



Retrieval of PMC Properties from CIPS: Algorithm description, error analysis and cloud detection sensitivity.

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I. CIPS Measurement Technique & Sampling



CIPS employs four nadir-pointing cameras to image clouds.
 $\lambda_0 = 265 \text{ nm}$, $\Delta\lambda = 15 \text{ nm}$

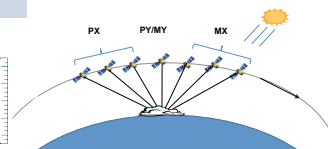
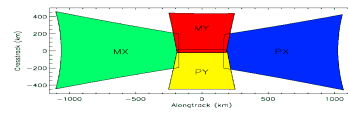


Fig. 1. CIPS sampling frequency provides multiple measurements of a given air parcel at different scattering angles.

CIPS Sampling for a Northern Hemisphere Orbit

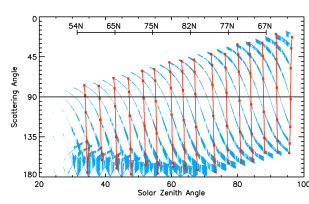
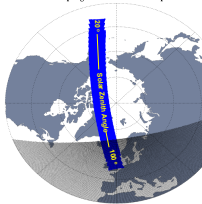


Fig. 12 Left – typical measurement coverage for a Northern Hemisphere orbit. Solar zenith angle coverage is ~ 20 – 100 deg. Right – range of scattering angles observed in one orbit. Note that forward scattering (< 90°) points are better sampled at higher solar zenith angles. The corresponding latitudes are shown at the top (ascending and descending nodes).

Information Distribution Along the Orbit

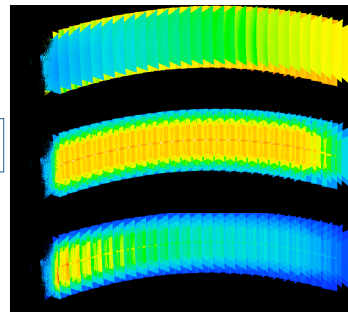


Fig. 4 Top panel - the smallest scattering angle as a function of location in an orbit strip. Brightest colors indicate largest scattering angles where the ability to detect clouds is reduced. Middle panel - the number of observations at each location. Brightest colors indicate the largest number of observations and the best ability to detect clouds. Bottom panel - the number of observations at each location divided by the smallest scattering angle observed there. Bright colors indicate increased detection sensitivity. Detection sensitivity is highest at high zenith angle and along the center of the orbit strip. On the edges of the orbit strip, detection capability is reduced and varies strongly spatially.

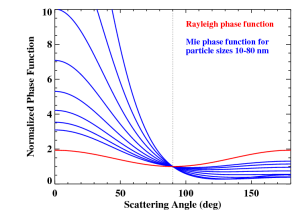


Fig. 3 The CIPS cloud detection and retrieval techniques utilize the fact that the cloud scattering signature is strongly forward-peaked, whereas the atmospheric Rayleigh-scattered background is symmetric about 90° scattering angle.

II. Separation of Background & Cloud Signal

- The albedo measured by CIPS at a given location is a sum of contributions due to the Rayleigh background plus cloud scattering:

$$A_{\text{obs}} = A_{\text{Ray}}[\Phi, \theta, \varphi, C, \sigma] + A_{\text{CL}}[\Phi, \varphi, A_{\text{PMC}}, R_p]$$

Where Φ = scattering angle, θ = viewing angle, φ = solar zenith angle

- The essential task of the retrieval algorithm is to determine the Rayleigh background, and retrieve effective cloud parameters from the residual PMC signal. We therefore need a parameterization of these two terms which allows for a direct retrieval of both background and cloud parameters.

- The Rayleigh term can be written in a simple analytical form. The primary assumptions required are that the Rayleigh scattering extinction is negligible compared to ozone absorption, and that the ratio of the ozone scale height to the atmospheric scale height is constant.

$$A_{\text{Ray}} = \frac{P_{\text{Ray}}(\Phi) \Gamma(\sigma + 1) \beta N_{\text{air}}}{\mu \left(\frac{1}{\mu} + \frac{1}{\mu_0} \right) (aC)^{\sigma}} \quad \text{where} \quad \begin{aligned} \mu &= \cos^{-1}(\theta) \\ \mu_0 &= \cos^{-1}(\varphi) \rightarrow \cos^{-1}(\varphi), \varphi \leq 90 \text{ deg} \\ C &= N_{\text{O}_3} / \text{ozone column density} \\ N_{\text{air}} &= \text{air column density} \\ \sigma &= H_{\text{O}_3} / H_{\text{air}} - \text{scale height ratio (constant)} \end{aligned}$$

"C/s model"

- Taking the log and rearranging, this model can be rewritten in a simple linear form that is useful for cloud detection:

$$Y = aX + b \quad Y = \ln \left(\frac{\mu A}{P_{\text{Ray}}(\Phi)} \right) \quad X = \ln \left(\frac{1}{\mu} + \frac{1}{\mu_0} \right) \quad \text{Eq. 2}$$

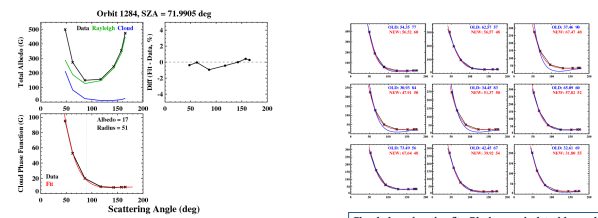
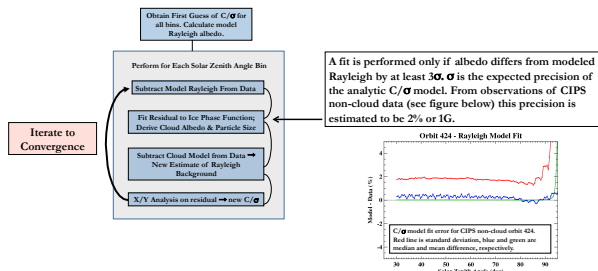
For a pure Rayleigh atmosphere, Y should be a simple linear function of X with a slope of $-\sigma$. This leads to a simple way of obtaining C/s from the observations. If a cloud is present, the slope is changed, the effect is different for forward scattering angles versus backward scattering angles.

- The cloud albedo is written in the following form, where P_{mic} is the assumed theoretical ice scattering phase function, R_p is the mean particle radius and A_{PMC} is the nadir albedo if the cloud is observed at 90° scattering angle.

$$A_{\text{CL}} = \frac{A_{\text{PMC}} P_{\text{mic}}(\Phi, R_p)}{\cos(\theta)} \quad \text{Eq. 3}$$

III. Version 4.0 Algorithm

In the Version 4.0 algorithm we make the assumption that the background ozone field, as parameterized by [C/s] in Eq. (1), is uniform over an area much larger than individual cloud pixels. The analysis divides the orbit into 0.25 deg solar zenith angle bins. These bins are essentially cross-track slices and span an area of ~25 x 800 km². A single [C/s] is retrieved in each bin and used to characterize the Rayleigh background for all points in that bin. The flow of the V4.0 algorithm is summarized in the diagram below.



Example of a CIPS retrieval for a single pixel. Top left panel shows measured scattering profile (black), and its decomposition into cloud and Rayleigh components. Bottom panel shows residual cloud phase function and the fit to the theoretical ice phase function, including retrieved cloud albedo and mode radius.

Cloud phase function fits. Black curve is data, blue and red curves are fits. "Old" & "new" refer to assumed spherical particles and a Gaussian distribution of width 14 nm. V4.0 assumes non-spherical particles (AR=2) & distribution width = 1/3 the Gaussian mean radius.

Overview

The Cloud Imaging and Particle Size (CIPS) instrument is a nadir-viewing UV imager aboard the Aeronomy of Ice in the Mesosphere (AIM) satellite. CIPS measures scattered solar radiation at 265 nm using a unique four-camera configuration providing an instantaneous field of view of 120° (along-track) by 80° (cross-track). By combining data from multiple cameras, CIPS observes a given volume of air at multiple scattering angles ranging from 20 to 180 degrees. This poster gives an overview of the CIPS Version 4.0 algorithm and data analysis, which is still in the evaluation and test phase, with data release planned for early 2010. The Version 4.0 Level 2 processing, which includes PMC detection and cloud parameter retrievals, yields cloud data products (cloud albedo, particle radius and ice water content) at a spatial resolution of 25 km².

The fundamental problem in the CIPS data analysis is to remove the background atmospheric Rayleigh signal from the total albedo measured by the instrument. This provides a direct measurement of the PMC ice phase function, from which cloud microphysical parameters may be derived. In previous CIPS data versions the Rayleigh background was retrieved pixel-by-pixel, resulting in increased retrieval noise in the presence of clouds. The Version 4.0 algorithm takes a fundamentally different approach, assuming that the underlying ozone parameters that modulate the Rayleigh albedo vary smoothly over an area spanning many CIPS pixels. This provides a much smoother and more constrained cloud parameter retrieval, which may be done at much higher resolution than the previous algorithm.

We present a summary of the CIPS data set and the Version 4.0 algorithm. The CIPS cloud detection threshold varies with solar zenith angle (and hence latitude) due to both the CIPS measurement sampling characteristics and the geophysical variation in the Rayleigh background. Simulations show that it also depends on the mean cloud particle radius, as well as the desired spatial resolution of the cloud product (data binning). Quantifying these dependencies via retrieval simulations will allow us to account for varying detection sensitivity in interpreting the cloud occurrence frequencies observed by CIPS, particularly the latitude dependence. This understanding provides a quantitative foundation for comparing the CIPS observations with other data sets.

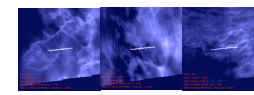
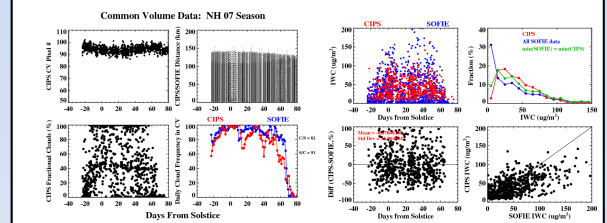
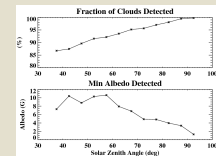
IV. Results

Retrieval Simulations

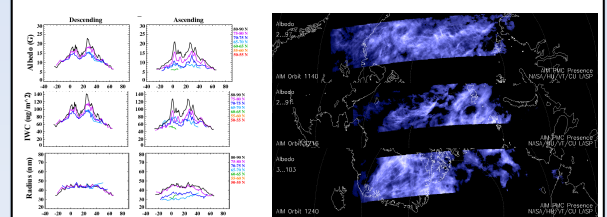
- We are in the process of running detailed simulations of the Version 4.0 retrieval algorithm.

- These studies will be used to test new ideas in the algorithm development, as well as characterizing the retrievals in terms of cloud detection sensitivity and random and systematic errors.

- This plot shows the frequency of detection and minimum retrieved cloud albedo as a function of solar zenith angle for an orbit of simulated data. At low solar zenith angles it is more difficult to detect dim clouds because the background Rayleigh signal is very bright and CIPS loses its forward scattering sampling (see the figures in I).



Comparisons between CIPS and the SOFIE solar occultation instrument on AIM. CIPS makes coincident measurements with the SOFIE line-of-sight (LOS) in the AIM common volume (CV). The images at left show the SOFIE LOS projected onto the CV portion of the CIPS Level 2 image.



CIPS Level 4 summary data for the Northern Hemisphere 2007 season. This data is binned in 5-degree latitude bins.

CIPS Level 2 cloud albedo images for three orbits from the Northern Hemisphere 2007 season.