Applying GSI 3DVAR-Ensemble Hybrid Data Assimilation System for Rapid Refresh with Global and Regional Ensembles

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Introduction to RAP

- **The Rapid Refresh (RAP)** is a NOAA operational hourly updated regional numerical weather prediction system. Applications including aviation, energy, and severe weather forecasting.

**Configuration:**
- 13 km horizontal North American grid
- Twice daily *partial cycles* from GFS atmospheric fields
- Hourly *continue cycled* land-surface fields

**Model:**
- WRF-ARW dynamic core

**Data Assimilation:**
- GSI 3D-VAR/GFS-ensemble hybrid *data assimilation*
- GSI non-variational cloud/precipitation hydrometeor (HM) analysis
- Diabatic Digital Filter Initialization (DDFI) using hourly radar reflectivity observation

**Timeline:**
- RAP version 1 operational implementation: 01 May 2012
- RAP version 2 operational implementation: 24 February 2014
- **HRRR v1** is planned to operational implementation in **September 2014**
RAPv2 Data Assimilation

GFS EnKF 80-member ensemble
Available four times per day
valid at 03z, 09z, 15z, 21z

80-member GFS EnKF
Ensemble forecast valid at
15Z (9-hr fcst from 6Z)
RAP GSI 3DVar/Ensemble hybrid

• RAPv2 hybrid configurations:
  o With half Ensemble BE and half Static BE
  o Ensemble grid is 3 times coarser than background grid
  o Analysis grid is 2 times coarser than background grid
  o Ensemble forecasts are available every 6-hour
  o Horizontal localization scale is 110 km
  o Vertical localization scale is 3 grid levels
  o No vertical changes in localization scale

• Baseline retrospective tests
  o May 28th to June 4th, 2012
  o Only difference are analysis: 3DVar versus Hybrid
RAPv2 baseline test results

RMSE Vertical Profiles: Soundings from 1000-100 mb

- **RAP Hybrid**
- **RAP No Hybrid (3D-VAR)**

Upper Air RMS Vertical Profile for 6 hour forecast

Upper Air RMS Time Series for 6 hour forecast

Consistent improved upper-air environment

Little impact to the ceiling forecast, surface forecast, precip forecast
Tuning for RAPv2 implementation

• GFS/EnKF Ensemble forecast resolution used in the RAP GSI
  GSI Hybrid using Ensemble grid that is 1X or 3X coarser than background grid

• GFS EnKF ensemble forecast available frequency
  GSI hybrid using ensemble forecast available hourly versus 6-hourly
Ensemble Resolution Test

RMSE Vertical Profiles: Soundings from 1000-100 mb

- **Hybrid, Ensemble grid is 3X coarser than background grid**
- **Hybrid, Ensemble grid is background grid**

Upper Air RMS Vertical Profile for 6 hour forecast

**Summary:** The GSI hybrid DA using **coarser** ensemble grid data produces the same quality forecast as one using ensemble grid same as original background grid.
GFS EnKF Ensemble forecast available frequency

Upper Air RMS Vertical Profile for 3 hour forecast

Upper Air RMS Vertical Profile for 6 hour forecast

Red - Hybrid with 6-hourly GFS/EnKF ensemble Forecast
Blue - Hybrid with hourly GFS/EnKF ensemble Forecast
Further tests based on RAPv2

- Ensemble BE and Static BE ratio
  GSI Hybrid with 50%, 75%, and 100% Ensemble BE

- Horizontal localization scale
  GSI hybrid with horizontal localization scale set to 110 km, 160 km, 220 km, and 330 km

- Vertical localization scale
  GSI hybrid with vertical localization scale set to 3 levels, 9 levels, and -0.15 (about 100 hPa)
Ratio of Ensemble and Static BE

3h forecast - Upper Air RMS error - Vertical Profile

- Red - Hybrid with 50% Ensemble BE and 50% Static BE
- Blue - Hybrid with 75% Ensemble BE and 25% Static BE
- Black - Hybrid with 100% Ensemble BE and 0% Static BE

6h forecast - Upper Air RMS error - Vertical Profile

Wind

RH

T

Red - Hybrid with 50% Ensemble BE and 50% Static BE
Blue - Hybrid with 75% Ensemble BE and 25% Static BE
Black - Hybrid with 100% Ensemble BE and 0% Static BE
Horizontal Localization Tests – Single T obs

Temperature analysis increments:

- Horizontal cross section
- Single temperature observation at 500 hPa
- Hybrid with 50% ensemble BE and 50% static BE
- Vertical localization scale is 3 levels
Horizontal Localization Test Results

**6h Forecast - Upper Air RMS Error - Vertical Profile**

- **Red** - Hybrid with $s_{ens_h}=110$ km
- **Blue** - Hybrid with $s_{ens_h}=160$ km
- **Orange** - Hybrid with $s_{ens_h}=220$ km
- **Black** - Hybrid with $s_{ens_h}=330$ km

**12h Forecast - Upper Air RMS Error - Vertical Profile**

- **Wind**
- **RH**
- **T**
Vertical Localization Test – Single obs

Single T obs at 500 hPa

Single T obs at 1000 hPa

Temperature analysis increments:
- Vertical cross section
- Hybrid with 75% ensemble BE and 25% static BE
- Horizontal localization scale is 330 km
**Vertical Localization Test Results**

**0h forecast (analysis) - Upper Air RMS fit to raobs - Vertical Profile**

- **Red** - hybrid with vertical localization scale = 3
- **Blue** - hybrid with vertical localization scale = 9

**6h forecast - Upper Air RMS error Vertical Profile**

- **Red** - hybrid with vertical localization scale = 3
- **Blue** - hybrid with vertical localization scale = 9
Vertical Localization Test results

0h forecast (analysis) - Upper Air RMS fit to raobs - Vertical Profile

6h forecast - Upper Air RMS error Vertical Profile

Red - hybrid with vertical localization scale = 3
Blue - hybrid with vertical localization scale = -0.15
Evaluate Flow-dependent contributions

• The consistent improved upper-air forecast of applying GSI-hybrid are coming from the follow-dependence features in BE induced through real-time ensemble

• How much contributions from the follow dependence?

• New retro experiment: June 15-22, 2014
  – GSI-hybrid with 2014 RAP configuration
  – Control: Use 6-hourly available GFS ensemble
  – Constant ensemble: Use a single set of the ensemble on June 15, 2014 for all cycles.
Evaluate Flow-dependent contributions

### Upper Air RMSE Vertical Profiles:
6 h forecast error from 1000-100 mb

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<tr>
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<th>2012 retro</th>
<th>GSI Hybrid</th>
<th>GSI 3DVAR</th>
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<tbody>
<tr>
<td><strong>Wind</strong></td>
<td><img src="image1.png" alt="Graph" /></td>
<td><img src="image2.png" alt="Graph" /></td>
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2014 retro
- RAP 2014 with constant ensemble
- RAP 2014

Hybrid DA: Consistent Improved upper-air forecasts
little impact to the ceiling forecast, surface forecast, precip forecast
Evaluate Flow-dependent contributions

RMSE Vertical Profiles: Errors from 1000-100 mb in 2014 Retro

- RAP 2014 with constant ensemble
- RAP 2014

3h forecast - Upper Air RMS error – Time Series

6h forecast - Upper Air RMS error – Time Series

Flow dependent: Consistent Improved upper-air forecasts
But better BE definition from correct ensemble fcsts also contributes
Summary

• The RAP GSI 3DVar-Ensemble hybrid improved mid-to upper-tropospheric wind and moisture forecasts up to 12-h duration

• The RAP GSI hybrid with ensemble forecast valid at each hourly analysis time gives a very slight benefit over one with 6h available ensemble forecast. Constant ensemble (not correct in time) still can improve forecasts.

• 75% Ensemble BE in hybrid assimilation can further consistent improve wind and RH forecast over 50/50, but results for 100% Ensemble BE are mixed

• Localization scales set to 110 horizontal and 3 levels vertical give the best short-term (0-9h) forecasts

• Current GFS EnKF ensemble BE mainly improves larger scale features of the RAP forecast
Future Work

- **Need Regional Ensemble forecast BE:**
  - Increase spread in low levels to improve surface data assimilation
  - Create covariances for multi-species hydrometeor fields to improve cloud and storm assimilation

- **Near future:**
  - Conduct regional ensemble forecasts initialized from GFS/EnKF ensemble forecasts
  - Build and test RAP EnKF/Ensemble forecast system

- **Build and test North American Rapid Refresh Ensemble (NARRE) by 2016, co-development between ESRL and NCEP/EMC**