Impact of assimilating humidity sounder radiances with the NICAM-LETKF system

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NICAM: Non-hydrostatic ICosahedral Atmospheric Model

Grid division level 0 is the original Icosahedron. The horizontal resolution can be increased by splitting one triangle into four triangles.

<table>
<thead>
<tr>
<th>Grid division level</th>
<th>Horizontal resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>112 km</td>
</tr>
<tr>
<td>7</td>
<td>56 km</td>
</tr>
<tr>
<td>8</td>
<td>28 km</td>
</tr>
<tr>
<td>9</td>
<td>14 km</td>
</tr>
<tr>
<td>10</td>
<td>7 km</td>
</tr>
<tr>
<td>11</td>
<td>3.5 km</td>
</tr>
<tr>
<td>12</td>
<td>1.7 km</td>
</tr>
<tr>
<td>13</td>
<td>0.87 km</td>
</tr>
</tbody>
</table>
Conventional observations (NCEP PREPBUFR)

6 hourly observation
AMSU-A (after thinning)

Thinning distance: 250km
NOAA-15, 16, 18, 19
6 hourly observation

Different colors show the observations at different time slot
Bias correction

airmass bias

scan bias

\[ y - Hx^f - p^T \beta - b_{scan} \]
Estimating airmass bias

Ensemble-based variational bias correction method

\[ \delta \beta = (B_\beta^{-1} + pR^{-1}p^T)^{-1}pR^T(y - H\bar{x} - p^T\beta) \]

<table>
<thead>
<tr>
<th>Predictor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Integrated weighted lapse rate (1000-200 hPa)</td>
</tr>
<tr>
<td>Integrated weighted lapse rate (200-50 hPa)</td>
</tr>
<tr>
<td>Surface temperature</td>
</tr>
<tr>
<td>Satellite zenith angle</td>
</tr>
</tbody>
</table>
Estimating scan bias

\[ b_t^{scan_{new}}(n) = \alpha b_t^{scan}(n) + (1 - \alpha) \left( b_t^{scan_{est}}(n) - b_{t-1}^{scan}(n) \right) \]

- AMSU-A observations have different biases at each scan position
- Estimating scan bias from the innovation statistics

AMSU Scanning Geometry and Resolution

(http://tropic.ssec.wisc.edu/real-time/amsu/explanation.html)
Estimated bias

Ch. 6 of NOAA-18

Coefficients of airmass bias

- IWLR (1000–200 hPa)
- IWLR (200–50 hPa)
- Surface Temperature
- Satellite zenith angle

scan bias

Footprint Number

November–2011 December–2011
o-b (AMSU-A)

\[ y - Hx^f - p^T \beta - b_{\text{scan}} \]

- (a) o-b w/o bias correction
- (b) o-b w/ bias correction
- (c) Precipitation (GSMaP)
- (d) Scan bias correction
- (e) Airmass bias correction

- Scan bias correction
- Precipitation (GSMaP)
Global RMSD for temperature (vs. ERA-interim)

Only PREPBUFR

PREPBUFR+ AMSU-A

Difference

2 months (00Z 01 Nov. 2011 – 18Z 31 Dec. 2011)  
Ensemble size = 40
Summary

• Terasaki et al. (2015) introduced NICAM-LETKF systems
  – Assimilating only conventional observations (NCEP PREPBUFR)

• Assimilating satellite observations (AMSU-A)
  – Developing the observation operator for satellite radiances with RTTOV
  – Adaptively estimating the airmass and scan biases
  – Analysis becomes more accurate in the troposphere
Why Humidity Sounder?

- AMSU-A radiances are sensitive to temperature.
- There are a few observations of humidity over ocean.
- It is expected to have a positive impact on the humidity analysis by assimilating humidity sounder in the NICAM-LETKF system.
Impact of assimilating humidity sounder radiances with the NICAM-LETKF system

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Introduction

• Miyoshi et al. (2010)
  • Compared LETKF and 4D-Var using JMA global model.
  • Developed the adaptive bias correction for satellite radiances.
  • Showed LETKF and 4D-Var have comparable performance.

• Better handling of satellite observations for operational use of LETKF

• Terasaki et al. (2015)
  • Implemented LETKF with NICAM (Assimilating only PREPBUFR data)
  • Direct use of NICAM icosahedral grid (ICO-LETKF).
  • ICO-LETKF showed overall acceleration in computation.

• Terasaki and Miyoshi (2017)
  • Assimilated AMSUA radiances with the NICAM-LETKF system.
  • Online estimation of scan and air-mass bias for radiance observations.
  • Showed considerable improvement in the analysis.

• Goal: To assimilate MHS radiances with the NICAM – LETKF system
MHS Characteristics

- 3 Channels centered around the water vapor line (183.31 GHz)
- 2 window channels (H1 and H2)
- Possible to get the humidity signatures from H3, H4 and H5

<table>
<thead>
<tr>
<th>Instrument</th>
<th>IFOV type</th>
<th>IFOV size (deg)</th>
<th>Sampling interval (across-track) (deg)</th>
<th>IFOV size (nadir) (km)</th>
<th>Samples per scan line</th>
<th>Scan separation (km)</th>
<th>Swath width (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AMSU-A</td>
<td>circular</td>
<td>3.3</td>
<td>3.33</td>
<td>47.63</td>
<td>30</td>
<td>52.69</td>
<td>±1026.31</td>
</tr>
<tr>
<td>MHS</td>
<td>circular</td>
<td>1.1</td>
<td>1.11</td>
<td>15.88</td>
<td>90</td>
<td>17.56</td>
<td>±1077.68</td>
</tr>
</tbody>
</table>

Courtesy: EUMETSAT
Quality control of MHS radiances

- RTTOV model as forward operator
- QC of MHS radiances is similar to the operational scheme used for GSI
  - Step 1: Calculation of Liquid Water Path (LWP)\textsubscript{index} and Total Precipitable Water (TPW)\textsubscript{index} ( \( \text{LWP}_{\text{Index}} = F(\text{Ch1}_{o-b}, \text{Ch2}_{o-b}) \) )
  - Step 2: Remove : TPW\textsubscript{index} > 1
  - Step 3: Remove pixels with \( \text{abs}(O-B)_i > 3e_i \)
- Observations from 1-15 and 75-90 FOVs are not considered
- Horizontal thinning distance is set to 140 km (Refer to Terasaki (2015) and Terasaki (2017) for more details on horizontal thinning)
- Superobing of MHS over 3x3 grid box (Only 20 FOVs)
Bias predictors for MHS

**Miyoshi et al. (2010)**
1. IWLR
2. Surface Temperature
3. $1/\cos \theta$
4. constant

**Kazumori (2014) (JMA)**
1. 2 - IWLR
2. Surface Temperature
3. $1/\cos \theta$

**ECMWF**
1. 1000 - 300 hPa thickness
2. 200 - 50 hPa thickness
3. 10 - 1 hPa thickness
4. 50 - 5 hPa thickness

**NCEP GSI**
1. 2 - IWLR
2. Surface Temperature
3. $1/\cos \theta$
4. TCWV

**Present study**
- Exp 1 – 4 Predictors
- Exp 2 – 3 Predictors
- Exp 3 – 2 Predictors
4 Predictors for VarBC

NOAA 19 Ch-3

NOAA 19 Ch-4

NOAA 19 Ch-5

Time history of bias predictor coefficients
4 Predictors for VarBC

Time history of scan bias values
3 Predictors for VarBC

NOAA 18 Ch-3

NOAA 18 Ch-4

NOAA 18 Ch-5

Time history of bias predictor coefficients
2 Predictors for VarBC

NOAA 18 Ch-3

NOAA 18 Ch-4

NOAA 18 Ch-5

Time history of bias predictor coefficients
O-B Statistics

3 Predictors

Time history of O-B mean and standard deviation

2 Predictors
Percentage improvement based on RMSE (MHS vs AMSUA)
In all the three cases there is a considerable improvement in the analysis after assimilating MHS radiances.

The humidity bias between 600 – 400 hPa layer has reduced considerably.

Fast convergence of bias predictor coefficients for channel 3 and 4.

Further experiments on assimilating MHS radiances, use only 2 predictors for air-mass bias correction (ECMWF)

- IWLR (1000 – 300 hPa)
- IWLR (200 – 50 hPa)
A Case Study
Indian Summer Monsoon

- Monsoon – surface wind reversal
- The onset of ISM denotes the beginning of primary rainy season in India
- Up to 70% of Indian rainfall from ISM (June to September)
- Indian monsoon tied to the socio-economic life

From Tropical Meteorology by T. N. Krishnamurthi
The case of Indian Summer Monsoon Onset

- Test case: Indian monsoon onset – 2012
- Actual onset on 5th June 2012 (IMD monsoon report)
- ISM onset date declared by IMD using subjective methods.
- Various onset indices have been developed in the recent times
- Here in this study we report the onset using the ISM index developed by Wang et al. (2009)
Indices for monsoon onset

ISM index: $U_{850}(1) - U_{850}(2)$

Onset Circulation Index (OCI):

Average 850hPa 'U' wind over lat-lon box: 5–15N, 40–80E

“The date of onset is defined as the first day when OCI exceeds 6.2 m/s, with the provision that the OCI in the ensuing consecutive 6 days also exceeds 6.2 m/s” – Wang et al. 2009

From Wang et al. (2009)
NICAM-LETKF Analysis experiments

- 3 months analysis with AMSUA and MHS radiances
- Forecast experiments with NICAM
- ISM index calculated for the above analysis experiment and validated with the ERA Interim data
- Both MHS and AMSUA analysis captures the ISM index variation
Climatological value of OCI for onset (~6.2 m/s)
NICAM-LETKF Analysis experiments

% improvement for 2012 case
NICAM forecast experiments

NICAM forecast initialized from 15 May 2012 using analysis from MHS and AMSUA assimilation cycles.

Onset date:

IMD : 05 Jun 2012
ERA : 28 May 2012
MHS : 25 May 2012
AMSUA : 24 May 2012

OCI – Onset Circulation Index
Average 850hPa ‘U’ wind over lat-lon box : 5–15N, 40–80E
Error in the onset date (in Days) from NICAM model forecast when compared with the onset date from ERA using OCI

+ve -> Late onset
-ve -> Early Onset

ERA Onset date using OCI: 28 May 2012

Avg Error (15-25May):
AMSUA: ~3.1 Days
MHS: ~1.9 Days
OLR in W/m²
(Averaged over 60E to 80E)
MHS forecast produce strong westerlies which is indicator of ISM onset
Conclusions

- The addition of MHS radiance to the existing NICAM-LETKF system improves the humidity analysis fields especially in the middle troposphere.
- Several set of predictors for MHS radiance bias correction were tested and for the case study only 2 predictors were used.
- ISM onset index based on the analysis from MHS and AMSUA assimilation compares well with the ERA Interim data.
- The analysis of the NICAM model forecast of ISM onset is underway.
- Comparison of the forecast initialized with MHS and AMSUA analysis is being done.

Limitations:
- Only MHS pixels over ocean is assimilated.
- Objective definition of Indian Monsoon Onset based on the model OLR values.
- Owing to the resolution of NICAM model, precipitation values were not compared for the Monsoon experiments.
Thank you for your attention!