CLOUD AND AEROSOL RETRIEVAL
FOR THE 2001 GLAS SATELLITE LIDAR MISSION

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1. INTRODUCTION

The Geoscience Laser Altimeter System (GLAS) is scheduled for launch in July of 2001 aboard the Ice, Cloud and Land Elevation Satellite (ICESAT). In addition to being a precision altimeter for mapping the height of the Earth's icesheets, GLAS will be an atmospheric lidar, sensitive enough to detect gaseous, aerosol, and cloud backscatter signals, at horizontal and vertical resolutions of 175 and 75m, respectively. GLAS will be the first lidar to produce temporally continuous atmospheric backscatter profiles with nearly global coverage (94-degree orbital inclination). With a projected operational lifetime of five years, GLAS will collect approximately six billion lidar return profiles. The large volume of data dictates that operational analysis algorithms, which need to keep pace with the data yield of the instrument, must be efficient. So, we need to evaluate the ability of operational algorithms to detect atmospheric constituents that affect global climate. We have to quantify, in a statistical manner, the accuracy and precision of GLAS cloud and aerosol observations.

Our poster presentation will show the results of modeling studies that are designed to reveal the effectiveness and sensitivity of GLAS in detecting various atmospheric cloud and aerosol features. The studies consist of analyzing simulated lidar returns. Simulation cases are constructed either from idealized renditions of atmospheric cloud and aerosol layers or from data obtained by the NASA ER-2 Cloud Lidar System (CLS). The fabricated renditions permit quantitative evaluations of operational algorithms to retrieve cloud and aerosol parameters. The use of observational data permits the evaluations of performance for actual atmospheric conditions. The intended outcome of the presentation is that climatology

community will be able to use the results of these studies to evaluate and quantify the impact of GLAS data upon atmospheric modeling efforts.

2. GLAS DATA PRODUCTS

The GLAS data products, which will be produced in near real time at Goddard Space Flight Center, will be designed to allow investigators to attain the scientific goals of GLAS as stated in Palm, et al.,1999. These goals are: a) determine the radiative forcing and vertically resolved atmospheric heating rate due to cloud and aerosol by directly observing the vertical structure and magnitude of cloud and aerosol parameters that are important for the radiative balance of the earth-atmosphere system; b) directly measure the height of atmospheric transition layers (inversions) which are important for dynamics and mixing, including the planetary boundary layer and lifting condensation level. Palm, 1999 also contains descriptions of the algorithms used to derive the products. Table 1 summarizes the products.

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Designation	Description
GLA02	532, 1064 nm normalized lidar signal-Level 1a
GLA07	532, 1064 nm calibrated, attenuated backscatter coefficient profiles, 40Hz , 5Hz Level-1b
GLA08	Planetary Boundary Layer (5Hz, 0.25Hz) Height; Elevated aerosol layer top and bottom height (0.25Hz, 0.05 Hz) - Level 2
GLA09	Cloud layer top and bottom height, 40Hz, 5Hz, 1Hz, 0.25Hz - Level 2
GLA10	532nm attenuation corrected backscatter and extinction coefficient profiles - Level 2
GLA11	Thin cloud and aerosol layer optical depth - Level 2

Table 1. GLAS atmospheric channel data products

This manuscript describes the atmospheric modeling technique that will be used in simulations of GLAS observations. The simulations will form the basis for the testing and evaluation of the GLAS processing algorithm. The poster presentation will present the results of studies based upon these simulations. The studies will show the potential for GLAS observations to detect geometrical and optical properties of cloud and aerosol layers that influence global radiative balance.

3. OBSERVATIONS AND MODELS

We currently have two methods to generate atmospheric models for GLAS lidar simulation. The first uses actual observations taken during TOGA/COARE and CEPEX deployments of 1993. These observations from the western equatorial Pacific Ocean were chosen because they contain a wide variety of atmospheric conditions. They represent a broad sampling of the types of atmospheric profiles that GLAS will encounter. They provide a means to simulate GLAS performance on atmosphere conditions with realistic variability. The CLS data were processed to extract attenuated backscatter coefficient.

The second method consists of generating backscatter coefficient profiles of cloud and aerosol layers that are computed from a specified structure. The vertical structure of each fabricated cloud and aerosol layer is computed by constructing a Gaussian distribution of backscatter coefficient to represent the distribution of particles. The backscatter coefficient for a layer is given by

$$\beta(v) = \beta_m (1/2\pi)e^{-(1/2)v^2} \tag{1}$$

where β is backscatter coefficient, β_m is the maximum β within a layer, and v is a parameter that is a function of altitude and given by

$$v = \frac{z - z_m}{\sigma} \tag{2}$$

Here z is altitude, z_m is altitude of β_m, and σ is a measure of the spread (standard deviation) of the distribution. The optical depth of a cloud layer described by (1) is given by

$$\tau_p = \frac{S_p \beta_m \sigma}{\sqrt{2\pi}} \int_{v_0}^{v_1} e^{-(1/2)v^2} dv \tag{3}$$

where τ_p is optical depth, S_p is extinction to backscatter ratio, and v_0 and v_1 are v at the bottom ($z=z_0$) and top ($z=z_1$) of the layer, respectively. A vertical distribution of backscatter coefficient is defined by specifying S_p, τ, σ, z_0, and z_1. Once a

backscatter coefficient distribution is defined for each cloud layer in a profile, an attenuated backscatter coefficient profile can be found from

$$\beta'(z) = \beta(z)T^2(z) \tag{4}$$

where $T(z)$ is total transmission from the top of the profile to z. Total transmission is given by

$$T^2(z) = e^{-2[\tau_p(z) + \tau_m(z)]} \tag{5}$$

where τ_p is the optical depth of particulates and τ_m is molecular optical depth.

4. COMPUTED GLAS PROFILE

The simulation of a GLAS profile follows that described by Spinhirne, 1993. Given a profile, $\beta'(z)$ derived from either observed data or from a specified distribution of particulates, the simulated single-scattering GLAS lidar signal is computed from

$$n_s(z) = C\frac{\beta'(z)}{R^2} \tag{6}$$

where n_s is the number of photons per unit time, C is the system calibration constant, and R is range from the spacecraft. Overlap correction is not needed and sensor dead time corrections are not shown here. The simulated signal is computed in photons since GLAS will operate in a photon counting mode. C is a function of the laser energy, optical, electrical, geometrical, and quantum characteristics of the instrument's components. The contribution from reflected solar energy (background signal) is computed with

$$n_b = kI_r \tag{7}$$

where k is a system constant and I_r is the intensity of reflected solar energy that reaches the instrument. Random noise of any observation sample can be computed with

$$\varepsilon(z) = N(z)G(0,1) \tag{7}$$

where $\varepsilon(z)$ is a random excursion at z, $G(0,1)$ is a random number sampled from a Gaussian distribution of mean 0 and variance 1, and $N(z)$ is given by

$$N(z) = \sqrt{[n_s(z) + n_b(z)]\Delta t} \tag{9}$$

where Δt is the time duration of a sample at z. A noisy $\beta'_n(z)$ profile is constructed using

$$\beta'_n(z) = [n_s(z) + \varepsilon(z)]R^2/C \tag{10}$$

5. CLOUD/AEROSOL CATEGORIES

For purposes of this study, we separate cloud and aerosol types into a few simplified categories. For clouds, the categories are a) tropical tropopause cirrus; b) synoptic-scale cirrus layers; c) synoptic-scale cumulus and stratocumulus layers. The categories for aerosol layers are a) stratospheric aerosol; b) tropospheric aerosol; c) boundary layer aerosols; d) polar stratospheric clouds (PSC). Except for PSC, the primary criterion for distinction of the categories in each group is the altitude of the layer. PSC is grouped with aerosols because they are composed primarily of hydrated acidic particles.

6. SIMULATED GLAS DATA SEGMENT

We use time series of simulated GLAS profiles to judge the ability of GLAS to detect cloud and aerosol layers. The profiles shown here are generated at full GLAS time resolution. These time series mimic, in an idealized manner, the type of data segments that will be produced by GLAS. The GLAS algorithms are applied to these data segments in a manner much like what will be done in the production mode. Since we know the physical parameters used to generate the layers, we have the means to evaluate the ability of the algorithms to retrieve them from the data set.

An example of a simulated GLAS profile sequence is shown in Fig.1. Two layers of clouds and a region of boundary layer aerosols are included in the cross-section. A ground signal is also shown. Noisy attenuated backscatter coefficient (β') is the physical quantity that is displayed, as computed from equation (10). The simulation image contains a layer of high cirrus at about 17 km. The optical depth of the layer is a sine function with a mean of 0.1 and amplitude of 0.05. Small undulations in the cloud layer top and bottom are included. The optical depth of the cloud layer between 8 and 12 km ranges from 2 on the left to about 0.05 on the right. The cloud was designed to have a geometrical cloud thickness of 4 km. on the left side. However, the signal to noise ratio is small enough at the top and bottom of the layer so that the cloud signal becomes indistinct from the particle free atmosphere. The boundary layer aerosol layer was defined uniformly across the width of the image. It becomes evident and detectable only where the attenuation of the cloud layers is small enough, on the right side of the image.

Details of the simulation are illustrated by the profiles shown in Fig.2 and Fig. 3. The figures show attenuated backscatter coefficient profiles (the smooth dark lines) superposed on noisy profiles, which represent GLAS signal profiles. The profile in Fig. 2 is selected from the far left of the image Features of the cloud layers and the aerosol layer are obscured by signal attenuation and noise. The profile in Fig. 3 is from the far right portion of the image. Since attenuation is less, the boundary layer signal is evident even in the noisy signal. The ground signal is evident in both profiles.

7. DISCUSSION

The simulated data segments shown in this manuscript serve to illustrate the challenge that will be imposed upon GLAS production mode algorithms. To be useful in meteorological and climatological studies, the production software will have to be able to determine meaningful properties from noisy lidar signals. The computations will be done virtually continuously. Analysts will monitor the quality of the output products only on a sampling basis. Studies done on simulated data permit us to evaluate expected algorithm performance. These evaluations will be distributed to the user community. This will permit users to judge the value of the GLAS data products when used in atmospheric studies.

8. REFERENCES

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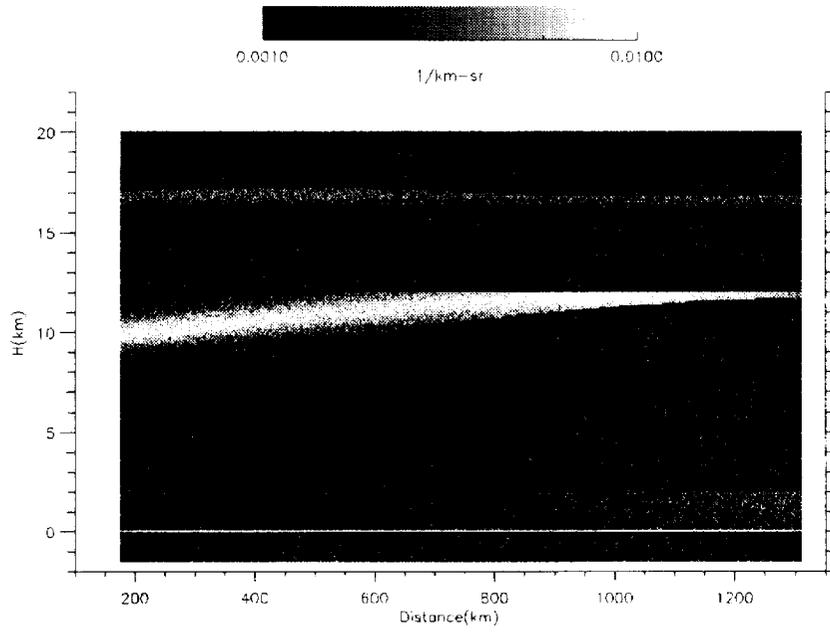
**Figure 1. Model atmosphere composed of 800 attenuated backscatter profiles computed from equation (10).**
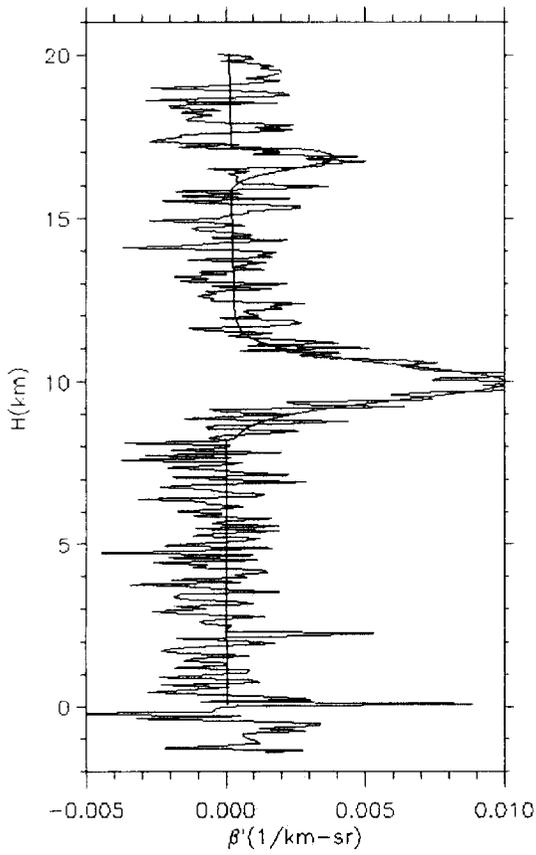
Figure 2. Fabricated profile from left side of Fig. 1 profile sequence.
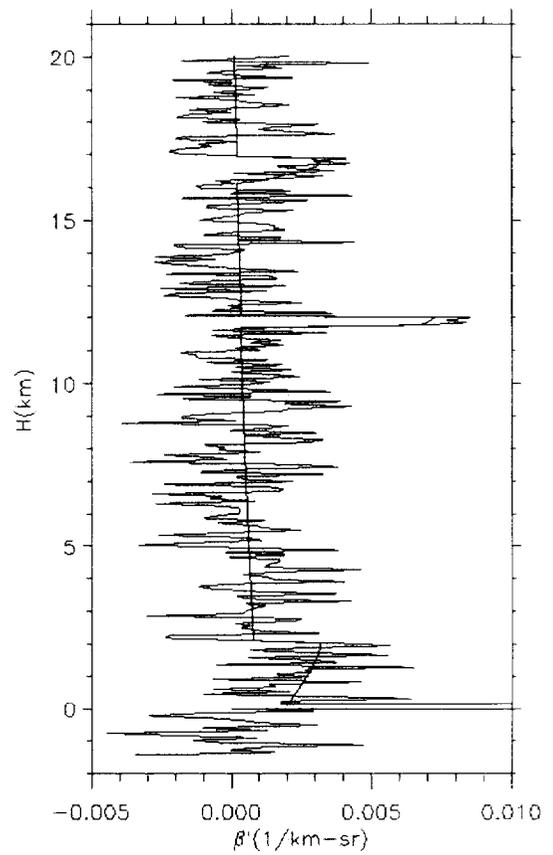
Figure 3. Fabricated profile from right side of Fig. 1 profile sequence.