Small Satellite Constellation for Global Aerosol Monitoring of the Stratosphere (GAMS)

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**The 2013 IPCC report clearly states, “…clouds and aerosols continue to contribute the largest uncertainty to estimates and interpretations of the Earth’s changing energy budget.” While the focus of previous assessments of aerosol-climate effects has mainly been on anthropogenic aerosols in the troposphere, there is a growing body of evidence suggesting the importance of aerosols in the upper troposphere and lower stratosphere (UTLS).** In particular, observations showed a positive trend in stratospheric aerosol loading of 4 – 7% per year for the decade following the year 2000, despite a lack of increased input to the stratosphere from any major volcanic eruptions (e.g., the 1991 Mt. Pinatubo eruption in the Philippines, which led to a two-order of magnitude increase in the stratospheric aerosol burden). At a global scale, this increase of the stratospheric aerosol burden was mainly caused by a series of moderately sized volcanic eruptions occurring at high northern latitudes. Anthropogenic pollution sources, however, can contribute to changes in the regional loading (e.g., over the Asian monsoon region), and large wildfires contribute a so-far unquantified input. Regardless of the source of this increased stratospheric aerosol burden, these particles are primarily scattering and their radiative effects have resulted in a global cooling that offset about 1/3 of the warming expected from increases in greenhouse gases (GHGs) over the same time period.

These increases in stratospheric aerosol loading were neglected by the climate models contributing to the last IPCC report, suggesting these models might, if anything, be underestimating the warming associated with increasing greenhouse gases. Synthesizing observations of stratospheric aerosol to include their effects in climate models is thus a priority for the Earth science community. Given the lack of observations, appropriately accounting for the properties of these aerosols is challenge. The sizes, composition, and optical properties of naturally occurring background stratospheric aerosols such as carbonyl sulfide are different from particles that result from anthropogenic sources or injections from wildfires (e.g., carbonaceous aerosols). Furthermore, inputs of sulfur dioxide directly into the stratosphere from volcanic eruptions are known to perturb the particle size of the stratospheric aerosol layer, which changes the mass scattering efficiency—and so the cooling—caused by these particles. Uncertainties in particle sizes and composition of the stratospheric aerosol layer, and how those properties change as the aerosol load is perturbed, are thus a key impediment to appropriately including the radiative effects of these particles in climate models.

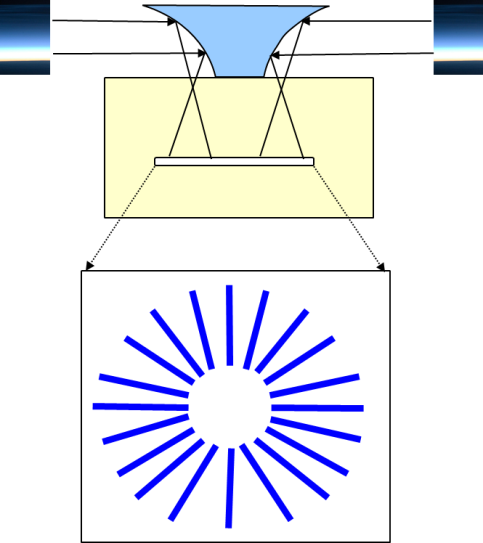
Finally, while the above discussion has focused on natural and inadvertent anthropogenic perturbations to the stratospheric aerosol layer, consideration must be given to proposals to deliberately engineer climate to offset global warming by changing the loading or size and composition of the stratospheric particles in a Solar Radiation Management (SRM) program. Detection, attribution, and efficacy of such efforts require not only monitoring but also a proper characterization of the prior state of the aerosol layer. Furthermore, as such scenarios are being explored in climate models, it has become apparent that the models themselves have a wide diversity of results even for a commonly prescribed perturbation. Issues of transport and aerosol size and composition in models, which can potentially be resolved by bringing more observations to bear on the problem, must be addressed before these models are used to make any quantitative statement about a possible geoengineering program.

**There is an immediate need to better understand the stratospheric aerosol.** As discussed above, the background loading of the stratospheric aerosol appears to be anything but constant, and the increases in the stratospheric aerosol optical depth over recent years are evidently offsetting some of the warming expected from increases in GHGs. This is happening now. Less well known is how these changes in the stratospheric aerosol layer are affecting the specific microphysical and optical properties of the aerosol, and therefore their climate effects. The need to characterize the changes in the stratospheric aerosol layer and monitoring the climate response to its variations argues for a robust observing system, including satellite observations for spatial and temporal coverage, and ground-based and airborne observations for calibration and validation. The timeliness argument is bolstered by the need to precisely constrain the anthropogenic contributions to global temperature change, as well as current consideration of geo-engineering scenarios.

**Satellite observations are absolutely vital to improving our understanding of stratospheric aerosols.** Stratospheric aerosols are inhomogeneously distributed in both the horizontal and vertical directions, and their distributions can be dramatically impacted by impulsive events such as volcanic eruptions. The effects of perturbations evolve in a complex way from a possibly highly localized origin, over time scales ranging from a few hours to many months. Satellite measurements with global spatial coverage and high vertical resolution are necessary to adequately monitor this evolution.

A long record of observation exists from instruments viewing the Earth’s limb. Historically, high vertical resolution observations have been obtained from sensors such as the SAGE and POAM series that make solar occultation measurements (i.e., observing sunrise and sunset over the Earth’s limb). These observations are self-calibrating, high precision extinction measurements that obtain vertical resolutions of approximately 1 km, but have limited spatial sampling because they see only a single sunrise and sunset pair per orbit. By contrast, limb scattering measurements obtain a much greater sampling density because observations can be made continuously throughout the satellite orbit. Limb-scattering instruments such as SCIAMACHY on Envisat, OSIRIS on Odin, and OMPS LP on Suomi NPP have 2 km vertical resolution with near daily global sampling (along a single or perhaps several curtains per orbit). Scattering measurements require a retrieval that assumes some properties of the aerosol observed, but increased spectral coverage can result in better constraints on these assumptions. An important factor in designing a limb scattering observing system is that the scattered radiance signal observed from space will have a strong angular dependence due to variations in the aerosol particle scattering phase function (i.e., angular distribution of scattered light, dependent on particle size and composition). OMPS LP, for example, views the limb behind the satellite orbit trajectory and, because of its viewing geometry, has a view angle sensitivity that is a strong function of the observation latitude. The result is a relatively higher sensitivity to aerosols in the northern than southern hemisphere.

We propose a small satellite constellation for Global Aerosol Monitoring of the Stratosphere (GAMS). GAMS will build off the OMPS LP heritage, but will realize several advantages over the present design. Forward and rearward looking observation slits will disentangle the view angle sensitivity discussed above, since in each orbit the same scenes will be observed under both forward and backscattering directions. Adding off-axis slits (looking to the side of the satellite trajectory) would increase spatial coverage, which can alternatively be realized by flying multiple copies of the basic 2-slit instrument in orbits with different local equator crossing times. The notional GAMS observing concept is illustrated in the Figure. Wavelength selection is simplified by using one or more narrow band spectral filters for each slit. Wavelengths in the visible and near-IR region, such as 675 nm, provide the information needed for aerosol characterization. Using additional aerosol wavelengths would depend on the results of scientific and engineering trade studies. Separate measurements at a near-UV wavelength such as 350 nm will provide altitude registration using the vertical dependence of the Rayleigh scattered radiance profile. Simple linear CCDs can provide improved vertical sampling (< 0.5 km) for each slit, while measuring the entire altitude range of interest simultaneously.



The upper portion of the figure shows a side view of the GAMS optical system. The small images on each side represent a nominal view of the Earth’s limb, with brighter signals near the surface. The white rectangle indicates the detector surface.

The lower portion of the figure shows a view of the detector surface from above. Each blue line represents the vertical image from a single slit, with high altitude (faint) signals towards the center and low altitude (bright) signals towards the outside.

The GAMS design is configured towards low-cost flight opportunities, such as CubeSats, that offer both frequent availability and different orbit options. Initial development of the GAMS design is currently being supported by a recently awarded NASA GSFC internal grant. Continued development of this design towards a flight-ready demonstration system would require additional investment through competitively awarded or directed funding. This development effort also takes advantage of the synergy with the extensive aerosol-climate modeling program at GSFC, a key component of the mission design. Such models are a natural beneficiary of the proposed measurements, as the increased frequency and density of observations provides improved constraints to refine the physical mechanisms incorporated in the models.

At the moment, the only operating limb-scattering instruments are OMPS LP, launched in 2011, and OSIRIS, launched in 2001. The other sensors discussed in this white paper are no longer operational. A SAGE III instrument will deploy to the ISS beginning in 2016, and a follow-on OMPS LP instrument is planned to fly on JPSS 2 with a planned launched date of 2022. Developing GAMS ensures a source of critical stratospheric aerosol measurements to bridge any potential gap between SAGE III and JPSS-2, as well as complementing continued OMPS LP observations under the JPSS program.