Probabilistic Cloud Optimized Day-Ahead Forecasting System Based on WRF-Solar

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May 23, 2017

Proposal No: 1649-1543

Topics

- Background
- Technical Objectives
- Approach
- Anticipated Outcomes
- Summary

Background: Solar Forecasting I

WRF-Solar improvements included

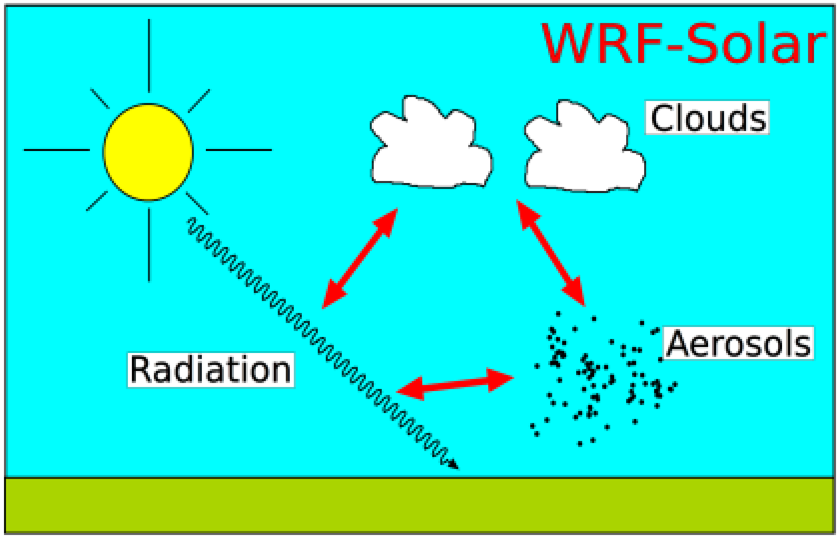
•Fast model for frequent radiative transfer calculations.

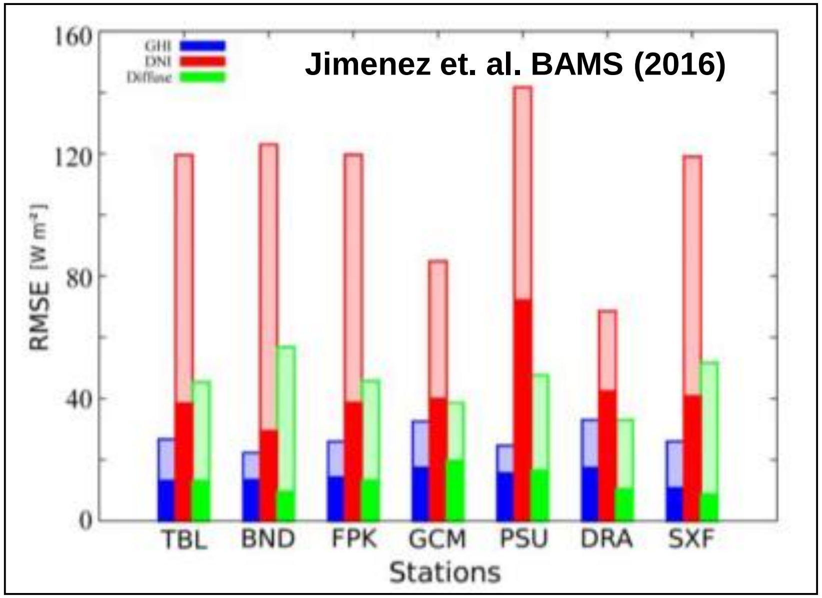
•Output of both global and direct radiation.

•Realistic aerosol for improved clear sky estimates.

•Aerosol cloud interactions.

•Sub-grid scale cloud feedback.





Background: All sky conditions

Model Biases are a result of -

•Under-prediction of clouds

•Underestimation of cloud optical depth

Cloud formation and dissipation involves complex processes involving multiple modules.

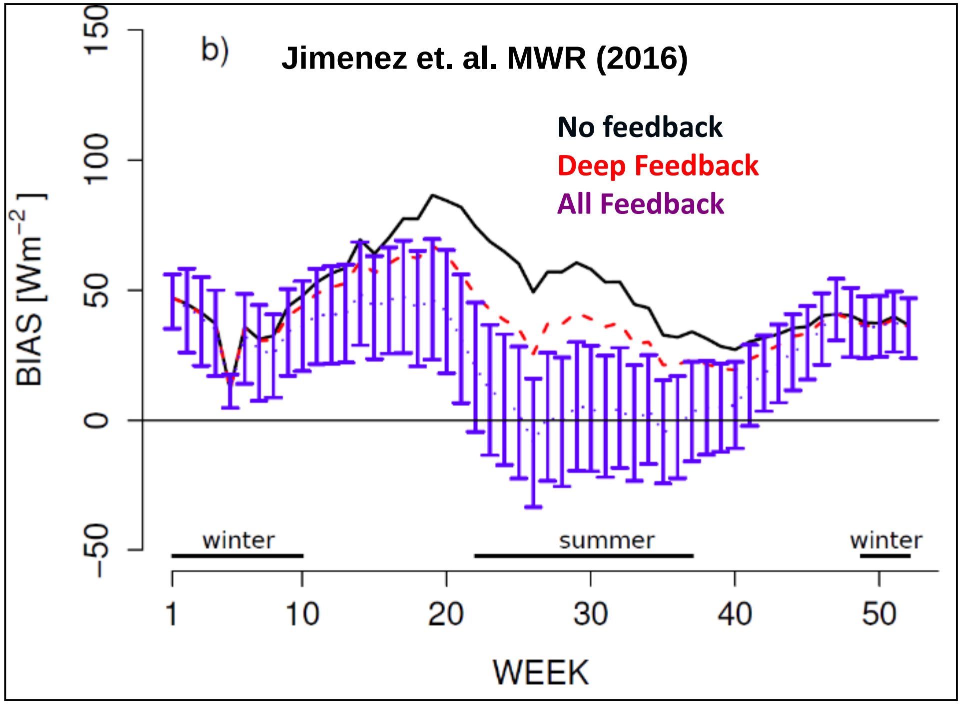
Difficult to resolve by solely improving physics due to

•The extensive feedback between processes

•Uncertainty in initial and boundary conditions.

•Limitation on model resolution and the requirement of physics representation.

Requires model calibration steps that can reduce errors in bias and spread.



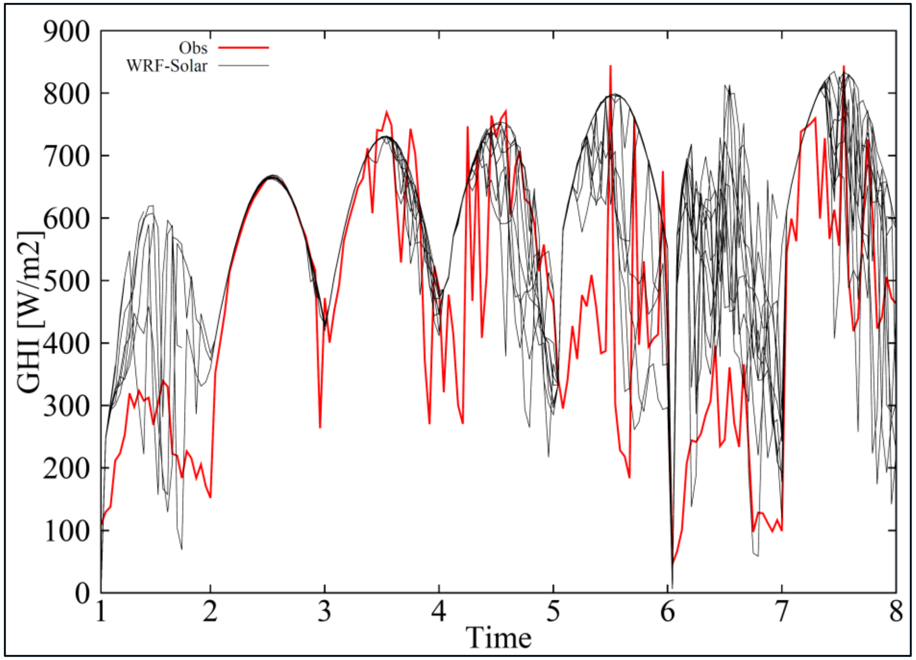
Background: Deterministic Vs Probabilistic Forecast

Deterministic forecast can potentially result in incorrectly predicting clear sky (day 5).
Deterministic forecast does not inform us about how confident we are on the predictions.
Under-prediction of clouds in the ensemble (easily seen on day 1 and day 6).
<u>What do we need:</u>

•Ensemble based probabilistic forecast.

•Careful selection of relevant variables to perturb the ensembles.

•Calibration to provide unbiased forecasts with accurate ensemble spread.



The ensemble perturbs temperature and winds which is not the optimal for solar irradiance forecasting

Technical Objectives

Develop Solar Forecasting System based on WRF-Solar that-

•Provides probabilistic forecasts for the grid.
•Ensemble members tailored for solar forecasts.
•Optimized to operate with few ensemble members.
•Calibrated to remove bias in forecasts and meaningful quantification of the uncertainties.
•Improves the current-state-of-art solar forecasts and reduces uncertainty by 50% from current levels.
•Improves both average irradiance and ramp forecasts.

Approach

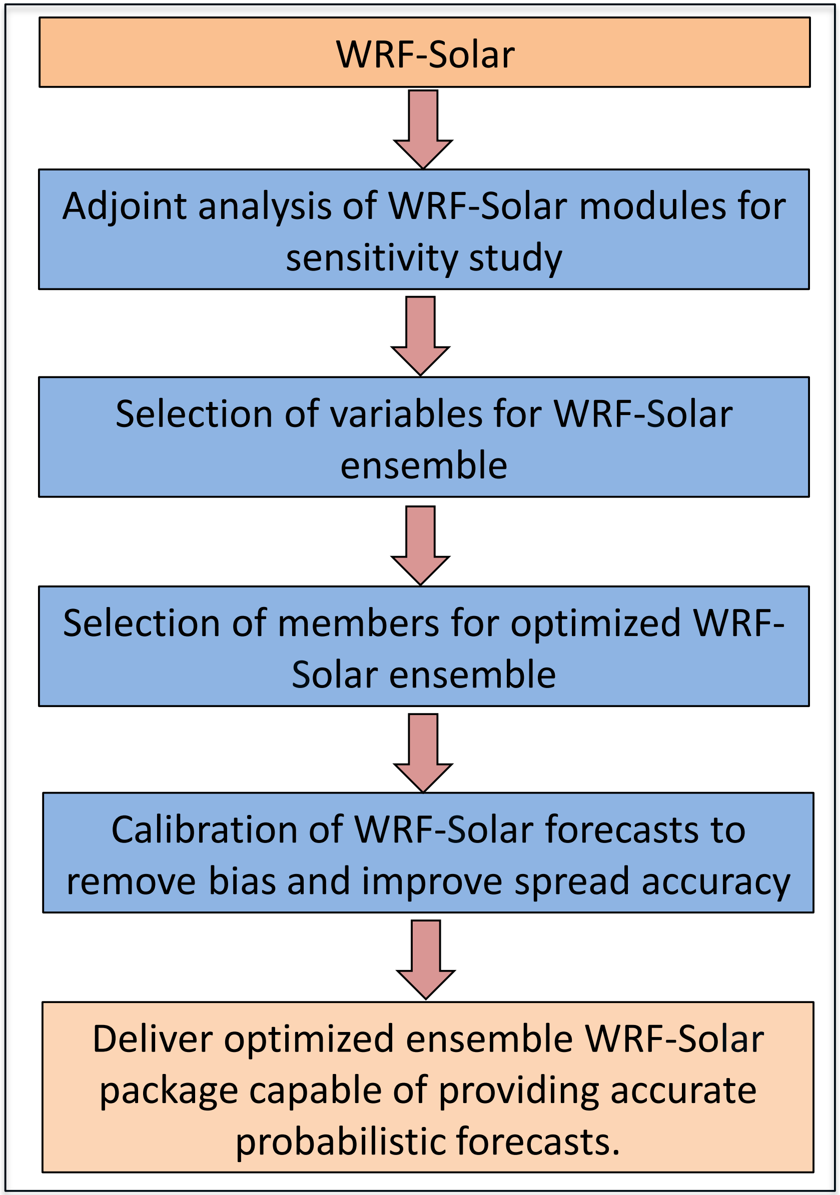
•Identify variables that significantly influence the formation and dissipation of clouds and solar radiation through an **adjoint analysis** of WRF-Solar modules that influence cloud processes.

•Consolidate the variables identified in step (a) to develop the **WRF-Solar ensemble** forecasting system.

•**Calibrate the WRF-Solar ensemble system** using measurements to ensure that the forecasts' trajectories are unbiased and provide accurate estimates of forecast uncertainties under a wide range of meteorological regimes.

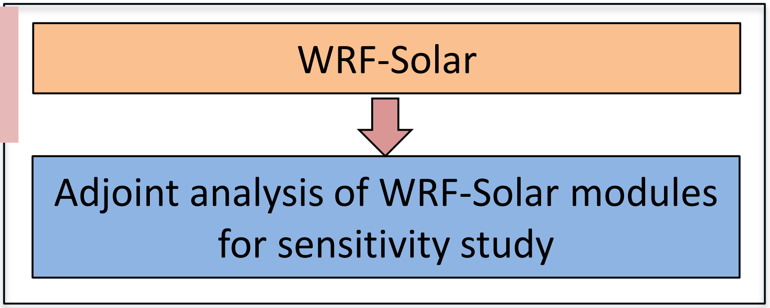
•**Demonstrate the improvements** delivered by the probabilistic forecasts for the regions and locations identified by Topic Area 1.

•Develop and deliver an **open-source probabilistic WRF-Solar system** for the solar energy community.



Approach: Adjoint model

Goal: Study sensitivity of inputs to WRF-Solar modules that influence clouds and radiation.

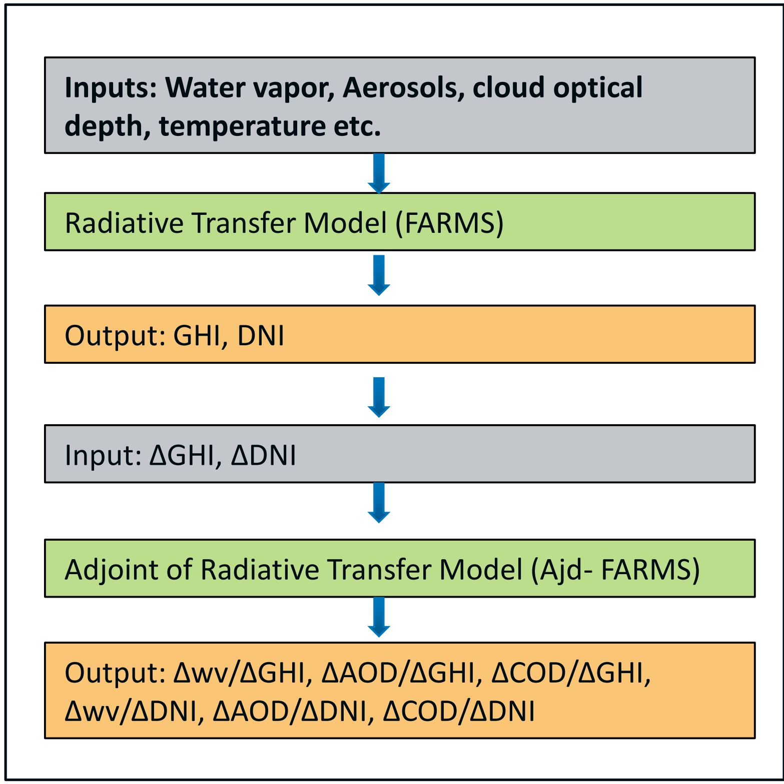


What does an adjoint do –

- Provides the sensitivity of model input for given perturbation of model output.
- Provides a fast an elegant method to analyze contribution to errors in model output.
- Used in 4D-Var data assimilation to operate NWP model backwards in time to incorporate observations during analysis phase.

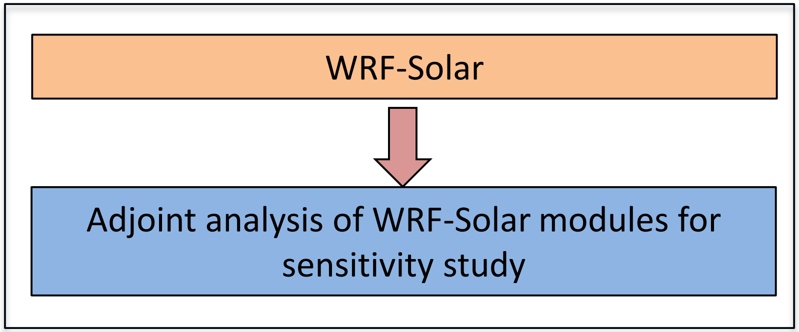
Our approach is innovative –

- Extract modules that significantly influence clouds and solar radiation in WRF-Solar.
- Build offline adjoints using automated adjoint compilers and test for stability and accuracy.
- Develop sensitivity analysis for all modules.
- Identify variable that significantly influence the formation and dissipation of clouds and solar radiation.



Approach: Adjoint model

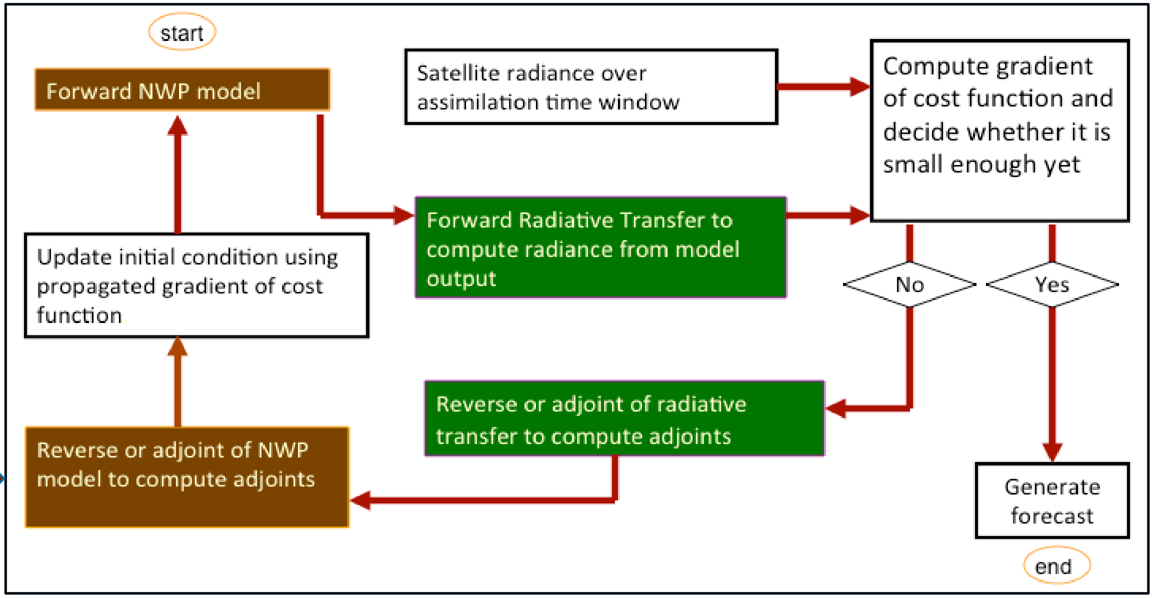
Goal: Study sensitivity of inputs to WRF-Solar modules that influence clouds and radiation.



Develop offline adjoints for the following WRF-Solar modules:

1.- Radiative transfer model
2.- Land surface model
3.- Cloud microphysics (clouds explicitly resolved by the model).
4.- Boundary layer clouds
5.- Subgrid-scale clouds

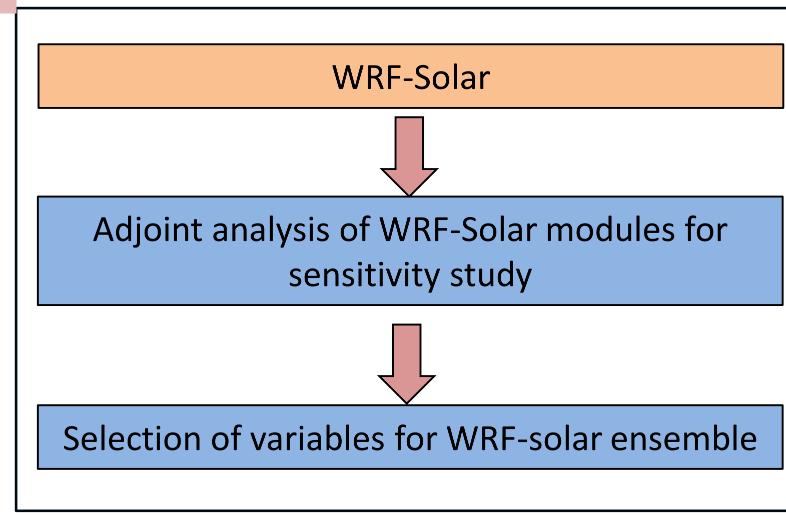
Adjoint of NWP model is used in 4-Dvar system.



Approach: Variable Selection

Goal: Identify set of variables that significantly influence cloud and radiation for developing optimized WRF-Solar Ensembles.

- Consolidate the variables identified during the adjoint analysis to develop the WRF-Solar ensemble forecasting system.
- Develop WRF-Solar capability to perturb the variables and parameters relevant for solar energy applications.
- The user will configure the model via a namelist.



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

Approach: Down-selection

Goal: Identify optimized ensemble members set that allows for shorter model runtimes while covering the full range of output uncertainty.

<u>Down-select WRF-Solar ensemble members</u>

•Develop multiyear simulation of a large number of ensembles.
•Determine optimal numbers of ensemble members through cluster analysis.

<u>Cluster Analysis optimizes –</u>
the variables/parameters to perturb in each member.
Selection of a set of ensemble members with different set of perturbed variables/parameters.

WRF-Solar

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Adjoint analysis of WRF-Solar modules for sensitivity study

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Selection of variables for WRF-solar ensemble

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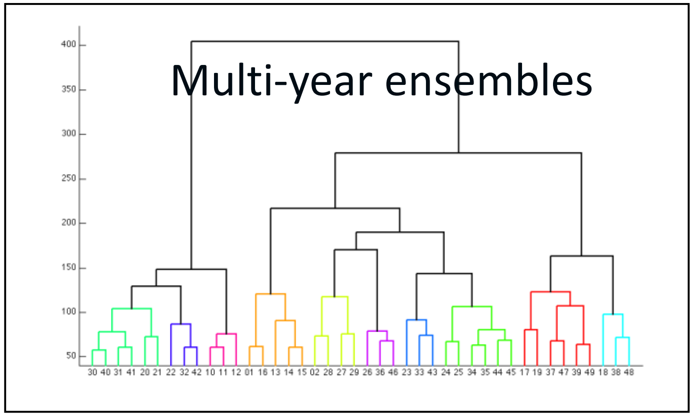
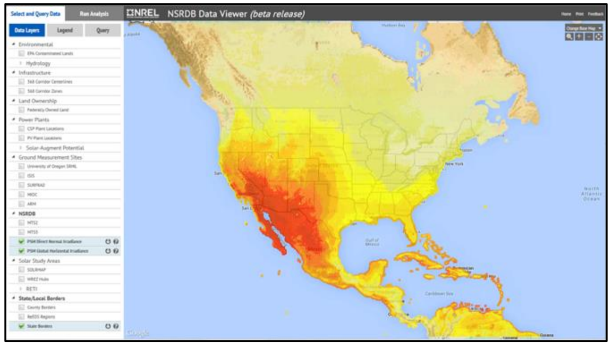
Selection of members for optimized WRF-solar ensemble



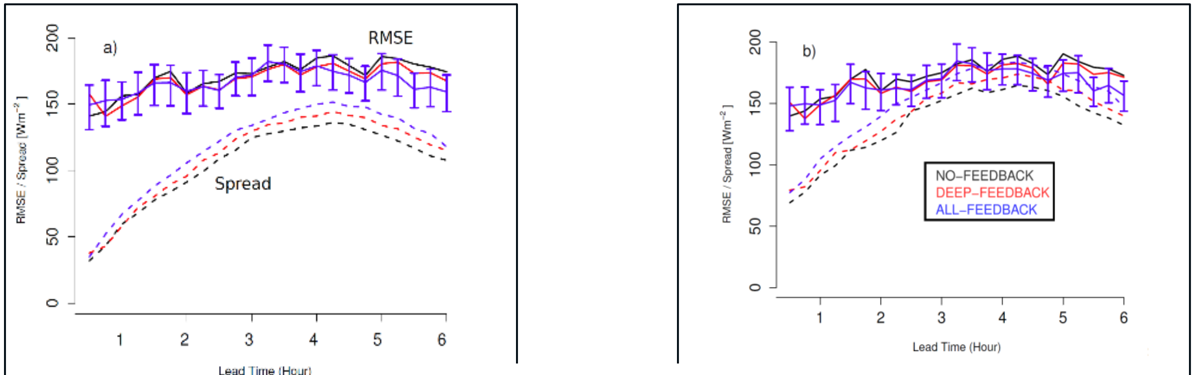
Approach: Calibration

Goal: Use measurements to ensure that the forecasts' trajectories are unbiased and provides accurate estimates of forecast uncertainties under a wide range of meteorological regimes.

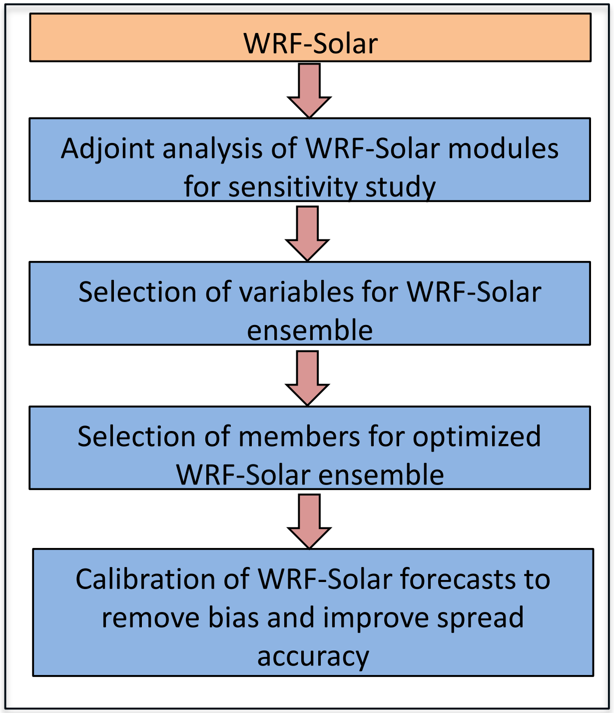


Calibrate the WRF-Solar ensemble system

- Develop database of long-term observation of solar radiation (GOES/GOES-R from NSRDB, First Solar and Southern Company sites)
- Remove biases in the forecast by comparing to observations.
- Calibrate the ensemble so that the spread of the ensemble (standard deviation of the estimations) matches the error of the forecast.



Jimenez et. al. MWR (2016)



Approach: Assessment and delivery

Goal: Demonstrate the improvement delivered by the probabilistic forecasts for the regions and locations identified by Topic Area 1.

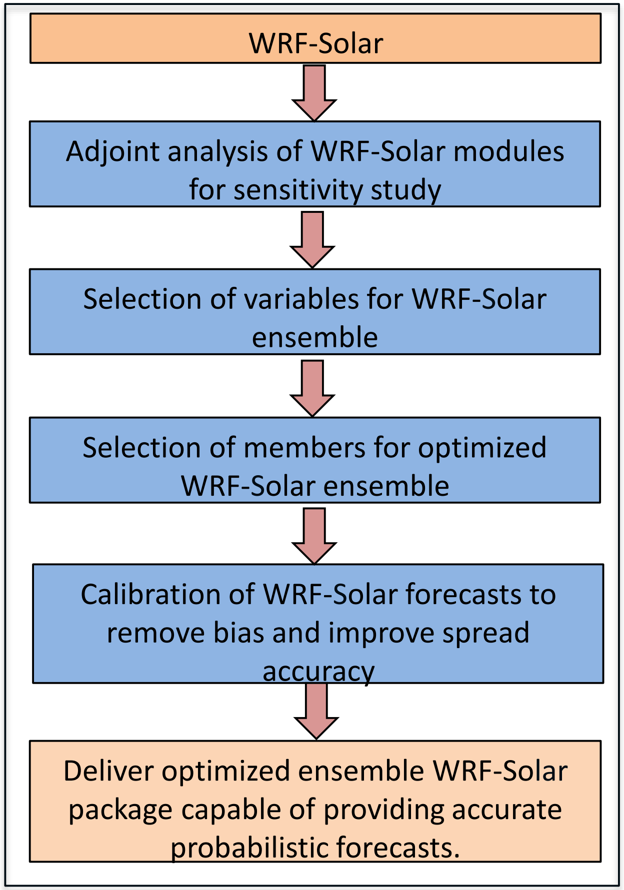
Forecast evaluation will be performed over the regions identified by Topic Area 1.

Datasets used for validation:

- Cloud optical depth and solar radiation data from the National Solar Radiation Data Base (NSRDB).
- Solar radiation and power data from multiple sources: First Solar and Southern Company.
- Coordination with the awardee of Topic Area 1.
- Peer-reviewed publications to be expected from various stages of project.

Final Goal: Create an open-source probabilistic WRF-Solar system for the solar energy community.

- Deliver public-version of Ensemble WRF-Solar through existing WRF-Solar delivery mechanism.
- Provide support to users through training.



Anticipated Outcomes

- Publicly available probabilistic forecast system based on WRF-Solar that can easily be used by forecast providers.
- Optimized to deliver forecast using small set of ensembles.
- Calibrated to deliver unbiased forecast with accurate forecast spread.
- Reduces forecast errors by 50% compared to current baseline as determined by Topic Area 1.

Summary

- Project enhances scientific advances produced through Solar Forecasting 1 developed WRF-Solar.
- Uses innovative adjoint-based approach to determine variables that influence NWP based solar forecasts.
- Develops multi-year ensemble forecasts to determine ensemble members through cluster analysis.
- Uses multi-year ensemble forecasts to calibrate forecasts using Bayesian model averaging.
- Develops ensemble WRF-Solar system that has minimal bias and realistic spread.
- Validates forecasts in collaboration with Topic Area 1 awardee.
- Deliver’s the first ever publicly available ensemble forecasting system for solar applications.

Thank You:

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Calibration

Example for zonal wind

CRPS quantifies both the accuracy of the forecast (e.g. RMSE) and the RMSE-spread consistency.

Calibration reduces the CRPS.

A reduced set of ensembles can provide better CRPS than the full ensemble.