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Biases in Diffuse Fraction of Radiation in Global Data Products: Implications and Corrections

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Diffuse radiation is an important, albeit understudied, component of the Earth's radiation budget, impacting ecosystem response and solar energy generation capacity. The diffuse fraction (diffuse radiation/total shortwave radiation) is hard to estimate due to its strong dependence on location, aerosol optical properties, and cloud cover. The simulation of aerosol optical properties in climate models depend on accurate aerosol emission inventories while clouds are parameterized, since they cannot be resolved by the course resolution of these models. These limitations and assumptions lead to significant uncertainties within and between models. Reanalysis datasets reduce some of these uncertainties by constraining some of these variables using observations. However, clouds are still parameterized and observed aerosol optical properties are assimilated in very few reanalysis datasets, like in the Modern-Era Retrospective analysis for Research and Applications, Version 2 (MERRA-2). Here, we evaluate the radiation budget in MERRA-2 with a focus on the diffuse fraction. We evaluate the monthly averaged shortwave radiation, longwave radiation, and diffuse beam radiation in MERRA-2 using the Global Energy Balance Archive (GEBA) database. MERRA-2 overestimates shortwave radiation (Mean Bias Error (MBE) = 23 W m^{-2}), and underestimates longwave radiation (MBE=-19 W m^{-2}). This is consistent in sign and magnitude with previous studies and is due to the underestimation of clouds, with MERRA-2 showing the best results under clear-sky conditions. We also perform the most comprehensive evaluation of MERRA-2 modeled diffuse radiation at a global scale (around 15500 months of data) and demonstrate that it is significantly underestimated (MBE=-22 W m^{-2}) compared to observations. The combined underestimation of total shortwave and diffuse radiation reduces diffuse fraction by around 30%. Counter-intuitively, diffuse fraction is better simulated under cloudy conditions, implying issues with the parameterizations of cloud properties in MERRA-2. We extend our evaluation to the widely-used NCEP/NCAR reanalysis, as well as the results of a coupled Community Earth System Model (CESM) run and find similar underestimation in diffuse fraction. Since these biases have significant implications on ecosystem response in these models, we deploy a random forest algorithm to correct this bias. The bias correction factor is a strong function of cloud fraction, with cloud optical depth and zenith angle playing minor roles. Month-specific correction algorithms produce the best results, reducing the MBE for annual diffuse fraction from -0.26 to -0.02 in MERRA-2. The most useful feature of this algorithm is that it can used to correct MERRA-2 and NCEP diffuse products without relying on any external observational data, which makes it more applicable for global scale studies than previous similar corrections for shortwave radiation. To test the implications of these biases, the Community Land Model (CLM) is coupled with MERRA-2 forcing with and without the correction to examine the impact of this underestimation on model results. We observe a 10-15% reduction in evaporative fraction in tropical forests due to this bias, which would affect both the surface energy and water budgets.