Investigation of the Influences of Cloud Microphysics and Aerosol-Cloud Interactions on Solar Irradiance Using WRF-Solar Model

Xin Zhou[1], Yangang Liu[1], Wuyin Lin[1], Satoshi Endo[1], and Shinjae Yoo[1]

[1]Brookhaven National Laboratory

November 24, 2022

Abstract

Accurate forecast of solar irradiance remains a major challenge, especially under the influences of aerosols, clouds and aerosol-cloud interactions due to their inadequate parameterizations in numerical prediction models. This study focuses on the impacts of cloud microphysics and the indirect aerosol effect on solar irradiance. The state of art Weather Research and Forecasting model specifically designed for simulating and forecasting solar radiation (WRF-Solar) is employed to investigate the sensitivity of the total solar irradiance and its partitioning into direct and diffuse irradiances to aerosol and cloud properties. First, a number of microphysical schemes will be tested against the measurements of shallow cumulus and stratiform clouds at the DOE ARM SGP site. Efforts will be made to quantify the uncertainty spread. The effects of cloud microphysics on surface solar irradiance will be identified. Second, the indirect aerosol effect on cloud formation and thus surface solar irradiance will be investigated by using the Thompson aerosol aware microphysical scheme and different treatment of aerosols. In particular, we will examine the aerosol indirect effects in different cloud regimes. To address the aforementioned problems, we will introduce a new model evaluation framework based on different WRF-Solar setups (nested WRF, WRF-LES, and single column WRF). In addition, different evaluation metrics will be used, including the RMSE, MAPE, and relative Euclidean distance. The results will provide physical insight into the understanding of aerosol-cloud-radiation interactions and into improving solar radiation forecast in cloudy conditions.

GC53F-1179

Investigation of the Influences of Cloud Microphysics and Aerosol-Cloud Interactions on Solar Irradiance Using WRF-Solar Model

Xin Zhou, Yangang Liu, Wuyin Lin, Satoshi Endo, and Shinjae Yoo
Brookhaven National Laboratory, Upton NY, USA

AGU 2019 Fall Meeting

Introduction

Clouds tremendously affect the surface solar irradiance and its direct and diffuse partitions; accurately forecasting solar radiation in cloudy conditions poses a major challenge. This study employs a new model evaluation framework based on WRF-Solar model to investigate the effects of cloud microphysics and cloud-aerosol interactions on solar irradiance. This work has three objectives:

- ➢ To investigate the uncertainty spread of surface solar radiation and its partitions due to different cloud microphysics schemes.
- ➢ To explore the aerosol-cloud-radiation interactions.
- ➢ To identify the physical causes that lead to model bias for future improvement

Model Evaluation Framework

WRF-Solar testbed suite: Three different configurations based on the state of art Weather Research and Forecasting model specifically designed for simulating and forecasting solar radiation (WRF-Solar).

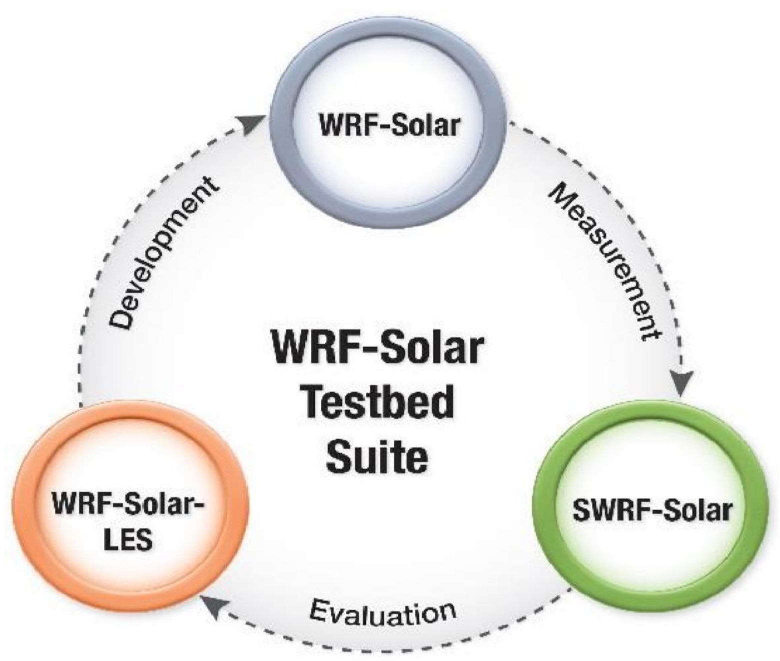


Figure 1. WRF-Solar suite, the modeling framework.

WRF-Solar :

- Solar energy applications
- Aerosol-radiation feedbacks
- Aerosol indirect effect
- Fully coupled aerosol-cloud-radiation system

Three configurations:

- Nested WRF-Solar (3km grid)
- Large eddy simulation (LES)
- Single column model (SWRF)

Evaluation metrics suite: Mean bias, Standard deviation, Correlation coefficient, RMSE, Percent error and Relative Euclidean distance (D).

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

Indirect Aerosol Effects

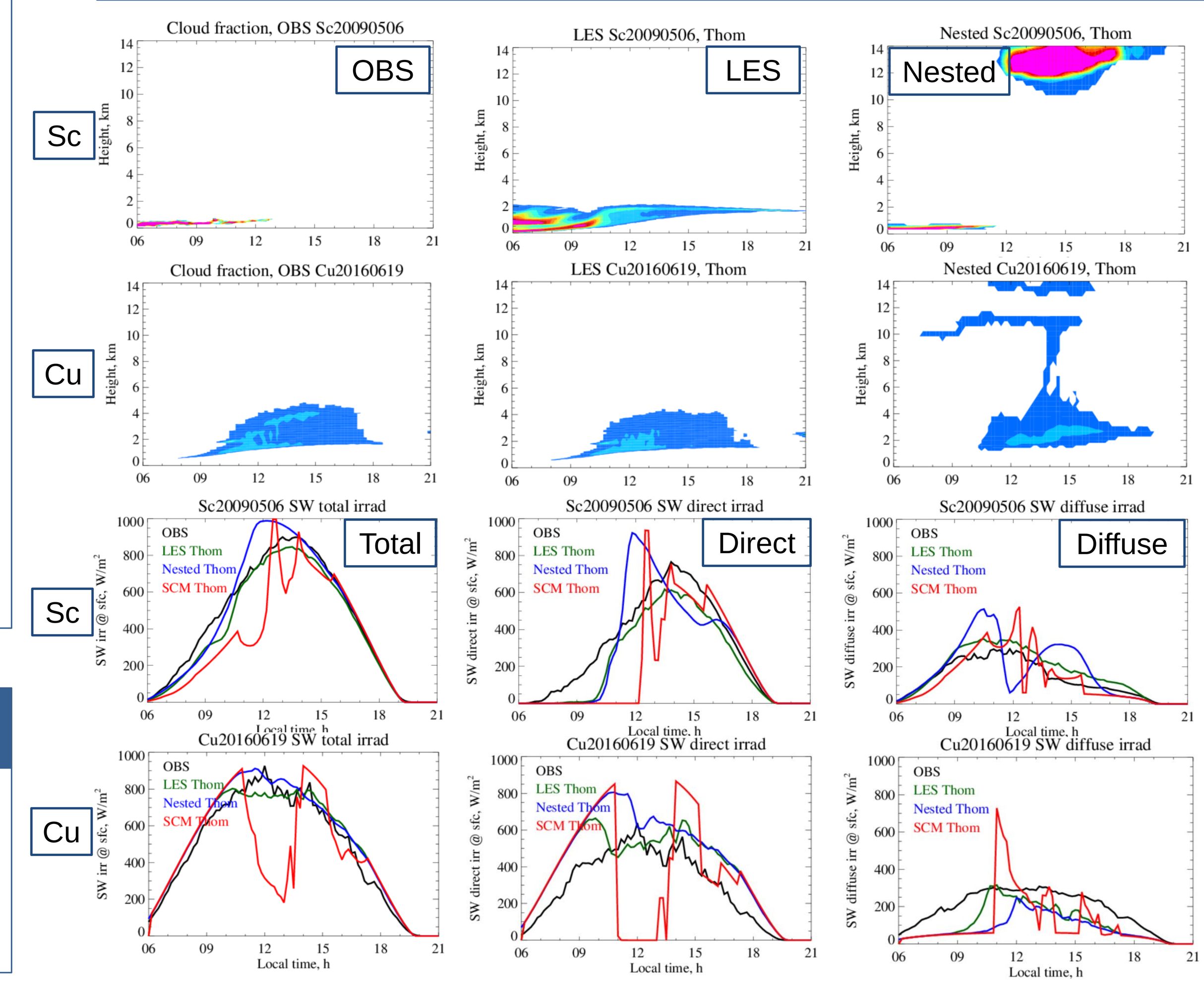
First: **CCN↑ → Nc↑ → mean volume radius↓ → effective radius↓ → cloud optical depth↑ → relative cloud radiative forcing (RCRF)↑ → SW@surface↓**

$$RCRF = (F_{all} - F_{clear})/F_{clear}$$

Second: **CCN↑ → Nc↑ → mean volume radius↓ → autoconversion↓ → precip efficiency↓ → cloud duration, fraction, LWP↑ → SW@surface↓**

Cloud Fraction & Solar Irradiance

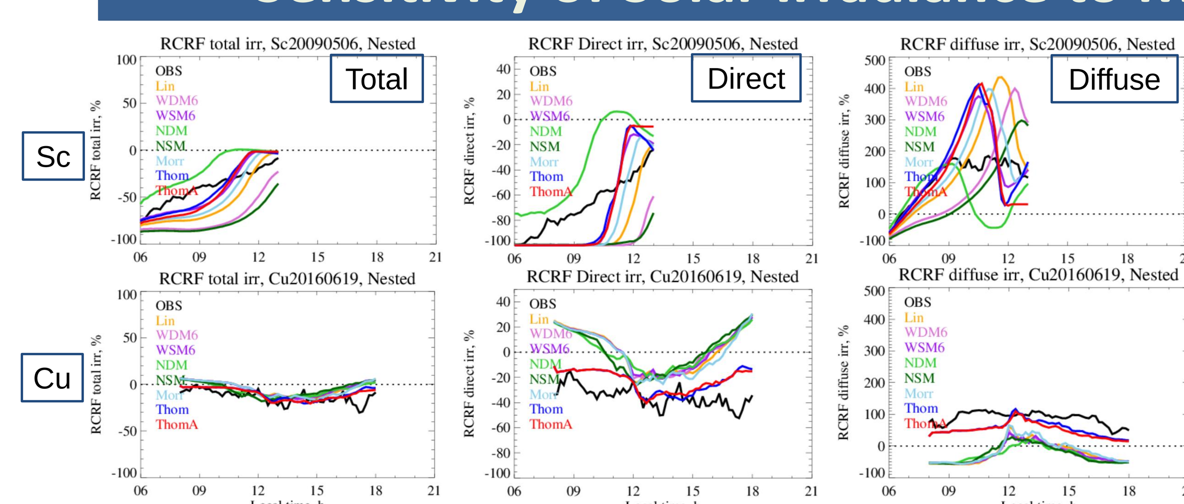
Cases @ ARM SGP facility: Sc on 2009-05-06; Cu on 2016-06-19



- LES reproduces the cloud fraction well.
- Total irradiance is better simulated than the direct and diffuse components.
- Cloud occurrence and transition influence solar irradiance greatly.

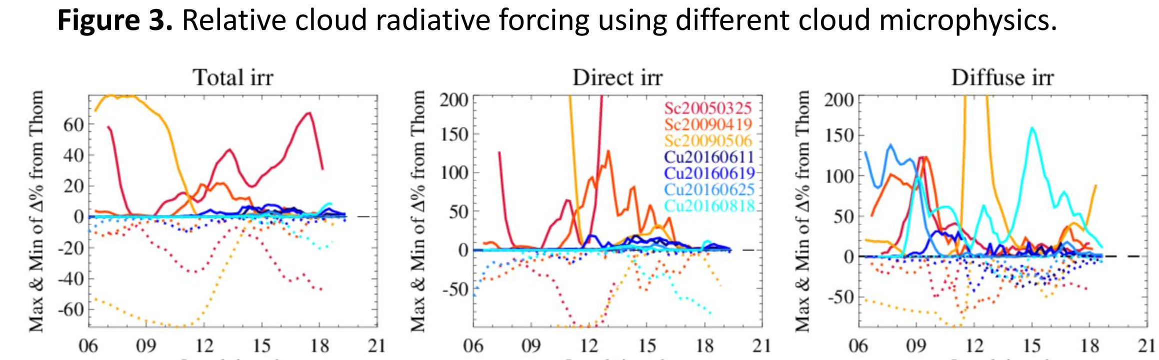
Figure 2. Comparison of simulated clouds and solar irradiance to observation.

Sensitivity of Solar Irradiance to Microphysics



- Clouds reduce direct but enhance diffuse solar irradiance.
- Cloud microphysics has huge impact on the solar irradiance.

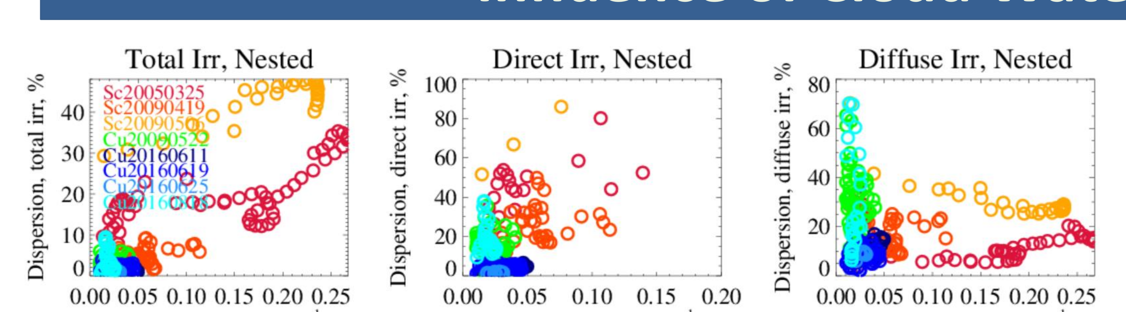
Figure 3. Relative cloud radiative forcing using different cloud microphysics.



- Solar irradiance in stratocumulus cases have larger sensitivity to cloud microphysics.

Figure 4. Maximum and minimum difference in solar irradiance from the baseline simulation using Thompson scheme (Thom) for different cloudy cases.

Influence of Cloud Water

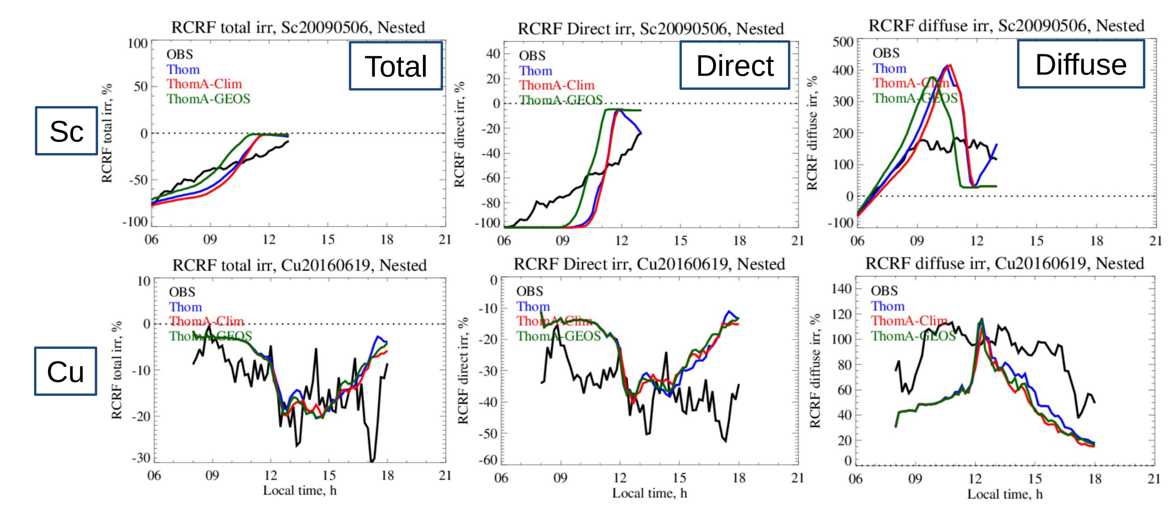


- Solar irradiance is more sensitive to cloud microphysics when cloud water mixing ratio is large, e.g. in Sc cases.

Figure 5. Dispersion in solar irradiance using different microphysics v.s. averaged total cloud water mixing ratio.

Aerosol Indirect Effect

Thompson aerosol aware scheme (ThomA) with different aerosol inputs



- Larger aerosol # conc results in larger cloud radiative forcing.
- Model simulates abrupt cloud dissipation leading to large errors.
- Larger aerosol # conc leads to larger cloud water, droplet # conc and smaller droplet sizes.

Figure 6. RCRF with different aerosol inputs. ThomA-Clim has larger aerosol # conc and ThomA-GEOS has smaller aerosol # conc.

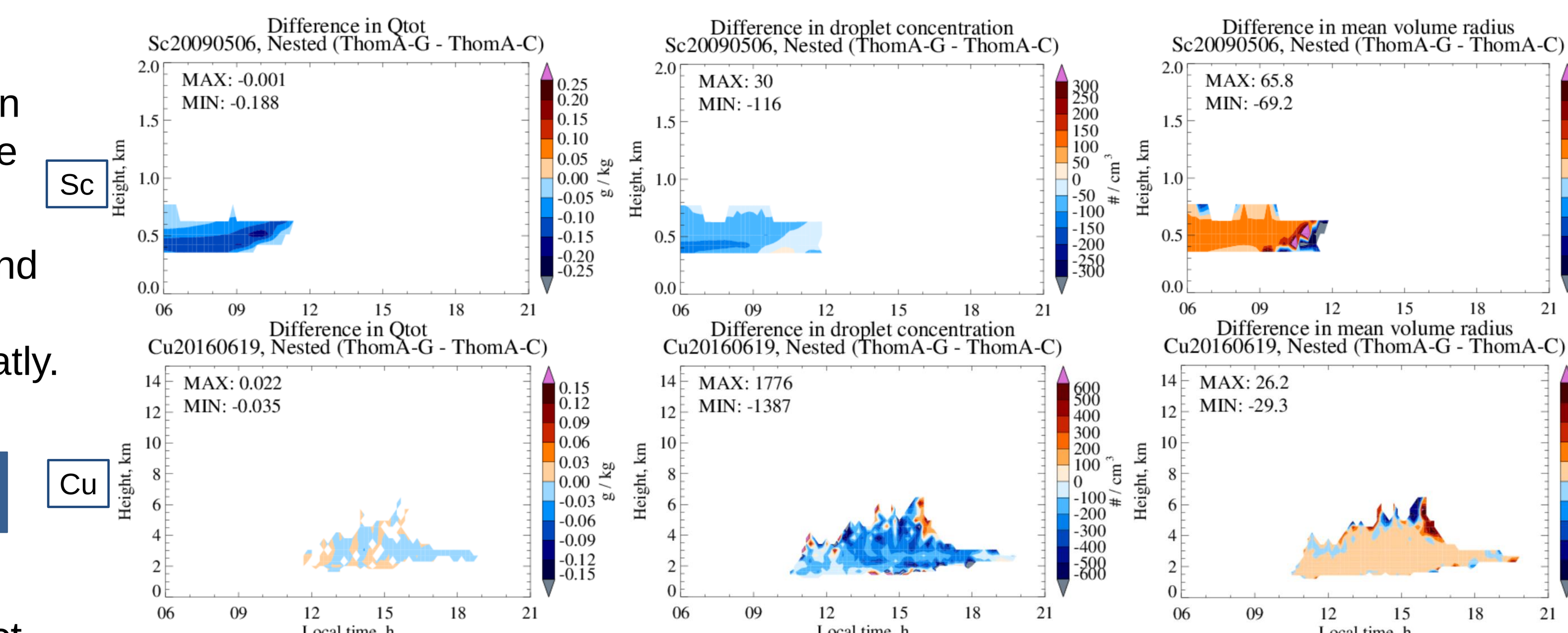
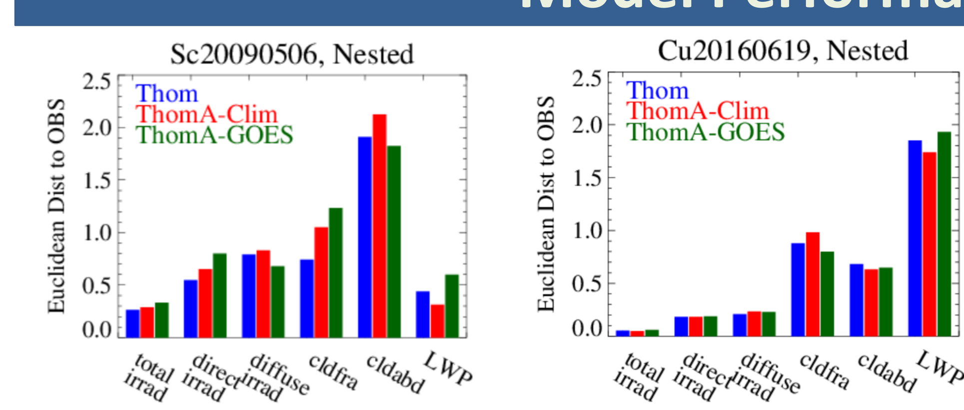


Figure 7. Comparison of cloud properties with different aerosol inputs.

Model Performance



- Better simulated radiative properties.
- Better simulated cumulus case.
- Complex relationships to changing aerosols.

Figure 8. Relative Euclidean distance of radiative and cloud properties.

Conclusions

- ➢ Total irradiance appears reasonable due to cancellation of model biases in direct and diffuse irradiances.
- ➢ Model simulates better radiative properties than cloud properties.
- ➢ Model simulates better solar irradiance in Cu cases than in Sc cases.
- ➢ Different microphysics schemes lead to a significant spread of simulated solar irradiance, especially in the Sc cases.
- ➢ Different aerosols lead to differences in clouds and solar irradiances.
- ➢ Ongoing work on improving cloud microphysics and radiative transfer.

Contact

Xin Zhou
Brookhaven National Laboratory
Environmental & Climate Sciences Department
Email: xzhou@bnl.gov

References

Jimenez, P. A., and Coauthors, 2015: WRF-Solar: Description and Clear-Sky Assessment of an Augmented NWP Model for Solar Power Prediction. *Bull. Amer. Meteor. Soc.*, **97**, 1249–1264, https://doi.org/10.1175/BAMS-D-14-00279.1.

Wu, W., Y. Liu, and A. K. Betts, 2012: Observationally based evaluation of NWP reanalyses in modeling cloud properties over the Southern Great Plains. Journal of Geophysical Research: Atmospheres, **117**, doi:10.1029/2011JD016971.

Acknowledgements

This work is supported by the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy (EERE) under Solar Energy Technologies Office (SETO) Agreement Number 33504