Aerosol remote sensing with the NASA Glory mission

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One of the principal objectives of the NASA Glory mission is to determine the global distribution of detailed aerosol and cloud properties with unprecedented accuracy, thereby facilitating the quantification of the aerosol direct and indirect radiative forcings. This objective will be met by flying the Aerosol Polarimetry Sensor which will collect accurate multi-angle photopolarimetric measurements of the Earth along the satellite ground track within a wide spectral range extending from the visible to the short-wave infrared.

INTRODUCTION

The Earth's climate depends upon the balance between incident solar radiation and the response of the atmosphere and surface via absorption, reflection, and re-radiation. Long-term changes in the composition of the atmosphere can cause global climate change and thereby affect local weather patterns having impact on the quality of human life. The composition of the atmosphere is influenced by both natural and anthropogenic effects, such as the byproducts of modern industrial societies. Over the past century the average temperature at the Earth's surface has increased by approximately 0.7°C. Accurately attributing this increase and the concomitant climate change to either natural events or anthropogenic sources (or both) is of primary importance to the establishment of scientifically and economically effective policy.

Both natural and anthropogenic aerosols are important constituents of the atmosphere affecting global temperature. Although the climate effects of aerosols are believed to be nearly comparable to those of the green-house gases, they remain poorly quantified and represent the largest uncertainty regarding climate change. Numerous recent studies have indicated that the current uncertainties in the aerosol forcings are so large that they preclude the requisite climate model evaluation by comparison with observed global temperature change. These uncertainties must be reduced significantly for uncertainty in climate sensitivity to be adequately constrained. Helping to address this overarching objective is the main purpose of the Aerosol Polarimetry Sensor (APS) on-board the NASA Glory mission, a remote-sensing Earth-orbiting observatory scheduled for launch in November 2010 as part of the A-Train constellation of Earth-orbiting satellites [1].

SCIENTIFIC OBJECTIVES OF THE GLORY APS

The Glory APS is intended to meet the following three scientific objectives:

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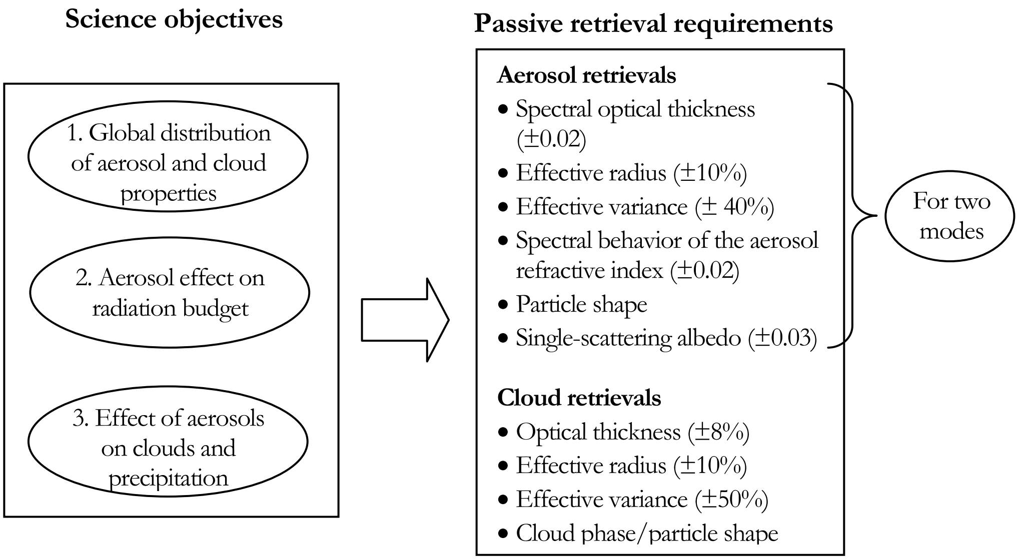

Figure 1. Flowdown of geoscience objectives into specific retrieval requirements for a passive aerosol/cloud satellite instrument [2].

- Facilitate the quantification of the aerosol direct and indirect effects on climate by determining the global distribution of the optical thickness and microphysical properties of natural and anthropogenic aerosols and clouds with much improved accuracy.
- Provide better aerosol representations for use in aerosol assessments by other operational satellite instruments.
- Provide an improved framework for the formulation of future comprehensive satellite missions for aerosol, cloud, and ocean color research.

The left-hand panel of Fig. 1 summarizes the overall scientific objectives of a coordinated and systematic approach for dramatically improving our understanding of aerosol climate impacts and environmental interactions. To achieve these objectives, one needs advanced models coupled with a comprehensive set of accurate constraints in the form of *in situ* measured and remotely retrieved aerosol and cloud distributions and properties. Accordingly, the right-hand panel of Fig. 1 lists the minimal set of aerosol and cloud parameters that must be contributed by a passive satellite instrument in order to facilitate the global quantification of the direct and indirect aerosol effects on climate.

The aerosol measurement requirements include the retrieval of the total column optical thickness (OT) and average column values of the effective radius and effective variance, the real part of the refractive index, and the single-scattering albedo. Since the aerosol population is typically bimodal, all these parameters must be determined for each mode. The refractive index must be determined at multiple wavelengths in a wide spectral range since this is the only means of constraining aerosol chemical composition from space. An integral part of the retrieval procedure must be the detection of nonspherical aerosols such as dust-like and soot particles since nonsphericity can significantly affect the results of optical thickness, refractive index, and size retrievals. The respective minimum cloud measurement requirements include the retrieval of the column cloud OT and the average column cloud droplet size distribution as well as the determination of the cloud phase and detection of cloud particle nonsphericity.

The criteria for specifying the corresponding measurement accuracy requirements in the right-hand panel of Fig. 1 are dictated by the need to

- detect plausible changes in the direct and indirect aerosol radiative forcings estimated to be possible during the next 20 years; and
- quantify the contribution of these forcings to the planetary energy balance.

APS DESIGN

The unique APS design allows one to take full advantage of the extreme sensitivity of high-accuracy polarization data to aerosol and cloud particle microphysics coupled with the advanced modeling capabilities and thereby ensures the retrieval of all the quantities listed in the right-hand panel of Fig. 1. The flowdown of APS measurement capabilities into the requisite aerosol and cloud retrieval capabilities is summarized in Table 1. The key measurement requirements for the retrieval of aerosol and cloud properties from photopolarimetric data are *high accuracy*, a *broad spectral range*, and observations from *multiple angles*, including a method for reliable and stable *calibration* of the measurements. The APS built for the Glory mission by Raytheon [1] meets these requirements.

The measurement approach required to ensure *high accuracy* in polarimetric observations employs a Wollaston prism. The field stop constrains the APS instantaneous field of view (IFOV) to 8±0.4 mrad which, at the nominal Glory altitude (705 km), yields a geometric IFOV of 5.6 km at nadir. The spatial field is defined by the relay telescope and is collimated prior to the polarization separation provided by the Wollaston prism. This method guarantees that the measured orthogonal polarization states come from the same scene at the same time and allows the required polarimetric accuracy of 0.2% be attained. To measure the Stokes parameters that define the state of linear polarization (I, Q, and U), the APS employs a pair of telescopes with one telescope measuring I and Q and the other telescope measuring I and U. The *broad spectral range* of the APS is provided by dichroic beam splitters and interference filters that define nine spectral channels centered at the wavelengths $\lambda = 410$, 443, 555, 670, 865, 910, 1370, 1610 and 2200 nm. Blue enhanced silicon detectors are used in the visible and near-IR channels, while HgCdTe detectors, passively cooled to 160 K, are used in the short-wave IR channels and offer the very high signal-to-noise ratio required to yield a polarimetric accuracy better than 0.3% for typical clear sky scenes over the dark ocean surface.

All spectral channels but the 910- and 1370-nm ones are free of strong gaseous absorption bands. The 1370-nm exception is centered at a major water vapor absorption band and is specifically intended for characterization of thin cirrus clouds and stratospheric aerosols. The locations of the other APS spectral channels are consistent with an optimized aerosol retrieval strategy because they take advantage of several natural circumstances such as the darkness of the ocean at longer wavelengths in the visible and near-infrared, the lower land albedo at shorter visible wavelengths, and the potential for using the 2200-nm band to characterize the land surface contribution at visible wavelengths. The 910-nm band provides information on column water vapor amount.

The ability to view a scene from *multiple angles* is provided by scanning the APS IFOV along the spacecraft ground track with a rotation rate of 40.7 revolutions per minute with angular samples acquired every 8±0.4 mrad, thereby yielding ~250 scattering angles per scene. The polarization-compensated scanner assembly includes a pair of matched mirrors operating in an orthogonal configuration and has been demonstrated to yield instrumental polarization less than 0.05%. The APS viewing angle range at the Earth is from +60° to –80° with respect to nadir. The scanner assembly also allows a set of *calibrators* to be viewed on the side of the scan rotation opposite to the Earth. The APS on-board references provide comprehensive tracking of polarimetric calibration throughout each orbit, while radiometric stability is tracked monthly using observations of the moon to ensure that aerosol and cloud retrieval products are stable over the period of the mission.

Table 1. Flowdown of APS measurement characteristics into specific retrieval capabilities.

Measurement characteristics	Retrieval capacity
Precise and accurate polarimetry (~0.1%)	Particle size distribution, refractive index, shape
Wide scattering angle range for both intensity and polarization	Particle size distribution, refractive index, shape
Multiple (> 30) viewing angles for both intensity and polarization	(i) Particle size distribution, refractive index, shape (ii) Ocean surface roughness
Multiple (> 60) viewing angles for polarization	Cloud particle distribution, refractive index
Multiple (> 30) viewing angles and accurate polarimetry	Aerosol retrievals in cloud-contaminated pixels
Wide spectral range (400–2200 nm) for both intensity and polarization	(i) Separation of submicron and supermicron particles (ii) Spectral refractive index → chemical composition
1370 nm channel for both intensity and polarization	Detection and characterization of thin cirrus clouds and stratospheric aerosols
2200 nm polarization channel	Characterization of the land surface contribution at visible wavelengths
910 nm channel	Column water vapor amount

REFERENCES

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