9.04

All-sky assimilation of infrared radiances at water vapor bands of Himawari-8 in the global data assimilation system at JMA

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Content

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

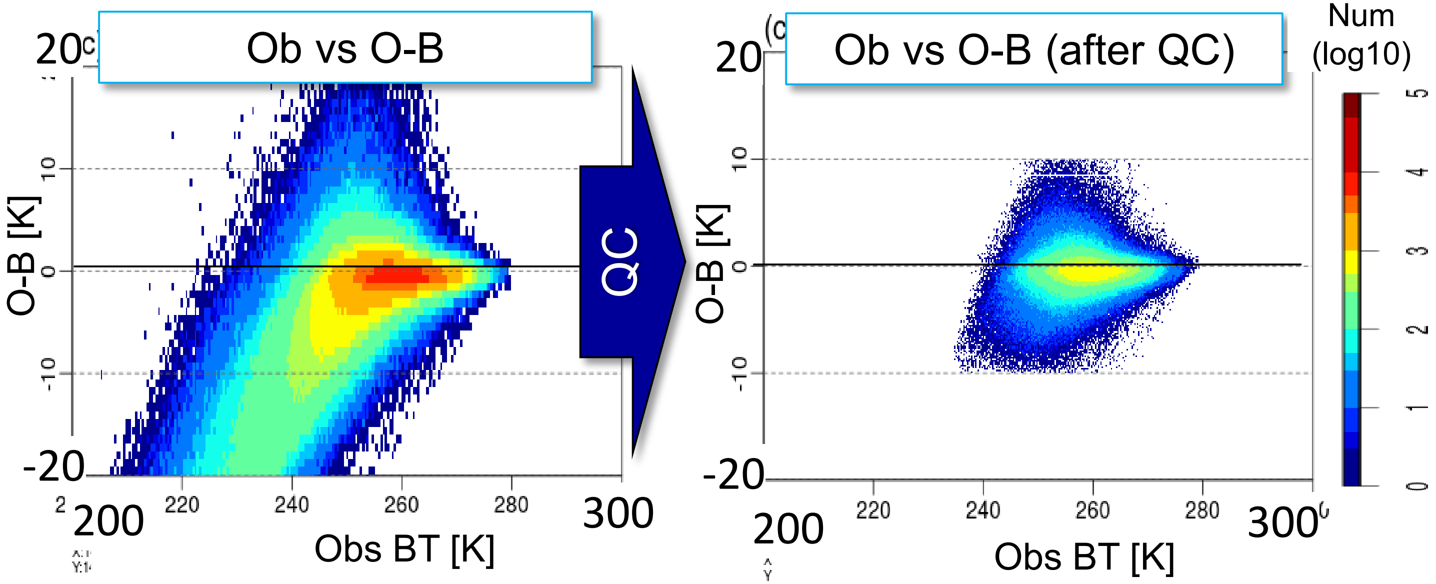
- Improve analysis & forecast by assimilating IR ASR in JMA's global system
  - Start with Himawari-8 (and will expand to other IR sensors on Geo/Leo satellites)

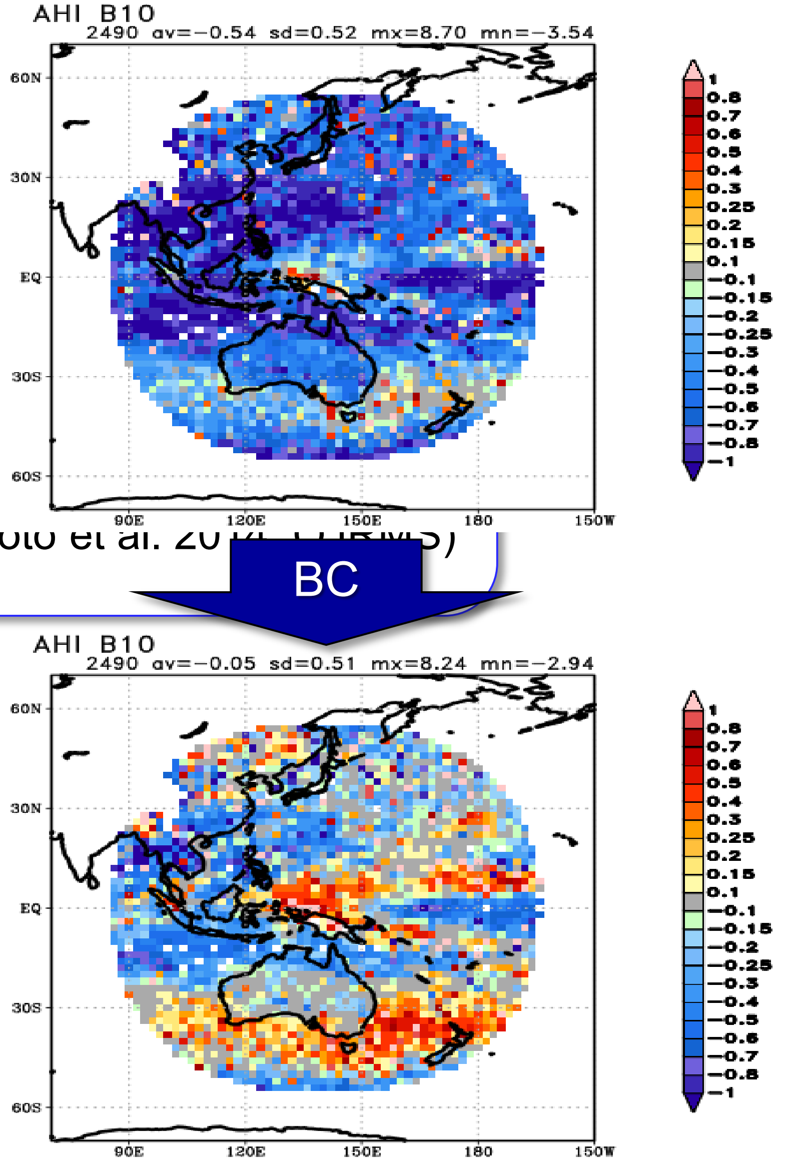
- 1. Examine the reproducibility of ASR simulations from JMA global model
  - Okamoto et al. 2021 QJRMS
- 2. Develop ASR assimilation processings
  - Cloud-dependent Quality Control (QC), Bias Correction (BC), obs error model,,,
- 3. Assess impacts of ASR assimilation relative to CSR assimilation

2-1. Quality Control (QC) and Bias Correction (BC)

- QC removes scenes poorly simulated:
  - low observed BT (BT13<230K), thick ice, large land sensitivity
  - high inhomogeneity (standard deviation BT13>5K),
  - large cloud-affected (CA-QC), large O-B, inconsistent btw inner/ou
- → O-B becomes more symmetric (and Gaussian) safter QC but negative bias remains
- → Bias correction (VarBC)

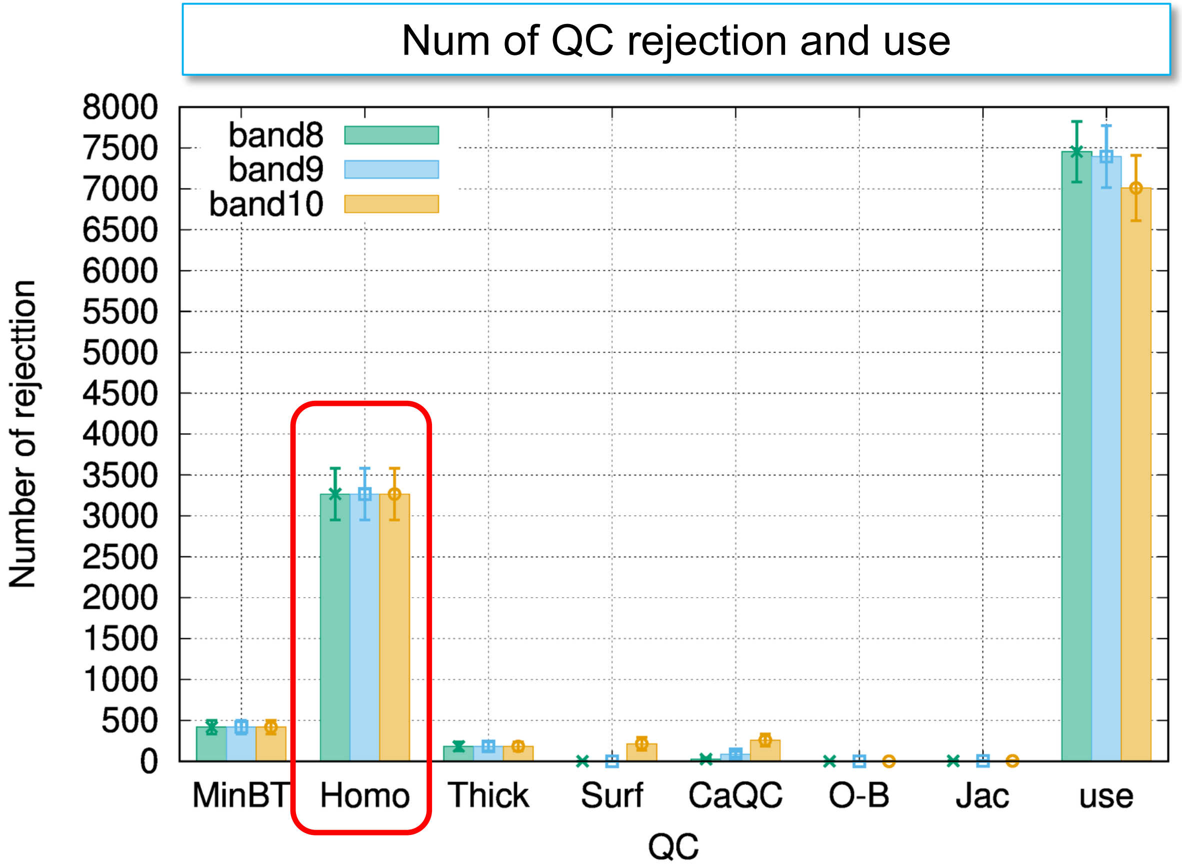
Clouc
CA=(
Bclr=
(Okamoto et al. 20

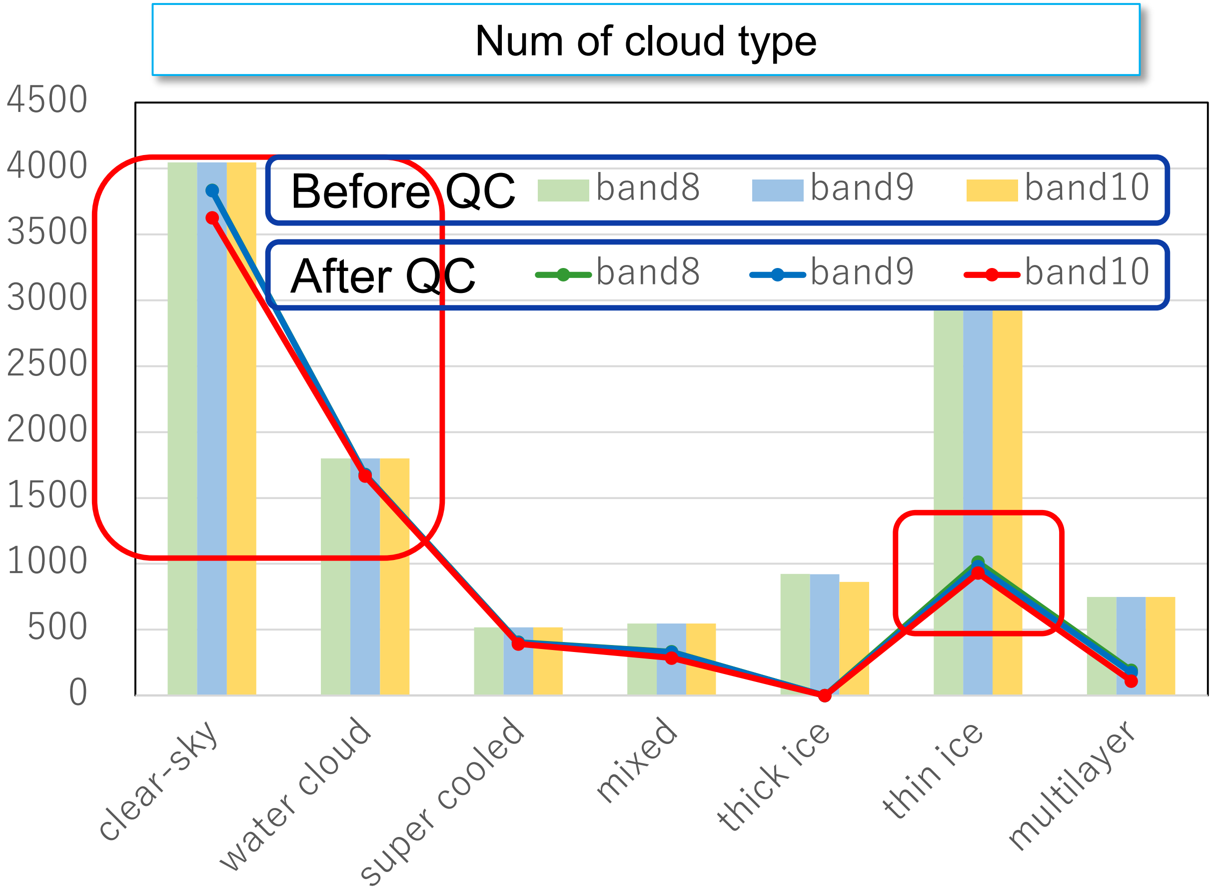




2. Development of ASR assimilation
QC

- Homogeneity check plays major role
- ASR adds obs in water clouds and thin ice clouds to clear-sky obs

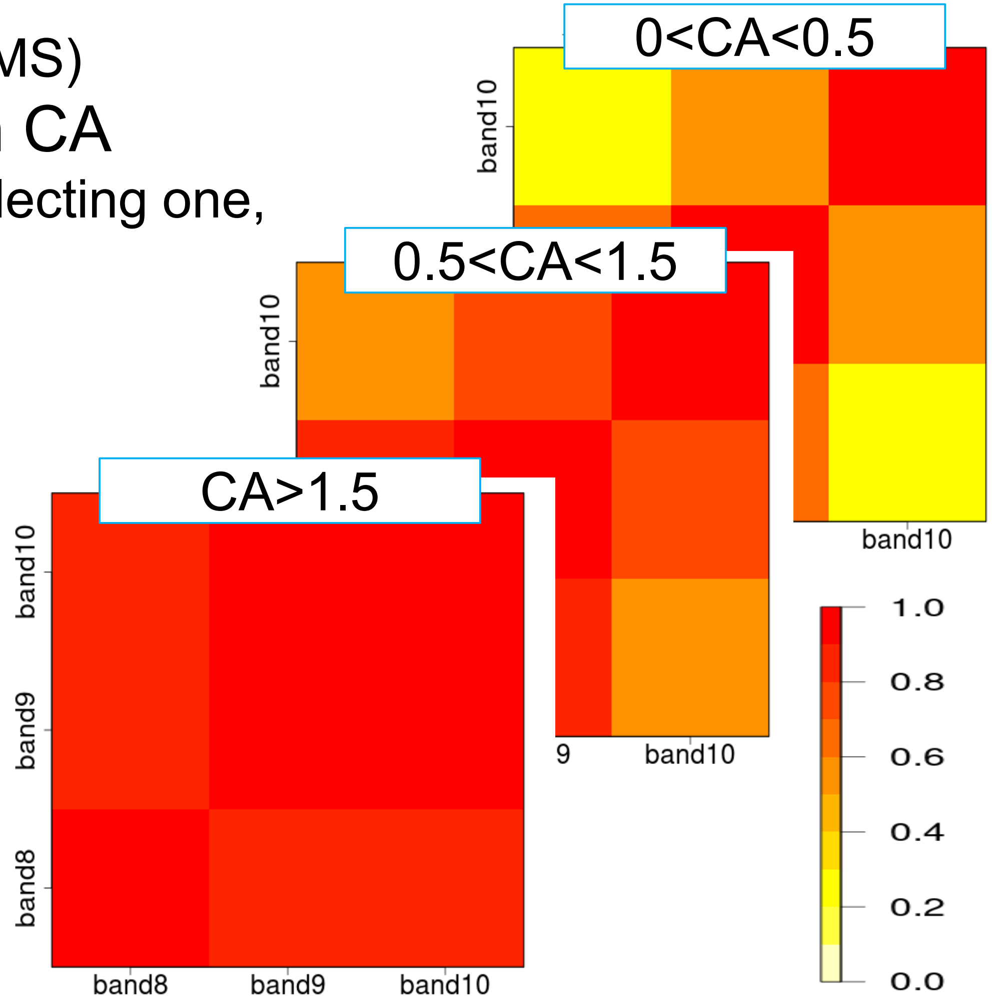




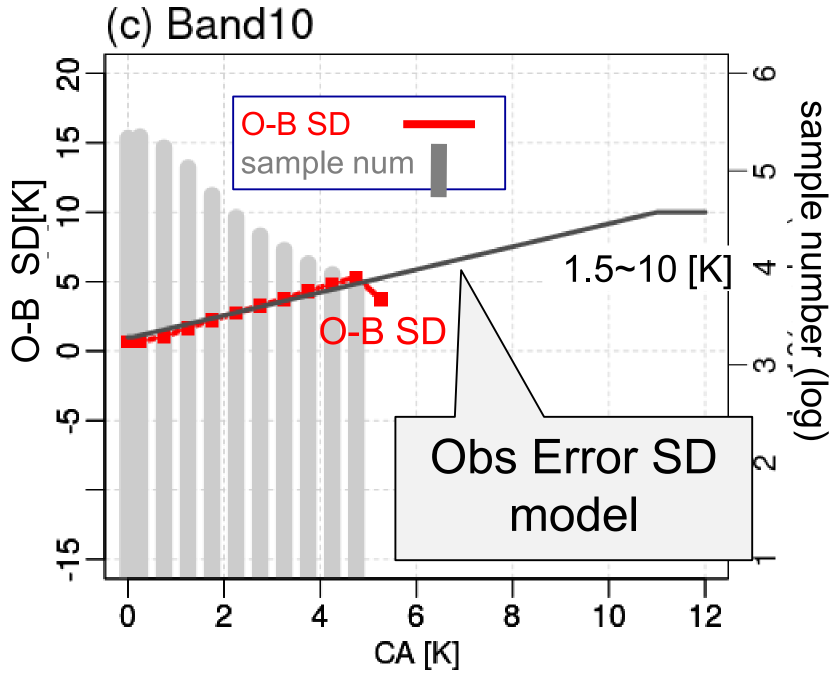
2-2. Obs error covariance model

- 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

obs error orrelation



O-B SD and obs error SD model at band10



Content

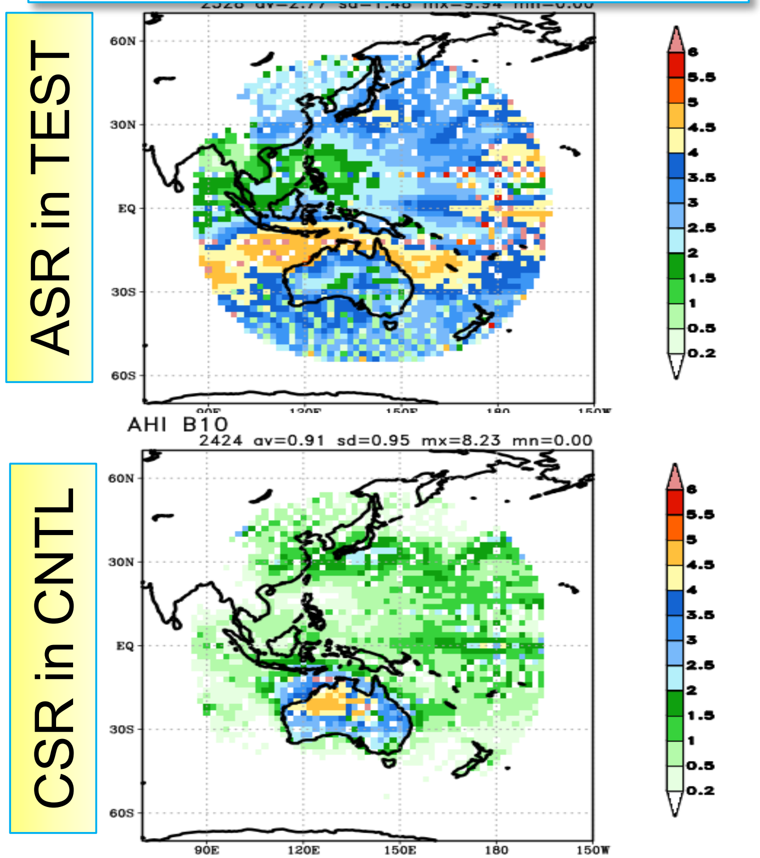
3. Data assimilation experiment

- Assimilation system
  - Operational global DA system of JMA (as of Dec. 2019)
  - Hybrid-4DVar
    - 4DVar + LETKF, TL959L100 (20km grid), MW ASR assimilation
      - RTTOV13.0
- Obs Configuration
  - CNTL: Same as the operational configuration (Himawari-8/CSR)
  - TEST: Assimilate Himawari-8/ASR, instead of CSR
    - All the WV bands (8,9,10), 220km thinning
    - CSR is assimilated for GOES and MSG in all the experiments
- Period
  - Analysis: 10 Jul. – 17 Sep. 2020
  - Forecast: 12UTC, 20 Jul. – 6 Sep. 2020,

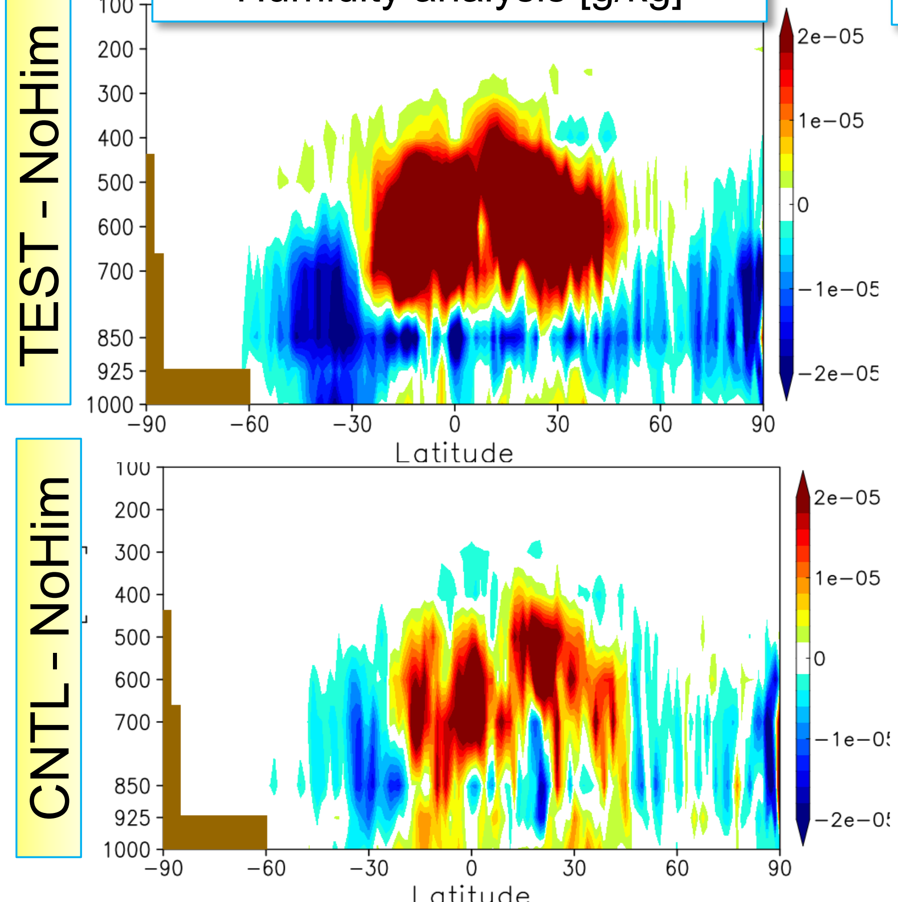
3-1. Change in number of used data and humidity analysis

- 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

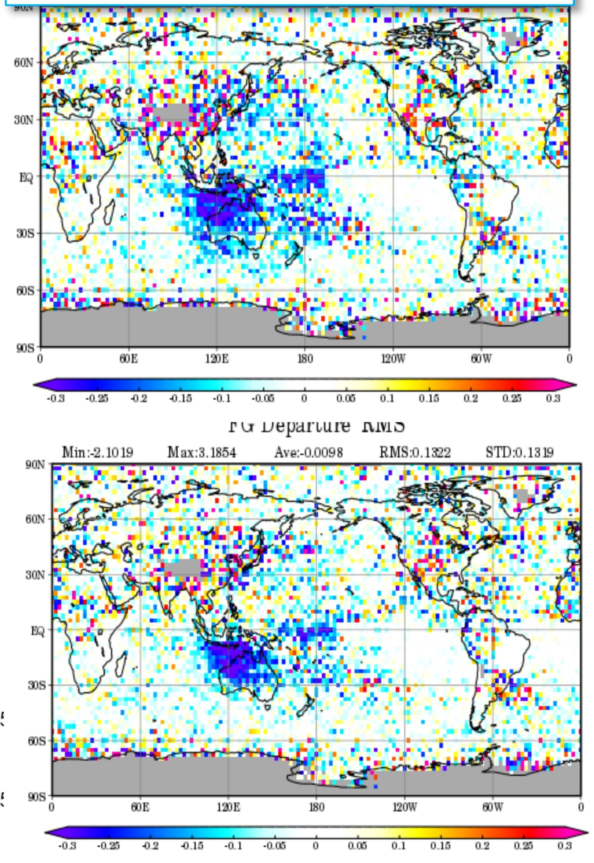
Averaged num of assimilated data



Humidity analysis [g/kg]

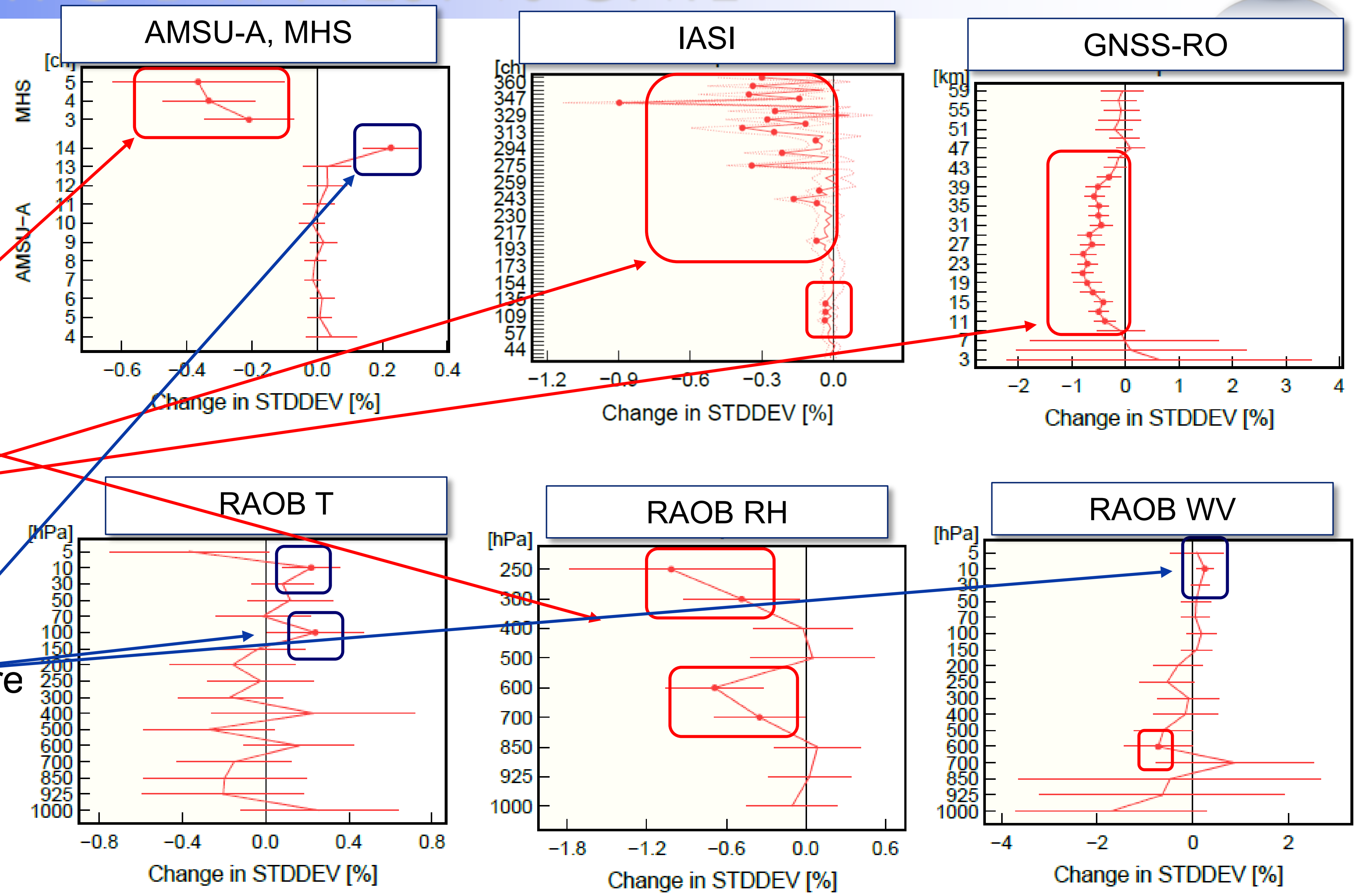


O-B SD in MHS ch4 [K]



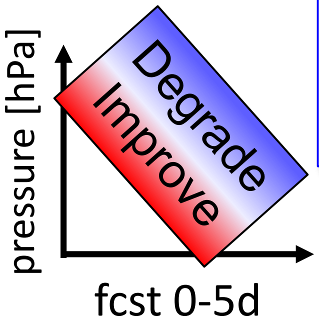
3-2. Impact on O-B fit : TEST vs CNTL

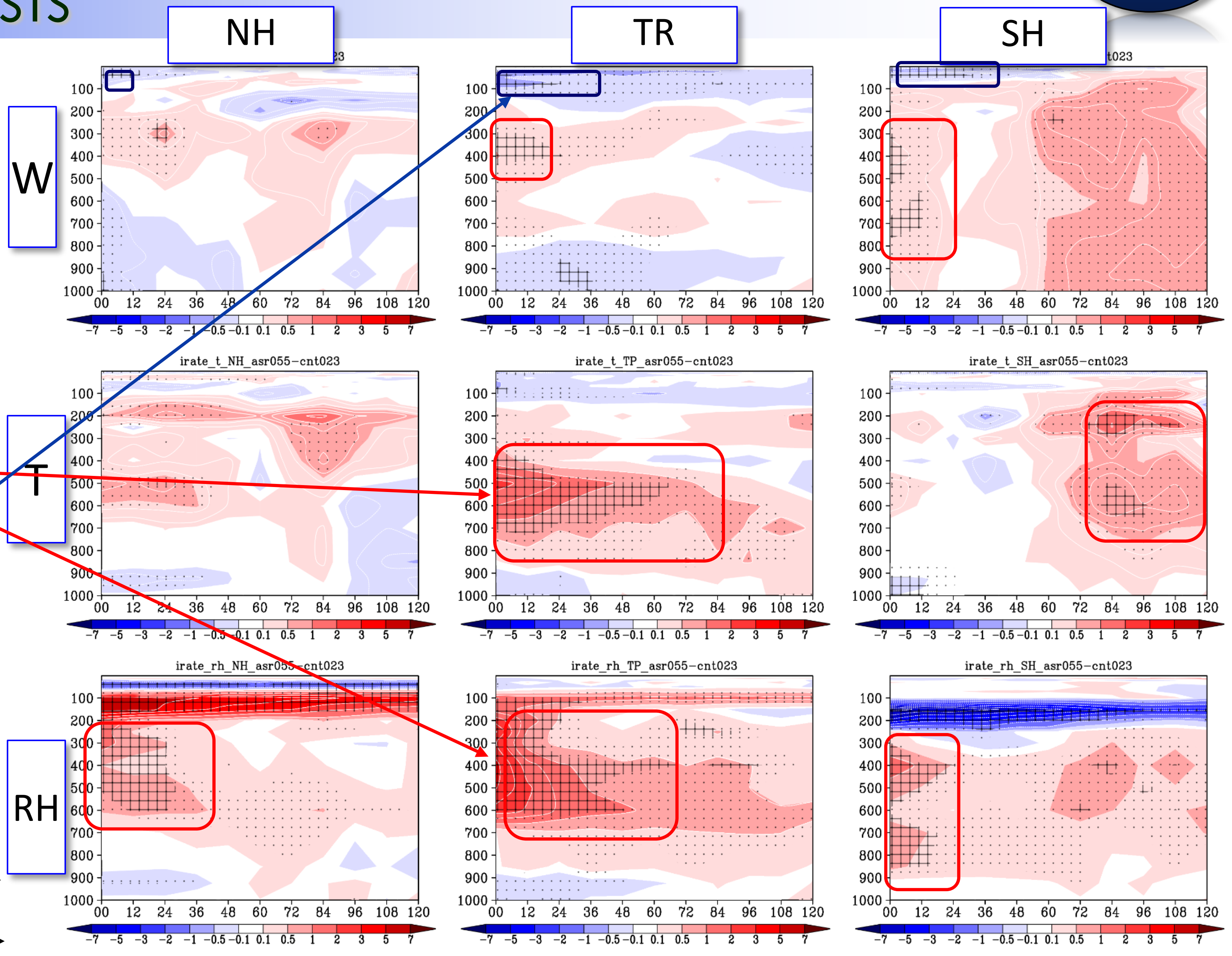
- Global O-B fit difference
  - Negative means ASR better improve background than CSR
- Significant improvement
  - Mid- and upper-tropospheric humidity
    - MHS, RAOB
  - Tropospheric Temperature
    - IASI, GNSS-RO
- Degradation in upper stratospheric temperature and wind
  - AMSU-A, RAOB



3-3. Impact on forecasts

- Forecast improvement rate (TEST vs CNTL)
  - Warmish (Positive) shade means ASR improves forecast over CSR
- Improvement in mid- and upper-tropospheric humidity and temperature up to 48-h especially in Tropics
- Degradation in stratospheric wind





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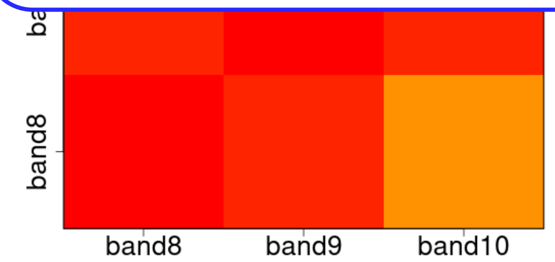
4. Additional impact studies
cloud-dependency of obs error covariance

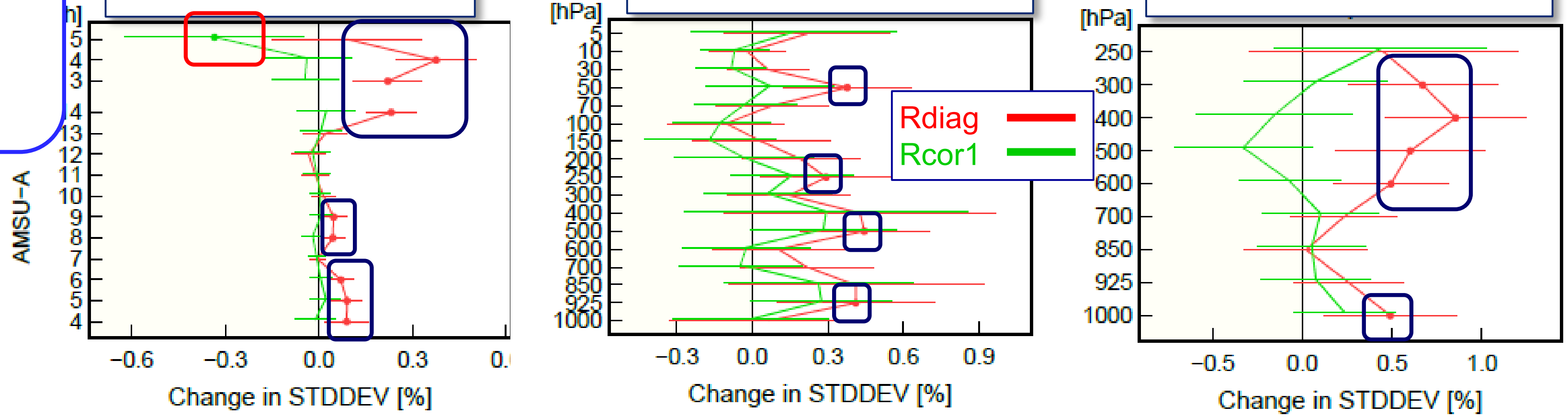
- Compare TEST (cloud-dep obs error covariance (both SD and correlation)) with
- Rdiag: Cloud-dep. SD but no correlation (diagonal R)
  - Significant degradation
  - → Inter-band correlation is critical when using multiple WV bands
- Rcor1: Cloud-dep. SD but fixed correlation
  - Not significant difference or slightly better
  - → Cloud-dep. of error correlation is not as critical as that of SD

	SD	corr
TEST	cld.dep	cld.dep
Rdiag	cld.dep	no corr
Rcor1	cld.dep	No cld.dep (fixed)

Inter-band correlation is critical, but its cloud dep. is not as important as SD



Rdiag vs TEST, Rcor1 vs TEST



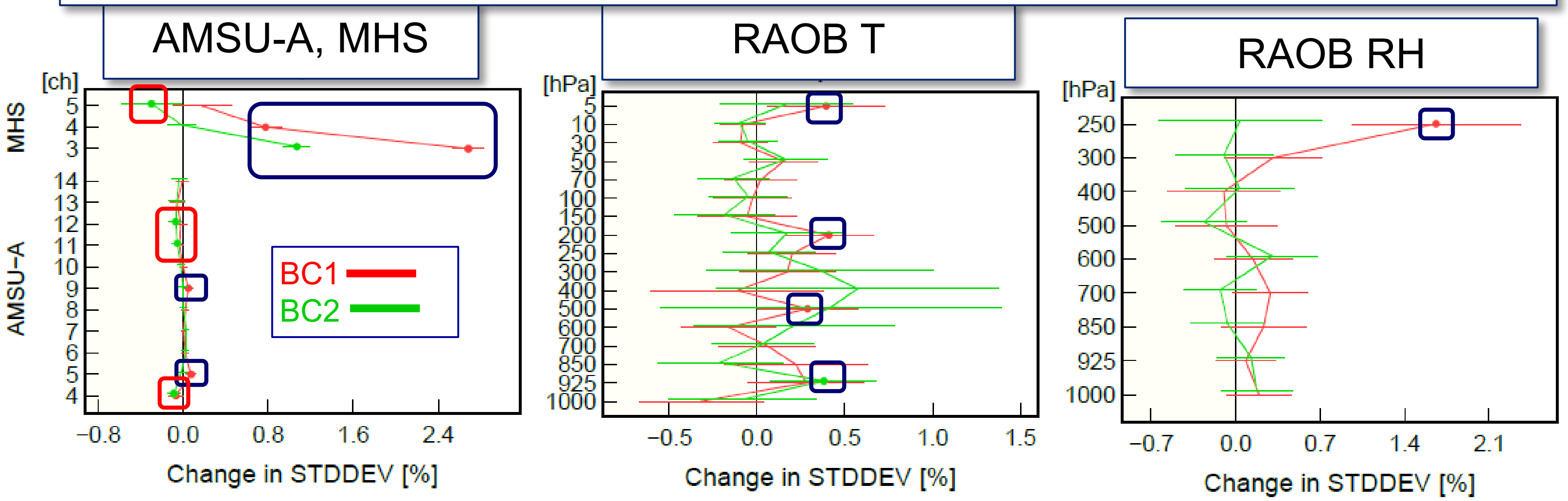
4. Additional impact studies
cloud-dependency of BC

- Examine VarBC predictors
  - Ref: **CSR BC = c_1*Bclr + c_2*1/cos(θ) + c_3**
  - TEST: **BC = CSR BC + c_4*CA + c_5*CA^2**
- BC1: Equivalent to CSR: BC = c_1*Bclr+c_2*1/cos(θ)+c_3
  - Coefficients calculated from samples with O-Bclr > 1K
  - → Significant degradation
- BC2: Obs-based predictors (Otkin & Potthast 2019): BC=c_1*O+c_2*O^2+c_3*O^3+c_4*1/cos(θ)+c_5
  - → Equivalent skills as TEST

θ: sat. zenith angle
Bclr: clear-sky background BT
O: all-sky obs BT

Cloud-dep predictors are important in the presence of significant O-B bias

BC1 vs TEST, BC2 vs TEST



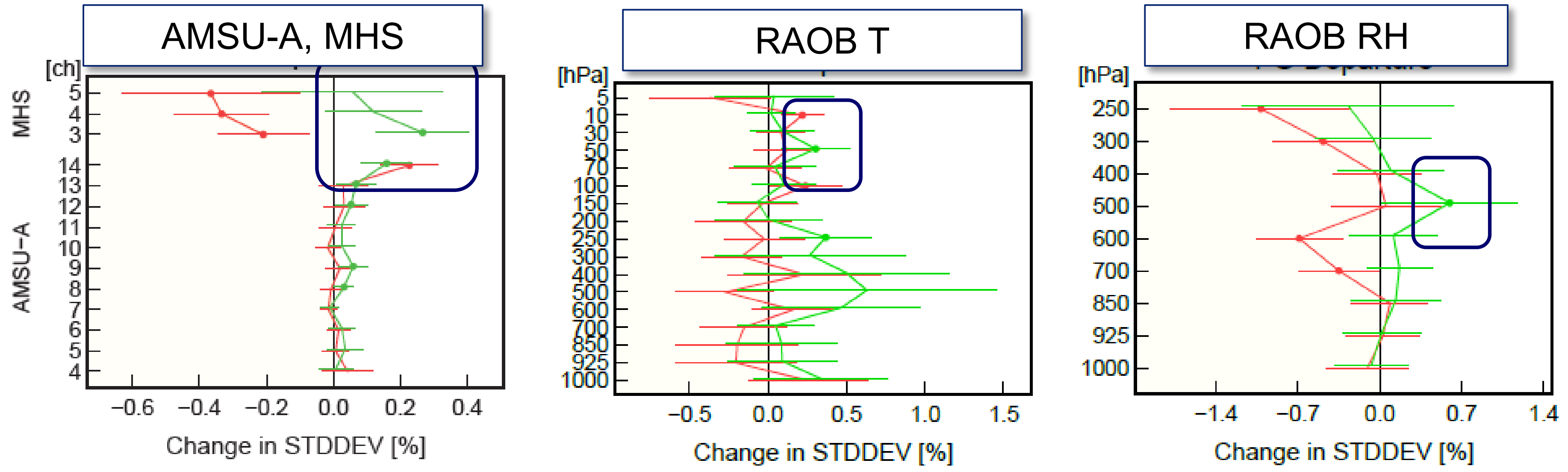
1-band ASR vs 3-band CSR/ASR

	band8	band8	band10
CNTL	CSR	CSR	CSR
TEST	ASR	ASR	ASR
BND9	N/A	ASR	N/A

- TEST: Assimilate ASR at bands 8, 9 and 10
- BND9: Assimilate ASR at only band 9
  - As many previous studies did in regional DA systems

Single band ASR assimilation was inferior to multiband CSR assimilation, not to mention multiband ASR assimilation

TEST vs CNTL,
BND9 vs CNTL



5. Summary and plans

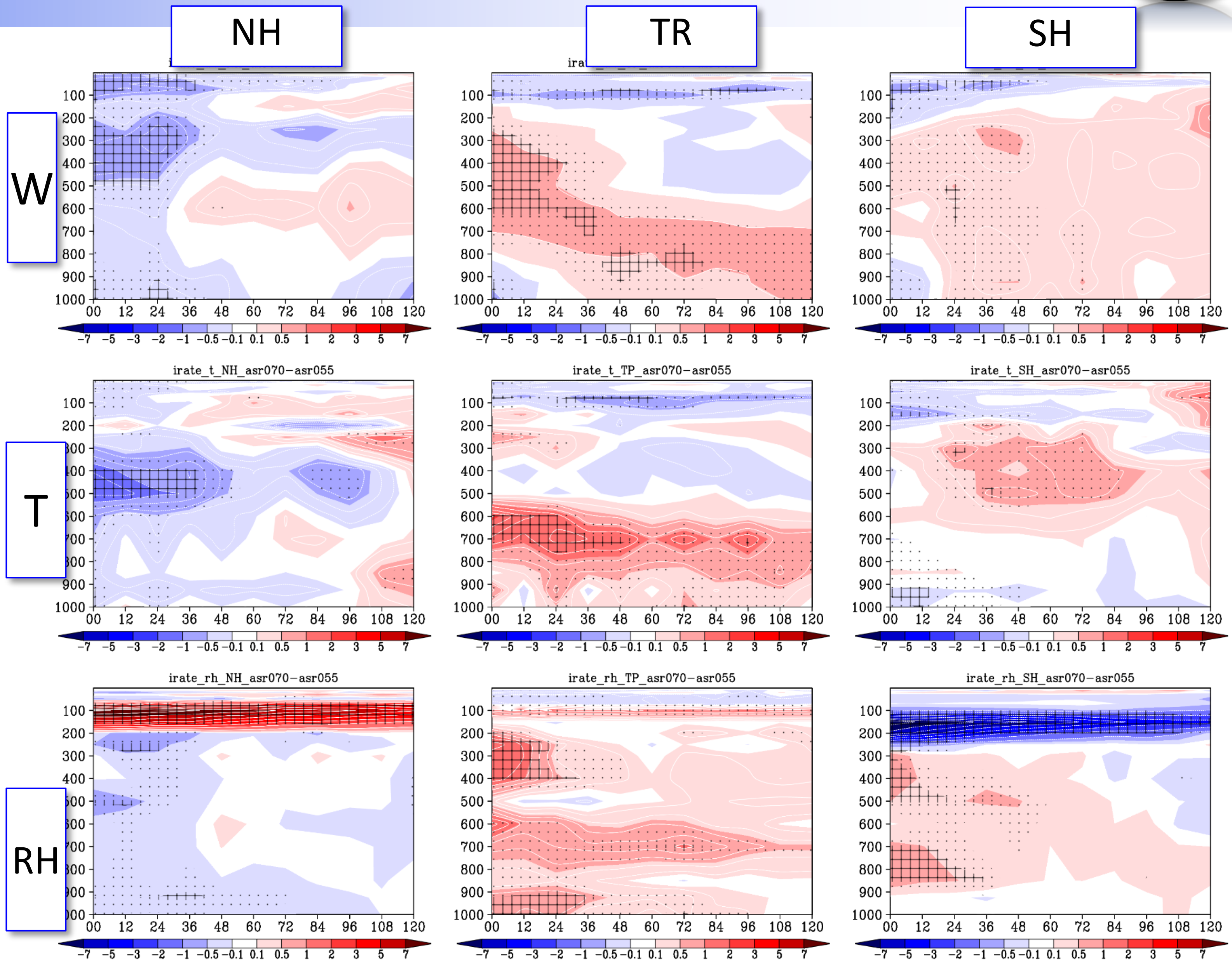
- Developed IR all-sky radiance assimilation in global data assimilation system
  - Cloud-dependent QC, BC and obs error covariance model
- ASR assimilation, relative to CSR assimilation
  - Significantly increase observations assimilated by 2.8 times
  - Increase mid- and upper tropospheric humidity 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
  - Single band ASR is inferior to multiband CSR, not to mention multiband ASR
  - Obs error correlation and cloud-dep SD are important, but cloud-dependency of correlation is not so much.
  - Cloud-dep BC predictors are essential in the presence of large (negative) O-B bias

- Ongoing studies and Plans
  - Assess impacts of ASR from GOES and MSG
  - Extend the development to meso-scale DA and hyperspectral IR sounders

Preliminary experiments with ASR of all Geo ASR (Him+MSG+GOES)

- vs Him8 ASR + MSG+GOES CSR
- Significant improvement in winds, temperature and humidity in tropics and SH
- But degradation in NH

  - Fewer ASR over land due to much stricter QC and poorer treatment of land skin temperature than CSR



Backup Slides

2. Development of ASR assimilatio

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