Atmospheric Data Assimilation with WRFDA-3DVAR: lessons learned from ASR

Zhiquan Liu (liuz@ucar.edu)

Hui-Chuan Lin & Ying-Hwa Kuo (NCAR/MMM)

Dave Bromwich, Lesheng Bai (OSU)

NCAR is sponsored by the National Science Foundation
Outline

• Arctic System Reanalysis
  – Analysis/forecast cycle
  – Observations used

• Lessons learned from 60km ASR experiments

• Summary
3D Variational data assimilation formulation

• 3DVAR is to minimize a cost function

\[
J(x) = \frac{1}{2} (x - x_b)^T B^{-1} (x - x_b) + \frac{1}{2} [H(x) - y]^T R^{-1} [H(x) - y]
\]

which measures the weighted distance of the model state \( x \) to the model “background” \( x_b \) and the observations \( y \).

Contribution to the final analysis from \( x_b \) and \( y \) is determined by the background error covariance \( B \) (having spatial correlation and multivariate-correlation) and observation error covariance \( R \) (no spatial correlation).

\( H \) is “observation operator”, which transforms the model state to observation space.
ASR reanalysis scheme

WRF Preprocessing (WPS, real)

wrfinput

Update Low BC

Cycled Background

wrfbdy

NCEP PREPBUFR
Radiance BUFR
GPSRO BUFR
3h frequency

y^o, R

NCAR WRFDA 3DVAR

WRFDA-3DVAR analyses are performed in 3-hr intervals

B_0

OSU Polar WRF 3h Forecast with DFI

Global Fields ERA-Interim

Background Error Statistics
WRF model configuration (NCAR test)

- Polar WRF 3.2
  - WSM5
  - RRTMG
  - MYNN2.5
  - NoahLSM
  - Fractional Sea ice
  - GWD
  - DFI
  - No Nudging
  - Polar projection
  - 60km/10hPa top
  - 180*180*71L
  - Single domain
Observations used in ASR

- **Surface**
  - U/V, T, Q, P: SYNOP, METAR, SHIPS, BUOY, SONDE_SFC,
  - U/V: QuikSCAT over ocean

- **Upper air**
  - SOUND (U/V, T, Q), AIREP (U/V, T), PROFILER (U/V), GEOAMV (U/V)

- **GPS Radio Occultation (refractivity)**
  - Use data between 2km~18km

- **Microwave radiances from polar satellites**
  - Brightness temperature
observation coverage snapshot at 2007120100 with 3-h time window

- synop
- metar
- ship
- buoy
- sound
- gpsref
- profiler
- airep
- quikscat
- geoamv

- More than 4000 surface stations
- Around 300 sounding stations
Typical land surface stations: 20070101013

More than 4000 stations used.
## Satellite MW radiance data used (2000~)

<table>
<thead>
<tr>
<th></th>
<th>AMSU-A</th>
<th>AMSU-B</th>
<th>MHS</th>
</tr>
</thead>
<tbody>
<tr>
<td>NOAA-15</td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>NOAA-16</td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>NOAA-17</td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>NOAA-18</td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>NOAA-19</td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>METOP-2</td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>EOS-2 (Aqua)</td>
<td>X</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Total 12 sensors**

AMSU-A: assimilate channels 5~9.
AMSU-B/MHS: assimilate channels 3~5.

**Data availability depends on year.**
Outline

• Arctic System Reanalysis
  – Analysis/forecast cycle
  – Observations used

• Lessons learned from 60km ASR experiments

• Summary
Lesson 0: robustness/efficiency of computing environment

- Ohio Supercomputer Center (OSC)
  - Good in term of number of processors, resource allocated for ASR project
  - Stability, parallel scalability, slow disk I/O issues

- We initially started tests from nested 90km/30km
  - Took long time to complete month-long test (experiments were often interrupted due to machine stability)
  - We had to switch to 60km single domain test

- Machine performs better at late stage of the project.
Lesson 1: Seasonal variation of model forecast errors (matrix B statistics from 24h FC - 12h FC valid at same time)

Winter
(larger error at high levels)

Summer
Lesson 2: importance of radiance data monitoring

• Need to carefully do quality control, channel selection, bias correction, and obs error specification.

• Data Monitoring is crucial and common practice of NWP centers
  – 9-yr (2000-2008) radiance monitoring run has been done to guide sensor/channel selection for OSU production run.
  – Calculate the difference of observed minus model-simulated (from ERA-Interim) brightness temperature
Lesson 3: challenge of radiance DA over snow/seaice

Small N of obs during winter

Most obs rejected over snow/seaice
Lesson 4: GPSRO impact: 3h forecasts vs. ERA-I analysis

RMSE 2007010112-2007013112 (Fcst 03h)

GTS+GPSRO

GTS
Lesson 4: GPSRO impact: 3h forecasts vs. ERA-I analysis

Bias 2007010112-2007013112 (Fcst 03h)
GPSRO impact: 1-yr Sound OMB/OMA

Adding GSPRO leads to more sound obs used, indication of better 3-h forecasts.
Lesson 5: Radiance impact
3h forecast vs. Sound

2-yr aggregated statistics.
Forecasts valid at 00 Z,
i.e., initialized from analyses
at 21 Z, when very few
sounding obs available.

NOTE: both exps. Include
GPSRO data.
Lesson 5: Radiance impact
3h forecast vs. GPSRO
Lesson 6: Complexity of surface analysis
Psfc ANA: SLP obs vs. Psfc obs

use SLP report

use Psfc report
Lesson 6: Complexity of surface analysis
Psfc 3h FC: SLP obs vs. Psfc obs

use SLP report

use Psfc report
Lesson 6: Complexity of surface analysis
T2m ANA: effect of terrain correction & use of more obs

Before improvement

After Improvement
Lesson 6: Complexity of surface analysis

Q2m ANA: consider ice effect when calculating Qs

-synop Q OMB

-synop Q OMA
ASR-60km vs. ERA-Interim: against SYNOP

\[
\frac{\text{rmse(ERA)} - \text{rmse(ASR)}}{\text{rmse(ERA)}}
\]
Summary

- Computing challenge for ASR
  - 10km ASR will switch from NETCDF to GRIB I/O to save disk space and speed up WRF I/O

- Larger forecast errors during winter, thus more weight to observations in winter data assimilation

- Satellite observations are important, but need careful QC, bias correction (for radiance)
  - Monitoring is a powerful way to guide QC decision and bias correction
  - Radiance DA over snow/seaice is still very challenging

- Surface analysis is complex, improvements were made through ASR project
  - will also benefit to WRFDA in general applications.