Framework for assimilating all-sky MHS radiance data in the KIM forecast system

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Background

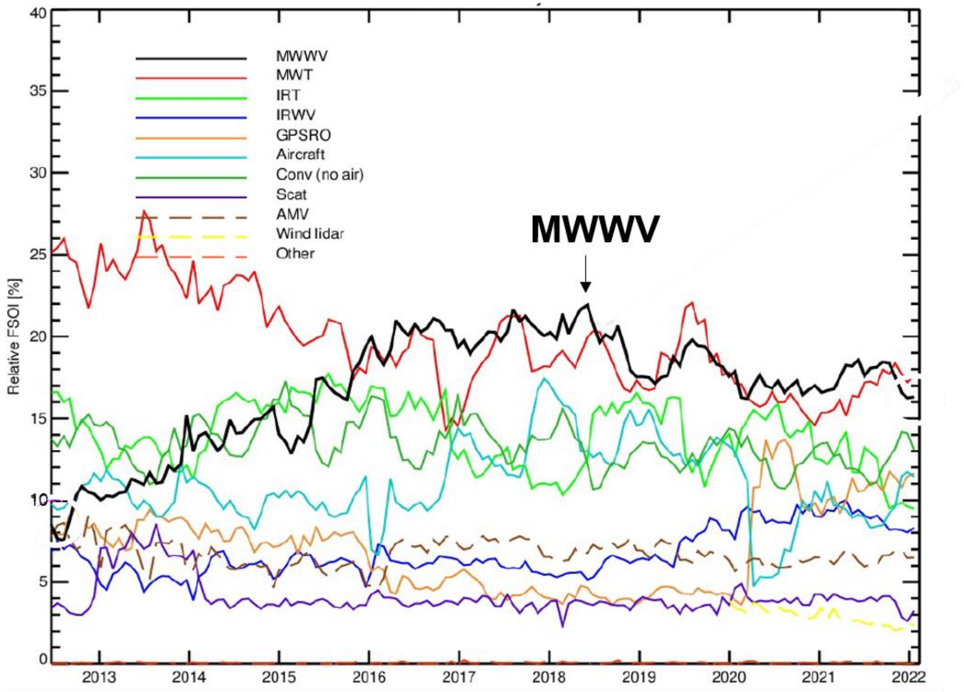
“All-sky radiance assimilation improves the analysis and shorter-range forecasting of otherwise poorly observed weather phenomena as diverse as tropical cyclones and wintertime low cloud” (Geer et al., 2018).

Some NWP centers already assimilate cloud- and precipitation-affected radiances operationally.

In this talk, the framework for assimilating all-sky MW radiance data in the KIM system will be introduced.

- **Requirements for all-sky radiance assimilation**
  - observations
  - forecast model that represents cloud and precipitation
  - data assimilation system that can handle nonlinearity
  - fast observation operator that represents cloud and precipitation
  - observation error model

FSOI of major observing systems in ECMWF operations

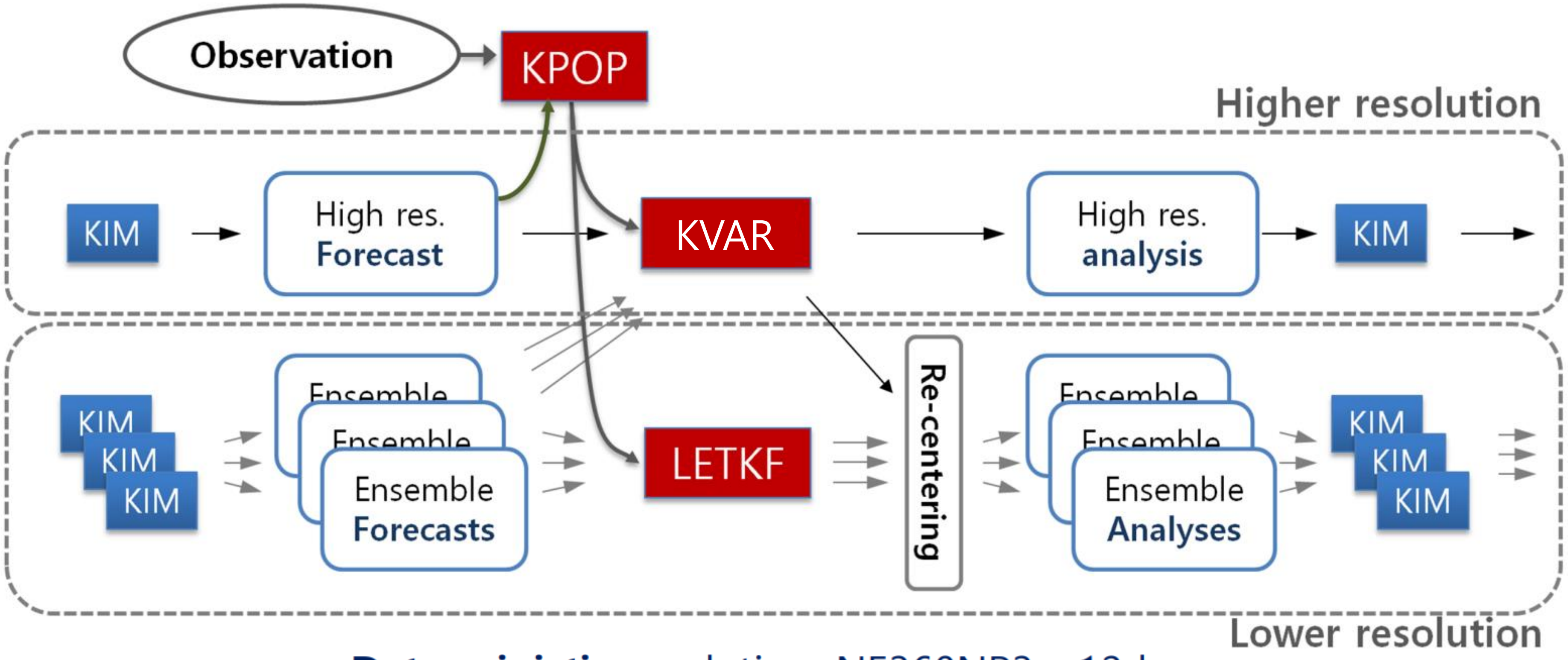


B. Ingleby (2021) ECMWF DA Training course

Framework for all-sky DA in the KIM system

Operational KIM system

- Ensemble DA: **50-member LETKF**
- Deterministic DA: **Hybrid-4DEnVar**



Deterministic resolution: NE360NP3 ~12 km
Ensemble resolution: NE144NP3 ~32 km
Analysis resolution: NE144NP3 ~32 km

Ensemble B fraction:
0.7 at equator, 0.45 at poles

Observation operator

- **RTTOV-SCATT v.13.0** is employed for the observation operator of MW satellite radiance data.

RTTOV-SCATT v13 hydrometeors

hydro_frac(1) : nlevels of cloud cover (0-1)

hydro(1) : nlevels of rain (kg/kg)

hydro(2) : nlevels of frozen precipitation (kg/kg)

hydro(3) : nlevels of graupel (kg/kg)

hydro(4) : nlevels of liquid water (kg/kg)

hydro(5) : nlevels of ice water (kg/kg

↕ match up

KIM hydrometeors

cld : cloud fraction in atmosphere layer (0-1)

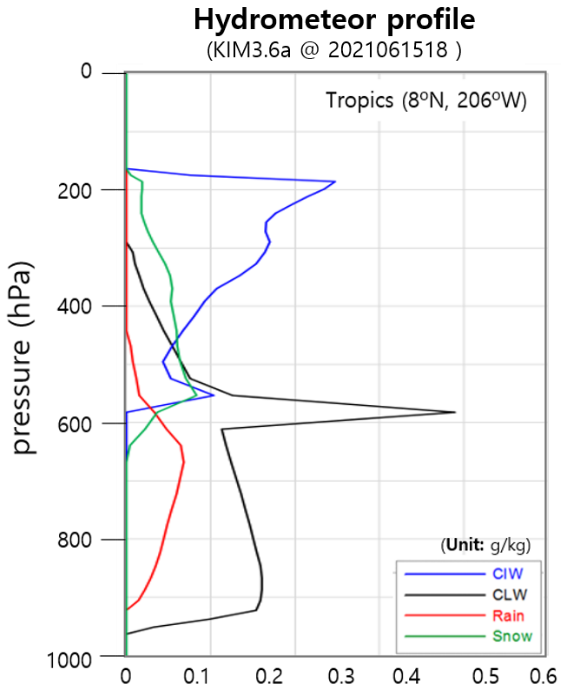
tqr : rain water content from mps*, cps** and scv*** (kg/kg)

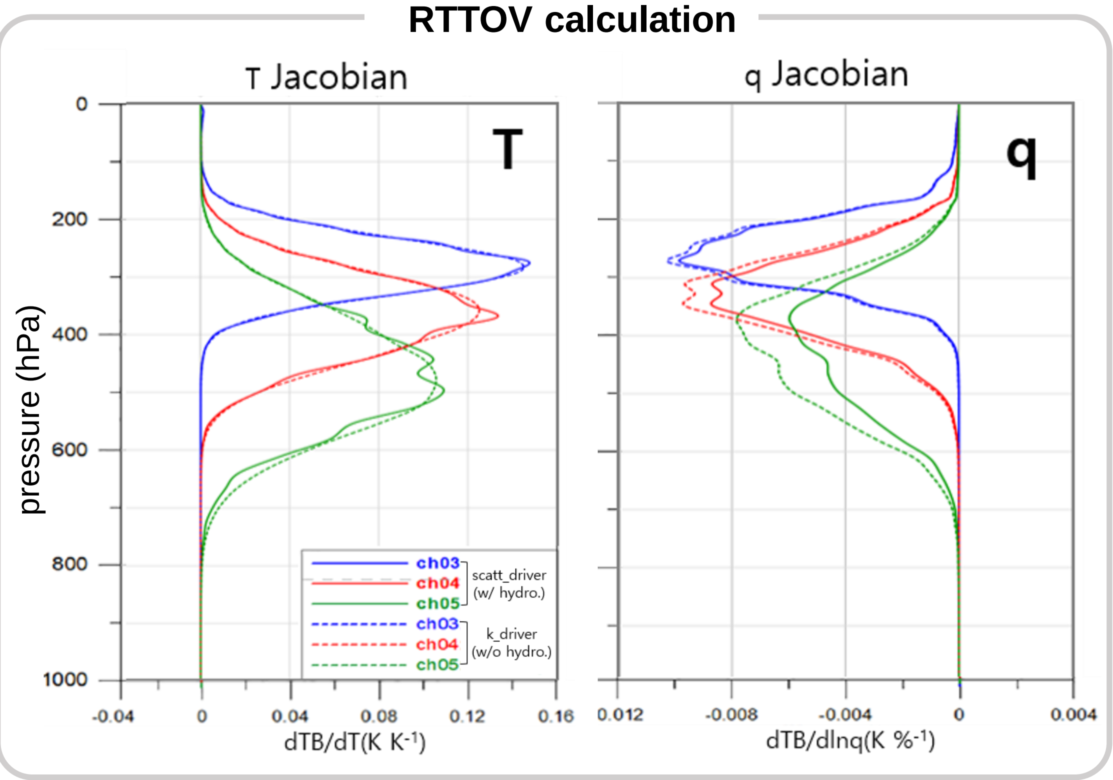
tqs : snow content from mps, cps and scv (kg/kg)

qg : graupel content from mps (kg/kg) → 0.0

tqc : cloud liquid water from mps, cps and scv (kg/kg)

tqi : cloud ice content from mps, cps and scv (kg/kg)





*mps : microphysical scheme (grid-scale, prognostic)

**cps : convective parameterization scheme (subgrid-scale, diagnostic)

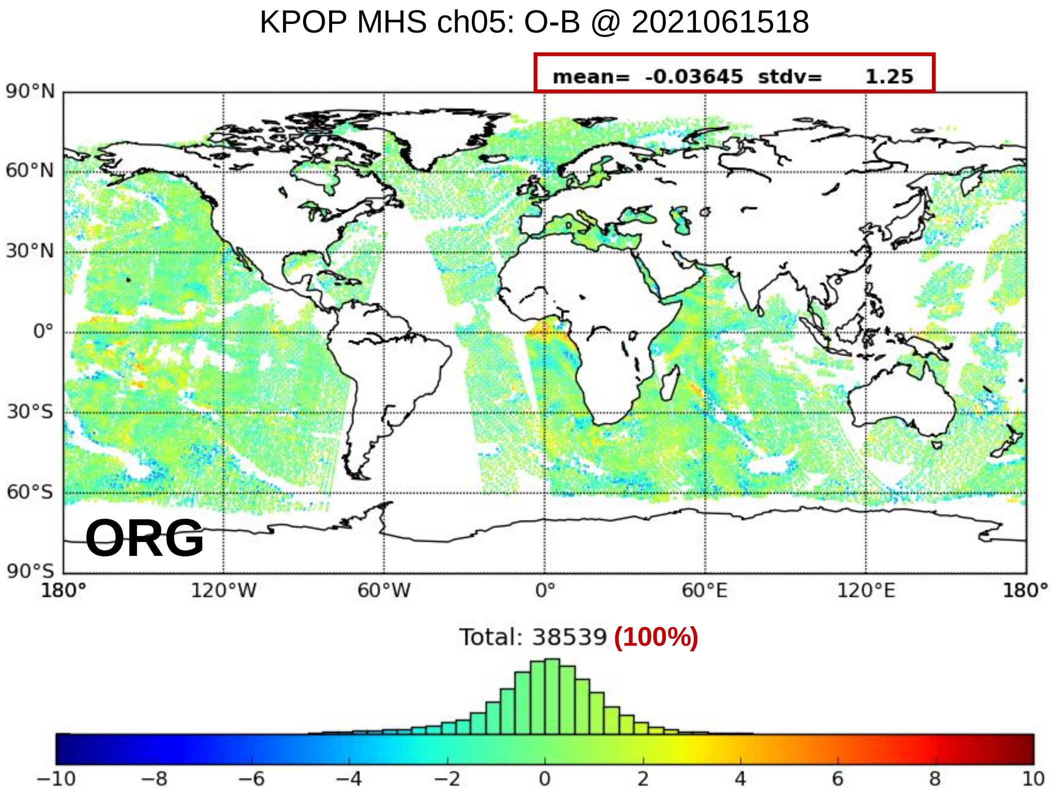
***scv : shallow-convection parameterization scheme (subgrid-scale, diagnostic)

Simulated TBs calculated from RTTOV

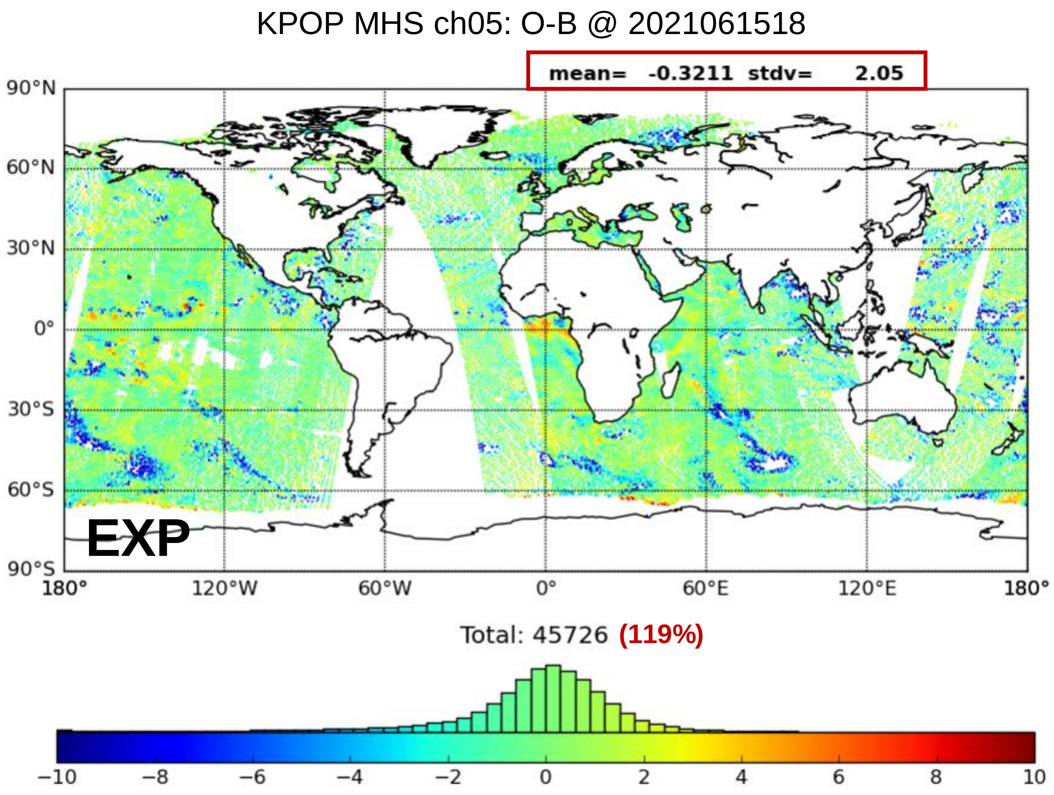
MHS	scatt_driver	k_driver
CH3	236.5	237.0
CH4	250.2	251.7
CH5	259.7	263.2

Global distribution of O-B

Clear-sky assimilation

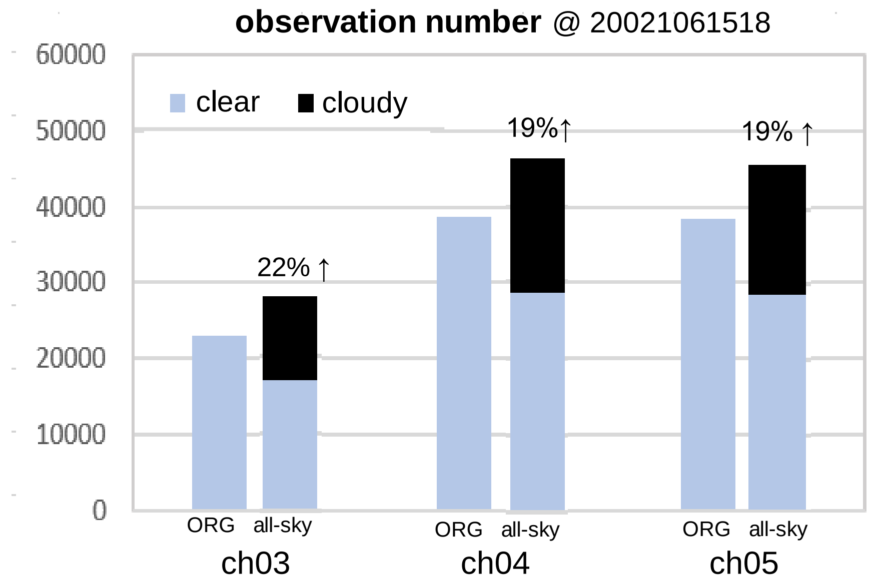


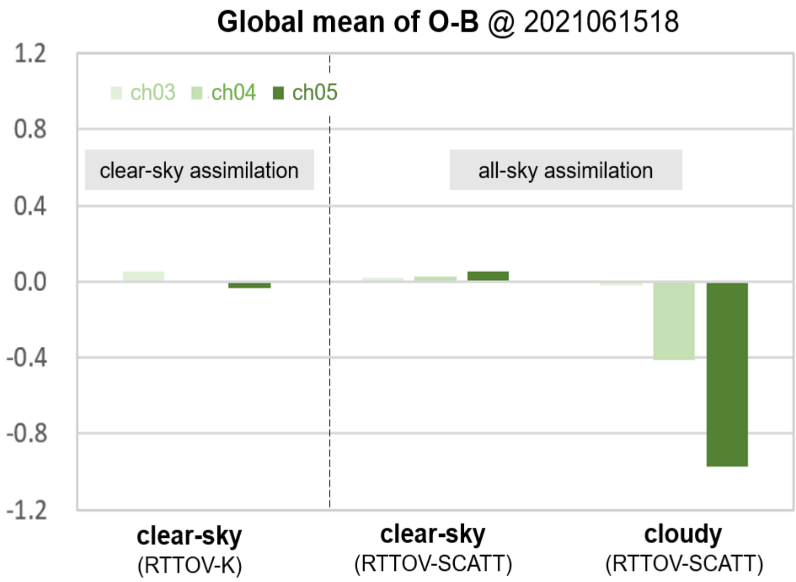
All-sky assimilation

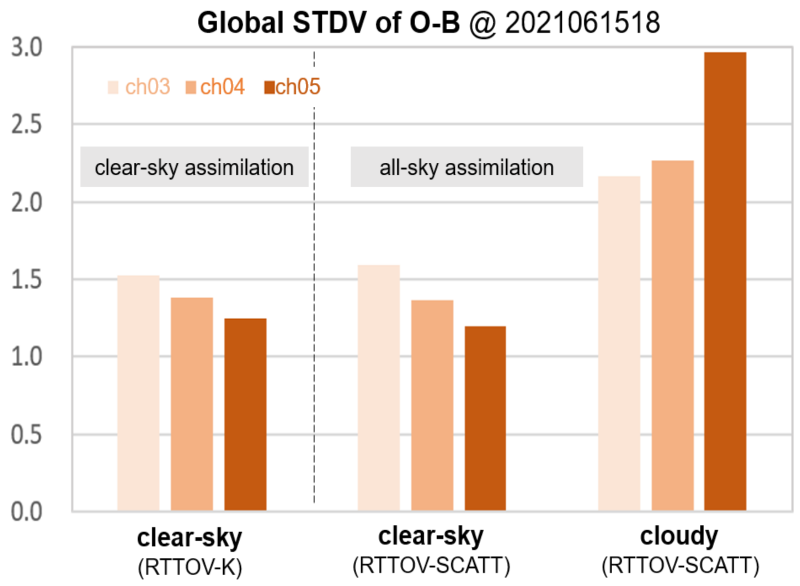


All-sky assimilation	**Quality control** - removal of cloud masking - O-B check as a function of symmetric cloud amount	**Bias correction** - selection of clear pixels to calculate BC coefficients - clear-pixel : symmetric cloud amount ≤ 0

O-B statistics







Approximately 20% more observations are assimilated in all-sky approach.

In both experiments, O-B statistics at clear-pixels are similar.

Mean and standard deviation of O-B are relatively large in cloudy pixels (especially, MHS lowest channel), which will be considered in observation error.

Observation error

Geer et al. (2014) method

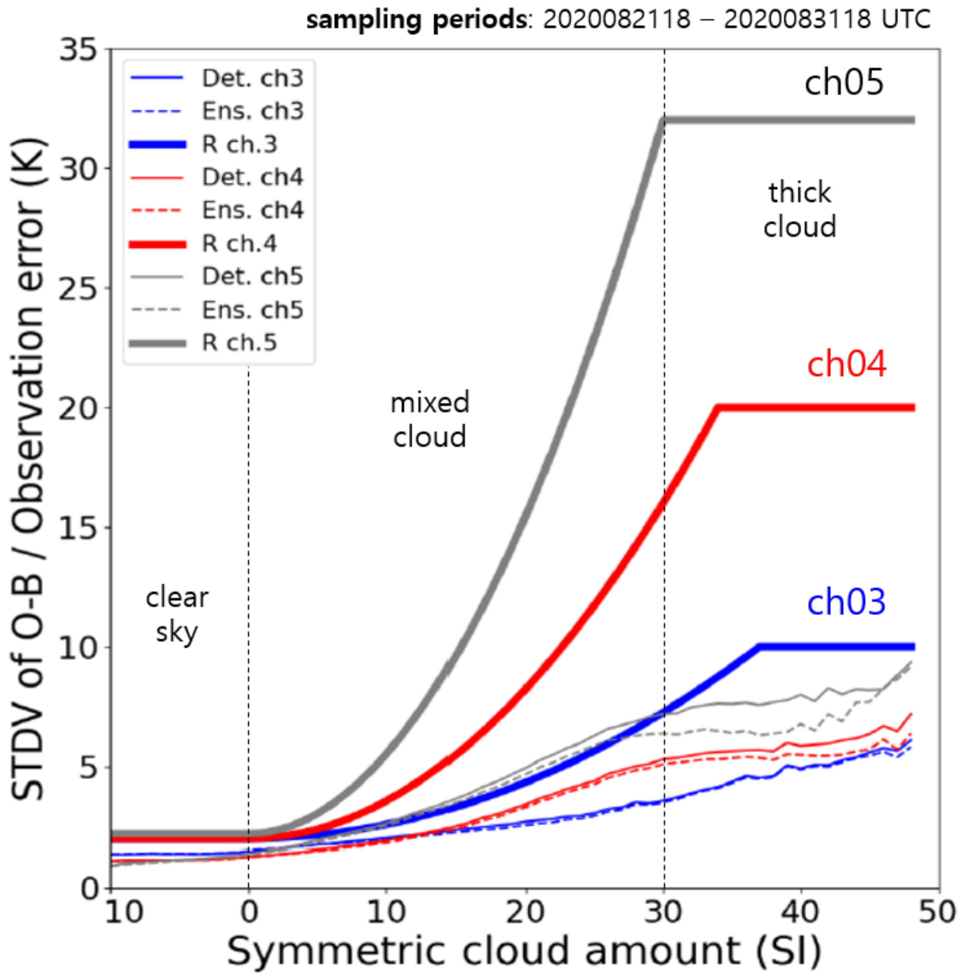
- observation error calculation as a function of <u>symmetric cloud amount</u>
  (average of **SI_bkg** and **SI_obs**)

$$g(C_{SYM}) = g_{clr} + (g_{cld} - g_{clr})\left(\frac{C_{SYM}-C_{clr}}{C_{cld}-C_{clr}}\right)^2 \quad \in C_{clr} < C_{SYM} < C_{cld}$$

$g(C_{SYM})$: total error C_{SYM} : symmetric cloud predictor

(e.g.) MHS ch05

- clear sky : obs_error = 2 (K)
- mixed cloud : obs_error = 2.2+(32-2.2)(avg_SI/30)**2 (K)
- thick cloud : obs_error = 32 (K)



※ Scattering Index (SI) is used for cloud predictor.

※ For beneficial impact of all-sky assimilation, optimization of observation error will be needed.

Preliminary results

Cycled analysis and forecast experiment

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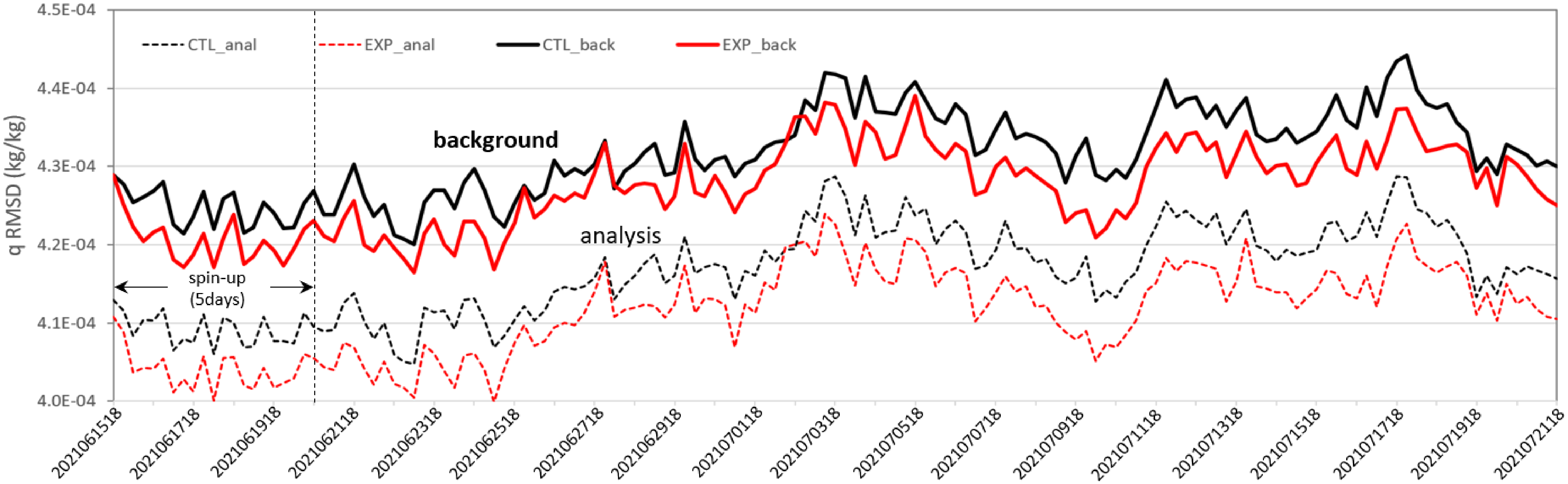
- **Period :** 2021061518 - 2021072118 UTC (36 days)
- **Used observation :** Sonde, Surface, Aircraft, GPS-RO, Scatwind, AMV, AMSU-A, MHS
  (**CTL :** clear-sky MHS, **EXP :** all-sky MHS)
- **Verification :** IFS analysis (0.25˚x0.25˚)

KIM_v3.7 (NE180NP3 ~ 25 km)
KVAR_r224 (NE144NP3 ~ 32 km)
KPOP_r564 (NE180NP3 ~ 25 km)

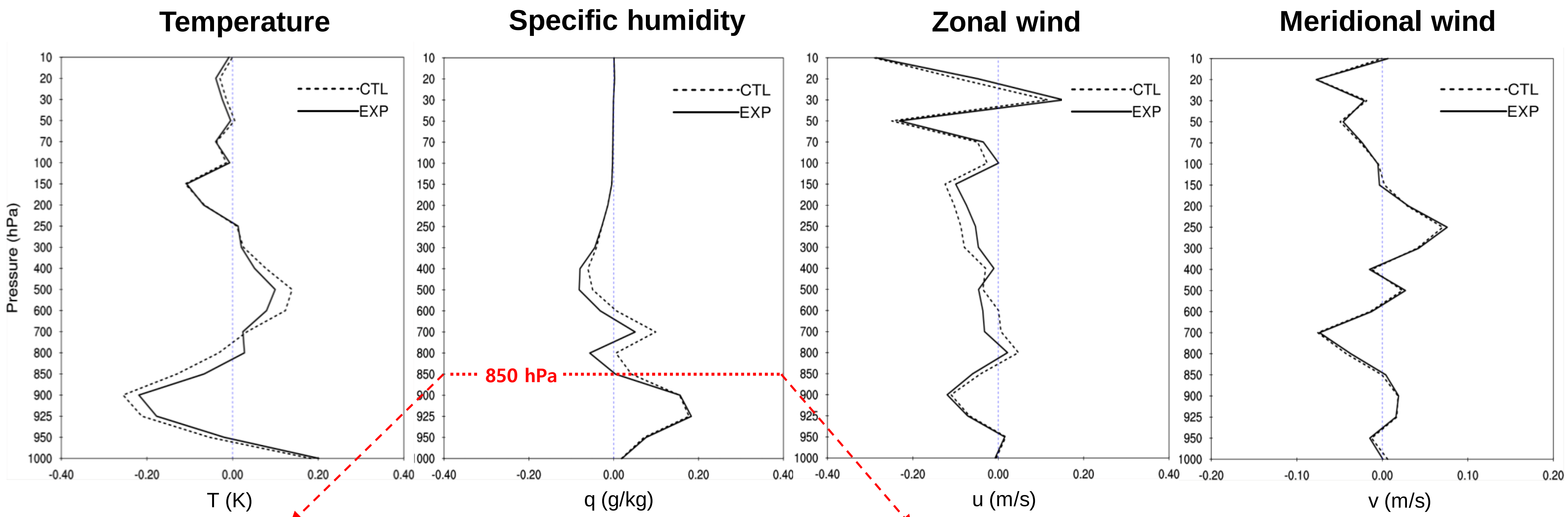
Timeseries of global **specific humidity** RMSD

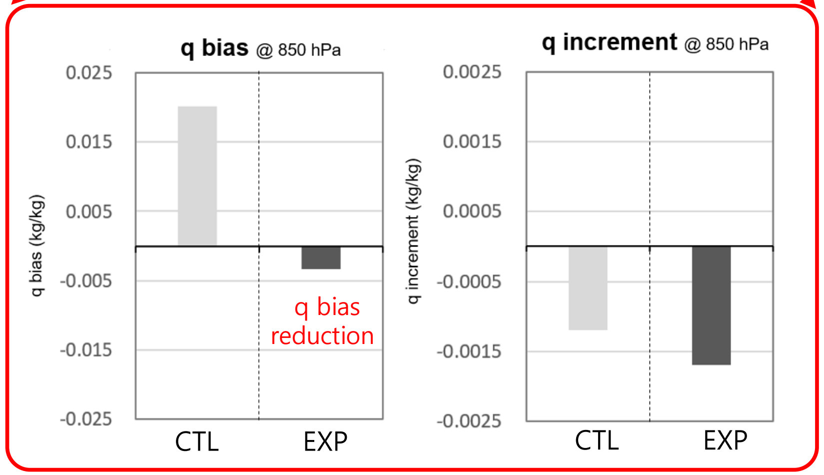


Vertical profile of background bias against IFS analysis

KIAPS

*** Period:** 2021062100 – 2021072118 UTC (31 days)





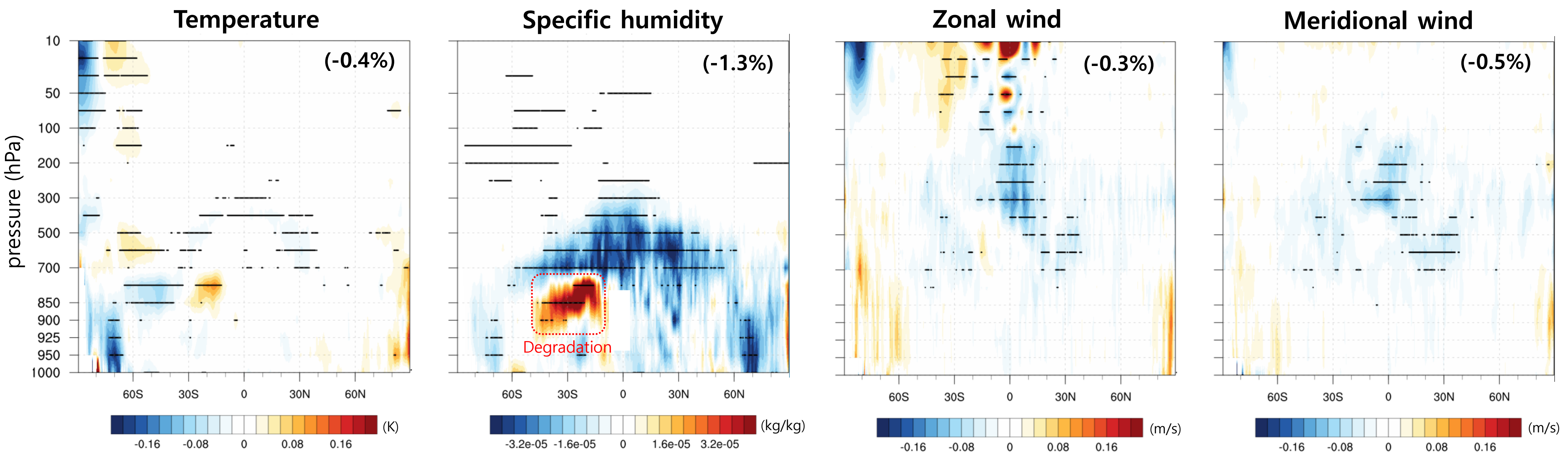
In the cycled experiments, all-sky assimilation of MHS (EXP) gives a beneficial impact on mass and wind background fields.

The background of EXP has become drier in the mid troposphere.

Zonal plot of analysis RMSD against IFS analysis

*** Period:** 2021062100 – 2021072118 UTC (31 days)

Difference of analysis RMSD (EXP – CTL)



* Blue color means beneficial analysis impact of all-sky assimilation.

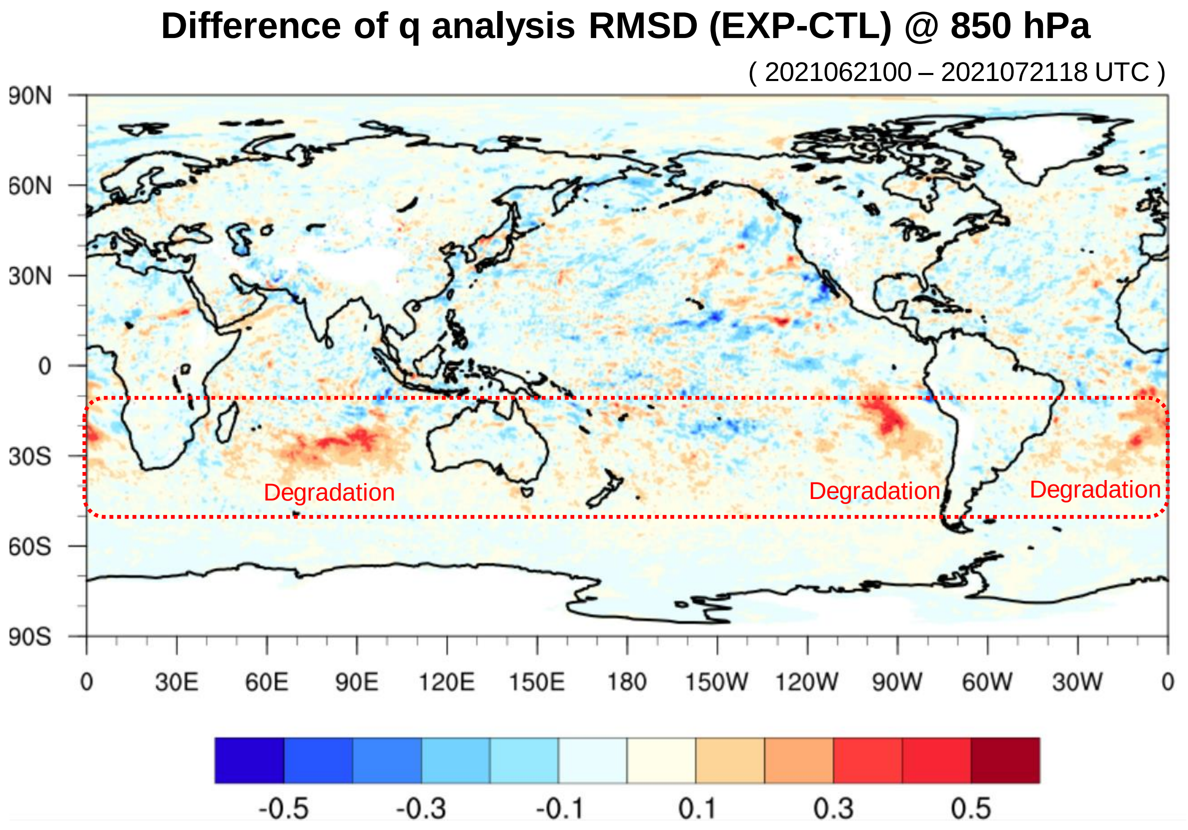
* Small black dots show a 95% significant difference, verified by a *t*-test, between CTL and EXP.

Overall, assimilation of MHS observations in cloudy regions gives a beneficial impact on T, q and wind analyses.

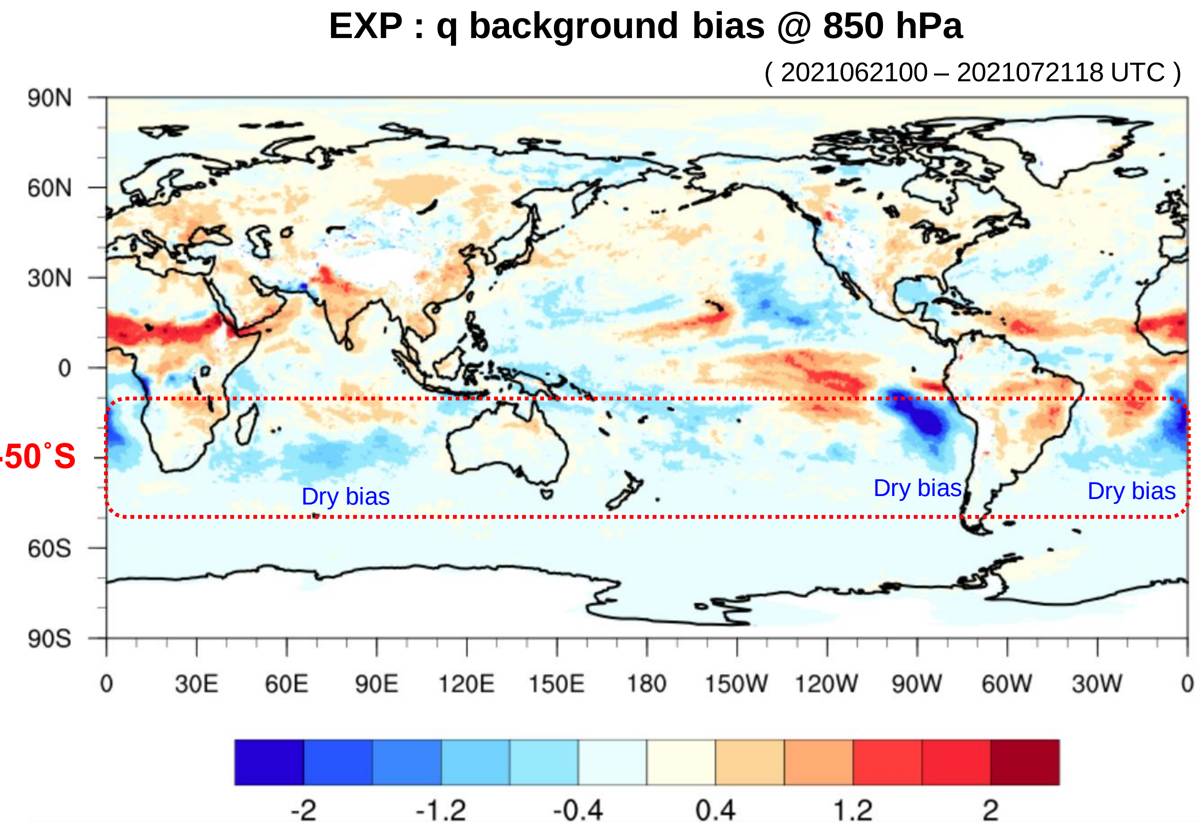
However, the degradation of q analysis in the SH midlatitudes (10-50˚S) for the lower tropospheric levels is shown.

Mean field of specific humidity at 850 hPa

*** Verification :** IFS analysis

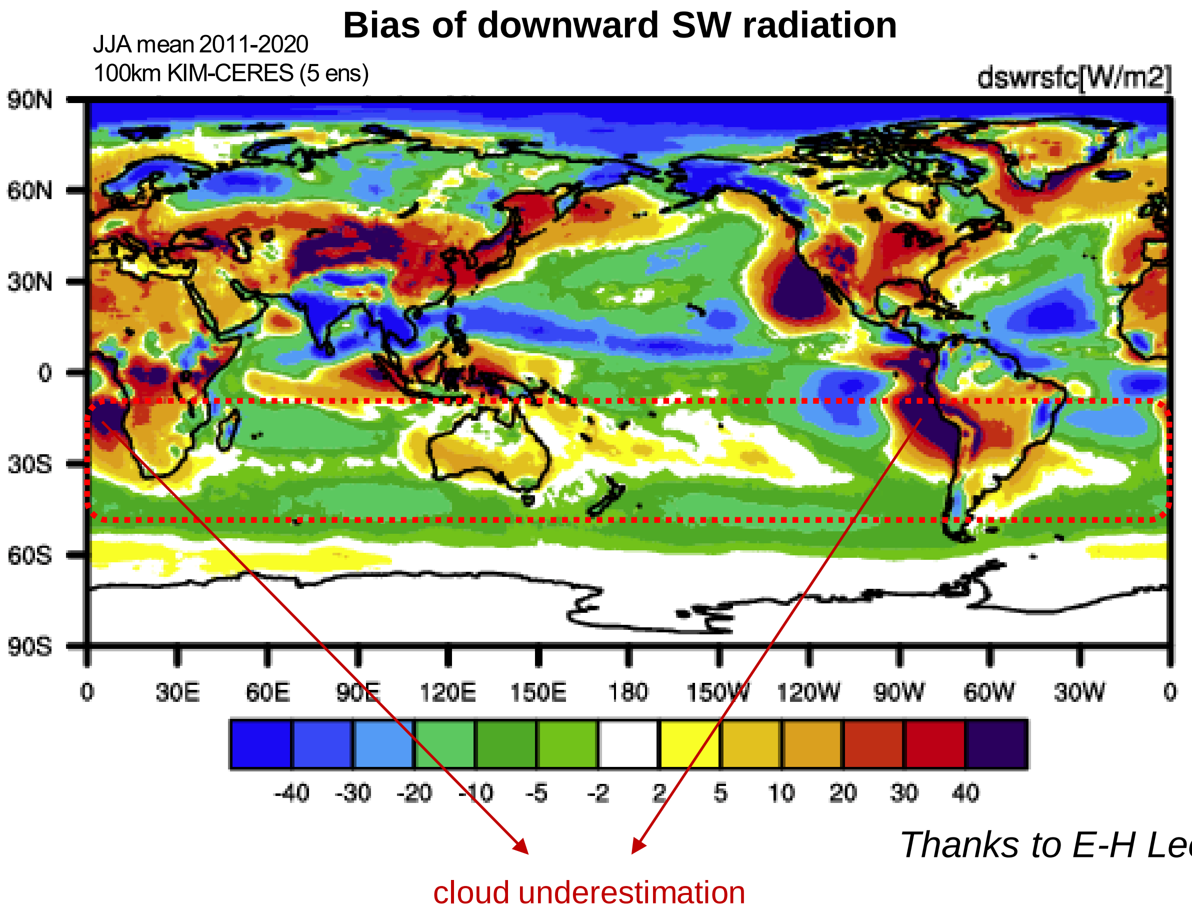


10-50˚S



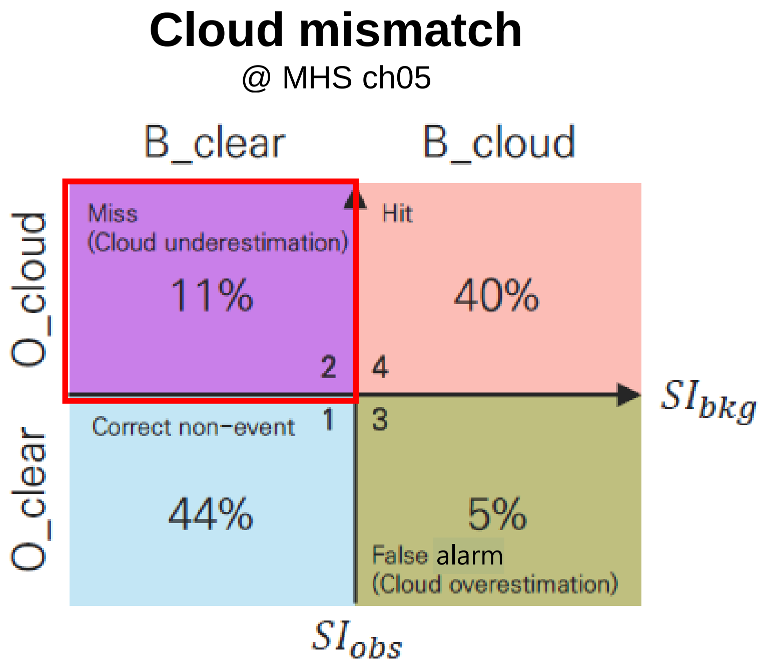
The degradation of q analysis from all-sky DA (EXP) appears in dry-biased background areas.

Cloud estimation



Thanks to E-H Lee

In the SH midlatitudes, the areas with dry bias correspond to areas with underestimated cloud.



*** Period:** 2021062500 – 2021073118 UTC

Thanks to H-B Jeong

In the cloud underestimated region (O_cloud/B_clear), all-sky pixels should be assimilated more conservatively. (e.g., observation with inflated observation error)

→ **see *H-B Jeong's Poster (9p.03)***

Summary

- The Korean Integrated Model (KIM) forecast system has been extended to assimilate all-sky radiances from microwave satellite sensors (e.g., MHS and ATMS).
- RTTOV-SCATT version 13.0 (observation operator) was implemented to assimilate the MW water vapor channels over the ocean.
- The observation error model of Geer et al. (2014) has been adopted for all-sky assimilation in the hybrid-4DEnVar (KVAR) system.
- Overall, assimilation of MHS observations in cloudy regions gives a beneficial impact on T, q, and wind analyses in the cycled analysis and 6-hr forecast experiments.
- However, it is necessary to improve the analyses in the SH midlatitudes, because specific humidity analyses are degraded in dry-bias areas.

THANK YOU

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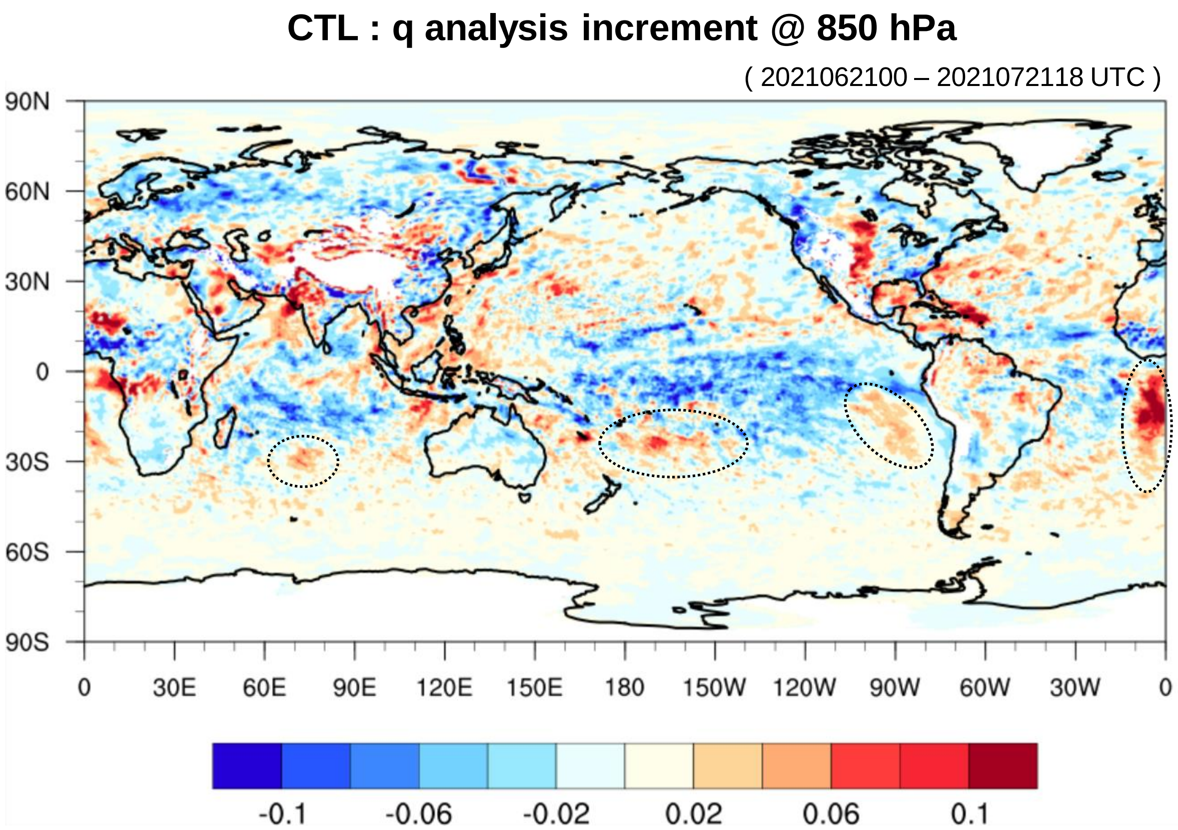
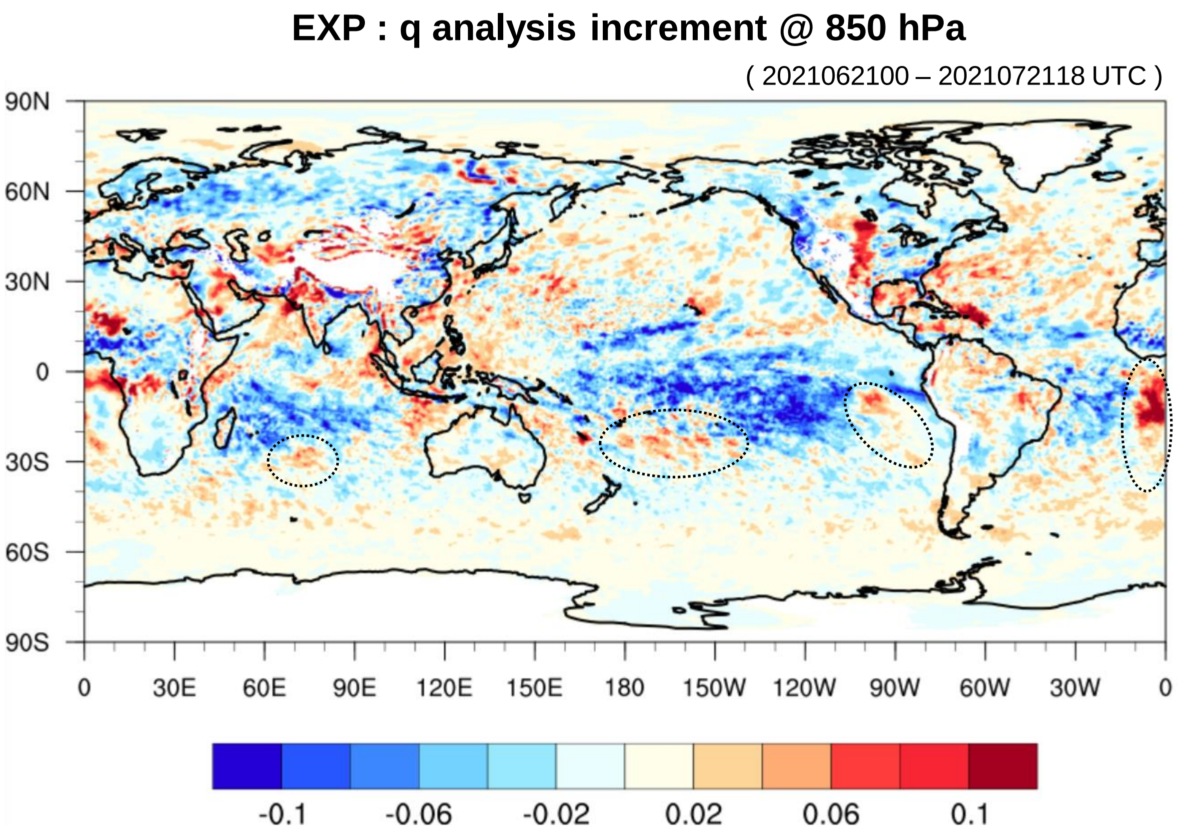
q analysis increment at 850 hPa

Back-up





Although the global distributions of q analysis increment for both experiments are similar, the magnitude of positive (negative) q increment is relatively weaker (stronger) in the EXP.