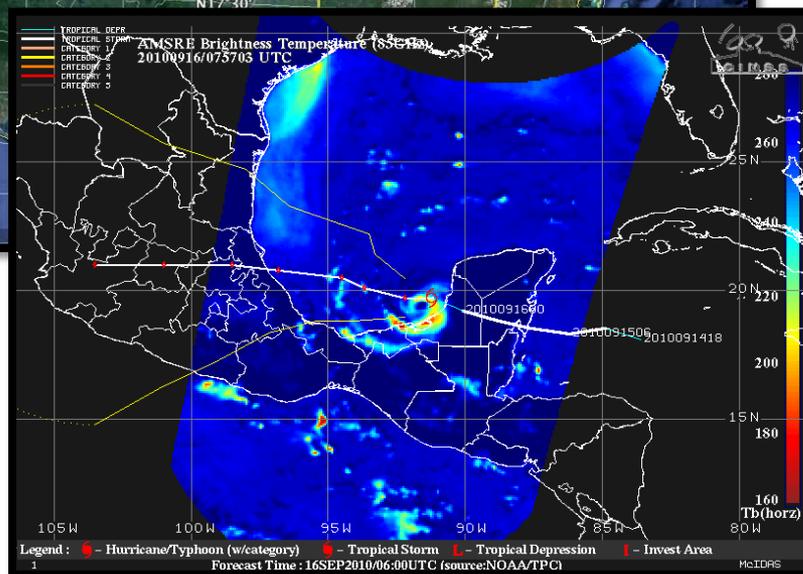
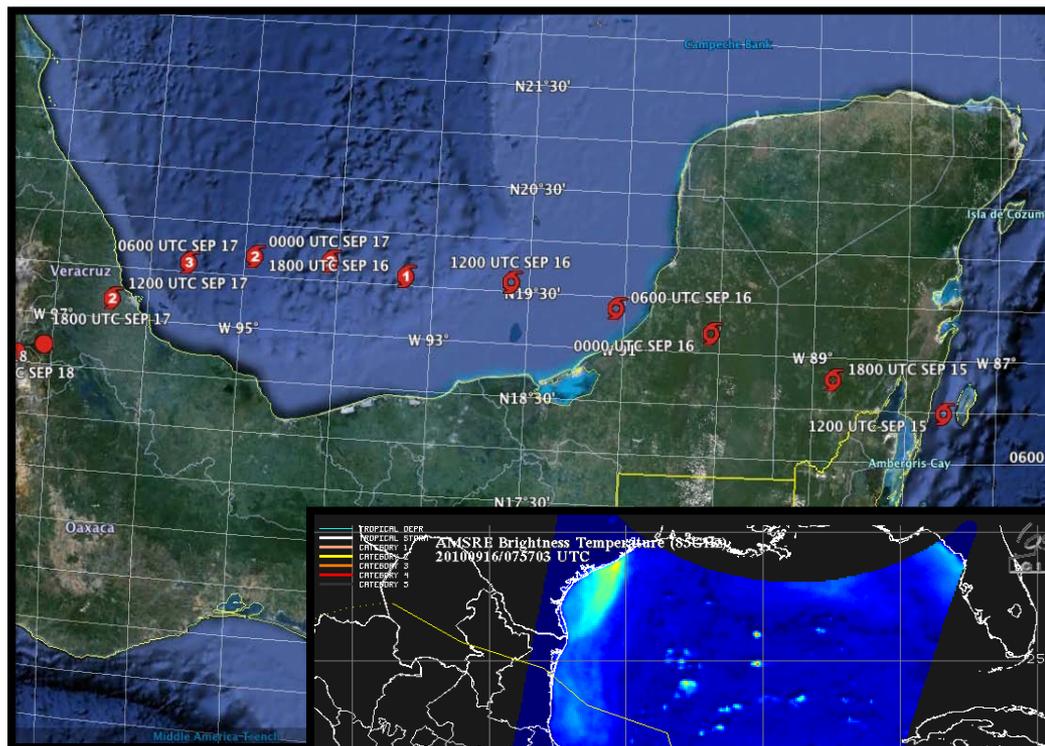


# Development of a WRF-EnKF system for GH: Very preliminary results for Karl (2010)

Jason Sippel and Scott Braun - NASAs  
GSFC

Special thanks to Yonghui Weng - PSU

# Hurricane Karl: 'Unexpected' RI



- In contrast to nearly all forecasts, Karl did not weaken to a TD while over the Yucatan Peninsula
- With an intact inner core, RI commenced almost immediately upon emerging into BoC

# Hurricane Karl: Forecast error



Intensity (Maximum Wind Speed) Probability Table  
Tropical Storm Karl Advisory Number 6  
10:00 PM CDT Sep 15 2010



| Wind Range (mph)           | Forecast Time        |                      |                      |                      |                      |                      |                       |
|----------------------------|----------------------|----------------------|----------------------|----------------------|----------------------|----------------------|-----------------------|
|                            | 12 hour for 7 AM Thu | 24 hour for 7 PM Thu | 36 hour for 7 AM Fri | 48 hour for 7 PM Fri | 72 hour for 7 PM Sat | 96 hour for 7 PM Sun | 120 hour for 7 PM Mon |
| Dissipated                 | <1%                  | 1%                   | 2%                   | 3%                   | 36%                  | 52%                  | NA                    |
| Tropical Depression (<39)  | 8%                   | 9%                   | 10%                  | 8%                   | 33%                  | 20%                  | NA                    |
| Tropical Storm (39-73)     | 88%                  | 79%                  | 68%                  | 59%                  | 27%                  | 22%                  | NA                    |
| Hurricane (all categories) | 3%                   | 11%                  | 21%                  | 31%                  | 5%                   | 6%                   | NA                    |
| -- Category 1 (74-95)      | 3%                   | 11%                  | 18%                  | 25%                  | 4%                   | 5%                   | NA                    |
| -- Category 2 (96-110)     | <1%                  | 1%                   | 3%                   | 4%                   | 1%                   | 1%                   | NA                    |
| -- Category 3 (111-130)    | <1%                  | <1%                  | 1%                   | 2%                   | <1%                  | <1%                  | NA                    |
| -- Category 4 (131-155)    | <1%                  | <1%                  | <1%                  | <1%                  | <1%                  | <1%                  | NA                    |
| -- Category 5 (>155)       | <1%                  | <1%                  | <1%                  | <1%                  | <1%                  | <1%                  | NA                    |
| Forecast Maximum Wind      | 50 mph               | 60 mph               | 65 mph               | 75 mph               | 30 mph               | 25 mph               | NA                    |

75 80 120 70 x x

Official forecast error:

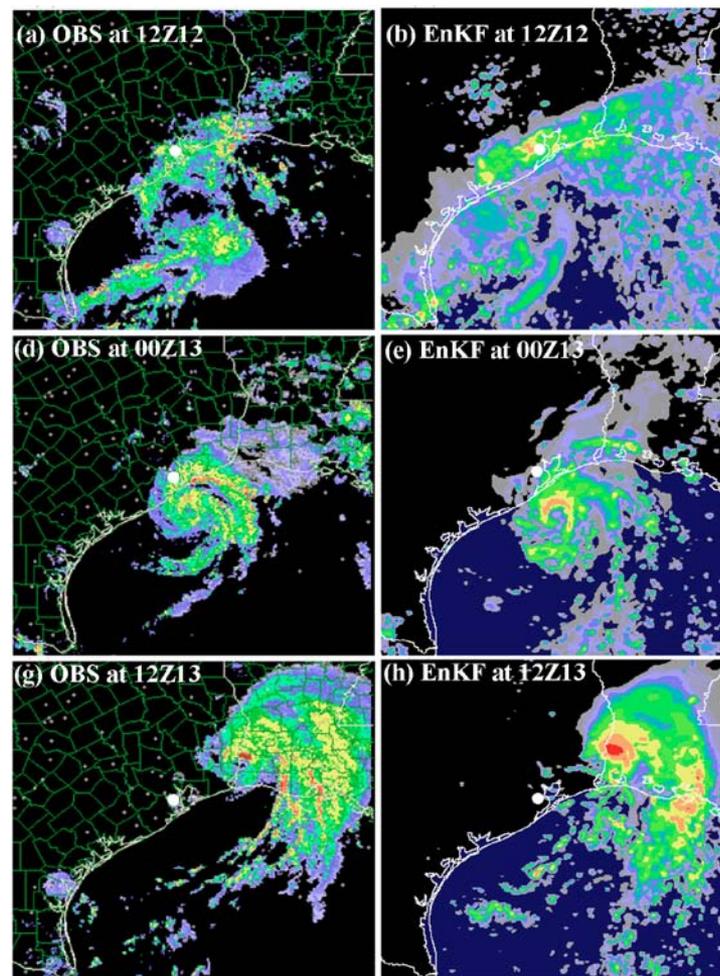
position > climo

intensity >> climo (~15 mph @ 36 h)

# WRF-EnKF system

- Proven successful, even with difficult storms
- Same EnKF as used for:
  - WSR-88D Vr assimilation in Hurricane Humberto (Zhang et al. 2009, MWR)
  - P3 Vr assimilation in Hurricane Katrina (Weng and Zhang, MWR under review)
  - Penn. State University HFIP real-time WRF/EnKF

Humberto: Obs vs. EnKF analysis



# Objectives

1. Generate an ensemble of Hurricane Karl without data assimilation
2. Perform OSSEs by extracting simulated observations taken from Global Hawk, particularly HIWRAP (taken from 'extra' ensemble member)
3. Evaluate performance/improvement, make changes if necessary
4. Eventually, assimilate real data

# WRF-EnKF system setup

- Standard EnKF used to update mean
- EnSRF used to update members
- Covariance inflation ( $\alpha=0.8$ ):

$$-x_{new}^{a'} = (1-\alpha)x^{a'} + \alpha x^{f'}$$

- Differing ROI used for Vr (SCL)
  - 1215 km ROI for 1/9 of obs D1-3
  - 405 km ROI for additional 2/9 on D2-3
  - 135 km for an additional 6/9 on D3

# WRF-EnKF system setup

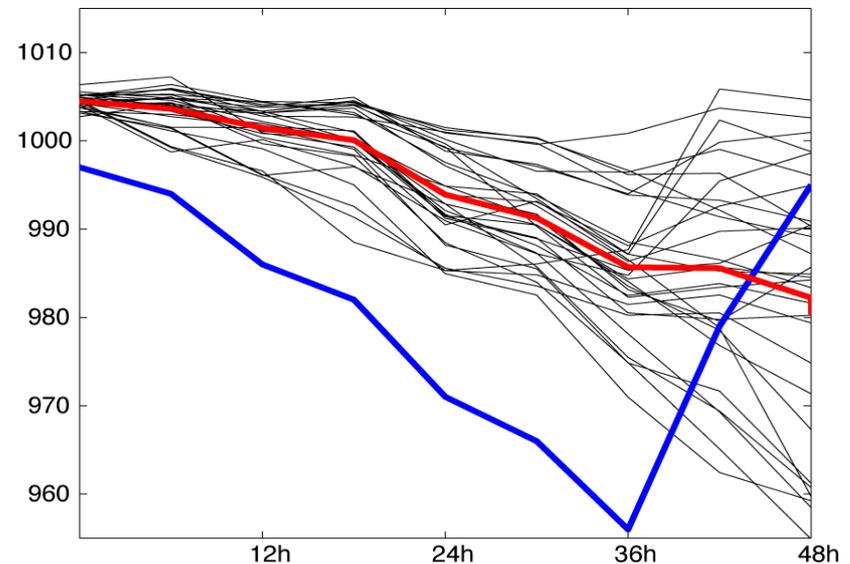
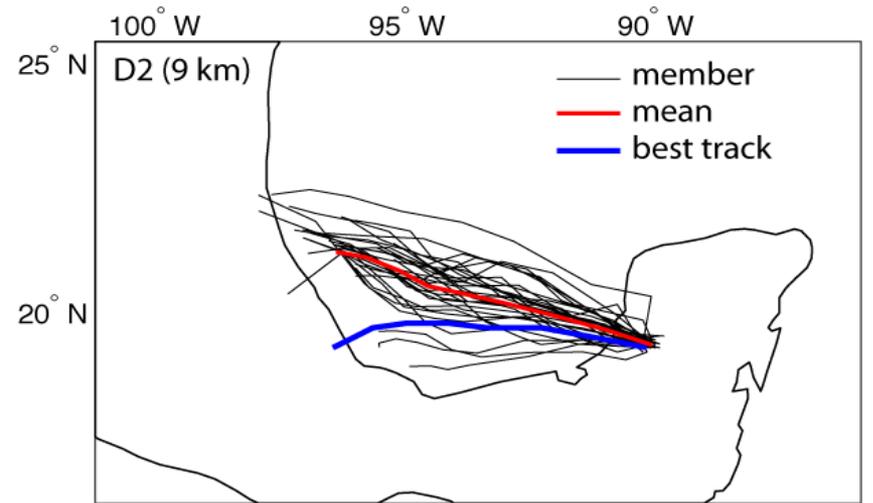
## WRF details:

- 30-member ensemble + 1 ‘truth’ member, IC and BC perturbations
- Initialized at 00 UTC 16 September
- 27/9/3-km domains
- WSM-6 mp, YSU PBL

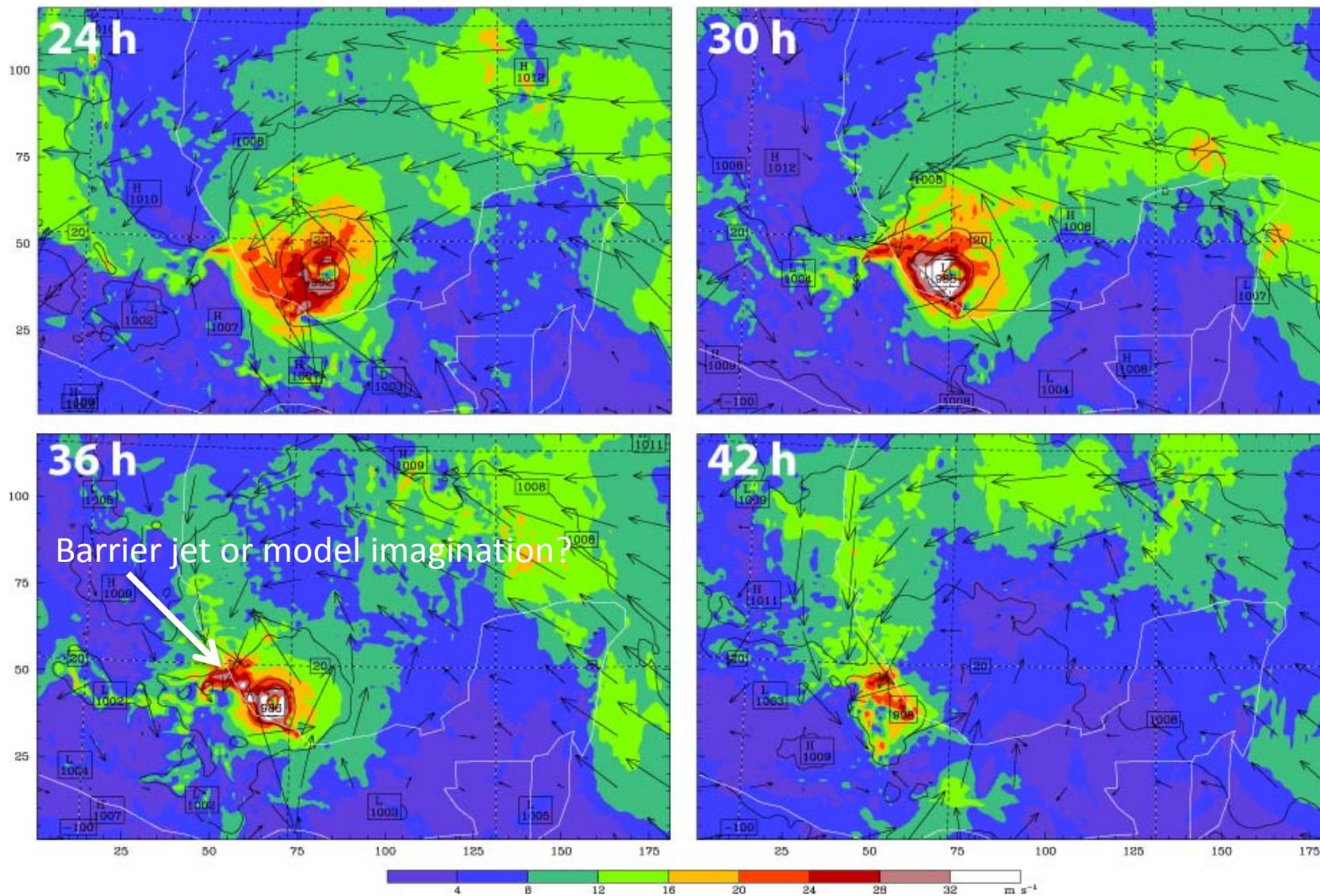


# Pure ensemble performance

- RI captured by a number of members
- Observed intensity *never* spanned by ensemble, largely an IC problem
- Track spanned, but considerable error growth near end

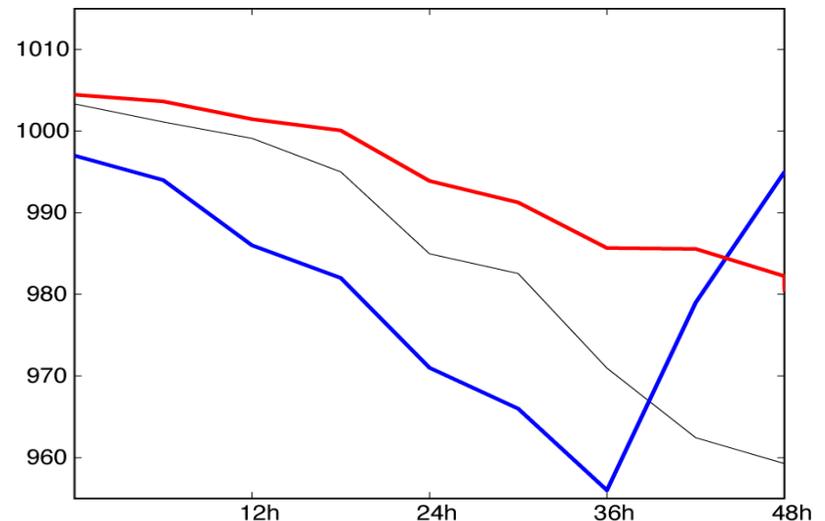
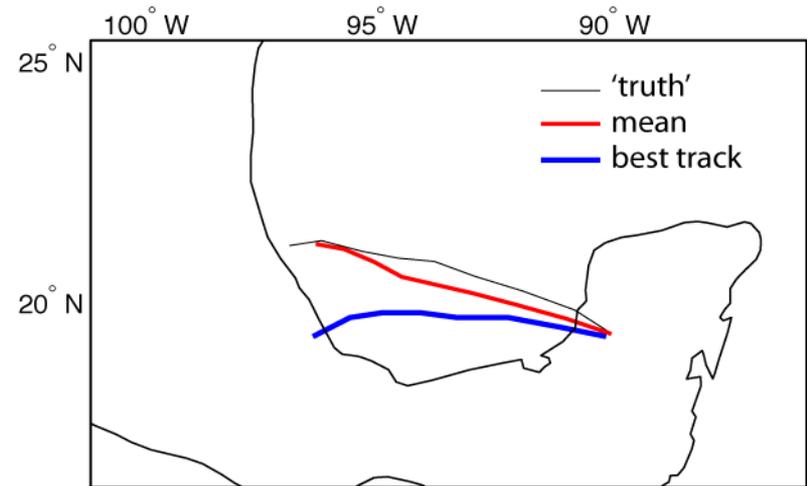


# Interesting landfall simulations

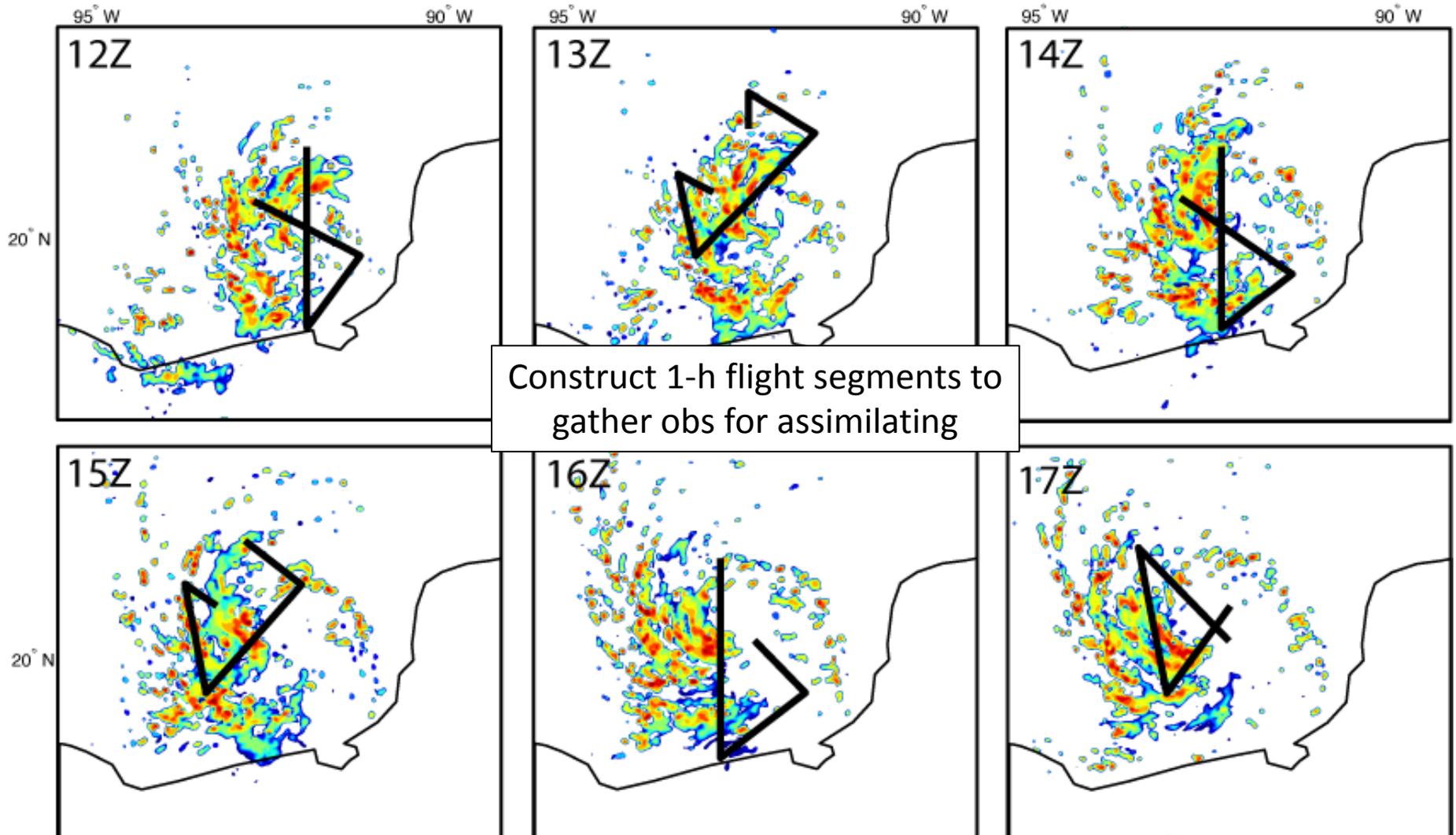


# 'Truth' simulation for OSSEs

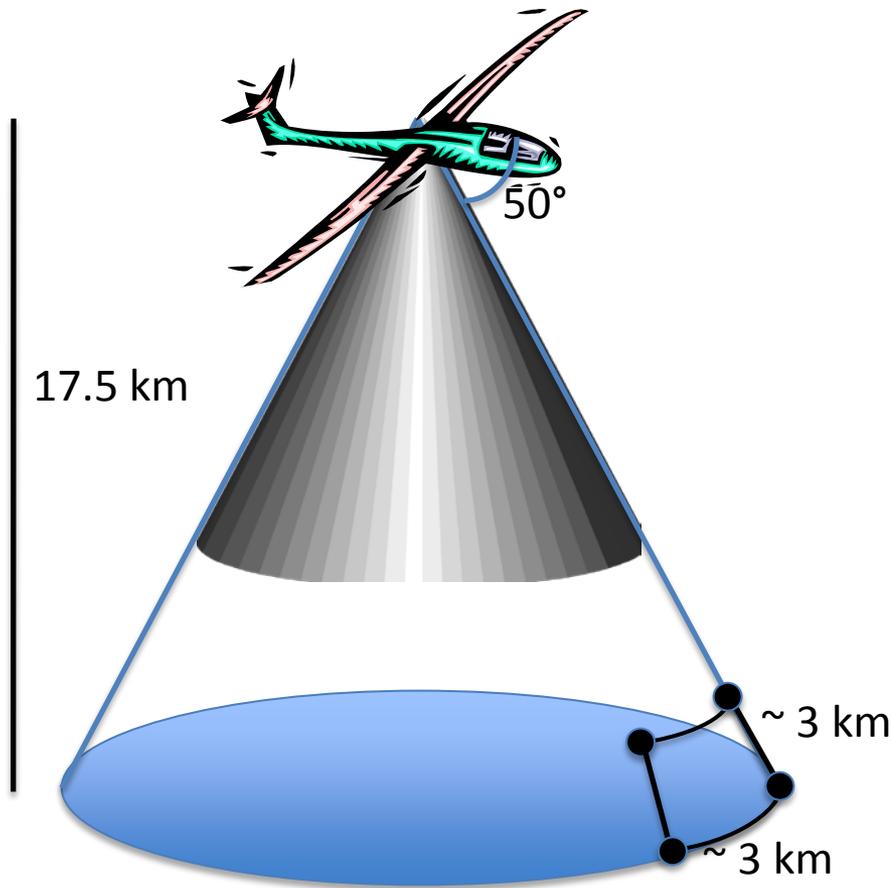
- Not necessary to have a perfect simulation for an OSSE
- 'Truth' has similar RI to Karl, but it starts out ~5 hPa too weak
- Similar track error as operational models



# 'Truth' simulation GH flight

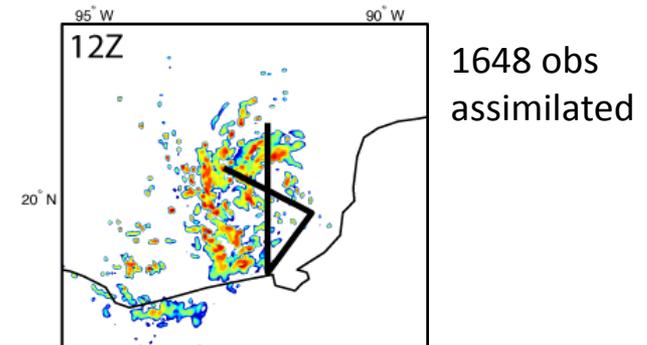
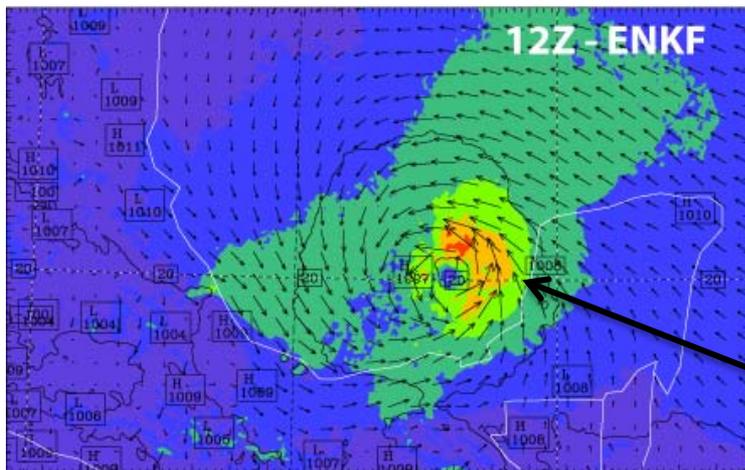
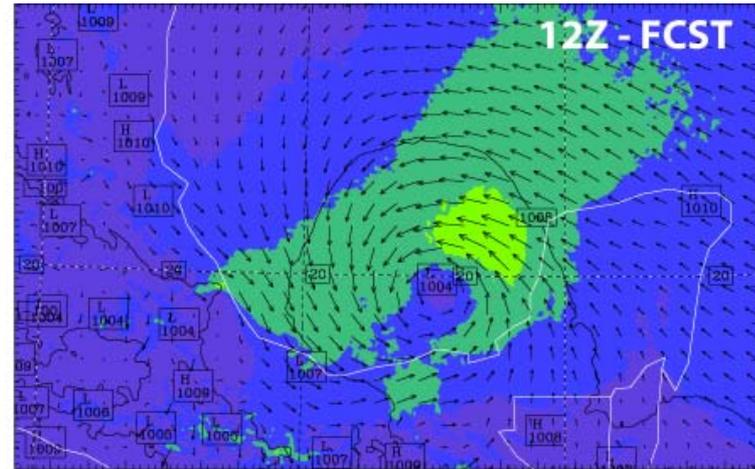
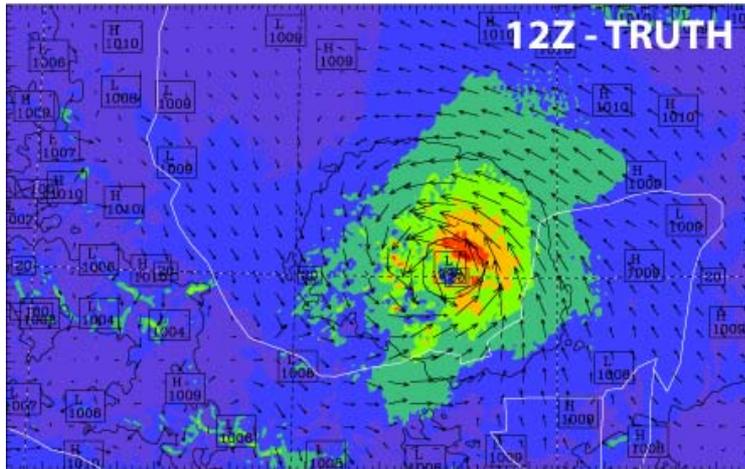


# Simulated HIWRAP observations



- Assuming instantaneous scan
- Using one scan every  $\sim 28$  km ( $\sim 0.25^\circ$  lat)
- Approximately constant  $\sim 3$ -km spacing between obs on surface of cone
- Only assimilate when  $\text{dBZ} > 10$

# Assimilating Vr at 12Z



Intensity, structure, and position have been considerably improved with just one cycle.



# Summary

- WRF-EnKF system being developed for assimilating GH-based data
- Pure ensemble simulation of Hurricane Karl produces interesting results
- Very preliminary EnKF results are hopeful
- Next step is to assimilate other simulated data and compare effects on analyses
- Ultimately, we want to assimilate real-time data

# WRF-EnKF system setup

1. Populate initial ensemble ICs with large-scale perturbations generated by WRF-3DVAR
2. Integrate 9-12 h to generate mesoscale covariance, which is used estimate forecast error covariance  $\mathbf{P}^f$
3. Assimilate observations
4. Integrate ensemble forward to next assimilation cycle, repeat 3-4

# WRF-EnKF system details

- Classic KF assimilation equations:
  - $\mathbf{x}^a = \mathbf{x}^f + \mathbf{K} (\mathbf{y} - \mathbf{H}\mathbf{x}^f)$
  - $\mathbf{K} = \mathbf{P}^f \mathbf{H}^T (\mathbf{H}\mathbf{P}^f \mathbf{H}^T + \mathbf{R})^{-1}$
- EnKF serial assimilation, update mean:
  - Sample  $\mathbf{P}^f$  and  $\mathbf{x}^f$  from ensemble
  - $\mathbf{x}_{i}^{\text{am}} = \mathbf{x}_{i}^{\text{fm}} + c_i / d * (\mathbf{y}_o - \mathbf{x}_{o}^{\text{fm}})$
  - $c_i / d = \text{cov}(\mathbf{x}_{i}^f, \mathbf{x}_{o}^f) / (\sigma_r^2 + \sigma_f^2)$

# WRF-EnKF system details

- Due to covariance underestimation, ENSRF used to update ensemble members:

$$-x^{a'}_i = x^{f'}_i - (1 + (\sigma_r^2 / (\sigma_r^2 + \sigma_f^2)))^{1/2} * c_i / d * x^{f'}_o$$

- Covariance inflation also used to combat filter divergence

$$-x^{a'}_{new} = (1-\alpha)x^{a'} + \alpha x^{f'}$$

-Here,  $\alpha=0.8$

# Hurricane Karl: GRIP mission

- Global Hawk has unprecedented 20 passes over eye during single science flight (Cat 1-3)
- Global Hawk, DC-8, WB57, NOAA42, NOAA49, AF-C130

