Assimilation of radar radial velocity data with the WRF ensemble-3DVAR hybrid system for the prediction of hurricane IKE (2008)

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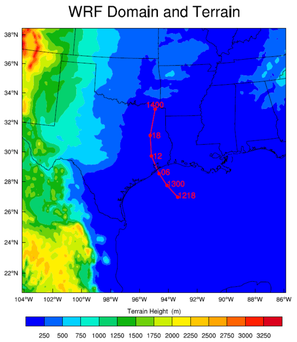
1. Introduction

The hybrid ensemble-3DVAR data assimilation system was developed for the Weather Research and Forecast (WRF) model (Wang et al. 2008ab). Wang et al. 2008ab tested the hybrid DA system over a winter month for the North America domain and showed that forecasts initialized by the analyses generated by the hybrid method was more accurate than 3DVAR, due to the use of flow-dependent ensemble covariance provided by the ensemble transform Kalman filter (ETKF, Wang and Bishop 2003, Wang et al. 2004, Wang et al. 2007b). Wang 2010 implemented the system for hurricane track forecast and found the hybrid data assimilation system produced more accurate hurricane track forecast than 3DVAR. So far the implementation of the hybrid system is mostly on relatively coarse resolution (30-200km). This study applies the hybrid DA method for convective scale radar data assimilation for the prediction of hurricane IKE 2008 before and during landfall.

2. Hurricane IKE 2008 radar data assimilation experiment set up



•Single domain: 5-km 401x401x41
•Ensemble size: 40 members
•Hybrid DA and forecast:
6-h ensemble initialized at 18Z12 Sep.
Radar DA cycling starting 00Z13 Sep. every 30 min for 3 hrs
21 hr deterministic and ensemble forecast from 03Z13 to 00Z14 Sep.
•3DVAR and forecast: Similar set up as Hybrid
•Observations: Radial velocity data from two WSR88D radars (KHGX, KLCH)

The cost function for ensemble-3DVAR hybrid (Wang et. al. 2008) ,

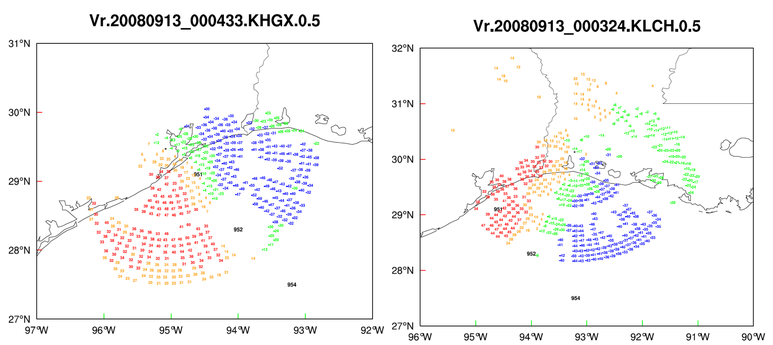
$$J(x_1',a)=\beta_1\frac{1}{2}(x_1')^{T}B^{-1}(x_1')+\beta_2\frac{1}{2}(a)^{T}A^{-1}(a)+\frac{1}{2}(y^{o'}-Hx')^{T}R^{-1}(y^{o'}-Hx')$$

$$x'=x_1'+\sum_{k=1}^{K}(a_k\circ x_k^{e})\text{----------}>\frac{1}{\beta_1}+\frac{1}{\beta_2}=1$$

x'	total increment	x_1'	3DVAR increment
a_k	extended control variable	x_k^e	ensemble perturbation
β_1	coefficient for 3DVAR	β_2	coefficient for ensemble covariance
B	3DVAR covariance	A	ensemble covariance localization
$y^{o'}$	observation innovation	H	forward operator.

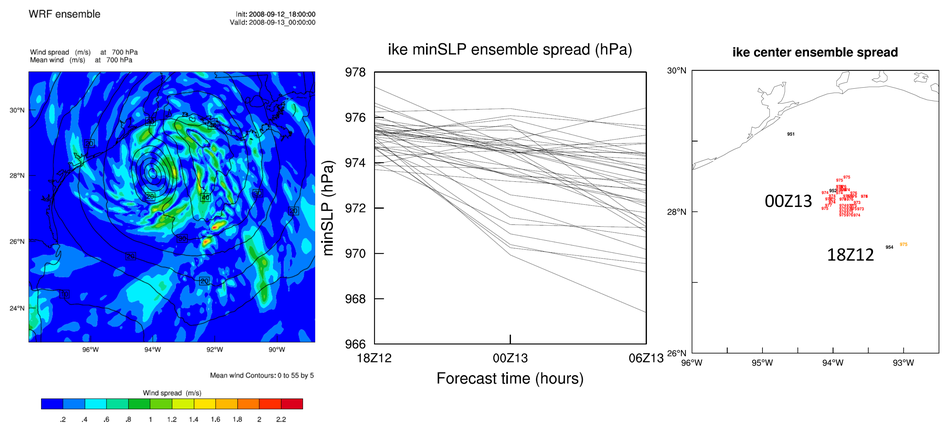
3. Results

3.1 Radar radial velocity



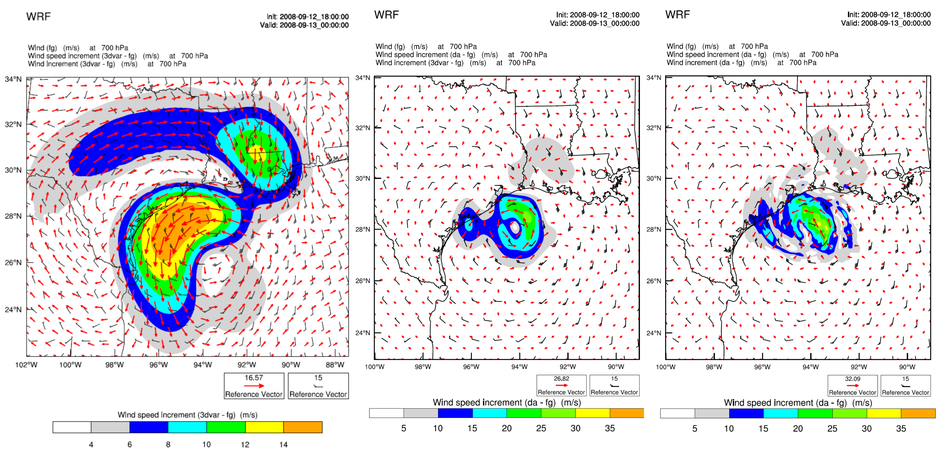
Radar radial velocity preprocessing
•Raw data: WSR88D Level II. KHGX left. KLCH right.
•Use wind profile based on RAOB and GFS grid data to create background
•De-aliasing using a modified version of Four Dimensional Doppler radial velocity de-aliaisng sceme (4DD) (James and Houze, 2001)
•Thinning: 500 m in vertical and 10 km in horizontal

3.2 Spread of 700 hPa wind, central sea level pressure, hurricane IKE center location



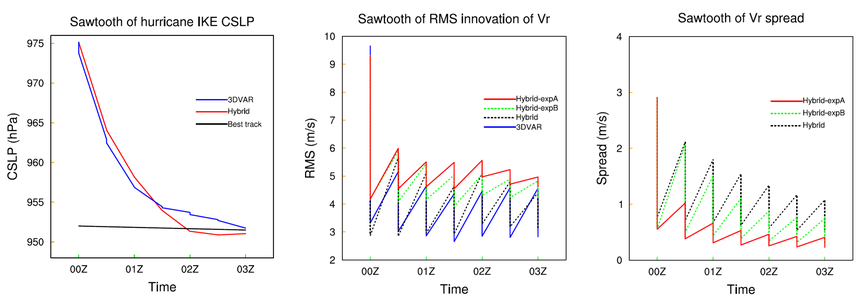
The 6-h forecast spread are initialized by WRF 3DVAR randomcv at 18Z UTC 12 Sep. 2008.

3.3 700 hPa wind analysis increment



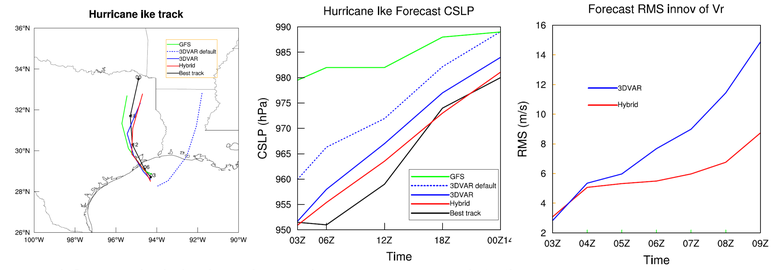
•WRF 3DVAR wind increment by lengthscale from NMC-method without tuning shows a dipole structure, a pair of cyclone and anticyclone (left).
•After lengthscale is reduced with a factor 0.3, the dipole is no longer seen. The maximum wind increment is shifted from left-front to right-front as expected (middle).
•Hybrid wind increment shows a cyclone with small feature corresponding with the spread.

3.4 Sawtooth of analysis central pressure, Vr RMS innovation, and Vr spread



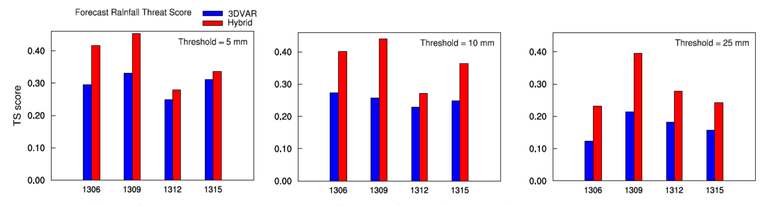
•Hybrid uses ensemble covariance relax inflation $x^{new} = (1-\alpha)x^{a} + \alpha x^{f}$ (α=0.5 here) and vertical localization (EOF)
•Hybrid-expA is hybrid without both inflation and vertical localization
•Hybrid-expB is hybrid with inflation but without vertical localization
•CSLP for both 3DVAR and hybrid at 03Z13, end of cycling, is close to observation
•Both inflation and vertical localization reduce root mean squared innovation of Vr
•The root mean squared innovation of Vr for hybrid and 3DVAR are close to each other
•Both inflation and vertical localization raise spread

3.5 Forecast of track, central sea level pressure, and root mean squared Vr innovation



•Track forecast by hybrid was better than WRF 3DVAR and similar to GFS
•Hybrid predicted a stronger IKE (closer to the best track) than WRF 3DVAR and GFS.
•WRF 3DVAR with tuned lengthscale predicted track and intensity better than WRF 3DVAR with default lengthscale.

3.6 Threshold score for precipitation forecast



•TS score formula TS = C/(F+O-C) C is the number of correct forecast.
F is the number of the forecast. O is the number of the observation.
•TS score for hybrid is higher than that for 3DVAR for all criteria.

4. Conclusion

The hybrid ensemble-3DVAR system developed for WRF (Wang et al. 2008ab) was successfully implemented for convective scale assimilating radar radial velocity for the prediction of hurricane IKE 2008. Our preliminary results have shown that due to the use of the flow-dependent ensemble covariance in the hybrid DA system,

(1) An appropriate Kalman filter ensemble inflation relax coefficient 0.5 is obtained.
(2) The Vertical localization (EOF) is realized well.
(3) The WRF 3DVAR lengthscale is adjusted so that dipole structure in increment fields is no longer seen.
(4) An model hurricane is generated as deep as observed at the end of DA cycling for both 3DVAR and hybrid.
(5) Forecast of the track and central sea level pressure are all improved by the hybrid DA method compared to the 3DVAR.
(6) The precipitation TS scores obtained by hybrid are higher than that by 3DVAR.
(7) The forecast root mean squared innovation of radial velocity by hybrid is much smaller than that by 3DVAR.

5. References

James, C. N., and R. A. Houze, 2001: A real-time four-dimensional Doppler dealiasing scheme. J. of Atmos. And Oceanic Technology. 18, 1674-1683.

Lorenc, A. C., 2003: The potential of ensemble Kalman filter for NWP-A comparison with 4DVAR. Quart. J. Roy. Meteor. Soc., 126, 2991-3012.

Wang, X, and C H Bishop, 2003: A comparison of breeding and ensemble transform Kalman filter ensemble forecast schemes. J. Atmos. Sci., 60, 1140-1158.

Wang, X., C. H. Bishop, and Simon J. Julier, 2004: Which is better, an ensemble of positive-negative pairs or a centered spherical simplex ensemble? Mon. Wea. Rev., 132, 1590-1605.

Wang, X., T. M. Hamill, J. S. Whitaker, and C. H. Bishop, 2007b: A comparison of hybrid ensemble transform Kalman filter, OI, and ensemble square-root filter analysis schemes. Mon. Wea. Rev., 135, 1055-1076.

Wang, X., D. Barker, C. Snyder, T. M. Hamill, 2008a: A hybrid ETKF-3DVAR data assimilation scheme for the WRF model. Part I: observing system simulation experiment. Mon. Wea. Rev., 136, 5116-5131.

Wang, X., D. Barker, C. Snyder, T. M. Hamill, 2008b: A hybrid ETKF-3DVAR data assimilation scheme for the WRF model. Part II: real observation experiments. Mon. Wea. Rev., 136, 5132-5147.

Wang, X., 2010: Impact of flow-dependent ensemble covariance for hurricane track forecast: a study using the hybrid ETKF-3DVAR data assimilation system for WRF. Mon. Wea. Rev.,

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