Using MODIS cloud products to study glaciation level

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Introduction

Where a cloud glaciates is subject to a variety of factors including pollution. It has been hypothesized that polluted clouds will glaciate at a higher altitudes than clean clouds (Martins et al, 2007). The preparatory work for studying the correlation between pollution and cloud glaciation level includes a general study of relevant MODIS products and the relationship between glaciation and optical depth. Preliminary analysis indicates that temperature is a more important factor in defining the glaciation level for thick clouds than for thin clouds. Furthermore, there is indication that thicker clouds reach glaciation at higher temperatures than thin clouds.

Data

Glaciation depends on a variety of factors, e.g. pressure, temperature, optical depth, surface temperature, and aerosol. The MODIS cloud product supplies the parameters of interest for this initial study, primarily phase, pressure, temperature, and optical depth.

A small section of ocean off the shore of the United Kingdom and France is used for this study. The area covered is 1000 km by 500 km, longitude -5 to -25, latitude 45N to 49N. The data used is for two weeks in March and two weeks in September for 8 years (2000-2007). The 250 m cloud mask was used to ensure the most reliable cloud detection. Also, multilayer clouds and undetermined clouds were not used in analysis.

Methodology

Probability of glaciation is determined by dividing the number of ice clouds by the number of water and ice clouds in a region. Not included are mixed phase clouds. A probability curve for a range of temperatures or pressures is produced by calculating these probabilities for 25-30 bins, usually 2 K or 20 mbar in width, across the range of interest, 300-800 mbar or 230-280 K. The resulting curve has a sigmoid shape and an example of this is shown in Figure 1.

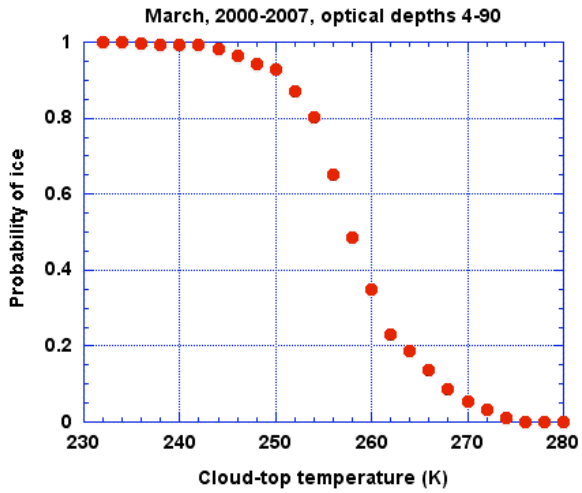

Figure 1: Ice probability curve with respect to cloud-top temperature for all MODIS data for longitude -5 to -25, latitude 45N to 49N, two weeks in March, eight years (2000-2007), and optical depths 4-90. 50% glaciation is at 257 K (~4.6 km). The bin width is 2 K for each point.

50% glaciation is calculated by fitting the probability curve to a polynomial and extrapolating the temperature or pressure that corresponds to 0.5 probability of ice.

When glaciation is analyzed with respect to optical depth the probability curves are not as smooth as that shown in Figure 1 and issues with cloud-top temperature/pressure and phase retrievals become apparent. This is shown in Figure 2 and discussed below.

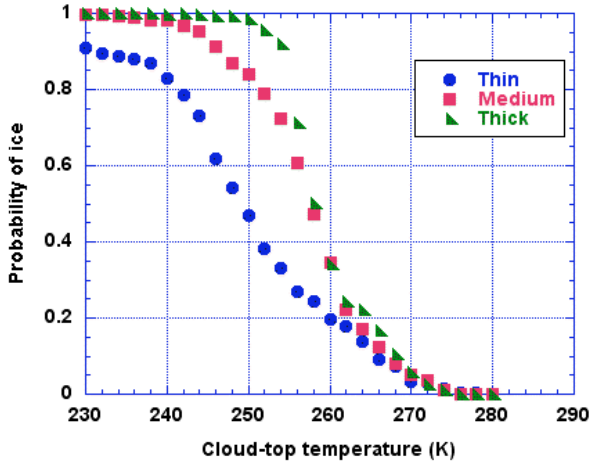

Figure 2: The same data used in Figure 1 broken into three optical depth categories: thin (Tau < 3.6), medium (3.6 < Tau < 23), and thick (23 < Tau < 90), (Rossow and Schiffer, 1999). 10% of thin clouds are still retrieved as water at 230 K. This is due to issues with phase retrieval. Also, the thick clouds have a discontinuity between 250 and 260 K, which is even more obvious in plots of pressure.

The first issue is the misclassification of phase. The retrieval of phase for thin clouds is particularly difficult (Platnick et al, 2003). This is apparent in the probability curve for thin clouds in Figure 2. The thin clouds (Tau < 3.6) do not reach 100% glaciation by 230 K. This corresponds to 300 mbar or 9.5 km.

The solution for this is to omit the thinnest clouds from the analysis. The cut-off was determined by plotting different ranges of optical depths. The cut-off is where the 100% glaciation is first reached by 230 K. Various optical depth ranges are shown in Figure 3. Only optical depths greater than 4 have the most reliable phase retrievals according to these conditions.

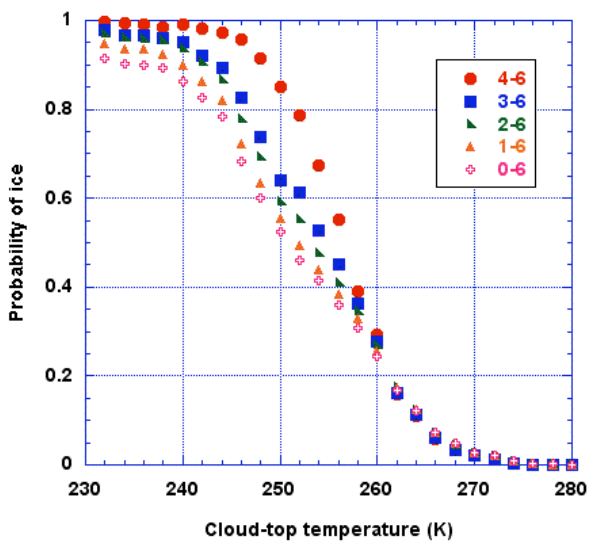

Figure 3: Various ranges of thin optical depths are plotted to find the cut-off for most reliable phase retrieval. Optical depths less than 4 do not reach 100% glaciation by 230 K.

Another issue with phase retrieval is most obvious in the probability curve for thick clouds, see Figure 2. Thick clouds (23 < Tau < 90) begin to have a discontinuity between 250 and 260 K. This corresponds to 550 mbar and 5 km. This behavior is most likely the result of using two algorithms for cloud-top temperature and pressure retrievals. One is used primarily above 500 mbar and one is used primarily below 500 mbar. CO2 slicing is best for pressures less than 450 mbar, IR window technique is best for pressures greater than 550 mbar. The region between where one or the other works best, 450-550 mbar, is the region where glaciation happens. As retrievals are switching from one to another it is likely that the pressure scales are not matching entirely.

The cloud retrieval method flag cloud product tells which technique is used and further studies could be done by separating data according to algorithm. For current work, Tau > 60 is being omitted because those are the clouds that appear to be most affected by the switch of algorithm.

The last relevant retrieval issue is that cloud-top temperature and pressure are 5 km products while phase and optical depth are 1 km products. The 5 km product often blurs

cloud edges, removing detail when the area contains two clouds of distinct heights. There is no immediate solution for this given the amount of data being analyzed.

Analysis

The probability curve at 50% glaciation has a slope that indicates whether temperature (or pressure) is the main factor in determining glaciation. A steep slope indicates it is the main determining factor. A flat slope indicates that the variable is not the main determining factor.

The probability curves for various ranges of optical depths are shown in Figure 4. Derivatives were calculated for each of these curves by taking an average of three slopes, each with 3, 4, or 5 points surrounding the location of 50% glaciation, as defined earlier. The derivatives are shown in Figure 5. Slopes are steeper for thick clouds than for thin clouds indicating that temperature is a more important factor defining the glaciation level for thick clouds than for thin clouds.

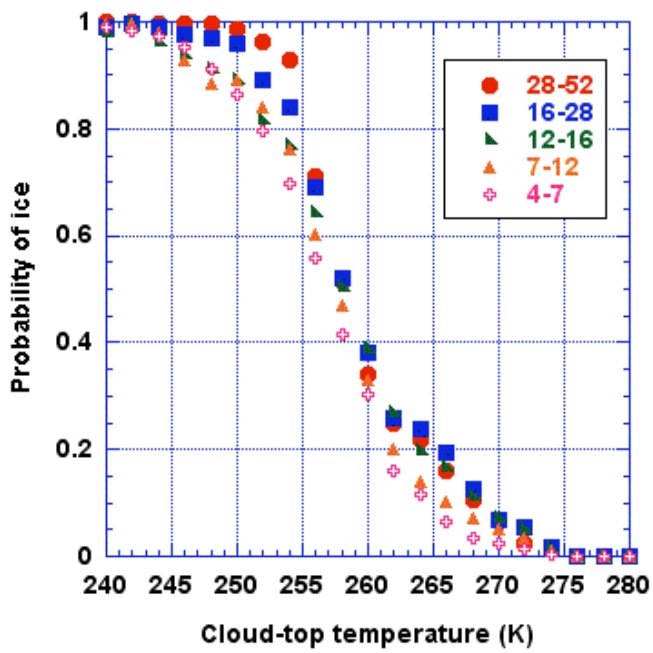

Figure 4: The same data as used in Figure 1, now broken into optical depth categories 4-7, 7-12, 12-16, 16-28, and 28-52 Tau. Each point on the plot represents a count on the order of 10,000 clouds.

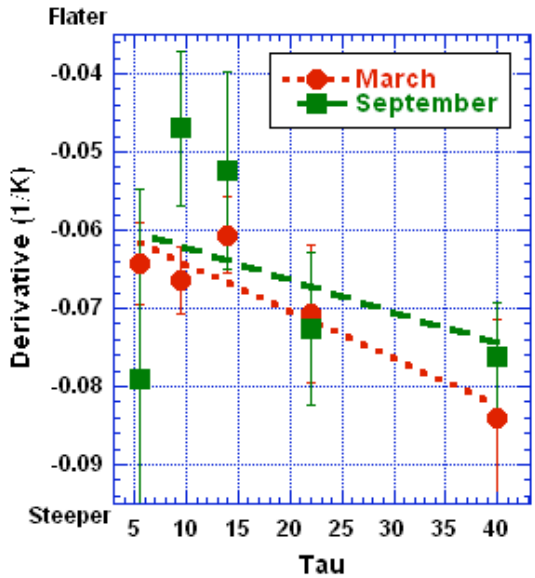

Figure 5: Derivatives for optical depth categories 4-7, 7-12, 12-16, 16-28, and 28-52 Tau. Derivatives are given for both March and September. There is less data that meets requirements for analysis in September and the curves are very rough particularly for the thin clouds. Slopes are steeper for thicker clouds than for thin clouds.

Investigation of isotherms shows that thick clouds reach glaciation at higher temperatures than thin clouds. All the isotherms have positive slopes. This means that the probability curves are arranged by optical depth with the curve for thin clouds having the lowest probability of ice at any temperature or pressure and the curve for thick clouds having the greatest probability of ice at any temperature or pressure. This is shown in Figure 6.

Probability curves for brightness temperature rather cloud-top temperature were also investigated to avoid the retrieval issues for cloud-top temperature and pressure listed above. Brightness temperature at 11 µm was used. The same conclusions regarding glaciation of thick vs. thin clouds were found by these studies. However, brightness temperatures of thin clouds and high altitude clouds are too high to be considered actual cloud temperatures in many cases. This is because the brightness temperature includes the temperature of the Earth and atmosphere below the cloud if the cloud itself does not obscure these things. This is shown in Figure 7 where cloud-top temperature is contrasted with brightness temperature. The similar behavior between cloud-top temperature and brightness temperature confirms trends for glaciation of thick vs. thin clouds, but the temperatures themselves can't be compared to those from cloud-top temperatures.

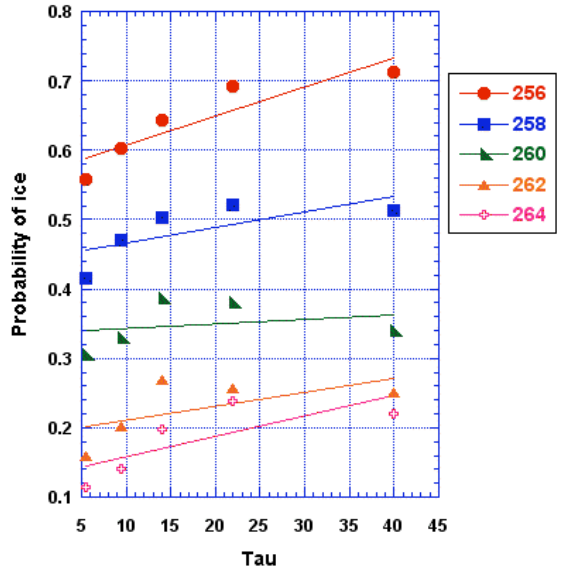

Figure 6: Isotherms for March. Optical depth categories are 4-7, 7-12, 12-16, 16-28, and 28-52 Tau. The slopes are positive indicating that thick clouds reach glaciation at higher temperatures than thin clouds. The slopes are more pronounced for September.

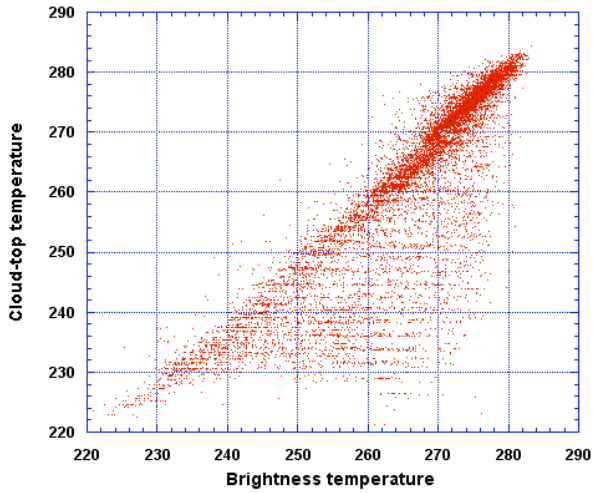

Figure 7: Brightness temperature vs. cloud-top temperature. For high cloud-top temperatures, the two appear to be one-to-one. At lower temperatures there is less one-to-one behavior. It is likely that the brightness temperature of colder or high altitude clouds is often supplemented by the surface temperature.

Comparison of March and September shows that glaciation occurs (as an average of optical depths 4 < Tau < 40) at the same temperature regardless of season but that the pressure level of glaciation changes. For temperature, both months have 50% glaciation at 258 K, see Figure 8. For pressure, 50% glaciation is at 583 mbar in March and 538

mbar in September, see Figure 9. In the late summer glaciation occurs at a lower pressure than in late winter. This is likely due to the different sea surface temperatures.

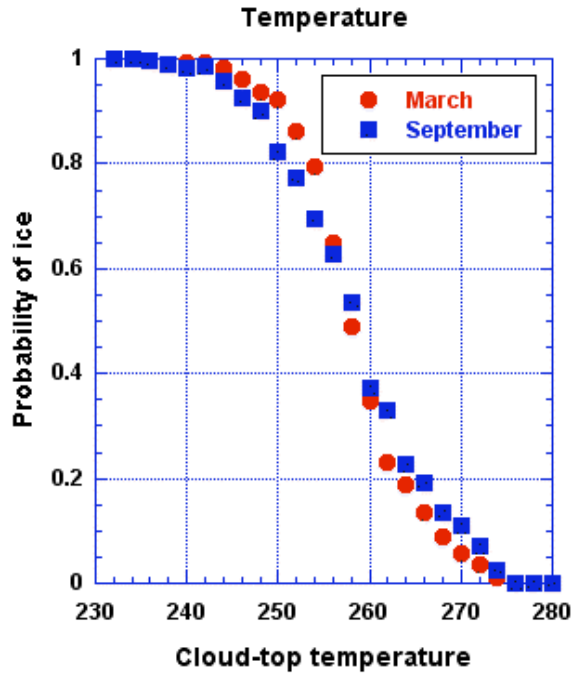

Figure 8: The probability curves for cloud-top temperature are shown for both March and September. All years and optical depths 4 < Tau < 40 are used. For both months 50% glaciation is at 258 K, by extrapolation.

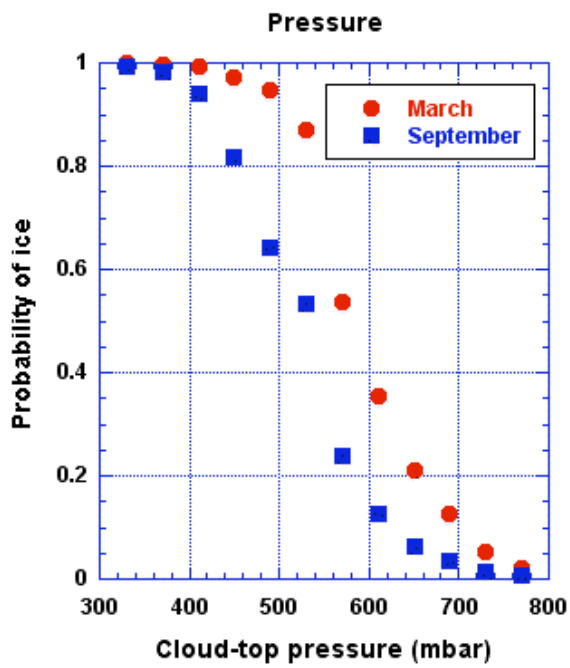

Figure 9: The probability curves for cloud-top pressure are shown for both March and September. All years and optical depths 4 < Tau < 40 are used. 50% glaciation is at 583 mbar in March and 538 mbar in September.

Conclusions

Analysis of both cloud-top temperature and brightness temperature indicate that for thicker clouds temperature is a more important factor defining the glaciation level. Furthermore, there is indication that thicker clouds reach glaciation at higher temperatures than thin clouds. Comparison between March and September indicates that glaciation occurs at lower pressures in September than in March, but at the same temperatures.

Future work

The studies done in this summer program were part of a larger project likely to be continued at Michigan Technological University. Future studies will include additional quantitative studies of cloud thickness and glaciation, analysis of other regions and possible global studies, comparison of individual years, and a study correlation between aerosol and glaciation.

Reference

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