EPA

www.epa.gov

Progress on Implementing Additional Physics Schemes into MPAS-A v5.1 for Next Generation Air Quality Modeling

Jerold A. Herwehe, Robert C. Gilliam, O. Russell Bullock Jr., Jonathan E. Pleim, and Hosein Foroutan

Computational Exposure Division, National Exposure Research Laboratory, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, USA

Jerold A. Herwehe | herwehe.jerry@epa.gov | 919-541-0166

1. Objective and Background

A team of U.S. Environmental Protection Agency (EPA) scientists are developing a next generation air quality modeling system employing the Model for Prediction Across Scales – Atmosphere (MPAS-A) as its meteorological foundation. Several preferred physics schemes and options available in the Weather Research and Forecasting (WRF) model are regularly used by the EPA with the Community Multiscale Air Quality (CMAQ) model to conduct retrospective air quality simulations. These include the Pleim-Xiu (PX) land surface model with fractional land use for a 40-class National Land Cover Database (NLCD40), the Pleim surface layer (PSL), the Asymmetric Convective Model 2 (ACM2) planetary boundary layer scheme, the Kain-Fritsch (KF) convective parameterization with subgrid-scale cloud feedback to the radiation schemes and a scale-aware convective time scale, and analysis nudging four-dimensional data assimilation (FDDA). All of these physics modules and options were first implemented by the EPA into MPAS-A v4.0, tested, and evaluated (please see the presentations of R. Gilliam and R. Bullock at this workshop). Since the release of MPAS v5.1 in mid-May 2017, these EPA enhancements have now been implemented into the MPAS-A v5.1 code. Preliminary evaluation of the initial tests are presented here, focusing on model sensitivity to a few of the KF updates.

2. Approach

Test simulations of July 2013 were conducted on a global 92-25 km variable resolution mesh with the higher resolution cells centered over the contiguous United States (CONUS). Driving fields for the FDDA and soil nudging were provided by NOAA/NCEP's GDAS/FNL, GFS, and RUC analyses. Results from the MPAS-A v5.1 sensitivity simulations utilizing the added EPA physics schemes were evaluated against observations available from NCEP's Meteorological Assimilation Data Ingest System (MADIS) and PRISM data.

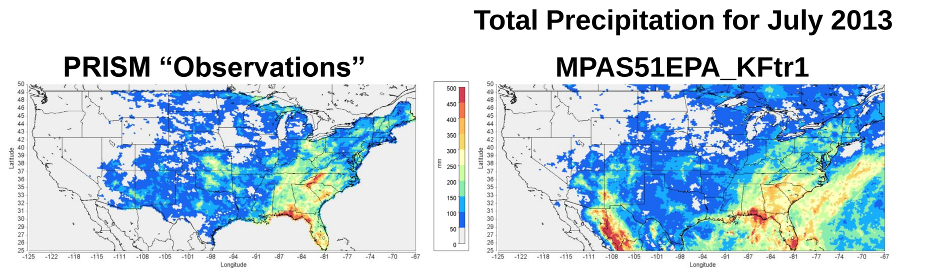
Simulations presented here are labeled as follows:

1) **MPAS51rel** = unmodified released code version of MPAS-A v5.1 using Noah LSM, M-O sfc. layer, YSU PBL, KF CPS (default from WRF v3.2.1)
2) **MPAS51EPA_KFtr1** = EPA-modified MPAS-A v5.1 using all added EPA enhancements and recent KF (based on WRF v3.8.1) with trigger 1 and scale-aware convective time scale, but feedback to radiation disabled
3) **MPAS51EPA_KFtr1f** = same as 2) but KF feedback to radiation enabled
4) **MPAS51EPA_KFtr2** = same as 2) but using KF trigger 2
5) **MPAS51EPA_KFtr2f** = same as 4) but KF feedback to radiation enabled

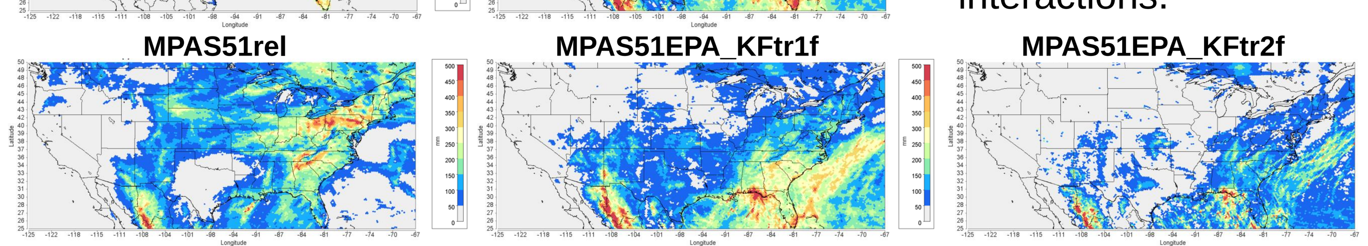
Other options used by all simulations included RRTMG SW and LW radiation schemes (without O_3 climatology), WSM6 microphysics, grid-scale cloud fraction based on relative humidity, SST updates without fractional sea-ice, and no gravity wave drag over orography.

3.1. Results: Precipitation

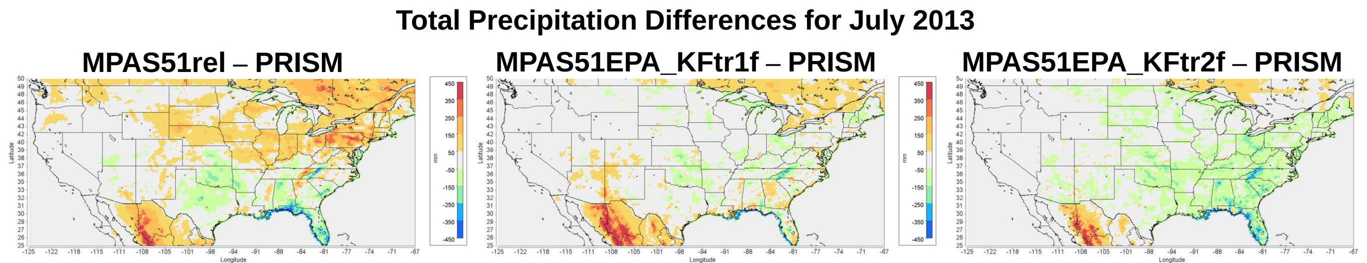
Total Precipitation for July 2013



Default KF typically overestimates rainfall due to a lack of cumulus-radiation interactions.



Total Precipitation Differences for July 2013

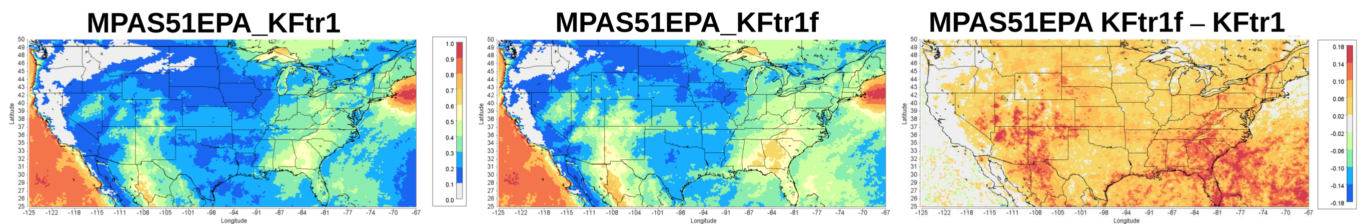


[**Note:** Please disregard differences in Mexico and Canada due to lack of PRISM data there.]

MPAS51rel lacks FDDA, so the general precipitation pattern differs significantly from observations. With FDDA, the other simulations produce patterns similar to PRISM, though selecting KF trigger 2 tends to underestimate the monthly precipitation. Using KF trigger 1 with feedback to radiation (MPAS51EPA_KFtr1f) produces the best match to PRISM.

3.2. Results: Cloudiness

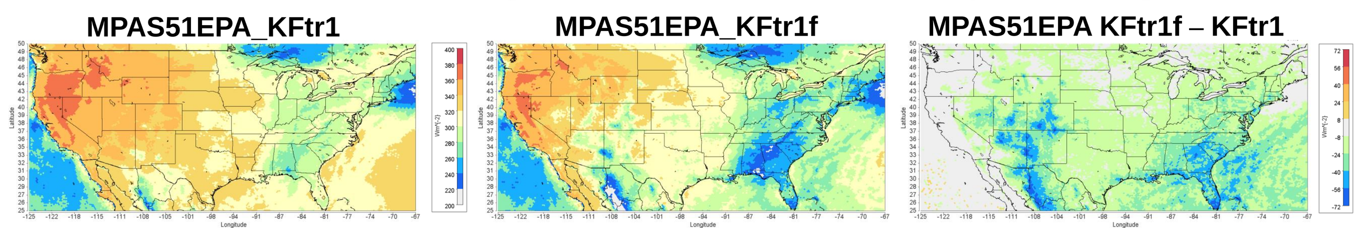
Column-Integrated Total Cloud Fraction and Difference, July 2013 Average



Sections 3.2-3.5 examine the effects of enabling cumulus-radiation interactions (i.e., KF feedback) with KF trigger 1 in MPAS-A, while keeping all other model options the same. Resolved or grid-scale cloud fraction is based on relative humidity (as shown for KFtr1). The increase in mean monthly cloudiness when including subgrid-scale cumulus clouds is shown in the KFtr1f and difference figures. For July 2013, average total cloudiness increased nearly everywhere, including by up to 18% in the Southwest and Southeast U.S. where convection dominated.

3.3. Results: Shortwave Radiation

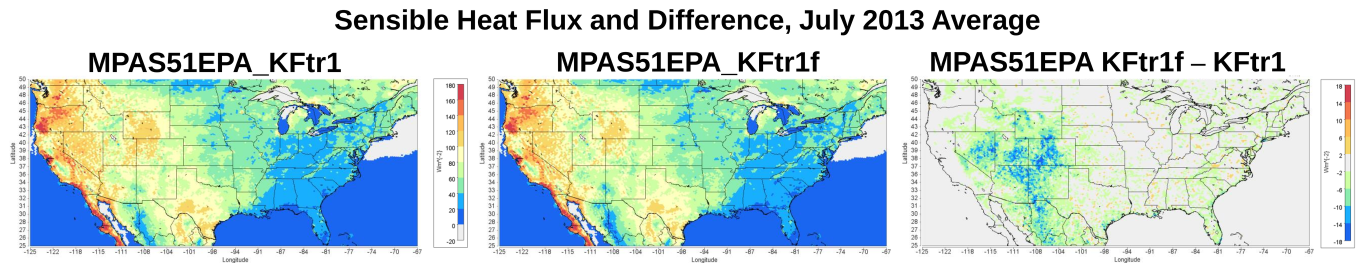
Shortwave Downwelling at the Surface and Difference, July 2013 Average



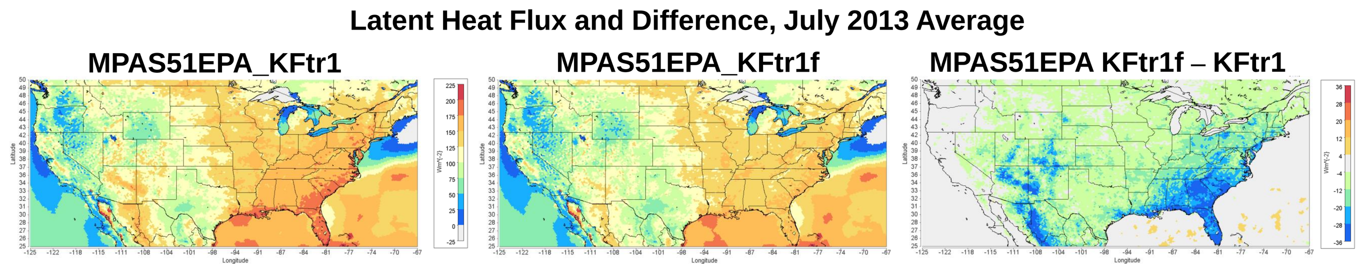
As expected, accounting for the subgrid-scale cumulus cloudiness in addition to the normal resolved cloudiness reduced the average July 2013 shortwave radiation reaching the surface by nearly 20% in the Southwest and Southeast U.S., with an average reduction of at least 8 W m^{-2} over most of the U.S. The pattern for this decrease in shortwave downwelling roughly corresponds to the pattern of increased cloudiness shown in Section 3.2. Note that all temporal averages presented here were calculated over all hours (day and night), which reduces the effect of the KF feedback when compared to the shortwave radiation reduction that might be seen in a typical afternoon, for example.

3.4. Results: Sensible & Latent Heat Fluxes

Sensible Heat Flux and Difference, July 2013 Average



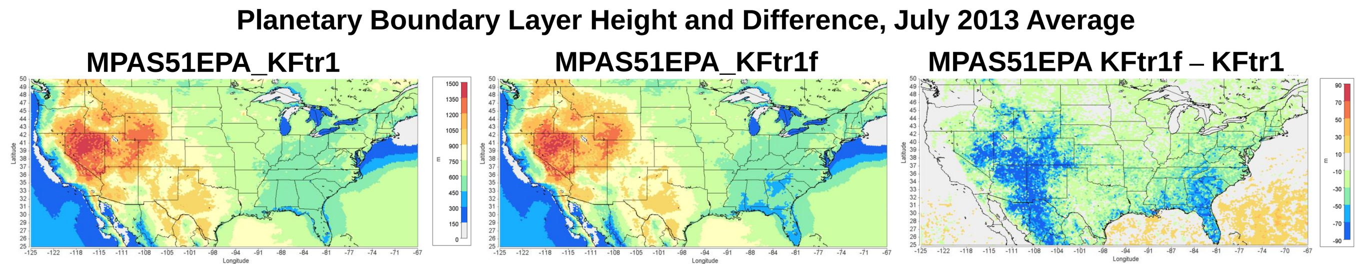
Latent Heat Flux and Difference, July 2013 Average



Impacts from enabling KF feedback were also significant for the surface energy budget. The relatively dry ground of the Intermountain West was a factor for the largest reduction in sensible heat flux (HFX) when cumulus clouds were added to the July 2013 simulation, with smaller mixed effects on HFX in the more moist eastern U.S. Areas with more precipitation in the Southwest and Southeast saw average latent heat flux reductions of nearly 25%, along with general reductions of at least 4 W m^{-2} elsewhere in the U.S.

3.5. Results: Planetary Boundary Layer Hgt.

Planetary Boundary Layer Height and Difference, July 2013 Average

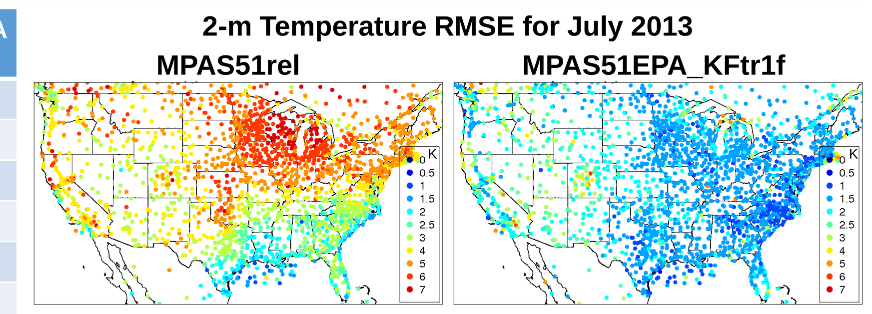


Enabling KF feedback to the radiation schemes also reduced the average planetary boundary layer height (HPBL), which could lead to greater simulated pollutant concentrations due to less dilution of near-surface primary emissions and secondary pollutants. The KFtr1f – KFtr1 HPBL difference plot shows small reductions generally everywhere, but with 10% to nearly 20% reductions over the southern Intermountain West and the Southeast. PBL height is an important factor in assessing human exposure to pollutants. Evaluation of the HPBL reduction over an average diurnal cycle will be conducted due to the diurnal behavior of most pollutants.

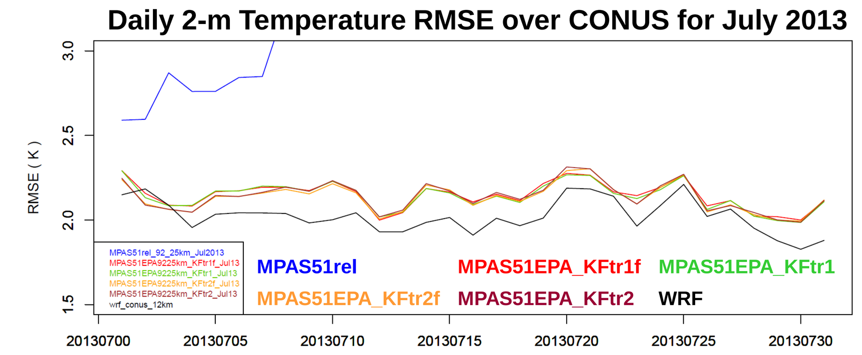
3.6. Results: 2-m Temperature

Statistic for T_{2m}	MPAS51rel	MPAS51EPA KFtr1f
RMSE (K)	4.692	2.150
MAE (K)	3.517	1.599
NME (%)	6.952	3.197
MB (K)	0.632	0.002
NMB (%)	1.249	0.004
Corr.	0.694	0.932

2-m Temperature RMSE for July 2013



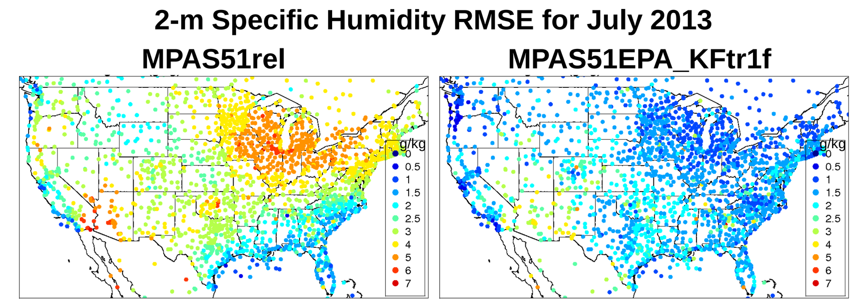
Daily 2-m Temperature RMSE over CONUS for July 2013



Analyses in Sections 3.6-3.8 utilized AMET2.0. Here, T_{2m} statistics are much improved when using all of the EPA enhancements compared to the release version of MPAS v5.1.

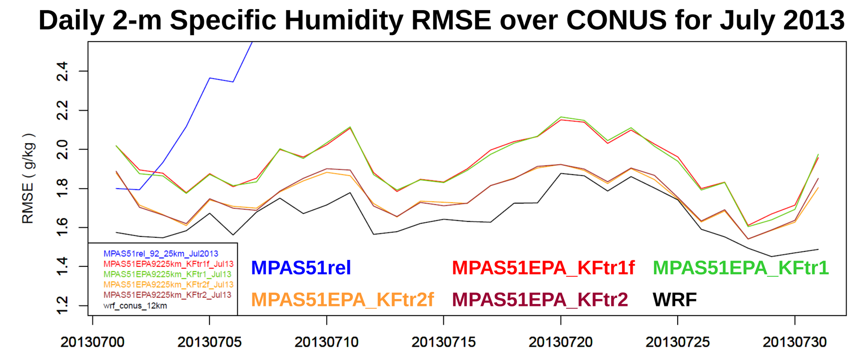
3.7. Results: 2-m Specific Humidity

2-m Specific Humidity RMSE for July 2013



Statistic for Q_{2m}	MPAS51rel	MPAS51EPA KFtr1f
RMSE (g/kg)	3.525	1.924
MAE (g/kg)	2.690	1.427
NME (%)	9.509	4.986
MB (g/kg)	0.355	0.219
NMB (%)	1.255	0.764
Corr.	0.640	0.900

Daily 2-m Specific Humidity RMSE over CONUS for July 2013

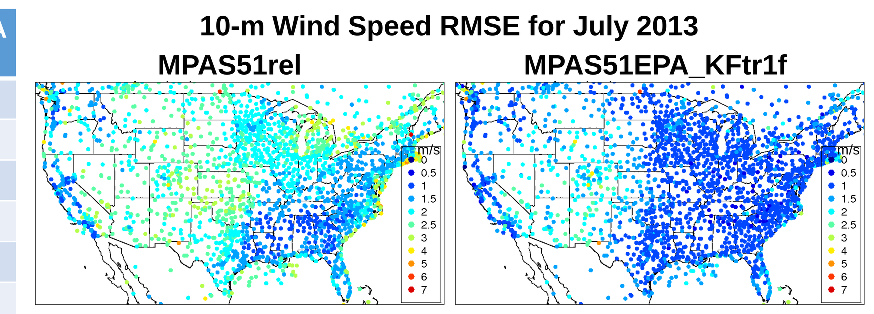


Like T_{2m}, Q_{2m} has a much lower RMSE with the EPA modifications than the default MPAS-A simulation. MPAS51rel would likely benefit from FDDA. WRF simulated on a 12-km grid.

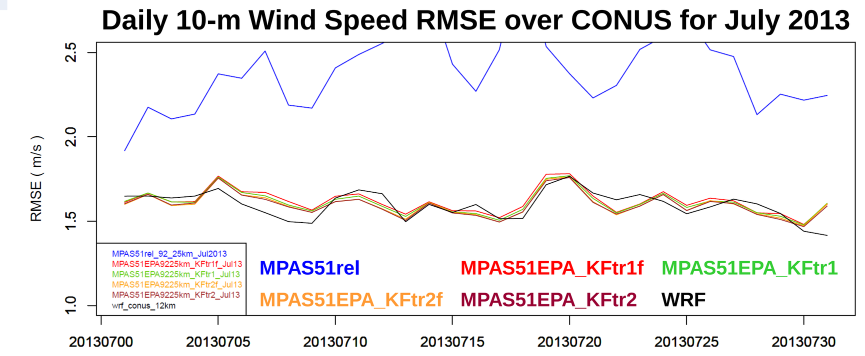
3.8. Results: 10-m Wind Speed

Statistic for WS_{10m}	MPAS51rel	MPAS51EPA KFtr1f
RMSE (m/s)	2.412	1.622
MAE (m/s)	1.823	1.164
NME (%)	2.060	1.316
MB (m/s)	0.300	-0.137
NMB (%)	0.339	-0.154
Corr.	0.242	0.578

10-m Wind Speed RMSE for July 2013



Daily 10-m Wind Speed RMSE over CONUS for July 2013



WS_{10m} also improved using the EPA enhancements. As with T_{2m}, the "MPAS51EPA" runs generally agree with each other, and even with 12-km WRF in this case.

4. Conclusions

- The following EPA physics enhancements and options were successfully implemented into MPAS-A v5.1: PX LSM with NLCD40 fractional land use and MODIS-based initialization of deep soil moisture; PSL; ACM2 PBL; KF v3.8.1 with feedback to radiation, scale-aware convective time scale, and extended lookup table; FDDA analysis nudging; a custom vertical grid.
- These EPA enhancements improved statistical agreement with MADIS obs.
- KF trigger 1 and feedback reproduced July 2013 PRISM precipitation best.
- Enabling KF feedback to radiation exhibited the expected impacts to associated MPAS-A model variables, mainly by reducing the solar radiation shining on wet ground under precipitating convective clouds.

5. Future Plans

- Test and evaluate the EPA-modified MPAS-A v5.1 at finer resolutions, preferably at least on the 46-12 km variable mesh to allow compatible comparisons over CONUS to WRF on a 12-km grid.
- After more thorough testing and evaluation, source code for the EPA physics enhancements will be submitted back to the MPAS GitHub repository for future use by the MPAS modeling community.
- The EPA team will finish implementing a chemistry framework for coupling CMAQ modules to MPAS-A to build a global online coupled next generation air quality model (please see the H. Foroutan presentation).