Global Ice Cloud Observations and Statistics from Aqua MODIS

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I. Introduction

The Moderate-resolution Imaging Spectroradiometers (MODIS) on NASA's Terra and Aqua platforms offer valuable observations of the earth-atmosphere system, facilitating significant research in the atmospheric sciences. Specifically, the implementation of the 1.375-μm channel, located in a water vapor absorption band, allows for exclusive investigations of ice clouds (e.g., cirrus clouds). In this study, a method to retrieve global ice cloud optical depth from cirrus reflectance measurements (derived from the 0.66- and 1.375-μm channels) is detailed. A four-year (September, 2002 through August, 2006) ice cloud optical depth database is then constructed. From this database, an in-depth time series analysis (correlation, etc.) has begun, with the ultimate goal of determining ice cloud source/sink regions.

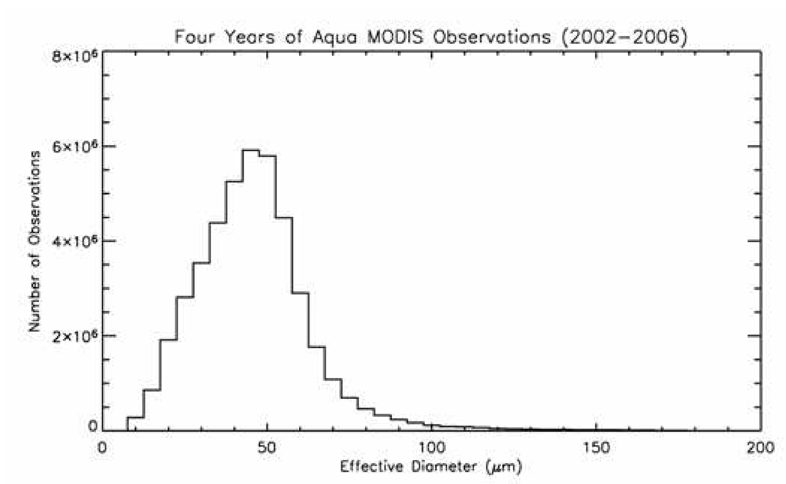
II. Methodology

Previously, a method was introduced, following a simple look-up table approach, to retrieve the optical depth of tropical cirrus clouds using isolated cirrus reflectance in a visible channel (Meyer et al., 2004). The visible cirrus reflectance is derived from the 0.66-μm channel using corresponding reflectance in the 1.375-μm channel (Gao et al., 2002). We have updated this method, to remain consistent with MODIS algorithms, by using the new ice cloud scattering properties developed for the Collection 5 algorithms (Baum et al., 2005a,b). This now allows us to retrieve ice cloud optical depth throughout the globe.

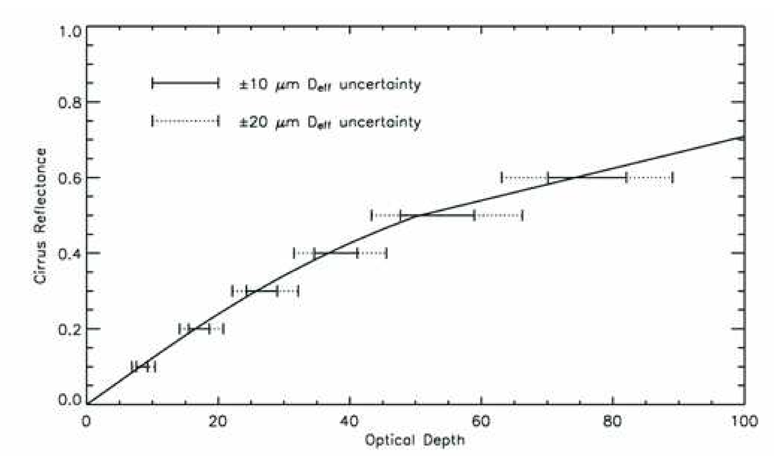
We then extend this algorithm to MODIS Collection 5 level-3 daily global data. Input data are taken directly from the level-3 daily atmosphere product, and include the average cirrus reflectance and solar/satellite view geometries. An ice cloud optical depth archive has been created using four years of Aqua MODIS data, from September 2002 through August 2006. Mean and variance calculations (not shown here) are weighted using the SWIR pixel count (I.e., the number of pixels with cirrus clouds detected) included in the atmosphere product.

An ice cloud optical depth time series statistical analysis, following the cloud analysis method of Cahalan et al. (1981), is then performed. Statistical tools such as correlation functions are used to determine the persistence and movement of ice cloud patterns. In the present study, we consider the three full summer (June, July, August) and three winter (December, January, February) seasons in the Aqua MODIS dataset (2002-2006).

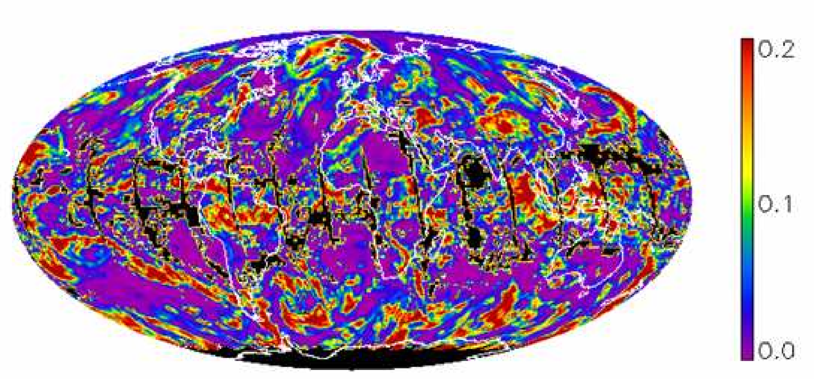
III. Results



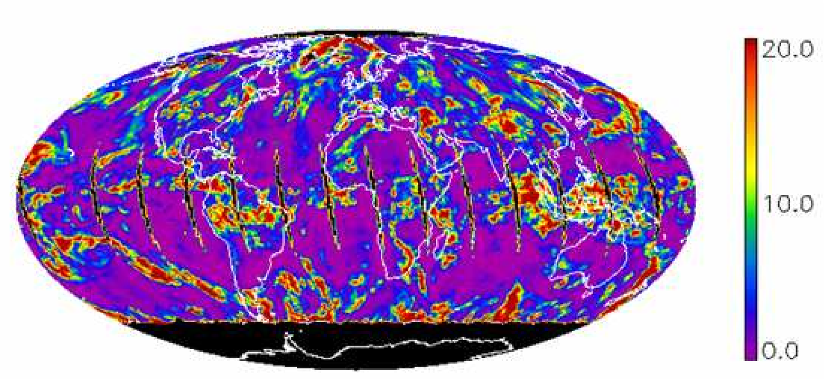
Visible cirrus reflectance is sensitive to ice particle effective size. Here, a histogram of effective diameter, taken from four years of the Aqua MODIS atmosphere product, is shown. The peak of the distribution lies around 50 μm.



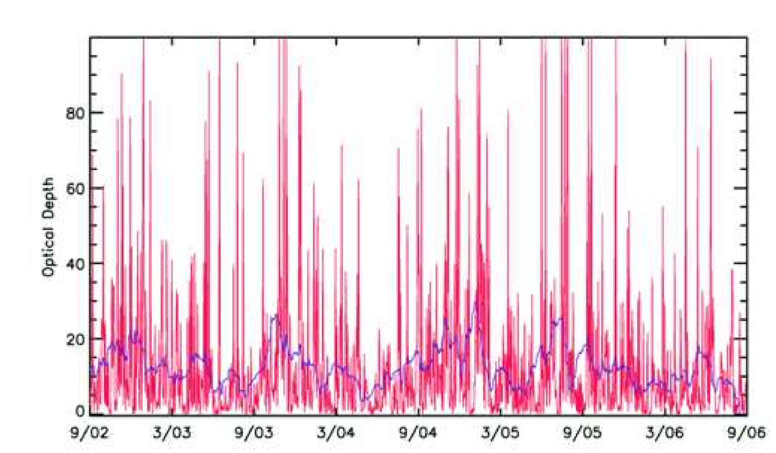
From the histogram at left, we assume the peak (50 μm) as the representative effective size of ice clouds, and use the corresponding look-up tables in the retrieval. Here, a sample 50-μm look-up table is shown, with error bars denoting uncertainties due to errors in effective diameter of ±10 μm (solid) and ±20 μm (dotted).



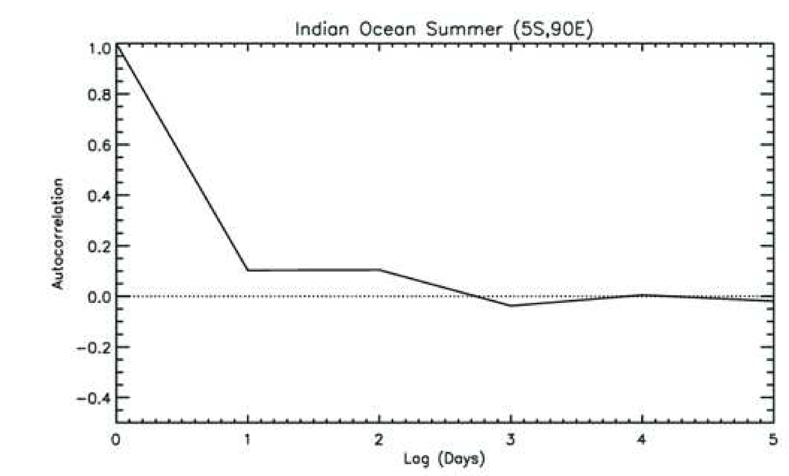
Here, a sample cirrus reflectance image, taken from Aqua MODIS on April 23, 2006, is shown. The image is scaled as shown by the color bar. Regions of black denote missing data. The orbital tracks of the satellite are clearly visible in this image.



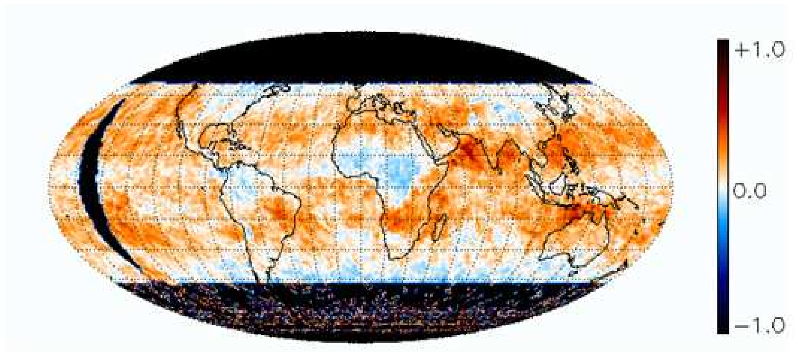
Retrieved ice cloud optical depth corresponding to the image at left is shown here. Orbital tracks appear more "filled in" in this image. Analysis of pixel counts reveals that some data reported as missing in the reflectance image are, in fact, locations with no observed ice clouds.



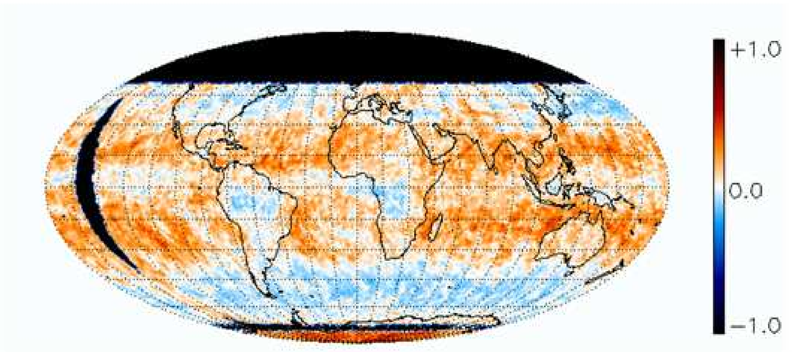
A four year time series of ice cloud optical depth, taken from Aqua MODIS over a location in the Indian Ocean (5S,90E), is shown in red. Optical depth is highly non-gaussian, as its distribution closely resembles that of a lognormal variable. Seasonal variations are also quit evident here. We have therefore subtracted a 31-day moving average (shown in blue), which removes seasonality and transforms the data into a near-normal distribution.



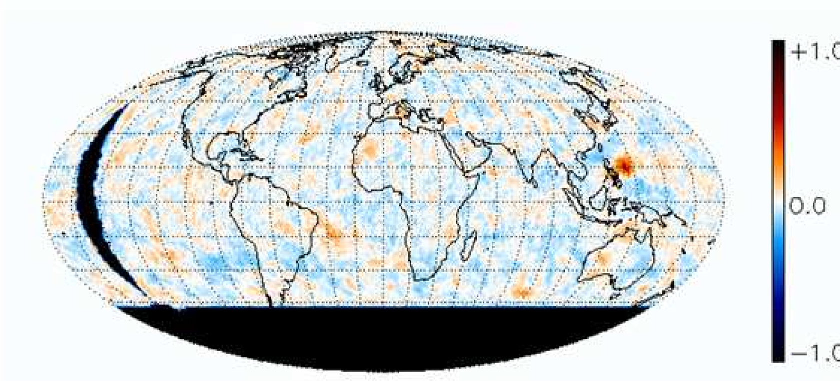
Transforming the optical depth data into near-normality allows for correlation calculations. Here, the autocorrelation function of the time series at left is plotted. Once autocorrelation falls below 1/e (~0.4), the time series is said to have no "memory" of itself, i.e., the pattern does not persist. Such statistical tools allow us to determine the persistence of ice clouds in the atmosphere.



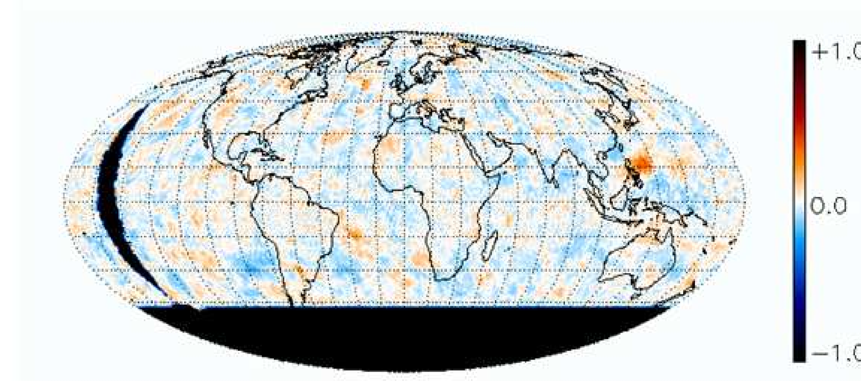
Global average 1-day lagged autocorrelation for the summer months of June, July, and August, is shown here. Black denotes regions with insufficient data.



This image is the same as that at left, except for the winter months of December, January, and February.



Cross correlation allows us to determine the movement of patterns, i.e., ice clouds, through time and space. This can ultimately lead us to determining source/sink regions of ice clouds. Here, 0-day cross correlation is shown for the summer months for a location over the western Pacific Ocean (15N,130E), denoted by the dark red spot.



The 1-day cross correlation for the location at left is shown here. Note the movement of the region of maximum correlation, as well as the decrease in correlation.

IV. Discussion

The present ice cloud optical depth retrieval method is quite useful for global studies of ice clouds. However, evaluation of the method is still required. Comparison with other methods will be valuable in determining the validity of the retrievals.

The time series statistical analysis, while promising, is still a work in progress. A more comprehensive study will be required. Correlation calculations over a global grid of locations will allow us to construct "streamlines" of ice cloud movement, which we can use to locate source/sink regions.

V. References

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