Mesoscale OSSE for the potential impact of a geostationary hyperspectral infrared sounder

Tadashi Fujita[1], Kozo Okamoto[1], Hiromu Seko[1],
Michiko Otsuka[2], Hiromi Owada[3], Masahiro Hayashi[1]

1 Meteorological Research Institute, 2 Meteorological College,
3 Japan Meteorological Agency

This work is based on the operational NWP system developed by Numerical Prediction Division, Japan Meteorological Agency.

GeoHSS OSSE

- OSSE (Observing System Simulation Experiment) to evaluate the effect of a GeoHSS (hyperspectral infrared sounder on a geostationary satellite).
    - GeoHSS is a promising candidate to be an onboard instrument of the Himawari follow-on satellite.
    - GeoHSS can provide high-frequency measurements at a high spectral resolution over a wide fixed area.

- JMA is working on an impact study on JMA Global and Mesoscale NWP systems, assimilating GeoHSS pseudo-observations (Okamoto et al. 2020, SOLA 16, 162-168).

- Reanalysis-based OSSE
    - using ERA5 as the pseudo-truth atmospheric profile. (nature-run is not used)
        - Pseudo observations are generated from ERA5 (truth)
            - => Forecasts do not outperform those initiated with ERA5.
        - Forecasts can be verified against real observations in addition to the truth (ERA5).
            - => Verification is possible using real cases, including high impact severe weather events.

Mesoscale OSSE

- OSSE based on the former JMA operational Mesoscale Analysis
  - 3-hourly 4D-Var cycle (the outer model resolution 5 km, the inner model resolution 15 km)
  - JNoVA 4D-Var (Honda et al. 2005, Outline of NWP (JMA 2019), operated until Mar. 2020)

- T and RH GeoHSS pseudo-observation data
  - 1D-Var retrievals from simulated all-sky BTs (Hayashi et al. 2021, Oyama et al. 2019)
    - BTs are simulated from ERA5, using the satellite position of Himawari, and the spectral characteristics of IRS.
      - Temperature channels: 700 – 742 cm^{-1}, water vapor channels: 1660 – 1984 cm^{-1}.
    - Cloud-affected channels (difference between BTs without and with cloud scattering > 1 K) are excluded.
    - Pseudo-observations are rejected if they are derived using only few BT channels in 1D-Var.

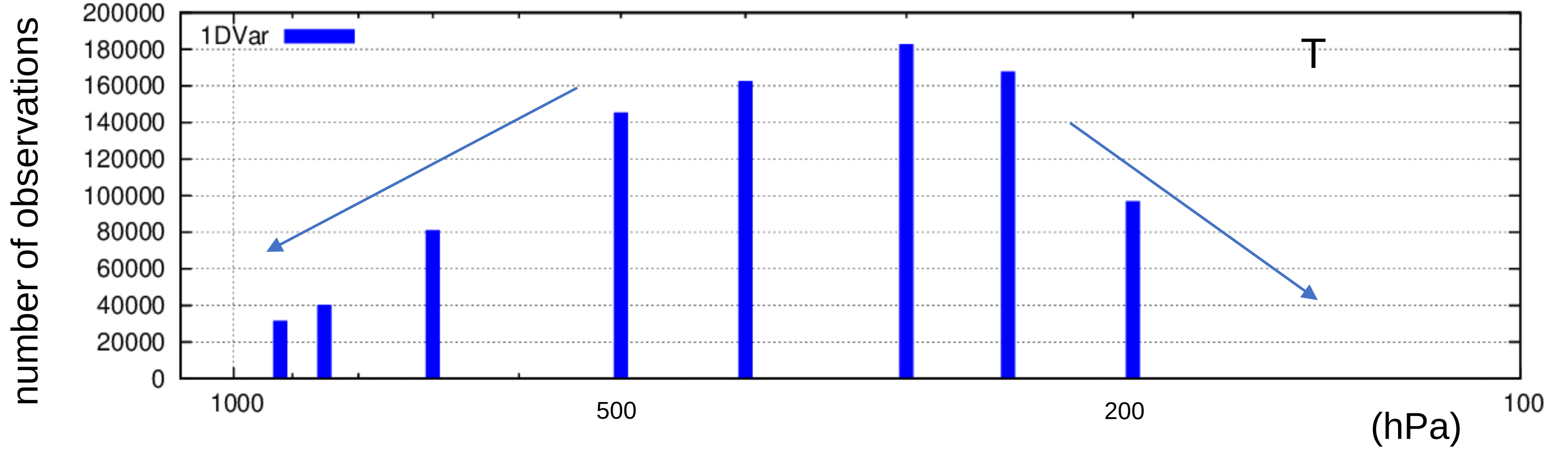
- Horizontal thinning spacing: 45 km, Time interval: 1h
- T: 13 altitudes up to 50 hPa, RH: 7 altitudes up to 300 hPa

- Experimental periods during the Baiu seasons in July 2017 (Case 3), 2018 (Case 1), and 2020 (Case 2).
  - TEST: with pseudo-observations. LBCs from the Global OSSE with (BT) pseudo-observations.
  - CNT: without pseudo-observations. LBCs from the Global OSSE without pseudo-observations.

The distribution of GeoHSS pseudo-observations

The number of T pseudo-observations

(The period of Case 1: 0000 UTC July 1 to 2100 UTC July 7, 2018)

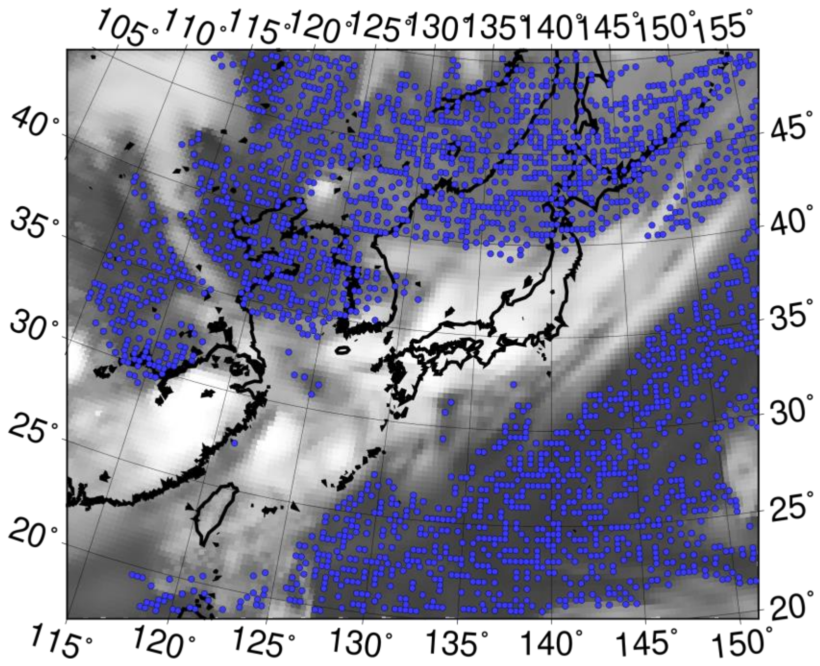


Area under clouds increases at the lower levels.

Low sensitivity above 200 hPa.

The lower limit of observed wave number (700 cm^{-1}) is in the spectral range sensitive to the upper troposphere – stratosphere.

T pseudo-observations 500 hPa (0000 UTC July 6, 2018)

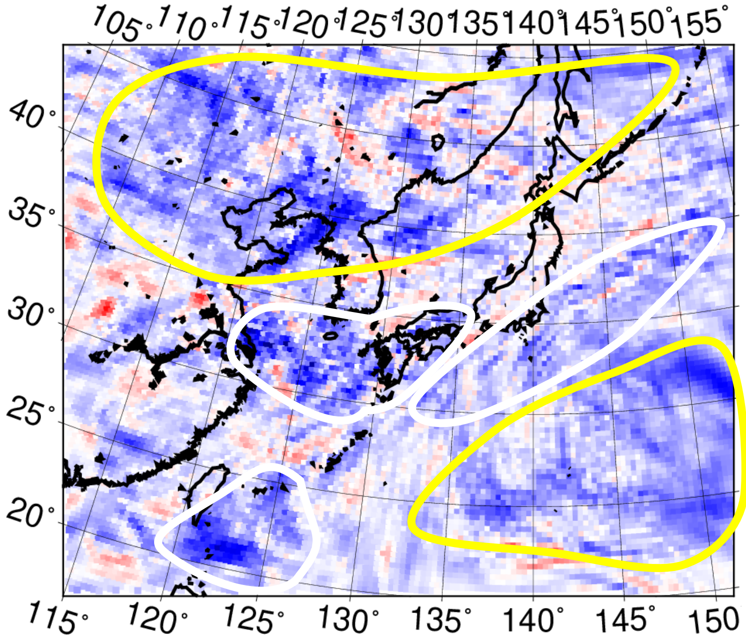


Pseudo-observations primarily distribute over clear-sky areas.

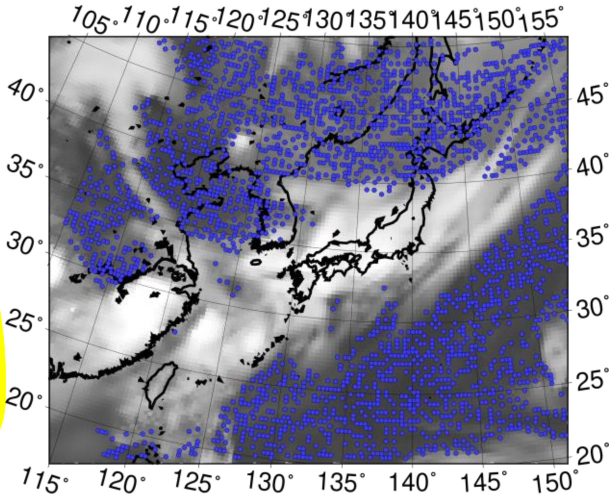
Difference of the deviation (RMSD) from ERA5
500 hPa RH TEST – CNT

Averaged over the period of Case 1
0000 UTC July 1 to 2100 UTC July 7, 2018

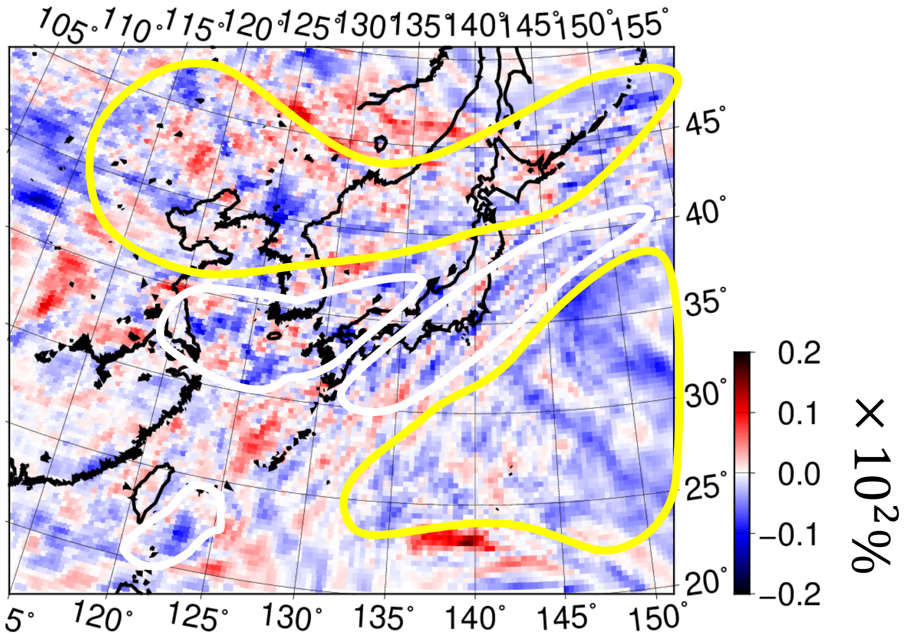
FT = 0



T pseudo-observations
500 hPa



FT = 21



The deviation reduces throughout the domain.

Large decrease occurs over areas where the pseudo-observations are assimilated (yellow).
In addition, the area of decrease also extends to cloudy areas along the atmospheric flow through the DA cycle (white).

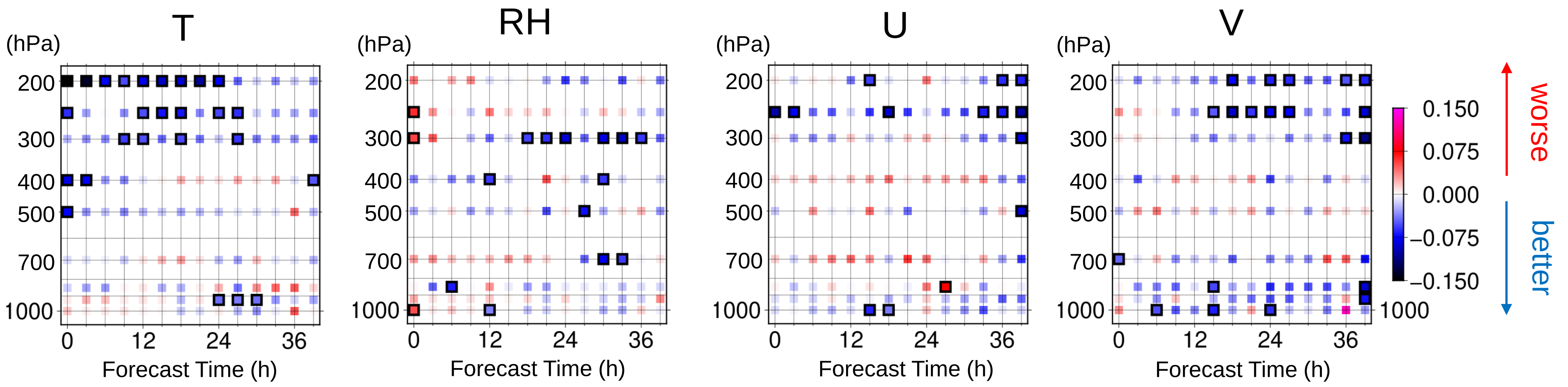
The effect of GeoHSS gradually reduces as the FT progresses.
However, the effect persists over a wide range, particularly in areas with pseudo-observations (yellow) and their flow downstream (white).

Verification Against Radiosonde

The period of Case 1
0000 UTC July 1 to 2100 UTC July 7, 2018

[RMSE(TEST) – RMSE(CNT)] / RMSE (CNT)

A framed larger mark indicates statistical significance at the 95% confidence level.

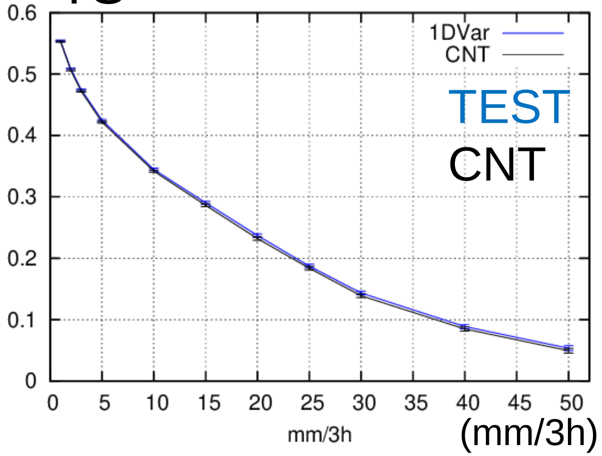


Improvement persists beyond FT=24.
The impact is large in the upper and middle levels.

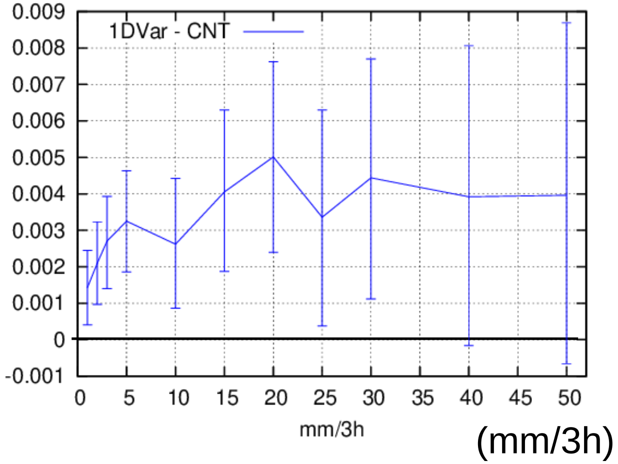
The impact extends to wind components that do not directly assimilate the pseudo-observations. Improvement propagates through the DA cycle and forecasts.

Verification of 3 h accumulated precipitation against radar/rain gauge analyzed precipitation

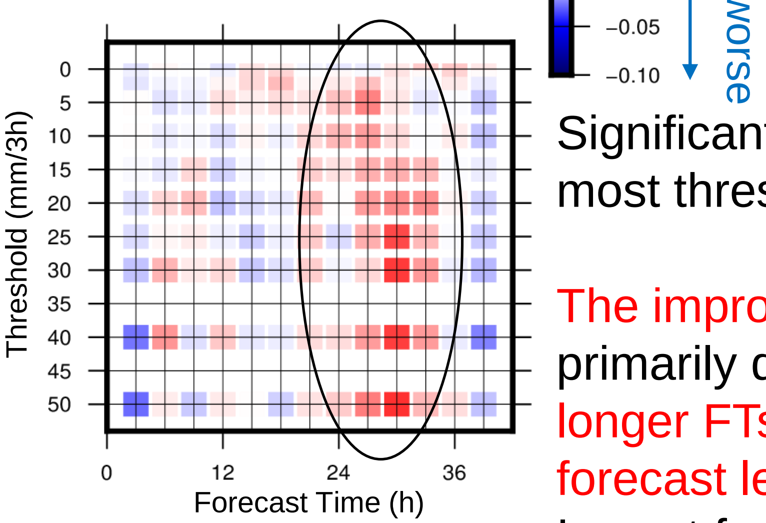
TS



TS TEST – CNT



TS TEST – CNT

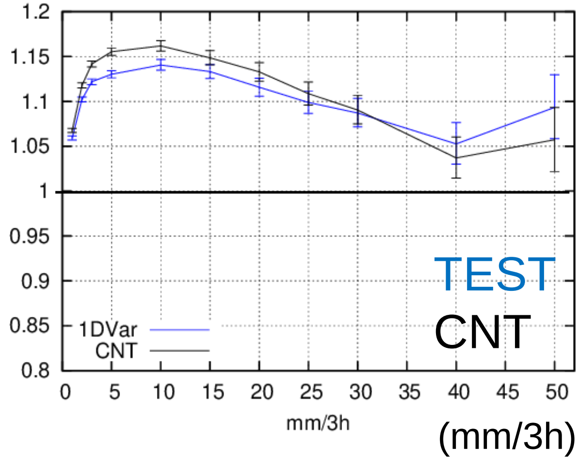


Significant improvement at most thresholds.

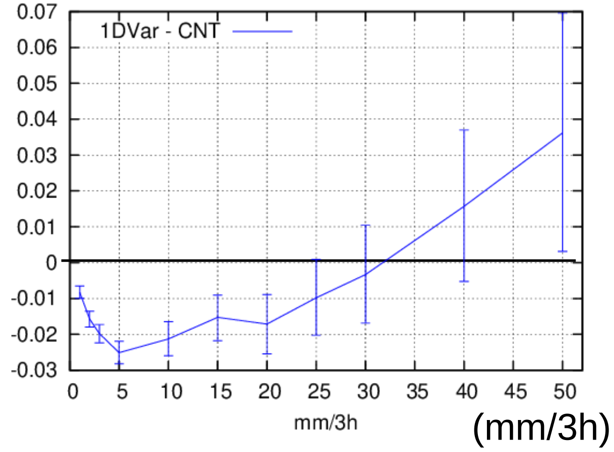
The improvement is primarily distributed at longer FTs, increasing the forecast lead time.

Impact from distant clear-sky locations propagates through DA cycle and forecasts.

BI



BI TEST – CNT



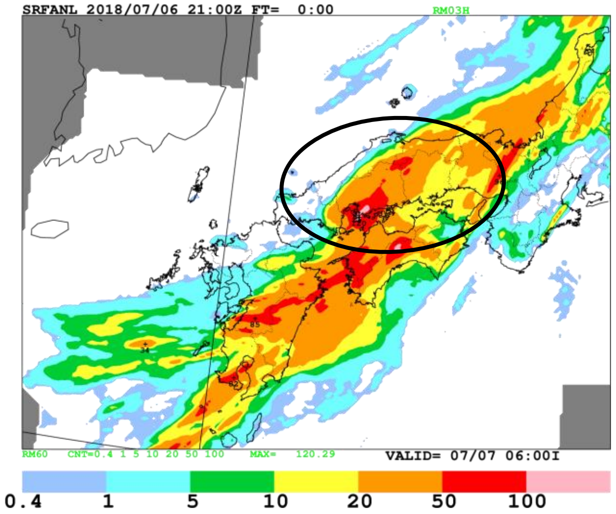
TEST mitigates excess precipitation in CNT.

The period of Case 1
0000 UTC July 1 to 2100 UTC July 7, 2018

Case 1: heavy rainfall in the Chugoku region in July 2018

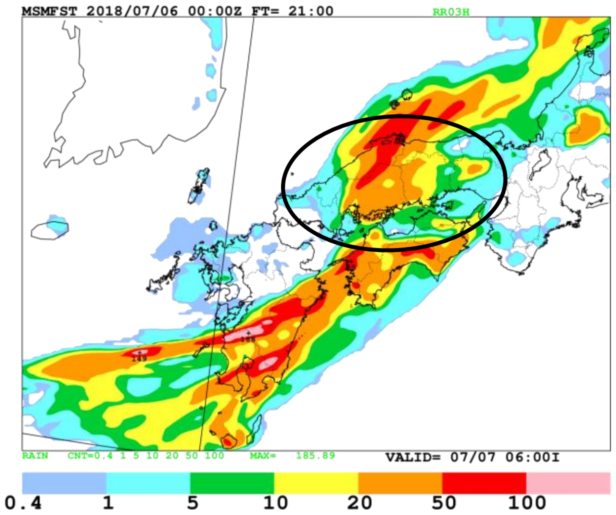
3-h accumulated precipitation 2100UTC July 6, 2018

Observation



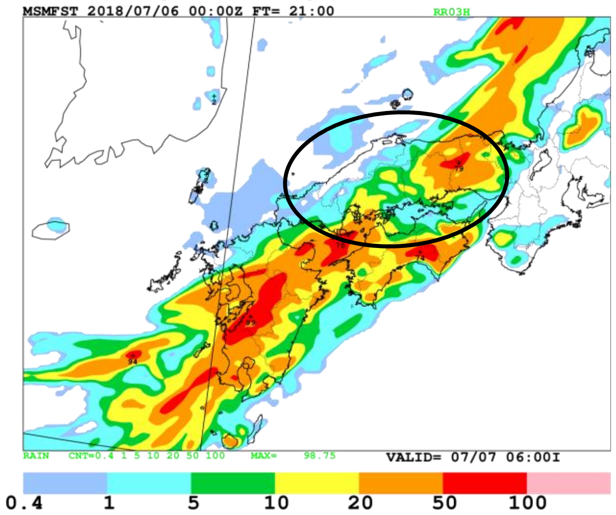
mm/3h

TEST (FT=21)



mm/3h

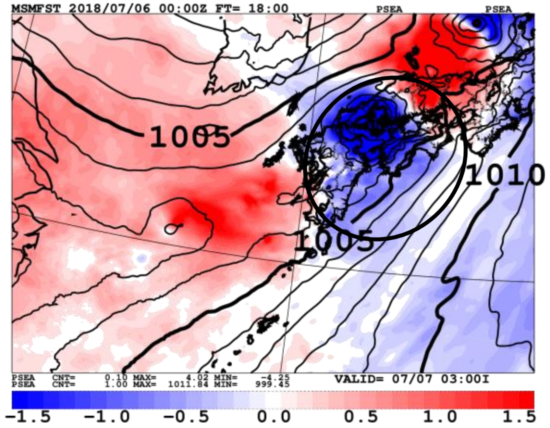
CNT (FT=21)



mm/3h

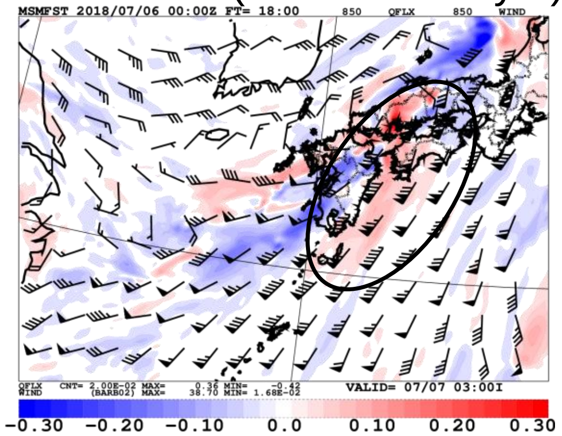
TEST intensifies precipitation over the Chugoku region, showing higher consistency with the observation than CNT.

Psea TEST – CNT (1800UTC July 6)



hPa

Water Vapor Flux 850hPa
TEST – CNT (1800UTC July 6)



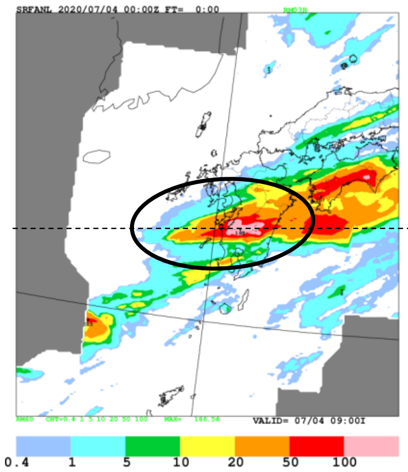
kg m^{-2} s^{-1}

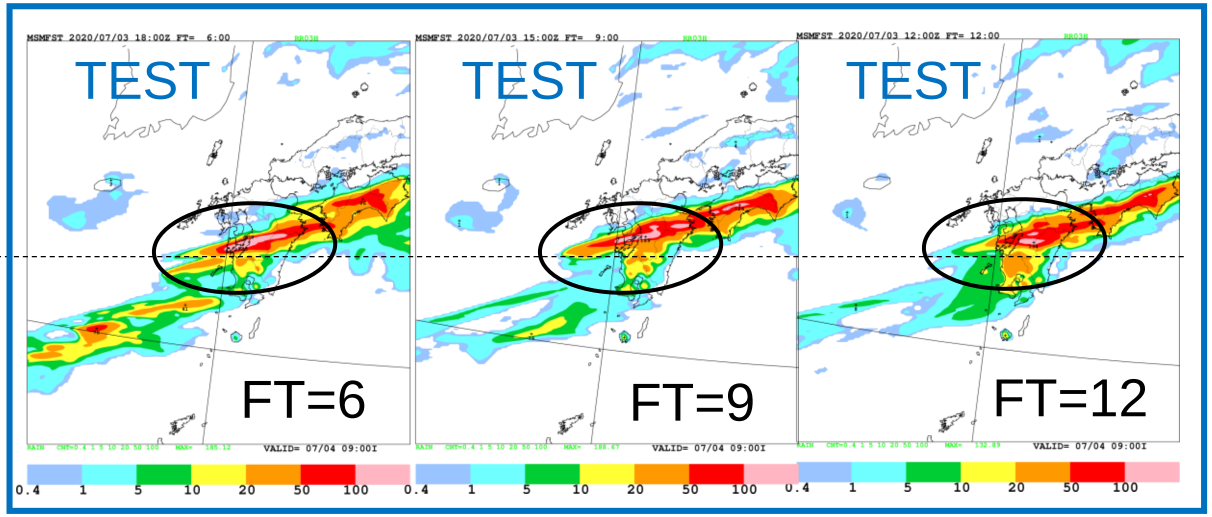
TEST predicts a small low over the Baiu front passing through the Chugoku region.
The low enhances the low-level water vapor flux from the southwest, contributing to the intense rainfall.

Case 2: The July 2020 heavy rainfall event

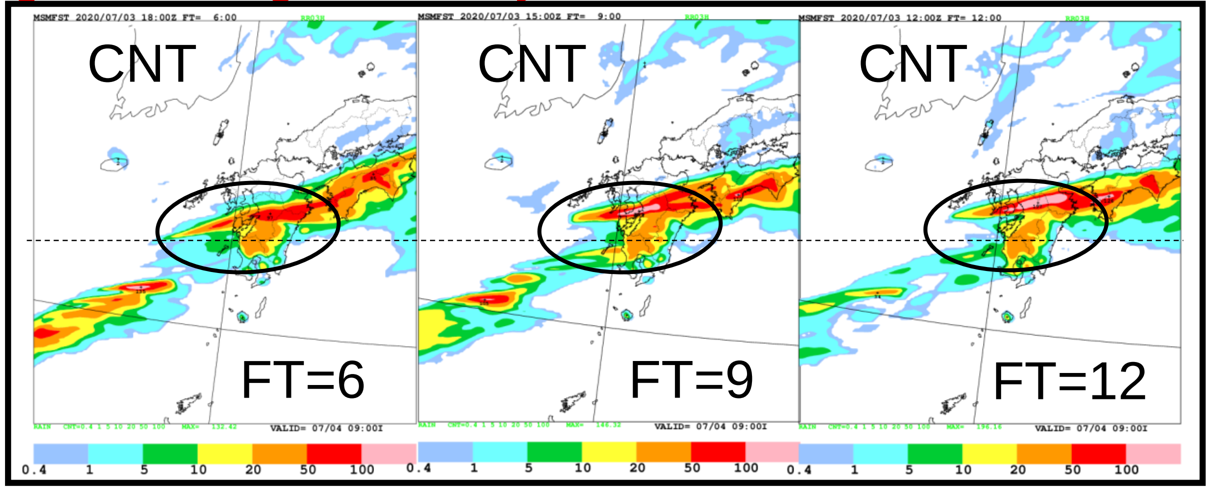
3h accumulated precipitation valid at **2020.07.04 0000 UTC**

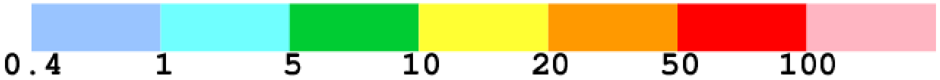
Observation





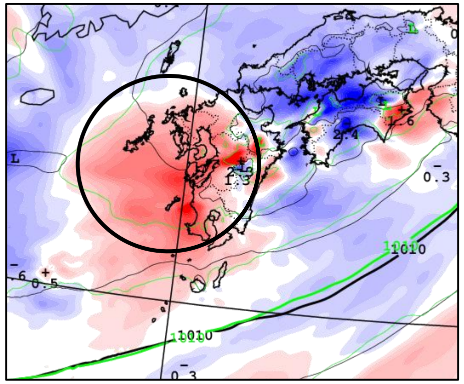
TEST mitigates the northward shift of precipitation band of CNT.
The impact persists over successive forecast updates, indicating the impact propagation through the DA cycle.





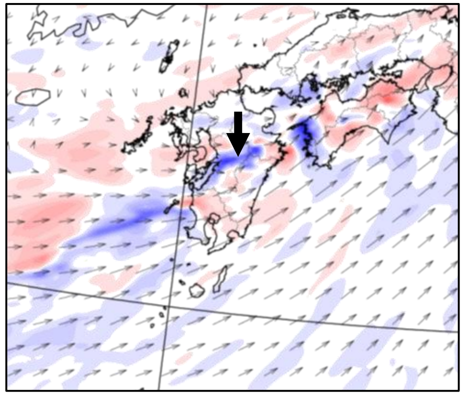
mm/3h

Psea TEST – CNT (FT=9)



TEST weakens a small low over the Baiu front passing through northern Kyushu.

Water Vapor Flux 900hPa
TEST – CNT (FT=9)

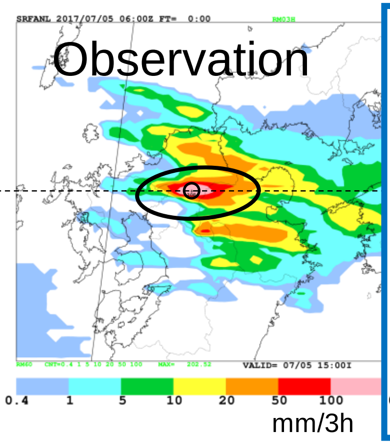


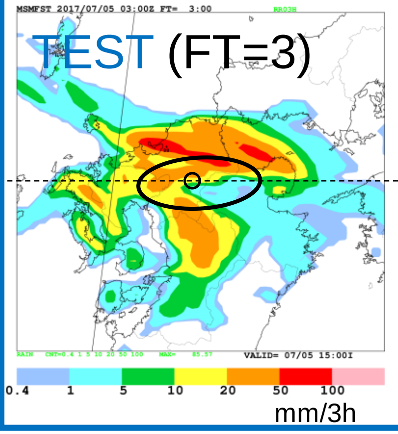
TEST weakens the low-level warm moisture flow from the southwest, to shift the low-level wind's convergence line to the south, shifting the precipitation band to the south.

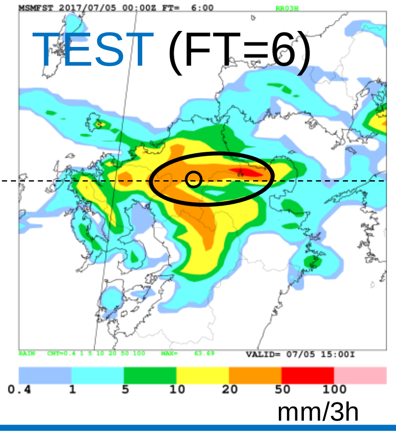
Case 3: The July 2017 northern Kyushu heavy rainfall event

0600UTC July 5, 2017

3-h accumulated precipitation

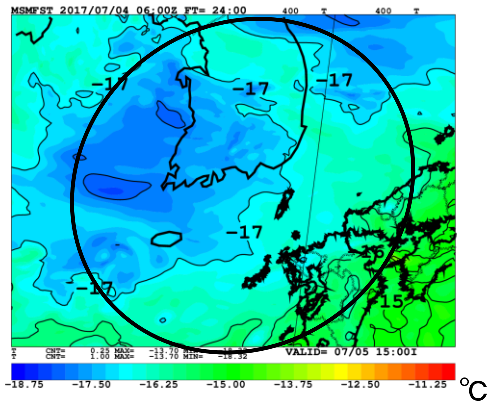






T 400 hPa

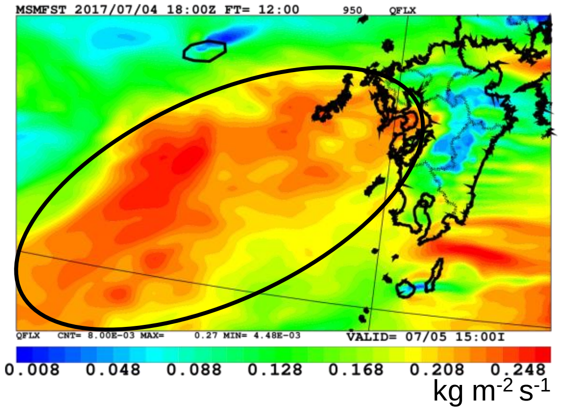
TEST (FT=24)



Water Vapor Flux

950hPa

TEST (FT=12)



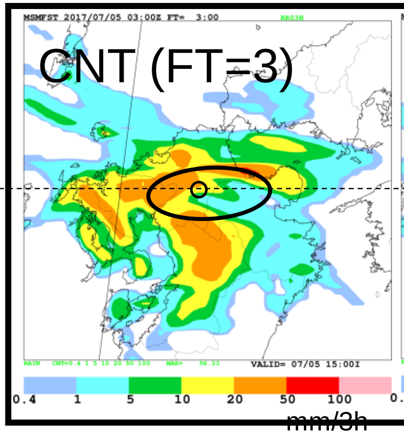
TEST and CNT intensify precipitation over northern Kyushu. However, in both TEST and CNT, the localized precipitation concentration is weaker, and displaced more downstream to the east than the observation.

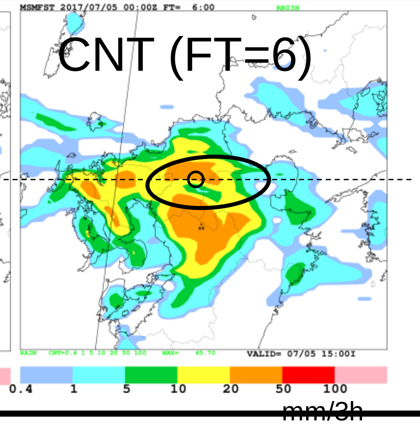
Forecast variation is large, depending on the initial times.

TEST strengthens the upper-level cold air.

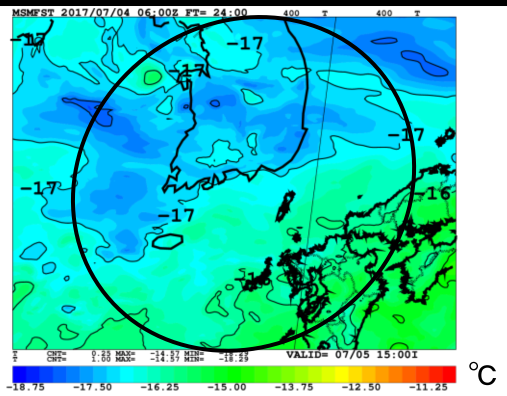
TEST strengthens the low-level warm moisture flow.

TEST extends the forecast lead time of large-scale environments.

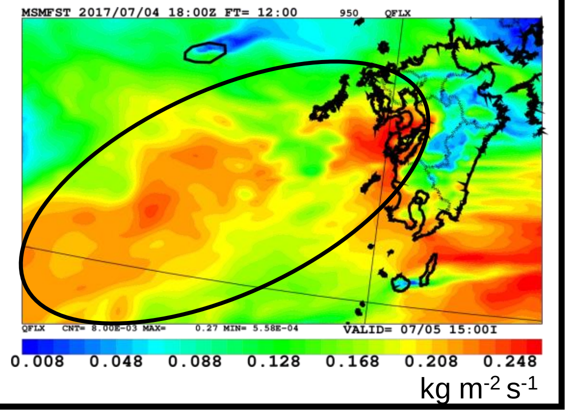




CNT (FT=24)



CNT (FT=12)



Summary

- The impact of a GeoHSS on a regional NWP system was investigated assuming the Himawari-follow-on satellite.

- RA-OSSE technique was applied using ERA5 as the pseudo-truth. 1D-Var retrieval pseudo-observations were generated from ERA5.

- The statistical verification against radiosonde observations showed an overall improvement.
- The impact in precipitation forecasts was larger at longer FTs, extending the forecast lead time.

- Case studies
  - Case 1 (2018) and Case 2 (2020): These cases showed impacts on precipitation accompanied by an improved prediction of depressions on the Baiu front. These are considered to be due to large-scale impacts over clear-sky areas, propagating to precipitation areas through the DA cycle and forecasts.
  - Case 3 (2017): There was an impact on the large-scale environments. However, the prediction of localized heavy rainfall was insufficient even at short FTs, owing to the limited resolution of the pseudo-observations, the DA system, and the forecast model in the present OSSE.