**The Role of Systematic Aircraft Measurements**

**in Characterizing Aerosol Air Masses**

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1. **What are the key challenges or questions for Earth System Science across the spectrum of basic research, applied research, applications, and/or operations in the coming decade?**

Since 1995, Inter-governmental Panel on Climate Change (IPCC) assessment reports have highlighted, as leading uncertainties in understanding Earth’s climate, the direct impact of airborne particles on the planetary energy balance, and the indirect impact they have on clouds, atmospheric stability, and regional circulation. Further, the presence of aerosols often necessitates large corrections to other space-based measurements of independent parameters, such as ocean color and productivity [e.g., *Gordon*, 1997], and they cause much more premature mortality than ozone, NO*x*, or other pollutants [*Lelieveld et al*., 2015]. As such, frequent, global aerosol-air-mass-type mapping, of value in itself for air quality, material transport, and other applications, represents critical test and validation data for climate modeling. (In satellite remote sensing, “aerosol type” describes the categorical component and mixture distinctions made from varying observational information content about particle size, shape, and absorption.)

Besides measuring total-column aerosol optical depth, some current satellite remote-sensing instruments are capable of deriving vertical backscatter profiles and constraints on the size, shape, and light-absorption properties of airborne particles. Next-generation multi-angle, multi-spectral polarimeter-imagers and high-spectral-resolution lidars (HSRLs) promise to provide tighter constraints on aerosol type, under a broader range of conditions.

However, space-based radiance observations are only as good as their inherent information content, and the retrieval algorithms or assimilation and other models that interpret them in terms of geophysical quantities. Satellite and suborbital remote-sensing data alone cannot constrain the microphysical, optical, and chemical properties of airborne particles sufficiently to reduce the aerosol-related direct and especially indirect forcing uncertainties to levels comparable to that of greenhouse-gas forcing. Nor can health effects be derived solely from remote-sensing data. For example, Mass Extinction Efficiencies (MEEs) are required to translate between remote-sensing-derived particle optical properties and aerosol mass, which is the fundamental quantity tracked in aerosol-transport and climate models. MEEs must be obtained from *in situ* measurements, estimated from modeled particle composition and size distributions, or simply assumed. Similarly, particle water uptake (hygroscopicity), required to account for humidity-dependent particle optical property changes as well as particle activation conditions that initiate cloud formation, cannot be derived from remote-sensing observations except under special conditions [*Pahlow et al*., 2006]. And even advanced future remote-sensing instruments will only loosely constrain particle light absorption properties, helpful for aerosol source-attribution such as identifying anthropogenic components, and a key to simulating atmospheric heating profiles, cloud evolution, especially in polluted or smoky environments, and broader climate effects.

Characterizing particulate matter in Earth’s atmosphere adequately for many climate and air quality applications requires the *combination* of space-based sensors, suborbital observations including *in situ* measurements, and models.

1. **Why are these challenge/questions timely to address now especially with respect to readiness?**

We already have over 15 years of satellite data from the NASA Earth Observing System (EOS) instruments. This represents a data record sufficiently long to begin identifying trends in aerosol forcing, assessing regional air quality changes, providing aerosol-forcing constraints on climate models, and testing climate and air quality model performance. However, the missing particle microphysical, chemical, and associated optical detail limits the utility of the satellite data for these applications. Obtaining systematic *in situ* measurements of the major aerosol air masses globally would allow the field to advance significantly even with existing satellite data, and would provide context and impetus for future space-based aerosol missions. And to the degree that current imperatives include reducing uncertainty in climate modeling, as well as air quality mapping over extended populated and vegetated areas, such data offers a timely and essential component.

1. **Why are space-based observations fundamental to addressing these challenges/questions?**

Aerosols are extremely variable in time and space; they have localized sources, short atmospheric lifetimes, and are removed intermittently, mainly by precipitation. No surface or aircraft *in situ* instruments can come close to measuring the distribution of aerosols with the frequent, global coverage achieved by space-based sensors. Yet assimilation models and most retrieval algorithms that ingest space-based-sensor radiances require aerosol property constraints that, if not assumed, can only be obtained from *in situ* measurements. So an approach to global aerosol measurement that combines extensive satellite remote-sensing observations, but having limited information content, with the detail available from *in situ* methods, provides a major opportunity to improve the overall flow from sensor to final scientific product.

In addition to satellite and suborbital remote-sensing, the challenge of measuring particulate matter in Earth’s atmosphere calls for a suite of instruments in a moderately sized aircraft package, to measure *in situ* aerosol microphysical, chemical, and associated optical properties *operationally,* *at a level-of-detail unobtainable from space or ground-based remote sensing*, with the aim of complementing and adding value to existing and future global satellite aerosol observations. The aircraft measurements would: (1) improve the aerosol property assumptions made in most satellite aerosol-retrieval-algorithm climatologies and radiance-assimilation models, (2) reduce the uncertainties in comparing and constraining modeled, species-specific aerosol size and mass with satellite aerosol optical values, and (3) provide missing data needed to reduce direct and indirect aerosol forcing uncertainties. Technologies capable of making all the requisite measurements have flown before. However, the *collection* of coincident measurements needed to adequately characterize the particles in a given aerosol air mass has never before been made, let alone acquired repeatedly, as is needed to represent aerosol air masses statistically and build a large-scale climatology. The effort would draw upon the aerosol aircraft community to provide instruments and data products, the satellite measurement and aerosol modeling communities to offer context for the measurements and to develop climatologies of aerosol-air-mass-type space-time distribution. It would require the combined expertise of all these communities to interpret the data, assess tradeoffs, and make decisions to efficiently meet the objectives.

Systematic Aircraft Measurements to Characterize Aerosol Air Masses (SAM-CAAM) is feasible because, for most aerosol sources and specified seasons, emitted and evolved particle properties tend to be repeatable, even if the aerosol loading varies from season-to-season and year-to-year. For example, the amounts of wildfire smoke from Alaskan boreal forests and desert dust from the Bodele Depression vary dramatically with time, but the particle properties from each of these sources remain pretty constant. This important simplifying attribute means that an airborne observing program designed to routinely and economically measure particle properties *in situ* could capture probability distribution functions (PDFs) of these properties, characterizing the major aerosol air mass types in the detail needed to adequately address the key aerosol and climate-related questions raised above. The PDF statistics will also provide important clues to the degree aerosol properties from given sources are repeatable, both near-source and downwind.

This capability would require an operational data stream and a dedicated, Sherpa or Twin-Otter-class aircraft to fly routinely from a base of operations, with several pre-defined flight plans, until the accessible aerosol air masses are statistically characterized, after which it would move to another base of operations and repeat the process. As such, it would be a modest but critical adjunct to the satellite instruments, more like the Aerosol Robotic Network (AERONET) than the typical aircraft field campaign.

**References**

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