GLOBAL OBSERVATIONS OF CLOUD MICROPHYSICS THROUGH TERRA DATA FUSION

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EXECUTIVE SUMMARY:

The Moderate Resolution Imaging Spectroradiometer (MODIS) is our most advanced satellite instrument for long-term, global observations of effective radius (Re) of the cloud drop size distribution. Here we show that the fusion of data collected by MODIS and the Multi-angle Imaging SpectroRadiometer (MISR), both on NASA's Terra satellite, can be used to characterize the space-time varying biases in the MODIS Re product. The biases are determined to range from 3 to 11 µm for marine liquid water clouds, which, when removed, provides a very different understanding of the distribution of liquid cloud drop sizes in our atmosphere compared to what previously was determined from the original MODIS data. This greatly advances the utility of the Terra data for weather and climate research.

INTRODUCTION

Clouds cover about 68% of our planet. They are one of the most interconnected components of the Earth system, playing a key role in the Earth's hydrological cycle, regulating the incident solar radiation field more than any other atmospheric variable, and acting as the most important greenhouse constituent in our atmosphere. As such, they modulate a wide range of processes on Earth. The Intergovernmental Panel on Climate Change (IPCC) affirms that the role of clouds remains the leading source of uncertainty in anthropogenic climate change predictions. In addition, the role of cloud microphysics and cloud-radiation interactions in the timing and intensity of weather events remains an active area of research.

To make headway in reducing uncertainty in weather and climate predictions, the World Meteorological Organization and the IPCC defined a list of Essential Climate Variables (ECVs) requiring global observations (http://www.gosic.org/gcos). This list includes a wide range of cloud properties, most of which are primarily derived from satellites. While significant advancements have been made over the past four decades in retrieving cloud properties from space, most still do not meet accuracy requirements for climate research [1].

Here, we focus on Re for liquid water clouds over the ocean. Re is an ECV with a target accuracy of 5% or 0.5 µm. This accuracy has not yet been met, largely because the remote sensing algorithms used in the retrieval of Re assume clouds and the radiative boundary conditions to be horizontally homogeneous. This greatly simplifies the radiative transfer to 1D. However, a simple look at clouds shows that they are not horizontally homogeneous over a wide range of scales. This leads to a bias in the retrieved Re when the algorithms are applied to structured (3D) clouds. The bias co-varies with the underlying structure of the cloud field and the sun-view geometry, leading to an inability to disentangle true space-time variability in cloud drop sizes from variability in the biases caused by the 1D assumption [2]. Based on 3D radiative transfer simulations applied to a small number of synthetic 3D cloud fields, it has been suggested that errors as high as 100% are possible [3]. The extent to which the results from these simulations are globally representative in nature remains unknown–until now.

METHODS & RESULTS

MODIS provides a global dataset of Re based on the spectral signatures that it measures and a 1D radiative transfer formulation of the inverse problem. Also on Terra is MISR, which samples the angular anisotropy of upwelling scattered sunlight. As fully described in [4], spectral signatures from MODIS and angular signatures from MISR were used synergistically to provide upper and lower bound estimates on MODIS Re-biases in the face of 3D radiative effects.

Figure 1 shows an example of our results: the January zonal-mean Re and bias. The results show that the zonal variations in the bias meet the expectation that regions with more cumulus (structured) cloud contribution to the total cloud samples (e.g., ~10°N and ~35°S) will have the largest bias in Re due to the greater deviations from the 1D assumption used in the MODIS retrievals. Quantitatively, the biases are large. The sample zonal mean values from MODIS Re range from about 13 to 18 µm, while the bias-corrected values range from 7 to 12 µm. The latter is in much better agreement with in situ observations of marine liquid water clouds [5]. In addition, latitudinal gradients in zonal-mean Re are also very different between the original and bias-corrected products. Given these large spatially varying biases, implications for studies that use the original MODIS products–say for retrieving liquid water content [6] and cloud drop number concentration [7], evaluating cloud microphysical parameterizations in climate models [8], and in characterizing cloud-aerosol interactions [9]–need to be drawn out.

Our characterization of the space-time varying biases in the MODIS Re product advances the utility of this important dataset for weather and climate research and paints a radically different picture on the distributions of liquid cloud drop sizes in our atmosphere compared to what was previously determined from the original MODIS data. It is also an excellent demonstration of what can be accomplished through MISR and MODIS data fusion. With more than 1 PB of Terra data and counting, such data fusion projects call for high-performance computing facilities and enhanced national infrastructures for data distribution. Our work on Re has provided an excellent use case for improving this infrastructure, as highlighted below.

WHY BLUE WATERS

The Terra data is > 1 PB and growing. Key advantages of using Blue Waters for access, usage, and distribution of Terra data fusion products are that the Terra data and processing are local, with access and sharing that are global. Having the Terra data local, with processing tuned to a massively parallel system with excellent sharing services, in one of the largest storage and bandwidth computing facilities in the country, provides an optimum framework for large-scale processing, analytics, and mining of the entire Terra record. In addition, the Blue Waters staff provides expertise critically needed to optimize workflows. For example, Blue Waters staff worked closely with NASA to make substantial improvements to NASA's cyberinfrastructure for transferring MISR data from its data center to Illinois.

PUBLICATIONS

Liang, L., L. Di Girolamo, and W. Sun, Bias in MODIS cloud drop effective radius for oceanic water clouds as deduced from optical thickness variability across scattering angles, *J. Geophys. Res. Atmos.*, 120, (2015), doi:10.1002/ 2015JD023256.

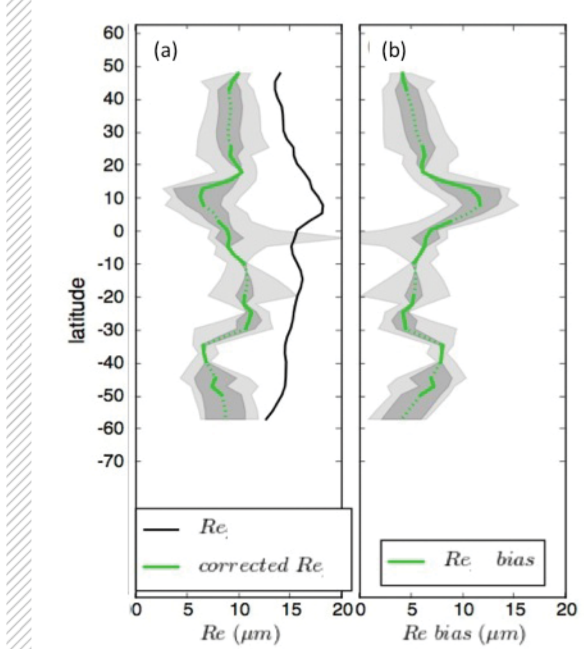

FIGURE 1 (RIGHT): (a) MODIS-Re (black) and bias-corrected Re (green). The dark shade represents the region between the upper and lower bounds of Re, and the light shade represents the region that is one standard deviation of the sample mean below the lower bound and above the upper bound of Re. The green line connects the midpoints of upper and lower bounds of Re. (b) Biases in MODIS-Re.