Vortex-Scale Hurricane Data Assimilation:

OSSE Results with Airborne Doppler Radar and Dropsondes Using NOAA/AOML/HRD's HWRF Ensemble Data Assimilation System (HEDAS)

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NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
NOAA
U.S. DEPARTMENT OF COMMERCE

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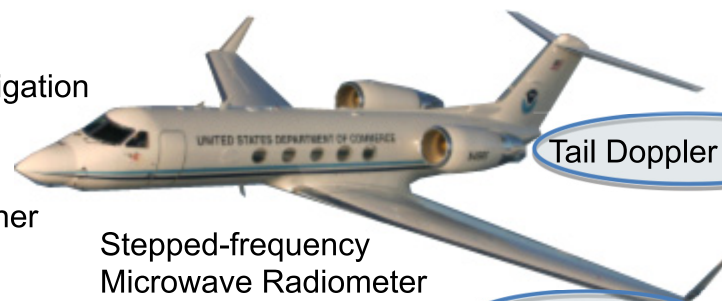
RSMAS
ROSENSTIEL SCHOOL
OF MARINE AND ATMOSPHERIC SCIENCE

NOAA Operates Three Aircraft to Observe Hurricane Environment and Vortex Structure:

P-3 Aircraft
(core penetrations)

HRD EnKF Effort Primarily Focusing on
***Dropsonde, Doppler Radar,* and *Flight-Level* Obs**

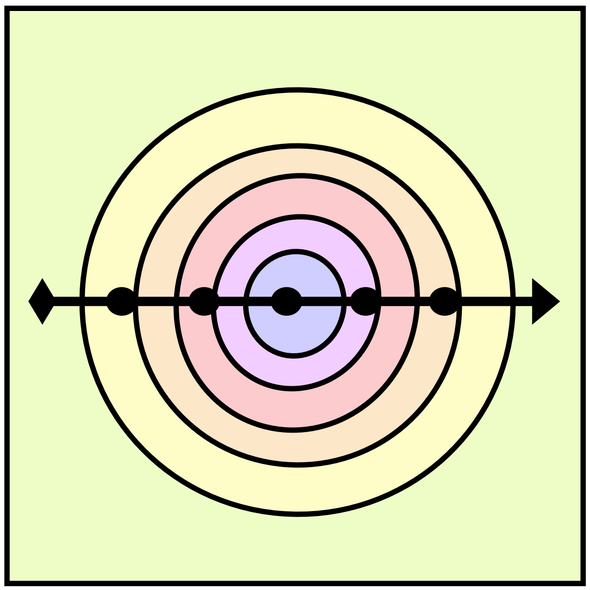
G-IV Aircraft
(synoptic surveillance)



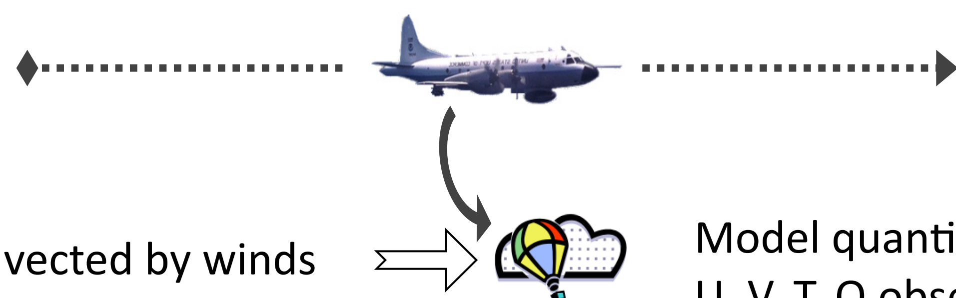
NOAA/AOML/HRD's HWRF Ensemble Data Assimilation System (HEDAS)

- **Forecast model:**
  - Experimental Hurricane WRF (HWRF-X); WRF NMM core
  - 2 nested domains (9/3 km horizontal resolution, 42 vert. levels)
  - Static inner nest to accommodate covariance computations
  - Ferrier microphysics, explicit convection on inner nest
- **Ensemble system:**
  - Currently initialized from GEFS ensemble member analyses
  - 30 ensemble members
- **Data assimilation:**
  - Square-root EnKF filter (Whitaker and Hamill 2002)
  - Assimilates inner-core NOAA P-3 aircraft data on the inner nest
  - Covariance localization (Gaspari and Cohn 1999)
  - Prior state inflation (10%) and covariance relaxation (50%)
  - Filter solver parallelized using OpenMP

Simulation of Aircraft Dropwindsonde Observations:



- One complete leg per assimilation cycle
- Total leg length = 500 km
- Drop release points determined based on starting point, track direction, release point resolution
- Release point resolution = 25 km
(i.e., 20 release points per leg)
- Track direction rotated by 50° between legs

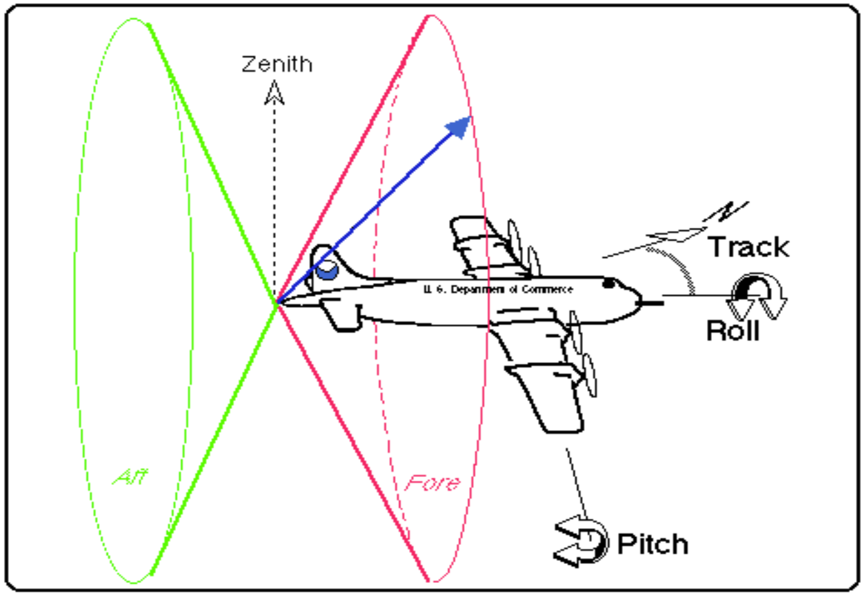


Flight altitude = 700 mb

Dropsonde advected by winds

Model quantities extracted every ~ 50 mb
U, V, T, Q observed

Simulation of Aircraft Radar Doppler Wind Observations:



- Same track information as dropwindsonde observations used
- Radar beam(s) are simulated for each assumed observation location along simulated track
- Observation location spacing = 5 km
- 40 bins are extracted along simulated radar beams with 0.5-km vertical and 3-km horizontal resolution

New doppler wind forward operator:

- **Coordinate transformation from aircraft-relative to Earth-relative azimuth and elevation (Lee et al. 1994)**
- **Interpolation of model U, V, W to observation location and computation of Doppler wind:**

```
Vr = U*sin(az)*cos(elev) + V*cos(az)*cos(elev) + W*sin(elev)
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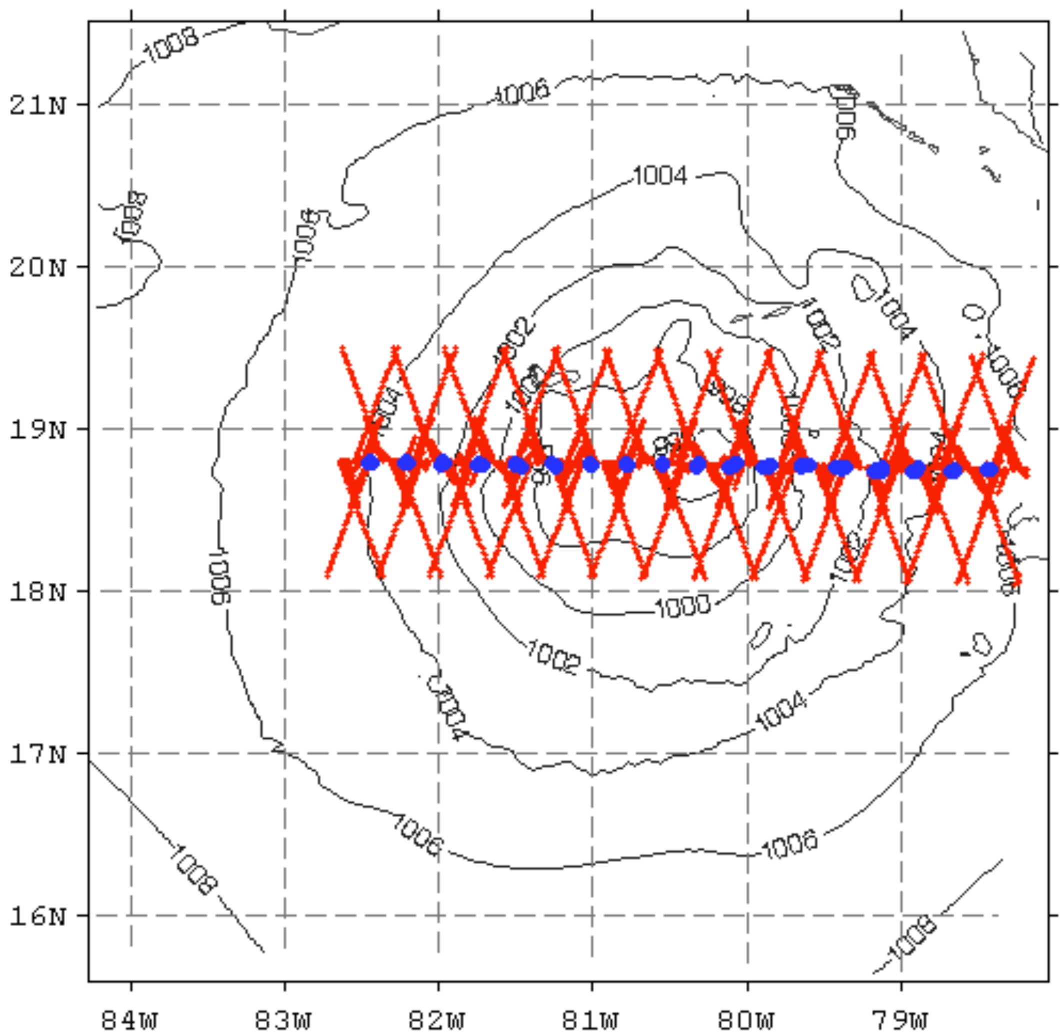
The Nature Run: Extracted Observations at 00Z



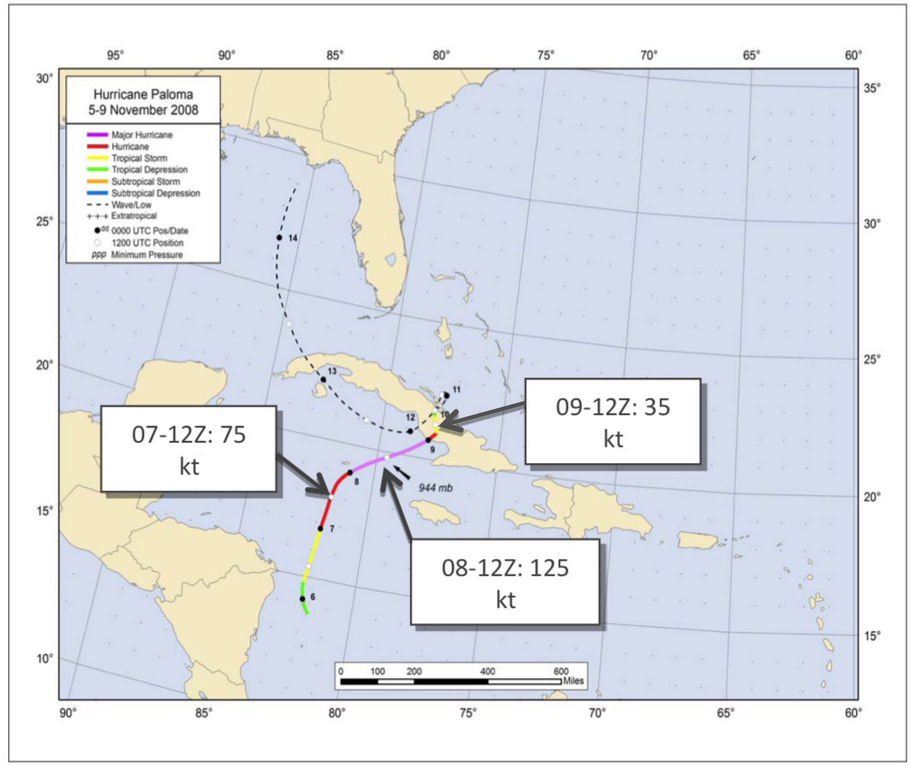
Starting Leg (1 hr):
Doppler wind observation locations (~10^4 obs / leg)
&
Dropsonde locations (~10^3 obs / leg)

Track orientation rotated by 50° between assimilation times, centered at respective storm center

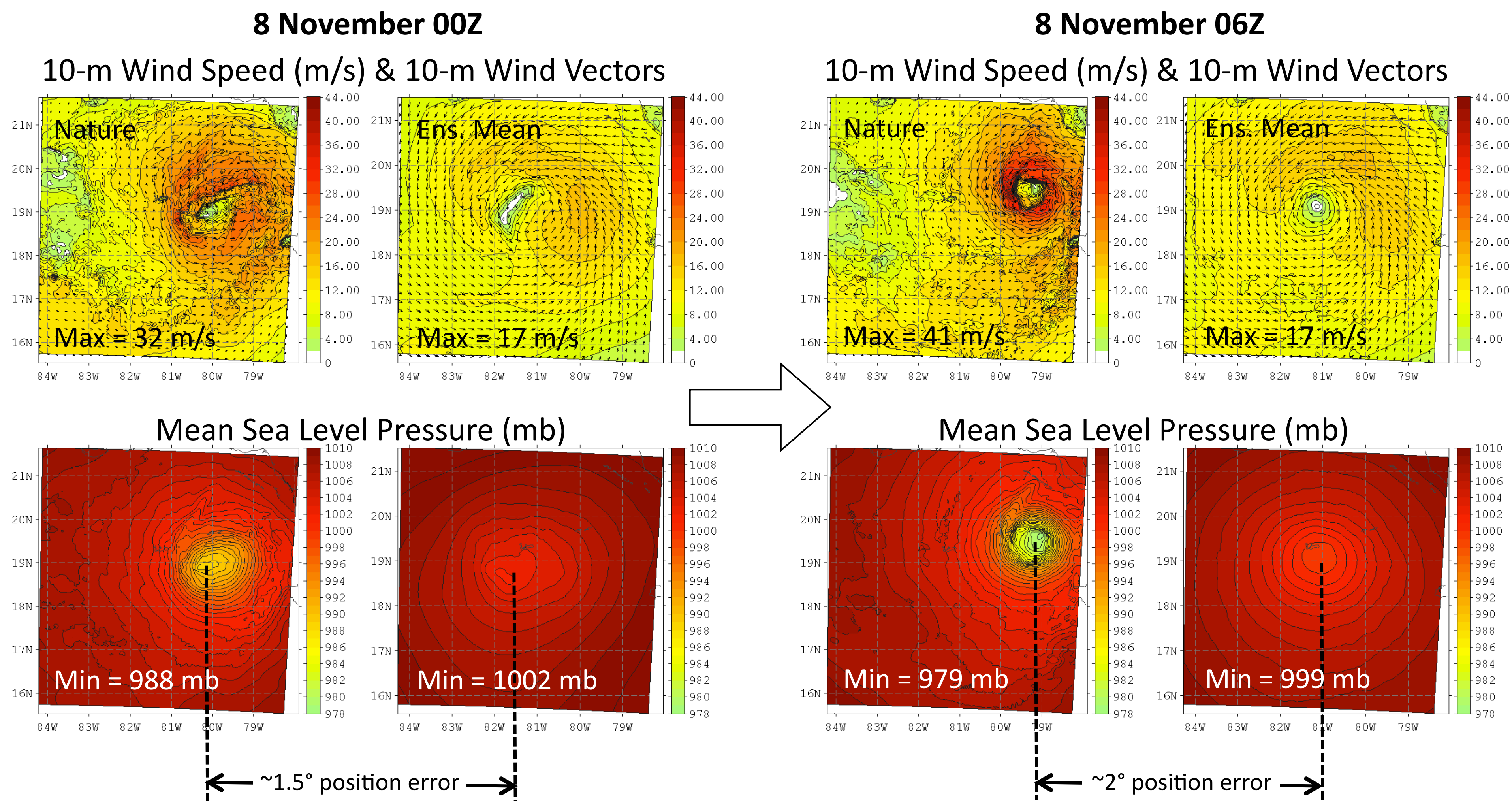
For each assimilation time, all legs are simulated for evaluation purposes.

Test case : Hurricane Paloma (November 7-9 2008)

- **Nature run:**
  - Initialized from one GEFS ensemble member on 07 00Z
  - Higher resolution (3/1 km) with explicit convection in all domains
  - Observations extracted every 1 hour between 08 00Z – 08 06Z
- **DA run:**
  - Initialized from GEFS ensemble member analyses on 07 18Z (6-hour spin-up before DA cycle)
  - Observations assimilated every 1 hour for a 6-hr analysis cycle between 08 00Z – 08 06Z (7 observation sets, 6 cycles)
  - Vortex-scale observations assimilated on inner (3-km) nest



The Ensemble Forecast without DA
6-Hour Vortex Evolution (00-06Z)

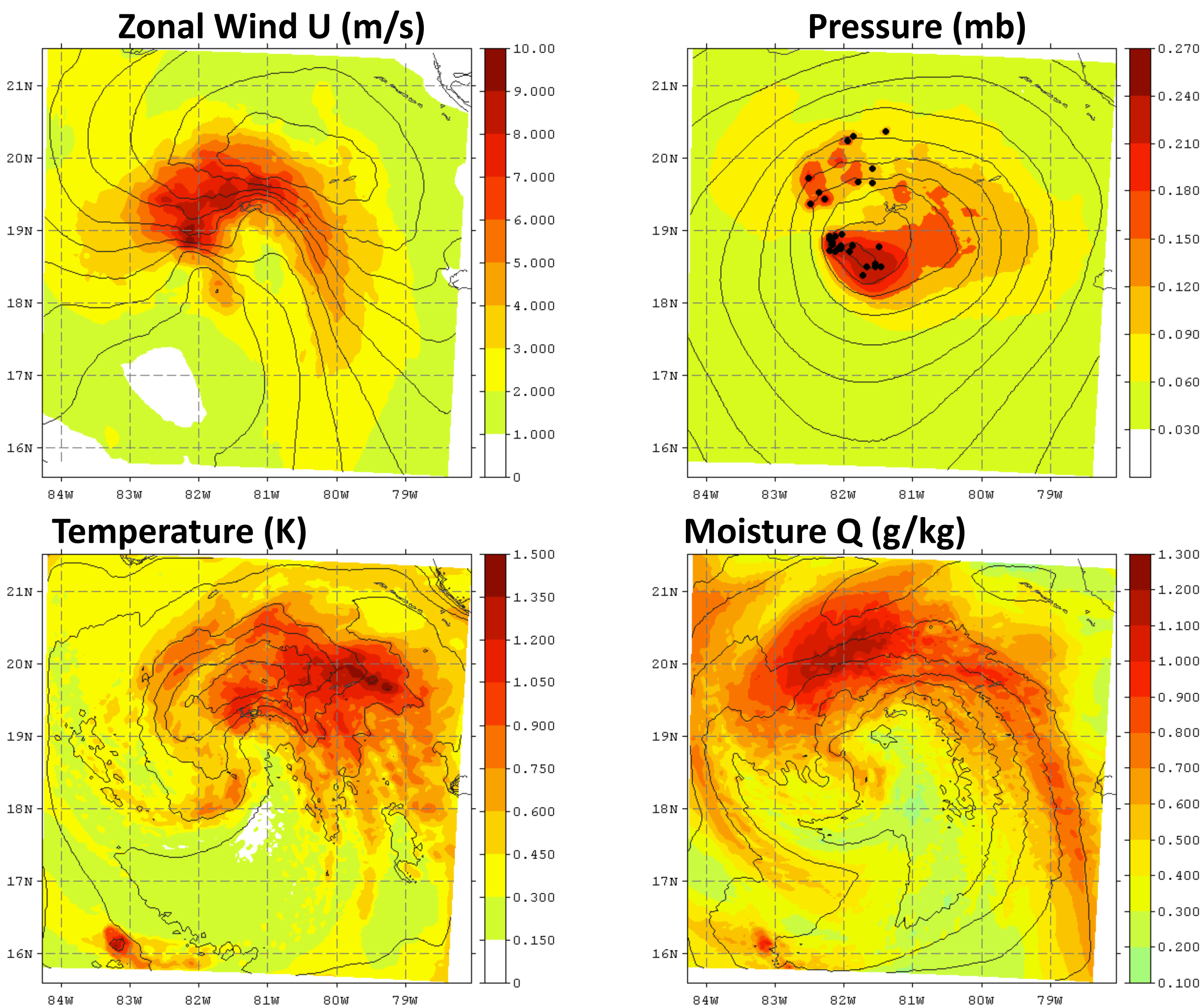


The Ensemble Forecast without DA
Ensemble Spread at Initial Time (00Z)

Ens. Spread – shaded

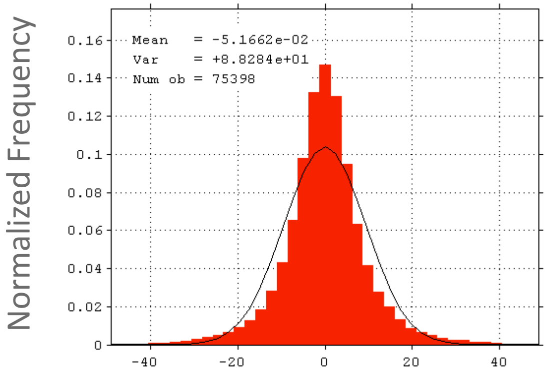
Ens. Mean – contoured

(All fields are plotted at lowest model level, ~ 30 m)

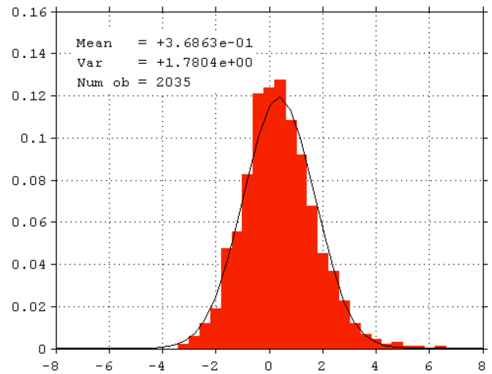


Observation Space Statistics: Prior Innovation Distributions (00Z)

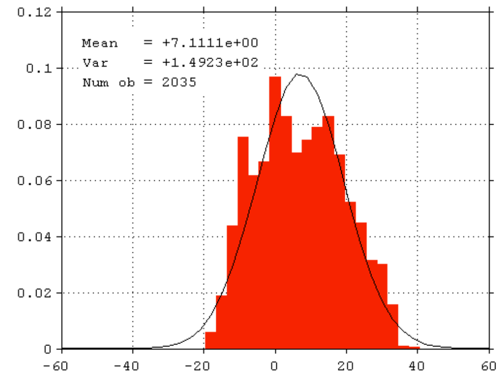
Doppler Wind (m/s)



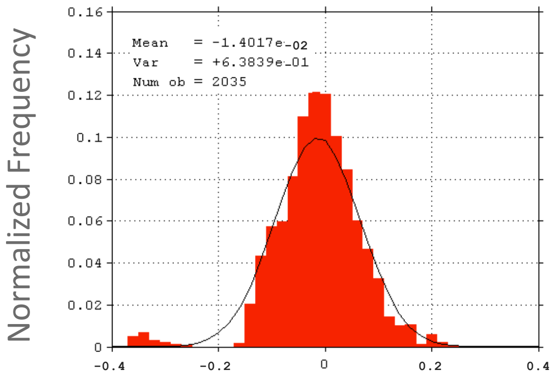
Dropsonde T (K)



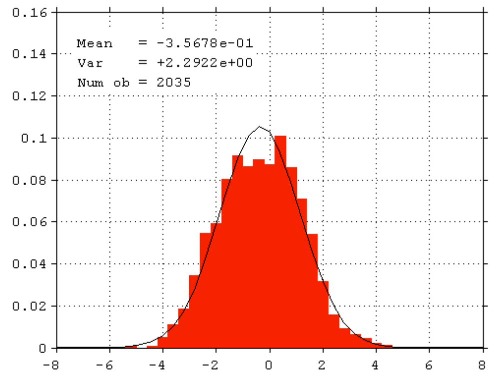
Dropsonde U (m/s)



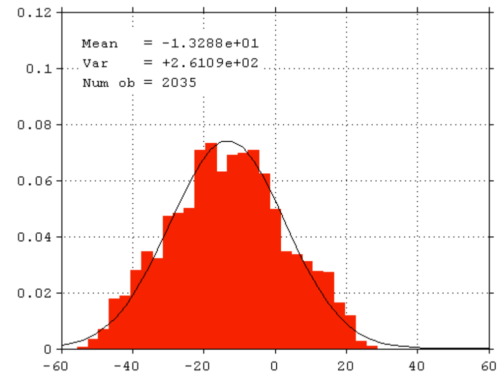
Dropsonde P (hPa)



Dropsonde Q (g/kg)



Dropsonde V (m/s)



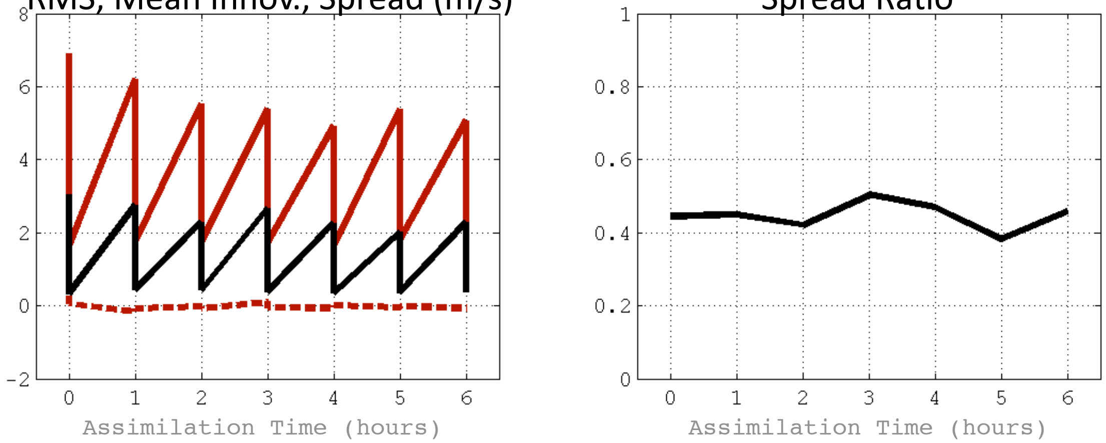
Assimilation of Doppler Wind: Observation Space Statistics – Doppler Wind

Assimilated Tracks

RMS Innovation

Ensemble Spread

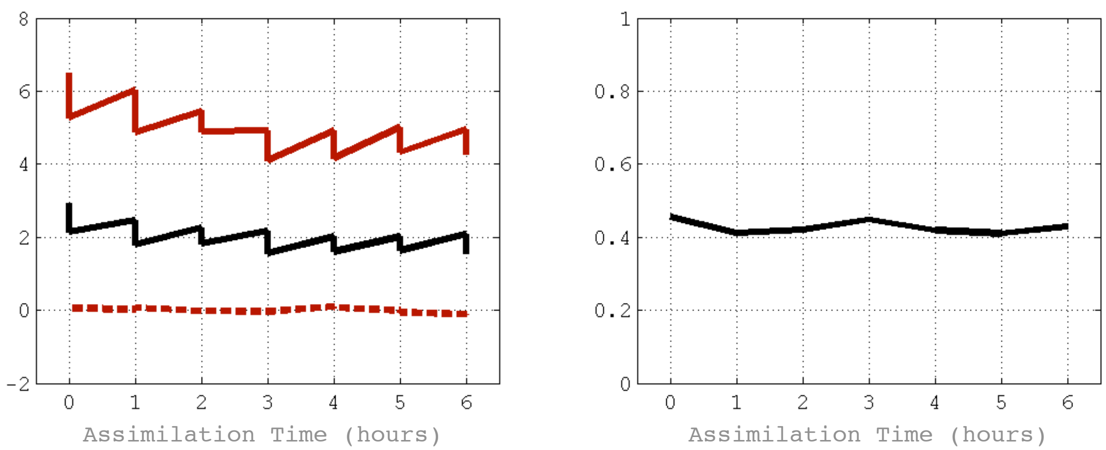
Mean Innovation



$$\text{Spread Ratio} = \frac{\langle s_f \rangle}{\sqrt{\langle r^f \rangle^2 - \sigma_{ob}^2}}$$

Spread Ratio is the ratio of forecast ensemble spread to "optimal" ensemble spread

Evaluated Tracks

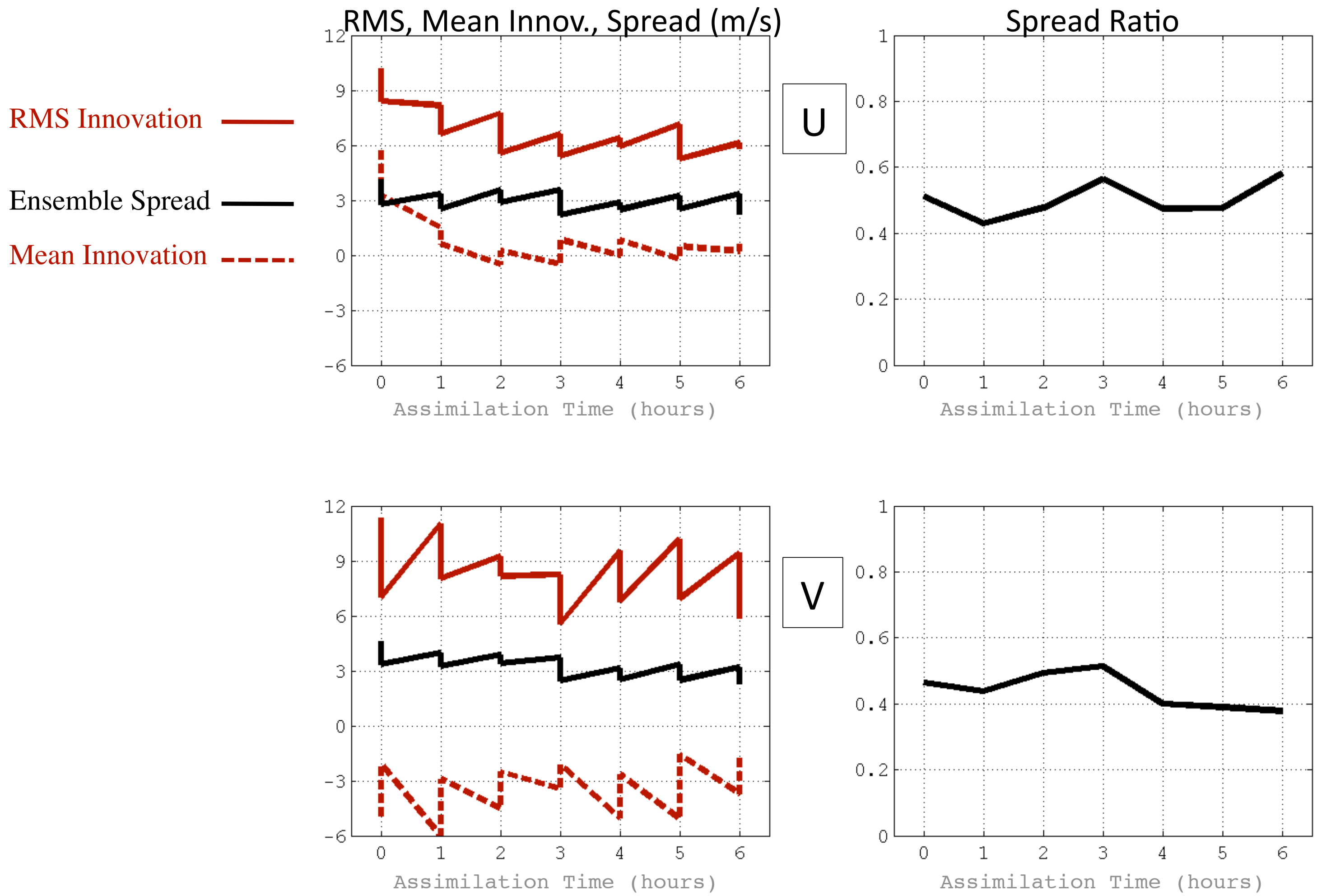


Ideally, we would like the actual/optimal spread ratio to be close to 1; but this is difficult to attain

Ideally, we would like

Assimilation of Doppler Wind: Observation Space Statistics – Dropsondes

All Tracks Are Evaluated



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Assimilation of Doppler Wind: Observation Space Statistics – Dropsondes

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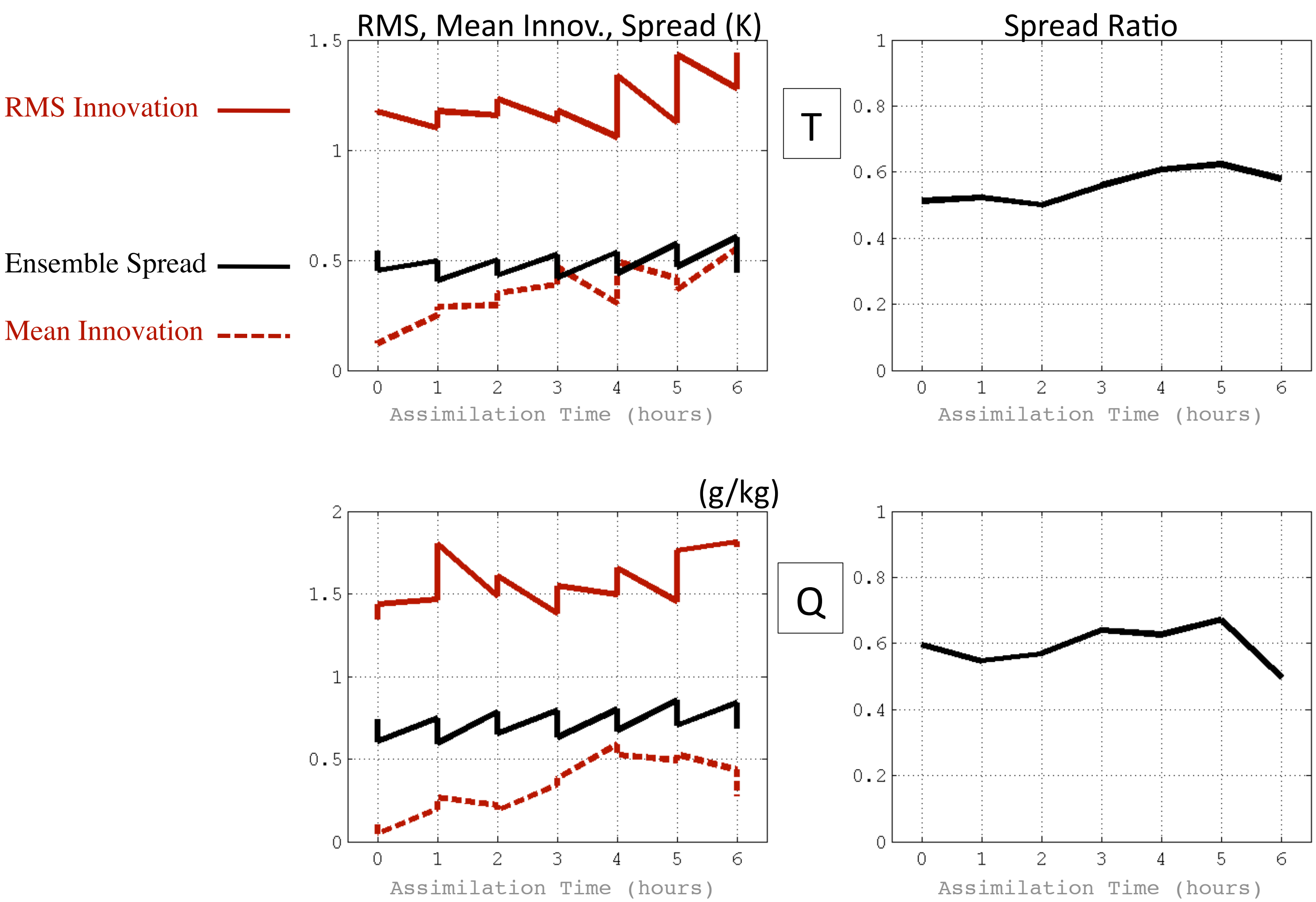

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Assimilation of Doppler Wind: Observation Space Statistics – Dropsondes

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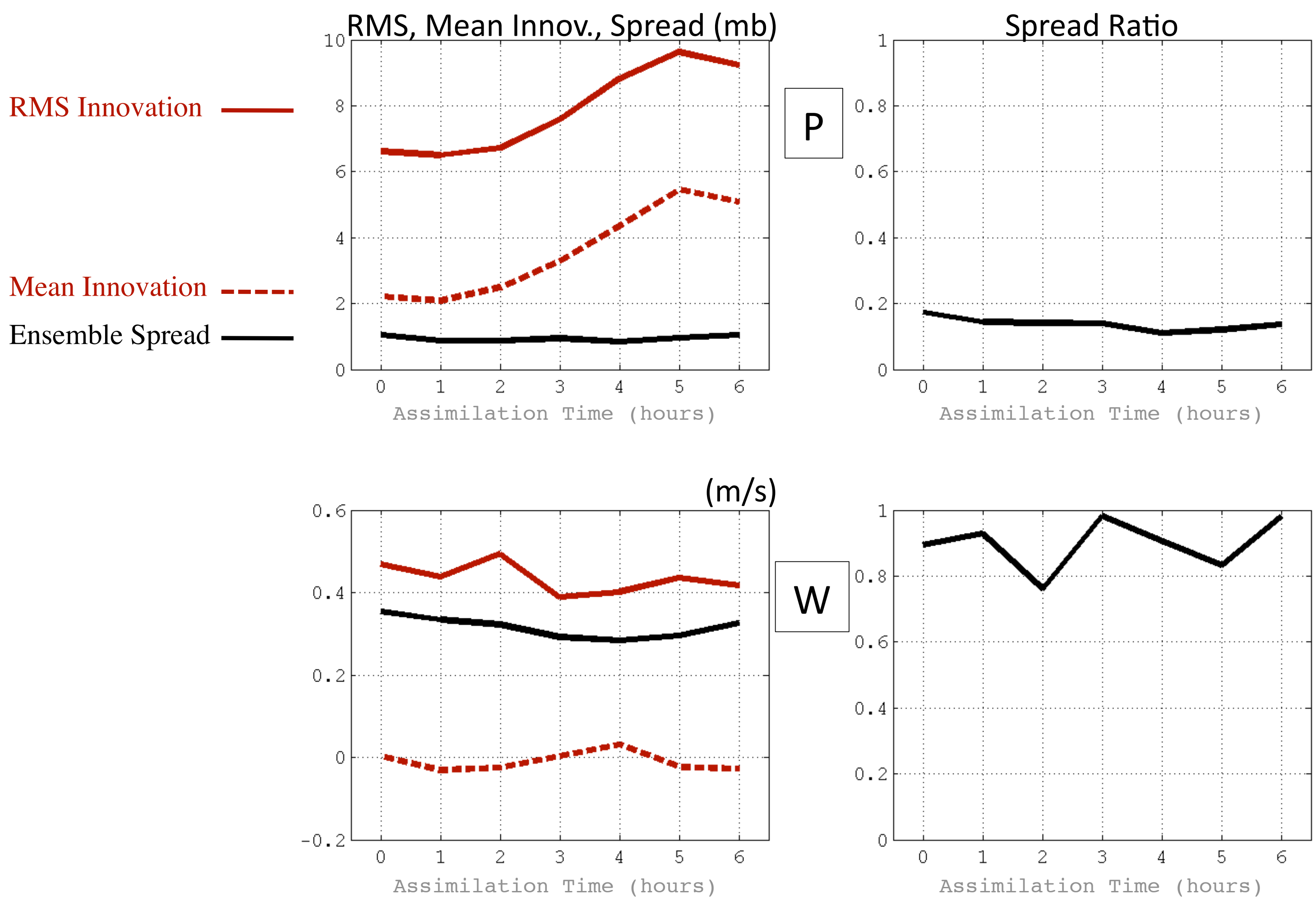

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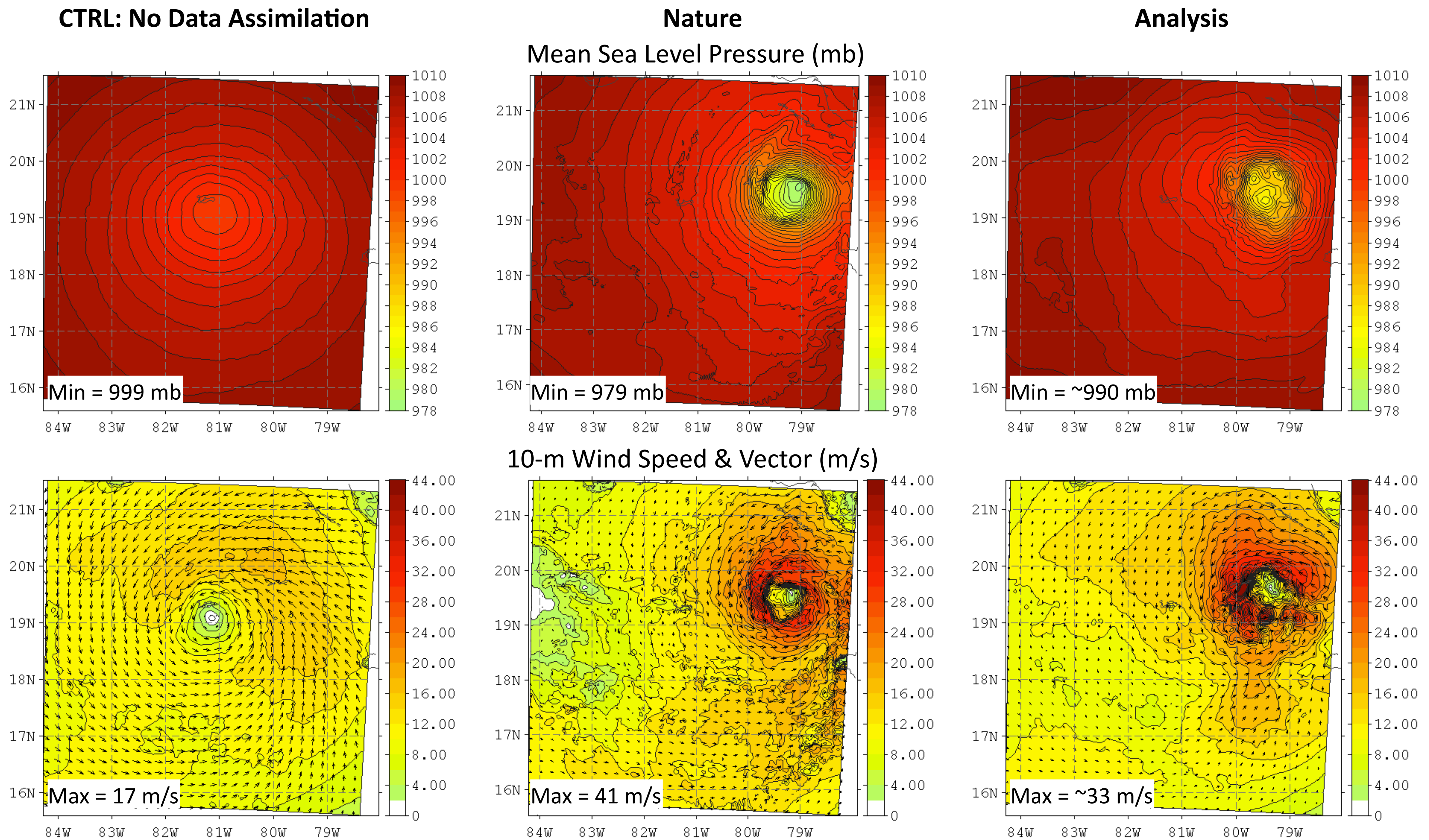
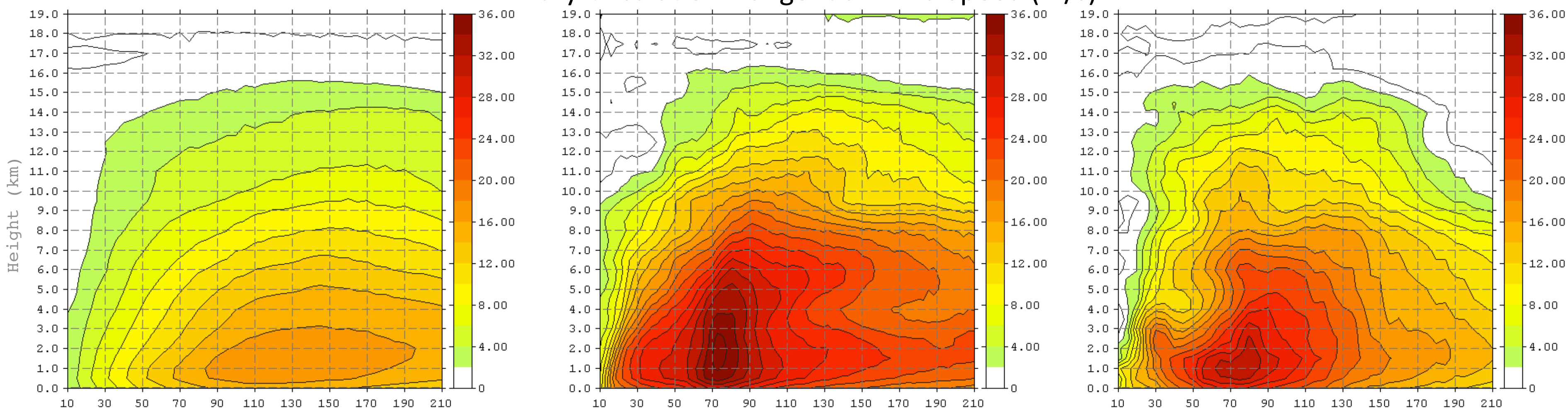
Final (06Z) Analysis Storm Structure: MSLP, Surface Wind Speed/Vectors



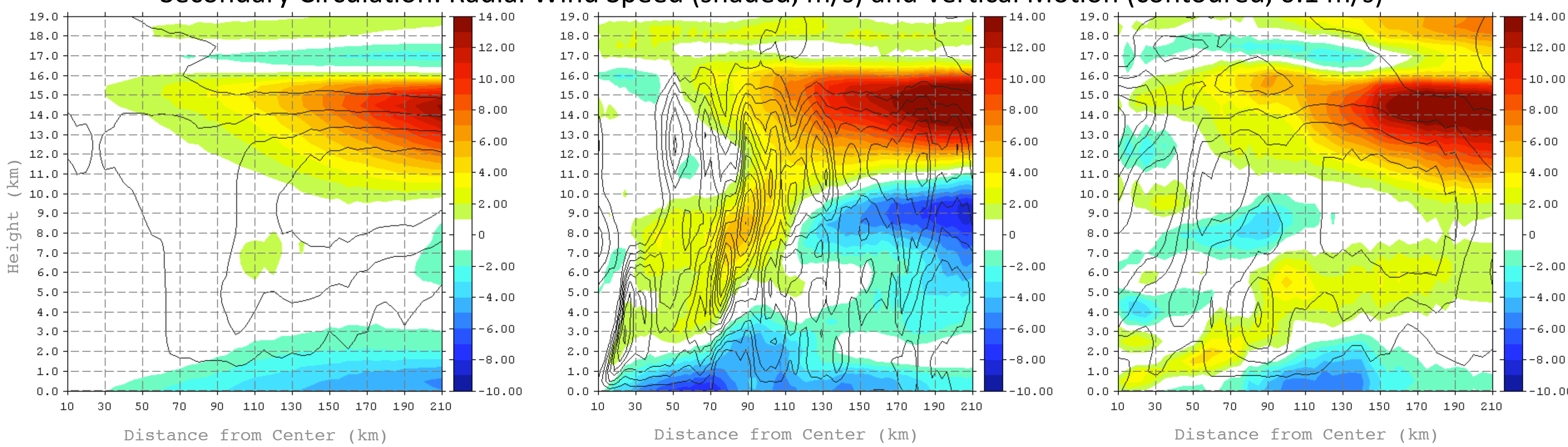
Final (06Z) Analysis Storm Structure:
R-Z Mean Primary and Secondary Circulations

CTRL: No Data Assimilation | **Nature** | **Analysis**

Primary Circulation: Tangential Wind Speed (m/s)



Secondary Circulation: Radial Wind Speed (shaded, m/s) and Vertical Motion (contoured, 0.1 m/s)

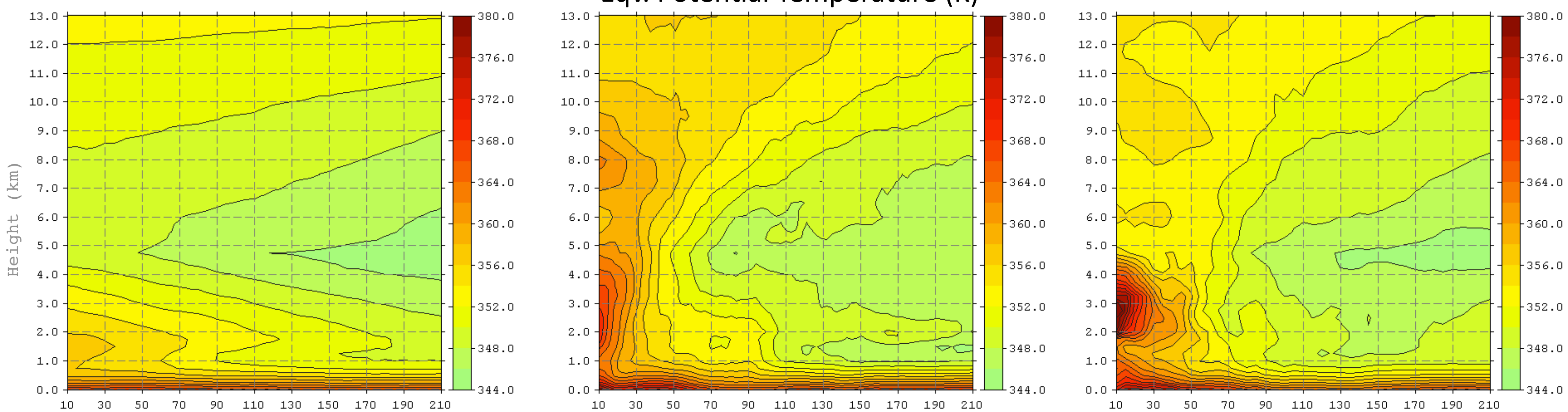


Final (06Z) Analysis Storm Structure:

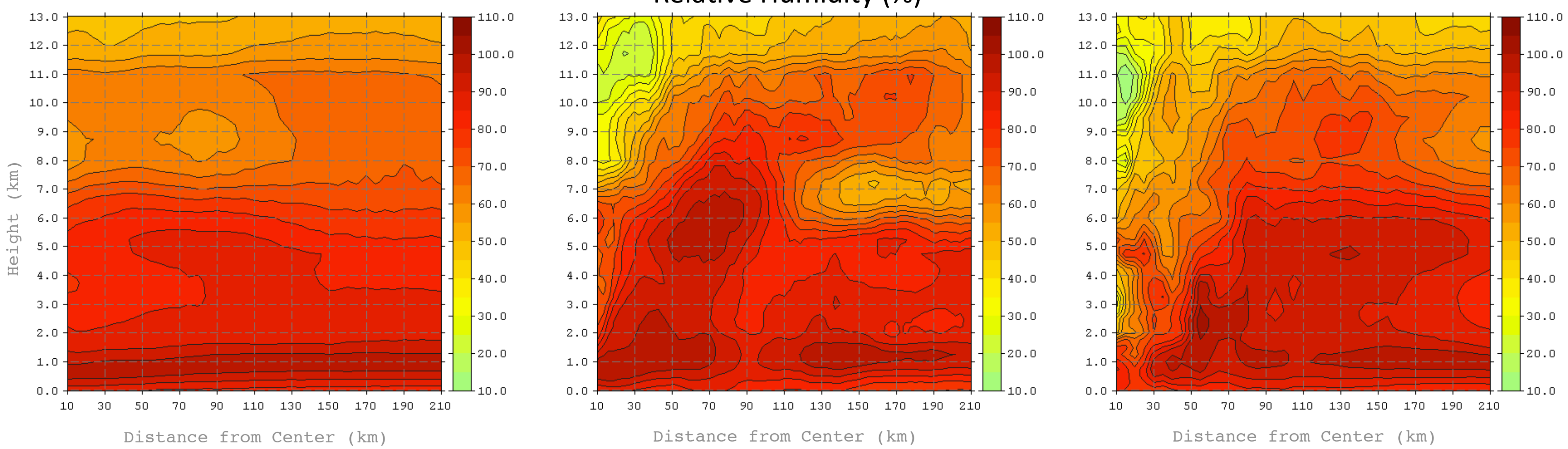
R-Z Mean Eqv. Pot. Temp. and Rel. Hum.

CTRL: No Data Assimilation | **Nature** | **Analysis**

Eqv. Potential Temperature (K)



Relative Humidity (%)



Further Planned HEDAS Development (2010-12)

- Real-time runs to start with the 2010 hurricane season
- Address ensemble spread issue:
    - Explore GFS-EnKF ensemble initial conditions
    - Explicitly account for intensity-related model error – parameter perturbations within the surface physics to introduce uncertainty into surface fluxes of momentum and heat
- Toward full coupling with the global EnSRF system NOAA/ESRL):
    - Transition to using GFS-EnKF analyses as initial/boundary conditions
    - Assimilate synoptic data through GSI operators on the parent nest
    - Transition to common EnSRF solver
- Assimilation of new airborne observation platforms, potentially including ocean data (SFMR-II, LIDAR, AXBTs, etc.)
- Diagnostics and assimilation of satellite data in the inner-core region
- Parameter estimation