SUMMARY OF GLOBAL RESULTS FROM THE GLAS SATELLITE LIDAR

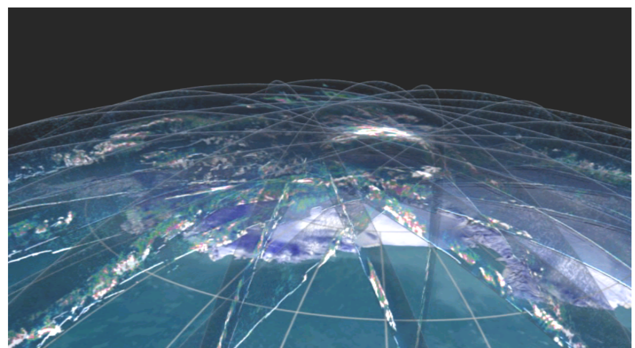
James D.Spinhirne[(1)] , Stephen P. Palm[(2)] , William D. Hart[(2)] and Dennis L. Hlavka[(2)]
(1)NASA Goddard Space Flight Center, C613.1, Greenbelt MD 20771, USA, James.Spinhirne@NASA.gov
(2)SSAI/NASA Goddard Space Flight Center, C613.1, Greenbelt MD 20771, USA, first.last@NASA.gov

ABSTRACT

Space borne observations by a high performance polar orbiting lidar, initiated in 2003 by the launch of the Geoscience Laser Altimeter System (GLAS), have provided fundamentally new results on the global distribution of clouds and aerosol. The primary advance from the active optical sensing is an unambiguously accurate, and highly resolved, measurement of the distribution for atmospheric scattering layers. In addition the lidar data provides an extreme sensitive detection of the thinnest aerosol and cloud layers and their optical thickness. The initial analyzed results for GLAS from fall 2003 show the total global cloud cover is 69% and cloud overlap, defined as the detection of a second cloud layer before full optical attenuation, is found to be present in 40% of cloudy areas globally. The global pattern of retrieved cloud altitude is significantly different than results from passive sensors. The measured penetration height of cirrus clouds in the tropics is observed to be a significant factor for stratosphere/troposphere exchange. The optical depth frequency distribution of cirrus is found to peak at 0.02. For atmospheric aerosol, regions of heavy loading – North Africa, the Indian Ocean, Asia and biomass burning – with elevated aerosol layers above and overlapping clouds are a normal occurrence. Defining clear as aerosol and cloud optical depths of less than 0.01, GLAS shows 20% of the global atmosphere as clear. From interpretation of the aerosol height distribution a unique global data product of PBL height has been produced. The PBL height data have been applied as a new validation for the ECMWF and other global circulation models. The GLAS data are limited to eight months, but demonstrate the value of active optical remote sensing that is to continue with three additional instruments to be launched by NASA and ESA in the next seven years.

1. INTRODUCTION

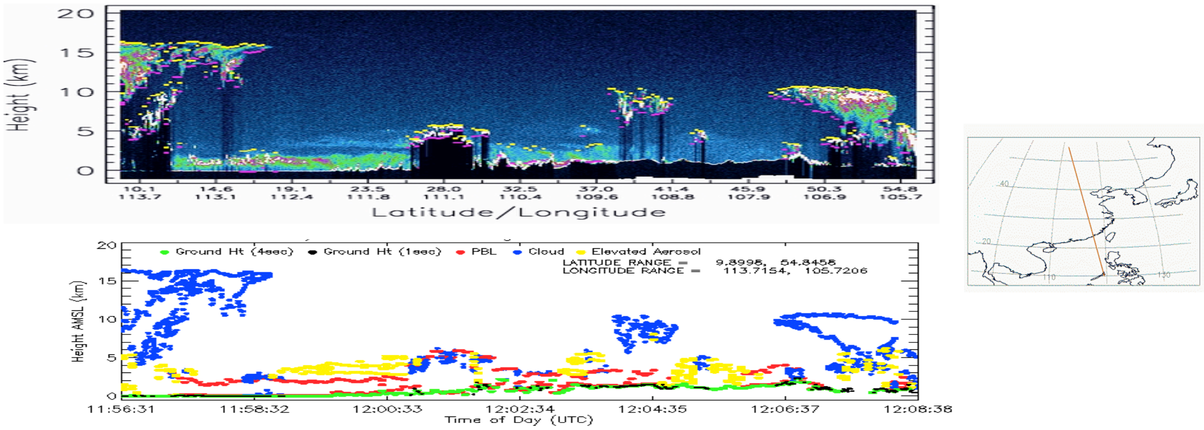
The Geoscience Laser Altimeter System (GLAS) launched in 2003 provides the first global profiling from an active laser remote sensing instrument in space - a fundamentally new measurements for atmospheric research. From results a very accurate new measurement of the coverage and height distribution of global cloud cover is obtained. The results now show significant limitation of and paths to improve passive satellite data on cloudiness. In particular there is an accuracy leap forward in the measurement of polar clouds from space. Further we have the first global measurements and maps of boundary layer height and aerosol optical depth of the planetary boundary layer which have been applied to initial model intercomparisons. The PBL measurements are part of the broader frame of the first global measurements of the true height distribution of global aerosol layers. From these and other applications, the GLAS measurements represent an important new tool for earth science and global change research [1].



1. Above is a depiction of one day of GLAS measurements over Antarctica. The measurements give a very accurate detection and height profile of all significant clouds and aerosol layers in the atmosphere. The structure is an Antarctica storm system overlain by polar stratospheric clouds.

2. Data Products

The GLAS measurements provide the capability to resolve atmosphere scattering layers from resolutions below 100m to globally girded data results. Examples of these unique measurements are shown in first two figures. GLAS data visualization as in Fig. 1 are arresting and instructive, but the true value of the data is in the data products that are derived from the laser signals. One product is the accurate detection and definition heights for cloud and aerosol layers. Up to the limit of signal attenuation, GLAS detects all radiatively significant cloud and aerosol layers along its observation track. From the basic lidar signal a data product is produced that represents the corrected and calibrated attenuated



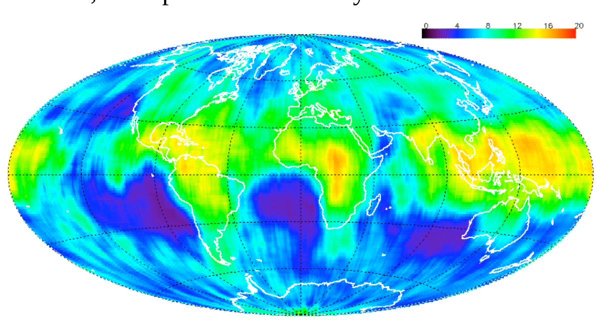
2. GLAS cloud and aerosol signal over China on October 23, 2003. Also shown are the GLAS cloud height data product produced from analysis of the signal. The yellow line is the detected cloud top height, and the purple line is the cloud base height (for optically transmissive clouds). The scattering layers not outlined here are aerosol dust and pollution, segregated in processing from cloud layers. In this case the aerosol is part of consistent dense haze in the Asian region sometimes termed the "atmospheric brown cloud".

backscatter cross section at both system wavelengths, 532 and 1064 nm. The first panel of Fig. 2 shows an example of this product for the 532 nm channel. From the corrected signals a sophisticated thresholding and filtering routine is used to determine the upper and lower boundaries of scattering layers, and further multi component analysis is applied to discriminate between cloud and aerosol layers. An example of the scattering layer boundary data products is shown in the second panel of Fig. 2. The other major class of data products for atmospheric observations are the optical depth and height distribution of extinction cross section for aerosol and thin cloud layers. These parameters are derived from algorithms employing several approaches including in appropriate cases a direct retrieval based on attenuation of the molecular scattering signal. The measurements are fundamentally different and additionally accurate to passive satellite retrieval of aerosol and cloud optical thickness

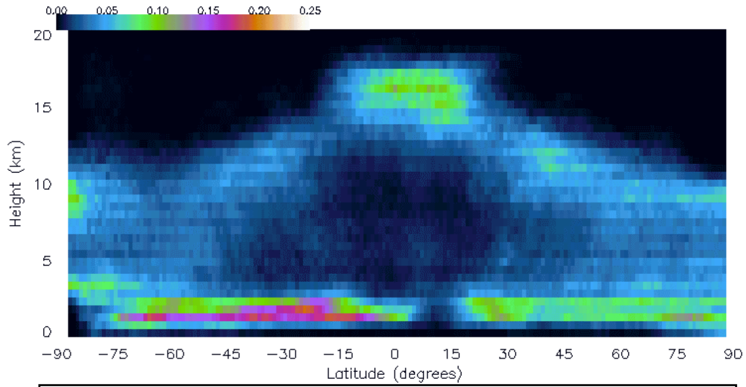
3. GLOBAL CLOUDINESS

Cloud feedback is thought by some in the modeling communities to be the largest uncertainty for global warming. A basic question is "if cloud cover may be changing – are current observation sufficient to detect change to the level need". The global cloud detection products by GLAS have been shown to reliably detect cloud layers down to optical depth less than 0.01. The cloud height distribution including multiple layers is unambiguous and accurate. Even with nadir only coverage, the lidar results alone give a new and more accurate global view of cloud cover over monthly means. Examples of these new and unique measurements are shown in Fig. 3 and 4 which show the maximum global cloud height and the zonal average height of clouds. The results show significant cloud reaching into the lower stratosphere, a significant result for tropospheric/stratospheric exchange. Overall GLAS has found that the actual coverage of the globe by clouds is 69% of which a 45% are single layered within the limits of optical attenuation and a surprising 76% of clouds are sufficient to block the optical surface return. The best GLAS cloud products require the 532 nm channel data which is limited to approximately two months of observations due to laser failures [1].

As an important applidation and result for cloud cover, GLAS data products may be compared to other existing satellite retrievals that have longer term measurements and greater sampling coverage. The comparison show limitations and possible improvements for overall cloud retrievals. One type of comparison is direct pixel-by-pixel intercomparisions. With the current multi month data set, it is possible to readily construct observational



3. Global maximum cloud height derived from GLAS for October 2003. In each 1x1 degree grid box the maxim detected cloud top height over the month is shown. These are the first measurements of this parameter. In significant cases, cloud exchange into the stratosphere is observed.



4. The zonal average frequency distribution of cloud height detection for GLAS data from October 2003.

data sets of thousands of pixel scale comparisons that are within a few seconds of each other. One such study [2] showed a 40% nighttime misidentification of the MODIS cloud mask for polar regions. Another comparison is between monthly averaged cloud retrieval. The comparison of the zonal average MODIS global cloud fraction and the values derived from GLAS show generally good agreement is found except in polar regions. The cloud height results from GLAS are accurate and unambiguous. Important understanding of existing cloud climatologies from comparison to GLAS is even more significant for cloud height. A result between GLAS and the MODIS cloud product in terms of cloud top pressure is shown in Fig. 5. In this case the comparative interest is in the definition of the passive retrieval which represents some level defined by the radiative source function. For the MODIS result we find the definition is typically on the order of 150 hPa below the actual cloud type.

A special cloud application for GLAS data is for polar cloud cover. It is well known that passive cloud observations are limited both by the short wave brightness of the background very low thermal brightness temperatures in polar regions. Adequate data on the nature of Antarctica clouds was so lacking prior to GLAS that a special experiment was developed at the South Pole station in order to be able to correctly model the instrument performance. We believe that the GLAS data and data products have now given the most accurate picture of polar cloud cover to date. As mentioned before, significant limitations in the MODIS cloud products for polar regions have been found by comparing to GLAS [2]. In addition a comparison of month mean cloud coverage and height shows large difference to the MODIS cloud product [3].

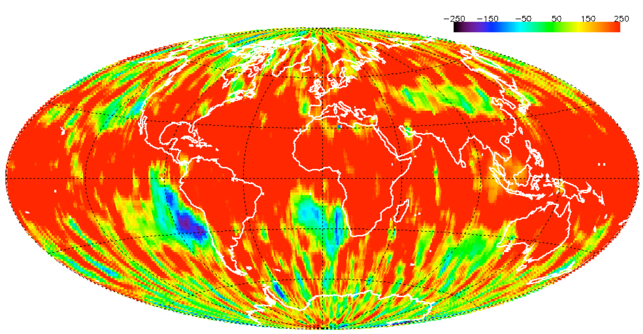
There are other unique applications of the GLAS cloud observations. One is the relative distribution between cloud and aerosol layers. Current research shows that the indirect effect of aerosol on clouds is a very important issue for climate forcing. The GLAS data reveal the relative height and coverage distributions between clouds and aerosol layers that is not possible with passive data [4]. Another unique application of the GLAS data comes from spectacular observation of the distribution of polar stratospheric clouds [5].

4. GLOBAL AEROSOL DISTRIBUTION

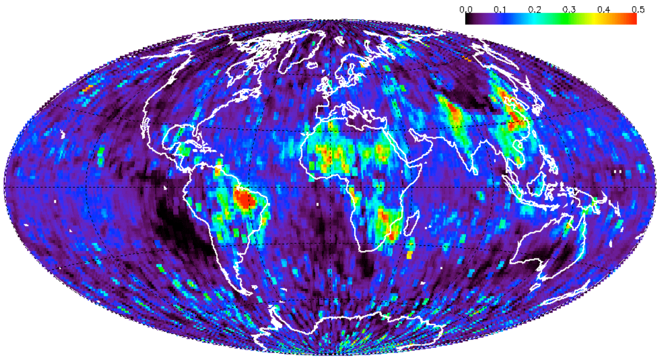
In terms of completely new science data, the global aerosol profiling measurements from space by GLAS are likely the most unique. The GLAS algorithms detect two types of aerosol layers: the fist the one at the surface and associated with the planetary boundary layer (PBL) and the second elevated layers that are clearly separated from the lowest layer. One application of the aerosol height information is in its use with global aerosol source and transport models. The question that can be answered with the GLAS data is whether the models place aerosol at the appropriate level. A related application is the effect of aerosol radiative heating, for example the role of elevated absorbing aerosol suppressing cloud formation and precipitation [4].

A further aspect of aerosol detection is the relation between the aerosol capping level and the actual PBL height. The PBL height is a highly significant dynamic variable for coupling surface facts to the atmosphere and one not previous derived from satellite data. A separate algorithm employs knowledge of the relation between aerosol distribution and PBL height to derive the global PBL height for the first time from GLAS data. Palm et al. [6] describe global PBL height retrievals from GLAS and their comparison to results from the ECMWF global circulation model, the first such comparison.

The GLAS aerosol data allows a fully independent measurement of the global aerosol optical depth. Unlike passive retrieval, the separation of signals reflected from



5. The difference between GLAS and MODIS cloud height in hPa of pressure for October 2003.



5. The initial aerosol optical thickness for the globe derived from the GLAS 532 nm data for October 2004. .

the surface and atmosphere is unambiguous. Thus the retrieval over land surfaces is the same as the ocean and likely more accurate than the existing aerosol optical thickness over continents from shortwave passive data. A preliminary aerosol optical depth from GLAS for the globe is shown in Fig. 5. The current algorithm employs a regional based aerosol model for conversion from backscatter to extinction, but an improved algorithm is in testing which employs model output for aerosol type. The algorithm performance for aerosol optical thickness is validated by intercomparison to airborne and ground based measurement and is expected to undergo further improvements [7]. A new approach is being tested for direct retrieval of optic depth by employing the calibrated ocean pulse reflectance [8]. Basic results such as finding 20% of the atmosphere are 'clear' are already sufficiently valid to be applied [9]

5. CONCLUDING

As an EOS mission, GLAS data are freely available through the NASA Distributed Active Archive Centers (DAAC) system [10]. Both data sets and data input and visualization tools are available. In addition the atmospheric group maintains a web portal with convenient access to quick look images of all data and other information such as documents describing observations and data products [11].

The GLAS instrument was designed with three lasers to obtain a three to five year mission life. Life testing indicated that each laser should last for two years. During the initial on orbit test operation with the first GLAS laser there was a premature failure of a pump diode module. After the two months of full operation in the fall of 2003, the operational plan for GLAS has been to operate for a one-month periods out of every three to six months in order to extend the time series of measurements, and operations are continuing to present. Although the laser reliability failure limits the use of the GLAS data for climate applications requiring a time series of measurements, overall the mission has clearly demonstrated the important applications for space borne lidar and created a unique data set from thousands of orbits with many research applications.

6. REFERENCES

1. "Cloud and aerosol measurements from GLAS: overview and initial results", J. D. Spinhirne, S. P. Palm, W. D. Hart, D. L. Hlavka and E J. Welton, Geophs. Res. Lett., 32, L22S03, doi:10.1029/2005GL023507, 2005.
2. "Passive and active detection of clouds: Comparisons between MODIS and GLAS observations," A. Mahesh, M. A. Grey, S. P. Palm, W. D. Hart and J. D. Spinhirne, J. Geophys. Res., 108, L04108-L04108, 2004.
3. "Antarctica cloud cover for October 2003 from GLAS satellite lidar profiling," J. D. Spinhirne, A. Mahesh, S. P. Palm, W. D. Hart,and D. L. Hlavka, Geophs. Res. Lett., 32, L22S05, doi:10.1029/2005GL023782, 2005.
4. "Height distribution between cloud and aerosol layers in the Indian Ocean region from the GLAS spaceborne lidar", W. D. Hart, J. D. Spinhirne, S. P. Palm, and D. Hlavka, Geophs. Res. Lett., 32, L22S06, doi:10.1029/2005GL023671, 2005.
5. "Observations of Antarctic Polar Stratospheric Clouds by GLAS," S. P. Palm, J. D. Spinhirne, and W. D. Hart, Geophs. Res. Lett., 32, L22S04, doi:10.1029/2005GL023524, 2005.
6. "Validation of ECMWF global forecast model parameters using GLAS atmospheric channel measurements," S. P. Palm, A. Benedetti, J.D Spinhirne, W. Hart and D. Hlavka, Geophs. Res. Lett., 32, L22S09, doi:10.1029/2005GL023535, 2005.
7. "Aerosol and cloud optical depth from GLAS: Results and verification for an October 2003 California fire smoke case," D. L. Hlavka, S. P. Palm, W. D. Hart, J. D. Spinhirne and E. J. Welton, Geophs. Res. Lett., 32, L22S07, doi:10.1029/2005GL023413, 2005.
8. "Scattering layer statistics from space borne GLAS observations", 2005 F. M. Bréon, D. M. O'Brien, and J. D. Spinhirne Geophys. Res. Lett., 32, L22802, doi:10.1029/2005GL023825.
9. "Laser pulse reflectance of the ocean surface from the GLAS Satellite Lidar," R. Lancaster, J. D. Spinhirne and S. P. Palm, Geophs. Res. Lett., 32, L22S10, doi:10.1029/2005GL023732, 2005.
10. Internet web address: http://nsidc.org/daac/icesat/
11. Internet web address: http://glo.gsfc.nasa.gov/