All-sky infrared radiance assimilation of Himawari-8 in the global data assimilation system at JMA

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Content
1. Background and objective
2. Development of ASR assimilation
3. Data assimilation experiments
4. Additional impact studies
5. Summary and plans

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1. Background

IR radiance assimilation is significantly beneficial for NWP
- Mostly limited to clear-sky radiances (CSR)

IR all-sky radiance (ASR) assimilation will be more beneficial because
- Increasing obs coverage (homogeneous spatial and temporal distribution)
- Reducing sampling bias (e.g. dry bias)
- Exploiting cloud and unique obs info (e.g. vertically resolved temperature at cloud top)

Challenges of ASR assimilation (compared with CSR assimilation)
- Poorer representation in radiative transfer model (RTM) and forecast model
- Stronger situation-dependency of obs statistics
- Higher non-Gaussianity and non-linearity

Encouraging results in many recent studies
- Zhang et al. (2016, GRL), Honda et al.(2018 MWR; 2018 MWR, JGR ), Minamide & Zhang (2017 MWR; 2018 MWR), Okamoto et al. 2019, QJRMS), Sawada et al. (2019, JGR)
- However, few studies in global DA system
1. Objective

- Improve analysis & forecast by assimilating IR ASR in JMA’s **global** system

1. Examine the reproducibility of ASR simulations from JMA global model
   - Okamoto et al. 2021 QJRMS

2. Develop ASR assimilation processings
   - Handle the challenges by developing **Quality Control (QC), Bias Correction (BC), obs error model,**

3. Assess impacts of ASR assimilation relative to CSR assimilation

- Start with **Himawari-8** (and will expand to other Geo/Leo)
2. Development of ASR assimilation
2-1. Quality Control (QC)

QC removes scenes poorly simulated:

- 1. low observed BT (BT13<230K),
- 2. high inhomogeneity (standard deviation BT13>5K),
- 3. thick ice,
- 4. large land sensitivity,
- 5. large CA (CA-QC),
- 6. large O-B,
- 7. large cloud Jacobian

⇒ O-B becomes more symmetric (and Gaussian) after QC

Cloud effect parameter:
\[ CA = \frac{|B - B_{clr}| + |O - B_{clr}|}{2}, \]
where \( B_{clr} \) is clear-sky first-guess (Okamoto et al. 2014, QJRMS)

Ob vs O-B

Num of samples rejected by each QC
2. Development of ASR assimilation

2-2. Bias Correction (BC)

- **BC**: Apply variational BC (VarBC) to mainly correct the negative O-B
  - Add CA and CA^2 to CSR predictors
  - To avoid excessive correction, CA-QC excludes samples that could be substantially affected by model bias

- Remaining bias can be negligible because of large obs error assigned
2. Development of ASR assimilation

2-3. Obs error covariance model

- O-B variability can be predicted with a simple function of CA
- Obs error standard deviation (SD) is modeled with a linear stepwise function of CA
  - Geer & Bauer (2011, QJRMS); Okamoto et al. (2014, QJRMS)
- Evident inter-band error correlation, increasing with CA
  - Account for cloud-dependent obs error correlation by selecting one, according to CA, from 3 correlation matrices precalculated

O-B SD and obs error SD model at band10

Obs Error SD model

Obs error correlation

0<CA<0.5

0.5<CA<1.5

CA>1.5
3. Data assimilation experiment

Assimilation system
- Operational global DA system of JMA (as of Dec. 2019)
- Hybrid-4DVar
  - 4DVar + LETKF, TL959L100 (20km grid), MW ASR assimilation

Obs Configuration
- CNTL: Same as the operational configuration (Himawari-8/CSR)
- TEST: Assimilate Himawari-8/ASR, instead of CSR
- NoHim: Exclude Himawari-8 radiances
  - All the WV bands (8,9,10), 220km thinning
  - CSR is assimilated for GOES and MSG in all the experiments
  - RTTOV13.0

Period
- Analysis: 10 Jul. – 17 Sep. 2020
- Forecast: 12UTC, 20 Jul. – 6 Sep. 2020,
3. DA experiment

3-1. Change in number of used data and humidity analysis

- ASR is more numerous and homogenous than CSR: 21,840 vs 7,802 (2.8 times)
- ASR increase mid- and upper tropospheric humidity more than CSR
  - More effectively reduce dry bias than CSR
3. DA experiment

3-2. Impact on O-B fit : TEST vs CNTL

- Global O-B fit difference
  - Negative means ASR better improve background than CSR
  - Significant improvement
    - Mid- and upper-tropospheric humidity
      - MHS, RAOB
    - Tropospheric Temperature IASI, GNSS-RO
  - Degradation in stratospheric temperature (and wind)
    - AMSU-A, RAOB
3. DA experiment
3.3. Impact on forecasts

- Forecast improvement rate (TEST vs CNTL)
  - Warmish (Positive) shade means ASR improves forecast over CSR

- Significant improvement in upper-tropospheric humidity and temperature up to 48-h especially in Tropics

- Significant degradation in stratospheric temperature and wind
4. Additional impact studies
cloud-dependency of BC

- Examine how to represent bias in VarBC
  - Ref: CSR BC = $c_1 \cdot \text{Oclr} + c_2 \cdot 1/\cos(\theta) + c_3$
  - TEST: $\text{BC} = \text{BC1} + c_4 \cdot \text{CA} + c_5 \cdot \text{CA}^2$
  - BC1: Equivalent to CSR: $\text{BC} = c_1 \cdot \text{Bclr} + c_2 \cdot 1/\cos(\theta) + c_3$
    - Coefficients calculated from samples with O-Bclr > 1K
    - $\rightarrow$ Significant degradation
  - BC2: Obs-based predictors (Otkin & Potthast 2019):
    $\text{BC} = c_1 \cdot \text{O} + c_2 \cdot \text{O}^2 + c_3 \cdot \text{O}^3 + c_4 \cdot 1/\cos(\theta) + c_5$
    - $\rightarrow$ Equivalent skills as TEST

Cloud-dep predictors are important in the presence of significant O-B bias
4. Summary and plans

- Developed IR all-sky radiance assimilation in global data assimilation system
  - Cloud-dependent QC, BC and obs error covariance model
- ASR assimilation, relative to CSR assimilation
  - Significantly increase observations assimilated by 2.8 times
  - Increase mid- and upper tropospheric humidity to better alleviate dry bias than CSR assimilation does
  - Improve short-range forecast (~48h) of Q, T and W in the mid- and upper troposphere, especially in Tropics
  - Degrades stratospheric T and W
- Sensitivity experiments
  - Cloud-dep BC predictors are essential in the presence of large (negative) O-B bias
  - Obs error correlation and cloud-dep SD are important, but cloud-dependency of correlation is not so much.

- Ongoing studies and Plans
  - Investigate the degradation in upper stratospheric T and W
  - Assess impacts of ASR from GOES and MSG
  - Extend the development to hyperspectral IR sounders