Distributed Regional Aerosol Gridded Observation Networks (DRAGON) White Paper

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Executive Summary

Aerosol measurement observations from ground-based sun photometers and sun/sky radiometers have played a critical role in developing, reformulating and validating satellite algorithms to characterize aerosol optical depth, modal aerosol retrievals and single scattering albedo among other parameters. New and improved algorithms are being developed for current and future satellite missions that will place a greater demand on the accuracy and fidelity of the ground-based measurements for validation, multi data set synergism and long- term climate research. Heretofore satellite validation studies using sun and sky scanning spectral radiometer measurements such as AERONET have relied on point observations extrapolated to a two dimensional domain to compare to the satellite retrieval. Additionally few of the ground-based remote sensing measurements have had a rigorous comparison or validation against other ground-based measurements particularly the more common *in situ* observations of aerosol scattering, size and absorption. Finally NASA has a rich history of international collaboration. AERONET in particular is well positioned to collaborate with agencies, universities and individual scientists in China, Korea and Japan. To implement this collaboration, we propose that NASA and through affiliation with field programs in the US and research and operational entities abroad participate in two joint field campaigns in which a mesoscale gridded network of sun photometers is established for eight weeks over the Washington DC metropolitan area in 2011 and the Beijing metropolitan area, the Seoul metropolitan area and the Tokyo metropolitan area in 2012 for validation of satellite aerosol products and comparison/validation of ground-based aerosol retrievals. These networks will be strategically located to take advantage of the *in situ* and airborne resources available in all regions, as well as provide comprehensive assessment of very different aerosol regimes for analysis.

DRAGON Campaign Objectives

A dense network of ground-based remote sensing instrumentation is expected to provide:

- A 1-, 2-, 3- and 4-D validation data set for satellite remote sensing of aerosol optical properties
- A comparison to related surface and airborne *in situ* measurements.
- An assessment of the evolution of aerosol properties from transported/advected particulates

Introduction

Earth system science has progressed over the last twenty years owing to more and better observations from ground-based, airborne and satellite systems that take advantage of *in situ* and RS techniques. Measurement observations of well maintained measurement networks have greatly added to the data available for geophysical research and in particular have provided validation data products for satellite retrievals, contributed to calibration of satellite systems and measured fundamental aerosol properties for atmospheric correction of satellite imagery. Prominent among those is the Aerosol Robotic Network (AERONET) made up of a federation of collaborating partners that adhere to the standardization requirements of calibration, measurements, and processing. The network is global and represents a significant percentage of the globally ground-based aerosol observations. Other networks providing significant data for the scientific community include SKYNET, Precision Filter Radiometer (PFR), Bureau of Meteorology (BOM) and China Aerosol Remote Sensing Network (CARSNET). All networks provide Aerosol Optical Depth (AOD) that is a directly measured aerosol product and is similarly computed by all networks. However few comparisons have been preformed between the networks to verify the comparability between them [Che et al., 2009]. Certainly routine comparisons to unify the networks are not done.

Sun-sky scanning radiometers used in the AERONET, SKYNET, CARSNET and other unaffiliated programs provide additional microphysical and radiative information from inverting the radiative transfer equation thus providing important column integrated aerosol properties. On a few occasions during large field campaigns some of these retrievals have been compared to airborne *in situ* observations for comparison but no comprehensive program has been developed to assess the accuracy of these retrievals based on independent physical measurements nor has a well designed experiment been preformed to assess the horizontal variability of such retrievals given the known variability of the input parameters such as surface reflectance and 3-D aerosol distributions through time.

Chemical transport models, regional assimilation models and global climate models are simulating chemical, radiative and optical properties of aerosols and thus have a great requirement to compare their results to actual measurement values. Likewise advanced satellite observational systems such as Glory and NPP plan to make advanced retrievals of aerosol properties.

Sun-sky spectral radiometer retrieval validations

Sun and sky scanning spectral radiometer observations can be processed to retrieve particle size distribution, complex index of refraction, single scattering albedo, phase functions (asymmetry parameter) and particle sphericity for all aerosol types including fine mode urban/industrial and biomass burning, coarse mode dust and sea salt and in mixtures of various types. Validating the retrieved parameters under the various aerosol environments has been elusive as it relied on expensive field campaigns of opportunity. A small number of simultaneous comparisons to *in situ* measurements have been published as an attempt to validate the AERONET inversion products. Likewise several indirect and highly averaged comparisons have been published. A few examples exist where a moderately dense network of

AERONET instruments have been deployed and retrievals summarized [Eck et al., 2008, 2003] however comparative observations have been either lacking fidelity or missing all together or are pending analysis and publication. Clearly validating AERONET inversion retrievals is extremely problematic because the parameters are derived from column integrated radiometric measurements thus the ideal validation would also provide a direct measure of the column integrated aerosol properties. *In situ* observations offer a more direct measurement of aerosol particles but sampling issues make this approach difficult and expensive. For example *in situ* sampling often requires a modification of the aerosol regime (i.e drying the aerosol) and thus potentially a modification of the aerosol properties in question. Additionally *in situ* samples are taken from surface or airborne systems and the properties represent only those that are from that particular position in a 3-D atmosphere.

Limited validations of single scattering albedo and particle size distributions have been published based on opportunistic data selected from several field campaigns over the past 16 years of AERONET observations. The first attempts at independent validation began with an airborne campaign to characterize 'Urban/Industrial' east coast aerosols near Wallops Island Virginia during the BASE-A campaign, (Remer et al., 1998). A PCASP was flown in eight vertical profiles over an AERONET site during the course of the campaign in August 1993. The analysis showed qualitative agreement with the skyrad.pak retrievals of fine and coarse mode size distributions. This data set was unique in that it included a middle mode due the Pinatubo volcanic aerosols that has not been observed since that time. Note the skyrad.pak inversion code of Nakajima et al., (1986) was subsequently replaced by the inversion code of Dubovik and King (2000) in 1999 now in Ver 2. Ramanathan et al., 2000 compared aerosol single scattering albedo observations over the Indian Ocean measured during the NE monsoon. These are fine mode dominated aerosols transported from the Indian subcontinent. Averaged regional measurements were compared including AERONET retrievals using the Dubovik Version 1 algorithm. The AERONET retrievals were towards the high end of the ensemble of both *in situ* measured and remotely sensed SSAs.

Biomass burning (BB) comparisons have been made from aircraft instrumented for *in situ* sampling conducted in southern Africa during SAFARI2000 and a several flights in Niger during the Dust And Biomass burning EXperiment (DABEX) in 2006. Haywood et al. (2003) in a flight over the Etosha Pan, Namibia AERONET site thru biomass burning aerosol showed marginal agreement with the AERONET SSA (Δ-0.05) but good agreement with the size distributions fine and coarse modes. Clearly a vertical integration is needed to compare to the column integrated AERONET parameters. Bergstrom et al., 2003 reported on SSA from two overflights of two AERONET sites during the SAFARI2000 campaign in Mozambique and Zambia. Although no comparisons to AERONET were made in the paper, the AERONET retrievals show much better agreement with airborne SSA under high AOD in Zambia (Δ±0.01) but the Mozambique comparison showed the AERONET retrieval to be spectrally neutral while the airborne estimates were significantly lower and spectrally decreasing with wavelength. Leahy using different data sets from the same campaign specifically compared *in situ* SSA from five AERONET site overflights in Zambia, Namibia and South Africa. They report the mean discrepancy is -0.01 (*in situ*-AERONET). Chand et al. (2006) analyzed smoke aerosol in southern Amazonia during the SMOCC campaign (two month period) and found the same SSA retrieved from AERONET and dried *in situ* ground-based measurements (particle soot absorption photometer, PSAP and nephelaomter) 0.92 in the mid-visible. Schafer et al. 2008 followed up the SMOCC analysis with five time coincident comparisons between the AERONET and *in situ* retrievals. The overall comparison (AERONET=0.90 vs *in situ*=0.92 at 550 nm) was within the expected uncertainty of each method (±0.03 and ±0.05 respectively) but each technique showed considerable variability.

Johnson et al. 2009 compared data from the airborne campaign DABEX in Niger that specifically measured a mixed dust and biomass burning aerosol regime. They we able to assess SSA, size distribution and asymmetry parameter for a single day with high aerosol loading. All were in good agreement, with the difference between *in situ* and AERONET retrieved SSA of 0.02. Osborne et al. (2008) compared 3 cases of aircraft flights (on 3 different days) over the same site during the same experiment but found that the aircraft in situ measured SSA values ranged from 0.04 to 0.07 higher than the AERONET Version 2 retrievals. However, for all three of these cases the aircraft measured Angstrom exponents were ~0.40 lower than the AERONET measured values. This discrepancy in α suggests that the aircraft may have sampled a different fine and coarse mode fraction mixture than the column integrated value measured by AERONET, and the higher SSA in conjunction with lower α measured by the aircraft are consistent with this possibility. In fact for the linear best fit of SSA versus α for all aircraft data from DABEX, reported in Johnson et al. (2008), a difference of 0.40 in α corresponds to a difference in SSA of ~0.06, almost the same value of the bias reported in Osborne et al. (2008).

Coarse mode size distributions comparisons from two campaigns representing dust dominated aerosol events (Puerto Rico, PRIDE; and United Arab Emirates, UAE2) were made between AERONET and geometric and aerodynamic *in situ* methods (Reid et al., 2003, Reid et al., 2008). In general, they found favorable comparability between AERONET volume mean diameters (4.1 to 4.7μm) (slightly higher) to APS (3.25 to 4.1 μm) depending on source region.

Thus over 16 years of aerosol focused field campaigns, measurements involving sun and sky scanning spectral radiometers, only ten papers have directly or indirectly addressed this issue. Several are out of date and/or are not highly relevant. Biomass burning comparisons largely come from one campaign in Southern Africa nine years ago and largely examine only SSA; dust size distribution was studied from Puerto Rico (transported) and the Arabian Gulf (mixed) and one case of mixed biomass burning and dust was reported for SSA and size distribution. Urban/Industrial aerosol SSA and size distribution were studied in places that were neither urban nor industrial and well over a decade ago with out-of-date retrievals.

Sea salt/maritime aerosols have not been directly compared at all for any parameters however average comparisons from published studies were made with a few averages from AERONET island sites using Ver. 1 processing (Smirnov et al., 2003). Clearly the comparisons/validations done to date are sparse for all parameters and some aerosol types are inadequately assessed (Table 1). Validating AERONET retrievals is very difficult, yet with the improved retrievals from satellites, the need for similar ground-based column integrated retrievals to routinely validate and corroborate the satellite measurements is crucial. It is of utmost importance that the scientific community have confidence in ground-based column integrated retrievals.

Parameter\Type	Urban	Biomass Burning	Dust	Sea Salt Maritime	Mixed
SSA (ω_o)	-Ra†#	-H@#, +L, B, C†, Sc&			-O@,+J@
Size Distribution dV/dlnr, r_v	-Re*	+H@#	+Rp#, +Ru	-S†#	+J@
Real Index (n)					
Imaginary (κ)					
Asymmetry (g)					+J@
% Sphericity					

†Regional comparisons

*Nakajima retrievals

#Version 1

@ Single point

& surface comparison

Table 1, shows the principle parameters measured by sun and sky scanning spectral radiometers for the aerosol types likely encountered. Eleven published validations/comparisons were made during field campaigns over the last 16 years; these are Ra=Ramanathan et al, 2000; Re=Remer et al., 1998; H=Haywood et al, 2003; L=Leahy et al., 2008; B=Bergstrom et al., 2003; Chand et al., 2006; Rp=Reid et al, 2003; Ru=Reid et al., 2008; S=Smirnov et al., 2003; Sc=Schafer et al., 2008, O=Osborne et al., 2008 and J=Johnson et al., 2009. Note that most categories are incomplete, not updated and/or lack relevance.

Issues Validating Satellite retrievals with ground-based sun-sky scanning spectral radiometers

The sun-sky photometer footprint is not precisely defined or known but can be assumed to range in shape and size from a single point with the sun at the zenith to a spheroid elongated in the direction of the sun along the solar path length for AOD observations. If we assume nominal conditions of an airmass of 2 and effective aerosols are within the boundary layer below 1 km elevation, the effective footprint is approximately 2 km in the direction of the sun and for the retrieval products that incorporate 360° almucantar measurements the effective footprint could be represented by a circle with a radius of 2 km. Given the potential variability of these measurements that are a function of the vertical and horizontal distribution of aerosols at the time of measurement(s), the time of day, season and latitude of observation, we may conservatively assume the effective footprint as a point is accurate with the uncertainty increasing radially from the point. Given the uncertainty in AOD based mainly on the calibration process is ±0.01 to ±0.02 for AERONET and the triplet variability is less than 0.01 we will assume for this proposal that a conservative estimate of the AERONET foot print is 2 km radius about the sun-sky radiometer site.

Spatially comparing sun and sky radiometer measurements most notably AOD and inverted aerosol products to satellite observations has required development of strategies to extrapolate the point ground-based measurements to one or more satellite product pixels often by minimizing the temporal measurement difference. Clearly satellite product pixels vary from 10s of m for high resolution instruments such as Landsat, 1 to 10 km square for the standard MODIS products to 200 by 250 km for global scale model simulations.

Various strategies have been implemented to address these issues (Ichoku, 2002, Kahn et al., 2005, Zhao et al. 2005 and many others) depending on satellite viewing geometry, location and 4-D sampling comparisons. For example, the current footprint size (i.e., horizontal resolution) of MODIS aerosol products is 10 km x 10 km. In order for such coarse resolution satellite data to be compared with the AERONET single point measurements, spatial and temporal variability of aerosols around the AERONET site need to be taken into account. To alleviate this problem, the methodology for collocating MODIS and AERONET is to calculate (1) the mean AOT values over MODIS 5x5 pixels (i.e., 50 km x 50 km) and (2) the averaged AERONET values within ±30 minutes from the MODIS overpass time. The choice of 50 km x 50 km and 30 minutes is to account for aerosol transport across the AERONET site. However, the validity of these selected values depends on local meteorology, in particular the wind speed at the altitude where aerosol plume resides. A densely gridded network of AERONET sites will provide an important solid test bed to verify these commonly used satellite validation strategies and to recommend an improved methodology for future satellite cal/val activities.

The experimental plan

Increasing importance of sun-sky scanning spectral radiometers for satellite retrieval validation, regional and global aerosol model validation, synergism with process models and long term climate change research requires that we have a more complete understanding of the relevance of the retrieval products in space and time than currently exists. We therefore propose a significant step in that direction by jointly partnering with CNSA and CMA and NASA to conduct two regional field campaigns in the Washington DC metropolitan region and the Beijing, Seoul and Tokyo metropolitan regions. From the validation section we note that essentially no ground-based retrieval products have been validated in urban industrial settings. We also note that typically urban industrial aerosol sources can be more variable in space and time thus calling into question the assumptions of spatial homogeneity. We therefore propose these regions because the aerosol loading is reliably high such that retrievals may be realized, the aerosol types between North America and East Asia is dramatically different (high SSA and fine mode dominated in Washington area, relatively low SSA and mixed mode in Beijing, Seoul and Tokyo), the regional background landscapes are similar (agricultural, urban and forested foothills) and there are considerable sun photometer and supporting scientific resources available.

Experimental Objectives

- Establish a mesoscale gridded network of sun photometers that encompasses, urban, agricultural and mountain landscapes over Washington DC and Asian metro areas
- Optimize the grid to validate/collaborate inversion products in conjunction with aircraft flights performing *in situ* measurements
- Optimize the gridded network to validate satellite retrievals from 50 m to 10 Km pixel resolution
- Supplement the gridded network with non gridded sites to capture known aerosol variability
- Develop a geo-referenced database that will accommodate supplementary/complimentary data sets

Experimental Design

A. **The gridded network:** We propose each gridded network be 90 km across track (East-West) and 40 Km along track (North-South). Sun-sky spectral radiometers should be sited at 10 Km intervals thus requiring 50 instruments. This will provide sufficient spatial characterization for most satellite and regional transport models. The placement of the network is approximated in Fig 1 (Washington DC) and 2 (Beijing).

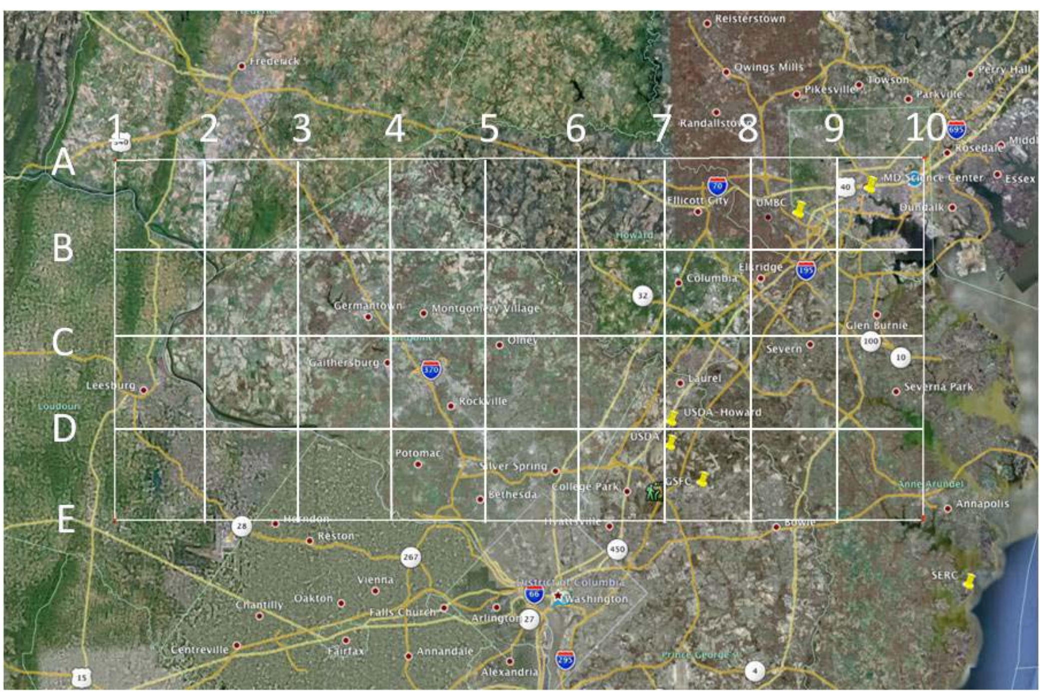

Figure 1 shows the proposed gridbox over the Washington DC/Baltimore

metropolitan areas in the eastern part of the grid box and rural agricultural and forested hills to the west.

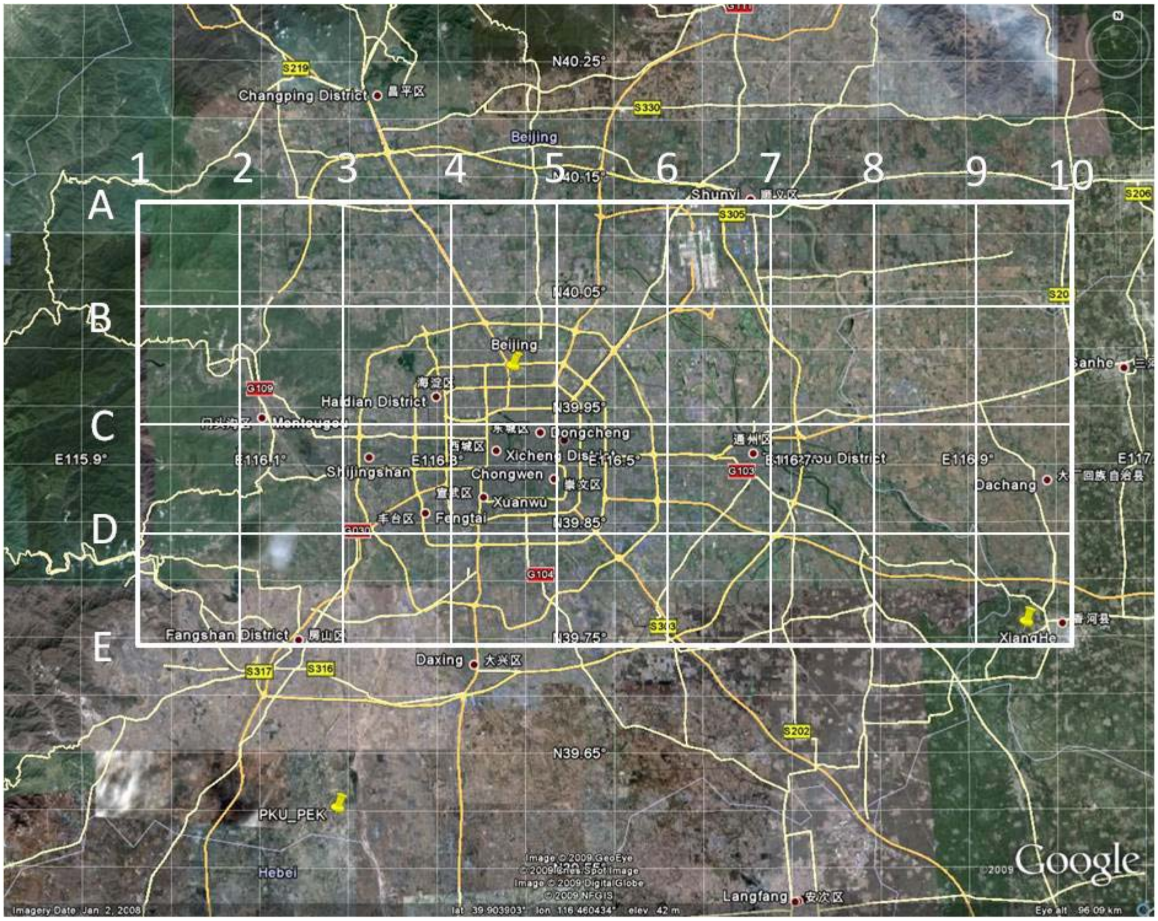

Figure 2 showing the 40 X90 Km gridbox over Beijing and vicinity. The gridbox encompasses low forested mountains to the west, the massive Beijing metropolitan area center and rural agriculture and villages to the east.

B. The time domain: Nominally we propose a six week campaign. Aerosol loading in the Washington DC metropolitan area climatologically has the greatest loading in July and August (τ_{500} = 0.45; σ=±0.28; $\alpha_{440-870}$=1.74, σ=±0.27) that AERONET retrievals will be sufficiently sensitive to aerosol properties. Thus we propose July 15 through August 31 for the Washington DC region. We also propose this campaign for 2011 in collaboration with the NASA venture class DISCOVERY AQ that incorporates airborne and surfec in situ aerosol measurements.

The East Asia campaigns are proposed for March through May 2012 (April: τ_{500} = 0.92, σ=±0.70; May: τ_{500} = 0.85, σ=±0.72). The background aerosol is expected to be urban/industrial fine mode with periodic intrusions of dust dominated aerosols (April: $\alpha_{440-870}$=0.87, σ=±0.37; May: $\alpha_{440-870}$=0.94, σ=±0.36), thus providing opportunities for mixed aerosol characterization.

C. Collaboration and responsibilities. The NASA AERONET program will be responsible for all logistical issues associated with deployment including authorizations to deploy instruments at the grid locations for the Washington field campaign. NASA will make all efforts to assist foreign entities to import equipment for this campaign. A pre and post field calibration will be preformed in May-June and again Sept. 2011 at the GSFC calibration facility. All efforts will be made to encourage supplementary observations such as MPLNET, EPA, local AWS, NOAA, NASA airborne validation programs to participate.

Likewise participating entities from the host countries will be responsible for all logistical issues associated with deployment including authorizations to deploy instruments at the grid locations for the Beijing field campaign. Host leads will make all efforts to assist US and foreign entities to import equipment for this campaign. A pre and post field calibration will be preformed in February 2012 and again June at the a designated calibration facility. All efforts will be made to encourage supplementary observations from entities that have *in situ* capabilities for ground-based validation/comparisons including the research aircraft.

D. Data policy: All data collected in these campaigns will be in the public domain and will be available to all researchers at all times. All AERONET data will be managed through the usual AERONET protocols and archive. All entities having Cimel sun and sky radiometers will contribute their raw data to the AERONET program for calibration and processing according to the AERONET protocols. Likewise all raw AERONET data will be provided to the CARSNET archive for calibration and processing according to the CARSNET protocols. All data will be ingested into a GIS database for spatial and temporal analysis.

E. Instrument Calibration: All instruments will be pre- and post-field calibrated for each field campaign against the NASA Master reference and host reference instruments.

F. Satellite validation: These ground-based networks will provide validation points for the NASA A-train retrievals including GLORY, the morning constellation, geostationary retrievals (e.g., MTSAT, GOES, CMA's FY series) as well as for European and Japanese satellite system aerosol products.

G. *In situ* Contributions: NASA and participating entities are encouraged to contribute additional resources and solicit data sets from other agencies, universities, private organizations and leverage existing field campaigns. These assets may include MPLNET and associated lidar measurements, airborne campaigns, PM 2.5 and 10 from environmental monitoring organizations (e.g., EPA).

H. Ground-based retrieval validation: These will be focused time limited events that will be implemented in association with airborne flights and coordinated with appropriate ground-based *in situ* observations.

I. Deployment Requirements: To optimize all measurements, site deployments must meet field of view requirements for measuring the direct sun and almucantar measurements. That is, direct sun and radiance measurements should not be obstructed by buildings, towers, trees, etc. and every attempt should be made to find a suitable instrument deployment location near a grid point. Data will be archived on site and must be sent daily to both AERONET and host lead institute for processing in an effort to monitor aerosol data quality and track instrument performance during the campaign.

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