# Comparing Variational, Ensemble-based and Hybrid Data Assimilations at Regional Scales

## Meng Zhang and Fuqing Zhang Penn State University

## Xiang-Yu Huang and Xin Zhang NCAR

4<sup>th</sup> EnDA Workshop, Albany, NY April 6~9 2010

## **Compare weakness and strength of DA methods**

- 3D-Var: Low cost Lack of flow-dependent
- 4D-Var: Trajectory fitting for asynchronous obs Implicit flow-dependent estimation
   Poor background error covariance
   High cost
- EnKF: Flow-dependent B; ensemble forecast Few coding works Highly depends on the quality of ensembles and first-guess; non-linear operator
- Hybrid: coupling EnKF with 4D-Var ~ get an optimal and flexible DA approach





(By Lacoche et al. 2007) erator

## The hybrid of variational and ensemble-based DAs in literature

- Hamill and Snyder (2000): Hybrid in Ensemble-based framework.
- Lorenc (2003): propose hybrid method, Alpha-control variable transform
- Etherton and Bishop (2004): hybrid 3D-Var and EnKF in QG model.
- Buehner (2005): Additional control variable
- Wang et al. (2008a, b): hybrid ETKF-3DVAR in WRF model
- Liu et al. (2008a, b): alternative minimization with ensemble-B preconditioning for 4D-Var without ajoint model.
- Zhang et al. (2009): coupling EnKF with 4D-Var in Lorenz model
- Buehner et al. (2010a, b): ensemble 4D-Var for a quasi-operational system

### **Configuration of WRF DA systems over June 2003**

- WRF-ARW V3.1 (Shamarock et al. 2005)<sup>50 N</sup> 90-km grids covering North America; 27 vertical levels up to 50 hPa; LBCs interpolated from FNL analysis
- EnKF (Meng and Zhang 2008a, b) 30
  40-member ensemble with multi-schemes 1800-km influence radius for localization 0.8 relaxation and perturbed LBCs



3D/4D-Var of WRFDA V3.1 (Barker et al. 2004; Huang et al. 2009)
 "NMC" background error covariance (B); Var-scale at 3.0 and Length-scale at 1.0
 6-h assimilation window (covering -3 to +3 h at every analysis time)

• Hybrid (coupling EnKF with 4D-Var, Zhang et al. 2009) Perturbations are updated by EnKF, while mean is updated by 4D-Var Ensemble-based B is introduced into cost function via Alpha-control transform (Lorenc 2003; Wang et al. 2007, 2008a, b) ensemble-B is localized with the influence radius of 1800-km ensemble-B and NMC-B are weighted at 0.8 and 0.2, respectively  $B = \frac{1}{\beta}B_{ens} + (1 - \frac{1}{\beta})B_{nmc}, \quad (\beta = 1.25)$ 

# • EXP 1 : Single-observation test

- 1-degree T difference is placed at 500 hPa, 00Z 06/08/2003
- the single-obs increments represent the B structure

# • EXP 2 : 10-day cycling DA test

- DA at every 12 h
- Data: radiosonde, profiler, satellite wind, aircraft surface and ship observations
- Verification on 12-h forecasts against radiosonde

## Temperature (shaded) and horizontal wind (vector) increments



## Temperature (shaded) and horizontal wind (vector) increments



## **Moisture (Qv, shaded) increments**



X 10<sup>5</sup>

### **Compare EnKF and Hybrid with small ensemble size (10 members)**



### EXP 2: 10-day DA tests during June 2003



#### 4D-Var and Hybrid assimilate 4~5 times more data than 3D-Var and EnKF

## Mean vertical profiles of U, V, T and Qv 12-h forecast RMSE (06/01/2003 ~ 06/10/2003 with 12-h interval)



## Temporal variations of U, V, T and Qv 12-h forecast RMSE (06/01/2003 ~ 06/10/2003 with 12-h interval)



# **WRF Data Assimilations for Katrina 2005**

•WRF Domains : D1-D3 with 40.5km, 13.5km, 4.5 km grids and 35 vertical levels; Data assimilations only applied on D1

•Forecasts: 126-h deterministic run with D1, D2, D3 (two-way nested and D3 movable) initialized from 17:30 Z August 23 2005 with various ICs

•Data assimilated: Doppler radial velocity (err=3m/s) from KMAX during 14:30~17:30Z August 25 2005

#### **Experiments:**

- a) Control run with GFS Analysis
- b) 4D-Var with 3-h window, obs at every 15 min
- c) Successive EnKF and 3D-Var with 1-h interval





### **DA Performances on Track and Intensity forecasts**



## Simulated SLP v.s. Observation at 21Z 08/25/2005









### Simulated Max Reflectivity v.s. Radar Obs at 00Z 08/26/2005



### DA performances with "bad" first guess



## **Remarks:**

✤ In hybrid system, ensemble-based B provides flow-dependent structures and multivariate correlations for 4D-Var, while 4D-Var gives additional flowdependent constrains via forward/backward integrations

Hybrid outperforms all other single methods in a 10-day DA comparison, which may benefit from both EnKF (flow-dependent B) and 4D-Var (assimilating more observations and implicit flow-dependent information)

In Hurricane Katrina case, hybrid method is insensitive to the quality of first guess and can get more consistent performances than EnKF

## **Future works:**

Test various DAs for a month-long period, with higher resolution

Multi-incremental 4D-Var and Dual-resolution EnKF in Hybrid

**\*** More case studies from mid-latitude weather systems to hurricanes