Experiments of Hurricane Initialization with Airborne Doppler Radar Data for the Advanced-research Hurricane WRF (AHW) Model

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Outline

- Motivations
- Airborne Doppler radar data
- WRF 3DVAR data assimilation
- Experiments and results
  - Hurricane Jeanne (2004)
  - Hurricanes Katrina and Rita (2005)
  - Statistical verification
- Summary and conclusions

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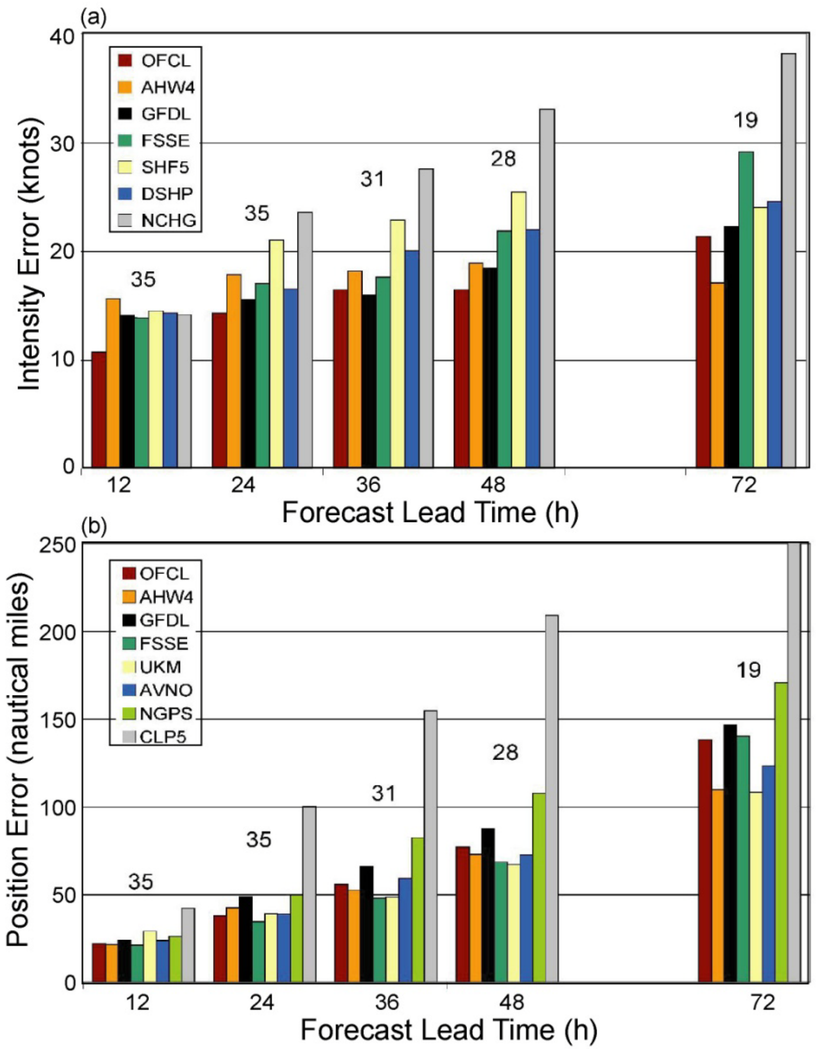
AHW previous results



- WRF ARW improved track and intensity over official forecast beyond 36 h.
- Short-term forecasts (< 2 days) show a rather poor skills in WRF ARW, due to model spin-up problem.
- An improved hurricane initialization, using advanced data assimilation technique, can augment the skills of short-term forecasts.

WRF hurricane forecast in 2005 (Orange), Davis et al. 2008

Motivations

- Airborne Doppler radar data provide high resolution wind and hydrometeor structure of hurricane vortex, and have a great potential for improved hurricane initialization.
- An improved hurricane initialization, using advanced data assimilation technique, can augment the skills of short-term forecasts, especially the hurricane intensity forecasts.

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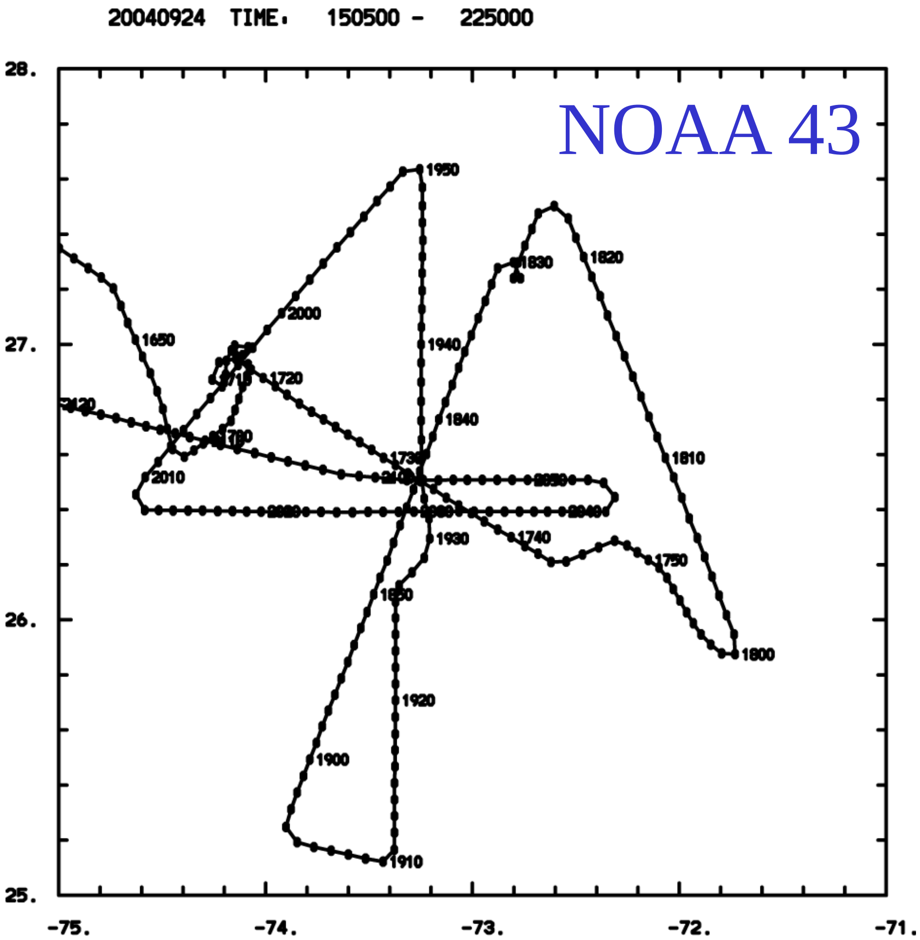
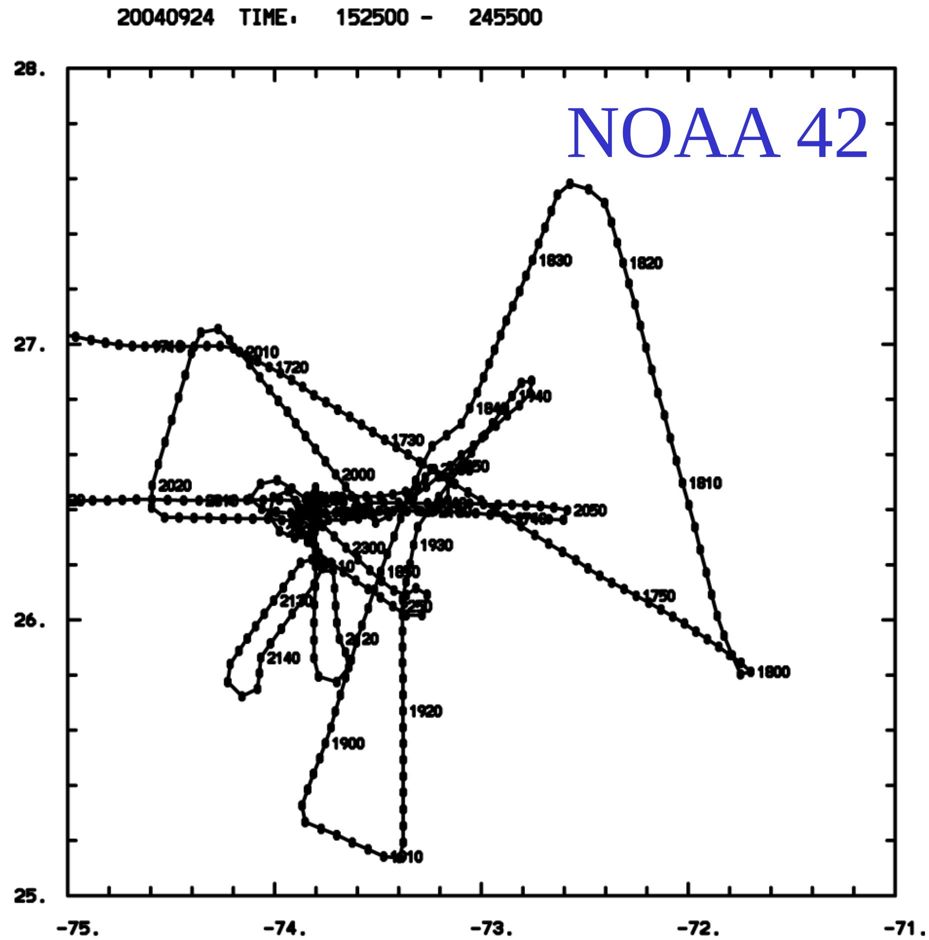
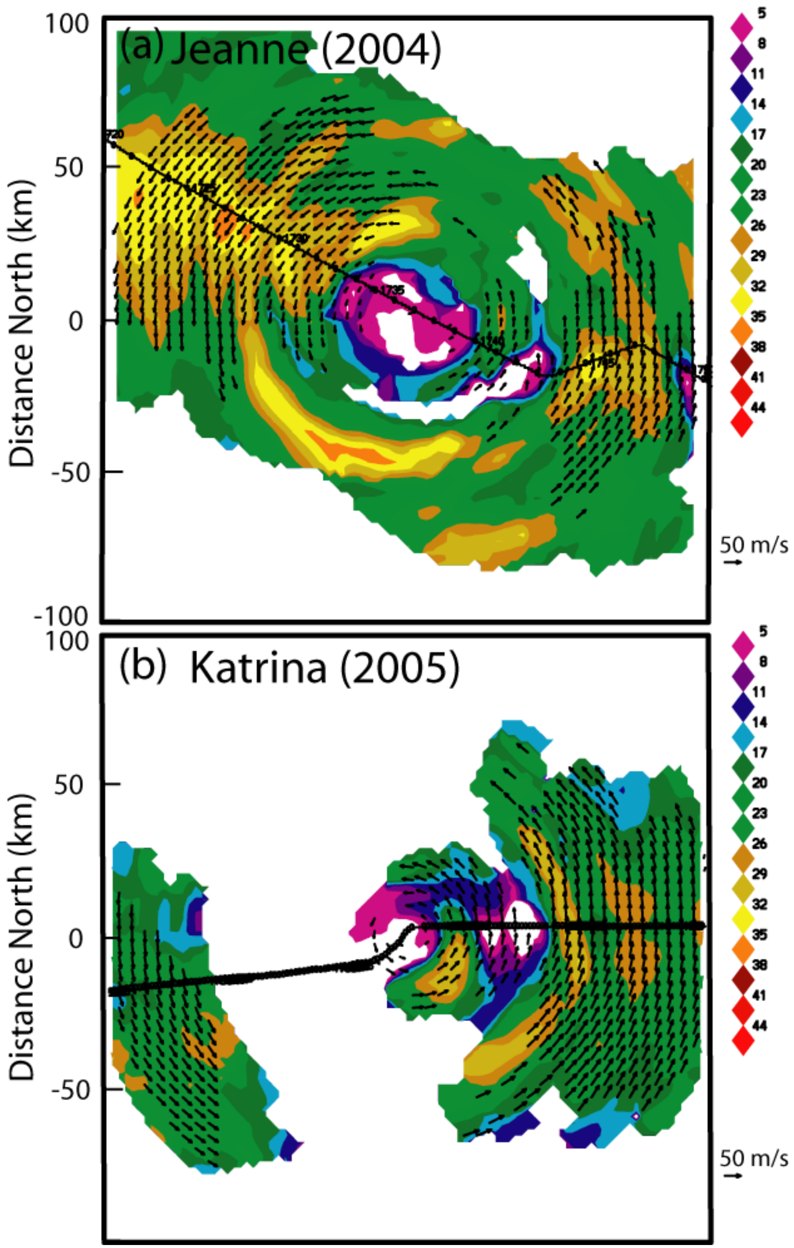
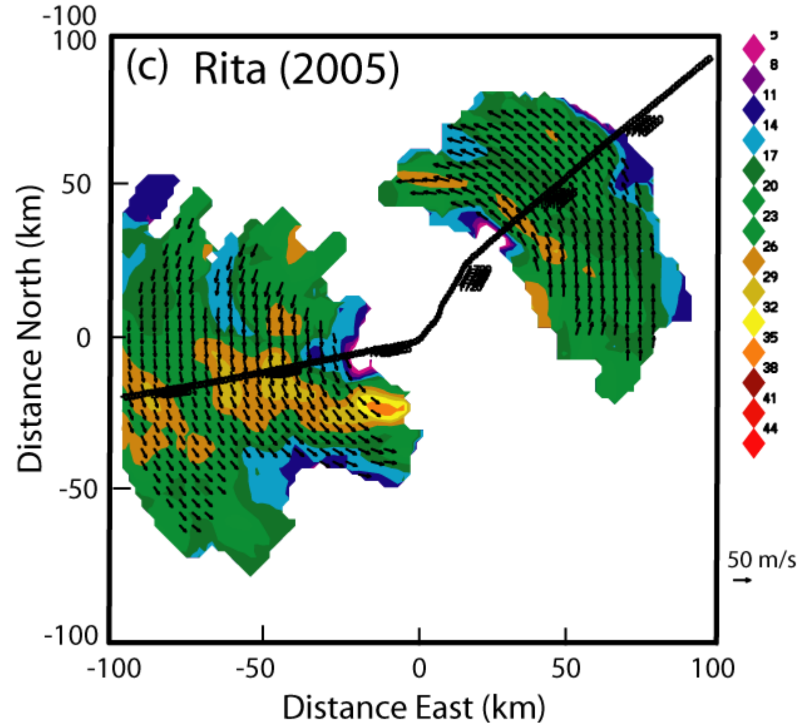
Airborne Doppler radar observations





Flight track for Hurricane Jeanne (2004)





Horizontal wind field and radar reflectivity at 2.5 km AMSL for Hurricanes a) Jeanne at ~1800 UTC 24 Sep 2004, b) Katrina at ~1800 UTC 27 Aug 2005 and c) Rita at ~1800 UTC 20 Sep 2005.

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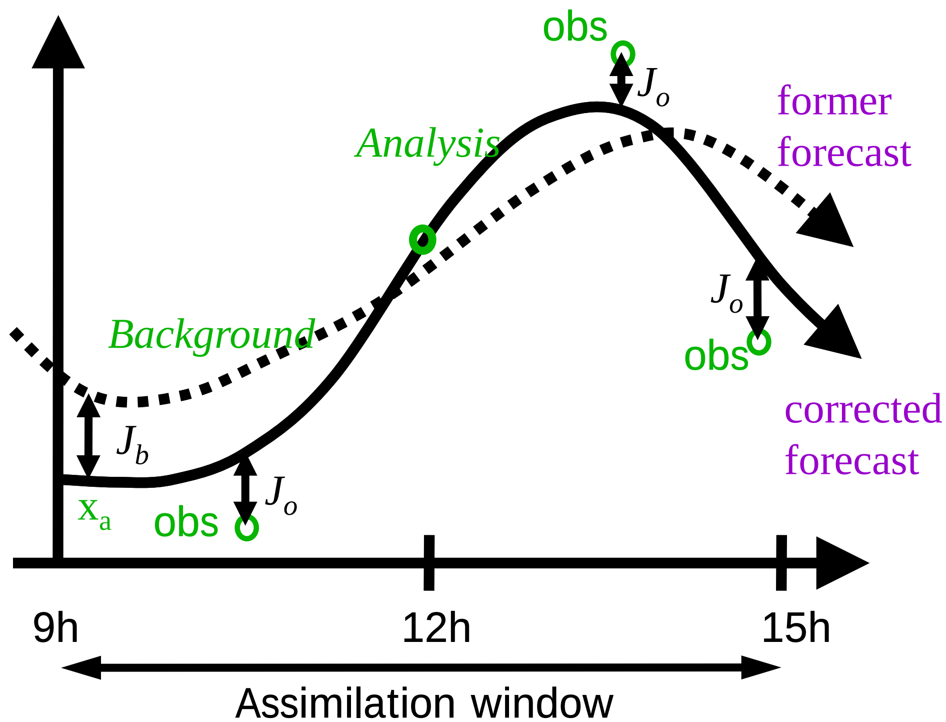
WRF-Var data assimilation system

$$J(\mathbf{x}) = (\mathbf{x}_b - \mathbf{x})^T \mathbf{B}^{-1} (\mathbf{x}_b - \mathbf{x}) + [\mathbf{y} - H(\mathbf{x})]^T O^{-1} [\mathbf{y} - H(\mathbf{x})]$$

Background constraint (J_b) **Observation constraint (J_o)**

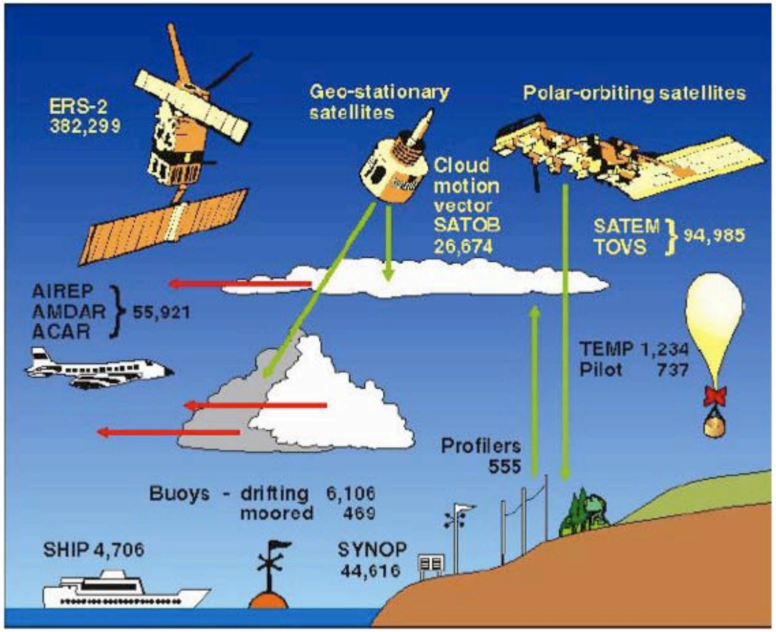
- $\mathbf{x}_b$: model **background**
  (former information)
- **H(x)** : **observation operator** (simulating observations from model)
- **[y – H(x)]** : **innovation** vector
  (new information)
- Minimum of the cost function **J(x),** (**analysis**) updates the background with new information from observations.



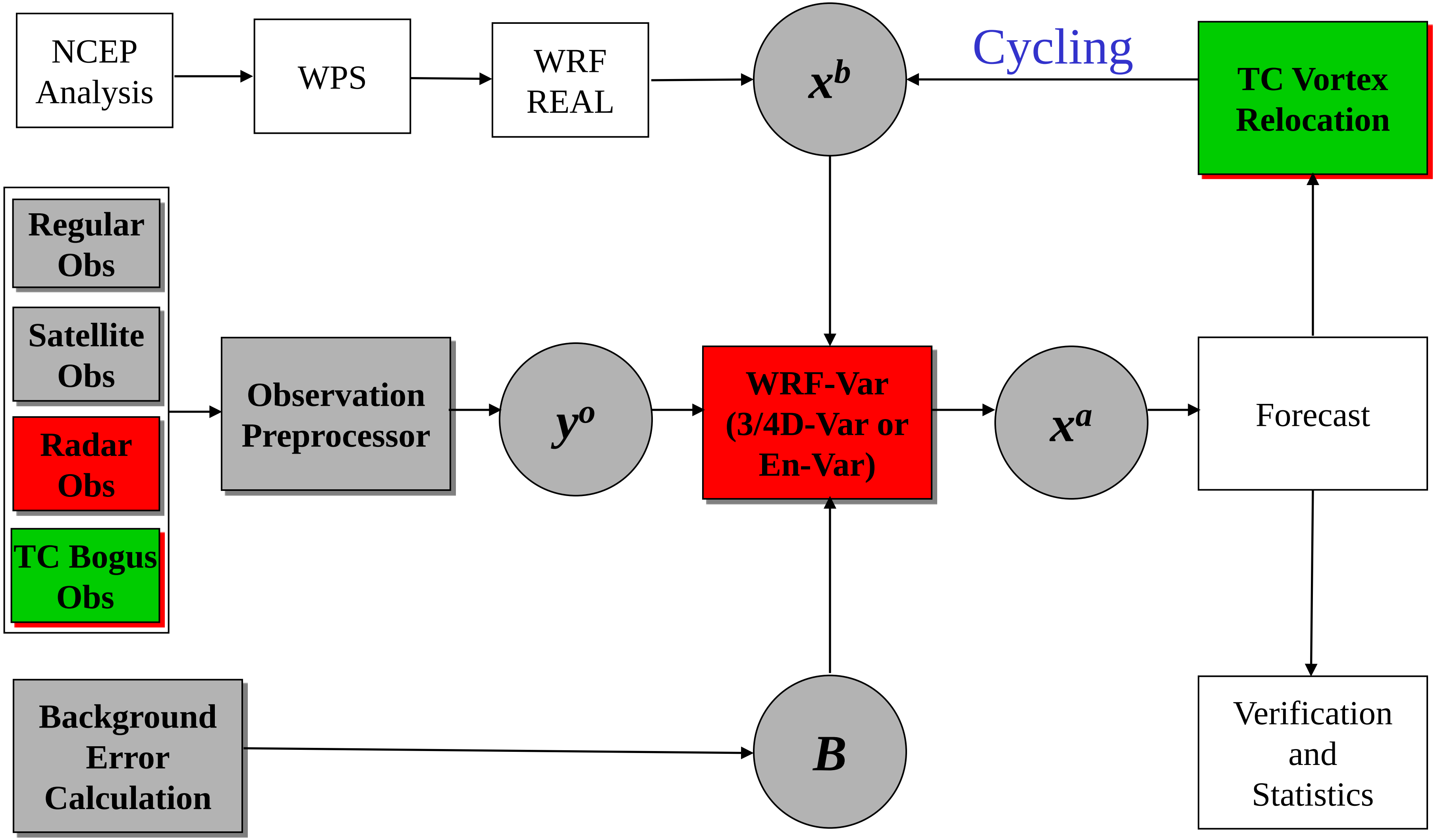
With hypotheses, the analysis estimates the true state of the atmosphere (in terms of max likelihood).

WRF-Var Capabilities

- WRF-Var is an advanced data assimilation system based on the variational technique.
- It includes WRF 3D-Var, 4D-Var, and ensemble/variational hybrid (En3D-Var, En4D-Var).
- It can assimilate all observational data, including satellite and radar data.
- It is robust, and facilitates research and real-time applications.



WRF-Var Flow Chart



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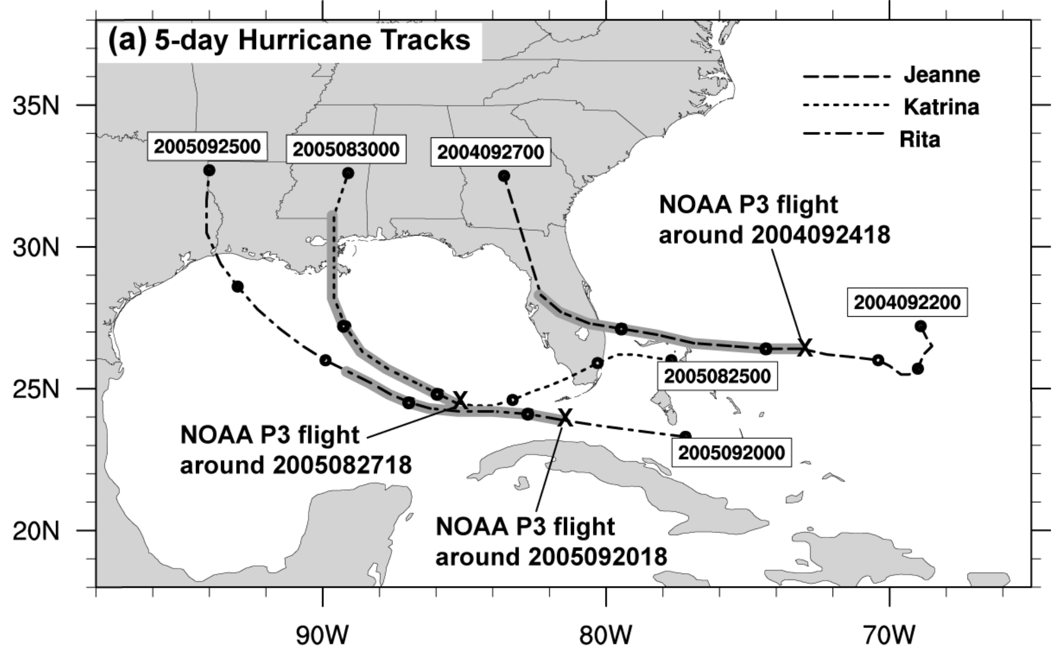
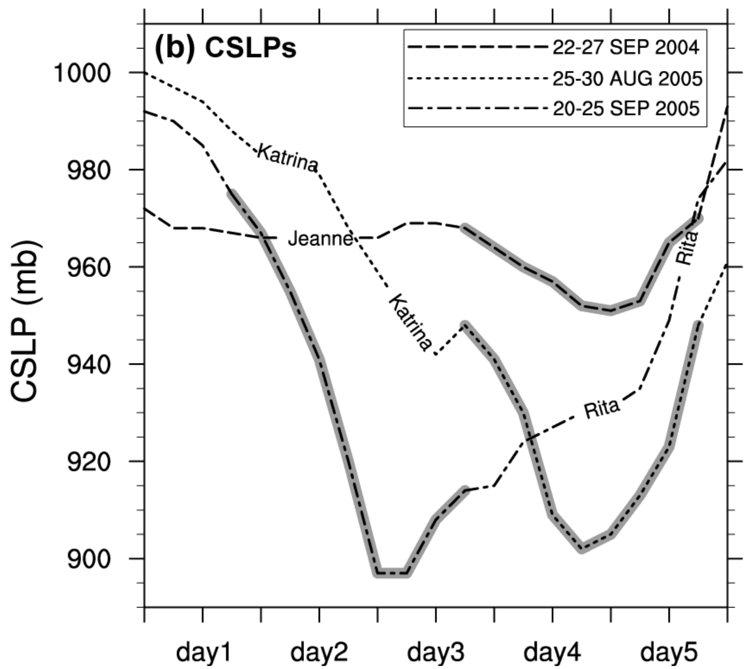
Track



Intensity

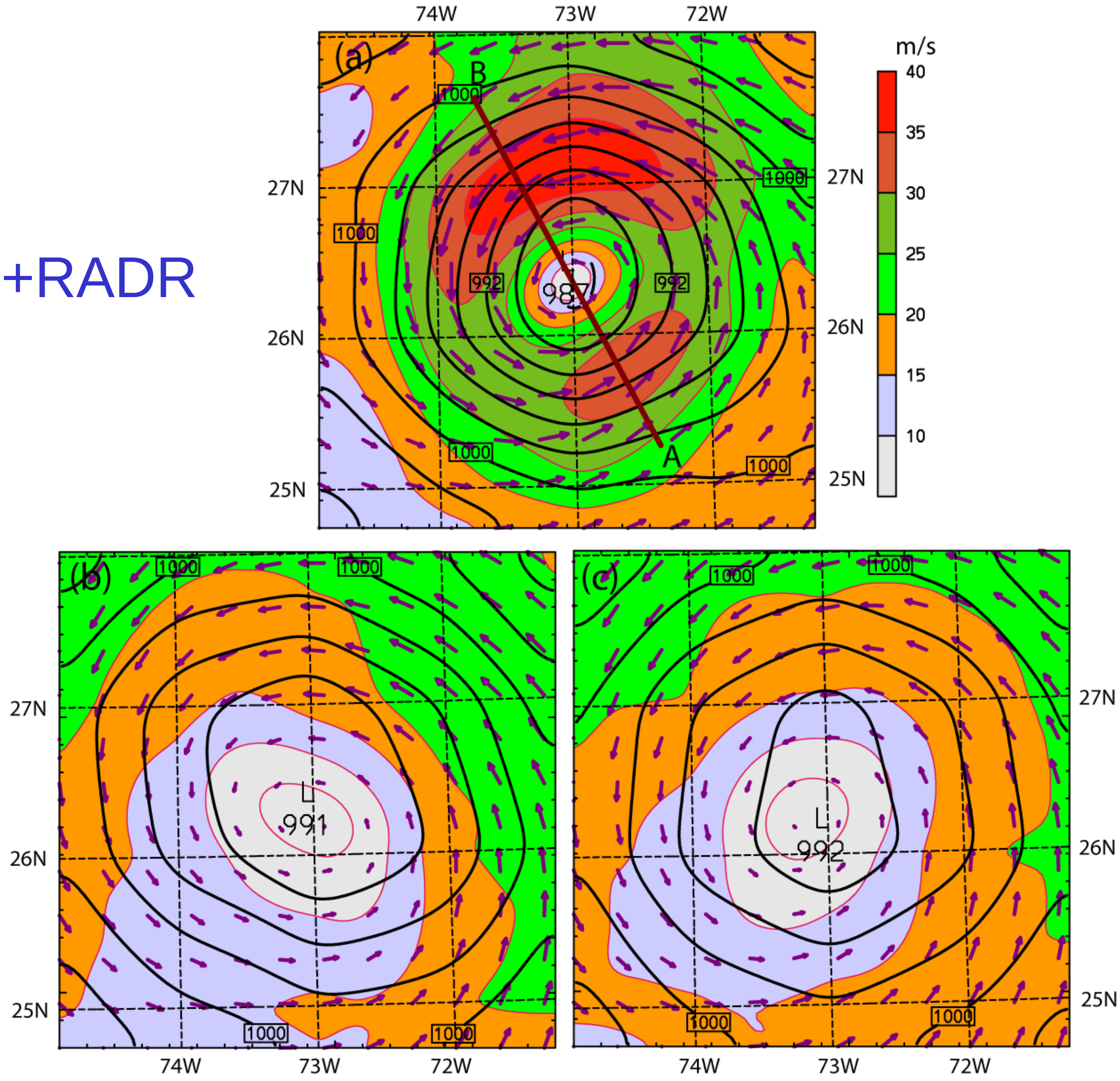


Jeanne (2004): Hurricane initialization

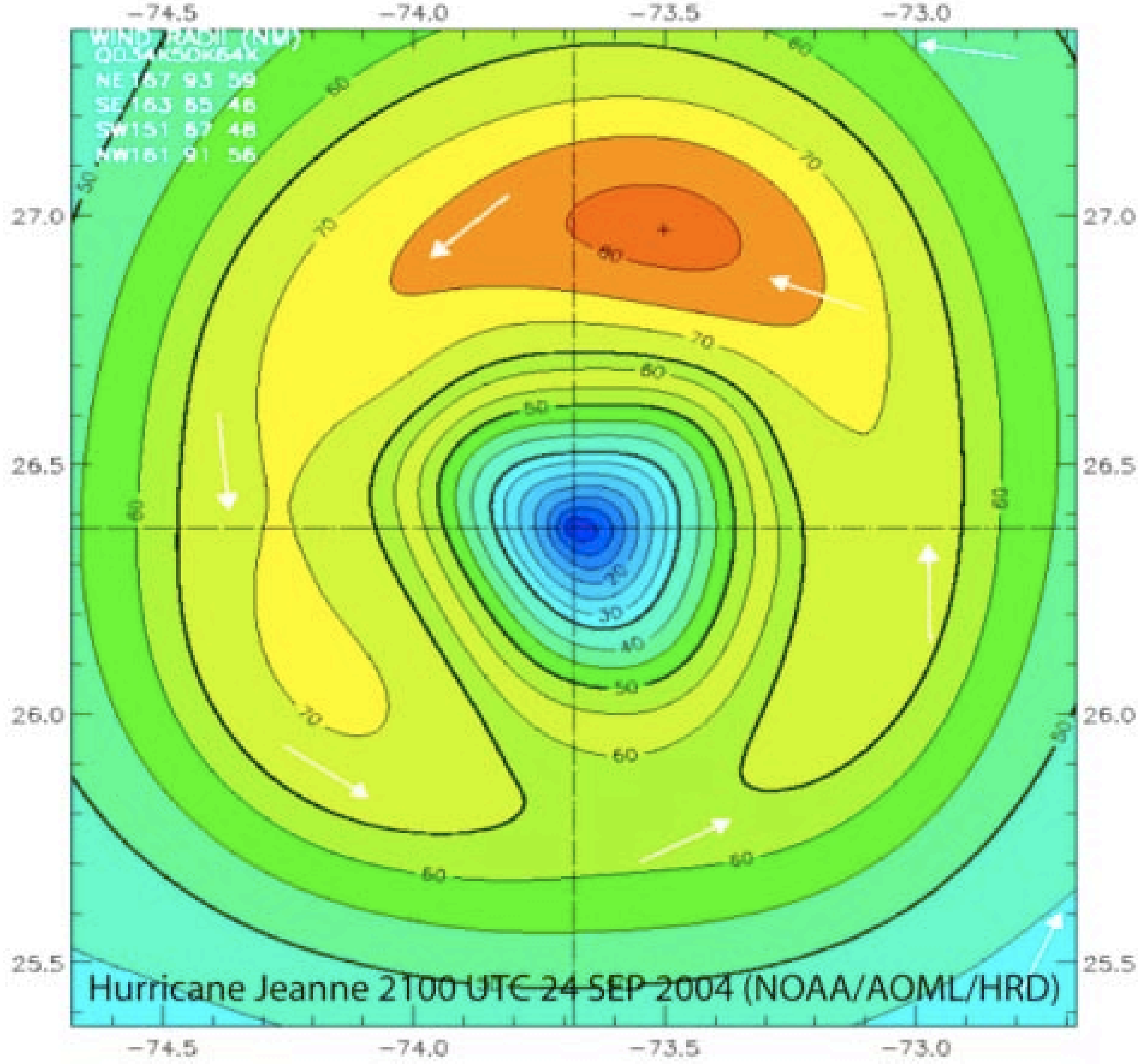
GTS+RADR

GTS only

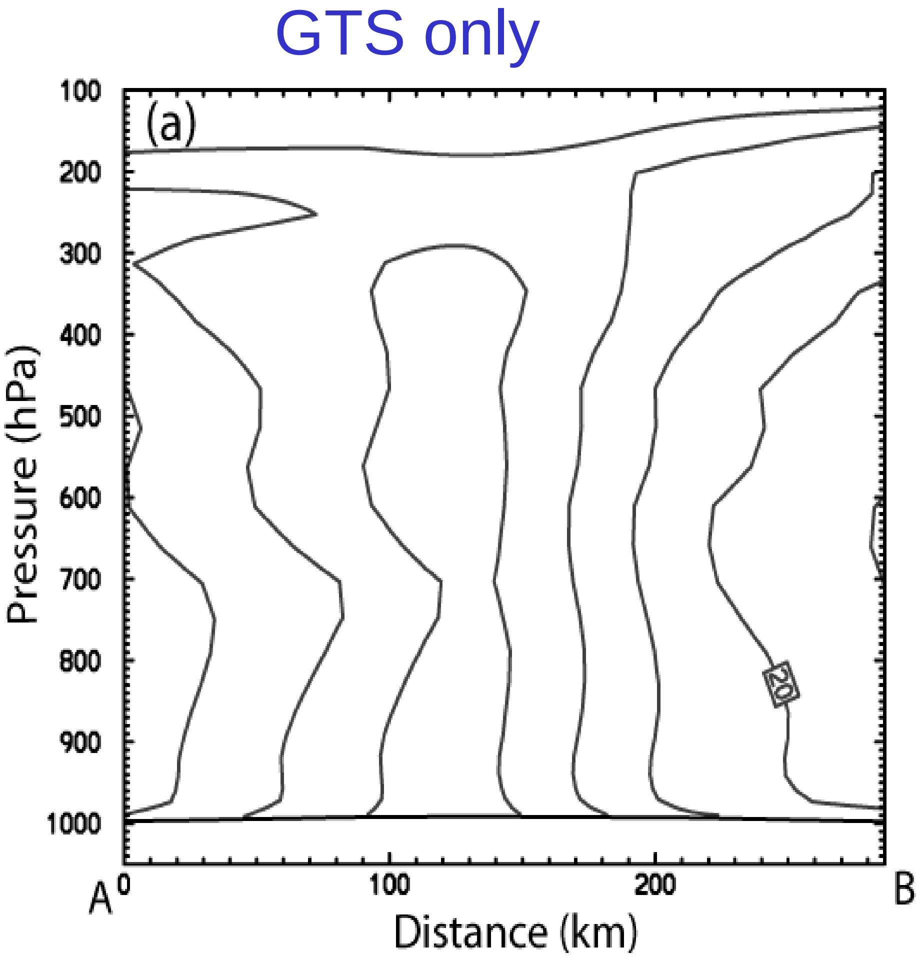
NO DA

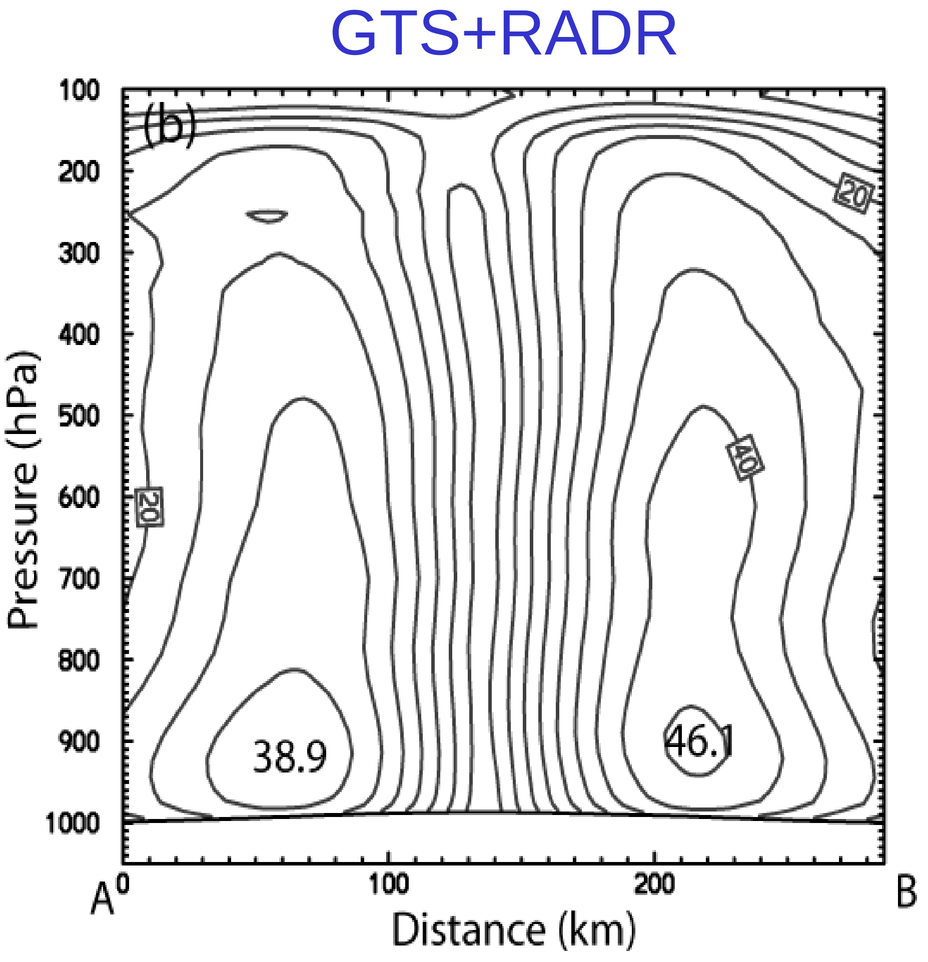


H-Wind from NOAA/ HRD

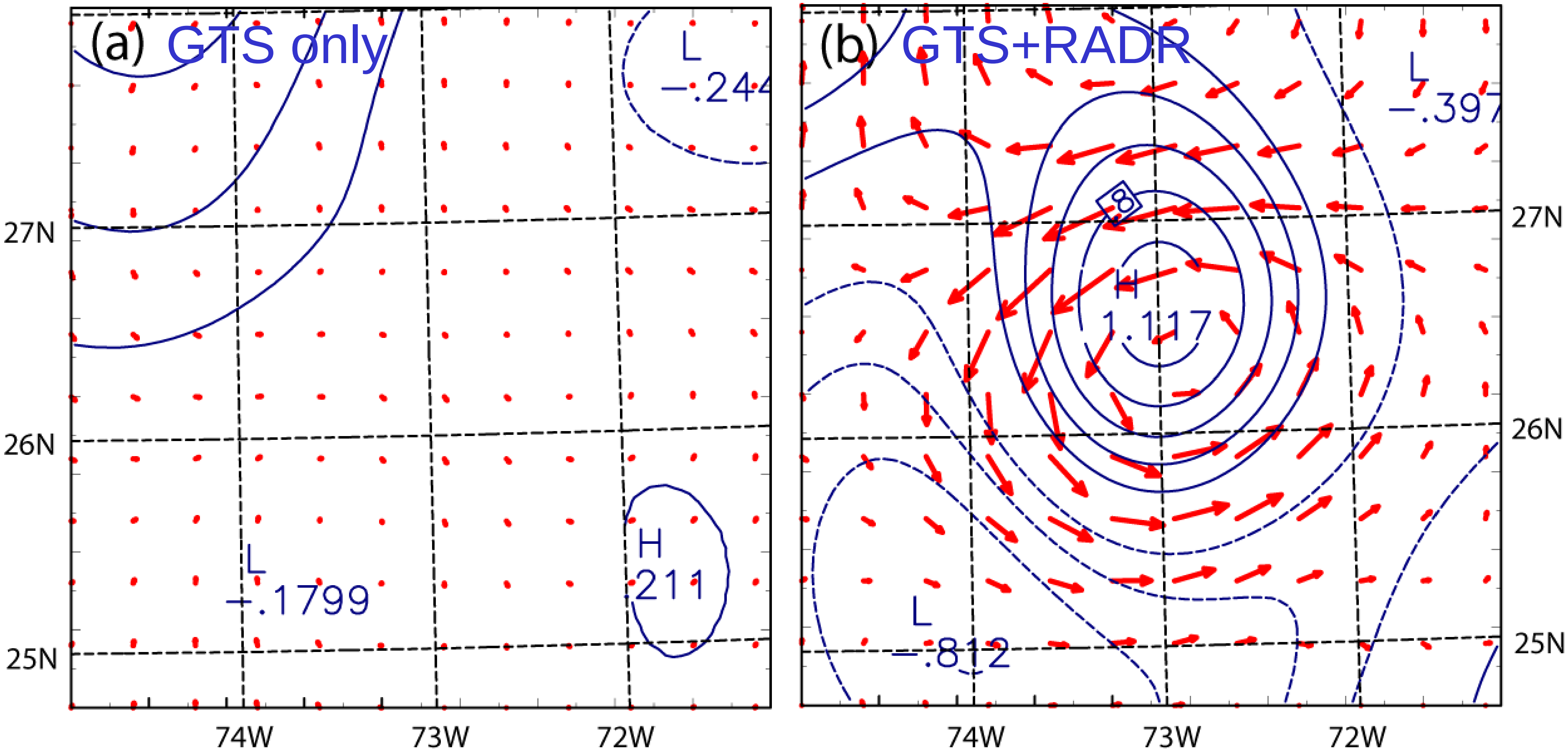


Vertical structure

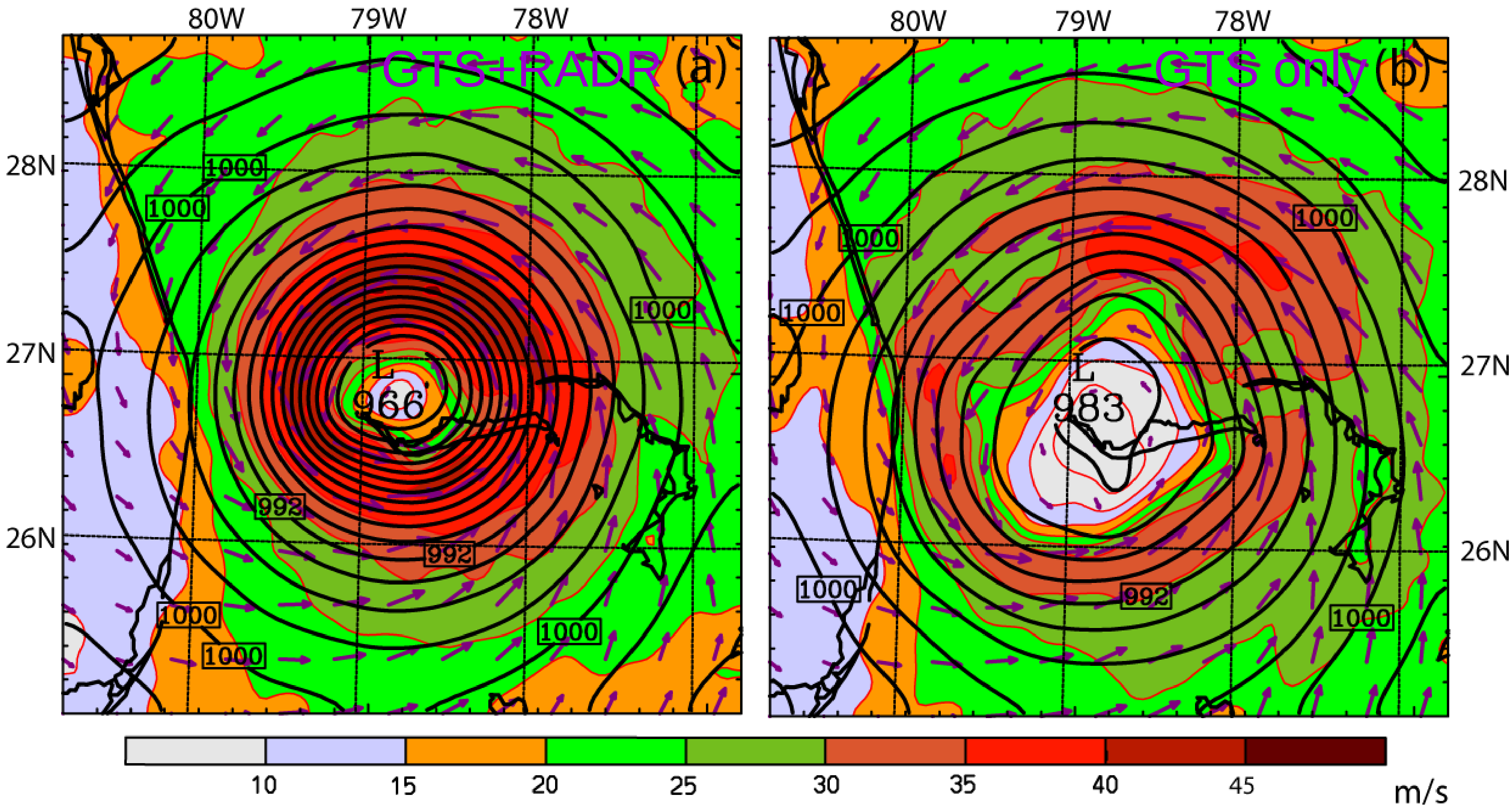




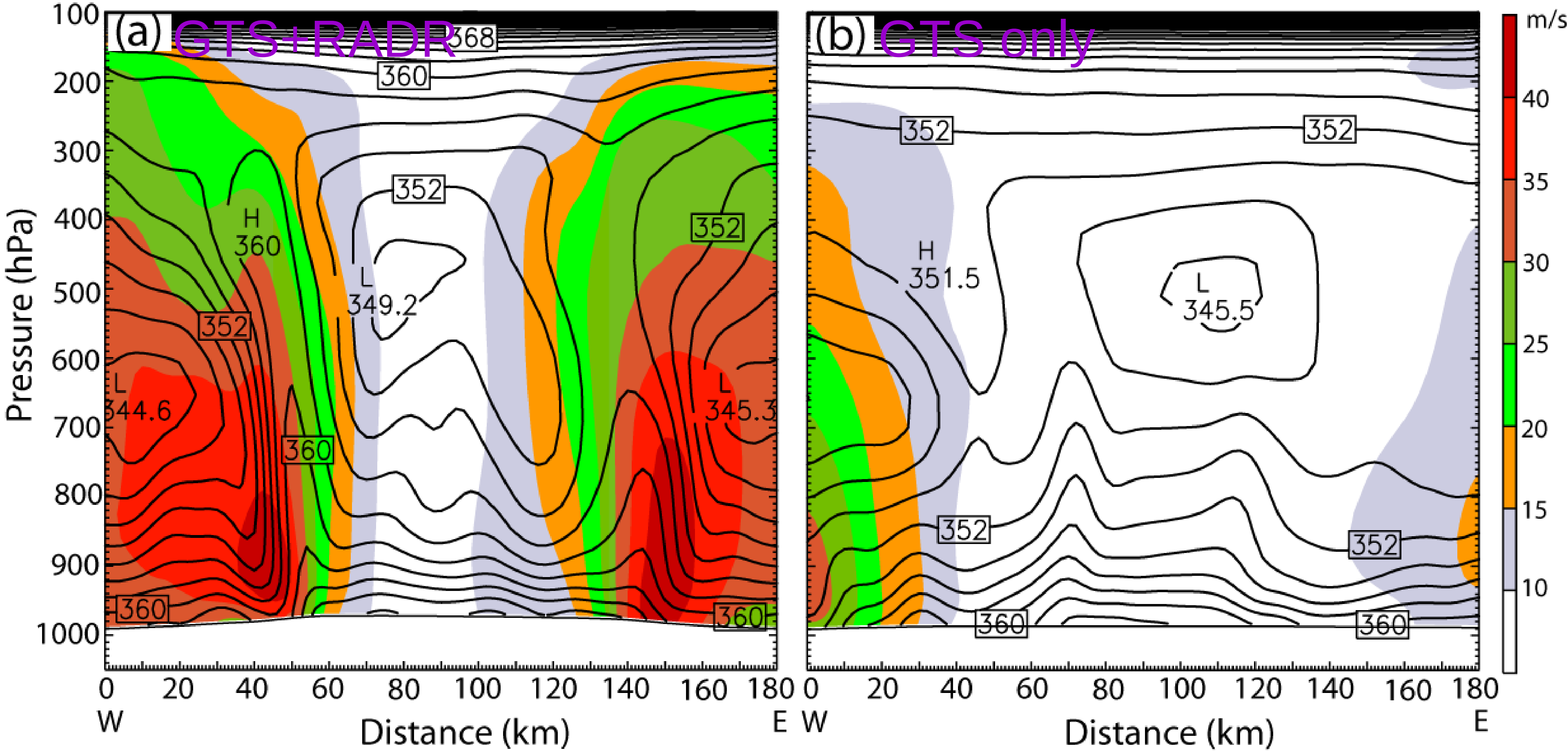
300 hPa analytical increments of wind vector (maximum vector represents 29.7 ms^{-1}) and temperature (isolines with contour interval of 0.2K, the negative value dashed)



24-h forecasts of SLP (thick solid isolines), and surface (10-m) wind vector and speed (shadings with thin isolines) for Hurricane Jeanne at 1800 UTC 25 Sep 2004

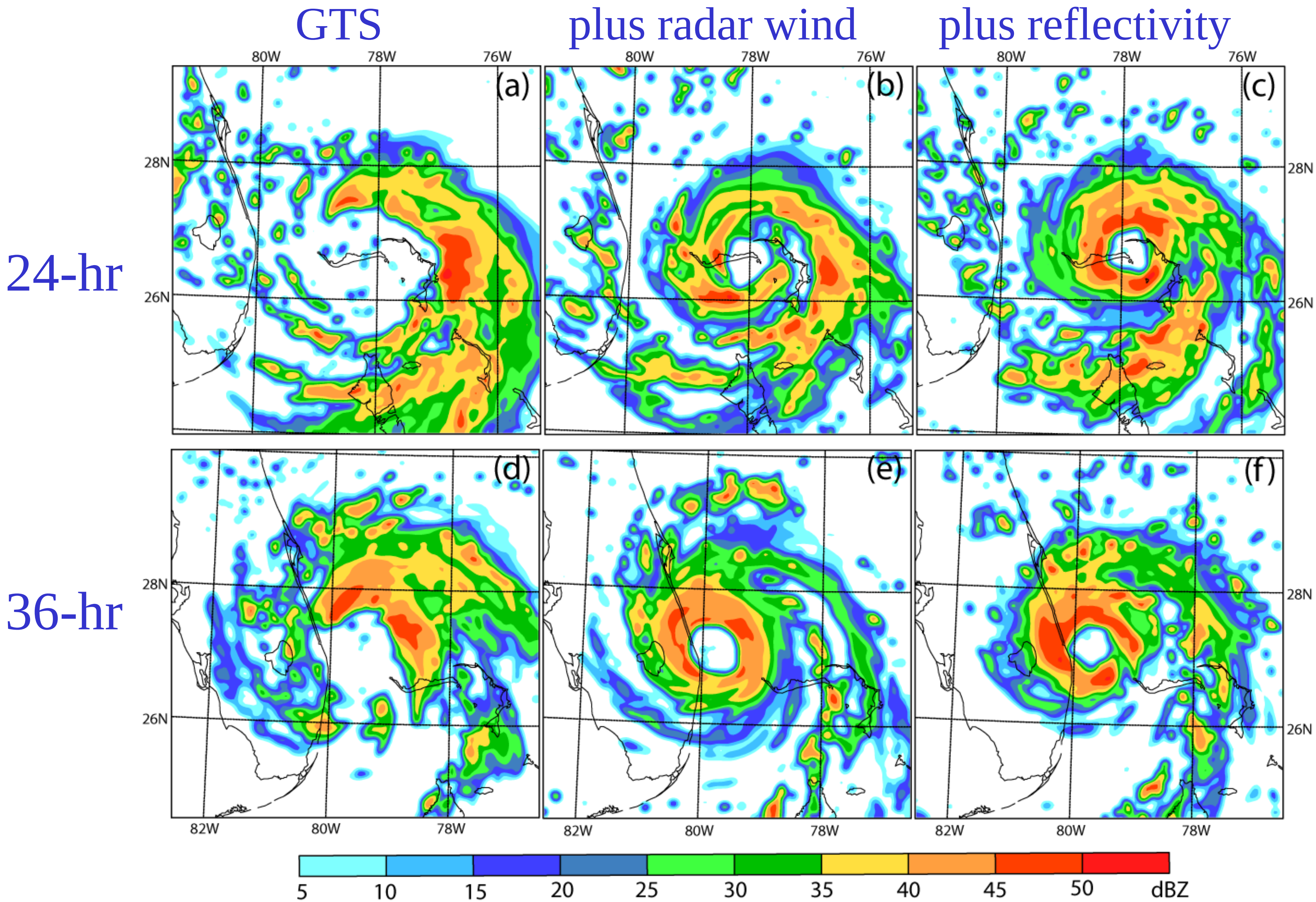


Vertical cross-sections of equivalent potential temperature and horizontal wind speed (shading with the scale on the upper right) at 1800 UTC 25 Sep 2004 (24-h forecast)

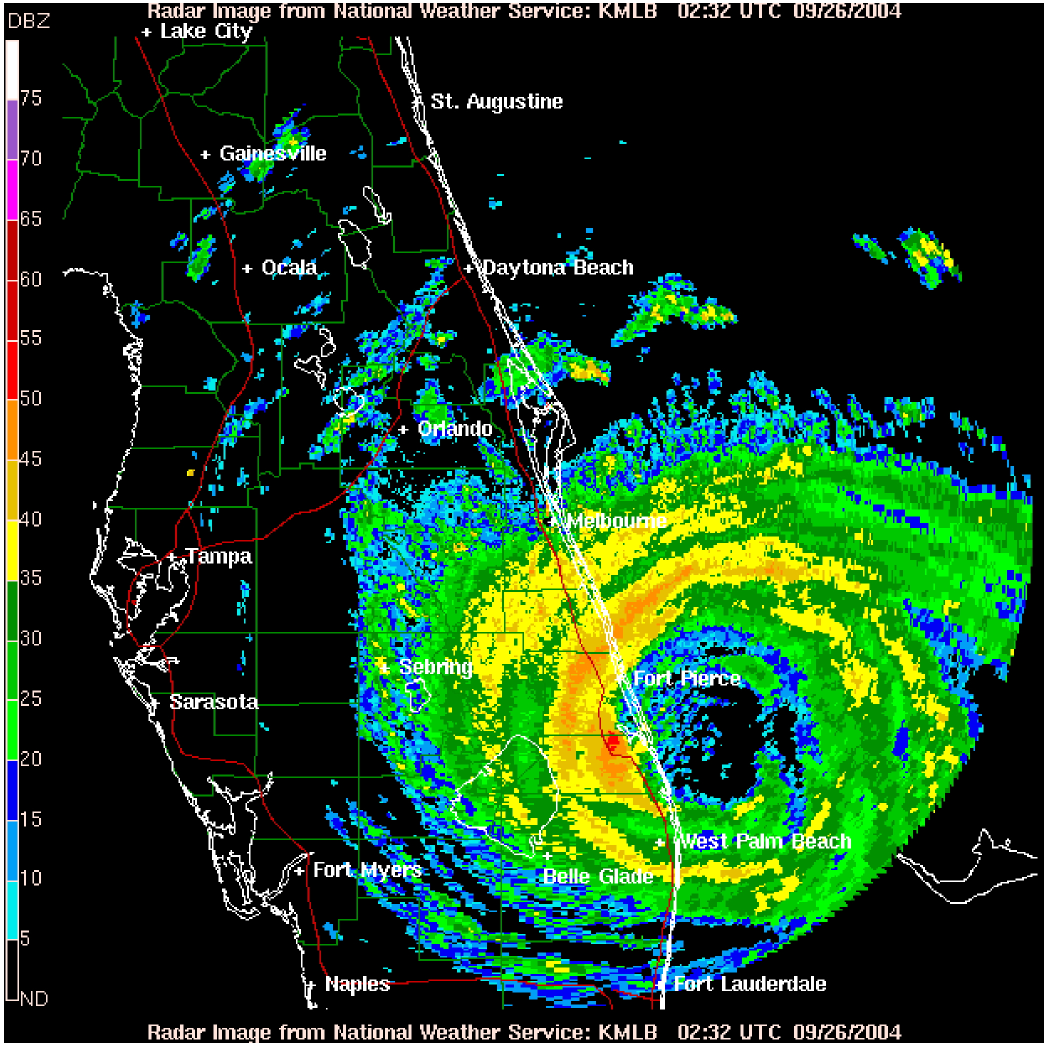


63rd Interdepartmental Hurricane Conference, March 2-5, 2009, St. Petersburg, FL

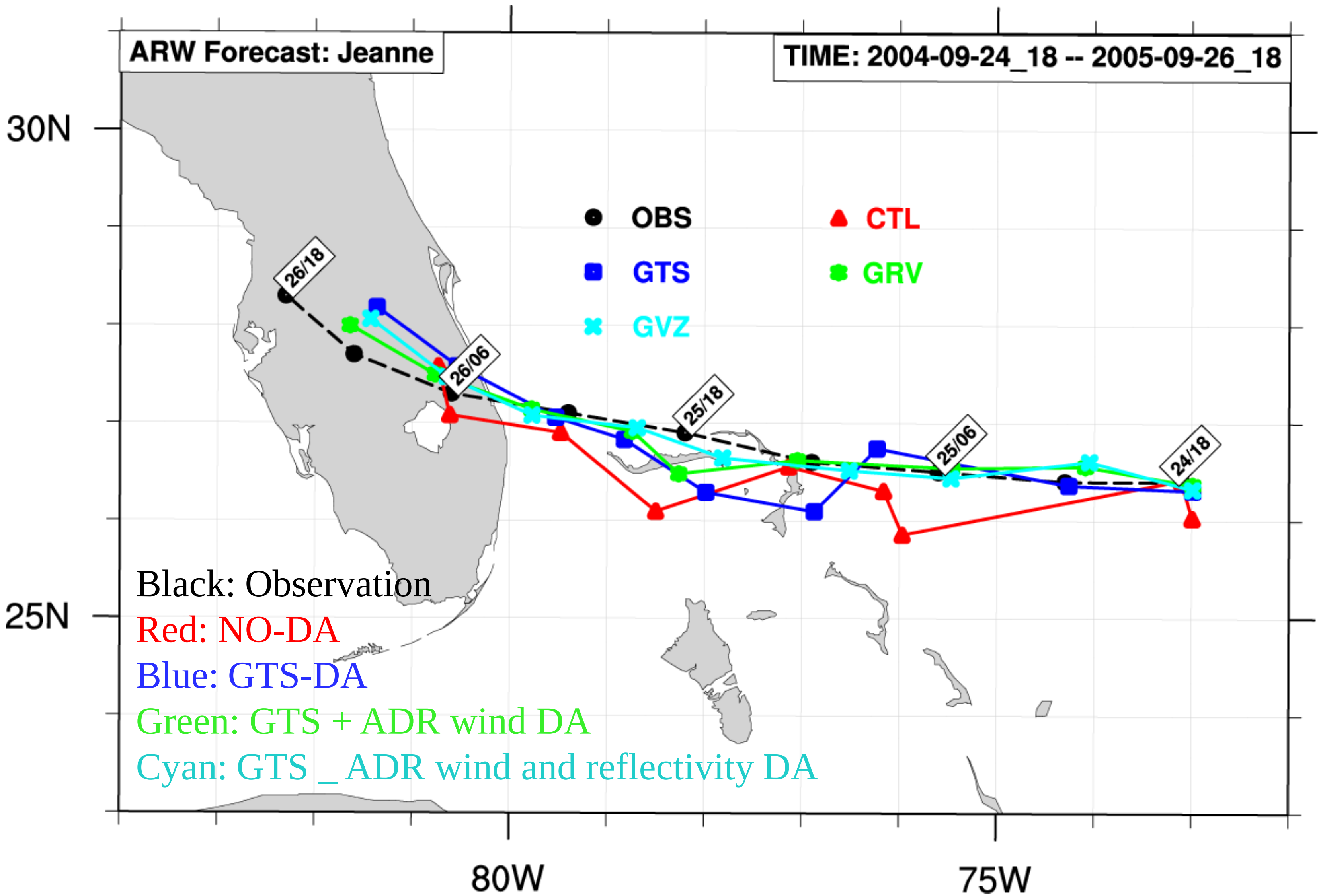
Hurricane forecast (reflectivity)



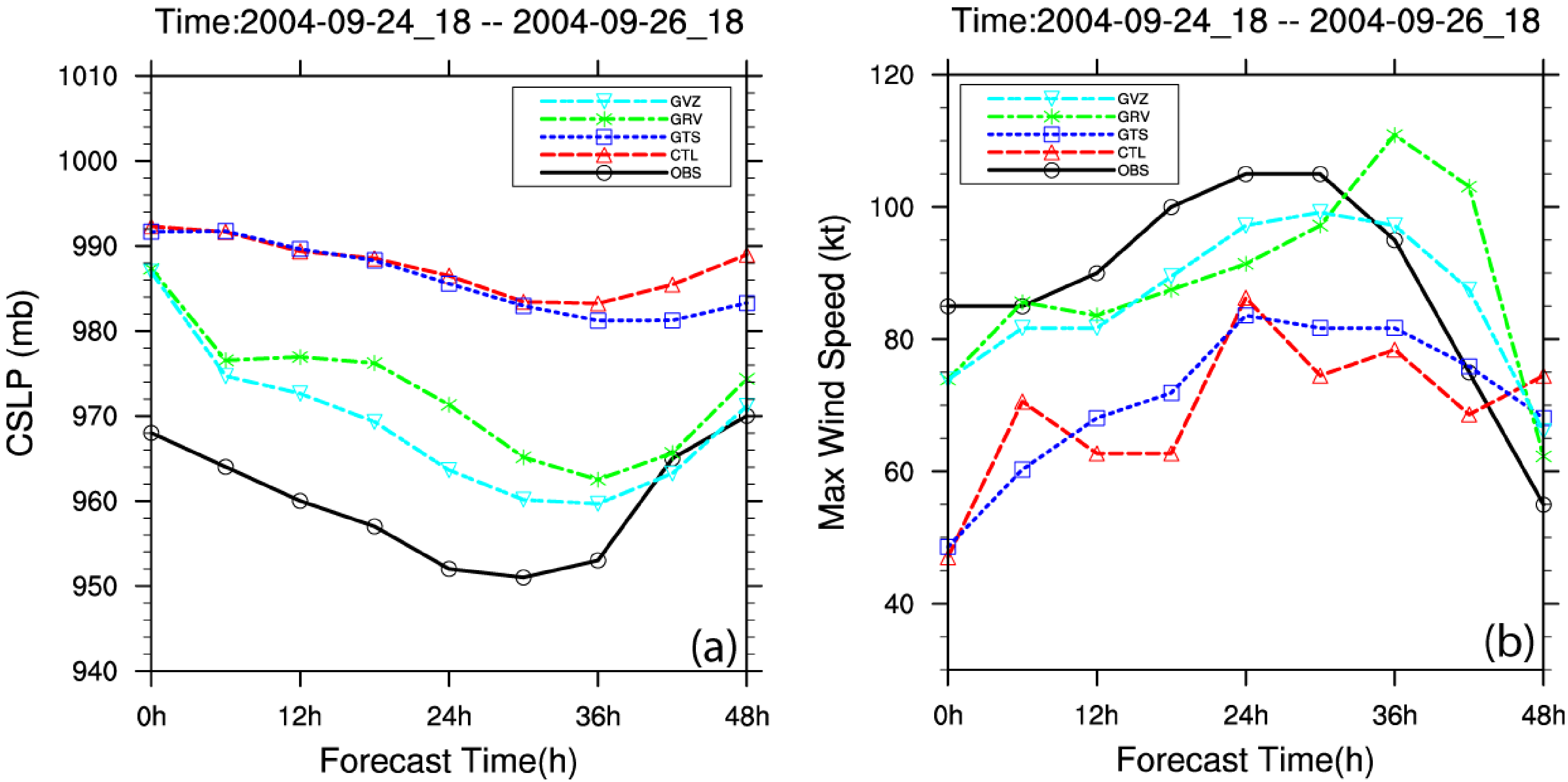
The reflectivity (dBZ) image from WSR–88D from Melbourne, Florida at 0232 UTC 26 Sep 2004



Hurricane track



Hurricane intensity

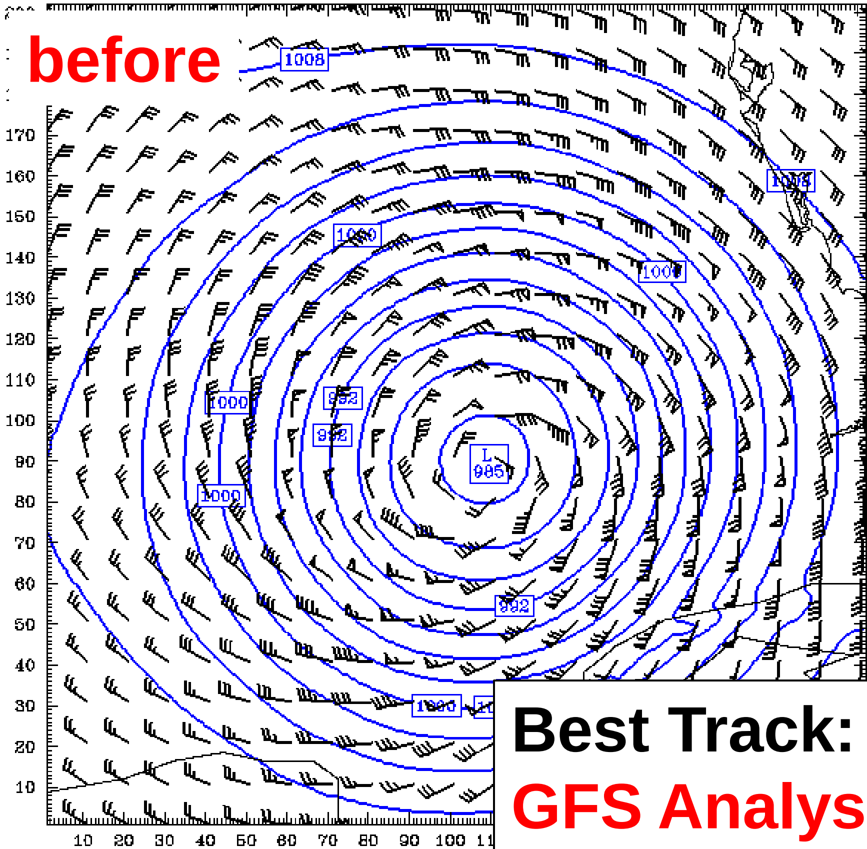


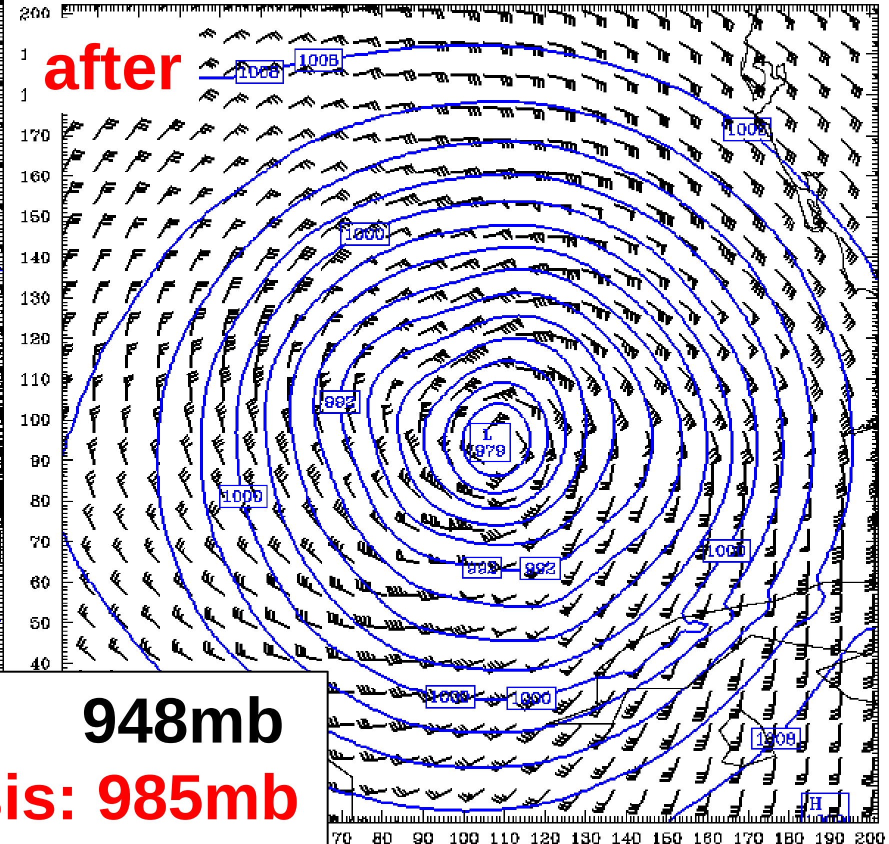
Black: Observation
Red: NO-DA
Blue: GTS-DA

Green: GTS + ADR wind DA
Cyan: GTS _ ADR wind and reflectivity DA

WRF 3DVAR analysis for Hurricane Katrina (2005)

SLP & Wind at 850mb



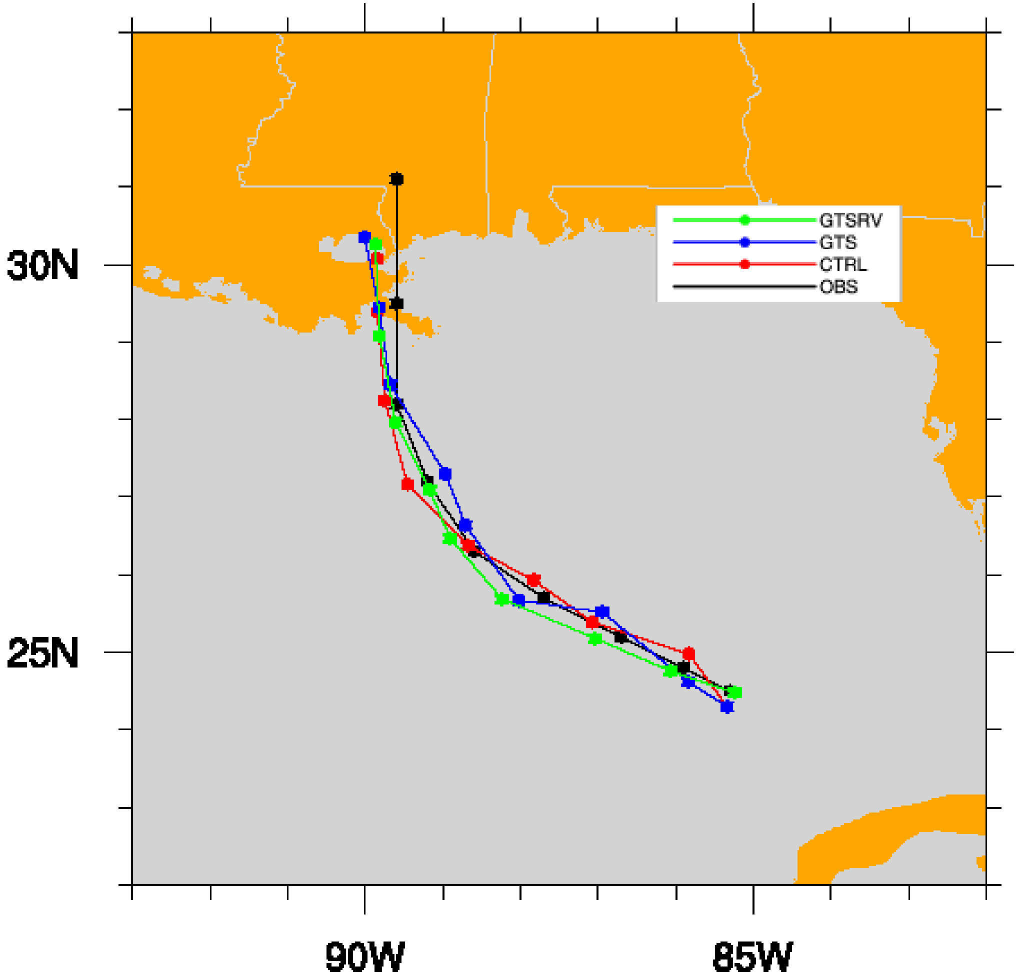


Best Track: 948mb

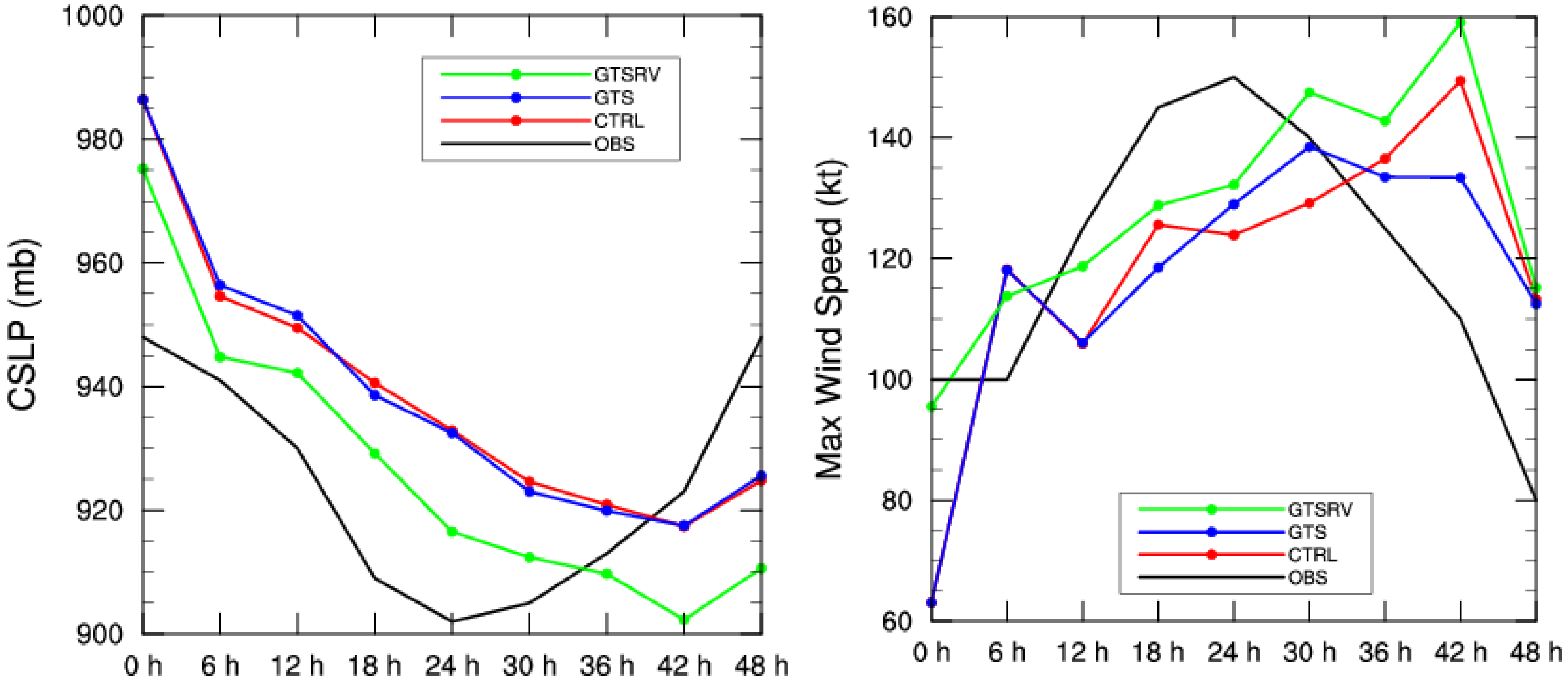
GFS Analysis: 985mb

GTSRV : 979mb

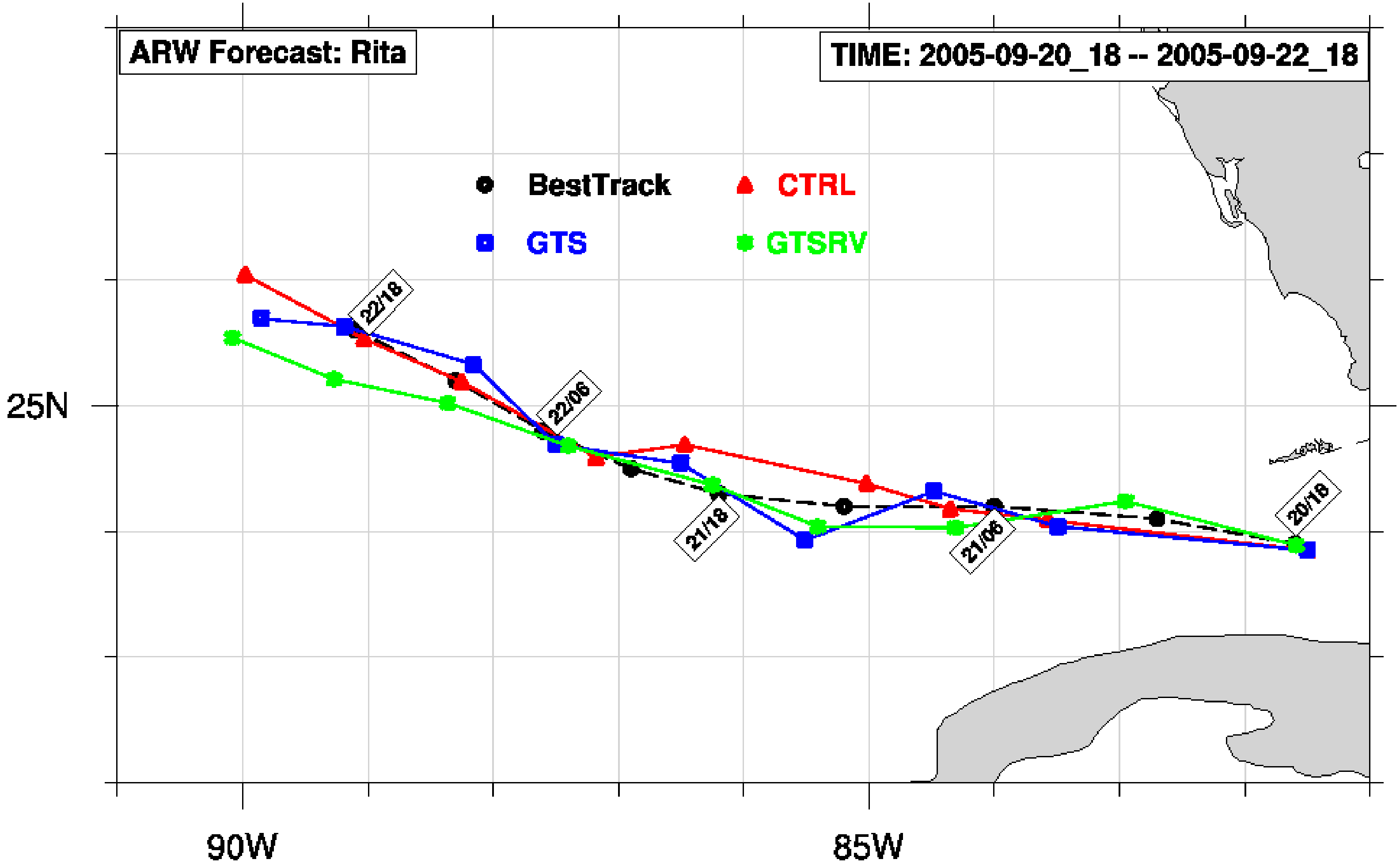
48-h Track Forecast for Katrina (2005)



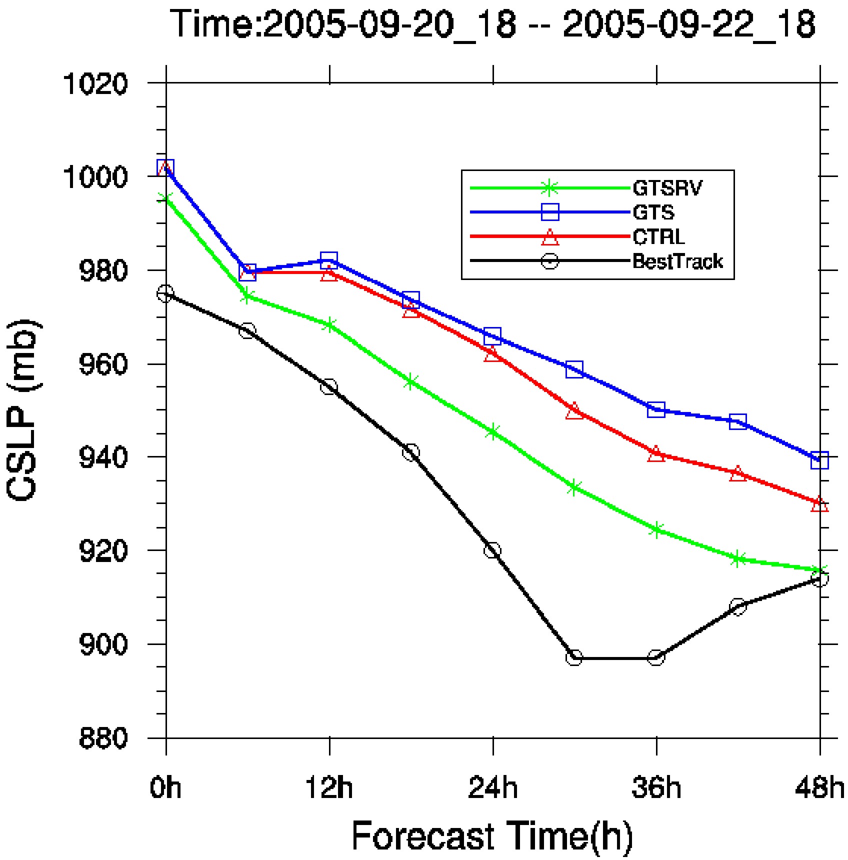
48-h Intensity Forecast for Katrina (2005)

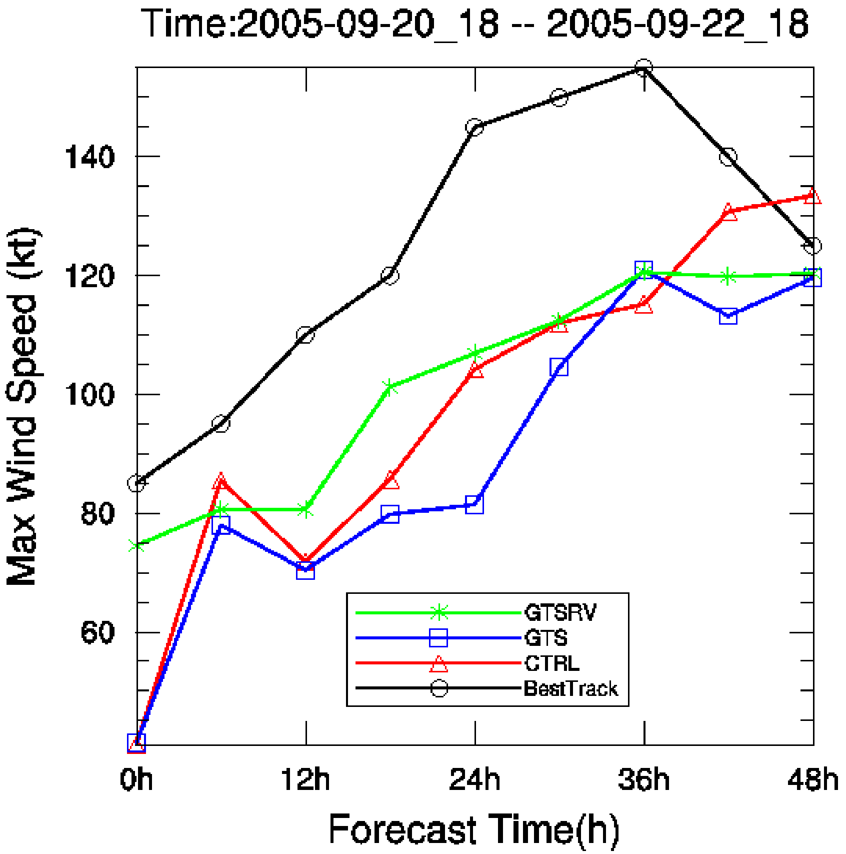


48-h Track Forecast for Hurricane Rita (2005)

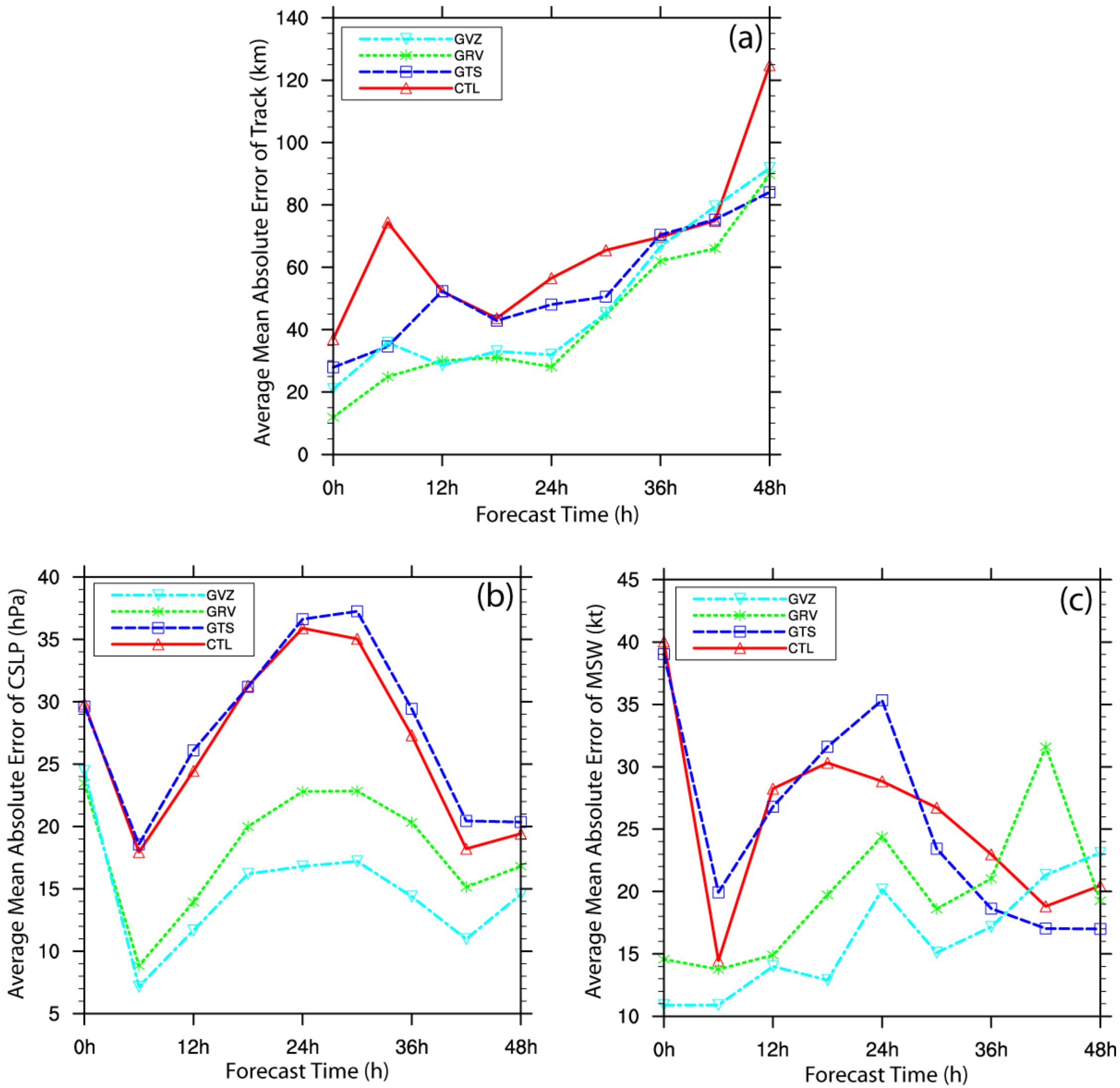


48-h Intensity Forecast for Rita (2005)





Average mean absolute errors for the three hurricanes a) track, b) CSLP, and c) MSW



Summary and Conclusions

- Airborne Doppler radar data have a more detailed hurricane inner-core structure. Assimilation of the data results in a better vortex initialization.
- Both the intensity and track forecast are improved after assimilating airborne Doppler radar wind data. The intensity forecast benefits more than track from airborne Doppler radar data assimilation.
- The benefits of airborne Doppler data assimilation are somewhat smaller for the stronger, rapidly intensifying hurricanes of Katrina and Rita (2005) than for Jeanne (2004).
- In terms of WRF 3D-Var for airborne Doppler data assimilation, some limitations also exist.
  - ✓ A specific background error covariance for hurricanes should be developed.
  - ✓ Reflectivity assimilation in WRF 3D-Var uses warm-rain process to bridge rainwater with other model variables in the analysis.
  - ✓ Observation error statistics for aircraft radar data are only crudely represented at present.
  - ✓ WRF 3D-Var does not take into account the time differences but instead ingests data at one instant in time.

Thank you!