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GHI calculation sensitivity on microphysics, land- and cumulus parameterization in WRF over the Reunion Island

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ABSTRACT

The sensitivity of different microphysics and dynamics schemes on calculated global horizontal irradiation (GHI) values in the Weather Research Forecasting (WRF) model is studied. 13 sensitivity simulations were performed for which the microphysics, cumulus parameterization schemes and land surface models were changed. Firstly we evaluated the model's performance by comparing calculated GHI values for the Base Case with observations for the Reunion Island for 2014. In general, the model calculates the largest bias during the austral summer. This indicates that the model is less accurate in timing the formation and dissipation of clouds during the summer, when higher water vapor quantities are present in the atmosphere than during the austral winter. Secondly, the model sensitivity on changing the microphysics, cumulus parameterization and land surface models on calculated GHI values is evaluated. The sensitivity simulations showed that changing the microphysics from the Thompson scheme (or Single-Moment 6-class scheme) to the Morrison double-moment scheme, the relative bias improves from ~45% to ~10%. The underlying reason for this improvement is that the Morrison double-moment scheme predicts the mass and number concentrations of five hydrometeors, which help to improve the calculation of the densities, size and lifetime of the cloud droplets. While the single moment schemes only predicts the mass for less hydrometeors. Changing the cumulus parameterization schemes and land surface models does not have a large impact on GHI calculations.

1. Introduction

Due to increasing environmental concerns and to the decreasing investment costs, the capacity of electricity production from photovoltaic systems is rising worldwide. Solar electricity production strongly depends on weather conditions, which cannot be controlled because of its intermittent nature. Moreover high temperatures and humidity levels in tropical regions and insular areas make weather predictability even more difficult. Numerical weather prediction models (NWPs) calculate a large number of meteorological parameters, including the global horizontal irradiance (GHI), which is the total amount of shortwave irradiation received at the Earth's surface, including the direct irradiation and the scattered (by e.g. clouds and aerosols) irradiation. Over the past two decades most attention has been spent on GHI calculations by numerical weather prediction models (NWP). For example Heinemann et al. (2006), Remund et al. (2008), Lorenz et al. (2009), and Perez et al. (2009). Several studies showed that clouds and aerosols contribute to the uncertainties in the calculation of solar irradiation variables (Zamora et al., 2005; Ineichen and Perez, 2010). To optimize the exploitation of solar power plants and improve the management of the electricity grid, accurate forecasts on the expected solar irradiance at ground level are crucial (Inman et al., 2013).

Recent work by Ruiz-Arias et al. (2014) included the calculation of GHI, Direct Normal Irradiation (DNI) and Diffuse Horizontal Irradiation (DIF) in the Weather Research Forecast model (WRF, http://wrf-model.org/index.php, Skamarock et al., 2005) version 3.5.1 and higher, which allows the user to perform diagnostic and prognostic calculations of the solar irradiation variables on a regional scale. More information about the description of the solar irradiation variables, together with the model evaluation, can be found in Ruiz-Arias et al. (2013 and 2014) and references therein. Some authors choose to improve GHI forecast skills by post-processing WRF results, in particular Diagne et al. (2014) and Lauret et al. (2014) focused over The Reunion Island.

To improve the quality of GHI calculations by a meteorological model it is important to know which physics schemes have the largest impact on cloud formation and dissipation and therefore on GHI calculations. Microphysical processes are known to be non-linearly dependent on the amounts of cloud liquid water (Pincus and Klein, 2000 and Larson et al., 2001). Therefore a good representation of the

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microphysical processes is very important to represent the cloud formation processes as realistic as possible. Several studies have investigated the impact of different microphysics schemes on convection, cloud formation and precipitation quantities and variability, for example Jankov et al. (2005, 2011), Morrison et al. (2005, 2009, 2015), Liu and Moncrieff (2007), Thompson (2004), Thompson et al. (2008), Morrison and Gettelman (2008), Vigaud et al. (2009), Wood et al. (2009), Hong et al. (2010), Rajeevan et al. (2010), Pohl et al. (2011), Crétat and Pohl (2011), Niu et al. (2011), Lee and Donner (2011), Molthan (2011), Song et al. (2012), Van Weverberg et al. (2013), Wheatley et al. (2014), Grabowski (2014), Storer et al. (2015), Min et al. (2015), Pieri et al. (2015), Halder et al. (2015) Khain et al. (2016) and many more. Also the role of microphysics on the uncertainties on climate projections has been studied, for example Seiki et al. (2015), Zhao (2014) and Zhao et al. (2016). Other studies, for example Kogan (2013), Kondowe (2014) and Li et al. (2015), investigated the impact of cumulus parameterization schemes on cloud formation and precipitation quantities. To our knowledge comparisons of different microphysics schemes on calculated GHI values by a WRF for Reunion Island have not yet been reported.

The objective of this study is to investigate the impact of different physics schemes on calculated GHI values by WRF by comparing with observations for Reunion Island.

2. Methodology

The WRF model (version 3.6.1) was used and operates on the 24 × 24 km and 8 × 8 km resolution domains (two-way nested i.e. feedback from nest to its parent domain). Fig. 1 presents the geographical position of the model grid domains; domain 2 has a dimension of 504 × 480 km. More details regarding the meteorological model are given in Section 2.1.

To evaluate WRF's capability in representing solar irradiation and the impact of different physics schemes over Reunion Island, we start our study by evaluating calculated GHI values for domain 2 (8 × 8 km) by comparing with observations of GreenYellow site in Reunion for 2014. Then we performed multiple sensitivity scenarios for which the microphysics, land surface model and cumulus parameterization schemes were changed. An overview and a description of the scenarios are given in Section 2.2. In addition we performed other simulations for a longer winter and summer period using the model set up for which the bias and RMSE are the lowest.

2.1. Description meteorological model WRF

The WRF-ARW system is a non-hydrostatic model (with a hydrostatic option) using terrain- following vertical coordinate based on hydrostatic pressure. The terrestrial data sets for WRF are built using the NCEP geographical data. These consist in global data sets for soil categories, land-use, terrain height, annual mean deep soil temperature, monthly vegetation fraction, monthly albedo, maximum snow albedo and slopes.

WRF uses land-use categories from United States Geological Survey (USGS) 24-category data, which are available for different horizontal resolutions (10′, 5′, 2′, 30″; ″ denotes arc seconds and ′ denotes arc minutes). The horizontal resolution is set by the user in the pre-processing step in WPS. We use the highest horizontal resolution available in the USGS land-use data set i.e. 30″, which corresponds to ~1 × 1 km (Anderson et al., 1976). The vertical discretization of WRF involves 29 levels up to about 18 km. The model is set up using New Thompson et al. (2008) microphysics scheme containing ice, snow and graupel processes, vapor, and rain. The model uses the 5-layer thermal diffusion with soil temperature in 5 layers. The planetary boundary layer (PBL) Yonsei University (YSU) scheme is used (Hong and Lim, 2006). In the

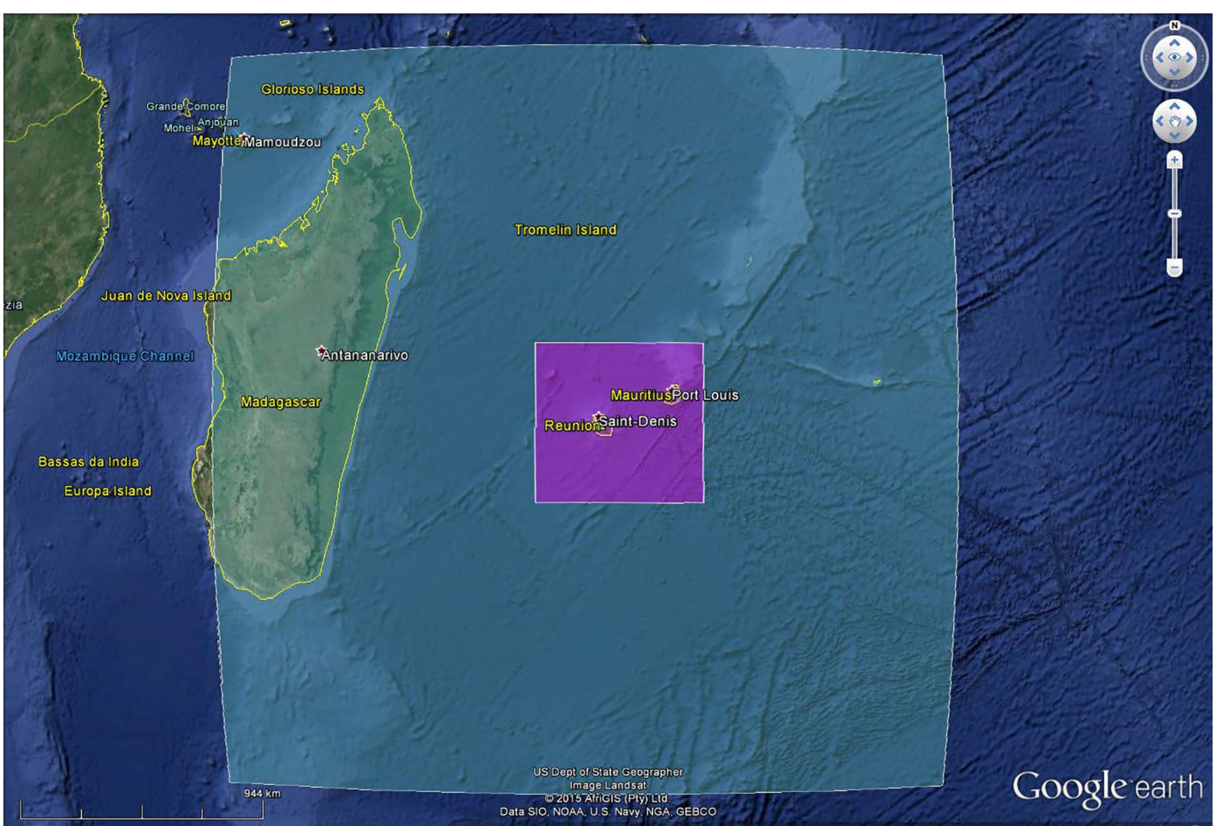

Fig. 1. Map of the locations of the WRF model domains. The larger domain has a horizontal spatial resolution of 24 × 24 km, and the smaller domain has a horizontal resolution of 8 × 8 km. Photo courtesy Google Earth™ mapping service.