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CLOUD VARIABILITY AND CLIMATE SIGNATURES IN MODIS LEVEL-3 DATA

Brent C. Maddux* and Steven A. Ackerman

Cooperative Institute for Meteorological Satellite Studies,
University of Wisconsin-Madison, Madison, Wisconsin

1. INTRODUCTION

Variability in the global cloud system is a key factor in understanding the global radiation budget, the hydrological cycle and in turn global climate variability. For this reason we must monitor the global climate system on a spatial and temporal scale that allows us to ascertain variability on all scales that influence the global cloud fields. This requires global observations on a temporal scale that capture the day-to-day variability and on spatial scales that resolves geographical variability of the global cloud system. The two Moderate Resolution Imaging Spectrometer (MODIS) instruments accomplish this together by glimpsing nearly the entire globe 4 times a day at a 1 km resolution. Combining this high spatiotemporal resolution with the 5-year record of the MODIS onboard the Earth Observing System's (EOS) Terra Platform and the 3-year records of the EOS Aqua MODIS we can gain an unprecedented ability to analyze cloud variability on local and regional scales.

With the understanding that the characteristics of the global climate system are the summation of all regional climates and that regional climates are the summation of local climates, we can attribute climate signatures on large spatiotemporal scales to relatively local influences. This paper will show how using MODIS level-3 binned and aggregated cloud statistics at varying spatial and temporal scales can capture systematic variability in the global cloud field.

For this study, we use the MODIS level-3 statistics as the primary source of data. The statistics are created for daily, 8-day and monthly time periods on a 1X1 degree equal-angle global grid. For further information about the construction of Level 3 see King et al. 2003. All statistics created within this paper from these level-3 statistics are not weighted by the number of observation but are weighted by the time period of the computed statistic. This creates an assumption that each set of daily observations adequately spans and characterizes the spatial field of interest.

2. ISLAND CASE STUDY

If the global cloud system is viewed on relatively small spatial and/or temporal scales the variability and noise of the system can be large enough to mask a discernable signal. For this reason we must look for localized and systematic perturbations in the cloud field that occur against a local data field that is relatively uniform. Such a perturbation occurs over and downwind of islands or lakes. We can view these islands as land anomalies on a fairly uniform background water field and lakes as water anomalies on a background land field. Since intuition would tell us that the cloud field above landmasses is more susceptible to local surface influences we will analyze an island example in this paper.

As Figure 1 shows, locations of the islands and their orographic effects can be seen above and downwind of their location. These effects are consistent with intuitive reasoning, as the locations downwind of predominately cloudy regions are clearer. This is quite evident around the islands within the Southern Hemisphere storm track.

If we take a closer view at one such case, South Georgia Island located in the Southern Atlantic Ocean, and use level-2 data, we find that predominately there exists a wake with distinctly different cloud properties from the background field downwind of the island. See examples in Figure 2 and Figure 3.

An evident reduction in the cloud effective radius within the wake cloud is seen in Figure 2, but an increase in the optical thickness maximums along the wake cloud in Figure 3. This would indicate that less mature clouds in the island's wake are thicker due to turbulence in the wake cloud that doesn't exist in the background cloud field. This wake cloud's properties are propagated through to the long-term mean created from the level-3 aggregated statistics.

It can also be noted that cloud frequencies over large islands, such as Madagascar, New Zealand, and Indonesia are consistent with spatial

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* *Corresponding author*: Brent C. Maddux, AOS/CIMSS, 1225 West Dayton Street, Room 1345, Madison, WI, 53706.
e-mail: brentm@ssec.wisc.edu

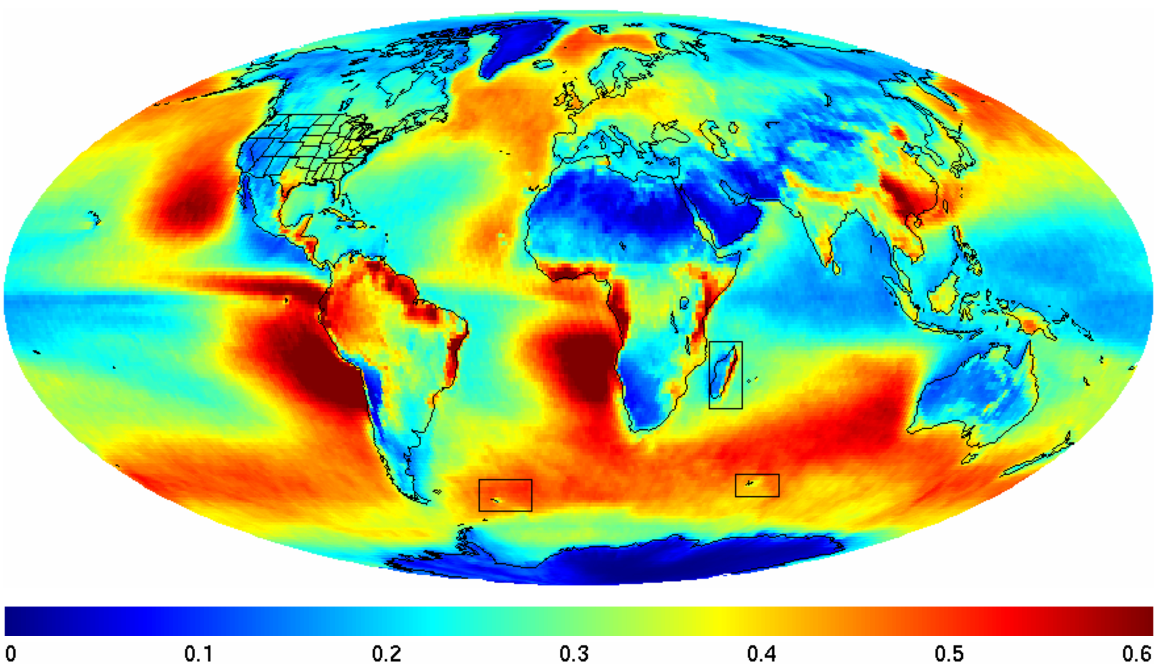

5-Year Mean Water Cloud Frequency

Figure 1: This five-year mean water cloud frequency was derived from the Level-3 Terra data set. It clearly shows the location and orographic influences of islands on the background cloud field. There are three islands indicated on the figure that have discernable wakes and patterns.

precipitation climatologies(McGregor and Nieuwolt, 1998). For example, the eastern coast of Madagascar receives considerably more precipitation each year then the western coast; this is reflected in the relatively higher cloud frequencies over the eastern coast of the island, see Figure 1.

Other islands influence the cloud field in ways that would be expected; such as the increase in water cloud frequency over islands near subsistence zones, e.g. the Caribbean. These clouds are primarily cumulus in nature and are the result of daytime convection or orographic lift.

These examples illustrate that the systematic, albeit small-scale, perturbations in a uniform background field are seen clearly in the long-term averages. This gives us some measure of confidence that the level-3 properties are accurately capturing the small spatiotemporal scale variability. Further statistical and more quantitatively rigorous analyses of this are required.

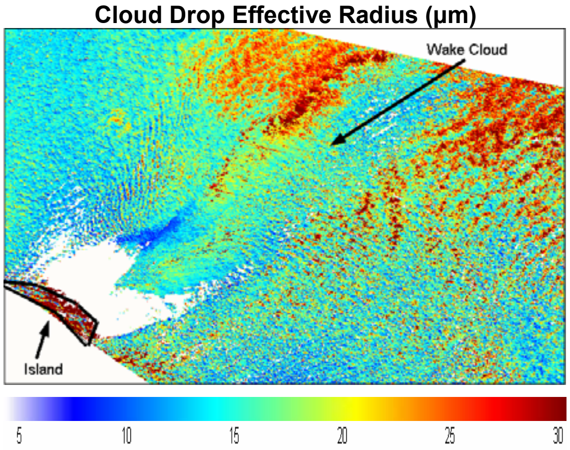

Cloud Drop Effective Radius (μm)

Figure 2: This spatial plot displays the effect the South Georgia Island wake has on the background effective radius field.

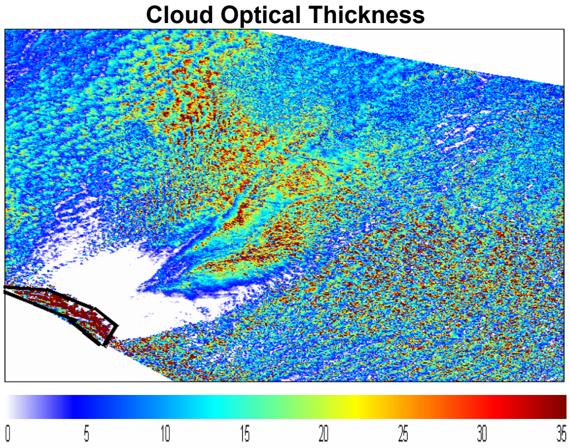

Cloud Optical Thickness

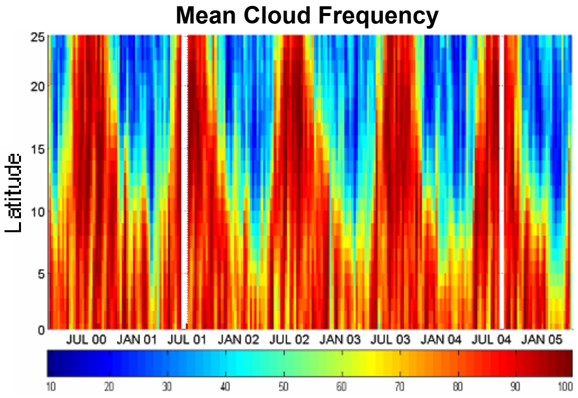
Figure 3: This spatial plot displays the effect the South Georgia Island has on the background cloud optical thickness field.

3. MONSOON CASE STUDY

Regional-scale climate oscillations and systematic weather phenomena are continuously present over nearly the entire globe. These systems oftentimes contain well-defined spatial cloud patterns with specific microphysical properties. These patterns can range from the relatively stable stratocumulus decks, to the more vigorous seasonal movement of the ITCZ to the extremely variable mid-latitude storm tracks.

One of the most studied atmospheric oscillations is the global monsoon. Depending on one's definition of a monsoon, they can occur in any season and on every continent except Antarctica. These monsoon cycles have far reaching effects on the local climate and culture; dictating the growing seasons and migration of animals. For this manuscript we will detail the MODIS level-3 signature of the Indian Summer Monsoon over a region from equator to 25°N and 70E to 110E.

The Indian Summer Monsoon begins in the middle of May, over Myanmar and Thailand, when oceanic, equatorial deep convection begins a north or northwestward movement. This transition of deep convection from over ocean to continents is rather abrupt, taking around a month for convection to move from the oceanic equatorial region to inland India and Pakistan during monsoon onset. However, the monsoon withdrawal is much more gradual. (Fasullo and Webster 2003). The movement of convective systems in the MODIS data tends to agree with the above onset and withdrawal characteristics of the monsoon. As can be seen in Figures 4 and 5 the onset, or northward movement of deep convection, of the monsoon occurs rather quickly. This is followed by a period of deep convection and the gradual withdrawal southward of the monsoon.


Mean Cloud Frequency

Figures 4: This Hovmoller diagram of Terra MODIS cloud frequencies illustrates the weekly change in cloud coverage in the Indian Monsoon region (equator to 25°N and 70E to 110E).

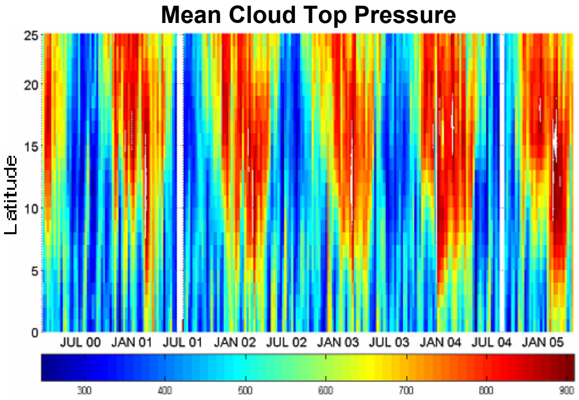

Mean Cloud Top Pressure

Figure 5: This Hovmoller diagram of Terra MODIS mean cloud top pressure displays how cloud top heights change in the Indian Monsoon region from week to week (equator to 25°N and 70E to 110E).

4. LONG-TERM TRENDS

Understanding the global cloud field is varying through time is the ultimate question regarding the global cloud fields. Several satellite campaigns have created various global cloud statistics for several continuous years (e.g. Wylie and Menzel 1999). These records have helped to quantify how the global cloud field has been changing. From Figure 6 we can see that MODIS indicates that the cloud fraction across the globe as a whole is relatively stable.

There is no statistically significant trend in the data for either Aqua or Terra MODIS. Also, only a small diurnal difference, approximately 2 percent, exists between the two instruments. The only distinct variability in the time series is the annual cycle. This cycle is primarily due to an increase in the cloud coverage over land during each hemispheres respective winter. Therefore, an increase in the cloud fraction occurs during the northern winter due to greater land coverage.

However, this says nothing about the variability of the global cloud field for each geographical location from year to year. In figure 7 we see that the differences in cloud frequency on a 1-degree grid can be as high as 20% from 2003 to 2004. Whereas in figure 6 there is no visual difference contained in the time series for the two years. This would lead us to conclude, without further analysis that the global cloud field as a whole doesn't deviate greatly from year to year. Rather the convection shifts from location to location. This is evident in the movement of the ITCZ in the equatorial Pacific Ocean.

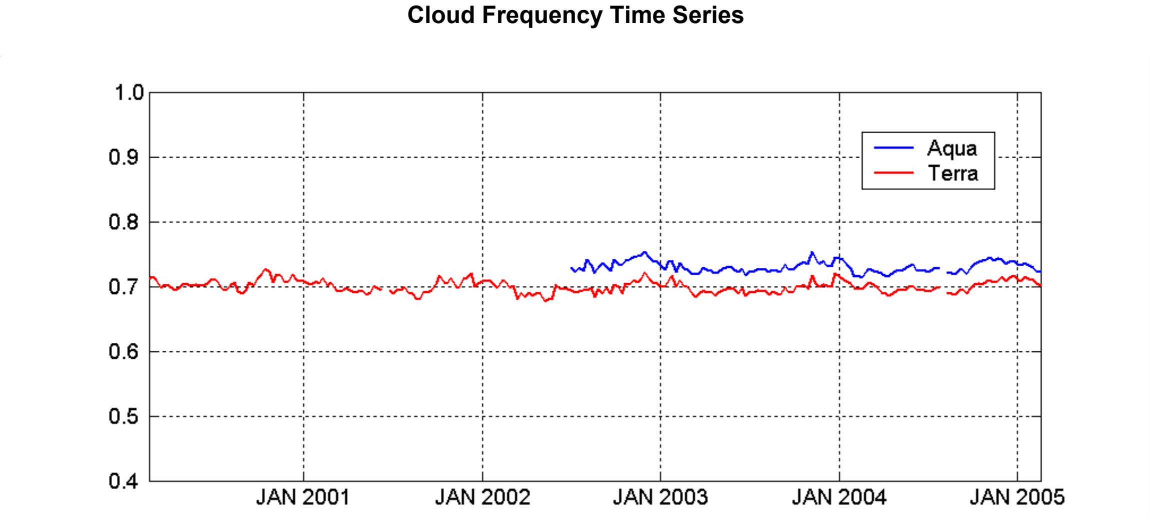

Cloud Frequency Time Series

Figure 6: This global cloud frequency time series was created from 8-day mean cloud fraction statistics. The annual cycle in the series is due to the north south movement of convection as well as the increase in cloud cover during winter time over the northern hemisphere.

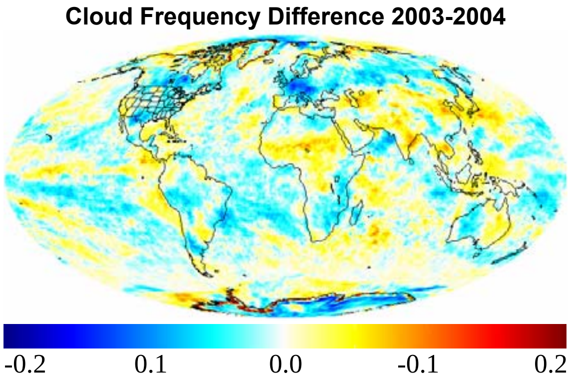

Cloud Frequency Difference 2003-2004

Figure 7: This is a difference of the mean annual cloud fraction for Terra MODIS for 2003 and 2004.

5. CONCLUSION

Countless examples of variability within the global cloud field exist that we could choose from. In this manuscript we opted for picking examples that were well grounded in physically meaningful phenomenon and had an reasonably intuitive basis. Here our purpose was not to analyze a less well understood phenomenon, but to look for well established and understood weather and climate signatures in the cloud field within MODIS level-3 data.

Ongoing and future work will include a detailed statistical analysis of these and other phenomena in the global cloud field and a quantitative characterization of the cloud fields and associated events.

ACKNOWLEDGEMENTS

The data used in this study were acquired as part of the NASA's Earth-Sun System Division and archived and distributed by the Goddard Earth Sciences (GES) Data and Information Services Center (DISC) Distributed Active Archive Center (DAAC).

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