WRFDA 2021 Update and Status of MPAS DA with JEDI

Zhiquan (Jake) Liu and Chris Snyder

On behalf of WRF and MPAS DA team
Mesoscale & Microscale Meteorology Laboratory
National Center for Atmospheric Research

2021 Joint WRF and MPAS Users' Workshop

June 8, 2021

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.

Two major new capabilities in WRFDA Release 4.3

- **Multi-Resolution Incremental 4DVAR (MRI-4DVAR): speed up 4DVAR**

Liu, Z., J. Ban, J.-S, Hong, and Y.-H. Kuo, 2020: Multi-resolution incremental 4D-Var for WRF: Implementation and application at convective scale, *Q. J. R. Meteorol. Soc.*, 146, 3661-3674.

- **Chemical/Aerosol DA for assimilation of surface data (PM2.5, PM10, O3, CO, SO2, NO2) using 3DVAR**

Sun, W., Liu, Z., Chen, D., Zhao, P., and Chen, M., 2020: Development and application of the WRFDA-Chem three-dimensional variational (3DVAR) system: aiming to improve air quality forecasting and diagnose model deficiencies, *Atmos. Chem. Phys.*, 20, 9311-9329.

3-stage MRI-4DVar involves WRFDA, standalone programs and script

Repeat 3-stage for multiple outer loops

- **Stage-1**: run WRFDA in "**Observer**" mode at full model resolution
  - Compute and write out OMB at different time slots within 4DVAR time window.

- **Stage-2**: run WRFDA in "**Minimizer**" mode at low resolution
  - Read OMB from Stage-1. Write out analysis and analysis increment at low resolution.

$$\mathbf{v}^a_{high} = \mathbf{U}^{-1}_{high}\mathbf{S}\mathbf{U}_{low}\mathbf{v}^a_{low}$$ if minimization resolution increased from previous loop

- **Stage-3**: do "**Regrider**" outside of WRFDA

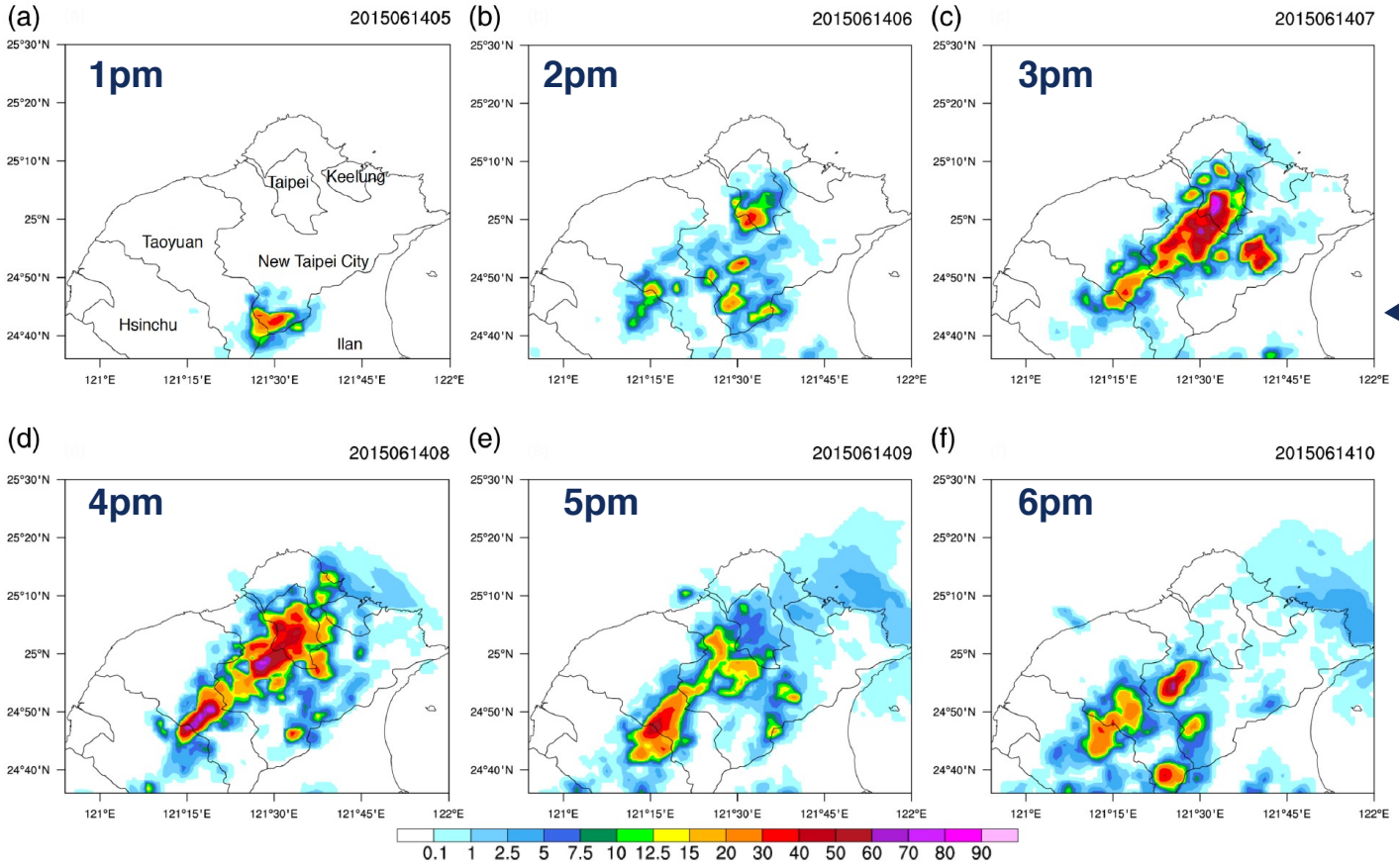
$$\mathbf{x}^a_{high} = \mathbf{x}^g_{high} + \mathbf{S}\mathbf{U}_{low}\mathbf{v}^a_{low}$$

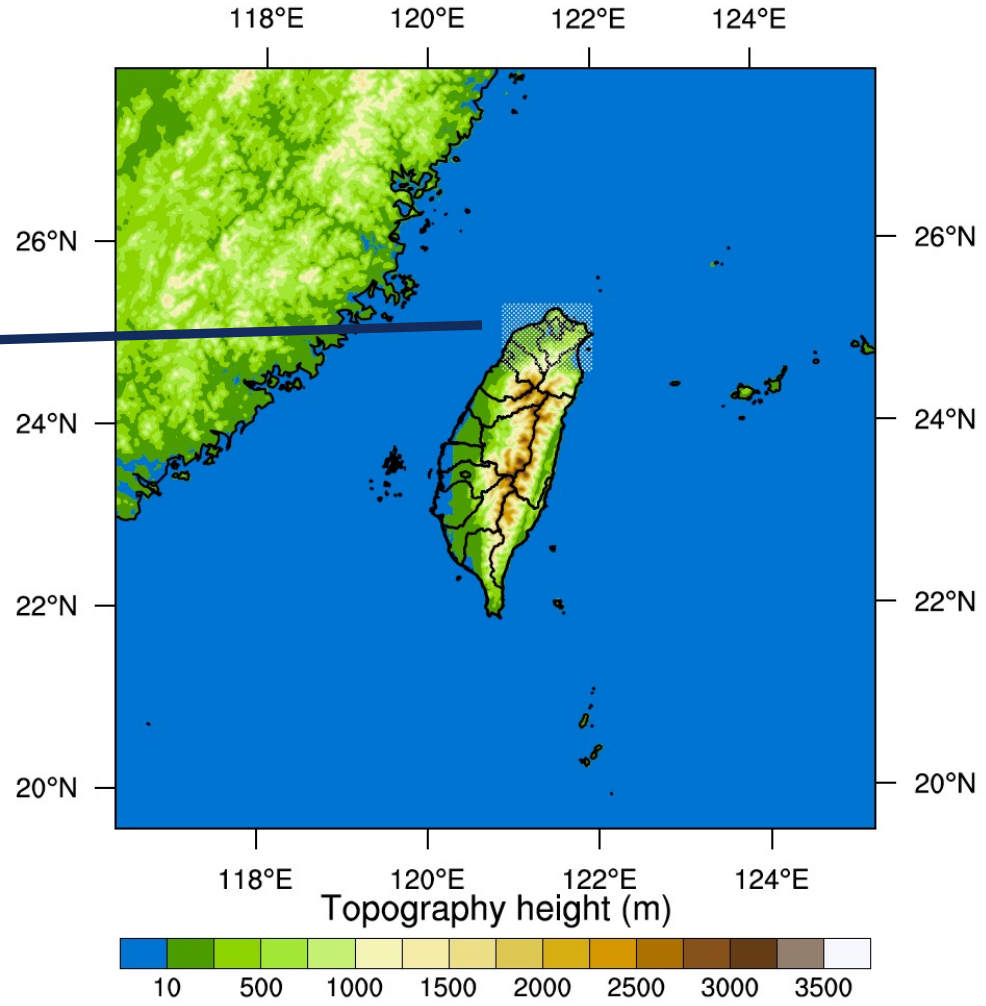
Sample script provided under ~var/mri4dvar

Works for cv_options=5,6,7

Afternoon thunderstorm case in Northern Taiwan

20150614





maximum hourly rainfall of 131mm at the Gongguan station in Taipei

Three 4DVar experiments with two outer loops

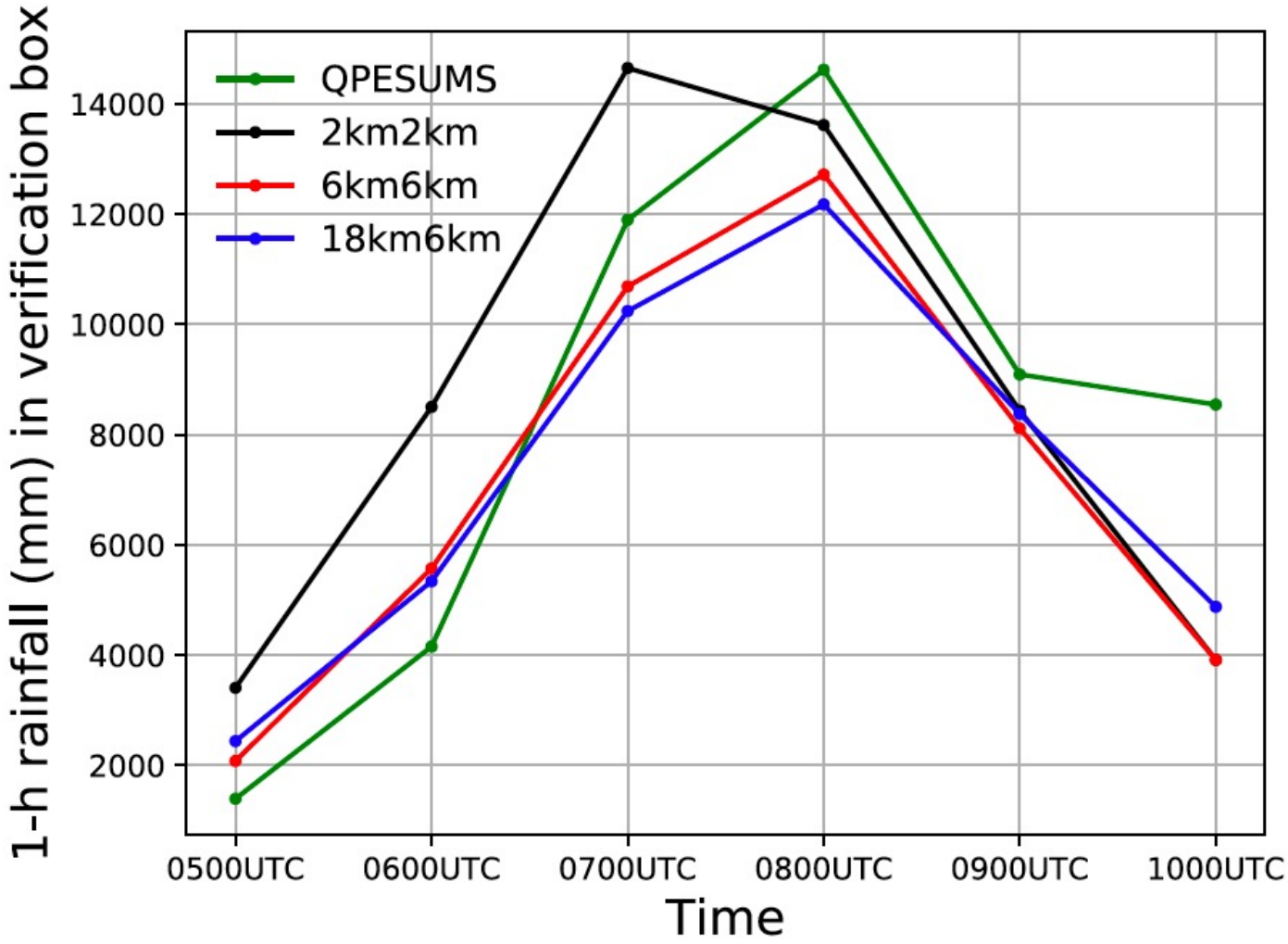
TABLE 1 Wall-clock times of three experiments on the NCAR Cheyenne computing system

Experiment	Nodes	Wall-clock time	
2 km 2 km	30	3 hr	
6 km 6 km	16	41 min	4.4x
18 km 6 km	2 (18 km), 16 (6 km)	24 min	7.5x

2-km resolution: 451 x 451 x 52L

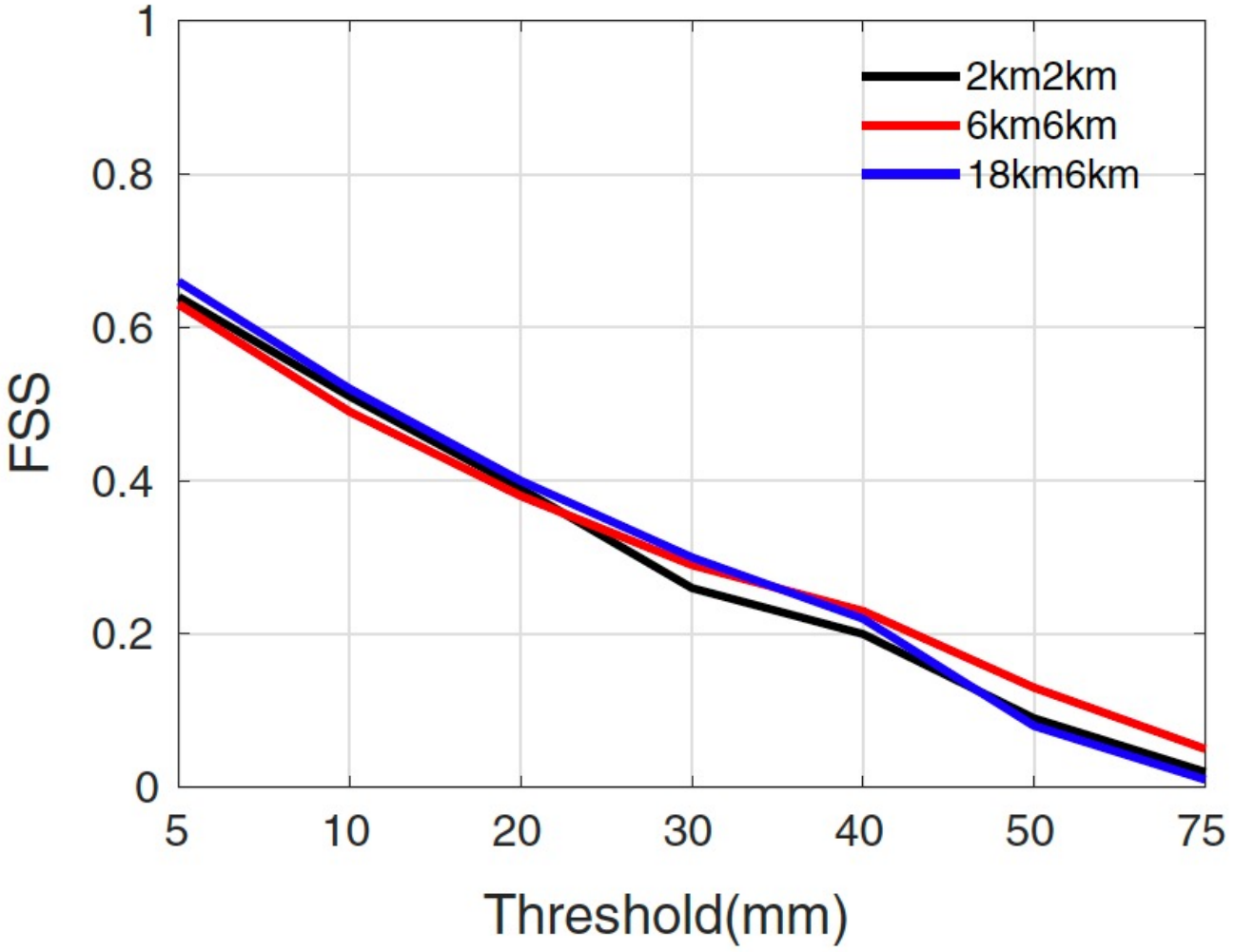
30-min 4DVar time window with 10-min surface obs

Grid-summed total hourly rainfall



Averaged over 6 forecasts with different lead times of 7-12 hours

Fractions Skill Score for 6-h accumulated rainfall



Aerosol/Chemical 3DVar DA for WRF/Chem initial condition

setenv WRF_CHEM 1

./configure wrfda

./compile all_wrfvar

Executable is still da_wrfvar.exe, but it can ingest a WRF/Chem forecast file as the background (the 'fg' file)

- Surface Obs:
  - PM2.5, PM10, O3, SO2, NO2, CO
- Analysis variables:
  - Gas phase: O3, SO2, NO2, CO
  - Aerosols: GOCART (15 species) or MOSAIC 4-bin (32 species)
- Univariate background error covariances
  - https://github.com/wrf-model/GENBE_2.0

https://www2.mmm.ucar.edu/wrf/users/docs/user_guide_v4/v4.3/users_guide_chap6.html#_Aerosol/Chemical_Data_Assimilation

Updated feature

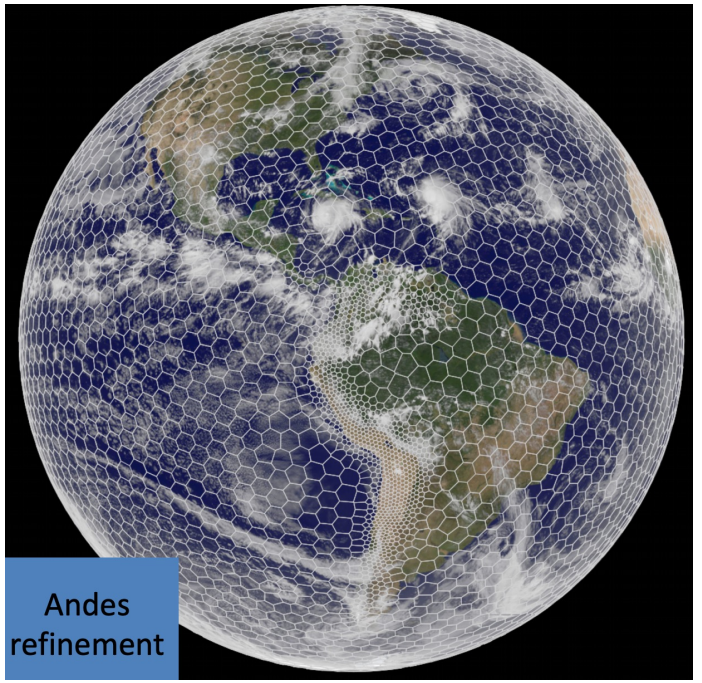
contributed by Jamie Bresch, NCAR

- WRFDA **gen_be_v3** is updated for cv_options=5 and ensemble applications.
  - See var/gen_be_v3/README.gen_be_v3.

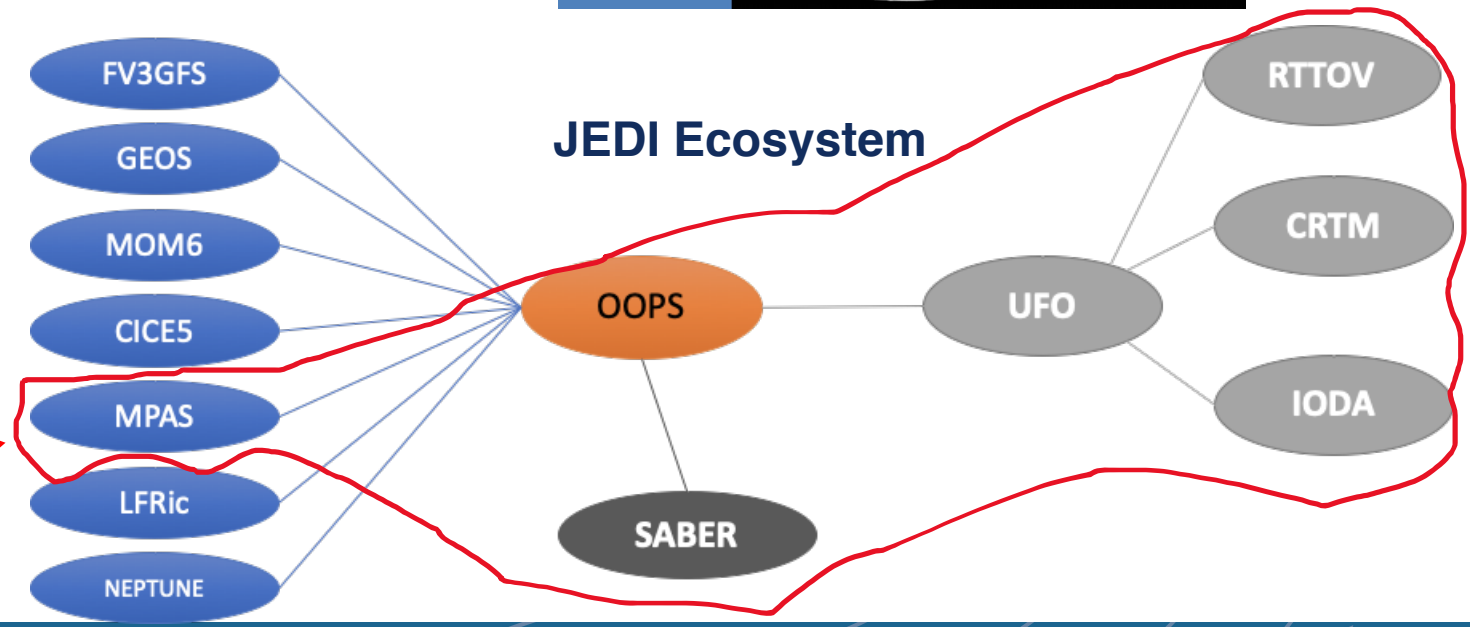
MPAS DA development in the JEDI framework

- PANDA-C (Prediction and Data Assimilation for Cloud) project
  - NCAR/MMM + JCSDA
  - USAF funded since 2018

- JEDI: Joint Effort for Data assimilation Integration, led by JCSDA
  - **OOPS**: abstract DA algorithms
  - **UFO**: observation operators + QC filters
  - **IODA**: obs I/O & data structures
  - **SABER**: background error covariance models
  - **+ interface to different models**



MPAS-JEDI



Capabilities currently available in MPAS-JEDI

DA Algorithms

- 3DEnVar/4DEnVar: deterministic analysis
- Ensemble of DA (EDA): ensemble analysis
- 3DVar: multivariate background error covariances
- Can run in dual-resolution mode

Observations

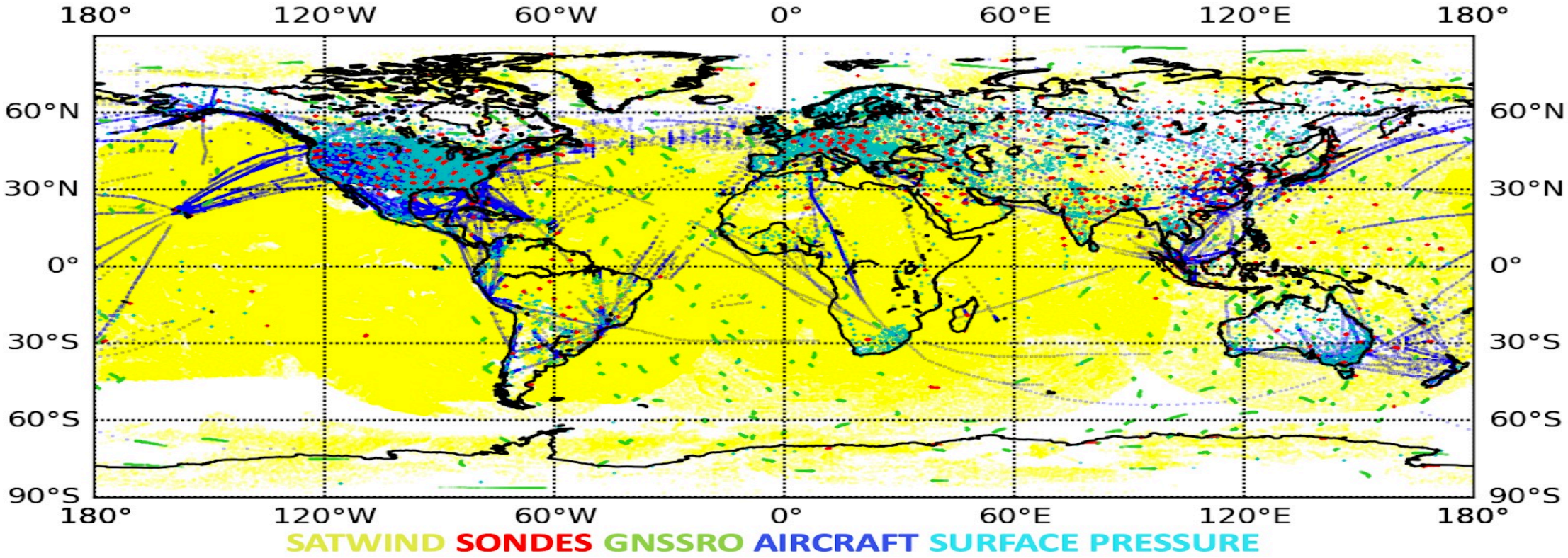
- Conventional data
- GNSSRO data
- Clear-sky radiances
- All-sky radiances: Microwave and Infrared

Analysis is done directly on MPAS unstructured grid
Works seamlessly for uniform mesh and variable mesh

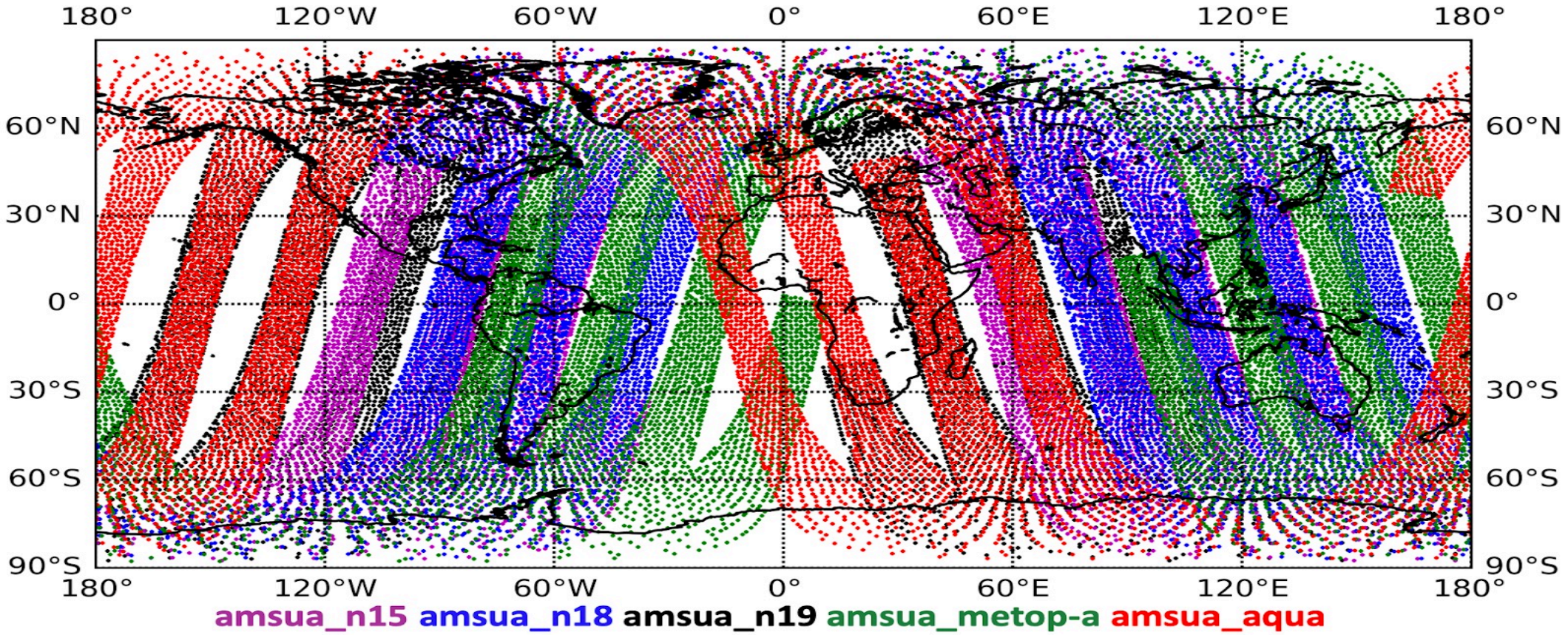
Global month-long cycling experiments using MPAS-JEDI

- Period: 15 April-15 May 2018
- Observations from NCEP/EMC
  - "Baseline" obs: conv obs + GNSSRO + clear-sky radiances from 5 AMSU-A
  - Processing, "pre-QC," and bias correction of radiances from GSI
  - Radiance DA using CRTM
- 3DEnVar: 30-km mesh with all-sky MW radiances
  - 20 members: MPAS 6-h forecasts from GEFS analysis
- 4DEnVar: 120-km mesh with hourly all-sky AHI WV channel radiances
  - 20 members: MPAS 3-9-h forecasts from GEFS analysis

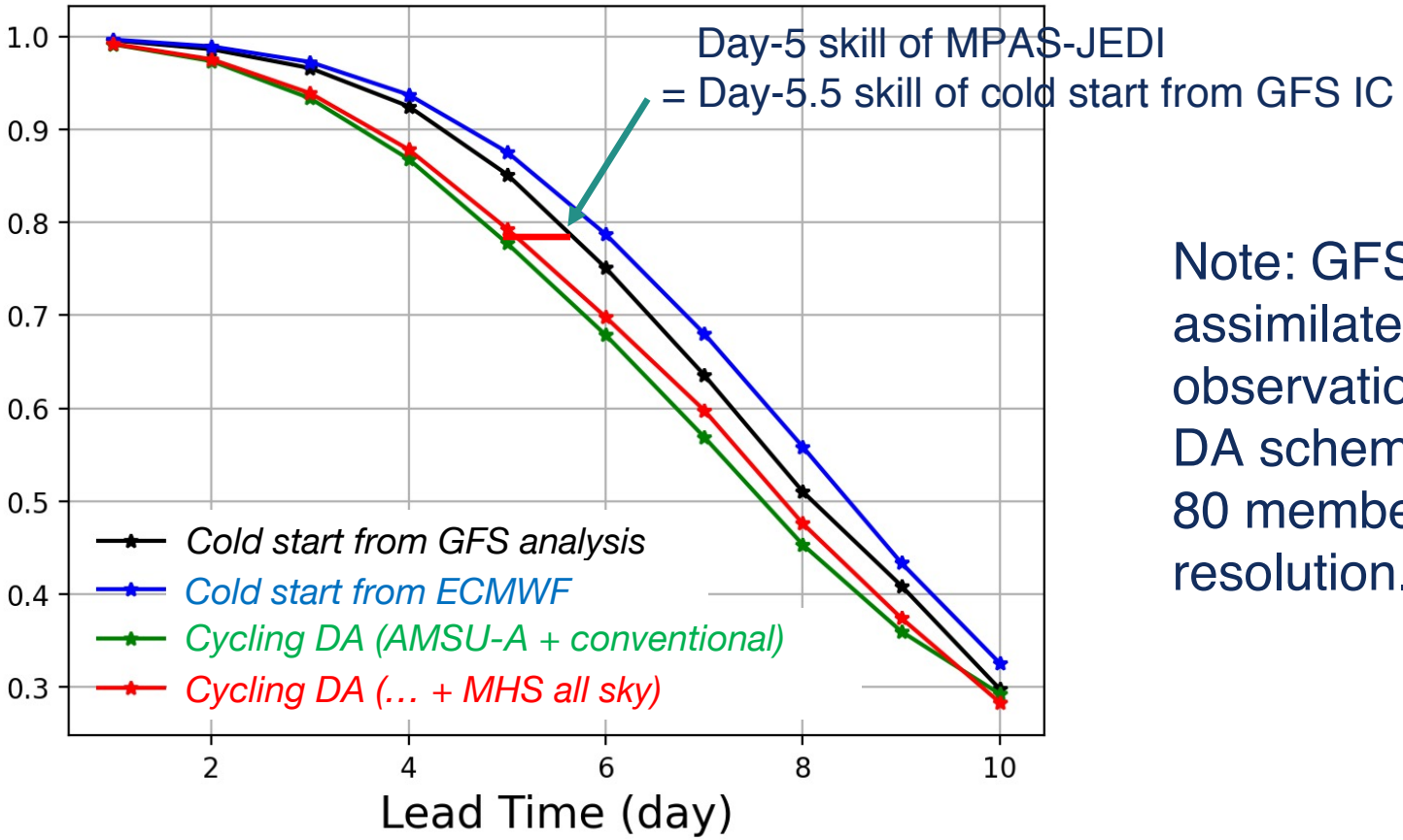
Conventional obs coverage at 2018041500



5 AMSU-A data coverage at 2018041500



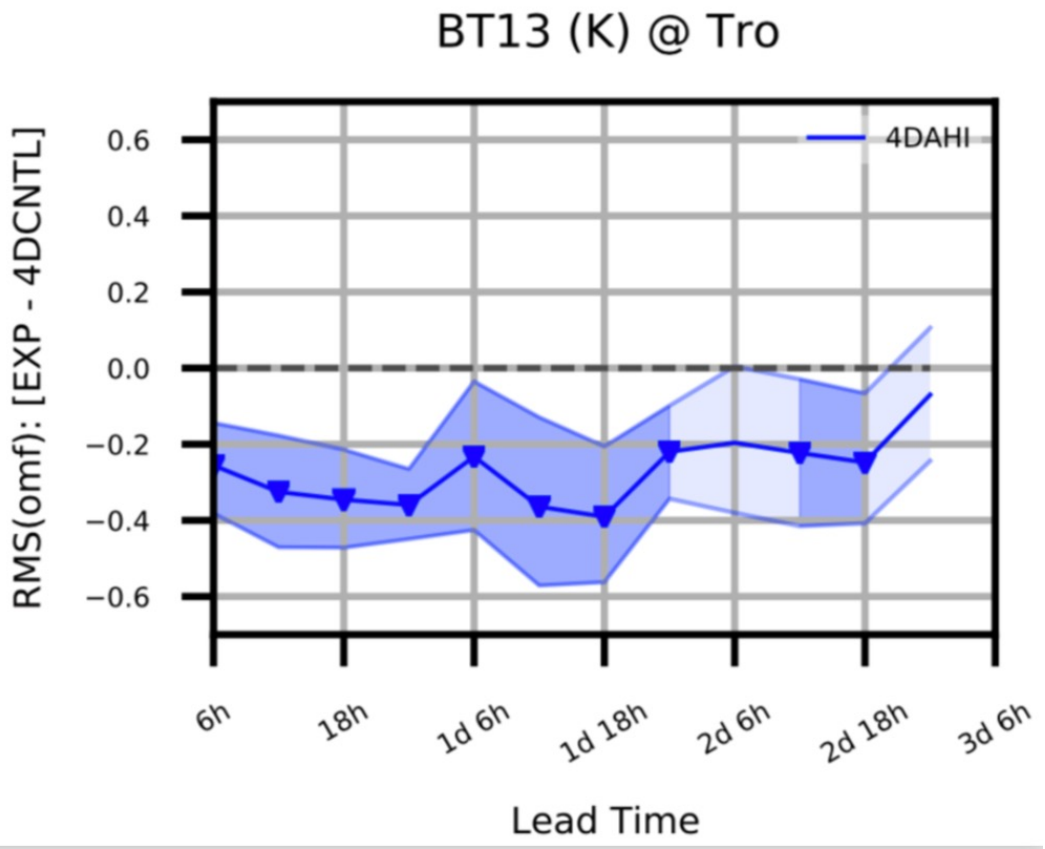
30-km mesh experiments: 500 hPa geopotential height ACC scores
3DEnVar with 20-member ensemble input



Note: GFS/ECMWF analysis assimilates a lot of more satellite observations with more advanced DA schemes (hybrid-4DEnVar with 80 member, 4DVAR) and higher resolution.

4DEnVar with hourly all-sky AHI radiances (120-km mesh)

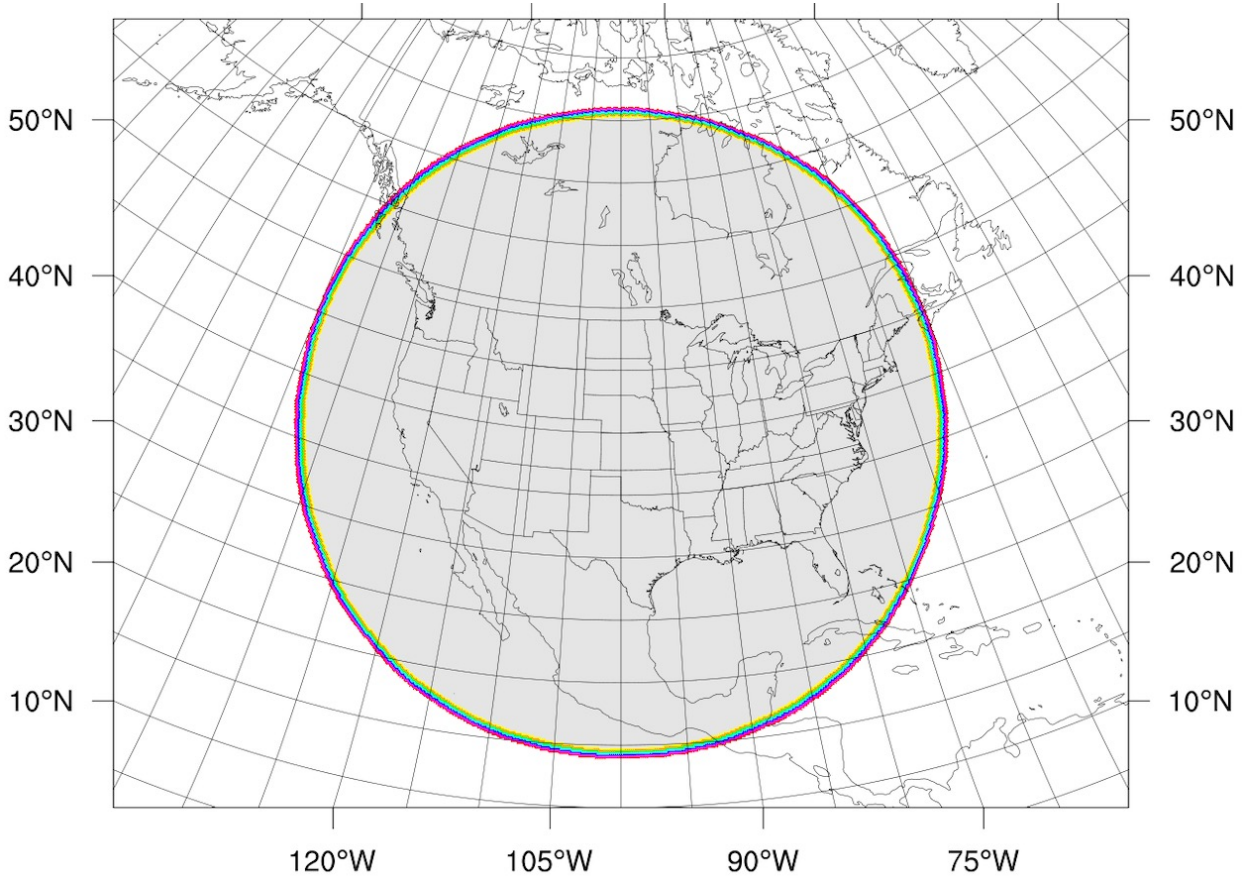
RMSE(4DEnVar w/ AHI – 4DEnVar w/o AHI), verification against AHI radiances



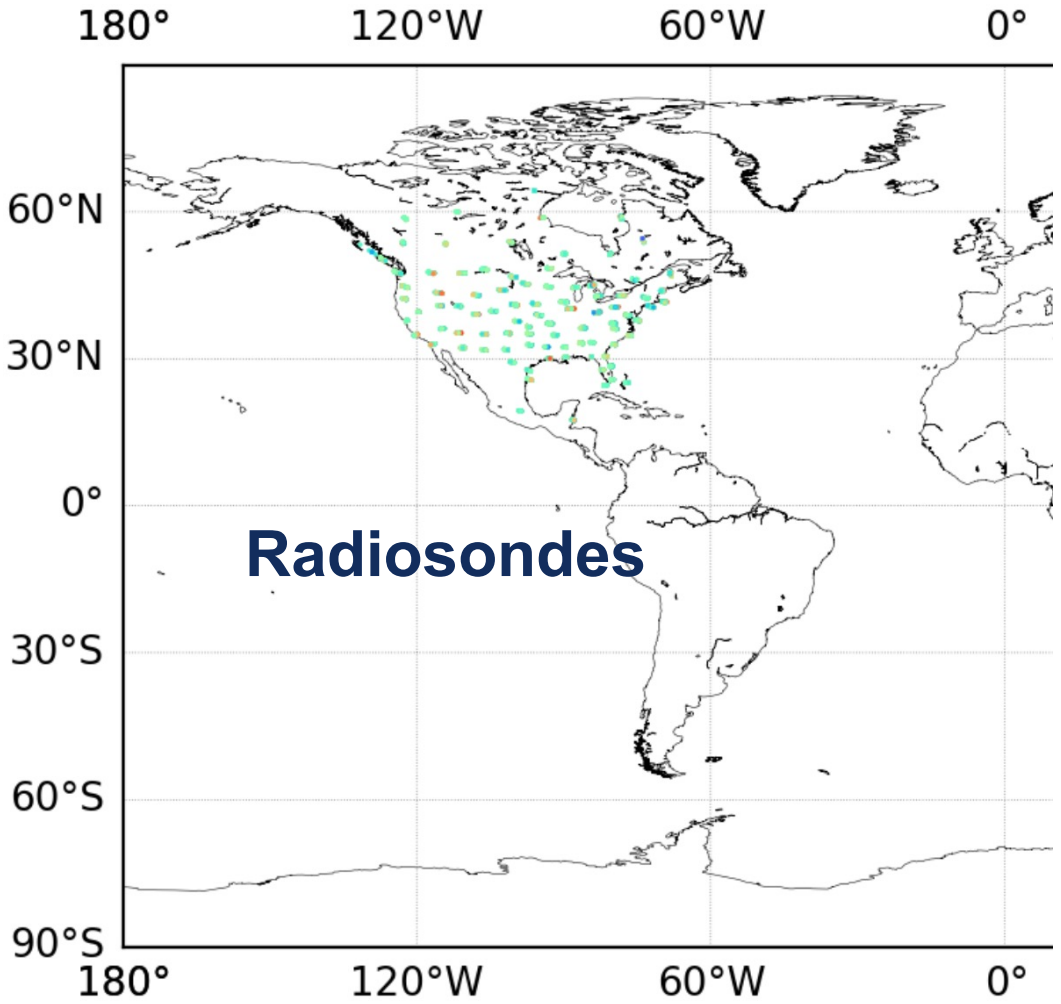
- Adding hourly AHI obs in the 4DEnVar clearly improved forecasts in the first 3 days
- Improvements are mainly in the Tropics

Regional MPAS-JEDI

2800 km radius over CONUS*



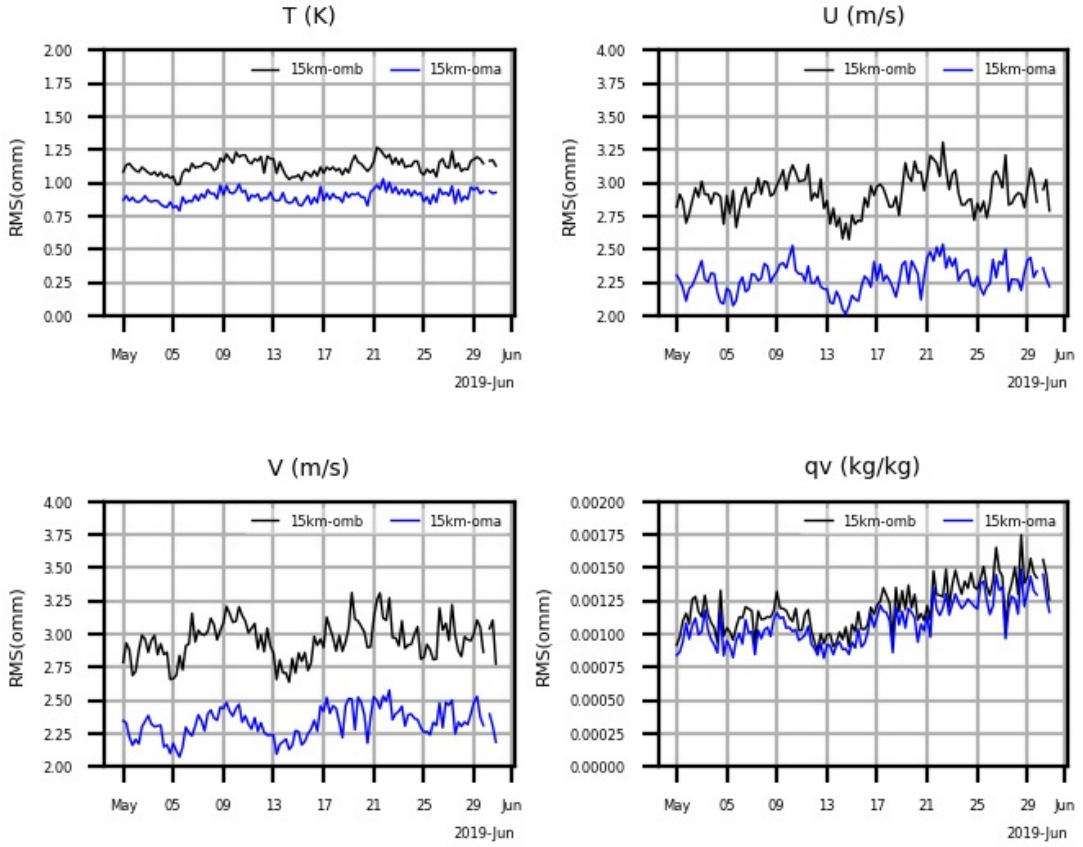
*at present, removing obs outside domain works only for circular domains



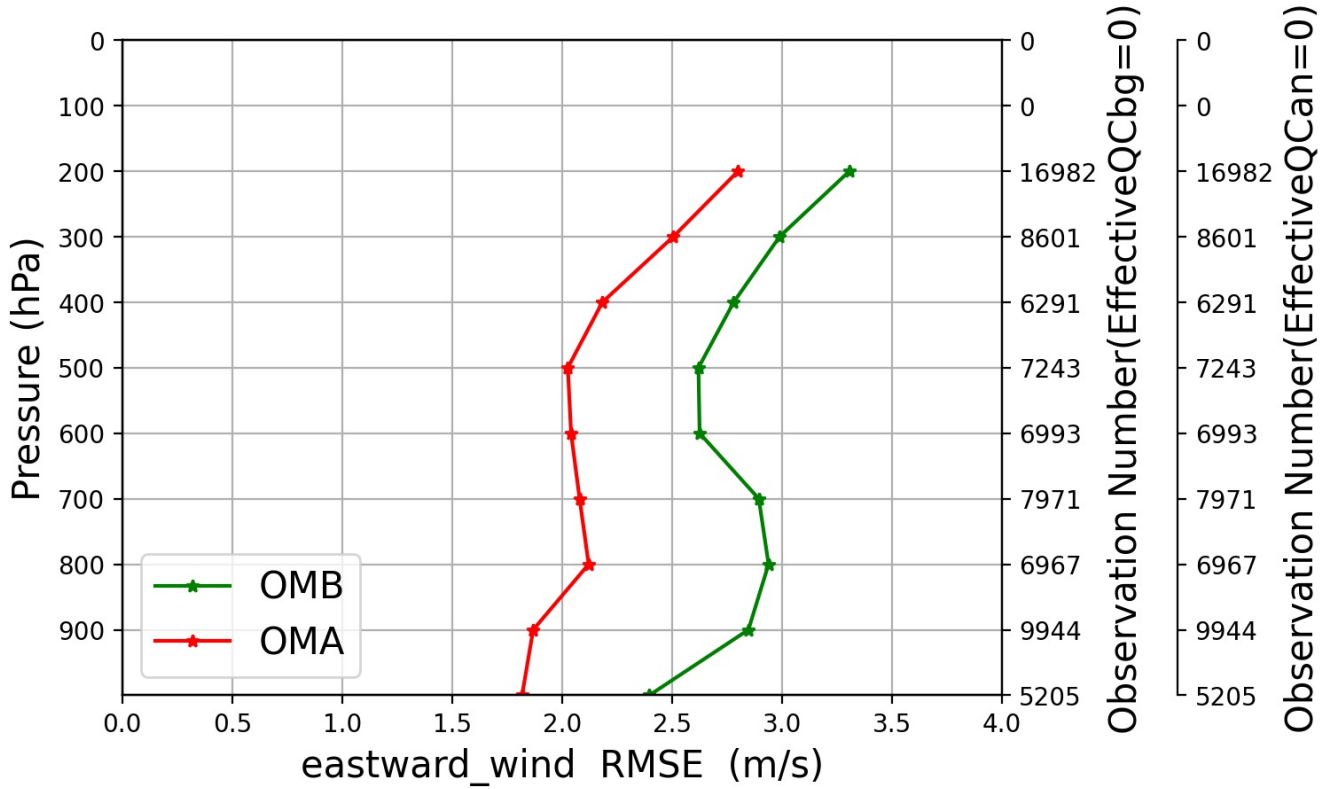
Regional 3DEnVar MPAS-JEDI cycling with 80-member ensemble

15km uniform mesh, 1-30 May 2019

Aircraft observations:
time series of OMB & OMA



Aircraft U wind:
OMB/OMA RMS profile at a single time



Final remarks

- WRFDA will be kept updated as needed. However, MMM no longer has resources to provide extensive support. No plans for future WRFDA tutorials.

- JEDI and MPAS-JEDI are under active development. MPAS-JEDI allows global and regional DA within the same framework. Expect first release to community in September.