Adjoint Sensitivity Analysis of FARMS for Forecasting Variables of WRF-Solar

Jaemo Yang[1], Manajit Sengupta[1], Yu Xie[1], Pedro A. Jimenez[2], Ju-Hye Kim[2]

[1]National Renewable Energy Laboratory, Golden, CO, USA

[2]National Center for Atmospheric Research, Boulder, CO, USA

1. INTRODUCTION

- A probabilistic solar forecast using the ensemble members created through the optimized perturbation of initial conditions enables the accurate prediction of confidence in solar power forecast.
- The Fast All-sky Radiation Model for Solar applications (FARMS) is the radiation component of WRF-Solar that efficiently computes solar radiation using the forecasting of cloud properties.
- Adjoint modeling allows an efficient estimation of sensitivity of model output with respect to inputs without requiring thousands of runs to perturb each input individually.

Objective: Develop an adjoint model to investigate the sensitivity of solar radiation to forecasted variables from FARMS.

2. THEORY OF ADJOINT

Tangent linear model (TLM)

- Derived from the forward model

$$\mathbf{Y} = \mathbf{M}(\mathbf{X})$$

$\mathbf{M}$: nonlinear model

$\mathbf{Y}$: vector of output variables

$\mathbf{X}$: matrix of input variables

- Tangent linear operator (**L**) gives the derivative of the forward model with respect to the independent variable

$$d\mathbf{Y} = \mathbf{L}d\mathbf{X} \qquad \mathbf{L} = \frac{\partial \mathbf{Y}}{\partial \mathbf{X}}$$

$d\mathbf{Y}$: tangent linear output

$d\mathbf{X}$: tangent linear input

$\mathbf{L}$: matrix of the partial derivatives of Y with respect to X (tangent linear operator or Jacobian)

Adjoint model (ADM)

- Derived from the tangent linear model
- If < , > is a scalar product and **A** is a linear operator, we define the adjoint of **A** as the operator $\mathbf{A}^{\mathrm{T}}$ satisfying:

$$\langle \mathbf{AX}, \mathbf{Y} \rangle = \langle \mathbf{X}, \mathbf{A}^{\mathrm{T}}\mathbf{Y} \rangle$$

for every choice of **X** and **Y**.

- Therefore, $\langle \mathbf{L}d\mathbf{X}, d\mathbf{Y} \rangle = \langle d\mathbf{X}, \mathbf{L}^{\mathrm{T}}d\mathbf{Y} \rangle$

$d\mathbf{Y}$: adjoint input

$d\mathbf{X}$: adjoint output

- Adjoint (LT) gives the transpose of the derivative of the forward model with respect to the independent variable

In this study, normalized d(GHI) and d(DNI) are analyzed with respect to the input variables for FARMS.

3. METHODOLOGY

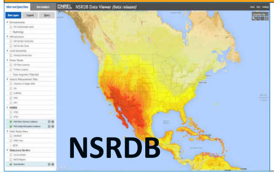
Phase1: Produce FARMS Tl/adj. codes by TAF

Transformation of algorithms in Fortran (TAF): automatic differentiation tool -> enables a sensitivity analysis of complex functions that have been coded into Fortran.

Phase 2: Linearity test and Tl/adj. test

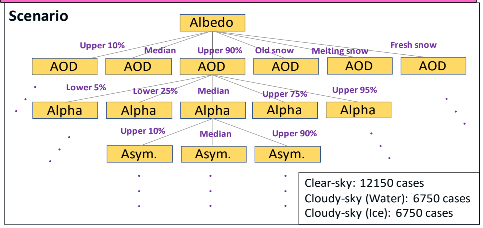
Check the validation of Tl/adj. codes for a linear approximation of radiative transfer model.

Phase 3: Probability distribution from NSRDB



Extract variables (e.g. AOD, cloud optical depth) from NSRDB and process the data for FARMS inputs at state-level (lower 10%, median, upper 90% in Northwest).

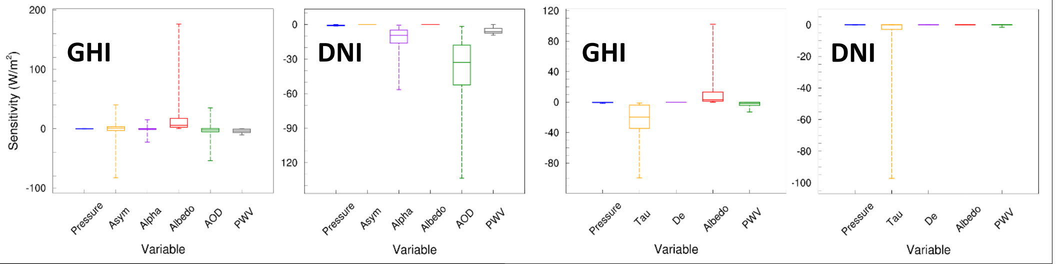
Phase 4: Scenario analysis



Clear-sky: 12150 cases
Cloudy-sky (Water): 6750 cases
Cloudy-sky (Ice): 6750 cases

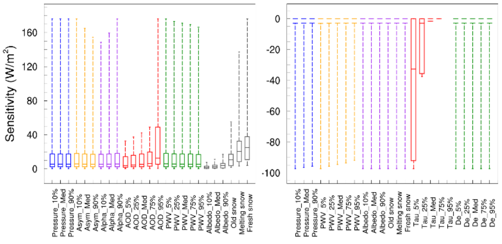
4. RESULTS

Analysis of all cases under clear and cloudy sky conditions


Clear-sky (12150 cases)

Cloudy-sky (6750 cases)

Example of scenario analysis


Sensitivity of GHI w.r.t Albedo (clear-sky)

Sensitivity of DNI w.r.t Tau (cloudy-sky)

5. CONCLUDING REMARKS

- As an initial step for developing the framework for WRF-Solar probabilistic forecasts, an adjoint model of FARMS is developed to identify the input variables with lower-/higher order sensitivities.
- Albedo and AOD has shown the highest sensitivities for GHI and DNI, respectively in clear-sky conditions.
- In cloudy-sky conditions, cloud optical depth (Tau) is the highest sensitive variable for GHI and DNI.

Further direction: The adjoint sensitivity of WRF-Solar variables will be analyzed for NOAH LSM, Thompson microphysics parameterization, MYNN boundary layer parameterization, and Deng shallow cumulus scheme.

This work was authored in part by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by U.S. Department of Energy Office of Energy Efficiency and Renewable Energy Solar Energy Technologies Office. The views expressed in the article do not necessarily represent the views of the DOE or the U.S. Government. The U.S. Government retains and the publisher, by accepting the article for publication, acknowledges that the U.S. Government retains a nonexclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this work, or allow others to do so, for U.S. Government purposes.

2019 Joint WRF/MPAS User's Workshop
Boulder, Colorado
10-14 June, 2019
NREL/PO-5D00-74092