Global assimilation of all-sky radiance from infrared imagers and sounders

Kozo OKAMOTO
Toshiyuki ISHIBASHI, and Izumi OKABE

JMA/MRI

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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
- 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
  - Otkin (2010, 2012, JGR), 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, except Geer et al. (2019, AMT) for IASI

1. Objective

- Improve analysis & forecast by assimilating IR ASR in a global NWP system

- 1. Examine the reproducibility of ASR simulations from JMA global model
  - Okamoto et al. 2021, QJRMS
- 2. Develop ASR assimilation procedures
  - Okamoto et al. 2014,2019, 2023 QJRMS
- 3. Assess impacts of ASR assimilation of AHI and IASI
  - AHI: Himawari imager (Okamoto et al. 2023, QJRMS)
  - IASI: Metop hyperspectral sounder (Okamoto et al. accepted, QJRMS)
  - Focus on upper- and middle-tropospheric Water Vapor (WV) ch: (6.2~7.3μm)

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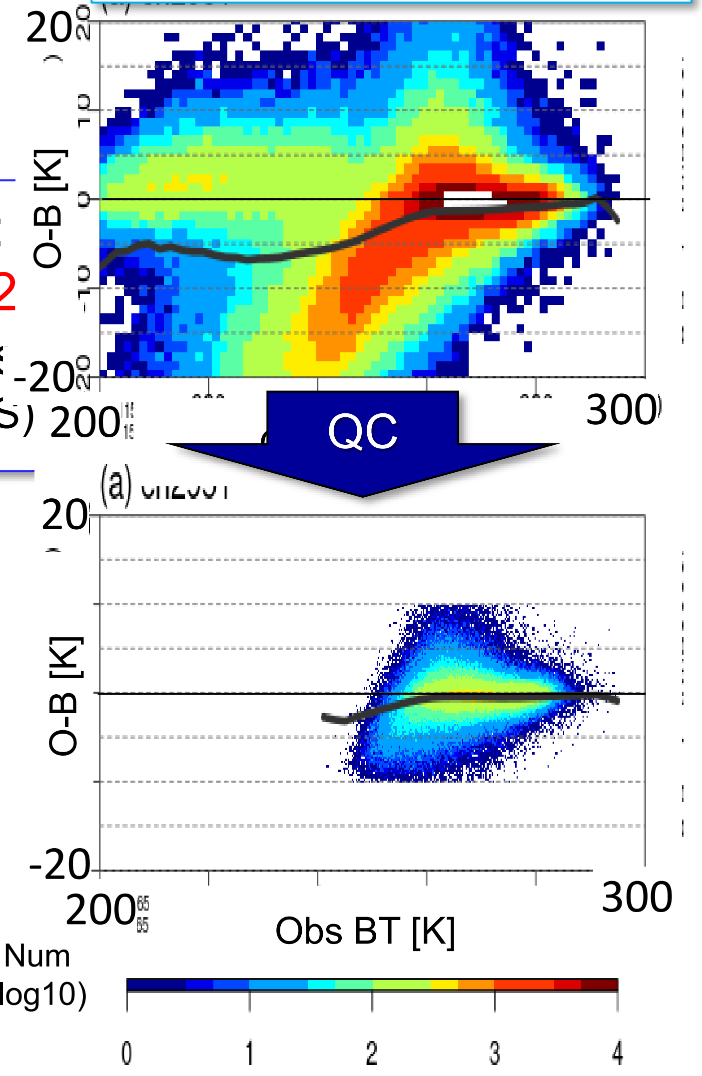
2 Assimilation procedures

2-1. Quality Control (QC)

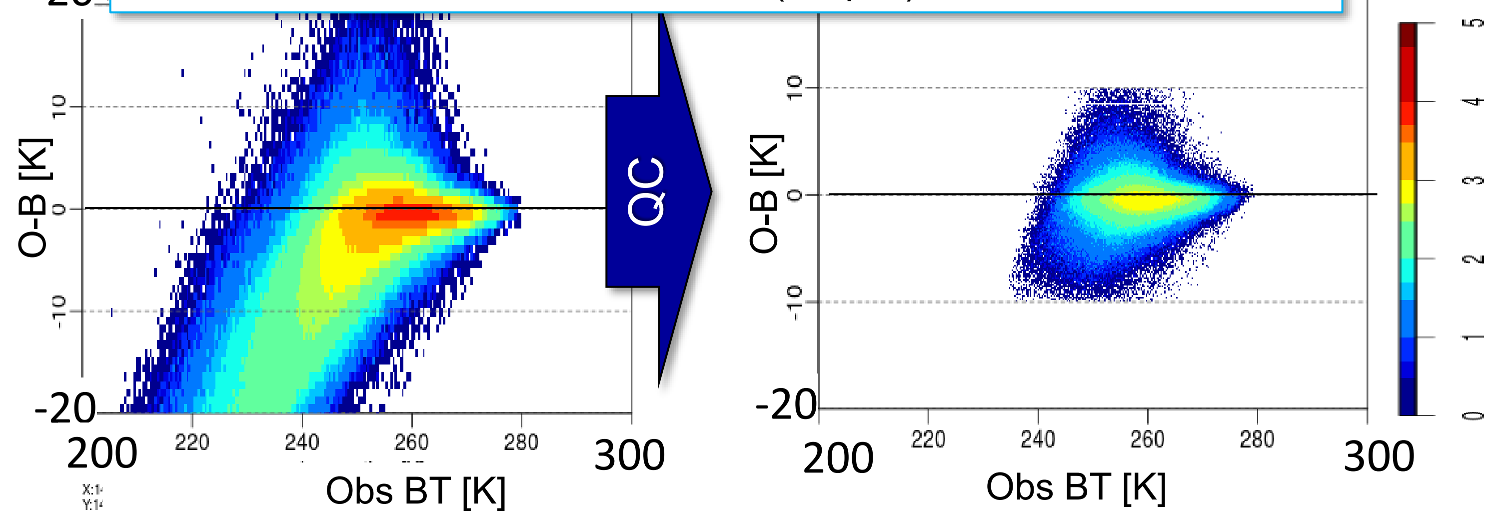
- Not all data are assimilated at the present time
- → Remove scenes poorly simulated where
  - low observed BT (BT13<230K), thick ice
  - high inhomogeneity (standard deviation of window ch >5K),
  - large cloud-affected, large O-B (CA>5K)
  - affected by land surf (large transmittance)
  - large FG departer (|O-B|>3*obs error)
  - over sea ice (only for IASI)

Cloud effect parameter:
CA=(|B-Bclr|+|O-Bclr|)/2
Bclr=clear-sky first-gues
(Okamoto et al. 2014, QJRMS)

IASI ch2951 (7.23μm)



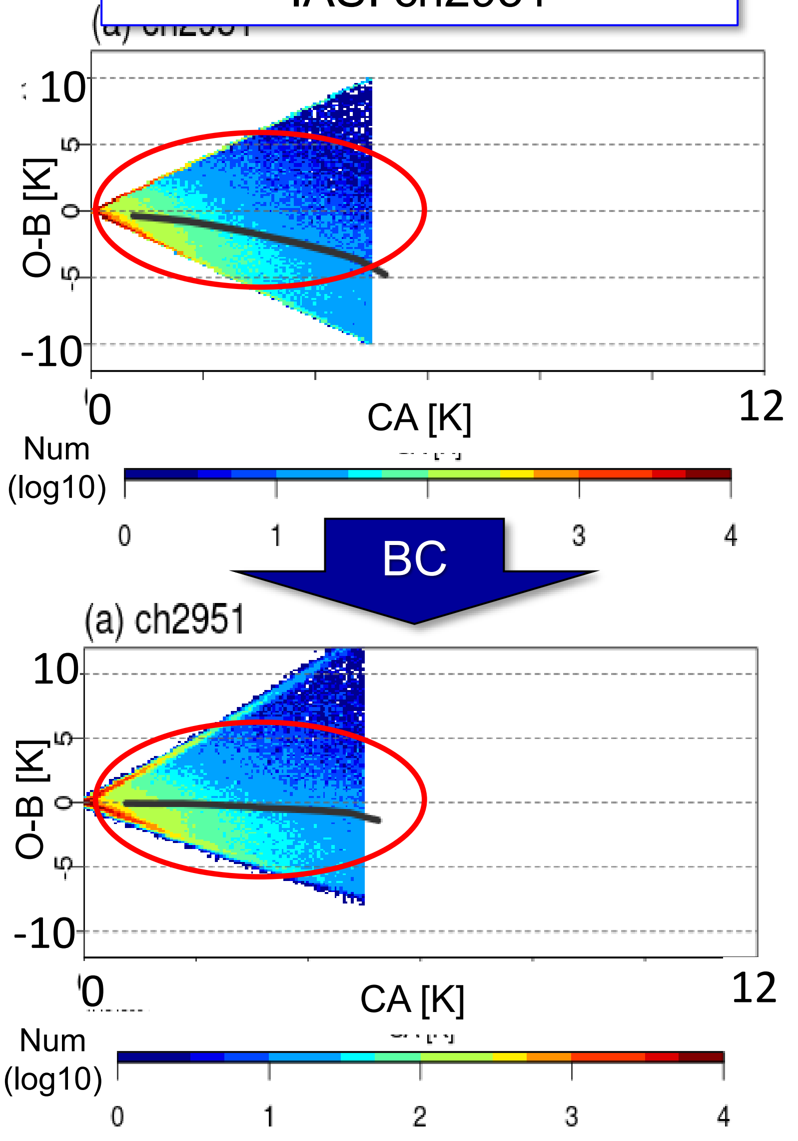
AHI band10 (7.2μm)



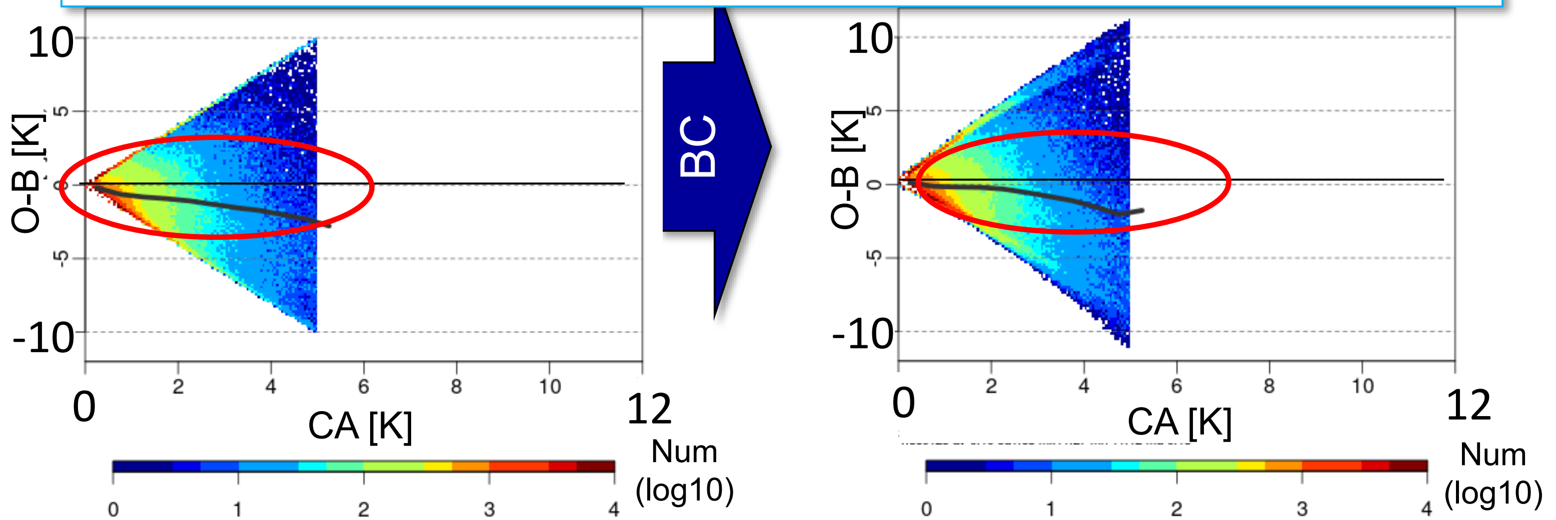
2-2. Bias Correction (BC)

- Apply VarBC to correct O-B bias
  - Add CA and CA^2 to CSR predictors
    - $AHI\_BC = c_1{*}Bclr + c_2{*}\ 1/\cos(\theta) + c_3 + c_4{*}CA + c_5{*}CA^2$
    - $IASI\_BC = c_1{*}dZ_{850} + c_2{*}\ dZ_{200} + c_3{*}\ dZ_{50} + c_4{*}\ dZ_{10} + c_5 + c_6{*}CA + c_7{*}CA^2$
- Need to avoid excessive correction due to the model bias
  - Exclude samples that could be substantially affected by model bias (~ large CA)

IASI ch2951

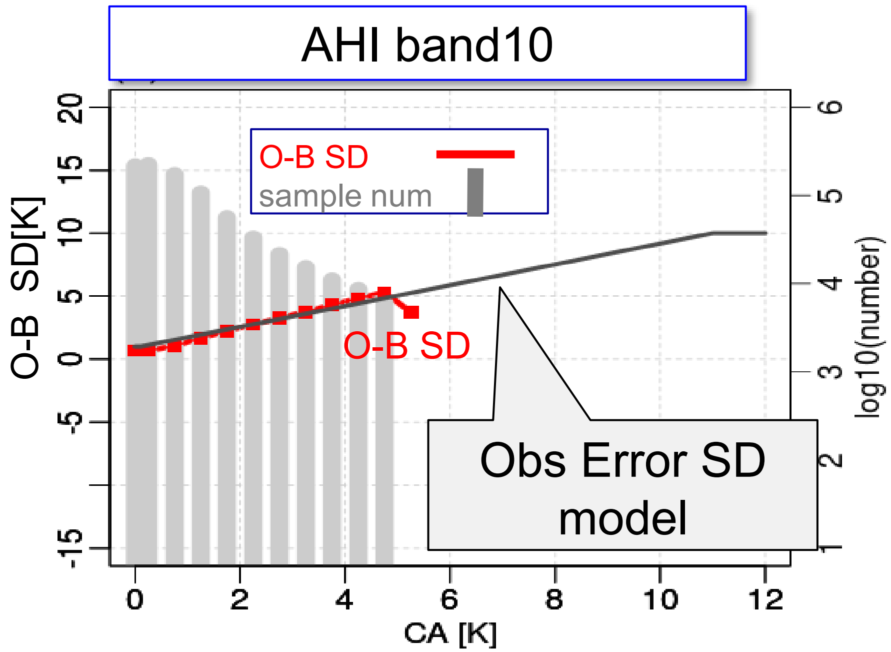


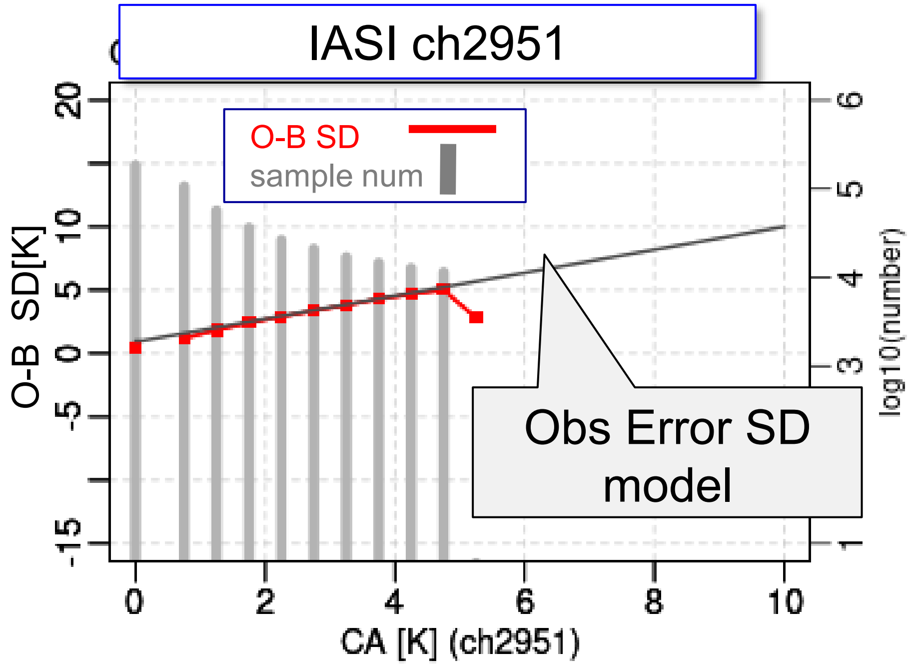
AHI Band10



2-3. Observation error covariance (1/2)

- Observation error covariance $R_{ij} = f^2 \sigma_i \sigma_j C_{ij}$
- f: inflation factor (=1.5)
- σi: observation error standard deviation (SD) of ch i
  - Estimated as a linear function of CA → cloud dependent
- Cij: Correlation between ch i and j



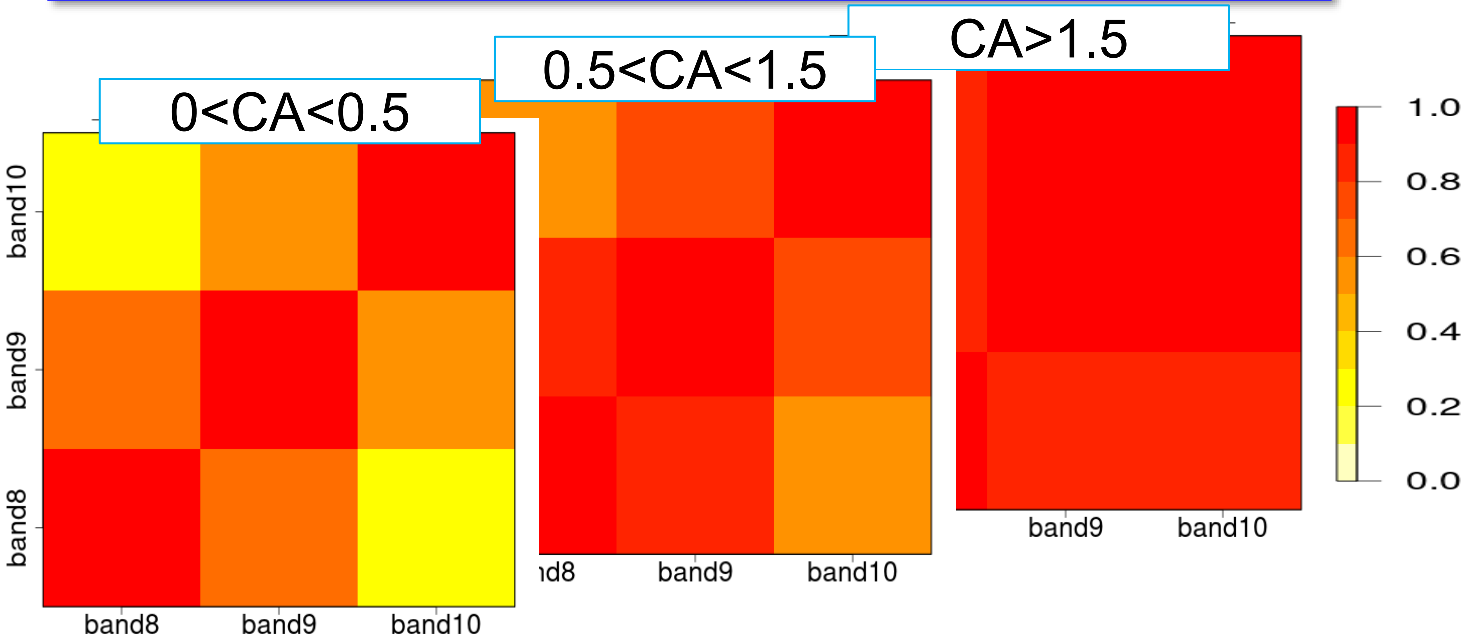


2-3. Observation error covariance (2/2)

- *Cij*: Correlation between ch i and j
  - Need to account for the correlation
  - Depend on cloud effect but cloud-dependent Cij did not show positive impacts (at the moment)

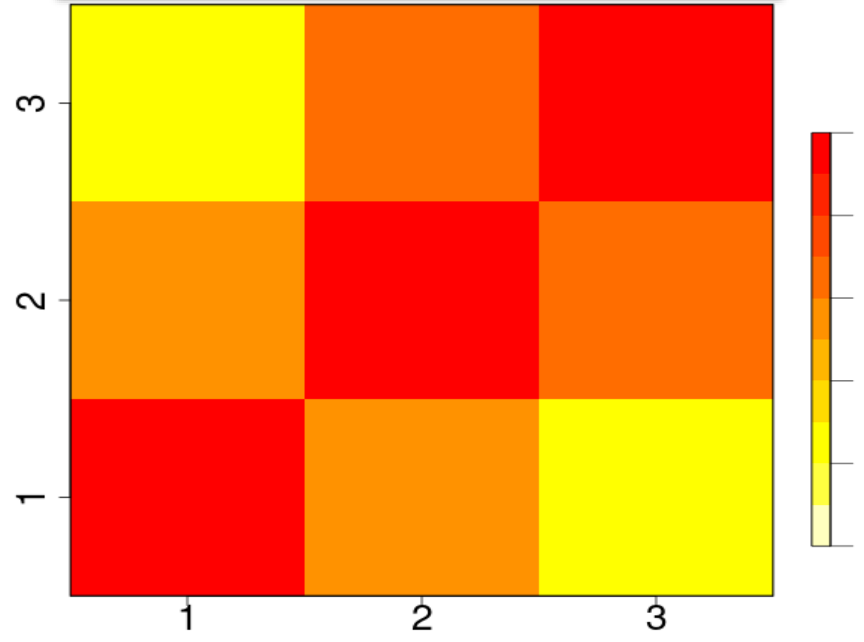
$$R_{ij} = f^2 \sigma_i \sigma_j C_{ij}$$

AHI *Cij*



SqrtDiag= 1.00 1.00 1.00

IASI *Cij*



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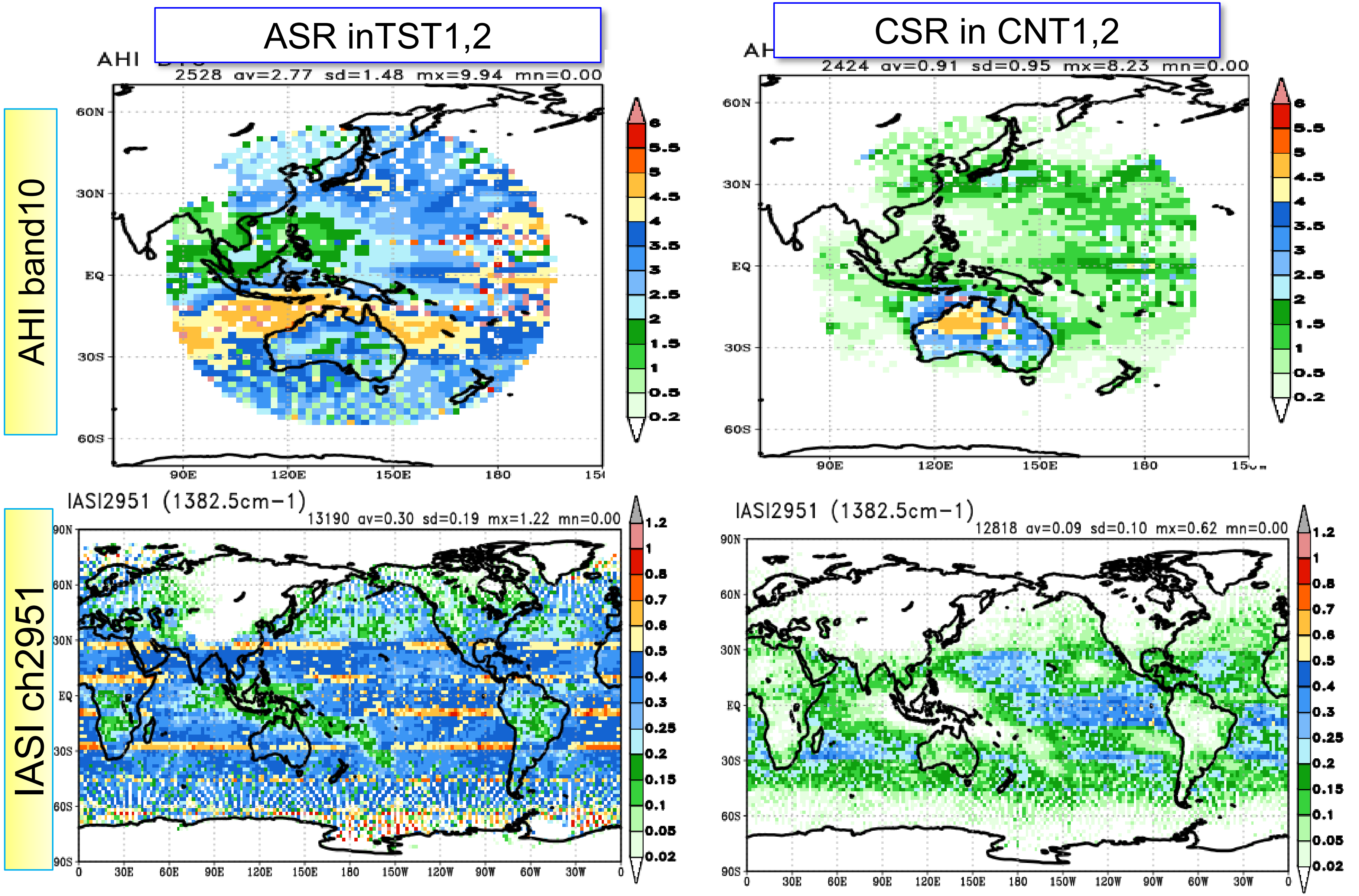
3. Data assimilation experiment

- Assimilation system
  - Operational global DA system of JMA (as of Dec. 2019) + RTTOV13.0
  - Hybrid-4DVar: 4DVar+LETKF
    - outer-loop:20km, inner-loop:55km, 100 layers
- 2 Experiments
  - AHI experiment: based on operational configuration
    - CNT1: 3 WVch CSR of AHI
    - TST1: 3 WVch ASR of AHI
  - IASI experiment: add WVch of IASI and CrIS
    - CNT2: 3 WVch CSR of IASI
    - TST2: 3 WVch ASR of IASI
- Period
  - Analysis: 10 Jul. – 17 Sep. 2020
  - Forecast: 12UTC, 20 Jul. – 6 Sep. 2020,

	AHI WVch	IASI WVch
CNT1	CSR	
TST1	ASR	
CNT2	CSR	CSR
TST2	CSR	ASR

Benefit of ASR over CSR

- Comparison of number of assimilated obs for ASR and CSR
  - Monthly average in 6-h analysis in 2x2 degree box
- Assimilated obs in ASR increases nearly threefold

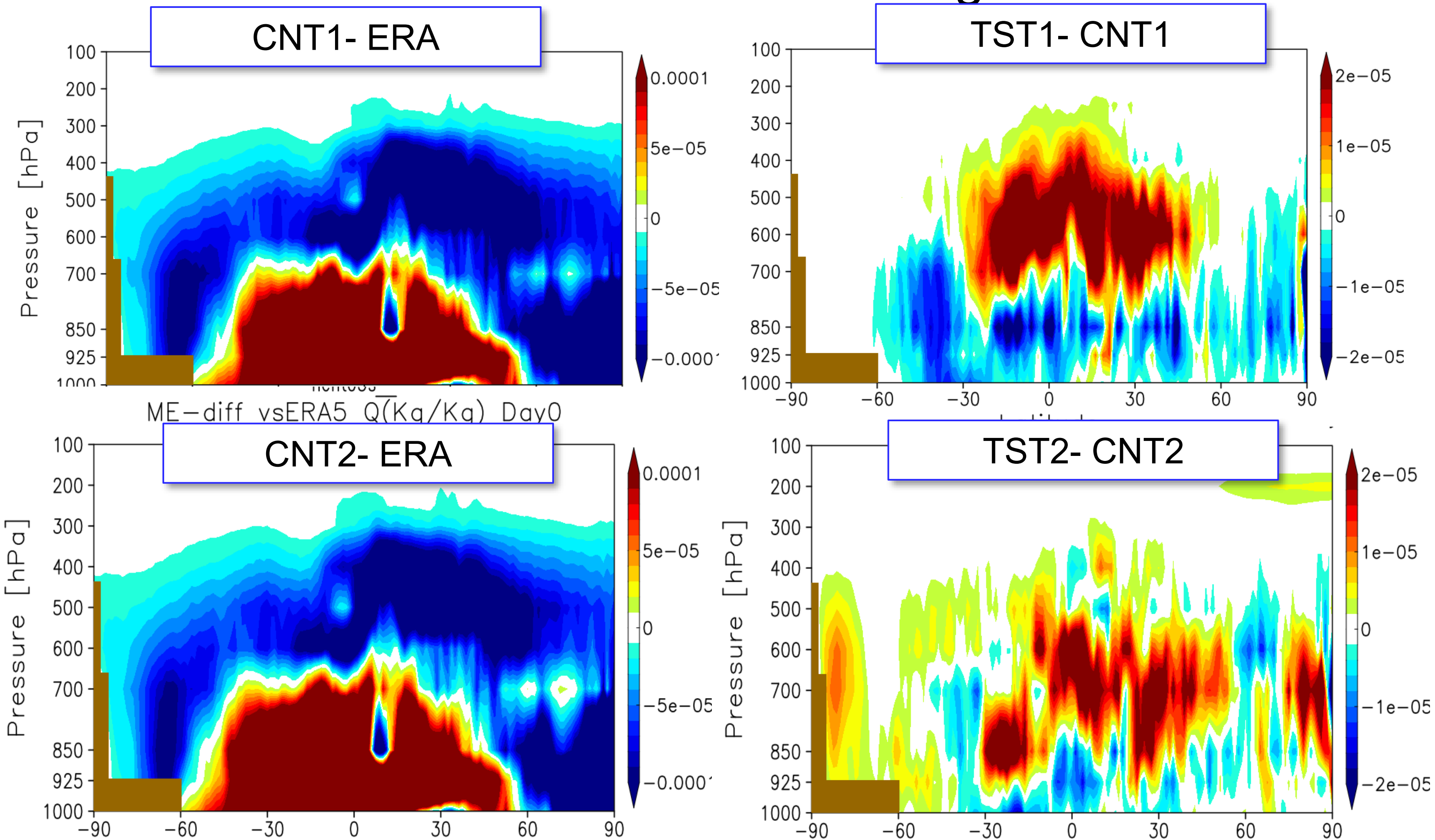


3-1. Change in humidity analysis

- ASR increase mid- and upper tropospheric humidity more than CSR
  - ➔ More effectively reduce dry bias than CSR
- The change is limited in low lat for AHI ASR but clear in high lat for IASI ASR

AHI
ASR vs CSR

IASI
ASR vs CSR

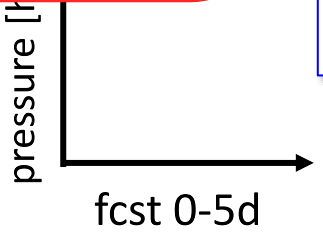


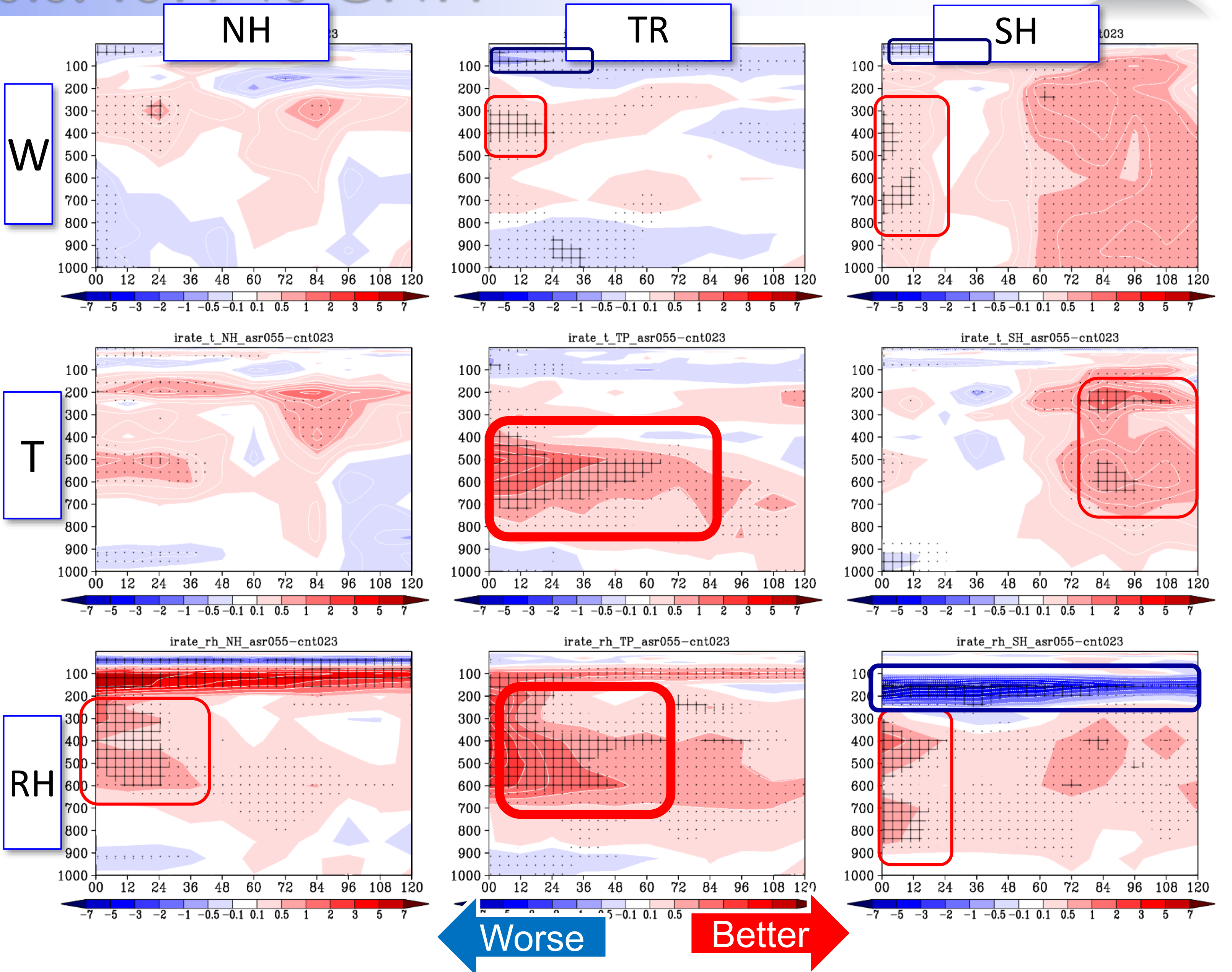
3-2. Impact on forecasts: TST1 vs CNT1

- Forecast improvement ratio for AHI ASR
- Warmish (Positive) shade means ASR improves forecast over CSR

TST1 > CNT1

ASR assimilation improves short-range forecast (~48h) of Q, T and W in the mid- and upper troposphere, especially in Tropics

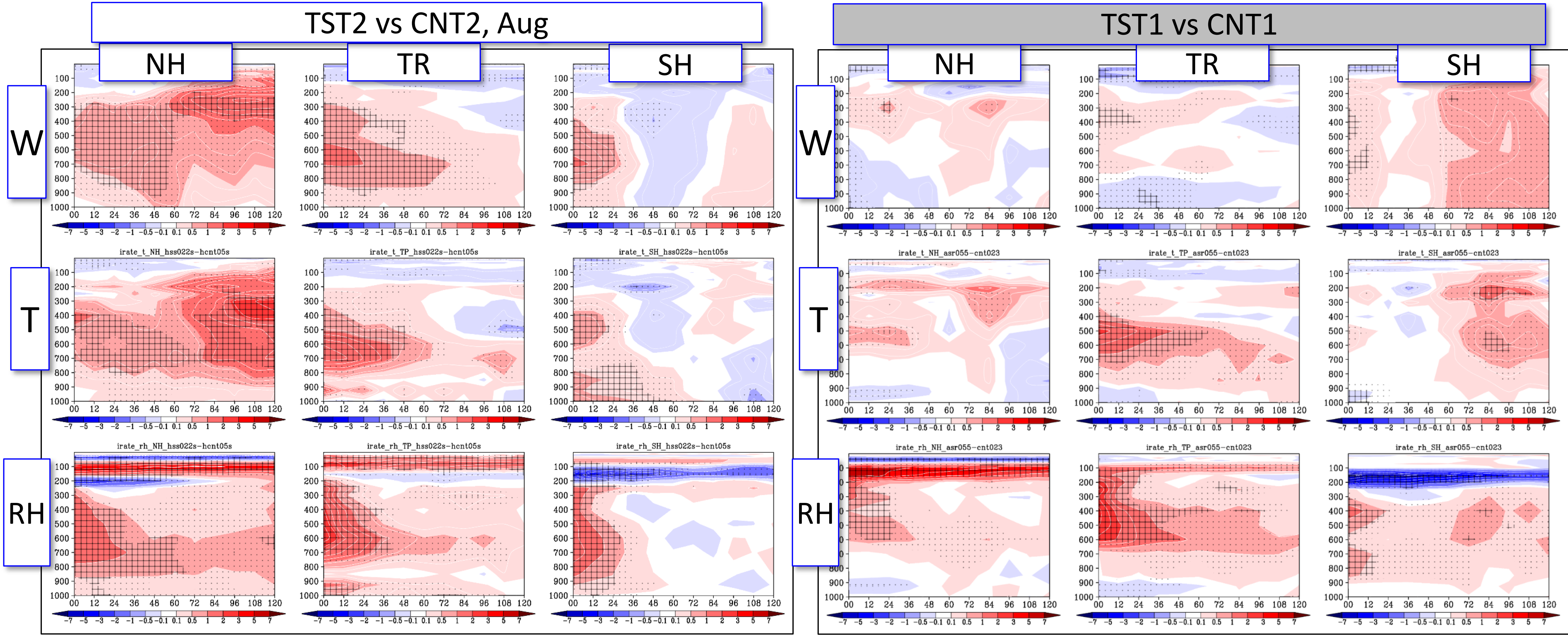




3. DA experiment

3-4. IASI ASR Impact: TST2 vs CNT2

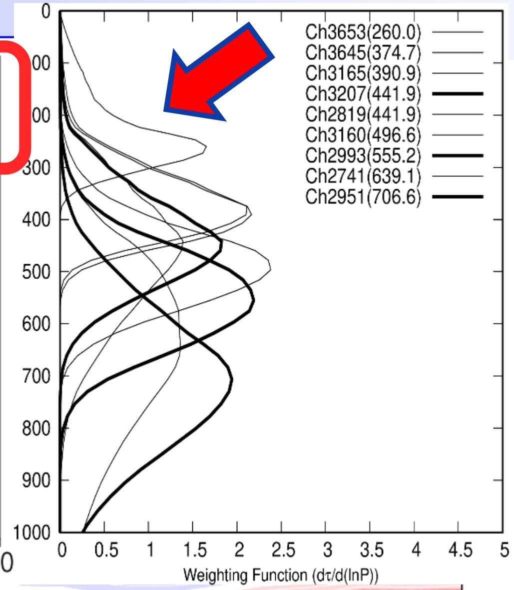
TST2 > CNT2
IASI ASR shows greater positive impacts, especially for N.H. and wind field, than AHI ASR

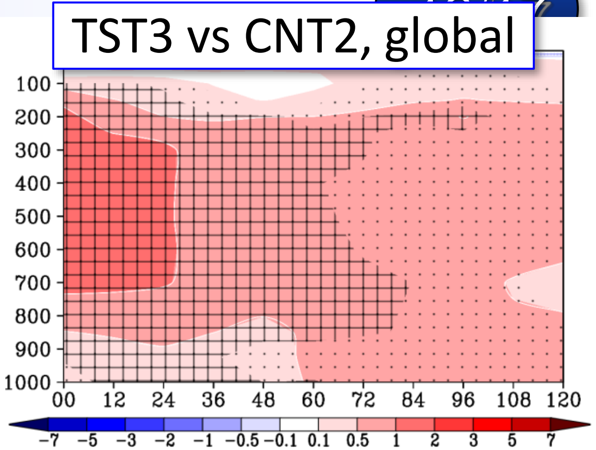


3. DA experiment

3-5. Increasi

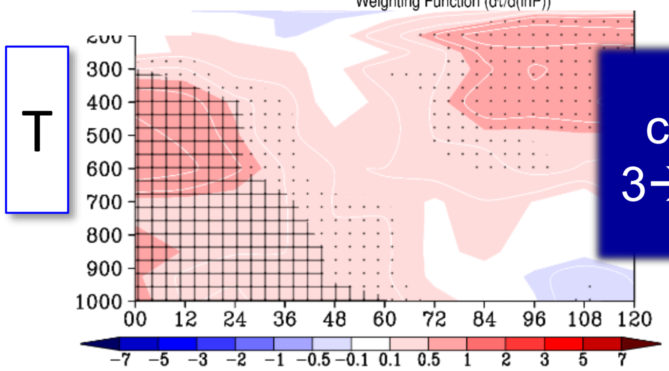
- TST3: 9 WVc
- TST2: 3 WVc



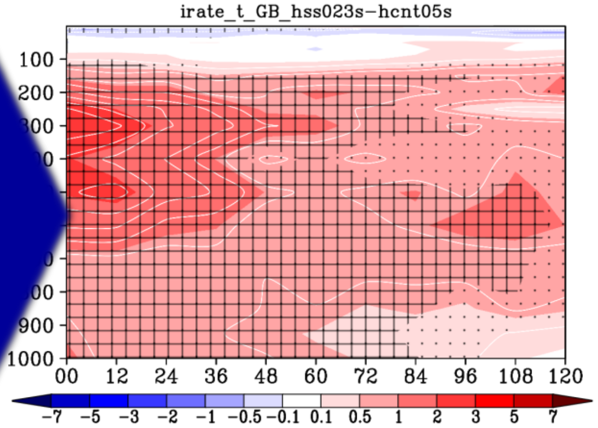


TST3 > TST2 > CNT2

- Increasing ch enhance positive improvement
- The negative impacts on RH200 turned positive

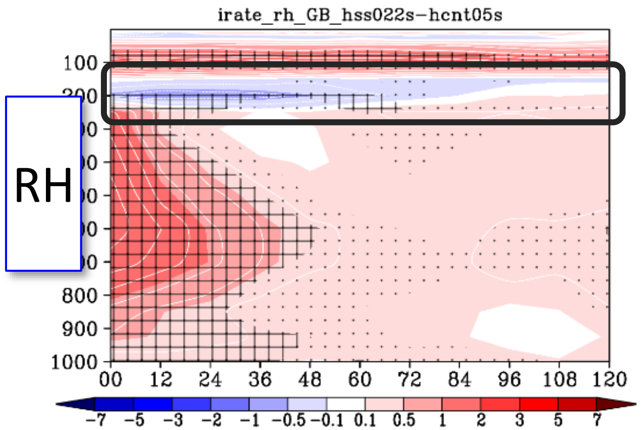


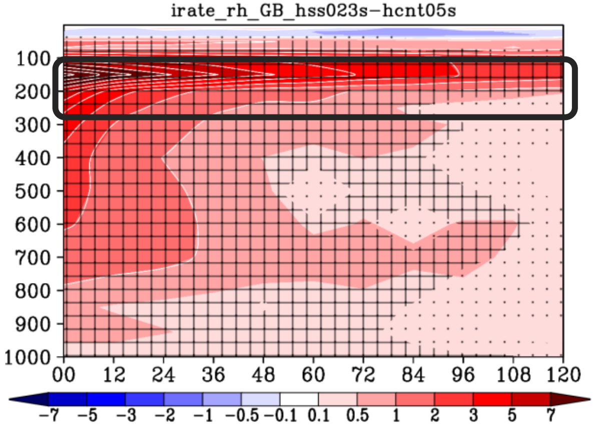
ch 3→9



← Additional ch sensitive to upper tropospheric humidity help reduce complex model bias

	AHI WVch	IASI WVch
CNT2	CSR	CSR 3ch
TST2	CSR	ASR 3ch
TST3	CSR	ASR 9ch





4. Summary

- Developed all-sky IR radiance assimilation for AHI and IASI WV ch in a global data assimilation system
  - Cloud-dependent QC, BC and obs error covariance model
- All-sky has significantly positive impacts over clear-sky assimilation
  - Increase obs number by almost 3 times
  - AHI all-sky improve Q and T in the mid- and upper troposphere
  - IASI all-sky further improve Q and T globally, as well as wind.
    - Increasing channels from 3 WV ch to 9 WV ch enhance the positive improvement
- Ongoing and future studies
  - Extend to other geo satellites (MSG and GOES)
  - Extend to other ch (e.g. T-sensitive ch)
  - Extend to other hyperspectral sounders, including geo-sounder (GIIRS, IRS, GHMS, OSE or OSSE)

AHI allsky: Okamoto et al (2023, QJRMS)
IASI allsky: Okamoto et al. (QJRMS, accepted)

All Geo ASR Impact: Himawari-8, GOES-16 and MSG-1,-4

Greater impacts from all Geo than AHI only

- Add QC and obs.error inflation to handle inconsistency btw obs and model especially in the Sahara and low-stratocumulus regions
- Add VarBC predictors of Sun zenith angle to mitigate diurnal change in model bias

Okabe et al. under preparation