Studies of all-sky radiance assimilation at NCEP

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Outline

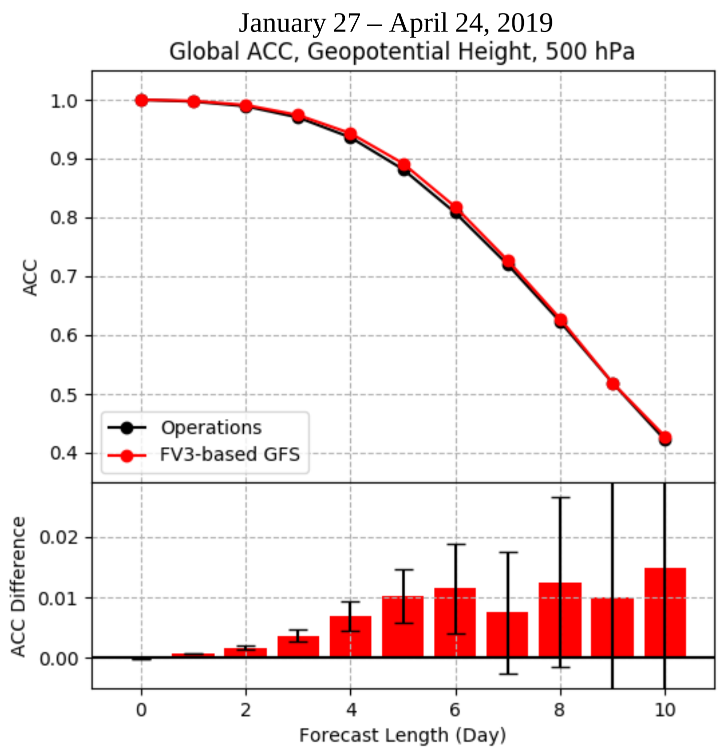
- Status of all-sky radiance assimilation in the operational FV3GFS
- Incorporation of convective clouds in the all-sky radiance assimilation
- All-sky radiance assimilation over land
- Ongoing work and future plan

FV3GFS hybrid 4DEnVar system became operational in June 2019

$$J(\mathbf{x}'_c,\mathbf{a}) = b_c\frac{1}{2}(\mathbf{x}'_c)^T\mathbf{B}_c^{-1}(\mathbf{x}'_c) + b_e\frac{1}{2}\mathbf{a}^T\mathbf{L}^{-1}\mathbf{a} + \frac{1}{2}\sum_{k=1}^{K}(\mathbf{H}_k\mathbf{x}'_{(t)k} - \mathbf{y}'_k)^T\mathbf{R}_k^{-1}(\mathbf{H}_k\mathbf{x}'_{(t)k} - \mathbf{y}')$$

$$\mathbf{z} = \mathbf{B}^{-1}\mathbf{x}'_c \qquad \mathbf{v} = \mathbf{L}^{-1}\mathbf{a}$$

- FV3 dynamic core, cubed-sphere grid, non-hydrostatic option
- Initial prototyping with (mostly) GFS physics (new: GFDL microphysics)
- Stochastic physics: SPPT + SHUM only
- C768 (~13km) L64 (55km top)
- Data assimilation: adaptation of original operational GSI hybrid 4DEnVar scheme with 80 ensemble members
- Ensemble and increment resolution have been increased from ~39km to ~25 km



(Kleist and Thomas, 2019)

Status of radiance data assimilation in the FV3GFS

Microwave:

- AMSU-A: NOAA-15, 18, 19, MetOp-A, MetOp-B, Aqua
- ATMS: NPP, NOAA-20
- MHS: NOAA-18, 19, MetOp-A, MetOp-B
- SSMIS: DSMP-F17
- SAPHIRE: Megha-Tropique

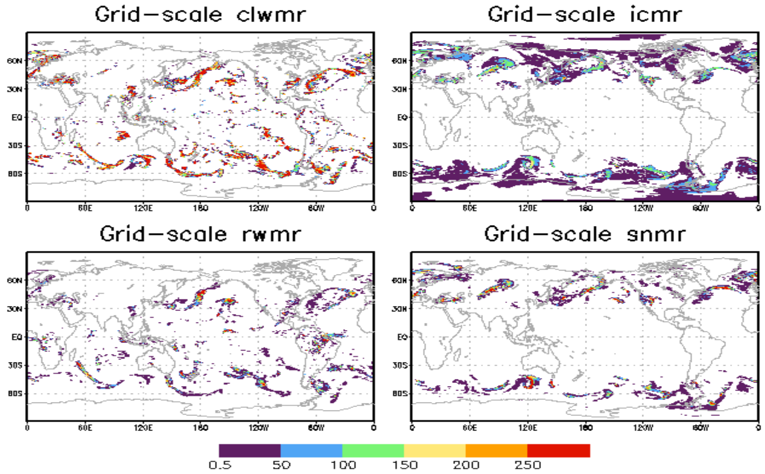
Infrared:

- AIRS: Aqua
- GOES-15 Sounder
- IASI: MetOp-A, MetOp-B
- CrIS: NPP, NOAA-20
- SEVIRI: MeteoSat-11
- AVHRR: MetOp-A, NOAA-18

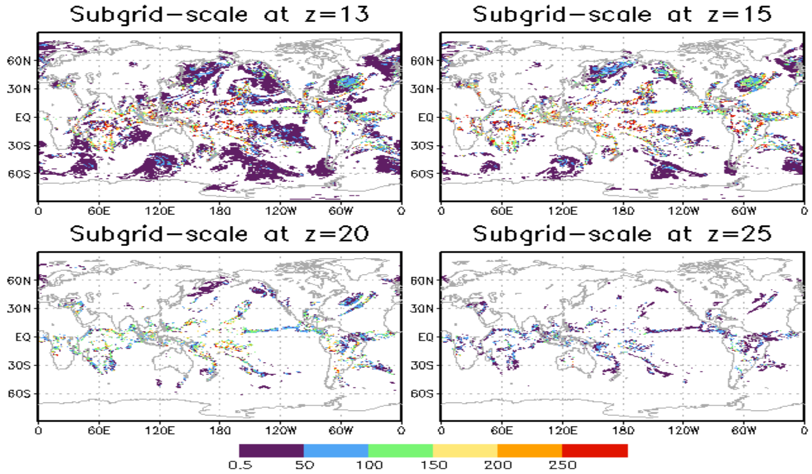
- ❑ Over ocean, both clear-sky and cloudy radiances from AMSU-A and ATMS over ocean FOVs are assimilated in the **all-sky** approach (Zhu et al. 2016; Zhu et al. 2019), only clear-sky radiances are assimilated from other sensors
- ❑ Over land, only clear-sky radiances are assimilated for all the sensors

In the cloudy radiance assimilation in the GFS, only grid-scale clouds have been used in the radiance simulation calculation. The lack of clouds in radiance simulation in tropics is clear.

Grid-scale (z=15, about 800hPa)



convective cloud (about 850-500hPa)

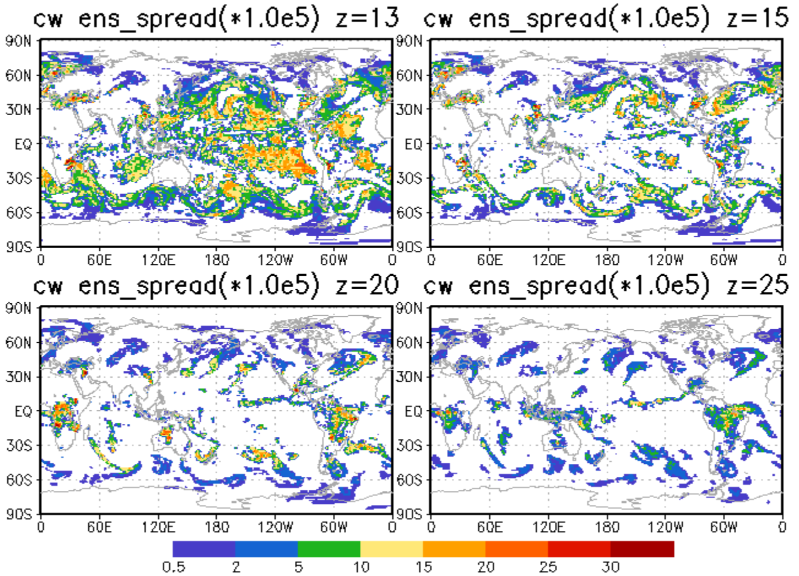


Convective cloud was added as an optional model output field later 2018.

To preserve forecast model water budget, convective cloud increments should not be fed back to the forecast model. Considered approaches to incorporating convective clouds:

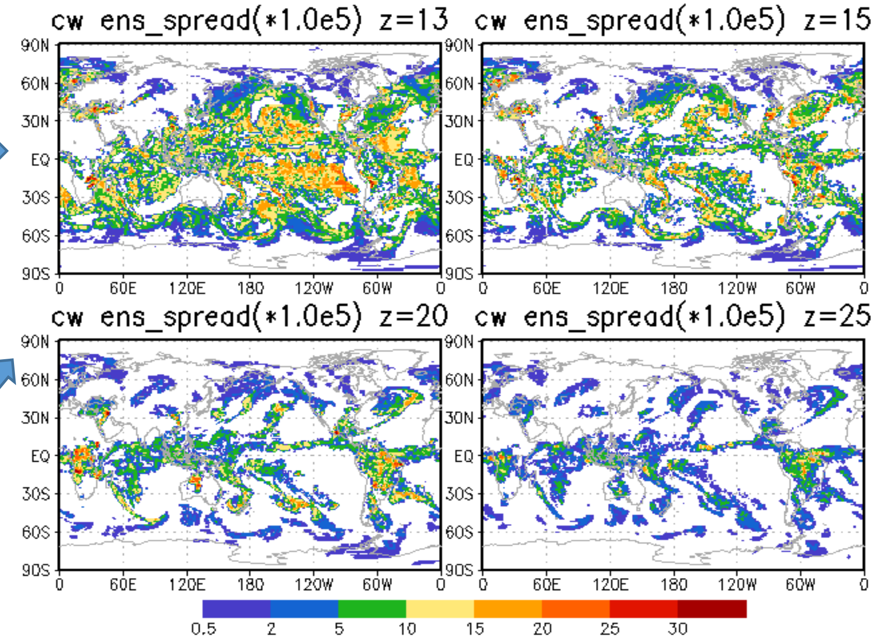
- Combine subgrid & grid scale clouds in the GSI, remove subgrid-scale clouds from cloud analyses before passing them back to model, or do not feed back cloud to model;
- Treat convective clouds separately as additional control variable(s).

Ensemble spread: grid-scale

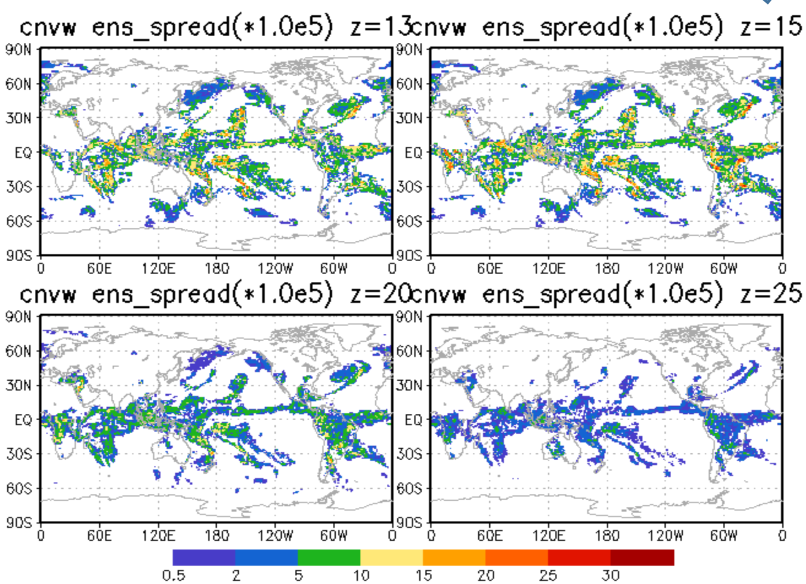


Different characteristics were observed for grid-scale and convective clouds

Combined ensemble spread



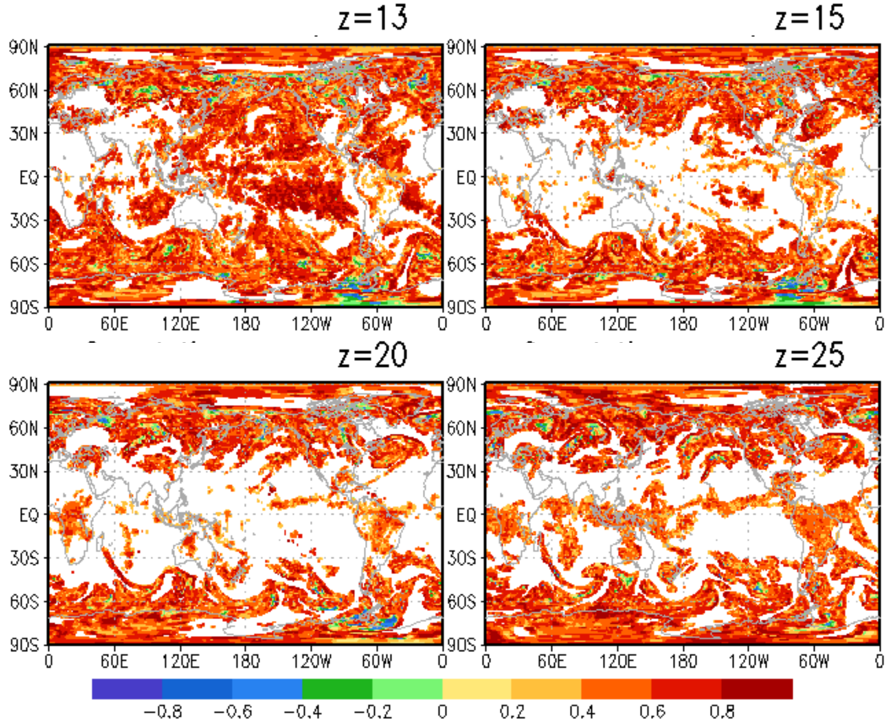
subgrid-scale



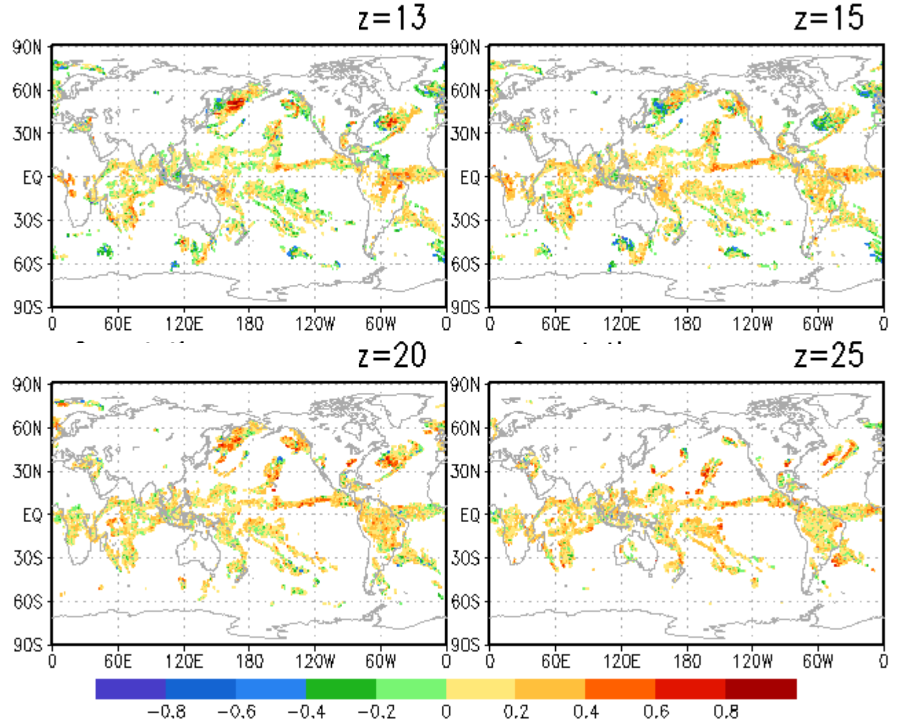
- In the tropics, the contribution from convective clouds is dominant (z14-25)
- The contribution from convective clouds corresponds clearly with the ITCS and SPCZ

Point-wise correlation between cloud water and RH

grid-scale (about 850-500hPa)



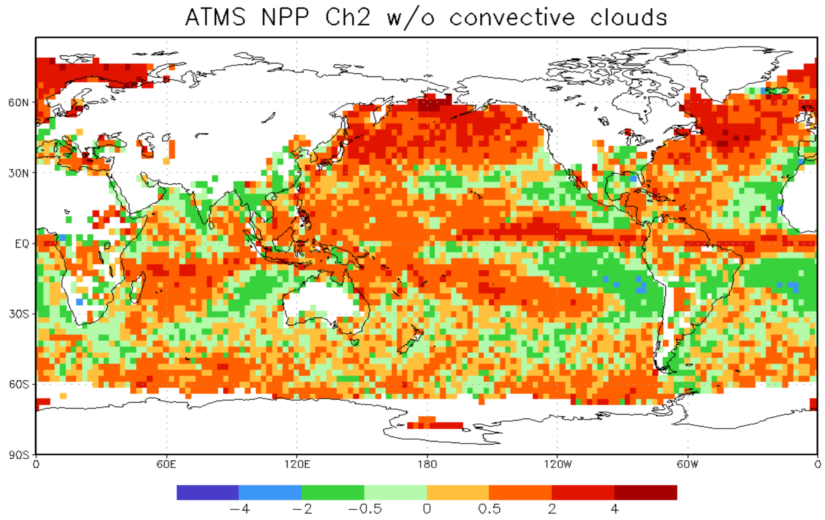
convective (about 850-500hPa)

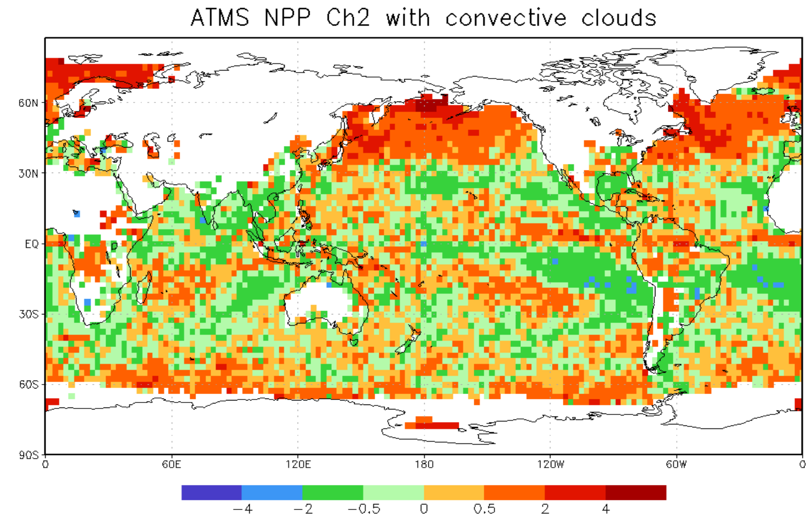


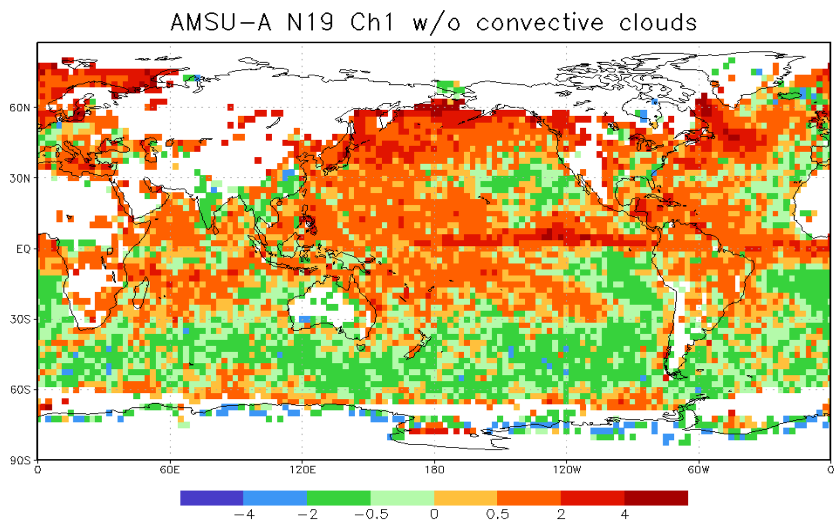
- High point-wise correlation between grids-cale clouds and RH
- Low correlation between convective clouds and RH
- Because of its large ensemble spread and low correlation with T and RH, we didn’t take the approach of using convective clouds as a separate cloud control variable as there are no direct cloud observations to constrain the field

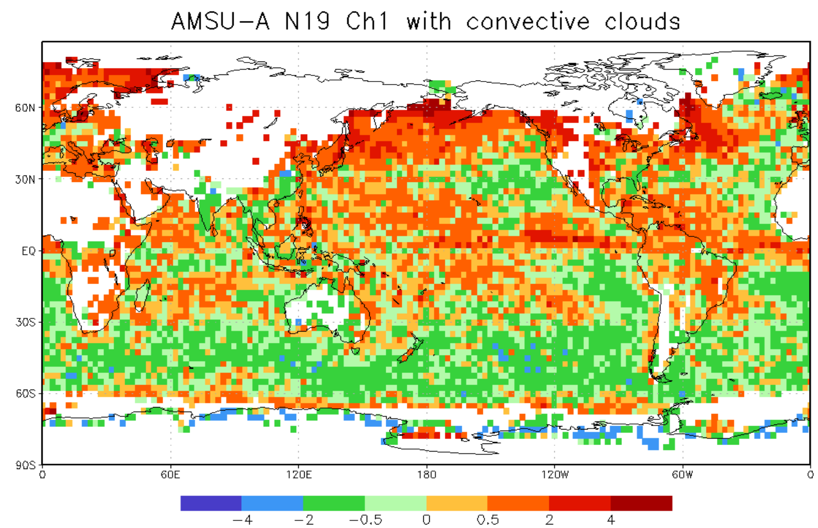
Impact of incorporating convective clouds

w/o convective clouds / with convective clouds









- Improve OmF with the much needed clouds in the tropics

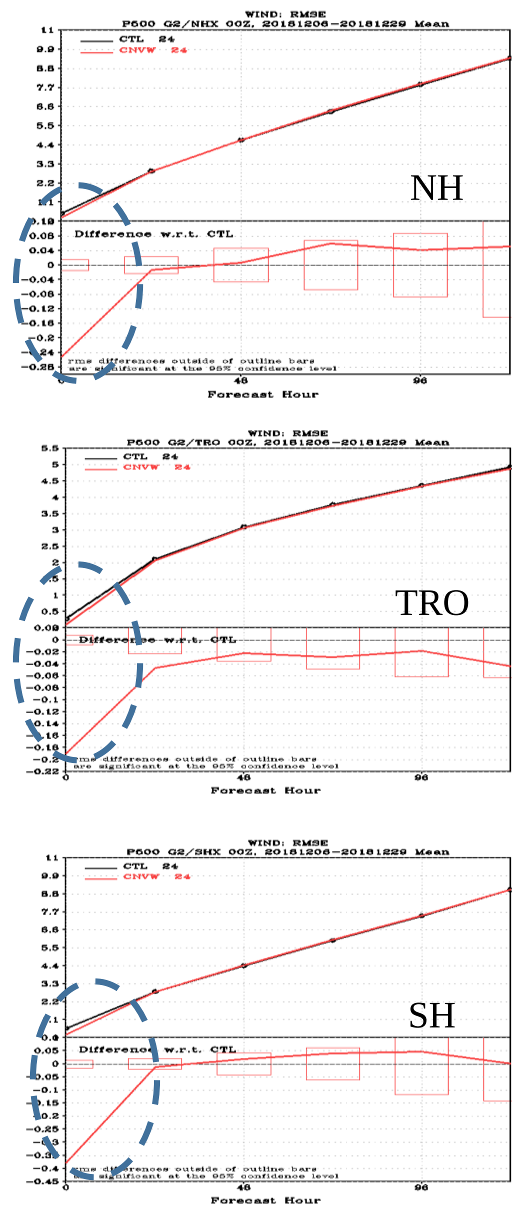
3D EnVar experiments were performed

- Improve OmF in the tropics;
- Provide realistic cloud ensemble spread in tropics;
- Improve model forecast spinup with reduced RMSE of wind & temperature;
- Prepare for using features of CRTM 2.3.0 (e.g. cloud fraction acts as reducing cloud for these MW data)
- However, forecast anomaly correlation is slightly degraded in Southern Hemisphere

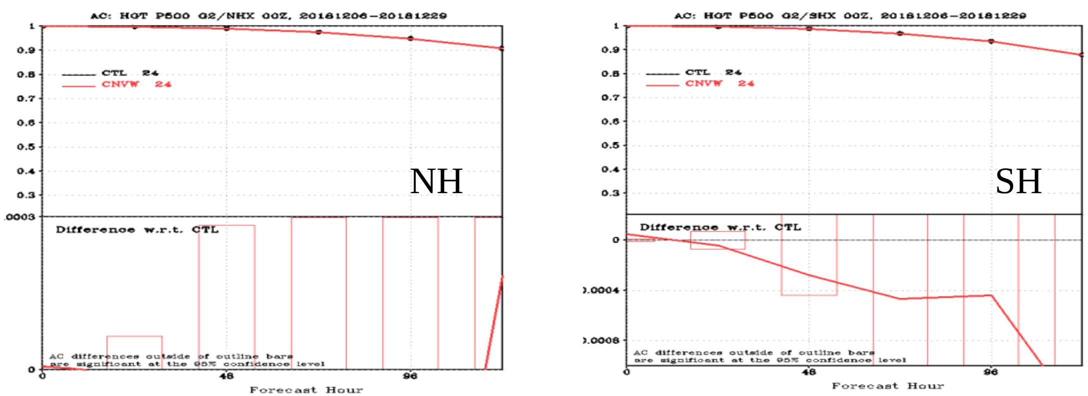
Work plan:

- Investigate the impact of applying smoothing to convective cloud ensemble as smoothing has been applied to other fields

Wind RMSE at 500 hPa



Geopotential height anomaly correlation at 500hPa



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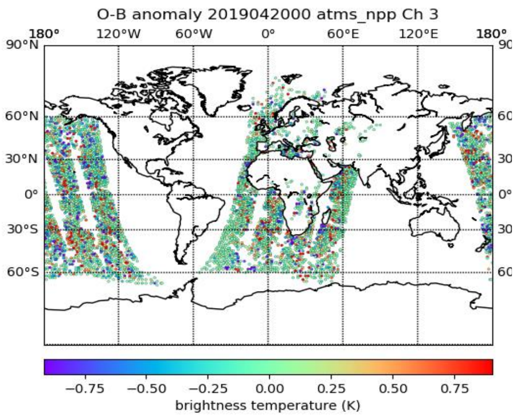
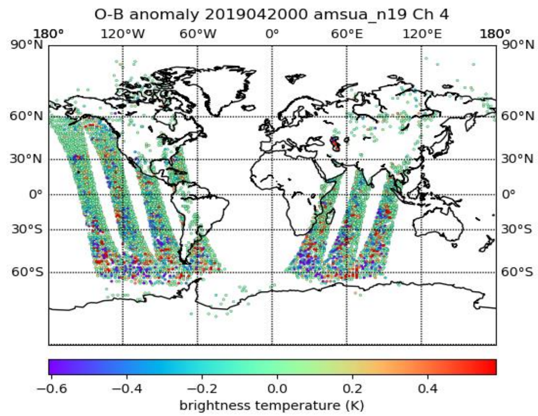
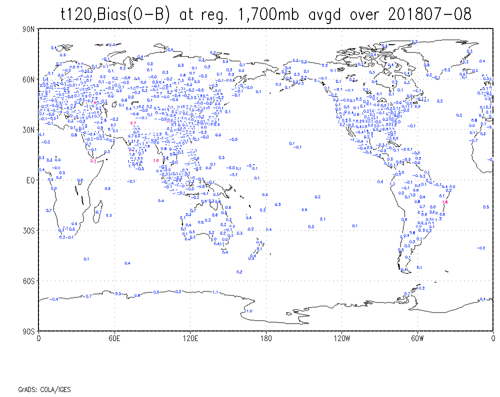
Challenges in assimilating surface-sensitive radiances over land

- Far fewer radiances are used over land than over ocean, only clear-sky radiances are used
- Radiance bias correction (Derber and Wu 1998; Zhu et al. 2014) is anchored on conventional data, bias correction estimate is currently dominated by radiances over ocean
- Challenges in assimilating surface-sensitive radiances over land
  - Uncertainties of NESDIS microwave land physical emissivity model in the CRTM
    - Radiance simulation is sensitive to emissivity accuracy
    - Emissivity sensitivity is used in bias correction & quality control, and it is required if emissivity is a control variable
  - Land surface model component in the forecast model: Uncertainties of land surface state properties, e.g. land surface skin temperature (LST) and soil moisture
  - Problematic cloud detection scheme over land where obs are compared with the equivalent clear-sky TBs







Radiosonde observation

GDAS Radiance Monitoring (NPP ATMS, NOAA-19 AMSU-A)

Instantaneous emissivity retrieval

(Prigent et al 2006; Karbou et al 2005; Baordo and Geer 2016; etc)

For a scattering-free atmosphere, assuming a flat and specular surface, observed brightness temperature BT can be expressed as:

$$BT_{obs} = \varepsilon\, T_s\, \Gamma + BT_{up} + \Gamma\, (1 - \varepsilon)\, BT_{down}$$

- BT_{up} atmospheric upwelling radiation
- BT_{down} atmospheric downwelling radiation
- Γ atmospheric surface-to-space transmittance
- T_s surface skin temperature (effective radiating temperature of the surface at the relevant frequency)

Surface emissivity can be calculated as:

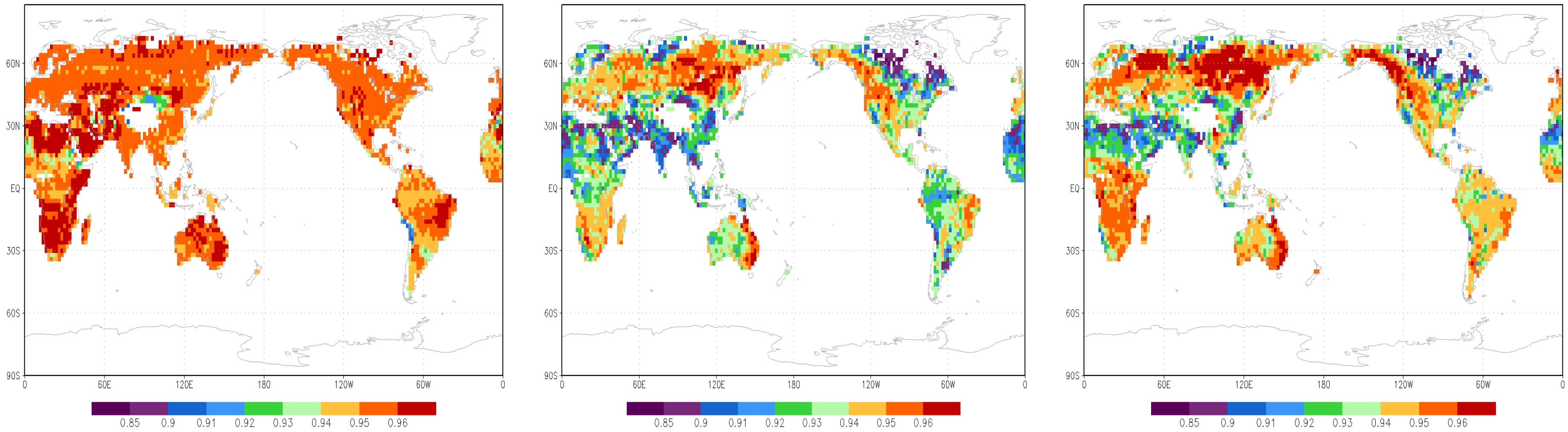
$$\varepsilon = \frac{BT_{obs} - BTup - BTdown\,\Gamma}{(T_s - BTdown)\,\Gamma}$$

Or with effective cloud fraction C

$$\varepsilon = \frac{BT_{obs} - (1-C)\left(BT_{up}^{clr} + BT_{down}^{clr}\,\Gamma^{clr}\right) - C\,(BT_{up}^{cld} + BT_{down}^{cld}\,\Gamma^{cld})}{(1-C)\left(T_S - BT_{down}^{clr}\right)\Gamma^{clr} + C\left(T_S - BT_{down}^{cld}\right)\Gamma^{cld}}$$

Comparison of a-warm-month averaged emissivity

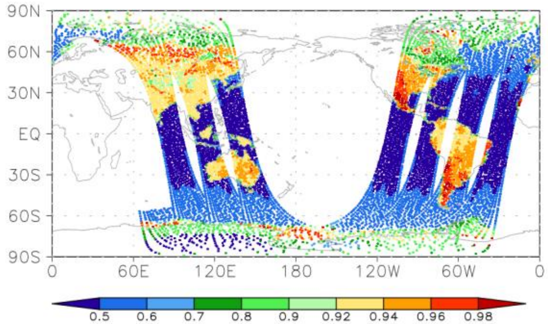
CRTM emissivity | instantaneous emissivity from GFS | climatology (TELSEM2)



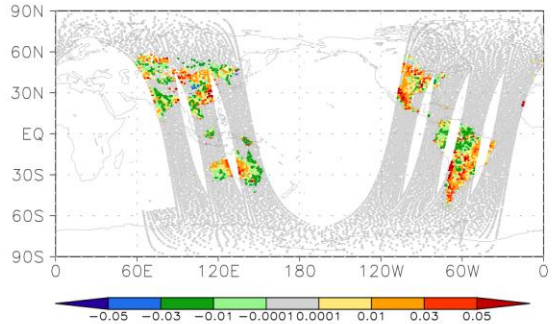
- The patterns of the instantaneous emissivity from the GFS data assimilation system are similar to the climatology from TELSEM2.
- Large differences are observed in some areas between the CRTM emissivity and the climatology.
- Warm and cold months of instantaneous emissivities from the GFS have been provided to CSEM developers for the machine learning study.

Issues with the emissivity sensitivity in the CRTM

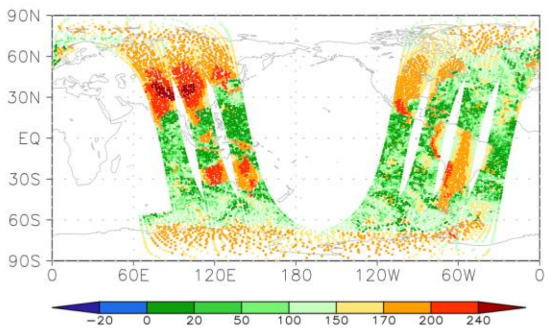
CRTM emissivity



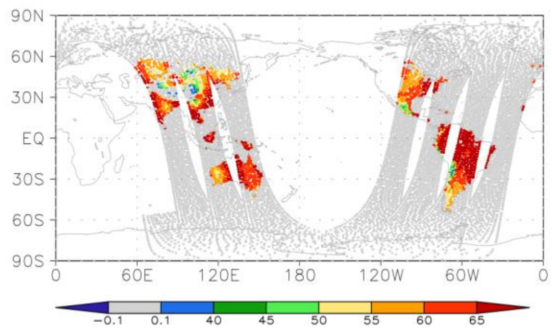
e_CRTM- e_(analytical+TELSEM)



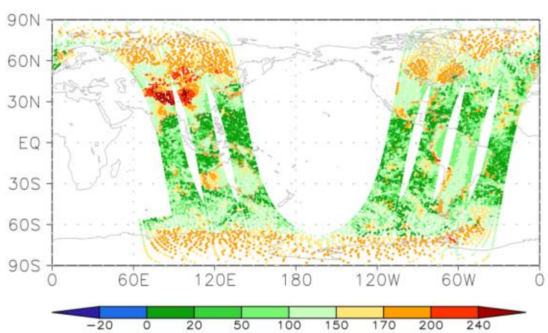
CRTM emissivity sensitivity (e_k)



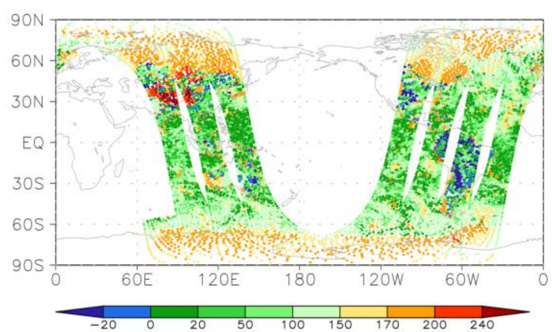
Diff e_k with user_emissivity (clr-sky)



e_k with user_emissivity (clr-sky)



e_k with user emissivity (cld-sky)



ATMS NPP ch3

When user supplied emissivity is used in the CRTM, emissivity sensitivity calculated is problematic.

- seems too low in clear sky case
- negative emissivity sensitivity in cloudy case, which is not physically meaningful.

The calculation is based on

- the simple Kirchhoff 's law over specular surface.
- the assumption that emissivity is an independent variable, which actually depends on surface temperature strongly.

Ongoing work and future plan

- **Intermediate goal**: using instantaneous emissivity retrieval from the GSI combined with TELSEM atlas, assimilate all-sky microwave radiances over land
    - Help Community Surface Emissivity Model (CSEM) developers to improve CSEM

- **Long-term goal**: with the improved CSEM, soil moisture and LST analyses using radiances from low-frequency (e.g. L-band) microwave satellite sensors, such as AMSR2, SMOS, GMI
    - Near-surface temperature and humidity observations (currently not assimilated in FV3GFS) are strongly influenced by soil moisture in appropriate conditions, and will also help to constrain radiance assimilation
    - Radiance observations involve variables from more than one components: both atmosphere and land data assimilations. Coupled data assimilation (Kleist 2019, personal communication)