Internal Research Report

(1) Assimilation of High-Resolution Hurricane Inner-Core Data with the HWRF Hurricane Ensemble Data Assimilation System (HEDAS): Evaluation of the 2008-2011 vortex-scale analyses

(2) Storm-relative data assimilation: Proof of concept with OSSE experiments

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Outline

- Description of the real-time HEDAS system
- Research results (1): Retrospective real-data cases
  - Overview of real-data cases
  - Performance of HEDAS analyses
  - Conclusions
- Research results (2): Storm-relative data assimilation
  - Motivation
  - Comparison of data distributions
  - Results from an OSSE experiment
  - Conclusions

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

- **Forecast model:**
  - Exp. HWRF with 2 nested domains (9/3 km hor. resolution, 42 vert. levels)
  - Static inner nest to accommodate covariance computations
  - Ferrier microphysics, explicit convection on inner nest
- **Ensemble system:**
  - Initialized (cold start) from *GFS-EnKF (NOAA/ESRL)* ensemble member analyses
  - 30 ensemble members
- **Data assimilation:**
  - Square-root EnKF filter (Whitaker and Hamill 2002)
  - Assimilates data only on the inner nest
  - Covariance localization (Gaspari and Cohn 1999)
  - No explicit covariance treatment in the real time HEDAS
  - Filter solver parallelized using OpenMP

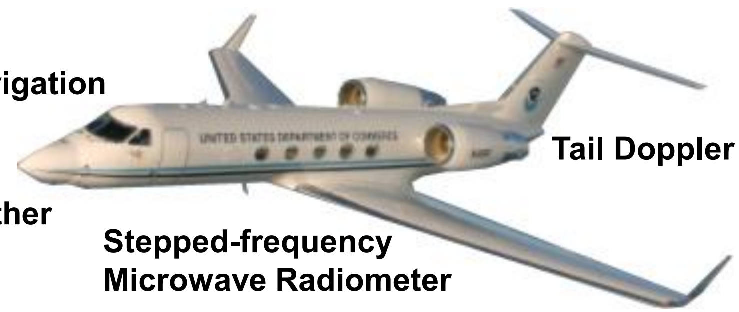
Aircraft Data of Interest

P-3 Aircraft (eye penetrations)

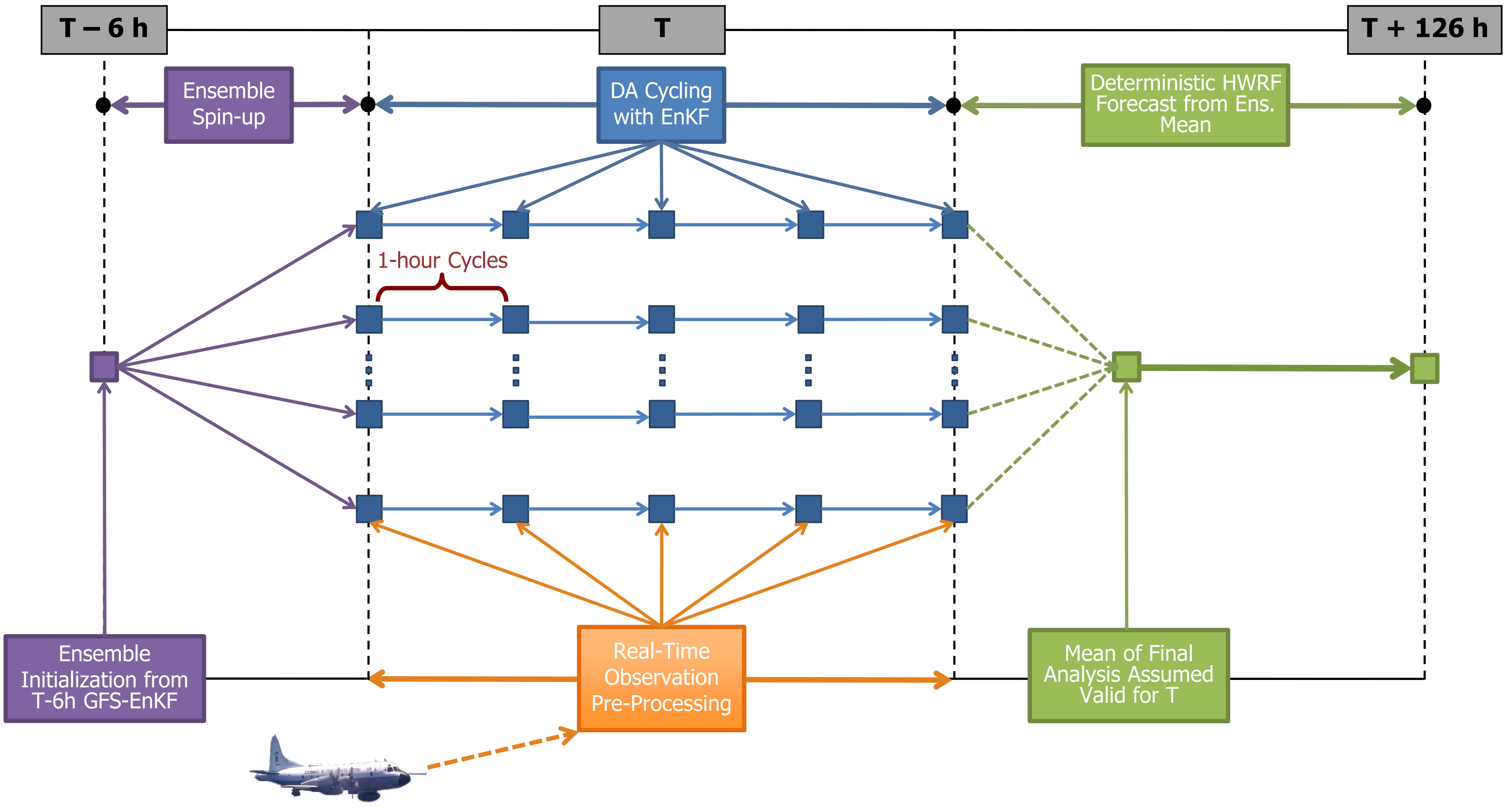
Observation	Error
Doppler wind speed	2 ms^{-1}
FL/Dropsonde Temperature	0.5 K
FL/Dropsonde zonal/merid. wind speed	2 ms^{-1}
SFMR	Variable, mean ~5 ms^{-1}

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

G-IV Aircraft (environmental)



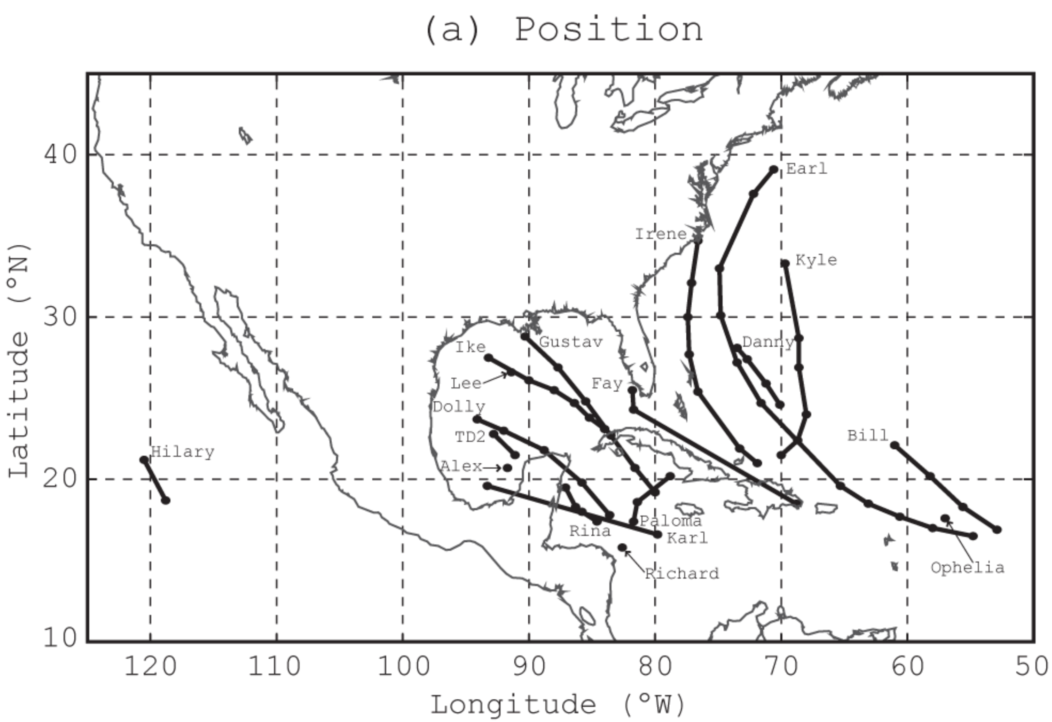
HEDAS Cycling Flow

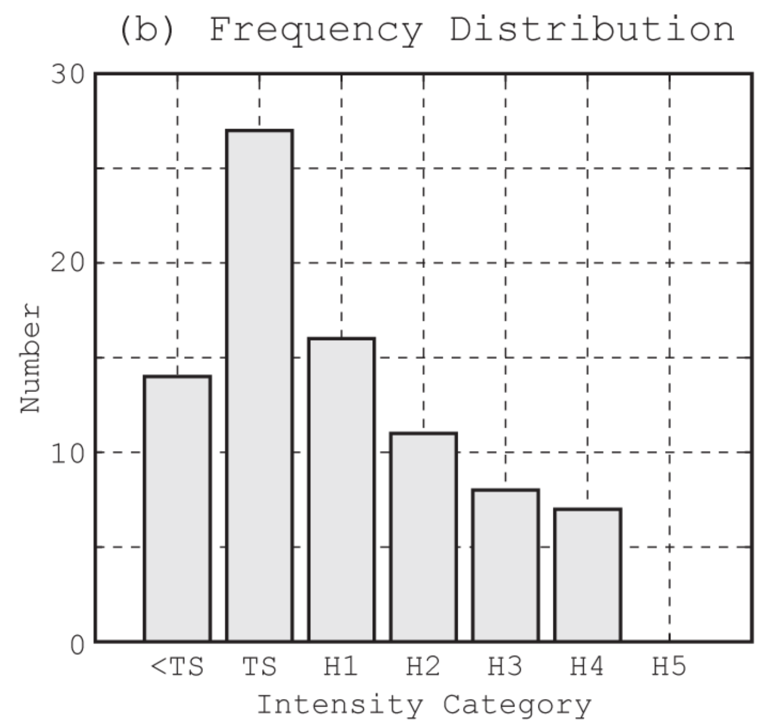


2008-2011 Real-Data Cases Considered

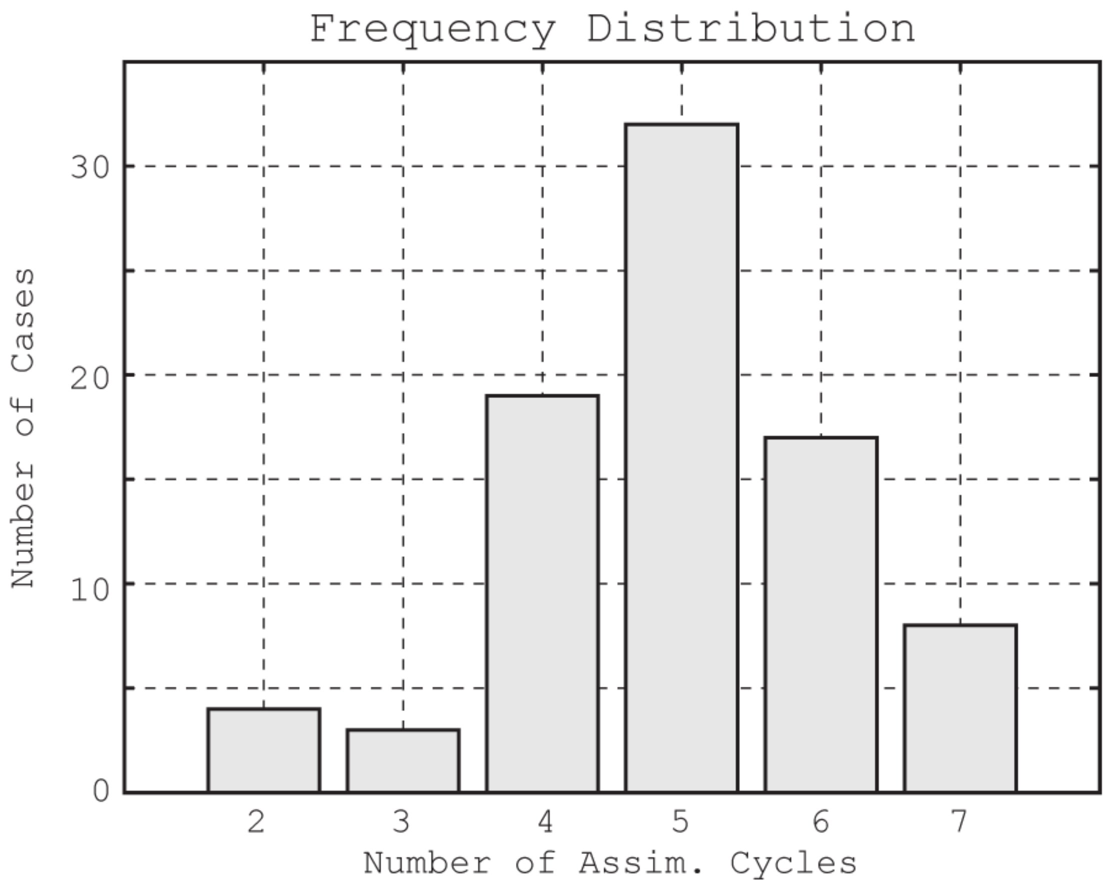
2008:		Ike	09-10-00Z	Danny	08-26-12Z	Karl	09-16-18Z
Dolly	07-20-12Z	Ike	09-10-12Z	Danny	08-27-00Z	Richard	10-23-06Z
Dolly	07-21-00Z	Ike	09-11-00Z	Danny	08-27-12Z	Tomas	11-04-00Z
Dolly	07-21-12Z	Ike	09-11-12Z	Danny	08-28-00Z	Tomas	11-04-12Z
Dolly	07-22-00Z	Ike	09-12-00Z	**2010:**		Tomas	11-15-00Z
Dolly	07-22-12Z	Ike	09-12-18Z	Alex	06-29-00Z	Tomas	11-06-12Z
Fay	08-14-12Z	Kyle	09-23-00Z	TD2	07-07-00Z	Tomas	11-07-00Z
Fay	08-15-00Z	Kyle	09-24-12Z	TD2	07-07-12Z	**2011:**	
Fay	08-15-06Z	Kyle	09-25-00Z	TD2	07-08-00Z	Irene	08-24-00Z
Fay	08-15-18Z	Kyle	09-25-12Z	Earl	08-29-00Z	Irene	08-24-12Z
Fay	08-18-18Z	Kyle	09-26-00Z	Earl	08-29-12Z	Irene	08-25-12Z
Fay	08-19-06Z	Kyle	09-26-18Z	Earl	08-30-00Z	Irene	08-26-00Z
Gustav	08-30-00Z	Kyle	09-27-00Z	Earl	08-30-12Z	Irene	08-26-12Z
Gustav	08-30-12Z	Kyle	09-27-18Z	Earl	08-31-00Z	Irene	08-27-00Z
Gustav	08-31-00Z	Paloma	11-07-06Z	Earl	09-01-12Z	Irene	08-27-12Z
Gustav	08-31-12Z	Paloma	11-07-18Z	Earl	09-02-00Z	Lee	09-02-00Z
Gustav	09-01-00Z	Paloma	11-08-18Z	Earl	09-02-12Z	Ophelia	09-24-18Z
Gustav	09-01-12Z	**2009:**		Earl	09-03-00Z	Hilary	09-28-18Z
Dolly	07-20-12Z	Ana	08-17-00Z	Earl	09-03-18Z	Hilary	09-29-18Z
Dolly	07-21-00Z	Bill	08-19-00Z	Earl	09-04-00Z	Rina	10-26-00Z
Dolly	07-21-00Z	Bill	08-19-12Z	Karl	09-13-00Z	Rina	10-26-18Z
Dolly	07-20-12Z	Bill	08-20-00Z	Karl	09-13-12Z	Rina	10-27-00Z
Dolly	07-21-00Z	Bill	08-20-12Z	Karl	09-14-00Z	Rina	10-27-18Z

Distribution of Cases

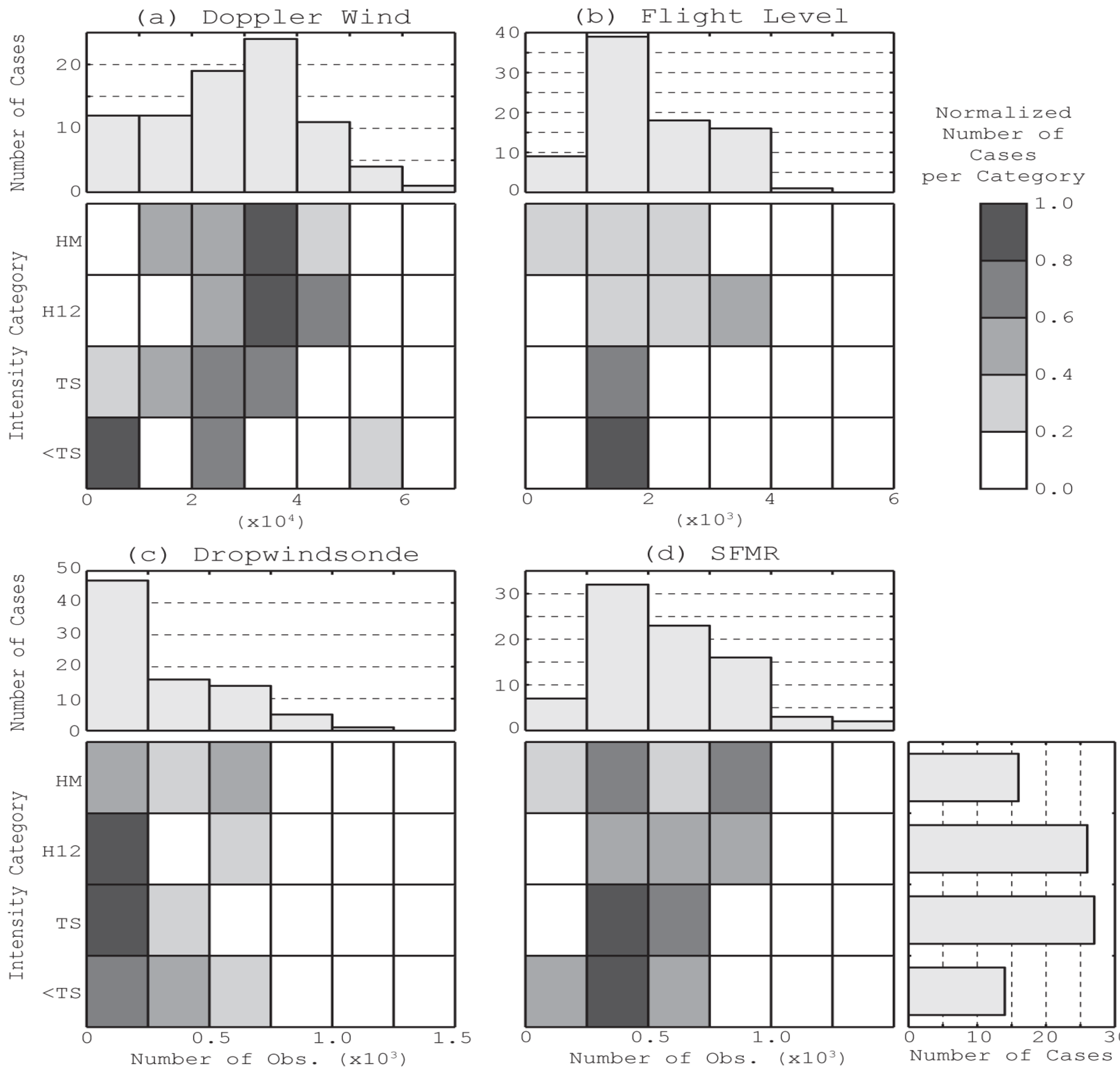




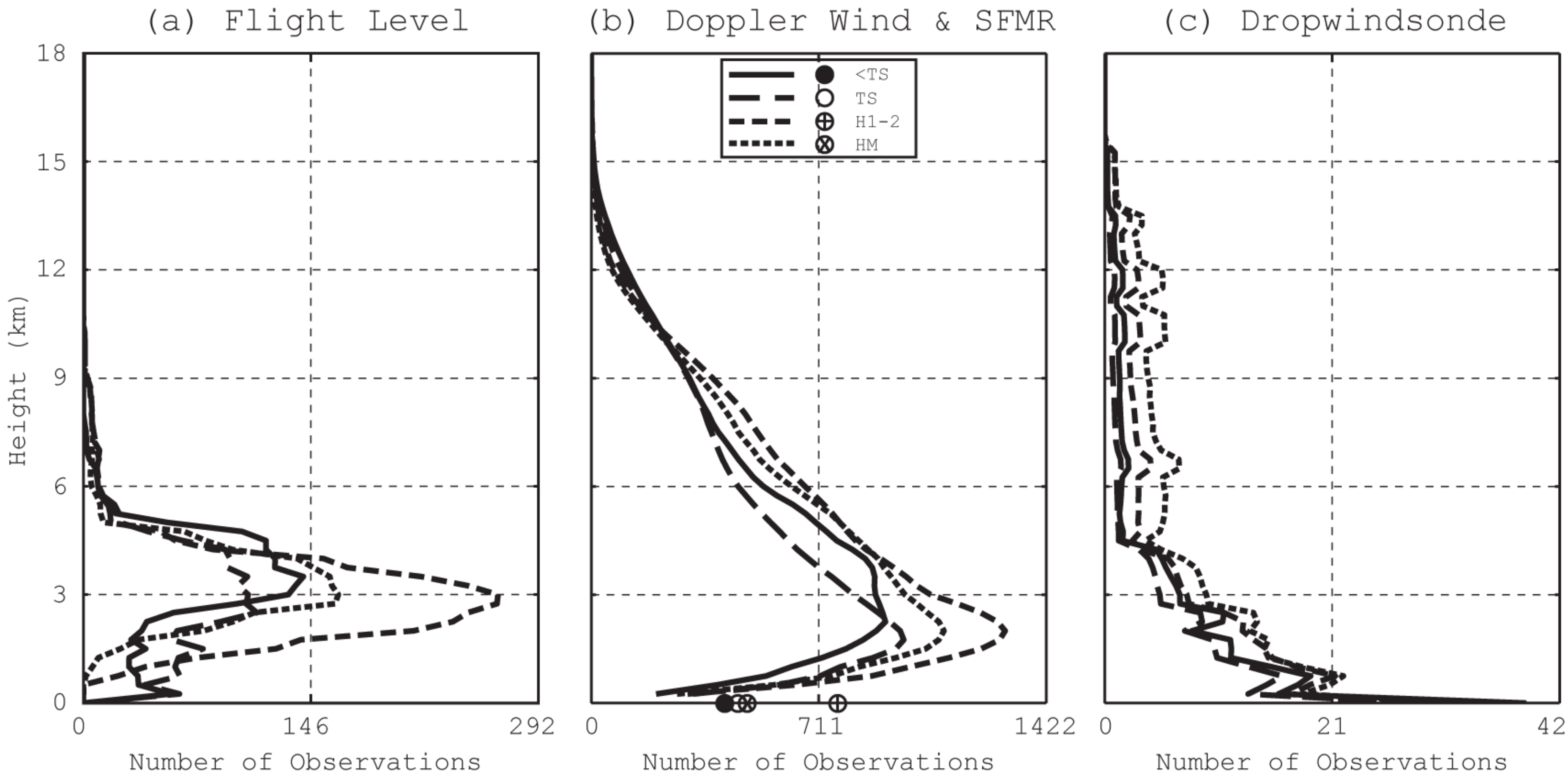
Number of Assimilation Cycles



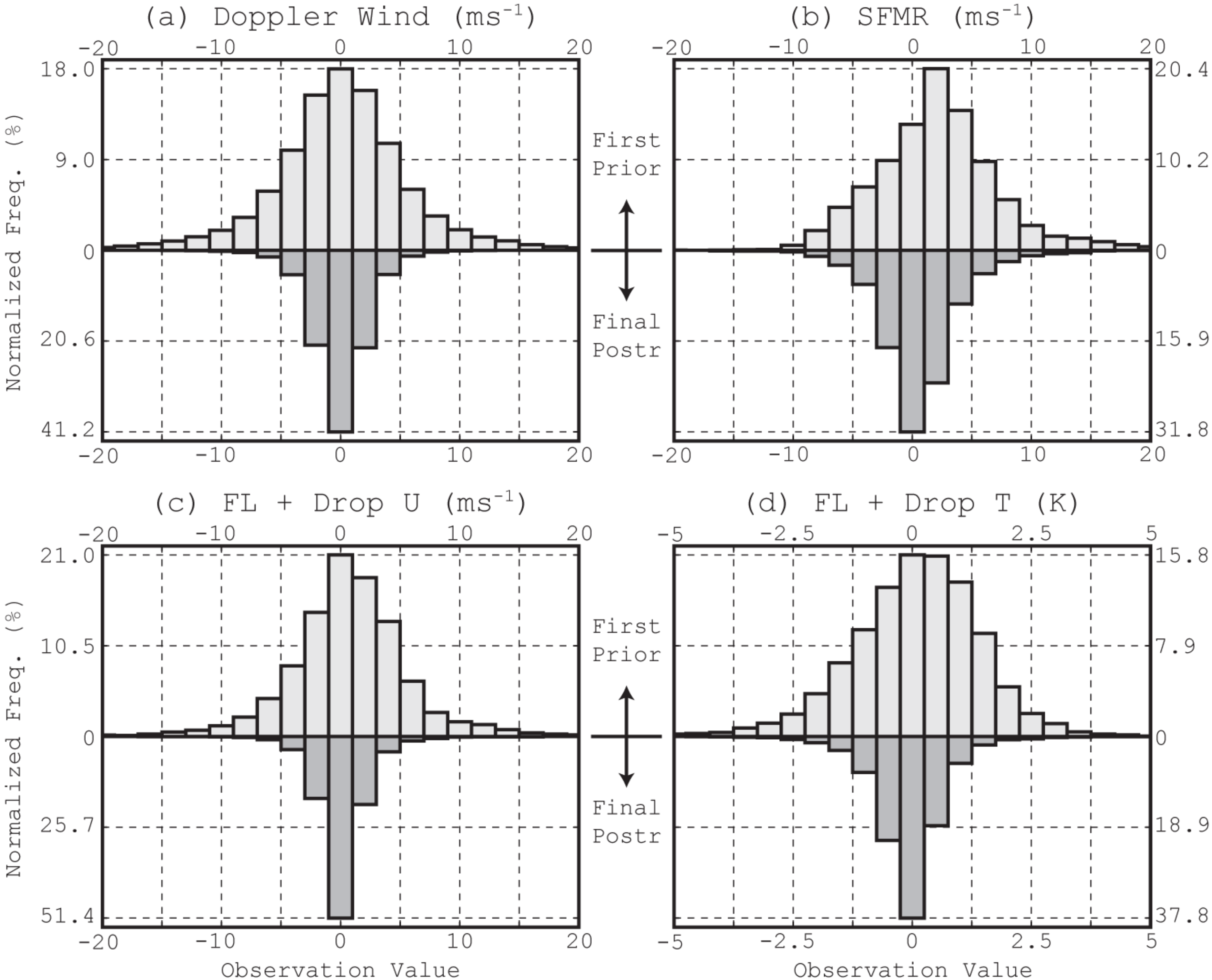
Number of Observations Assimilated



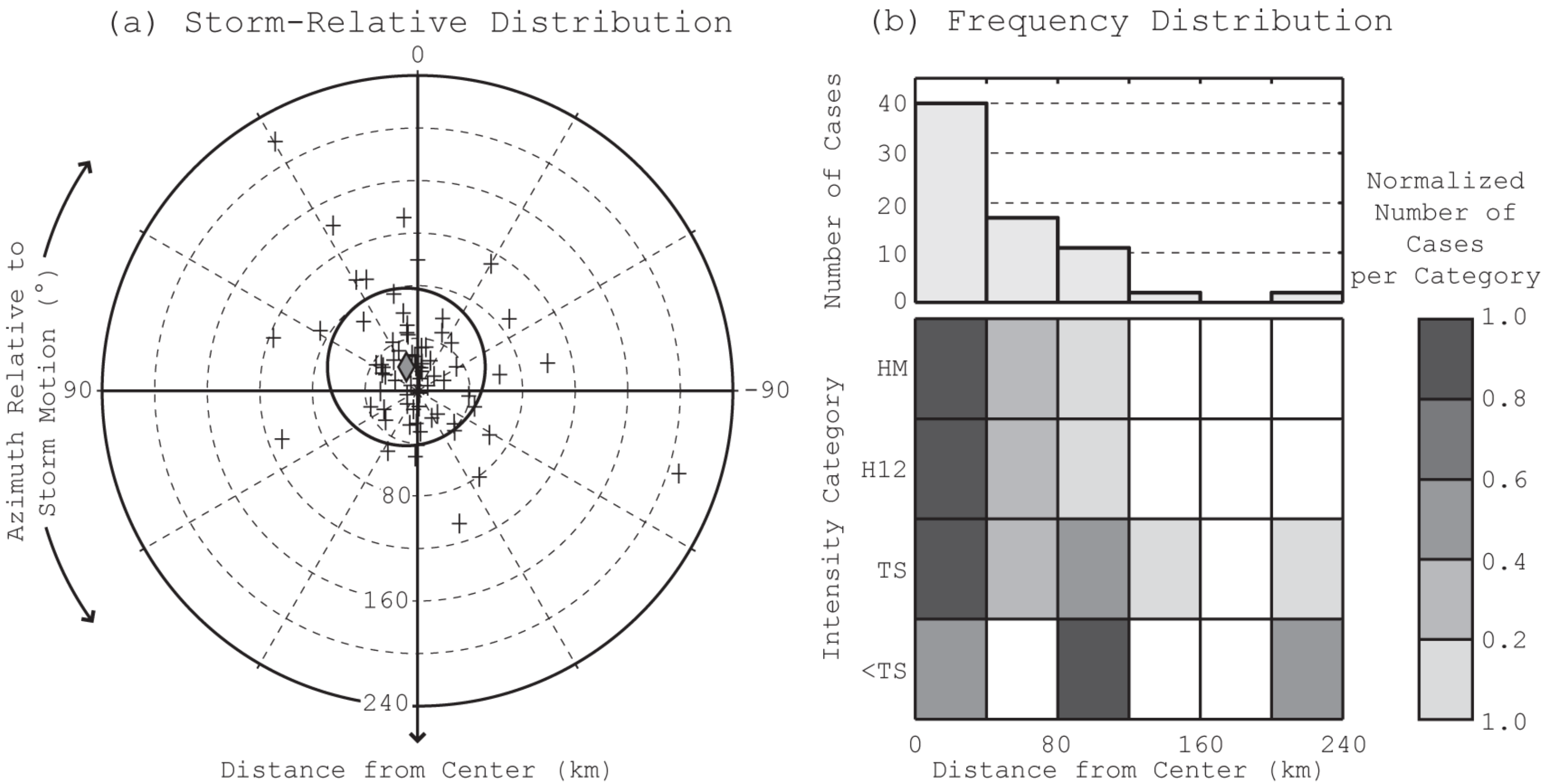
Number of Observations Assimilated



Distribution of Innovations (O-F & O-A)

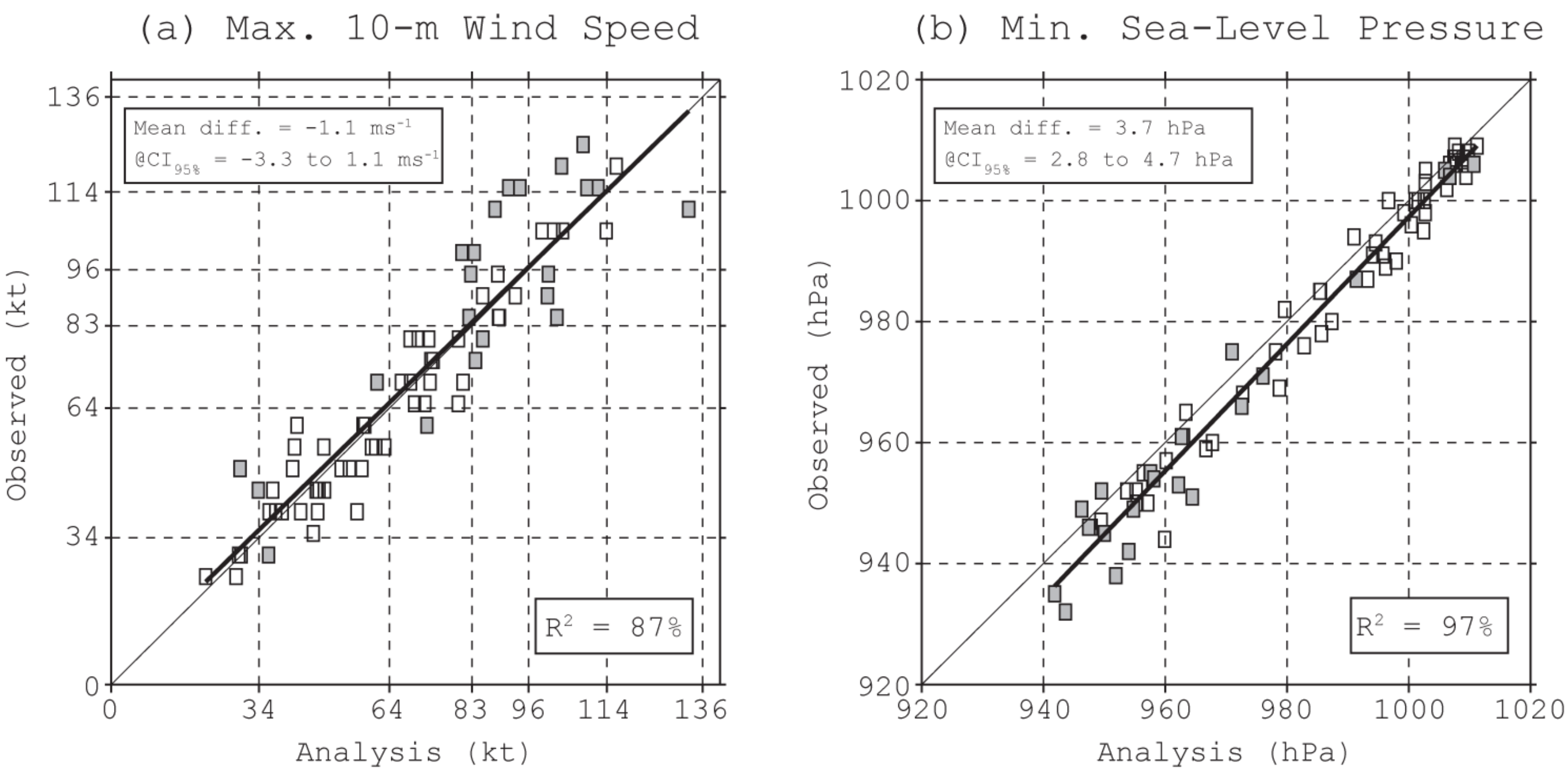


Position Error
(Analysis vs. Best Track)

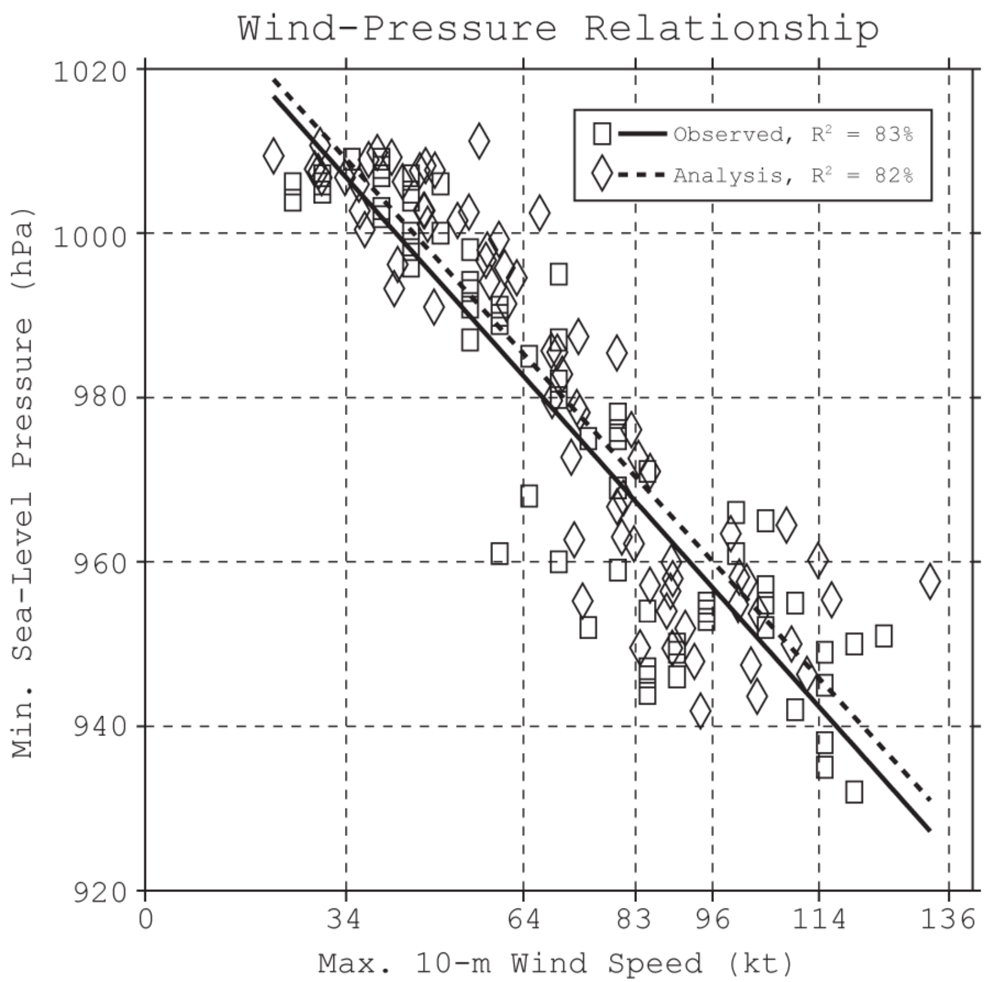


	Nearest Synoptic Time	Interpolation to Analysis Time
Mean Difference	57.7 km	38.3 km
Standard Error of Diff.	7 km	5.9 km

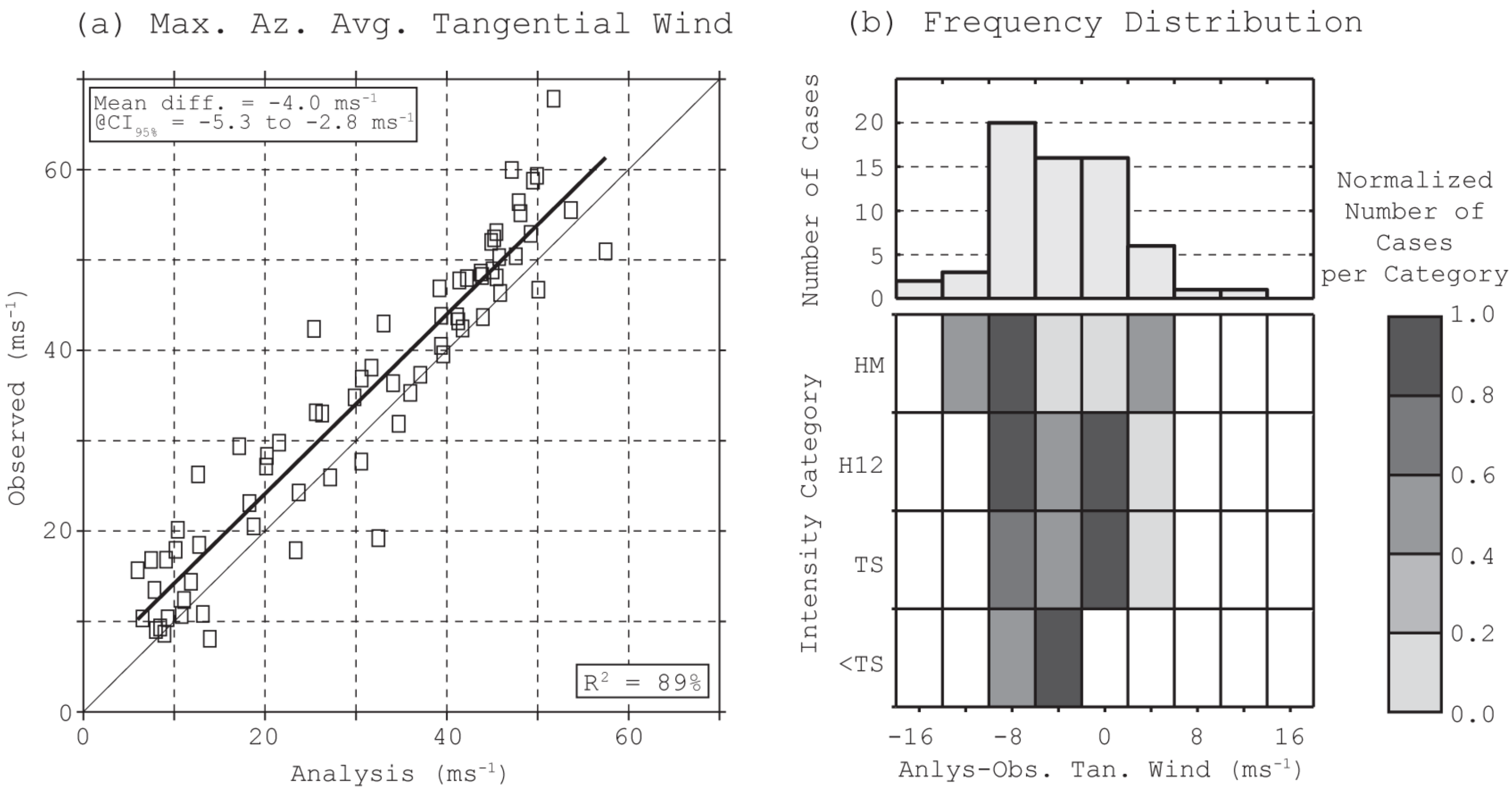
Intensity Error
(Analysis vs. Best Track)



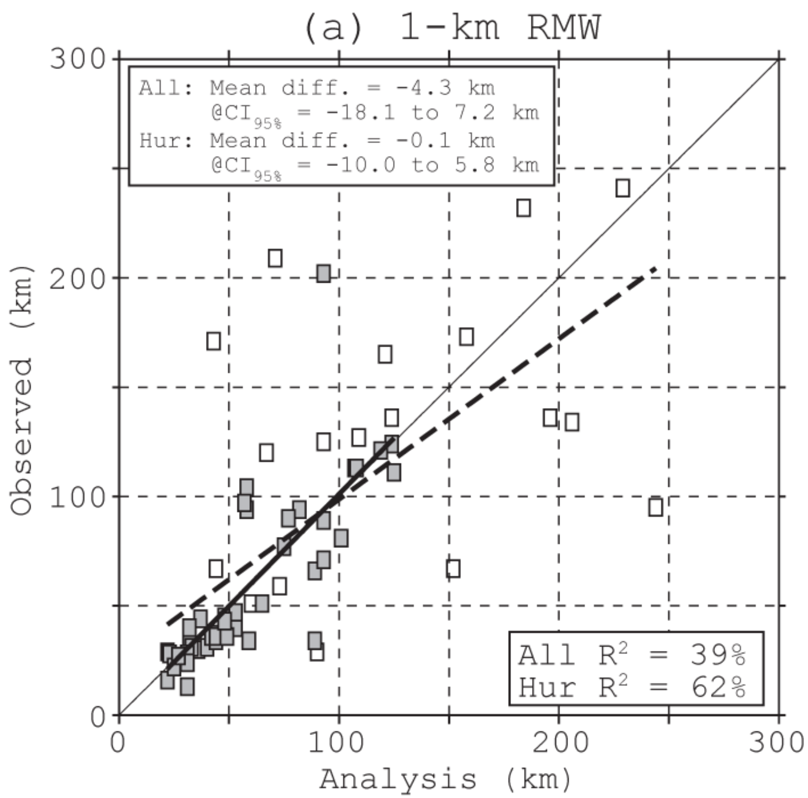
Wind-Pressure Relationship (Analysis vs. Best Track)

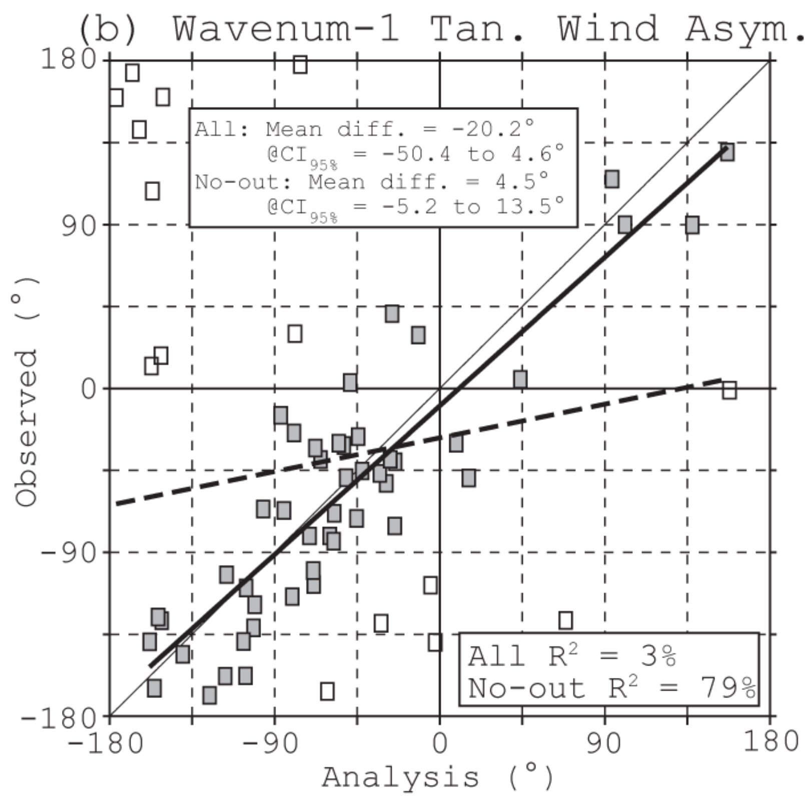


Max. Azim. Avg. Tangential Wind Speed (Analysis vs. Doppler-Derived)

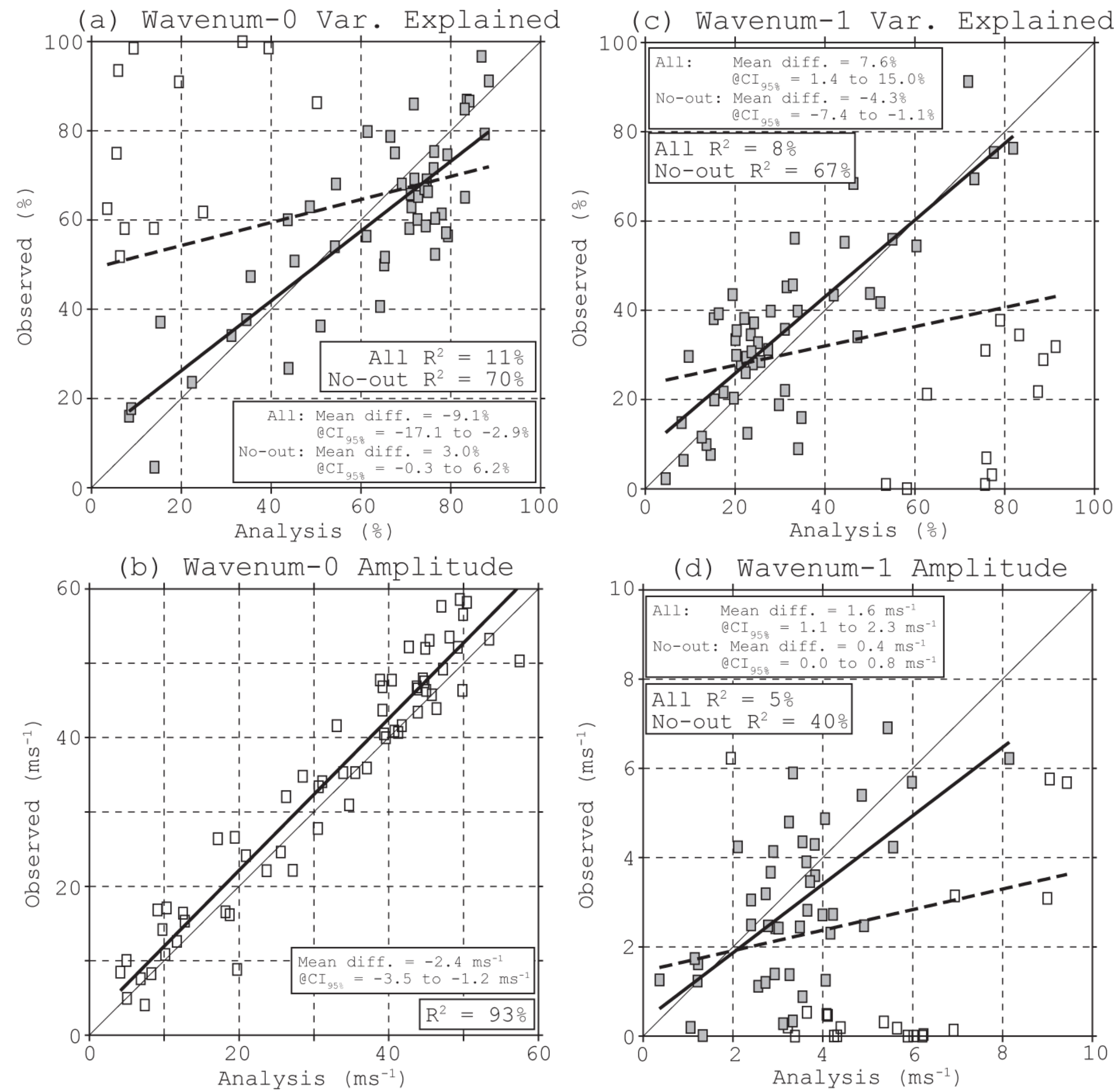


Radius of Max. Tan. Wind Speed and Wavenumber-1 Tan. Wind Asymmetry (Analysis vs. Doppler Derived)

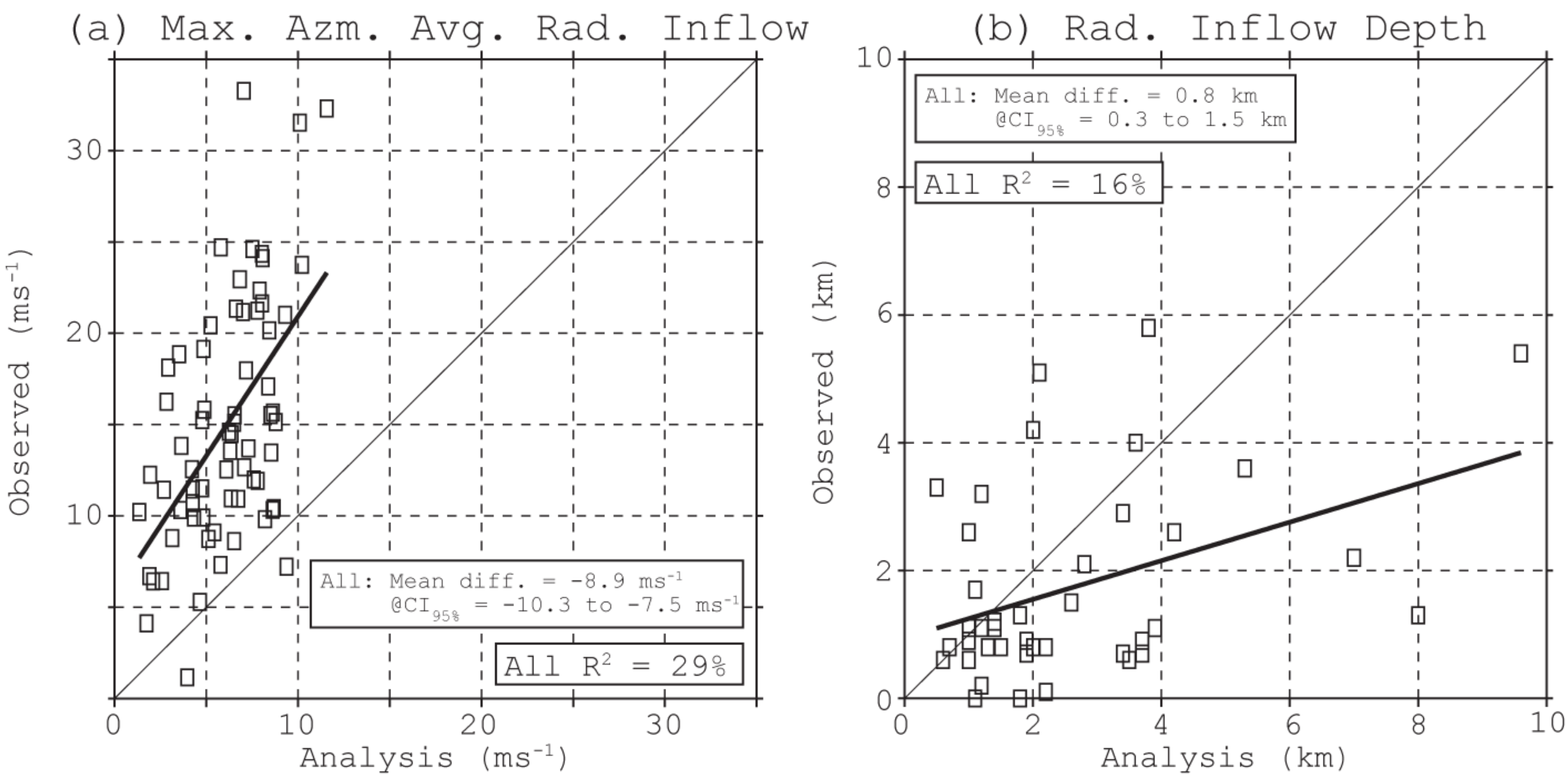




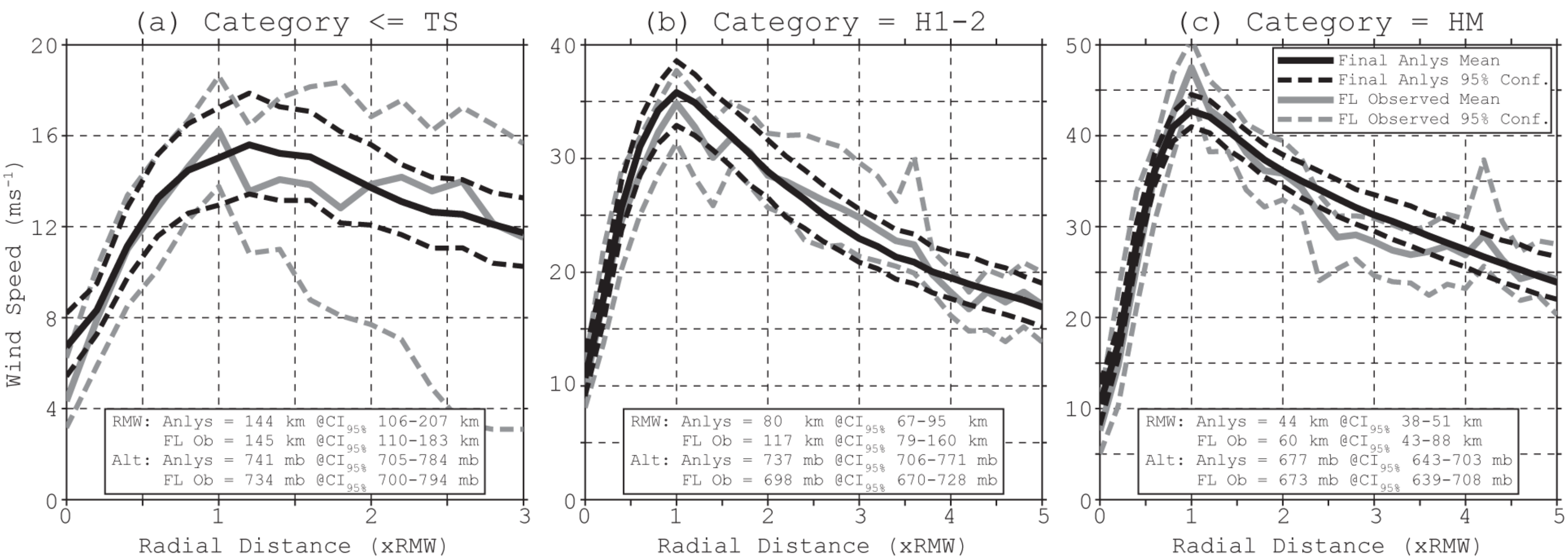
Wavenumber Decomposition (Analysis vs. Doppler Derived)



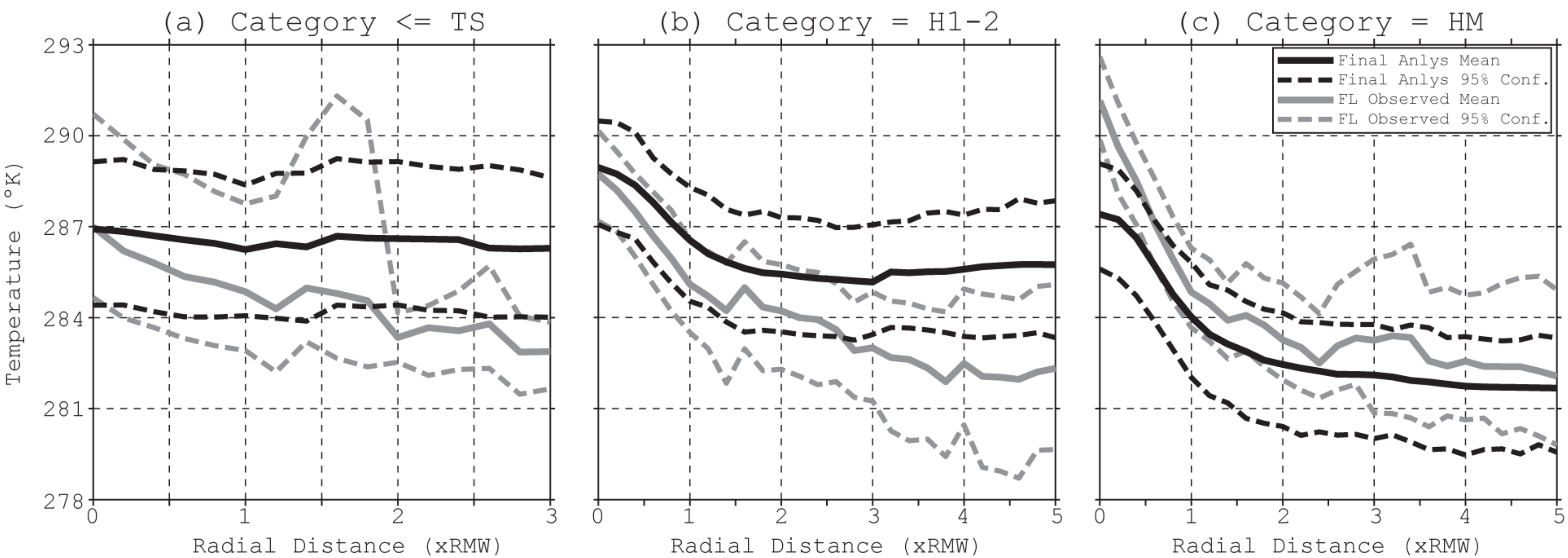
Azim. Avg. Radial Inflow and Inflow Depth (Analysis vs. Doppler-Derived)



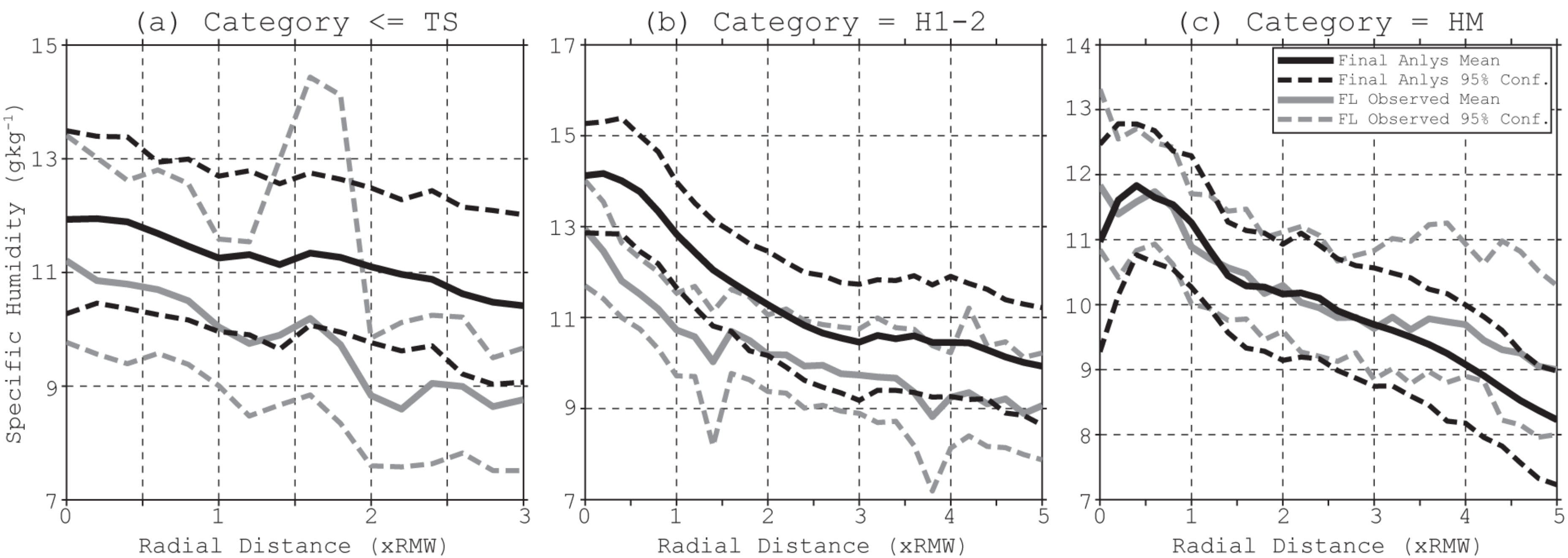
Radial Profiles – FL Wind Speed



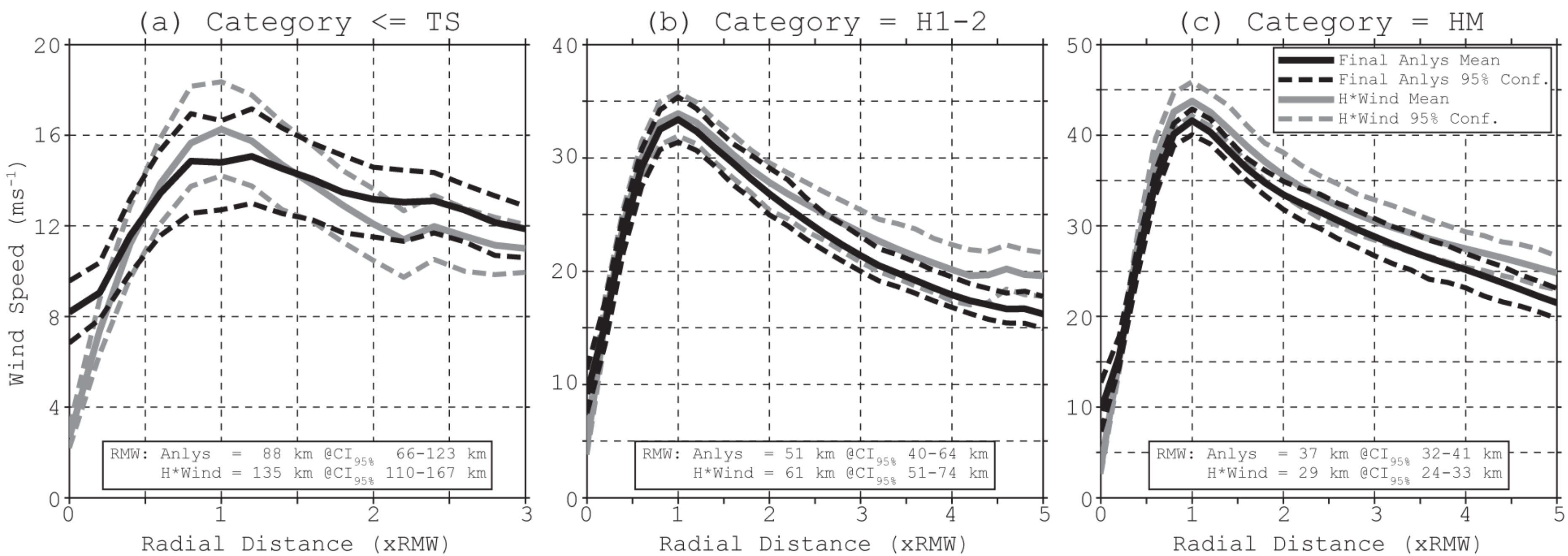
Radial Profiles – FL Temperature



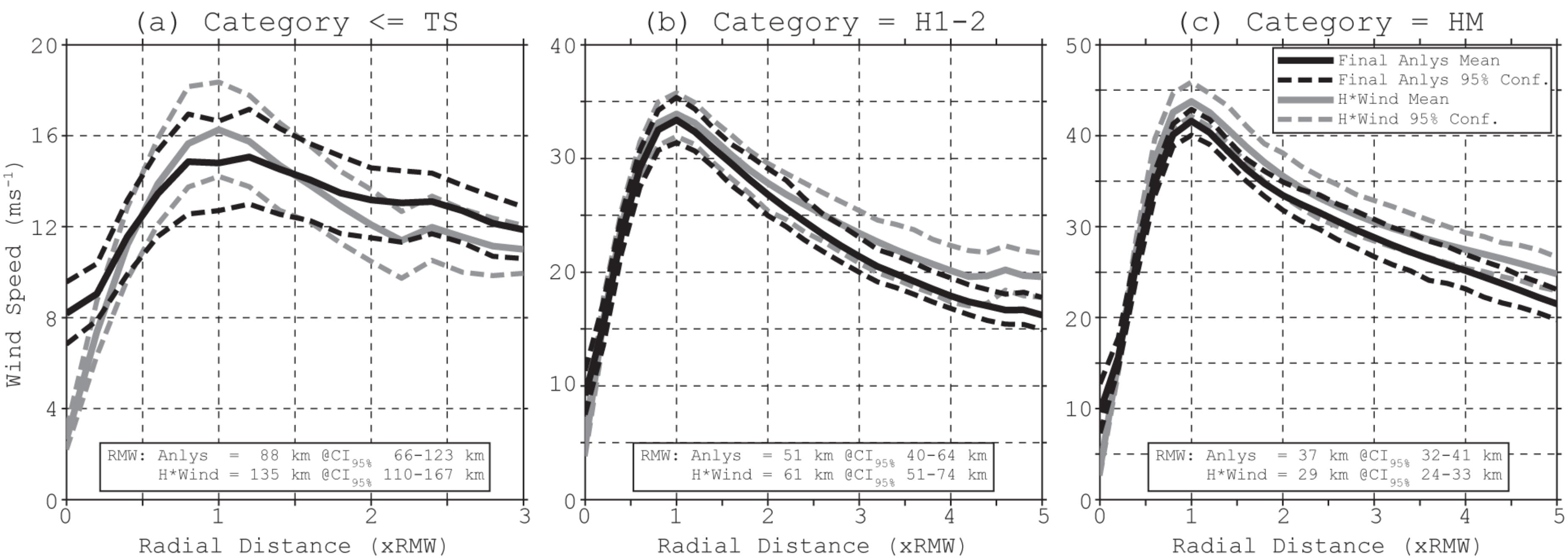
Radial Profiles – FL Specific Humidity



Radial Profiles – H*Wind Surface Wind Speed



Radial Profiles – H*Wind Surface Wind Speed



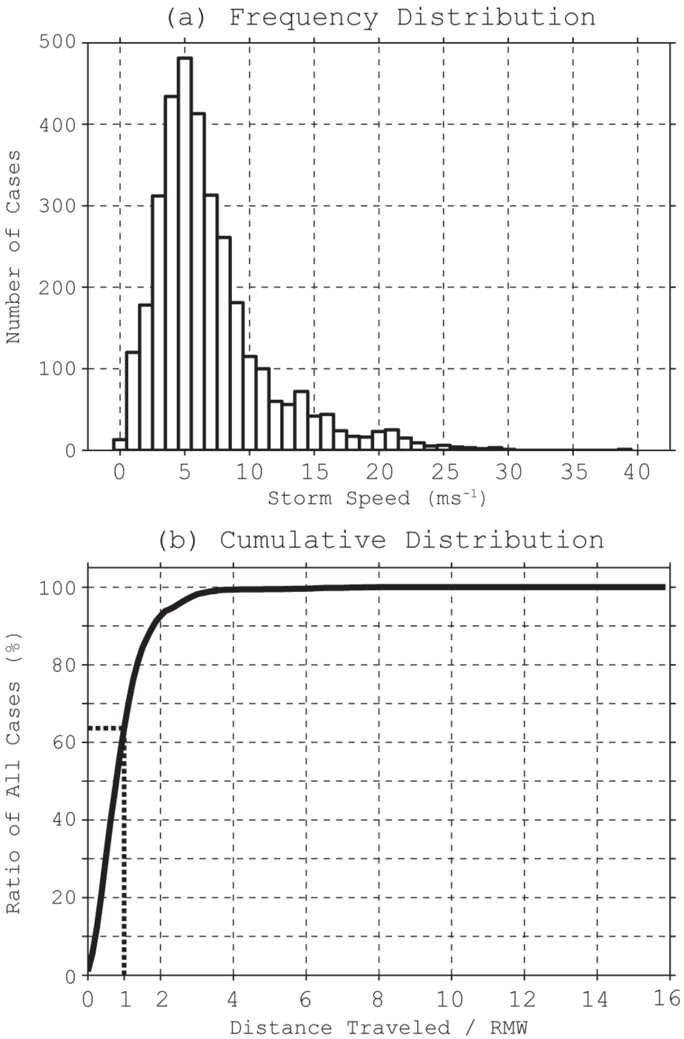
Summary - 1

- HEDAS runs with 83 cases from 2008-2011 seasons are analyzed
- Realistic distribution of cases by intensity (most are tropical storm to cat-1 hurricanes)
- In a typical run:
  - 4-5 cycles of data are assimilated
  - 30-40K observations are assimilated, but Doppler wind observations dominate
  - Best sampling is achieved below ~9 km
- Improvements in observation space are seen that can be directly associated with data assimilation

Summary - 2

- Position errors in analyses are on average ~40 km compared to the best track, when best track storm center is interpolated to analysis time
- Good fit of analysis intensity to best track is seen, but analyses are systematically weaker in MSLP by ~3 mb
- Structurally,
  - Very good fit for the primary circulation
  - RMW fit much better for hurricanes
  - Wavenumber 0 and 1 structures well captured
  - Azimuthal asymmetry is impacted by few outliers, especially from the 2008 season
  - Secondary circulation issues from boundary layer height

Storm-Relative Data Assimilation Motivation



Distribution of storm speed of all 1970-2010 Atlantic tropical cyclones with central pressure less than 990 hPa

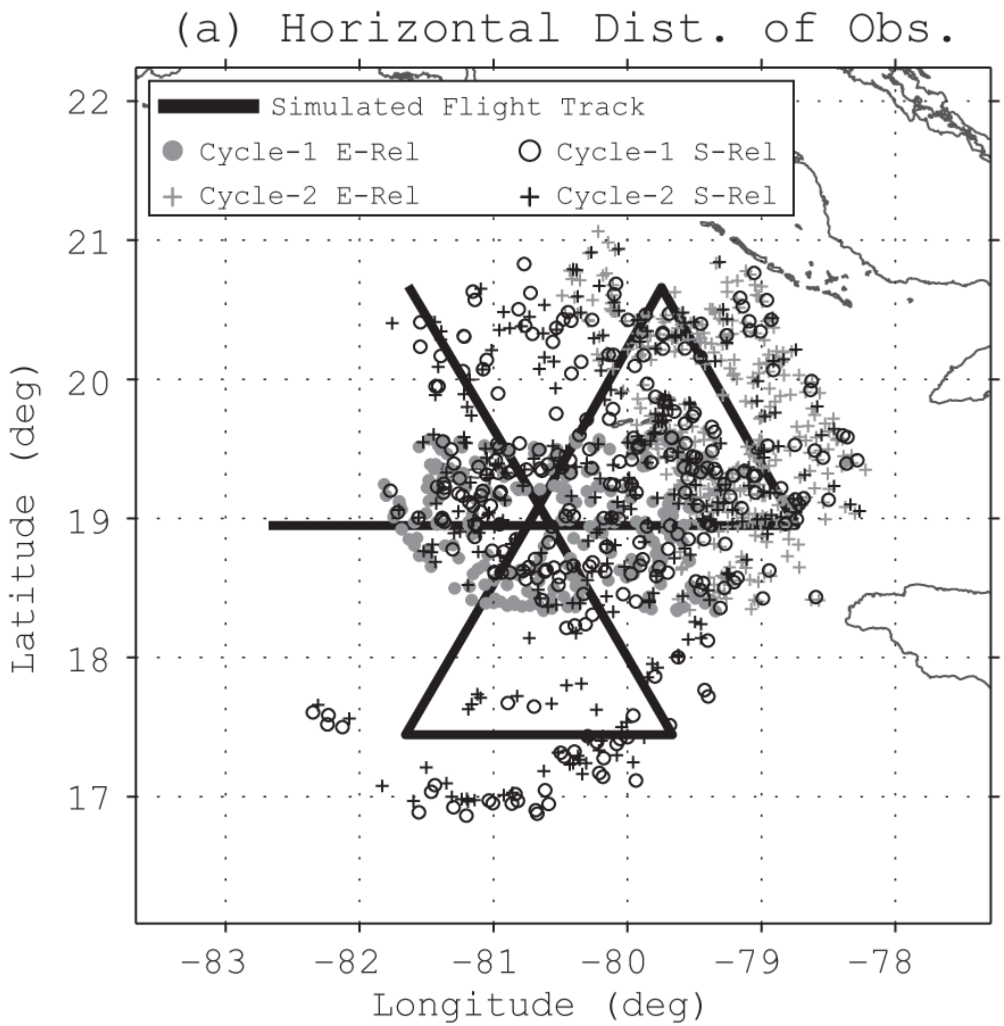
If storm speed is converted to distance using the typical 1-h assimilation window, and normalized by RMW

⇒ For ~35% of the TCs considered, DA would be carried out using observations that are more than 1 RMW apart!

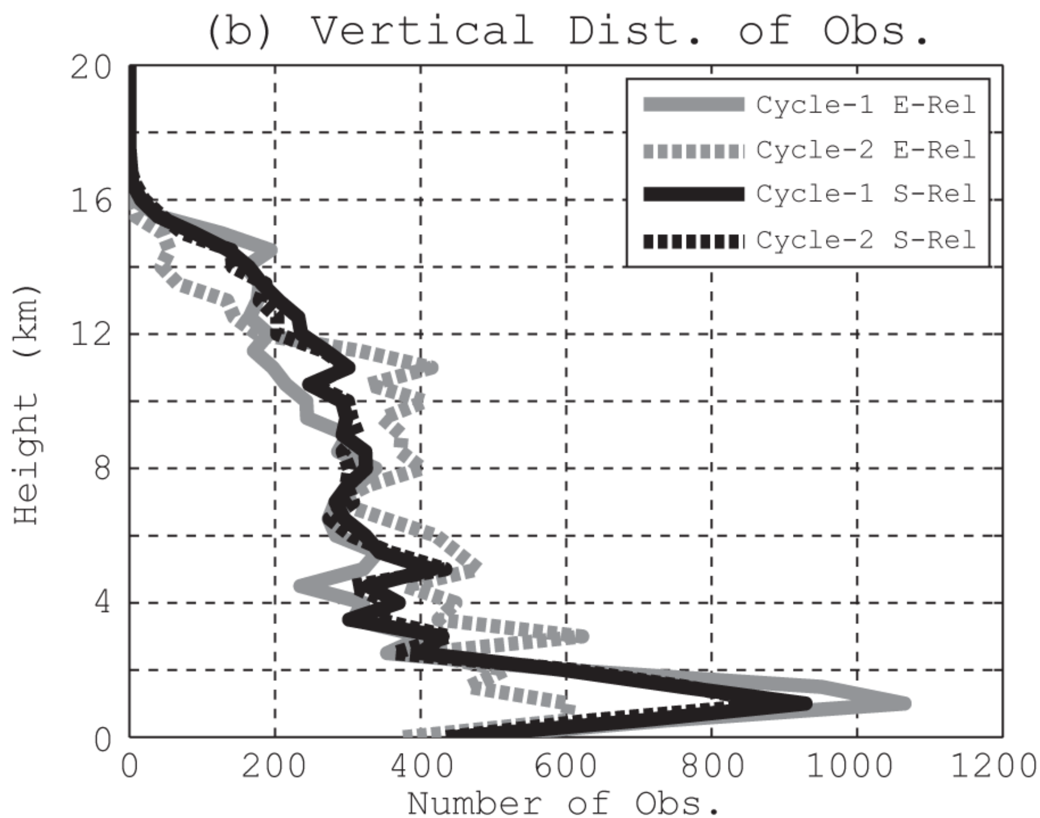
Storm-Relative Data Assimilation Potential Advantages

- Avoid assimilating observations that are more than one RMW apart as they would result in large and unrealistic cross-gradient innovations
- Assumption of simultaneity of all observations from a flight would allow for all observations to be randomly distributed to assimilation cycles, so that
    - More homogeneous observation distribution is achieved in each cycle
    - More flexibility is obtained in choosing an assimilation window length that best reflects the intrinsic time scales at the vortex scale

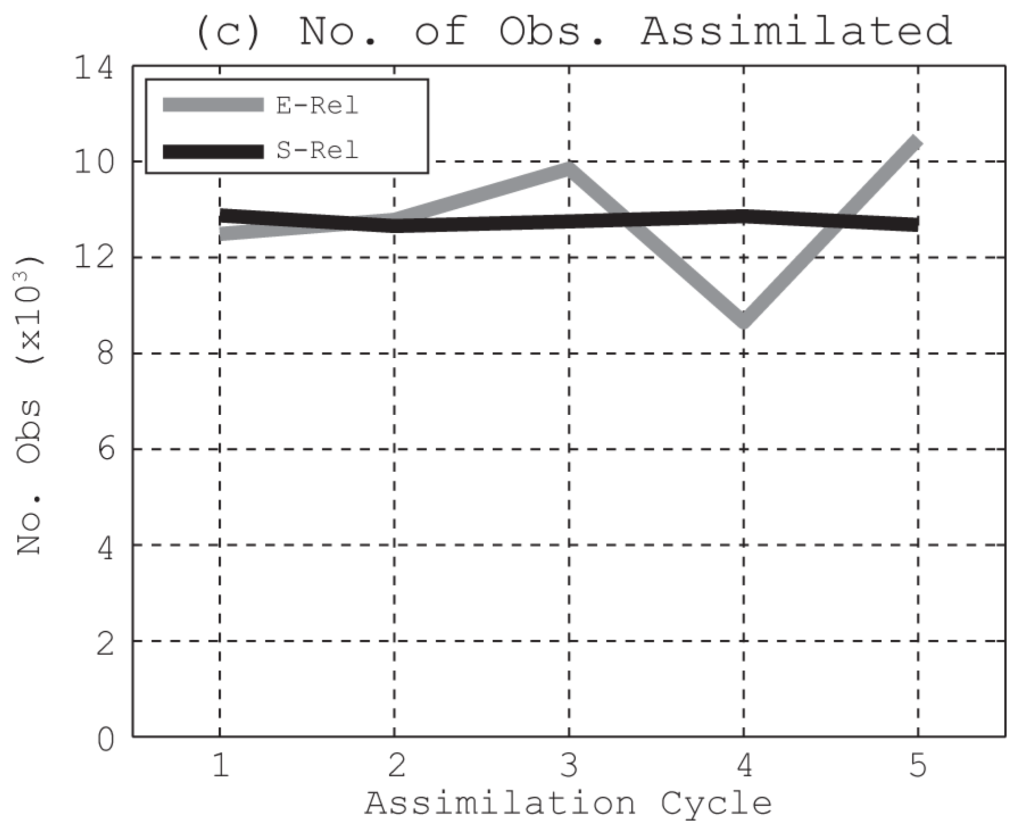
Horizontal Distribution of Observations
Earth-Relative vs. Storm-Relative



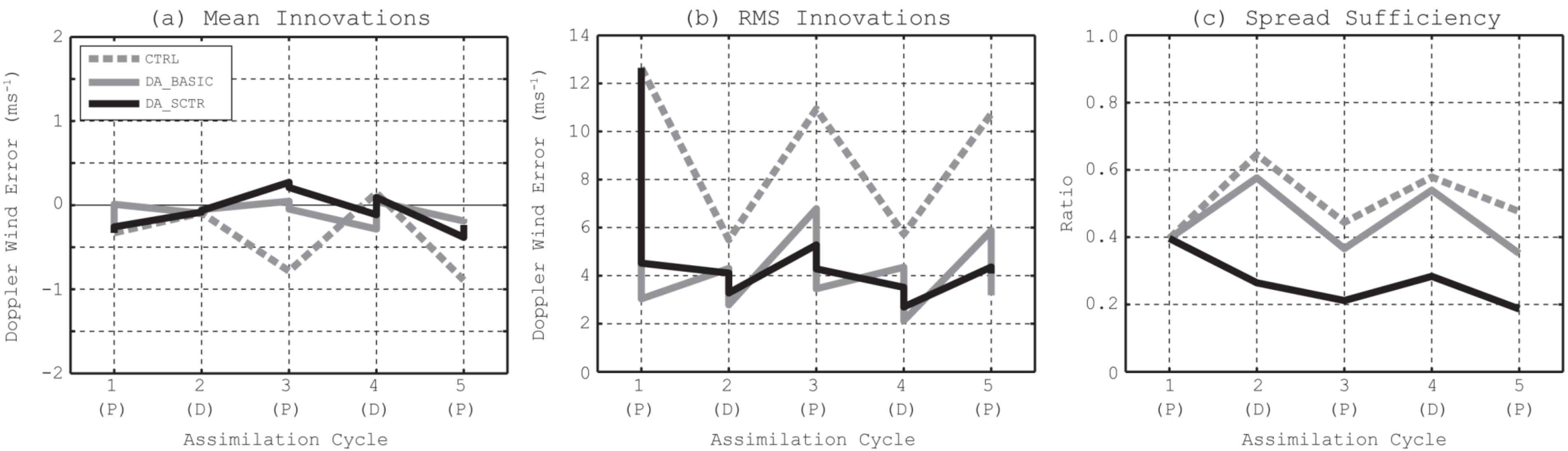
Horizontal Distribution of Observations Earth-Relative vs. Storm-Relative



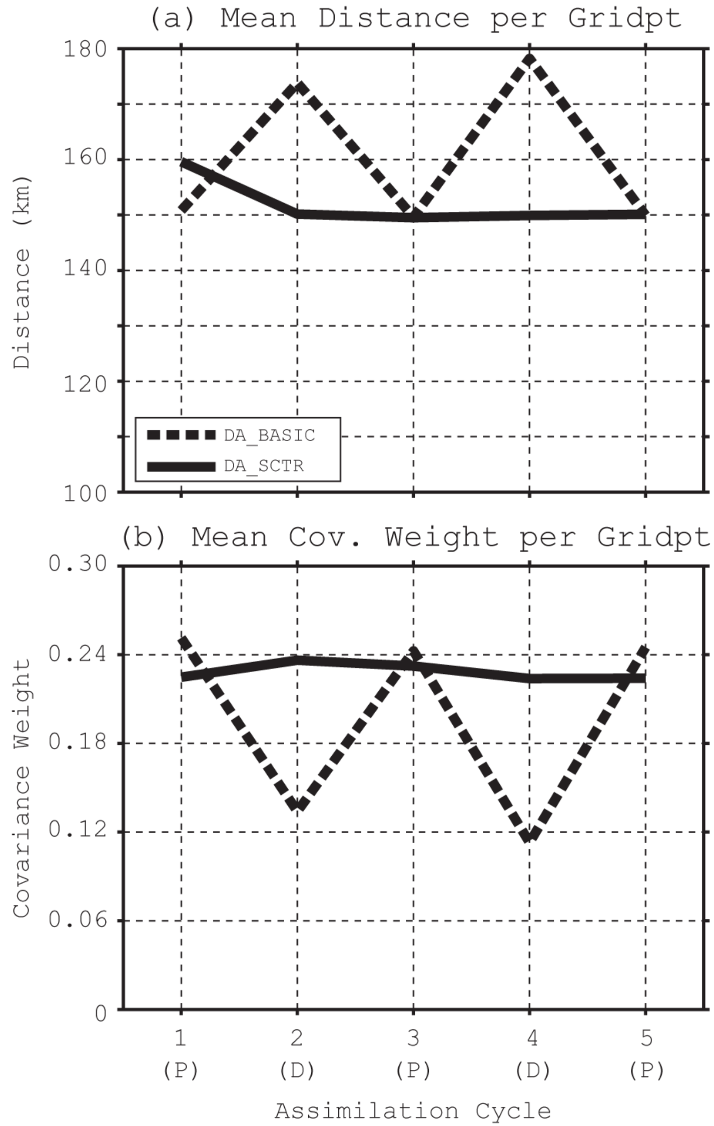
Horizontal Distribution of Observations Earth-Relative vs. Storm-Relative



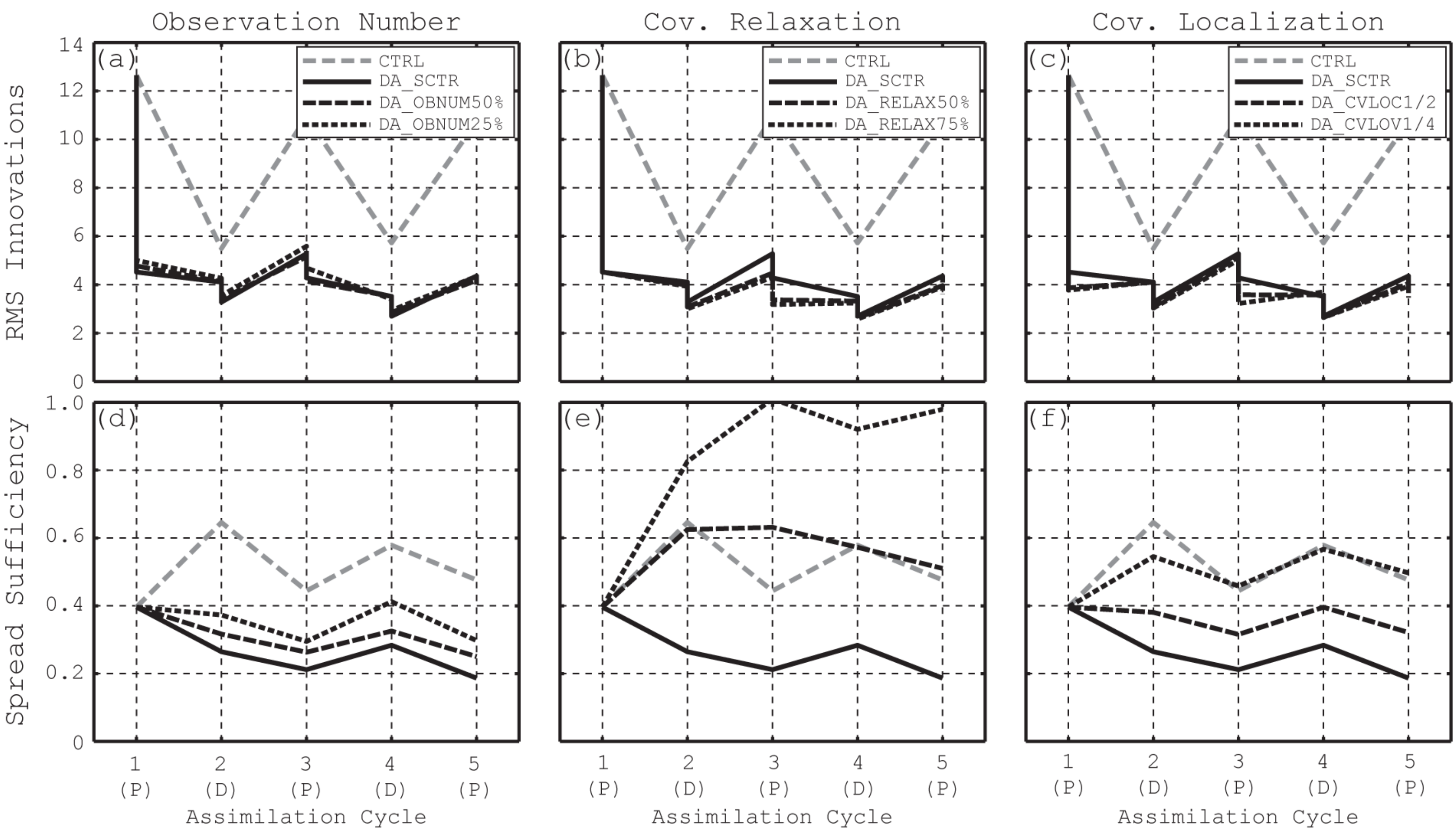
Observation-Space Performance for the Basic HEDAS Configuration



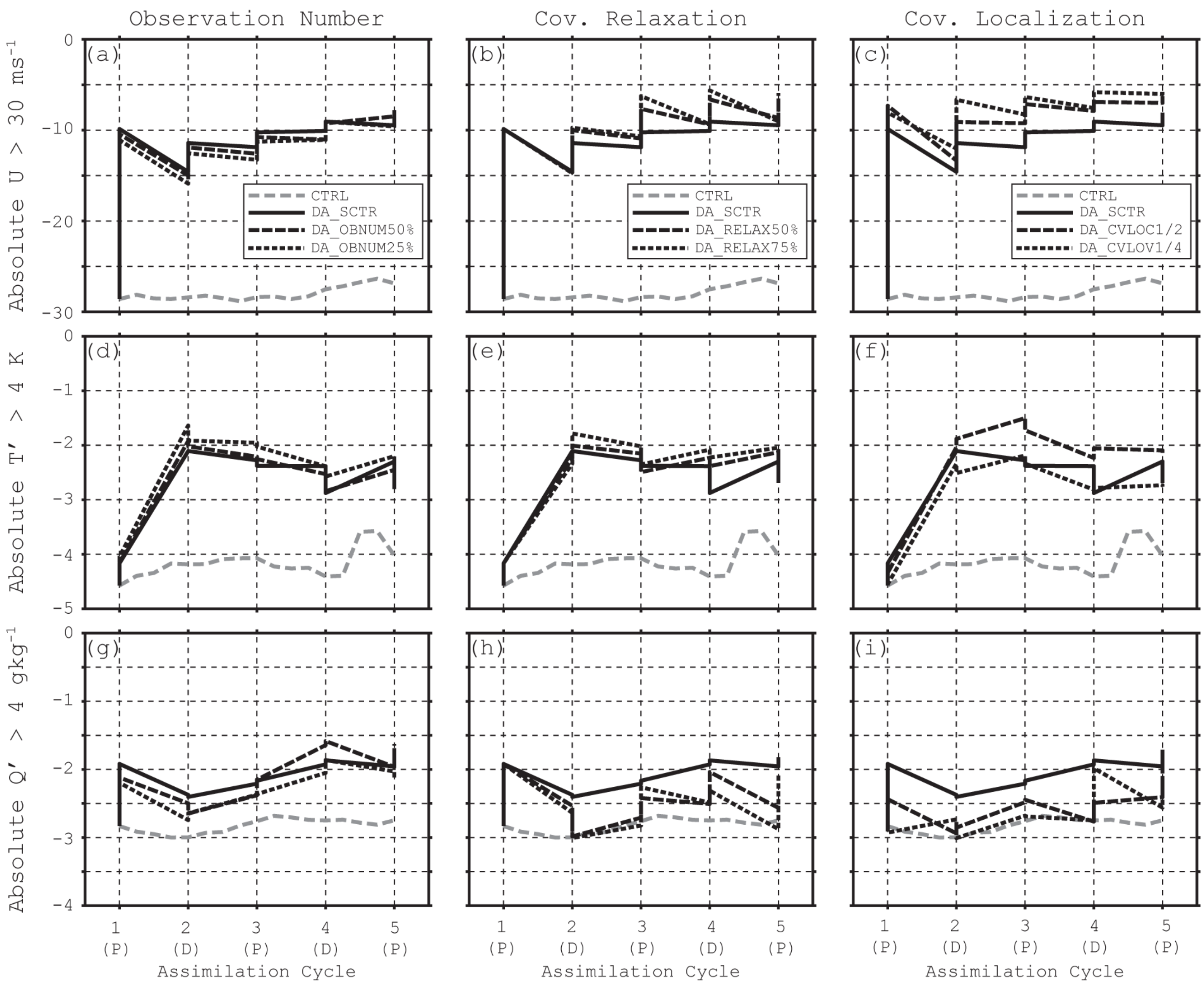
Why Does Ensemble Spread Suffer in Storm-Relative Data Assimilation?



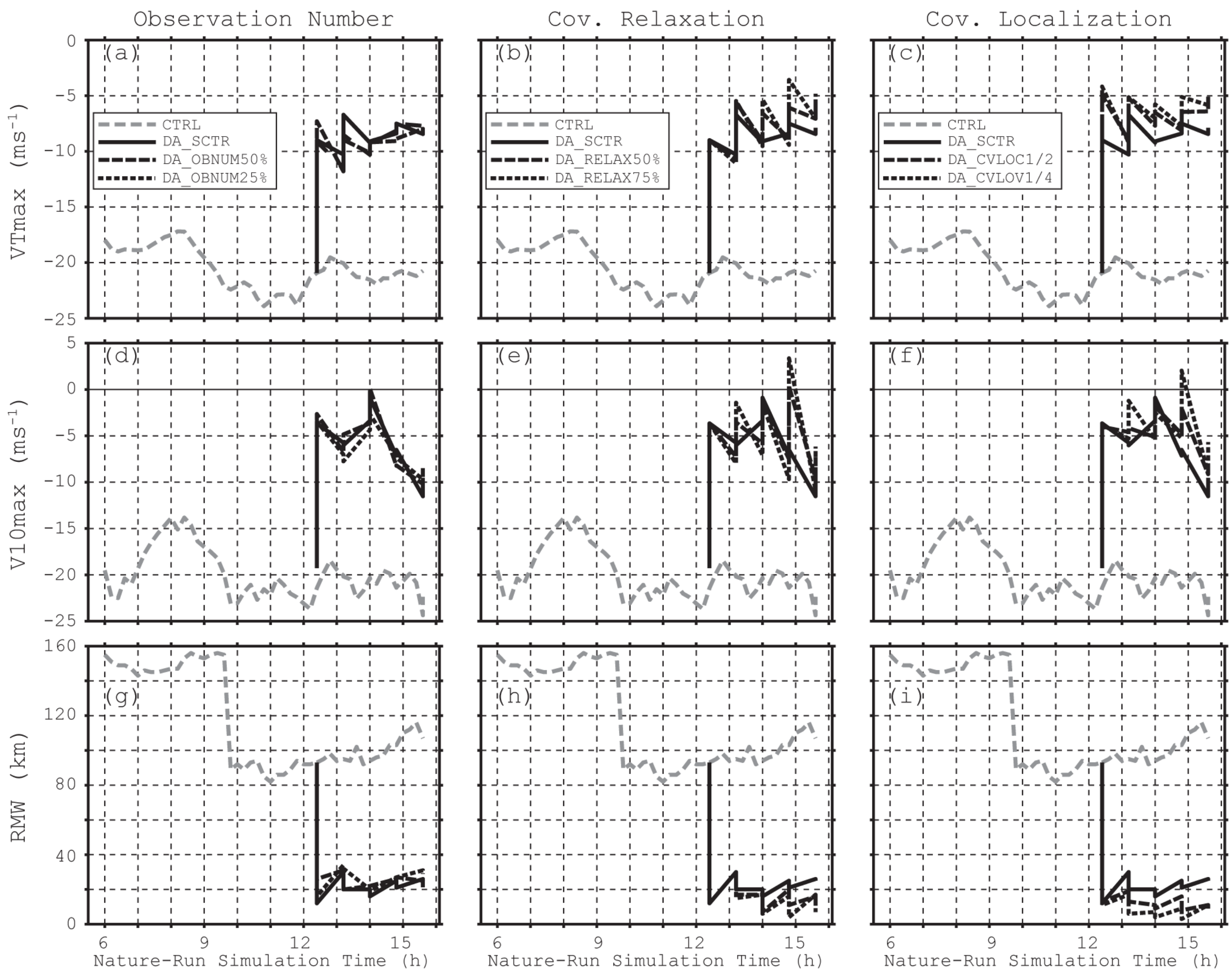
Observation-Space Performance with Variations in HEDAS Configuration



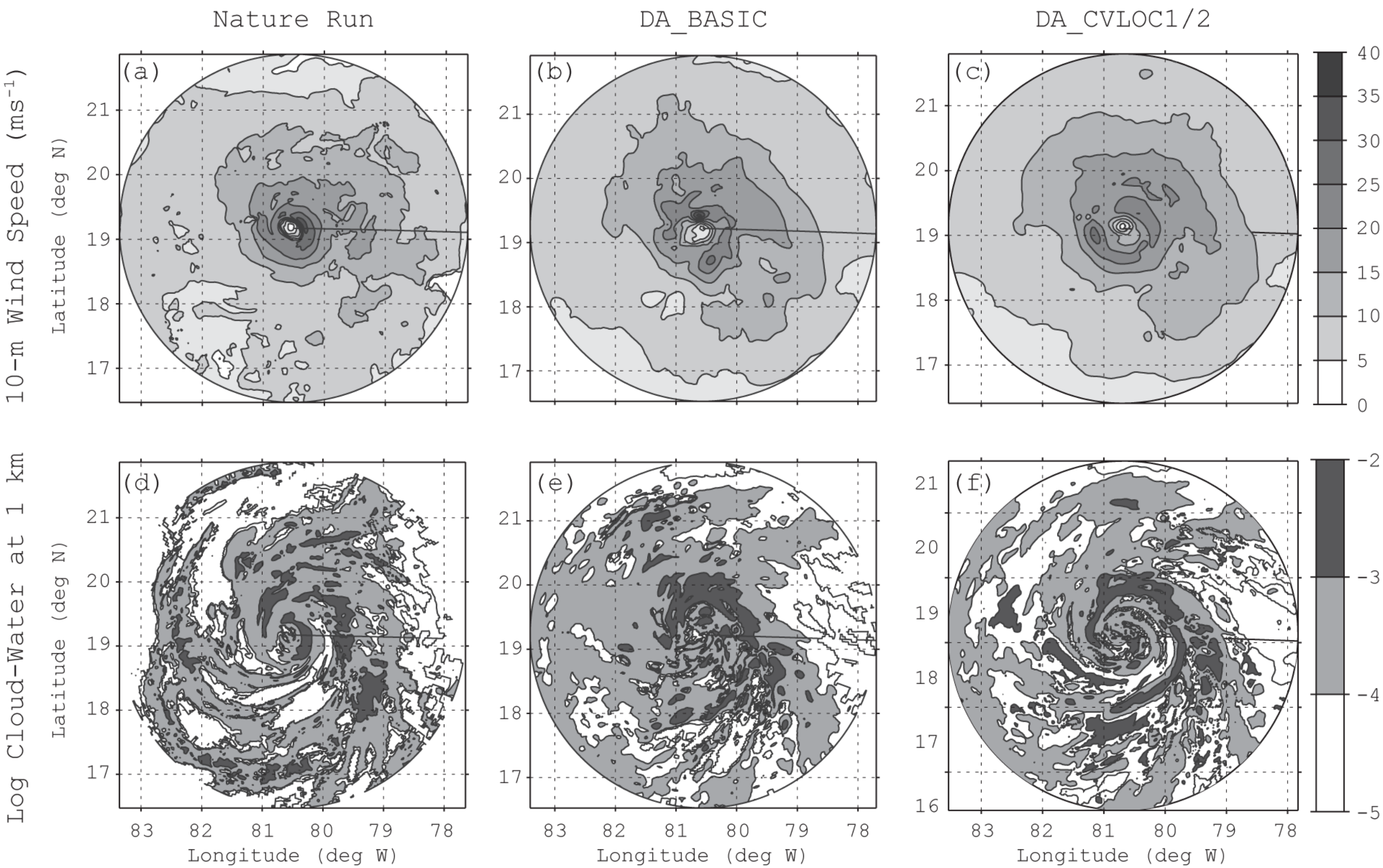
Model-Space Performance with Variations in HEDAS Configuration



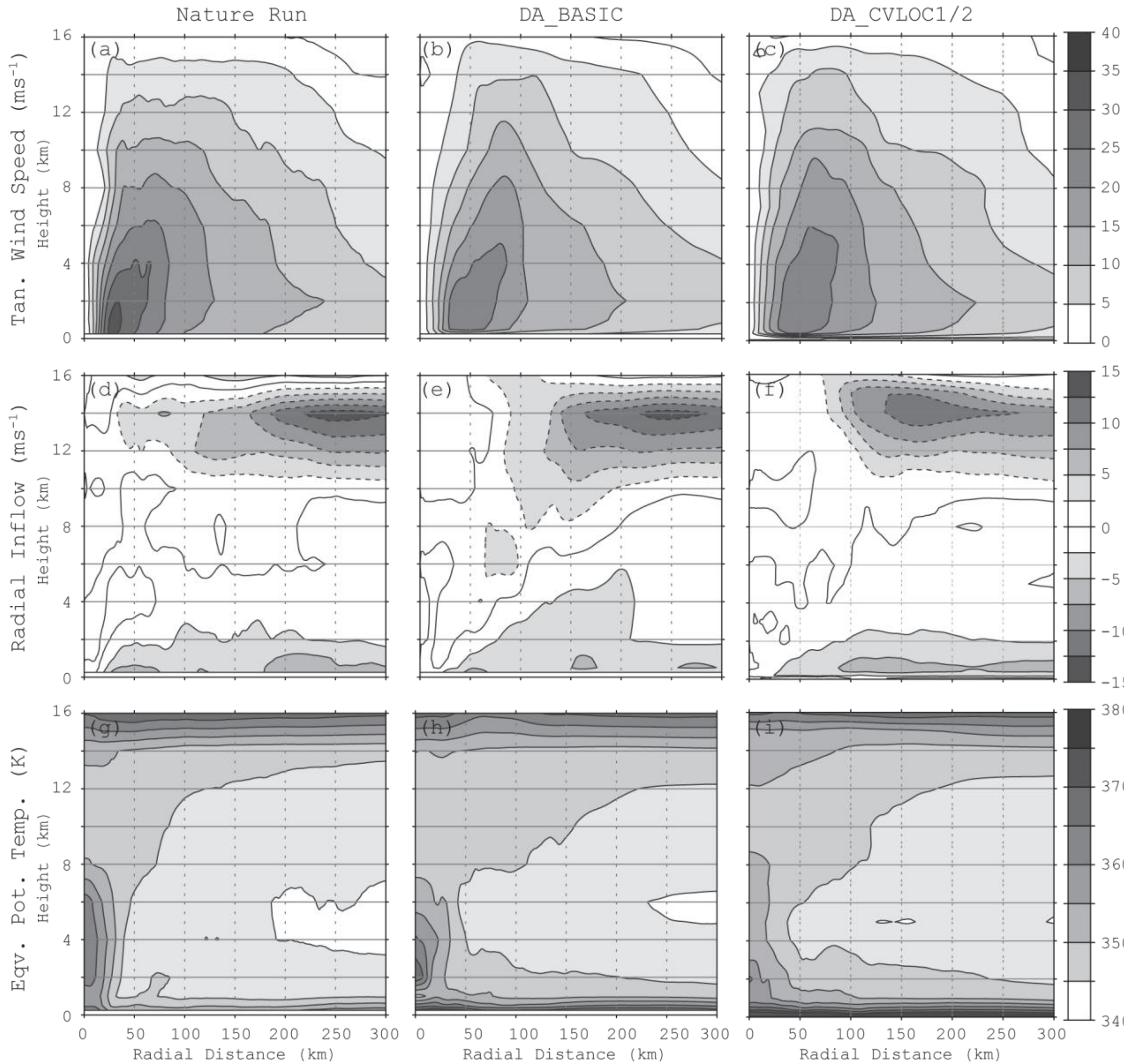
Intensity/Structure Performance with Variations in HEDAS Configuration



Performance of Storm-Relative DA: Comparison of 2-D Fields



Performance of Storm-Relative DA: Comparison of R-Z Mean Fields



Summary - 1

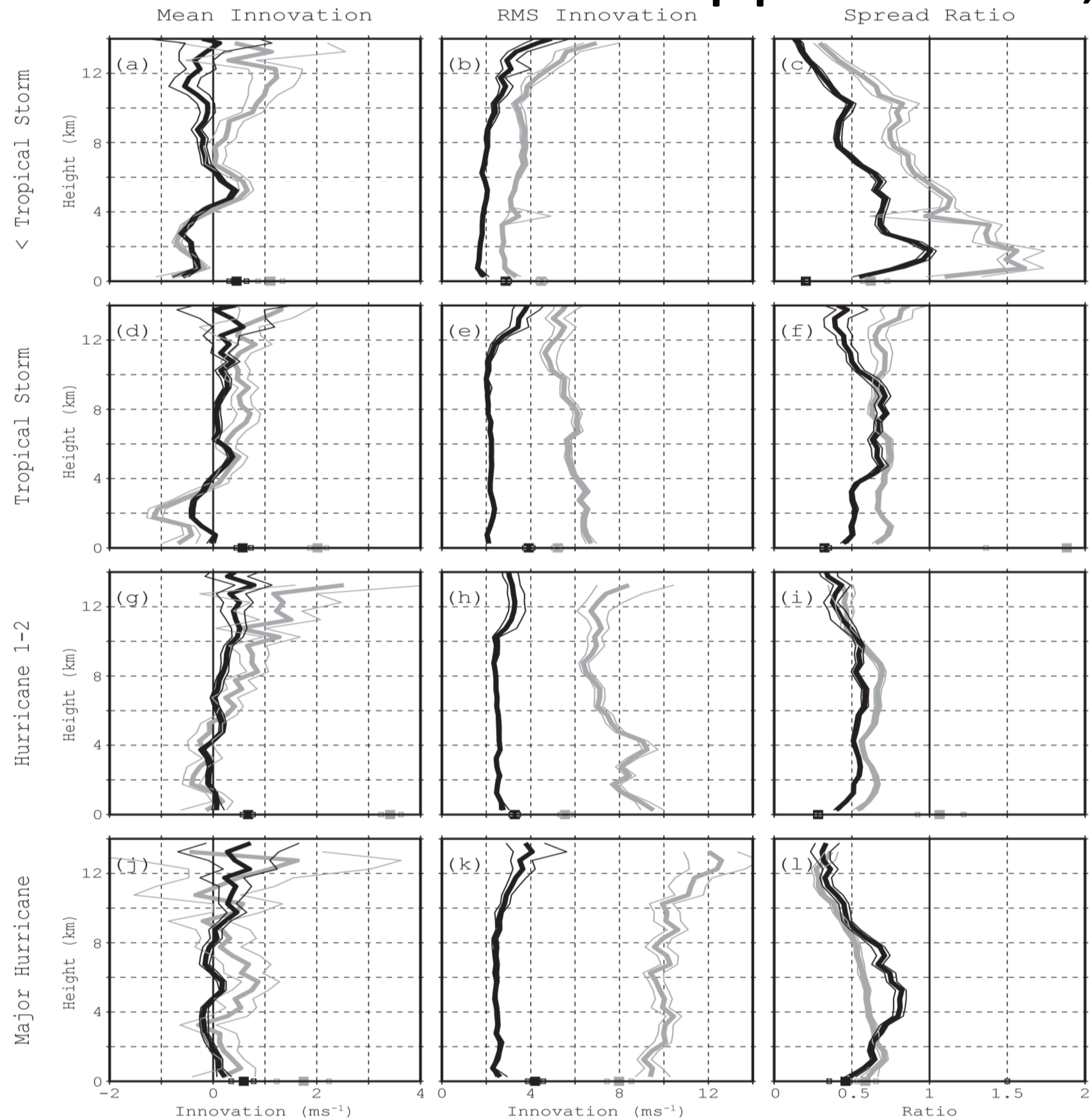
- When the traditional method of Earth-relative data assimilation is employed, in at least 35% of the cases, one can expect observations to be more than one RMW apart, potentially degrading the analyses
- Storm-relative data assimilation is expected to be advantageous against Earth-relative data assimilation also because:
    - Observations are more uniformly distributed spatially among assimilation cycles
    - Number of observations is more uniformly distributed among assimilation cycles

Summary - 2

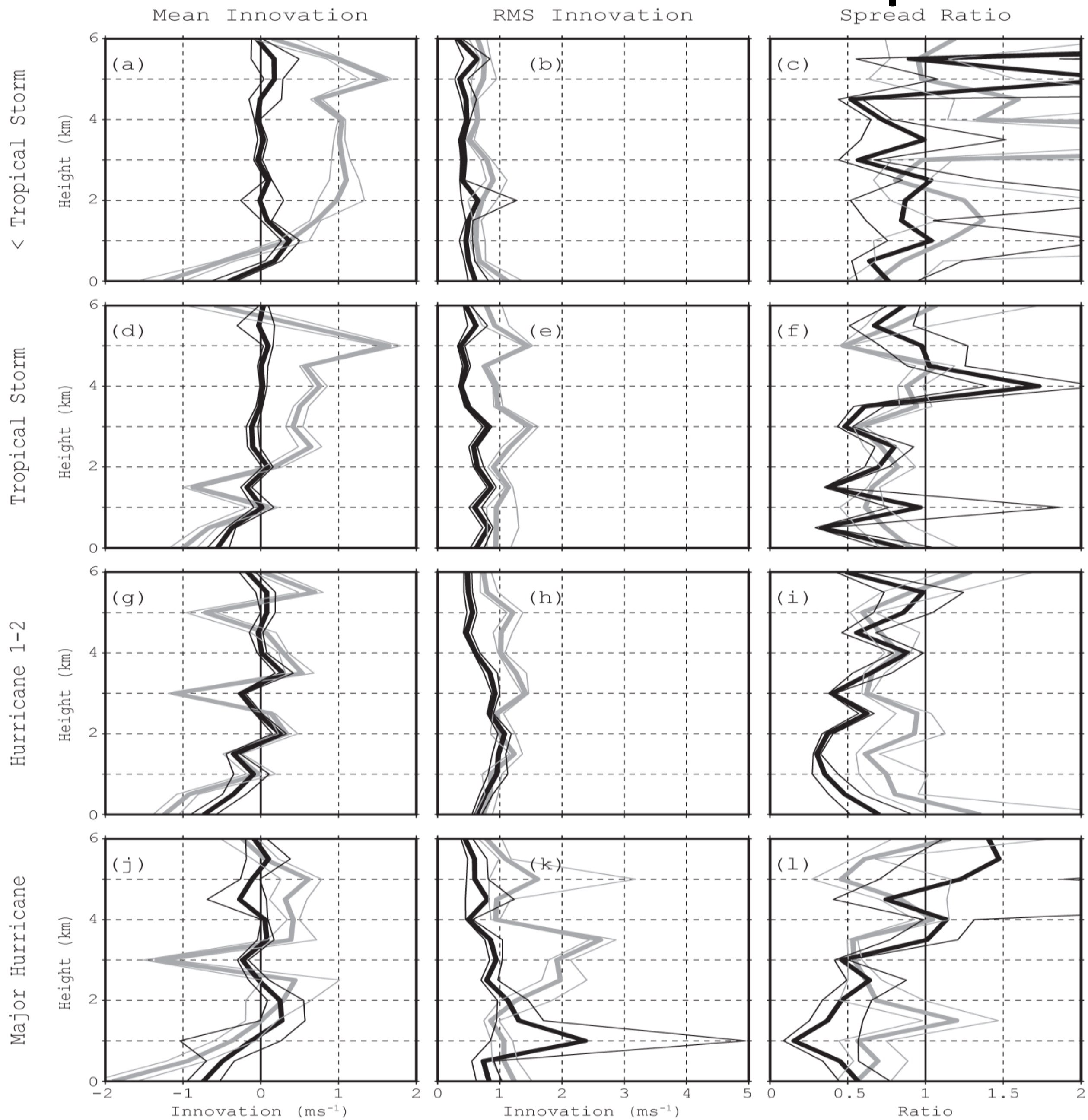
- Storm-relative data assimilation appears to have a stronger negative impact on ensemble spread – This was best encountered by reducing the covariance length scale
- Noticeable improvements are observed (over Earth-relative data assimilation) in the axisymmetric structure of the vortex (RMW, tangential wind speed)
- Storm-relative data assimilation also has led to smaller cycle-to-cycle error growth, which may have implications for achieving better balance in the analyses with respect to model dynamics

Thank You!

Innovation Statistics – Doppler Wind, SFMR



Innovation Statistics – Temperature



Innovation Statistics – Zonal Wind Speed