Recent additions to the WRF-Solar model: the WRF-Solar Ensemble Prediction System and the MAD-WRF short-term prediction component

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June 2022

This material is based upon work supported by the National Center for Atmospheric Research, which is a major facility sponsored by the National Science Foundation under Cooperative Agreement No. 1852977.

Motivation

- Previous WRF-Solar efforts have mostly focused on improving the representation of the cloud-aerosol-radiation feedbacks

- WRF-Solar was lacking a ensemble prediction system specifically tailored for solar applications. Having a probabilistic forecast is necessary to be able to provide uncertainty estimations (e.g. day ahead predictions).

- The WRF-Solar model was lacking a cloud initialization component. Solar irradiance nowcasting applications based on NWP models require a good analysis of the cloud location and hydrometeor (liquid and ice) content. **The challenge is to sustain the clouds introduced in the analysis.**

Outline

1. Motivation

2. The WRF-Solar EPS model for solar irradiance probabilistic forecasts
   See also talk at 9:30 am on Thursday June 9:

   Day-ahead forecasting of solar irradiance using WRF-Solar and evaluation using the National Solar Radiation Database. **J. Kim,**, *RAL/NCAR.*

3. The MAD-WRF model for short-term solar irradiance predictions

4. Summary

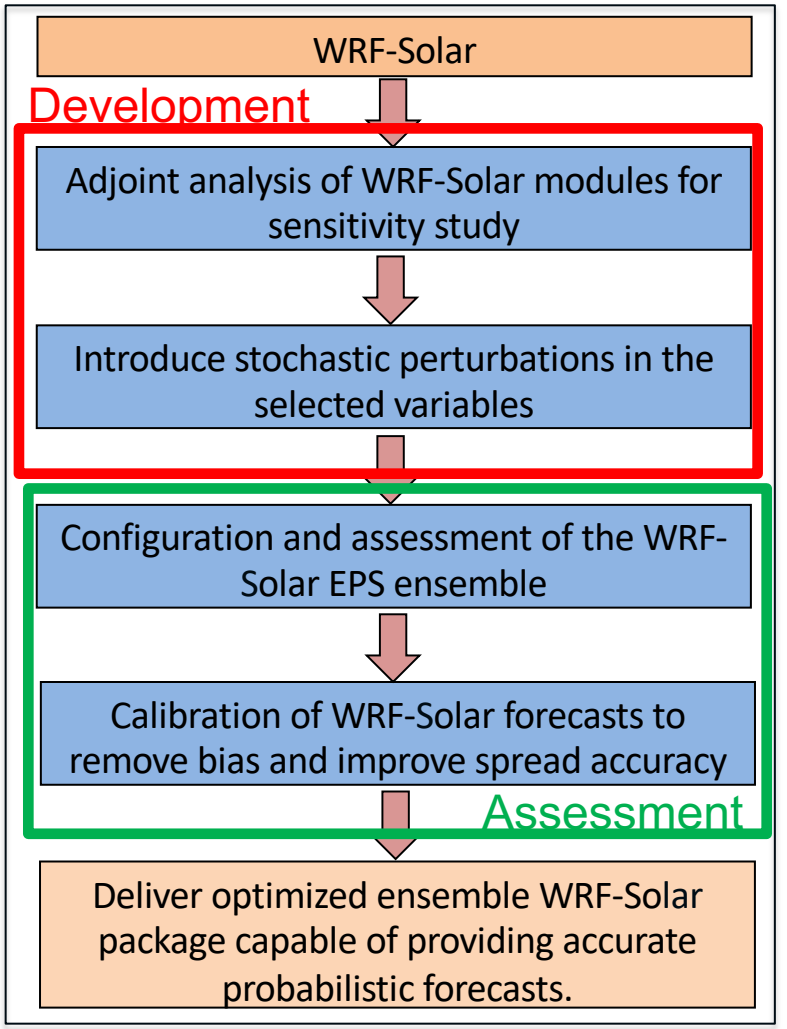
2. The WRF-Solar EPS model

- 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**

Yang, J., Kim, J.H., Jimenez, P.A., Sengupta, M., Dudhia, J., Xie, Y., Golnas, A., Giering, R., 2021: An Efficient Method to Identify Uncertainties of WRF-Solar Variables in Forecasting Solar Irradiance Using a Tangent Linear Sensitivity Analysis. Solar Energy, Vol. 220, pp.509-522.

- **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**

Kim, J.H., Jimenez, P.A., Sengupta, M., Yang, J., Dudhia, J., Alessandrini, S., Xie, Y., 2022: The WRF-Solar Ensemble Prediction System to provide solar irradiance probabilistic forecast. IEEE J. Photovoltaics, 12, 141-144



WRF-Solar is the first numerical weather prediction model specifically designed to provide probabilistic irradiance forecast. **WRF-Solar EPS available in WRF version 4.4**

WRF-Solar EPS technical aspects

Characteristics of the perturbations defined in the WRF/run/STOCHPERT.TBL configuration file

#	Variable Name	σ	λ (m)	τ (s)
1	Albedo	0.1	100000	86400
2	Aerosol optical depth	0.25	100000	3600
3	Ångström wavelength exponent	0.1	100000	3600
4	Asymmetry factor	0.05	100000	3600
5	Water vapor mixing ratio	0.05	100000	3600
6	Cloud water mixing ratio	0.1	100000	3600
7	Ice mixing ratio	0.1	100000	3600
8	Snow mixing ratio	0.1	100000	3600
9	Ice number concentration	0.05	100000	3600
10	Potential temperature	0.001	100000	3600
11	Turbulent kinetic energy	0.05	80000	600
12	Soil moisture content	0.1	80000	21600
13	Soil temperature	0.001	80000	21600
14	Vertical velocity	0.1	80000	21600

Main parameters to control WRF-Solar EPS

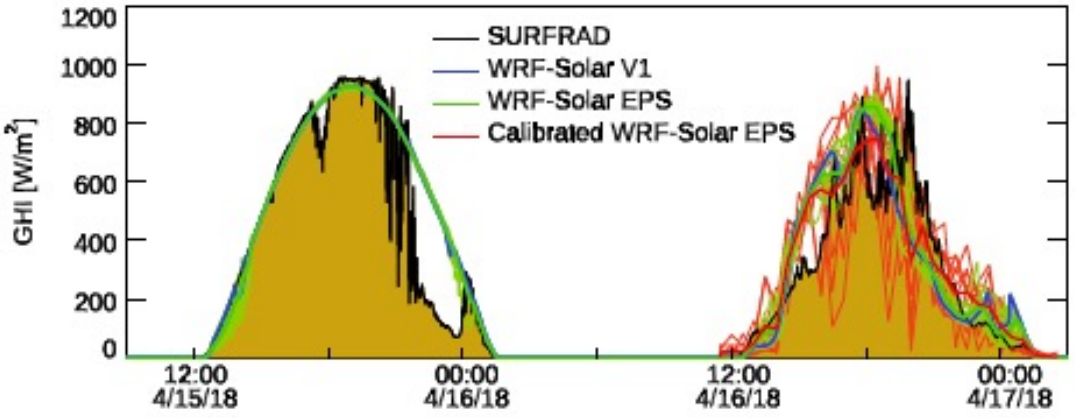
Characteristics of the perturbation
σ: Standard deviation which is used as tunning parameter to control the amplitude of the perturbation
λ: Length scale [m]
τ: Time scale [s]

Activation of the perturbations in the WRF namelist

```
&Stoch
Multi_perturb = 1
nens = 10
spdt = -1 ! Freq to update perturbs (<0 => every dt)

pert_farms = .true.
pert_farms_albedo = 1.0 ! 1.0 perturbs, 0) no perturb.
pert_farms_aod = 1.0
pert_farms_angexp
…
```

See WRF/run/README.namelist for a full list of the WRF-Solar EPS options

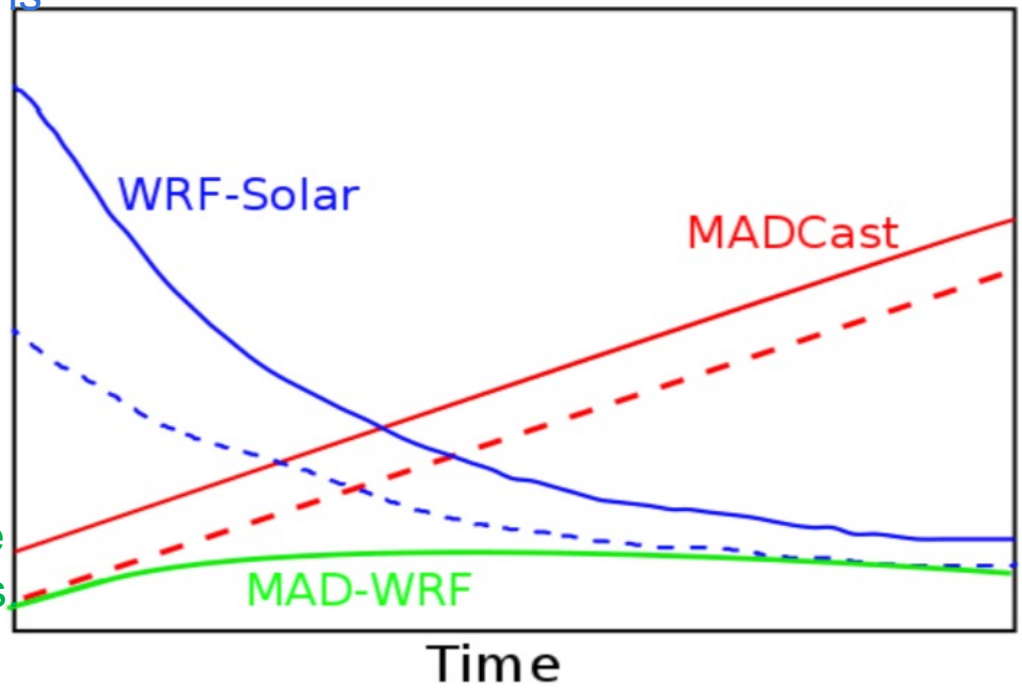


NCAR UCAR

2. MAD-WRF model

MAD-WRF combines the strengths of fundamental ideas from the satellite-based nowcasting system (MADCast) with a NWP-based nowcasting approach (WRF-Solar) to create an improved end-to-end solar irradiance forecast system.

Parameterizations to represent the aerosol-cloud-radiation interactions



MAD-WRF active: nudges the hydrometeors to the hydrometeor tracers WRF-Solar physics.

Advects and diffuses the cloud fraction without activating parameterizations

MAD-WRF passive: advects and diffuses the hydrometeors (liquid, ice and snow) without activating the microphysics

MAD-WRF model

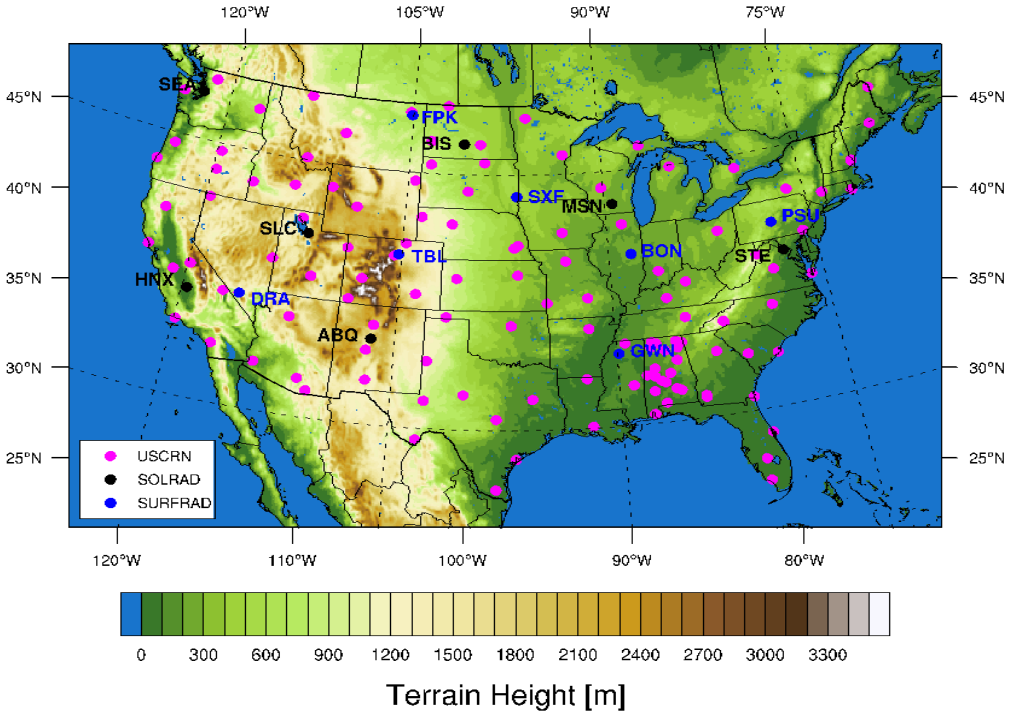
- **Cloud initialization**:
  - The cloud field is initialized using hydrometeors (if available) and relative humidity.
  - The cloud field can be refined by imposing the cloud mask and the cloud top/base height
- **MAD-WRF passive**: advects and diffuses the initial hydrometeors with no cloud microphysics
- **MAD-WRF active**: advects and diffuses the initial hydrometeors as tracers, 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 WRF/doc/README.madwrf describes how to use the model

Jimenez, P.A., J. Dudhia, G. Thompson, J. Lee, and T. Brummet, 2022: Improving the cloud initialization in WRF-Solar with enhanced short range forecasting functionality: The MAD-WRF model. Solar Energy, 239, 221-233

Evaluating MAD-WRF's performance

- Forecasts from the demonstration: March 1 2020 – Feb 28 2021
  Data is available in the website: http://www.webservice-energy.org/
- Initial conditions typically from the HRRR 1h forecast (3 km grid spacing)
- Simulations every hour. 6 h lead time
- 9 km of horizontal grid spacing over CONUS
- Assimilation cloud mask from GOES-16 and cloud top/base height from GOES-16 and METAR observations
- GHI observations from the SURFRAD, SOLRAD and USCRN networks

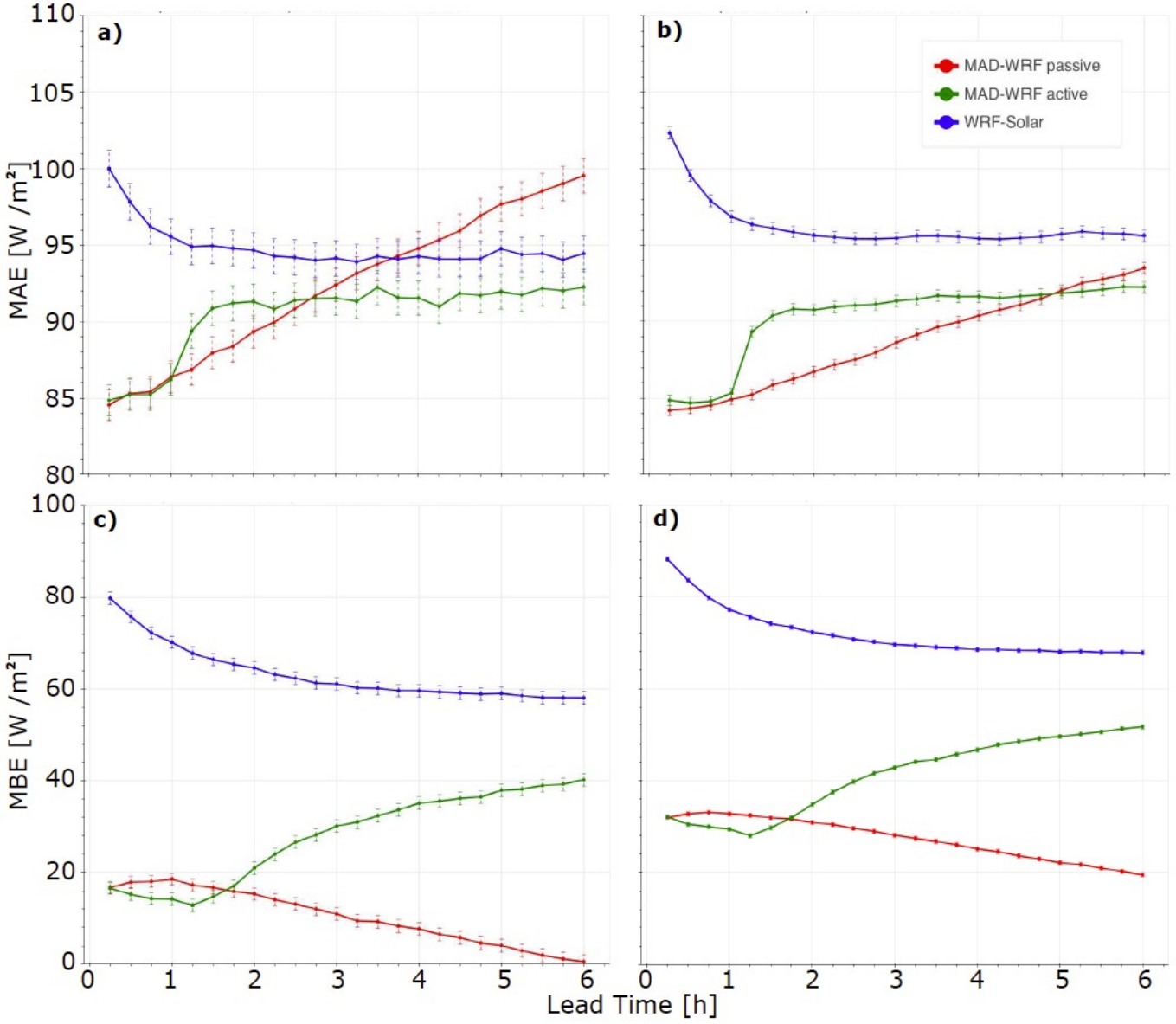
Jimenez, P.A., J. Dudhia, G. Thompson, J. Lee, and T. Brummet, 2022: Improving the cloud initialization in WRF-Solar with enhanced short range forecasting functionality: The MAD-WRF model. Solar Energy, 239, 221-233



Errors as a function of the lead time

SURFRAD-SOLRAD

USCRN



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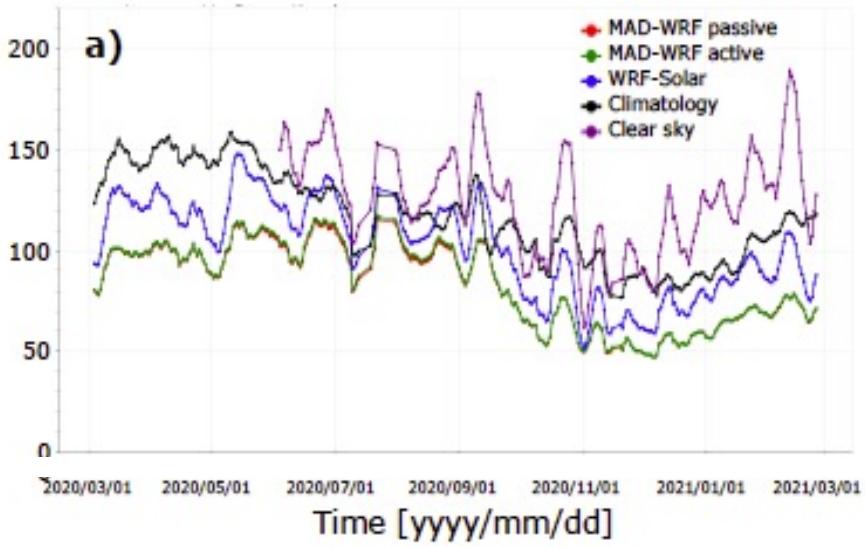
Errors as a function of the day of the year

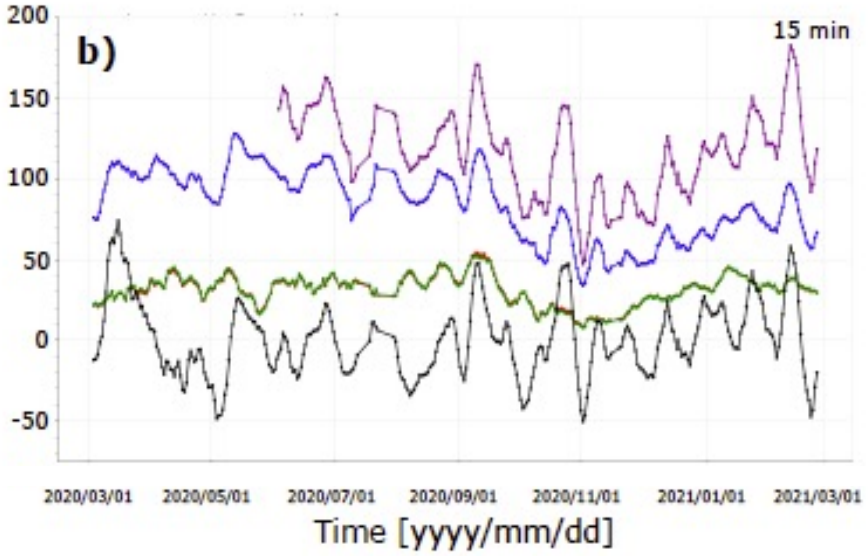
USCRN

MAE

MBE

15 Min





Summary

- The WRF-Solar EPS model has been developed to provide probabilistic solar irradiance nowcasts tailored for solar energy applications

- MAD-WRF is a nowcasting system designed for solar energy applications.
  - Cloud initialization module
  - Two modes of operation:
    - MAD-WRF passive: Assimilate cloud related observations (if available) + advect and diffuse hydrometor content with no cloud microphysics.
    - MAD-WRF active: Assimilate cloud related observations (if available) + hydrometeor content is advected and diffused as tracers and the resolved hydrometeors are nudged towards these tracers at the beginning of the simulation (first hour here)

- Both MAD-WRF and WRF-Solar EPS are available in the WRF official release

Resources

- WRF-Solar website:
  https://ral.ucar.edu/solutions/products/wrf-solar

- WRF-Solar EPS website:
  https://ral.ucar.edu/solutions/products/wrf-solar-eps

- MAD-WRF website:
  https://ral.ucar.edu/solutions/products/mad-wrf

- WRF-Solar/MAD-WRF Forum for technical assistance:
  https://forum.mmm.ucar.edu/phpBB3/viewforum.php?f=104

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