Evaluation of Developments Toward a Multiscale Kain-Fritsch Convection Parameterization in WRF

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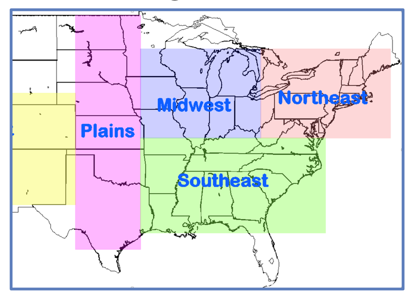
1. Background

Within the Weather Research and Forecasting model (WRF), enhancements are being developed for the Kain-Fritsch (KF) convection parameterization to allow its smooth application across scales down to ~1 km grid spacing (see the associated Alapaty et al. presentation at this conference). The new multiscale KF (MSKF) scheme includes new formulations and physics updates for the convective adjustment timescale, the entrainment of environmental air, the fallout of condensates from updrafts, the elimination of precipitation "double counting" when utilizing both grid-scale and subgrid-scale cloud formulations within a grid cell, and the impact of convective updrafts and downdrafts on grid-scale vertical velocity. These new developments build upon the implementation of KF-RRTMG radiation interactions into WRF (Alapaty et al., 2012; Herwehe et al., 2014), which has been included as an option beginning with the release of WRF v3.6.

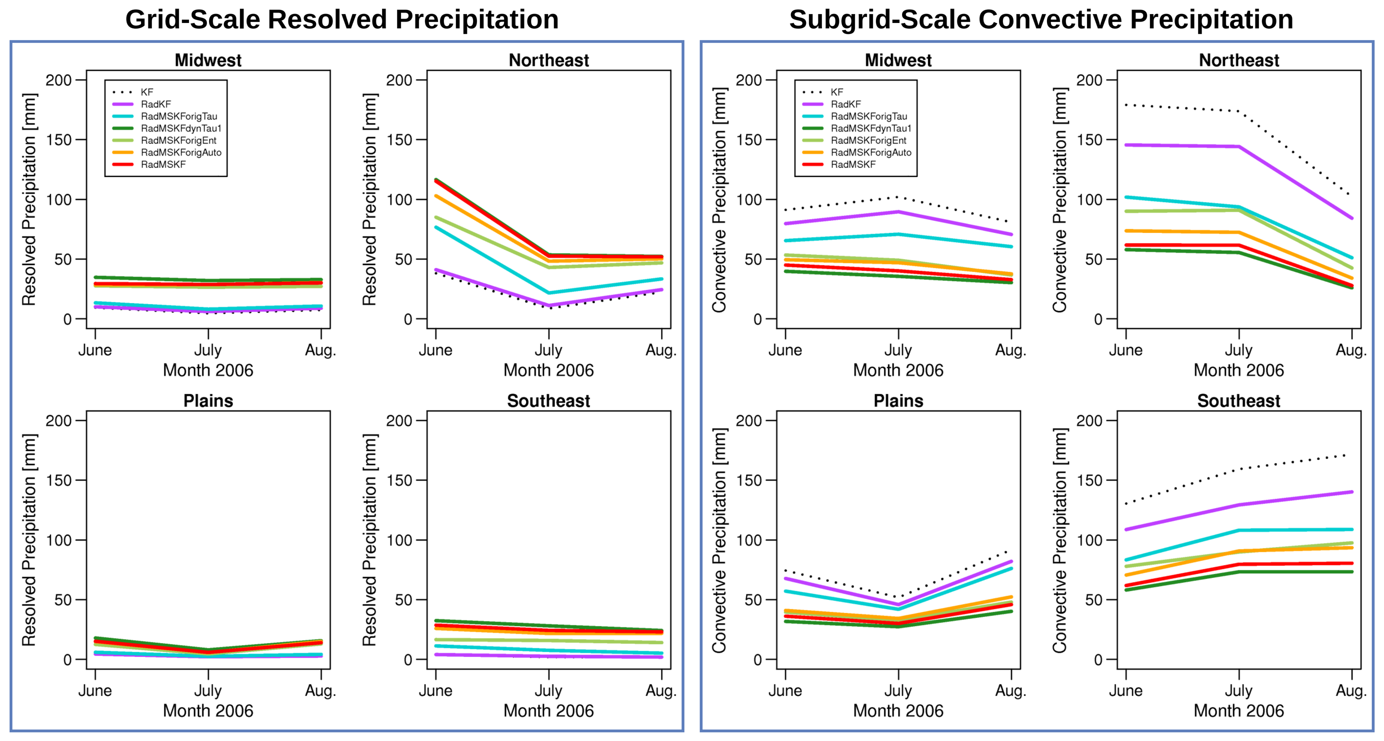
2. Approach

Three-month summer season (June-August 2006) simulations were conducted with various KF configurations using WRF v3.6.1 for a sensitivity study of impacts on regional climate parameters such as surface precipitation (grid- and subgrid-scale), cloudiness, temperature, radiation, and surface fluxes. All simulations used some form of KF convection (standard and with modifications), WSM6 microphysics, RRTMG SW and LW radiation, Noah land-surface model, YSU PBL scheme, 34 layers up to a 50 hPa domain top, covering the eastern two-thirds of the U.S. with 12 km horizontal grid spacing. Initial and boundary conditions came from NCEP-DOE AMIP-II Reanalysis (R-2) data, which also provided fields for FDDA analysis nudging of wind, temperature, and moisture above the PBL. Note that temporal averages shown in this study include all hours (day and night). Monthly time series were computed for land points only and averaged over each of the four regions shown at right (→). Evaluation was conducted via comparison with the North American Regional Reanalysis (**NARR**), the Climate Forecast System Reanalysis (**CFSR**), and the Parameter-elevation Regressions on Independent Slopes Model (**PRISM**) data sets. Except for the standard KF simulation, all other simulations used the KF-RRTMG (cumulus-radiation) interactions (denoted by the **Rad** prefix). Experiments with MSKF started with the full updated form, then downgraded individual components to test their effect. Nomenclature for the simulations in this study: **KF** (standard KF), **RadKF** (with KF-RRTMG interactions), **RadMSKForigTau** (with original adjustment timescale, τ), **RadMSKFdynTau1** (with first dynamically adjusted τ), **RadMSKForigEnt** (with original entrainment), **RadMSKForigAuto** (with original autoconversion), and **RadMSKF** (the multiscale KF, or MSKF, with all the latest updates).



3.1. Results: Precipitation

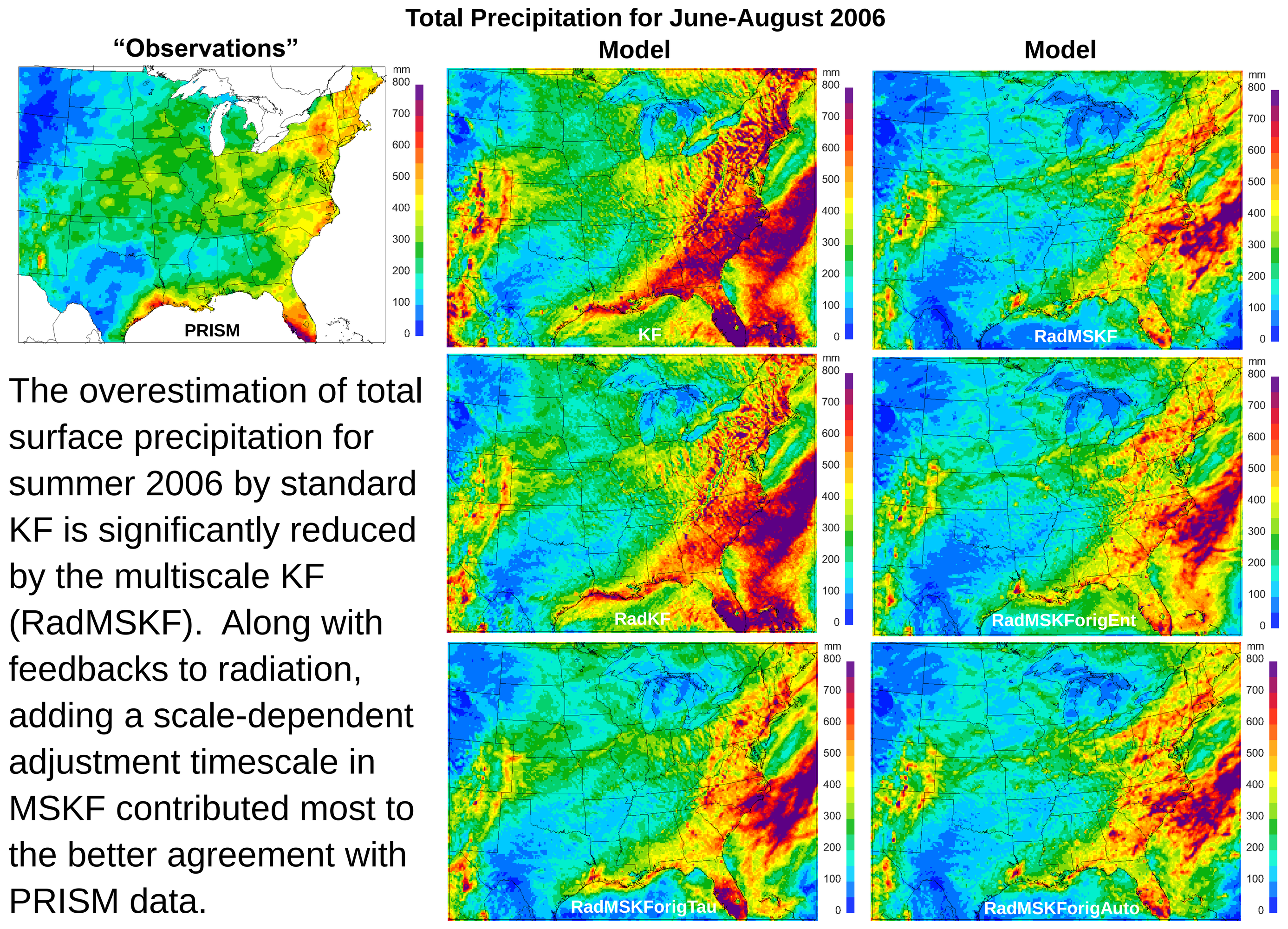
Grid-Scale Resolved Precipitation / Subgrid-Scale Convective Precipitation



In addition to illustrating a regional dependence, these time series also reveal the different sensitivities of the resolved and convective precipitation to the various KF configurations. RadMSKF, RadMSKFdynTau1, and RadMSKForigAuto reapportion the greatest amounts of precipitation from the convective to the resolved scales. Compared with the standard KF case, significant reductions of over 60% are seen in regionally-averaged monthly convective precipitation for the RadMSKF case in the Northeast (NE) and Southeast (SE) regions.

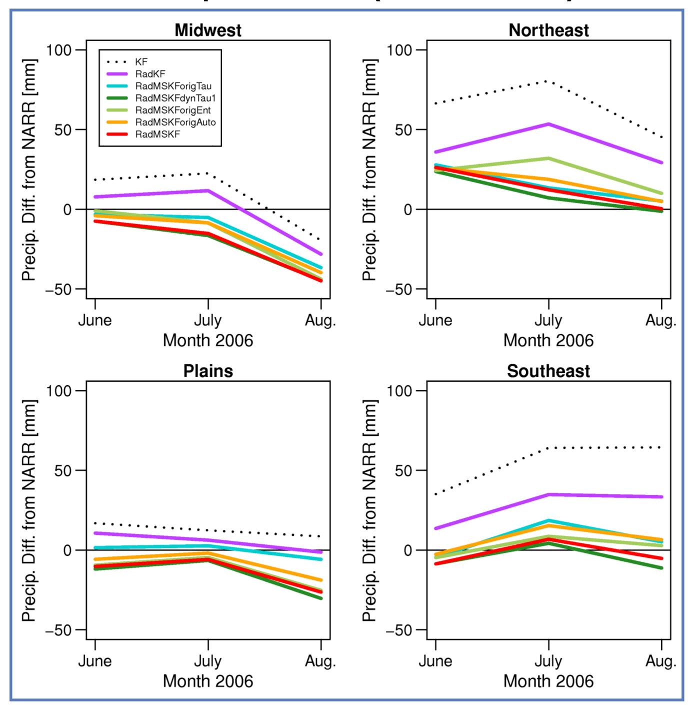
3.1. Results: Precipitation (cont'd)

Total Precipitation for June-August 2006



The overestimation of total surface precipitation for summer 2006 by standard KF is significantly reduced by the multiscale KF (RadMSKF). Along with feedbacks to radiation, adding a scale-dependent adjustment timescale in MSKF contributed most to the better agreement with PRISM data.

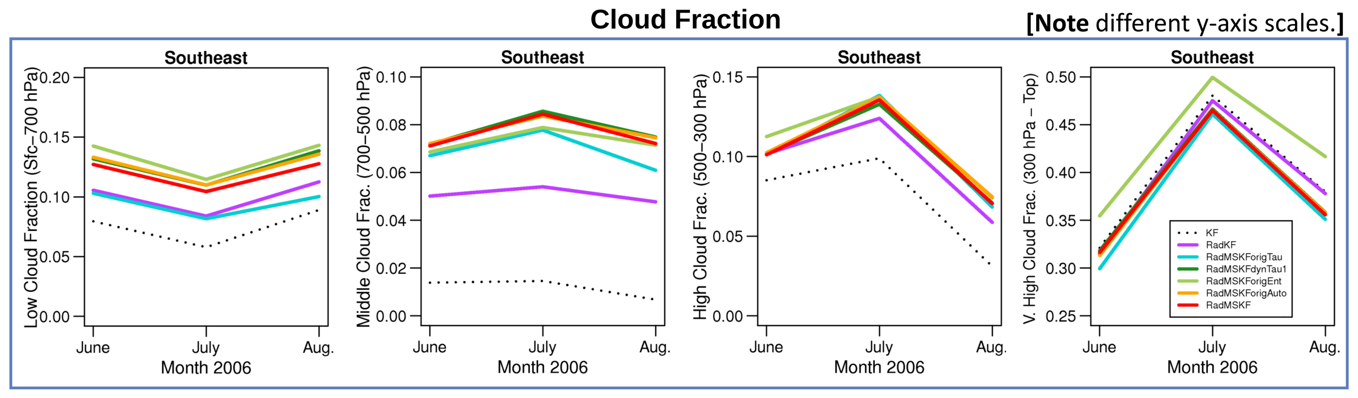
Precipitation Bias (Model – NARR)



The monthly time series of precipitation bias compared with NARR show that using some form of MSKF produces the smallest bias for the NE and SE, but the MSKF cases create a dry bias in the Midwest (MW) and Plains states (PL). This may be due to the low level jet, wind shear, and convergence (processes not treated in a convective parameterization) dominating the dynamics in the MW and PL, while pure convection from surface heating often drives summer dynamics in the SE.

3.2. Results: Cloudiness

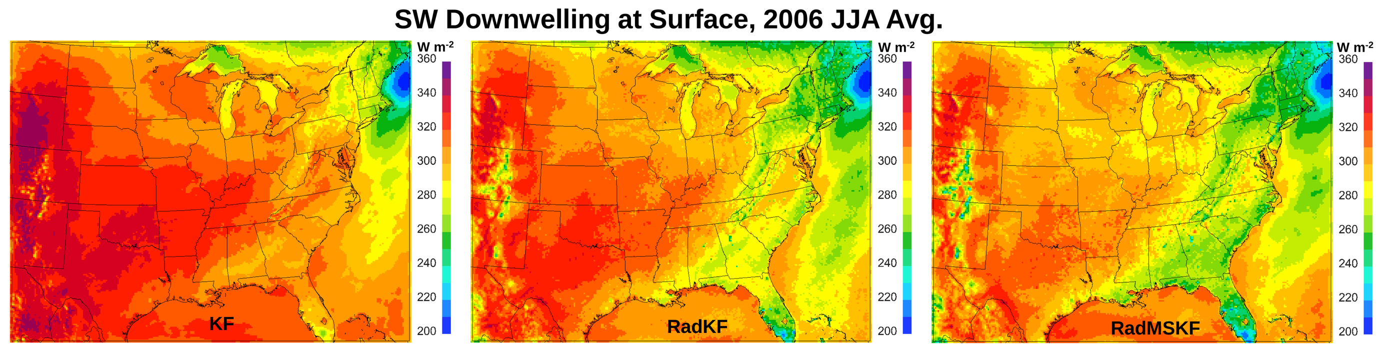
Cloud Fraction [**Note** different y-axis scales.]



In the SE, the MSKF cases generally produce the most cloudiness for the low, middle, and high layers, but a slight decrease in very high clouds over standard KF (except for the RadMSKForigEnt case with the original entrainment).

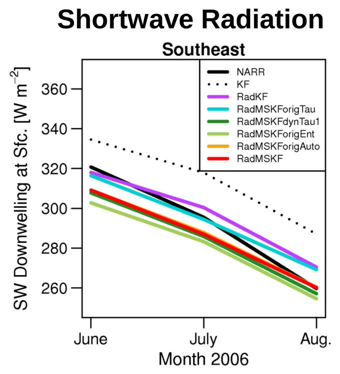
3.3. Results: Shortwave Radiation

SW Downwelling at Surface, 2006 JJA Avg.



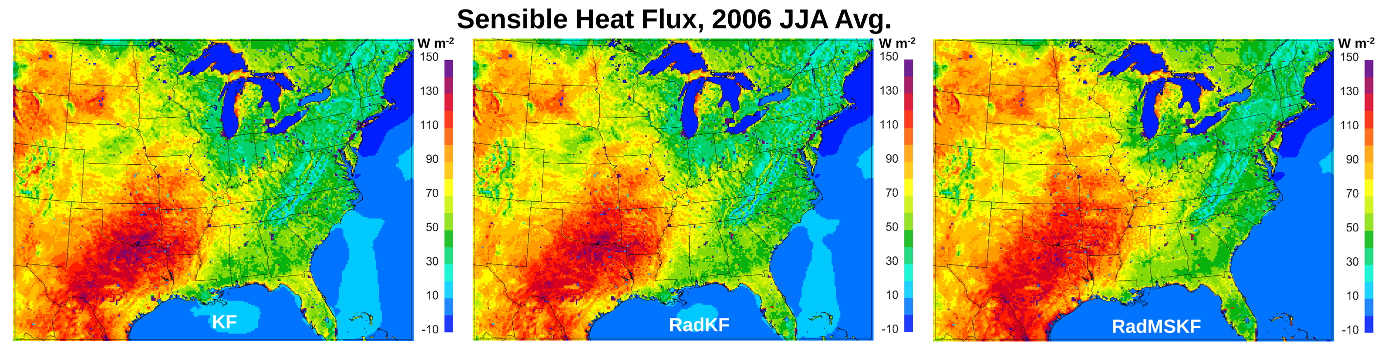
Accounting for subgrid-scale cloudiness in RadKF causes significant reductions in the shortwave (SW) radiation reaching the surface when compared with the standard KF. The additional cloudiness from the multiscale enhancements to KF further reduces downwelling SW (RadMSKF case). Despite computing these seasonal SW averages over all hours (day and night), reductions of 40 W m^{-2} (~14%) can be seen in some areas. The monthly time series for the SE shows that the 8-11% decrease in SW for RadMSKF compared to standard KF is due to the cumulus-radiation interactions (RadKF) and the dynamic τ (e.g., RadMSKFdynTau1).

Shortwave Radiation

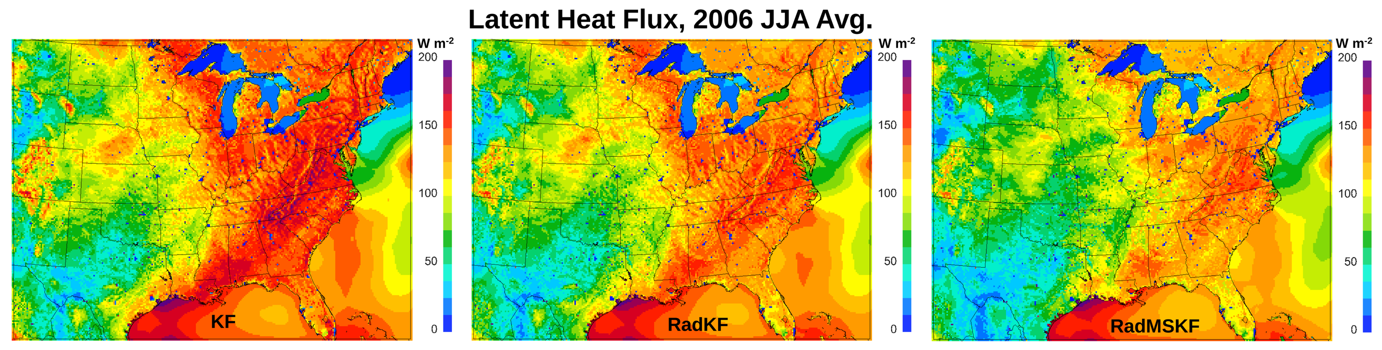


3.4. Results: Sensible and Latent Heat Fluxes

Sensible Heat Flux, 2006 JJA Avg.



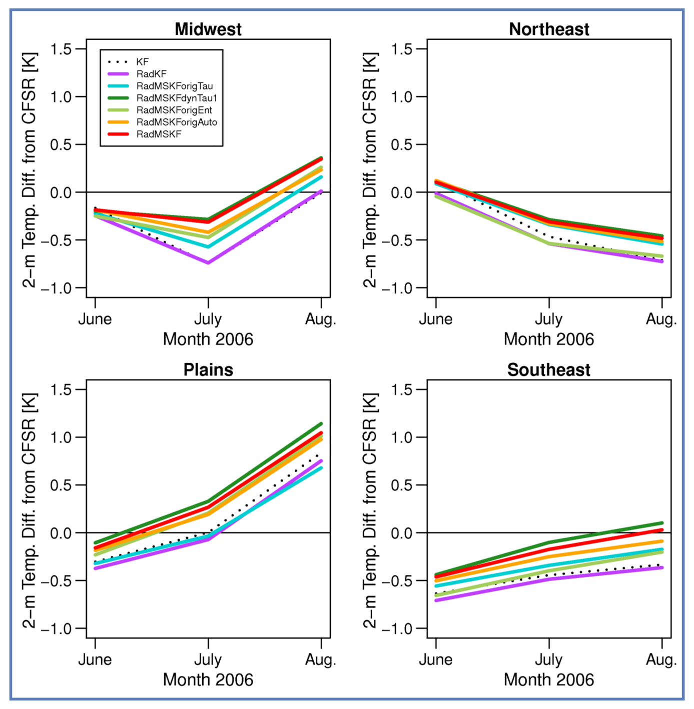
Latent Heat Flux, 2006 JJA Avg.



These summer-averaged heat fluxes further illustrate the impacts of the KF enhancements on the surface energy budget. Compared with the base KF case, adding more consistency in WRF between the subgrid cloudiness, radiation, and convective precipitation increases the average Bowen ratio by slightly increasing the sensible heat flux in most regions while decreasing latent heat flux by up to 25% or more, especially in the verdant areas east of the Mississippi River.

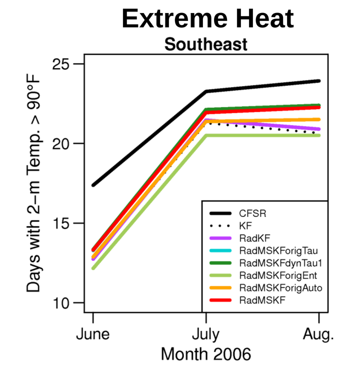
3.5. Results: 2-m Temperature

Temperature Bias (Model – CFSR)



For near-surface atmospheric temperature (T_{2m}), the RadMSKF and RadMSKFdynTau1 cases provide better agreement with CFSR for the MW, NE, and SE regions, but add some warm bias to the Plains. Note that after slight initial cooling due to the addition of subgrid clouds by going from the KF to the RadKF case, other cases showed a T_{2m} increase (up to 0.5 K) over the standard KF. This may be due to more low, middle, and high clouds with fewer very high clouds, balanced against an increased Bowen ratio.

Extreme Heat



Though the RadKF modification produced better agreement of this extreme heat index (DT90) to CFSR on 36 km grid cells (see Herwehe et al., 2014), RadKF is nearly ineffectual on a 12 km grid. However, RadMSKF improves the agreement with CFSR in the present study, likely due to RadMSKF having more sensible heat flux and less latent heat flux, which offsets RadMSKF having less SW downwelling at the surface than either the standard KF or RadKF cases.

4. Conclusions

This preliminary initial analysis and evaluation of results from a sensitivity study of a new multiscale Kain-Fritsch convection parameterization have shown:

- A strong regional dependence in the response to the individual KF formulations;
- WRF's overestimation of summer precipitation is greatly reduced;
- Significant changes in the surface energy budget (e.g., SW and Bowen ratio);
- A reduction in WRF's cool bias for most regions (except the Plains);
- Improved prediction of heat extremes for all regions (though only shown for SE).

♦ Use of the multiscale KF scheme will impact air quality simulations through changes to meteorological parameters such as precipitation, temperature, cloudiness, and the radiation budget; this impact on AQ is currently being studied.

References

Alapaty, K., J. A. Herwehe, T. L. Otte, C. G. Nolte, O. R. Bullock, M. S. Mallard, J. S. Kain, and J. Dudhia (2012), Introducing subgrid-scale cloud feedbacks to radiation for regional meteorological and climate modeling, *Geophysical Research Letters*, *39*(24), L24808, doi:10.1029/2012gl054031.

Herwehe, J. A., K. Alapaty, T. L. Spero, and C. G. Nolte (2014), Increasing the credibility of regional climate simulations by introducing subgrid-scale cloud-radiation interactions, *J. Geophys. Res. Atmos.*, 119, 5317–5330, doi:10.1002/2014JD021504.