Impact of assimilating all-sky microwave radiances on cloud forecasts, evaluated using ABI/AHI radiances

Jake Liu, Junmei Ban, Ivette H. Banos,
Kate Fossell, Byoung-Joo Jung, Chris Snyder

Prediction, Assimilation and Risk Communication (PARC) Section
Mesoscale & Microscale Meteorology (MMM) Laboratory
National Center for Atmospheric Research

NCAR

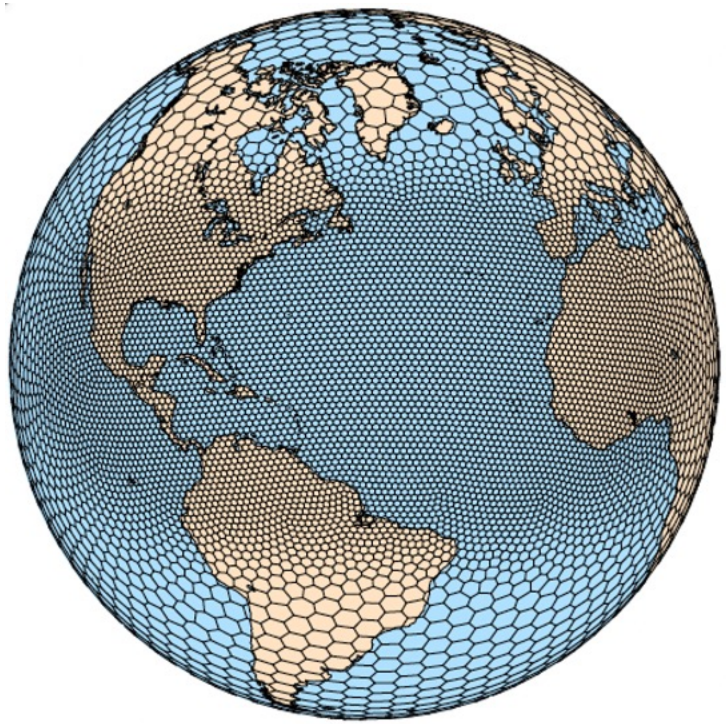
DoD Cloud Post-Processing and Verification Workshop
September 13-14, 2023, Boulder

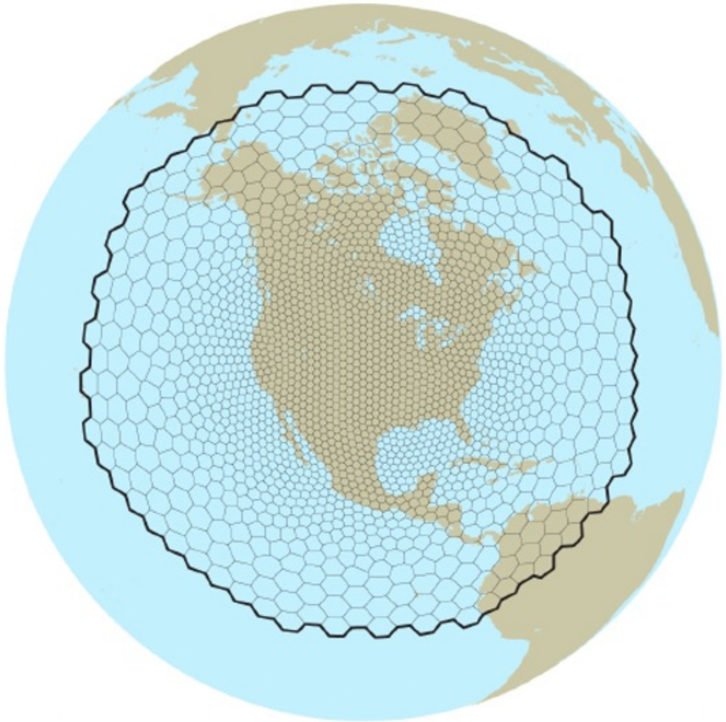
NSF

This material is based upon work supported by the National Center for Atmospheric Research, which is a major facility sponsored by the National Science Foundation under Cooperative Agreement No. 1852977.

MPAS-A: MMM's new-generation global/regional-unified atmospheric model built on unstructured grids (First public release in 2013)

MPAS-A: Model for Prediction Across Scales - Atmosphere





Allow variable-resolution mesh; Same source code for all applications

MPAS-JEDI: relatively-new data assimilation system for MPAS-A, based on JEDI (Joint Effort for Data assimilation Integration) framework

- Been developed since 2018 by NCAR/MMM+JCSDA, with a USAF-funded project named ‘**PANDA-C**’ (**P**rediction **AND** **A**ssimilation for **C**loud)

- Can do both deterministic analysis and ensemble analysis using various DA techniques

- Analysis directly done on **MPAS unstructured grid** for uniform or **variable-resolution mesh, global** or **regional mesh**

- The first MPAS-JEDI tutorial is next week here, with the latest public version-2 release in June!

All-sky satellite radiance DA with MPAS-JEDI

- So far mostly using CRTM, though could also use RTTOV in the future
- Mixing ratios of (cloud water, cloud ice, rain, snow, graupel) as part of analysis variables
- Situation-dependent observation error models (similar to that in Ivette's talk)
- Variational Bias Correction

Input needed for cloudy radiance simulation by CRTM

- Temperature and moisture profiles
- Surface properties

- Layer water content of hydrometeors (liquid cloud, ice cloud, rain, snow, graupel)
- Effective radius of hydrometeors (with assumed particle size distributions of a microphysics scheme)
- Cloud fraction: diagnosed by Xu&Randall scheme in the MPAS-A model

- Pre-computed look-up table of single-scattering properties for hydrometeors
  - Also with assumed particle size distributions, not necessarily consistent with those of a microphysics scheme
  - Particle shape assumption: spherical vs. non-spherical

Microwave Instrument Characteristics

Channel	Freq.(GHz)	Channel	Freq.(GHz)	PeakWF (hPa)
AMSU-A 1	23.8	ATMS 1	23.8	Surface
AMSU-A 2	31.4	ATMS 2	31.4	Surface
AMSU-A 3	50.3	ATMS 3	50.3	Surface
		ATMS 4	51.76	Surface
AMSU-A 4	52.8	ATMS 5	52.8	850
AMSU-A 5	53.596	ATMS 6	53.596	700
AMSU-A 6	54.4	ATMS 7	54.4	400
AMSU-A 7	54.94	ATMS 8	54.94	250
AMSU-A 8	55.5	ATMS 9	55.5	200
AMSU-A 9	fo=57.29	ATMS 10	fo=57.29	100
AMSU-A 10	fo±0.217	ATMS 11	fo±0.217	50
AMSU-A 11	fo±0.3222±0.048	ATMS 12	fo±0.3222±0.048	25
AMSU-A 12	fo±0.3222±0.022	ATMS 13	fo±0.3222±0.022	12
AMSU-A 13	fo±0.3222±0.010	ATMS 14	fo±0.3222±0.010	5
AMSU-A 14	fo±0.3222±0.045	ATMS 15	fo±0.3222±0.045	2
AMSU-A 15	89.0	ATMS 16	88.2	Surface
MHS 1	89.0			
MHS 2	157.0	ATMS 17	165.5	Surface
MHS 5	190.31	ATMS 18	183.31±7.0	800
		ATMS 19	183.31±4.5	700
MHS 4	183.31±3.0	ATMS 20	183.31±3.0	500
		ATMS 21	183.31±1.8	400
MHS 3	183.31±1.0	ATMS 22	183.31±1.0	300

Window channels(1-3,16,17) sensitive to the surface and hydrometeors

Temperature sounding channels (surface to upper stratosphere)

Window channel

Window channel

Humidity sounding channels (surface to upper troposphere)

4 month-long global DA cycling experiments

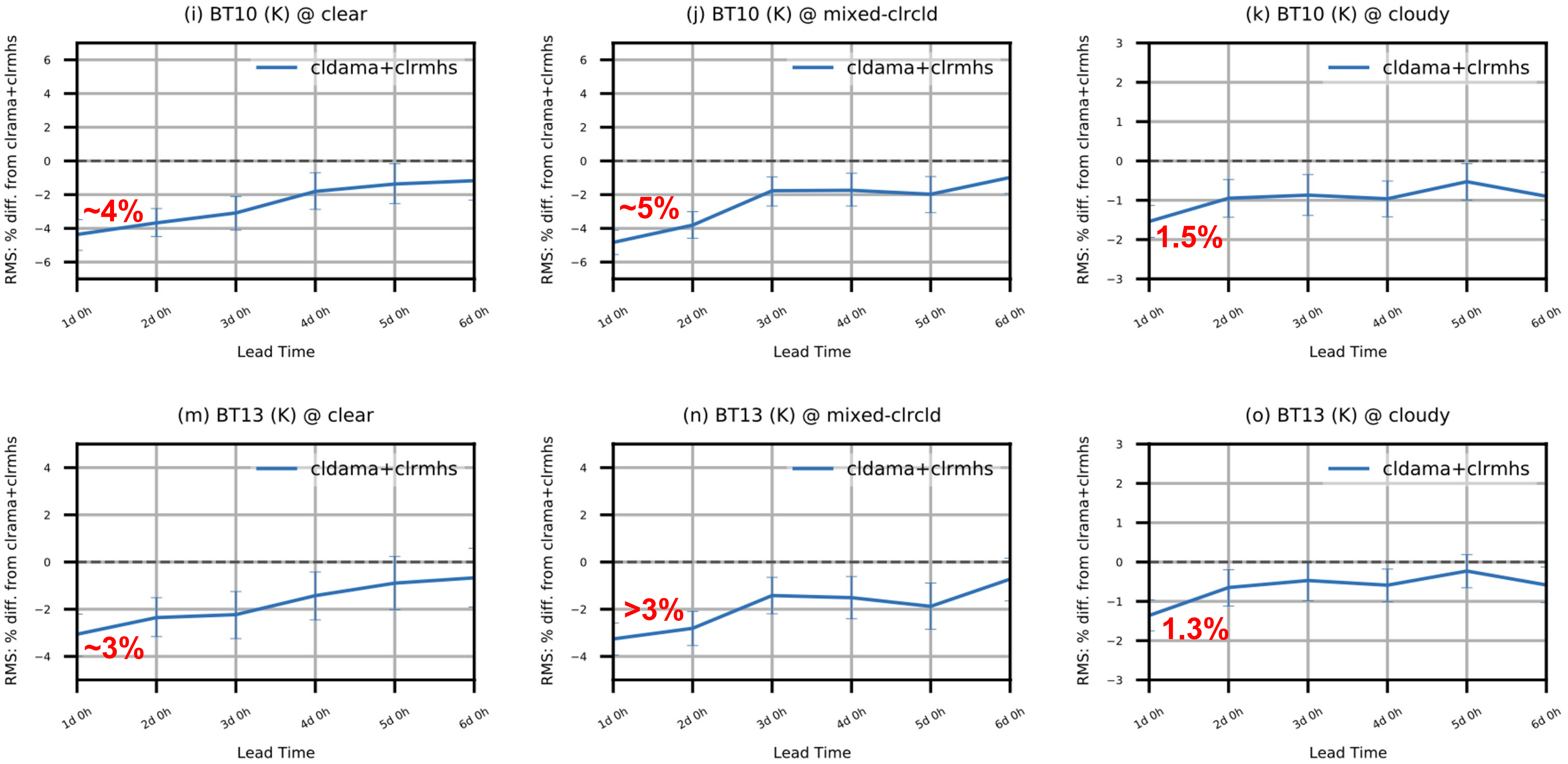
- Benchmark: Conventional obs + clear-sky AMSU-A temperature channels from 6 satellites (noaa-15/18/19, metop-a/b, aqua) + clear-sky MHS water vapor channels from 4 satellites (noaa-18/19, metop-a/b)
- Benchmark + all-sky AMSU-A window channels over water from 5 satellites (noaa-15/18/19, metop-a/b)
- Benchmark + all-sky ATMS T/Q-channels over water/land and window channels over water from 2 satellites (NPP, noaa-2019)
- Benchmark + all-sky AMSU-A + all-sky ATMS

Common configurations in all 4 experiments

- 30km-60km dual-resolution hybrid-3DEnVar
- 80-member ensemble input produced from MPAS-JEDI's own EDA cycling at 60km mesh
- Cycling period: 04/15 – 05/14, 2018, 6-hourly cycling
- 30km 5- or 6-day free forecast at each 0000 UTC
  - Mesoscale_reference physics suite with the one-moment WSM6 microphysics scheme
- Compare CRTM-simulated brightness temperatures from model forecasts with super-obbed ABI/AHI brightness temperatures

Impact of all-sky AMSU-A radiance DA vs. benchmark

verify against AHI data



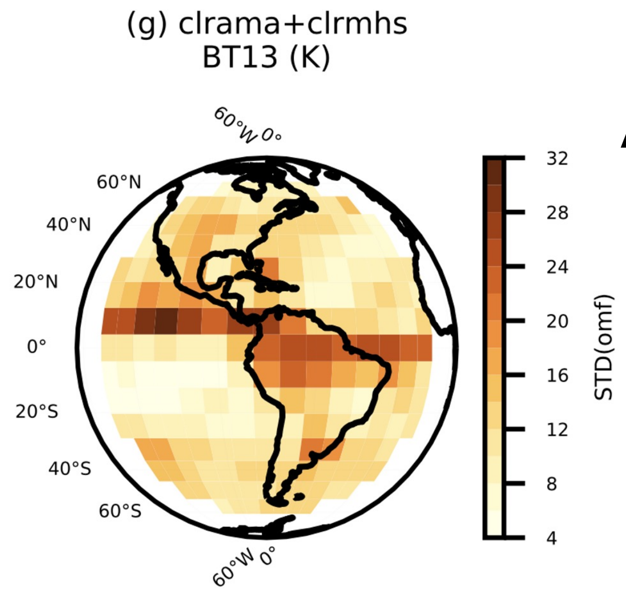
Water vapor channel 10
middle troposphere Q

Window channel 13
Surface/cloud-sensitive

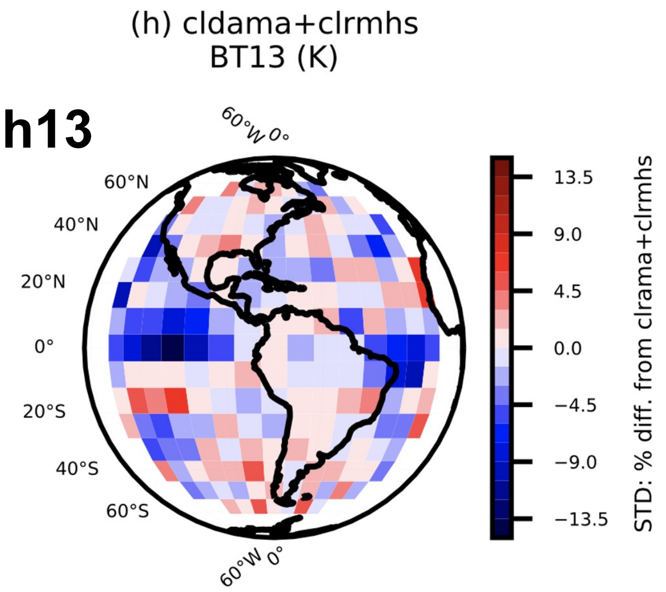
clear-superobs

partly-cloudy superobs

overcast superobs



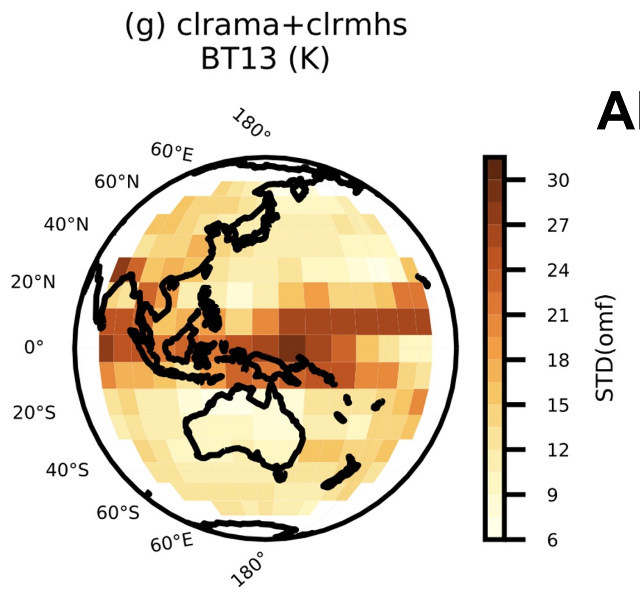
ABI Ch13



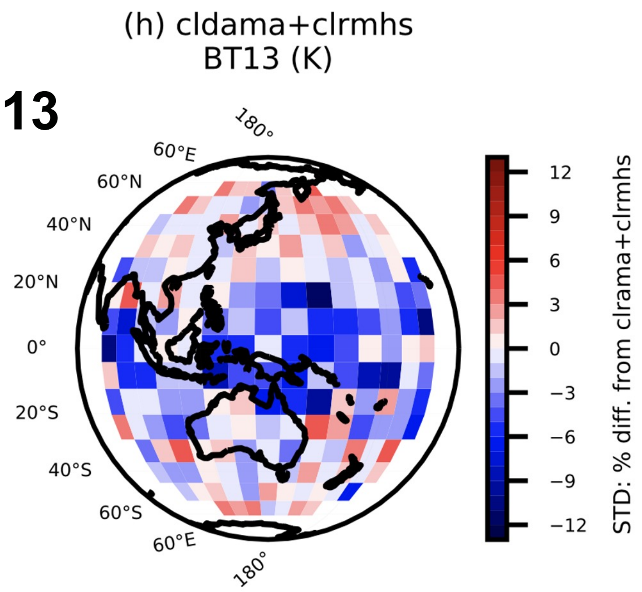
Impact of all-sky AMSU-A radiance DA

Day-1 forecast

Error STD reduction



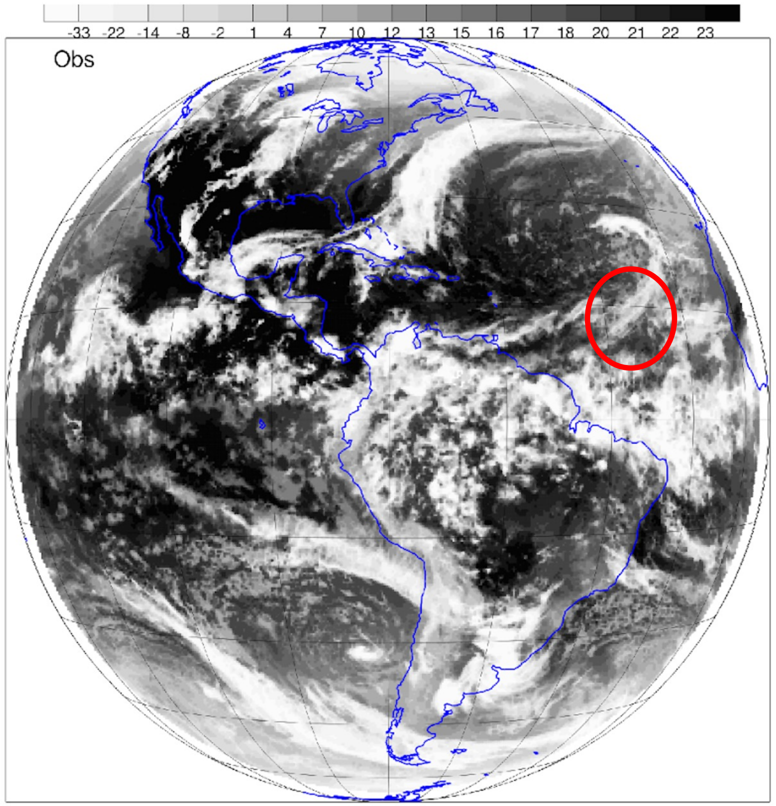
AHI Ch13



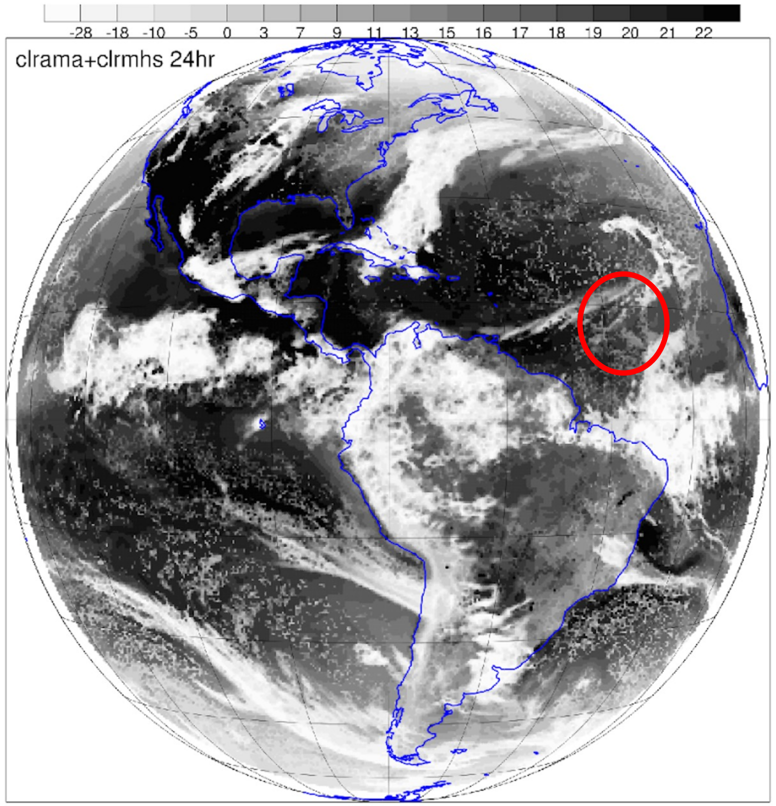
Improvement concentrated in cloudy regions of Tropics
Up to 12-14%

Observations vs. Day-1 forecast

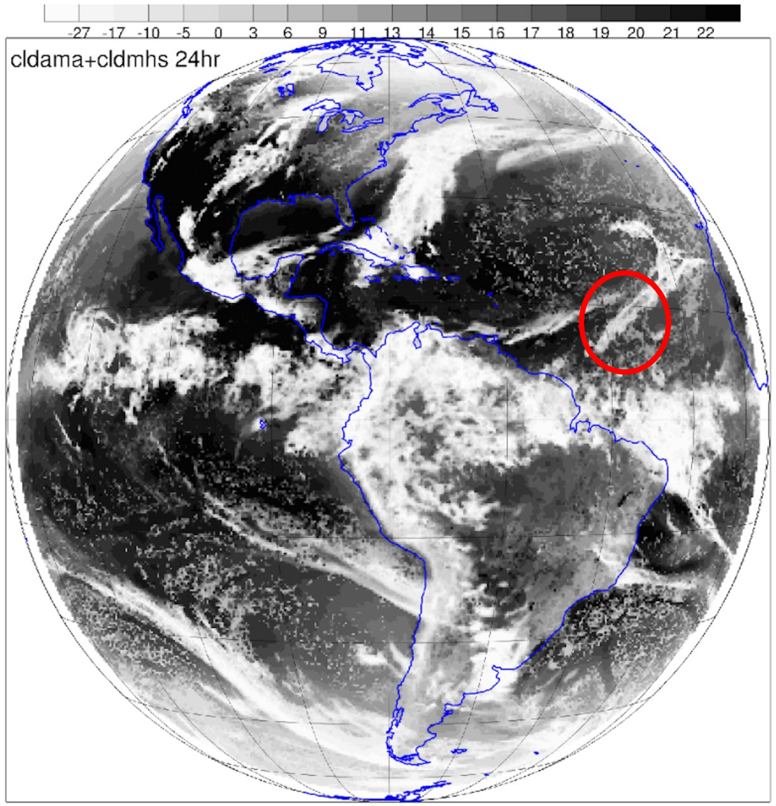
Observations



Clear-sky DA



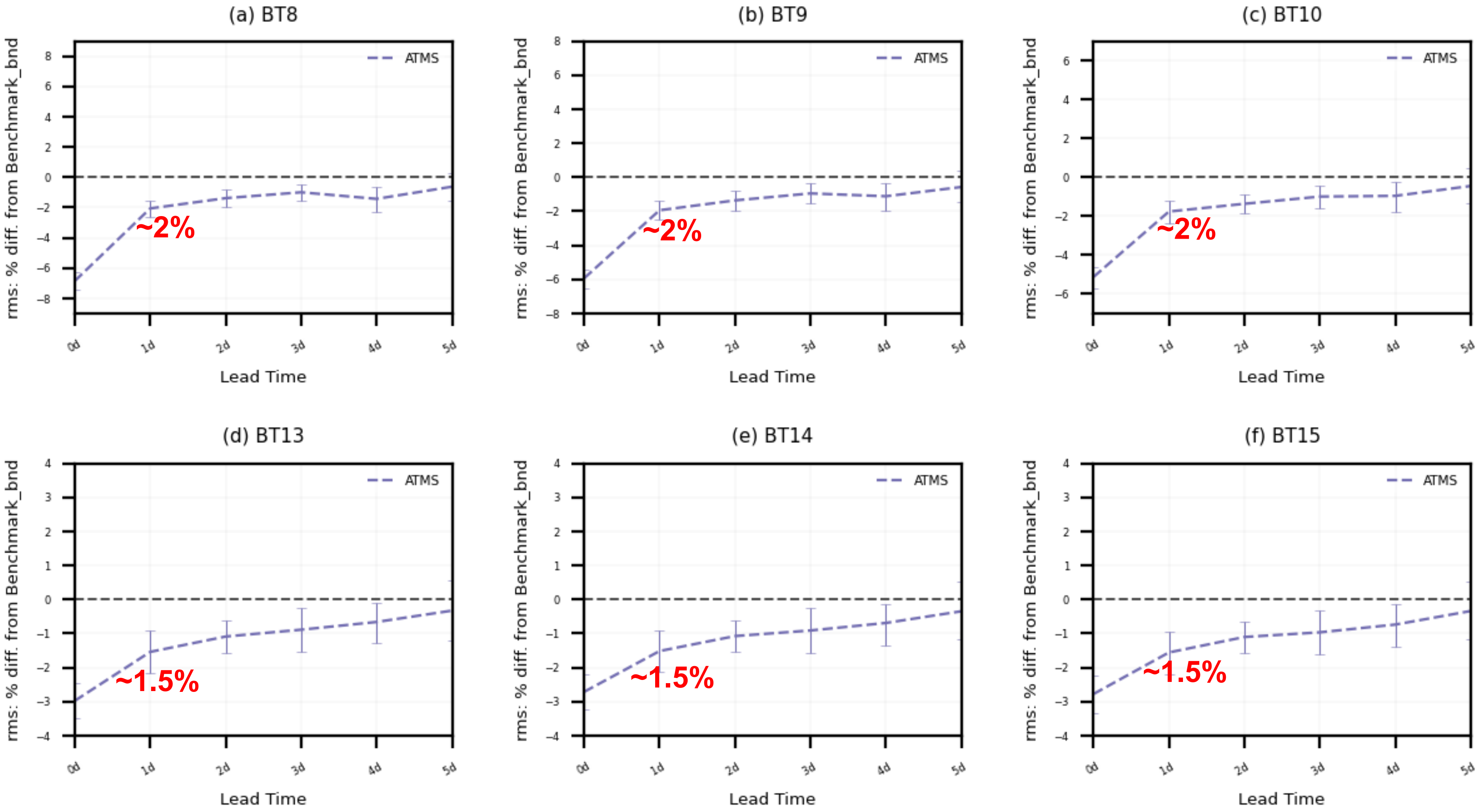
All-sky DA



ABI channel 13 BTs (degree C) valid at 00 UTC 9 May 2018

Impact of all-sky ATMS radiance DA vs. benchmark

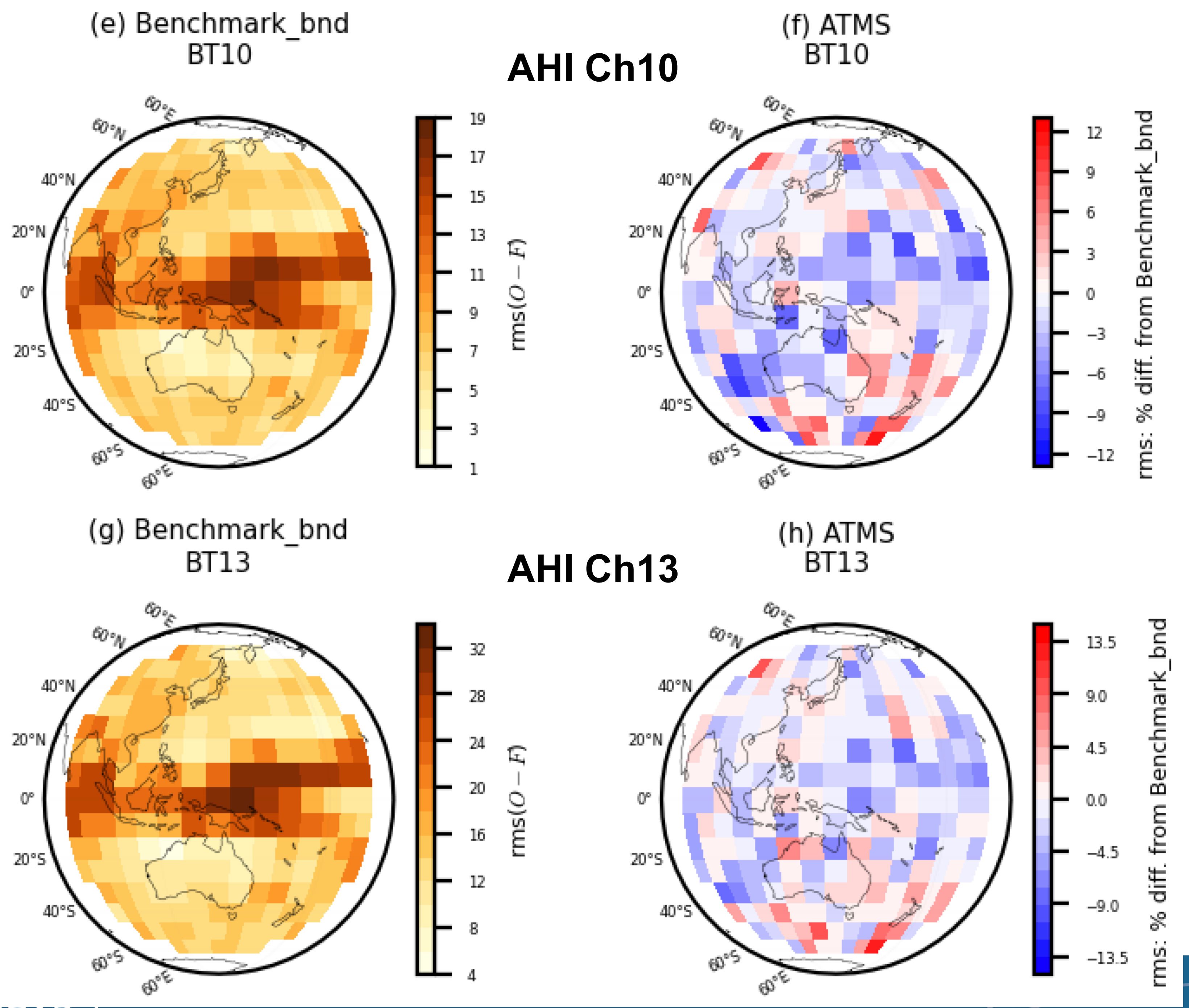
verify against AHI data



Water vapor channels

From analysis time to day-5 forecast

Window channels



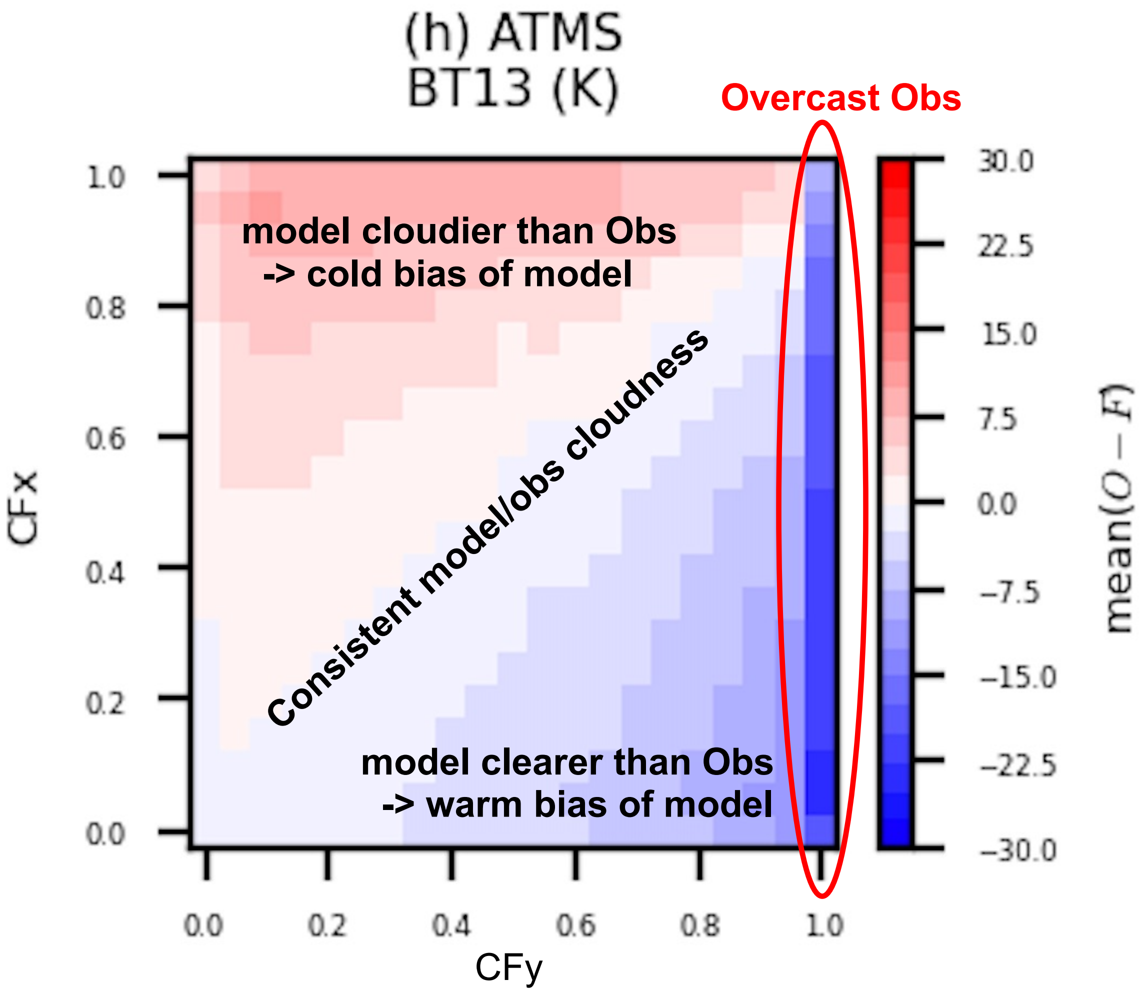
Impact of all-sky ATMS radiance DA

Day-2 forecast

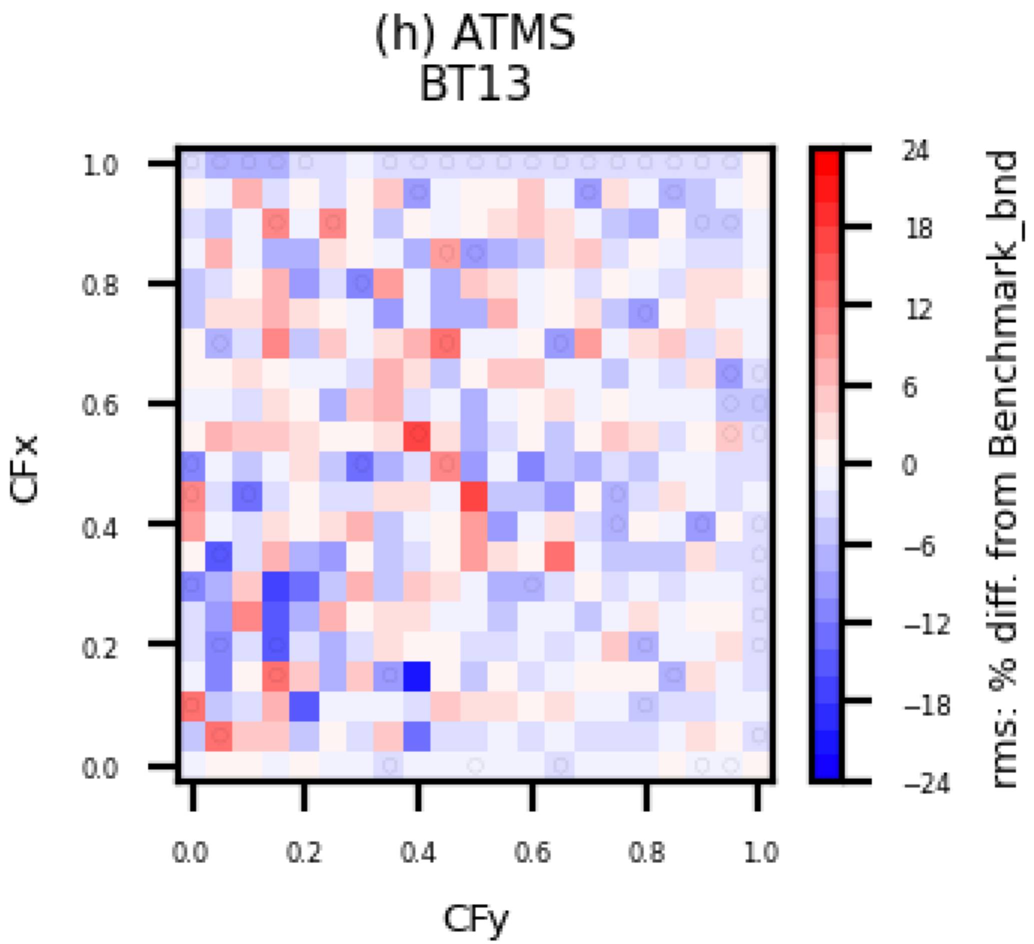
RMSE reduction

Impact of all-sky ATMS radiance DA vs. benchmark

verify against ABI channel 13



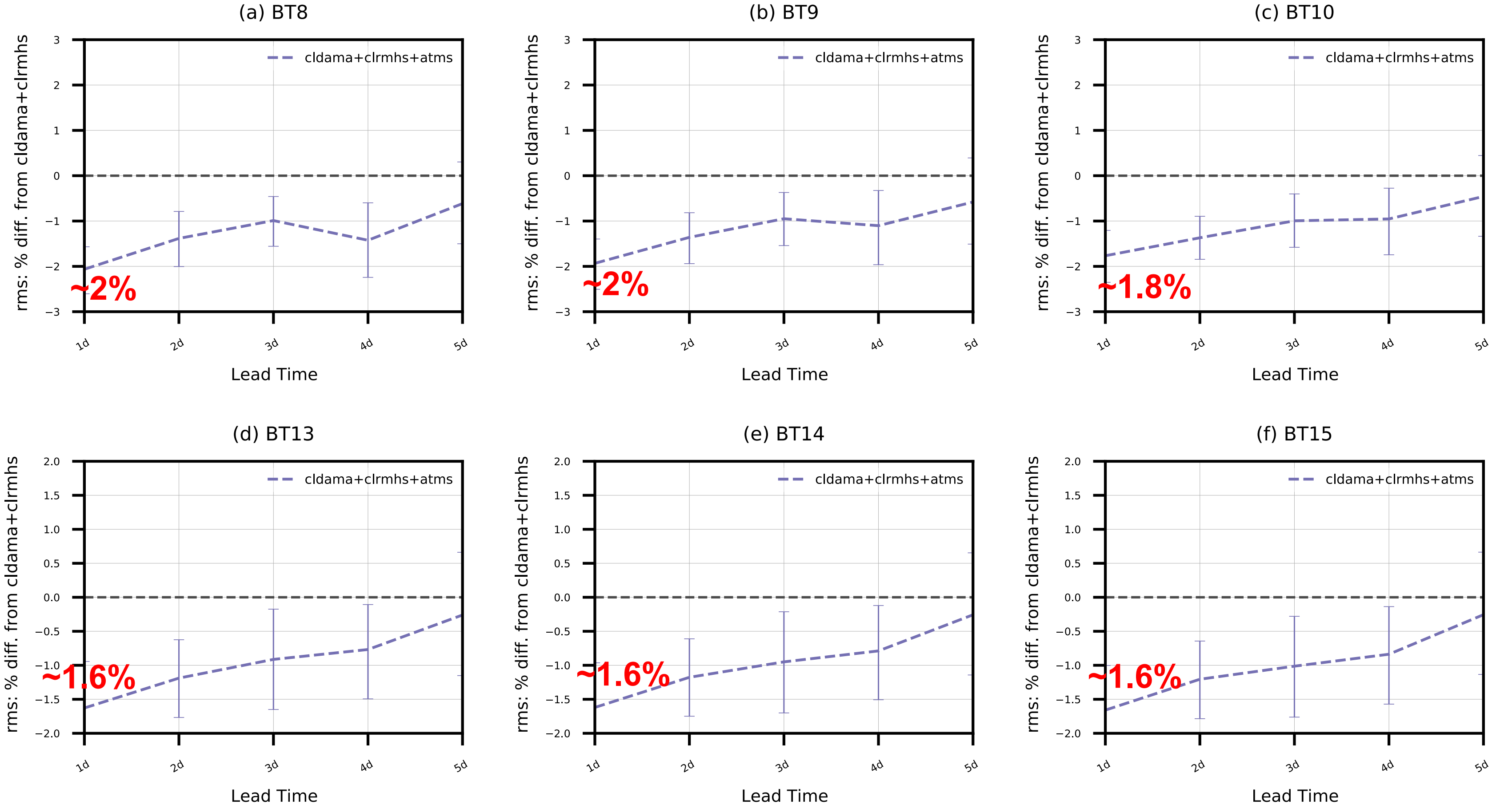
Day-1 forecast bias as a function of cloud fraction from model (CFx) and observation (CFy)



Day-1 forecast RMSE % change by adding ATMS as a function of CFx and CFy

Impact of adding all-sky ATMS above all-sky AMSU-A

verify against AHI data



Water vapor channels

From day-1 to day-5 forecast

Window channels

NCAR UCAR

Concluding Remarks

- Cloud fraction mis-match between model and obs seems to be the largest error source when verifying cloud forecast in ABI/AHI brightness temperature space
- All-sky microwave radiance DA is overall effective to reduce cloud forecast errors, especially over tropical regions
- Larger improvement expected by using more advanced DA method (e.g., hybrid-4DEnVar) and higher model resolution, and assimilating more satellite data
- Future considerations:
  - Cloud fraction as a model prognostic variable and also an analysis variable in all-sky DA
  - For 2-moment microphysics scheme, also analyze number concentration of hydrometeors
  - Combination of DA and other techniques (e.g., AI/ML) could be more powerful