Impact of microwave radiance assimilation over land using dynamic emissivity in the global NWP system of JMA

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Motivation

- It is important to estimate land surface emissivity for the radiance assimilation in the NWP systems.
  - The emissivity spatiotemporally varies depending on surface conditions.
- In the current global NWP system of JMA, the climatological atlas emissivity is used for the microwave (MW) radiance assimilation over land.

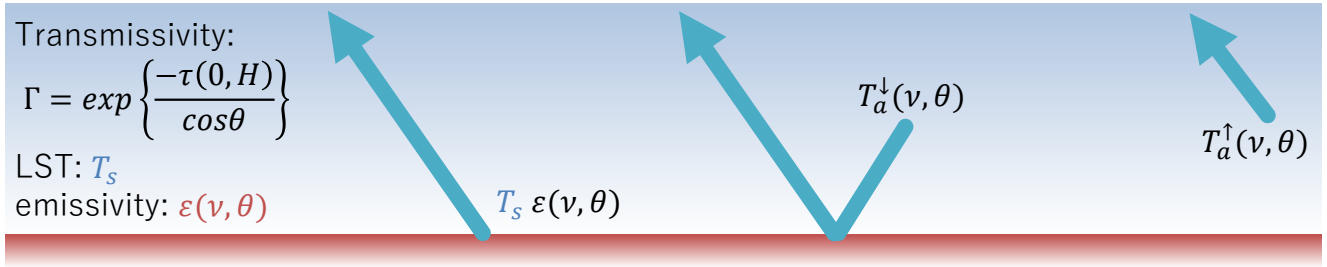
- JMA/MRI is working on applying a dynamic emissivity (DE, Karbou et al. 2006) method to the global NWP system of JMA to reduce uncertainty related to the radiative transfer calculation.
  - The DE method can dynamically estimate the emissivity.
  - Land surface temperature (LST) was additionally estimated by using satellite observations.

Dynamic Emissivity (Karbou et al. 2006)

- Radiative transfer equation under clear sky condition

$$T_b(\nu,\theta) = T_s\varepsilon(\nu,\theta)\Gamma + \{1-\varepsilon(\nu,\theta)\}\Gamma T_a^{\downarrow}(\nu,\theta) + T_a^{\uparrow}(\nu,\theta)$$

$T_b(\nu,\theta)$: brightness temp.
ν: frequency
θ: zenith angle
T_s: land surface temp. (LST)
$T_a^{\downarrow}$: downwelling T_b
$T_a^{\uparrow}$: upwelling T_b
Γ: transmissivity



- Estimated land surface temperature (LST) T_s

$$T_s = \frac{T_b(\nu,\theta)-(1-\varepsilon_{atlas})T_a^{\downarrow}(\nu,\theta)\Gamma-T_a^{\uparrow}(\nu,\theta)}{\varepsilon_{atlas}\Gamma}$$

T_s is estimated from observed T_b, atmospheric model variables and monthly mean ε_{atlas}.

- Estimated emissivity $\varepsilon(\nu,\theta)$

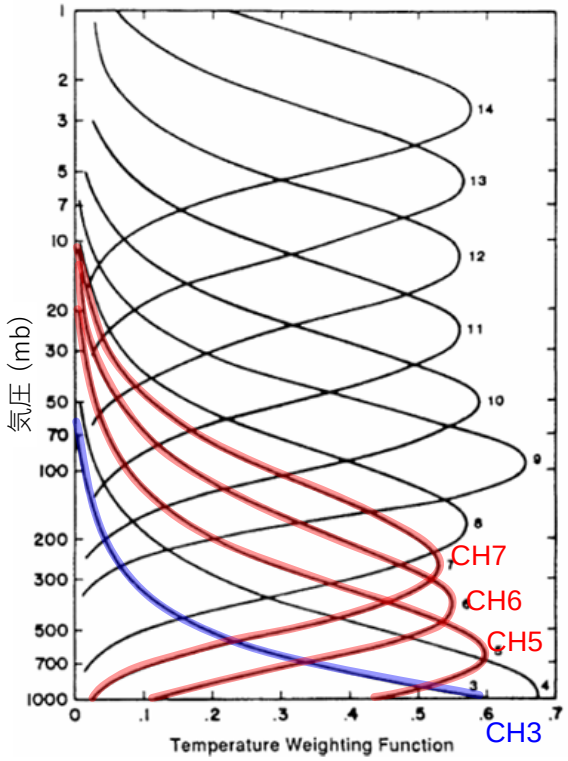
$$\varepsilon(\nu,\theta) = \frac{T_b(\nu,\theta) - T_a^{\downarrow}(\nu,\theta)\Gamma - T_a^{\uparrow}(\nu,\theta)}{\left(T_s - T_a^{\downarrow}(\nu,\theta)\right)\Gamma}$$

$\varepsilon(\nu,\theta)$ is estimated from observed T_b and atmospheric model variables.
Here, a model surface temperature is used as T_s.

Target sensors of DE

- Target sensors : AMSU-A, ATMS
- Emissivity is estimated at 50.30 GHz (Bormann et al. 2017).
- LST is also estimated at 50.30 GHz.
- The estimated emissivity is used at surface-sensitive CHs over land.
  - AMSU-A
    - 53.596 GHz+115 MHz (ch5)
    - 54.40 GHz (ch6)
    - 54.94 GHz (ch7)
  - ATMS
    - 53.596 GHz+115 MHz (ch6)
    - 54.40 GHz (ch7)
    - 54.94 GHz (ch8)

CH	Central frequency	Absorption	Assimilation (Operational)
1	23.800 GHz	H_2O	
2	31.400 GHz	window	
3	**50.300 GHz**	O_2	
4	52.800 GHz	O_2	○ (sea)
5	**53.595 GHz ± 115 MHz**	O_2	○ (sea)
6	**54.400 GHz**	O_2	○
7	**54.940 GHz**	O_2	○
8	55.500 GHz	O_2	○
9	57.290 GHz (=f0)	O_2	○
10	f0 ± 217 MHz	O_2	○
11	f0 ± 322.2 MHz ± 48 MHz	O_2	○
12	f0 ± 322.2 MHz ± 22 MHz	O_2	○
13	f0 ± 322.2 MHz ± 10 MHz	O_2	○
14	f0 ± 322.2 MHz ± 4.5 MHz	O_2	○
15	89.000 GHz	window	



Weighting functions of AMSU-A (Janssen,1993)

Preliminary investigation (Passive cycle)

- To investigate impacts of DE, calculating radiative transfer model and QC are performed without DA cycles.
  - Background brightness temperature (Tb) is calculated from the given first guess by using the estimated emissivity and is compared with observation Tb.
  - This is not a DA cycle experiment.
- Global NWP system of JMA (operational system as of Dec. 2021)
  - Hybrid 4D-Var system (Outer: TL959L128 (20 km), Inner: TL319L128 (55 km))
- Experimental settings
  - The DE is applied to AMSU-A/chs. 5, 6, 7 and ATMS/chs. 6, 7, 8 over land.
    - AMSU-A/ch5 and ATMS/ch6 are not used over land in the operational system of JMA because they contaminated analyses and degraded forecasts.
    - However, this experiment is not a DA cycle, therefore the contaminated analyses are not used.
- Period: Aug. 2021, Jan. 2022

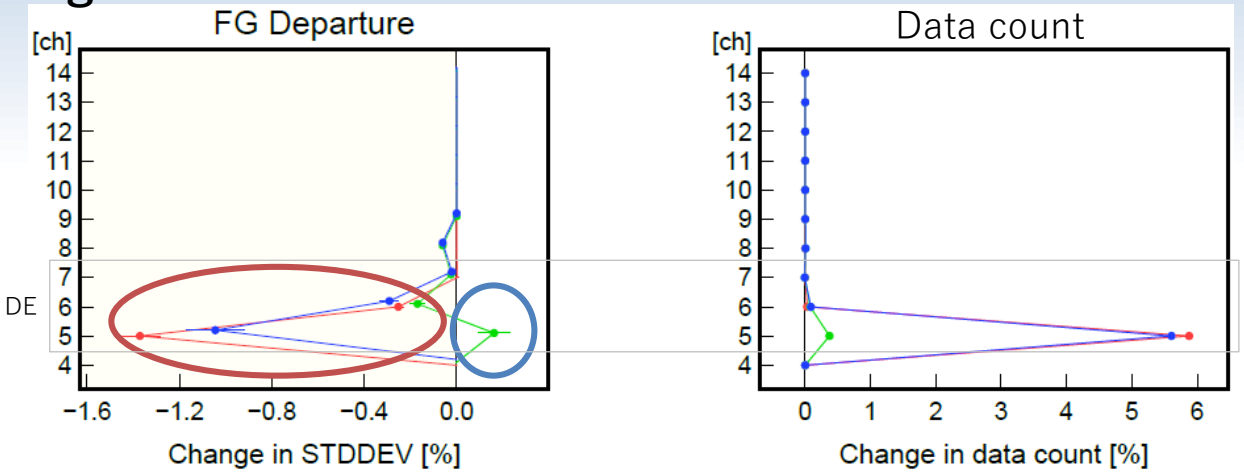
Name	Emissivity	LST
CNTL	Atlas emissivity	Model LST (as same as the operational settings)
TEST1 (DE)	**DE**	Model LST
TEST2 (LST)	Atlas emissivity	**Retrieved LST**
TEST3 (DE+LST)	**DE**	**Retrieved LST**

Statistical verification of O-B STD

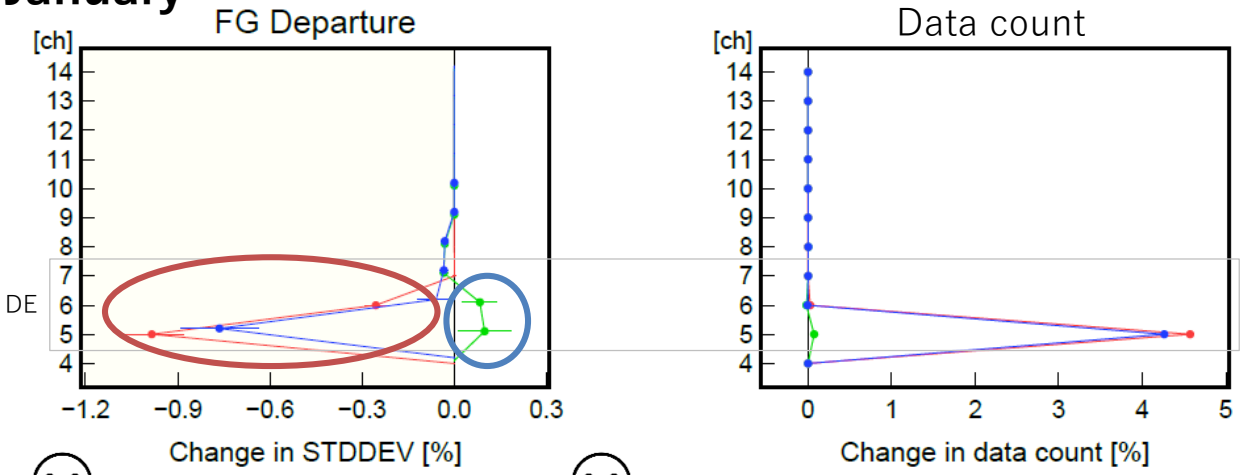
TEST1: DE
TEST2: LST
TEST3: DE+LST

AMSU-A

August

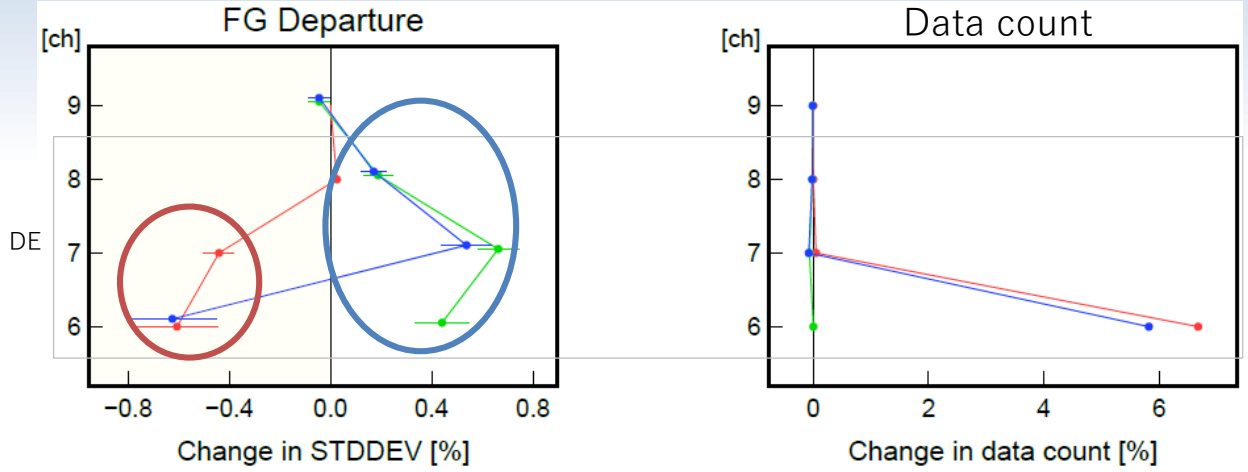


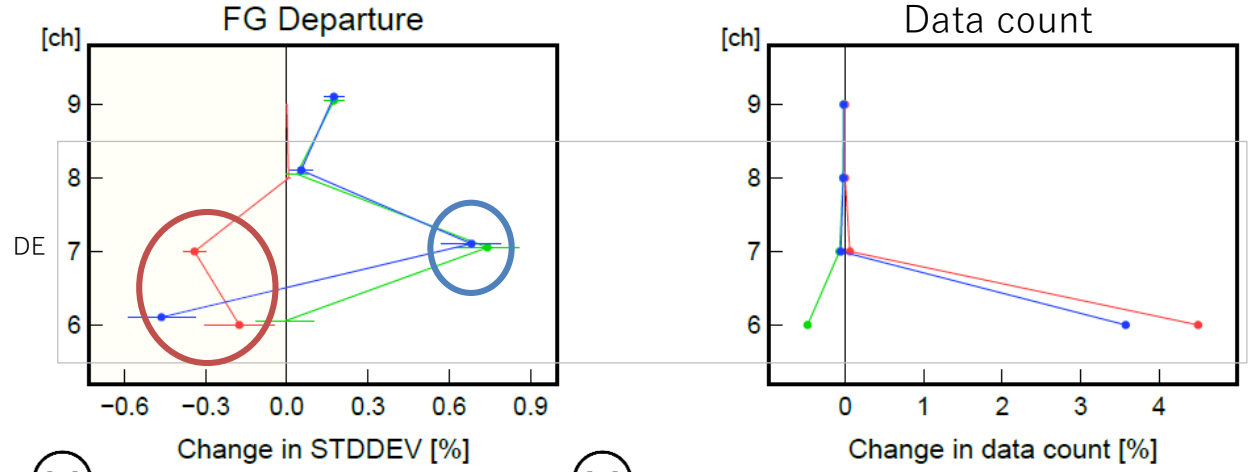
January



decreased increased

ATMS





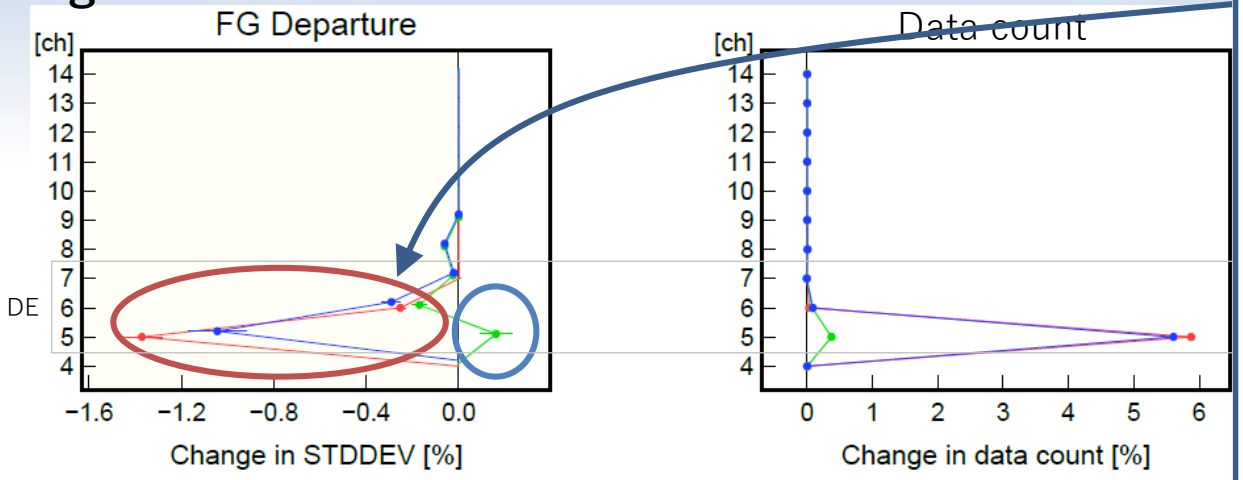
decreased increased

Statistical verification of O-B STD

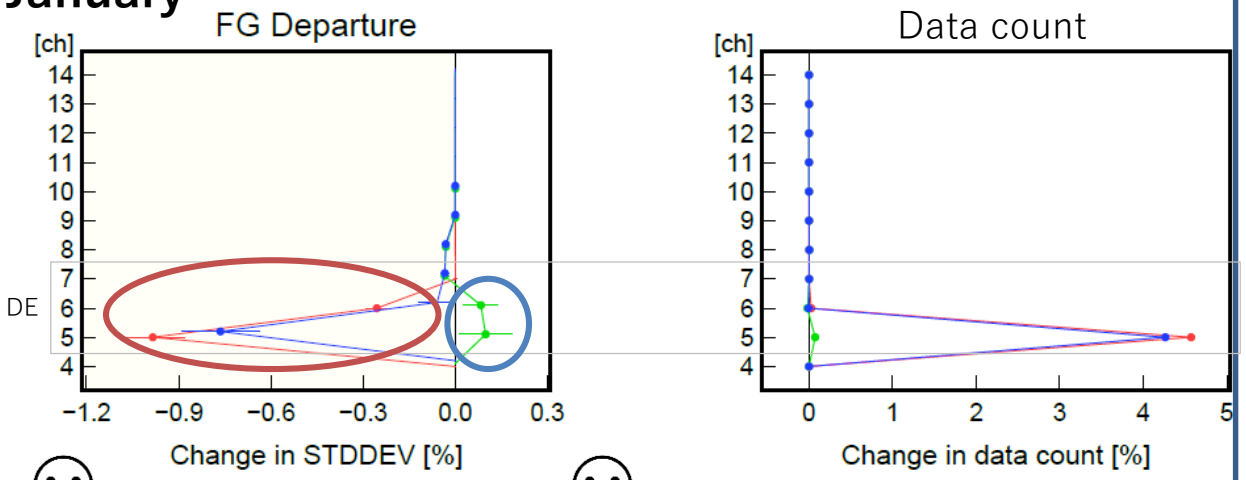
TEST1: DE
TEST2: LST
TEST3: DE+LST

AMSU-A

August

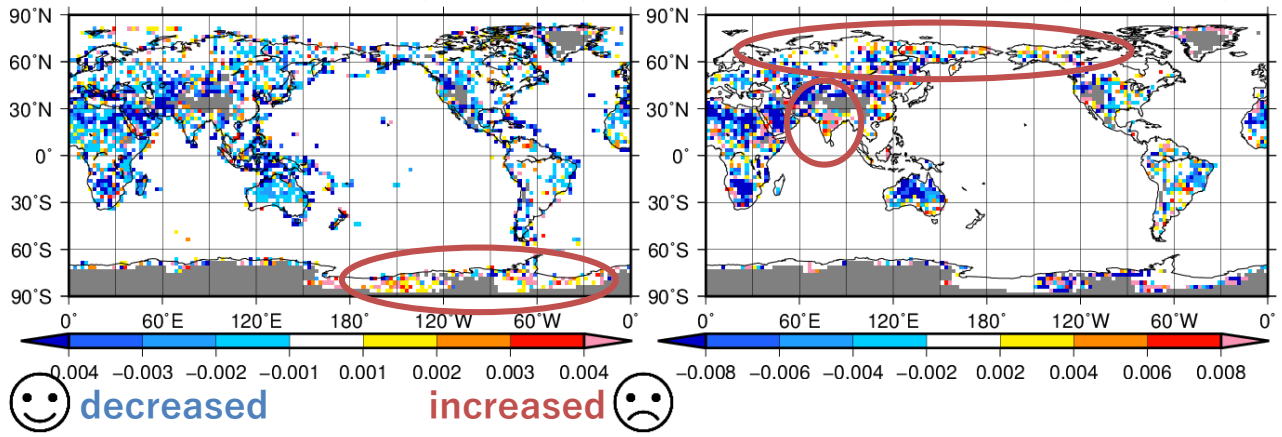


January



decreased increased

Difference between O-B STDs



TEST1 (DE)

- The FG is generally closer to the observation, particularly over the arid areas and coastlines.
  - The DE is applied over the coastline.
- Over the Antarctic, the STD of O-B is increased.
  - Negative impact from snow ?

TEST2 (LST)

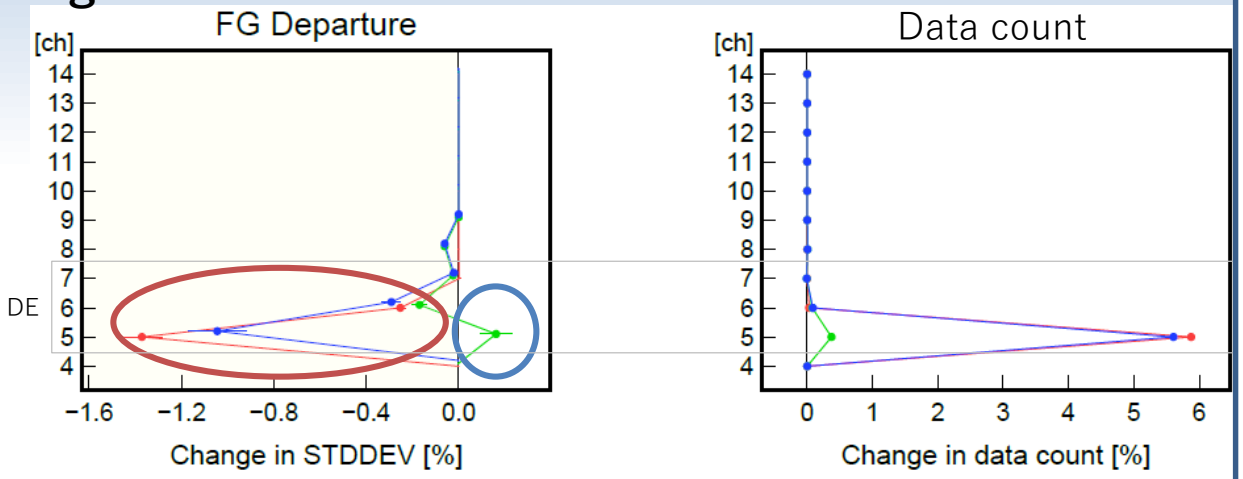
- The FG is closer to the observation over the arid areas.
- The STD is increased over high latitude and India.

Statistical verification of O-B STD

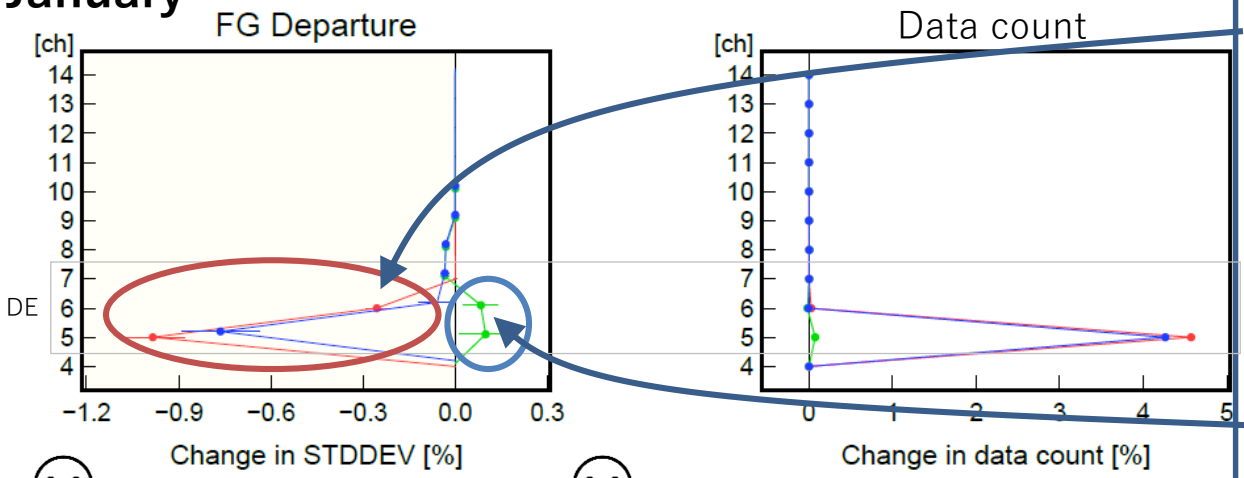
TEST1: DE
TEST2: LST
TEST3: DE+LST

AMSU-A

August

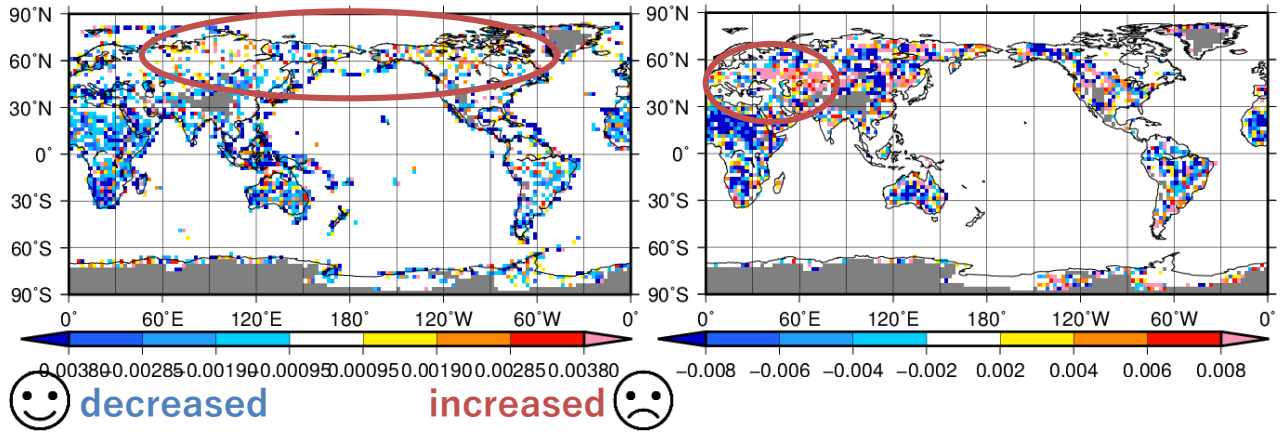


January



decreased increased

Difference between O-B STDs



TEST1 (DE)

- The STD of O-B gets smaller over Africa.
- However, over the high latitude areas, the STDs are increased.
  - Negative impact from snow ?

TEST2 (LST)

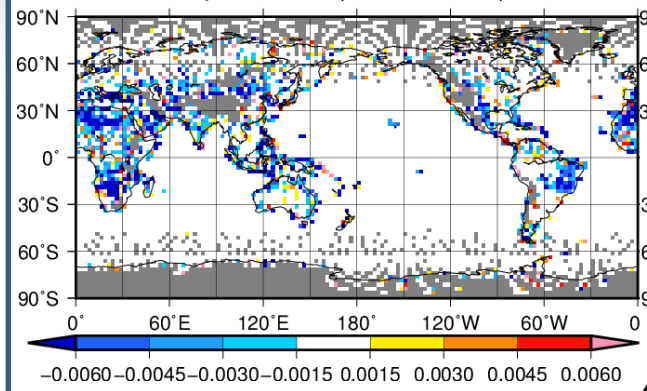
- The increase and decrease of STD are different from TEST1.
  - The STD gets much larger than that of TEST1 over the mid Asia.

Statistical verification of O-B STD

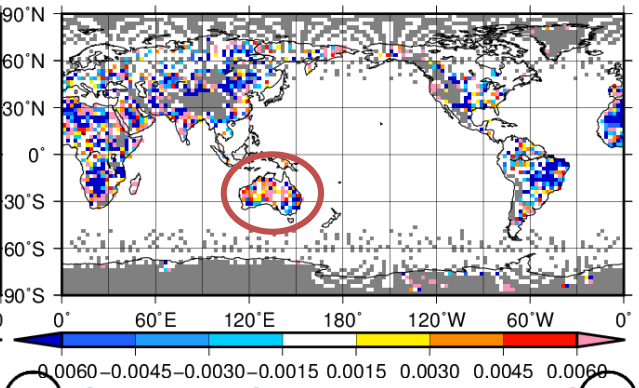
TEST1: DE
TEST2: LST
TEST3: DE+LST

Difference between O-B STDs

ATMS/ch7 (TEST1)



ATMS/ch7 (TEST2)



decreased　increased

TEST1 (DE)

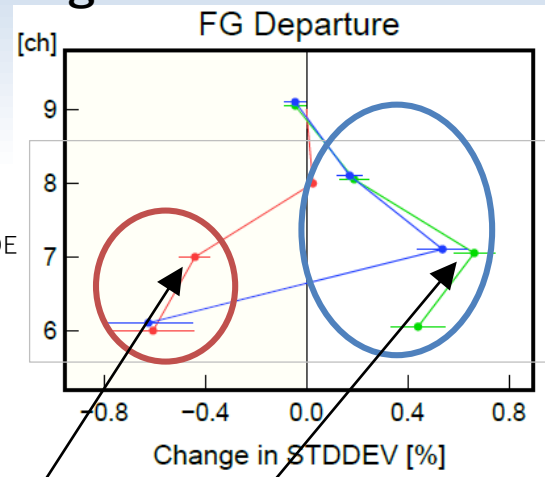
- Generally, the STD of O-B becomes small in the same areas as AMSU-A.

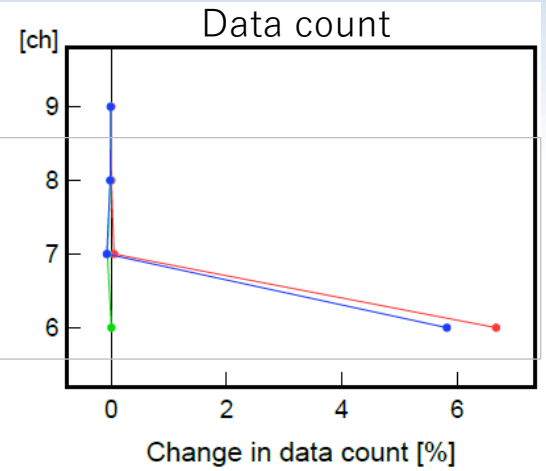
TEST2 (LST)

- As different from AMSU-A, the STD is increased over the Australia.
  - Bias corrections or local times of satellites?

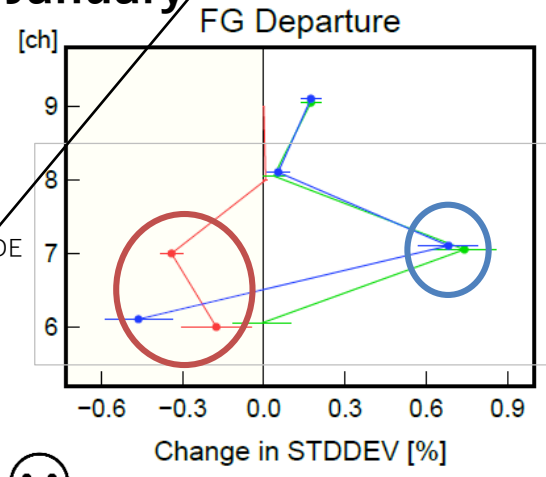
ATMS

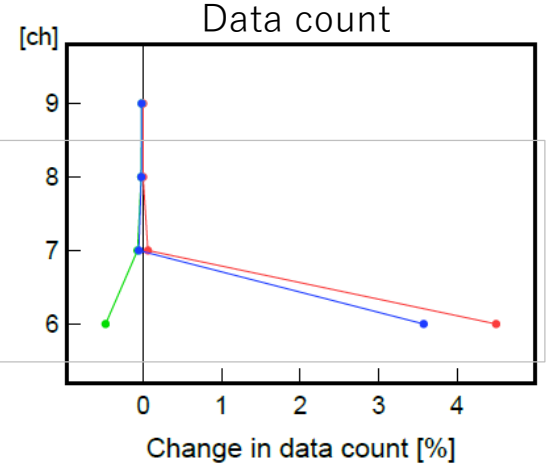
August





January



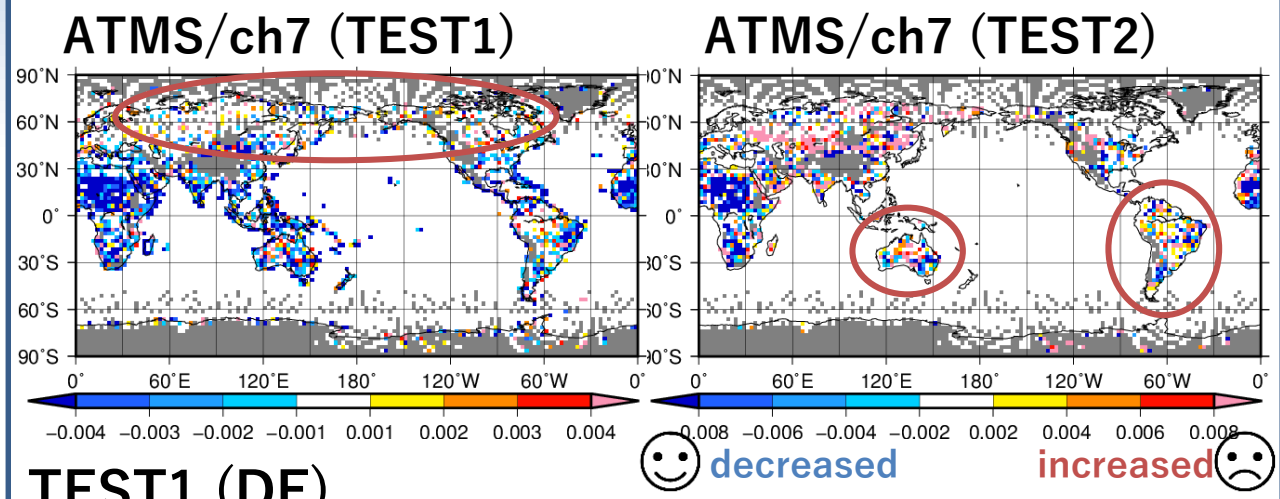


decreased　increased

Statistical verification of O-B STD

TEST1: DE
TEST2: LST
TEST3: DE+LST

Difference between O-B STDs



TEST1 (DE)

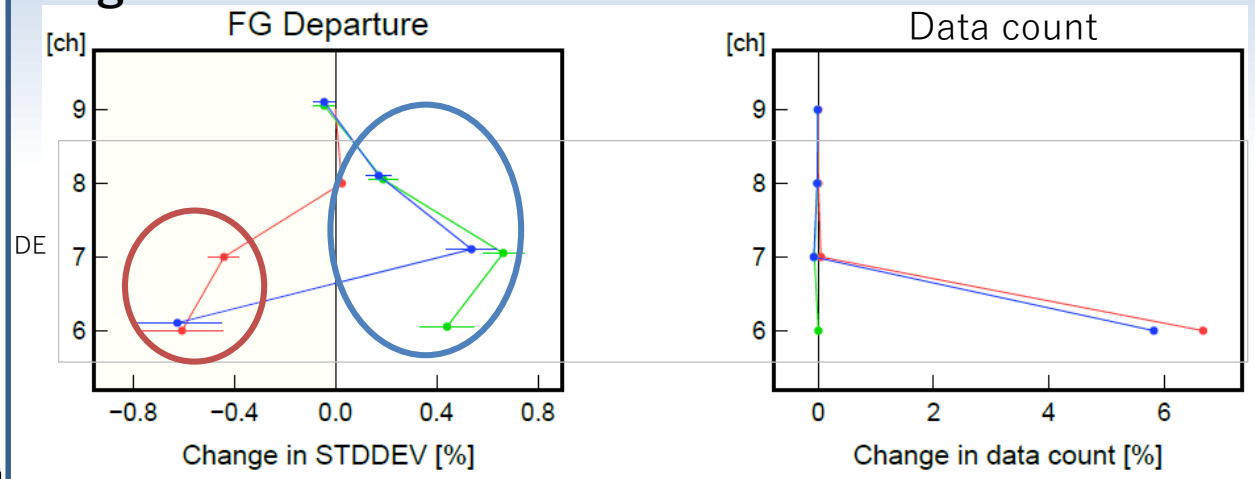
- Similar to AMSU-A,
  - the STD gets smaller over Africa.
  - the STDs are increased over the high latitude areas.
    - Negative impact from snow ?

TEST2 (LST)

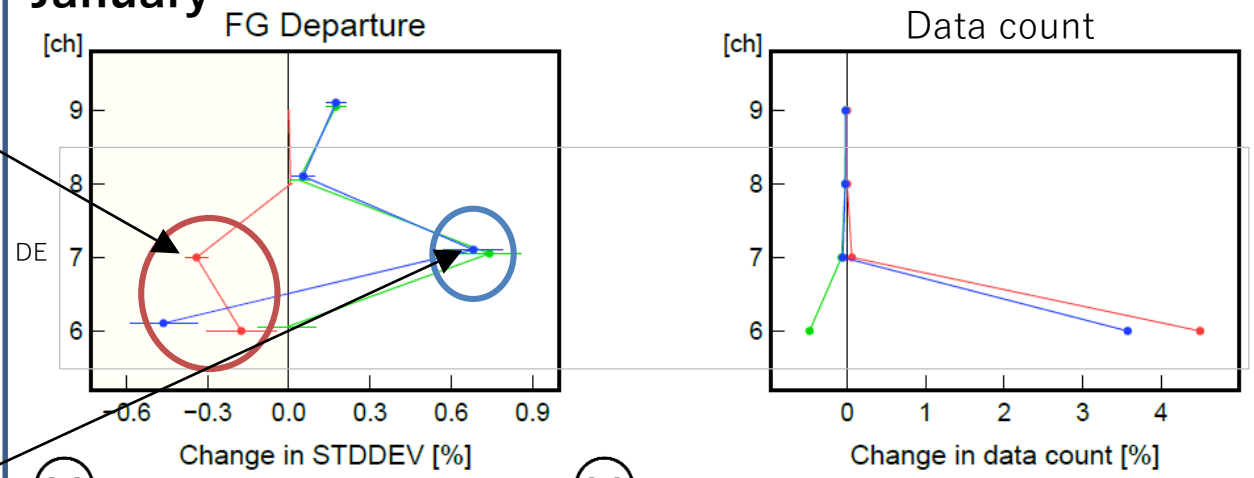
- As different from AMSU-A, the STDs are increased over Australia and South America.

ATMS

August



January



Summary of preliminary investigation

AMSU-A

- TEST1 (DE)
  - The FG is generally closer to the observation, particularly over the arid areas and coastlines. Over the Antarctic and high latitude areas in winter, the STDs of O-B are increased.

    → Negative impact from snow ?
- TEST2 (LST)
  - The increase and decrease of STD are different from TEST1.
  - The STD gets much larger than that of TEST1 over the mid Asia and India.

ATMS

- TEST1 (DE)
  - Generally, the STD of O-B becomes small in the same areas as AMSU-A.
- TEST2 (LST)
  - As different from AMSU-A, the STDs are increased over Australia and South America.

  → Bias corrections or local times of satellites?
- Impacts from the retrieved LST (TEST2 or TEST3) are different from AMSU-A even if the frequencies are the same.
  - The STDs of FG are increased over Australia and South America, which should be investigated.

Performance: TEST1 ≥ TEST3 > TEST2

» DA cycle experiments are performed for TEST1 and TEST3

Experimental settings of DA cycle

- Global NWP system of JMA (operational system as of Dec. 2021)
  - Hybrid 4D-Var
  - Outer model: TL959L128 (20 km)
  - Inner model: TL319L128 (55 km)
- settings
  - The DE is applied to AMSU-A/chs. 6, 7 and ATMS/chs. 7, 8 over land.
    - Although AMSU-A/ch5 and ATMS/ch6 are used over land in the preliminary investigation to investigate their impacts, they are not used in the operational settings.

Name	Emissivity	LST
CNTL	Atlas emissivity	Model LST (as same as the operational settings)
TEST1 (DE)	**DE**	Model LST
TEST3 (DE+LST)	**DE**	**Estimated from observation**

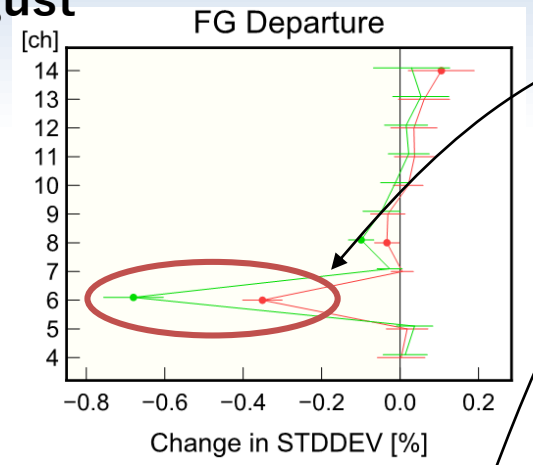
- Period: 21 Jul. 2020 – 11 Sep. 2020,
  21 Dec. 2020 – 11 Feb. 2021

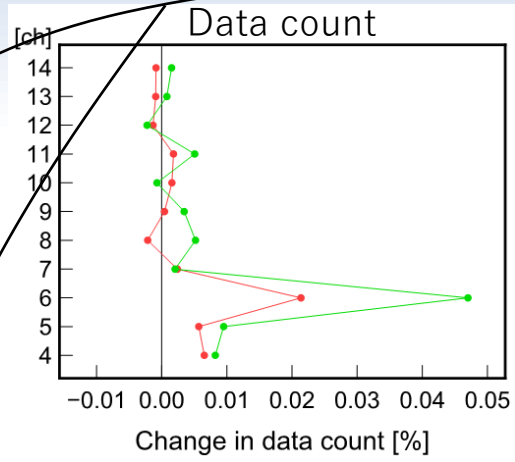
Statistical verification of O-B STD

TEST1: DE
TEST3: DE+LST

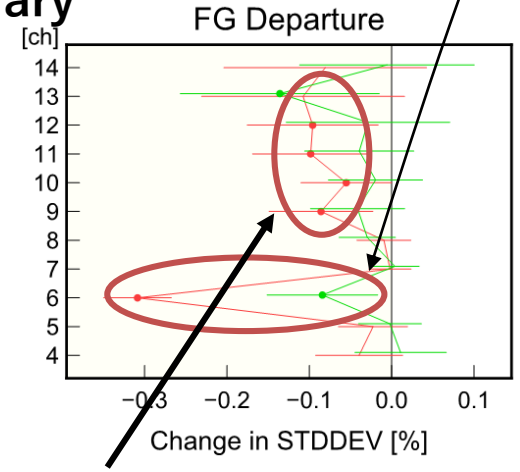
AMSU-A

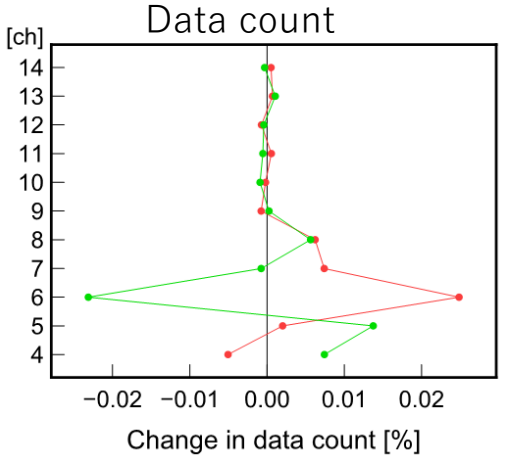
August



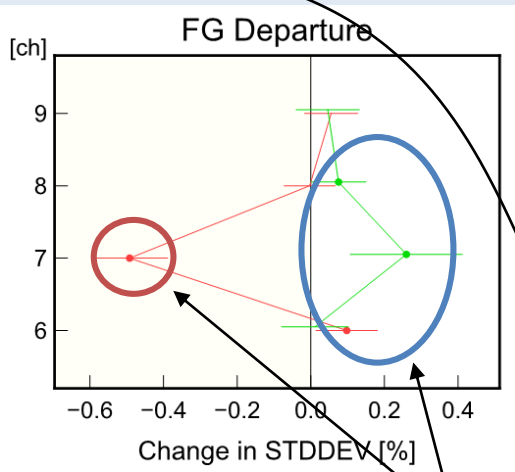


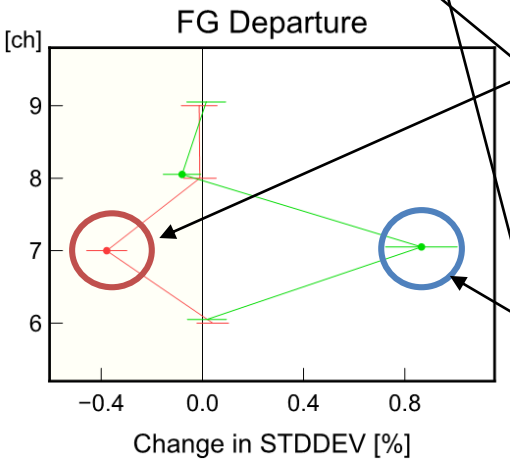
January





ATMS





Almost similar impacts of the preliminary investigation are obtained.

AMSU-A

- The FG is generally closer to the observation, particularly over the arid areas.

ATMS

TEST1 (DE)

- Generally, the STD of O-B becomes small in the same areas as AMSU-A.

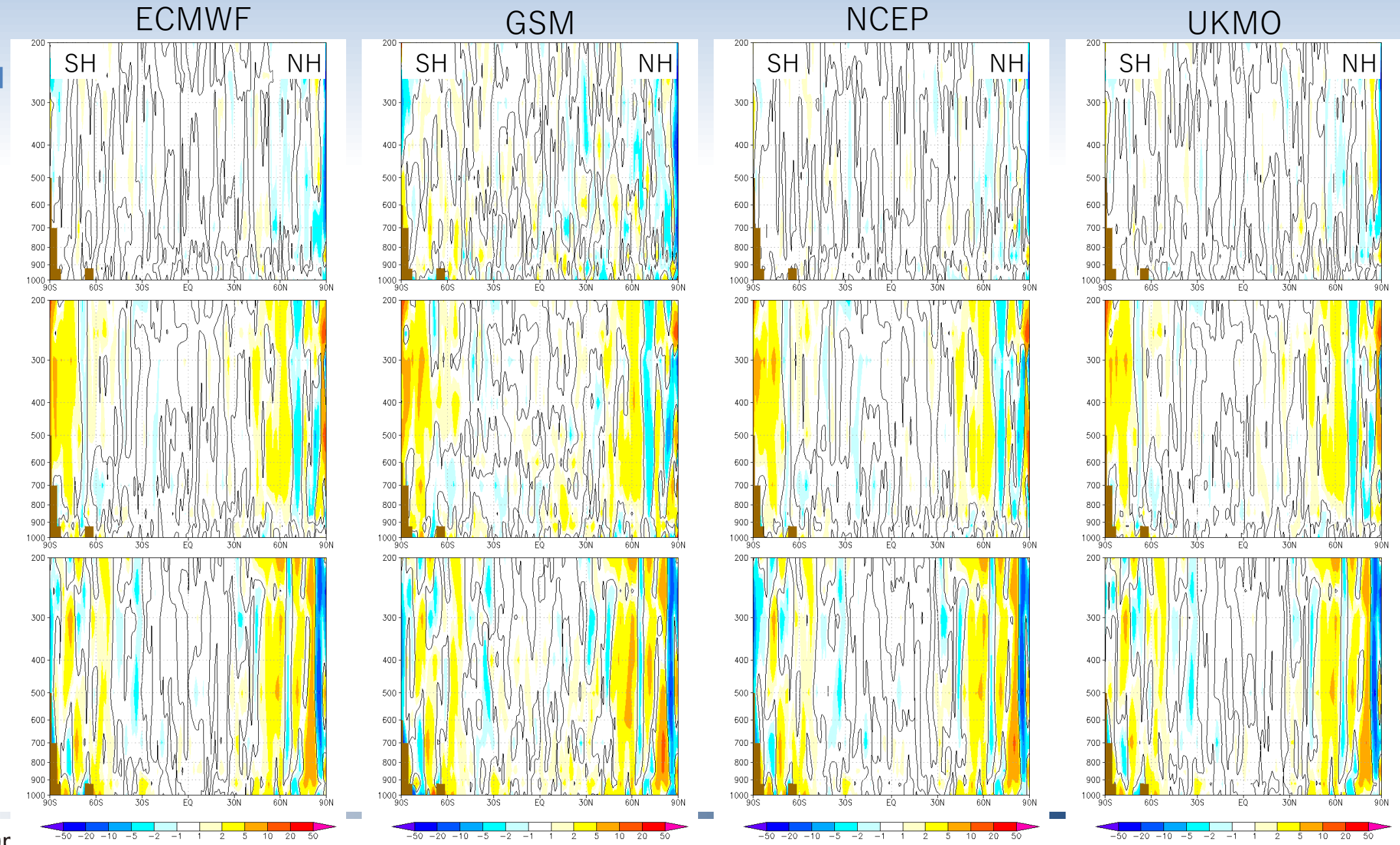
TEST3 (DE+LST)

- As different from AMSU-A, the STD is increased.

- At chs.9-12 in January, the STD of TEST1 is decreased, namely the FG is improved, which may come from the DA cycle impact.

Comparison with multi-center analyses (TEST1, T, Aug.)

Red: improved
Blue: degraded



Comparison with multi-center analyses (TEST1, T, Jan.)

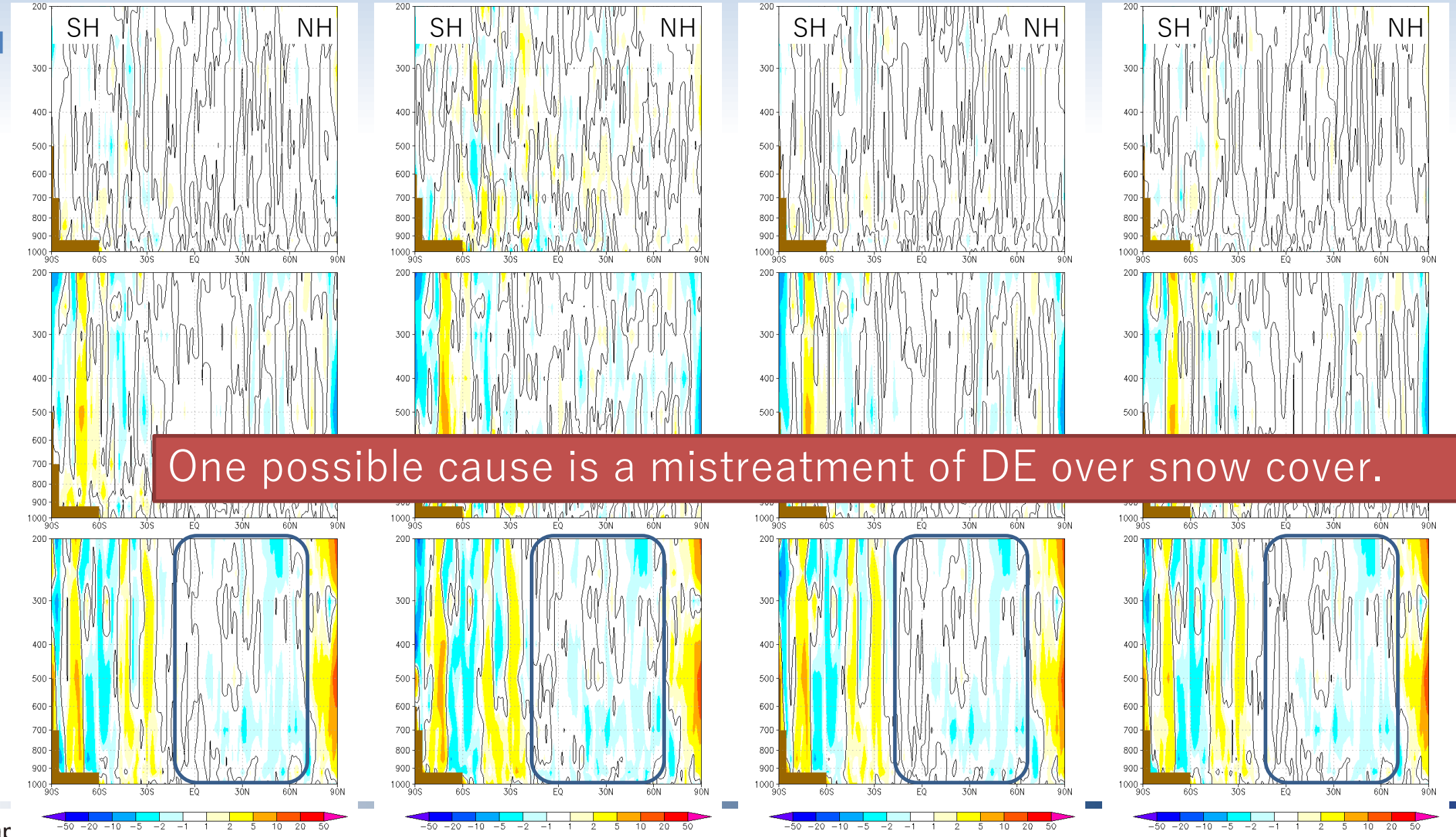
Red: improved
Blue: degraded

ECMWF | GSM | NCEP | UKMO

FT24

FT72

FT120



One possible cause is a mistreatment of DE over snow cover.

Summary of DA cycle experiments

- The DE method was investigated by using the global NWP system of JMA for MW temperature sounders over land to improve analysis and forecast.
  - The DE method improves the forecast in August, but degrades it in January in the NH.
    - One possible cause is a mistreatment of DE over snow cover.

Future works

- We will investigate the impacts on the DE and retrieved LST as follows,
  - Difference between AMSU-A and ATMS
  - Satellite local time, bias corrections
  - Snow cover, desert and coast line
- Assimilating more surface-sensitive channels (AMSU-A/ch5, and ATMS/ch6) over land should be investigated to improve forecasts of lower atmosphere.
- QC parameters for precipitation detection over land will be determined to avoid the negative influence from thick clouds and precipitations.


THANK YOU VERY MUCH!