AM 6.2 Global and polar cloud cover from the Geoscience Laser Altimeter System, observations and implications

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1. INTRODUCTION

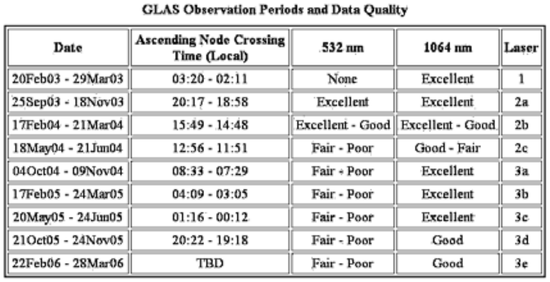
The Geoscience Laser Altimeter System (GLAS) was launched into orbit aboard the ICESAT spacecraft on January 12, 2003. GLAS is a dual purpose active remote sensing laser instrument. It serves both as an atmospheric lidar and as a precision altimeter that accurately measures the earth's surface profile. Results of atmospheric measurements will be covered in this presentation.

GLAS has three Nd:YAG lasers that have been operated consecutively. The doubled frequency at 532 nm wavelength is the primary atmospheric channel. Measurements at the fundamental frequency at 1064 nm were intended to provide supplemental information. By design, the 532 nm channel is more sensitive to an atmospheric signal. Details of the GLAS lidar system and data processing are given in Spinhirne et al., (2005) and the Algorithm Theoretical Basis Document (ATBD, Palm *et* all, 2001).

By measuring backscattered energy from laser pulse transmitted in a near-nadir direction, GLAS provides a vertical cross-section, 0-40 km vertically, of the cloud and aerosol conditions along the orbital track of the spacecraft. GLAS is in an orbit inclined at 94^{o} to the equator, so that it provides measurements to within 4^{o} of North and South Poles. It is at an altitude of about 600 km in a 91-day orbital track repeat cycle and an 8-day approximate repeat sub-cycle. This periodicity enables GLAS to make repeated observations at geographic points at which statistics and trends can be detected on approximately a monthly and longer time scale. The multiple year lifetime of GLAS permits comparison of results year to year to ascertain changes and trends.

It was originally intended that GLAS operate continuously for at least 3 years with each laser transmitting for a least a year. However, the stress of operating in a spacecraft environment truncated these expectations. The first laser failed after 37 days. Also, testing indicated that the 532 nm detectors should outgas in vacuum for some time before they were operated. So, during the first operational period, no green data were available. Turned on in late September, the second laser suffered rapid performance degradation. Based upon studies, operations of the second and third lasers were modified to short intermittent periods in order to conserve the longevity of the instrument. An additional problem with the third laser subsequently resulted in greatly degraded 532-energy. These difficulties resulted in reduced sensitivity of the 532 channel to clouds and has forced increased emphasis on the 1064 channel measurements in analysis. GLAS has operated during specific time segments of about 5 to 6 week duration since February 2003. The periods are shown in Table 1. Despite these limitations, the GLAS measurements have resulted in over two months of highly sensitive measurements of the global cloud distribution with the 532 nm channel and currently almost a year of data with the 1064 nm channel and weaker 532 nm performance.

In this presentation, we use the current GLAS atmospheric products to map and describe global cloud occurrence, locations, and optical properties. GLAS results are compared with similar results from other satellite observation systems MODIS and ISCCP. GLAS cloud products that are used in this analysis are cloud layer detection with the top and bottom altitudes of transmissive layers and cloud layer optical



GLAS Observation Periods and Data Quality

Date	Ascending Node Crossing Time (Local)	532 nm	1064 nm	Laser
20Feb03 - 29Mar03	03:20 - 02:11	None	Excellent	1
25Sep03 - 18Nov03	20:17 - 18:58	Excellent	Excellent	2a
17Feb04 - 21Mar04	15:49 - 14:48	Excellent - Good	Excellent - Good	2b
18May04 - 21Jun04	12:56 - 11:51	Fair - Poor	Good - Fair	2c
04Oct04 - 09Nov04	08:33 - 07:29	Fair - Poor	Excellent	3a
17Feb05 - 24Mar05	04:09 - 03:05	Fair - Poor	Excellent	3b
20May05 - 24Jun05	01:16 - 00:12	Fair - Poor	Excellent	3c
21Oct05 - 24Nov05	20:22 - 19:18	Fair - Poor	Good	3d
22Feb06 - 28Mar06	TBD	Fair - Poor	Good	3e

Table 1. GLAS observational periods, data quality, and local overpass time.

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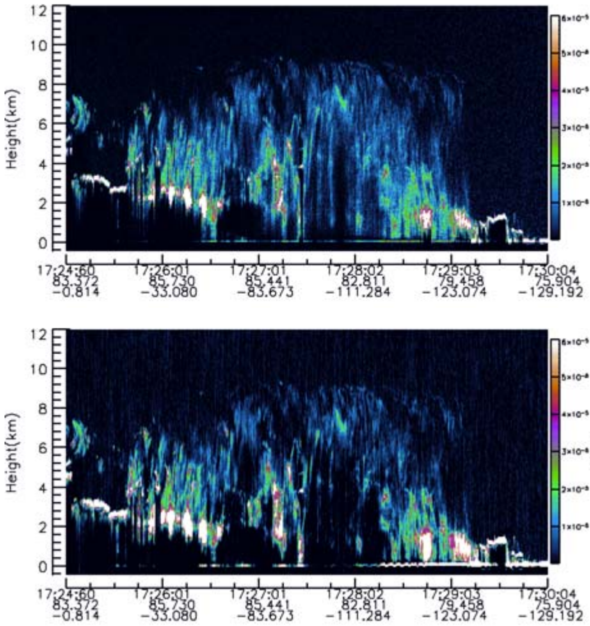

Fig. 1. GLAS attenuated backscatter coefficient from October 15, 2003. Top is 532 nm and bottom is 1064 nm. Difference in channel sensitivity is apparent.

depth determined from the 532 nm. channel. The 1064 nm channel is also separately used to determined layer occurrence and highest layer top altitude.

Clouds observations in polar regions are of special interest (Spinhirne et al., 2005b). The radiative background in polar regions present a special difficulty to passive observation analysis. The ice cover surface is highly reflective to solar energy and cold. These characteristics camouflage the bright and cold properties that used to detect clouds. Comparisons of GLAS cloud detection with other detection methods will provide some insight into the efficacy of other detection methods.

The presence of optically thin clouds produces a significant effect on the precise altimetry measurements made by GLAS. Multiple scattering in transmission through clouds produces a delay in the measured reflected pulse. We examine such effects in the polar region by showing a monthly average map of range delay.

Initial results of GLAS atmospheric analysis have been published on a variety of topics. Palm, et al. (2005), Hlavka, et. al. (2005), Hart et al (2005), Spinhirne et al (2005) and Lancaster et al (2005) describe some of the work that has been done. The research presented in those papers will be expanded as more data becomes available.

2. DATA AND RESULTS

Examples of GLAS attenuated backscatter coefficient are shown in Fig. 1. The data are taken from the North Polar Region and show a tenuous cloud extending from the earth's surface to about 9 km. Cloud location results are based upon backscatter coefficient magnitude and gradient. Clouds with this extended vertical depth are often found in the polar-regions. Comparison between the two images shows the greater sensitivity of the 532 nm. channel.

Cloud occurrence frequency has a significant influence on climatology, and so, it is a routine parameter derived for cloud observing

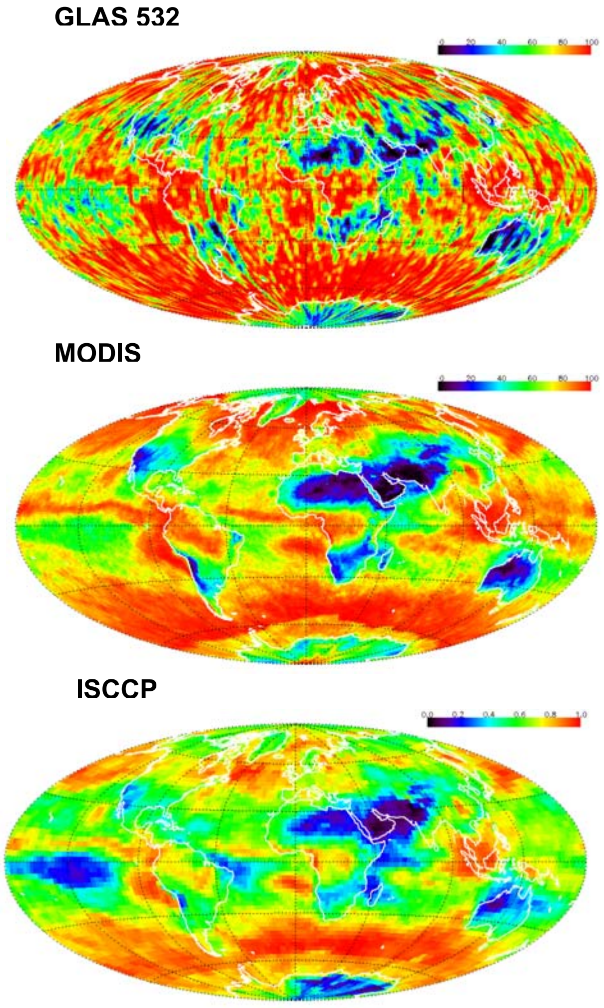

Figure 2A: Global maps of cloud frequency for GLAS, MODIS, ISCCP for October. 2003.

satellites. An active system such as GLAS may enhance and complement cloud observations made by radiometer techniques. To illustrate characteristics results of different system, we present a comparison of results from GLAS, ISCCP, and MODIS. Figure 2A presents a global map of cloud frequency derived from the three sources for the month October, 2003.when GLAS was at its optimal performance. The GLAS map was derived from the 532 nm. 5Hz cloud layer product. The sampling was done on a 1 degree longitude by 1 degree latitude grid, with the total number of 5Hz observations in each cell ranging from a few with zero to a few with about 200. GLAS included only PM observations which represent the afternoon cloud status to better match AQUA MODIS observations in time and atmospheric conditions. ISCCP results are based upon observations taken throughout the diurnal cycle, thereby including times of day when cloud formation is less active.

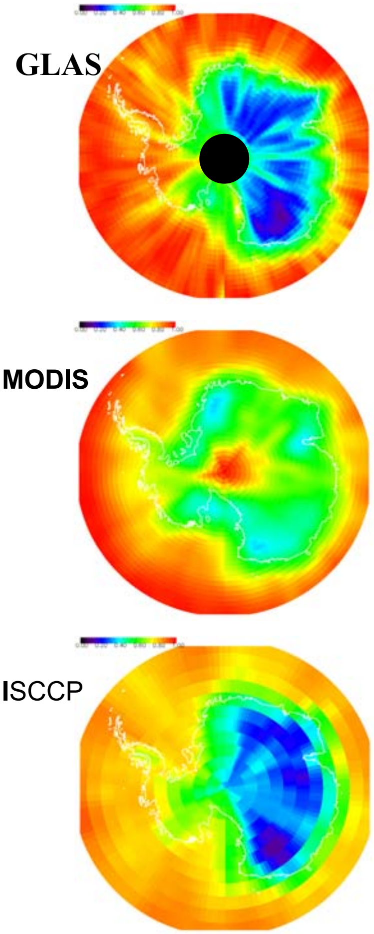

Figure 2B: Maps of cloud frequency over Antarctica for GLAS, MODIS, ISCCP for Oct. 2003 in

Comparisons show that cloud detection by the three methods result in similar large scale patterns. GLAS has different sampling characteristics that cause a rougher appearance. ISCCP shows the effects of full day sampling with generally lower cloud frequency than the other two. The region of special interest is Antarctica and surrounding latitude bands up to -30°. The view around Antarctica is expanded in Figure 2B. Over the continental region, GLAS cloud detection method provides a nearly unambiguous result. The radiometer techniques employed by MODIS and ISCCP are influences by the bright, cold background. Visual inspection suggests that GLAS and ISCCP results are in closer agreement with lower cloud frequency while MODIS is greater. In the ocean regions to the immediate north of Antarctica to about -55°, GLAS is indicating high cloud frequency while MODIS and ISCCP have lower results. One possible explanation for this is the presence of sea ice in the southern hemisphere spring but further study is needed. Between -55° and -30° latitude, all three methods show roughly similar results. Calculations of the global cloud fraction for October, 2003 for each of the methods are: GLAS, 76% for PM only observations; MODIS/AQUA, 73%; and ISCCP, 66%. ISCCP results are derived from full day observations, which would tend to result in fewer cloud observations than afternoon only observations.

A method to summarize the global cloud frequency is compute the cloud fraction for latitude bands around the entire earth and plot the result as a function of latitude. Results for October, 2003 are shown in Fig. 3. The MODIS

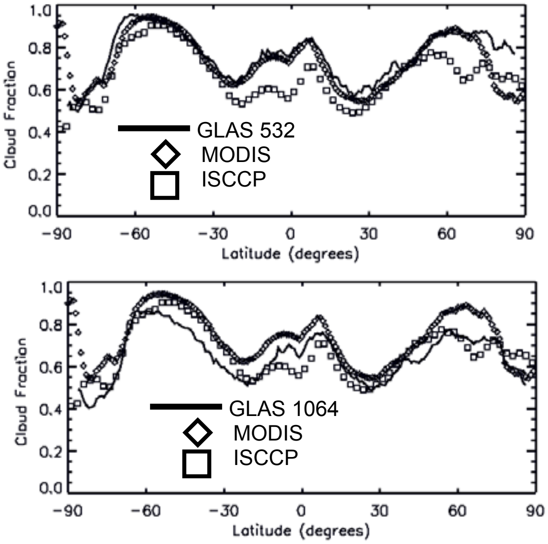

Fig. 3. Zonal cloud fraction for GLAS, ISCCP, and MODIS for October, 2003.

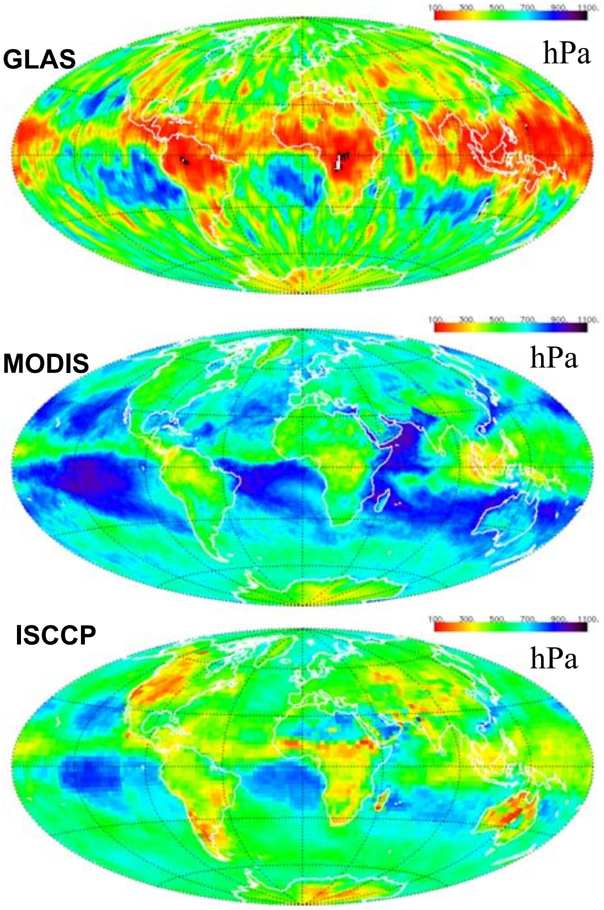

Fig. 4 Global average cloud tops for October, 2003 for GLAS, MODIS, and ISCCP

and ISCCP results are the same for each plot. The top plot shows GLAS 532 and the bottom show GLAS 1064 nm. results. The GLAS 532 nm. and MODIS show generally good agreement for afternoon observations while ISCCP, which uses observations from the entire day, is somewhat lower. The results in the Antarctic region reflect what was seen on the global maps. The generally lower results for the 1064 nm. channel compared to 532 channel result from its decrease sensitivity. The 1064 nm. channel sensitivity remains much more constant over time than 532 nm. channel making it better for inter-year comparisons.

Cloud altitude is an important parameter to be derived from satellite observations. The impact of the presence of clouds upon earth's energy exchange is strongly influenced by cloud temperature, which is determined by the vertical position of the cloud. Lidar observations find the geometrical altitude of clouds while infrared radiometers find an altitude based upon the influence of the cloud on upwelling energy. The temperature and density of the cloud modulate this result. The passive radiometer cloud top

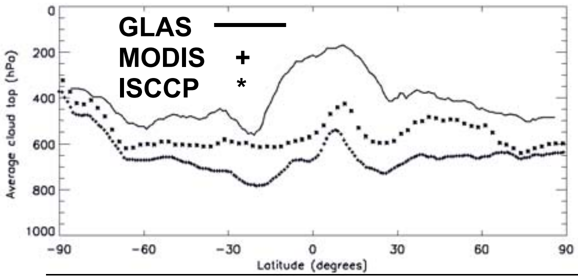

Fig. 5. Zonal average cloud top for GLAS, ISCCP, and MODIS for October, 2003.

altitude will be lower than the lidar altitude. Fig. 4 shows global maps of cloud top pressure determined by GLAS, MODIS, and ISCCP for October, 2003. All three show the highest clouds in the tropical regions and large areas of low clouds off the west coasts of continents. Cloud top estimates are highest altitude for GLAS and lowest for afternoon MODIS/AQUA even though ISCCP results are based upon 24 hour observations. Latitude zone cloud top averages are shown in Fig. 5. The three systems show a maximum in the near-equator region associated with the inter-tropical convergence zone and local minimums in the subsidence regions associated with Hadley cells. In the northern hemisphere, GLAS show a high to low slope from south to north to the Arctic region at which a slight rise is extends toward the pole. ISCCP shows a similar pattern at a lower altitude. MODIS show a rise in altitude toward the pole. In the southern hemisphere, all three systems show a rise in altitude from about -70° to converge on approximately the same value near the South Pole.

To examine the change in global cloud fraction from October, 2003 to October, 2004, we show the zonal cloud fraction for three systems in Fig. 6. GLAS 532 nm. channel had deteriorated by that time, so the 1064 nm. channel was used. Its low sensitivity biases its result to the low side. Also, the time range was not exactly calendar month October (see table 1). The shapes of the

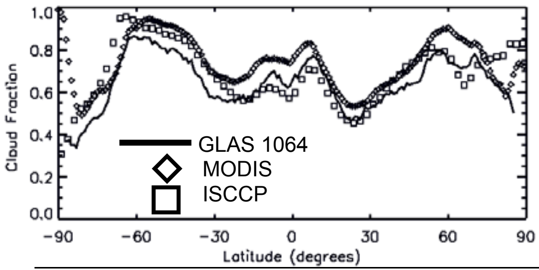

Fig. 6. Zonal cloud fraction for GLAS, ISCCP, and MODIS for October, 2004.

GLAS and ISCCP curves match well except north of about +60°. The localized maxima of all three curves are approximately coincident in latitude position. In October, 2003 the global average cloud fraction for GLAS (1064 nm. analysis) was 0.647, MODIS was 0.735, and ISCCP was 0.665. In October, 2004, the global cloud fraction was 0.646, 0.735, and 0.693 for GLAS, MODIS, and ISCCP, respectively. ISCCP shows a moderate increase while GLAS and MODIS remain constant. Additional analysis for other time periods is needed to reveal trends in global cloudiness.

GLAS is a dual purpose laser instrument. In addition to atmospheric lidar measurements, precision altimetry is a function. The goals of GLAS altimetry are to measure the earth's ice surfaces to centimeter precision. Multiple scattering by atmospheric particles can delay photon travel time and influence the altimetry measurement. The lidar measurements of GLAS provide a means to estimate the delay time. An example of an average of these estimates for October, 2003 is shown in Fig. 7. As expected, the magnitude of the range delay is greatest where the average cloud cover is the greatest and least where there is less cloud cover (see Fig. 2B). Appropriate use of the range delay estimates will enhance the accuracy of the altimeter results.

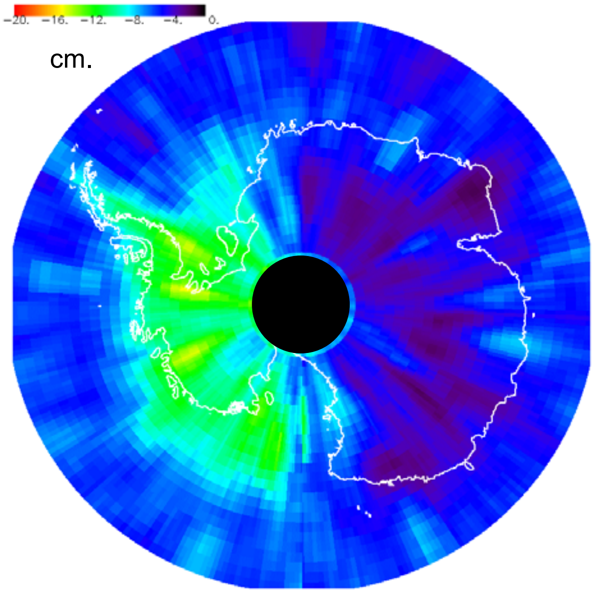

Figure 7: Average range offset induced by multiple scattering for October, 2003.

3. SUMMARY AND CONCLUSIONS

In our presentation, we show global cloud occurrence frequency and cloud top height distributions derived from the GLAS observations that comprise part of the standard GLAS cloud data product. Corresponding results are shown for MODIS and ISCCP. These results establish the effectiveness of using GLAS cloud products for climatological studies. We demonstrate that spaceborne lidar is a sensitive tool for making routine long term global cloud observations. As an active instrument, It. has advantages over radiometers in determining the altitude of tenuous high clouds and detecting occurrences of multiple layers We show that lidar can complement and validate cloud radiometer observations. We find that continuous long term observations by GLAS can provide valuable information for determining cloud cover changes and trends, even when the 1064 nm. channel, which has reduced sensitivity, is used for analysis. Analysis of GLAS over its entire operational life will yield meaningful results for climatologicl studies.

ACKNOWLEDGEMENTS

MODIS:
The data used in this study were acquired as part of the NASA's Earth Science Enterprise. The algorithms were developed by the MODIS Science Teams. The data were processed by the MODIS Adaptive Processing System (MODAPS) and Goddard Distributed Active Archive Center (DAAC), and are archived and distributed by the Goddard DAAC.

The ISCCP D2 data/images were obtained from the International Satellite Cloud Climatology Project web site http://isccp.giss.nasa.gov maintained by the ISCCP research group at the NASA Goddard Institute for Space Studies, New York, NY. on January, 2005. Rossow, W.B., and Schiffer, R.A., 1999: Advances in Understanding Clouds from ISCCP. Bull. Amer. Meteor. Soc., 80,2261-2288

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