Towards the assimilation of all-sky infrared radiances of Himawari-8

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1: JMA/MRI, 2: RIKEN/AICS

Outline

1. Background
2. OB-FG statistics
3. Observation error
4. Preliminary assimilation experiments
5. Summary and plans
1. Background

- Cloud/rain-affected satellite data have been underused especially for infrared (IR) radiances
  - Complicated cloud/rain process in NWP and RT models, Non-linearity, Non-Gaussianity,

- IR radiances
  - Mostly assimilated in clear-sky condition, and in overcast conditions at some operational centers
    - Issues: miss meteorologically important info, suffer from unexpected cloud contamination, cause dry bias,
  - All-sky MW radiance assimilation has been successfully implemented
  - Provide higher temporal/horizontal/vertical information, despite limited availability, compared with MW radiances

- Objective: Improve T/Q/W analysis and forecast by effectively assimilating all-sky IR radiance
  - Especially for Himawari-8
Himawari-8/AHI

- Launched in Oct. 7, 2014
  - Start the operation in Jul. 7, 2015
  - Geo-sat after MTSAT2
  - Himawari-9 to be launched in 2016

- Advanced Himawari Imager (AHI)
  - 16 bands, including 3 VIS, 3 NIR, 3 humidity, 3 window, and 1 CO2
  - 1.0/0.5 km for VIS and NIR, 2.0 km for IR and NIR
  - 10 min. for full disk, 2.5 min. for Japan regions and target regions

<table>
<thead>
<tr>
<th>Band</th>
<th>Wavelength [μm]</th>
<th>Spatial Resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.43 - 0.48</td>
<td>1km</td>
</tr>
<tr>
<td>2</td>
<td>0.50 - 0.52</td>
<td>1km</td>
</tr>
<tr>
<td>3</td>
<td>0.63 - 0.66</td>
<td>0.5km</td>
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<tr>
<td>4</td>
<td>0.85 - 0.87</td>
<td>1km</td>
</tr>
<tr>
<td>5</td>
<td>1.60 - 1.62</td>
<td>2km</td>
</tr>
<tr>
<td>6</td>
<td>2.25 - 2.27</td>
<td>2km</td>
</tr>
<tr>
<td>7</td>
<td>3.74 - 3.96</td>
<td>2km</td>
</tr>
<tr>
<td>8</td>
<td>6.06 - 6.43</td>
<td>2km</td>
</tr>
<tr>
<td>9</td>
<td>6.89 - 7.01</td>
<td>2km</td>
</tr>
<tr>
<td>10</td>
<td>7.26 - 7.43</td>
<td>2km</td>
</tr>
<tr>
<td>11</td>
<td>8.44 - 8.76</td>
<td>2km</td>
</tr>
<tr>
<td>12</td>
<td>9.54 - 9.72</td>
<td>2km</td>
</tr>
<tr>
<td>13</td>
<td>10.3 - 10.6</td>
<td>2km</td>
</tr>
<tr>
<td>14</td>
<td>11.1 - 11.3</td>
<td>2km</td>
</tr>
<tr>
<td>15</td>
<td>12.2 - 12.5</td>
<td>2km</td>
</tr>
<tr>
<td>16</td>
<td>13.2 - 13.4</td>
<td>2km</td>
</tr>
</tbody>
</table>
2. OB-FG statistics
JMA-NHM (Non-hydrostatic model)
- Operational meso-scale model of JMA since 2004 (Saito et al. 2006)
- Cloud microphysics
  - Explicit three-ice bulk scheme based on Lin et al. (1983)
    
    | Mix.ratio | Cloud water | Cloud ice | Rain | Snow | Graupel |
    |------------|-------------|-----------|------|------|---------|
    | Qc         | Qi          | Qr        | Qs   | Qg   |
    | Num.density| Ni          |           |      |      |         |
    | DSD        | Mono-disperse|          |      |      | Exponential |

- 5km, L50, 461x481 grids, Japan region

RTTOV v11.3
- Cloud scattering (Matricaldi 2005) : scaling approximation (Fu et al. 1999), cloud fraction by stream method
- Input: 6-h forecast from JMA-NHM
  - Profiles of temperature, humidity, Liquid cloud, ice cloud, cloud fraction
  - Ice cloud : the sum of ice, snow and graupel
  - Cloud fraction is estimated by Tompkins and Janiskova (2004)
Comparison of AHI obs and simulation

- Super-ob (2x2 pixels average)
  - For better representation of 5km model

- Remove highly inhomogeneous scenes (inhomogeneity-QC)
  - Standard deviation (SD) in super-ob (SDso) at band 13 > 2.0 K
  - $\rightarrow$ Justify making IR super-ob and mitigate difficulty in partial cloud effect in RT calculation
  - SDso is estimated from original pixels inside super-ob

- Thinned in 20 km box (4 model grids)

The comparison was made for four different meteorological conditions

- Result in a stationary rain band case is only shown: 00 UTC Sep 7~18 UTC Sep 9, 2015, every 6-h
OB and FG at band13 (10.4 μm)

- Insufficient simulation for low BT
- CRTM can generate more low BT but occasionally excessive
OB vs FG, OB vs OB-FG with RTTOV

- **B8** (6.2μm)
- **B10** (7.3μm)
- **B13** (10.4μm)

Log(Num)
Cloud effect and QC

- A parameter to represent cloud effect on radiance: \( Ca \)
  - \( Ca = 0.5*(|FG-FGclr|+|OB-FGclr|) \), \( FGclr=\) clear-sky \( FG \)
  - \( OB-FG \) variability monotonically increases with \( Ca \)
  - \( \rightarrow \) predict (cloud-dependent) \( OB-FG \) SD using \( Ca \)
  - Details in Okamoto et. al. (2014, QJRMS)

- 2 additional QCs
  - Too low TB (\( OB<230K \))
  - Large \( OB-FG \) with Cloud-dependent criteria
Apply QC and normalization that takes the cloud effect into account
→ PDF at bands 8 and 10 become closer to Gaussian, but not at band 13

inhomoQC only

3QC+ cld-depend SD
3. Observation error
Observation error statistics for all-sky rad

- Estimate obs error at humidity bands based on Desroziers diagnostics
- Obs error SD = 1.7 K (band8), 1.9 K (9) and 2.5 K (10)
- Distance at corr<0.2 = 150 km (bands 9 & 10), 250km (8)
- Strong spectral correlation
  - band8-9: 0.83,
  - band8-10: 0.52,
  - band9-10: 0.85

Assimilate only band 9, Thinned to 150 km
Comparison of cloudy and clear-sky rad

- Separate cloudy (Ca>0.5) and clear-sky (Ca<0.5)
- Larger SD and spatial/spectral correlation in cloudy conditions
  - Obs error SD = 0.4, 0.4, 0.4 (clear-sky) → 1.9, 2.3, 3.0 (cloudy) at bands 8, 9, 10
  - Dist (corr < 0.2) = 60 km (clear-sky) → 180 km (cloudy) at band 9
  - Corr (band8-10) = 0.03 (clear-sky) → 0.60 (cloudy)
- Consistent to all-sky MW 85GHz statistics (Bormann et al. 2011)
Assume a linear model with $Ca$

$r = r_0$ for $Ca < Ca_0$

$r_1$ for $Ca > Ca_1$

$r_0 + (r_1-r_0)*(Ca_1-Ca)/(Ca_1-Ca_0)$ for others

$r_0$, $r_1$: min, max error, estimated from Desroziers diagnostics $\rightarrow r_0=0.4K$, $r_1=6.3K$

Non-diagonal component will be included in future
4. Preliminary assimilation experiments
**Experiment Design**

- **NHM-Letkf (Kunii 2014)**
  - 15km, 50 members, 273x221 grids
  - 6-h cycle with 1-h slot to ingest observations
  - Inflation: RTPS (relaxation-to-prior spread)
  - Localization: 200 km and 0.2 lnP coordinates

- **Period:** 06 UTC 4 ~ 18 UTC 10 Sep, 2015

- **Observations**
  - CNTL: conventional data
    - RAOB, SYNOP, ship, aircraft, Wind Profiler, Doppler Radar, GPS ground, Atmospheric Motion Vector from MTSAT-2
  - TEST: CNTL + all-sky TB of AHI

- **AHI all-sky TB**
  - Super-ob (6x6 pixels)
  - Band 9 (6.9μm), Thinning 150km
  - Cloud dependent obs error (0.4~6.3K)
  - 3 QC, over sea
  - No bias correction (future work!)
Single Obs Experiment (1/2)

- OB=231.712, FG=248.018 at 142E, 24N ← FG underestimates cloud
- AN(w/o AHI)=247.155, AN(wAHI)=240.091
- Rad assimilation increases humidity and snow at 7~9 km around obs
  - JMA-NHM produces more snow than other frozen hydrometeors
Single Obs Experiment (2/2)

- OB=249.288, FG=243.820 at 138E,26N ↪ FG overestimate cloud
- AN(w/o AHI)=243.860, AN(w/AHI)=251.116
- Rad assimilation reduces humidity and snow

FG, FG & AN difference along the cross-section at 24 NC
Ratio of FG RMSE against AH1 rad

- $\text{RMSE}_{\text{TEST}}/\text{RMSE}_{\text{CNTL}} < 1.0$ : better fitting of FG
- $\Rightarrow$ Improve FG fitting to rad obs at not only band 9 but other bands

Time sequence of SDtest/SDcntl
FG RMSE against RH and wind

- 7 - 10 September
- Improvement in V200 and RH500
- Degradation in RH850 and V in mid Troposphere

![Graph showing RMSE of FG against RH and V](image)

Statistics from 7 – 10 Sep 2016
Verification of Rain and Psea forecast

- 30-h forecast from 12 UTC 8 Sep, 2015
- rain[ (mm/3h), Psea (hPa)]
- TEST (AHI with cloud-dep obs err) better predicts rainband
- But the result is not robust
5. Summary and plans

- Models (JMA-NHM and/or RTTOV) significantly underestimate low BT, resulting in negative OB-FG bias.

- Develop 3 QCs to alleviate the discrepancy btw model and obs
  - Inhomogeneity QC, low BT QC, and cloud-dependent gross error QC

- Estimate obs error and its spatial/spectral correlation
  - Determine thinning distance and cloud-dependent obs error
  - Cloudy obs error (variance and correlation) is larger than clear-sky one

- Preliminary assimilation experiments
  - Assimilate rad at only band (at the moment)
  - Agreement of FG to obs is better for rad at IR bands, but mixed for RAOB and aircraft.
  - Better precipitation forecast can be found, but the result is not robust at the moment

- Plans
  - Develop bias correction
  - Redesign assimilation setup: longer period, cycle period, resolution,
  - Compare impacts of clear-sky radiance assimilation
  - Apply for the operational global data assimilation system (4D-Var)
OB and FG distribution

OB

FG

Observation/Background[K]

2.5kmOB  5kmOB  20kmOB  2.5kmOV  5kmOV  5kmPC  20kmPC  5kmCRTM

O-B.SD= 15.00  14.97  16.03
30-h forecast from 12 UTC 8 Sep, 2015

- **Obs, Analysis**
- **CNTL**
- **TEST (+AHI)**
- **TEST2 (+AHI, but fixed ober)**

**Variables**:
- Rain (mm/3h) & Psea (hPa)
- EPT (K) & Wind at 850hPa
- Rh (%) & Wind at 500 Pa