Recent advances in he WRF-Solar model

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and
the WRF-Solar team

NCAR

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Join WRF/MPAS Users' Workshop 2021

NSF

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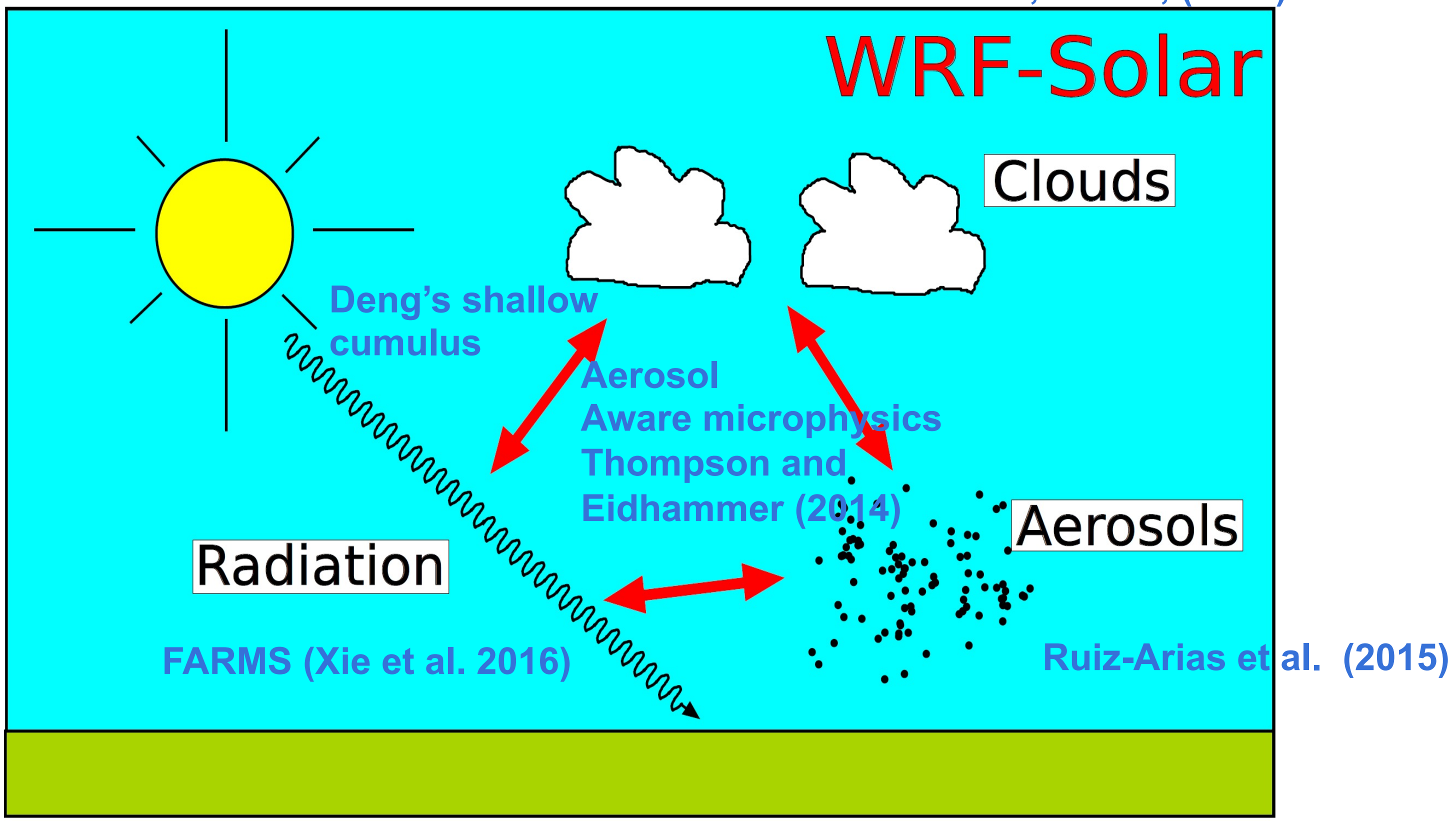
Outline

- Current status WRF-Solar
- Ongoing WRF-Solar developments

WRF-Solar are upgrades to the WRF model to:
Provide an appropriate numerical framework for solar energy applications
Improved feedbacks between radiation - clouds - aerosols

Jimenez et al., BAMS, (2016)



The WRF-Solar Community Model

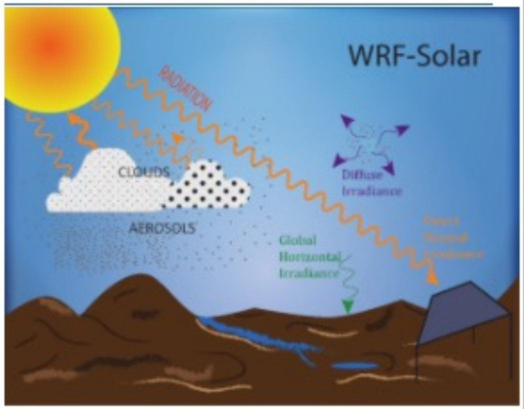
WRF-Solar became fully integrated in the major WRF release of 2020 (WRF version 4.2). WRF-Solar website (https://ral.ucar.edu/projects/wrf-solar):

WRF-SOLAR®

Overview | Description | User's Guide | Reference Config | Ongoing Developments

WRF-Solar® is the first numerical weather prediction model specifically designed to meet the growing demand for specialized numerical forecast products for solar energy applications (Jimenez et al. 2016). WRF-Solar is a specific configuration and augmentation of the **Weather Research and Forecasting (WRF) model**. The version 1 of the model was developed within the Sun4Cast® project funded by the U.S. Department of Energy that targeted to improve solar power forecasts at a wide range of temporal scales (Haupt et al. 2016).

The Community Version of WRF-Solar is in the public domain and can be downloaded from the **official WRF Github repository**. The WRF version 4.2 includes the enhancements of WRF-Solar Version 1 with upgrades in the physical parameterizations as well as other developments.**Users are encouraged to use version 4.2.2 or upcoming versions.**



Sketch representing the physical processes that WRF-Solar® improves. The different components of the radiation are indicated.

This website provides a description of the model, the user's guide, a reference configuration that should be used as a baseline for comparison by the WRF-Solar community, and ongoing developments.

Please visit the **WRF-Solar forum** if you are having troubles running the model.

Solar diagnostic package

Adds 2D cloud/radiation variables to the standard output

```
&diags
solar_diagnostics = 1,
/
```

If tslist option is activated the Solar diagnostic package adds the 2D variables to the selected locations (See run/README.tslist for more information)

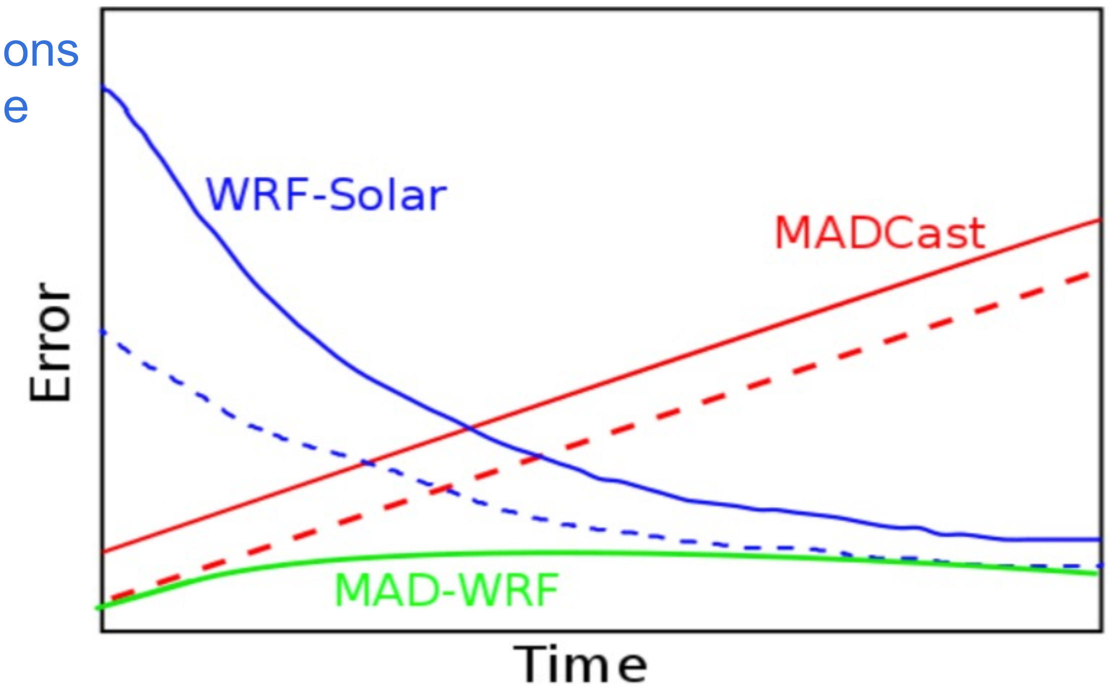
```
cldfrac2d:     2-D MAX CLOUD FRACTION (%)
wvp:           WATER VAPOR PATH (kg m-2)
lwp:           LIQUID CLOUD WATER PATH (kg m-2)
iwp:           ICE CLOUD WATER PATH (kg m-2)
swp:           SNOW CLOUD WATER PATH (kg m-2)
wp_sum:        SUM OF LWP+IWP+SWP (kg m-2)
lwp_tot:       LIQUID CLOUD WATER PATH RES + UNRES (kg m-2)
iwp_tot:       ICE CLOUD WATER PATH RES + UNRES (kg m-2)
wp_tot_sum:    SUM OF LWP+IWP+SWP RES + UNRES (kg m-2)
re_qc:         MASS-WEIGHTED LIQUID CLOUD EFFECTIVE RADIUS (m)
re_qi:         MASS-WEIGHTED ICE EFFECTIVE RADIUS (m)
re_qs:         MASS-WEIGHTED SNOW EFFECTIVE RADIUS (m)
re_qc_tot:     MASS-WEIGHTED LIQUID CLOUD EFFECTIVE RADIUS RES + UNRES (m)
re_qi_tot:     MASS-WEIGHTED ICE EFFECTIVE RADIUS RES + UNRES (m)
tau_qc:        MASS-WEIGHTED LIQUID CLOUD OPTICAL THICKNESS ()
tau_qi:        MASS-WEIGHTED ICE OPTICAL THICKNESS ()
tau_qs:        MASS-WEIGHTED SNOW OPTICAL THICKNESS ()
tau_qc_tot:    MASS-WEIGHTED LIQUID CLOUD OPTICAL THICKNESS RES + UNRES ()
tau_qi_tot:    MASS-WEIGHTED ICE OPTICAL THICKNESS RES + UNRES ()
cbaseht:       CLOUD BASE HEIGHT (m)
ctopht:        CLOUD TOP HEIGHT (m)
cbaseht_tot:   CLOUD BASE HEIGHT RES + UNRES (m)
ctopht_tot:    CLOUD TOP HEIGHT RES + UNRES (m)
clrnidx:       CLEARNESS INDEX ()
sza:           SOLAR ZENITH ANGLE (deg)
```

And surface irradiances for clear sky and all-sky conditions

The MAD-WRF nowcasting system

We have blended an improved version of a satellite-based initialization system (MADCast) with a NWP-based nowcasting approach (WRF-Solar) to create an improved end-to-end solar irradiance forecast system called MAD-WRF.

Parameterizations to represent the aerosol-cloud-radiation interactions



Advects and diffuses the cloud fraction without activating parameterizations

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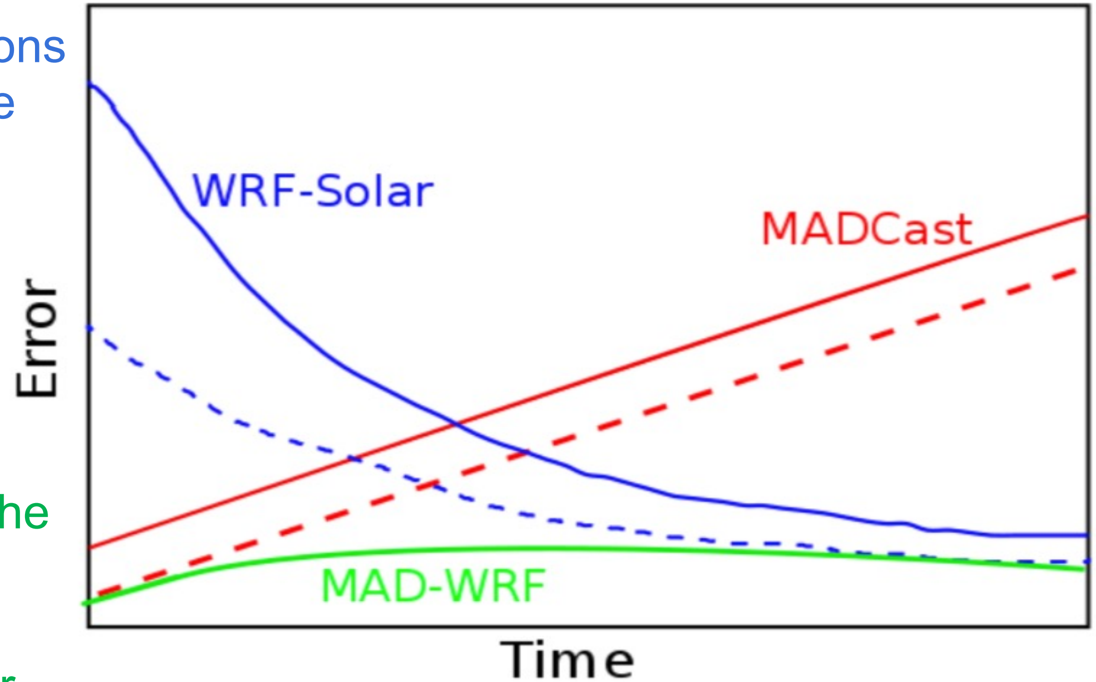


Nudges the hydrometeors to the tracers advecting and diffusing the initial hydrometeor content

Advects and diffuses the hydrometeors (liquid, ice and snow)

The MAD-WRF nowcasting system

- The cloud field is initialized using hydrometeors (if available) and relative humidity. The cloud field could be refined by imposing observations of the cloud mask or the cloud top/base height

- MAD-WRF passive mode advects and diffuses the initial hydrometeors as tracers

- MAD-WRF active mode, andvects and diffuses the initial hydrometeors as traces and, at the same time, nudges the resolved hydrometeors towards the tracers

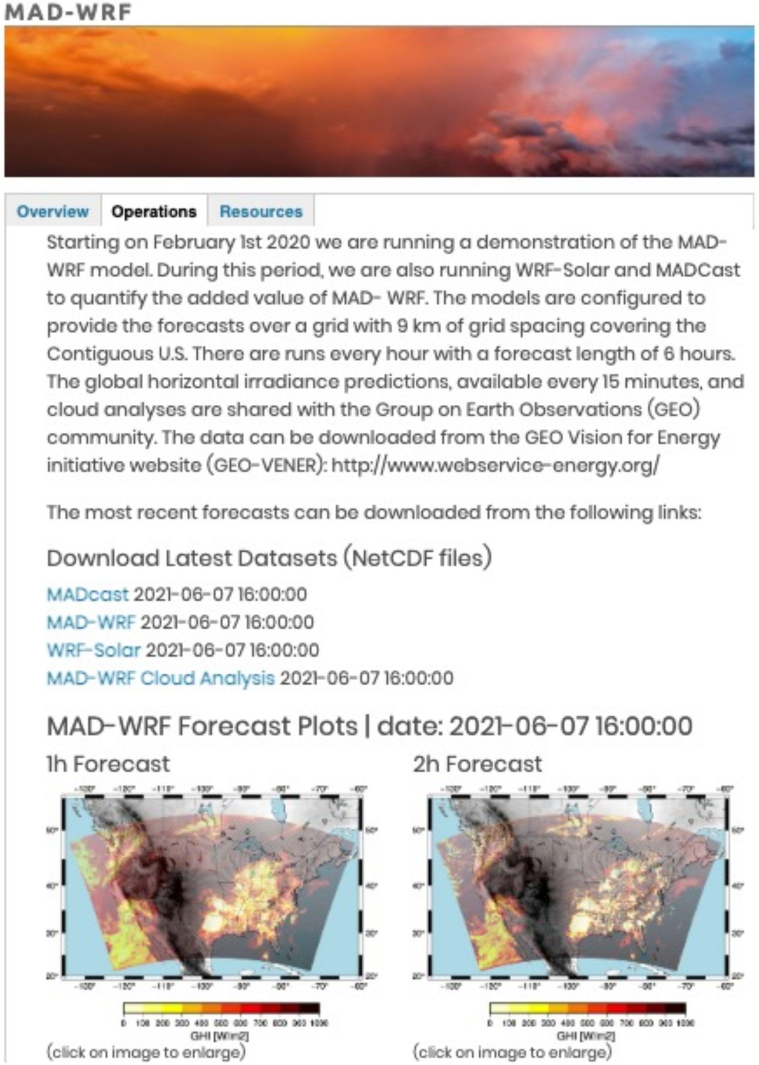
- Nudging is applied only to the beginning of the simulated period (~1 h)

The MAD-WRF nowcasting system

- WRF-Solar and MAD-WRF in active and passive mode are being run quasi-operationally in a demonstration of MAD-WRF since February 1st 2020

- Data is being shared via GEO-VENER channels: http://www.webservice-energy.org/

- Data is also shared through the MAD-WRF website https://ral.ucar.edu/projects/mad-wrf



MAD-WRF

Overview | Operations | Resources

Starting on February 1st 2020 we are running a demonstration of the MAD-WRF model. During this period, we are also running WRF-Solar and MADCast to quantify the added value of MAD- WRF. The models are configured to provide the forecasts over a grid with 9 km of grid spacing covering the Contiguous U.S. There are runs every hour with a forecast length of 6 hours. The global horizontal irradiance predictions, available every 15 minutes, and cloud analyses are shared with the Group on Earth Observations (GEO) community. The data can be downloaded from the GEO Vision for Energy initiative website (GEO-VENER): http://www.webservice-energy.org/

The most recent forecasts can be downloaded from the following links:

Download Latest Datasets (NetCDF files)

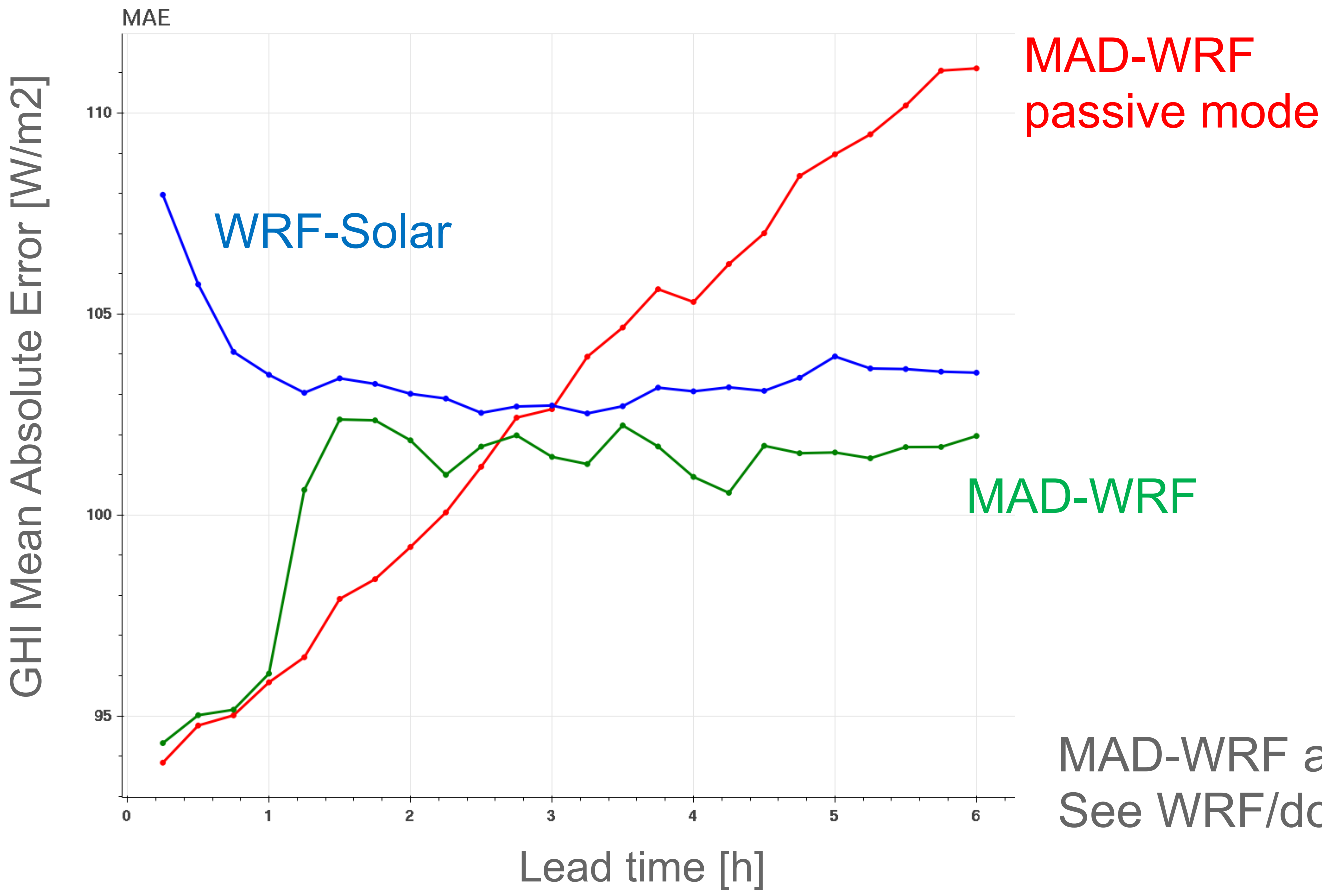
MADcast 2021-06-07 16:00:00
MAD-WRF 2021-06-07 16:00:00
WRF-Solar 2021-06-07 16:00:00
MAD-WRF Cloud Analysis 2021-06-07 16:00:00

MAD-WRF Forecast Plots | date: 2021-06-07 16:00:00

1h Forecast | 2h Forecast

(click on image to enlarge) | (click on image to enlarge)

Evaluation against USCRN observations with simulations spanning the period from February 1st 2020 until August 31st 2020



MAD-WRF available in WRF v4.3
See WRF/doc/README.madwrf

Ongoing WRF-Solar developments

- Enhancing WRF-Solar® to provide probabilistic forecasts: The WRF-Solar ensemble prediction system (WRF-Solar EPS). The National Renewable Energies Laboratory (NREL) is leading a project and collaborates with NCAR to:
  - Incorporate a probabilistic framework specifically tailored for solar energy applications.

- Enhancing WRF-Solar physics for version 2. The Pacific Northwest National Laboratory (PNNL) is leading a project collaborating with NCAR to
  - Enhance the WRF-Solar physics (solar diagnostic package, incorporating black carbon, parameterization of the solar variability)
  - Quantify uncertainties to model parameters

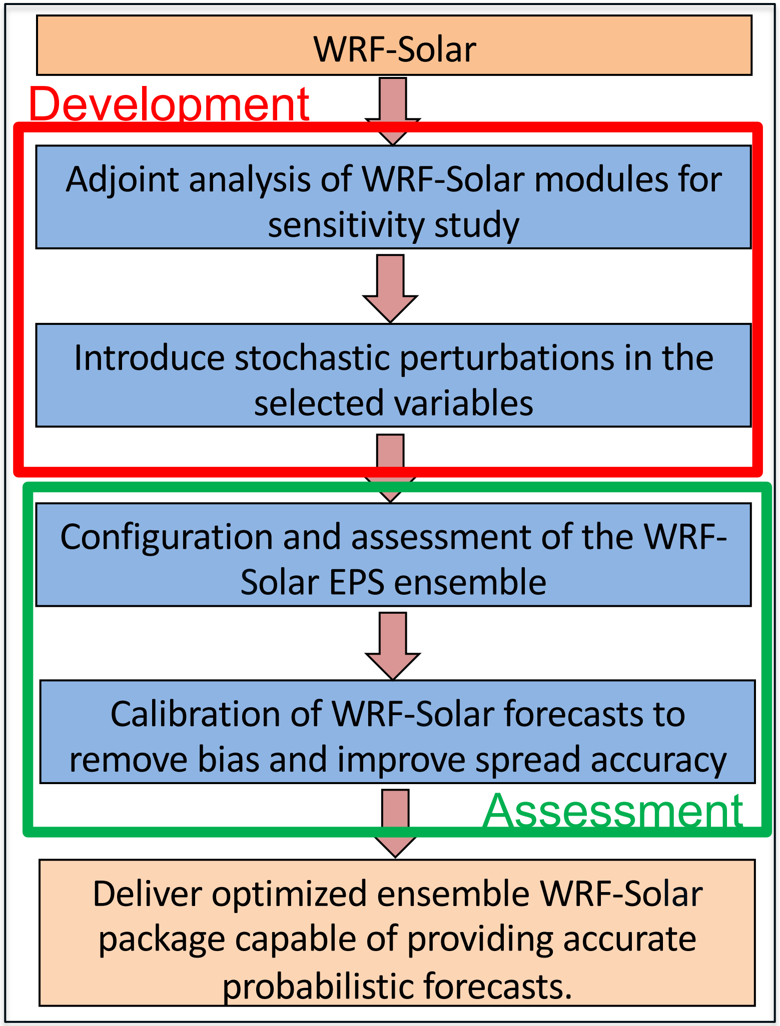
- PV modelling: Arizona State University is incorporating an online parameterization of PV panels production.

- Enhancing microphysics and DNI modelling: Brookhaven National Laboratory (BNL) is leading a project to enhance the WRF-Solar microphysics as well as to improve the representation of the cloud interactions with the DNI.

Ongoing WRF-Solar developments: WRF-Solar EPS

P.I: M. Sengupta (NREL)

- Identify variables that significantly influence the formation and dissipation of clouds and solar radiation through an **tangent linear analysis** of WRF-Solar modules that influence cloud processes.
- Introduce stochastic perturbations in the variables identified in previous step to develop **WRF-Solar EPS**
- **Calibrate WRF-Solar EPS** using observations to ensure that the forecasts' trajectories are unbiased and provide accurate estimates of forecast uncertainties under a wide range of meteorological regimes
- **Demonstrate the improvements of WRF-Solar EPS**
- Incorporate WRF-Solar EPS in the WRF-Solar community model as an open-source probabilistic framework (https://ral.ucar.edu/projects/wrf-solar-eps)

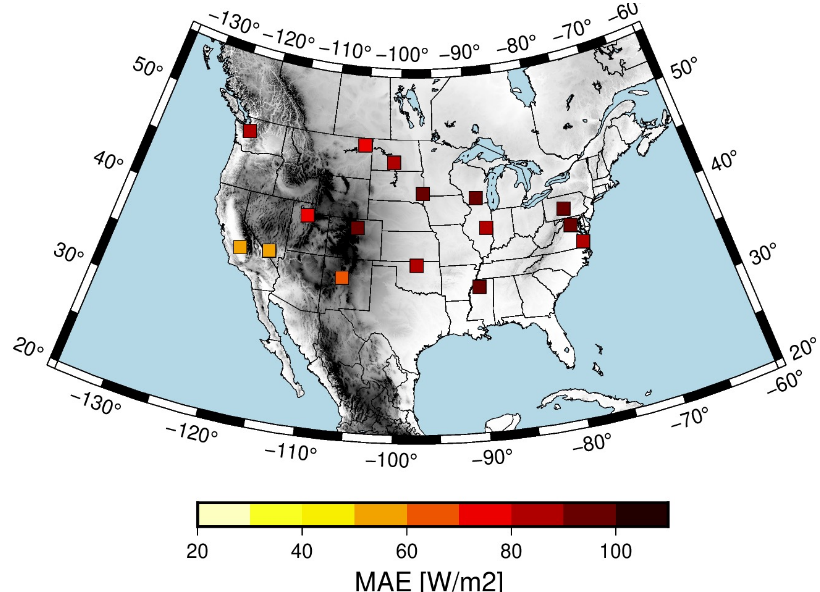


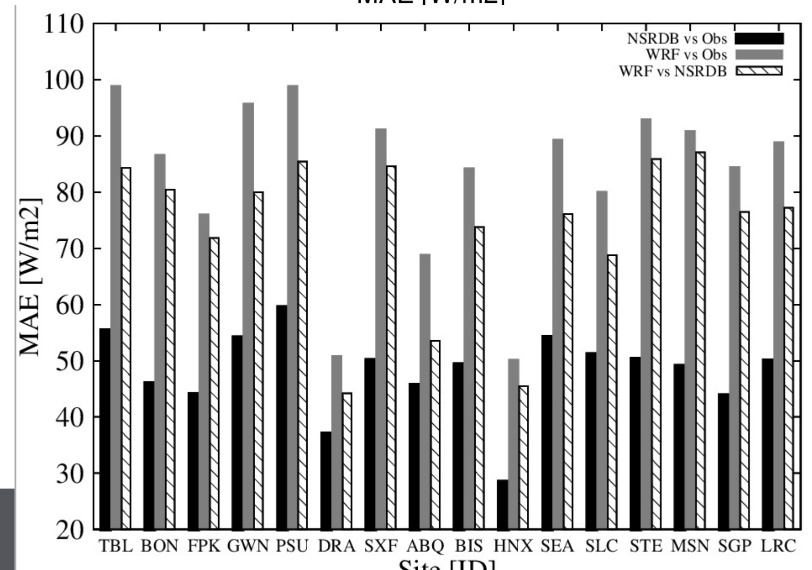
WRF-Solar will be the first numerical weather prediction model specifically designed to provide probabilistic irradiance forecast.

WRF-Solar EPS assessment and calibration

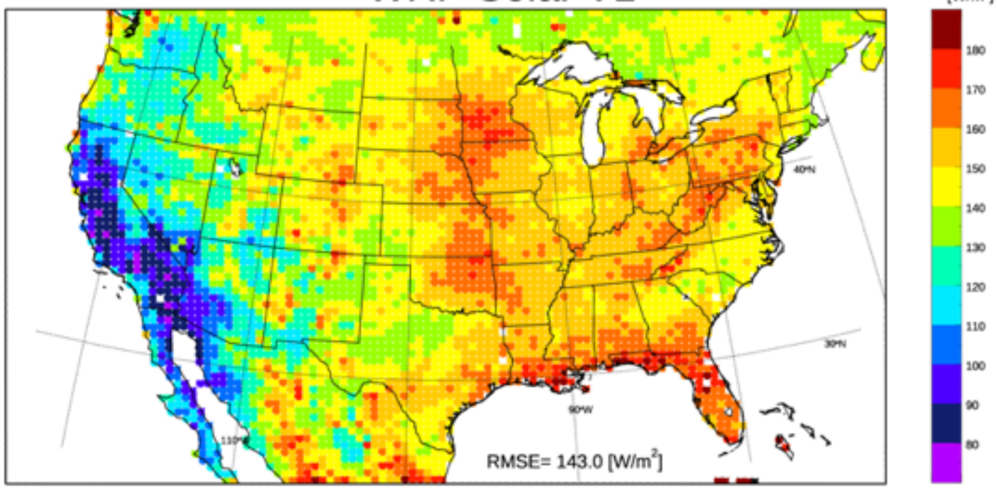
We are using satellited derived GHI and DNI products to assess and calibrate WRF-Solar EPS

Conventional high quality irradiance observations over the CONUS



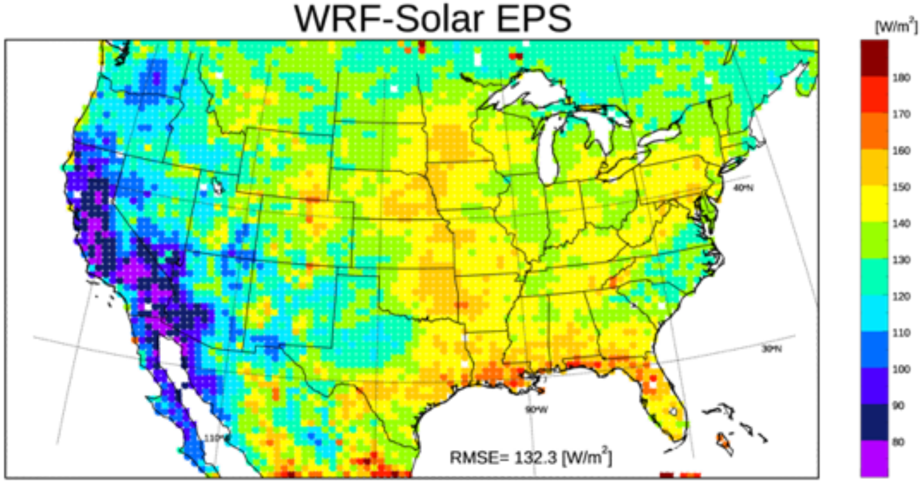


WRF-Solar V1

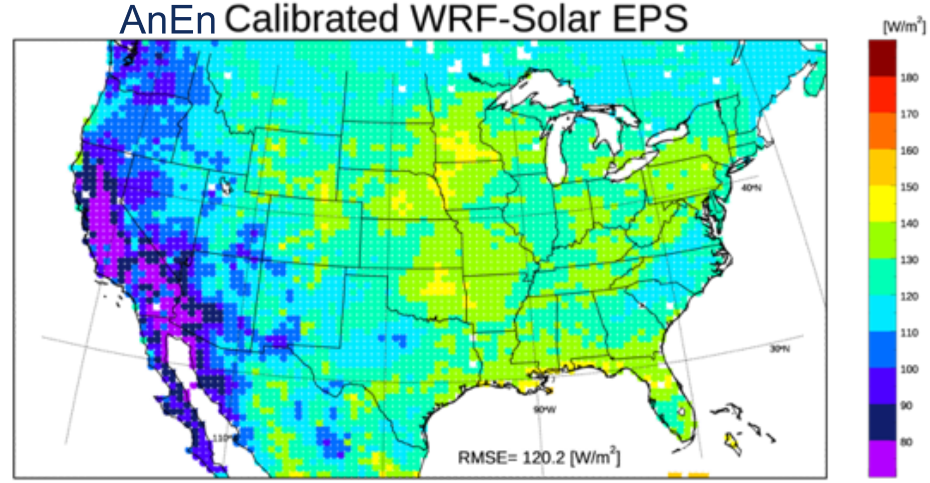


The calibrated **WRF-Solar EPS reduces the errors** in the day ahead GHI forecasts from WRF-Solar reference configuration **by 16 %** during the year of 2018.

WRF-Solar EPS



AnEn Calibrated WRF-Solar EPS



Summary

- WRF-Solar is designed to provide an appropriate numerical framework for solar irradiance forecasts

- Main developments focus on improving the representation of the aerosol-cloud-radiation system. Ongoing developments to enhance the physics and to provide probabilistic forecast (WRF-Solar EPS)

- The MAD-WRF model is contributing to enhance the cloud initialization and the short-range irradiance forecast

Questions? WRF Forum
or send email to jimenez@ucar.edu