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 JMA global NWP system, the climatological atlas emissivity is used for the microwave (MW) radiance assimilation over land.

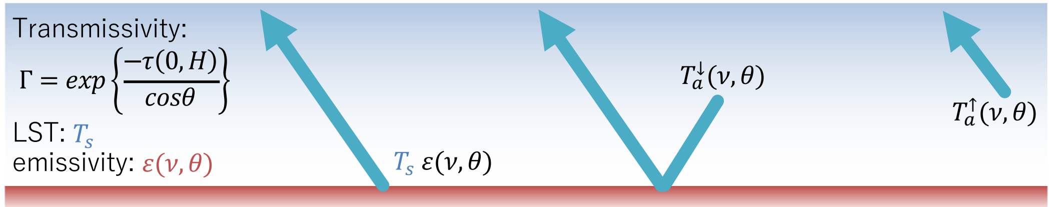
- JMA/MRI is working on applying a dynamic emissivity (DE, Karbou et al. 2006) method to the global NWP system of JMA to reduce uncertainty related to the radiative transfer calculation.
  - The DE method can dynamically estimate the emissivity.
  - Initial implementation of the DE method did not improve forecast scores.
  - 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



Step1: 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}.

Step2: 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.
We can use either estimated T_s or model T_s.

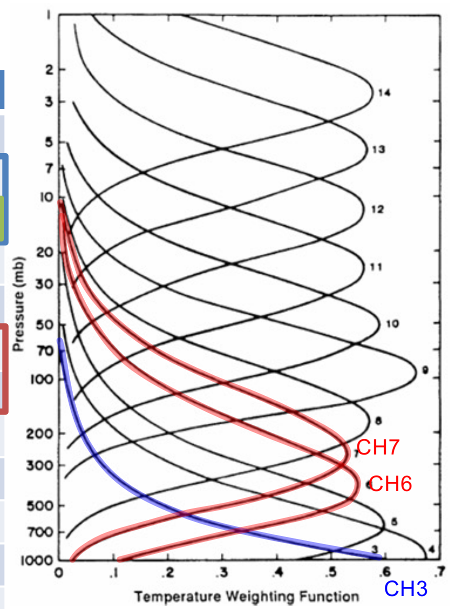
When T_s and ε are estimated simultaneously, different channels are used for them.

Target sensors of DE

- Target sensors : AMSU-A, ATMS
- LST is estimated at 50.3 GHz.
- DE is estimated at 31.4 GHz or 50.30 GHz (Bormann et al. 2017).
- DE is used at surface-sensitive CHs over land.
  - AMSU-A
    - 54.40 GHz (ch6)
    - 54.94 GHz (ch7)
  - ATMS
    - 54.40 GHz (ch7)
    - 54.94 GHz (ch8)

CHs. 4 and 5 are not assimilated over land.

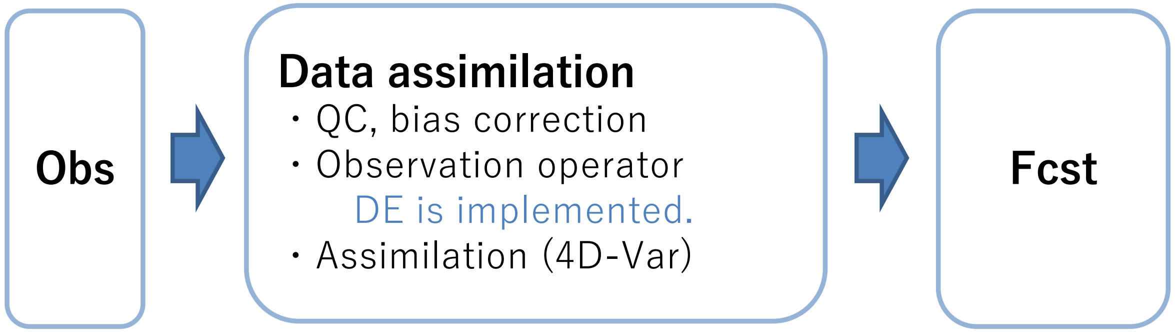
CH	Central frequency	Absorption	Assimilation
1	23.800 GHz	H_2O	
2	**31.400 GHz**	**window**	
3	**50.300 GHz**	**O_2**	
4	52.800 GHz	O_2	○ (sea)
5	53.595 GHz ± 115 MHz	O_2	○ (sea)
6	**54.400 GHz**	**O_2**	○
7	**54.940 GHz**	**O_2**	○
8	55.500 GHz	O_2	○
9	57.290 GHz (=f0)	O_2	○
10	f0±217 MHz	O_2	○
11	f0±322.2 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 for AMSU-A (Janssen,1993)

Implementation of DE

- DE is implemented and tested in an experimental system based on the operational system of JMA.



- Impact investigations for DE
  – Monthly mean emissivity$_{atlas}$(CNTL) vs. DE (TEST1r)
    - Forecast scores were not improved because of the model LST.
  – Replace the model LST with the estimated LST in the DE method (TEST10).
    1. LST is estimated with observation brightness temperature using atlas emissivity.
    2. DE is calculated by using the estimated LST.

Experimental settings

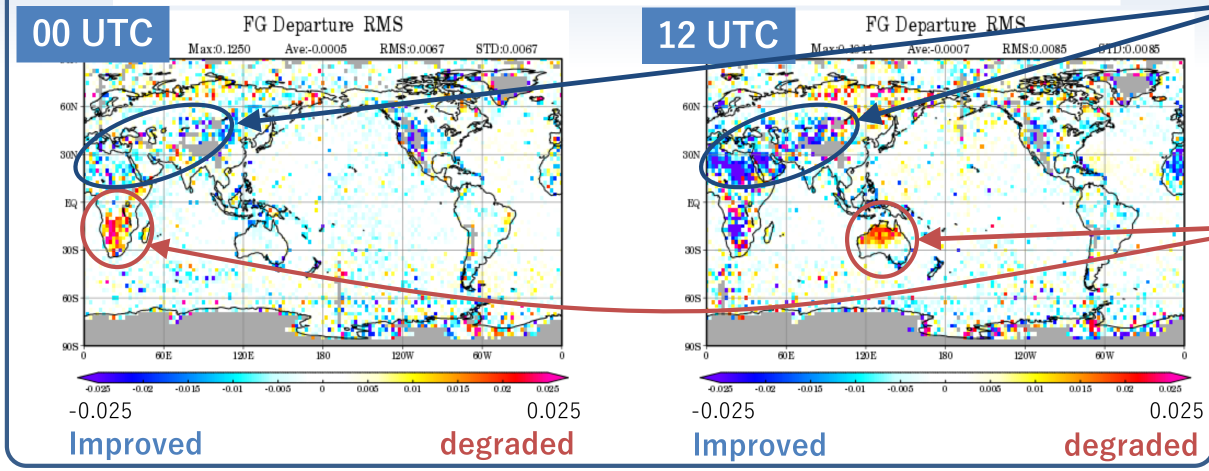
- Global NWP system of JMA (operational system as of Dec. 2019)
  - Hybrid 4D-Var
  - Outer model: TL959L100 (20 km)
  - Inner model: TL319L100 (55 km)
- Experiments

Name	Emissivity	LST
CNTL	Monthly mean	Model LST (operational settings)
TEST1r	**DE**	Model LST based on canopy temperature (LST_{canopy} is corrected to be consistent with MODIS)
TEST10	**DE**	**Estimated from observation**

- Period: 10 Jul. 2018 – 11 Sep. 2018

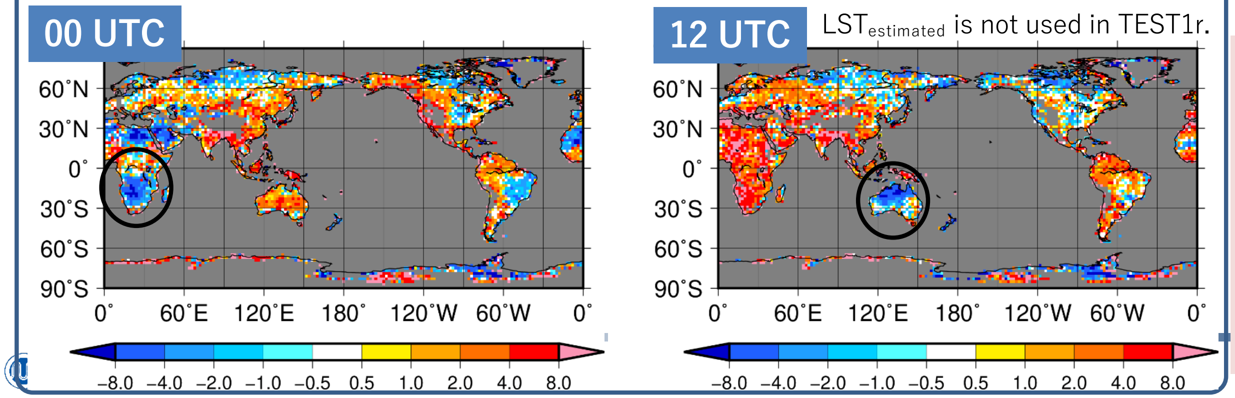
Forecast consistency with obs. and LST

Difference between O-B (FG-obs.) RMSs for AMSU-A CH6 (CNTL - TEST1r with DE & LST_{canopy})



LST_{canopy} - $LST_{estimated}$

$LST_{estimated}$ is not used in TEST1r.



- DE improves the first-guess (FG) mainly over the Africa and central Asia.
- Over arid areas in the night
  - FG of TEST1r is not consistent with observations.
    - The FG brightness temp. of TEST1r is lower (not shown).
  - $LST_{canopy} < LST_{estimated}$

In the TEST1r, the discrepancy between FG and observation would comes from the low LST_{canopy}.

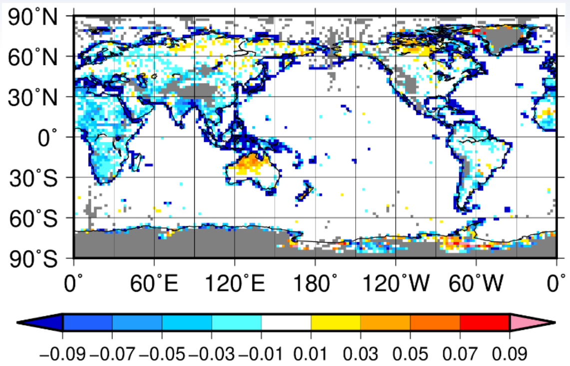
Therefore, TEST10 uses the LST estimated from observation to reduce the discrepancy over arid areas in the night.

Atlas emissivity (CNTL) vs. estimated emissivity (TEST1r, 10)

(Monthly mean emissivities of AMSU-A ch6, on 12 UTC)

TEST1r (DE+LST_{canopy}) − **CNTL**

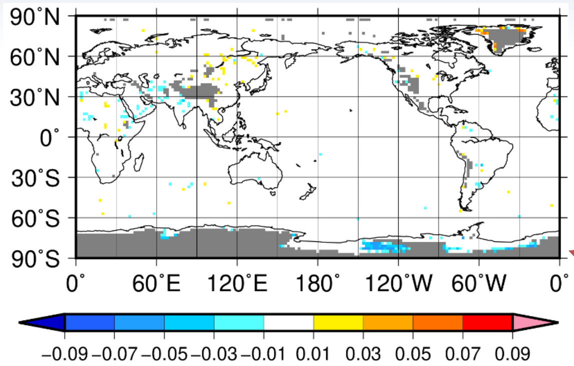
Diff. between $emis_{Atlas}$ and DE



DE is applied on the coast lines.

TEST10 (DE+$LST_{estimated}$) − **CNTL**

Diff. between $emis_{Atlas}$ and DE

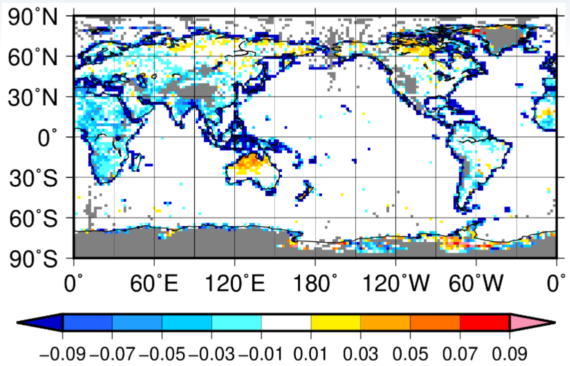


- The $emis_{Atlas}$ and DE_{TEST1r} are widely different.
  - It should be more consistent?
  - That may be caused by poor accuracy of LST_{canopy}.
- By applying estimated LST instead of LST_{canopy}, the difference between $emis_{Atlas}$ and DE_{TEST10} becomes small.

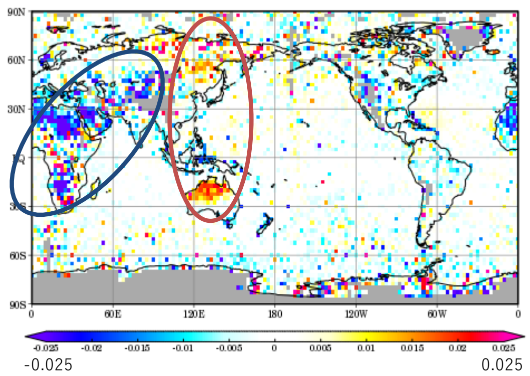
Statistical verification of O-B (AMSU-A ch6, 12 UTC)

TEST1r (DE+LST_{canopy}) − **CNTL**

Diff. between $emis_{Atlas}$ and $emis_{DE}$

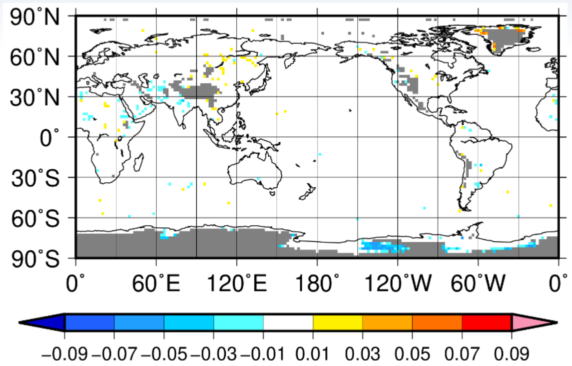


Difference between O-B RMSs

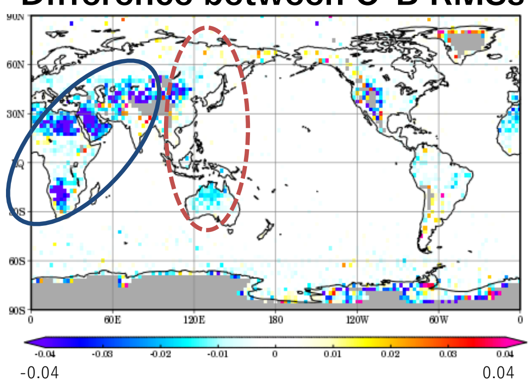


TEST10 (DE+$LST_{estimated}$) − **CNTL**

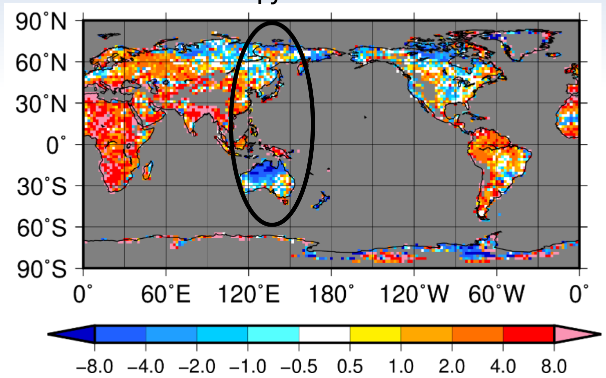
Diff. between $emis_{Atlas}$ and $emis_{DE}$



Difference between O-B RMSs



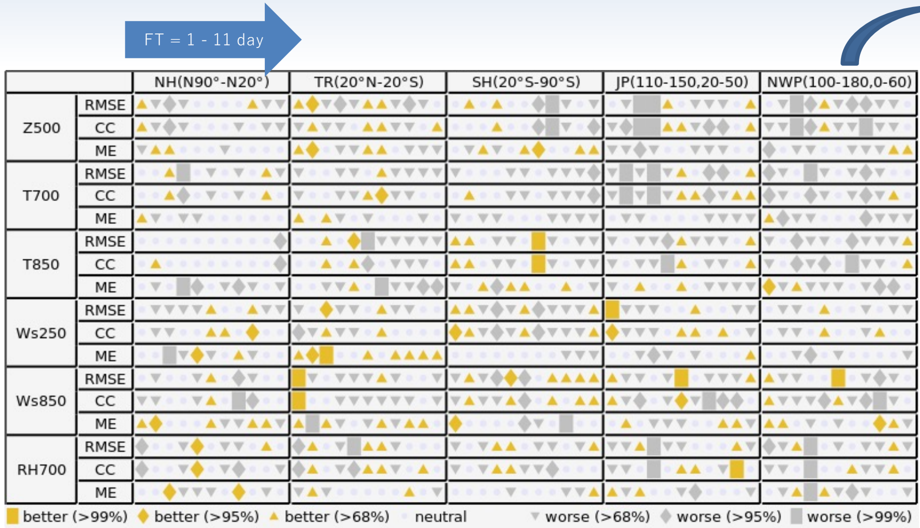
LST_{canopy} - $LST_{estimated}$



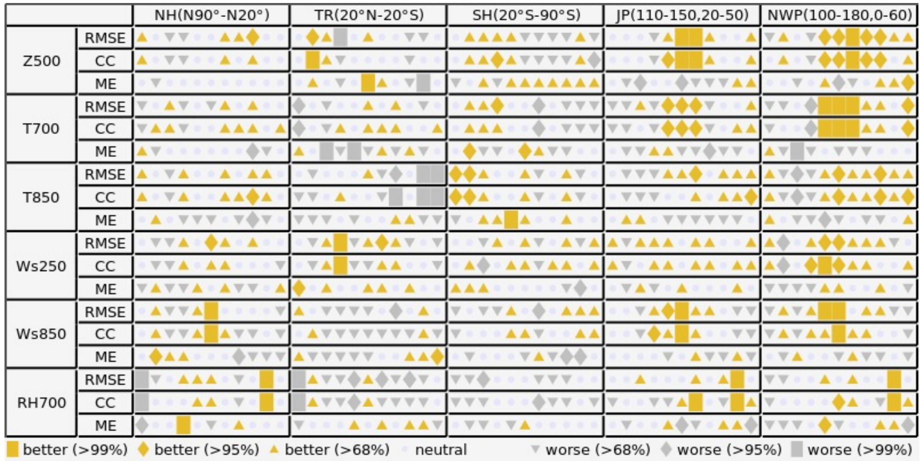
- Impact of DE
  - FG is closer to observations over the arid areas.
- TEST1r vs. CNTL
  - FG is degraded in the night due to LST_{canopy}.
- TEST10 vs. CNTL
  - $LST_{estimated}$ improves emissivity, and then the emissivity improves FG.

Impact of DE for forecast scores

CNTL vs. TEST1r (DE + LST_{canopy})



CNTL vs. TEST10 (DE + $LST_{estimated}$)



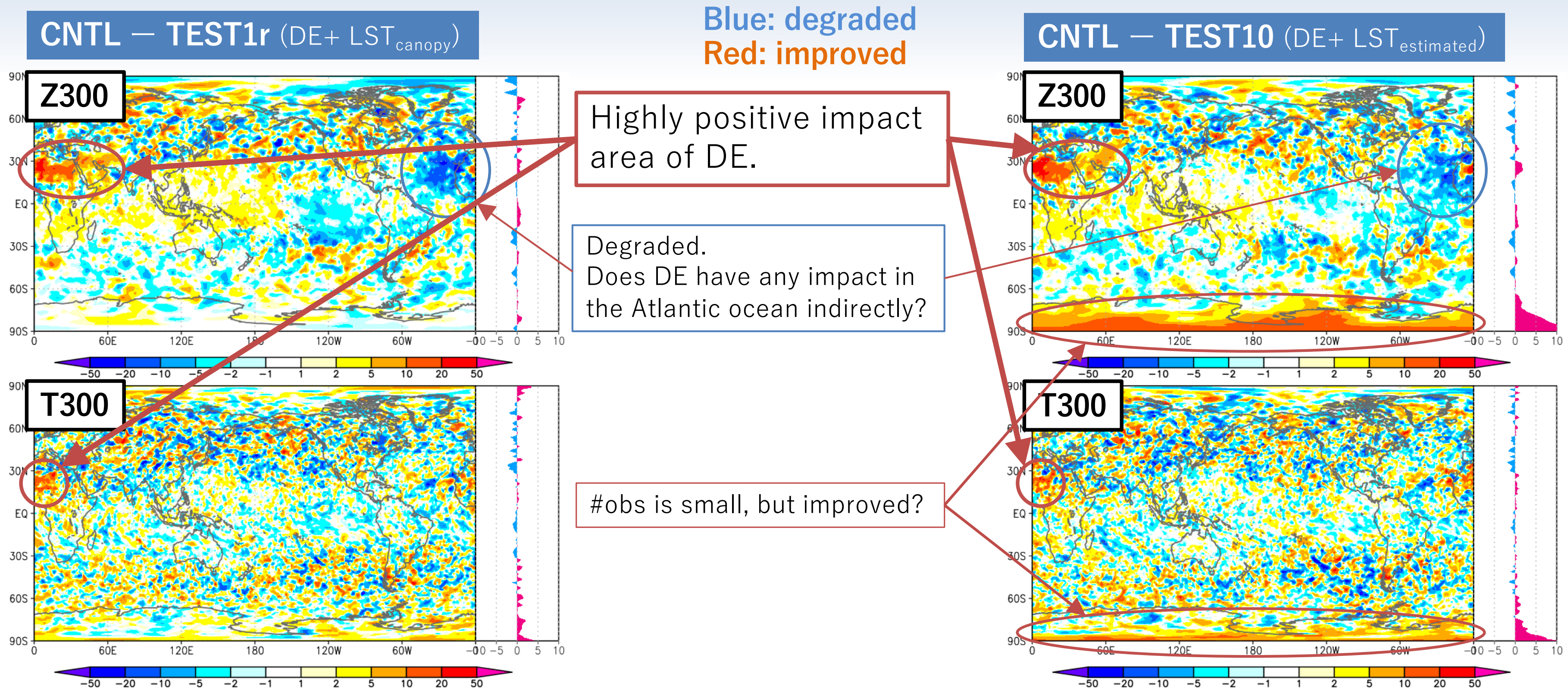
Yellow : improved
Gray : degraded

- CNTL and TEST1r are comparable.
- Forecast scores are degraded around the Japan.

- TEST10 is improved, and better than CNTL and TEST1r.

Improvement of forecast RMSEs (against ECMWF analysis, FT=24 hr)

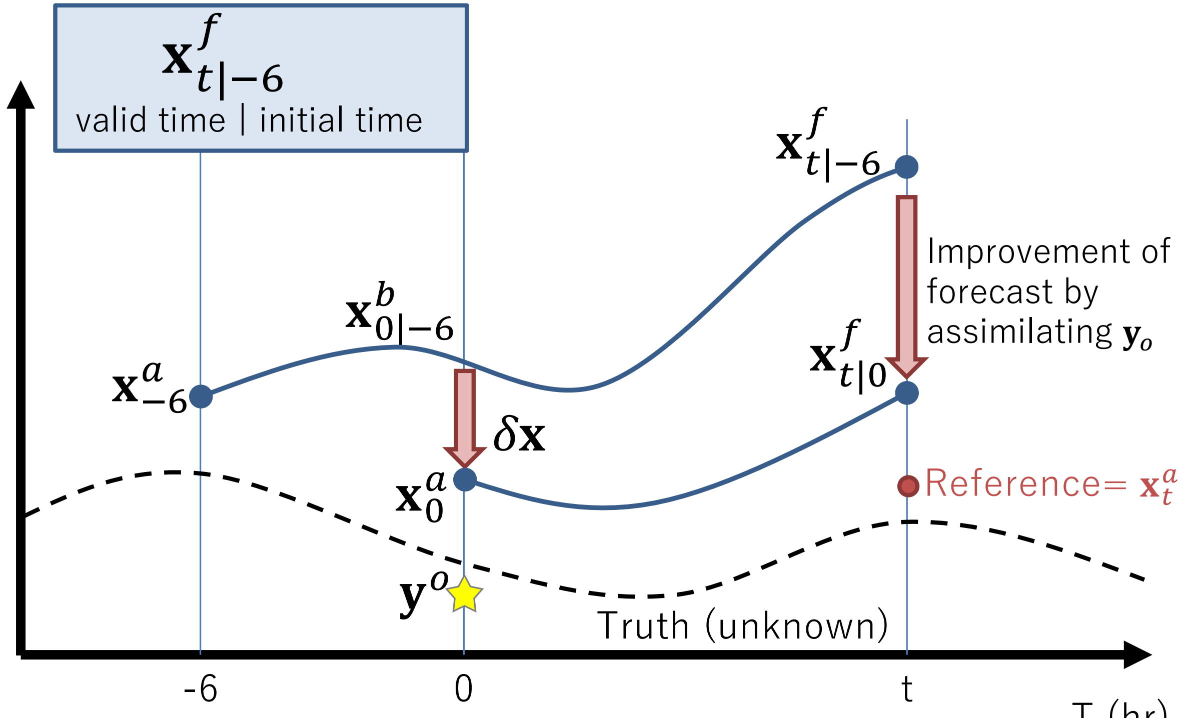
- Verification at 300 hPa where weighting functions for AMSU-A chs. 6, 7 have a peak.



- Forecasts get close to the analysis of ECMWF which has already implemented the DE.

Observation impact from FSOI

- FSOI: Forecast Sensitivity Observation Impact (Langland and Baker 2004)



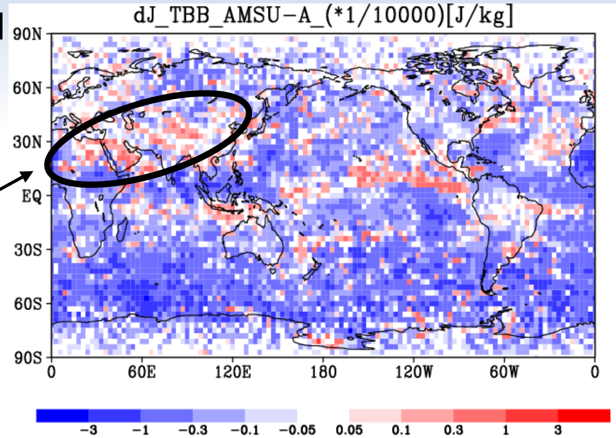
Kalnay et al. (2012), Kotsuki et al. (2019)

- Forecast is improved by assimilating $\mathbf{y}_o$
  - Observation $\mathbf{y}_o$ reduces forecast error.
- FSOI can quantitatively diagnose observation impact for every observation.
  - FSOI<0: beneficial
  - FSOI>0: non-beneficial

FSOI of AMSU-A

Spatial distribution of FSOI for AMSU-A CH6 in Aug. 2018 in the equivalent system of CNTL.

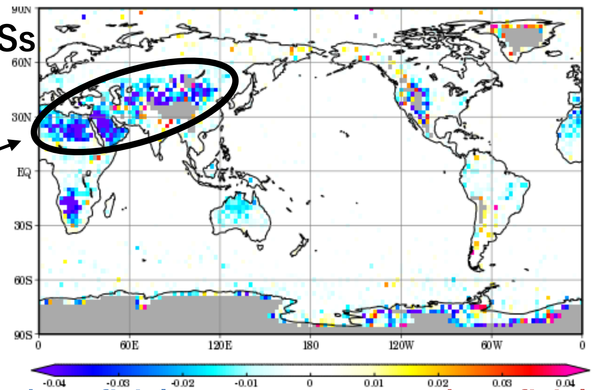
Non-beneficial impact



beneficial non-beneficial

Difference between O-B RMSs
(TEST10 (DE+$LST_{estimated}$) – CNTL)

Improved by DE



beneficial non-beneficial

- FSOI is diagnosed by JMA global NWP system without DE in Aug. 2018 (equivalent system of CNTL).
- Globally beneficial impacts.
  - Especially, in the SH the impacts are large.
- Area with non-beneficial impact over the northern Africa corresponds to the area improved by the FDE.
  - This suggests that the non-beneficial impact may be improved by DE.

Summary

- **The DE method was tested in JMA global NWP system for MW temperature sounders over land to improve analysis and forecast.**
  - Impact of DE
    - The FG with DE is closer to the observation.
    - The area improved by DE are the areas with non-beneficial impact of FSOI.
    - Over the arid areas in the night, the FG is degraded due to poor accuracy of LST_{canopy} which would include model bias.
      - To prevent the degradation of FG, LST is also estimated with atlas emissivity.
      - After LST is estimated, the DE is calculated by using the estimated LST.
  - Impact of estimated LST in the DE method.
    - The FG gets closer to the observations at the channels using the DE in the night.
    - In the DE method, the LST is important because the emissivity is calculated by the LST.
  - 24-hr forecast using DE gets consistent with the ECMWF analysis mainly in the northern Africa.
- **Future plans**
  - QC parameter for precipitation detection over land will be determined using a precipitation product (GSMaP).


THANK YOU VERY MUCH!