Assessment of AHI Level-1 Data for HWRF Assimilation

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Outline

• Concept on Satellite Data Assimilation (DA)
• A Baseline HWRF System for Satellite DA
• Impacts of GOES Imager Radiance Assimilation on Hurricane Track and Intensity Forecasts
• Assessment of AHI Data Applications to HWRF DA
• Summary and Conclusions
Concept of Satellite Data Assimilation

A process of incorporating all observations into weather forecast models to produce the “best” description of the atmospheric state at a desired resolution. Physical understanding of observations and weather structures and applicable mathematical optimal control and statistical estimate theories that match computer capabilities and are important for any success of satellite data assimilation.

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

\[ J(x_a) = \min_x J(x) \quad \forall x \text{ near } x_b \quad \text{<--- Maximum likelihood Estimate} \]

- \( x \) — analysis variable
- \( x_a \) — final analysis
- \( x_b \) — background
- \( B \) — background error covariance
- \( O \) — observation error covariance
- \( H \) — observation operator
- \( F \) — forward model error covariance
- \( y^{obs} \) — observations
- \( \mu \) — bias

The success of satellite DA of any instruments requires the science of satellite data and NWP be effectively integrated together into a DA system and the results from the DA system be carefully analyzed and interpreted.
• 2012 NCEP-trunk version 934 HWRF (three nested domains)
• System Modifications
  - Higher model top (0.5 hPa, 61 levels)
  - Warm start
  - Asymmetric vortex initialization
• Advanced POES and GOES DA
  - POES sounding instruments: AMSU, ATMS, CrIS, IASI, AIRS
  - New quality control (QC) for MHS
  - GOES-13/15 imager radiance
  - POES microwave imager radiance (AMSR2, GMI)
  - Surface sensitive channels through Community Surface Emissivity Model (CSEM)
A Newly Added Asymmetric Bogus Vortex to HWRF

Symmetric Vortex

Asymmetric Vortex

Tropical storm Debby at 1800 UTC June 23, 2012
# GOES-13/15 Imager Channel Characteristics

<table>
<thead>
<tr>
<th>Channel</th>
<th>Central Frequency ($\mu m$)</th>
<th>Band Width ($\mu m$)</th>
<th>Spatial Resolution (km)</th>
<th>Observation Error (K)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>GOES-13</td>
<td>GOES-15</td>
<td>GOES-13</td>
<td>GOES-15</td>
</tr>
<tr>
<td>1</td>
<td>0.65</td>
<td>0.19</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>2</td>
<td>3.90</td>
<td>0.34</td>
<td>4.0</td>
<td>4.0</td>
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<tr>
<td>3</td>
<td>6.55</td>
<td>1.50</td>
<td>4.0</td>
<td>4.0</td>
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<tr>
<td>4</td>
<td>10.7</td>
<td>1.00</td>
<td>4.0</td>
<td>4.0</td>
</tr>
<tr>
<td>6</td>
<td>13.35</td>
<td>0.70</td>
<td>8.0</td>
<td>4.0</td>
</tr>
</tbody>
</table>

- Imager channels 2-4 are to assimilated in NCEP GSI system
- GOES channel 5 (12.0 $\mu m$) had been changed to channel 6 (13.35 $\mu m$) since the launch of GOES-12
GOES-13/15 DA with an Asymmetric Vortex Initialization

Channel 3 Data Assimilated after QC

Asymmetric Relative Vorticity

GOES-13 data assimilated
GOES-13 data eliminated by QC

Analysis Difference

\[ \Phi_{\text{GOES DA, } 300 \text{ hPa}} - \Phi_{\text{without GOES, } 300 \text{ hPa}} \]

Tropical Storm Debby at 1800 UTC June 23, 2012
Impacts of GOES-13/15 Imager Radiance DA on Track Prediction

Asymmetric Vortex Initialization without GOES-13/15 Imager DA

Asymmetric Vortex Initialization with GOES-13/15 Imager DA

Impacts of GOES-13/15 Imager Radiance DA on Intensity Forecasts

Central Sea-Level Pressure (SLP)

Maximum Surface Wind Speed ($V_{\text{max}}$)
**Impacts of GOES-11/-12 Imager Radiance DA on QPFs**

- The added impacts of GOES imager radiance DA to different types of satellite data (AMSU-A, HIRS/4, HIRS/3, GSN, AIRS, MHS) was consistently positive on QPFs.
- The analysis and forecast errors are significantly reduced by GOES imager radiance DA when verified with independent observations from GOES sounders and AIRS.

Himawari-8 AHI Channels 7-16

<table>
<thead>
<tr>
<th>Channel Number</th>
<th>Central Wavelength</th>
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<tbody>
<tr>
<td>7</td>
<td>3.9 mm</td>
</tr>
<tr>
<td>8</td>
<td>6.2 mm</td>
</tr>
<tr>
<td>9</td>
<td>6.9 mm</td>
</tr>
<tr>
<td>10</td>
<td>7.3 mm</td>
</tr>
<tr>
<td>11</td>
<td>8.6 mm</td>
</tr>
<tr>
<td>12</td>
<td>9.6 mm</td>
</tr>
<tr>
<td>13</td>
<td>10.4 mm</td>
</tr>
<tr>
<td>14</td>
<td>11.2 mm</td>
</tr>
<tr>
<td>15</td>
<td>12.4 mm</td>
</tr>
<tr>
<td>16</td>
<td>13.3 mm</td>
</tr>
</tbody>
</table>
AHI Data

0130 UTC
August 4, 2015

Pressure (hPa)

Weighting Function

Ch12

Ch16

Ch14
Brightness Temperatures of AHI Ch14
Heidinger A. (2012), ATBD: ABI Cloud Mask

Cloud Mask within Typhoon Soudelor (1/2)

ETROP
Channel 14
Emissivity
Referenced to the Tropopause

EMISS
Emissivity Test at 4 μm

CIRH2O
Cirrus Water Vapor Test

NFMFT
Negative Four Minus Five Test

Heidinger A. (2012), ATBD: ABI Cloud Mask
Cloud Mask within Typhoon Soudelor (2/2)

TUT
Thermal Uniformity Test

RFMFT
Relative Four Minus Five Test

TEMPIR
Temporal Infrared Test

RTCT
Relative Thermal Contrast Test

Heidinger A. (2012), ATBD: ABI Cloud Mask
Cloud Mask within Tropical Convection (2/2)
Comparison between Two Different Cloud Masks

ETROP
Channel 14 Emissivity Referenced to the Tropopause

RFMFT
Relative Four Minus Five Test

Typhoon Soudelor
Tropical Convection
Comparison of Cloud Mask between Two Methods

Channel 14 Emissivity Referenced to the Tropopause

$$\varepsilon_{ETROP} = \frac{I_{\text{obs}}^{11.2 \mu m} - I_{\text{CRTM clear-sky}}^{11.2 \mu m}}{I_{\text{blackbody}} - I_{\text{CRTM clear-sky}}^{11.2 \mu m}}$$

The ETROP test assumes that clouds produce colder $11.2 \mu m$ brightness temperatures than what would have been observed under clear-sky conditions.

Positive Four Minus Five Test

$$\chi_{RFMFT} = \max_{5 \times 5} \Delta I_{11.2-12.3}^{\text{obs, NWC}} - \Delta I_{11.2-12.3}^{\text{CRTM clear-sky}}$$

$$\Delta I_{11.2-12.3}^{\text{obs}} = I_{\text{obs}}^{11.2 \mu m} - I_{\text{obs}}^{12.3 \mu m}$$

$$\Delta I_{11.2-12.3}^{\text{CRTM clear-sky}} = I_{\text{CRTM clear-sky}}^{11.2 \mu m} - I_{\text{CRTM clear-sky}}^{12.3 \mu m}$$

The basis for the RFMFT test is the variation in $\Delta I_{11.2-12.3}^{\text{obs}}$ for cloudy conditions.
Overlap of Cloudy Pixels Found by Nine Cloud Masks

Percentage of cloudy pixels detected by one CM but not by any other CMs for AHI data within two selected regions (105E-120E, 0-15N; 120E-150E, 0-30N) at 0130 UTC August 4, 2015. The total number of cloudy pixels within the two regions detected by nine CMs are 551,384 and 2,382,845.
AHI Observed and CRTM/ECMWF F Simulated Brightness Temperatures of Channel 16 in Clear-Sky Conditions

0130 UTC
August 4, 2015
Bias and Standard Deviation between AHI Observations and CRTM/ECMWF Simulations

All clear-sky data with satellite zenith angle being less than 25° over ocean in clear-sky conditions on August 4, 2015 at half-hour interval.
Estimated AHI O-B Biases and Standard Deviations

\[ \theta \leq 25^\circ \]
\[ \theta \leq 50^\circ \]
\[ \theta \leq 80^\circ \]

All clear-sky data over ocean on August 4, 2015 at half hour interval.
Bias and Standard Deviation between AHI Observations and CRTM/ECMWF Simulations

<table>
<thead>
<tr>
<th>Channel Number</th>
<th>Bias (K)</th>
<th>Std. (K)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\theta \leq 25^\circ$</td>
<td>$\theta \leq 50^\circ$</td>
</tr>
<tr>
<td>7</td>
<td>-0.47</td>
<td>-2.04</td>
</tr>
<tr>
<td>8</td>
<td>-0.65</td>
<td>-1.15</td>
</tr>
<tr>
<td>9</td>
<td>-0.11</td>
<td>-0.60</td>
</tr>
<tr>
<td>10</td>
<td>-0.62</td>
<td>-1.20</td>
</tr>
<tr>
<td>11</td>
<td>-0.58</td>
<td>-1.16</td>
</tr>
<tr>
<td>12</td>
<td>-0.83</td>
<td>-1.46</td>
</tr>
<tr>
<td>13</td>
<td>-0.41</td>
<td>-0.56</td>
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<tr>
<td>14</td>
<td>-0.34</td>
<td>-0.57</td>
</tr>
<tr>
<td>15</td>
<td>-0.67</td>
<td>-1.00</td>
</tr>
<tr>
<td>16</td>
<td>-1.51</td>
<td>-1.55</td>
</tr>
</tbody>
</table>

All data at half-hour interval over ocean in clear-sky conditions on August 4, 2015.
AHI O-B Bias Dependence on Zenith Angle

Channel 15

Channels 8-16
The AHI O-B bias increases with satellite zenith angle.

The O-B bias of AHI channel 16 increases from zero to about 6 K when the satellite zenith angle changes from zero to more than 70°.

All clear-sky data over ocean on August 4, 2015 at half hour interval.
O-B Biases of AHI Channel 8-11
O-B Biases of AHI Channel 12-15
Spatial Distribution of AHI O-B Bias and Standard Deviation of Channel 16

- Zenith dependent bias is independent of data count distributions
- Standard deviation is usually larger when data counts are smaller

All clear-sky data over ocean on August 4, 2015 at half hour interval.
Summary and Conclusions

- Assimilation of GOES imager radiance in HWRF resulted in improvements in hurricane track and intensity forecasts and coastal QPFs.

- GOES-R AWG cloud mask algorithm is fully vetted in the baseline HWRF/DA system for quality control of clear-sky radiance assimilation.

- The bias of AHI radiance data is evaluated with respect to the ECMWF forecast fields. In clear-sky conditions, O-B bias is dependent on scan angle.

- Future AHI data assessment will be extended to cloudy conditions and O-B bias features will be separately characterized according to different cloudy types and surface conditions.