Development of WRF-Solar v2—Improving Solar Forecasts

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Organization Leads: Larry Berg¹, Branko Kosovic², Jeff Lerner³, Laura Riihimaki⁴

¹PNNL, ²NCAR, ³Vaisala, ⁴NOAA
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
Defining project baseline: WRF-Solar v1 simulations

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

- CAISO SP-15
- ERCOT
- PJM West
- PJM East
- SPP-South
- SPP-North
- Florida
WRF-Solar v1 power forecasts

- Better results for locations with greater penetration and fewer clouds
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)
Improved treatment of shallow cumulus


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

Root Mean Square Error

- DNI
- GHI

Mean Absolute Error

- SGP
- GWN
- PSU

Time series from SURFRAD and DOE Sites
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

• 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 SURFRAD sites
Variability in solar irradiance

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

Time series from DOE ARM site in Oklahoma (Berg et al. 2011)
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
  \[ \sigma_{ET} = \text{Standard deviation of ET} \]
  \[ \sigma(\Delta ET) = \text{Variation of ET over a time window} \] (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

MODIS Image: 8/20/18

AOD measurements at PNNL
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