Impact of upper-air and near-surface observations on short-range forecasts from NOAA hourly assimilation cycles (RUC and Rapid Refresh)

- aircraft
- profiler
- VAD winds
- rawinsonde
- GPS precipitable water
- METARs
- radar reflectivity
- AMVs

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Wed 23 May 2012
WMO Workshop on Impact of Obs on NWP

http://rapidrefresh.noaa.gov
RUC / RAP hourly cycling

18-h fcst
18-h fcst
18-h fcst

Initial Condition Fields
Analysis Fields

Radar DDFI
DDFI

Background Fields

3DVAR

Obs

Hourly RUC or RAP

Time (UTC)
Hourly Updated NOAA NWP Models

Rapid Refresh (RAP) replaced RUC at NCEP 1 May 12
Uses WRF, GSI with RUC features

13km Rapid Refresh
new operational model, new 18h fcst every hour

13km RUC
prior operational model, new 18h fcst every hour
NOAA hourly updated models from RUC to Rapid Refresh RAP

Community-based advanced model and analysis in RAP

- **WRF-ARW**: advanced numerics, non-hydrostatic
- **GSI**: advanced satellite data assimilation

<table>
<thead>
<tr>
<th>Model</th>
<th>Domain</th>
<th>Grid Points</th>
<th>Grid Spacing</th>
<th>Vertical Levels</th>
<th>Vertical Coordinate</th>
<th>Pressure Top</th>
<th>Boundary Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>RUC</td>
<td>CONUS</td>
<td>451 x 337</td>
<td>13 km</td>
<td>50</td>
<td>Sigma/Isentropic</td>
<td>~50 mb</td>
<td>NAM</td>
</tr>
<tr>
<td>RAP</td>
<td>North America</td>
<td>758 x 567</td>
<td>13 km</td>
<td>50</td>
<td>Sigma</td>
<td>10 mb</td>
<td>GFS</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Model</th>
<th>Assimilation</th>
<th>DFI</th>
<th>Cloud Analysis</th>
<th>Cloud micro-physics</th>
<th>Radiation LW/SW</th>
<th>Conv param</th>
<th>PBL</th>
<th>LSM</th>
</tr>
</thead>
<tbody>
<tr>
<td>RAP</td>
<td>GSI w/radiances</td>
<td>Yes w/radar</td>
<td>Yes</td>
<td>Thompson (2008) – 6 species</td>
<td>RRTM/Goddard</td>
<td>Grell-3d</td>
<td>MYJ</td>
<td>RUC 2010</td>
</tr>
</tbody>
</table>
Topic of this presentation:
3 sets of regional observation denial experiments with NOAA hourly assimilation cycles

• Rapid Update Cycle experiments
  – Cold-season – Nov-Dec 2006 – 11 days
  – Warm-season – August 2007 – 10 days
  – Experiments used 2009 version of RUC

• Rapid Refresh
  – Warm-season – May-June 2011 – 14 days
  – Experiments used 2012 version of experimental RAP (ESRL version)
### RUC/Rapid Refresh Hourly assimilation cycle

**Cycle hydrometeors**
Cycle soil temp., moisture, snow

**Time (UTC)**

<table>
<thead>
<tr>
<th>Time (UTC)</th>
<th>11</th>
<th>12</th>
<th>13</th>
</tr>
</thead>
</table>

#### Analysis Fields

- **3DVAR**
- **Obs**

#### Background Fields

- **3DVAR**
- **Obs**

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#### Hourly observations (stations for raobs/profiles)

<table>
<thead>
<tr>
<th>Observation Type</th>
<th>RUC 2006-7 CONUS</th>
<th>RAP 2011 N.Amer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rawinsonde (T,V,RH)</td>
<td>85</td>
<td>120</td>
</tr>
<tr>
<td>Profiler – NOAA Network (V)</td>
<td>30</td>
<td>21</td>
</tr>
<tr>
<td>Profiler – 915 MHz (V, Tv)</td>
<td>flagged</td>
<td>25</td>
</tr>
<tr>
<td>Radar – VAD (V)</td>
<td>120</td>
<td>125</td>
</tr>
<tr>
<td>Radar reflectivity - CONUS</td>
<td>2km</td>
<td>2km</td>
</tr>
<tr>
<td>Lightning (proxy reflectivity)</td>
<td>-</td>
<td>NLDN</td>
</tr>
<tr>
<td>Aircraft (V,T)</td>
<td>1.4-7K</td>
<td>2-15K</td>
</tr>
<tr>
<td>Aircraft - WVSS (RH)</td>
<td>-</td>
<td>0-800</td>
</tr>
<tr>
<td>Aircraft – TAMDAR (V,T,RH)</td>
<td>0-1800</td>
<td>0-50</td>
</tr>
<tr>
<td>Surface/METAR (T,Td,V,ps,cloud, vis, wx)</td>
<td>1800-2000</td>
<td>2200-2500</td>
</tr>
<tr>
<td>Buoys/ships (V, ps)</td>
<td>100-200</td>
<td>200-400</td>
</tr>
<tr>
<td>Mesonet (T, Td, V, ps)</td>
<td>4500</td>
<td>flagged</td>
</tr>
<tr>
<td>GOES AMVs (V)</td>
<td>1000-2500</td>
<td>2000-4000</td>
</tr>
<tr>
<td>AMSU/HIRS radiances</td>
<td>-</td>
<td>Used</td>
</tr>
<tr>
<td>GOES cloud-top pressure/temp</td>
<td>13km</td>
<td>13km</td>
</tr>
<tr>
<td>WindSat scatterometer</td>
<td>-</td>
<td>2-10K</td>
</tr>
</tbody>
</table>
Rapid Refresh obs counts (not counting radar reflectivity, GOES cloud, polar sat radiances)

- **Ps**: METARs, buoys, ships, SYNOPs
- **UV**: Aircraft, profilers, raobs, VADs, AMVs
- **T**: Aircraft, raobs, sfc
- **Q**: Sfc, aircraft, raobs
# RUC/RAP observation denial experiments

<table>
<thead>
<tr>
<th>Experiments with observations denied</th>
<th>Aircraft</th>
<th>Profilers</th>
<th>VAD winds</th>
<th>RAOBs</th>
<th>Surface (w/ METAR clouds)</th>
<th>GPS prec water</th>
<th>Mesonet</th>
<th>Atmos motion vectors</th>
<th>Radar reflectivity</th>
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</thead>
<tbody>
<tr>
<td>RUC - Winter 2006</td>
<td>✓</td>
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<td>✓</td>
<td>✓</td>
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</tr>
<tr>
<td>RUC – Summer 2007</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>RAP – Summer 2011</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
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<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>
Observations assimilated in hourly update models (RUC, Rapid Refresh)
RUC/ RAP – specific analysis features

Cloud and hydrometeor

Cloud designation from observations

- Satellite CTP
- Radar
- METAR

Special treatments for surface observations

Elevation correction
If abs[Psf_{obs-model}] < 70 hPa.
Extrapolate obs from Psfc_{obs} to Psfc_{model}
Use model 1h low-level lapse rate.

Digital filter-based reflectivity assimilation

-20 min -10 min Initial +10 min + 20 min

Backwards integration, no physics
Forward integration, full physics with radar-based latent heating
Initial fields with improved balance, storm-scale circulation
RUC / RR HRRR model forecast
+ RUC/RR Convection suppression

PBL-based pseudo-observations

PBL-based sfc. assim. ➔ better retention of sfc. obs in model
RAOB verification – every 10 hPa
(Moninger et al. WAF 2010)

Verification against rawinsonde data over CONUS domain
RMS vector difference (forecast vs. obs)

RUC and RAP are able to use recent obs to improve forecast skill down to 1-h projection for winds
Location for 3 verification domains
Region 0 - National
Region 1 - Eastern
Region 2 - Midwest / Great Lakes
Diurnal dependencies for observations

• **Aircraft**
  – minimum in commercial traffic at night (06z-11z) over N.America

• **Profiler, VAD winds** –
  – vulnerable to bird migration contamination at night in spring/fall

• **Surface** –
  – Winds/temperature/dewpoint obs representative over deeper boundary layer in daytime
Breakdown for RUC/RAP OSE results

- 7-9 experiments (control, 6-8 obs denial experiments)
- 2 Regions
  - US National (data rich)
  - Midwest (very data rich)
- 4 layers
  - 1000-100 hPa (full depth)
  - 1000-800 hPa (near surface) or 1000-600 (lower trop)
  - 800-400 hPa (mid-troposphere)
  - 400-100 hPa (upper troposphere, lower stratosphere)
- 2 seasons
  - winter
  - summer
- Forecast duration
  - 3h, 6h, 9h, 12h
- Valid time of day
  - 00z, 12z

5 dimensions!
Q: HOW TO SUMMARIZE?
A: Composite plots
1st Breakdown for RUC OSE results

• 7-9 experiments (control, 6-8 obs denial experiments)
• 2 Regions
  • US National (data rich)
    • Midwest (very data rich)
  • 4 layers
    • 1000-100 hPa (full depth)
    • 1000-800 hPa (near surface)
    • 800-400 hPa (mid-troposphere)
    • 400-100 hPa (upper troposphere, lower stratosphere)
• 2 seasons
  • winter
  • summer
• Forecast duration
  • 3h, 6h, 12h
• Valid time of day
  • 00z, 12z

6 dimensions!
Q: HOW TO SUMMARIZE?
A: Composite plots
RH - national – 1000-400 hPa
#1 obs type = Raobs
#2 = GPS-PW
RH - national – 1000-400 hPa
#1 obs type = Raobs
Close #2 = aircraft
#3 – GPS at night
- VAD in day
- sfc – day/night

More cross-covariance effect w/ GSI/RAP for wind-moisture than w/ RUC
Temp - national - 1000-100 hPa
Tie for #1 = Aircraft, RAOBs
Aircraft more at 3h, RAOB-12h
Sfc ~ aircraft, RAOB in summer(!)
Temp - national - 1000-100 hPa
#1 = Aircraft
#2 = RAOBs
Aircraft more at 3h, RAOB-12h
Wind - national - 1000-100 hPa
#1 = Aircraft
#2 = RAOBs
Wind - national - 1000-100 hPa

#1 = Aircraft
#2 = RAOBs

Smaller players: prof, AMV, sfc
Wind - national - 1000-100 hPa
#1 = Aircraft
#2 = RAOBs
#3 = surface
Smaller players: sfc, VADs
2nd Breakdown for RUC OSE results

• 7 experiments (control, 6 obs denial experiments)

• 2 Regions
  • US National (data rich)
  • Midwest (very data rich)

• 4 layers
  • 1000-100 hPa (full depth)
  • 1000-800 hPa (near surface)
  • 800-400 hPa (mid-troposphere)
  • 400-100 hPa (upper troposphere, lower stratosphere)

• 2 seasons
  • winter
  • summer

• Forecast duration
  • 3h, 6h, 12h

Wind only
WINTER

Wind - national - 1000-800 hPa
Aircraft, VAD, sfc - 3h - winter
Sfc - 3h - summer

SUMMER
Wind - national – 1000-600 hPa
#1 = Aircraft
#2 = sfc (esp. night)
#3 = raob, prof

Valid 00z - daytime
Valid 12z - nighttime
Wind - national - 400-100 hPa
#1 overall - Aircraft, by far
#2 - RAOBS, distant #3- profiler
3rd Breakdown for RUC OSE results

- 7 experiments (control, 6 obs denial experiments)
- 2 Regions
  - US National (data rich)
  - Midwest (very data rich)
- 4 layers
  - 1000-100 hPa (full depth)
  - 1000-800 hPa (near surface)
  - 800-400 hPa (mid-troposphere)
  - 400-100 hPa (upper troposphere, lower stratosphere)
- 2 seasons
  - winter
  - summer
- Forecast duration
  - 3h, 6h, 12h

First, look at RH
RH - MIDWEST – 1000-400 hPa

#1 obs type = Raobs, aircraft

Closely followed GPS-PW

TAMDAR – strong RH effect
**RH - MIDWEST – 1000-600 hPa**

**Daytime**

#1 = sfc, aircraft

#3 = GPS

**Negative impact**

- VAD at night (bird migration?)
- Radar refl

**Valid 00z - daytime**

**Valid 12z - nighttime**

Aircraft, prof, GPS

```
A - withhold aircraft obs - Exp v6 - control
B - withhold all profiler obs - Exp v7 - control
C - withhold VAD winds - Exp v11 - control
D - withhold rawinsonde obs - Exp. v5 - control
E - withhold surface obs incl METAR cloud - Exp v9 - control
F - withhold GPS-Met PW obs - Exp v12 - control
G - withhold AMVs - Exp v10 - control
H - withhold radar refl- Exp v8 - control
```
Wind - GtLakes – 1000-600 hPa
Day- Aircraft, prof, VAD, sfc
Night – Sfc, VAD, aircraft, prof, GPS

Valid 00z - daytime

Valid 12z - nighttime

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
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<td>withhold aircraft obs - Exp v6 - control</td>
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<td>withhold AMVs - Exp v10 - control</td>
<td>withhold radar refl - Exp v8 - control</td>
</tr>
</tbody>
</table>
Other RAP-related OSE studies

- **PBL profilers for improved 50-100m wind forecasts**
  - Dept. of Energy funded Wind Forecast Improvement Project (WFIP)

- **Radar reflectivity assimilation**
  - Critical for 3km hourly updated High-Resolution Rapid Refresh (HRRR) experimental forecasts in US for aviation, severe weather, renewable energy

- **AIRS radiance / retrieval assimilation**
  - NESDIS-funded, GOES-R, goal: improve hourly assimilation impact for short-range RAP/HRRR forecasts
RAP/HRRR Reflectivity Verification

Eastern US, Reflectivity > 25 dBZ
11-21 August 2011

CSI 13 km

CSI 40 km

- 3km HRRR forecasts improve upon RAP 13km forecasts, especially at coarser scales
  much better upscaled skill
- Radar DDFI adds skill at both 13km and 3km
Wind Forecast Improvement Project
vertically averaged wind profiler RMSE

Improvement in 500-2000m wind out to ~8h due to 10 extra 915 MHz wind profiler in n. central US – both in RUC and RAP (RR)

Average over 7 sites, 500-2000 meters over the ground
AIRS Radiance Coverage in RAP

- 1.5-h time window (+/- 1.5 h), in 3-h cycle RAP retro run

Brightness temp (BT) from AIRS channel 791 – 8 May 2010

AIRS Impact Exps with RAP

- CNTL
- AIRS Ex. 1 (default 120 channels)
- AIRS Ex. 2 (selected 68 channels)

Haidao Lin, Steve Weygandt
CONUS, 6h/9h only, 12z+00z, RAP

RH 1000-600 –
Similar contribution from sfc, aircraft, raob, GPS

Wind 1000-100 –
#1 – aircraft, distant #2 – raob, sfc

Temp 1000-100 –
Aircraft, raob

6h F – 0h A for normalizing
V – 1.5 m/s, T – 0.6K
RH – 5%

Natl region, temperature averaged rms - matched
2011-05-29 thru 2011-06-13 (1000-100 mb)
Forecasts valid at 00 and 12 UTC

Errors reduced by 20%
Gt Lakes data-rich area, 12z/0z, 6h/9h only, RAP

**RH 1000-600** –
Profiler added (sfc, air, GPS, prof)

**Wind 1000-600** –
Profiler added (sfc, air, prof, GPS, raob, VAD)

**Temp 1000-600** –
Aircraft, sfc

GtLk region, temperature averaged rms - matched
2011-05-29 thru 2011-06-13 (1000-600 mb)
Forecasts valid at 00 and 12 UTC

6h F – 0h A for normalizing
V – 1.5 m/s, T – 0.6K
RH – 5%
Conclusions – RUC/RAP OSE exps

• Extensive obs impact study performed for 1 winter and 2 summer retro periods using RUC/RAP for 3-12h forecast impact

• Heterogeneous observing system in US effective for short-range (3-12h) forecasts for tropospheric RH, temp, winds.
  • Stronger wind-moisture cross-covariance with GSI in RAP than with RUC 3dVAR
• Aircraft data most important observation overall for short-range fcsts from troposphere-to-sfc (10-20% reduction for 6h fcst err for T/V/RH), but far from sole key observing system.
  • For RUC OSEs - RAOBs of #2 importance overall
  • For RAP OSEs (w/ GSI) – broader contribution evident from different obs systems - GPS-PW, surface, RAOB
• Data-rich Great Lakes area –
  • profiler provides similar wind/RH impact
  • 6 of 8 systems provide at least 5% err reduction for winds
  • 4 of 8 do same for RH (aircraft, sfc, GPS-PW, profiler)
Conclusions – RUC/RAP OSE exps #2

- Results needing follow-up
  - No additional value from mesonet data in RUC exps.
  - ESRL, NCEP efforts underway to determine station/time/wind direction-dependent biases to improve forward model
  - Test mesonet impact with RAP/GSI
  - Little value added from AMVs in RUC or RAP experiments
    - high obs error in GSI/RAP?
    - Test U.Wisconsin AMVs
  - VAD winds also show contribution but nighttime negative impact
    - need better bird migration QC?
  - Other RAP denial experiments needed
    - WindSat, buoy, GOES-cloud
  - Add cold-season retrospective impact tests for RAP/GSI
  - EnKF/hybrid/GSI efforts – hourly RAP, 6h for NOAA FIM global model

- RUC-OSEs - MWR article - June 2010 – Benjamin et al.
  - complements Moninger et al. 2010 W&F paper on TAMDAR impact study
Valid 00z - daytime

Valid 12z - nighttime

Temp - national – 1000-800 hPa
#1 = Aircraft
#2 = sfc
#3 = raobs (night), VAD (day)
Temp - MIDWEST - 1000-800 hPa

#1 = aircraft (incl. TAMDAR)
#2 = surface (winter and summer)
WINTER

Wind - national - 800-400 hPa #1 overall - Aircraft RAOBs - #1 winter @ 12h

SUMMER