Development of WRF-Solar v2—Improving Solar Forecasts

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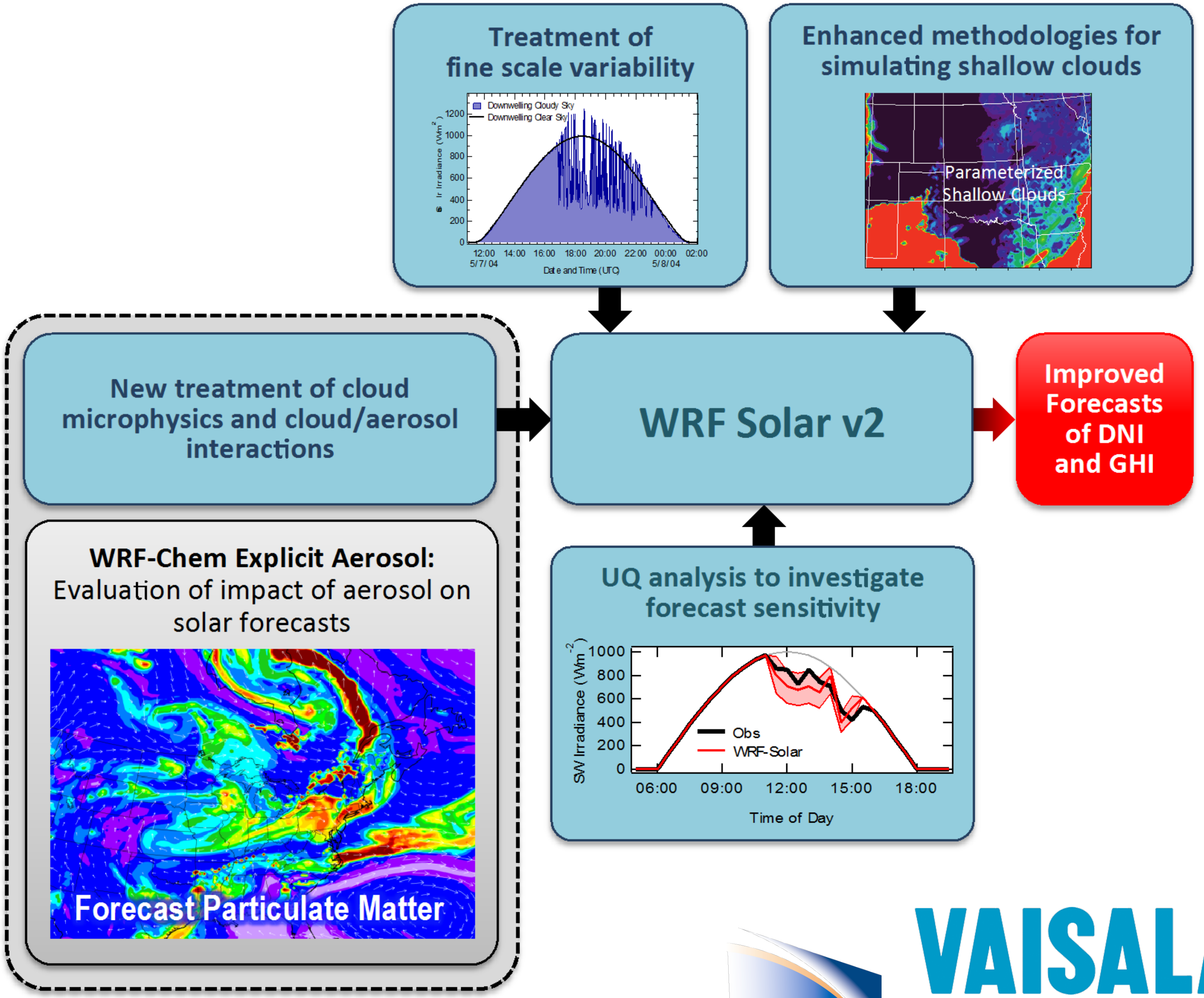
Improving physics in WRF-Solar

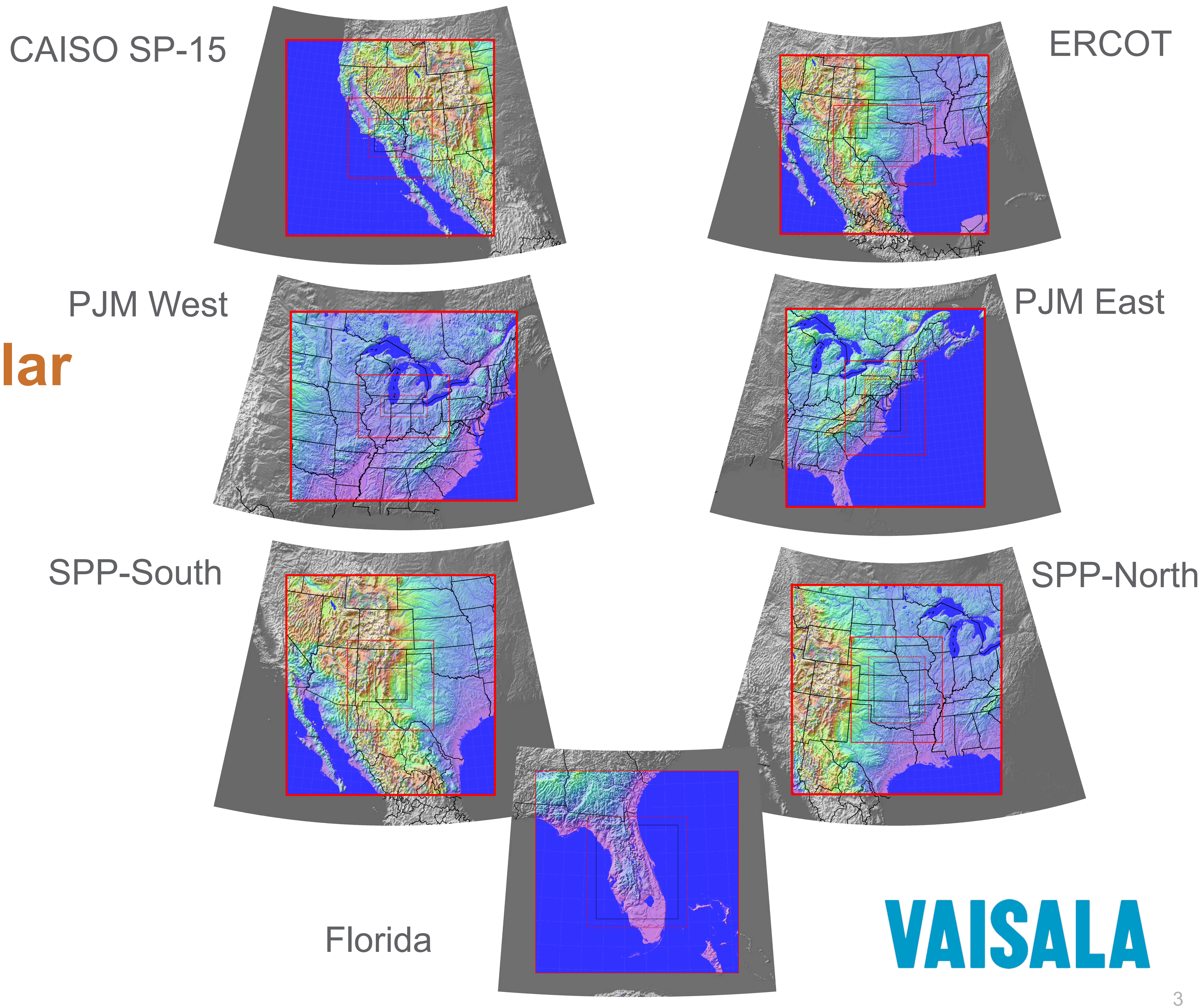
- Address shortcomings in WRF-Solar v1
- Project Goals:
  - Reduce forecast errors by 25%
  - Improve ramp forecasts
  - New estimates of sub-grid variability
- New tool for the community



NCAR

Defining project baseline: WRF-Solar v1 simulations

- Power forecasts generated using WRF-Solar v1 and Vaisala's forecast system for five geographic regions



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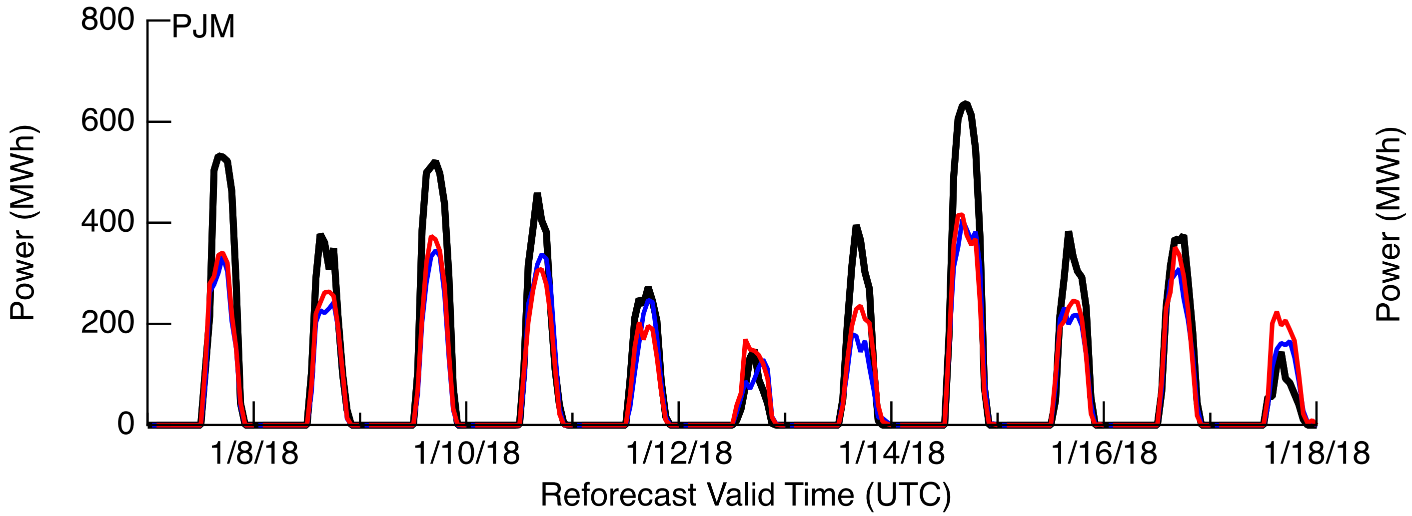
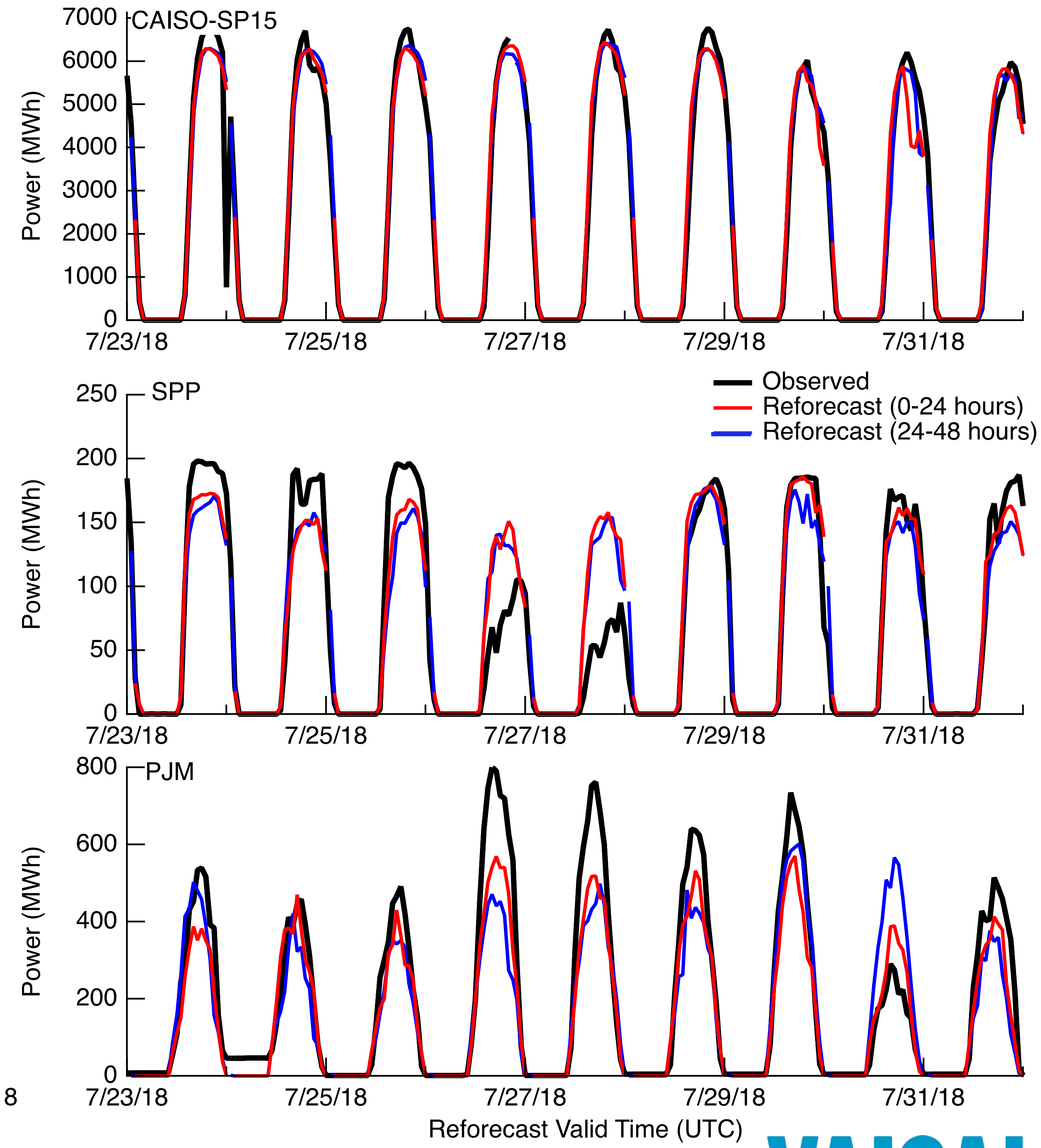
WRF-Solar v1 power forecasts

- Better results for locations with greater penetration and fewer clouds



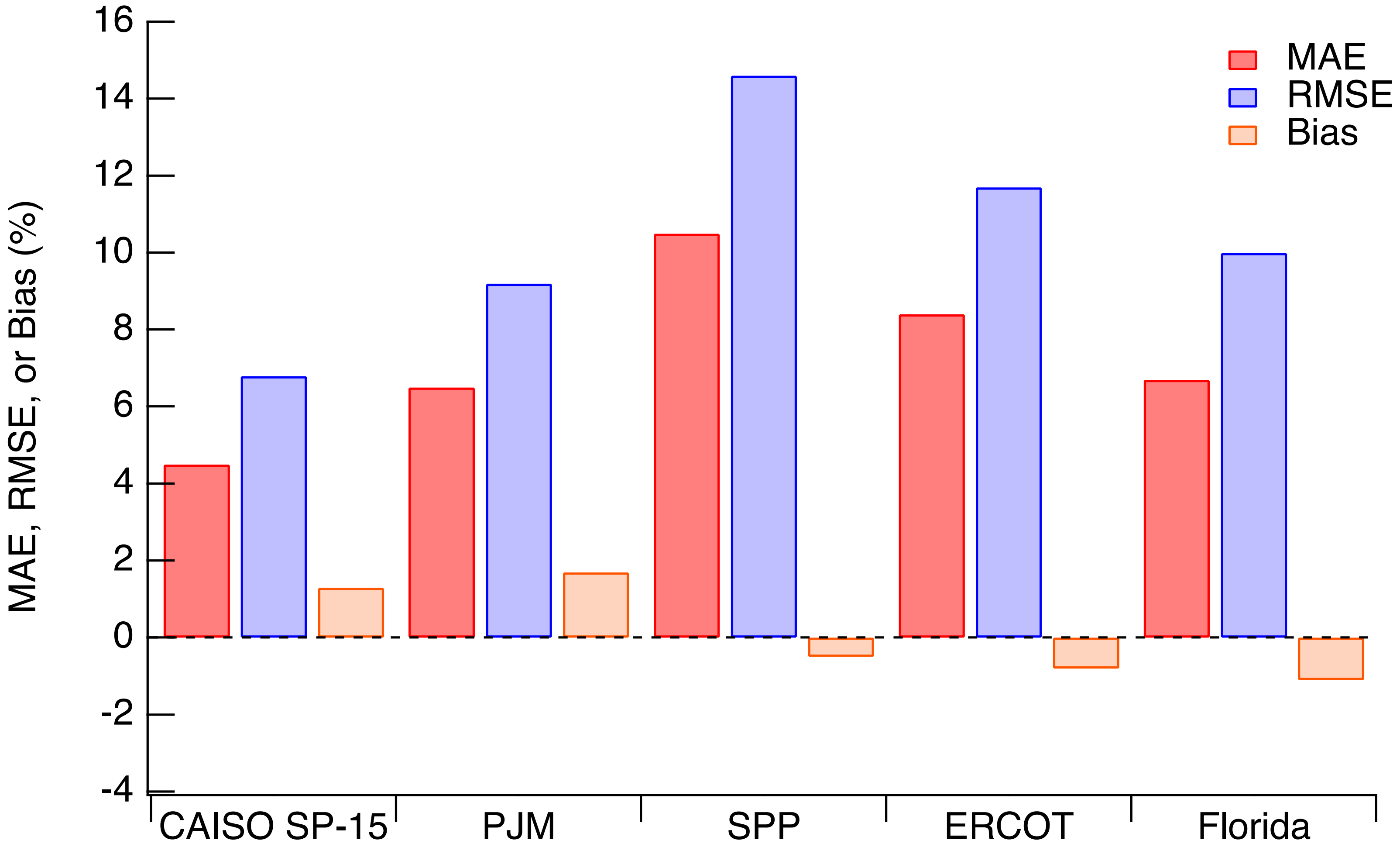
Winter



Summer

Baseline power forecast statistics

- Smallest MAE and RMSE for CAISO SP-14
- Largest MAE and RMSE at SPP
- Largest bias at PJM



Improving simulations of boundary layer clouds

Often neglected, but significant impact: ~45 Wm^{-2} (out of 612 Wm^2) at DOE site in Oklahoma (Berg et al. 2011).

Tested Parameterizations:

- All apply mass-flux approximation, main differences in trigger function
- Standard Kain-Fritsch (KF)—Based on standard KF parameterization, applies an add-hoc temperature perturbation as trigger function (Kain and Fritsch 1990).
- Deng—Trigger function based on boundary-layer TKE (Deng, Seaman, and Kain 2003)
- KF-Cup (Cumulus potential)—Distribution of temperature and humidity used as trigger function (Berg et al., 2013)

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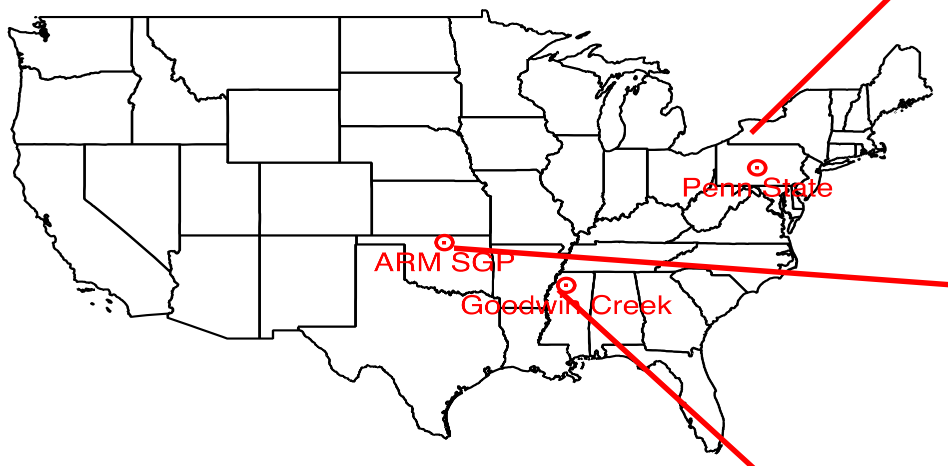
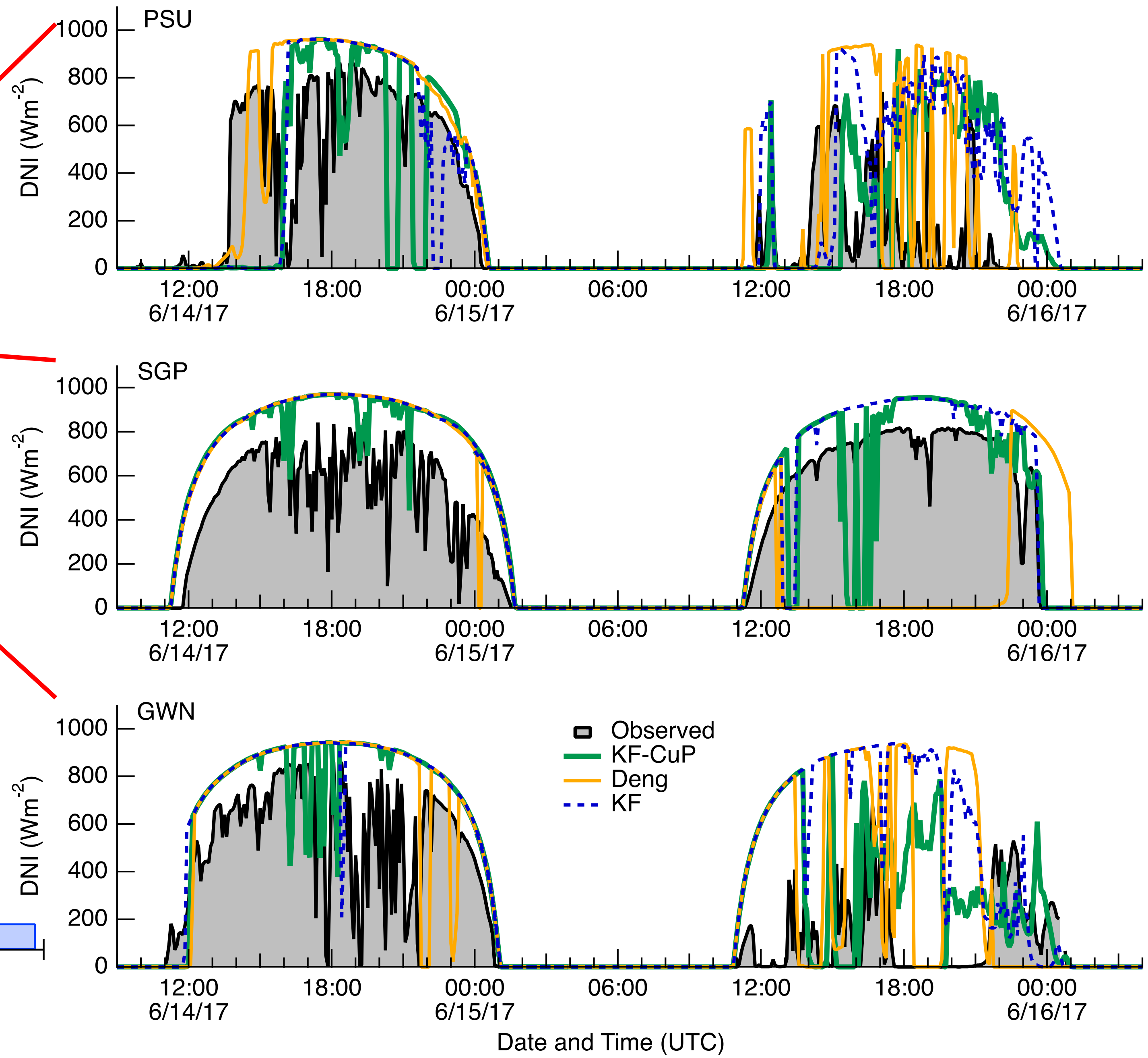
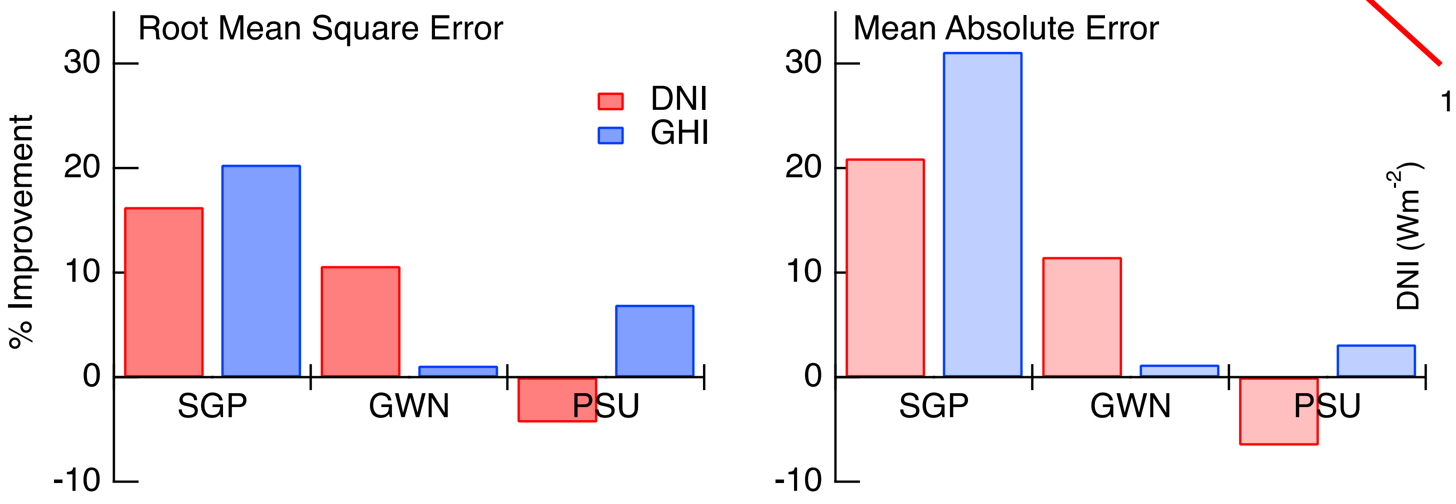
Improved treatment of shallow cumulus



Time series from SURFRAD and DOE Sites



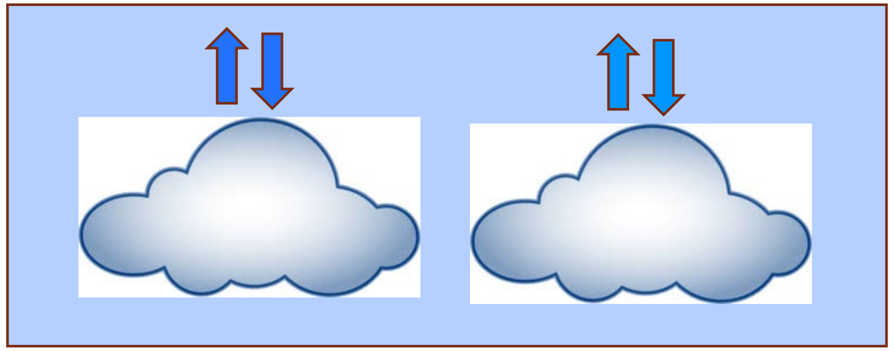
% improvement between KF-CuP and Deng (baseline) parameterizations over 20 case study days



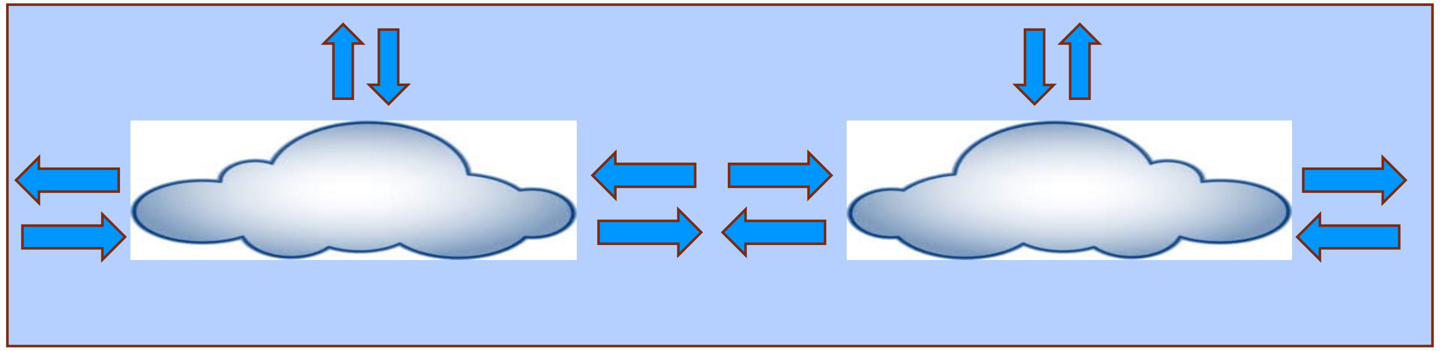
Kain, J.S., J.M. Fritsch, 1990, *J. Atmos. Sci.*
Deng, A., N.L. Seaman, and J.S. Kain, 2003, *J. Atmos. Sci.*
Berg, L.K., et al., 2013, *Mon. Wea. Rev.*

Improved treatment of cloud entrainment and microphysics

- Goal: better forecasts of solar irradiance and improved prediction of solar power
- Modified parameterizations of processes that control cloud fraction and lifetime through cloud entrainment
- PBL schemes do not account for horizontal diffusion and therefore horizontal cloud entrainment is not accounted for



Cloud-top entrainment

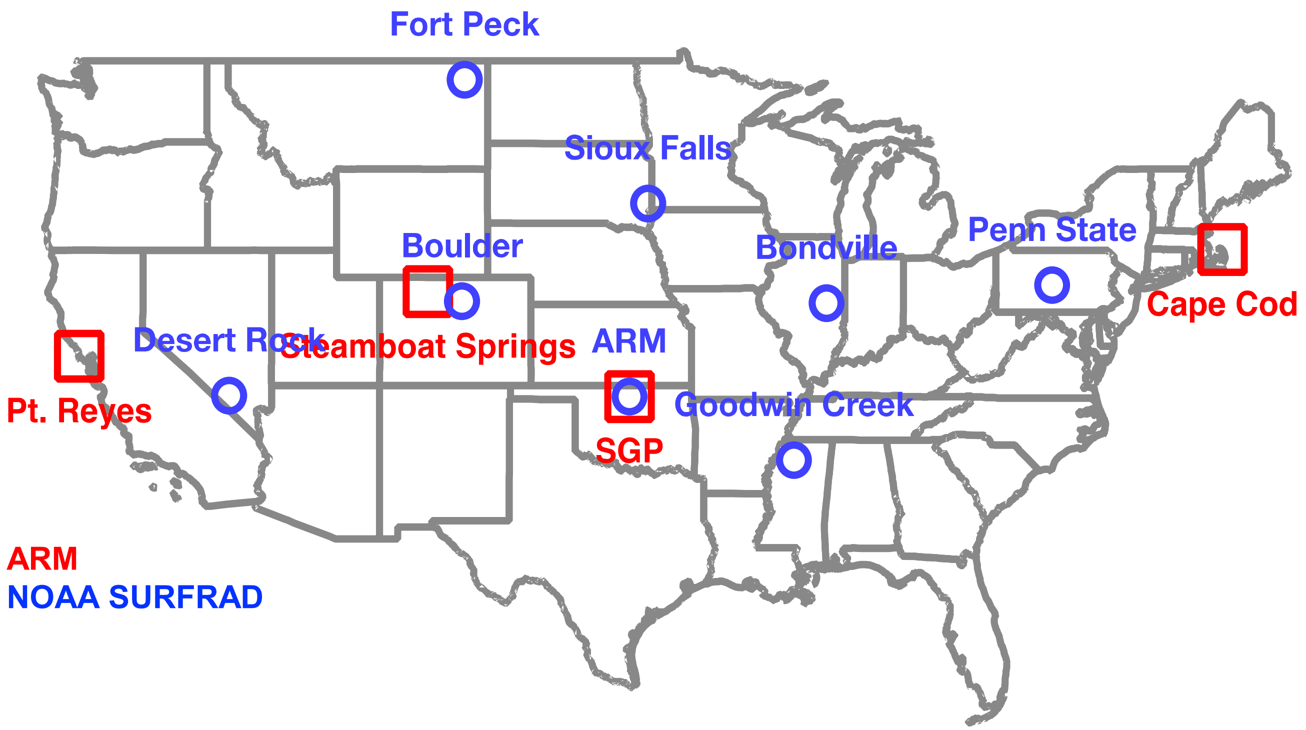


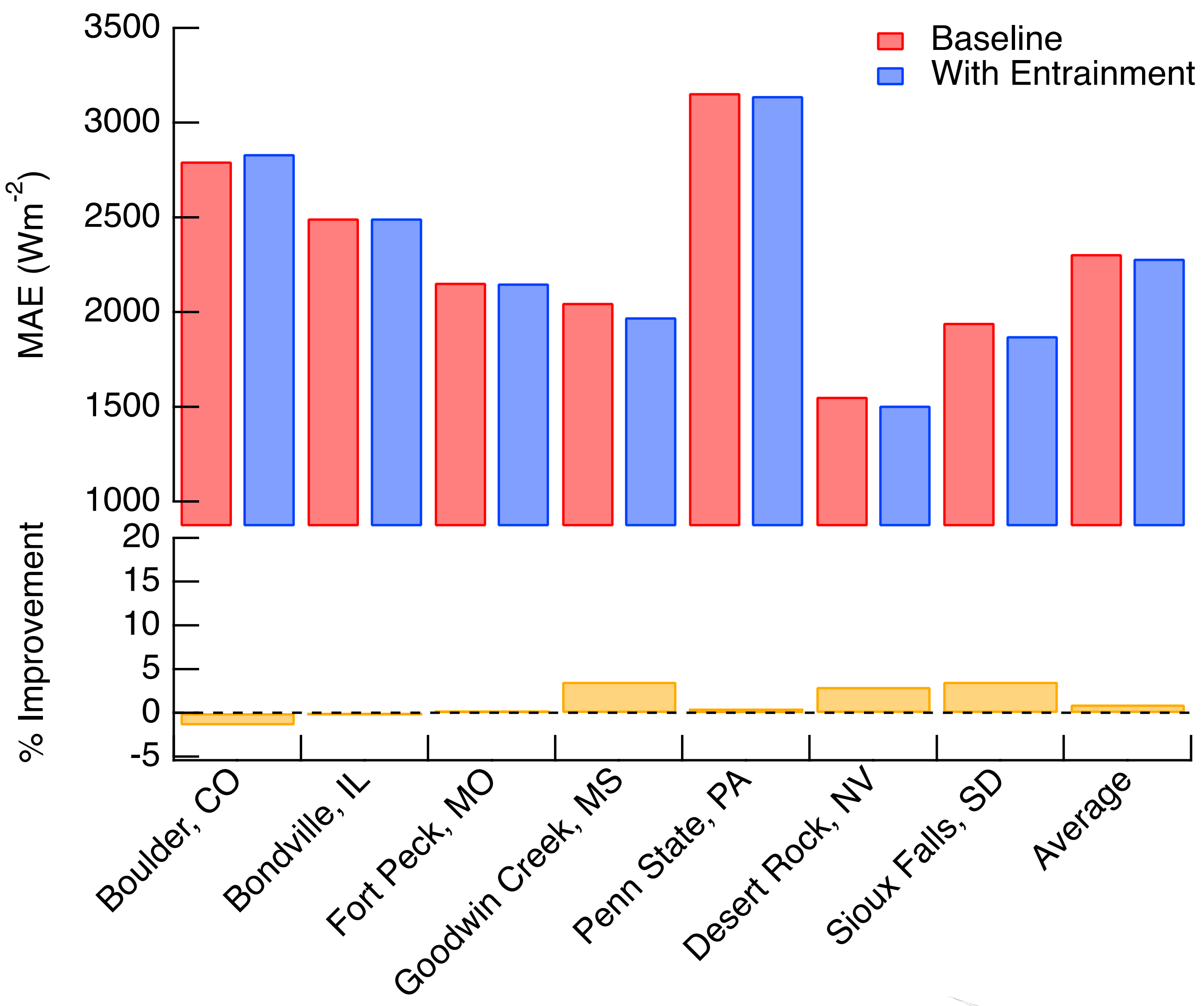
Cloud-top entrainment and lateral entrainment (2D diffusion)

- The lateral entrainment was modified by enhancing two-dimensional (2D) diffusion.
- The horizontal mixing coefficient is stability dependent

Results evaluated using SURFRAD data

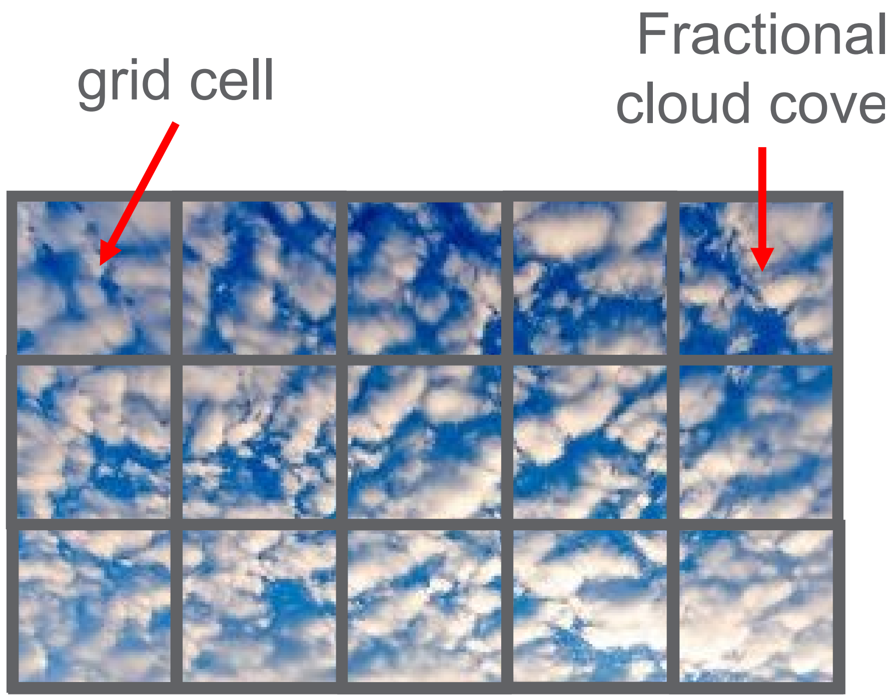
- Reforecasting of April 2018 over CONUS at 3 km grid spacing
- GHI measured at 7 SURFRAD sites compared to predictions
- **Modest improvement at 3 sites**

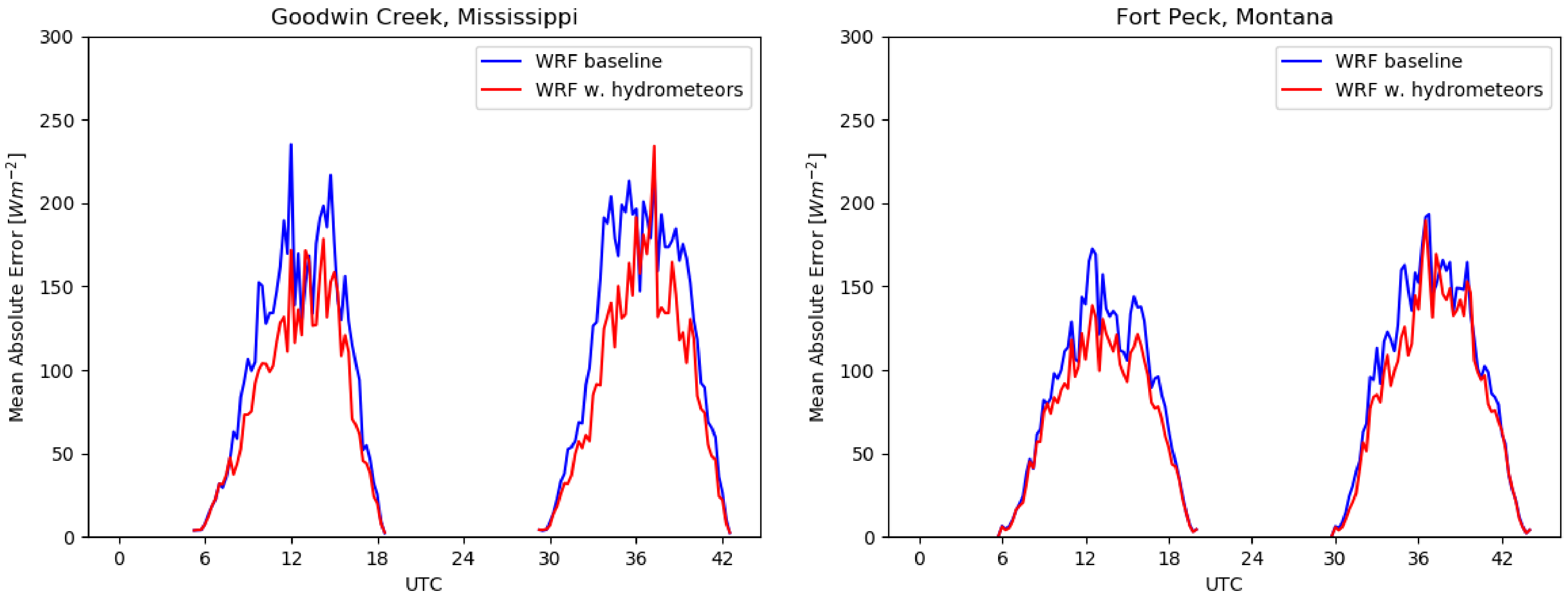




Effect of subgrid, unresolved hydrometeors

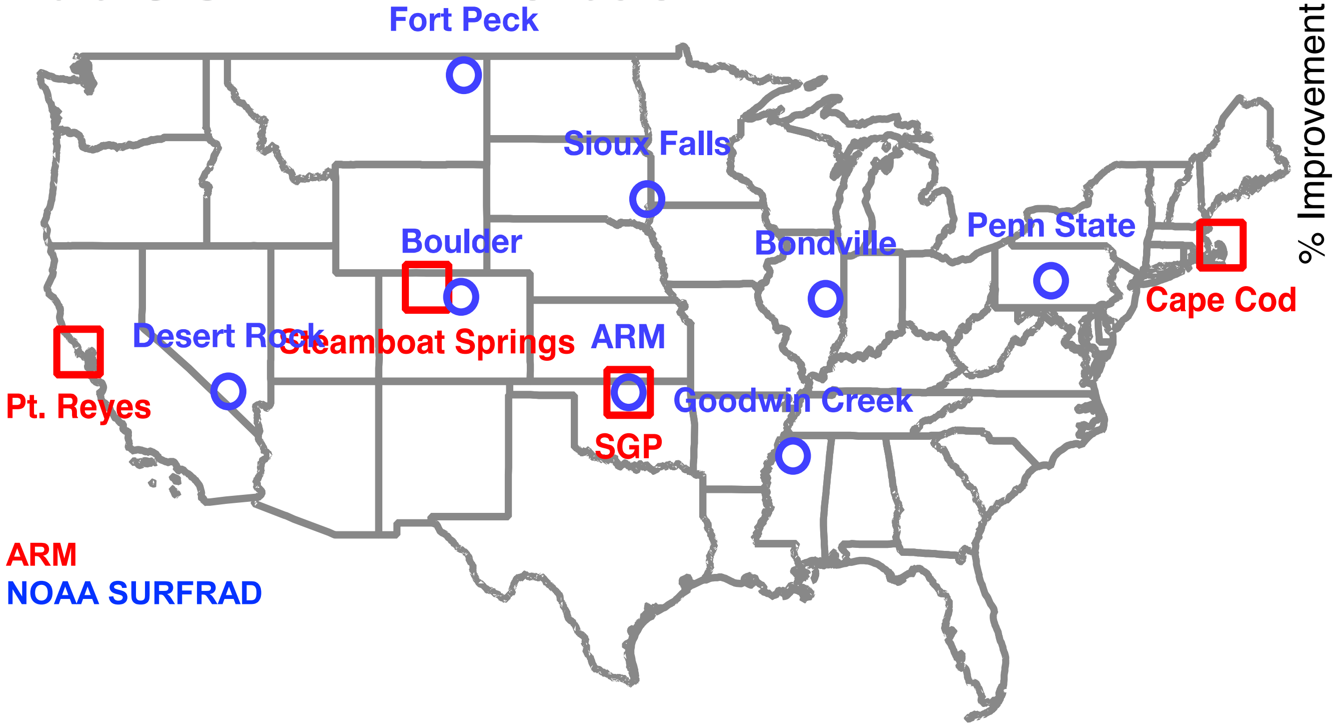
- Represent the radiative effects of the unresolved clouds (hydrometeors) using a parameterization based on relative humidity
- Horizontal cloud fraction calculated using relative humidity, liquid and ice water content calculated using adiabatic cloud model
- Hydrometeor contents and horizontal cloud fraction used to account for the radiative effects of unresolved clouds

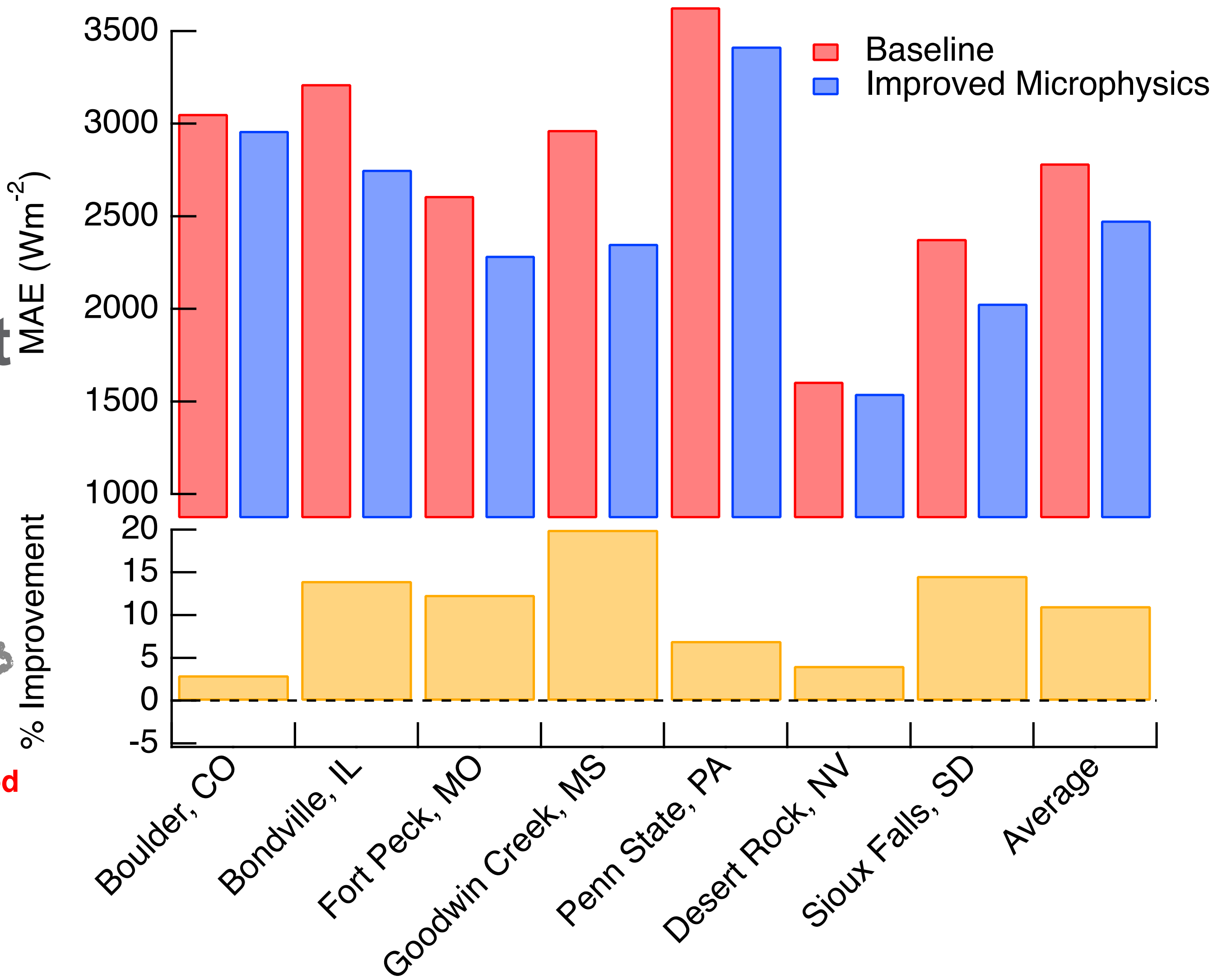




Assessed simulations using same data from April 2018

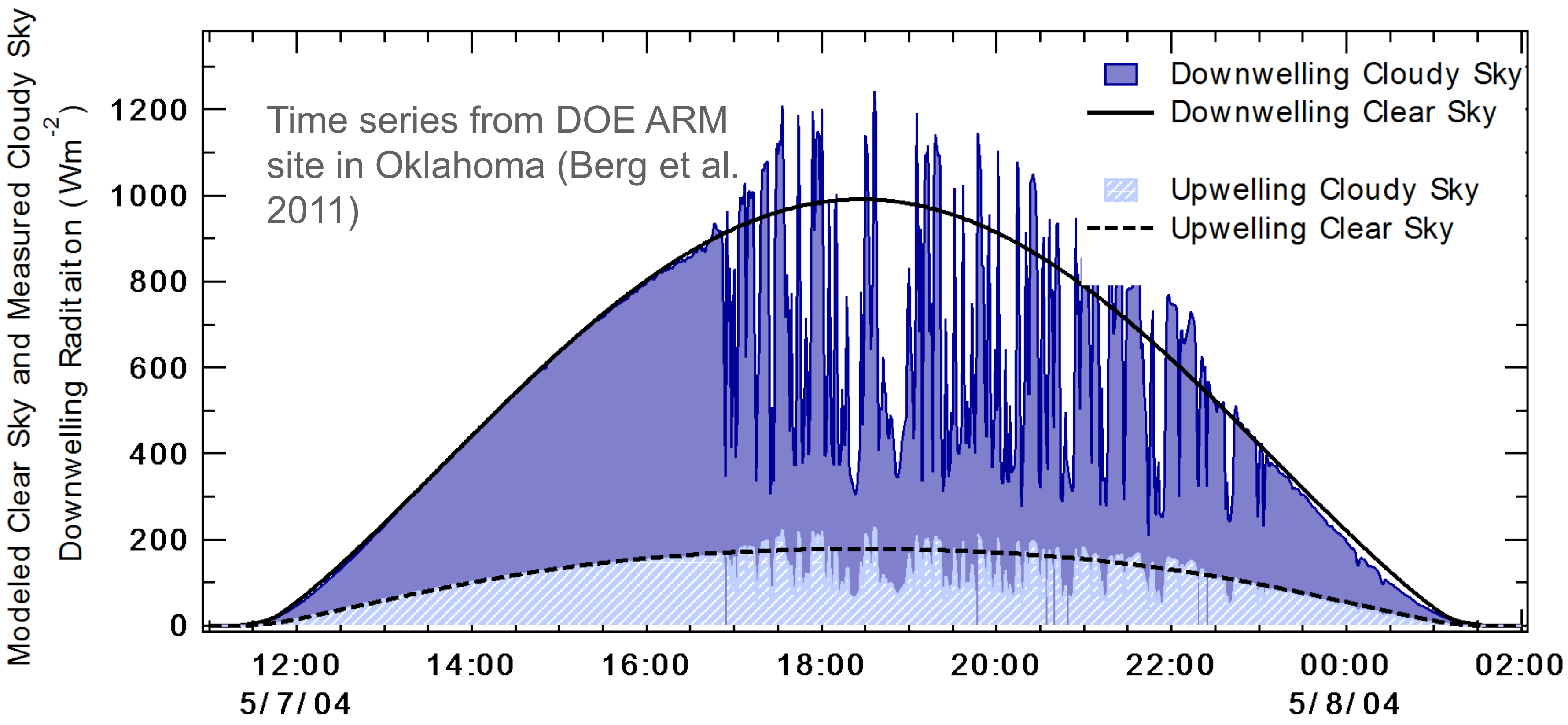
- We have carried out reforecasting of April 2018 over CONUS at 3 km grid cell size
- **Accounting for unresolved hydrometeors results in significant improvement in prediction of GHI at SURFARD sites**

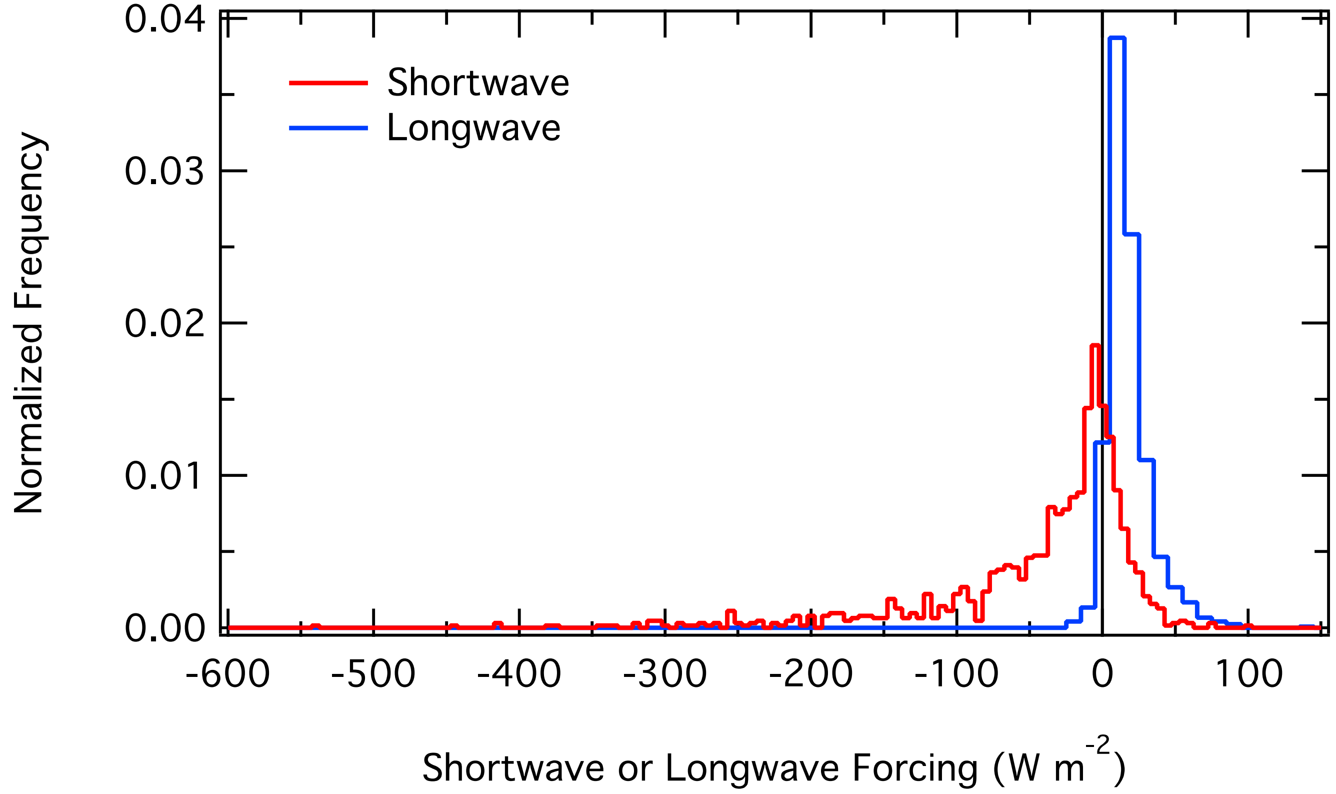




Variability in solar irradiance

- Broken cloud fields can lead to significant amounts of variability in solar irradiance



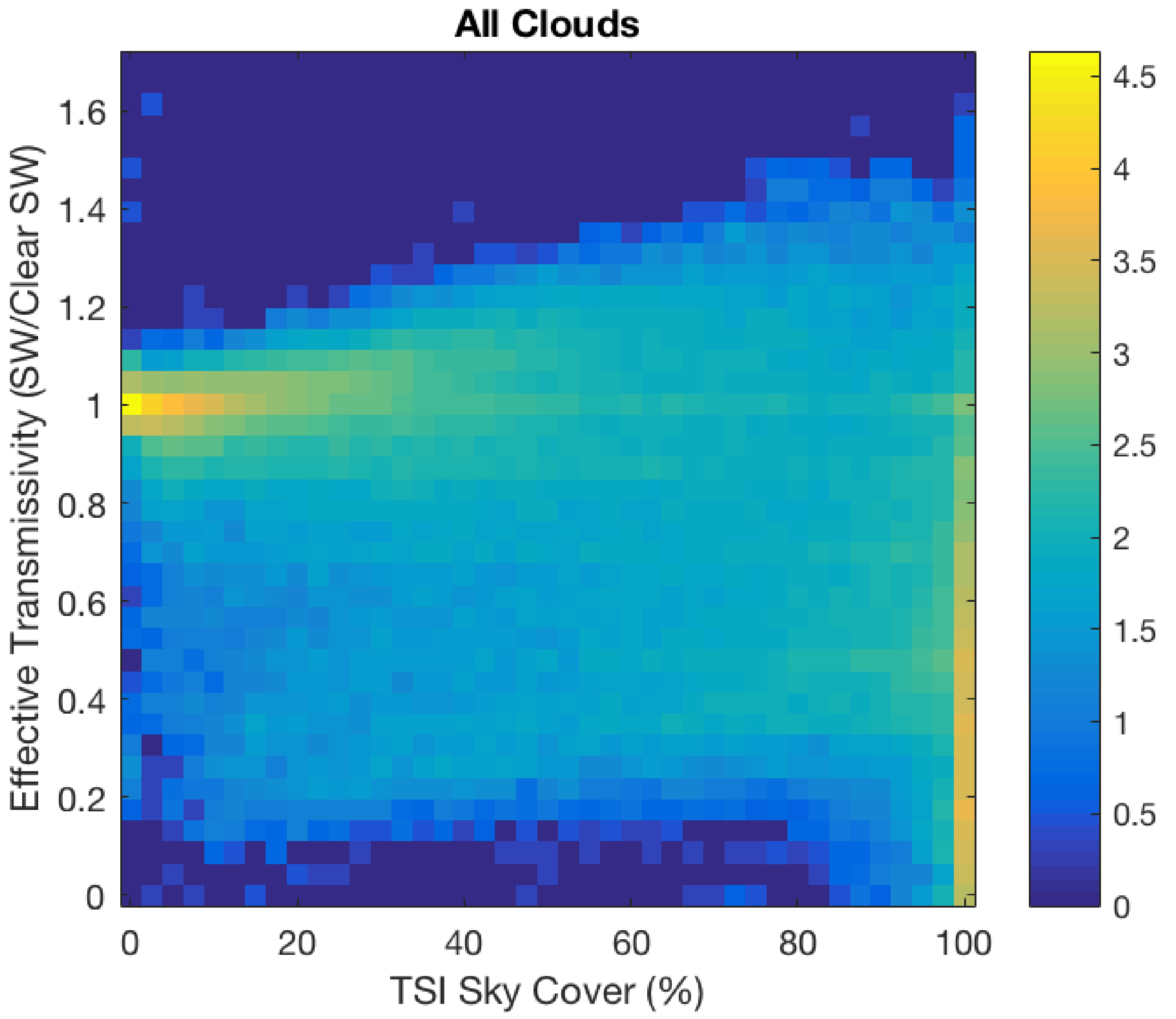


Improving representation of variability

- Using data from SGP to relate variability to cloud cover
- Focus on effective transmissivity (ET: measured irradiance/clear sky irradiance)
- Exploring different parameters to quantify the variability

σ_{ET} = Standard deviation of ET

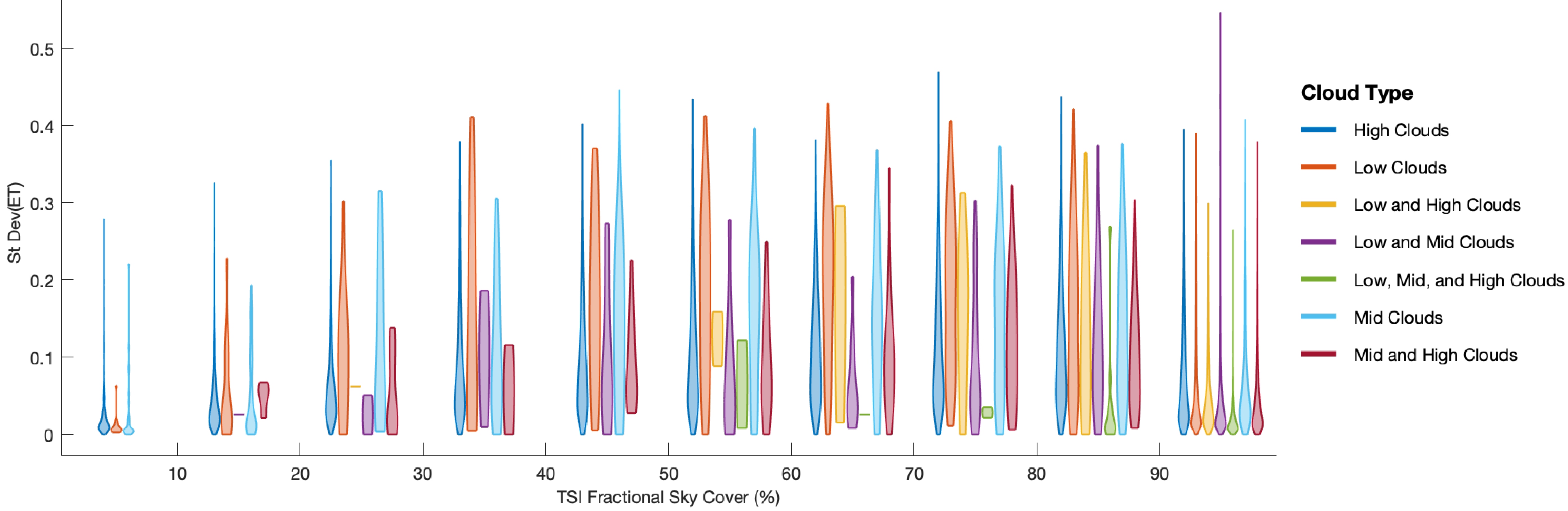
$\sigma(\Delta ET)$ = Variation of ET over a time window (also called nominal variability by Perez et al, 2016)



Goal: New treatment of variability applied in WRF-Solar

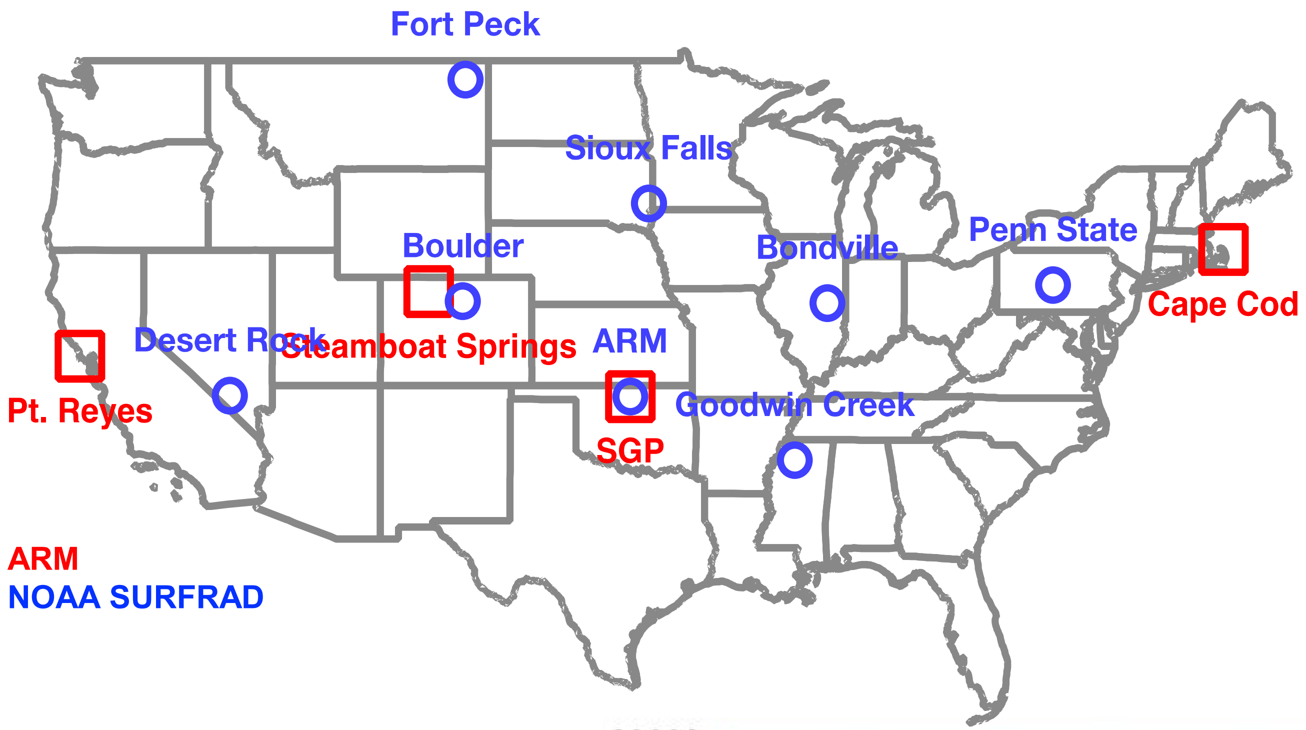
Variability by cloud type at the Southern Great Plains

- Use cloud radar and lidar to separate by cloud type

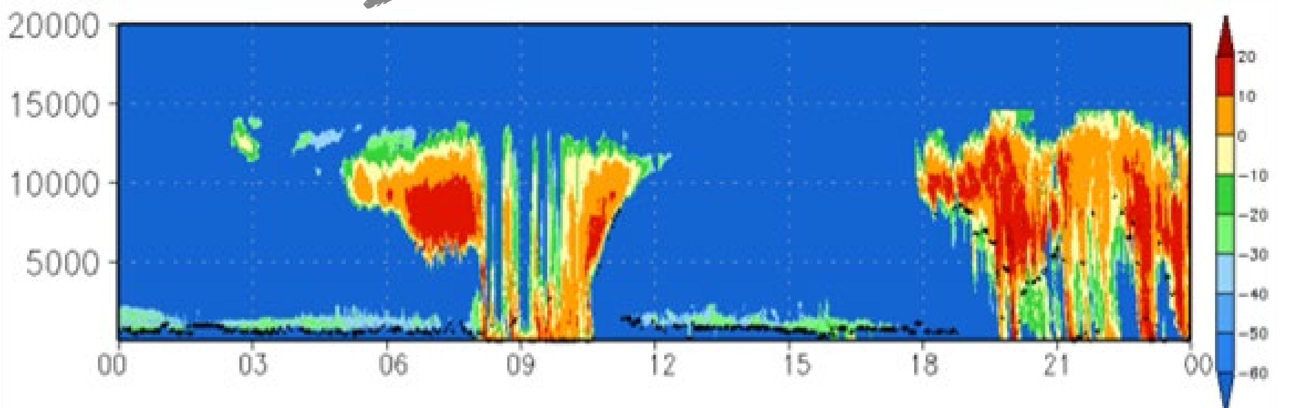


Expand analysis to more sites, including those with simpler measurements

- Year-long ARM deployments at Pt. Reyes, Steamboat Springs, and Cape Cod



Example time series from ARM cloud radar



Second year activities

Stratocumulus

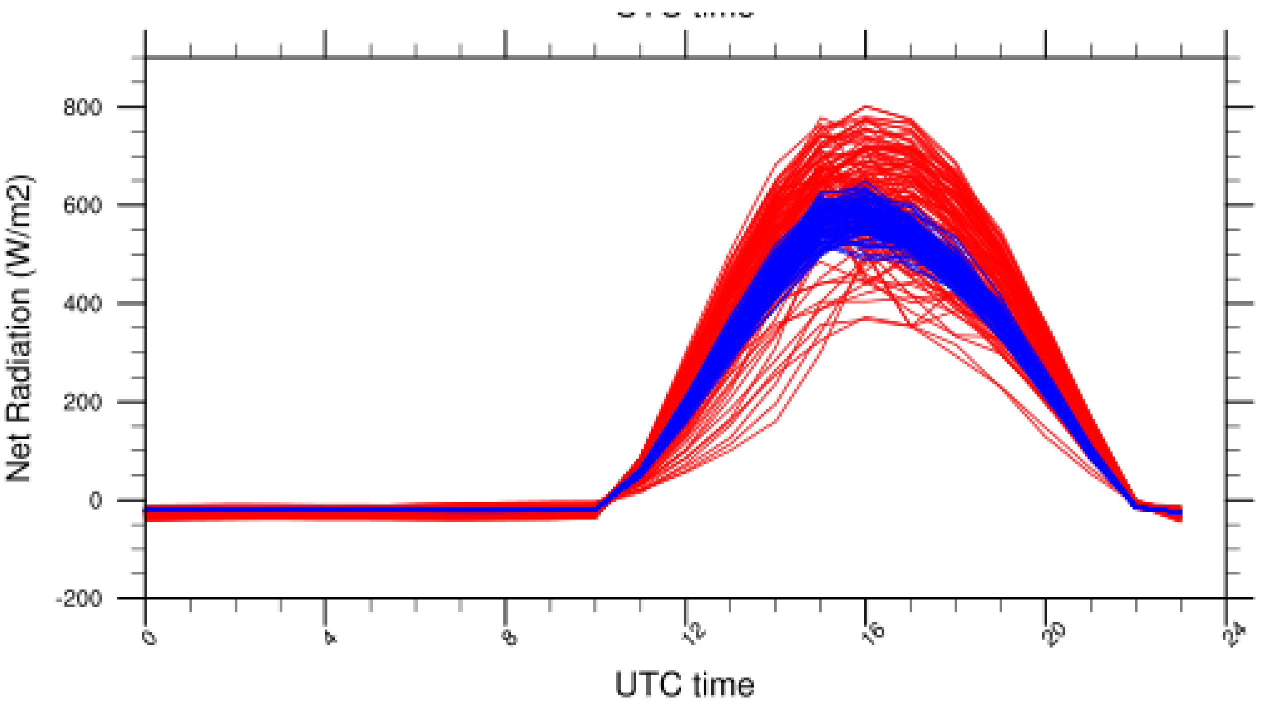
- Improve treatment of stratocumulus breakup

Uncertainty Quantification (UQ)

- Apply established approaches to better understand uncertainty in WRF-Solar v2 forecasts

Absorbing Aerosol

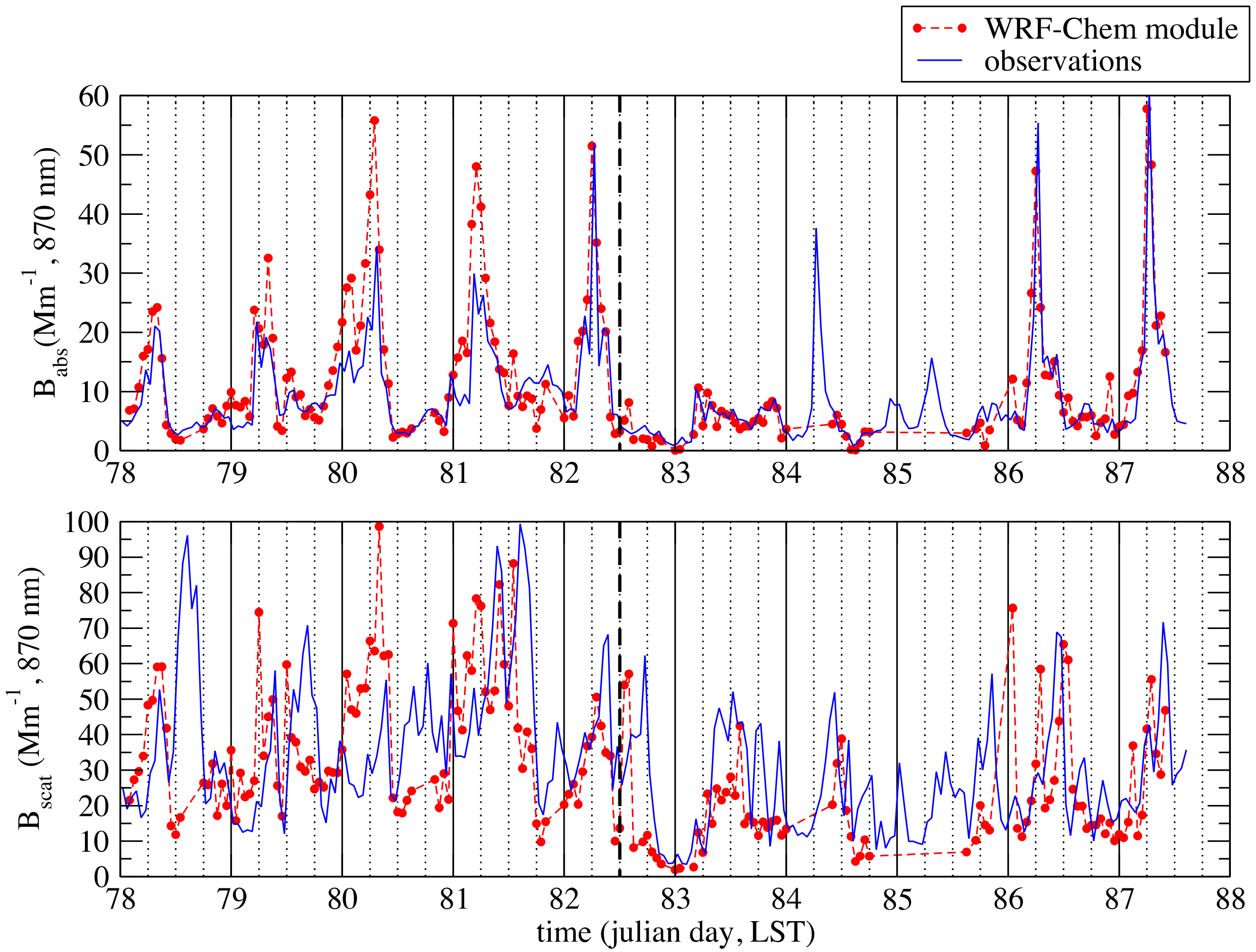
- Add new treatment to WRF-Solar v2



Net radiation simulated using WRF when apply different physics packages (including different microphysics, land surface, boundary layer, and cumulus parameterizations; red lines) and different parameter values (blue lines).

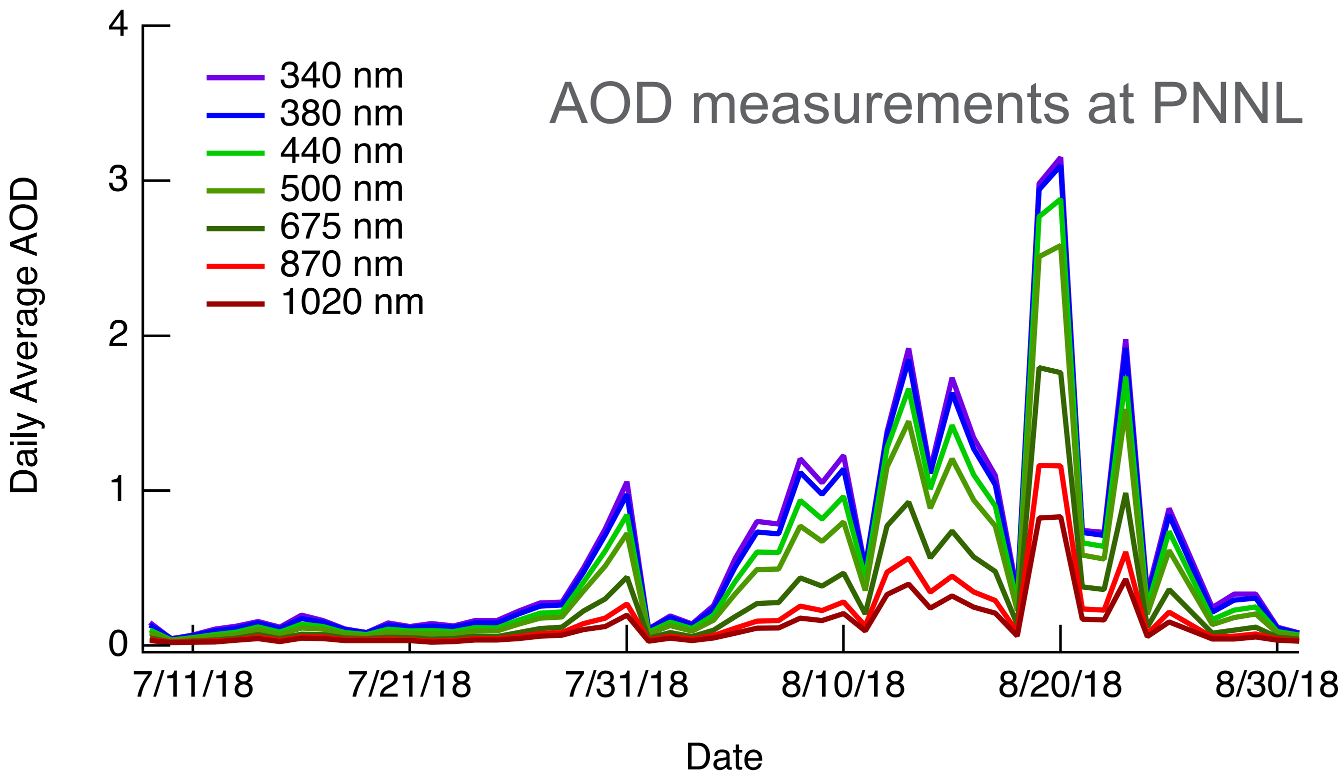
Improved treatment of absorbing aerosol

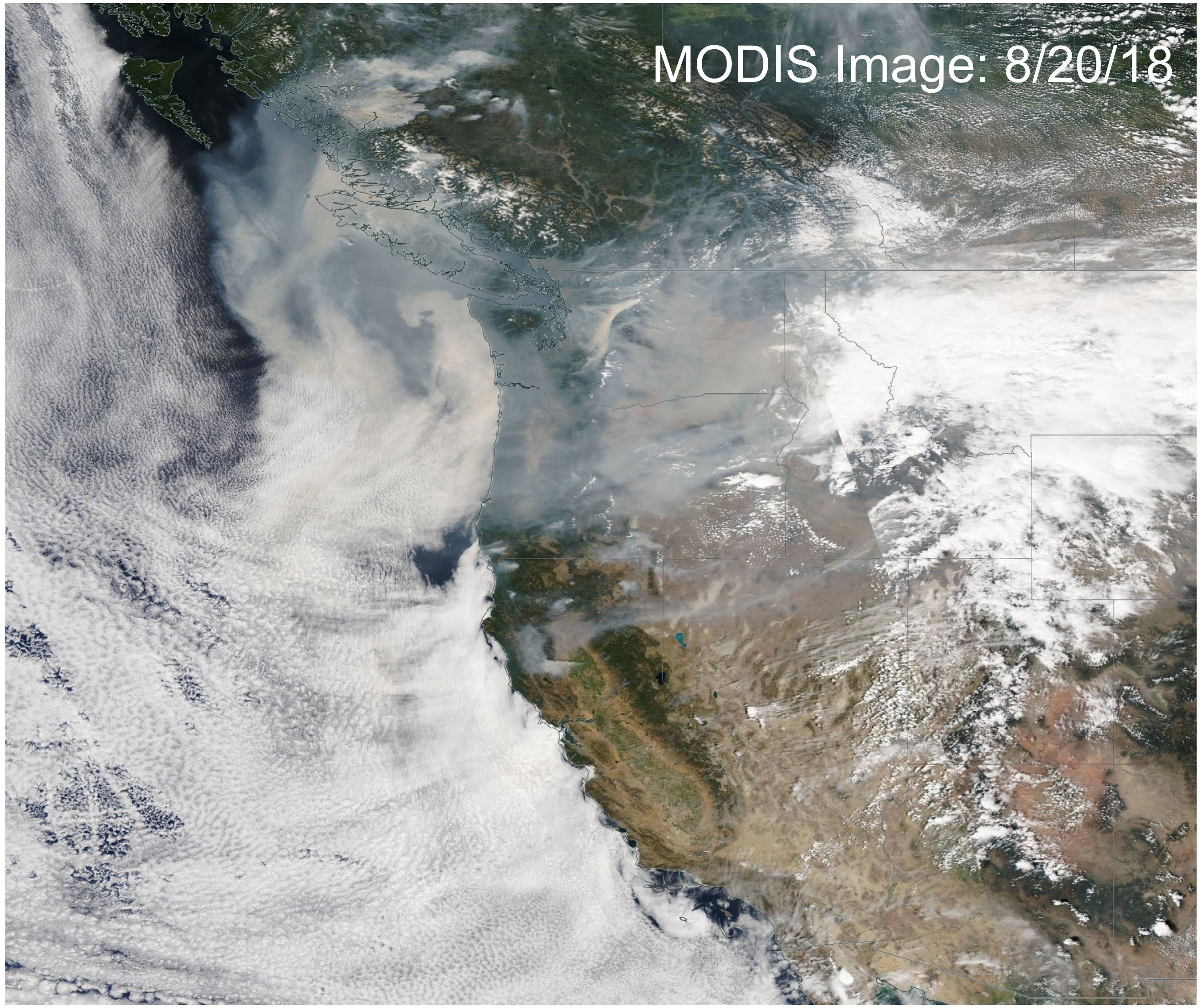
- Add new class of absorbing aerosol—only interact with radiation
- Black carbon (BC) emissions will be a function of the land use
- We will explore two approaches to the initialization of the BC mixing ratios:
  - Climatology of the black carbon similar to the way aerosols that act as CCN and IN are initialized,
  - Initialization of the three aerosols, CCN, IN and black carbon, from air quality forecasts (e.g. NASA GEOS5 forecasts or ECMWF CAMS model).
- Evaluate model performance with data and WRF-Chem



Absorbing aerosol case study

- Simulate period form the summer of 2018 with biomass burning events
- Extreme test case, move to anthropogenic cases associated with other field studies if time permits





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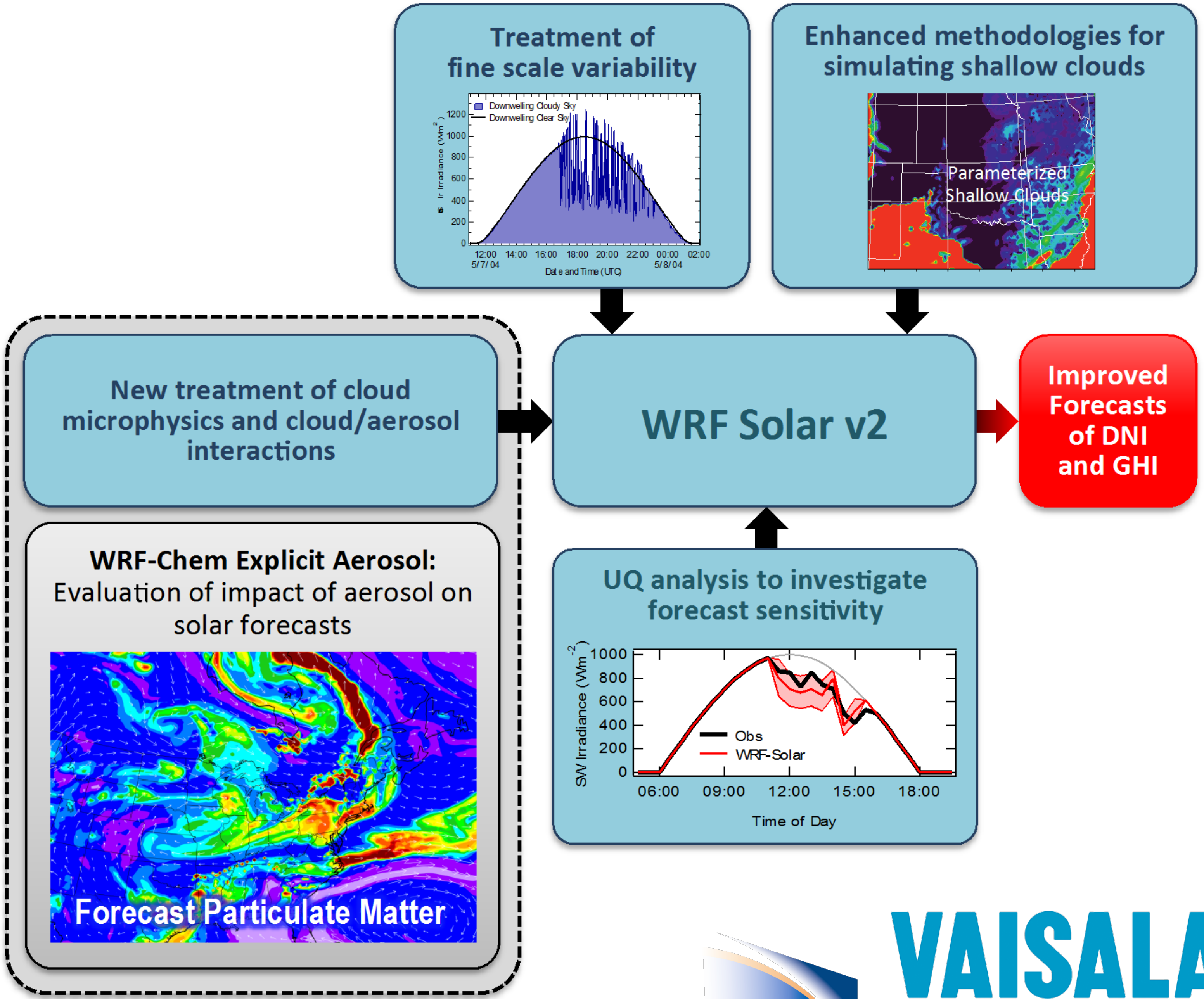
Improving physics in WRF-Solar

- Baseline power forecast completed
- Treatment of boundary-layer cumulus: 0-30% improvement
- Entrainment/broken cloud fields: 3-20% improvement
- Variability: Work on going
- Year 2: Stratocumulus, UQ, and absorbing aerosol



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