Exploring Effects of Cloud Microphysics and Domain Size on Surface Solar Radiation Using a New WRF-Solar Based Evaluation Framework

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Abstract

Although it has been well recognized that clouds tremendously affect the surface solar irradiance and its direct and diffuse partitions, accurately forecasting solar radiation in cloudy conditions remains a major challenge. This study focuses on two aspects of the challenge: impacts of cloud microphysics and model domain size. First, we will examine the sensitivity of surface solar radiation and its partitions to cloud microphysics by using the state of art Weather Research and Forecasting model specifically designed for simulating and forecasting solar radiation (WRF-Solar). A number of microphysical schemes will be tested, and comparison against the measurements of shallow cumulus clouds and stratiform clouds selected at the DOE ARM SGP Site. Efforts will be made to quantify the resultant uncertainty spread. Second, identifying the physical causes of the underlying model differences is even more challenging. To address this, we will introduce a new model evaluation framework based on different setups of WRF-Solar (single column, LES, and nested WRF). In particular, we will examine the effect of the number of LES grid columns and its lower limit producing reasonable results. Commonly used evaluation metrics will be used in our model evaluation, including the used RMSE, MAE, MAPE, and relative Euclidean distance. The results will provide physical insight into the understanding of cloud-radiation interactions and forecasting of solar radiation in cloudy conditions.

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Introduction

Clouds tremendously affect the surface solar irradiance and its direct and diffuse partitions, and accurately forecasting solar radiation in cloudy conditions remains a major challenge. This study employs a new model evaluation framework based on WRF-Solar model to investigate the surface solar irradiance in shallow cumulus condition. This work has three objectives:

- ➢To explore the effect of the number of large eddy simulation (LES) grid columns and its lower limit producing reasonable results.
- ➢To examine the sensitivity of surface solar radiation and its partitions to different cloud microphysics schemes.
- ➢To identify the physical causes that lead to model bias, therefore the model can be improved.

New Model Evaluation Framework

WRF-Solar testbed suite: The state of art Weather Research and Forecasting model specifically designed for simulating and forecasting solar radiation (WRF-Solar) is used to simulate the clouds and surface solar irradiance.

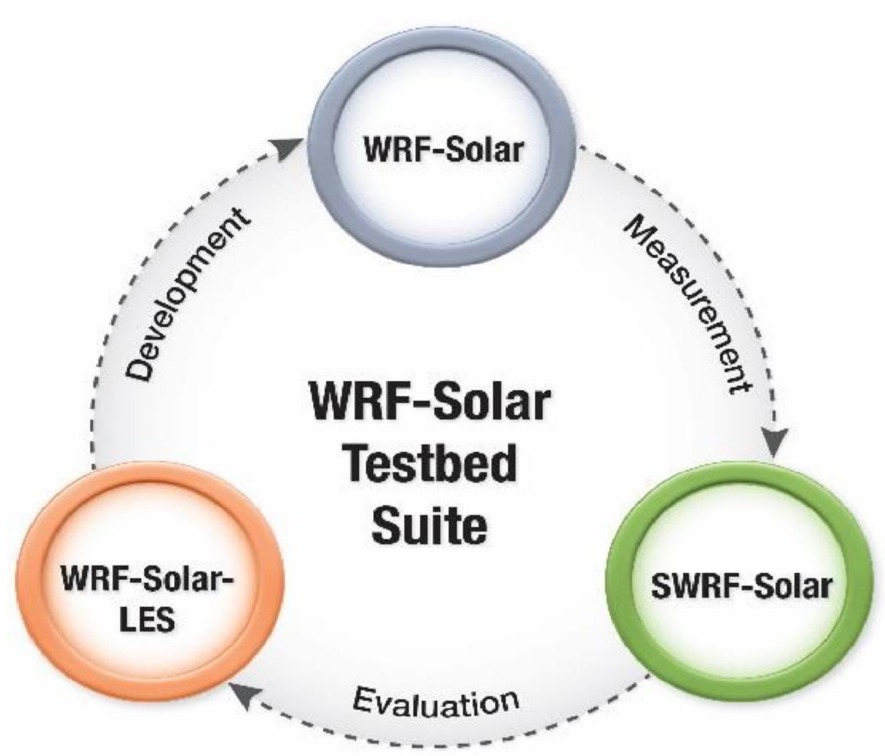


Figure 1. WRF-Solar suite, the modeling framework.

Three configurations of WRF-Solar :

- Conventional model (Nested WRF-Solar)
- Large eddy simulation (LES)
- Single column model (SCM)

Persistence model:

- P(t+dt) = P(t)

Evaluation metrics suite: A range of metrics are used to evaluate the model simulation:

- Mean bias, Standard deviation, Correlation coefficient, RMSE, Percent error and Relative Euclidean distance (D).

$$D = \sqrt{\left(\frac{\bar{x}-\bar{y}}{\bar{y}}\right)^2 + \left(\frac{\sigma_x-\sigma_y}{\sigma_y}\right)^2 + \left(c_{xy}-1\right)^2}$$

Cloud Fraction & Solar Irradiance

Case: shallow cumulus at ARM SGP site on 2016-06-19

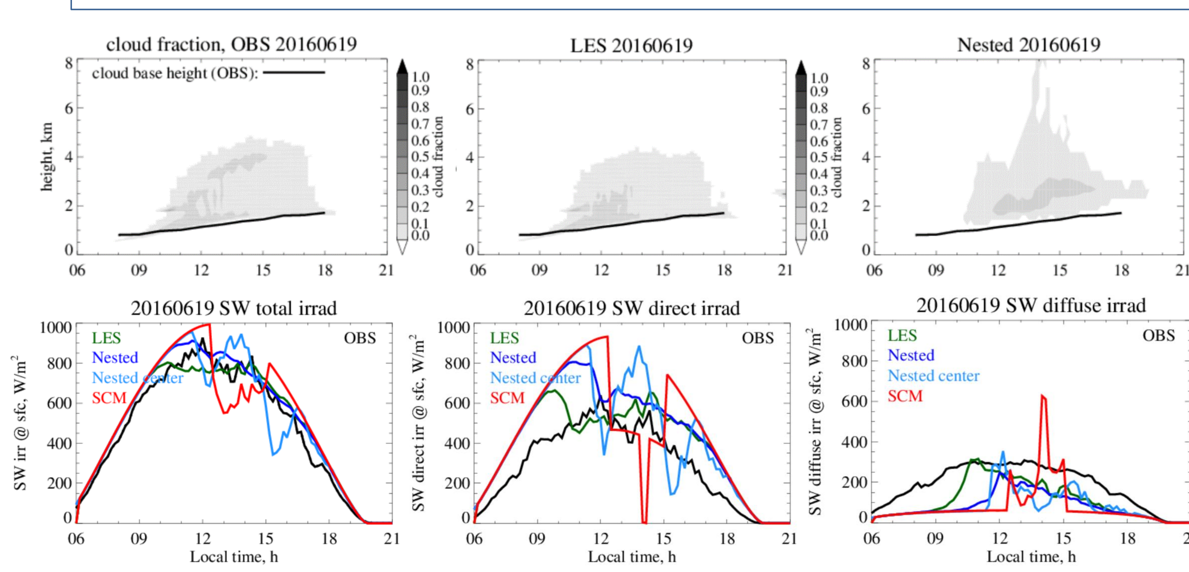


Figure 2. Comparison of simulated clouds and solar irradiance to observation.

- LES reproduces the cloud fraction well.
- Simulated total irradiance is closer to OBS.

Evaluation of WRF-Solar Suite

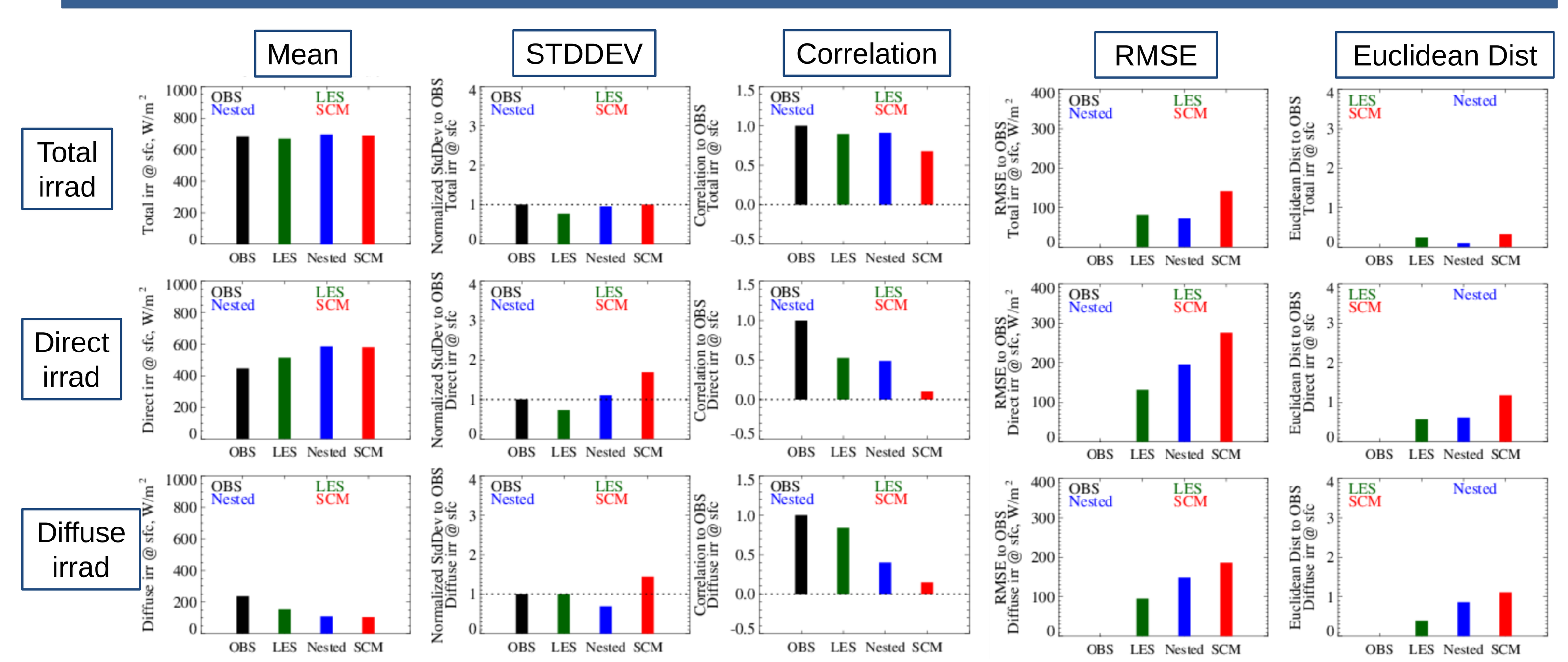
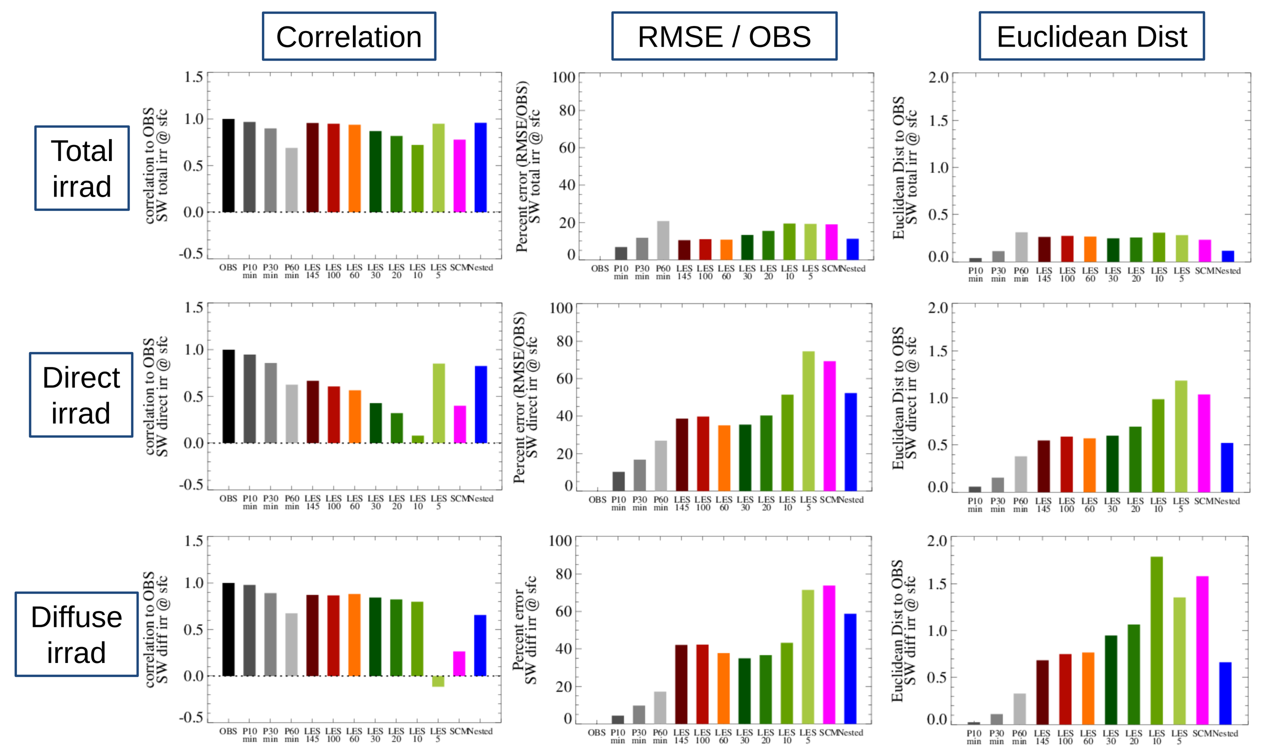


Figure 3. Evaluation metrics of total, direct, and diffuse solar irradiance.

- A single metric gives only part of the information.
- Simulated total irradiance is "correct" for "wrong" reason.

LES Domain Size Effect



- LES degrades with decreasing domain size.
- Remarkable degradation when size < 6km.
- The persistence model has biases comparable to physical model after ~ 1h.

Figure 4. Comparison of evaluation metrics among all models including LES (dx=100m) with different domain sizes.

LES Resolution Effect

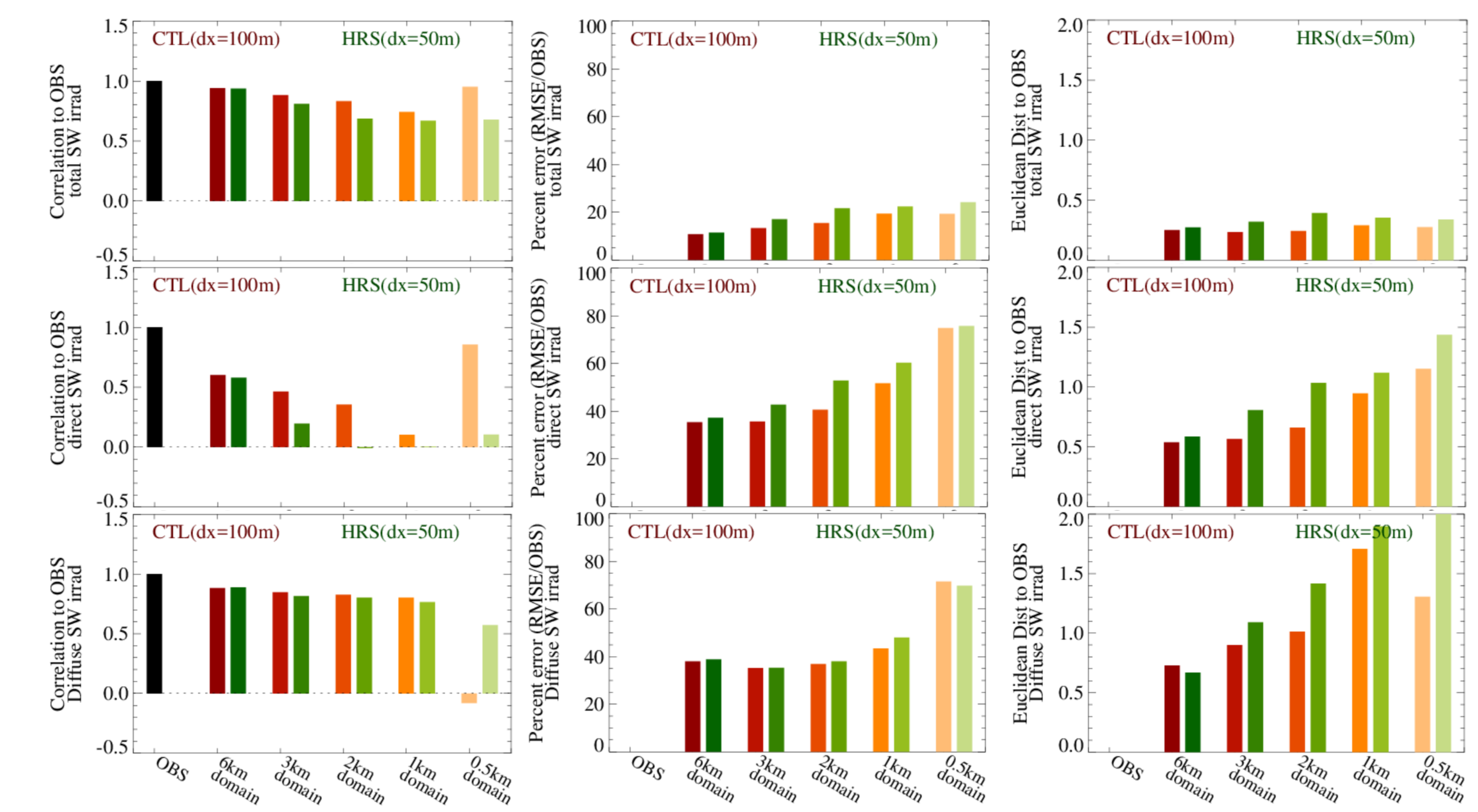


Figure 5. Comparison of evaluation metrics among LES with different domain size and resolution. 100m and 50m grid spacing are used for each domain size of 6km, 3km, 2km, 1km and 0.5km.

- Increased resolution does not necessarily improve the performance since higher resolution results in more cloud water leading to a more significant influence on solar irradiance.

Sensitivity of Microphysics

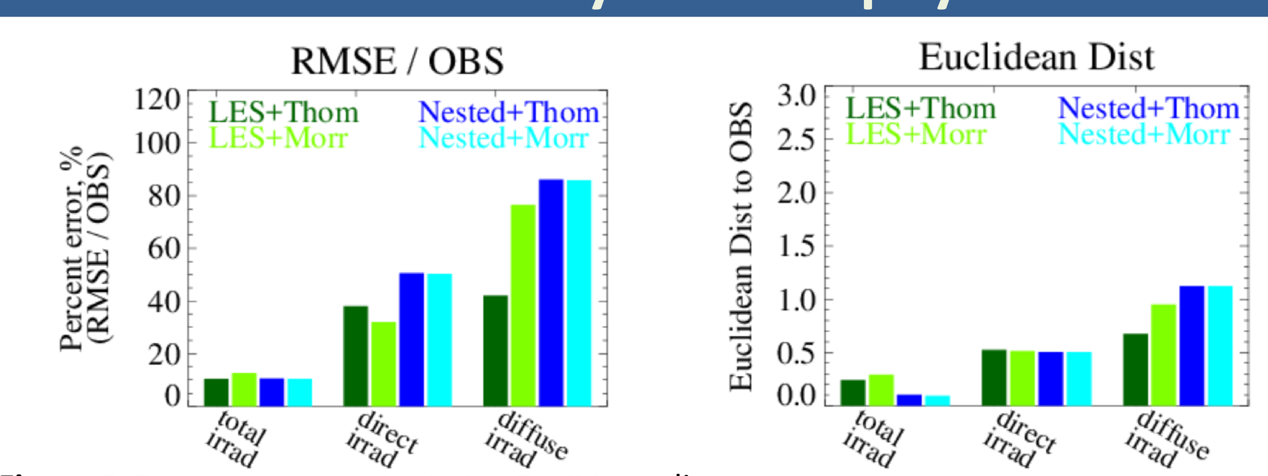


Figure 6. Percent error and relative Euclidean distance between Thompson and Morrison schemes.

- Morrison scheme produces larger bias in diffuse irradiance with LES configuration. Other than that, the simulated solar irradiance is comparable using Thompson and Morrison schemes.

Conclusions

- ➢ The total SW irradiance from all WRF-Solar simulations appears to be reasonable due to the cancellation of model biases in direct and diffuse irradiances. However, the physical processes may not be well represented in the model.
- ➢ LES produces more reasonable solar irradiances in the shallow cumulus condition when domain size is > ~ 6km.
- ➢ Increased resolution in LES does not improve the simulated solar irradiance.
- ➢ The two microphysics schemes (Thompson and Morrison) lead to differences in diffuse irradiance, but the results are inconclusive. More microphysics schemes need to be tested.

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References

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