Current status of the GMAO
Hybrid Ensemble 3D-Var

Amal El Akkraoui and Ricardo Todling
Global Modeling and Assimilation Office

1 Background and motivation

2 Some elements of the hybrid system

3 Results

4 Summary
Use flow-dependent background error information derived from ensemble techniques but still within the variational framework.

The 3D-Var cost function:

$$J(\delta x) = \frac{1}{2} \delta x^T B^{-1} \delta x + \frac{1}{2} (H \delta x - y')^T R^{-1} (H \delta x - y')$$

The hybrid 3D-Var cost function:

$$J(x') = \frac{1}{2} x'^T (\beta B + (1 - \beta) P^e \circ S)^{-1} x' + \frac{1}{2} (H x' - y')^T R^{-1} (H x' - y')$$

$$x' = \delta x + \sum_{k=1}^{K} a_k \circ x^e_k$$, and $$P^e = \sum_{k=1}^{K} x^e_k (x^e_k)^T$$
Background and motivation

GEOS DAS IAU-Based 3D-Var

6-hr cycle using IAU (Bloom et al. 1996):
- predictor step: create first-guess.
- corrector step: apply analysis increment as a model tendency.

1st guess (AGCM)  AANA (GSI)  Assimilation (AGCM)
GEOS DAS IAU-Based Hybrid 3D-Var

Background and motivation
Some elements of the hybrid system

Current hybrid configuration:

Hybrid 3D-Var:

1. 32 members; S-EnKF;
2. **Dual resolution** (central at 0.5°, ensemble at 1°);
3. Covariance weights: $\beta = 0.5$ (50% $B_{sta}$ / 50%$B_{ens}$);
4. Re-centering of the members around the central analysis;
5. Blending of the members in the upper stratosphere;
6. Multiplicative and additive inflation;
7. Vertically varying localization scales (same for the ensemble and the hybrid);
Some elements of the hybrid system

Covariance Weights: T increment for one T-obs at 45N

\[ \beta = 0 \text{ (full static)} \]

\[ \beta = 0.5 \]

\[ \beta = 1 \text{ (full ensemble)} \]
Some elements of the hybrid system

Covariance Weights: Vertically varying weights

- Original transition between 5 and 1 mb.
- Try deepening this layer (20 and 5 mb) to avoid the stratopause and the transition layer for the temperature gradients;
- Amsua-14 peaks at around 2mb;
- Interactions between vertical localization scales, covariance weights, and balance might be challenging.

Cov. weights ($\beta_{\text{stat}}$ and $\beta_{\text{ens}}$)
Covariance Weights: **Vertical transition layer**

1obs T inc (lev 5mb)

1obs T inc (lev 10mb)
Some elements of the hybrid system

**Ensemble post-analysis:** Re-centering & additive inflation

- The EnKF updates: the ensemble mean and the ensemble of background perturbations
- Both products go through some "post-analysis" step before the perturbations are evolved in time to the next cycle:
  - Inflation (additive and/or multiplicative) for the members;
  - Re-centering of the members around a new mean (central)
  ⇒ the ensemble mean is modified.

\[
\begin{align*}
\mathbf{x}_{i}^{\text{ana}} & \leftarrow \mathbf{x}_{i}^{\text{ana}} - \bar{\mathbf{x}}^{a} + \mathbf{x}^{c} + \alpha \epsilon_{i}^{\text{inf}} \\
\delta \mathbf{x}_{i}^{\text{ana}} & \leftarrow \delta \mathbf{x}_{i}^{\text{ana}} + \delta \mathbf{x}^{\text{rec}} + \alpha \epsilon_{i}^{\text{inf}}
\end{align*}
\]

- How large should the additive inflation be ... without compromising the enkf analysis?
- How does the dual resolution affect the size of the re-centering increment?
Mem1: Uwind analysis incr at 500mb + $\alpha \times$ additive inflation

$I_{\text{inc_mem1 (lev 500mb)}}$

$I_{\text{inc_mem1 (lev 500mb) } + 0.1 \times \text{pert}}$

$I_{\text{inc_mem1 (lev 500mb) } + 0.25 \times \text{pert}}$

$I_{\text{inc_mem1 (lev 500mb) } + 0.4 \times \text{pert}}$
Re-centering: Impact of the ensemble resolution

High/Low res Ensemble mean - Control analysis

H_res ensemale - control (T at 500mb)

L_res ensemale - control (T at 500mb)
Re-centering: Impact of the ensemble resolution

OMF - U wind raob
Some elements of the hybrid system

Low-res ens: inflation + re-centering

![T inc_mem1 (lev 500mb)](image1)

![T inc_mem1 (lev 500mb) + recentering only](image2)

![T inc_mem1 (lev 500mb) + inflation only](image3)

![T inc_mem1 (lev 500mb) + recentering + inflation](image4)
Some elements of the hybrid system

High-res ens: inflation + re-centering

T inc_mem1 (lev 500mb)

T inc_mem1 (lev 500mb) + recentering only

T inc_mem1 (lev 500mb) + inflation only

T inc_mem1 (lev 500mb) + recentering + inflation
Filter-free Hybrid 3D-Var:

- By-passing the EnKF: create the ensemble by "perturbing" the central analysis using the additive inflation perturbations.

Each ensemble member is created as:

\[ \{x\}_i = x^c + \alpha \{\epsilon^{inf}\}_i \]
Some elements of the hybrid system

Filter-free Hybrid 3D-Var:

500 hPa Height Global Domain

Anomaly Correlation

Difference (ref=GEOS-5)

Forecast Day (Apr 2012)
### Results: Showing Enkf-based hybrid results only

#### Control run (Ctl):
- Conventional 3D-Var;
- analysis at 0.5°;
- forecasts at 0.5°;
- close run to ops.

#### Ensemble:
- 32 members at 1°; S-EnKF;
- Additive inflation; Vertically varying localization scales;
- Re-centering around ctl ana.

#### Hybrid run (Hyb):
- **Dual resolution** (central at 0.5°, ensemble at 1°); $\beta = 0.5$;
- members re-centered around the central analysis.
- Time frame: mid-November through end of December 2011. 2-week spin up period, and hybrid starts on Dec 1st.
Results: OMF —— Hyb —— Ctl

Uwind

Temp

GMAO

April 1, 2013

Results
Results: Monthly means (Temperature)

**Ctl vs. NCEP**

**Hyb vs. NCEP**
Results: Monthly means (Temperature)

Ctl vs. ECMWF

Hyb vs. ECMWF
Results: Monthly means (U-winds)

Ctl vs. NCEP

Hyb vs. NCEP

GMAO

April 1, 2013
Results: Monthly means (U-winds)

Ctl vs. ECMWF

Hyb vs. ECMWF

GMAO
Results: Monthly means (U-winds at 200 mb)

vs. NCEP

vs. ECMWF

Ctl

Hyb
Forecast skills: Anomaly correlations (500 mb height)

500 hPa Height Northern Hemisphere

500 hPa Height Southern Hemisphere
Results

Forecast skills: Anomaly correlations (500 mb Uwind)

--- Ctl  --- hyb

500 hPa U-Wind Northern Hemisphere

500 hPa U-Wind Southern Hemisphere

GMAO
April 1, 2013 27 / 31
Forecast skills: Anomaly correlations (200/850 Uwind)

200 hPa U-Wind Northern Hemisphere

200 hPa U-Wind Southern Hemisphere

850 hPa U-Wind Northern Hemisphere

850 hPa U-Wind Southern Hemisphere
Results

Forecast skills: RMS (Temperature tropics)

--- Ctl    --- hyb

100 hPa Temperature Tropics

500 hPa Temperature Tropics

850 hPa Temperature Tropics
Forecast skills: RMS (Uwind tropics)

- **Ctl**
- **hyb**

### Results

**200 hPa U-Wind Tropics**

```
200 hPa U-Wind Tropics
```

**500 hPa U-Wind Tropics**

```
500 hPa U-Wind Tropics
```

**850 hPa U-Wind Tropics**

```
850 hPa U-Wind Tropics
```

GMAO

April 1, 2013

30 / 31
Overall

- 3D-hybrid approach results show positive impact: noticeable reduction of model biases and improved skill scores;
- The filter-free scheme is also showing promising results;
- More configurations are currently being tested (64-member ensemble, hi-resolution ensemble)