Aircraft-based Observations: Impact on weather forecast model performance

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ABO impact on weather models: Key points

#1: Aircraft data most important observation type over North America for 3-12h (situational awareness) forecast accuracy (winds, temperature, Rel. Hum.)

#2: Increased aircraft data has improved US (and global) forecast skill (2011-2015)

#3: Geographical and temporal gaps in aircraft data provide opportunity for improved forecast accuracy through improved aircraft participation
Rapid Refresh and HRRR
NOAA hourly updated models

13-km Rapid Refresh (RAP)

3-km High Resolution Rapid Refresh (HRRR)


Version 4 – GSD (including HRRR-AK)
NCEP – Spring 2018

Hourly updating maximize use of ALL observations
Use latest observations EACH HOUR to obtain freshest, most accurate “snapshot” of atmospheric state

Get more accurate short-range weather forecasts for decision making

Rapid Refresh **hourly cycling** improves guidance

WIND forecast errors

1 Jan - 10 Oct 2017 vector wind RMS error for CONUS rawinsondes for different forecast lengths

Wind forecast improvement from hourly updating for 1-h vs. 6-h forecast
<table>
<thead>
<tr>
<th>Hourly Observation Type</th>
<th>Variables Observed</th>
<th>Observation Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rawinsonde</td>
<td>Temperature, Humidity, Wind, Pressure</td>
<td>120 / 12h</td>
</tr>
<tr>
<td><strong>Aircraft</strong></td>
<td>Wind, Temperature</td>
<td>2,000 - 15,000 / hr</td>
</tr>
<tr>
<td><strong>Aircraft – WVSS, Tamdar (3 Aug)</strong></td>
<td>Humidity</td>
<td>0 – 800 / hr</td>
</tr>
<tr>
<td>Surface/METAR</td>
<td>Temperature, Moisture, Wind, Pressure, Clounds, Visibility, Weather</td>
<td>2200 - 2500</td>
</tr>
<tr>
<td>Surface/Mesonet</td>
<td>Temperature, Moisture, Wind</td>
<td>~5K-12K</td>
</tr>
<tr>
<td>Buoys/ships</td>
<td>Wind, Pressure</td>
<td>200 - 400</td>
</tr>
<tr>
<td>Profiler – 915 MHz</td>
<td>Wind, Virtual Temperature</td>
<td>20-30</td>
</tr>
<tr>
<td>Radar – VAD</td>
<td>Wind</td>
<td>125</td>
</tr>
<tr>
<td>Radar</td>
<td>Radial Velocity</td>
<td>125 radars</td>
</tr>
<tr>
<td>Radar reflectivity – CONUS</td>
<td>3-d refl ➔ Rain, Snow, Graupel</td>
<td>1,500,000</td>
</tr>
<tr>
<td>Lightning</td>
<td>(proxy reflectivity)</td>
<td>NLDN</td>
</tr>
<tr>
<td>GOES AMVs</td>
<td>Wind</td>
<td>2000 - 4000</td>
</tr>
<tr>
<td>Polar Orbiter Satellite</td>
<td>Radiances</td>
<td>very large</td>
</tr>
<tr>
<td>Geostationary Satellite</td>
<td>Radiances</td>
<td>large</td>
</tr>
<tr>
<td>GOES cloud-top press/temp</td>
<td>Cloud Top Height</td>
<td>100,000</td>
</tr>
<tr>
<td>GPS – Precipitable water</td>
<td>Humidity</td>
<td>260</td>
</tr>
<tr>
<td>WindSat Scatterometer</td>
<td>Winds</td>
<td>2,000 – 10,000</td>
</tr>
</tbody>
</table>
### Variables measured by each observation type

<table>
<thead>
<tr>
<th>Observation Types</th>
<th>Temp-erature</th>
<th>Wind</th>
<th>Rel. Hum.</th>
<th>Pres. / Height</th>
<th>cloud/ saturation/ Hydrometeor</th>
<th>Radiance</th>
<th>Extent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raob</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>---</td>
<td>---</td>
<td>3D, 2x/day</td>
</tr>
<tr>
<td>Surface</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>---</td>
<td>2D</td>
</tr>
<tr>
<td>Aircraft</td>
<td>Y (~15%)</td>
<td>Y</td>
<td>Y</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>3D</td>
</tr>
<tr>
<td>Radar Reflectivity</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>Y</td>
<td>---</td>
<td>3D (in precip)</td>
</tr>
<tr>
<td>Radar – Vr, VAD</td>
<td>---</td>
<td>Y”</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>3D, Column</td>
</tr>
<tr>
<td>GPS-met</td>
<td>---</td>
<td>---</td>
<td>Y</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>Column</td>
</tr>
<tr>
<td>GOES (cloud, AMV)</td>
<td>---</td>
<td>---</td>
<td>Y’</td>
<td>---</td>
<td>Y</td>
<td>---</td>
<td>3D</td>
</tr>
<tr>
<td>Satellite Radiance</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>Y*</td>
<td>3D</td>
</tr>
</tbody>
</table>

*Satellite radiance: a complex function of temperature and humidity profiles

“Radar radial velocity: single wind component; AMV winds: height assignment issues
Regional Observation Impact studies with RAP - GSD

• Observation gaps are major source in limiting forecast accuracy, even over US

• RAP observation impact study 3 seasons, 8 (9) observation types
  
  - Rawinsonde
  - Radar reflectivity
  - Surface obs
  - AMV (winds)
  - Aircraft obs
  - VAD winds
  - GPS-Met
  - GOES clouds
  
  (Satellite Radiance)

→ Aircraft observations most important observation type
  
  -- Ascent/descent and en route obs both important
  -- Water vapor observations (about 1/7 total) improve RH forecast accuracy
Aircraft observations -- most important data source for weather prediction skill

Impact on WIND in 1000-100 hPa layer

Forecast degradation for withholding each obs type

Withhold:
A - ALL Raob
B - ALL Aircraft
C - Aircraft above 350 hPa
D - Aircraft below 350 hPa
E - Aircraft temp/humidity
F - ALL Profiler
G - ALL Radar Reflectivity
H - ALL VAD winds
I - ALL surface obs
J - ALL GPS-Met PW
K - ALL AMVs winds
L - GOES (winds/clouds)

3/6/9/12 hr impact for each obs type

• Aircraft obs most important for wind accuracy at all forecast lengths
• Significant impact also from raob, surface observations, GOES observations (likely from clearing of spurious convection)
Most Observation impact: Aircraft, raobs, GOES

Relative humidity impact (%)

Wind impact (m/s)

Spring retrospective

Temperature impact (k)
Aircraft observation also important for global model forecast skill (satellite data dominates)

Global model obs impact: John Eyre UK Met Office - Impact on 24h global forecast error (FSOI)

Contributions to the total observation impact on a moist 24-hour forecast-error energy-norm, surface-150 hPa.
Global aircraft observation importance will increase as global models start hourly cycling.
RUC skill improved from more aircraft obs

RUC model frozen, skill improvement solely from more aircraft obs

Monthly aircraft obs counts

RUC
RAP

6-h upper-level Wind RMS error


Date


Based on reports received by the Canadian Meteorological Centre

http://www.wmo.int/pages/prog/www/GOS/ABO/data/statistics/aircraft_obs_cmc_mthly_ave_daily_reports_by_program.jpg
GOALS:
• Quantify gaps in airborne observations (spatial, temporal, parameter, etc.)
• Identify most cost effective ways to obtain airborne data

AMDAR obs density CONUS (obs/km**2) per 24h period

2017 MWR article by James and Benjamin
Regional Observation Impact studies with RAP - GSD

- Significant gap to achieve profiles every 300 km/3h
  -- achieving **frequent aircraft profiles** out of regional airports
  estimated to significantly improve forecast accuracy

- **Airborne observation study sponsored by FAA (GSD, AvMet)**

- **2017 article by James and Benjamin, MWR**

What are the coverage expansion priorities
For improved model skill?
Improved mesoscale fields will lead better small-scale forecasts

Previous results: Increased RAP skill leads to improved HRRR skill for thunderstorms and other weather hazards.

Improvements will be extended by ongoing storm-scale ensemble data assimilation for HRRR and future storm-scale ensemble forecast system.
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