Impact of clear-sky radiances at CO2 band in the JMA's global data assimilation system

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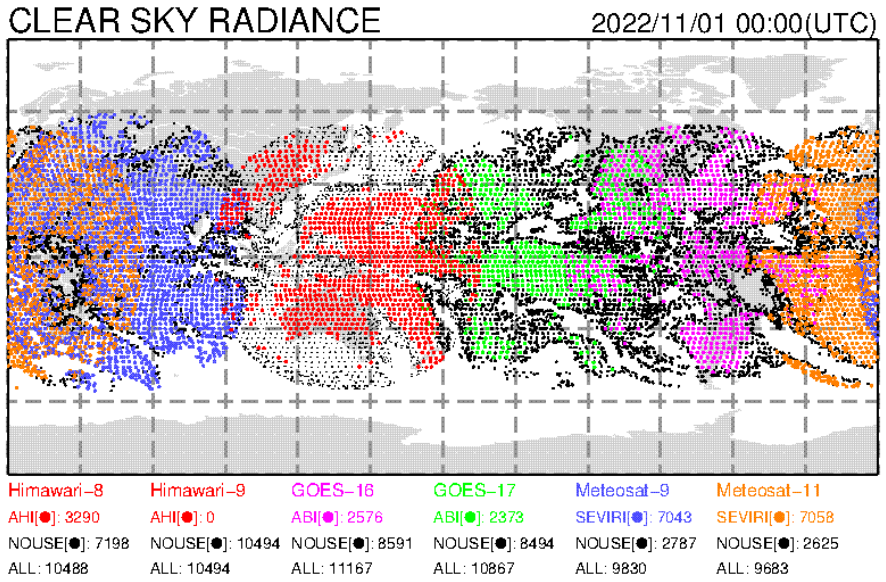
Introduction

- Clear-Sky Radiances(CSR) derived from geostationary satellites are assimilated in the JMA's operational global numerical weather prediction(NWP) system.
- CSRs at only water vapor(WV) bands 6.2, 6.9 and 7.3 μm are currently used and contribute to improvement of forecast about WV at the mid and upper troposphere.
- We are working on assimilation of CO2 band of CSRs to improve forecast of temperature.



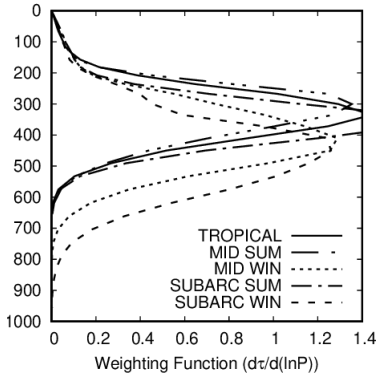
The figure shows CSR coverage map of JMA's global NWP system at analysis time of 00UTC Nov 1, 2022.
The assimilated CSRs are from Himawari-8, GOES-16/-17 and Meteosat-9/-11.

Weighting functions

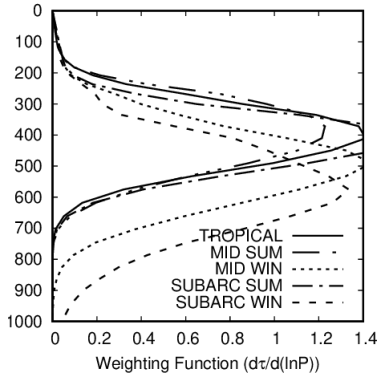
CO2 band (13.4-13.4 μm) has information about temperature and WV in the middle and lower troposphere.

Himawari-8/AHI

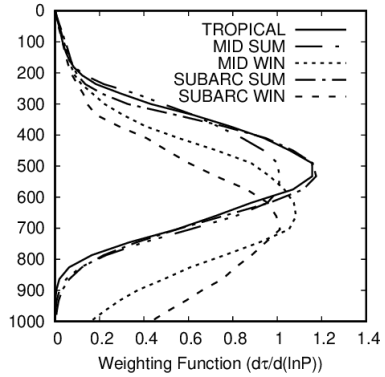
Band 8 (6.2μm)



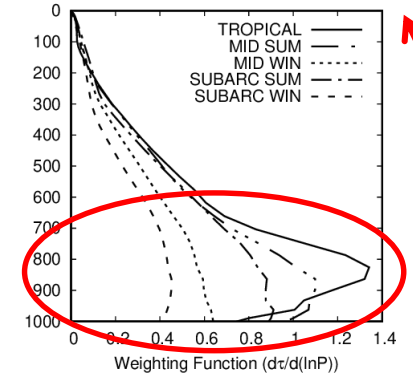
Band 9 (6.9μm)



Band10 (7.3μm)

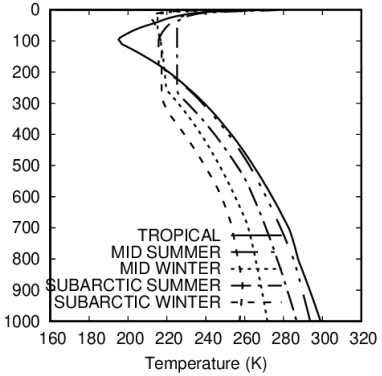


Band16 (13.3μm)



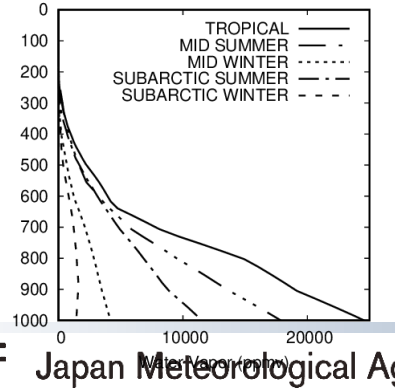
CO2 band

Temperature

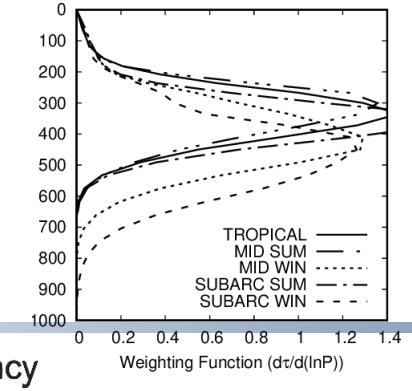


Meteosat-8/SEVIRI

Specific humidity

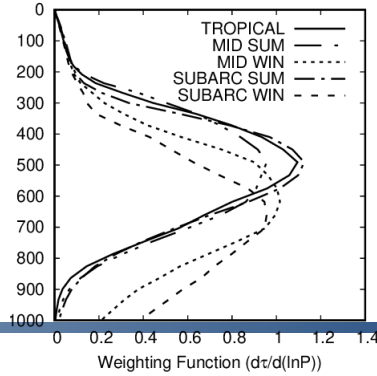


Band 5 (6.2μm)

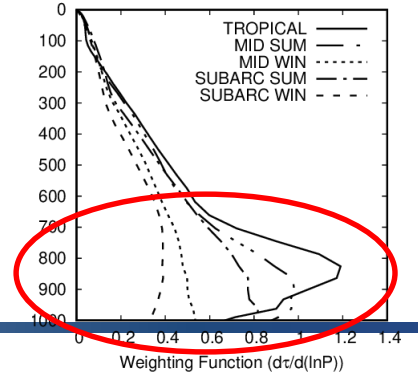


No band at 6.9 μ m

Band 6 (7.3μum)



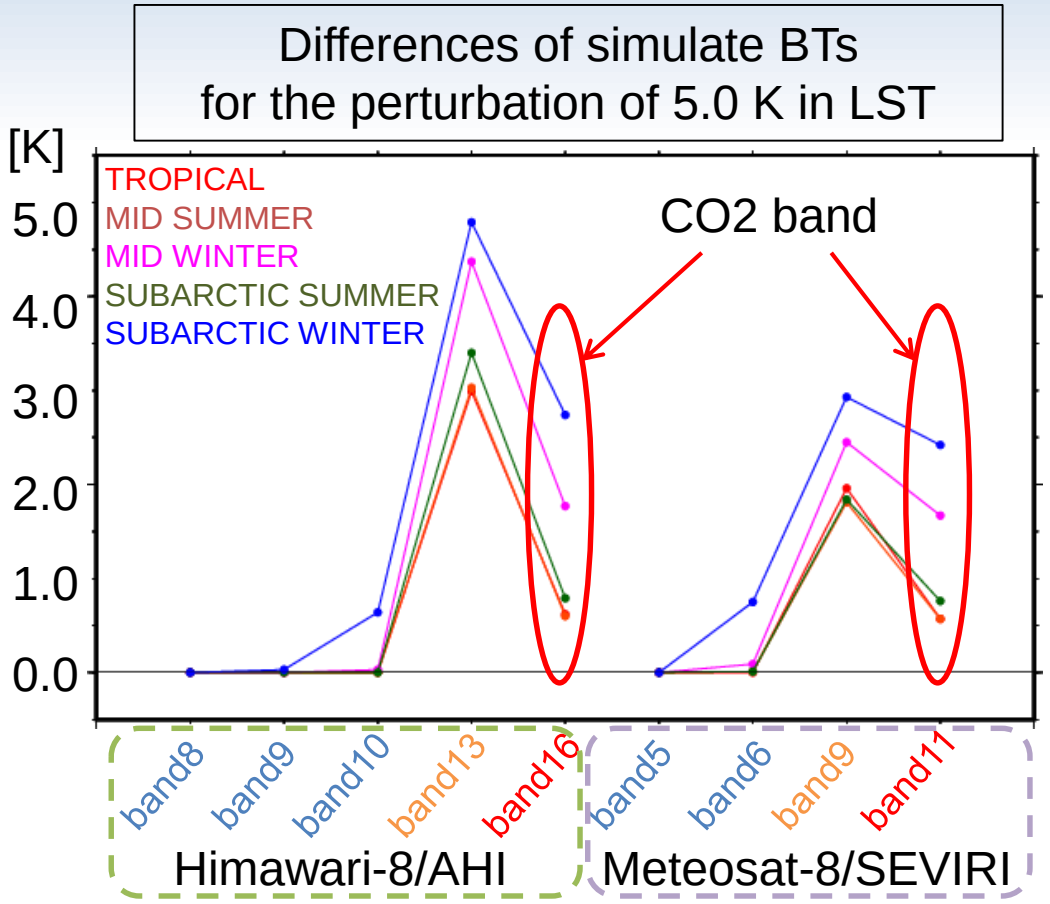
Band11 (13.4μm)



Sensitivity of CO2 band to LST

CO2 band has high transmittance and is influenced by radiance from surface. Especially, land surface temperature (LST) is uncertain. We investigated sensitivity of CO2 band to LST.

- Method:
  - ① Use RTTOV v12 for RT calculation.
  - ② simulate brightness temperature (BT) for some atmospheric profiles with different latitudes and seasons.
  - ③ simulate BTs again but for profiles with the perturbation of 5.0 K in LST (the model's LST has errors in such order).
  - ④ Take the differences between ③ and ②



The influence of error in LST on RT calculation is non-negligible.
Accurate LST is required.

Retrieval method of LST using window band

Retrieved LST is calculated from window band CSR observation and atmospheric profiles in a model through radiance transfer equation.

Radiative transfer equation:

Observation of window band CSR

Atmospheric profile of background in the model

$$B(\mathrm{BT}) = \tau_t \varepsilon_s B(\mathrm{LST}) + \int_{\tau_t}^{1} B(\mathrm{T}) d\tau + (1-\varepsilon_s)\tau^2 \int_{\tau_t}^{1} \frac{B(\mathrm{T})}{\tau^2} d\tau$$

Retrieved LST

These terms for window band are so small that the difference between actual observation and model is negligible.

B: the Planck function, BT: brightness temperature, τ_t: the surface to space transmittance, ε_s:the surface emissivity, τ: transmittance at a certain height, T: atmospheric temperature, h: the Planck constant, k: the Boltzmann constant, v: frequency, c: the light speed.

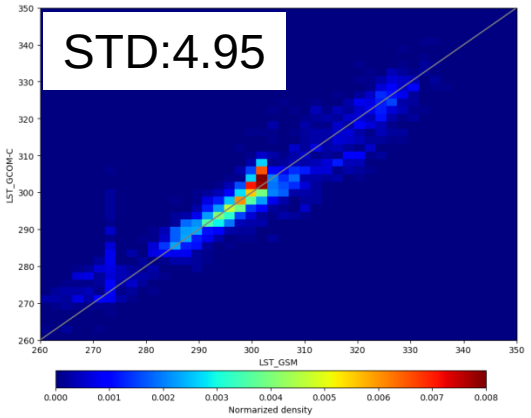
Validation with GCOM-C's LST

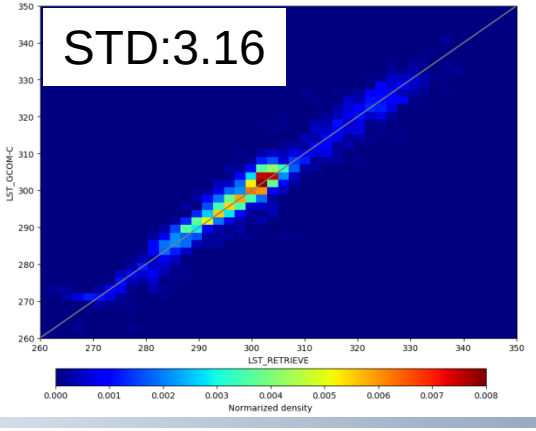
LST retrieved from window band CSR is validated with GCOM-C's LST product.
The result shows random error (standard deviation; STD) of the retrieved LST is 1.3 to 2.2 K smaller than the model's LST.

Horizontal axis :
Model's LST
Vertical axis :
GCOM-C's LST

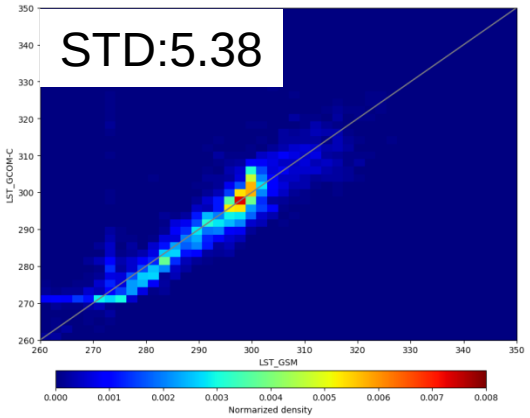
Horizontal axis :
Retrieved LST
Vertical axis :
GCOM-C's LST

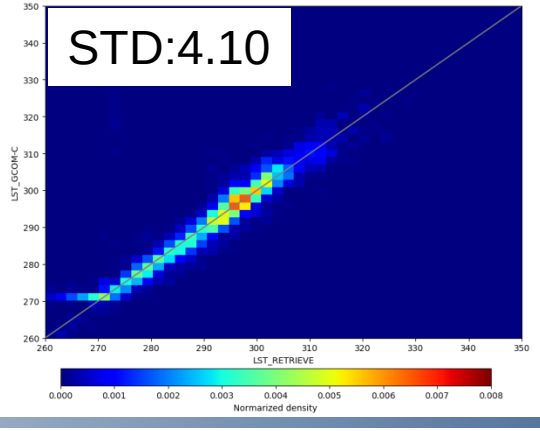
Himawari-8/AHI



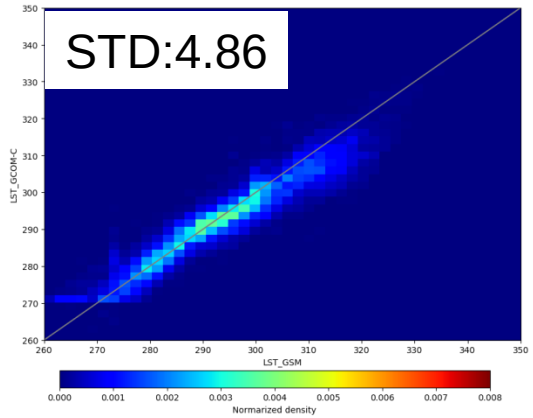


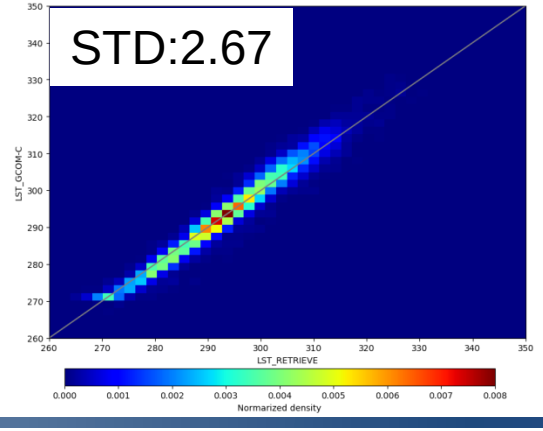
GOES-16/ABI





Meteosat-8/SEVIRI





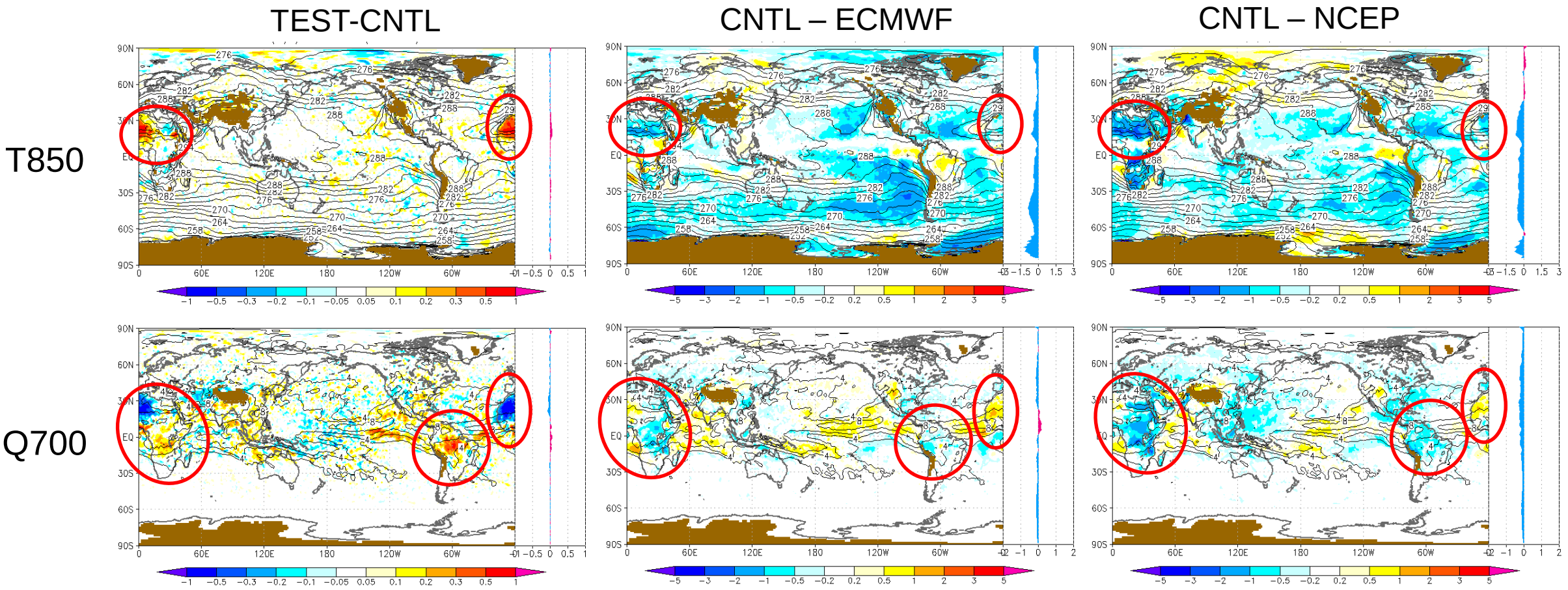
Statistical period:
January 2020

Experimental configuration

- Control: The global data assimilation system of JMA (the latest operational system) . The radiative transfer model is RTTOV-13.0 (Saunders et al. 2020).
  - Analysis time: 00, 06, 12, 18UTC
  - Hybrid 4D-Var
  - Outer model: TL959L128 (20 km)
  - Inner model: TL319L128 (55 km)
- Test: Same system configuration as Control except using CO2 band CSRs of Himawari-8, GOES-16, Meteosat-8 and -11.
- The quality control for CO2 band CSRs is based on it for WV band CSRs.
  - The threshold of standard deviation for Meteosat 8 and 11 is smaller than that for WV band CSRs in order to reject cloud contaminated data.
- Period: January and August 2020
- Forecast of JMA's Global Spectral Model(GSM) is also conducted.

Mean analysis (August 2020)

CNTL has bias of WV and temperature in the lower troposphere compared with other center analysis. TEST decreases bias of WV and temperature over South America and Africa on impact of assimilation of CO2 band CSRs. The decrease of bias over South America is also confirmed by radiosonde observation.

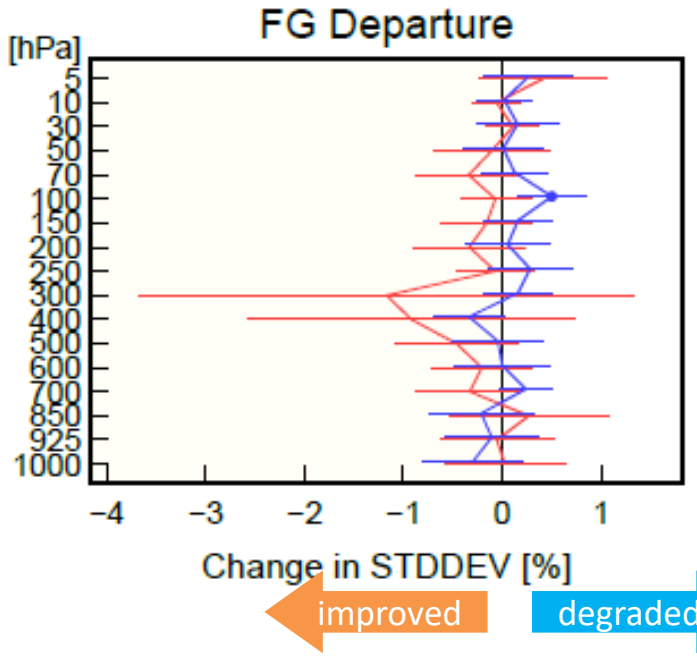


Short-range forecasts

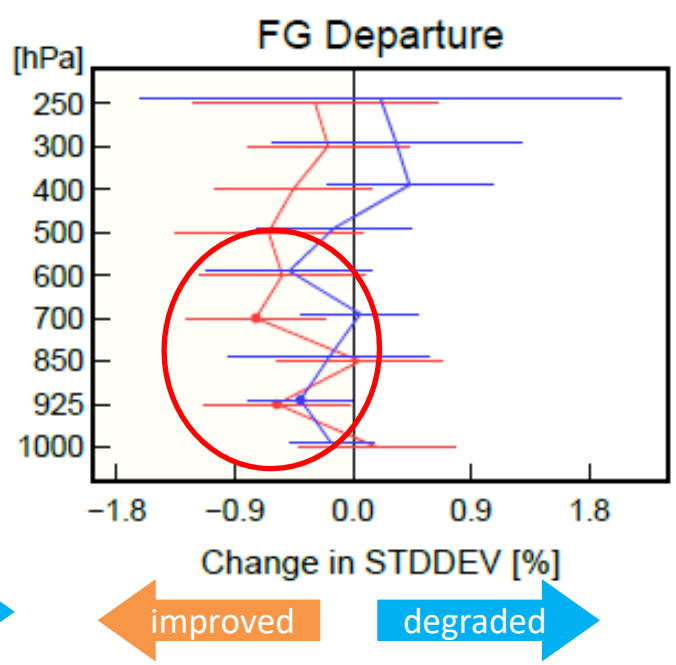
Fitting of First Guess (FG) to relative humidity from radiosonde is improved in lower troposphere and FG to temperature from land surface observation is improved. It suggests FG is improved.

—: Jan. 2020
—: Aug. 2020

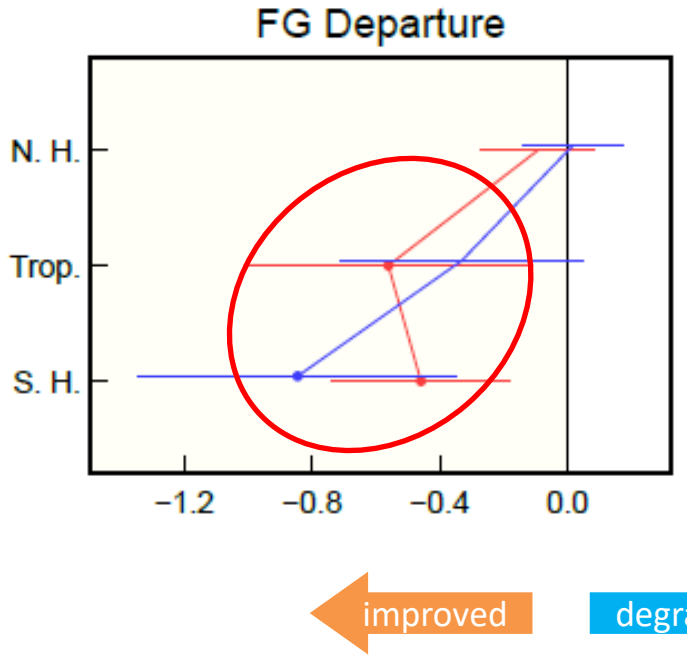
RAOB / T



RAOB / RH



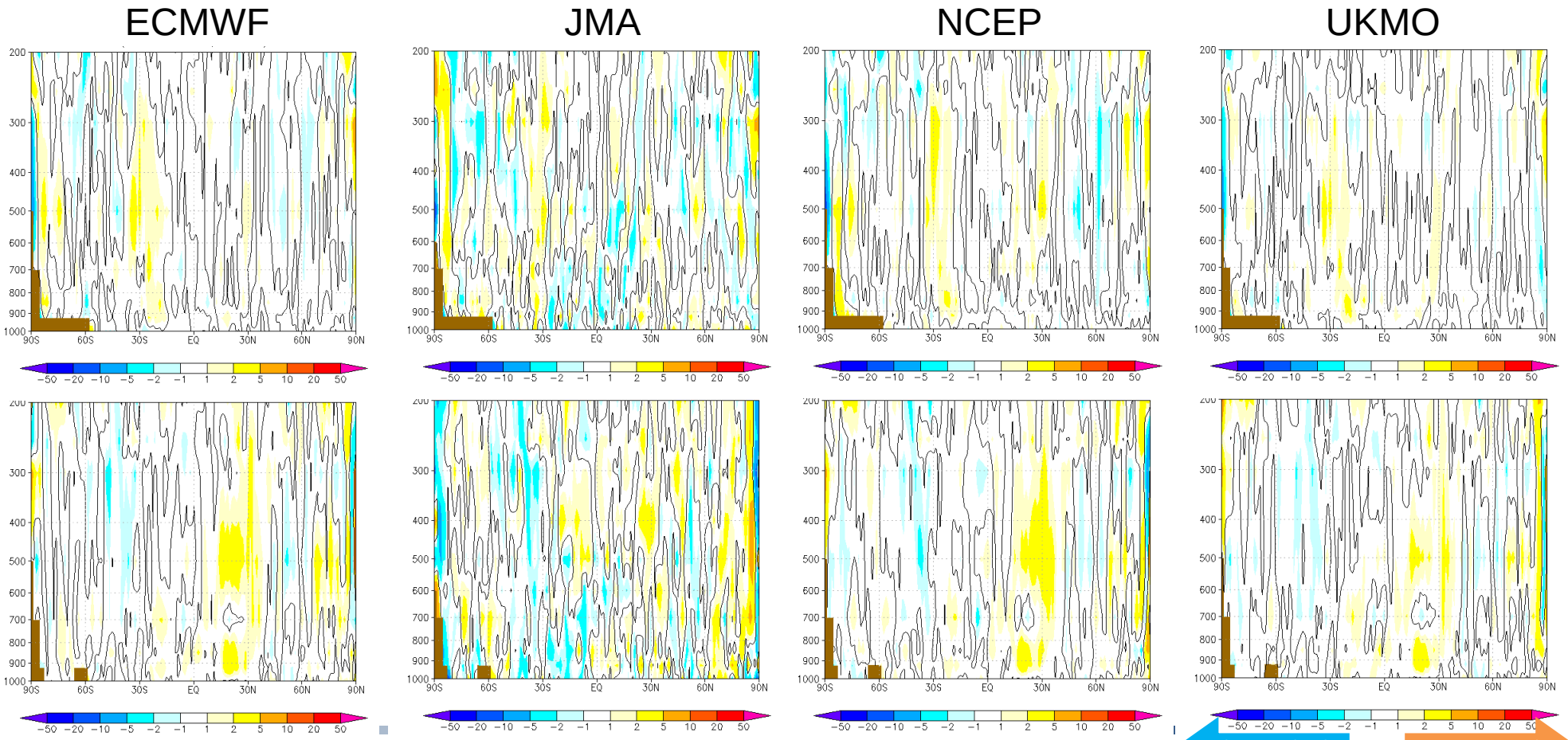
Land Surface / T



Figures: Change ratio of standard deviation of the first guest (FG) departure.

Middle range forecasts about temperature

Forecast scores of temperature are improved near 30 degrees in the summer hemisphere. Forecast score of specific humidity is also improved (not shown).
The score is defined as (RMSE_CNTL - RMSE_TEST)/RMSE_CNTL × 100.

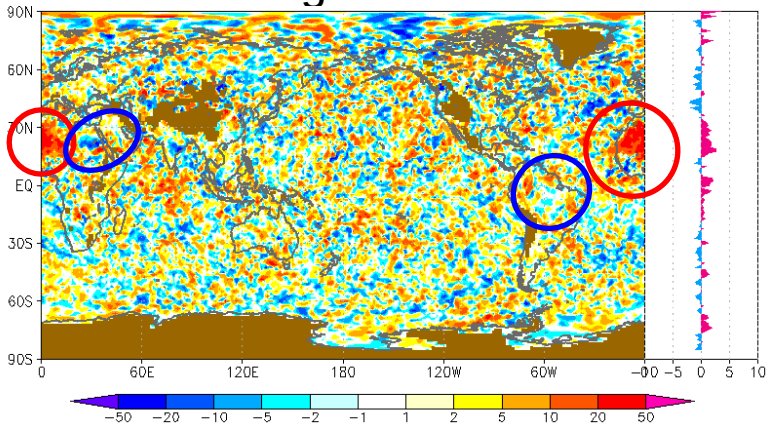


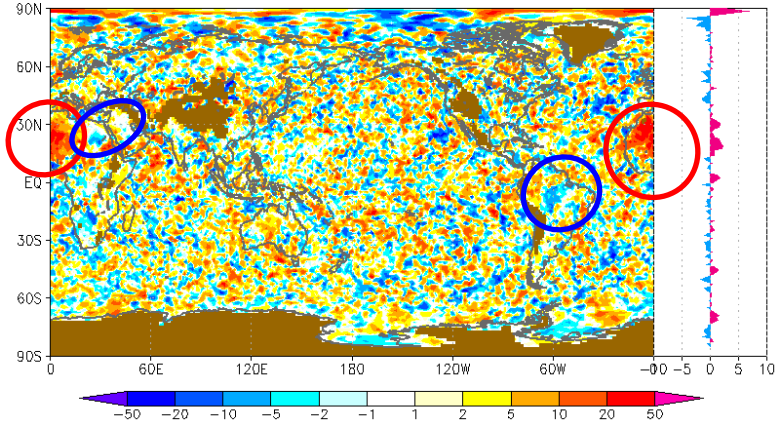
Middle range forecasts (August 2020)

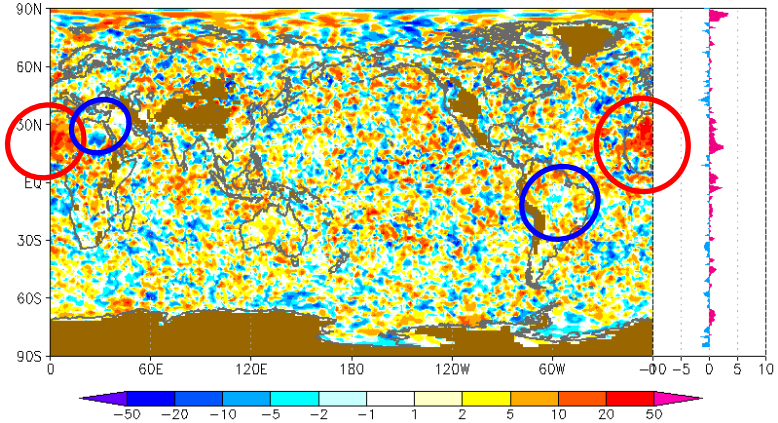
Forecast scores are improved due to decrease of bias over most of South America and Africa. But forecast score of temperature is degraded over part of South America and Africa.
The score is defined as (RMSE_CNTL - RMSE_TEST)/RMSE_CNTL × 100

Score against ECMWF | Score against NCEP | Score against UKMO

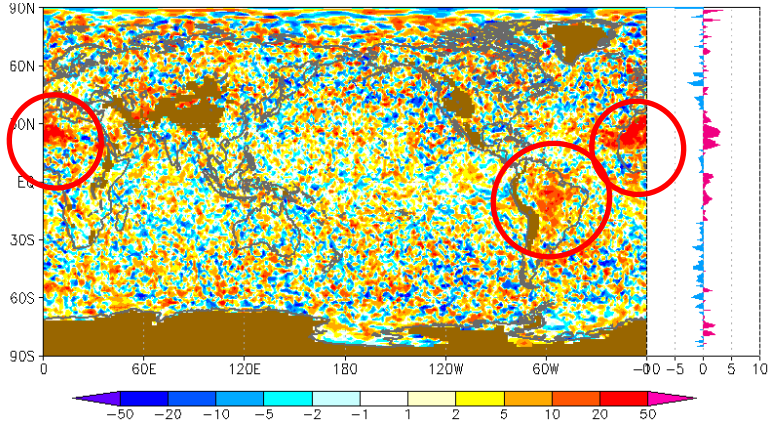
FT=24 T850

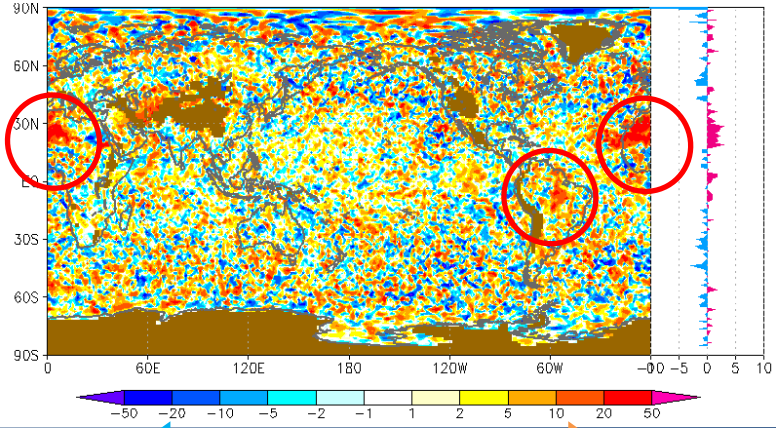






FT=24 Q850





Red circle: improved area of forecast
Blue circle: degraded area of forecast

Uwiremis dataset(Borbas and Ruston 2010) is used as land surface emissivity in experiments. A possible cause of the degradation is departure of emissivity from reality(under investigation).

Summary

- CO2 band (13.3-13.4 μm) CSRs have information about temperature and WV in the middle and lower troposphere.
- Accurate LST is necessary for assimilating CO2 band because it is sensitive to LST. Retrieval of LST enables the use of CO2 band over land. Assimilation of CO2 band CSRs improves forecast score of temperature in mid and lower troposphere.
- The degradation of forecast score over part of South America and Africa will be investigated further.

Future work

- New emissivity atlas, CAMEL climatology IR emissivity atlas is available in RTTOV-13. We will investigate impact of the emissivity atlas for further improvement of forecasts.