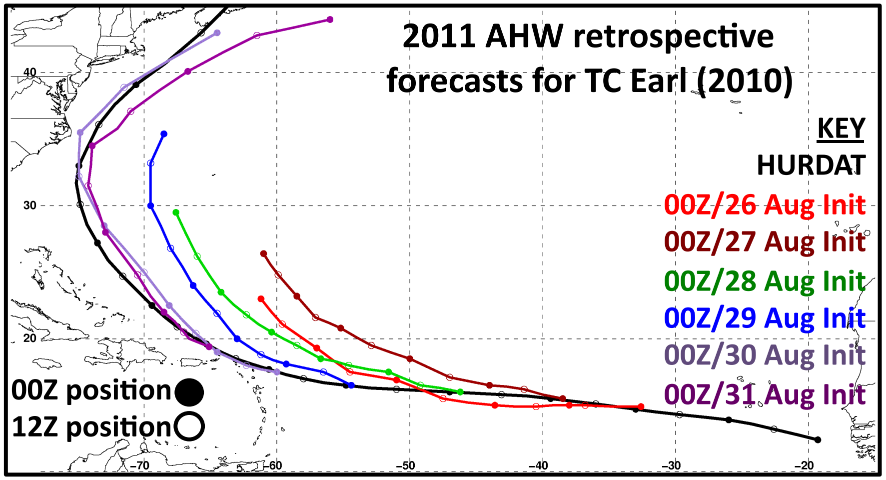
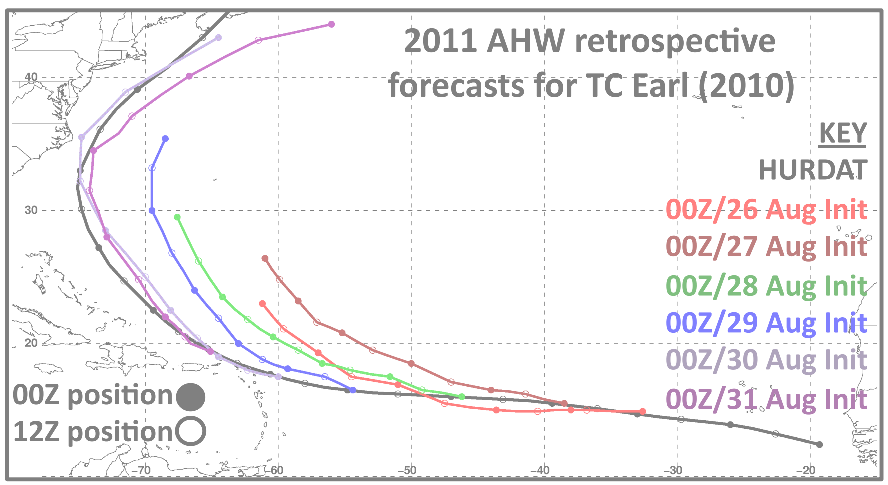


Research support provided by the Hurricane Forecast Improvement Program

NCAR is sponsored by the National Science Foundation

Diagnosing Forecast Errors in Tropical Cyclone Motion

Goal: To develop a diagnostic equation that will quantitatively diagnose forecast errors in tropical cyclone (TC) motion for any NWP model.



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Background

- TC forecast track errors commonly related to wind errors associated with synoptic-scale weather systems nearby the TC
  - e.g., Carr and Elsberry (2000); Brennan and Majumdar (2011)
- TC motion is controlled primarily by the environment wind in the 700–500 mb layer or tropospheric-deep-layer driven by nearby weather systems and the Beta effect
  - e.g., George and Gray (1976); Holland (1983); Fiorino and Elsberry (1989); Velden and Leslie (1991)
- TC motion also influenced by:
  - interaction with landmasses and the underlying ocean (e.g., Bender et al. 1993)
  - balanced motion in response to vertical shear (e.g., Wang and Holland 1996)

Data

- 0.5° Climate Forecast System Reanalysis (Saha et al. 2010)
- NHC Best Track (HURDAT)
- 2011 retrospective Advanced Hurricane WRF (AHW) forecasts (36-km domain only)

Steering Flow Definition

- **The environment wind (v_{env}) is the residual wind that results from the removal of local winds associated with the TC vortex**
  - **Remove all ζ and δ within a radius, *r***

- **The steering flow is the spatially averaged v_{env} that matches the TC motion, and so is a function of v_{env}**

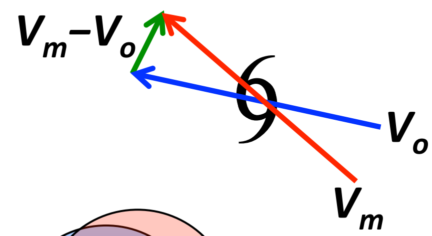
Steering Flow Computation

- **Compute an area-average v_{env} every 50 mb in the 850–200 mb layer using eight different radii ranging from 1°–8° from the TC center**
- **Compute the pressure-weighted vertical average v_{env} for layers of increasing depth**
  - **shallowest layer of 850–800 mb**
  - **deepest layer of 850–200 mb**
- **Select the steering flow depth and radius combination that best matches TC motion**
  - **minimize steering layer residual error**

TC Motion Error Diagnostic

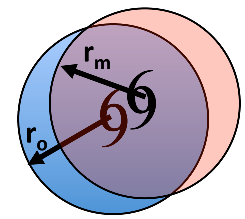
$$\vec{v}_o(p) = \frac{1}{\pi r_o^2}\int_0^{2\pi}\int_0^{r_o} \vec{v}_{obs}(x,y,p)\,r\,dr$$

area-average observed v_{env}
observed radius



$$\vec{v}_m(p) = \frac{1}{\pi r_m^2}\int_0^{2\pi}\int_0^{r_m} \vec{v}_{ahw}(x,y,p)\,r\,dr$$

area-average AHW v_{env}
AHW radius



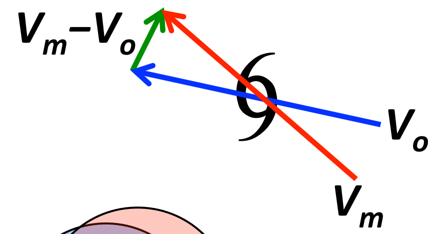
$$\hat{\vec{v}}_m(p) = \frac{1}{\pi r_o^2}\int_0^{2\pi}\int_0^{r_o} \vec{v}_{ahw}(x,y,p)\,r\,dr$$

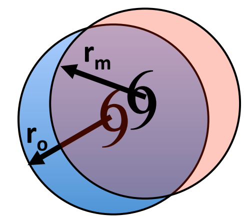
area-average AHW v_{env}
observed radius

$$\underbrace{\vec{V}_o}_{\text{observed storm motion}} = \underbrace{\frac{1}{p_b - p_{to}}\int_{p_{to}}^{p_b} \vec{v}_o(p)\,dp}_{\text{observed optimal steering flow}} + steering\ residual$$

$$\underbrace{\vec{V}_m}_{\text{AHW storm motion}} = \underbrace{\frac{1}{p_b - p_{tm}}\int_{p_{tm}}^{p_b} \vec{v}_m(p)\,dp}_{\text{AHW optimal steering flow}} + steering\ residual$$

TC Motion Error Diagnostic





$$\underbrace{\vec{V}_m - \vec{V}_o}_{storm\ \ motion\ \ error} = \underbrace{\frac{1}{p_b - p_{to}}\int_{p_{to}}^{p_b}\left(\hat{\vec{v}}_m - \vec{v}_o\right)dp}_{environment\ \ wind\ \ error} + \underbrace{\frac{1}{p_b - p_{tm}}\int_{p_{tm}}^{p_b} -\left(\hat{\vec{v}}_m - \vec{v}_m\right)dp}_{TC\ \ removal\ \ radius\ \ error}$$

storm motion error

v_{env} error

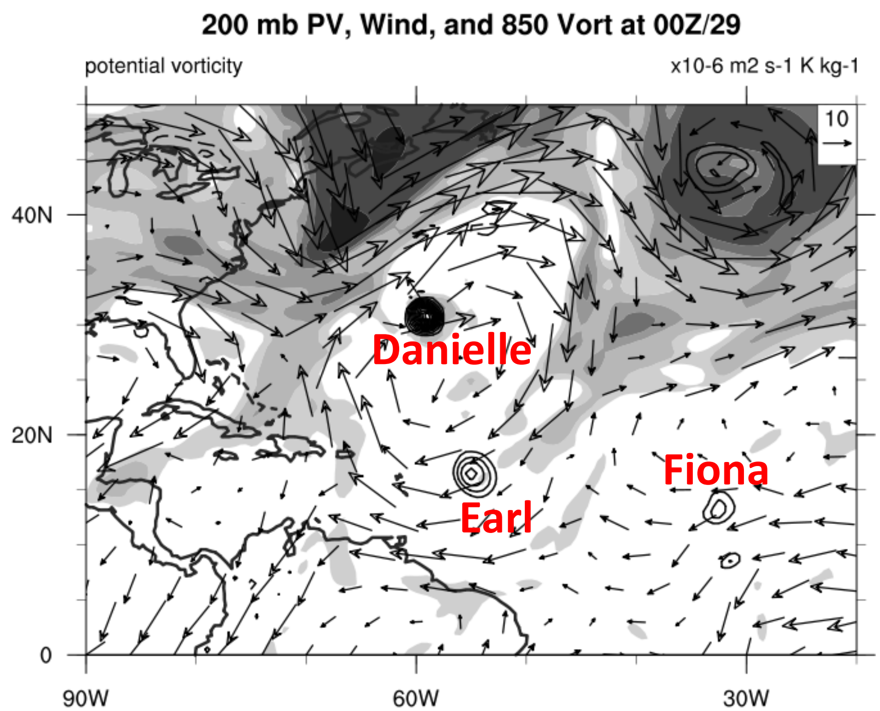
radius error

$$\underbrace{+\frac{1}{p_b - p_{tm}}\left[\int_{p_{to}}^{p_b}\left(\frac{p_{tm} - p_{to}}{p_b - p_{to}}\right)\hat{\vec{v}}_m dp + \int_{p_{tm}}^{p_{to}}\hat{\vec{v}}_m dp\right]}_{TC\ \ steering\ \ depth\ \ error} + residual\ term$$

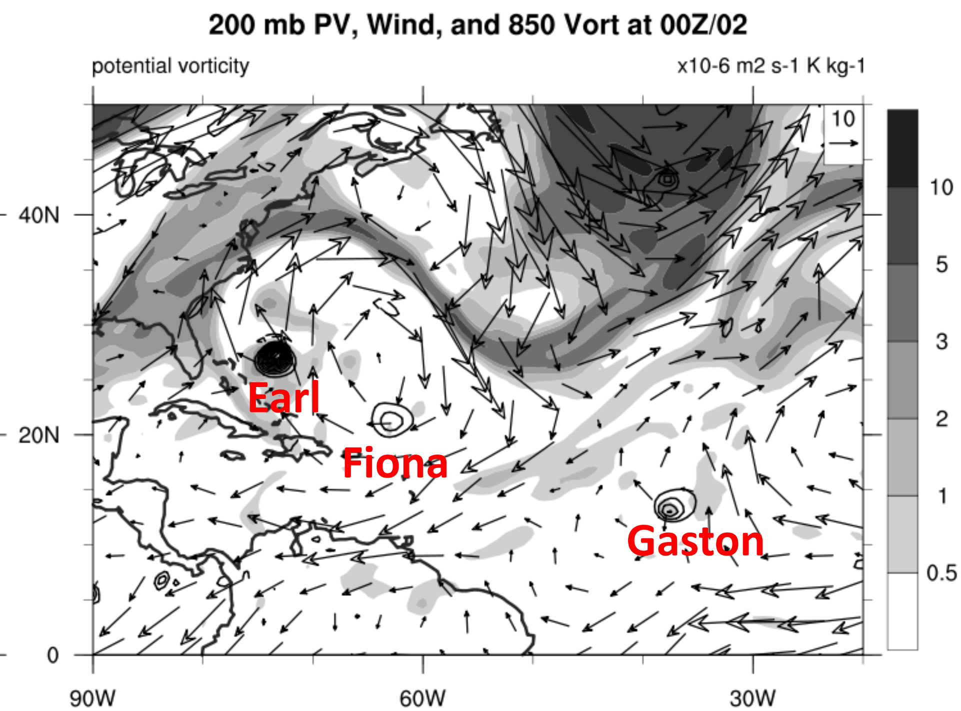
depth error

Synoptic Overview

200 mb PV (shaded in PVU), wind (arrows in m s^{-1}), and 850 mb ζ (contours every 8.0×10^{-5} s^{-1})



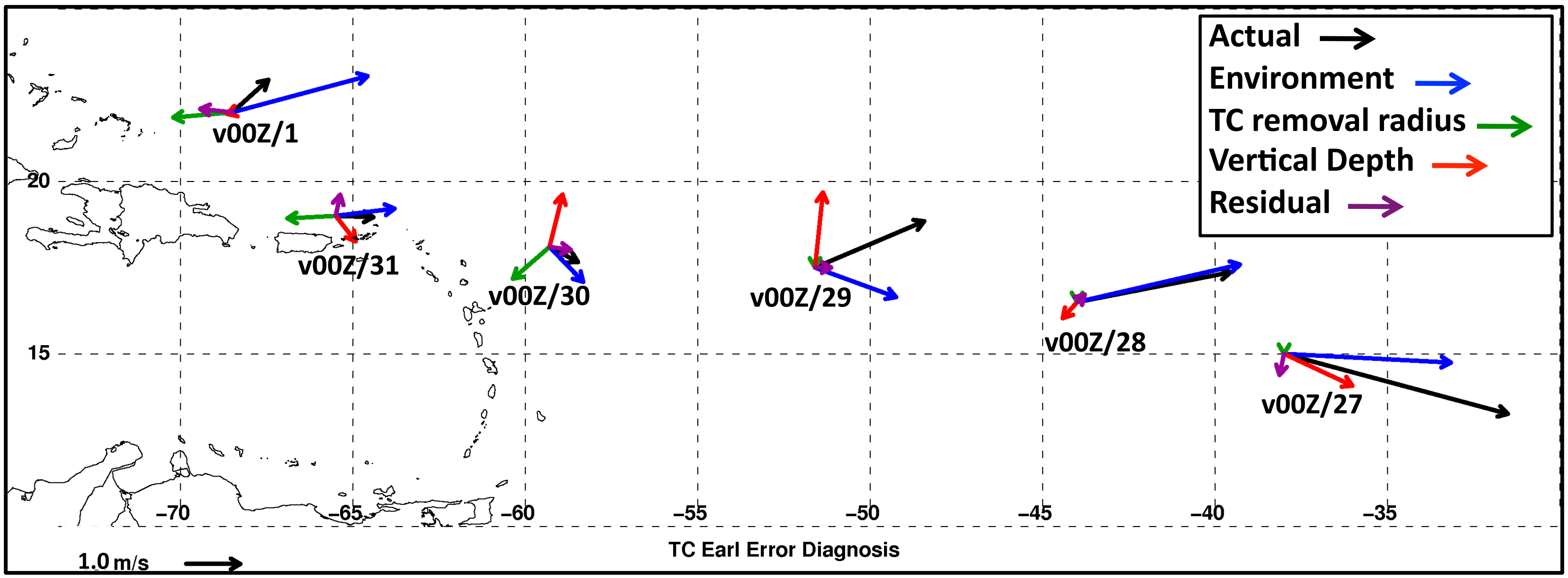
0000 UTC 29 August 2010



0000 UTC 2 September 2010

Motion Error Diagnosis: TC Earl

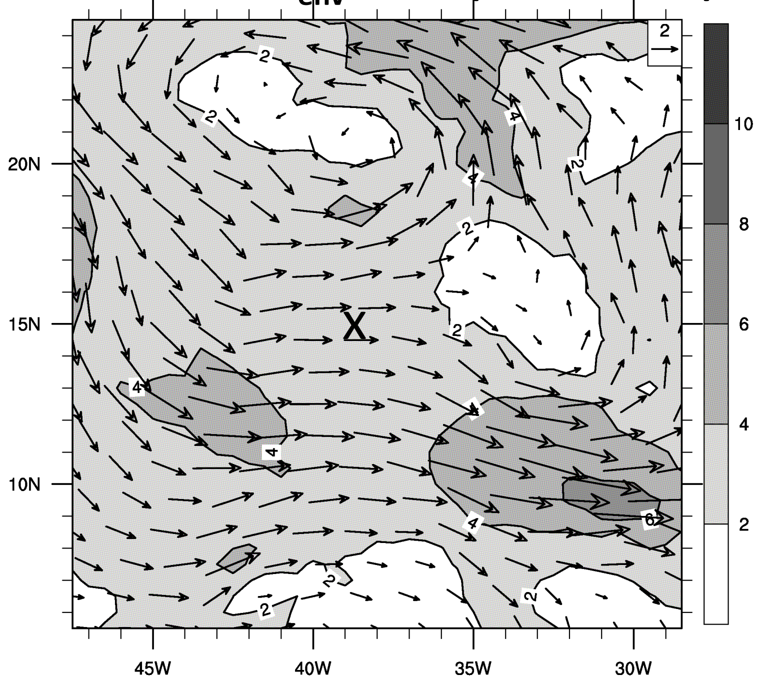
24-h AHW Forecasts
Verifying 0000 UTC 27 Aug–1 Sep 2010



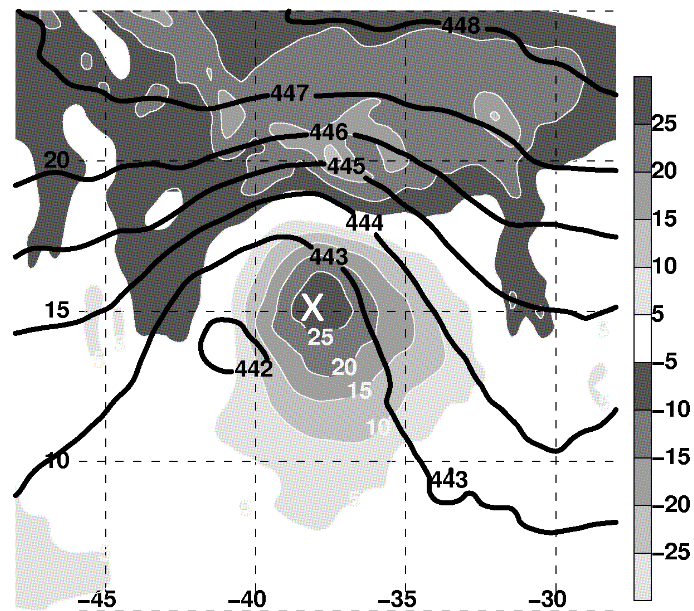
- v_{env} error is largest contributor to motion error overall
- Depth and radius error terms can be large at individual times

v_{env} Error for AHW 24-h Forecast verifying at 0000 UTC 27 Aug

850–450 mb v_{env} error (AHW–CFSR)



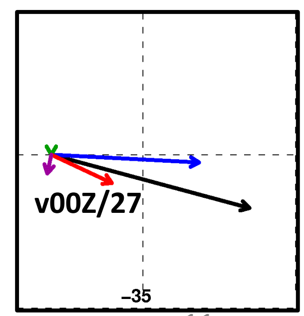
600 mb Z and Z error (AHW–CFSR)



AHW 24–h Fcst 600 HGT and Error at 100827/0000F000

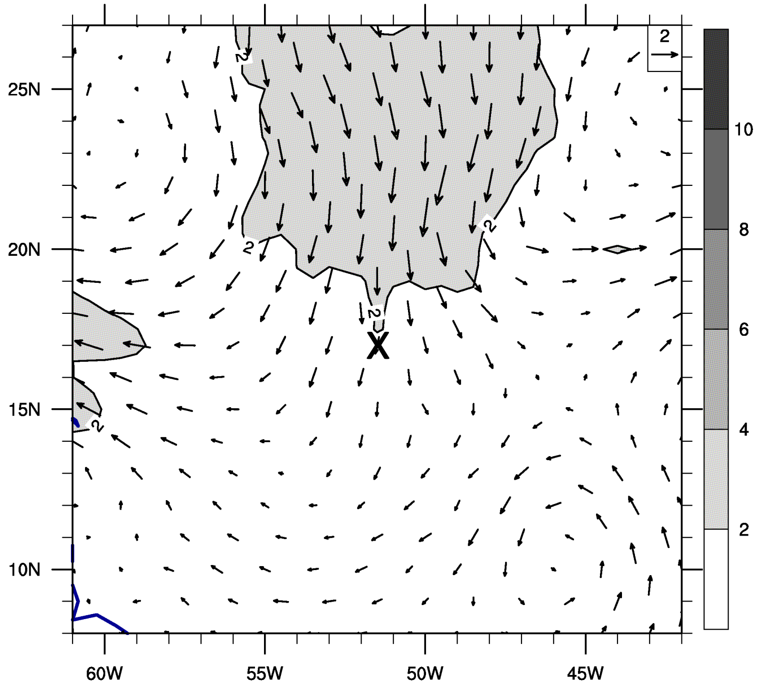
- v_{env} error in conjunction with weak subtropical ridge in AHW

$$\underbrace{\frac{1}{p_b - p_{to}} \int_{p_{to}}^{p_b} \left(\hat{\vec{v}}_m - \vec{v}_o \right) dp}_{environment\ wind\ error}$$

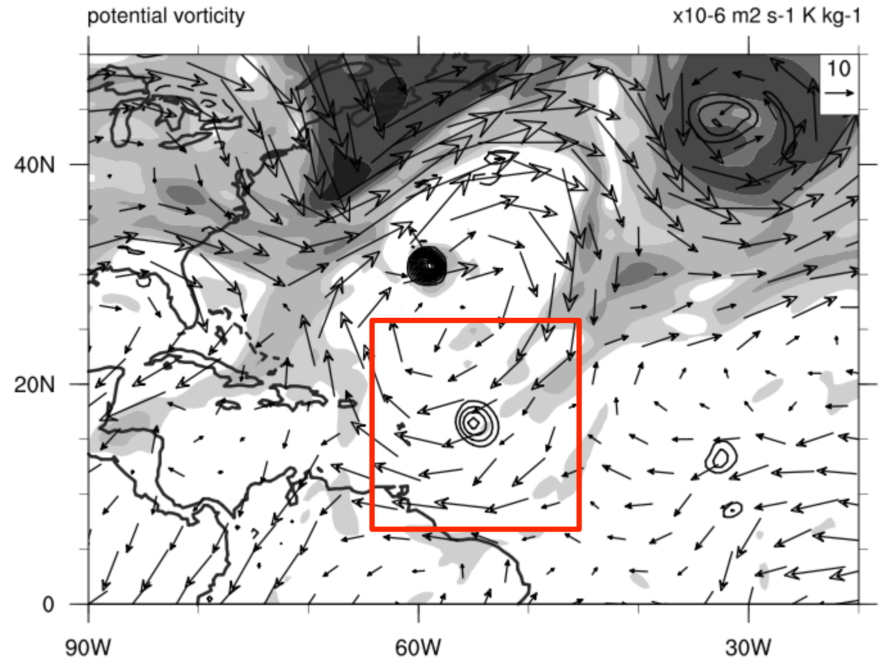


Depth Error for AHW 24-h Forecast verifying at 0000 UTC 29 Aug

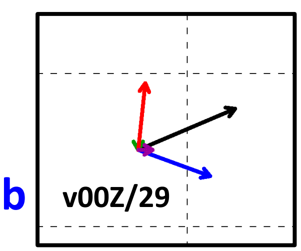
AHW Depth Perturbation Wind



200 mb PV, Wind, and 850 Vort at 00Z/29 (CFSR)



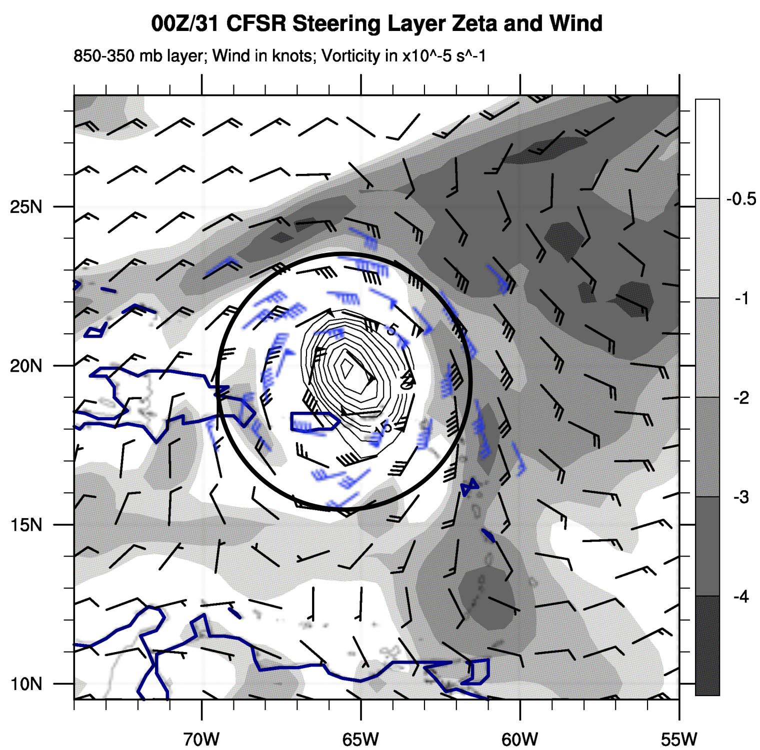
$$\underbrace{\frac{1}{p_b - p_{tm}}\left[\int_{p_{to}}^{p_b}\left(\frac{p_{tm}-p_{to}}{p_b-p_{to}}\right)\hat{\hat{v}}_m\,dp + \int_{p_{tm}}^{p_{to}}\hat{\hat{v}}_m\,dp\right]}_{TC\ steering\ depth\ error}$$

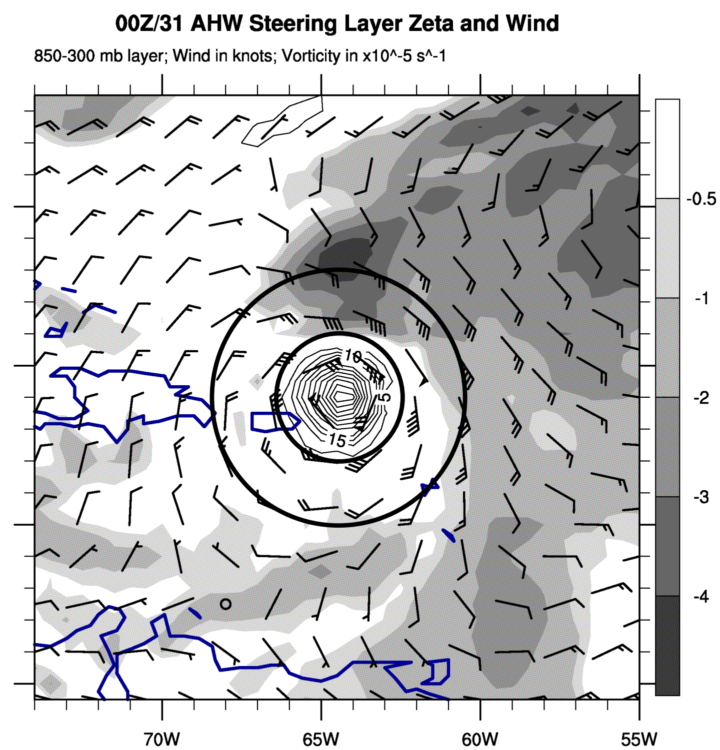


- **Depth error in conjunction with shallower steering layer in AHW; weaker/shallower vortex**

Observed depth 850–200 mb
AHW depth 850–350 mb

Radius Error for AHW 24-h Forecast verifying at 0000 UTC 31 Aug

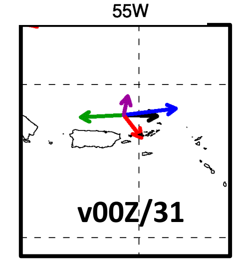




- **Radius error in conjunction with near-vortex asymmetries in AHW**

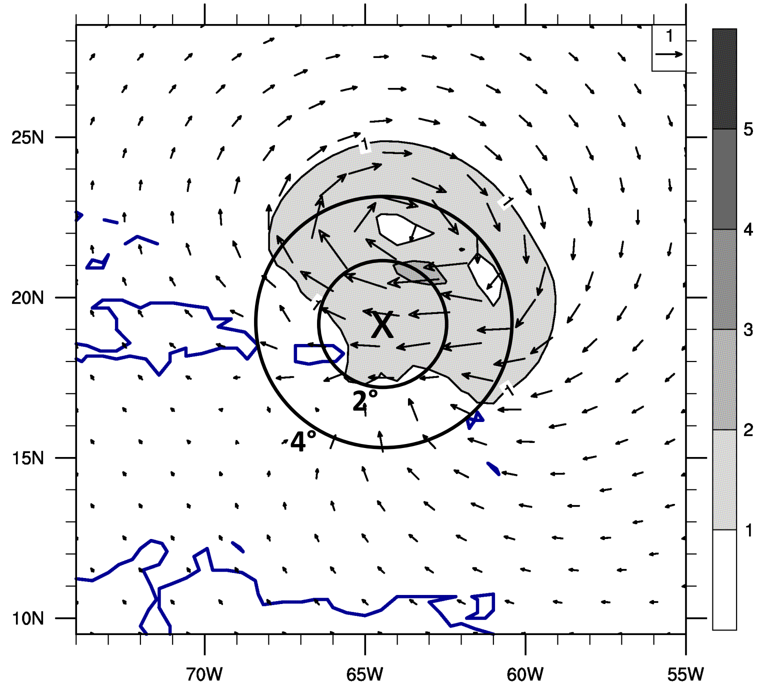
$$\underbrace{\frac{1}{p_b - p_{tm}} \int_{p_{tm}}^{p_b} -\left(\hat{\vec{v}}_m - \vec{v}_m\right) dp}_{TC\ removal\ radius\ error}$$

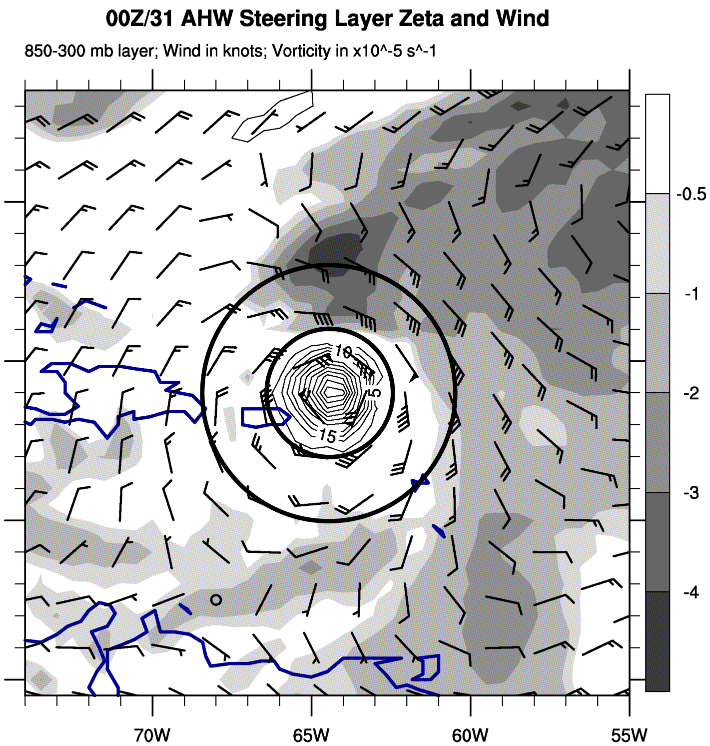
Observed radius 4°
AHW radius 2°



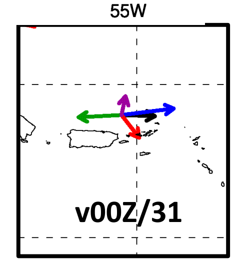
Radius Error for AHW 24-h Forecast verifying at 0000 UTC 31 Aug

AHW 850–300 mb Radius Perturbation Wind





$$\underbrace{\frac{1}{p_b - p_{tm}} \int_{p_{tm}}^{p_b} -\left(\hat{\vec{v}}_m - \vec{v}_m\right) dp}_{TC\ removal\ radius\ error}$$



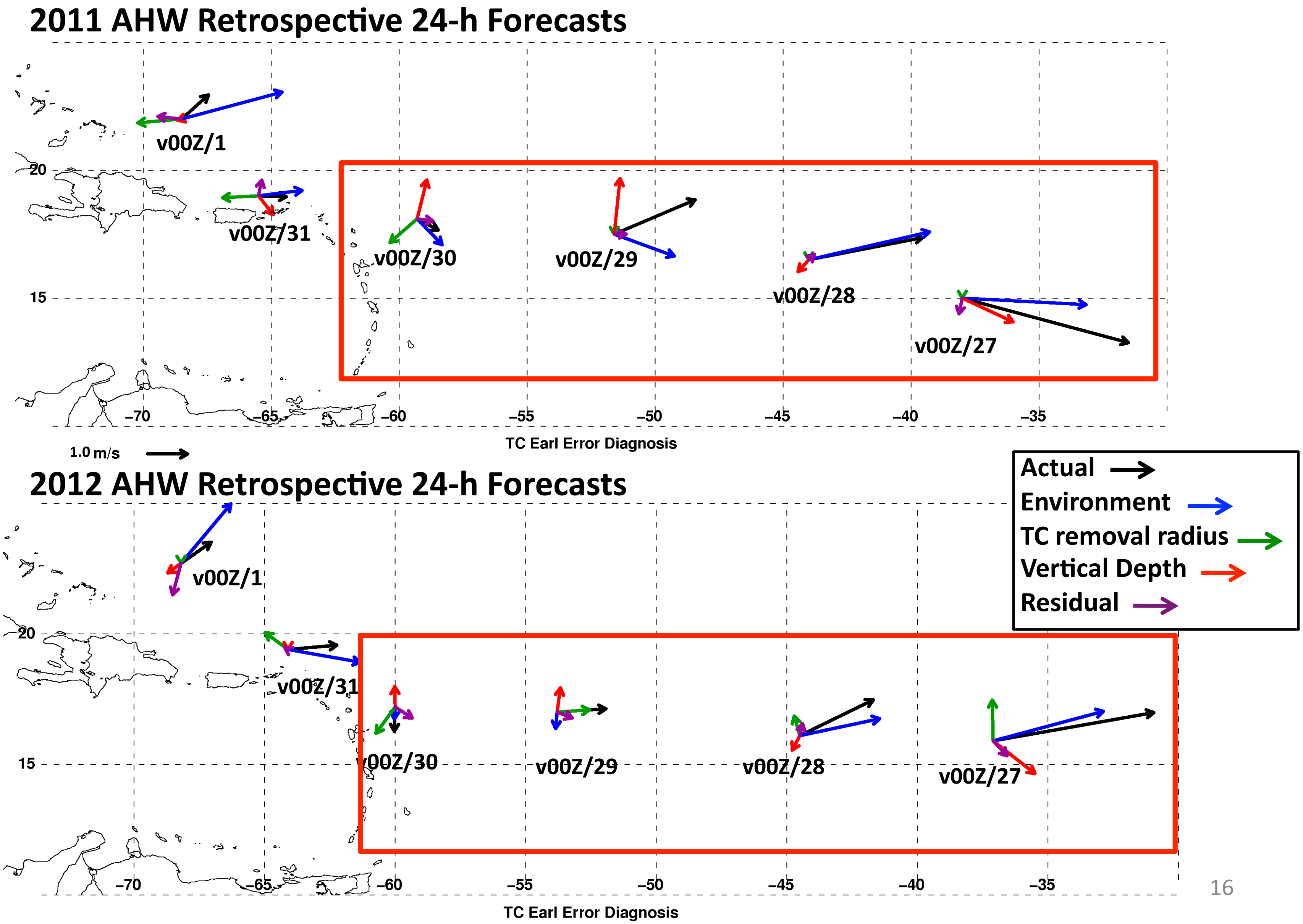
- **Radius error in conjunction with near-vortex asymmetries in AHW**

Observed radius 4°
AHW radius 2°

Concluding Remarks

- **We developed a method for computing steering layer flow and diagnosing TC motion errors in any NWP model**
- **The diagnostic equation allows quantification of the intersection between TC structure and position errors**
- **Analysis of AHW forecasts for TC Earl (2010) show that:**
  - **v_{env} errors are the largest contributor to TC motion errors overall -> Linked to subtropical ridge errors**
  - **Other terms can be large for individual forecasts**

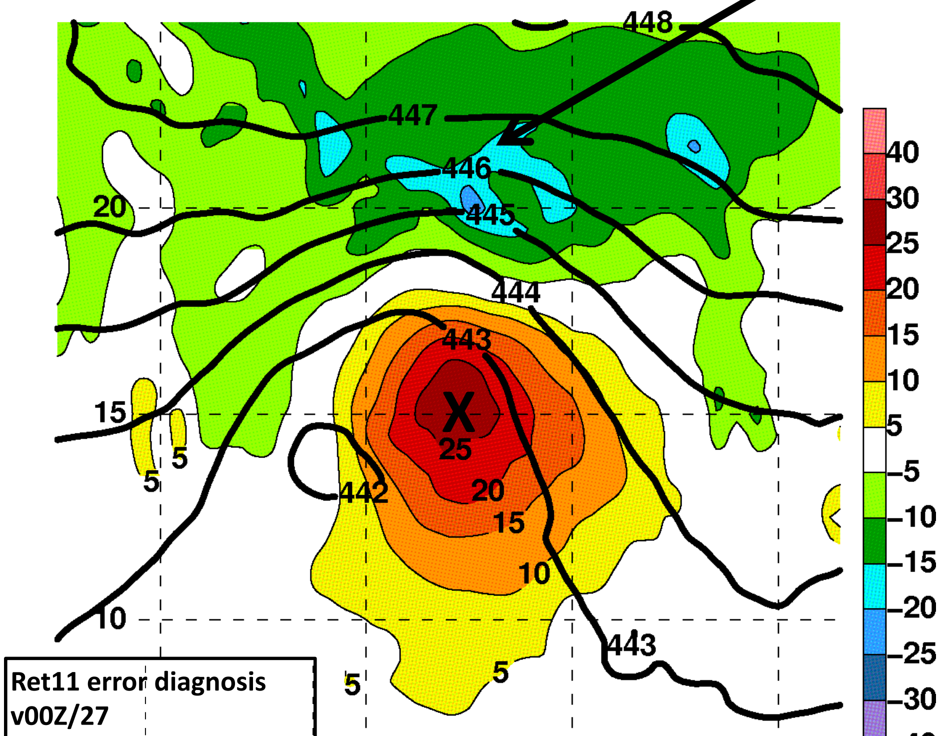
TC Earl (2010) Motion Error Diagnosis

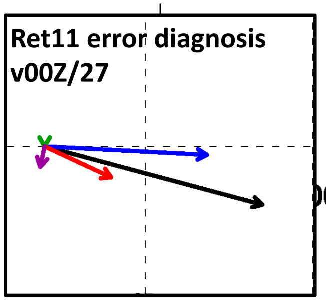


TC Earl (2010) 600 mb Z Error

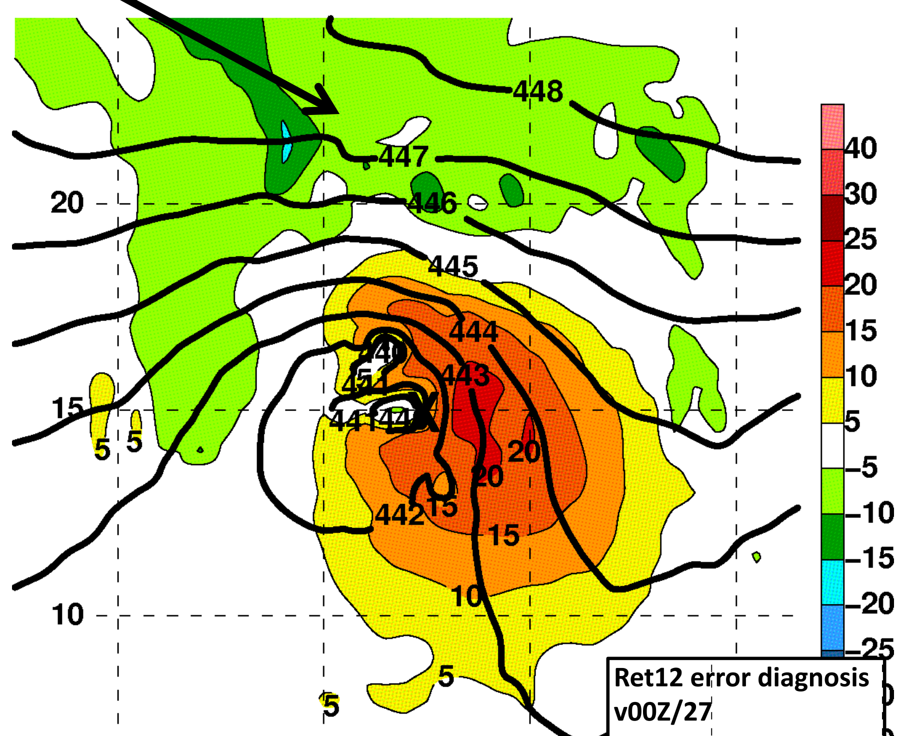
Subtropical ridge problem not as prominent in retro12

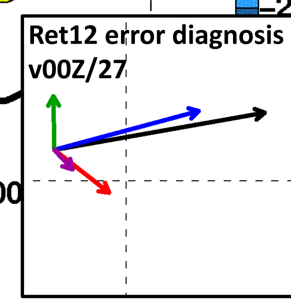
2011 AHW Retrospective





2012 AHW Retrospective



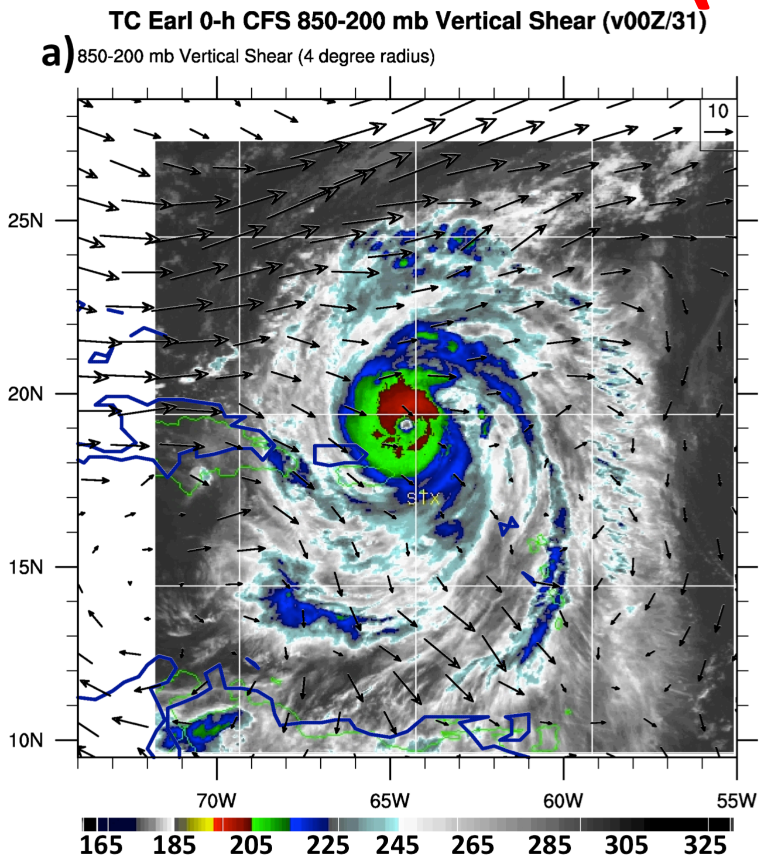


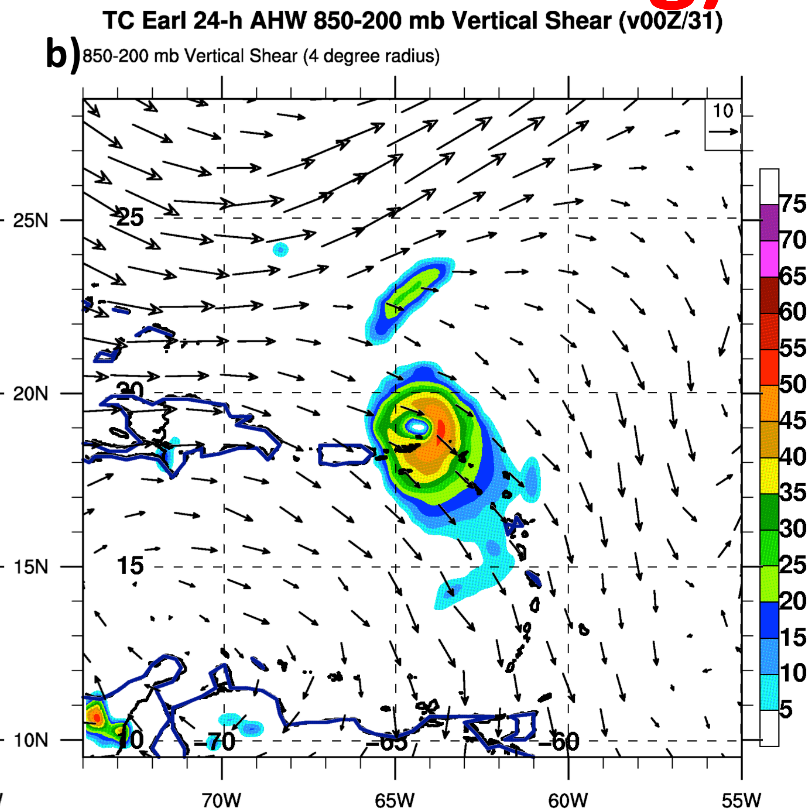
Inclusion of aerosols (not shown) in retro12 forecasts contributed to improvements of subtropical ridge structure and reduced environment wind errors

24-h AHW Forecast verifying at 0000 UTC 27 August 2010

Extra slides

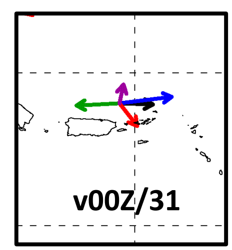
Errors Associated with Convection in Vertical Shear (0000 UTC 31 Aug)



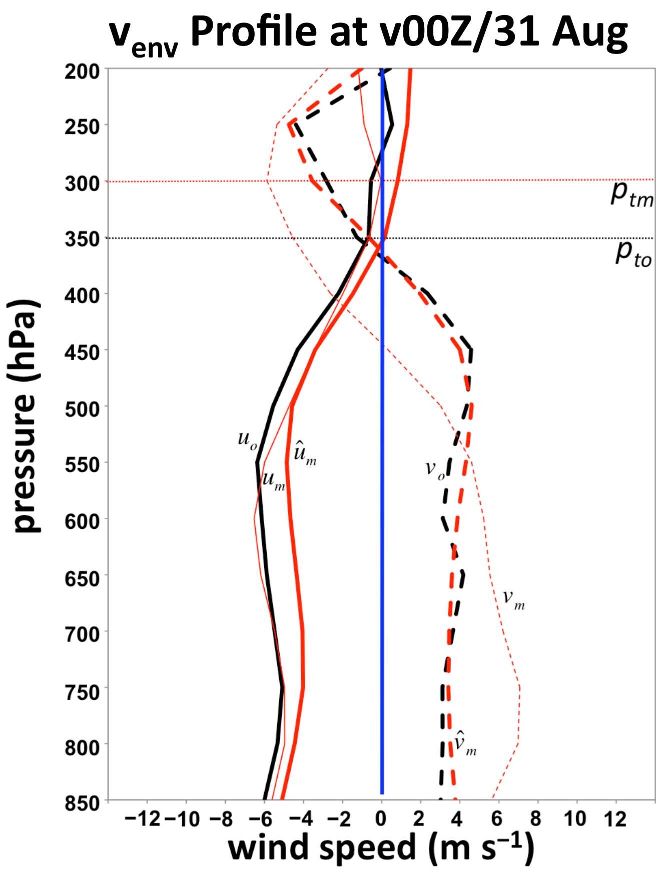


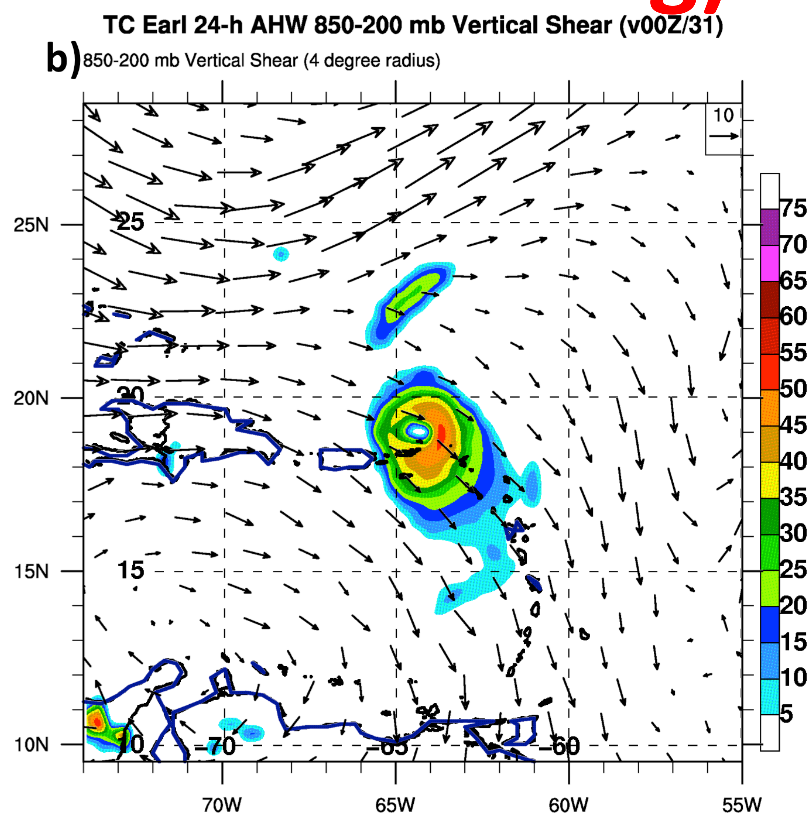
- **Convection more asymmetric in AHW in conjunction with stronger vertical shear**

Observed depth 850–350 mb
AHW depth 850–300 mb



Errors Associated with Convection in Vertical Shear (0000 UTC 31 Aug)





- **Algorithm will attempt to find steering layer that best matches TC motion influenced by convection; can result in steering depth error**

Observed depth 850–350 mb
AHW depth 850–300 mb