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GLOBAL AEROSOL MEASUREMENTS FROM THE GEOSCIENCE LASER ALTIMETER SYSTEM SATELLITE LIDAR

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1. INTRODUCTION

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 (Spinhirne et al., 2005). 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. For clouds, 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. If an optically opaque atmosphere is defined as a lack of a laser signal from the surface, then GLAS finds a surprising 49% of the global atmosphere to be optically opaque. The global pattern of retrieved cloud altitude is significantly different than results from passive sensors (Hart et al., 2006).

For atmospheric aerosol, GLAS observations represent the first global measurements of the true height distribution. In addition lidar gives a much more sensitive detection of aerosol layers than passive sensors and is not biased by land background. The data are analyzed for aerosol optical depth and extinction cross section with well know retrieval methods. Values obtained have an advantage for accurate measurements of low optical depth. Some results for GLAS aerosol measurements have already been reported. From interpretation of the aerosol height distribution a unique global data product of PBL height is produced. The PBL height data have been applied as a new validation for the ECMWF and other global circulation models (Palm et al., 2005). Data have also been used to determine the faction of the global atmosphere that is “clear” (Breon et al, 2005). Defining clear as aerosol and cloud optical depths of less than 0.01, GLAS shows 20% of the global atmosphere as clear. Hart et al. (2005) show how data define the height distribution between aerosol and cloud in the PBL. In this paper we summarize the current results for the global distribution of aerosol cross section and optical thickness.

Within the global data 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, and often dramatic, occurrence. Retrievals of accurate optical depth in cases of high optical depth can be problematic with standard lidar solutions. Recently an improved procedure using aerosol transport model output has increased the accuracy of retrievals.

Instrument problems have affected the quality and length of all GLAS observations (see Hart et al., 2006 Table 1). The GLAS data are currently limited to eleven months, and high quality data to three months. The global measurements for even this time period will be shown to represent a significant new result for aerosol, radiation and

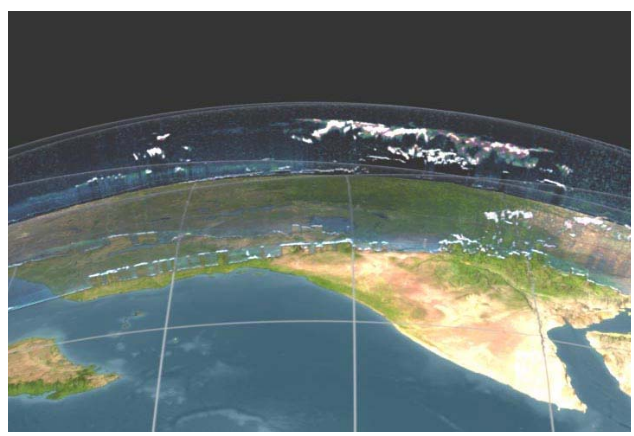

Figure 1. Depiction of one day of GLAS measurements over the middle east. The measurements give a very accurate detection and height profile of all significant clouds and aerosol layers in the atmosphere, but the coverage is limited to nadir only profiling.

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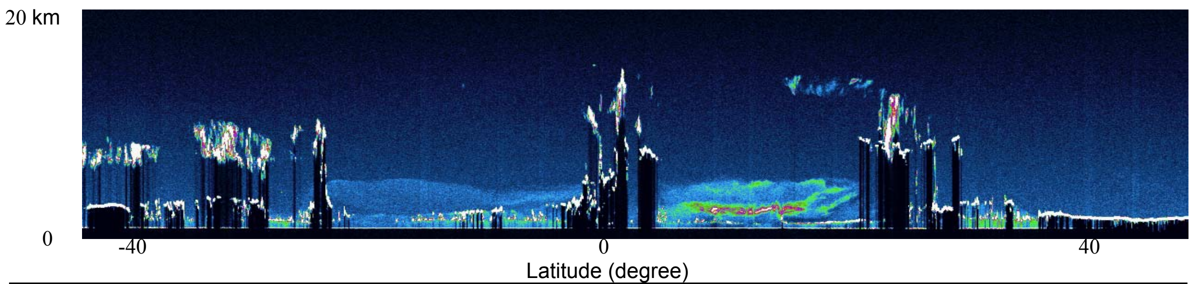


Figure 2. The GLAS 532 nm signal from aerosol and cloud layer for the Atlantic off the coast of West Africa on October 4, 2003. The elevated aerosol layers are transported dust from the Saharan desert. In addition to the aerosol layers are stratus, cirrus and convective cloud layers.

global change research.

2. DATA PRODUCTS

The GLAS measurements provide the capability to resolve atmosphere scattering layers from resolutions below 100m to globally girded data results. As depicted in Fig. 1, the sampling is nadir only, but the sixteen global orbits per day permit several sampling of major aerosol regions such as North Africa per day. A depiction of the observed lidar signal for a track over the Atlantic in Fig. 2 clearly shows the presence of boundary layer and elevated aerosol layers and is typical of the night time 532 nm data from fall 2003 when the best instrument results occurred.

GLAS data visualization as in Fig. 1 and 2 are informative, 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 backscatter cross section at both system wavelengths, 532 and 1064 nm. The data in 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 third panel of Fig. 3. and corresponds to a central segment of Fig. 2.

The other major data products for atmospheric observations are the optical depth and height distribution of extinction and backscatter cross section for aerosol and thin cloud layers. These parameters are derived from algorithms employing currently two basic approaches (Palm et al., 2002; Hlavka et al., 2005). In appropriate cases a direct retrieval based on attenuation of the molecular scattering signal can be obtained for elevated aerosol layers where a thresholding test indicates that a layer sufficiently close to molecular scattering exist below the aerosol layer. Such cases are rare in the overall data set. In the large majority of cases the forward integration retrieval mentioned before is used. The results are totally dependent on the assumed backscatter to extinction ration of the scattering. Currently a location based lookup table of the scattering ratio, dependent on aerosol type models, is used. As of release 26 of the GLAS data products the aerosol type mixture for global locations is updated daily based on the output of the Navy Aerosol Analysis and Prediction System Global Aerosol Model. Improved result in comparison with other measurements and validation data are found.

Examples of the aerosol extinction and backscatter cross section for the data image of Fig. 2 is shown in the first two panels of Fig. 3. The total optical thickness is found readily by integration of the extinction cross section over height, and for the layer shown, varies from 0.5 to 1. Data images as in Fig. 2 and 3 are producible directly from web based tools (web site 1). The example here represents only one short orbit track for one region. The aerosol structure, relation to dynamics and clouds and variation in type may be seen in the data for the many different unique aerosol regions of the world. To attempt a detailed examination of all regions from even the two months of good quality data now available is an overwhelming task.

3. GLOBAL AEROSOL DISTRIBUTION

In terms of completely new science data, the global aerosol profiling measurements from space by GLAS are now unique. The GLAS algorithms detect two types of aerosol layers: the fist the one at the surface and associated with the planetary

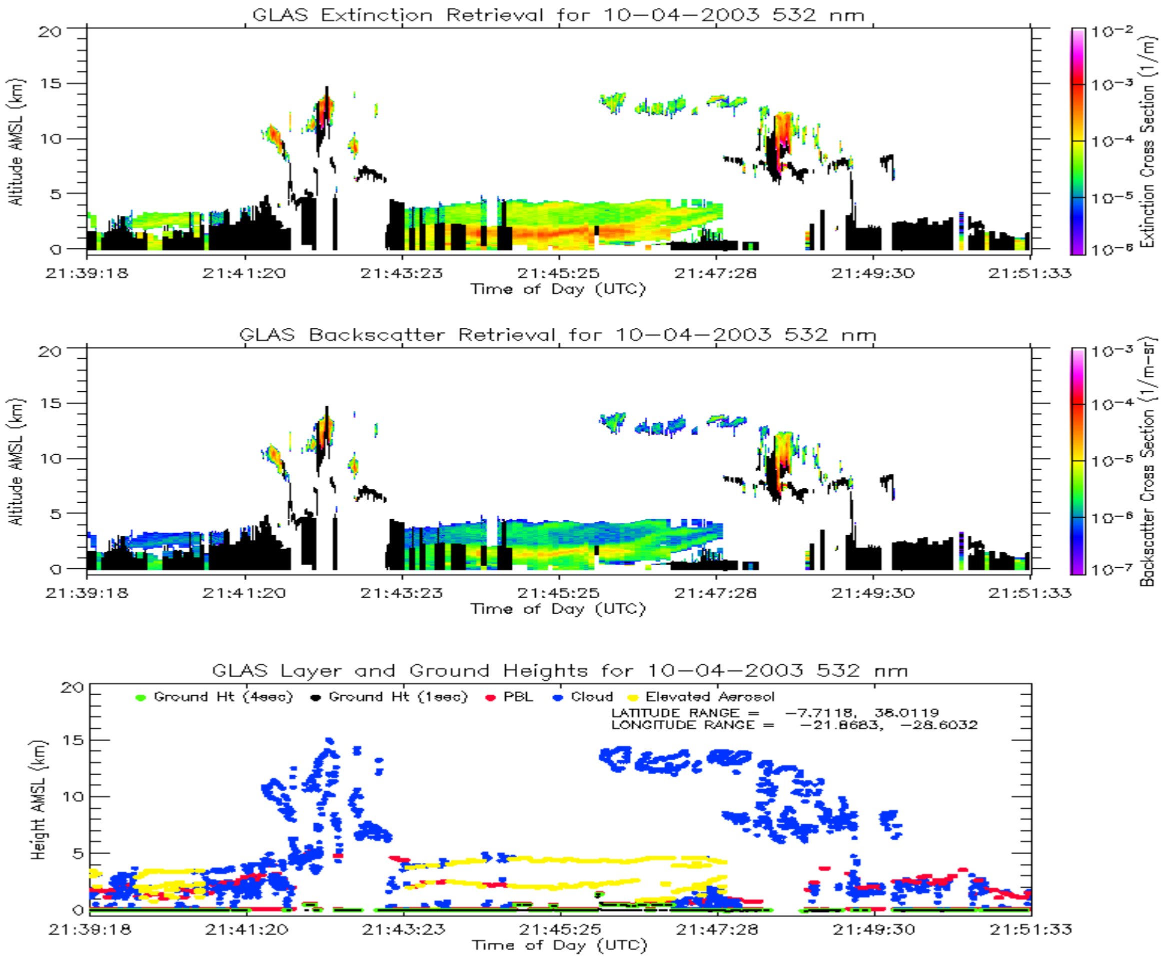
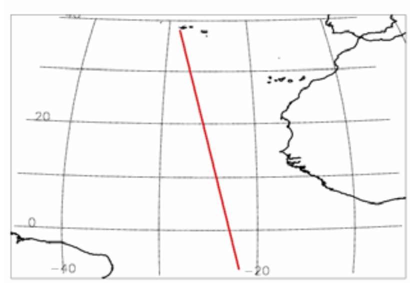


Figure 3. The GLAS GLA08, GLA09 and GLA10 data products shown for the orbit track example of Fig. 2 over the Atlantic west of Africa. The derived cloud and aerosol layer boundaries, GLA09 and GLA08 are shown in the bottom panel. Aerosol and cloud discrimination is through a multi-parameter analysis. Where there is both elevated and PBL height found, only the elevated aerosol boundary is shown. GLA10, the extinction and backscatter cross section for cloud and aerosol are shown at top. Dara flags delineate layer and boundary type.



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.

The GLAS aerosol data allows a fully independent measurement of the global aerosol optical depth. Unlike passive retrieval, the separation of signals reflected from 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. Detailed comparison with passive retrievals is possible from simultaneous measurements obtained during obit crossing. For example, Mahesh et al. (2004) were able to assemble thousands of coincident observations to MODIS that are within less than 15 seconds between the lidar and radiometer data.

A preliminary aerosol optical depth from GLAS for the globe is shown in Fig. 4. Limitations from the nadir only sampling are reflected in a

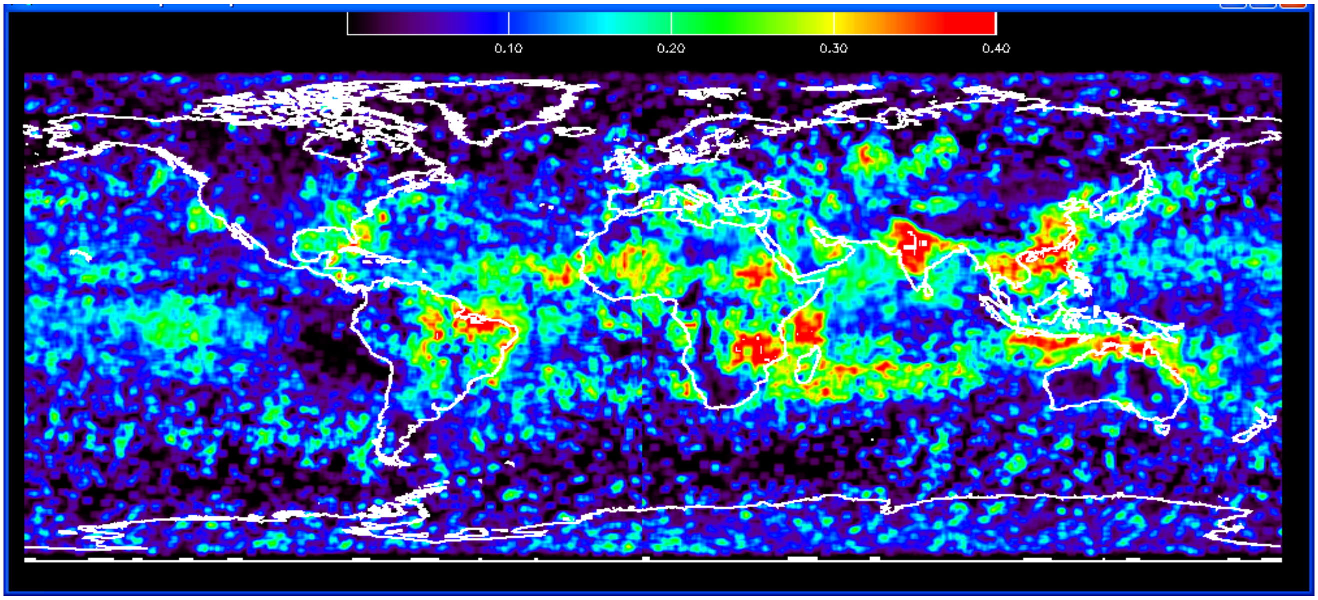


Figure 4. The optical depth is found by vertically integrating the extinction cross section retrieval for all cloud cleared aerosol layers detected. Here the averaged aerosol optical depth for all GLAS observations in October 2003 is shown. The globally averaged values show more variance than seen from passive satellite results for global optical thickness. Since aerosol loading of the atmosphere is episodic, limitations from nadir only sampling are expected.

greater variance within regions than is seen in such global results with passive sensors such as MODIS. However unlike passive sensors, a sensitive and accurate measurement of the vertical distribution is made. In Fig. 5 is shown a preliminary global latitudinal dependence of the zonally averaged aerosol extinction cross for October 2003. The cross section values compare well with previous aircraft experiment results (Menzies et al., 2002).

4. CONCLUDING

On orbit operations of the GLAS instrument and data processing have made available global data products on the height distribution of aerosol scattering. Though instrument problem limit the data of close to the intended quality to approximately two months of operation in fall 2003 and early 2004, unique data set from thousands of orbits with many aerosol and radiation research applications has been created. The measurements demonstrate the value of active optical remote sensing now planned to continue with three additional lidar instruments to be operated by NASA and ESA in the next seven years.

Special characteristics of the GLAS data will make them unique for the foreseeable future however. One is the use of noise immune photon counting detection. A very sensitive measure of the aerosol cross section loading in the upper troposphere beyond what has been attempted with the existing algorithms should be possible. Also the GLAS data include an accurate measurement of the laser pulse energy reflected by the earth's surface. Even with the best scattering ratio parameterization, the lidar retrieval of the optical depth of thick layers remains questionable in accuracy. The surface signal can serve as an independent boundary condition. A new approach is being tested for direct retrieval of optic depth by employing the calibrated ocean pulse reflectance (Hlavka et al., 2006; Lancaster et al., 2005).

As an EOS mission, GLAS data are freely available through the NASA Distributed Active Archive Centers (DAAC) system (website 2). Both data sets and data input and visualization tools are available. In addition our 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 (web site 1).

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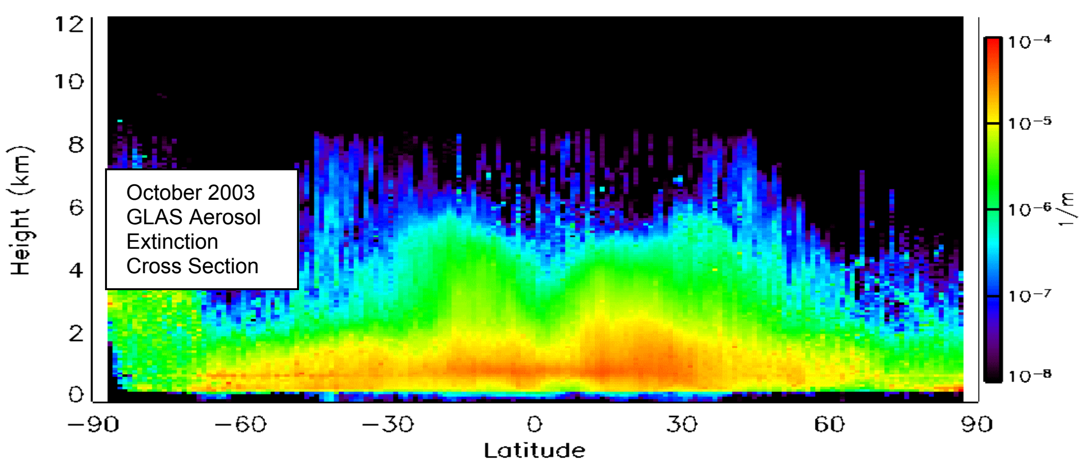

Figure 5. Preliminary zonal averaged aerosol extinction cross section for all aerosol layers observed by GLAS in October 2003. These values reflect processing through release 22 of the GLAS data products. Results from release 26 or higher will be shown at the conference and will correct some known problem such as cloud clearing over Antarctica. Further improvement in calibration, detection sensitivity and retrieval accuracy will be implemented with time.