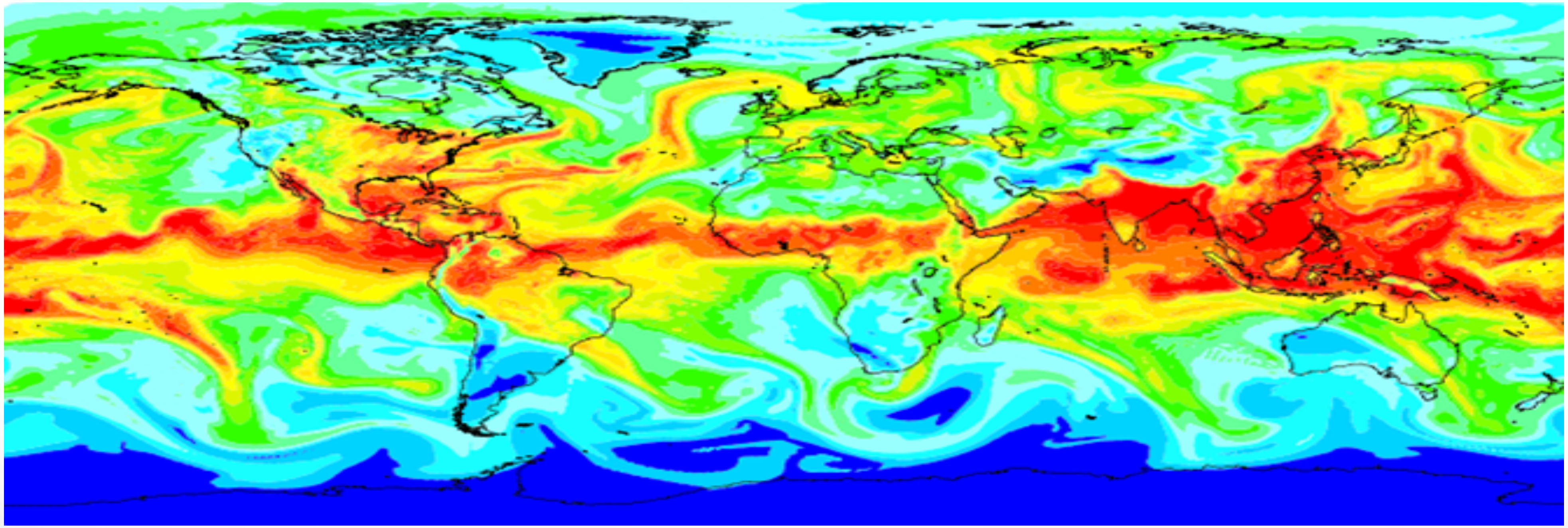
Preparing MPAS-A for Global Retrospective Air Quality modeling: An evaluation of a 2016 simulation with comparisons to WRF

Robert C. Gilliam, Jerold A. Herwehe, O. Russell Bullock Jr., Jonathan Pleim and David Wong

CED/NERL/ORD/USEPA



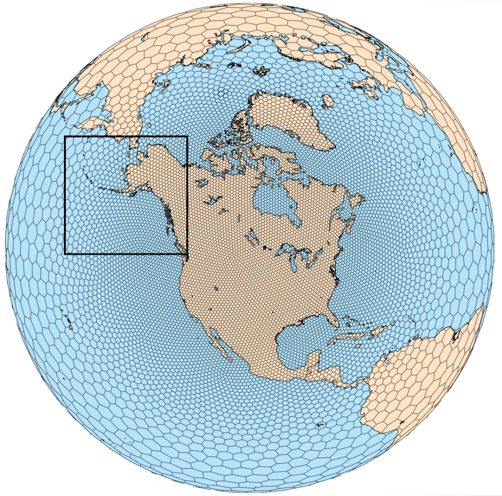
2018 WRF/MPAS Users' Workshop, June 11-15, Boulder, CO

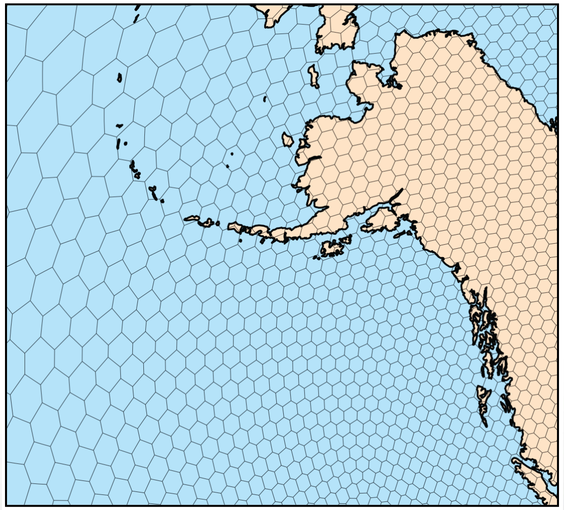
Outline

- Vision for US EPA's Next Generation AQ modeling system
- Evaluation of 2016 MPAS/WRF simulations
  - Surface meteorology
  - Precipitation
  - Radiation
  - Upper Air meteorology (raob)
- Next steps for MPAS/NextGen modeling system

Vision for Next Generation AQ Model

- Extend our AQ modeling to global scales using MPAS framework
  - Coarse global mesh with seamless refinement
  - Integrated chemistry (CMAQ components)
- Flexible configurations
  - Coupled global variable grid (e.g. MPAS-CMAQ)
  - Coupled regional (limited area WRF-CMAQ or MPAS-CMAQ)
  - Offline regional CMAQ using MPAS or WRF output
- Interoperability of chemistry model components
  - 1-D chemistry with the ability to couple to various met models like MPAS and FV3
  - Currently have a working MPAS-CMAQ prototype with testing limited to July 2013 and full 2016 underway
  - Comprehensive evaluation of the system next year

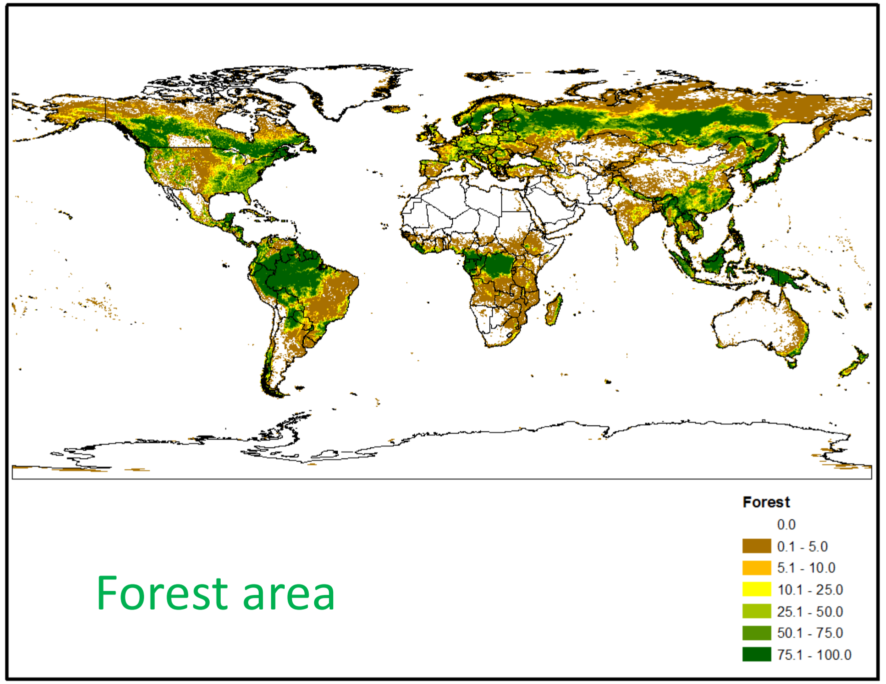




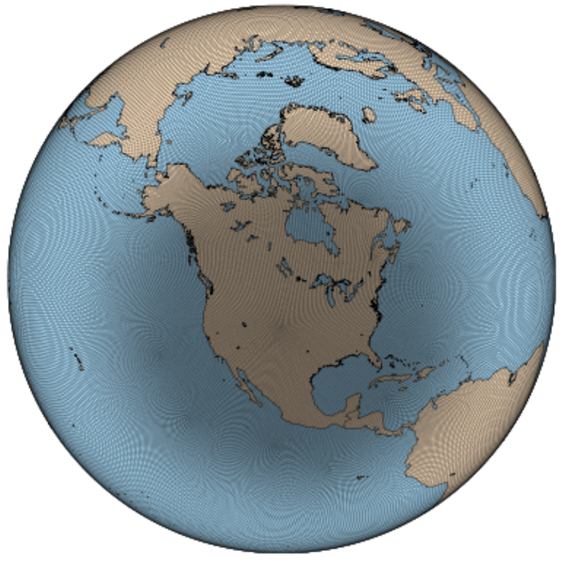
MPAS

MPAS Meteorology Development

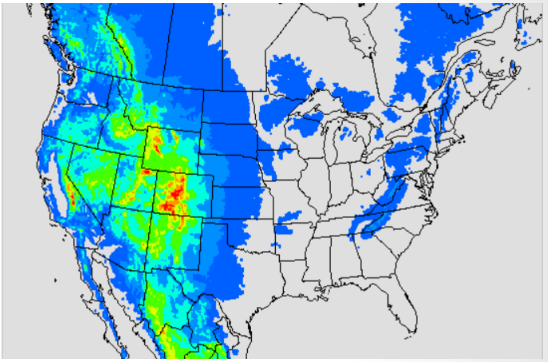
- Added US EPA physics package for retrospective simulations
  - ACM2 Boundary layer model
  - Pleim-Xiu Land Surface Model (PX LSM)
  - Updated Kain-Fritsch convective cloud scheme
    - including radiation feedback and dynamic lifetime
- Data Assimilation
  - Implemented FDDA similar to WRF
  - Implemented indirect soil moisture data assimilation in PX LSM
- Landuse
  - NLCD 2011 US Blended with MODIS 2013 including subgrid fractional coverage
- Model Evaluation
  - Atmospheric Model Evaluation Tool (AMET V1.3+)



Model Configurations



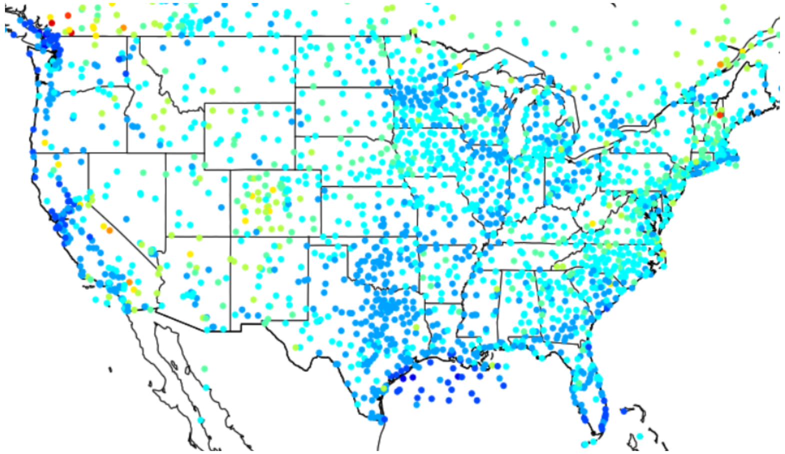
- Tested two MPAS mesh configurations for 2016 simulation (MPAS 5.2)
  - 92 km mesh resolution refined to 25 km over N. America
  - 46 km mesh resolution refined to 12 km over N. America
- 12 km CONUS WRF simulation (WRF3.8.1)
- Continuous simulations with FDDA, 10 day soil spin-up, no re-initialization
- EPA Physics and DA used in both MPAS and WRF:
  - PX LSM, ACM2 PBL and Pleim surface layer
  - RRTMG LW and SW Radiation
  - KF2 with subgrid Cu feedback (cu_rad_feedback = 1)
  - Morrison MP in WRF and WSM6 in MPAS
  - FDDA analysis nudging of T, Qv, U, V above PBL (GFS0.25deg in MPAS and NAM12 WRF)
  - Indirect soil moisture and temperature nudging in PX LSM using surface analysis based on NAM 12km blended with GFS 0.25 deg for MPAS and NAM 12km WRF

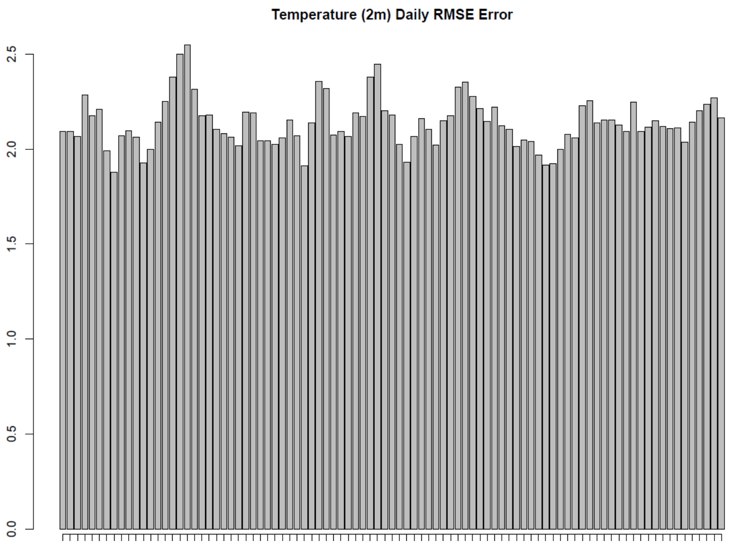


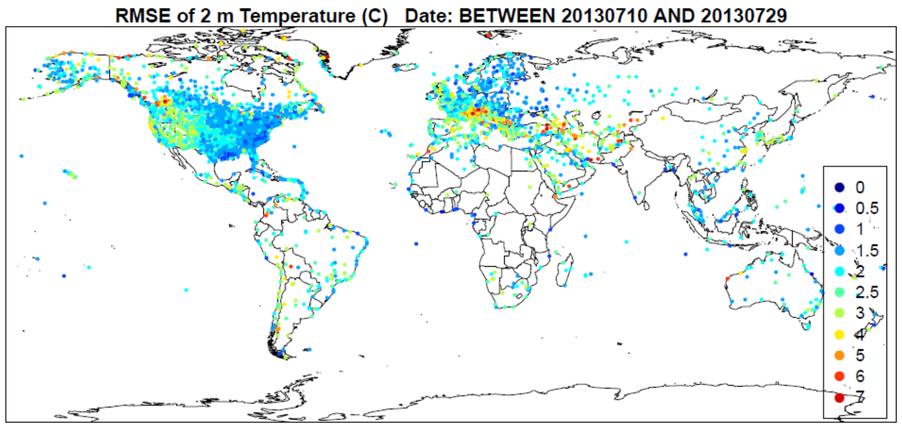
MPAS

Surface Meteorology

Comparing the MPAS 92 to 25 km, 46 to 12 km and 12 km WRF simulations with observed 2m temperature, 2m moisture and 10m wind.



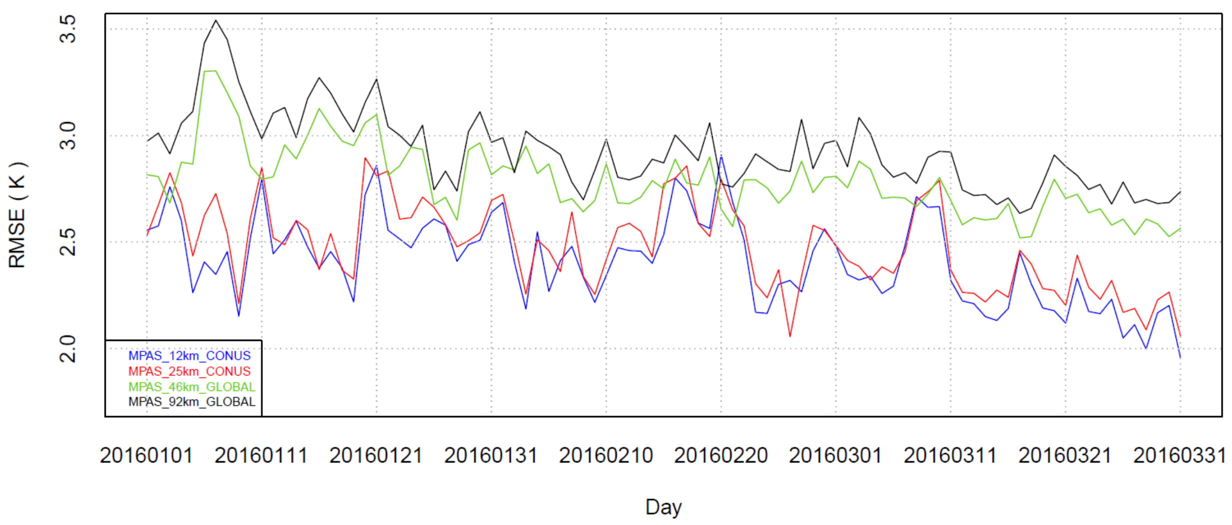




Grid Scale Influence (MPAS only)

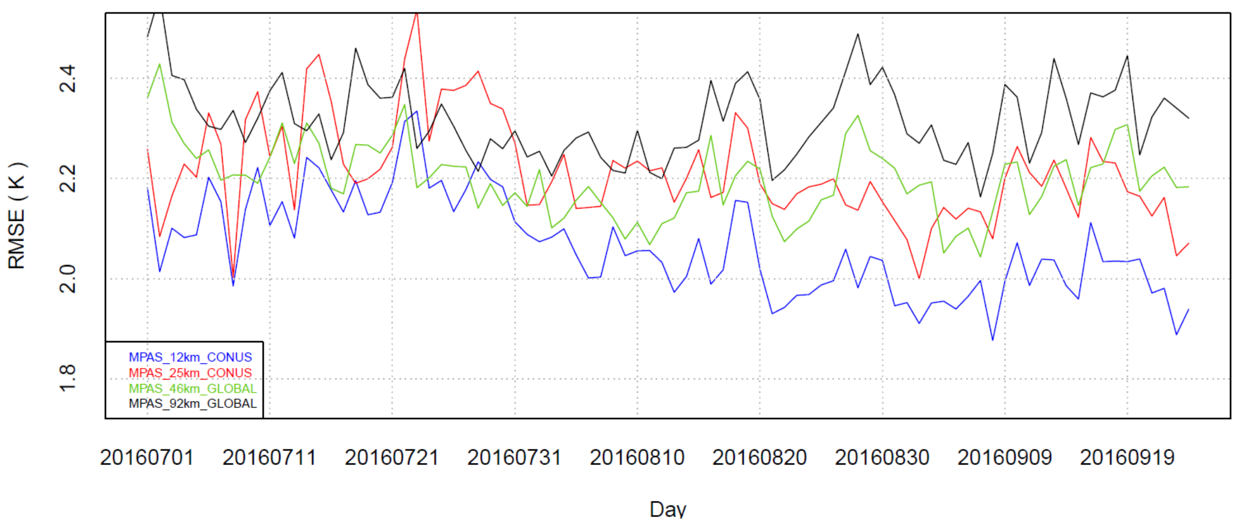
Jan-Mar

Daily RMSE of T2



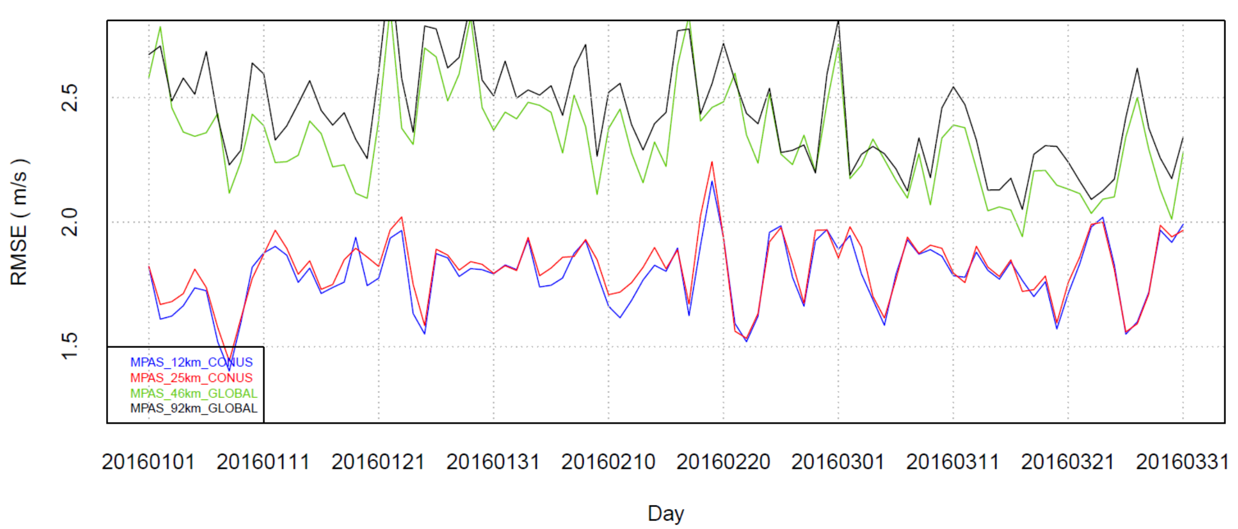
Jul-Sep

Daily RMSE of T2

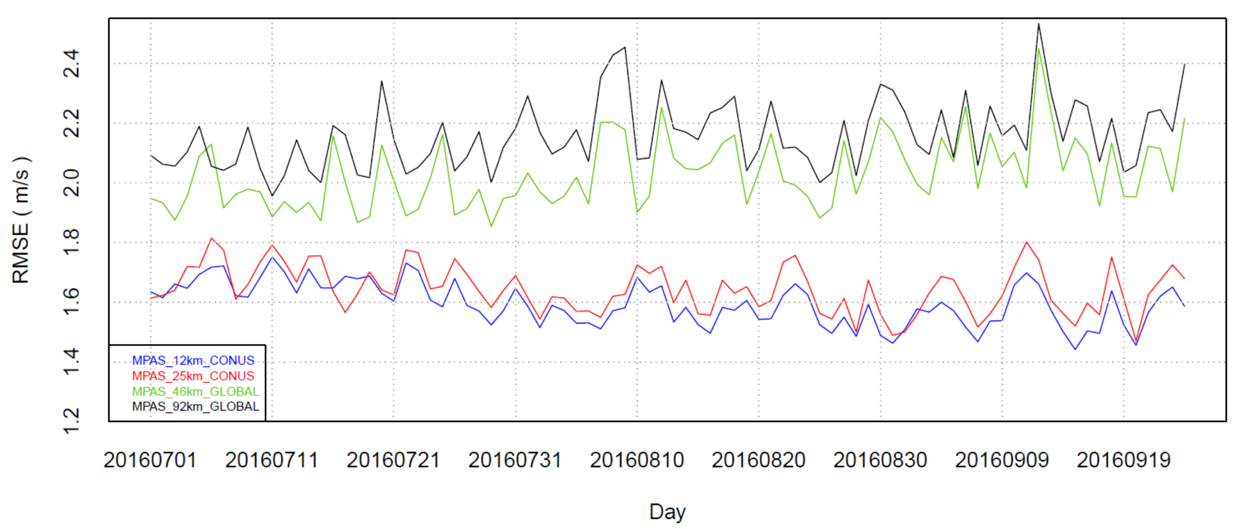


92km GLOBAL **46km GLOBAL** **25km CONUS** **12km CONUS**

Daily RMSE of WS10

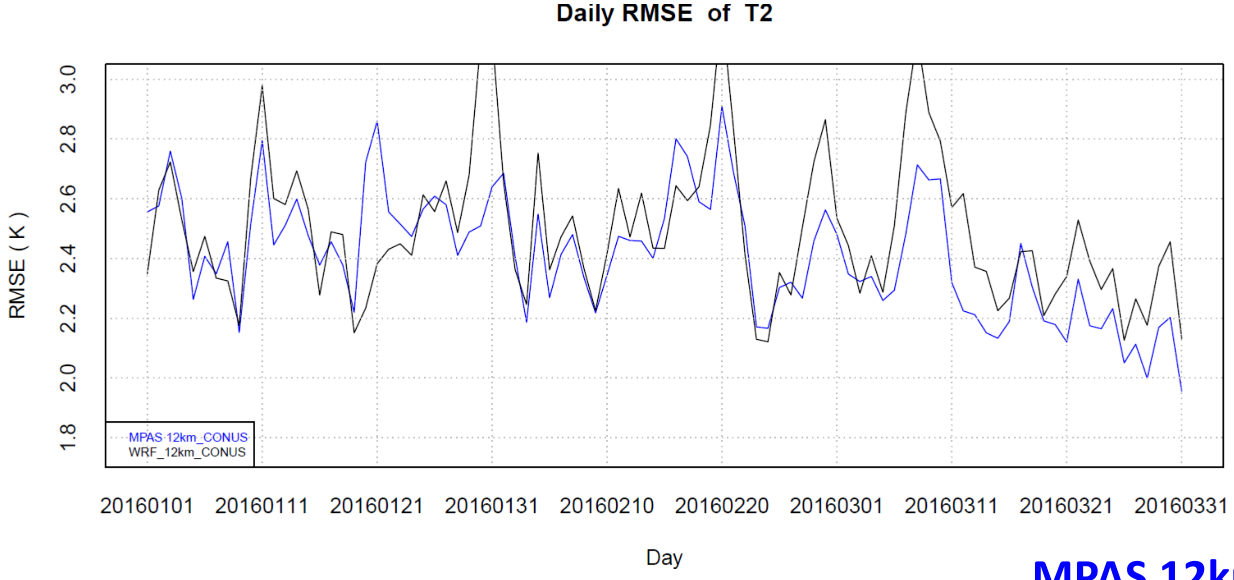


Daily RMSE of WS10

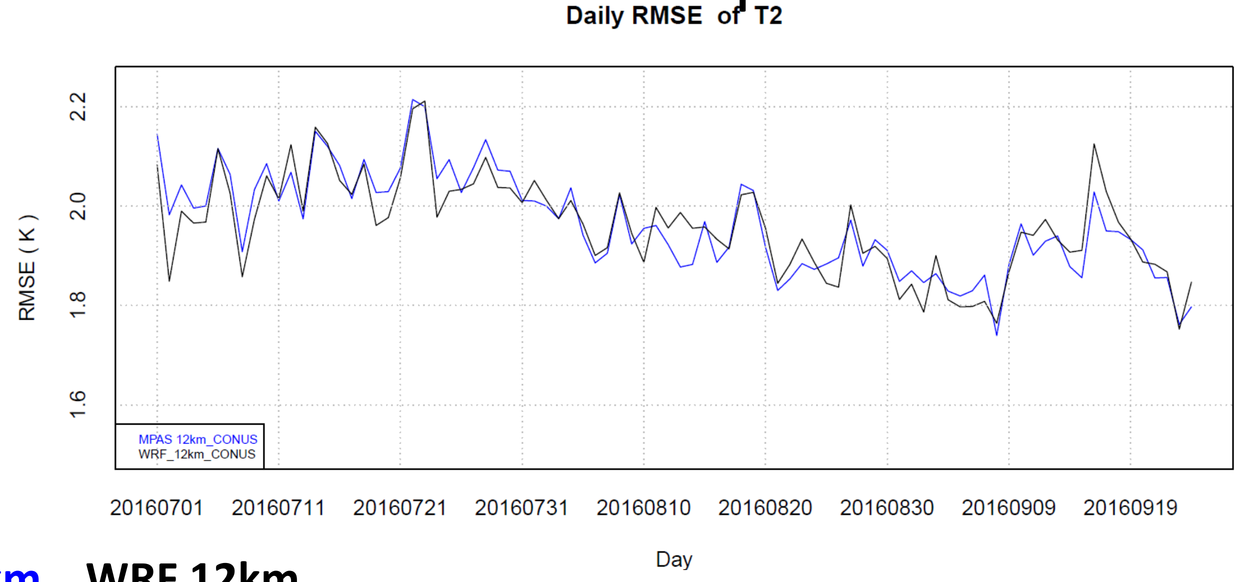


MPAS 12km vs. WRF 12 km CONUS

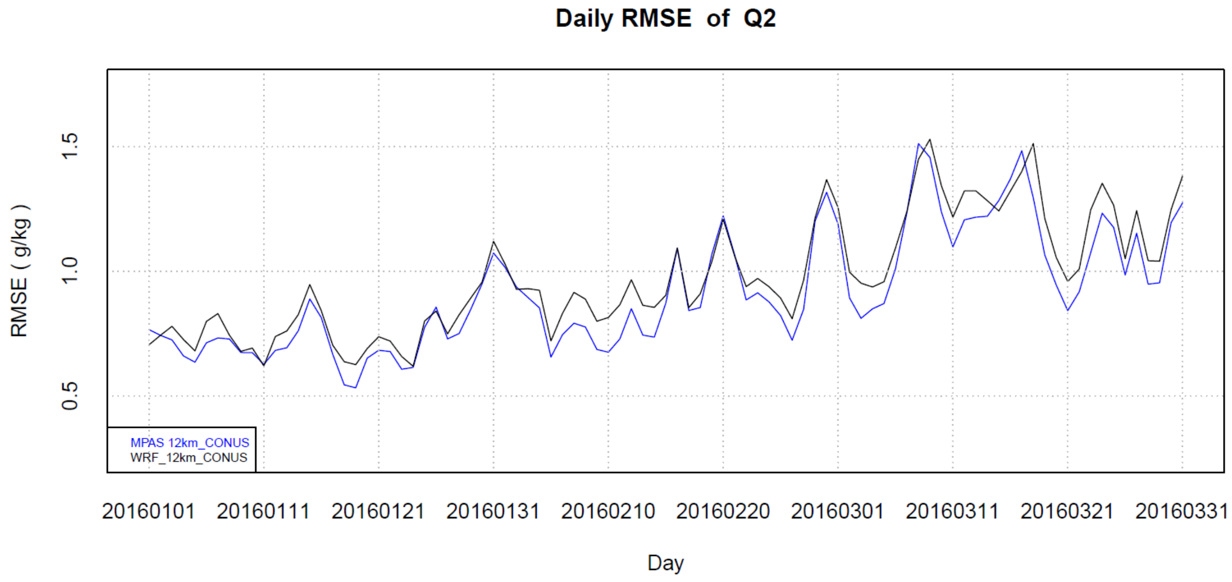
Jan-Mar

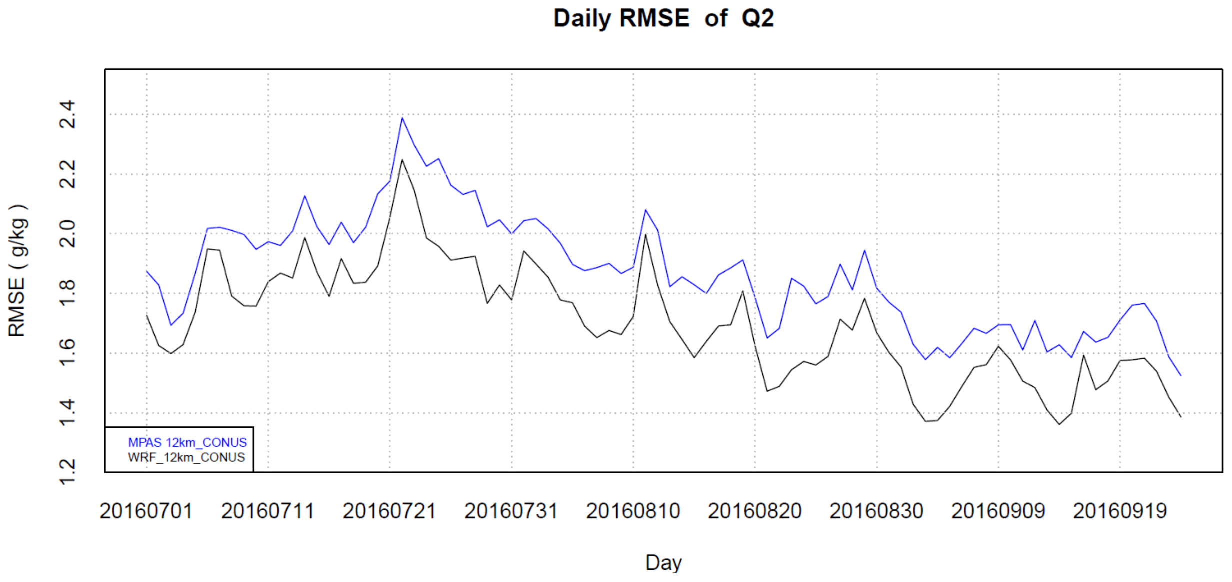


Jul-Sep



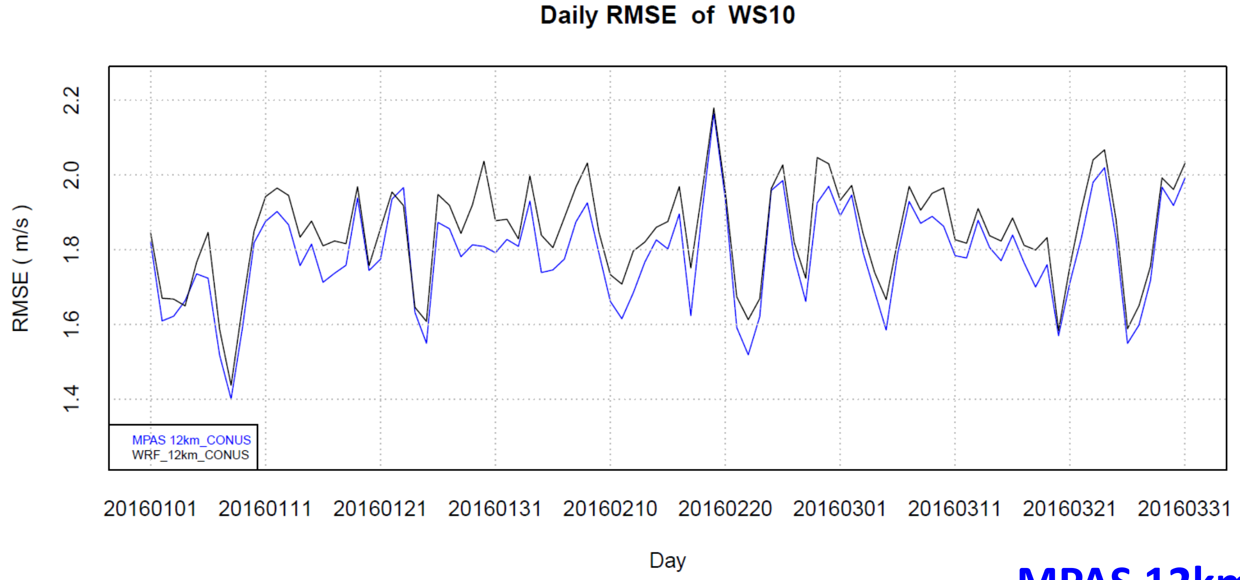
MPAS 12km **WRF 12km**



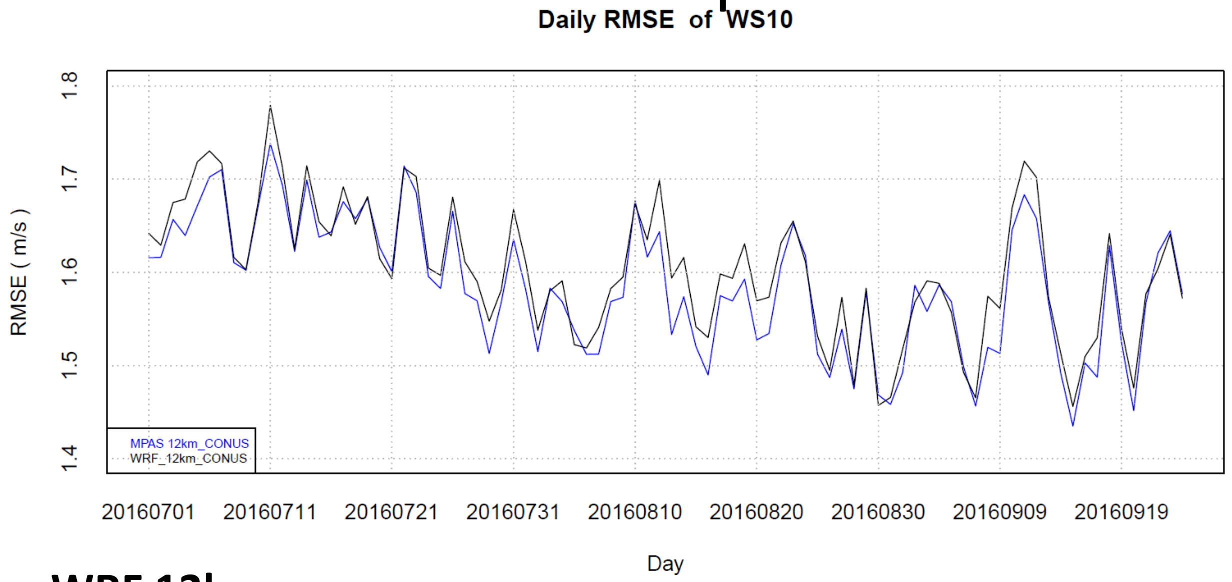


MPAS 12km vs. WRF 12 km Over CONUS

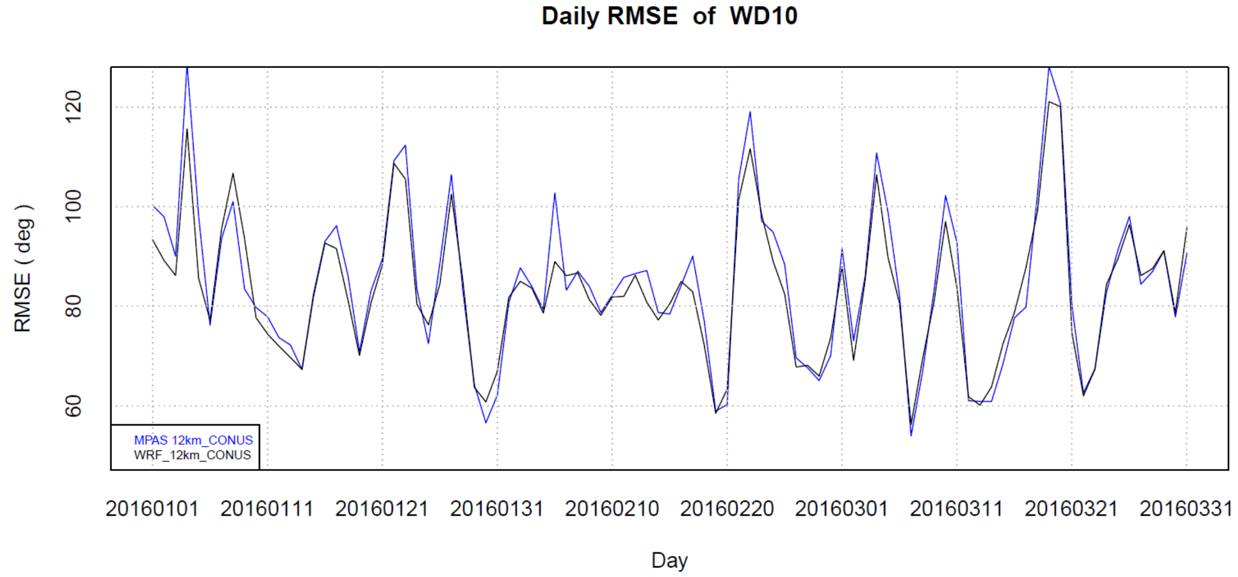
Jan-Mar

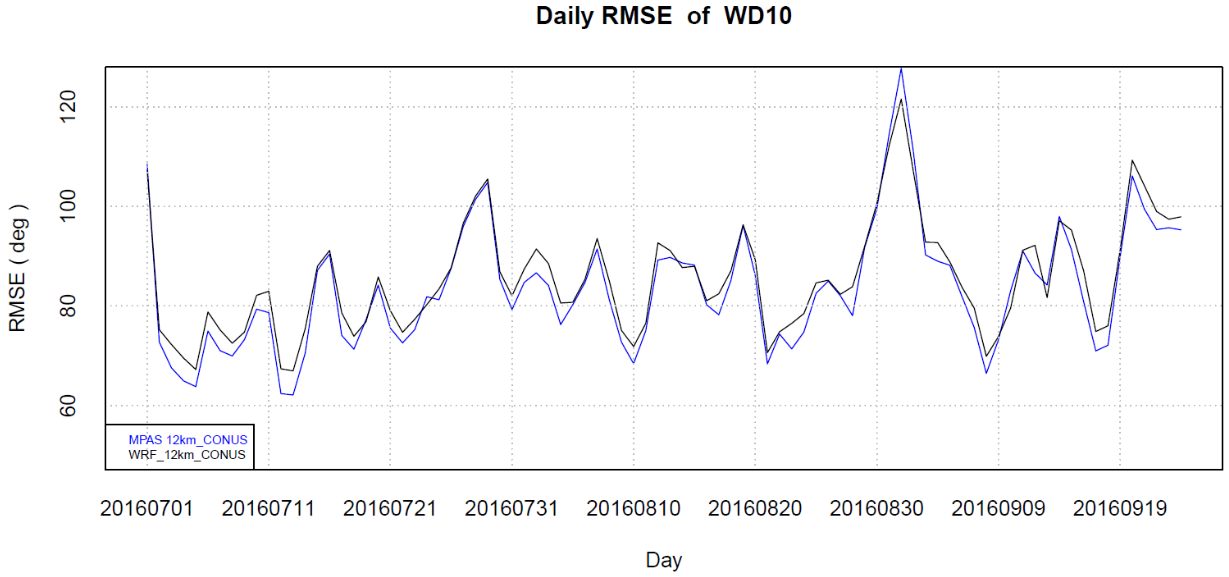


Jul-Sep



MPAS 12km **WRF 12km**

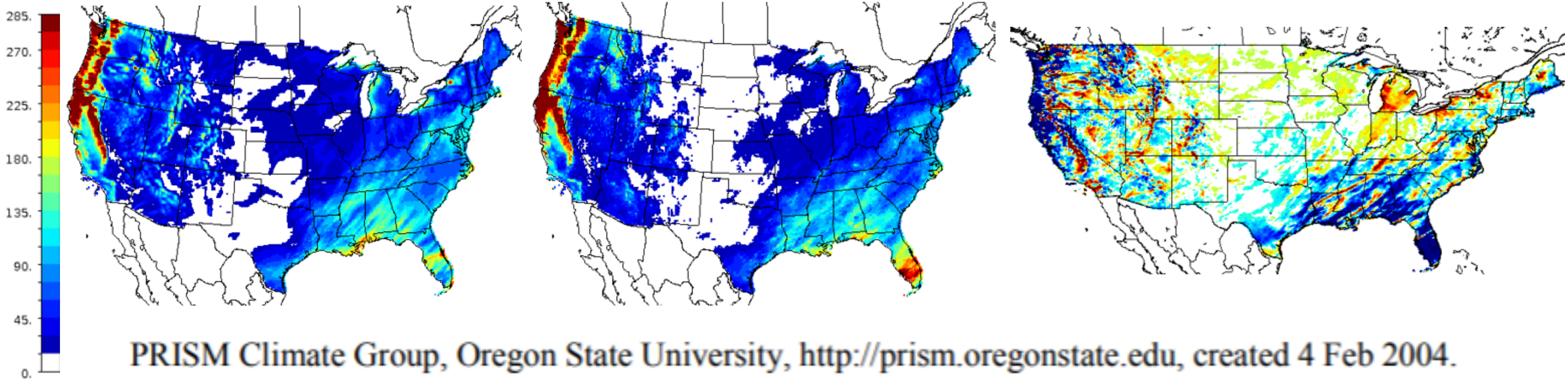




MPAS

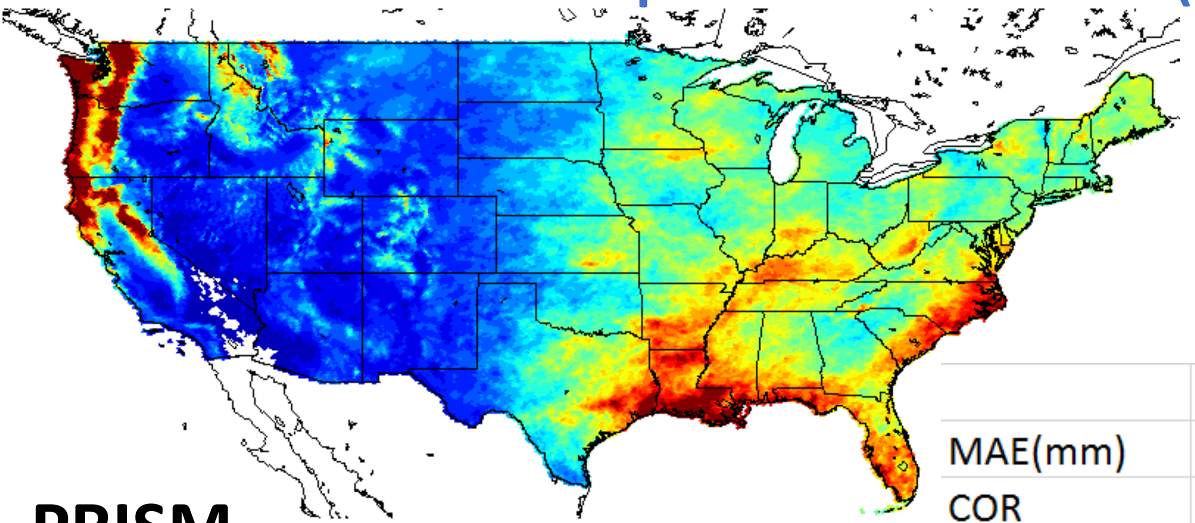
CONUS Precipitation

Comparing the MPAS 46 to 12 km and 12 km WRF simulations with 2016 PRISM precipitation



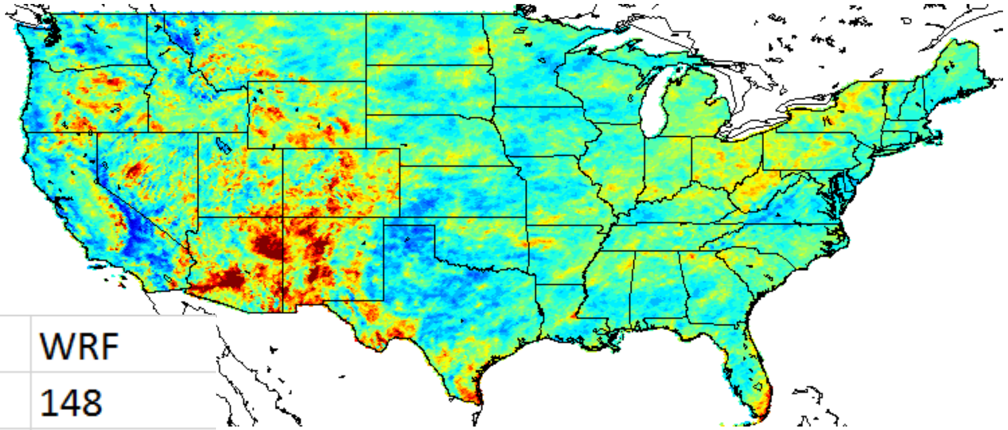
PRISM Climate Group, Oregon State University, http://prism.oregonstate.edu, created 4 Feb 2004.

Precipitation Total (mm) Jan-Dec 2016

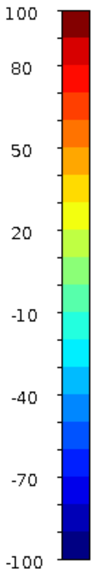


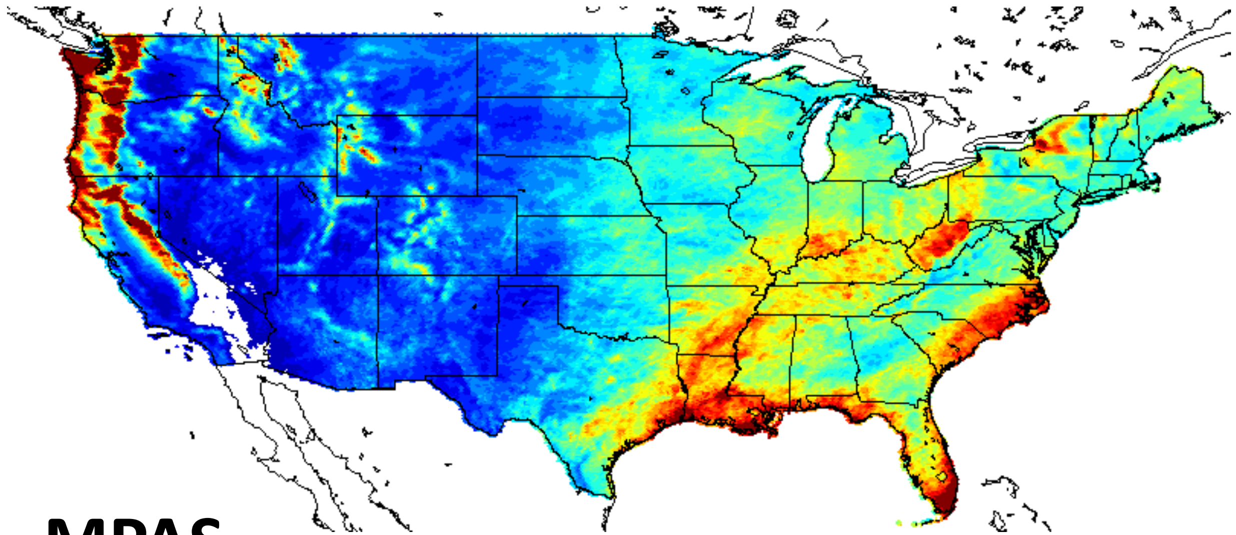
PRISM

	MPAS	WRF
MAE(mm)	137	148
COR	0.92	0.9

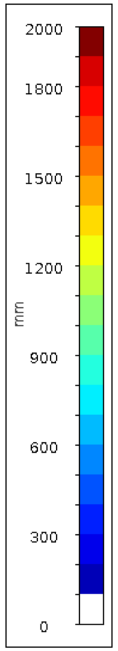


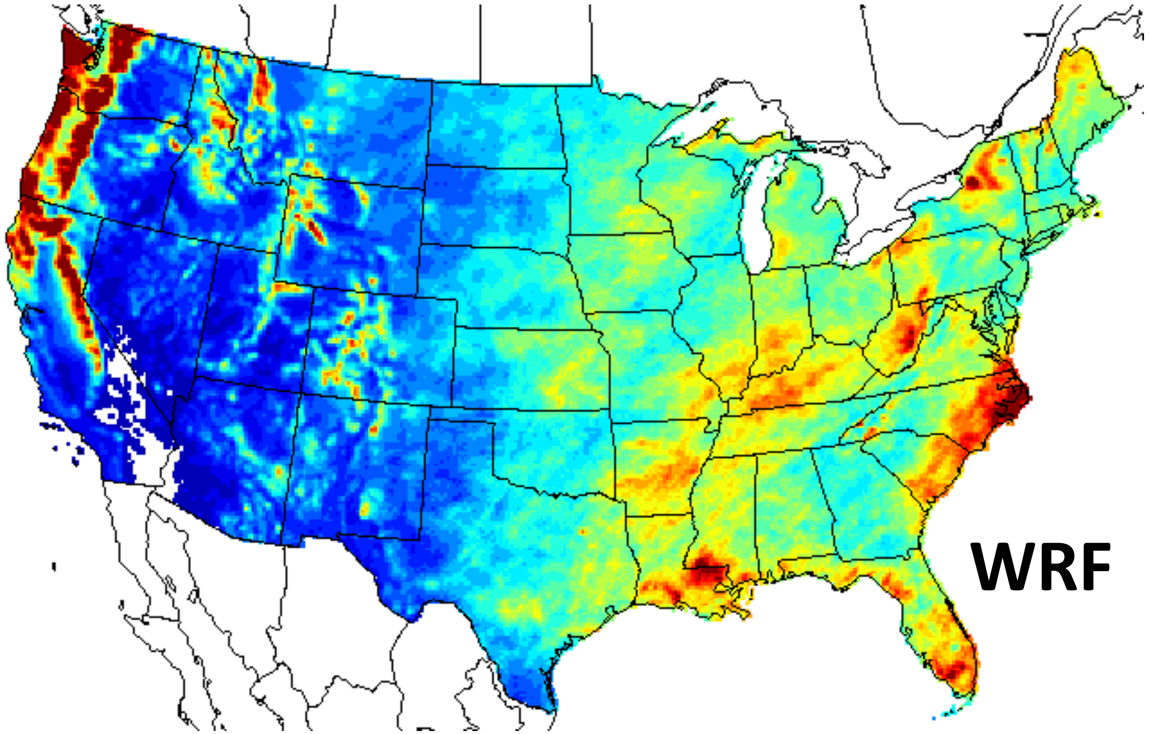
% Diff MPAS-PRISM





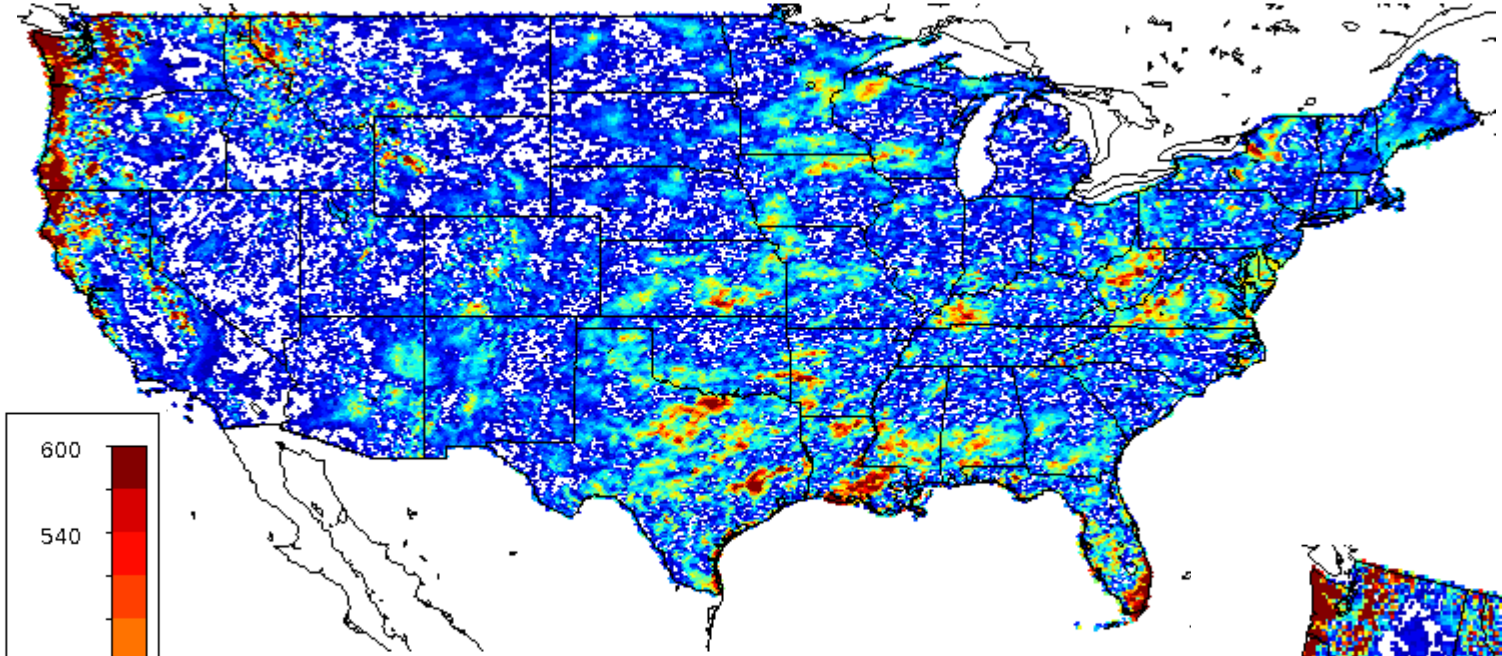
MPAS

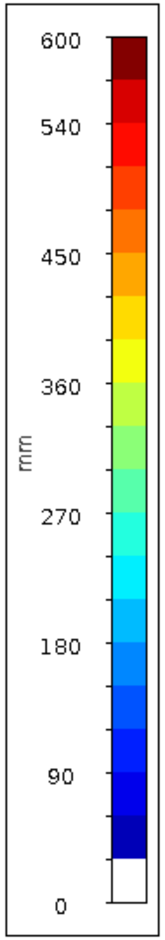




WRF

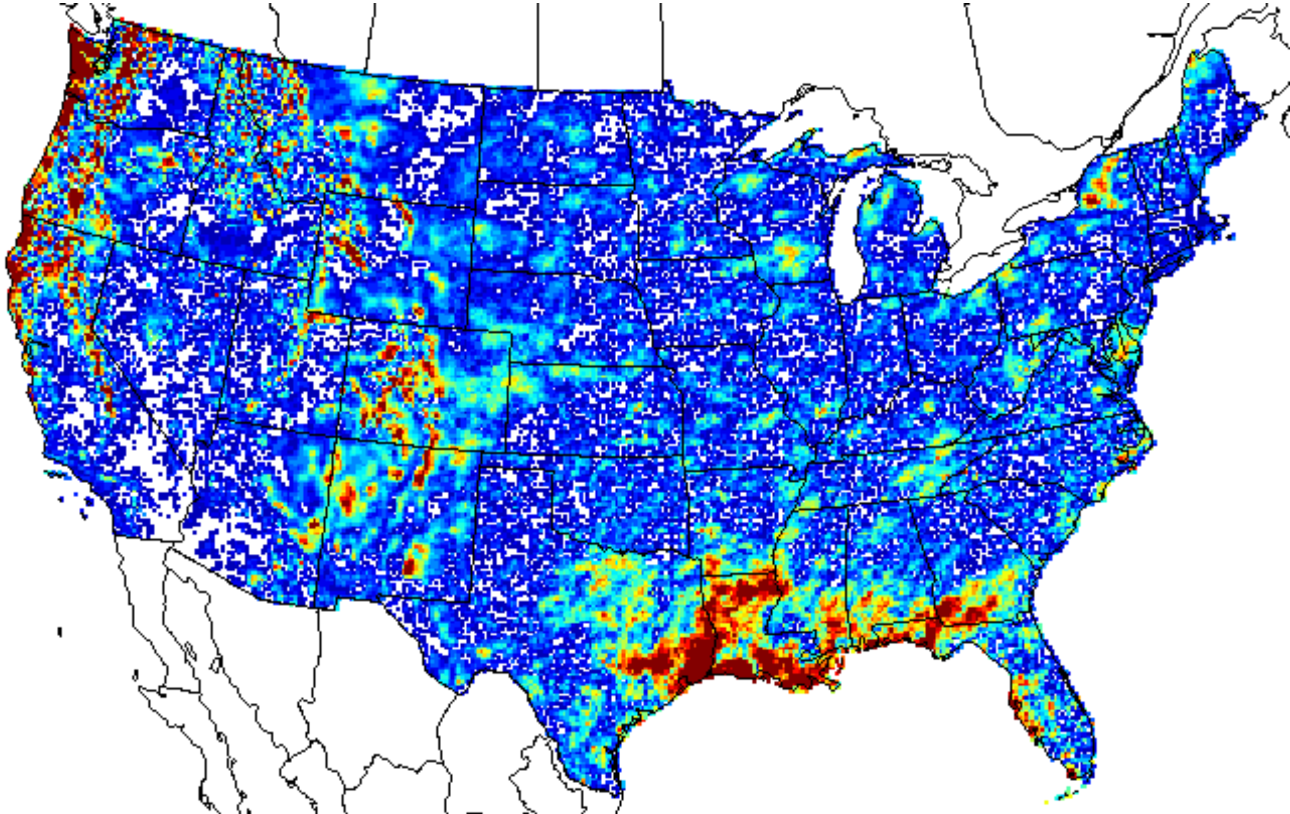
MPAS





Absolute Difference in Precipitation(mm) Jan-Dec 2016

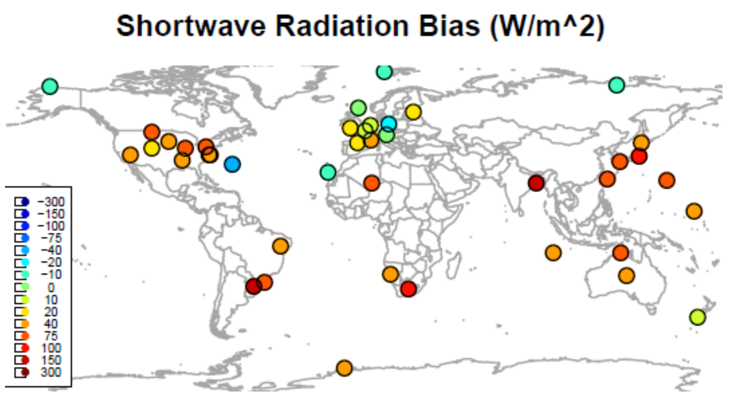
WRF

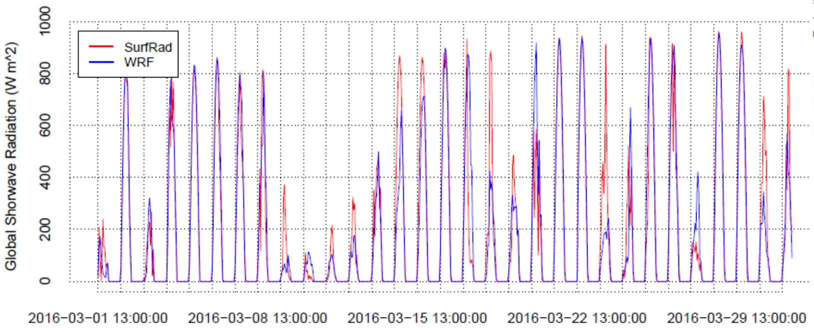


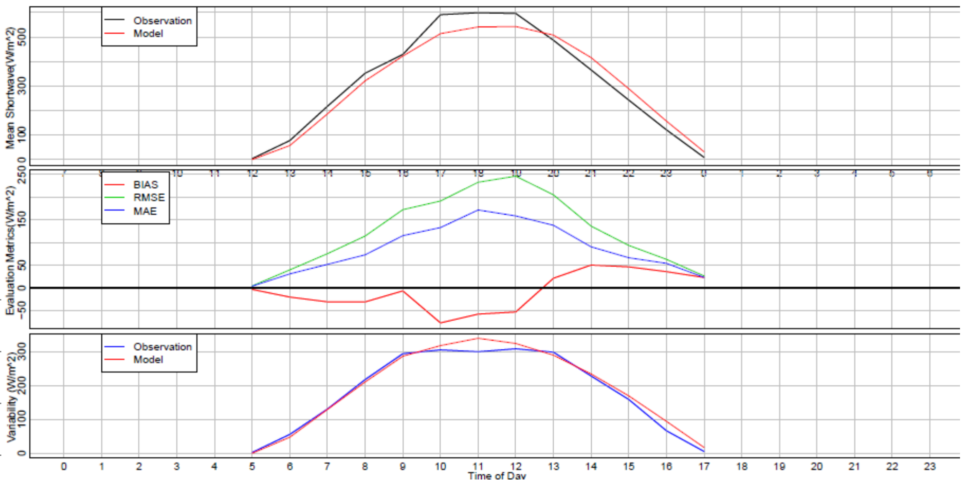
MPAS

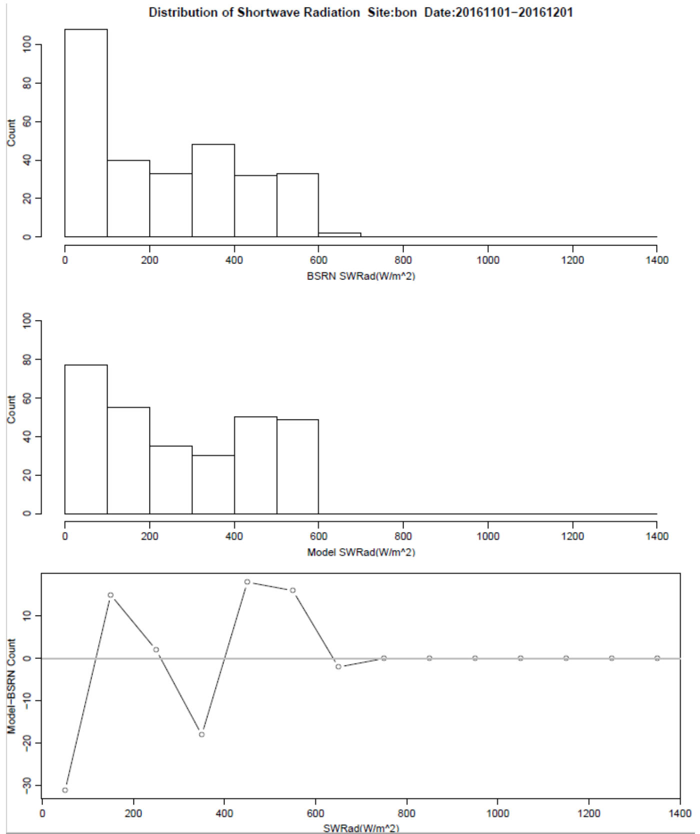
Surface Solar Radiation

Comparing the 46 to 12 km MPAS and 12 km WRF simulations with global BSRN shortwave radiation observations.

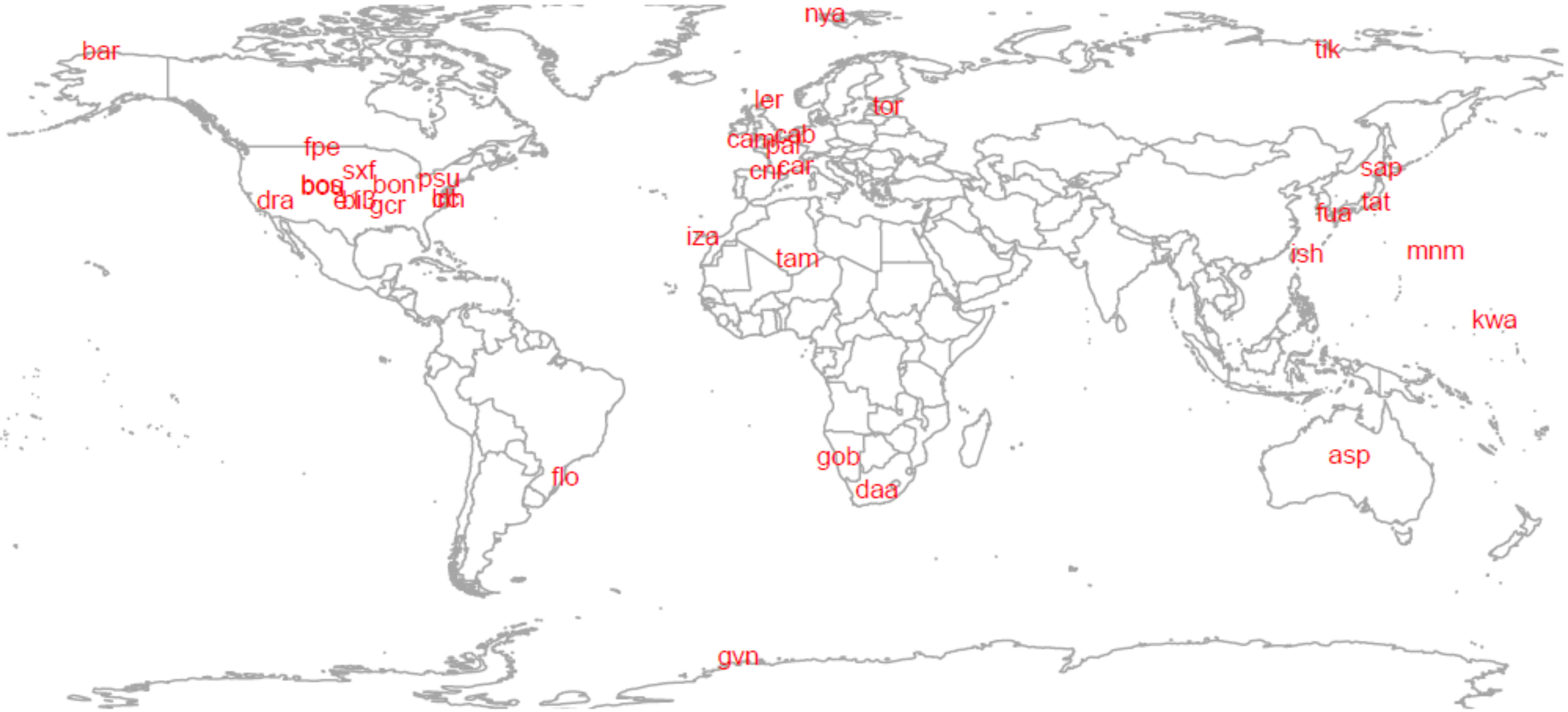








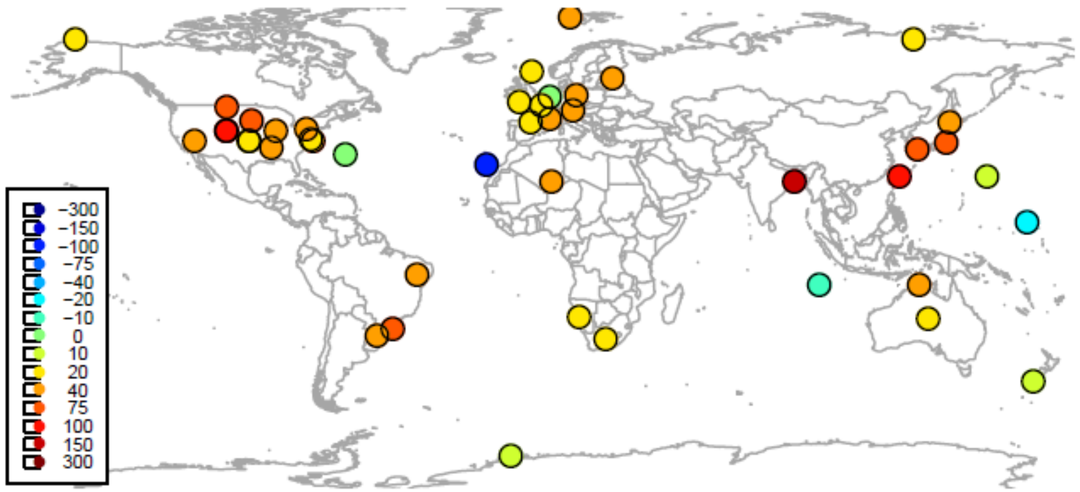
Baseline Solar Radiation Network (BSRN)



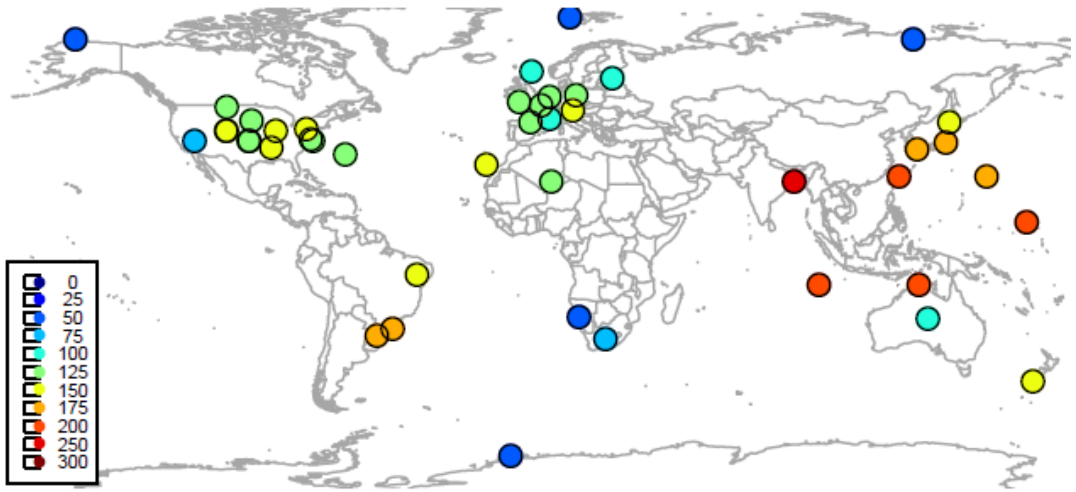
http://bsrn.awi.de/

Early Afternoon relative to Solar Noon
Feb-Dec 2016

Shortwave Radiation Bias (W/m^2)

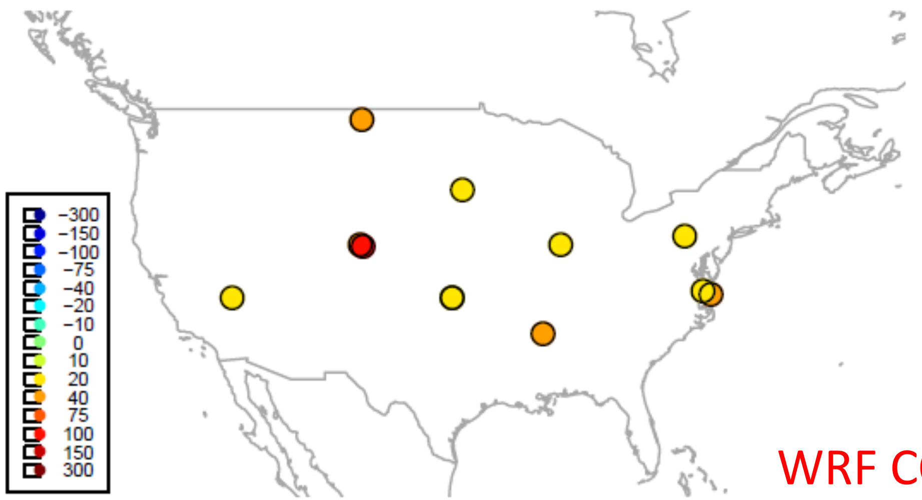


Shortwave Radiation MAE (W/m^2)

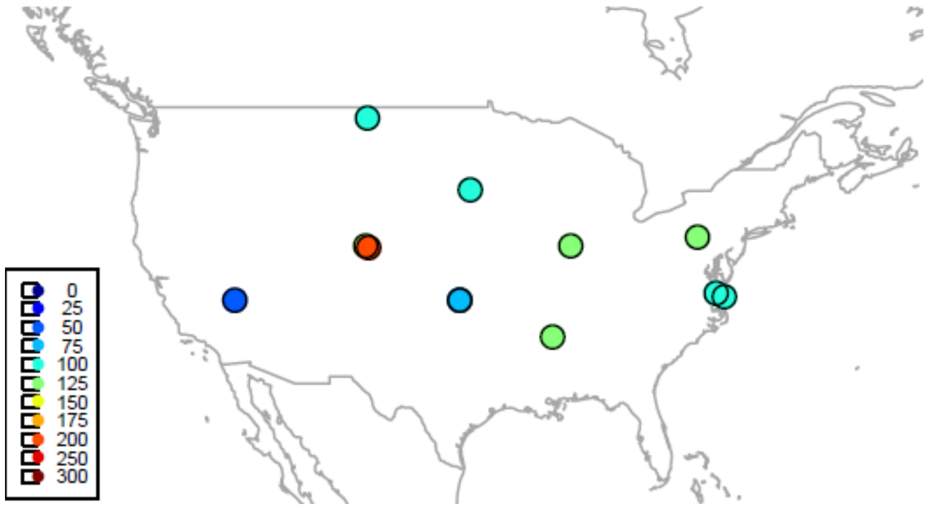


MPAS 46-12km

Shortwave Radiation Bias (W/m^2)

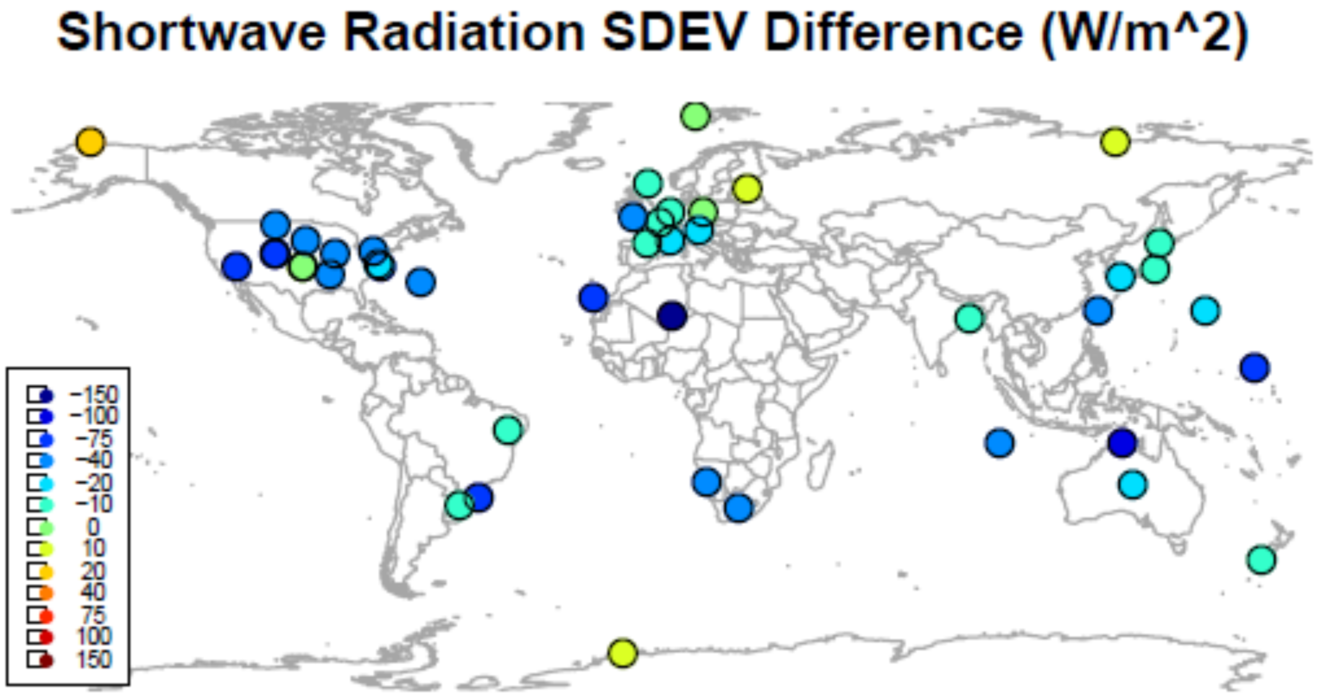


Shortwave Radiation MAE (W/m^2)

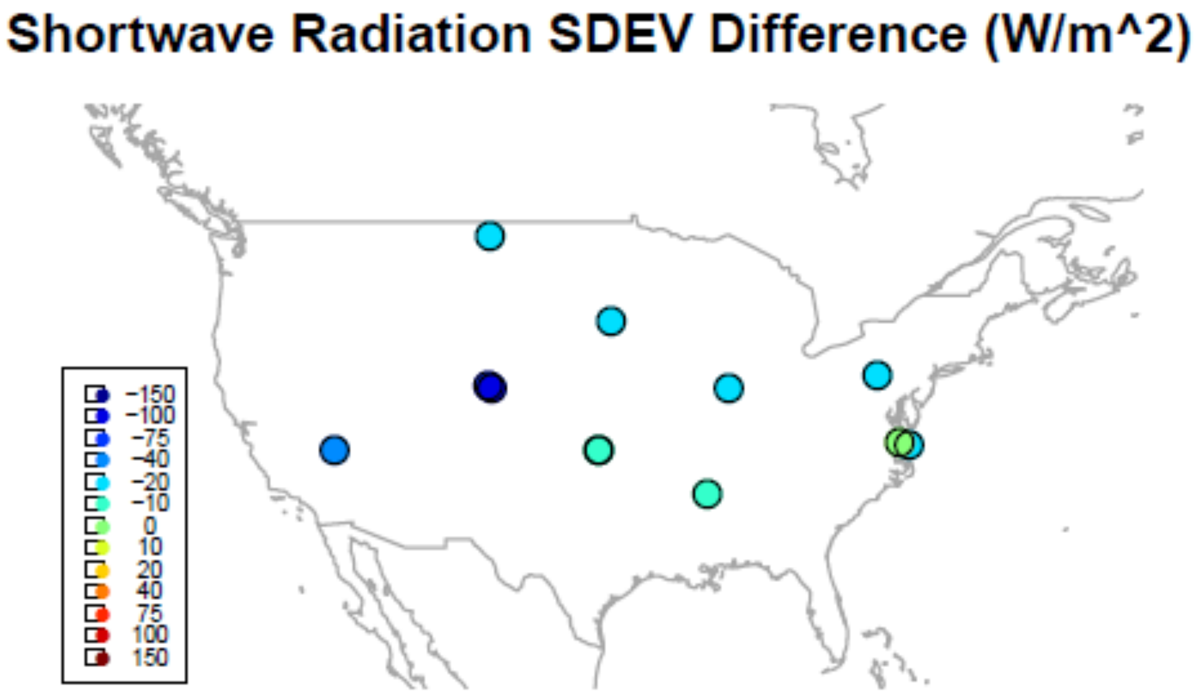


WRF CONUS12 OAQPS

Early Afternoon relative to Solar Noon
Feb-Dec 2016



MPAS 46-12km

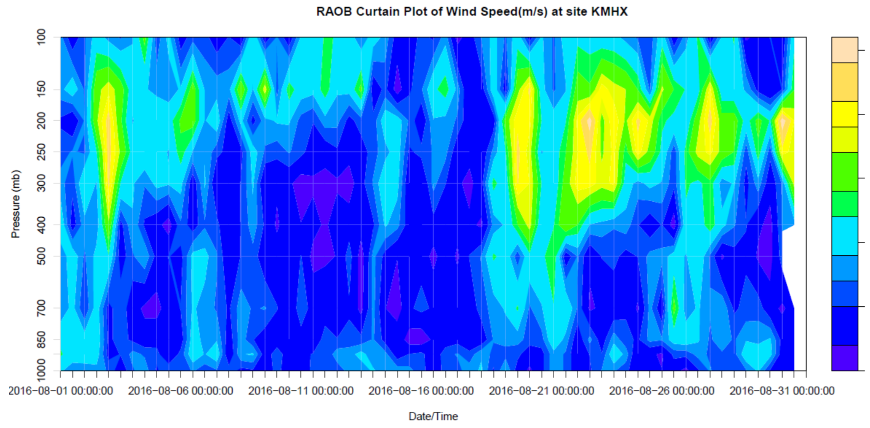


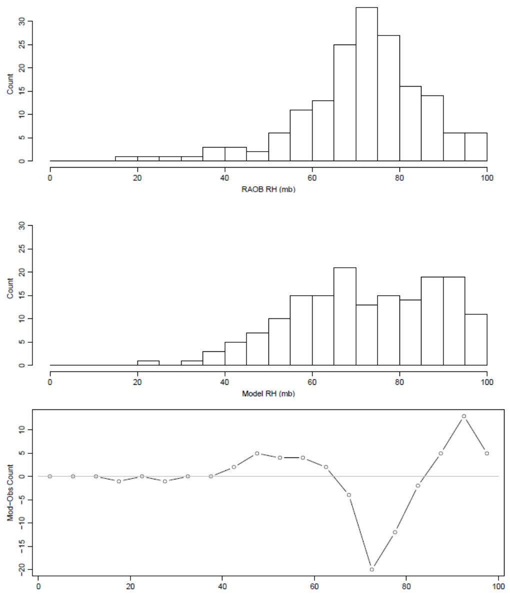
WRF CONUS12

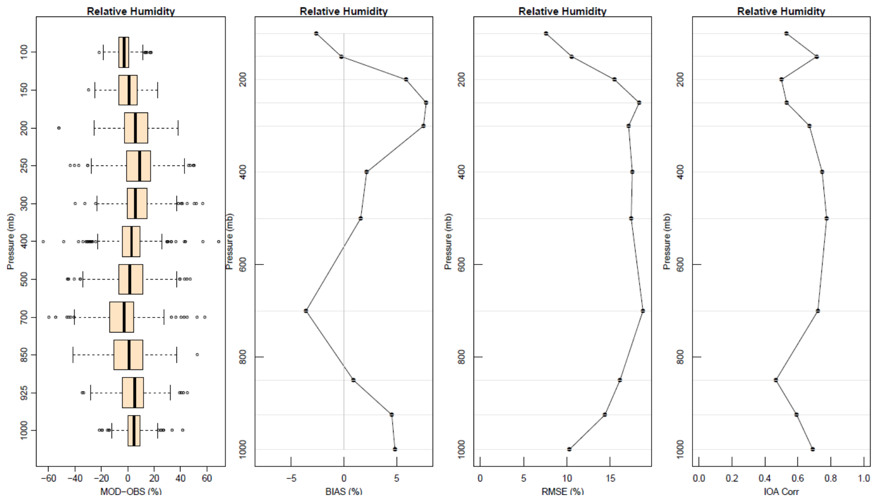
MPAS

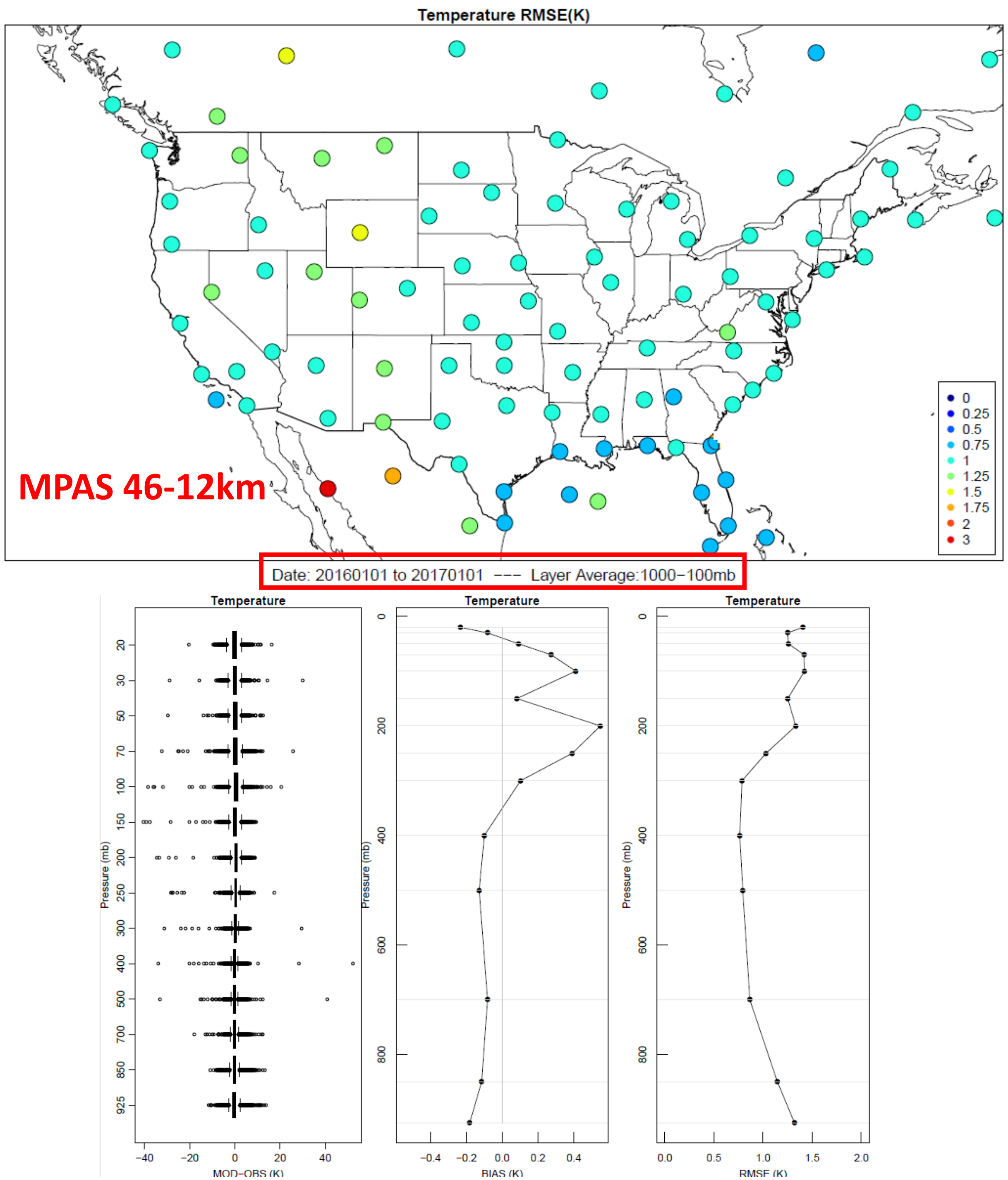
Upper Air Meteorology

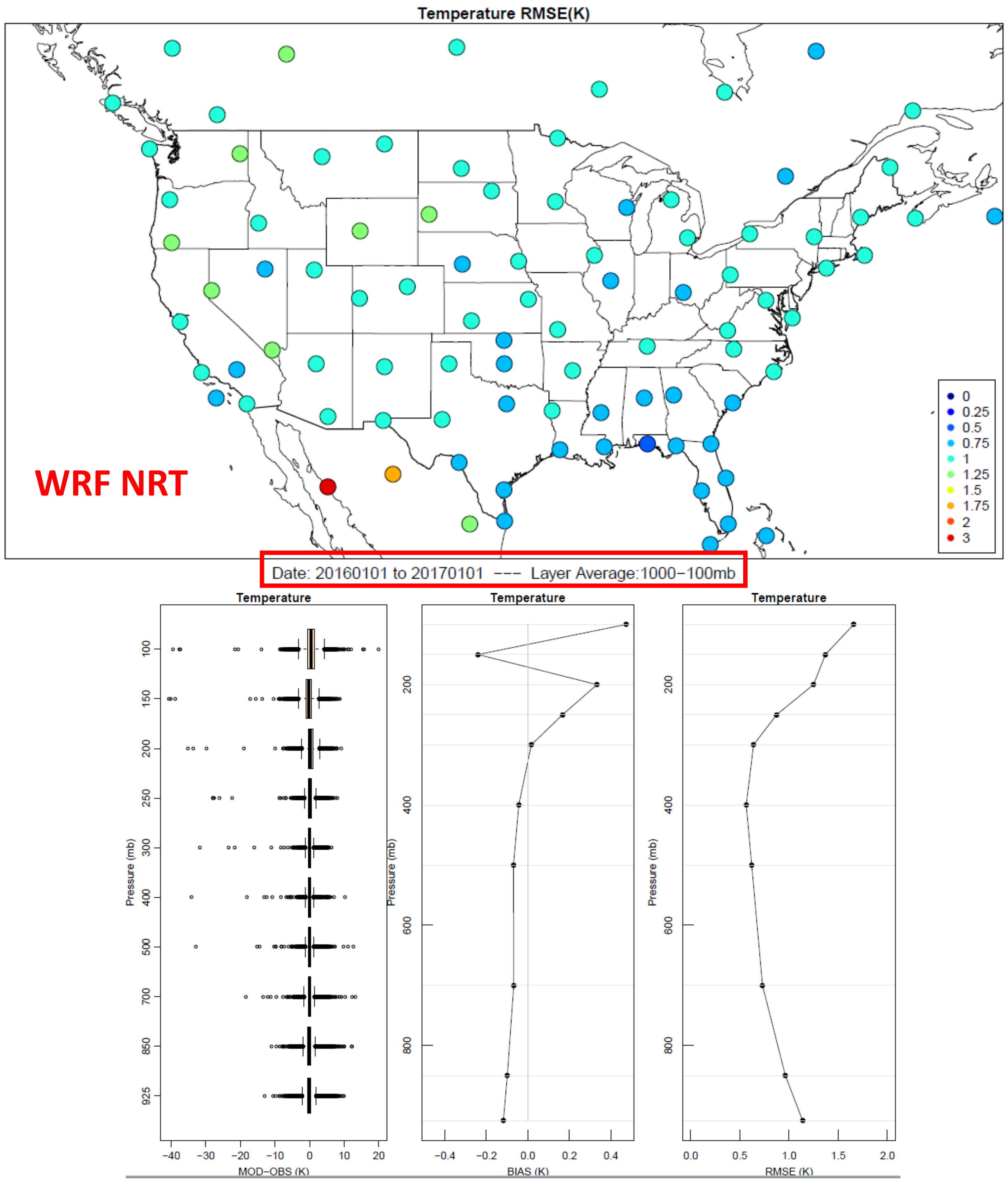
Comparing the 46 to 12 km MPAS and 12 km WRF simulations with rawindsonde soundings of temperature and wind.

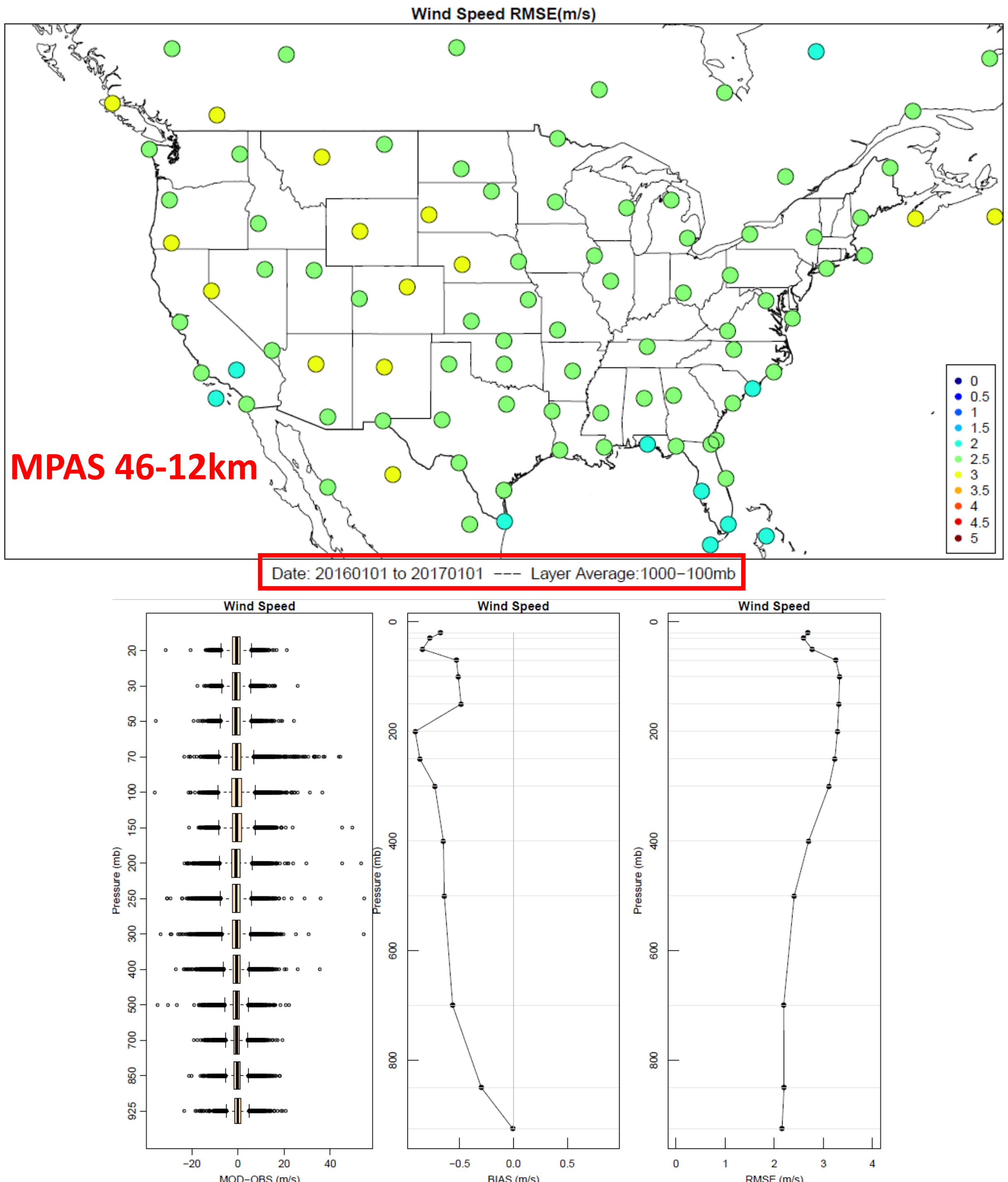


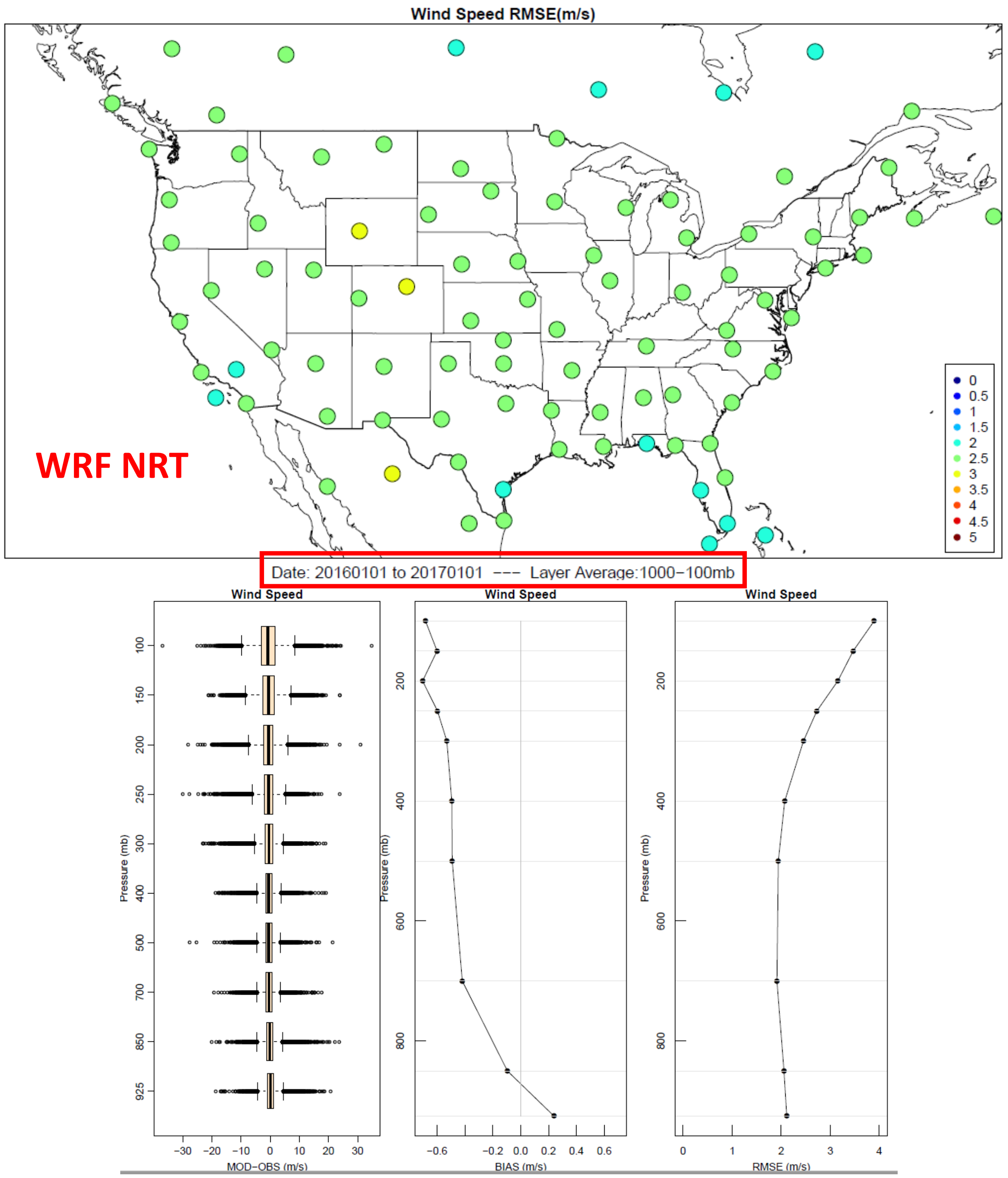





Temperature RMSE(K)
MPAS 46-12km
0
0.25
0.5
0.75
1
1.25
1.5
1.75
2
3
Date: 20160101 to 20170101 --- Layer Average:1000−100mb
Temperature
Pressure (mb)
MOD−OBS (K)
BIAS (K)
RMSE (K)

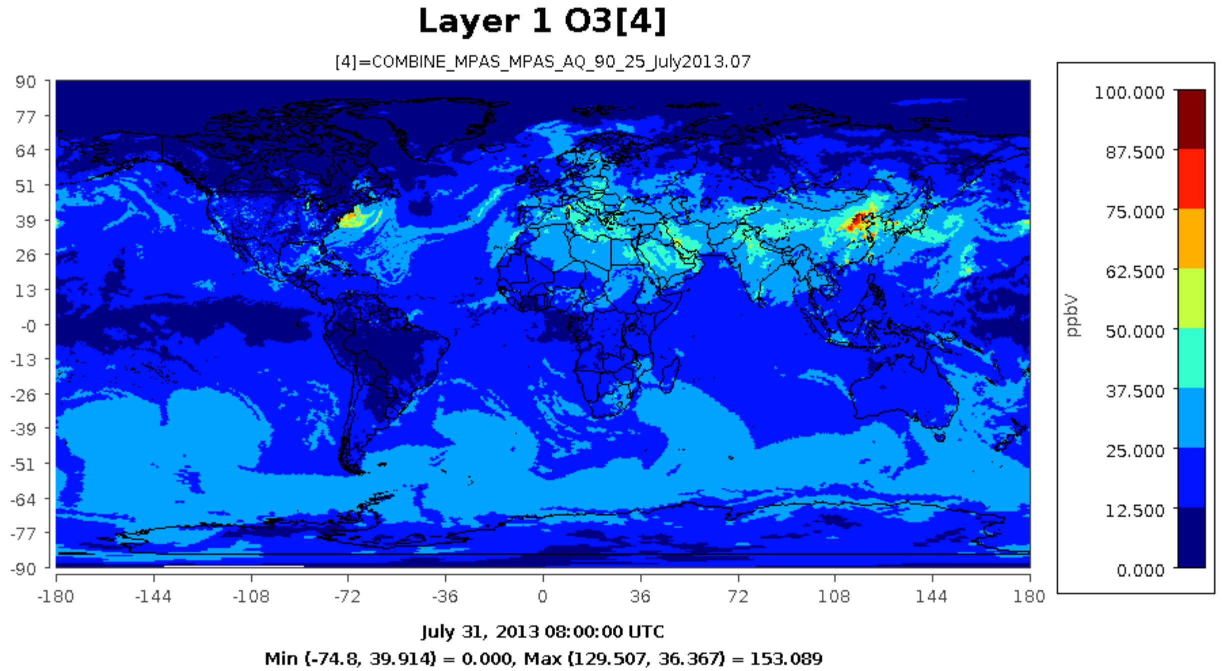

Temperature RMSE(K)
WRF NRT
0
0.25
0.5
0.75
1
1.25
1.5
1.75
2
3
Date: 20160101 to 20170101 --- Layer Average:1000−100mb
Temperature
Pressure (mb)
MOD−OBS (K)
BIAS (K)
RMSE (K)

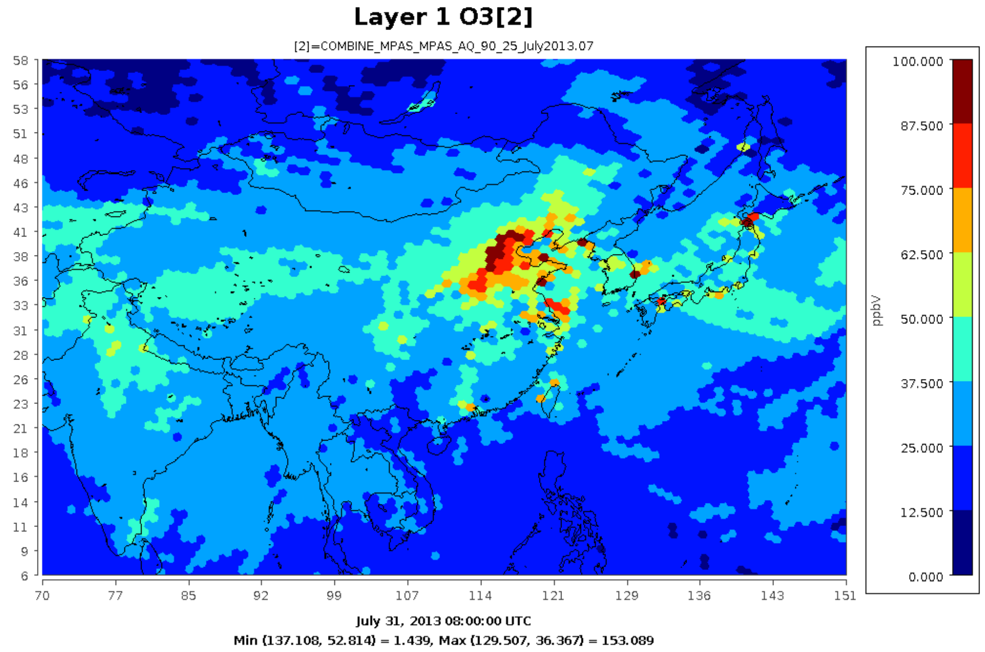

Wind Speed RMSE(m/s)
MPAS 46-12km
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
Date: 20160101 to 20170101 --- Layer Average:1000−100mb
Wind Speed
Pressure (mb)
MOD−OBS (m/s)
Wind Speed
BIAS (m/s)
Wind Speed
RMSE (m/s)


Wind Speed RMSE(m/s)
WRF NRT
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
Date: 20160101 to 20170101 --- Layer Average:1000−100mb
Wind Speed
Pressure (mb)
MOD−OBS (m/s)
Wind Speed
BIAS (m/s)
Wind Speed
RMSE (m/s)

MPAS-CMAQ initial testing

Layer 1 Ozone concentrations at July 31, 2013 at 8Z (4 pm China Time)





- Ozone concentrations realistic in high emission areas
- Too low in remote regions
- Longer spin-up needed

Plots were made with VERDI. An interactive Java-based vis tool for MPAS/WRF/CMAQ output. https://www.cmascenter.org/verdi/

Progress and Near-term plan

- First Phase: Global MPAS-CMAQ
  - Accomplished porting EPA WRF Physics to MPAS
    - Evaluated for July 2013 and full year 2016 at coarse (92-25 km) and fine (46-12 km) meshes
  - Accomplished coupling MPAS and CMAQ
    - Evaluating July 2013
    - Running full year 2016 with more refine emissions for US (NEI)
- Second Phase:
  - Nesting regional MPAS/WRF-AQ into the global MPAS-AQ
  - Experimenting with customized grid refinement
- Third Phase: redesigned AQ model
  - Redesign CMAQ from ground up to refresh model structure and coding
  - Improve efficiency and flexibility.

Disclaimer

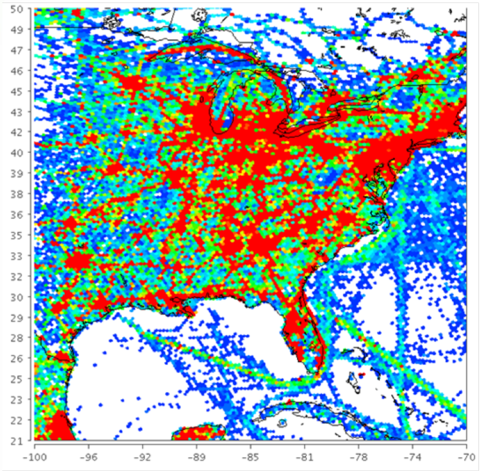
- The views expressed in this presentation are those of the authors and do not necessarily reflect the views or policies of the U.S. EPA

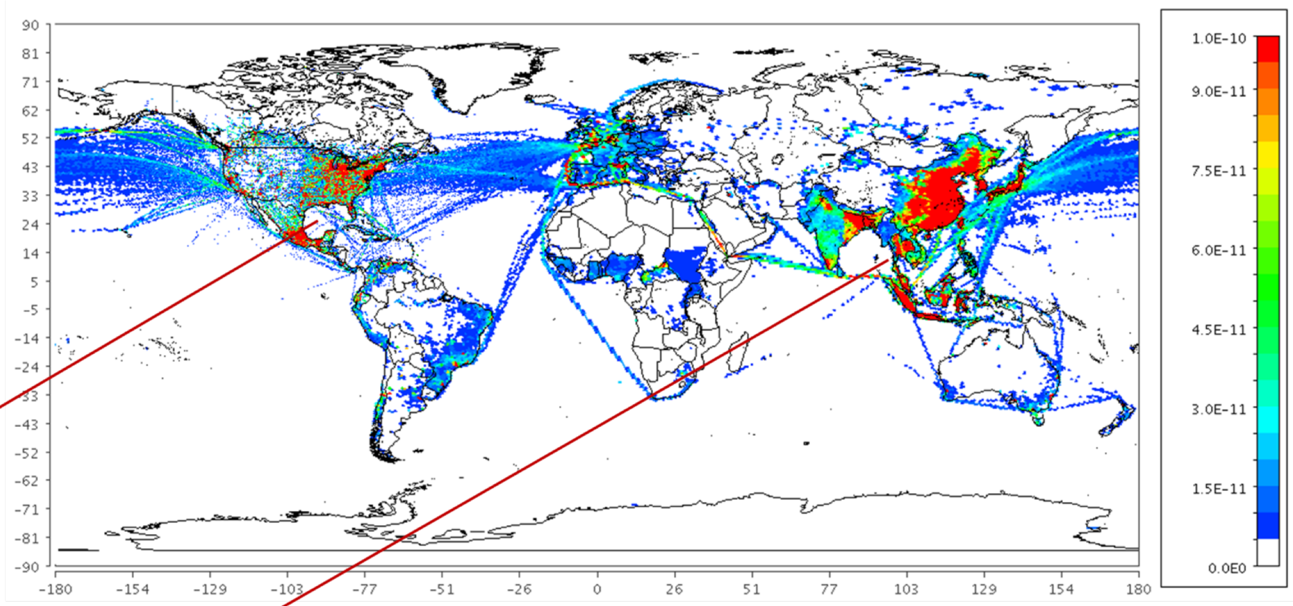
Extra Slides

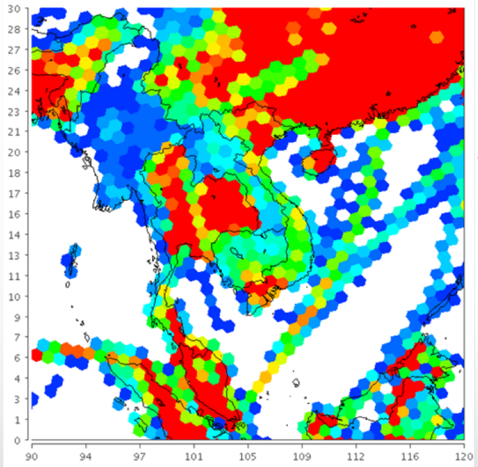
MPAS-CMAQ

- MPAS-CMAQ is an operational prototype of Next Gen AQ model
  - AQ is called as module in MPAS
  - 2-way data transfer through MPAS-AQ Coupler analogous to MPAS coupler for WRF Physics
  - Advection of chemical species in MPAS identical to meteorological scalars
    - no need for mass adjustment for continuity
  - MPAS uses z-coordinates in a hybrid terrain following layer structure
  - For CMAQ generalized coordinates the vertical Jacobian = 1, $\rho J = \rho$
  - The ACM2 PBL model has been rewritten in z-coords for both meteorology and AQ
  - Subgrid cloud fractions from KF in MPAS used to affect photolysis in AQ
  - GFS Ozone analysis for layers higher than 100 mb
- Initial testing for July 1-31, 2013 with no spin-up

Global emissions for MPAS-AQ

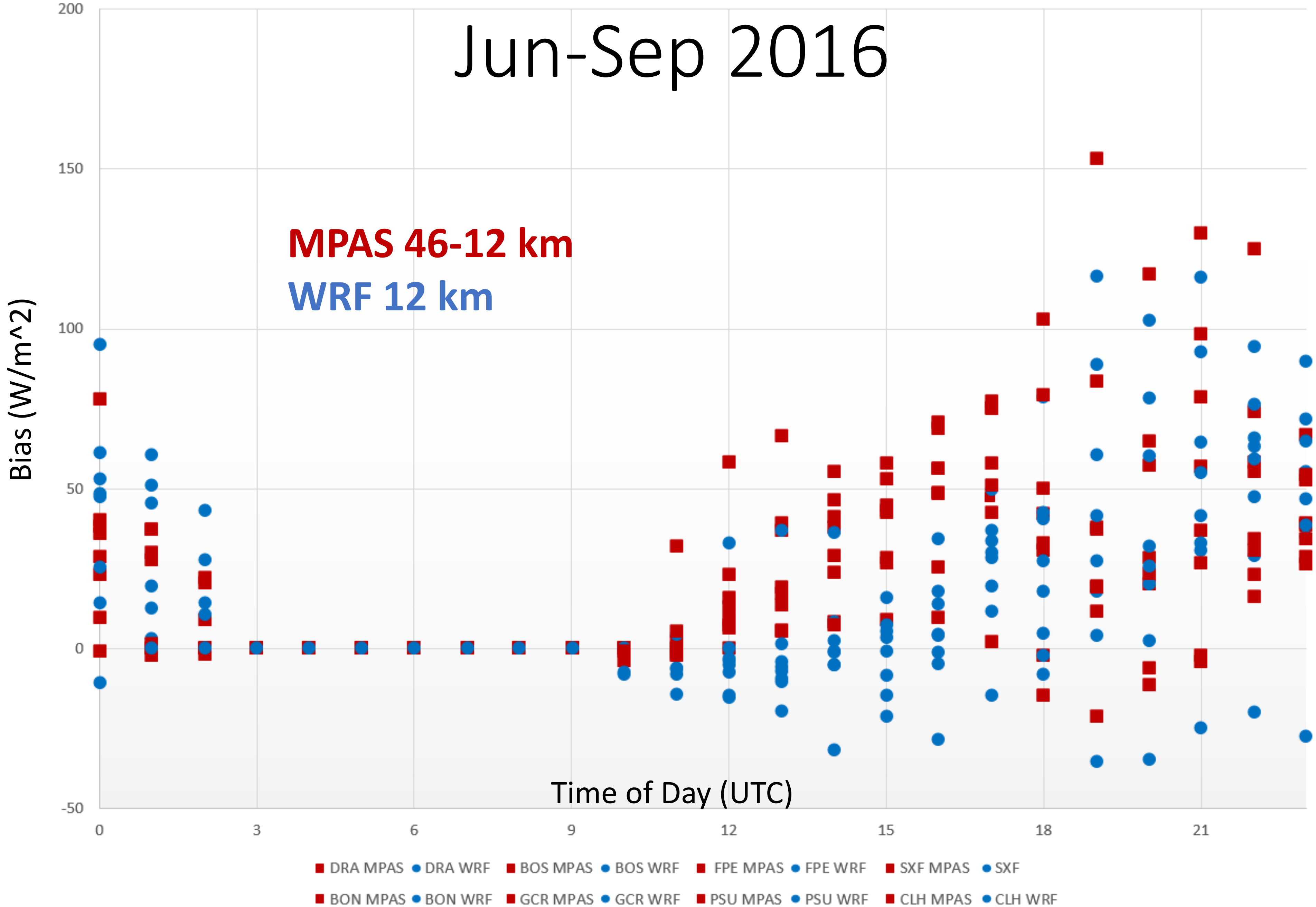




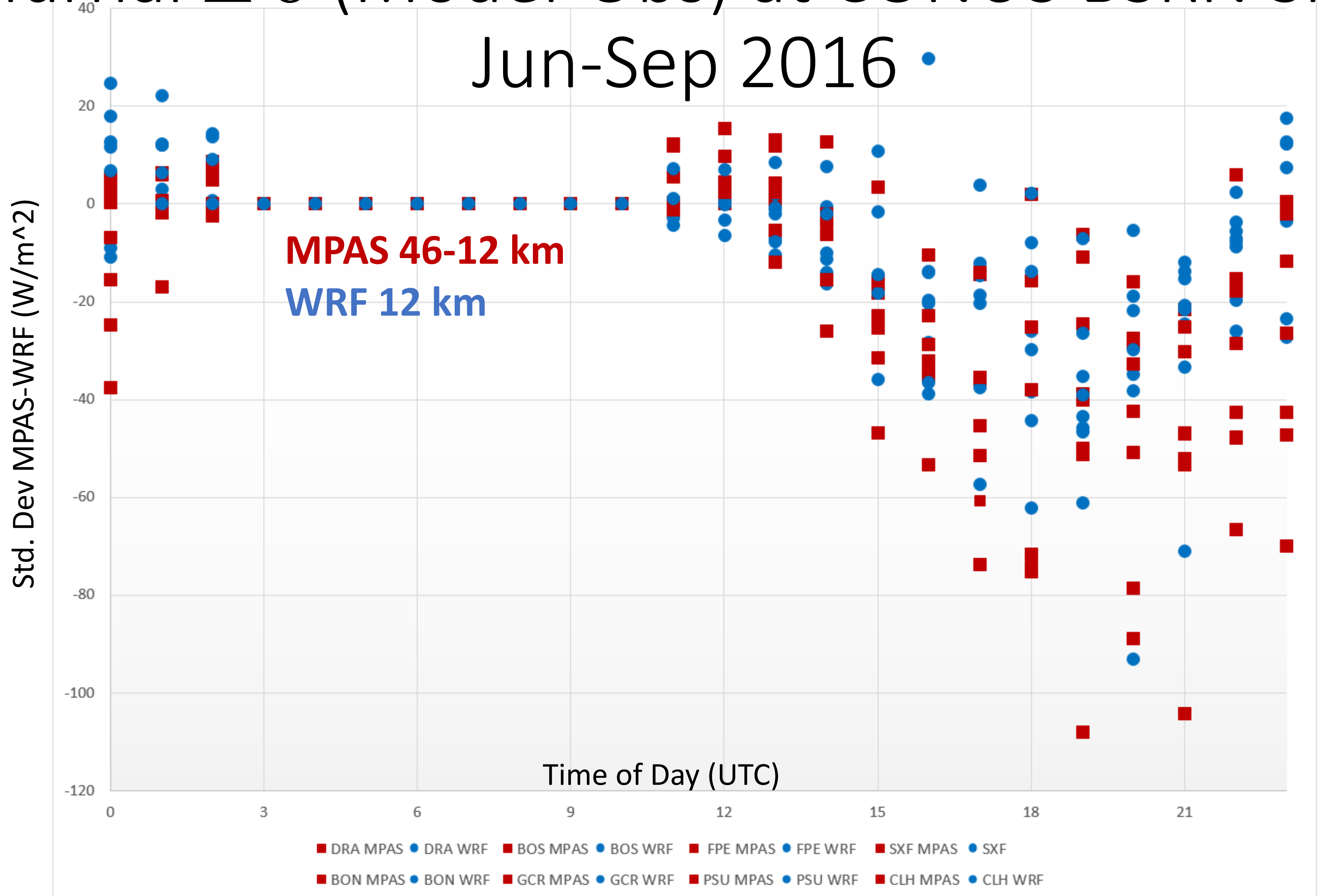


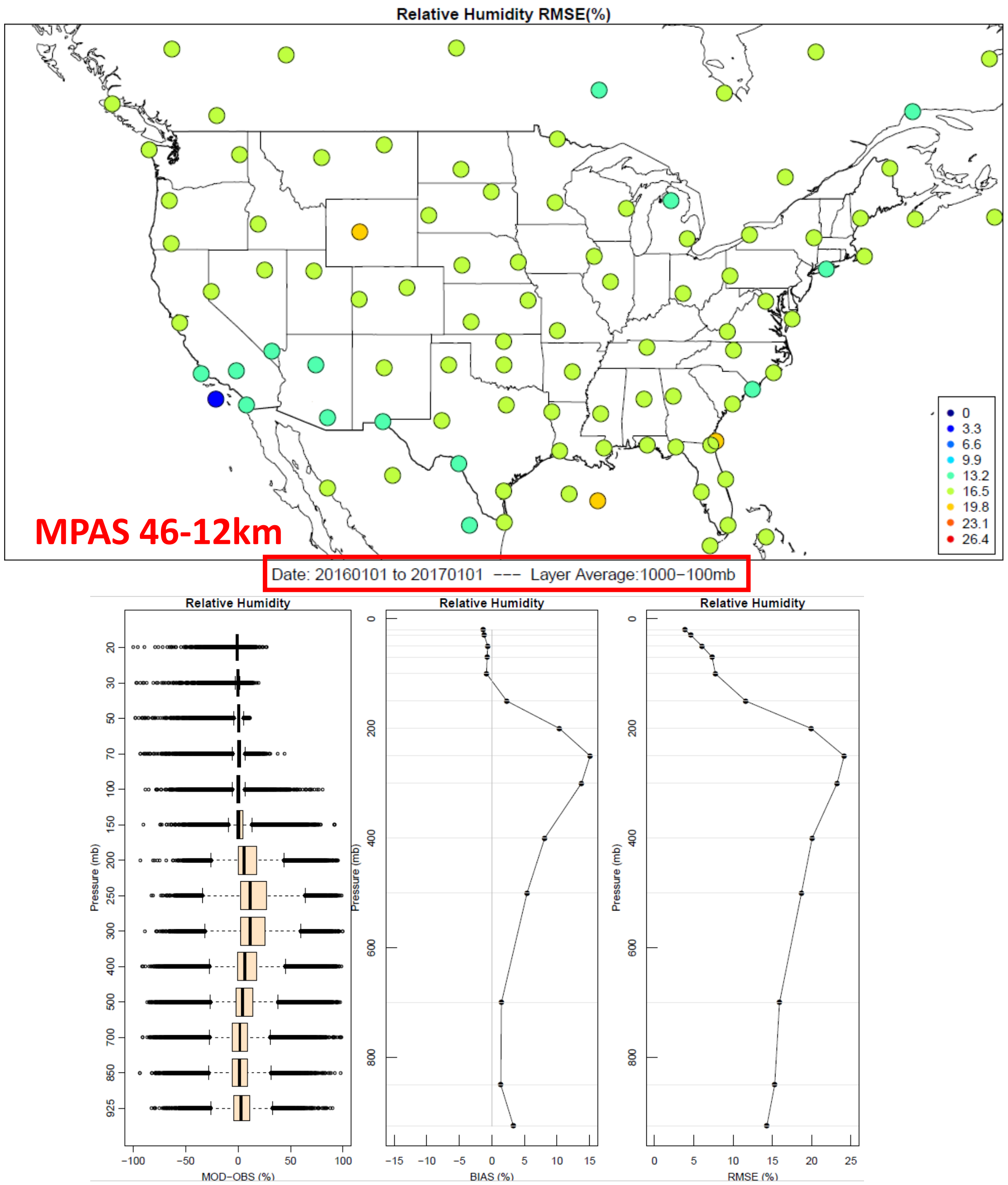
Global surface emissions of NO_2 (moles/m^2/s) from 0.1 x 0.1 degree HTAP_v2.2 [Janssens-Maenhout et al., ACP 2015] grid maps re-gridded to unstructured 92-25 km MPAS mesh.

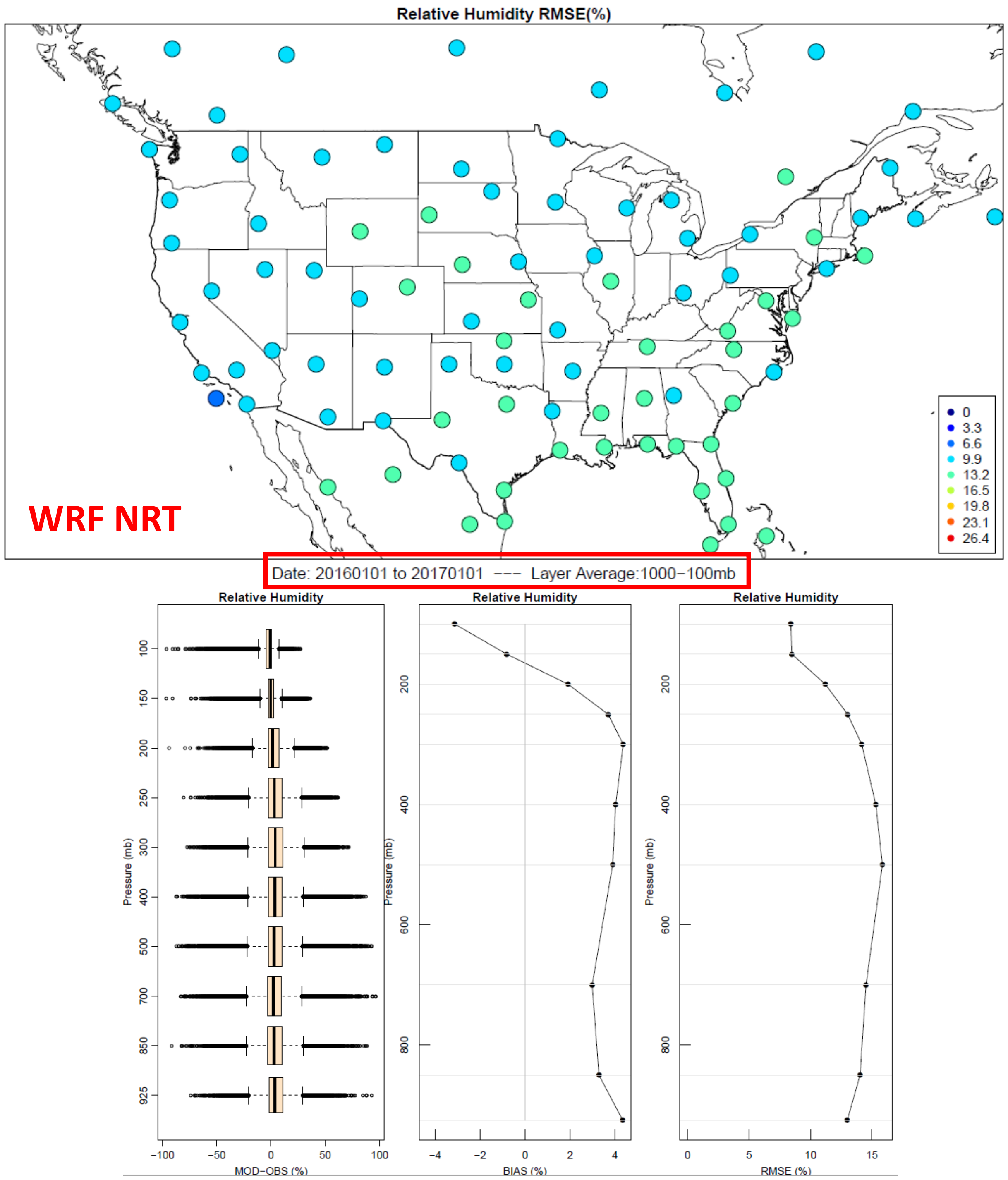
Diurnal BIAS at CONUS BSRN Sites
Jun-Sep 2016

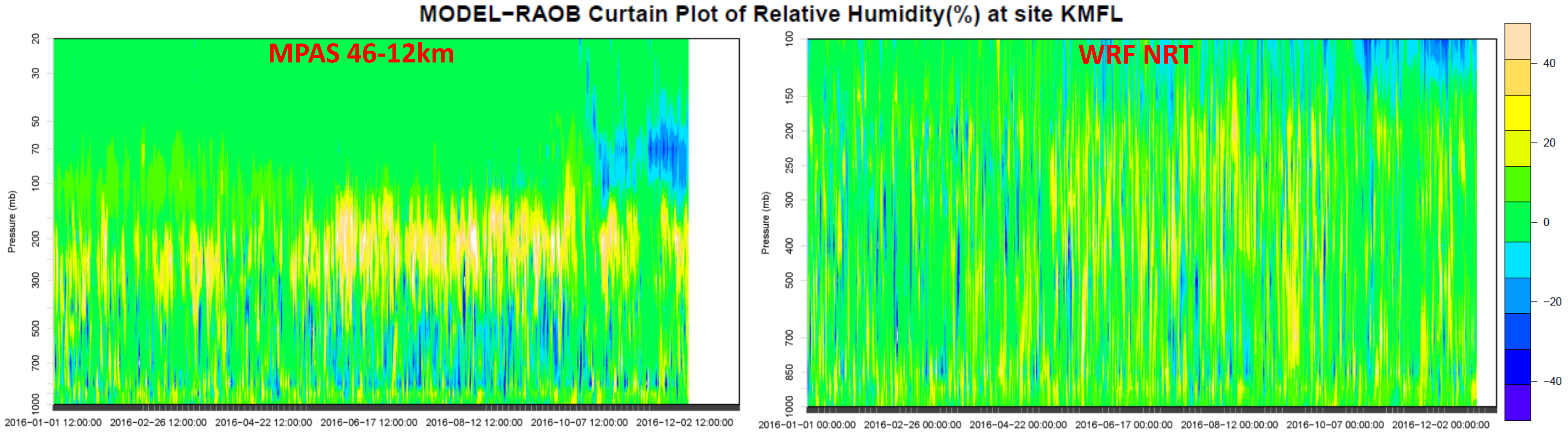


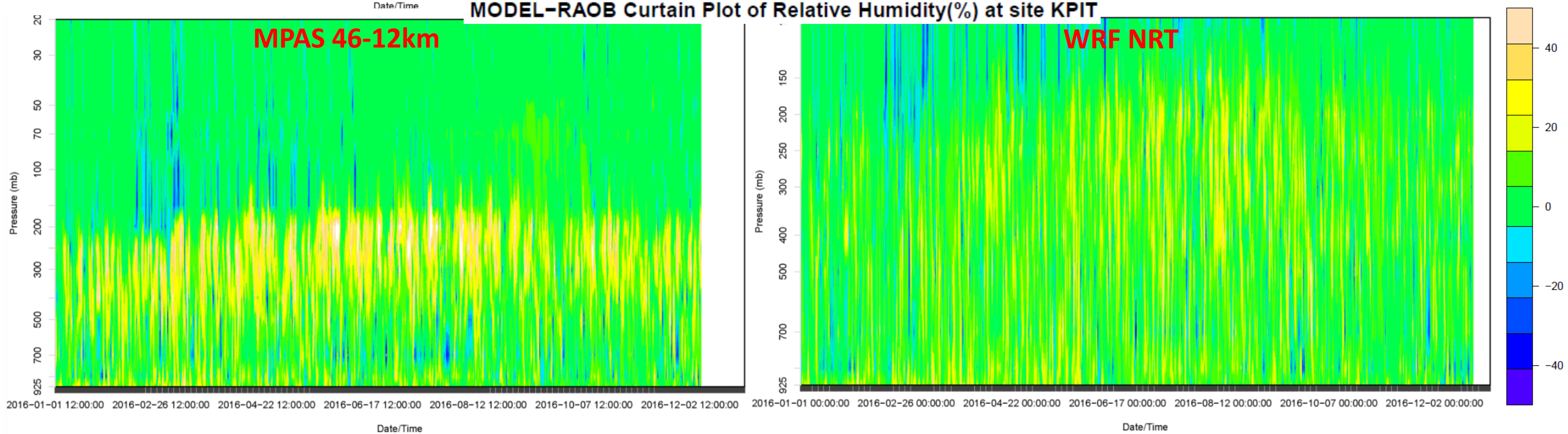
Diurnal Δ σ (Model-Obs) at CONUS BSRN Sites Jun-Sep 2016



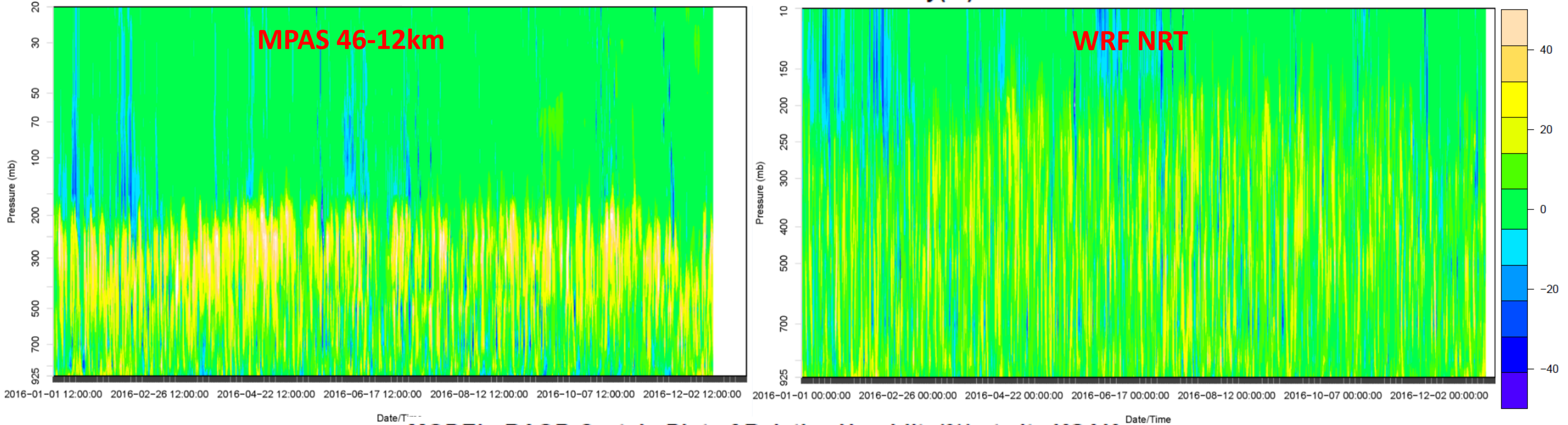

Relative Humidity RMSE(%)
0
3.3
6.6
9.9
13.2
16.5
19.8
23.1
26.4
MPAS 46-12km
Date: 20160101 to 20170101 --- Layer Average:1000−100mb
Relative Humidity
Relative Humidity
Relative Humidity
Pressure (mb)
MOD−OBS (%)
BIAS (%)
RMSE (%)


Relative Humidity RMSE(%)
0
3.3
6.6
9.9
13.2
16.5
19.8
23.1
26.4
WRF NRT
Date: 20160101 to 20170101 --- Layer Average:1000−100mb
Relative Humidity
Relative Humidity
Relative Humidity
Pressure (mb)
MOD−OBS (%)
BIAS (%)
RMSE (%)

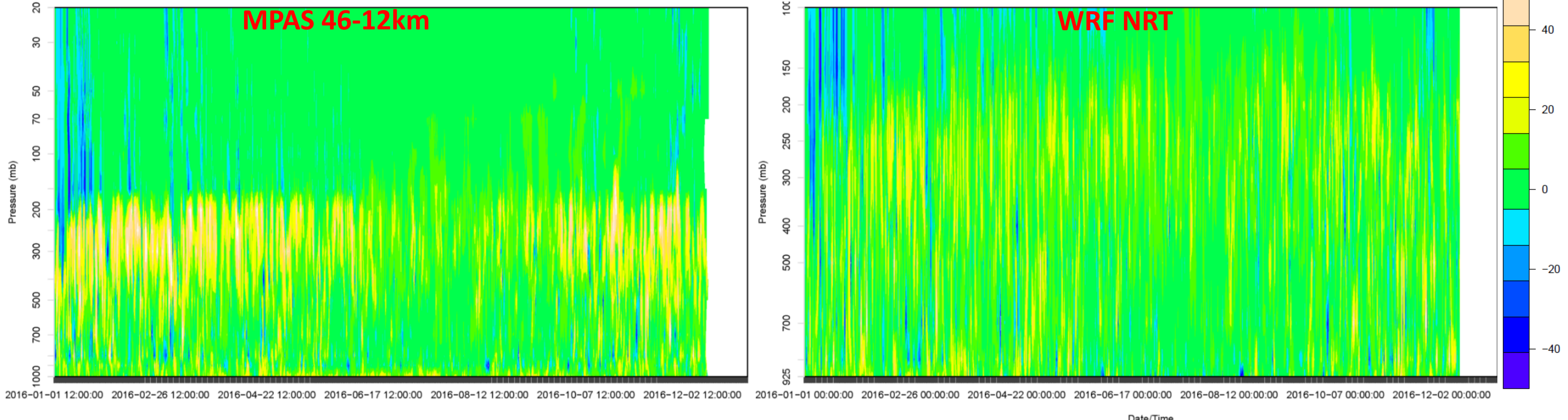

MODEL-RAOB Curtain Plot of Relative Humidity(%) at site KMFL
MPAS 46-12km
WRF NRT
Pressure (mb)
Date/Time
2016-01-01 12:00:00
2016-02-26 12:00:00
2016-04-22 12:00:00
2016-06-17 12:00:00
2016-08-12 12:00:00
2016-10-07 12:00:00
2016-12-02 12:00:00
2016-01-01 00:00:00
2016-02-26 00:00:00
2016-04-22 00:00:00
2016-06-17 00:00:00
2016-08-12 00:00:00
2016-10-07 00:00:00
2016-12-02 00:00:00
40
20
0
-20
-40


MODEL-RAOB Curtain Plot of Relative Humidity(%) at site KPIT
MPAS 46-12km
WRF NRT
Pressure (mb)
Date/Time
2016-01-01 12:00:00
2016-02-26 12:00:00
2016-04-22 12:00:00
2016-06-17 12:00:00
2016-08-12 12:00:00
2016-10-07 12:00:00
2016-12-02 12:00:00
2016-01-01 00:00:00
2016-02-26 00:00:00
2016-04-22 00:00:00
2016-06-17 00:00:00
2016-08-12 00:00:00
2016-10-07 00:00:00
2016-12-02 00:00:00
40
20
0
-20
-40

MODEL−RAOB Curtain Plot of Relative Humidity(%) at site KBIS

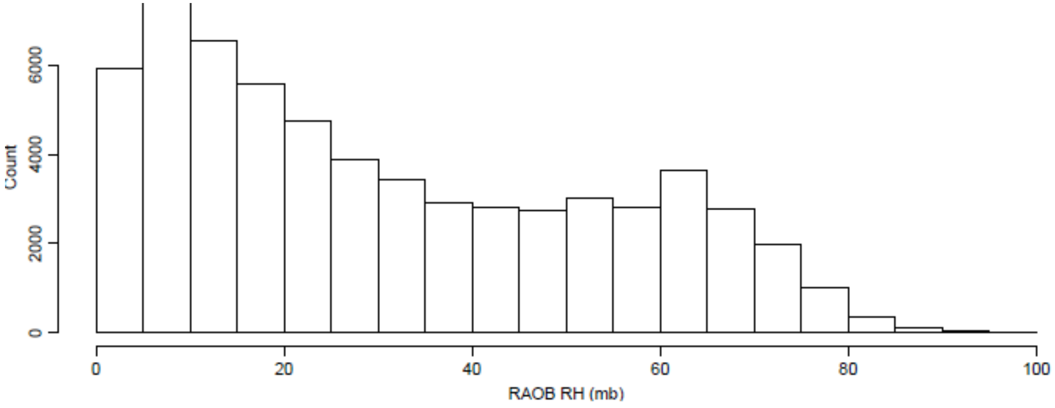


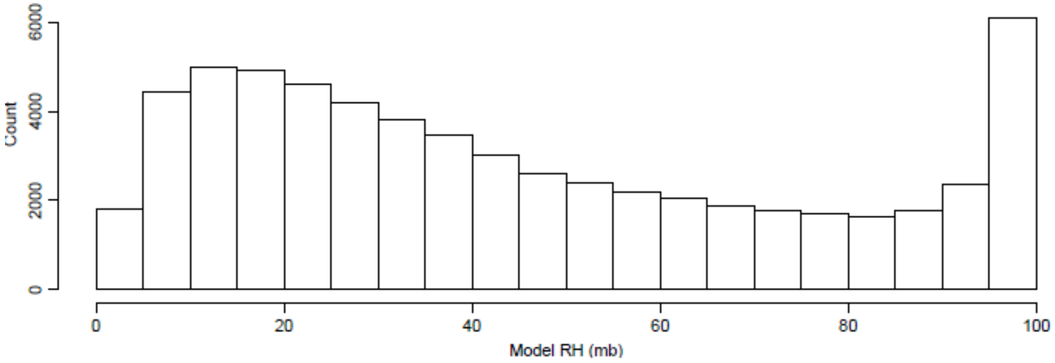
MODEL−RAOB Curtain Plot of Relative Humidity(%) at site KOAK

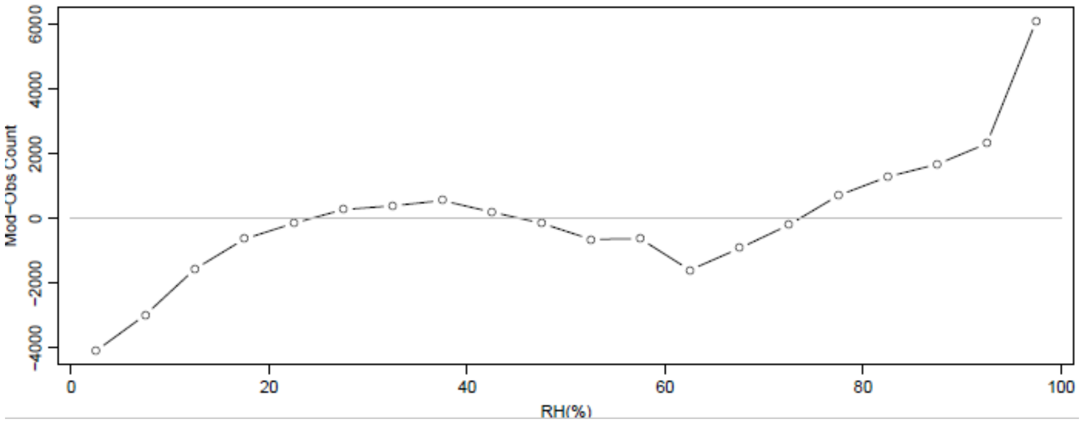


RH Distribution – All CONUS Sites – Jan-Dec 2016 – 300 mb

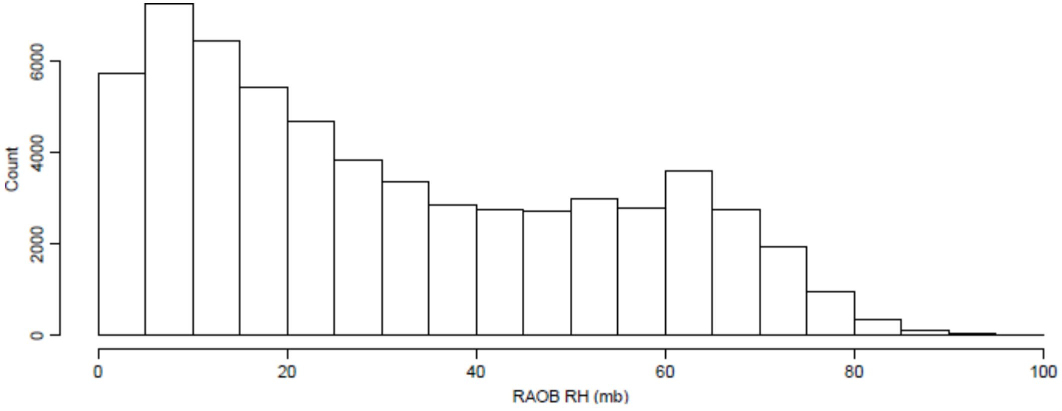
MPAS 46-12km

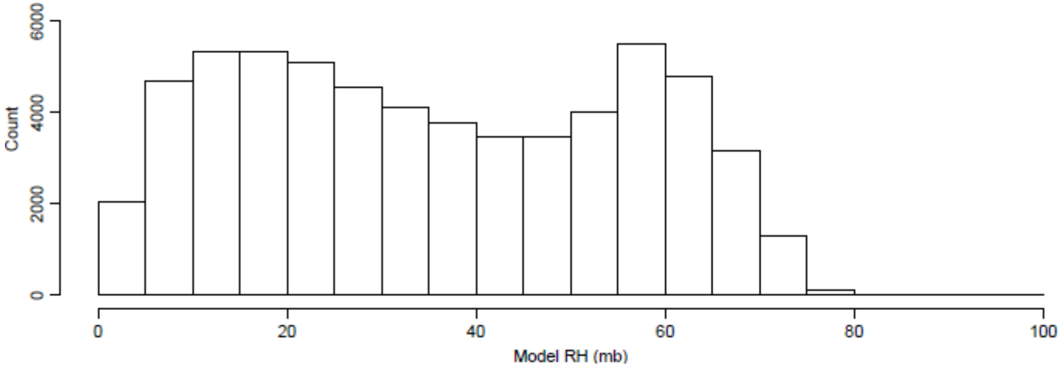


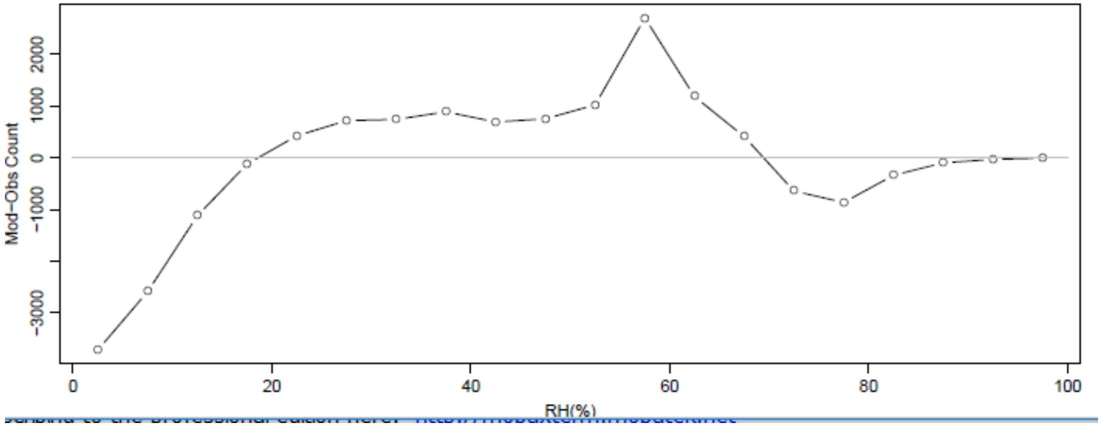




WRF NRT

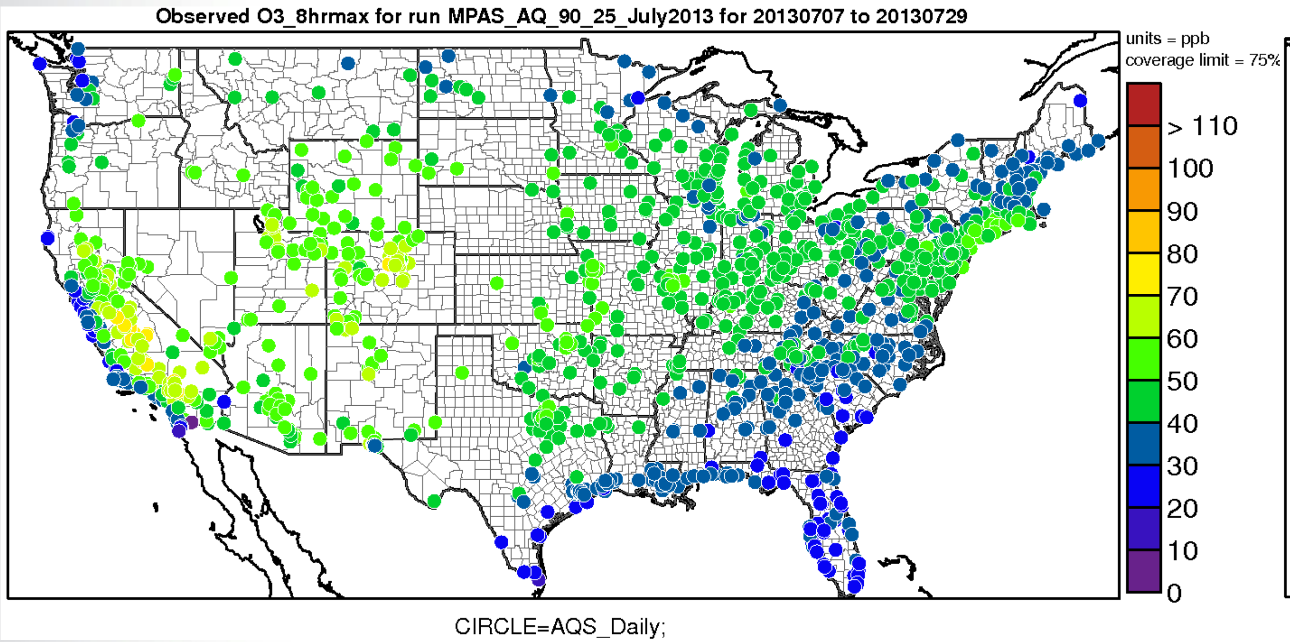




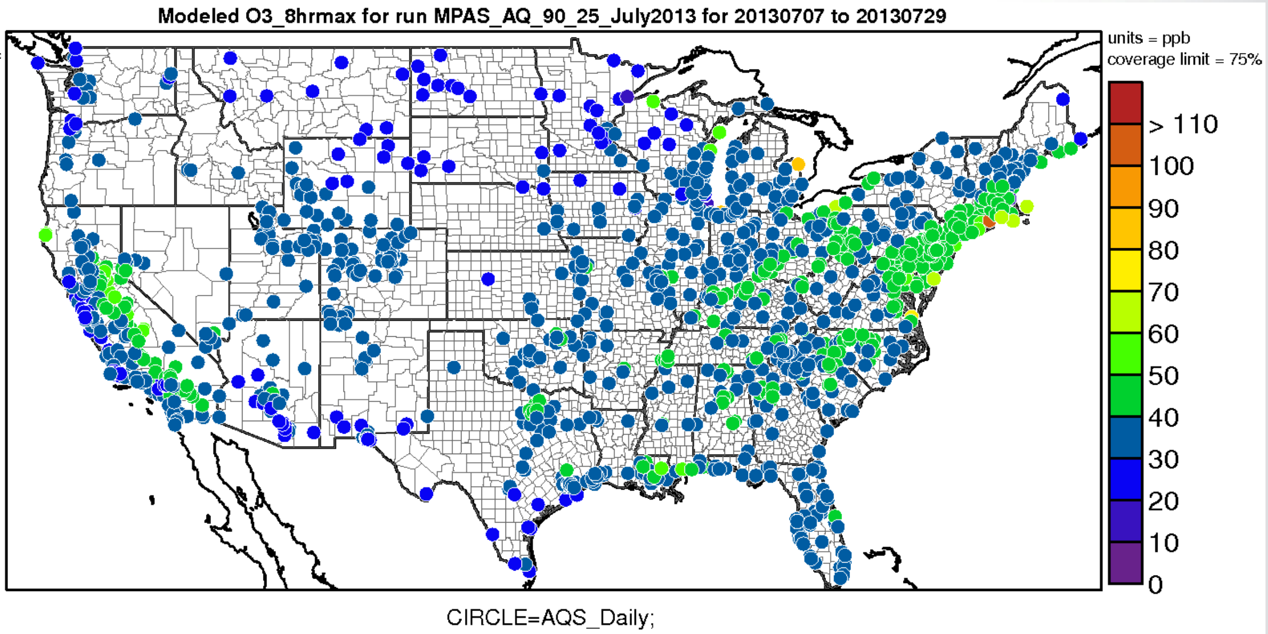


Preliminary ozone evaluation July 7-29, 2013

8-hr max O3 observations



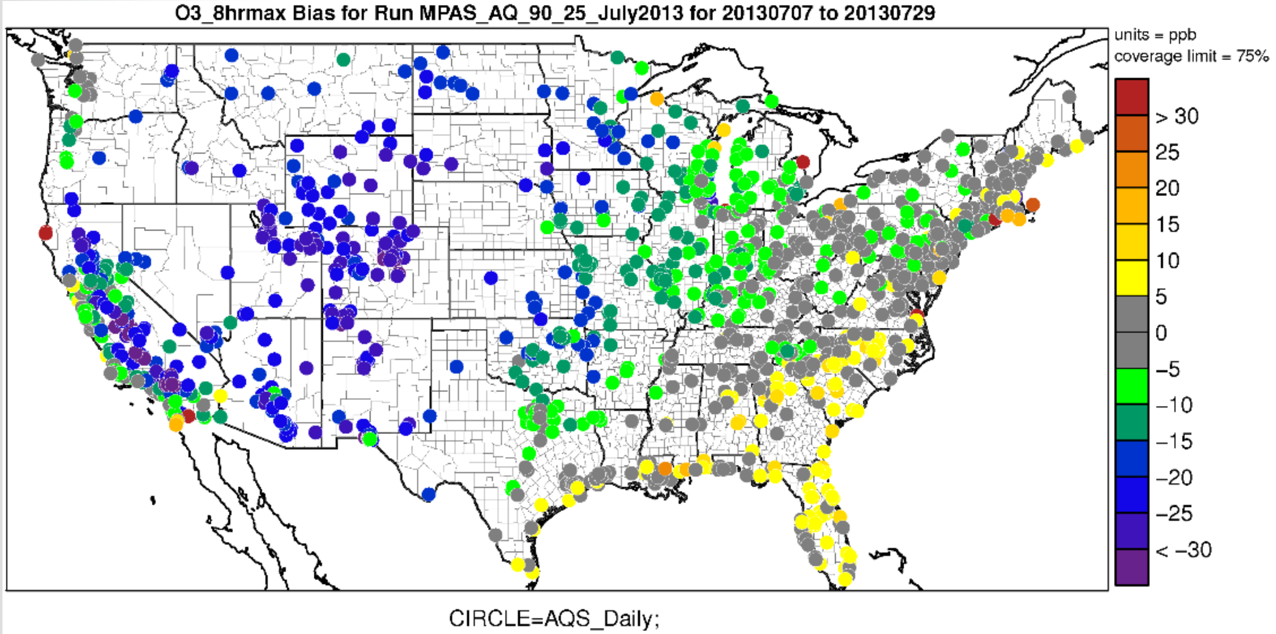
8-hr max O3 MPAS-CMAQ



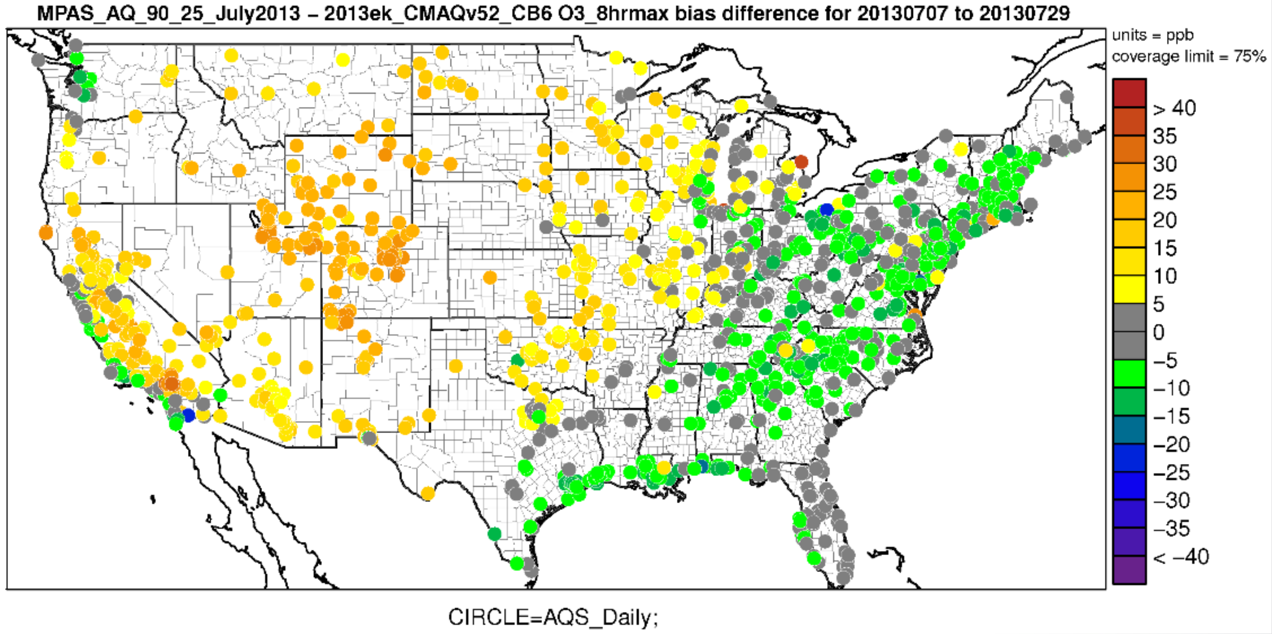
- Pattern of model ozone concentration is similar to observations in eastern U.S.
- Simulated ozone is too low in Mt West (CA, NV, CO) and central US

Max 8hr Ozone – July 7 - 29

MPAS-CMAQ Bias



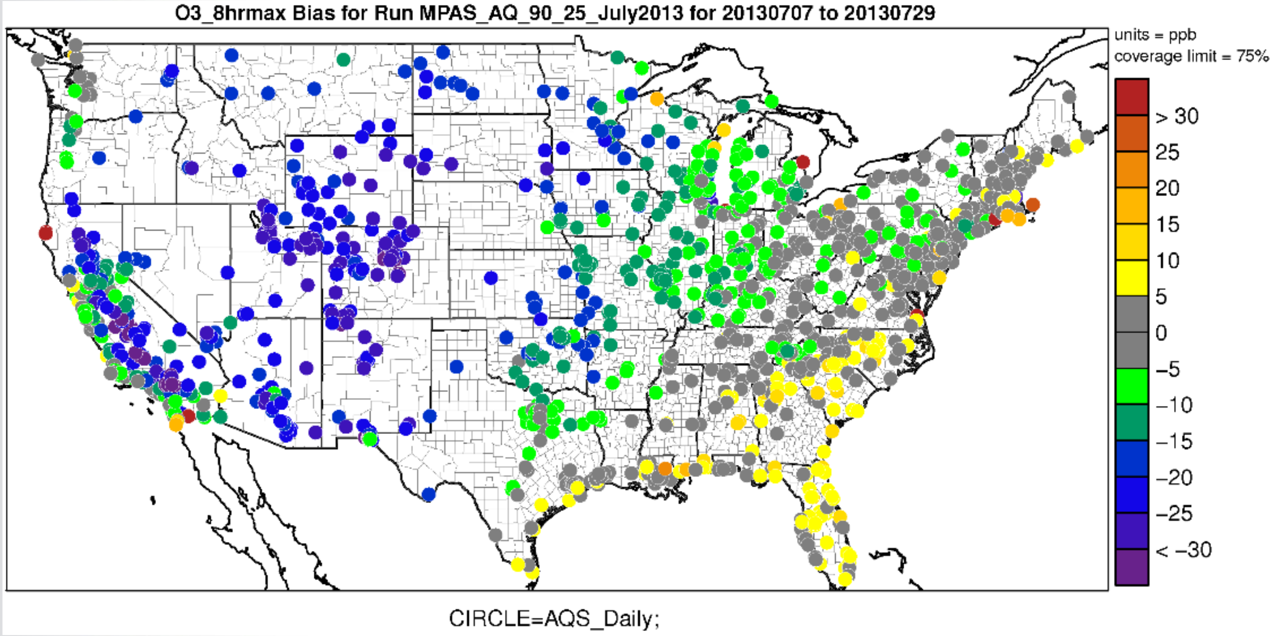
Bias difference (MPAS-CMAQ – WRF-CMAQ)



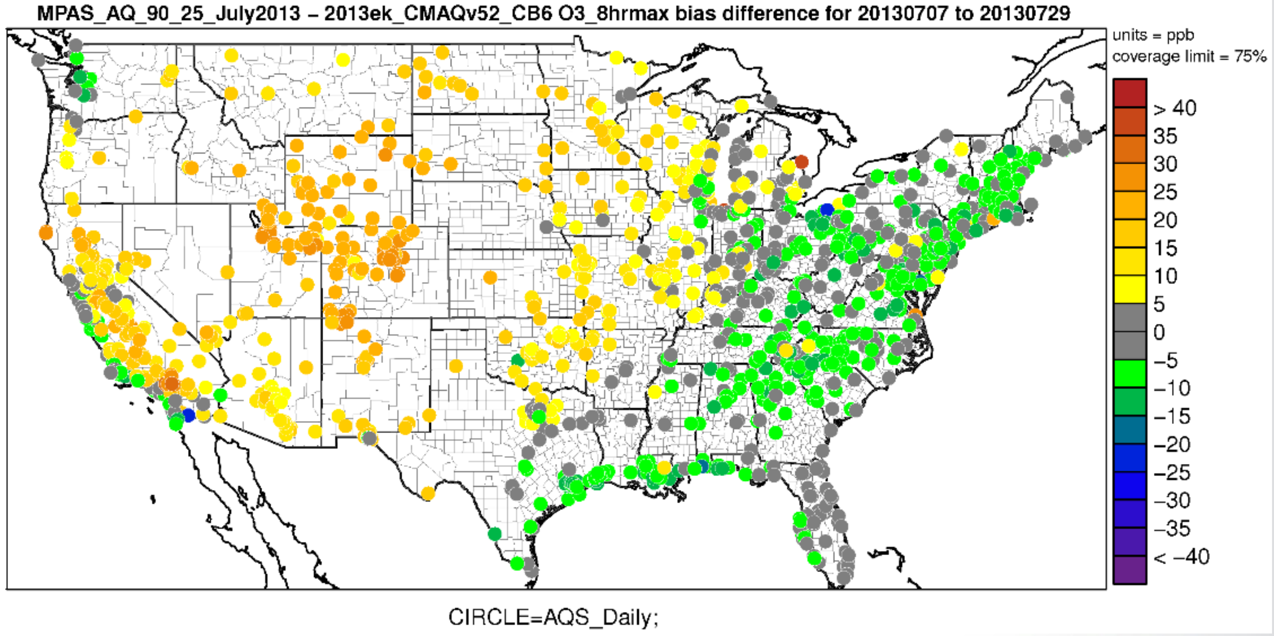
- MPAS-CMAQ is relatively un-biased in East but low biased in west
- Compared to WRF-CMAQ, MPAS-CMAQ has slightly lower bias in East but much greater bias in West

Max 8hr Ozone – July 7 - 29

MPAS-CMAQ Bias



Bias difference (MPAS-CMAQ – WRF-CMAQ)



- MPAS-CMAQ is relatively un-biased in East but low biased in west
- Compared to WRF-CMAQ, MPAS-CMAQ has slightly lower bias in East but much greater bias in West