Recent Advances in Vortex-Scale Data Assimilation using NOAA/AOML/HRD's HWRF Ensemble Data Assimilation System (HEDAS):

(1) Real-data results from a multi-case experiment
(2) Storm-relative data assimilation

Altuğ Aksoy[1,2],
Sylvie Lorsolo[1,2], Tomislava Vukicevic[1],
Sim Aberson[1], Kathryn Sellwood[1,2]

[1]NOAA/AOML Hurricane Research Division
[2]U. Miami RSMAS Coop. Inst. Marine Atmos. Studies

Collaborators:
Gopal, Xuejin Zhang, Thiago Quirino, Lisa Bucci,
Jeff Whitaker, Fuqing Zhang,
Bachir Annane, Shirley Murillo, Neal Dorst, Mike Page

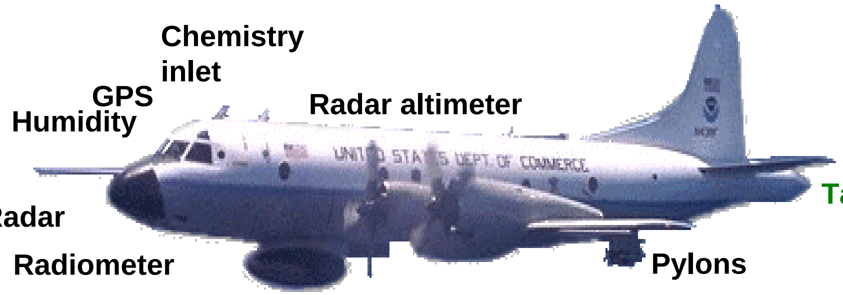
NOAA/AOML/HRD's HWRF Ensemble Data Assimilation System (HEDAS)

(Aksoy et al. 2012, MWR)

- **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

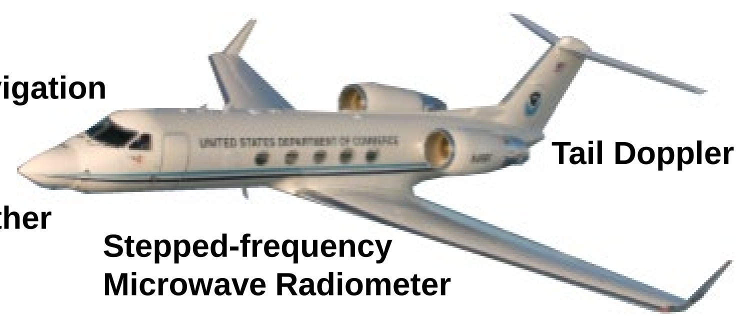
P-3 Aircraft
(eye penetrations)



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)



2008-2011 Real-Data Cases Considered

2008

Dolly	07-20-12Z
Dolly	07-21-00Z
Dolly	07-21-12Z
Dolly	07-22-00Z
Dolly	07-22-12Z
Fay	08-14-12Z
Fay	08-15-00Z
Fay	08-15-06Z
Fay	08-15-18Z
Fay	08-18-18Z
Fay	08-19-06Z
Gustav	08-30-00Z
Gustav	08-30-12Z
Gustav	08-31-00Z
Gustav	08-31-12Z
Gustav	09-01-00Z
Gustav	09-01-12Z
Ike	09-10-00Z
Ike	09-10-12Z
Ike	09-11-00Z
Ike	09-11-12Z
Ike	09-12-00Z
Ike	09-12-18Z
Kyle	09-23-00Z
Kyle	09-24-12Z
Kyle	09-25-00Z
Kyle	09-25-12Z
Kyle	09-26-00Z
Kyle	09-26-18Z
Kyle	09-27-00Z
Kyle	09-27-18Z
Paloma	11-07-06Z
Paloma	11-07-18Z
Paloma	11-08-18Z

2009

Ana	08-17-00Z
Bill	08-19-00Z
Bill	08-19-12Z
Bill	08-20-00Z
Bill	08-20-12Z
Danny	08-26-12Z
Danny	08-27-00Z
Danny	08-27-12Z
Danny	08-28-00Z

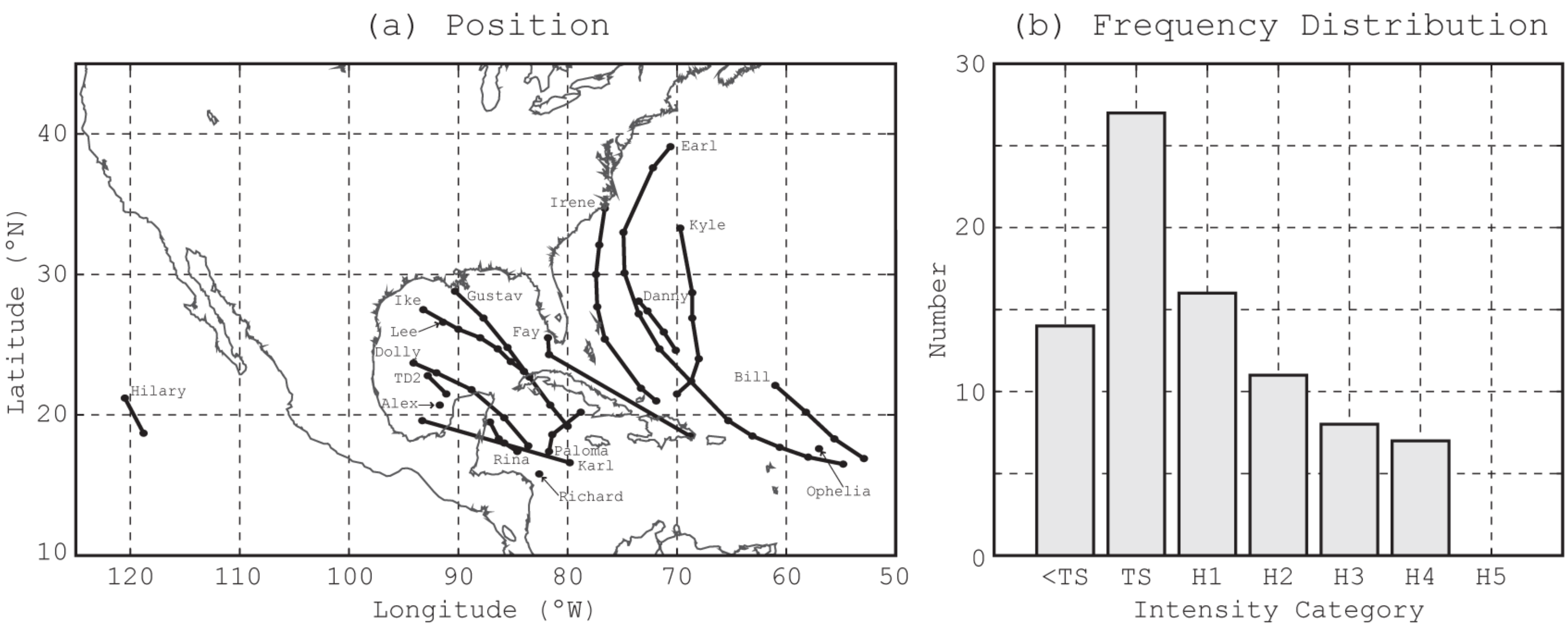
2010

Alex	06-29-00Z
TD2	07-07-00Z
TD2	07-07-12Z
TD2	07-08-00Z
Earl	08-29-00Z
Earl	08-29-12Z
Earl	08-30-00Z
Earl	08-30-12Z
Earl	08-31-00Z
Earl	09-01-12Z
Earl	09-02-00Z
Earl	09-02-12Z
Earl	09-03-00Z
Earl	09-03-18Z
Earl	09-04-00Z
Karl	09-13-00Z
Karl	09-13-12Z
Karl	09-14-00Z
Karl	09-16-18Z
Richard	10-23-06Z
Tomas	11-04-00Z
Tomas	11-04-12Z
Tomas	11-15-00Z
Tomas	11-06-12Z
Tomas	11-07-00Z

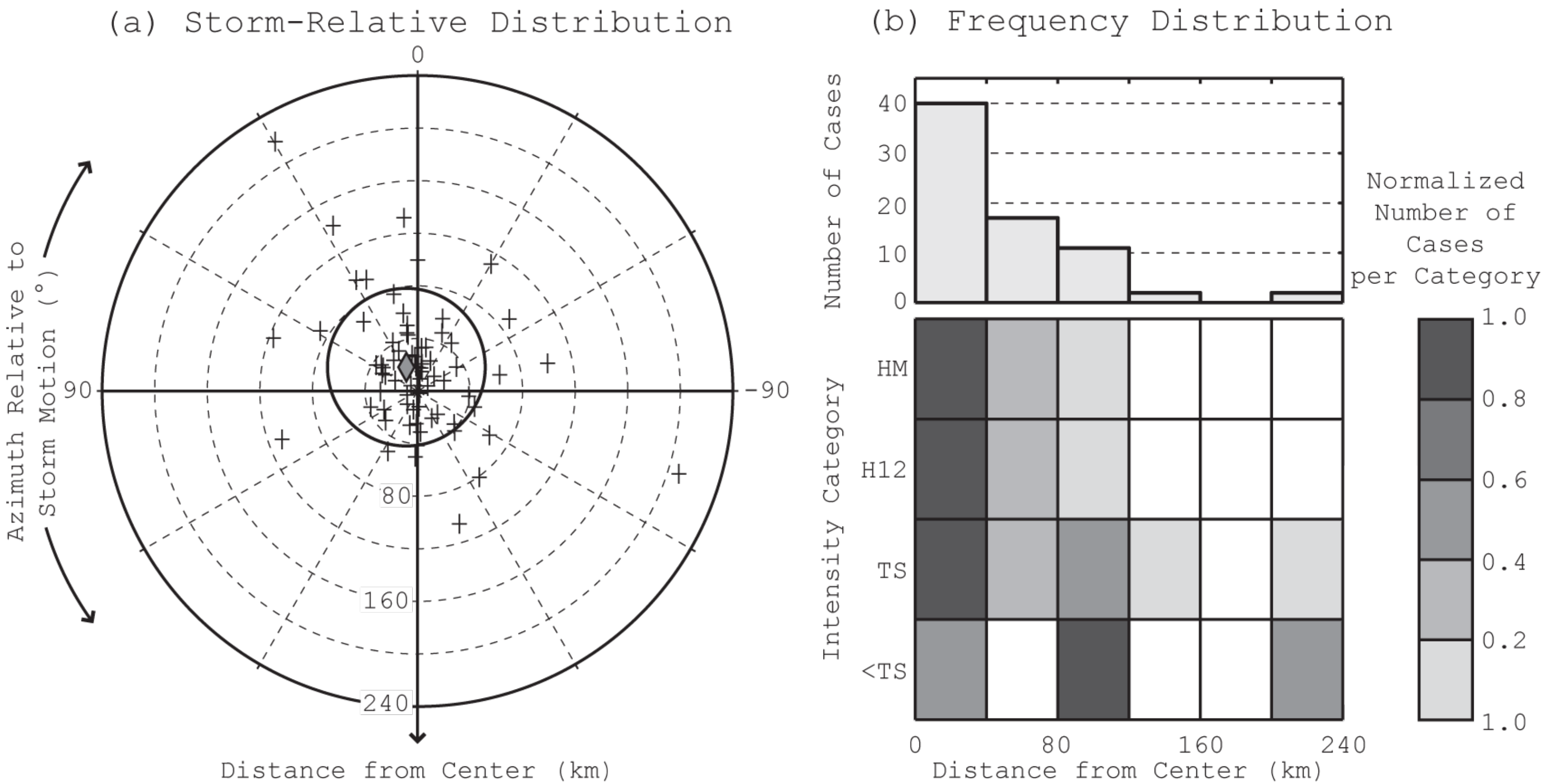
2011

Irene	08-24-00Z
Irene	08-24-12Z
Irene	08-25-12Z
Irene	08-26-00Z
Irene	08-26-12Z
Irene	08-27-00Z
Irene	08-27-12Z
Lee	09-02-00Z
Ophelia	09-24-18Z
Hilary	09-28-18Z
Hilary	09-29-18Z
Rina	10-26-00Z
Rina	10-26-18Z
Rina	10-27-00Z
Rina	10-27-18Z

Distribution of Cases

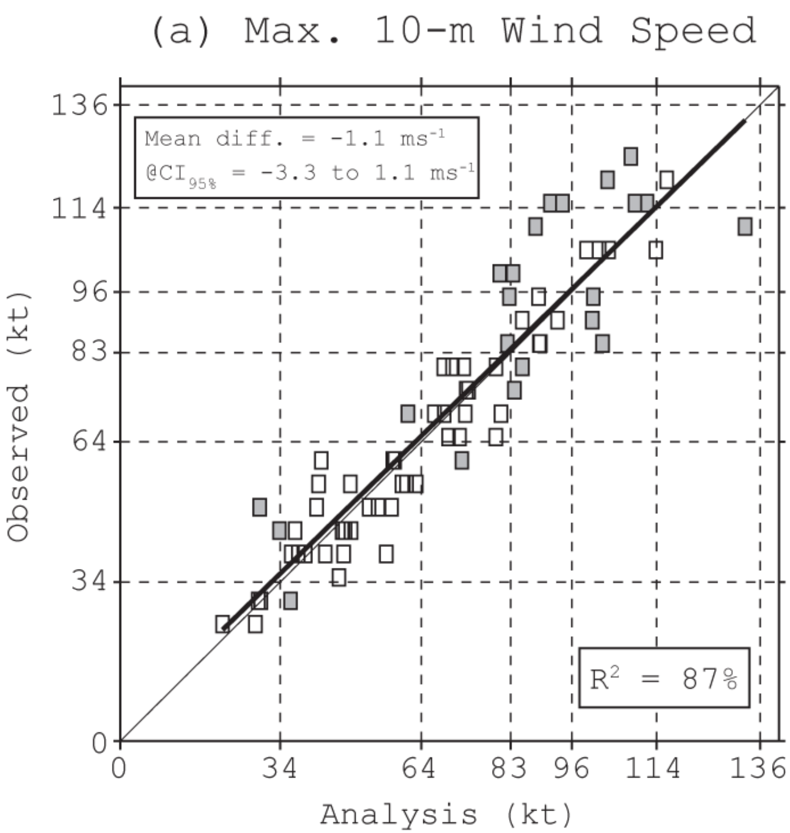


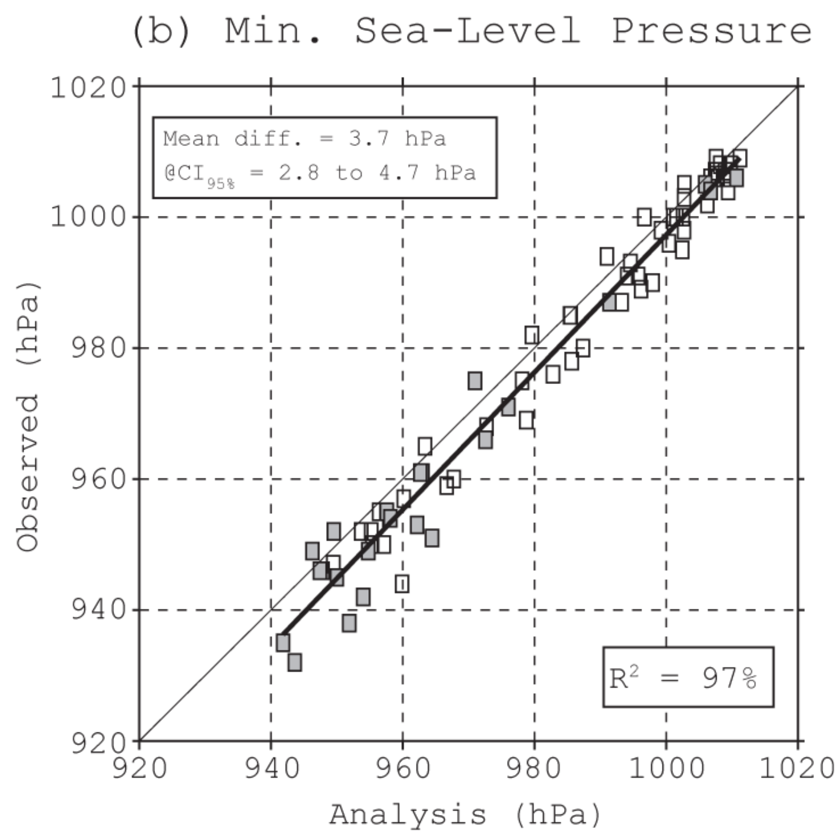
Position Error
(Analysis vs. Best Track)



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

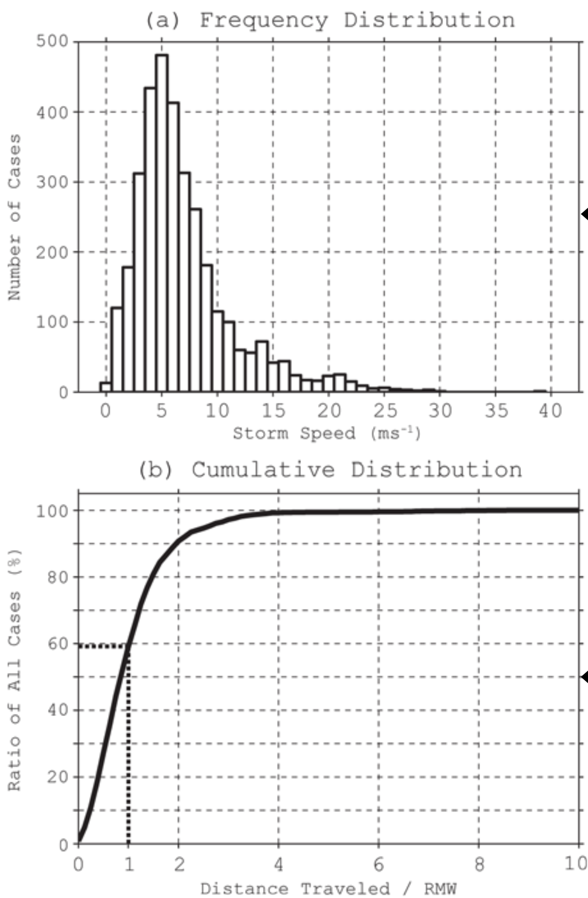
Intensity Error (Analysis vs. Best Track)





Storm-Relative Tropical Cyclone DA: Motivation

(Aksoy 2012, MWR)

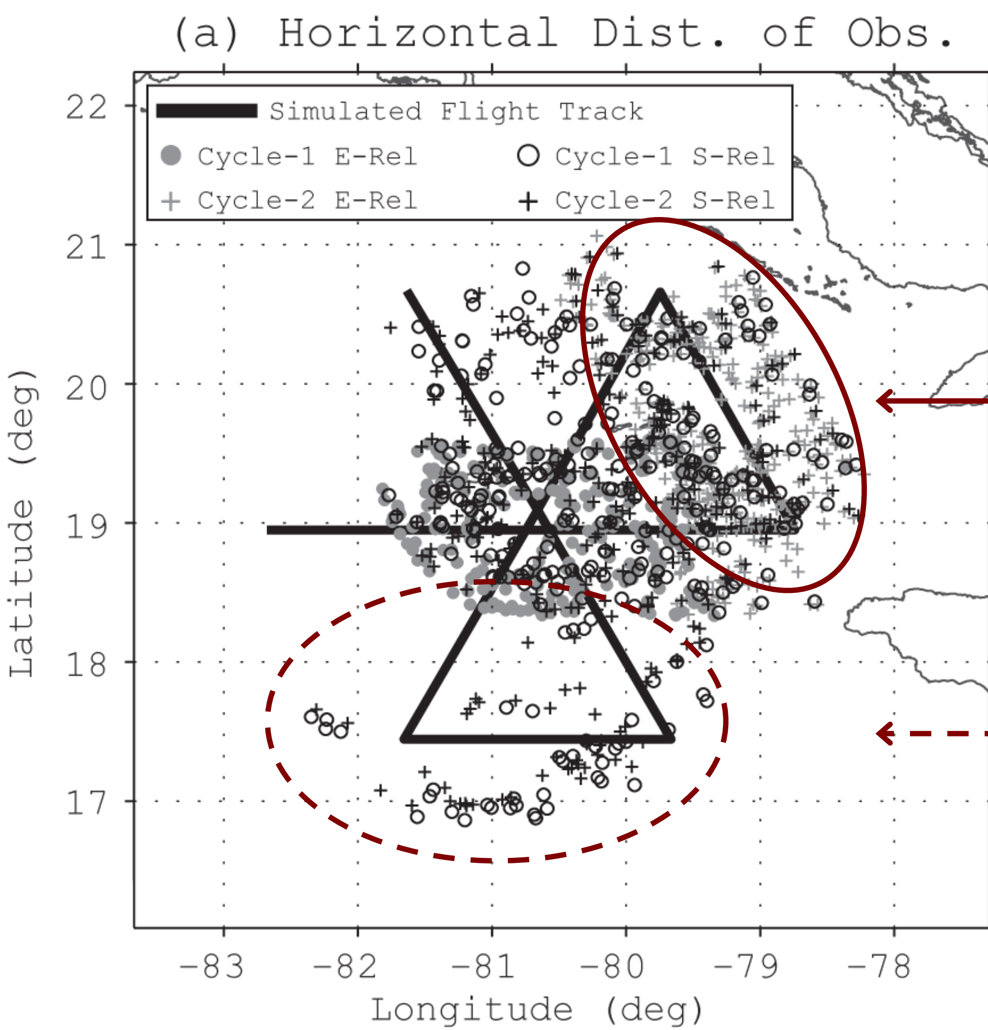


PDF of storm speed:
All 1970-2010 Atlantic tropical cyclones with central pressure less than 990 hPa

CDF of distance traveled / RMW:
If storm speed is converted to distance using a 2-h possible separation between obs and ctr, and normalized by RMW

⇒ For ~40% of the TCs considered, DA would be carried out using observations that are more than 1 RMW apart!

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

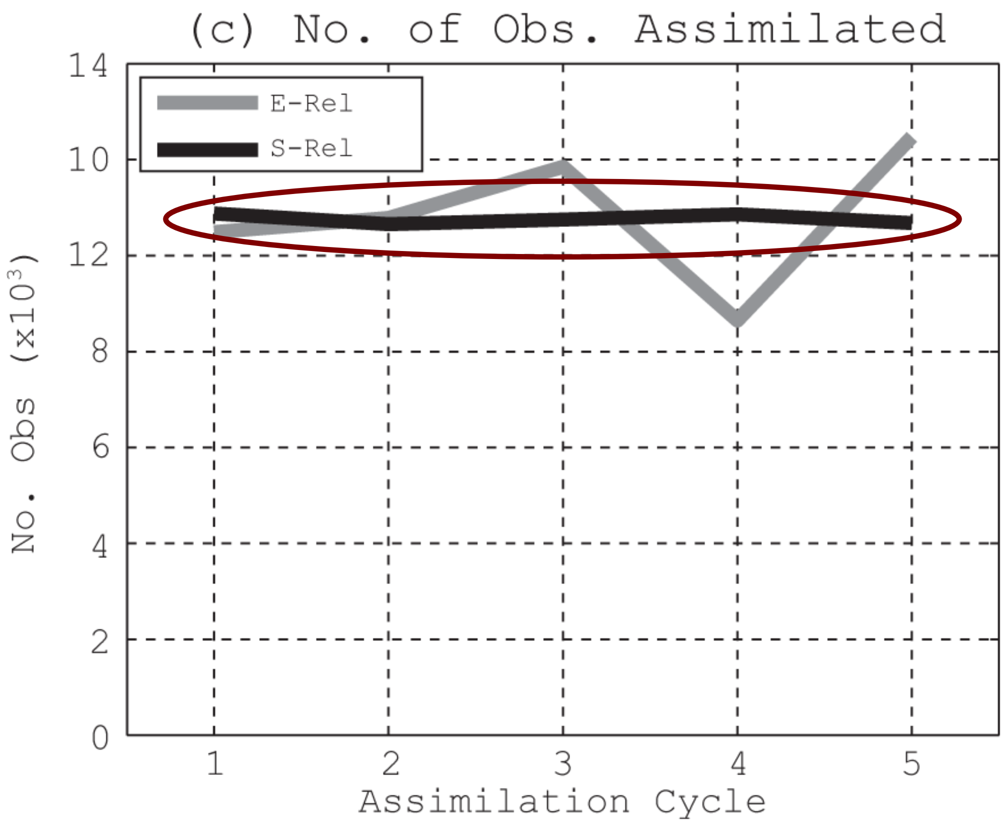


Cycle 2 - Downwind Leg:

Earth-relative: Observations limited in geographical location and away from storm center

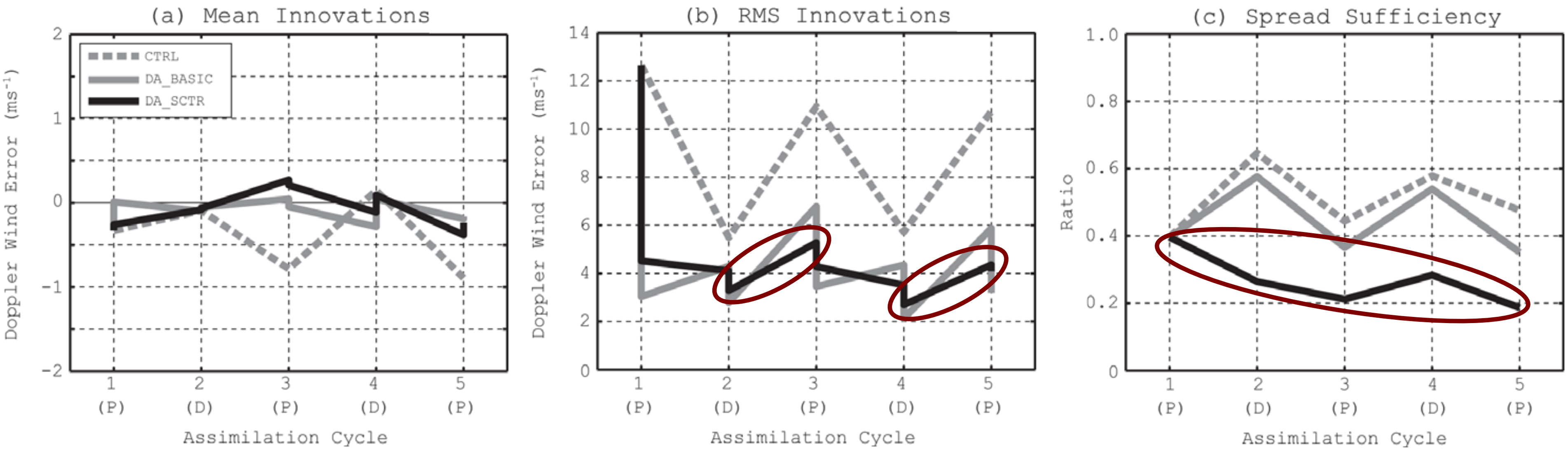
Storm-relative: Observations more uniformly distributed around the vortex

Number of Observations Assimilated per Assimilation Cycle: Earth-Relative vs. Storm-Relative



Storm-relative:
More uniform geographical distribution leads to better cycle-to-cycle number of observation consistency

Observation-Space Performance: Earth-Relative vs. Storm-Relative

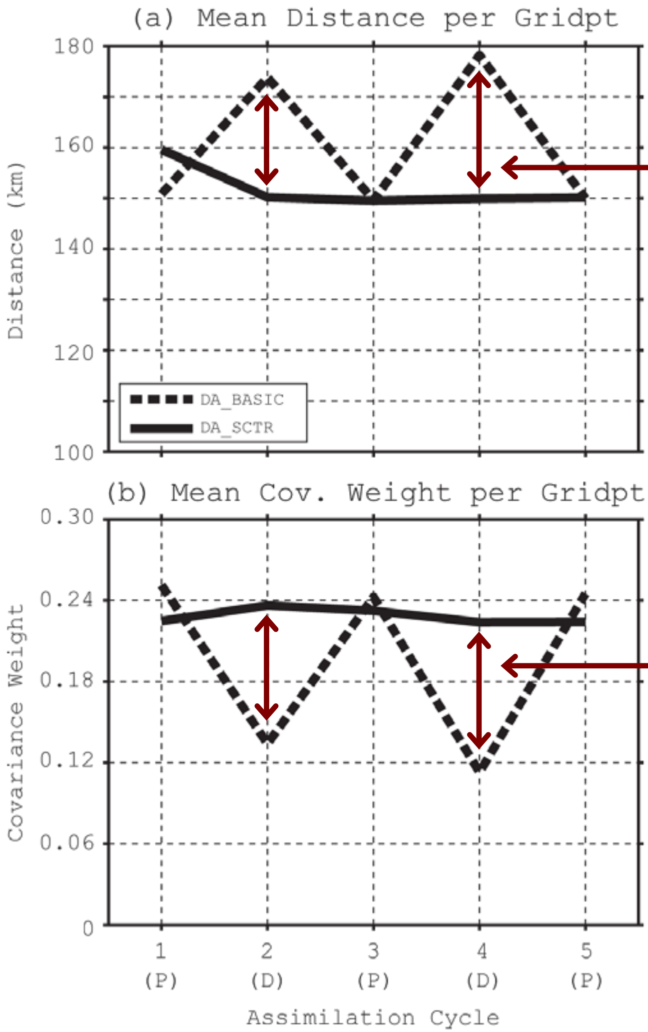


(1) Smaller analysis-forecast error growth

(2) Worsened spread sufficiency

CTRL : No DA
DA_BASIC: Earth-relative
DA_SCTR : Storm-relative

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



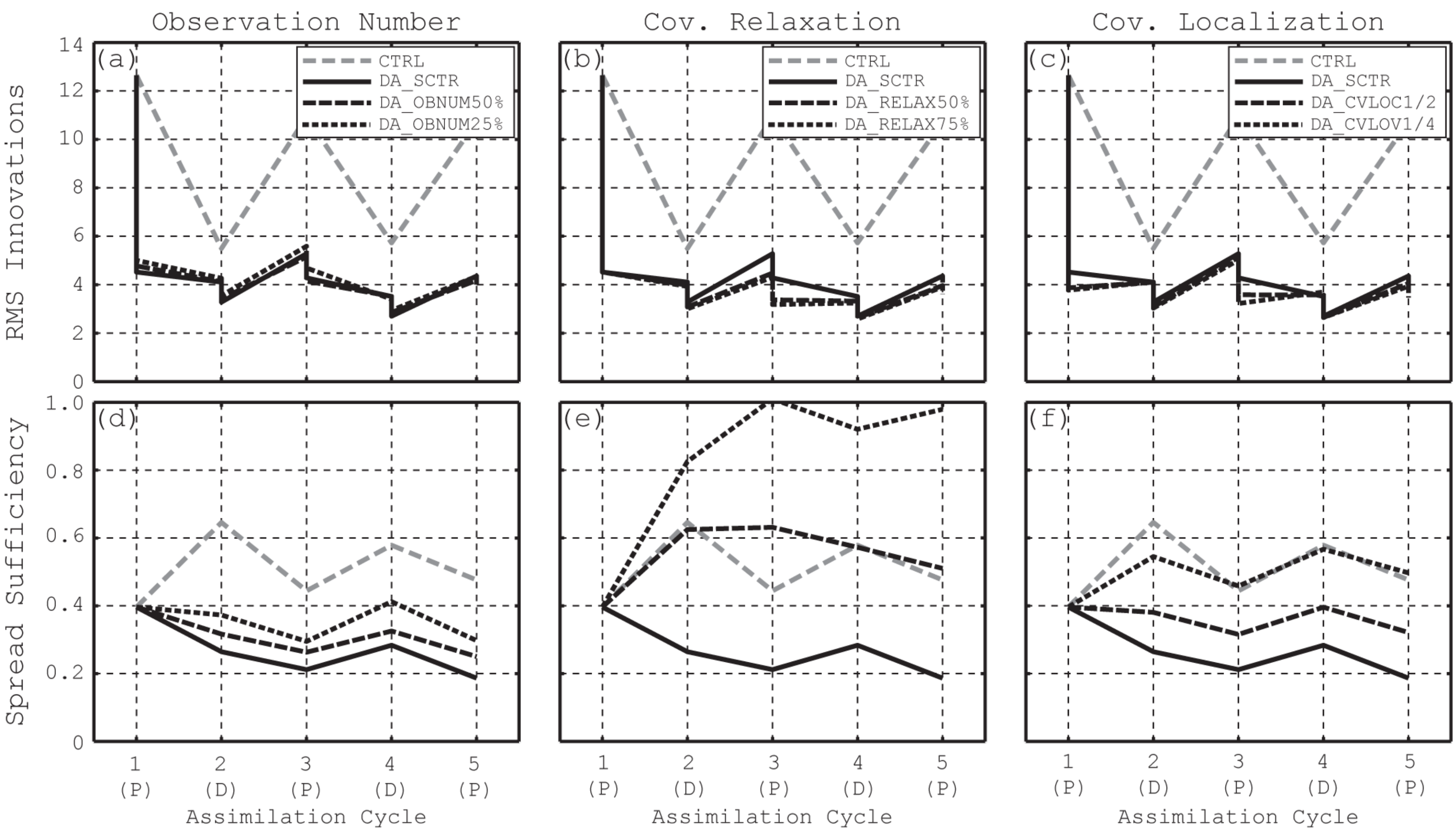
In storm-relative framework, observations are more uniformly distributed around the vortex

Per updated model grid point, this leads to a smaller average distance to assimilated observations, especially in downwind legs

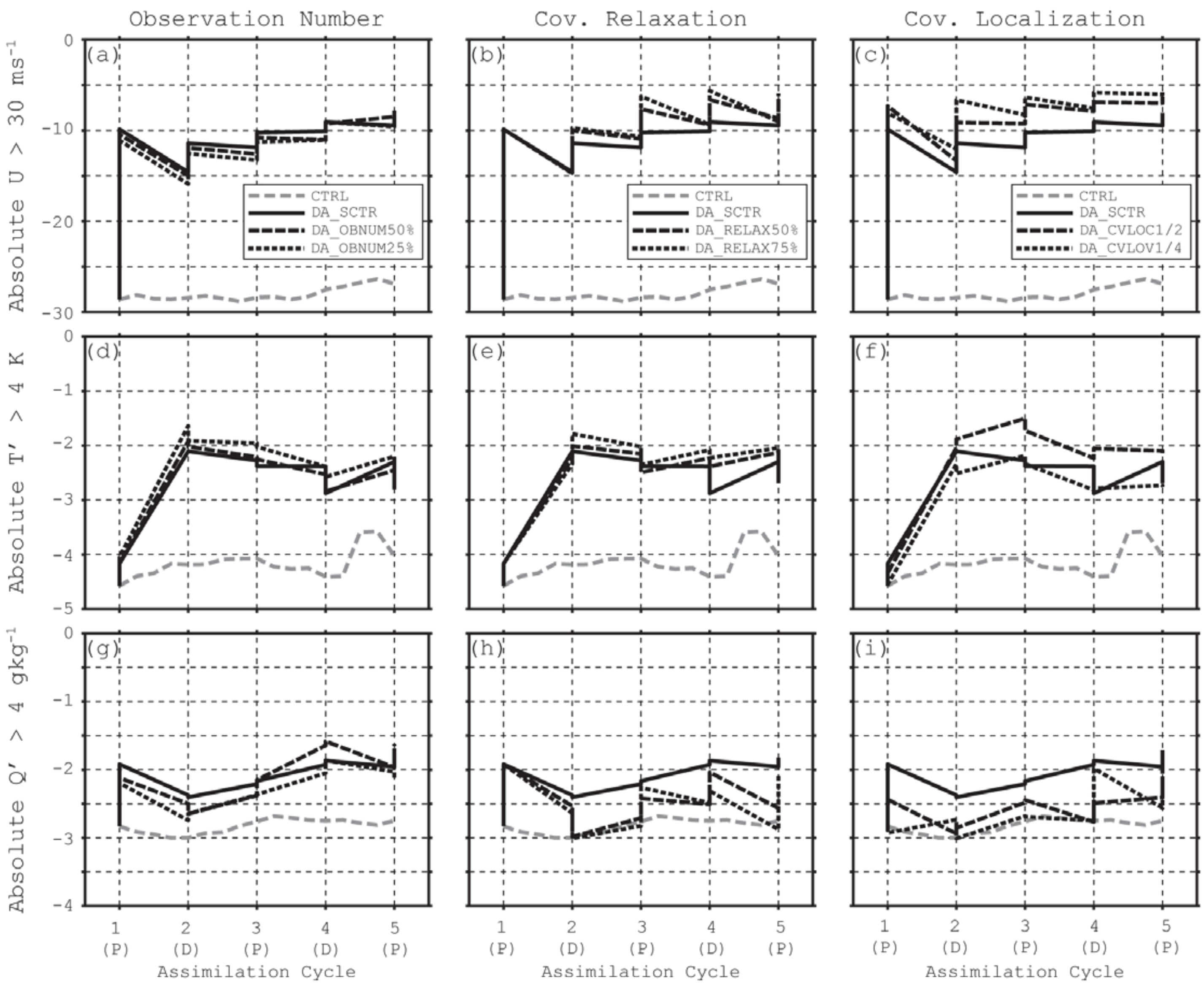
Smaller average distance translates to greater average covariance weight in covariance localization,
thus increasing the overall impact of obs.

DA_BASIC: Earth-relative
DA_SCTR : Storm-relative

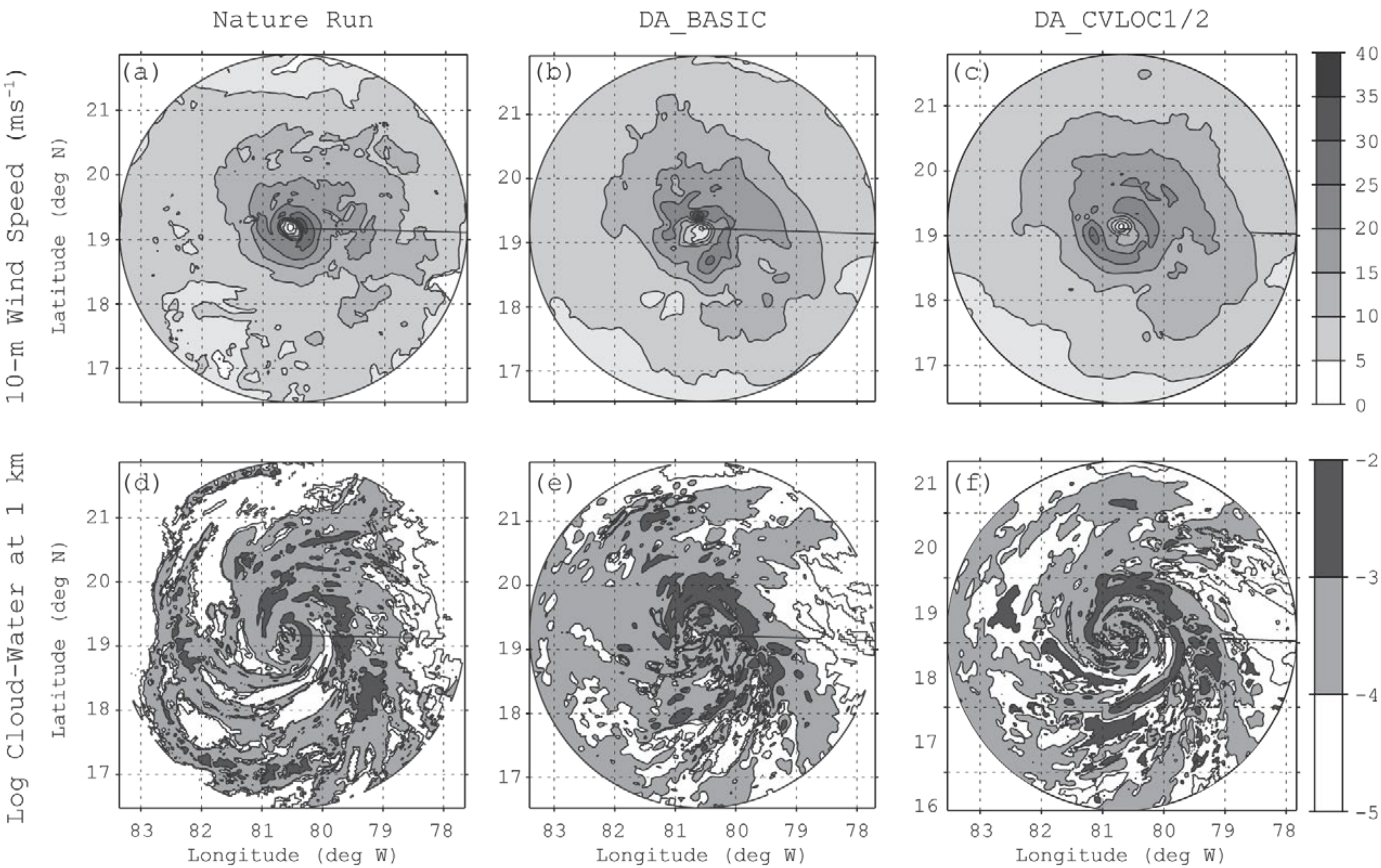
Observation-Space Performance with Variations in HEDAS Configuration



Model-Space Performance with Variations in HEDAS Configuration



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



Summary

- Successful implementation of HEDAS for vortex-scale data assimilation with inner-core radar observations (84 real-data cases spanning 4 years and variety of storms/categories)
- HEDAS analyses exhibit good statistical conformance with observed position/intensity/structure
- Assimilation of storm-relative observations result in improvements in analyses compared to Earth-relative observations
- Smaller analysis-to-forecast error growth during cycling is encouraging
- Worsened ensemble spread must be accounted for through stricter covariance localization and inflation