The Assimilation of *AMSU* and *SSM/I*

Brightness Temperatures in Clear Skies at the Meteorological Service of Canada

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Outline

• Objectives / experiment descriptions
• AMSU vs. SSMI: comparison of quality control
• Motivation for enhanced filtering of AMSU data
• Experiment results
• Conclusions and Future Work
Data Assimilation at MSC – May 2005

• Current operational global analysis system:
  – GEM Global model: 0.9°, 28 levels, 10 hPa model top
  – 4D-Var (March 15, 2005)
  – Direct assimilation of satellite radiances:
    • GOES-W, GOES-E (water vapour channel)
    • NOAA15, NOAA16, AQUA AMSU-A Tb
      – CHs 3-10 ocean, 6-10 land
    • NOAA15, NOAA16, NOAA17 AMSU-B Tb
      – CHs 2-5 ocean, 3-4 land
Objectives

1. Demonstrate the impact of assimilating SSM/I data
2. Implement stricter filtering of AMSU data and test

- **Experiment Setup**
  - **Period**: July 1 - July 31, 2003
  - **Control**: 3D-Var, Global 0.9° model, direct assim. of GOES-W, and NOAA15,16,17 AMSU-A & AMSU-B Tbs, plus conventional obs
  - **Experiment 1**: addition of SSM/I data over oceans in clear skies
  - **Experiment 2**: removal of AMSU-A CH3 and AMSU-B CH2, & reject AMSU-B CH3, 4, 5 over oceans where CH2 |O-FG| ≥ 5K & addition of SSM/I data
  - **Experiment 3**: removal of AMSU-A CH3, & reject AMSU-B CH2, 3, 4, 5 over oceans where CH2 |O-FG| ≥ 5K & addition of SSM/I data
Objectives

- Experiment Analysis
  - Evaluate monthly averaged analyzed fields using observations from AQUA AMSR-E (*Integrated Water Vapour - IWV*), QuikScat (*Surface Wind Speed - SWS*), GPCP (*Daily Precip. Rate - DPR*)
  - Validate 10-day forecasts using RAOBS and analyses
  - Verify QPFs over North America
## Instrument Properties

<table>
<thead>
<tr>
<th>Channel</th>
<th>Frequency (GHz)</th>
<th>Nominal Res. at nadir (km)</th>
<th>Assimilation</th>
</tr>
</thead>
<tbody>
<tr>
<td>AMSU-A 3</td>
<td>50.3 V</td>
<td>48</td>
<td>Ocean</td>
</tr>
<tr>
<td>AMSU-B 2</td>
<td>150.0 H</td>
<td>16.7</td>
<td>Ocean</td>
</tr>
</tbody>
</table>

↑ Data removed (EXP2,EXP3) ↑

↓ Data added (EXP1,EXP2,EXP3) ↓

<table>
<thead>
<tr>
<th>Channel</th>
<th>Frequency (GHz)</th>
<th>Nominal Res. at nadir (km)</th>
<th>Assimilation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>19.35 V</td>
<td>25</td>
<td>Ocean</td>
</tr>
<tr>
<td>2</td>
<td>19.35 H</td>
<td>25</td>
<td>Ocean</td>
</tr>
<tr>
<td>3</td>
<td>22.235 V</td>
<td>25</td>
<td>Ocean</td>
</tr>
<tr>
<td>4</td>
<td>37.0 V</td>
<td>25</td>
<td>Ocean</td>
</tr>
<tr>
<td>5</td>
<td>37.0 H</td>
<td>25</td>
<td>Ocean</td>
</tr>
<tr>
<td>6</td>
<td>85.5 V</td>
<td>12.5</td>
<td>Ocean</td>
</tr>
<tr>
<td>7</td>
<td>85.5 H</td>
<td>12.5</td>
<td>Ocean</td>
</tr>
</tbody>
</table>
## Operational Quality Control: AMSU vs. SSM/I

<table>
<thead>
<tr>
<th>Filter</th>
<th>AMSU-A</th>
<th>AMSU-B</th>
<th>SSM/I</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bias Corrections</td>
<td>Harris &amp; Kelly, 2001</td>
<td>Harris &amp; Kelly, 2001</td>
<td>Harris &amp; Kelly, 2001</td>
</tr>
<tr>
<td></td>
<td>Predictors: 1000-300mb, 200-50mb GZ</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Land/Ice/Sea-ice</td>
<td>√</td>
<td>√</td>
<td>√</td>
</tr>
<tr>
<td>Gross TB check</td>
<td>√</td>
<td>√</td>
<td>√</td>
</tr>
<tr>
<td>Clear-sky filtering</td>
<td>Grody scattering index (&gt;9)</td>
<td>Bennartz scattering index (&gt;15 over sea) NO cloud filter</td>
<td>Alishouse &amp; Petty: IWV, Precip. Screen F. Weng: CLW &gt; 0.01 mm</td>
</tr>
<tr>
<td>Background Check (O-FG)</td>
<td>$\sigma = 2$: CH 3</td>
<td>$\sigma = 2$: CH 2 $\sigma = 4$: CH 3,4,5</td>
<td>$\sigma = 2$: CH 1-7</td>
</tr>
<tr>
<td>Thinning</td>
<td>250 km</td>
<td>250 km</td>
<td>200 km</td>
</tr>
</tbody>
</table>
Enhanced Filtering of AMSU Data

- **Removal of AMSU-A CH3:**
  - Moderate sensitivity to water vapour and clouds
  - Current CLW threshold of 0.3 mm is very high (CLW not part of forward model)

**AMSU-A Sensitivity vs. Liquid Water Path (kg m⁻²)**

- **850-700 hPa**
- **700-500 hPa**

Emissivity = 0.5
Enhanced Filtering of AMSU Data

- Removal or additional filtering of AMSU-B CH2:
  - Moderate sensitivity to clouds
  - Currently no cloud filter for AMSU-B

AMSU-B Sensitivity vs. Liquid Water Path (kg m\(^{-2}\))

<table>
<thead>
<tr>
<th>Channel</th>
<th>Frequency</th>
<th>Sensitivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>CH1</td>
<td>89.0 GHz</td>
<td>Clear - Cloudy (K)</td>
</tr>
<tr>
<td>CH2</td>
<td>150.0 GHz</td>
<td>Not assimilated</td>
</tr>
<tr>
<td>CH3, CH4, CH5</td>
<td>183.31 GHz</td>
<td>Not assimilated</td>
</tr>
</tbody>
</table>

Layer: 850-700 hPa, TPW=28.50 kg m\(^{-2}\), EIA=30\(^\circ\)

Layer: 700-500 hPa, TPW=33.27 kg m\(^{-2}\), EIA=30\(^\circ\)
Enhanced Filtering of AMSU Data

- Extra filtering of AMSU-B CH2,3,4,5 over oceans (remove observations where CH2 |O-FG| ≥ 5K):
  - Weak sensitivity of CH3,4,5 to mid-level clouds
  - Currently no cloud filter for AMSU-B
  - Acts as proxy cloud filter: many obs in persistently cloudy, non-precipitating regions are no longer assimilated (see next slide)
  - Same filtering applied at ECMWF and Meteo-France
- Results in ~100 less obs assimilated for each channel every period (~7% loss)
Difference in # of obs assimilated for AMSU-B CH3:

Effect of Proxy Cloud Filter
Mean Analyzed Integrated Water Vapour (kg m$^{-2}$): July 2003

AMSRE – ANALYSIS

Correlation: 0.95

Standard Deviation (kg/m$^2$)

Bias (kg/m$^2$)
Mean Daily Precipitation Rate (mm/day): July 2003

GPCP – Accum. 6hr FCSTs

- Correlation: 0.50, 0.67, 0.84, 1.0

- Standard Deviation (mm/day)

- Bias (mm/day)

- Globe

- Correlation plots for different regions and correlation values.

- Standard deviation and bias plots showing model performance.
Forecast Validation Using Analyses

Anomaly Correlation
Temperature, 850 hPa, Tropics
Forecast Validation Using Analyses

RMS
Dewpoint Depression, 850 hPa, Southern Hemisphere
Vertical Distribution of Moisture

Percent Change in Specific Humidity:

$$100 \times \frac{Q_{\text{EXP1}} - Q_{\text{CNT1}}}{Q_{\text{CNT1}}}$$
Mean Analyzed Integrated Water Vapour (kg m\(^{-2}\)): July 2003

AMSRE – ANALYSIS

Correlation

Standard Deviation (kg/m\(^2\))

Bias (kg/m\(^2\))
Conclusions

• Proxy cloud filter is effective at removing AMSU-B observations in cloudy, non-precip. regions
• Evaluation of monthly averaged IWV, SWS, DPR fields shows improvements for EXP1, EXP2, EXP3
  – Mostly due to addition of SSM/I data
• Verification of forecasts against RAOBS shows little to no impact for EXP1, and small positive impact for EXP2, EXP3
  – Weak signal not surprising since most RAOBS are land based
• Verification of forecasts against analyses shows positive effects in AC and RMS for all experiments
  – Stronger signal for EXP2, EXP3 than EXP1 (SSM/I has little impact)
  – Exception: SH moisture field for EXP2
Conclusions (2)

- Results indicate that assimilating AMSU-B CH3,4,5 without CH2 leads to a less accurate vertical distribution of moisture
  - SSM/I unable to compensate, though the weighting function for SSM/I CH7 is similar to AMSU-B CH2
  - Very likely SSM/I and AMSU-B obs are not coincident, in which case, absent CH2, AMSU-B bias corrections need to be re-evaluated (?)
Future Work

• Re-compute bias corrections with a data set lacking ‘cloudy’ AMSU-B obs, and run experiment to see if humidity field returns to CNTL
  – Keep benefits of EXP2, EXP3; avoid negative effects
• Launch and evaluate Northern Hemisphere winter experiments with same configurations
• Launch and evaluate experiments using 4D-Var for a 2-month summer and a 2-month winter cycle
END
Verification of forecasts against **RAOBS** shows a neutral impact for EXP1 and small positive impacts for EXP2, EXP3

- Little impact within first 5 days
- No notable change to vertical profile of temperature (despite removal of AMSU-A CH3)
- Weak signal is not surprising since RAOBS are mostly land based
Acronyms

- DMSP: Defense Meteorological Satellite Program
- TRMM: Tropical Rainfall Measuring Mission
- TMI: TRMM Microwave Imager
- SSM/I: Special Sensor Microwave Imager
- AMSR-E: Advanced Microwave Scanning Radiometer for EOS
- AMSU: Advanced Microwave Sounding Unit
- GPCP: Global Precipitation Climatology Project
- TOVS: TIROS Operational Vertical Sounder
- TIROS: Television InfraRed Observation Satellite
Mean Analyzed Surface Wind Speed (m s$^{-1}$): July 2003

QSCAT – ANALYSIS

Globe

Correlation

Standard Deviation (m/s)

Bias (m/s)

CNTL CORR
EXP1 CORR
EXP2 CORR
EXP3 CORR

CNTL SD
EXP1 SD
EXP2 SD
EXP3 SD

Globe

40°N–60°N
20°N–40°N
EQ–20°N
20°S–EQ
40°S–20°S
60°S–40°S

0.0
0.5
1.0
1.5

-1.0
0.0
0.5
1.0
1.5

Canada
Weighting Functions wrt Humidity

AMSU-B

Tropical Profile: TPW=52.46 kg m\(^{-2}\)

- CH1: 89.0 GHz
- CH2: 150.0 GHz
- CH3: 183.31 (1) GHz
- CH4: 183.31 (3) GHz
- CH5: 183.31 (7) GHz

zenith angle = 45°

AMSUB
CH2

Not assimilated

AMSU-A

Tropical Profile: TPW=52.46 kg m\(^{-2}\)

- CH1: 23.8 GHz
- CH2: 31.4 GHz
- CH3: 50.3 GHz
- CH4: 52.8 GHz
- CH15: 89.0 GHz

zenith angle = 45°

AMSUA
CH3

Not assimilated
Weighting Functions wrt Humidity

SSM/I

Tropical Profile: TPW=52.46kgm\(^{-2}\)

- CH1: 19.4 GHz
- CH3: 22.2 GHz
- CH4: 37.0 GHz
- CH6: 85.5 GHz

zenith angle = 53°
Sensitivity wrt Surface Wind Speed

AMSU-B

AMSU-A

zenith angle = 30°

Not assimilated
Sensitivity wrt Surface Wind Speed

**AMSU-B**

- CH1: 89.0 GHz
- CH2: 150.0 GHz
- CH3: 183.31(1)GHz
- CH4: 183.31(3)GHz
- CH5: 183.31(7)GHz

Arctic Profile: TPW=5.13kgm$^{-2}$

**AMSU-A**

- CH3: 50.3 GHz
- CH4: 52.8 GHz
- CH5: 53.6 GHz

Arctic Profile: TPW=5.13kgm$^{-2}$
Sensitivity wrt Surface Wind Speed

SSM/I

Tropical Profile: TPW = 52.46 kg m\(^{-2}\)

Zenith angle = 53°

\[
\frac{dT_B}{dU} (\pm 0.5 \text{ m/s})
\]

Wind Speed (m/s)

0 3 6 9 12 15 18 21 24
### Independent Observations

**AMSR-E (IWV)**

<table>
<thead>
<tr>
<th>Channel</th>
<th>Freq. (GHz)</th>
<th>Res. (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 &amp; 2</td>
<td>6.925 V,H</td>
<td>56</td>
</tr>
<tr>
<td>3 &amp; 4</td>
<td>10.65 V,H</td>
<td>38</td>
</tr>
<tr>
<td>5 &amp; 6</td>
<td>18.7 V,H</td>
<td>21</td>
</tr>
<tr>
<td>7 &amp; 8</td>
<td>23.8 V,H</td>
<td>24</td>
</tr>
<tr>
<td>9 &amp; 10</td>
<td>36.8 V,H</td>
<td>12</td>
</tr>
<tr>
<td>11 &amp; 12</td>
<td>89.0 V,H</td>
<td>5.4</td>
</tr>
</tbody>
</table>

AQUA Research Satellite  
Conical scanner  
1445 km swath  
705 km altitude  
Sun-synchronous

**QuikSCAT (SWS)**

**active** scatterometer (MW radar)  
13.4 GHz channel @ 25 km res.  
Range: 3 – 20 m/s  
Accuracy: 2 m/s, 20°  
1800 km swath  
803 km altitude

Data source: Remote Sensing Systems  
[www.remss.com](http://www.remss.com)
AMSU-B coverage after thinning

AMSU-B observations 2005030300
1499 NOAA-15  1642 NOAA-16  1677 NOAA-17
SSM/I coverage after thinning

Date 2005030300