Investigating the impact of assimilating all-sky window-channel infrared radiances from GOES-ABI and Himawari-AHI on cloud analyses and forecasts

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All-sky satellite radiance DA

- Advances in the assimilation of satellite radiances allowed us to **directly** assimilate cloud-**free** and cloud-**affected** observations
- Significant improvements in analyses and weather forecasts has been found especially using **cloud-affected microwave radiances** (e.g., Geer et al., 2011, 2017, 2018; Zhu et al., 2016, 2019)
- Efforts towards the assimilation of **cloud-affected infrared radiances** (e.g., Okamoto et al., 2014; Geer et al., 2019; Zhu et al., 2022; Degelia et al., 2023), mostly using **water vapor bands**
    - exhibit more Gaussian characteristics than window channels (Okamoto, 2017)
- Cloud-affected infrared radiances from **window channels remains a challenge**:
    - Observation error distribution
    - Non-linear observation operators
    - Variational bias correction
    - Quality control procedures
    - Cloud representation in forecast models

All-sky satellite radiance DA in MPAS-JEDI

- ➔ Leverage several quality control filters, variational bias correction, and observations operators in UFO:
  - ◆ **Community Radiative Transfer Model (CRTM) interfaced in JEDI-UFO**:
    - All sensors and conditions (Liu and Collard, 2019)
    - Hydrometeor types: water, ice, rain, snow and hail and graupel
- ➔ 3DVar, 3D/4DEnVar, hybrid data assimilation, EDA, LETKF (recent, under testing) capabilities
- ➔ Analysis variables: temperature, specific humidity, zonal and meridional components of horizontal velocity, surface pressure, **mixing ratios of cloud liquid water, cloud ice, rain, snow, and graupel**
- ➔ Assimilate aircraft, sondes, surface (pressure), derived atmospheric motion winds (AMVs), GNSS radio occultation, radiances (AMSUA, MHS, ATMS, ABI, AHI)
  - ◆ AMSU-A window channels in all-sky scenes (Liu et al., 2022)
  - ◆ ATMS water vapor and window channels in all-sky scenes (Ban et al., 2023)
- ➔ Cycling experiments, HofX

Objective

Examine the assimilation of infrared window channel 13 from GOES-ABI and Himawari-AHI sensors, using the Model for Prediction Across Scales – Atmosphere (MPAS-A) coupled with the Joint Effort for Data assimilation Integration (JEDI)

- ❖ Estimate observation errors for ABI and AHI channel 13
- ❖ Estimate observation bias for bias correction
- ❖ Run cycling experiments
- ❖ Preliminary verification of cloud analysis and forecasts

Observation error model

Symmetric cloud impact (SCI) by Okamoto et al (2014):

$$\mathbf{CI_O = BT_{y,BC} - BT_{clr}}$$

$$\mathbf{CI_M = BT_x - BT_{clr}}$$

$$\mathbf{SCI = \frac{1}{2} (|CI_O| + |CI_M|)}$$

BT_y, BT_x: observed and simulated brightness temperature

BT_{clr}: clear-sky background brightness temperature without considering cloud-scattering

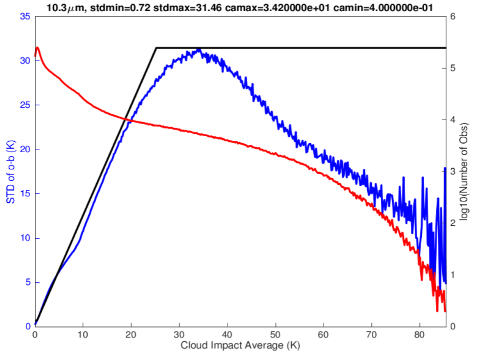
CI_M, CI_O: cloud impact on model and observation

OmB calculated using HofX:

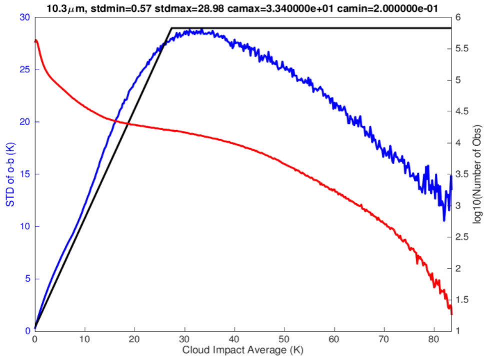
- 30-km forecast from hybrid 3DEnVar cycling experiment
- Observation without bias correction
- Only over water
- Maximum sensor zenith angle: 65.0
- 00Z 20 April - 18Z 14 May 2018

Observation error model

ABI

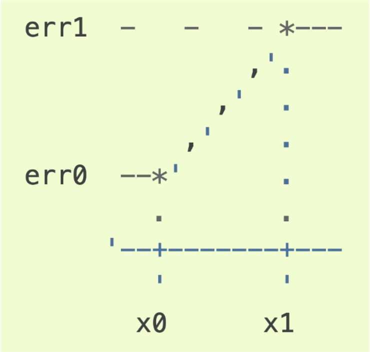


AHI



Parameterized ABI and AHI observation errors using a piece-wise linear function of UFO (ObsErrorModelRamp):

https://jointcenterforsatellitedataassimilation-jedi-docs.readthedocs-hosted.com/en/stable/inside/jedi-components/ufo/qcfilters/obsfunctions/ObsErrorModelRamp.html#obserrormodelramp



ABI

	x0	x1	err0	err1	clrbias
13	0.40	34.20	0.72	31.46	-1.13

AHI

	x0	x1	err0	err1	clrbias
13	0.20	33.40	0.57	28.98	-0.56

clrbias is used for constant bias correction for each sensor

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Experiments design

- MPAS-JEDI v2.0:
  - 00Z 15 April 2018 - 00Z 20 April 2018
  - Hybrid 3DEnVar
  - 30km-60km dual resolution, 80-member EDA forecast
  - 2 outer loops with 60 iteration each
  - CRTM observation operator
    - with cloud scattering effect for ABI and AHI channel 13 with no humidity sensitivity
  - AHI and ABI channel 13:
    - thinned on a 145-km mesh
    - only over water

- MPAS-A:
  - non-hydrostatic dynamical core
  - unstructured mesh
  - height-based terrain-following vertical coordinate
  - 55 levels, 30km top
  - quase-uniform 30 km grid
  - “mesoscale reference” physical parameterizations

Exp. name	Observations			
benchmark	Aircraft, AMVs wind, surface (pressure), sondes, GNSS RO bending angle	clear-sky AMSU-A (MetOp A, MetOp B, NOAA-15, NOAA-18, NOAA-19) - VarBC*	clear-sky MHS (MetOp A, MetOp B, NOAA-18, NOAA-19) - VarBC*	
ch13_raw	✓	✓	✓	ABI GOES-16 channel 13 AHI Himawari-8 channel 13
ch13_constBC	✓	✓	✓	ABI GOES-16 channel 13 AHI Himawari-8 channel 13 - constant offset bias correction

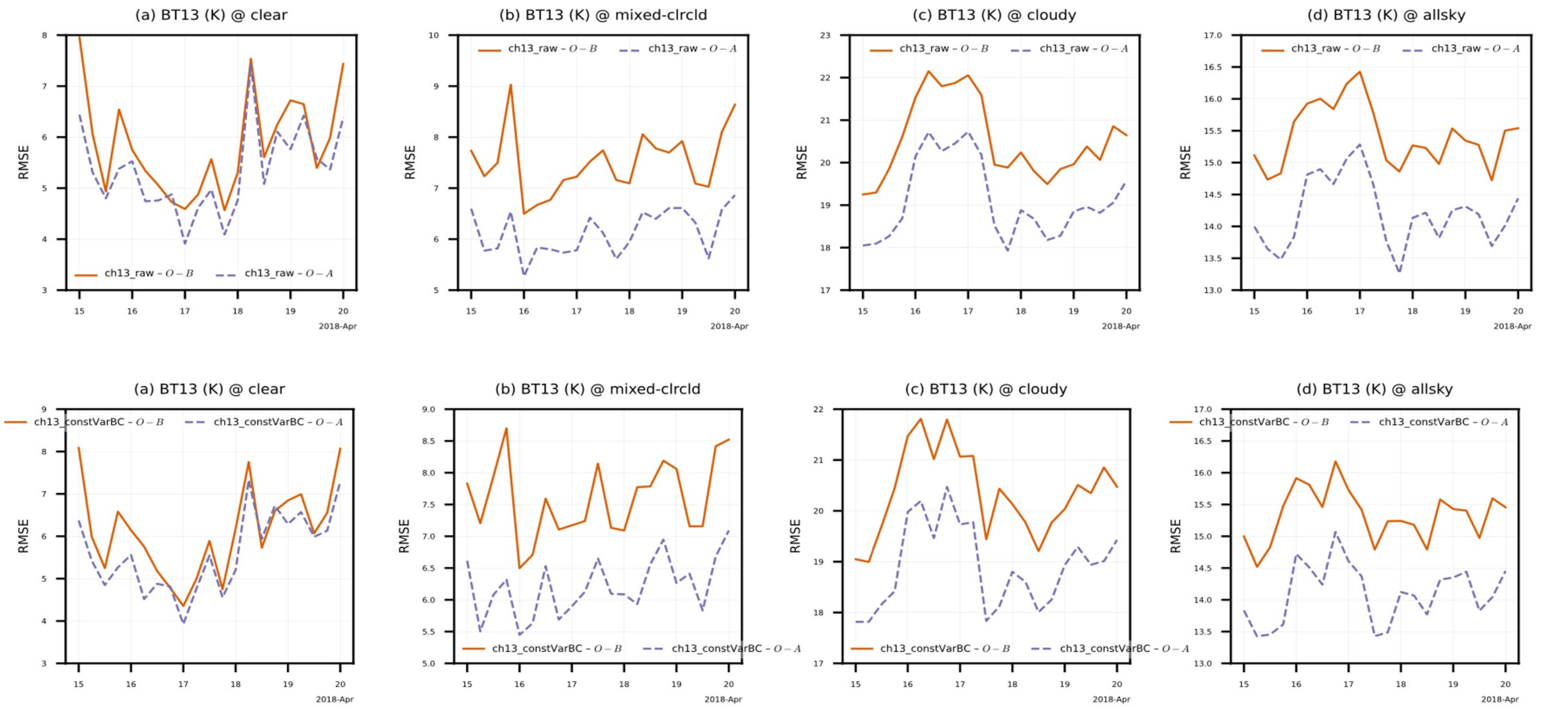
*Predictors: constant offset, lapse rate, emissivity, scan angle 2, scan angle 3 and scan angle 4

Observation space verification

AHI

raw

constBC



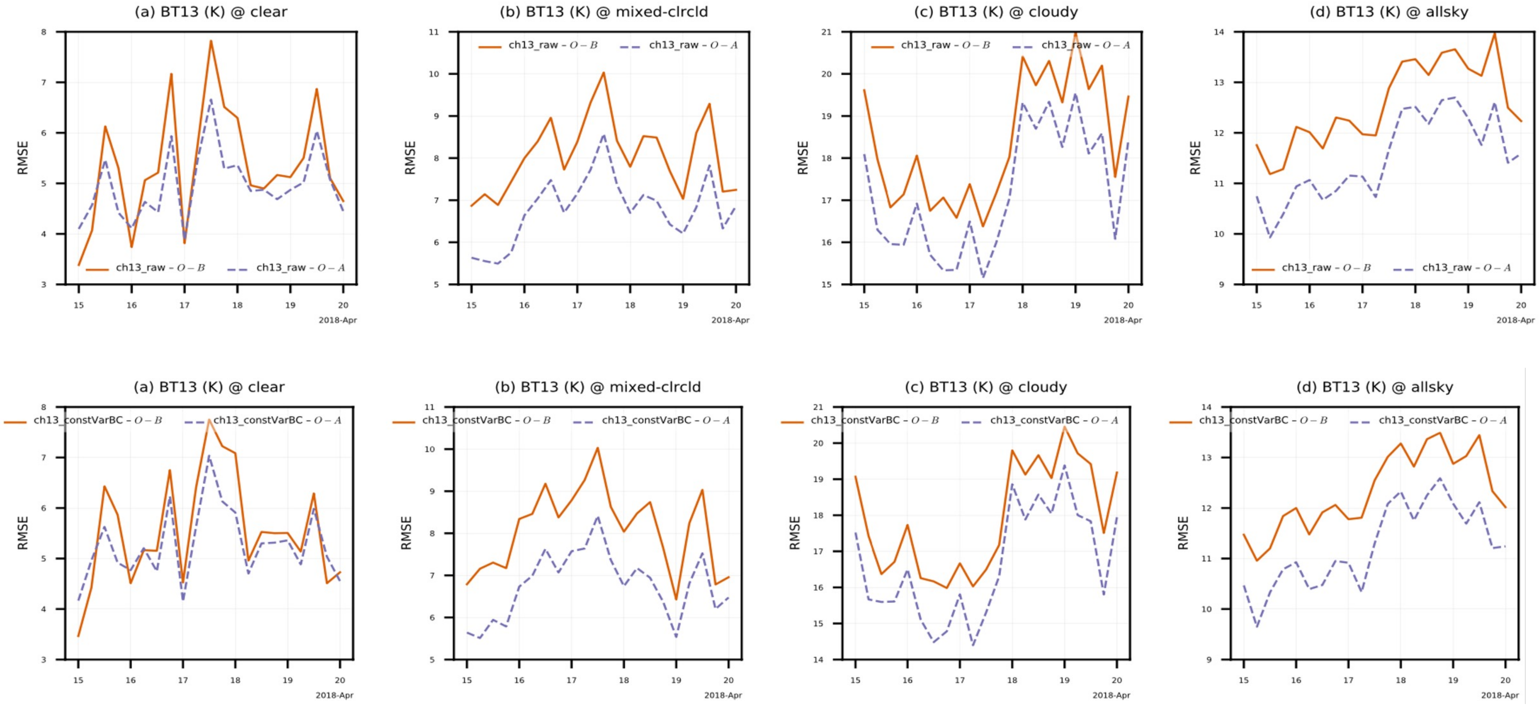
RMS (OmB) > RMS(OmA)

Observation space verification

ABI

raw

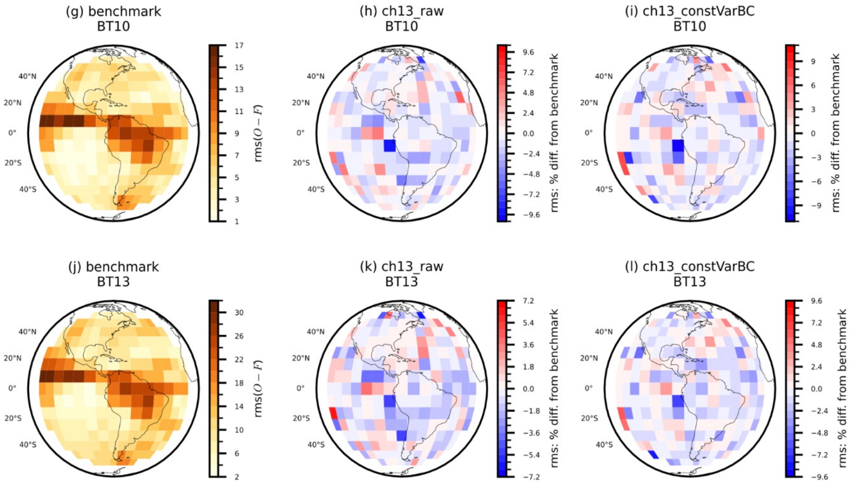
constBC



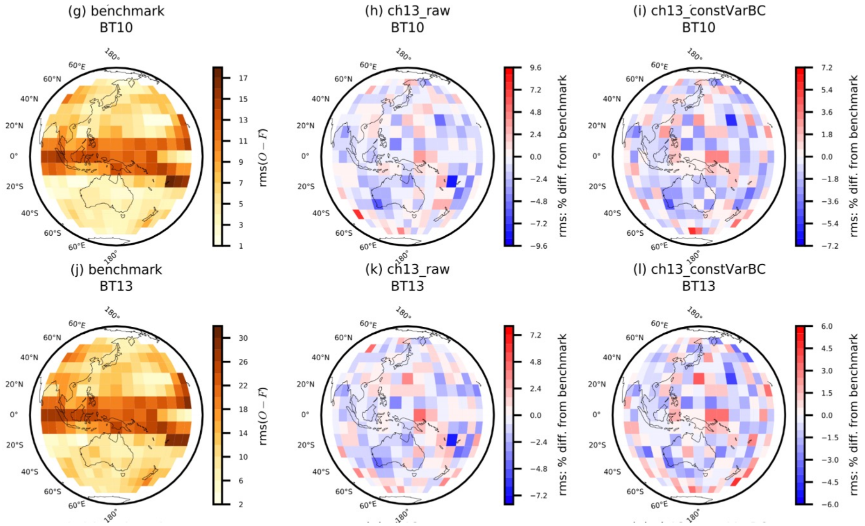
RMS (OmB) > RMS(OmA)

Observation space verification: 6-h forecast

ABI



AHI



➔ Experiment with channel 13 leads to improvements in window and water vapor channels for ABI and AHI

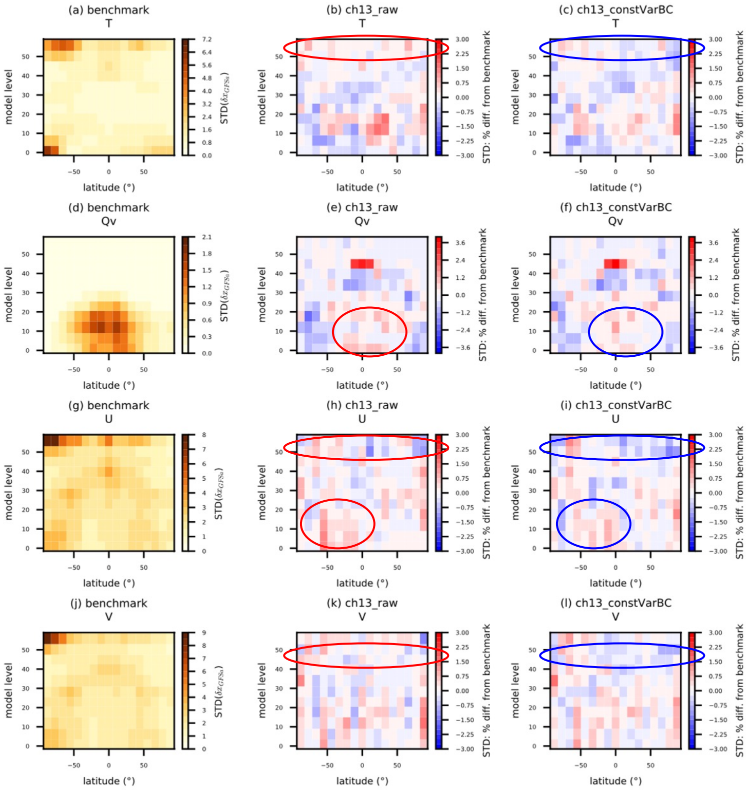
RMS **< 0 improvement** **> 0 degradation**

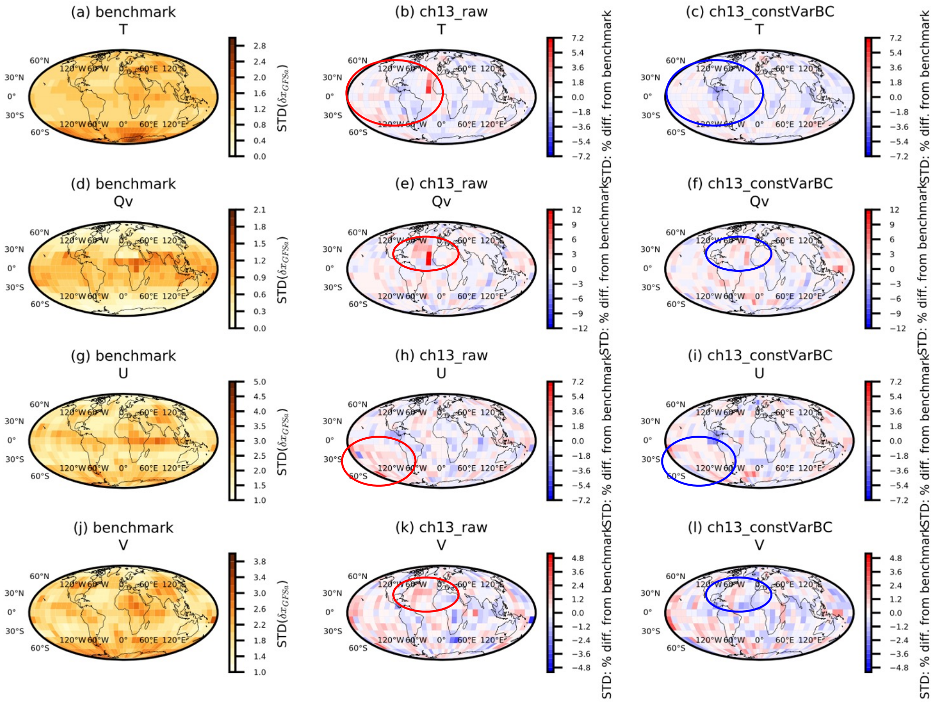
MPAS 6-h fcst vs GFS analysis

STD

< 0 improvement

> 0 degradation



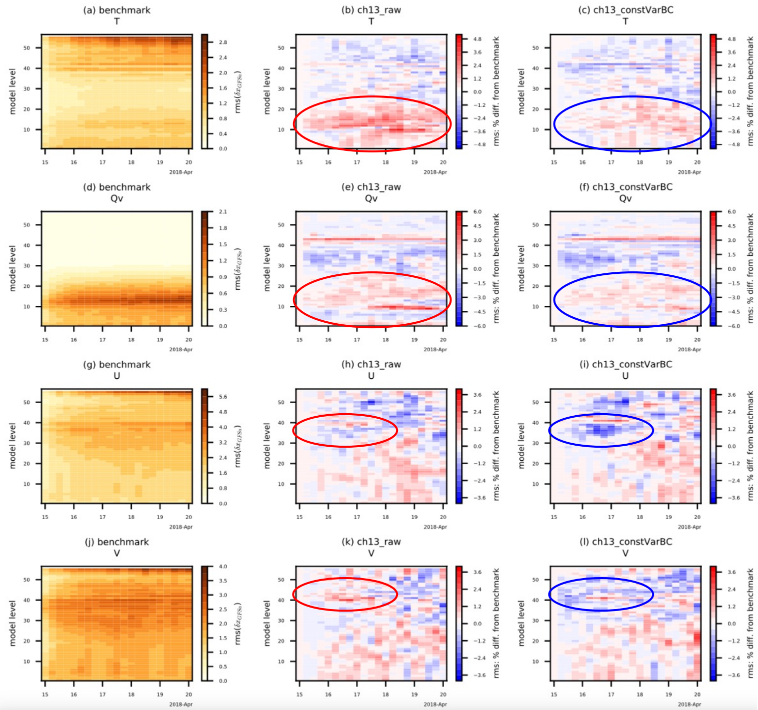


➔ More improvements are found in experiment with constant bias correction

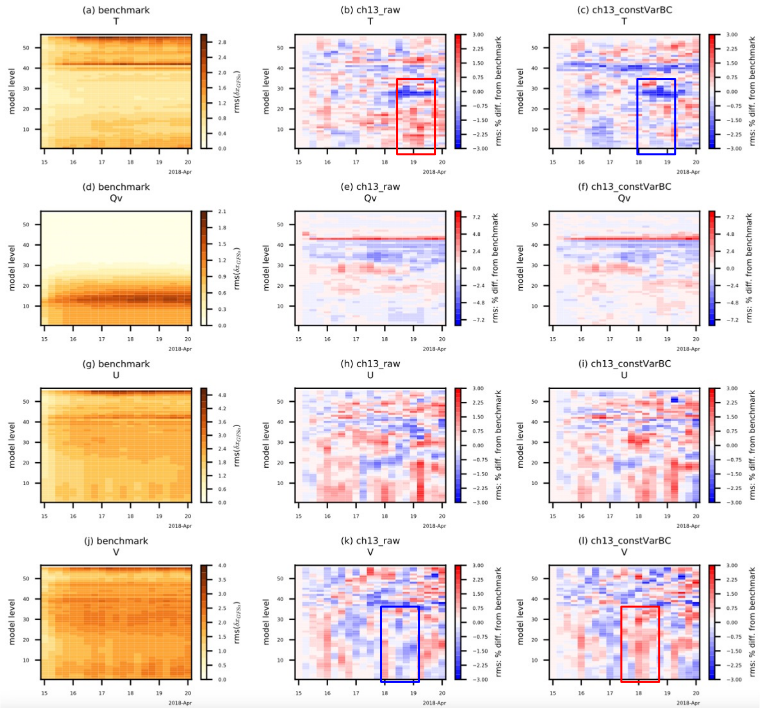
MPAS 6-h fcst vs GFS analysis

STD < 0 improvement
> 0 degradation

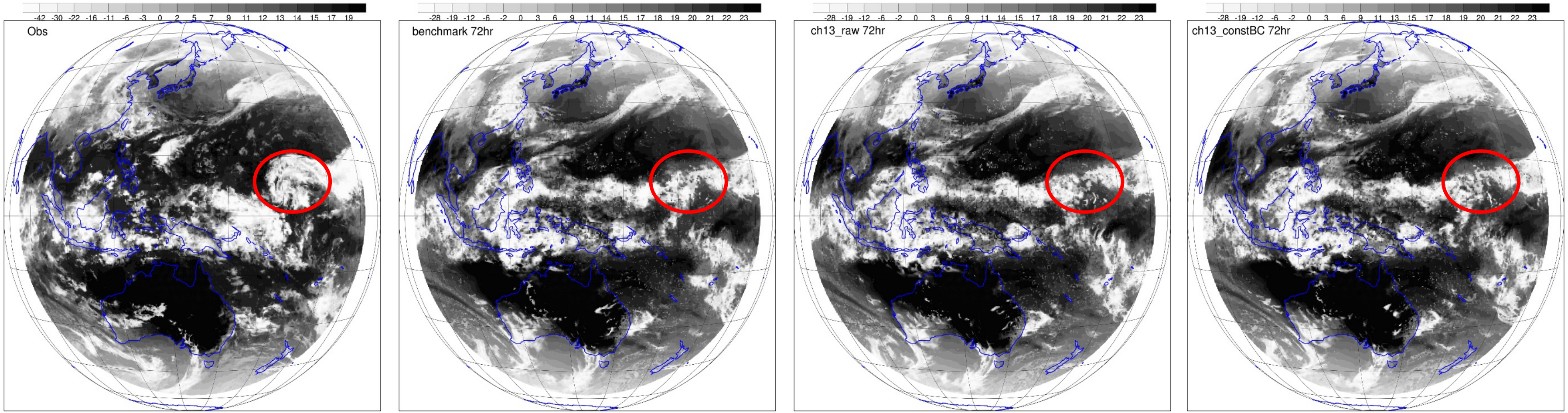
ABI region



AHI region

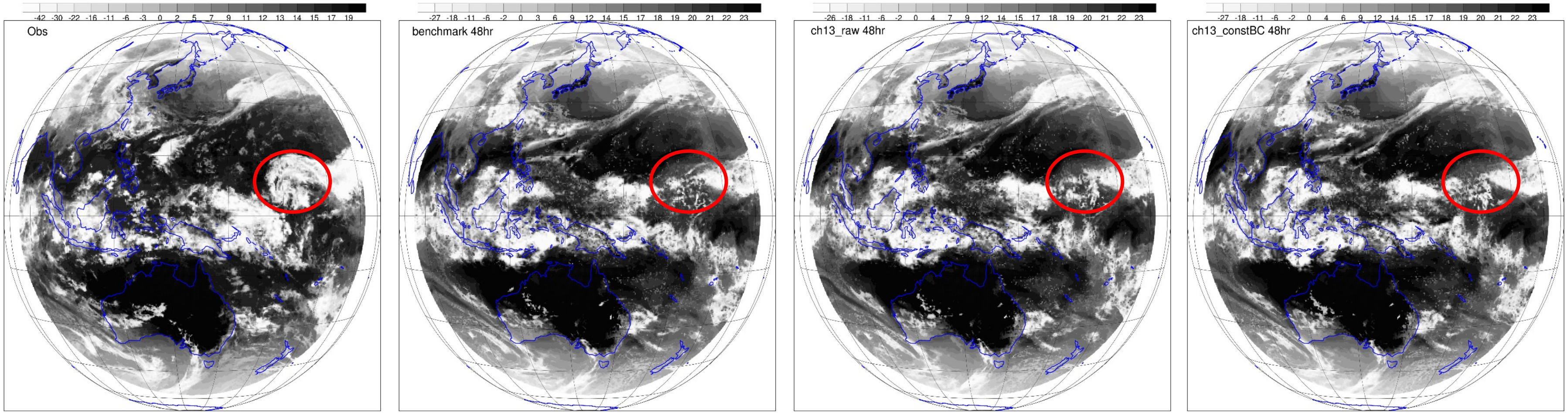


Observations vs. Day-3 forecast



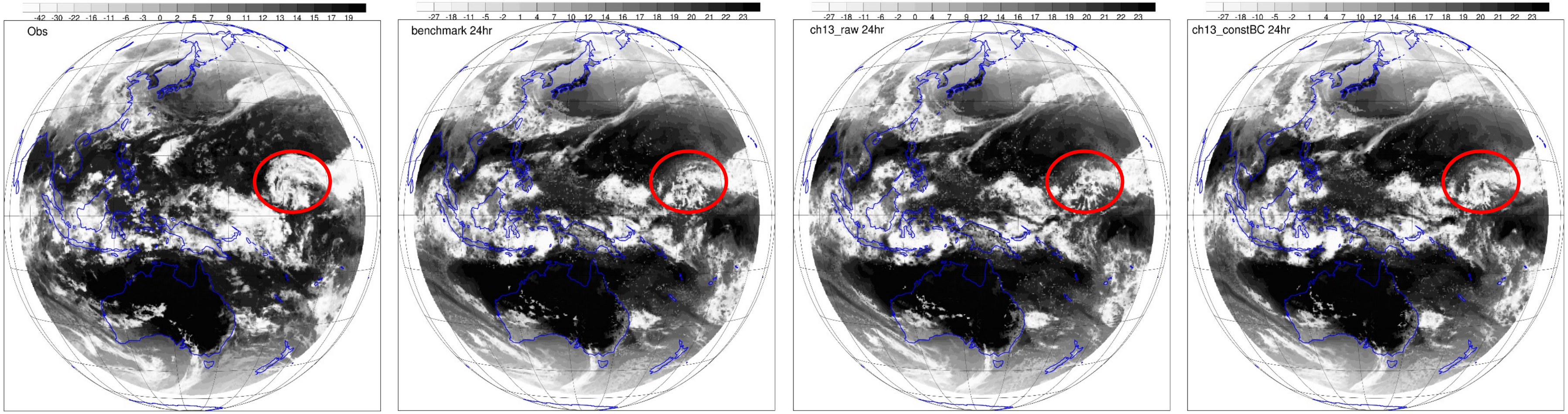
AHI channel 13 BTs (degree C) valid at 00 UTC 21 April 2018

Observations vs. Day-2 forecast



AHI channel 13 BTs (degree C) valid at 00 UTC 21 April 2018

Observations vs. Day-1 forecast



AHI channel 13 BTs (degree C) valid at 00 UTC 21 April 2018

Takeaways

- Demonstrated our capability to successfully do all-sky **infrared** DA with MPAS-JEDI
- Calculated observation errors and constant bias for ABI and AHI channel 13
- Assimilated ABI and AHI channel 13 with and without constant bias correction in a cycling experiment for 5 days
- More positive impacts are found in the MPAS 6-hr forecast when assimilating channel 13 with bias correction with promising results for longer forecast
- More work is needed in terms of the variational bias correction taking into account more adequate predictors (Okamoto et al., 2023 uses SCI as a predictor) and the observations operator

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Thank you!
Comments/questions?

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