ITSC-25 Session 10 – All-sky assimilation (03)

Global all-sky radiance assimilation for geostationary satellite imagers

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Contents

1. Introduction

- Clear-sky radiance (CSR) at water vapor (WV) bands from Geostationary (GEO) satellite is widely assimilated in most operational NWP systems.
  - Assimilation of WV band CSRs contributes to improve analysis accuracies of temperature and WV fields in the upper and middle troposphere.
- All-sky radiance (ASR) assimilation has benefits over CSR in terms of ..
  - Observation coverage
  - Reduction of sampling bias caused by the exclusion of cloudy-sky areas.
- But, it is challenging because of ..
  - Limited reproducibility of cloud due to its complex processes in NWP model.
  - Strong non-Gaussianity, nonlinearity, and large scale dependency… etc.
- OKA2023 succeeded in assimilation of Himawari-8 ASR
  - using the observation errors including inter-band correlation and varying depending cloud effect.

Our goal is to verify the effectiveness of their method when extended to ASRs for MSG and GOES, and to address issues, if any (three new methods were developed).

2. Method

- NWP system:
  - JMA's data assimilation + global spectral model (GSM) as of December 2019.
  - Spatial resolution: TL959 (about 20 km) for outer loop, TL319 (about 55 km) for inner loop
  - Vertical resolution: 100 levels up to 0.01 hPa
  - The analysis system is a hybrid of the Local Ensemble Transform Kalman Filter (LETKF) and the four-dimensional variational (4D-Var) method.
  - Radiative transfer model: RTTOV-13
- Radiance data from GEO satellites:
  - Products from Himawari-8, MSG-1, MSG-4, GOES-16 are used.
  - CSR : Mean brightness temperature of only pixels under clear-sky conditions in a segment. The resolution of a segment is about 30 to 48 km.
  - ASR : Mean brightness temperature of all pixels in a segment. The segment has the almost same resolution as CSR from the same satellite does.

2. Method

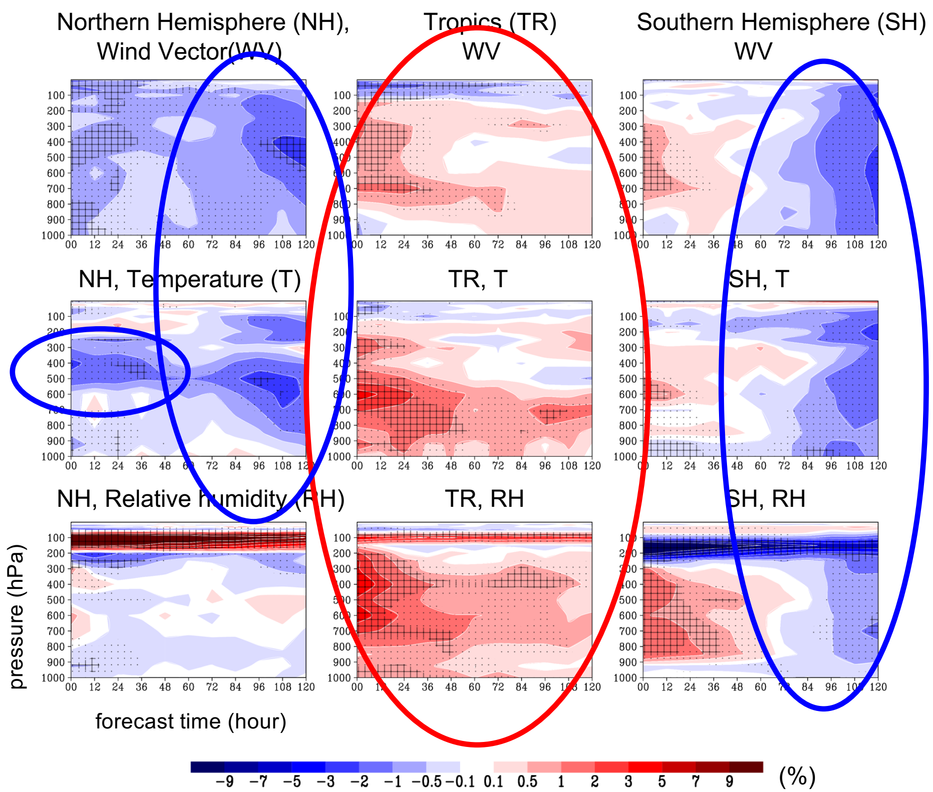
- Configuration of experiments:

Experiment	Use of CSR from GEO	Use of ASR from GEO	Add SZA and its square for VarBC predictors	Observation error for CSR/ASR	Inflation for ASR	QCs for ASR
BASE						
CNTL	✓			1.5 (K)		
TST0		✓		OKA2023	1.5	OKA2023
TST1		✓	✓	OKA2023	1.5	OKA2023
TST2		✓	✓	OKA2023	New	New QCs added to OKA2023

- Experiment period:
  - Analysis: From 10 July to 31 August 2020, 4 times per a day (00, 06, 12, 18UTC)
  - Forecast: From 20 July to 31 August 2020, 1 times per a day (only 12UTC)
- SZA : solar zenith angle

3.1. Preliminary experiment with OKA2023

Improvement ratio of TST0 over CNTL



Decreased

Improved

ASR assimilation outperforms CSR assimilation in the mid-troposphere over the TR.

Degradations of three elements from 2-day forecast in the NH and SH, and degradations of T in the mid-troposphere from 0-day forecast in the NH.

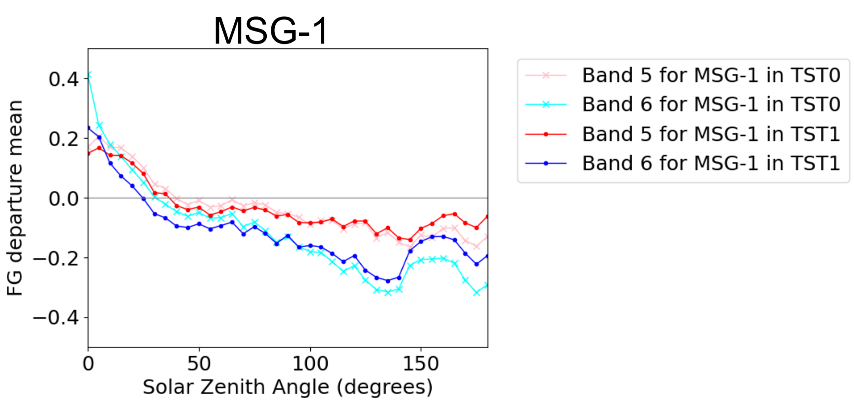
$$\text{Improvement ratio (\%)} = \frac{\text{RMSE(CNTL)} - \text{RMSE(TST0)}}{\text{RMSE(CNTL)}}$$

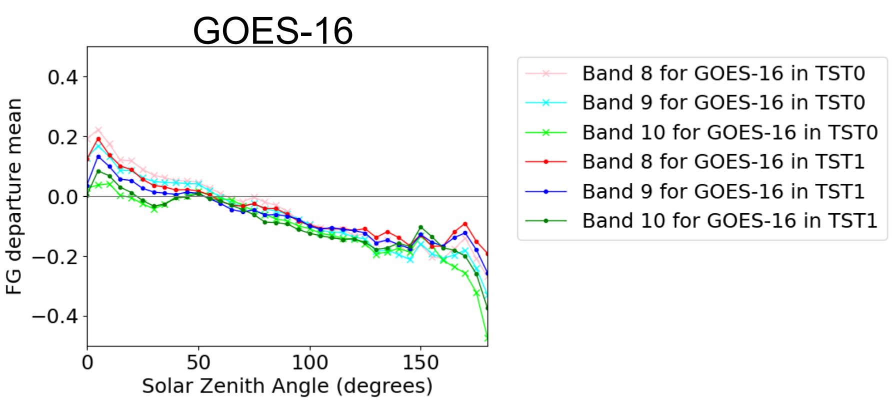
Reference: ERA5 reanalysis (Hersbach et al., 2020)

3-2. Usage of SZA as a predictor for bias correction

The variational bias correction (VarBC) method is based on an idea that there is little bias in the model.
However, there is a diurnal variation in the model bias, and the coverage of GEO satellite data is limited to certain periods of the day and changes with each analysis (00, 06, 12,18UTC).
Employing variables that follows changes in local time as predictors is effective.

Changes in O-B bias for different Solar Zenith Angle (SZA) values



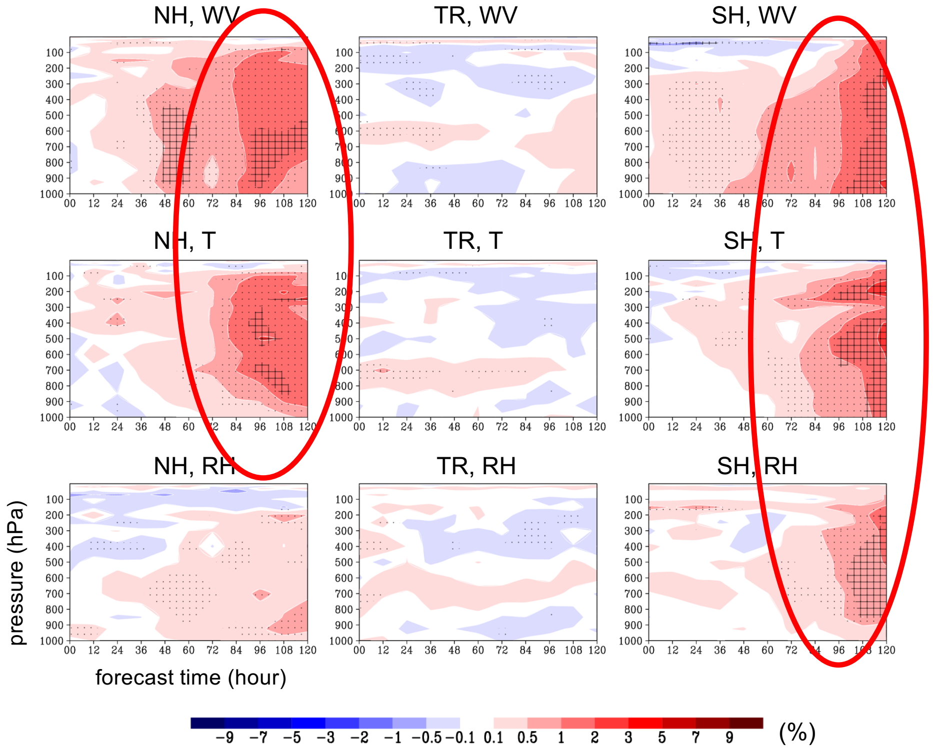


Statistic period: August 2020

Observation – background (O-B) varies depending on SZA.
→ SZA and SZA^2 were added as predictors in our experiments.

3-2. Usage of SZA as a predictor for bias correction

Improvement ratio of TST1 over TST0

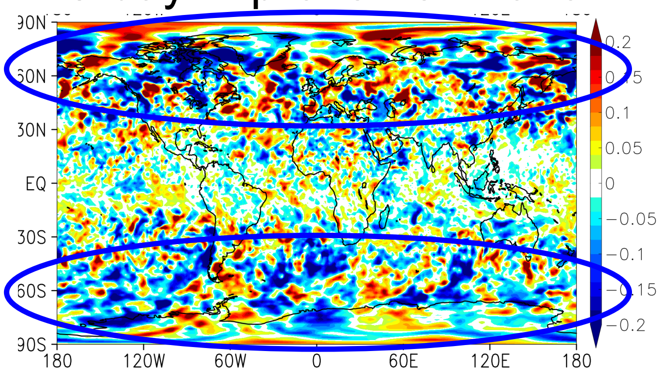


Decreased

Improved

New predictors improved forecast scores beyond the 2-day forecast for the NH and SH.

5-day improvement ratio



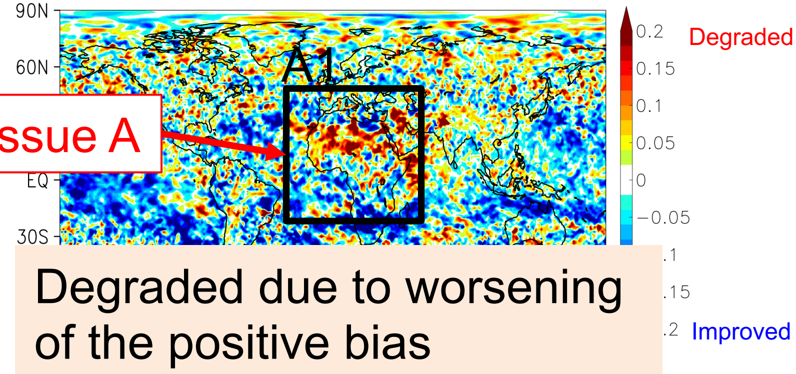
Improved

Notable improvement at high latitudes.

3-3. A new inflation for observation error and QCs

Reference: ERA5 reanalysis

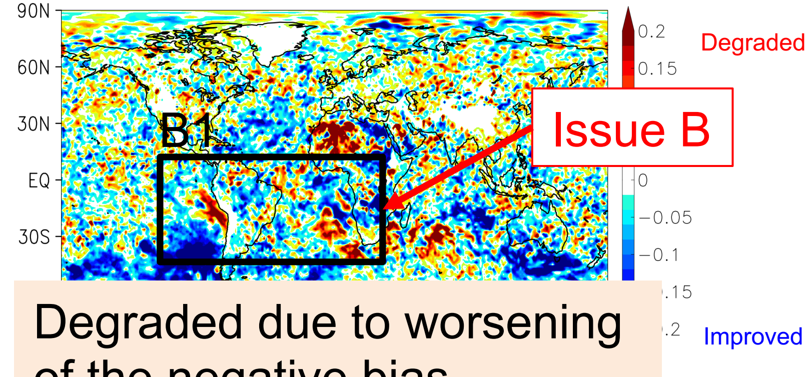
Change ratio in RMSD between TST0 and BASE for T500 analysis



Issue A

Degraded due to worsening of the positive bias

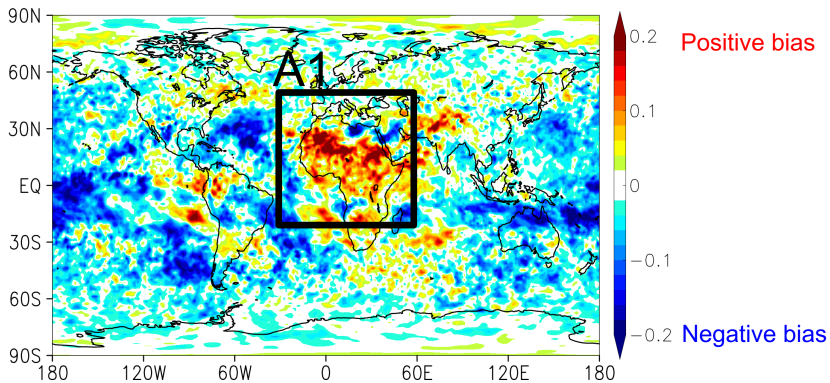
Change ratio in RMSD between TST0 and BASE for T850 analysis



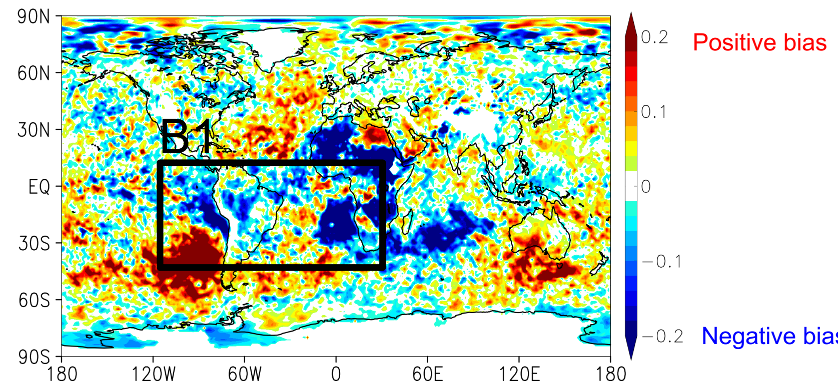
Issue B

Degraded due to worsening of the negative bias

Difference in MEAN between TST0 and BASE for T500 analysis



Difference in MEAN between TST0 and BASE for T850 analysis



Two parameters related to cloud effect

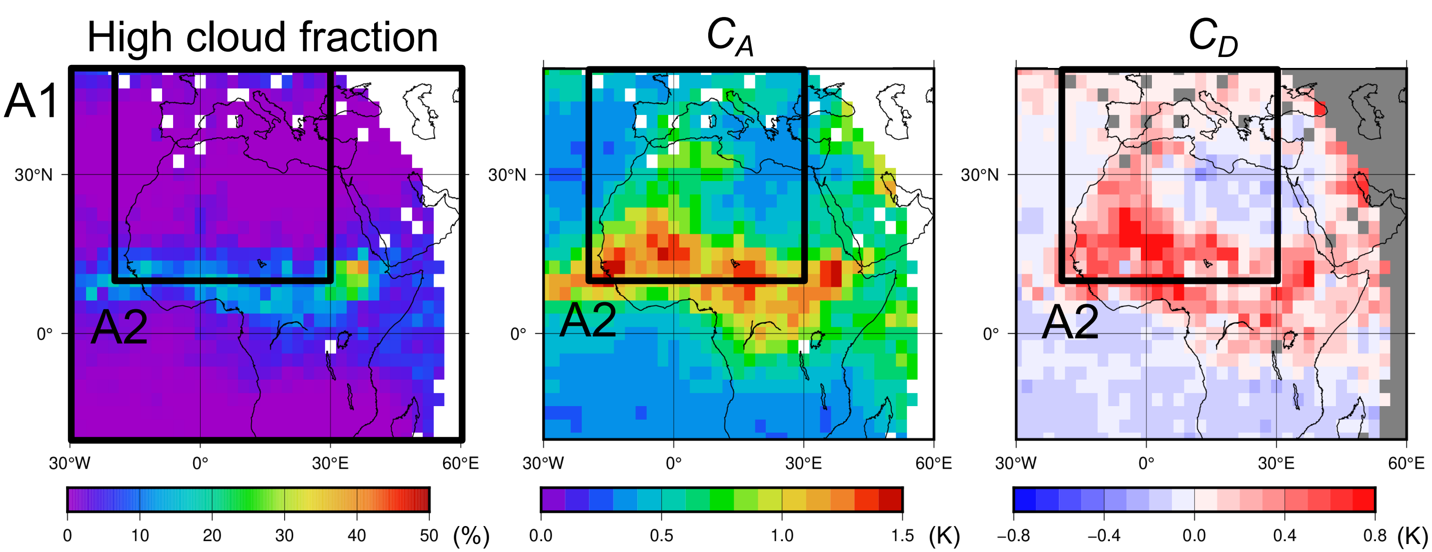
C_A is 'average' of cloud effects (Okamoto et al. 2014)
Observation error is stepwise linear function of C_A

O: observation of ASR
B: background of ASR
B_{clr}: background of CSR

$$C_A = \frac{\overbrace{|O - B_{clr}|}^{\text{Cloud effect of O}} + \overbrace{|B - B_{clr}|}^{\text{Cloud effect of B}}}{2}$$

C_D is 'discrepancy' of cloud effects.

$$C_D = |O - B_{clr}| - |B - B_{clr}|$$



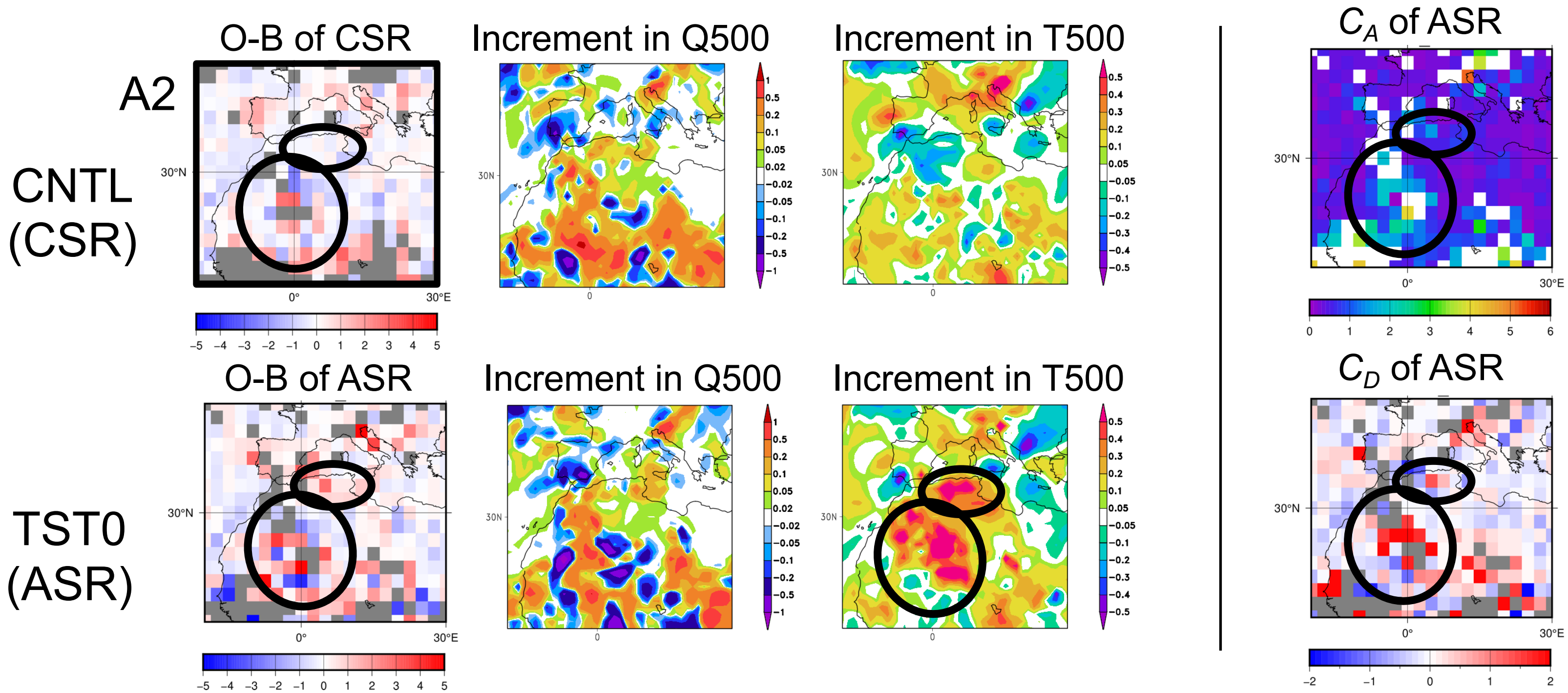
Average of the data used in TST0 (10-31 July 2020).

Why did the average temperature increase?

More positive O-B for ASR than CSR. B more affected by clouds -> lower than O.
Model represents more clouds than observed.

Positive O-B of BT leads to
① decrease in specific humidity (Q), ② increase in T
---> ① was expected but ② excessively occurred.

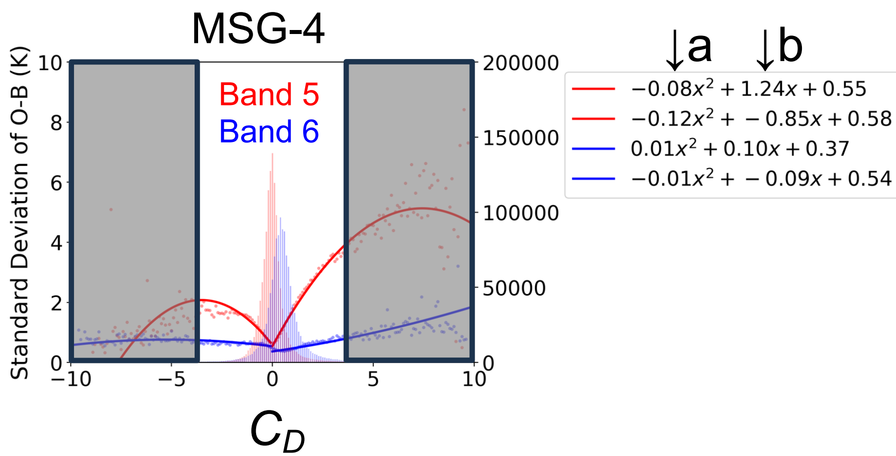
Used data and Increment for the analysis at 18 UTC on 11 Aug. 2020



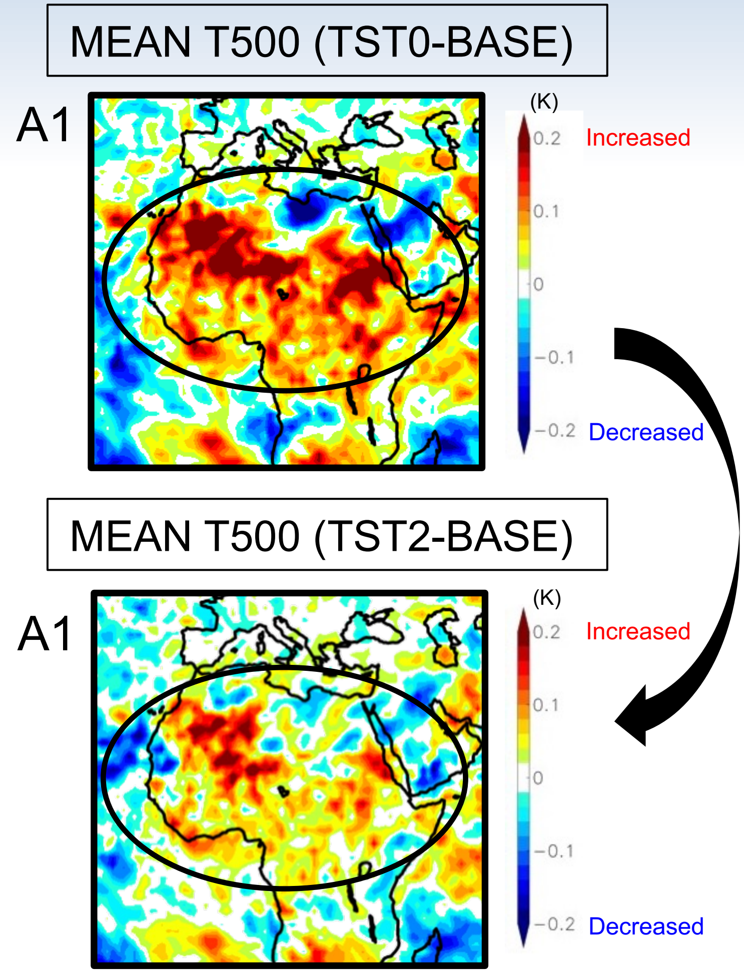
3-3. A new inflation for observation error and QCs

$$C_D = |O - Bclr| - |B - Bclr|$$

$$infl(C_D) = \mathrm{a} \cdot C_D^2 + \mathrm{b} \cdot C_D + 1.5$$



O-B SD increases with $|C_D|$.
Data with $|C_D| > 4.0$K are rejected.

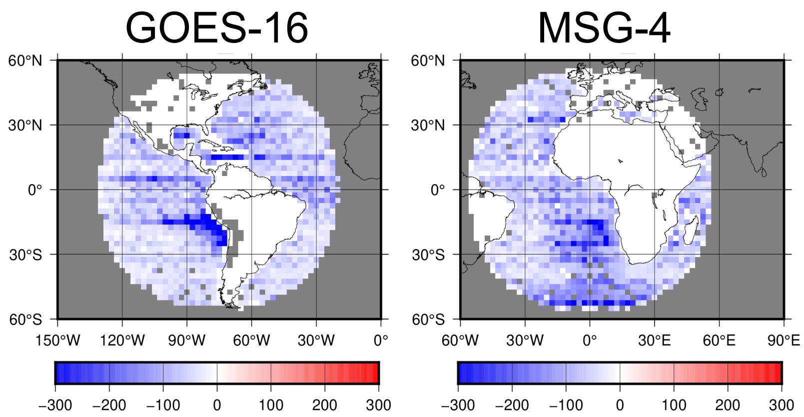


T500 degradation mitigated by new observation error inflation

3-3. A new inflation for observation error and QCs

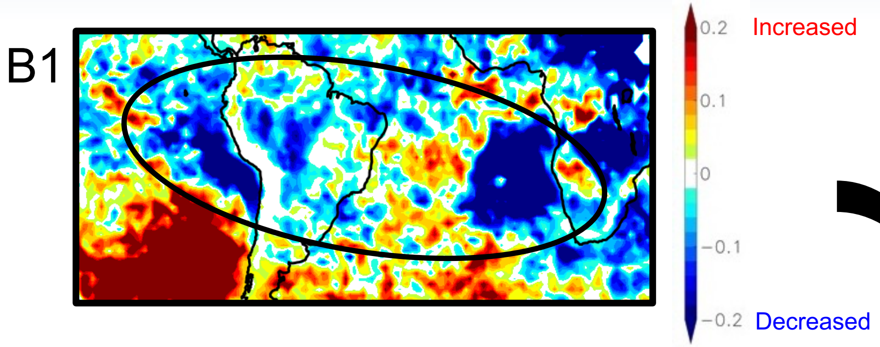
$$C_D > 1.0\ K$$
$$and$$
$$STD_{BTwin} < 3.0\ K$$

Used ASR data counts (TST2-TST0)

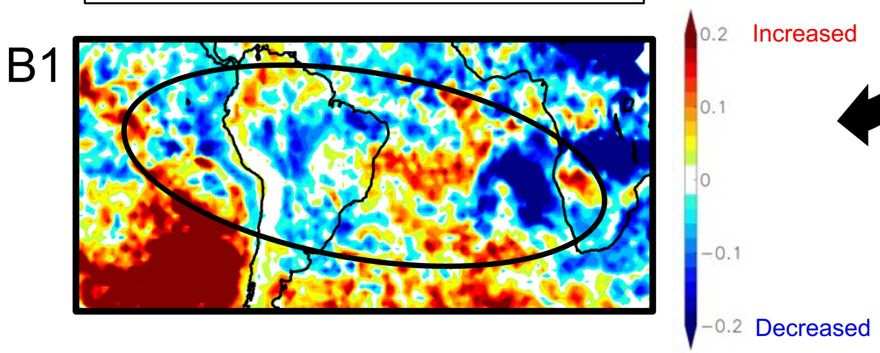


Data over oceans with low stratus clouds were rejected.

MEAN T850 (TST0-BASE)



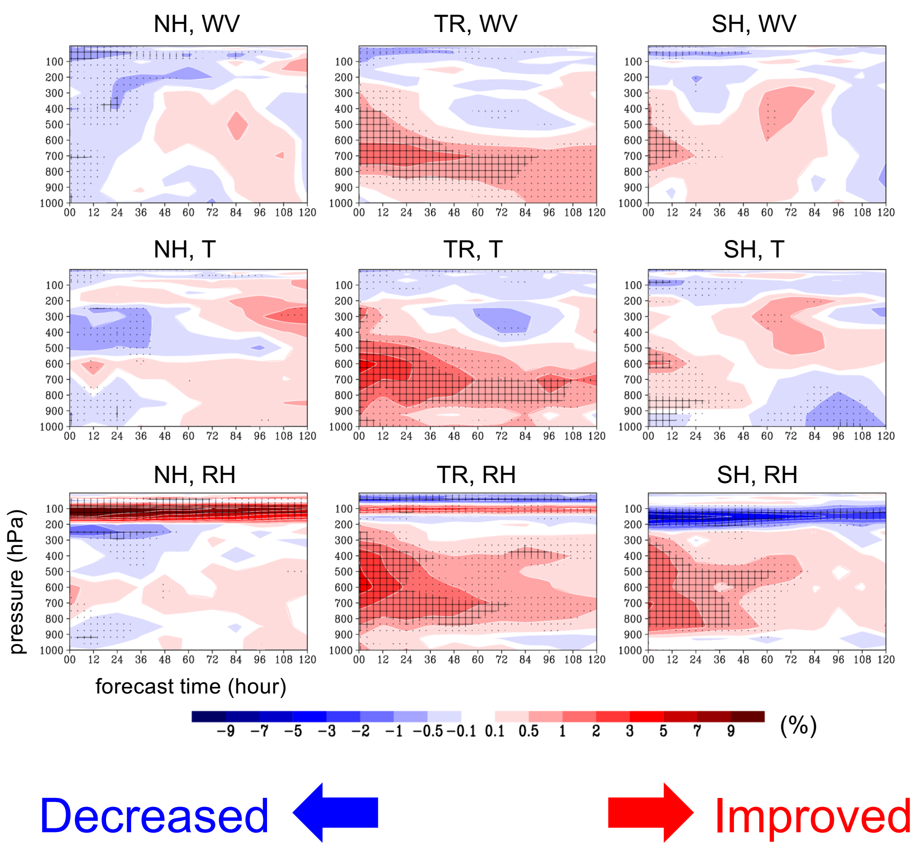
MEAN T850 (TST2-BASE)



T850 degradation mitigated by new QC

Final forecast scores

Improvement ratio of TST2 over CNTL



With new treatments, TST2 achieved the highest improvement ratio among all experiments in this study.

Degradations of T in the NH and in the later forecast periods were notably mitigated, while maintaining the high improvement ratio in the TR.

4. Summary and future plans

- OKA2023 was expanded to include ASRs for MSG and GOES.
- Forecast accuracy improved in the tropics.
- However, degradations was found
  - in the North and South hemispheres after three-day forecast, and
  - in the middle troposphere over the Sahara Desert and in the South Atlantic regions.
- Treatments were developed to address these issues.
  - Solar zenith angle and its squared term were used as VarBC predictors.
  - Inflation model for observation error and QCs using the parameter of 'discrepancy' in cloud effects (C_D).
- After applying the developed treatments, the degradation was notably mitigated.

Future plans:

- Okabe et al., (2025), "Global usage of all-sky radiances from geostationary satellites," currently under review for publication.
- Further investigation of the inappropriate increments. (e.g., Jacobians of ASR BTs and background errors.)

References

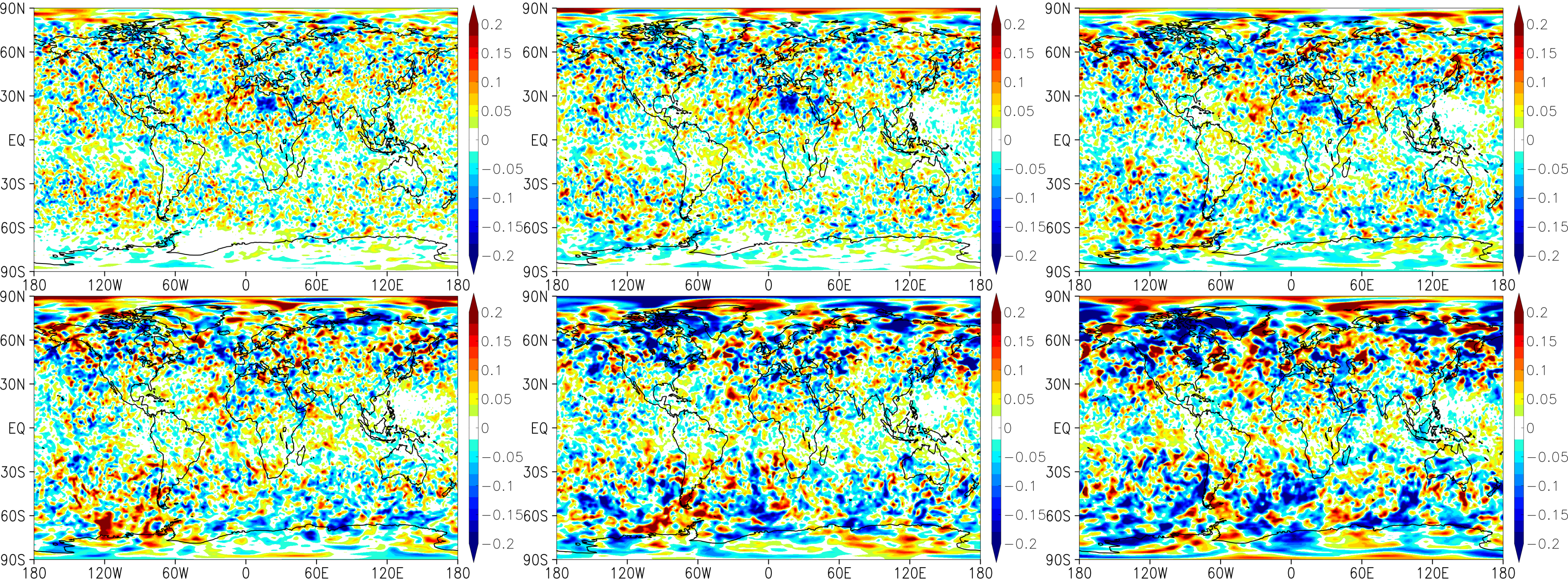
- Okamoto, K., McNally, A.P. and Bell, W. (2014) Progress towards the assimilation of all-sky infrared radiances: an evaluation of cloud effects. Q. J. R. Meteorol. Soc., 140, 1603–1614.

- Okamoto, K., Ishibashi, T. and Okabe, I. (2023) All-sky infrared radiance assimilation of a geostationary satellite in the Japan Meteorological Agency's global system. Q. J. R. Meteorol. Soc., 149(755), 2477–2503. https://doi.org/10.1002/qj.4516.

- Backup slides

RMSE-rate

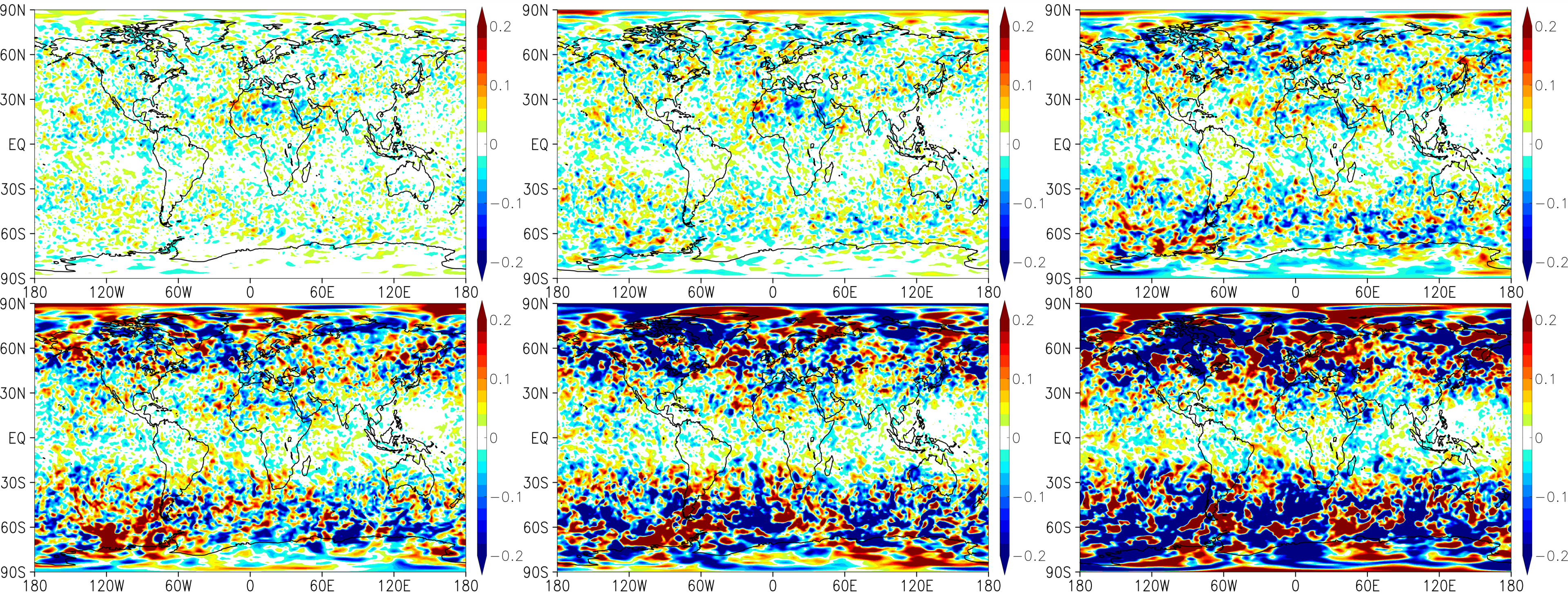
0-day 1-day 2-day



3-day 4-day 5-day

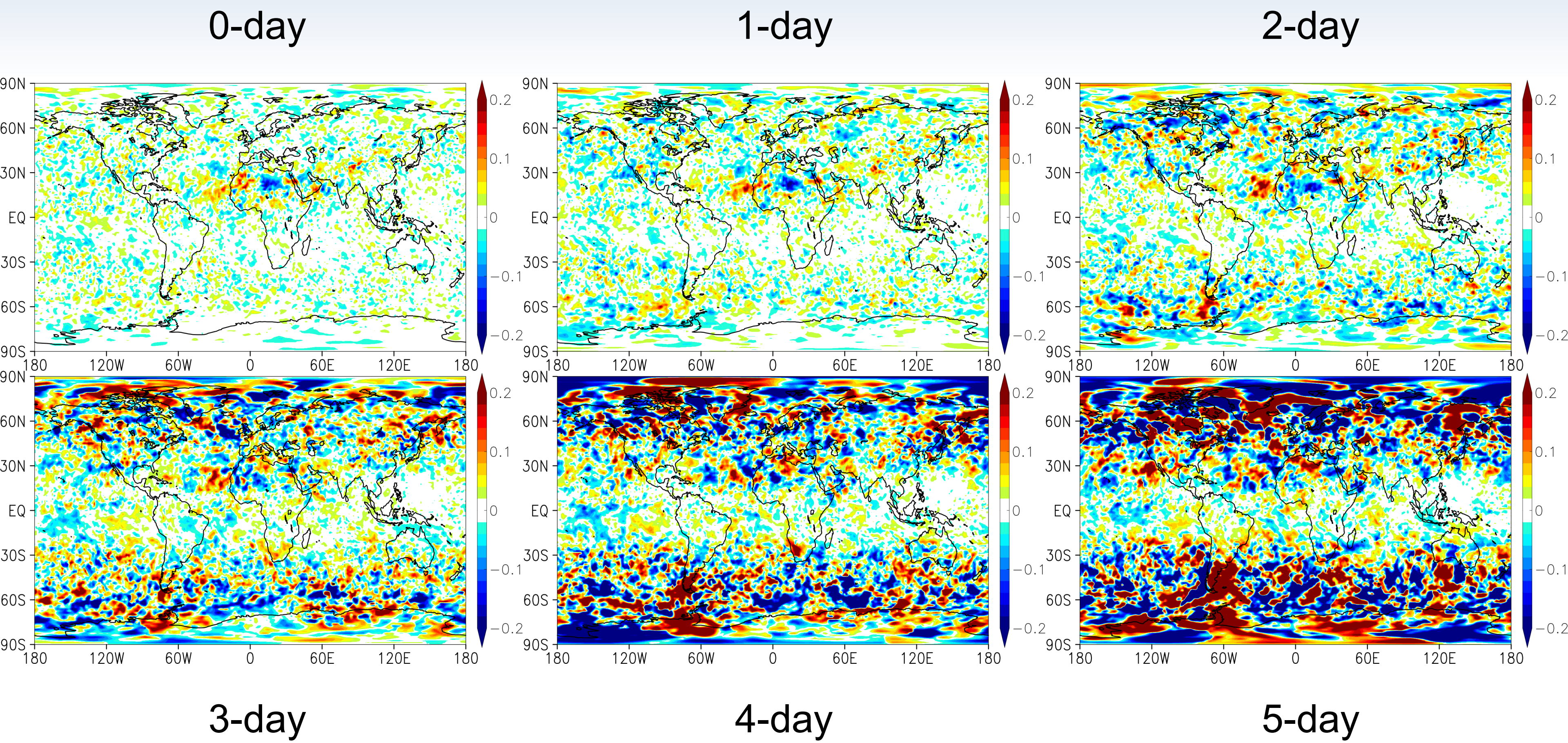
Difference in STD

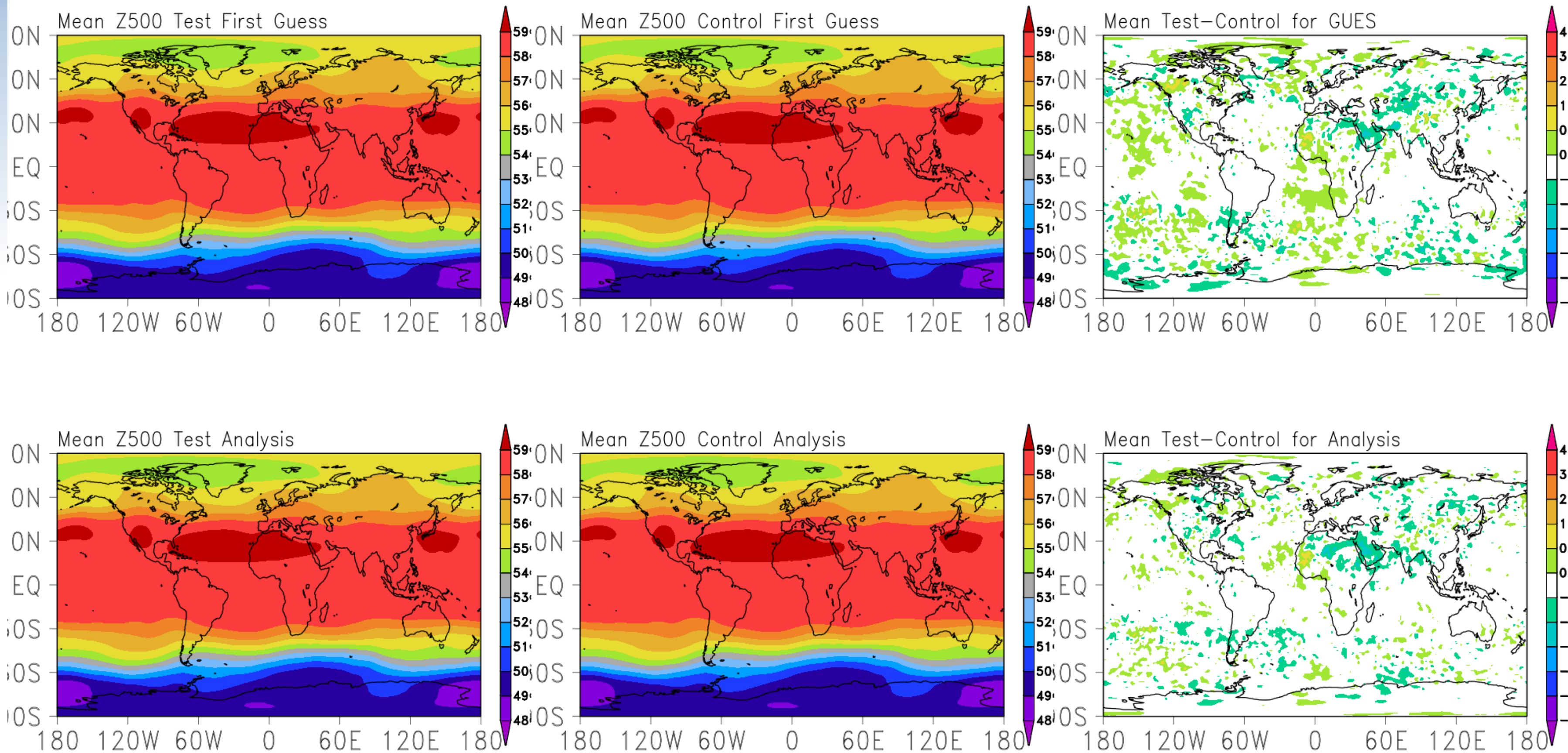
0-day 1-day 2-day

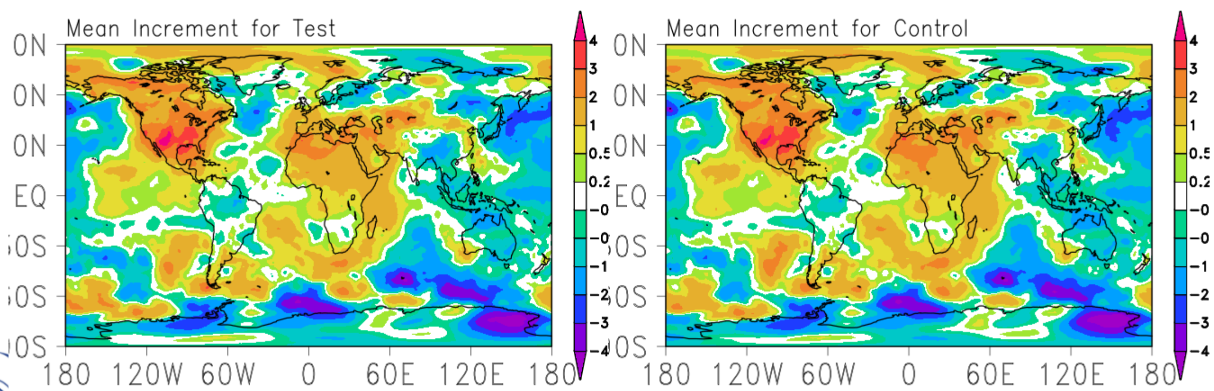


3-day 4-day 5-day

Difference in |MEAN|







Mean Increment Z500

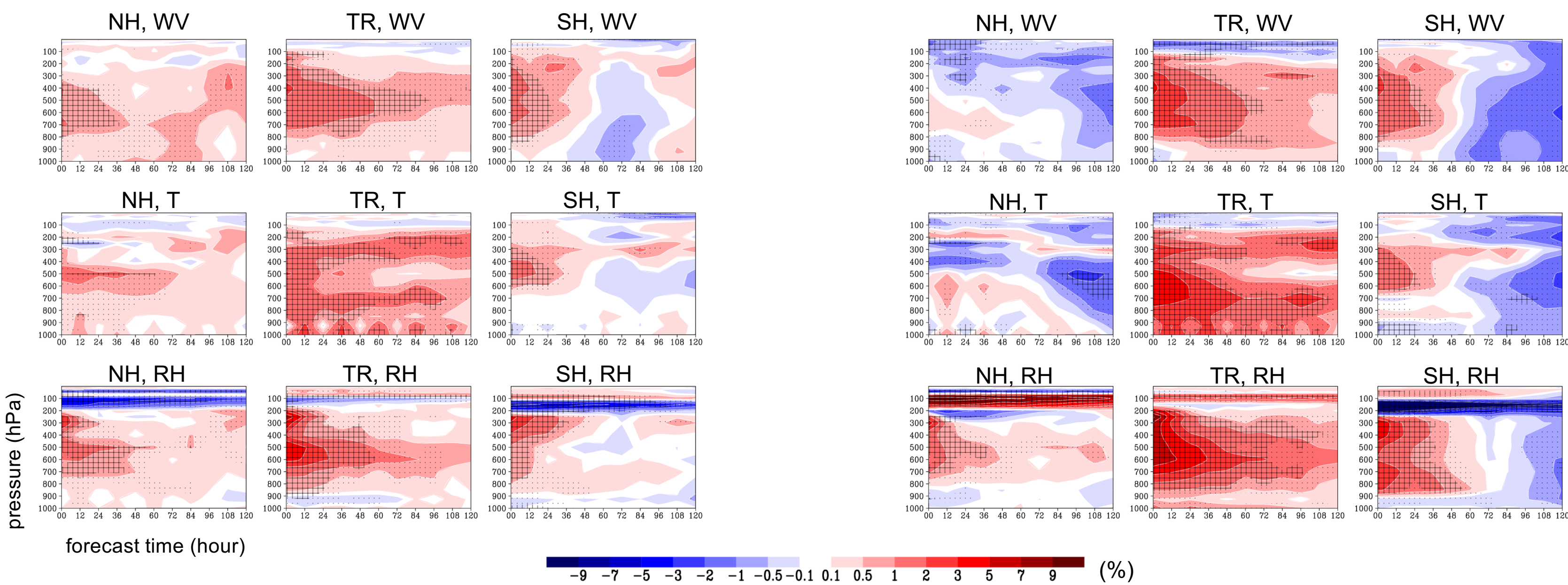
Period :– (valid)
(7.75 days : 31 cases average)

TEST um/08311200
CNTL sum/0831120

3.1. Preliminary experiment with OKA(2023)

Improvement ratio of CNTL over BASE

Improvement ratio of TST0 over BASE



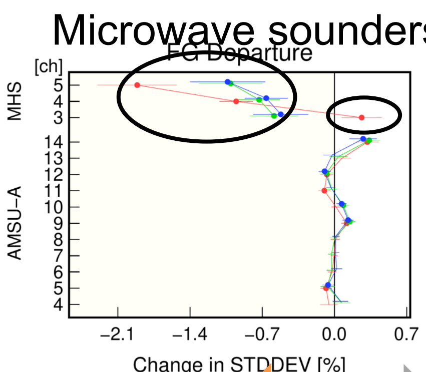
$$\text{Improvement ratio (\%)} = \frac{\text{RMSE(CNTL)} - \text{RMSE(TST0)}}{\text{RMSE(CNTL)}}$$

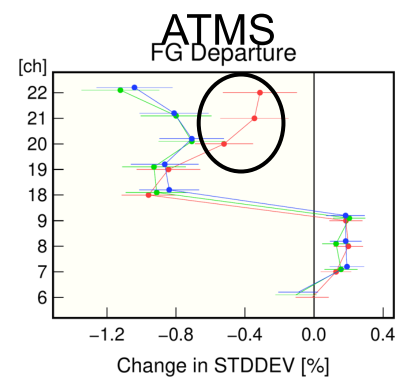
Reference: ERA5 reanalysis (Hersbach et al., 2020)

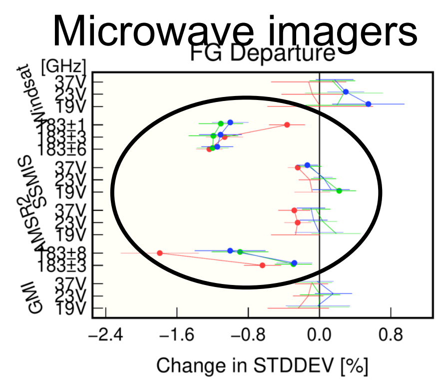
Short-range forecast (fitting to other obs.)

Fitting to observations which have WV or T information at the mid- and lower troposphere are better in ASR2 than those in ASR0 or ASR1.

Fitting to observations which have WV or T information at upper troposphere are better in ASR0 or ASR1 than those in ASR2.

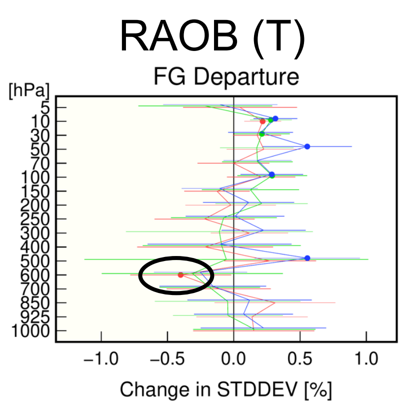


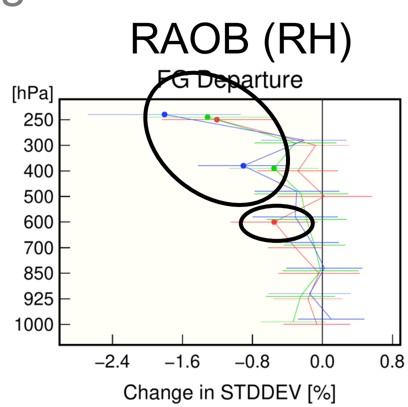


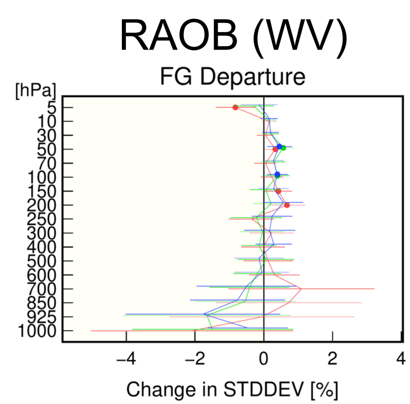


ASR2 over CSR
ASR1 over CSR
ASR0 over CSR

Improve Degrade





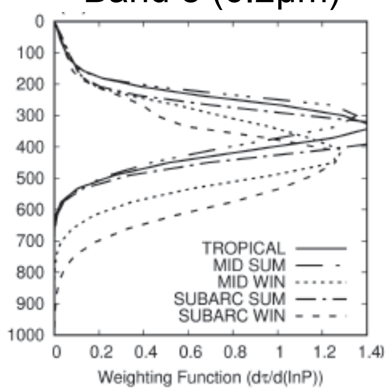


2. NWP system and observation data

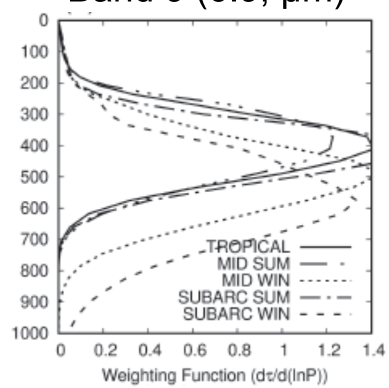
Weighting functions of used WV bands

Himawari-8

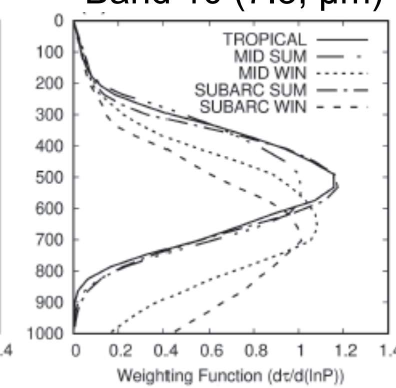
Band 8 (6.2μm)



Band 9 (6.9, μm)

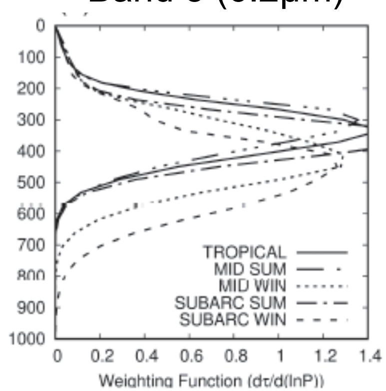


Band 10 (7.3, μm)



MSG-1

Band 5 (6.2μm)



Band 6 (7.3, μm)