Hybrid Data Assimilation without Ensemble Filtering

Ricardo Todling and Amal El Akkraoui

Global Modeling and Assimilation Office
NASA

International Conference on Ensemble Methods in Geophysical Sciences
Toulouse, France, 12-16 November 2012

Contributions from: D. Kleist, D. Parrish, R. Treadon, and J. Whitaker
Outline

1. GEOS DAS Hybrid 3d-Var
2. Problem Statement
3. Ensemble Spread & Forecast Error
4. Analysis Evaluation
5. Forecast Verification vs Observations
6. Forecast Verification vs Analysis
7. Summary
**Variational Formulations**

**FGAT 3dVar-ensemble Hybrid:**

\[
J(\delta x) = \frac{1}{2} \delta x^T B_h^{-1} \delta x + \frac{1}{2} \sum_{k=1}^{K} [H_k \delta x - d_k]^T R_k^{-1} [H_k \delta x - d_k] + J_x
\]

where

- \( B_h = \beta B + (1 - \beta) B_e \circ C \) is a *hybrid* of static and ensemble-based error covariances, \( B \) and \( B_e \) respectively
- \( C \) is a localization error covariance of compact support
- the control variable changes to be \( \delta x = \delta x_0 + \sum_{m}^{M} \delta x^e_m \circ \alpha_m \), for an ensemble with a total of \( M \) members \( \delta x^e_m \)
- GMAO and NCEP get \( \delta x^e_m \) by using the EnKF plus inflation
IAU-based 3dVar DAS Schematic

6-hr cycle using IAU (Bloom et al. 1996):
- predictor step: generate first-guess.
- corrector step: apply analysis increment as model tendency.
IAU-based Hybrid 3dVar DAS Schematic
Problem Statement

- Hybrid DA schemes include both multiplicative and additive inflation.

Evaluations in GEOS DAS suggest:

- Hybrid approach provides noticeable improvements only when using additive inflation, i.e., EnKF alone doesn’t do it.
- Forecasts from EnKF analyses plus additive inflation result in mild spread within the background time window.
- It seems that much of the initial (analysis) spread can be simulated with additive inflation alone.
- Appreciable background spread is obtained in the latter case.

Question: how does hybrid-DA perform when the ensemble filter is dropped and an ensemble of analyses is created from simply additively inflating the central analysis?
Problem Statement

- Hybrid DA schemes include both multiplicative and additive inflation.
- Evaluations in GEOS DAS suggest:
  - Hybrid approach provides noticeable improvements only when using additive inflation, i.e., EnKF alone doesn’t do it.
  - Forecasts from EnKF analyses plus additive inflation result in mild spread within the background time window.
  - It seems that much of the initial (analysis) spread can be simulated with additive inflation alone.
  - Appreciable background spread is obtained in the latter case.

*Question: how does hybrid-DA perform when the ensemble filter is dropped and an ensemble of analyses is created from simply additively inflating the central analysis?*
Hybrid Experimental Setting

- Central DAS: 0.5° outer and inner loops; 72-levels
- 32 Ensemble Forecasts: 1.0°; 72-levels
- GSI Hybrid/Static B: 50% / 50%
- TLNMC applied to both static & hybrid covariances
- Vertical & horizontal localizations applied to ensemble B
- Add/ve perturbations scaled from NMC-like 48-24hr forecasts
- Experiment period (after spin up): April 2012

EnKF
- Additive perturbation: 0.25
- EnKF (full obs but precip)

Filter-Free
- Additive perturbation: 0.6
- No Ensemble Filtering
0-hr Analyses Spread (before additive inflation)

EnKF-based hybrid

Filter-Free hybrid

Zonal Spread

Global Spread
3-hr Background Spread

EnKF-based hybrid

Filter-Free hybrid

Ricardo Todling and Amal El Akkraoui

Hybrid Data Assimilation without Ensemble Filtering
6-hr Background Spread

EnKF-based hybrid

Filter-Free hybrid

Ricardo Todling and Amal El Akkraoui

Hybrid Data Assimilation without Ensemble Filtering
GEOS DAS Hybrid 3d-Var
Problem Statement
Ensemble Spread & Forecast Error
Analysis Evaluation
Forecast Verification vs Observations
Forecast Verification vs Analysis
Summary

Zonal Spread
Global Spread

9-hr Background Spread

EnKF-based hybrid

Filter-Free hybrid

Ricardo Todling and Amal El Akkraoui
Hybrid Data Assimilation without Ensemble Filtering
Spread within 9-hr Background Period

EnKF-based hybrid

Filter-Free hybrid

Global (Tropospheric) Ensemble Spread (J/kg)

- 9hr
- 6hr
- 3hr
- 0hr

11APR 13APR 15APR 17APR 19APR 21APR

11APR 13APR 15APR 17APR 19APR 21APR

Ricardo Todling and Amal El Akkraoui

Hybrid Data Assimilation without Ensemble Filtering
Comparison w/ ECMWF: Zonally-Averaged Monthly Mean U-Wind

EnKF-based hybrid

Filter-Free hybrid

Ricardo Todling and Amal El Akkraoui

Hybrid Data Assimilation without Ensemble Filtering
Observation Impact on Analysis

Fractional

Beneficial

GEOS-5 Summary
1 Apr 2012-30 Apr 2012
Global Domain Fractional Impact

GEOS-5 Summary
1 Apr 2012-30 Apr 2012
Global Domain Fraction of Beneficial Obs

Ricardo Todling and Amal El Akkraoui
Hybrid Data Assimilation without Ensemble Filtering
6-hour

Raob Zonal Winds

Fits to background
Fits to forecast
24-hour

Raob Zonal Winds

Fits to background
Fits to forecast
GEOS DAS Hybrid 3d-Var
Problem Statement
Ensemble Spread & Forecast Error
Analysis Evaluation
Forecast Verification vs Observations
Forecast Verification vs Analysis
Summary

24-hour
Raob Temperatures

Fits to background
Fits to forecast

Ricardo Todling and Amal El Akkraoui
Hybrid Data Assimilation without Ensemble Filtering
GEOS DAS Hybrid 3d-Var

Problem Statement

Ensemble Spread & Forecast Error
Analysis Evaluation
Forecast Verification vs Observations
Forecast Verification vs Analysis
Summary

Forecast RMS Error
Forecast Anomaly Correlation

Ricardo Todling and Amal El Akkraoui
Hybrid Data Assimilation without Ensemble Filtering

24-hour: Zonal Winds

NH Tropics SH

<table>
<thead>
<tr>
<th>U-Wind Northern Hemisphere</th>
<th>U-Wind Tropics</th>
<th>U-Wind Southern Hemisphere</th>
</tr>
</thead>
<tbody>
<tr>
<td>x0005</td>
<td>hy005</td>
<td>hyA05</td>
</tr>
</tbody>
</table>
GEOS DAS Hybrid 3d-Var
Problem Statement
Ensemble Spread & Forecast Error
Analysis Evaluation
Forecast Verification vs Observations
Forecast Verification vs Analysis
Summary

Forecast RMS Error
Forecast Anomaly Correlation

24-hour: Temperature

NH  Tropics  SH

Ricardo Todling and Amal El Akkraoui
Hybrid Data Assimilation without Ensemble Filtering
Anomaly Correlations: H500

Northern Hemisphere  Southern Hemisphere

500 hPa Height Northern Hemisphere

500 hPa Height Southern Hemisphere

Anomaly Correlations: H500
Northern Hemisphere  Southern Hemisphere

Forecast RMS Error
Forecast Anomaly Correlation

Ricardo Todling and Amal El Akkraoui
Hybrid Data Assimilation without Ensemble Filtering
Summary

Advantages of Filter-Free Hybrid
- Really inexpensive way of generating ensemble
- Avoid maintenance of two analysis systems
- Avoid contradictions when calculating impact of obs on forecasts

Other Points
- Will examine role of imbalance in the ensemble spread
- Will study skill of NMC-like perturbations more closely
- Ongoing preliminary 4d-EnsVar exp point to similar conclusions