P1.9 CLOUD PROPERTIES IN THE WINTER ARCTIC FROM MODIS DATA

Linong Yan* and Jennifer A. Francis
Institute of Marine and Coastal Sciences,
Rutgers University, New Brunswick, New Jersey, USA

1. INTRODUCTION

Many studies have suggested that the polar regions play an important pole in the global climate (e.g., Wetherald et al, 1988). Clouds over snow- and ice-covered surfaces are important to the surface energy budget, are often difficult to detect in both visible and infrared satellite imagery, and they have unusual properties and origins. Clouds residing below surface-based temperature inversions result in little contrast in the infrared wavelengths as viewed from space, so normal global cloud retrieval algorithms have difficulty diagnosing these cloud properties.

The effects of clouds on the surface energy balance are profound, especially in winter. Clouds greatly increase the amount of downward infrared radiation, and reduce the energy lost by the snow and ice surface. Cloud forcing at the surface is most sensitive to variability in thin water clouds, especially low ones. The effect of the nearly ubiquitous and difficult-to-detect low ice clouds (so-called "diamond dust") can be significant as well.

Present algorithms perform poorly in Arctic winter conditions (Schweiger et al, 1999). For example, the International Satellite Cloud Climatology Project (ISCCP) method assumes that clouds are colder than the surface, which is often not true during the long Arctic winter. The standard CO_2 slicing technique for cloud-top height retrieval performs poorly for all thin clouds and especially for thin clouds below a near-surface temperature inversion. In fact, the definition of thin cloud top is ambiguous. The "effective cloud height" is defined as the height corresponding to the infrared radiative temperature of cloud-top. The actual cloud height is defined as the upper-most height where cloud particles exist.

There are a few algorithms using Moderate Resolution Imaging Spectroradiometer (MODIS) that estimate cloud type and cloud phase in winter high latitudes, but comparisons between the estimate values and the surface observation values are sparse because of its harsh environment.

The validation data for this study come from the Barrow, AK, Atmospheric Radiation Measurement (ARM) site. Our project's main purpose is to develop algorithms which can be applied to cloud retrieval in the nighttime Arctic. Estimated cloud properties will be validated them with data from surface-based instruments, including lidar and radar. A brief overview of the steps applied to accomplish the objectives of our study is the following:

1. A forward radiative transfer model is used to simulate relationships among brightness temperatures at the top of atmosphere in several infrared bands for varying cloud droplet effective radius, optical depth, and phase.
2. Cloud either over or in the inversion layer is detected using MODIS channels at 3.7 and 11.03 µm.
3. Cloud phase is identified using MODIS channels at 8.5, 11.03 and 12.02 µm.
4. Cloud-top height retrieval techniques are in progress.

2. DATA

The Terra Earth Observing System satellite was launched in December 1999. MODIS is one of five instruments aboard the platform. MODIS has collected data from February 2000 to present. The viewing swath of MODIS is more than 2,300 km wide. MODIS collects the entire global surface with narrow gaps at the equator every day. (http://terra.nasa.gov). The MODIS instrument provides high sensitivity (12 bit) in 36 spectral bands ranging in wavelength from 0.4 µm to 14.4 µm (Table 1). Due to lack of sunlight during the Arctic winter, we use only MODIS infrared channels in this project. MODIS infrared bands range from 3.7 µm to 14.4 µm. MODIS bands 20 (3.7 µm) and 31 (11.03 µm) are used to retrieve surface and cloud inner temperature; MODIS band 29 (8.5 µm) is used to test cloud phase; MODIS band 33 (13.3 µm) is used to estimate the cloud effective height.

Table 1: Central wavelengths and weighting function peaks of MODIS channels used in this study.

MODIS Band	Central Wavelength (µm)	Peak of Weighting function (mb)
20	3.750	1000
22	3.950	1000
23	4.050	1000
24	4.465	360
25	4.515	600
27	6.715	320
28	7.325	600
29	8.55	1000
31	11.03	1000
32	12.02	1000
33	13.335	670
34	13.635	520
35	13.935	400
36	14.235	200

* Corresponding author address: Linong Yan, Institute of Marine and Coastal Sciences, 71 Dudley Road, Rutgers University, New Brunswick, NJ 08901-8521; email: linong@imcs.rutgers.edu.

The surface-measured lidar or radar cloud information used for validation of our algorithm is from the Barrow measurement site. A major problem in studying the cloud properties in the Arctic region is the scarcity of surface measurements. In this project, the surface-measured cloud information comes from the Atmospheric Radiation Measurement (ARM) program, supported by the U.S. Department of Energy (DOE). The ARM program focuses on obtaining field measurements and developing models to better understand the radiative transfer processes in the atmosphere (especially in clouds) and at the Earth's surface.

The north slope of Alaska (NSA) ARM site is located at 71.17 °N; 203.22 °E. Providing a validation data set for satellite cloud sensors is the main purpose of this observation site. The instruments at this site include radar, microwave radiometer, and rawinsondes, which provide information regarding cloud amount, water content (mg/m^3), and ice particle or droplet sizes (µm). We use radar, microwave radiometer, and rawinsonde data to classify clouds. (http://www.etl.noaa.gov/et6/arctic/nsa/). Rawinsondes data are used as input to Streamer, a radiative transfer model by Key et al, 1988, to retrieve cloud-top pressure, water content, and particle size.

3. METHODOLOGY AND PRELIMINARY RESULTS

First, Streamer is used to simulate the relationships among brightness temperatures at the top of the atmosphere in several infrared bands for varying cloud droplet effective radius, optical depth, and phase. Second, the 3.7 and 11.03 µm channels are applied to detect the cloud. Third, the 8.5, 11.03, and 12.02 µm channels are used to identify cloud phase.

Streamer can be used for calculating the radiance and irradiance for variety of atmospheric and surface conditions. The program called DISORT by Tsay et al. (1989) is the root of Streamer.

Figure 1 presents the ice and water absorption coefficients across near-infrared and infrared wavelengths. The central wavelengths of MODIS channels are superimposed on these curves. The different and similar absorption coefficients between ice and water help explain the brightness temperature at the different MODIS central wavelengths.

Streamer is used to simulate the effects of various cloud properties on MODIS channels at the central wavelengths 3.7, 8.5, 11.03 and 12.02 µm. Ackerman et al. (1990) and Strabala et al. (1994) suggested an infrared (IR) trispectral algorithm using the 8.52, 11 and 12 µm channels to infer cloud thermodynamic phase (ice or water). Baum et al. (2000) applied this algorithm to MODIS data.

We simulate the difference in brightness temperature T_B between the 3.7 and 11.03 µm MODIS channels for clouds composed of water droplets and ice crystals existing in a layer above and below a temperature inversion whose top is at 900 mb. Clouds above the inversion layer tend to have positive 3.7-11.03 µm T_B differences and clouds below inversion layer tend to have negative 3.7-11.03 µm T_B differences (Figure 2). This occurs because the emission at 3.7 µm is from a deeper level (but not necessarily the base) in a cloud as compared to 11.03 µm when looking down on the cloud.

Figure 3 is same as figure 2 but the differences in T_B are between the 8.5 and 11.03 µm MODIS channels. The differences in T_B are less than 1 for high water clouds, and around 1 for high ice clouds. Ambiguity will be further reduced by using the differences in T_B between the 11.03 and 12.02 µm MODIS channels (figure 4). From figure 4, the differences in T_B between 11.03 and 12.02 µm are less than 1 for high ice clouds, and around 1 for high water clouds. Ice clouds tend to have larger differences in T_B between the 8.5 and 11.03 µm, and water clouds tend to have larger differences in T_B between 11.03 and 12.02 µm, because the ice and water absorption coefficients increase and diverge with increasing wavelength from 8.5 to 12.02 µm (Figure 1).

Figure 5, 6 and 7 show an example of our cloud detection and phase retrieval on 14 February 2001 at 0610 UTC. Lidar and radar suggest a cloud layer exists with the base near 1.5 km. The differences in T_B between the 3.7 and 11.03 µm is near 5.0 K at the location near Barrow, and indicate the presence of cloud with a normal internal lapse rate (temperature decreases with increasing height). From the sharpness of the lidar return in this case, the cloud may have a mixed phase. The near-surface temperature is about 263 K from the radiosonde, the 11.03 T_B is approximately 238 K, and the difference in T_B between the 8.5 and 11.03 µm is about 0.5 K. According to the curve illustrated in figure 4, we would infer from the MODIS data that the cloud over Barrow contains water droplets, which would likely overwhelm the signal from any ice crystals that exist.

A popular technique for estimating cloud-top height is the CO_2 slicing method developed at the University of Wisconsin (e.g., Wylie et al, 1994). This algorithm, however, does not work well with thin clouds, low clouds, nor clouds beneath the inversion layer, all of which are typical conditions in the winter Arctic. In our project, a technique is devised to estimate cloud-top height, both actual and effective, for these elusive clouds. Streamer is used to estimate clear-sky radiances in the sounding channels of MODIS to use in the classical CO_2 slicing technique applied to "normal" clouds (positive internal lapse rate). This method results in an estimate of the radiative cloud top, or the cloud level with the temperature corresponding to the observed MODIS brightness temperature at 11.03 µm. We then intend to use a combination of other channels to infer the "correction" to this radiating level to estimate the actual cloud-top, or the height seen by an instrument, such as lidar, that is sensitive to sparse cloud particles.

5. CONCLUSIONS

From Streamer results, the brightness temperature T_B differences between the 3.7 and 11.03 µm are helpful to detect the cloud either over the inversion layer or in the inversion layer. The infrared (IR) trispectral algorithm by using the 8.5, 11.03 and 12.02 µm MODIS channels can be used in the Arctic to retrieve cloud phase successfully.

6. FUTURE WORK

We have recently obtained a large number of MODIS granules which will be analyzed to further refine our algorithm, especially the low ice cloud retrieval algorithm. We also hope, enable us to identify relationships among channels that allow us to determine both the effective and actual cloud-top heights.

ACKNOWLEDGEMENTS

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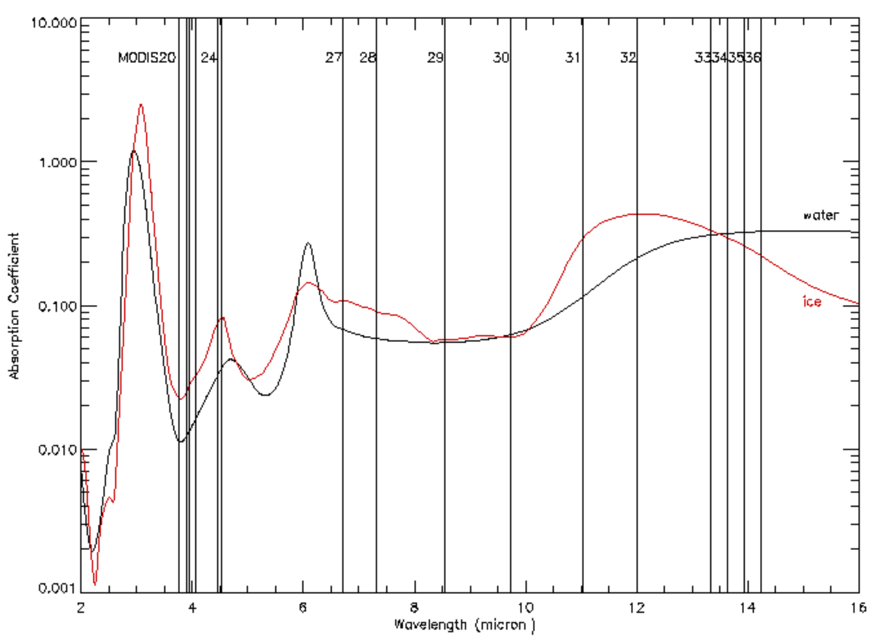


Figure 1: Absorption coefficients for water (purple) and ice (red) versus wavelength (data provided by S. Warren, U. of Washington). Central wavelengths of selected MODIS channels are indicated in black.

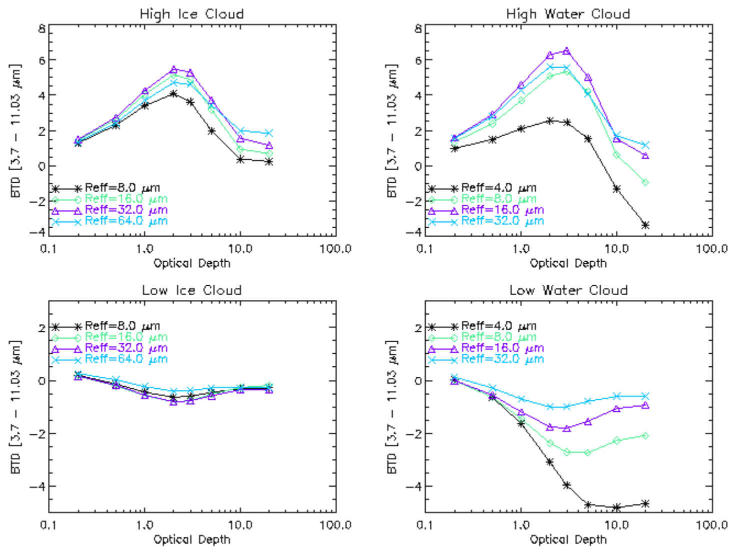
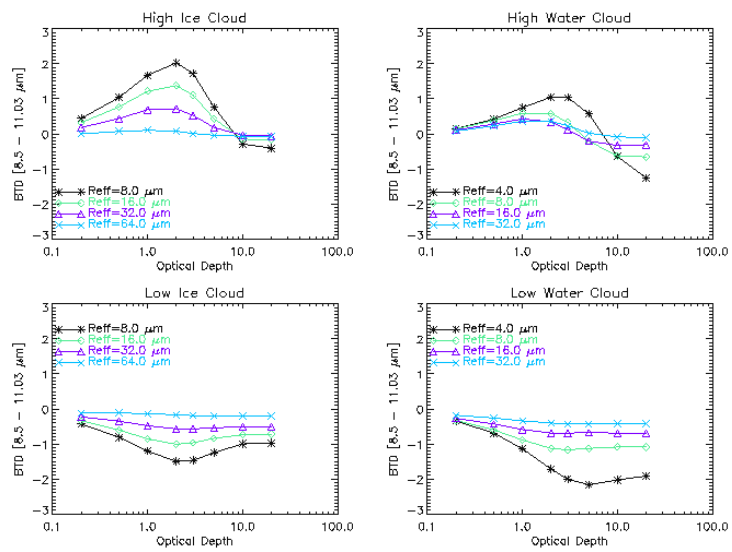


Figure 2: Simulated differences between 3.7 and 11.03 μm MODIS channels for clouds composed of ice crystals (left) and water droplets (right) existing in a layer above (top) and below (bottom) a temperature inversion whose top is at 900 mb. Typical winter Arctic conditions are used for the simulation. Varying effective particle sizes (μm) are represented by each curve versus optical depths.

Figure 3: Same as Figure 3 but for differences in T_B between the 8.5 and 11.03 MODIS channels.



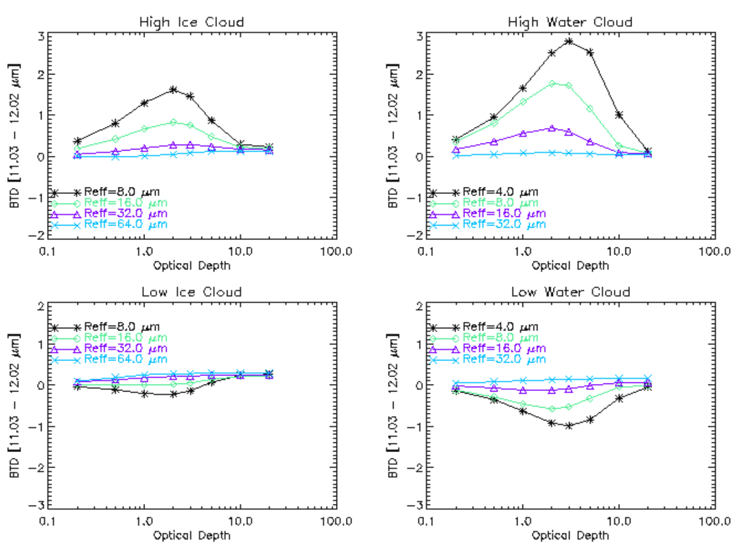


Figure 4: Same as Figure 3 but for differences in T_B between the 11.03 and 12.02 MODIS channels

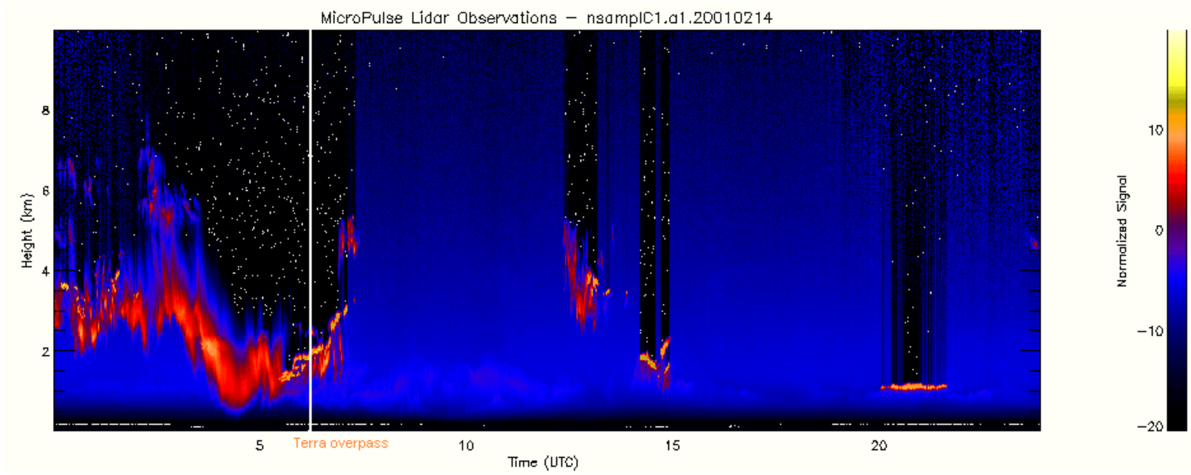
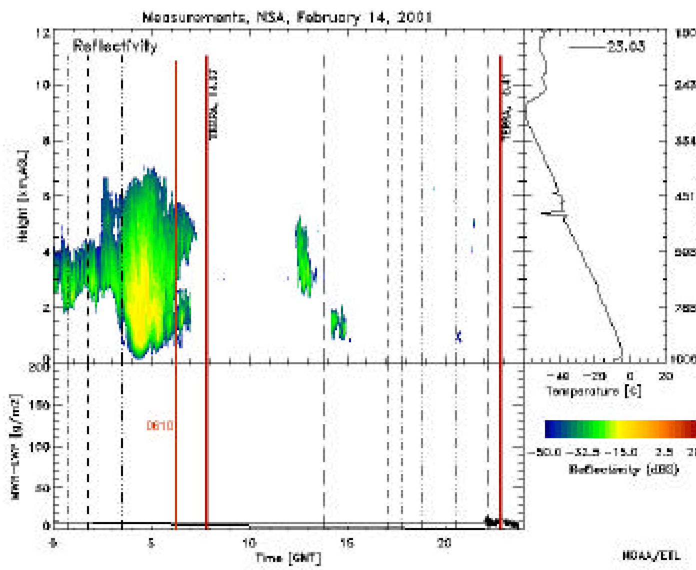


Figure 5: Surface-based micropulse lidar return strength on 14 February 2001 at the Barrow ARM site (from ARM/NSA website),

Figure 6: Raw MMCR radar reflectivity, retrieved liquid water path, and radiosonde temperature profile obtained from NOAA/ETL at http://www.etl.noaa.gov/et6/arctic/nsa/ on February 2001 at the Barrow ARM site.



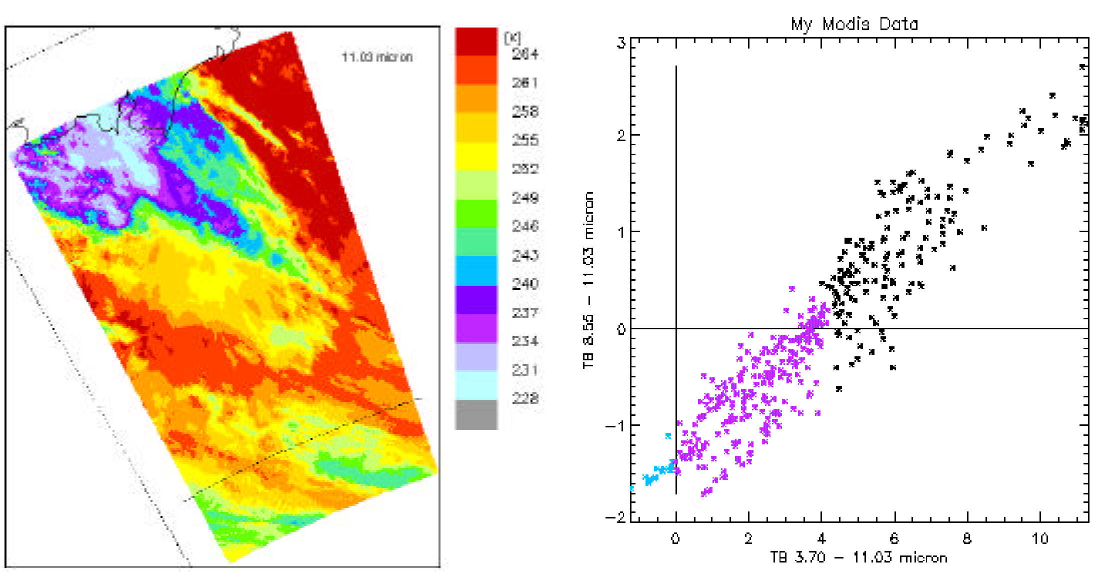


Figure 7: The 11.03 µm T_B over MODIS granule (left), and scatterplot of MODIS data for 3.7-11.03 and 8.5-11.03 µm T_B differences (right) at 0610 UTC on 14 February 2001 at the Barrow ARM site.