4DVar Data Assimilation of Airborne Doppler Radar Winds in Hurricane Ike (2008)

Ronald Gordon* and Shuyi S. Chen

Rosenstiel School of Marine Atmospheric Science
University of Miami

(The 11th WRF Users Workshop, 22-24 June 2010)

Thanks to: Drs. Hans Huang, Hongli Wang, Xin Zhang of MMM/NCAR

***Supported by Advanced Study Program (ASP) NCAR**

Motivation

- One of most challenging problems in forecasting hurricane intensity is model initial condition of storm structure in inner core region

Objectives

- To improve model initial condition in hurricane inner core by assimilating airborne Doppler radar 3D wind fields using WRF 4DVar
- To examine the impact of assimilating the inner core wind data on hurricane forecasts

MODEL

- WRFDA Version 3.1.1
- WRFPLUS (Adjoint + Tangent Linear models)
- WRFNL (ARW dynamics, simple PBL, WSM5 microphysics, Kain-Fritch cumulus)

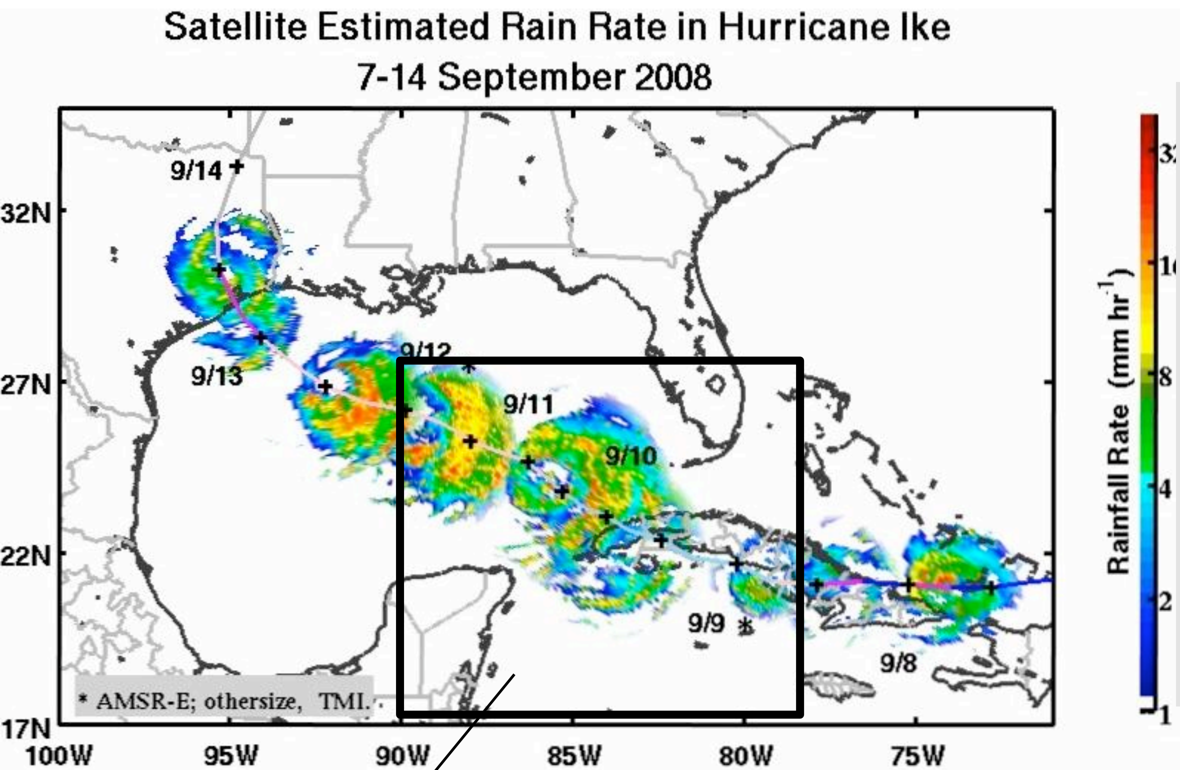
DATA

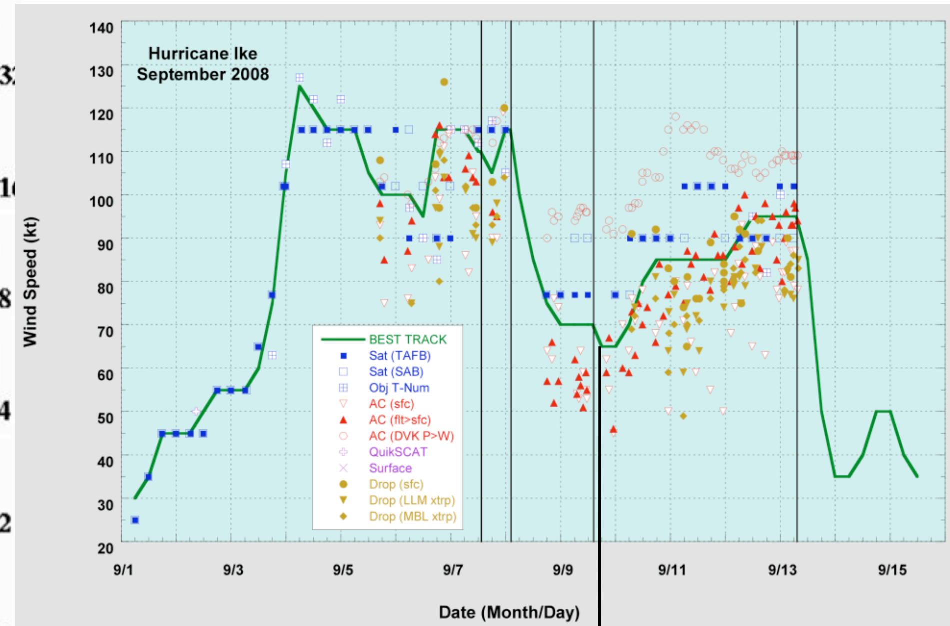
- GFS analysis as initial and lateral boundary conditions for WRF
- NOAA P3 airborne Doppler radar 3D wind field

4DVar (covariance)

- NCEP global climatological background error
- Airborne Doppler radar data ingested as pilots obs and observation error assigned from lookup table obtained from NCEP

Hurricane Ike (2008)





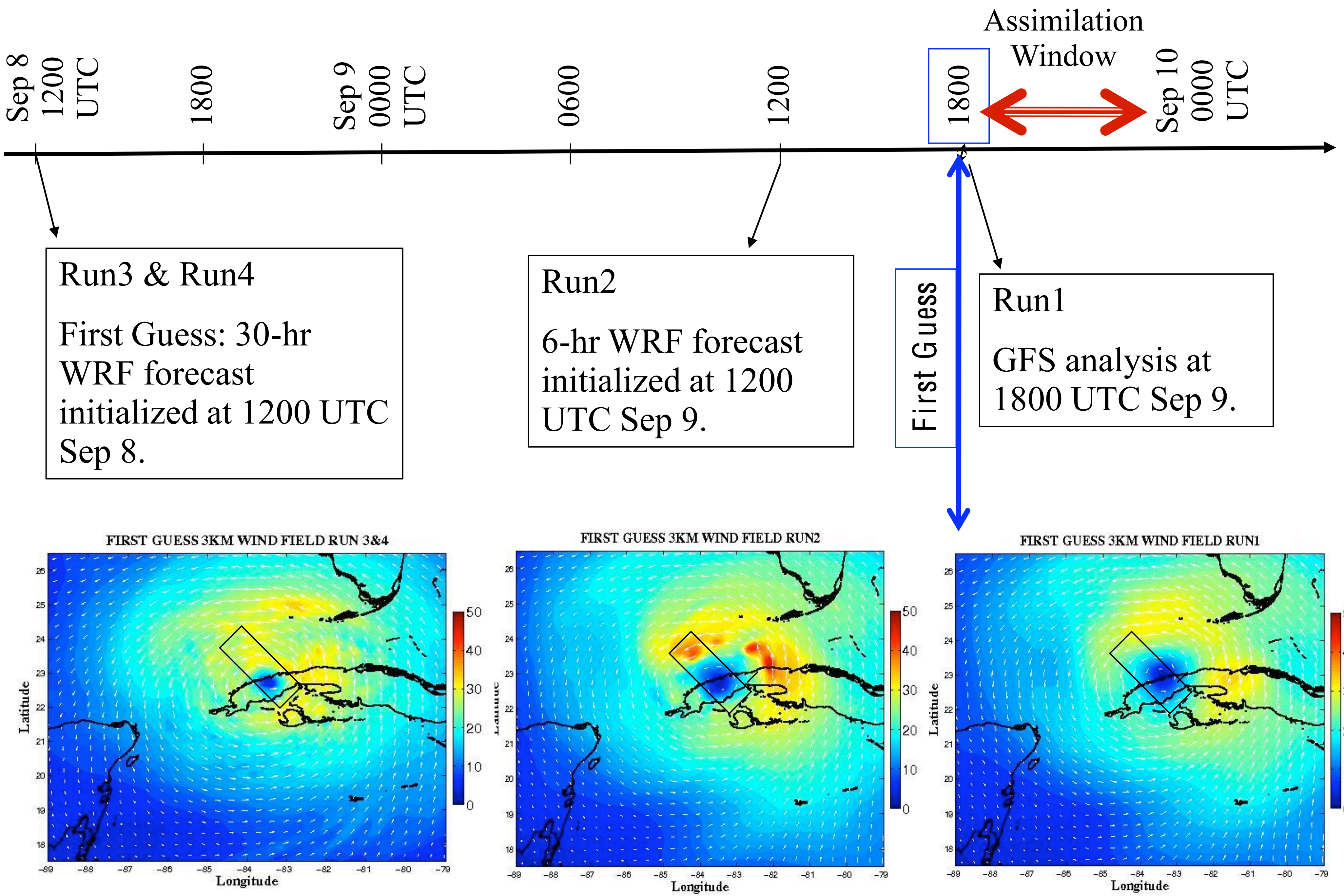
- Domain: 100x100
- 12-km grid spacing
- Vertical levels: 42 & 36

Best Track data at 1800 Sept 09

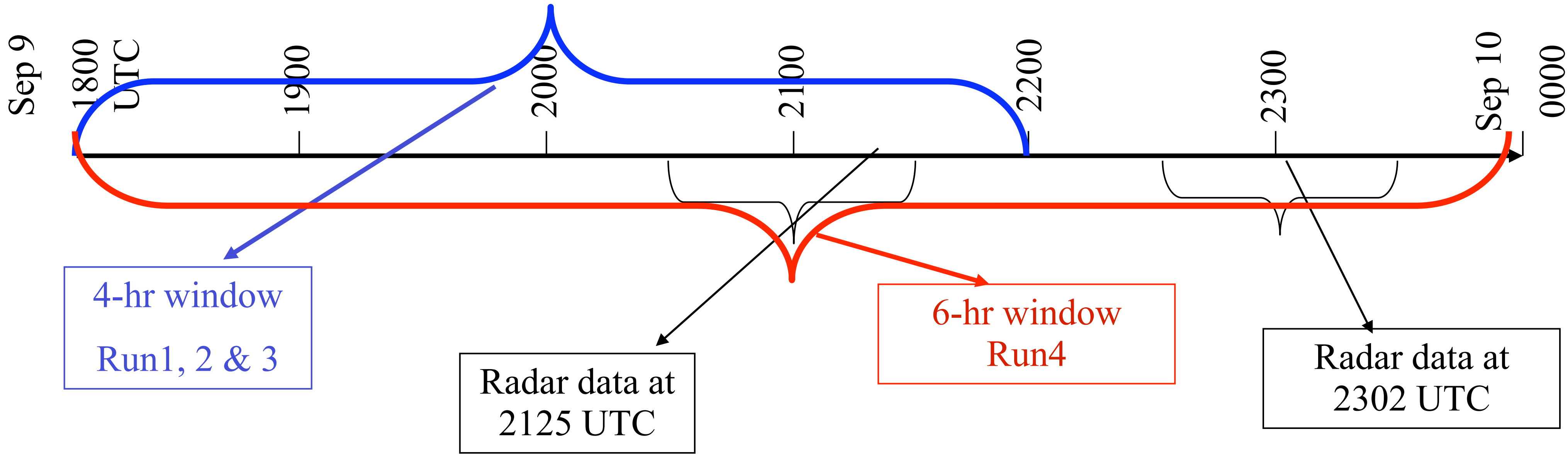
MSLP: 966 hPa

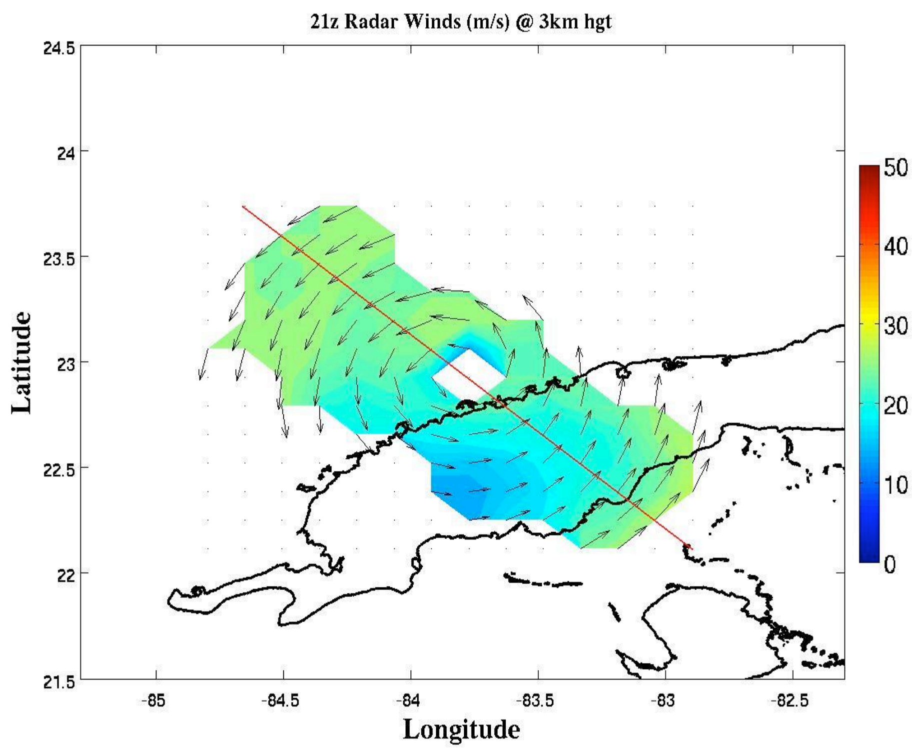
MaxWindSpeed: 65kts (33.4 m/s)

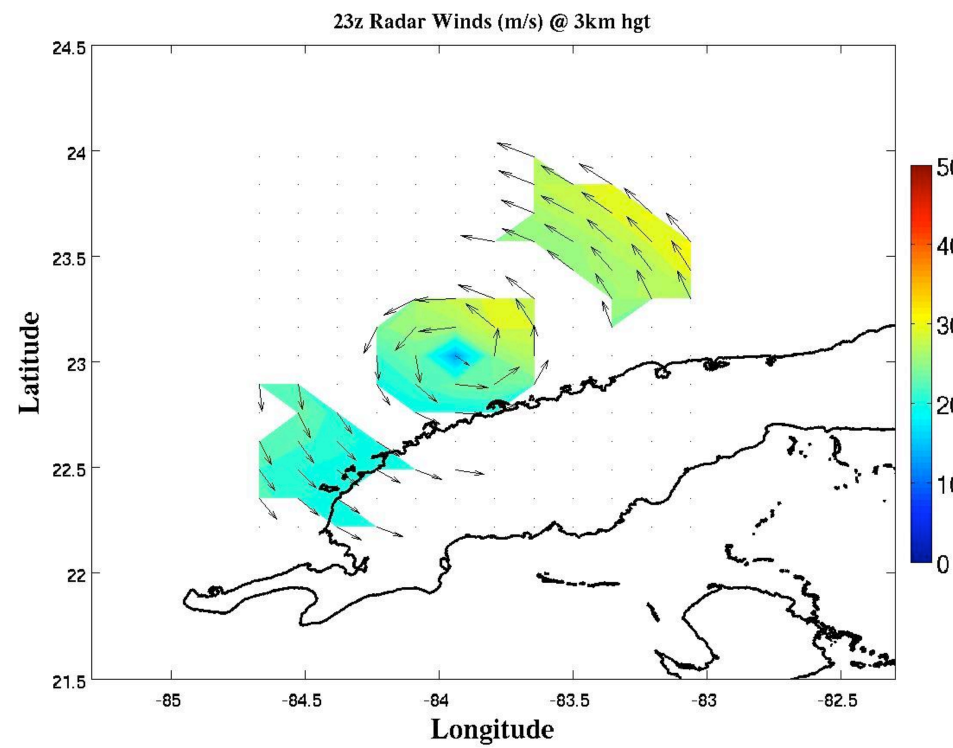
Time Flow Chart



4DVar Assimilation Window







4DVAR

Minimizing cost function:

$$J(\mathbf{x}) = \frac{1}{2}(\mathbf{x}_0 - \mathbf{x}^b)^T \mathbf{B}^{-1}(\mathbf{x}_0 - \mathbf{x}^b) + J_x$$
$$+ \frac{1}{2}\sum_{k=0}^{K}[\mathbf{h}(\mathbf{x}_k) - \mathbf{y}_k]^T \mathbf{R}_k^{-1}[\mathbf{h}(\mathbf{x}_k) - \mathbf{y}_k]$$

Where:

- $x \equiv [x_0, x_1, \ldots, x_k]$, x_0 = initial first guess, x_1, x_2, …x_6 = first guess propagated by

non-linear model (WRFNL)

- $y_0, y_1, \ldots y_k$ = observations at different time slots (k=4 and 6 in this case)

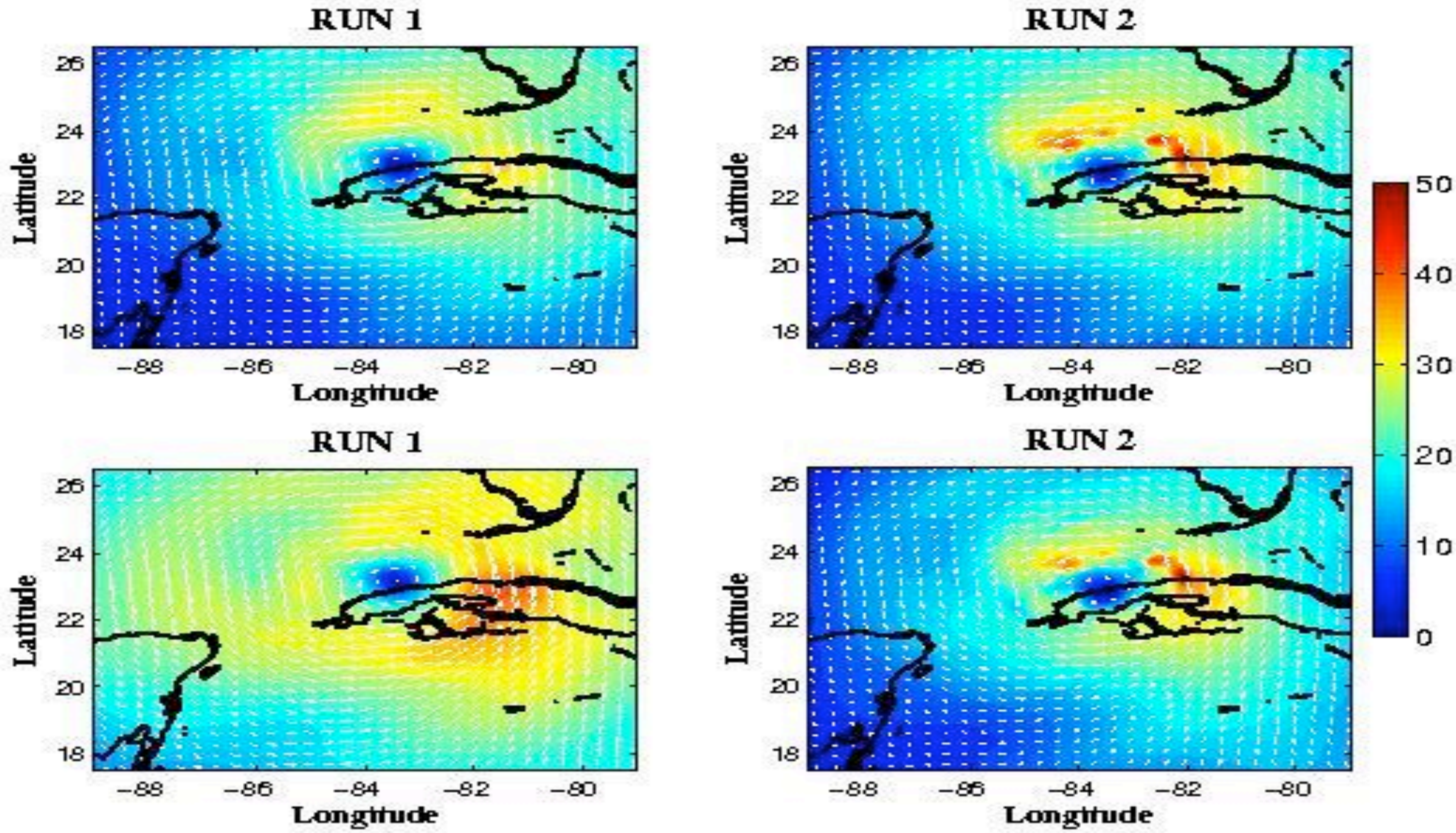
So in this case we had y_3 = 2100 UTC obs and y_5= 2300UTC obs

- B and R_k , background and observation error covariance, respectively
- h, non-linear observation operator
- J_x , extra constrains (not used in these experiments)

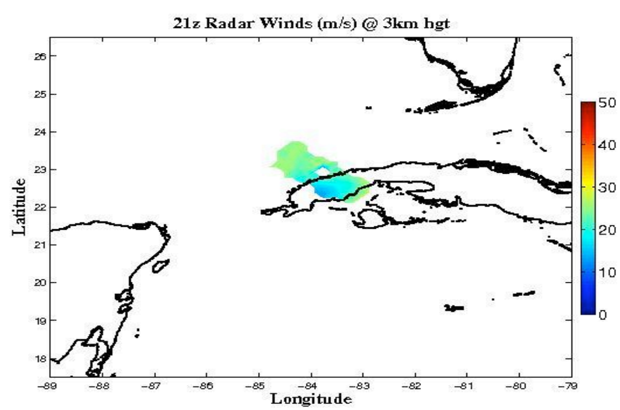
3-km level winds (m/s) at 1800 UTC Sep 9

First Guess

4Dvar



Radar Obs

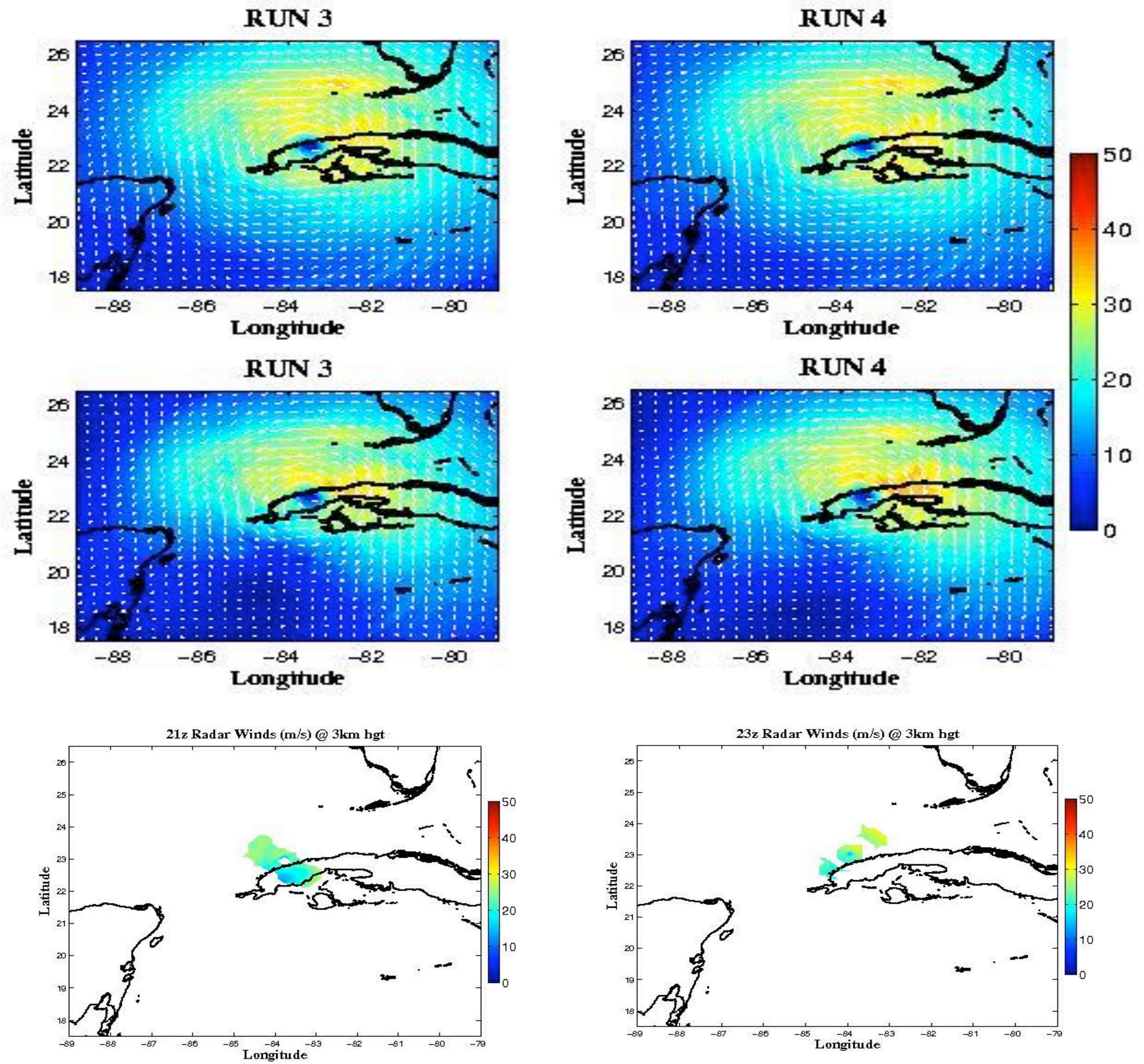


3-km level winds (m/s) at 1800 UTC Sep 9

First Guess

4Dvar

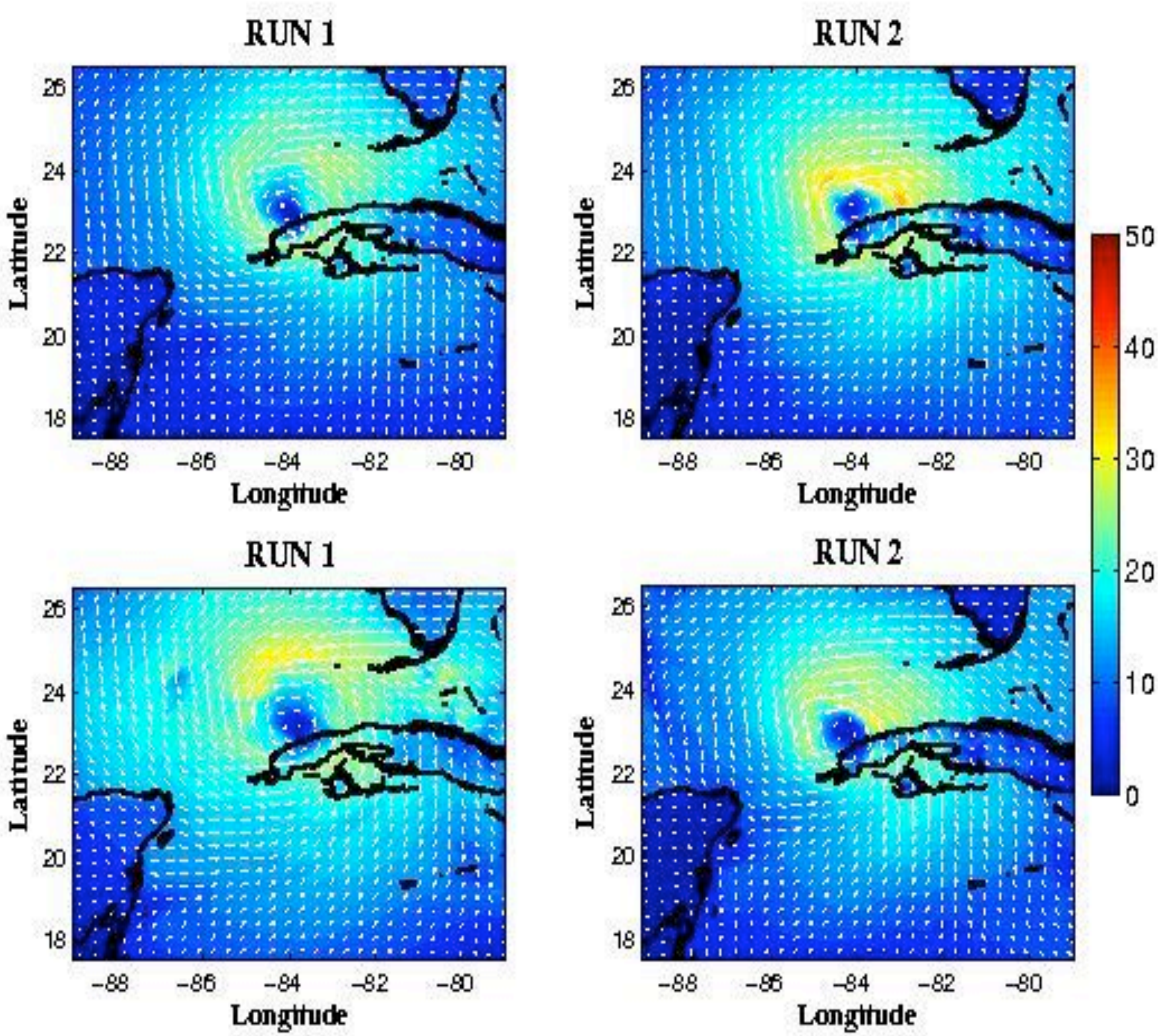
Radar Obs



Result: 5-hr Forecast 10-m Winds (m/s) valid at 2300 UTC Sep 9

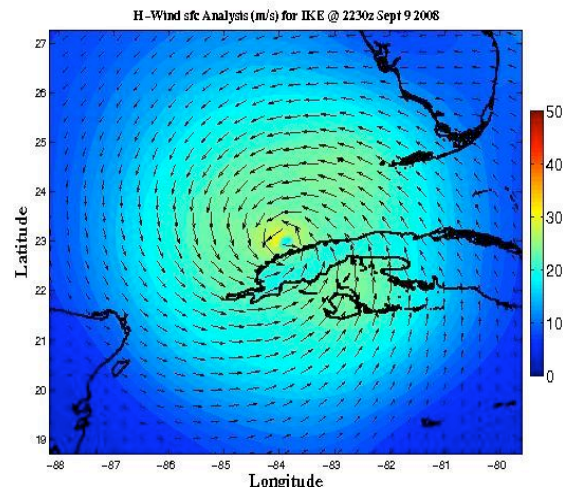
First Guess

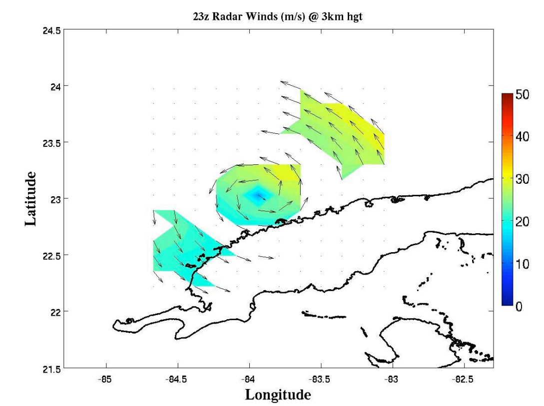
4dvar



Obs

H*Wind Analysis @ 2230 UTC





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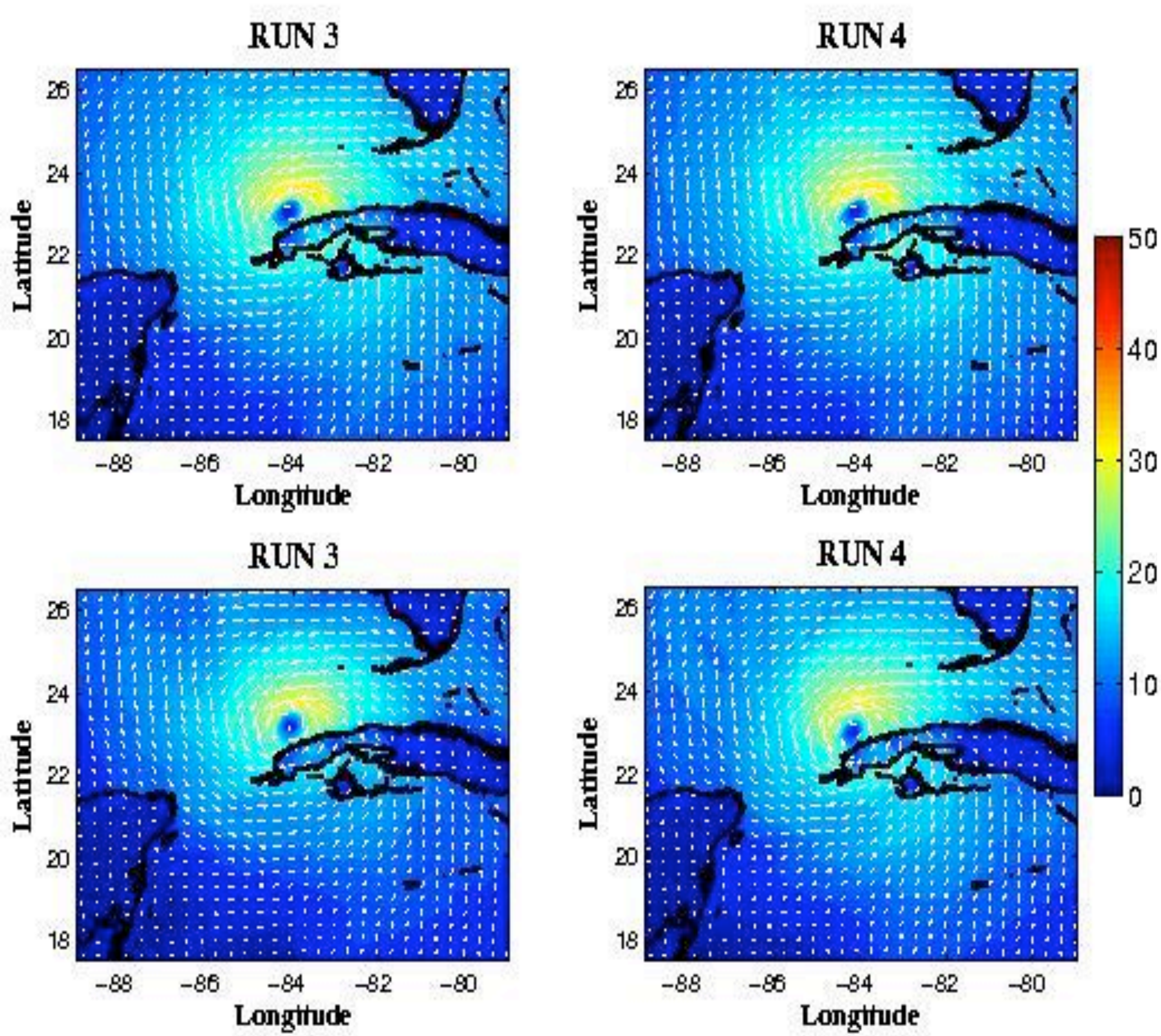
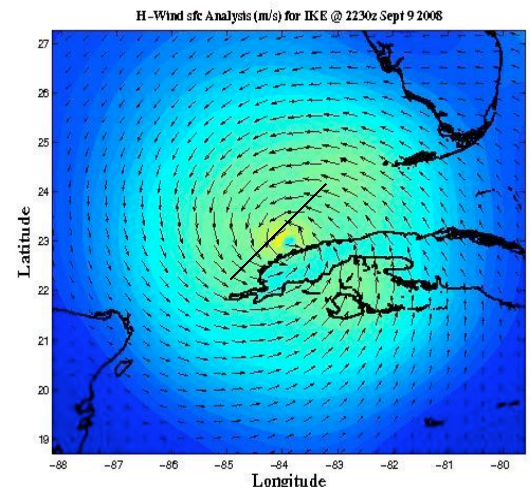
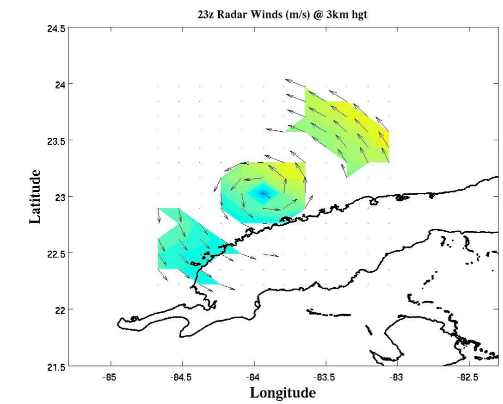


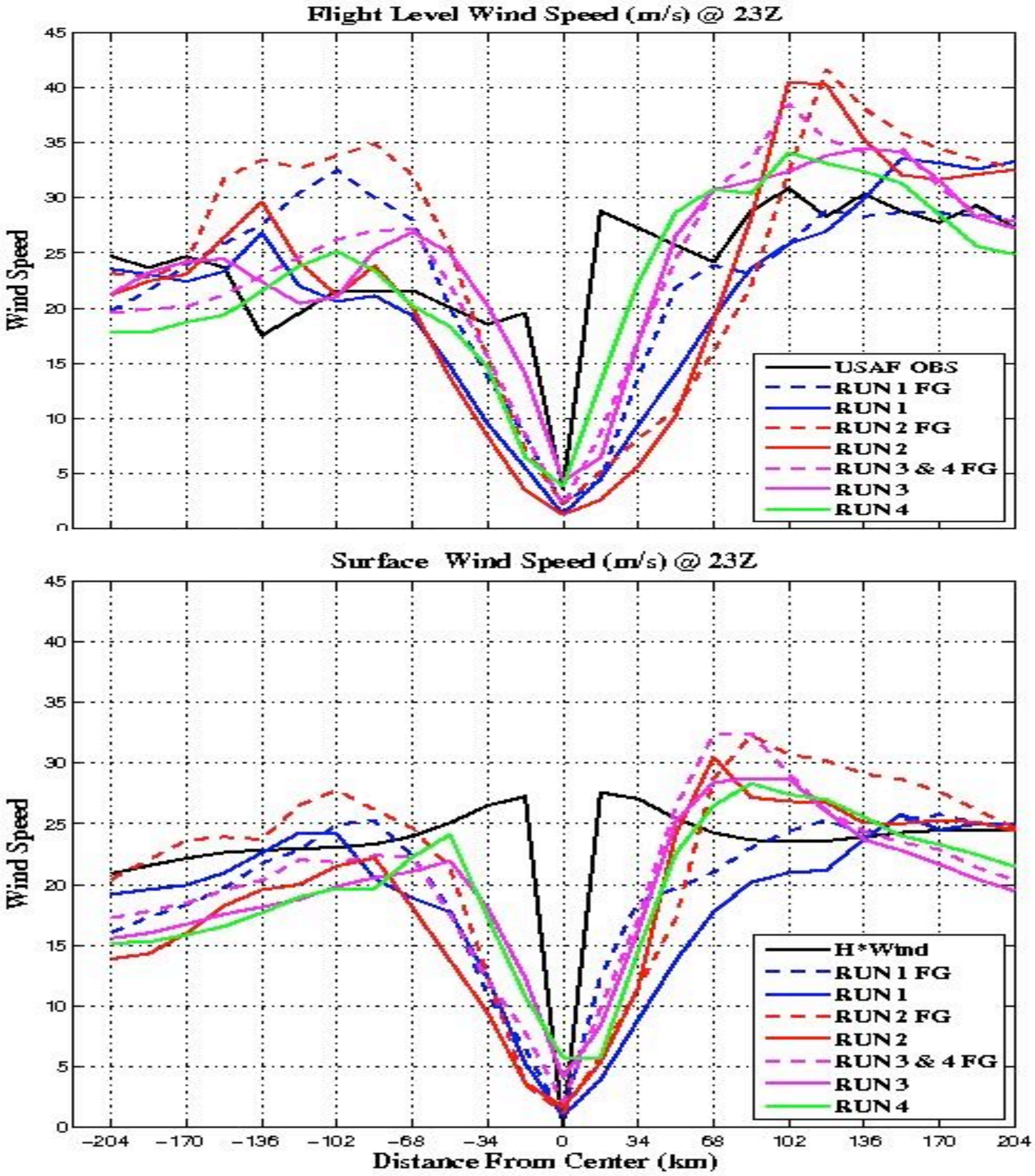
Obs

H*Wind Analysis @ 2230 UTC



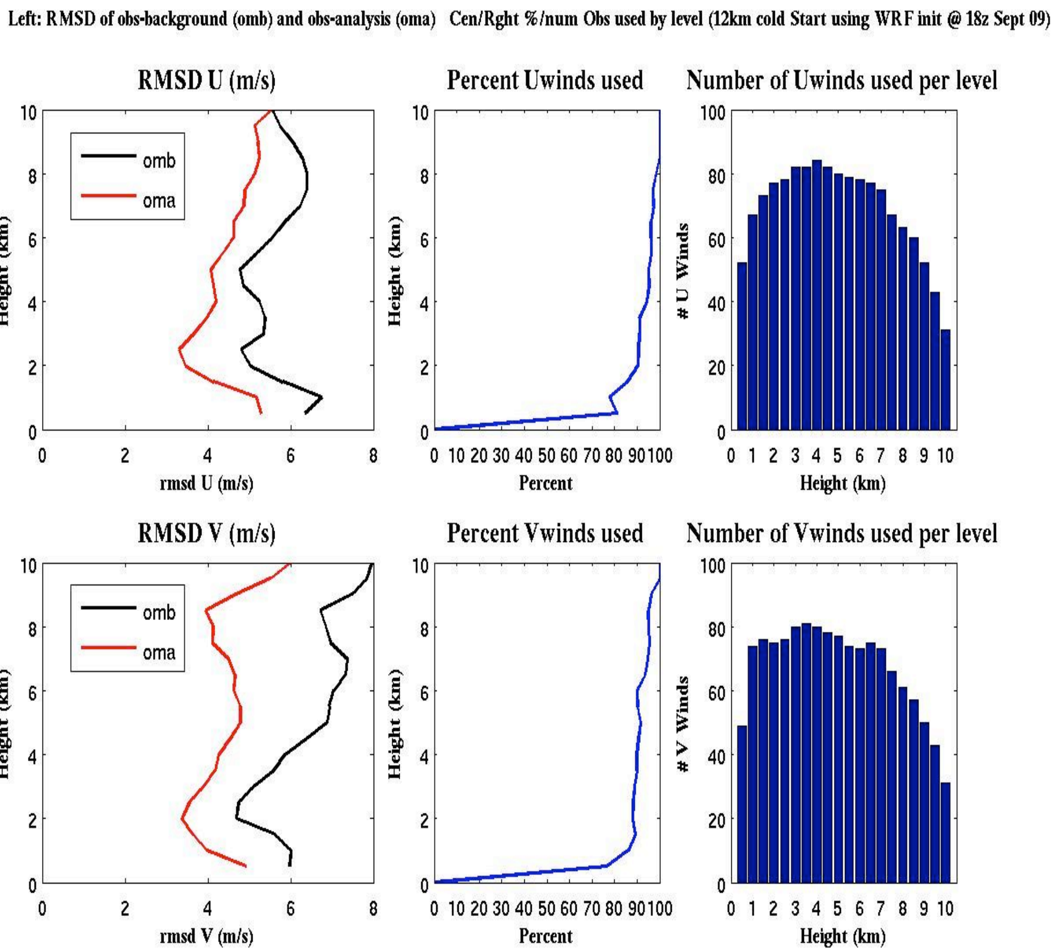


23z forecast: Cross-sections of 10m Wind Speed (top) Flight Level Wind Speed (bottom)

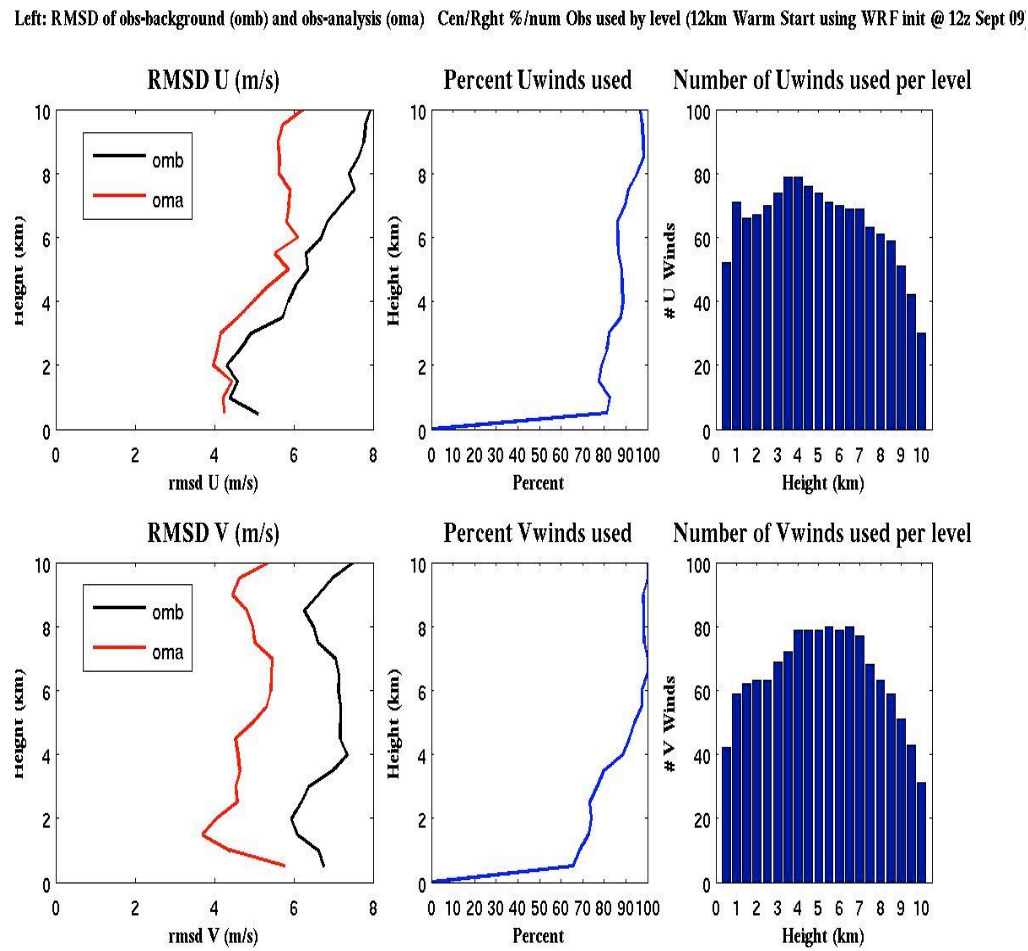


ROOT MEAN SQUARE DIFFERECE OBSERVATION-BACKGROUND AND OBS-ANALYSIS

RUN 1



RUN 2



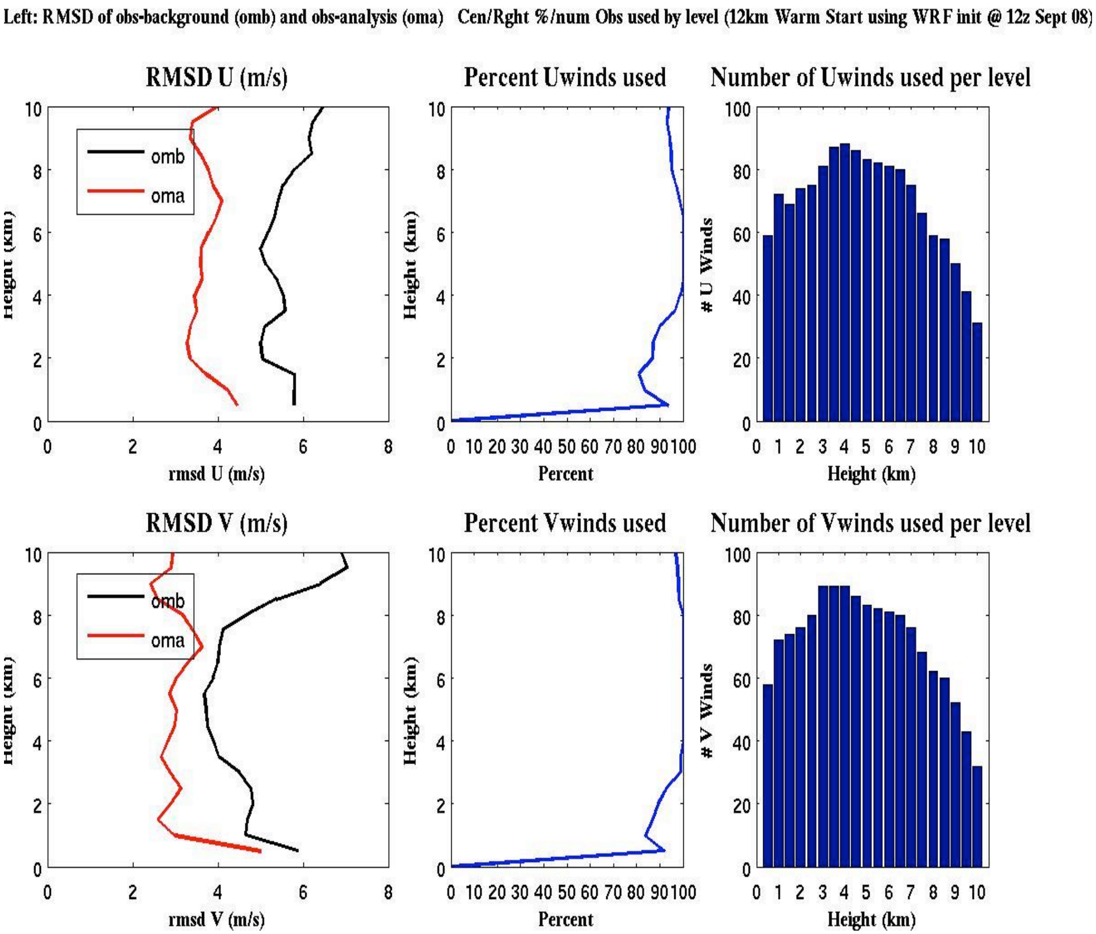
Recall 3rd term of cost function:

$$J(\mathbf{x}) = \frac{1}{2}(\mathbf{x}_0 - \mathbf{x}^b)^T \mathbf{B}^{-1}(\mathbf{x}_0 - \mathbf{x}^b) + J_x + \frac{1}{2}\sum_{k=0}^{K}[\mathbf{h}(\mathbf{x}_k) - \mathbf{y}_k]^T \mathbf{R}_k^{-1}[\mathbf{h}(\mathbf{x}_k) - \mathbf{y}_k]$$

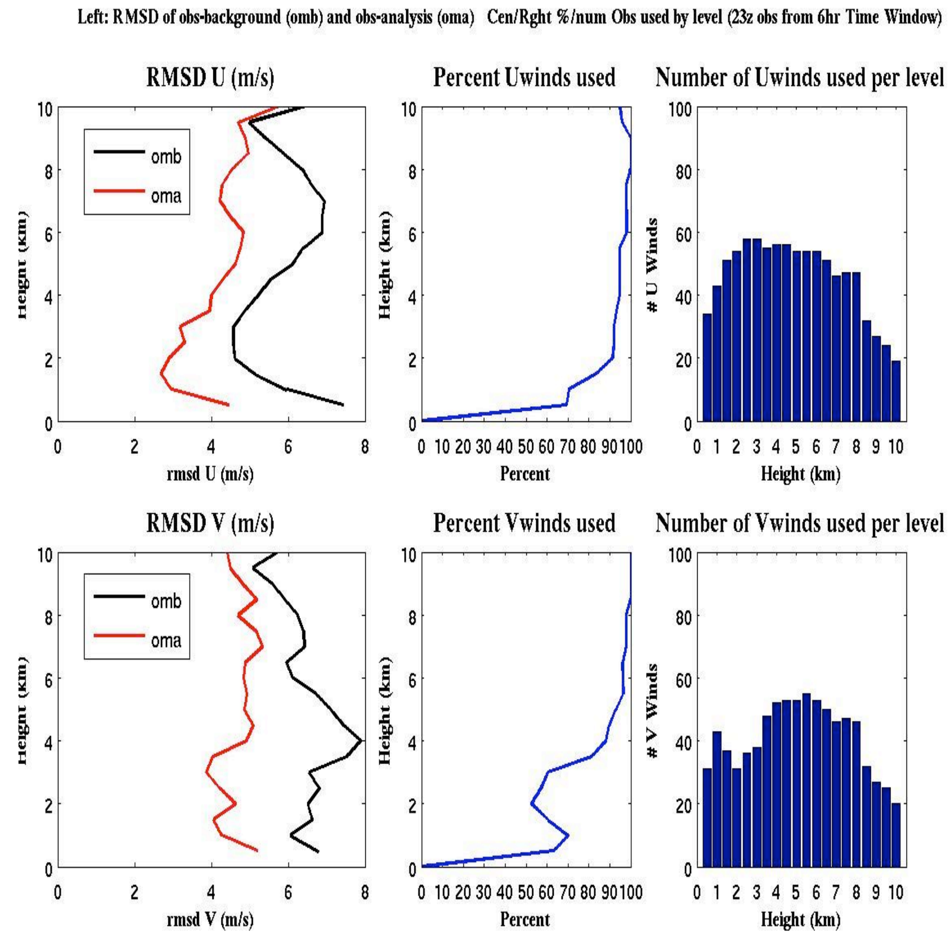
For first iteration this term corresponds to black line (omb) and for last iteration to red line (oma)

ROOT MEAN SQUARE DIFFERECE OBSERVATION-BACKGROUND AND OBS-ANALYSIS

RUN 3



RUN 4



Recall 3rd term of cost function:

$$
\begin{aligned}
J(\mathbf{x}) &= \frac{1}{2}(\mathbf{x}_0 - \mathbf{x}^b)^T \mathbf{B}^{-1}(\mathbf{x}_0 - \mathbf{x}^b) + J_x \\
&+ \frac{1}{2}\sum_{k=0}^{K}[\mathbf{h}(\mathbf{x}_k) - \mathbf{y}_k]^T \mathbf{R}_k^{-1}[\mathbf{h}(\mathbf{x}_k) - \mathbf{y}_k]
\end{aligned}
$$

For first iteration this term corresponds to black line (omb) and for last iteration to red line (oma)

Summary

- The impacts of assimilating airborne Doppler radar data at 12-km resolution are tested using three different first-guess fields (initial vortices)
- First guess from a previous WRF forecast more effective in using data near hurricane inner core resulting in a more realistic hurricane vortex.

  - smaller RMW, more comparable with H*wind analysis and radar data.
- Most 4dvar analysis enhances asymmetric structure of Ike's wind field, similar to the radar obs, especially in Run3 and 4 when the first-guess fields are closer to the observations.
- 4-hr and 6-hr time windows are used. However, benefit of using a longer time window is difficult to determine since second set of observations are penalized greater and more data been rejected than first set.
- Weaknesses: 1) lack of environmental data outside inner region

  2) un-tuned global climatological background error covariance
- Future improvements: 1) Assimilate over larger domain to include GTS data in outer environment and to facilitate longer forecast

  2) Use vortex-specific background error or hybrid approach with ensemble data assimilation