Code 940

September 28, 2000

VIA FEDERAL EXPRESS
Dr. D. James Baker, Administrator
National Oceanic and Atmospheric Administration
14th & Constitution Avenue, N.W.
Washington, DC 20230

Dear Jim,

On September 13 and 14 a workshop on long-term monitoring of tropospheric aerosols was held at the Geophysical Fluid Dynamics Laboratory. The program and attendees are given in Enclosure A. The need for the workshop was identified at the March 7 meeting of the NOAA Council on Long-Term Climate Monitoring chaired by Tom Karl. The workshop was organized at GFDL on the invitation of Jerry Mahlman.

Tropospheric aerosols are believed to cause a climate forcing comparable in magnitude to the climate forcing of greenhouse gases (IPCC, 1996 and 2001 draft). Greenhouse gases are monitored to high precision, which allows accurate calculation of annual and decadal changes in their climate forcing. In contrast, aerosols are not measured with an accuracy that allows determination of even the sign of annual or decadal trends of aerosol climate forcing (*op. cit.*). In the absence of this information it not possible to define optimum policies to address long-term global climate change or to assess progress in limiting anthropogenic climate forcing.

There are several reasons for the difficulty in measuring the aerosol climate forcing and identifying its anthropogenic component. The difficulty relates in part to the heterogeneity of aerosols. Different compositions can have opposite radiative effects; for example, sulfates cause cooling whereas black carbon causes warming. Thus aerosol monitoring must include composition-specific information. The indirect effect of aerosols on clouds adds further measurement challenges. For example, the number density of condensation nuclei and accurate microphysical cloud particle properties must be monitored. There are no existing or planned satellite missions with the required capabilities.

The high point of the workshop was the realization that much progress is being made in abilities to model the complex aerosol phenomena and measure the needed aerosol properties. There was optimism about the potential to obtain monitoring data that would yield the aerosol climate forcing. However, there was also agreement that a successful effort would require, in addition to capable satellite instrumentation, a focused integrated program of surface monitoring stations, field campaigns, aerosol and cloud modeling, and targeted laboratory measurements. We make additional comments below about the need for an integrated program.

We discussed modifications of the NPOESS IORD (Integrated Operational Requirements Document) needed to provide the aerosol and cloud measurements. It was agreed that it was necessary to characterize at least the two principal components of the aerosol size distribution, the accumulation and coarse aerosol modes. After discussing alternative proposed formats for the IORD specifications, we agreed on one of these with certain changes. The suggested modifications of the IORD, with accompanying rationale, are provided as Enclosure B.

The practical implication for NOAA, for satellite monitoring, is the need to include one or more instruments on NPOESS specifically designed for aerosols. Further, for two reasons, it seems highly desirable to have an aerosol instrument on the NPP (NPOESS Preparatory Project) mission. First, this would demonstrate the technical capability for the aerosol measurements, as appropriate for an operational requirement. Second, this would allow the required aerosol monitoring to begin much sooner. The possibility of including an aerosol instrument on NPP will be pursued with NASA managers, but it is our understanding that advocacy for such measurements must come from NOAA and/or DOD. It is unlikely that this endeavor will succeed without your strong advocacy.

A specific instrument is not being recommended here, but we note that the needed aerosol measurement capability exists and discuss here the range of possibilities. Specifically, we consider what is possible (1) in the era of NPOESS satellites, and (2) on the upcoming NPP mission. [In both cases, NPOESS and NPP, we assume that the satellite payload will include high spatial resolution calibrated imaging (such as VIIRS) and an infrared Fourier Transform Spectrometer (such as CrIS). These instruments provide important ancillary data for aerosol studies (on clouds, temperature and water vapor) as well as a measure of the aerosol optical depth and mean aerosol size. Determination of the aerosol forcing, its anthropogenic component, and its temporal change requires much more detailed information on the aerosol size distribution, number density, refractive index, absorption and particle shape. However, these relatively high resolution visible and infrared images provide scene definition that is an important complement to aerosol-specific measurements, thus making NPOESS and NPP the platforms of choice for aerosol monitoring.]

(1) NPOESS era: The ideal aerosol complement would include (a) multi-spectral (UV to IR) multi-angle high-precision polarimetric measurements as required to yield detailed aerosol and cloud particle microphysical information, and (b) simultaneous multi-spectral lidar backscattering measurements yielding high vertical resolution of aerosol layering. Polarimetric capabilities for measuring the detailed microphysical data simultaneously for the two principal aerosol size distribution modes have been demonstrated with a satellite prototype instrument (EOSP-lite) on aircraft. Although the European satellite instrument POLDER has limited spectral coverage and measures the polarizations sequentially to an accuracy an order of magnitude poorer than desired, it nevertheless demonstrates the potential of polarimetry for aerosol microphysical information. Lidar technology is developing and it seems possible that lidar will eventually be included on NPOESS, as it is relevant to wind measurements as well as aerosols. A relatively simple low-power lidar could provide aerosol profiling along the sub-satellite track.

We did not attempt to recommend a specific instrument(s) for NPOESS because of several trade-offs that need to be evaluated via the competitive process. One issue is whether daily global aerosol data is required. Instruments that measure only along the sub-satellite track need little resources and provide good sampling for long-term aerosol climate monitoring, including sampling of the diurnal cycle if they are included on three operational satellites. However, there would be benefits of wall-to-wall daily coverage of aerosol data products, especially for military operational applications. One approach would be to use more capable but complex satellite instrumentation, for example, a modification of existing imaging instruments such that they include polarimetric data of high precision. An alternative would be to use detailed sub-satellite aerosol data in combination with global imaging by instruments such as VIIRS or even instruments on other spacecraft such as the geostationary weather satellites. A better understanding of long-term options can be obtained via inclusion of an aerosol instrument on the NPP mission.

(2) NPP mission: It is important to begin monitoring of the aerosol climate forcing as soon as practical. The NPP mission is just now being defined and it is possible that it could accommodate a small aerosol instrument. NPP seems to be the ideal vehicle for demonstrating and initiating monitoring of aerosol climate forcing, because of its complement of supplementary measurements and its potential for initiating aerosol monitoring at the earliest practical date. Our understanding is that any instrument added to NPP would need to be free to the project.

In the course of the workshop we collected information on the characteristics and resource requirements for a range of instruments that can provide aerosol measurements. This information (Enclosure C) has been provided to the NPP project to help assess which of these can potentially be included on that mission. It is not certain that the NPP project will be able to add an instrument to the spacecraft, as the bus capabilities are just now being defined, and as there are competing suggestions for how the space should be used. However, the NPP project has been helpful in evaluating the prospects for aerosol measurements.

It appears from discussions with the project that at least one candidate instrument for NPP, the polarimeter (EOSP-lite), probably fits within the NPP requirement of only modest impacts on spacecraft resources. EOSP-lite is one of four experiments tentatively selected under the UnESS program to fly on the Space Station and funded for further study. Two of these four experiments will be confirmed and funded for instrument build next spring. If EOSP-lite passes this selection process, a copy of the instrument could be available to NPP at little cost, as the intention is to produce two instruments. If construction of EOSP-lite is not funded via the UnESS program, it would be necessary to obtain funding of approximately $7M to provide an instrument to NPP. It is assumed that cost of integrating an aerosol instrument onto NPP would be borne by the project.

The results of the workshop were presented at last week's meeting of the NOAA Council on Long-Term Climate Monitoring. The objective is to obtain NOAA advocacy of an aerosol monitoring instrument on NPP, as a first step toward aerosol monitoring from NPOESS. As suggested above, the "way" to aerosol measurements probably exists, but it is not likely to happen without a strong "will". The prerequisite for this is strong advocacy by NOAA.

In addition, the workshop reaffirmed a conviction of the community that successful determination and monitoring of the anthropogenic aerosol climate forcing requires an integrated aerosol program. Enclosures D and E are a heuristic sketch of the principal components of an integrated program and a more detailed flow chart of how these parts work together. Components of this integrated approach, in addition to satellite monitoring, include: (a) surface monitoring stations including the NOAA network, NASA's Aeronet, and others (Enclosure F), (b) comprehensive modeling and analysis of the direct and indirect aerosol forcings (Enclosures G and H), and (c) campaigns including upcoming field studies such as ACE-Asia and satellite missions such as PICASSO/CENA.

We note that this integrated approach to monitoring, modeling, and understanding the climate influence of tropospheric aerosols is complementary to ongoing and proposed research examining the influence of aerosols on human health in the context of current and prospective air quality standards.

Success in understanding the role of aerosols in climate change requires contributions from several agencies, and indeed recognition of the importance of this problem is growing among relevant U.S. agencies. DOE is proposing a substantial aerosol research program directed to aerosol chemical and physical processes beginning in FY2002 or sooner. NASA can contribute much via EOS, PICASSO/CENA, AERONET, and its Global Aerosol Climatology Project. NSF is a principal contributor to field campaigns and PI research projects. NOAA has a large role to play because of the critical need to monitor the global aerosol climate forcing, a task that requires long-term satellite measurements and tying together of different program components as summarized above.

Over the past several years it has become increasingly clear that aerosols can cause a climate forcing comparable to that from greenhouse gases, and yet the present and future trends of aerosol forcing are very uncertain. A strong case has been made for the need and potential to monitor the required aerosol properties. We are eager to obtain your review of this issue and your possible advocacy of aerosol monitoring.

Sincerely,

Original signed

James E. Hansen
NASA Goddard Institute for Space Studies

V. Ramaswamy
NOAA Geophysical Fluid Dynamics Laboratory

cc: Workshop attendees
Ghassem Asrar, Jack Kaye (NASA);
Tom Karl, Dan Albritton (NOAA)
Ari Patrinos, Peter Lunn (DOE)
Jay Fein, Anne & Marie Schmulter (NSF);
John Bachman, James Vickery (EPA)

Enclosure A

MONITORING GLOBAL AEROSOL FORCING OF CLIMATE: EVALUATING REQUIREMENTS FOR SATELLITE MONITORING, GROUND-BASED MONITORING, IN-SITU MEASUREMENTS AND GLOBAL MODELING

Workshop Objectives:
The objective of this workshop is to define what is needed to evaluate the anthropogenic aerosol climate forcing, its uncertainty, and its temporal change on decadal time scales.

The workshop will aim to:

- Define a strategy for obtaining the time-dependent aerosol climate forcing from a combination of satellite monitoring, ground-based monitoring, in-situ measurements, and global modeling.
- Evaluate the contribution that the NPOESS program could make to determination of the aerosol climate forcing.

AGENDA- Wednesday, September 13, 2000

8:30-8:45 am	Welcome, Logistics (V. Ramaswamy)
8:45-9:00am	Workshop Background and Objectives (Jim Hansen)
9:00-9:20am	Overview of NPOESS (Mike Haas)
9:20-10:20am	Aerosol Direct Forcing (Chair: Brian Soden) *(What are the key quantities that need to be measured?)* Observational Perspective (Steve Schwartz - 20 minutes) Model Perspective (V. Ramaswamy - 20 minutes) Discussion
10:20-10:50am	Break
10:50-Noon	Aerosol Indirect Forcing (Chair: Joyce Penner) *(What are the key quantities that need to be measured?)* Observational Perspective (Qingyuan Han - 20 minutes) Modeling Perspective (Ulrike Lohmann - 20 minutes) Discussion
Noon-13pm	Lunch
13:20-15:10pm	Satellite Instrument Capabilities (Chair: Kuo-Nan Liou) *(20 minutes each talk. The people representing each sensor should bring a table of performance specs with them.)* AVHRR (Larry Stowe/Michael Mishchenko) MISR: Ralph Kahn MODIS: Yoram Kaufman PICASSO: David Winker EOSP-Lite: Brian Cairns TRIANA: Francesco Valero Discussion
15:00-15:30pm	Break

AGENDA- Wednesday, September 13, 2000

15:30-16:30pm	Complementary Modeling Capabilities (Chair: Harshvardhan) Phil Rasch Tony Del Genio Discussion
16:30-17:30pm	Complementary Measurement Capabilities (Chair: Tim Bates) John Ogren Ells Dutton Discussion

AGENDA- Thursday, September 14, 2000

8:00-9:00am	IORD Requirements (Chair: Lucia Tsaoussi – *define IORD process*) Current IORD and Sensor Requirements (Eric Shettle) Proposed Requirements (Michael Mishchenko) Discussion
9:00-10:00am	Synthesis (Chair: John Ogren) Panel Discussion of Session Chairs *(How can we combine satellite observations, models, surface monitoring and within atmosphere observations to evaluate the anthropogenic aerosol climate forcing, and its uncertainty over decadal time scales.)* Discussion
10:00-10:30am	Break
10:30-12:30pm	Recommendations for NPOESS (Chair: Ramaswamy, Hansen) *How well can current and potential NPOESS measurements plus complementary M&M satisfy aerosol requirements? Writing assignments for workshop report*.

Participant List - Workshop on Monitoring Global Aerosol Forcing of Climate: Evaluating requirements for satellite monitoring, ground-based monitoring, in-situ measurements and global modeling

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Enclosure B

Suggested modifications of aerosol and cloud measurement requirements in NPOESS Integrated Operational Requirements Document (IORD)

1. Direct aerosol effect

The left column of Table 1 lists aerosol parameters that are needed for a reliable evaluation of the direct effect and its anthropogenic part.[1,2] All these quantities must be known in a wide spectral range from the near-UV to the near-IR. The aerosol optical thickness and single-scattering albedo are usually a direct product of applying a retrieval algorithm to satellite measurements, whereas the phase function and chemical composition can be determined provided that aerosol microphysical parameters such as the size distribution, spectral real refractive index, and shape are retrieved.

Table 1. Quantification of the direct aerosol effect

Required aerosol characteristics	Retrieved aerosol characteristics	
	Spectral optical thickness $\tau_{\mathrm{a}}(\lambda)$	for two modes
Spectral optical thickness $\tau_{\mathrm{a}}(\lambda)$	Effective radius $r_{\mathrm{e,a}}$	
Spectral single-scattering albedo $\varpi_{\mathrm{a}}(\lambda)$	Effective variance $v_{\mathrm{e,a}}$	
Spectral phase function $P_{\mathrm{a}}(\Theta,\lambda)$	Spectral real refractive index $m_{\mathrm{a}}(\lambda)$	
Chemical composition	Spectral single-scattering albedo $\varpi_{\mathrm{a}}(\lambda)$	
	Nonsphericity	

The right column of Table 1 lists aerosol parameters that must be retrieved from space in order to determine the required aerosol characteristics: the spectral optical thickness, the effective radius and effective variance of the size distribution, the real part of the spectral refractive index, the single-scattering albedo, and shape. Since the aerosol population is typically bimodal,[3] all these parameters must be determined for each mode. The effective radius has the dimension of length and provides a measure of the average particle size, whereas the dimensionless effective variance characterizes the width of the size distribution:[4]

$$r_{\mathrm{e}} = \frac{1}{\langle G \rangle} \int_{r_{\min}}^{r_{\max}} \mathrm{d}r\, n(r)\, \pi r^3 ,$$

$$v_{\mathrm{e}} = \frac{1}{\langle G \rangle\, r_{\mathrm{e}}^2} \int_{r_{\min}}^{r_{\max}} \mathrm{d}r\, n(r)\, (r - r_{\mathrm{e}})^2\, \pi r^2 ,$$

where $n(r)\mathrm{d}r$ is the fraction of particles with radii from r to $r + \mathrm{d}r$ and

$$\langle G \rangle = \int_{r_{\min}}^{r_{\max}} \mathrm{d}r\, n(r)\, \pi r^2$$

is the average area of the geometric projection per particle. It has been demonstrated[4] that different types of size distribution (power law, log normal, gamma, etc.) having the same values of the effective radius and effective variance possess similar scattering and absorption properties, thereby making r_e and v_e convenient universal characteristics of any size distribution.

The minimum proposed measurement requirements (thresholds[†]) include the retrieval of the total column optical thickness (4.1.6.2.1) and the average column values of the effective radius and effective variance of the size distribution (4.1.6.2.2), the real part of the refractive index, and the single-scattering albedo (4.1.6.2.2.a) for each mode of a bimodal aerosol population (Section 4). The optical thickness, the real part of the refractive index, and the single-scattering albedo must be determined at multiple wavelengths in the spectral range $0.4–2.4\,\mu\mathrm{m}$. An integral part of the retrieval procedure must be the detection of nonspherical aerosols such as dust-like and soot particles (4.1.6.2.2.a). It has been demonstrated that, if ignored, nonsphericity can seriously affect the results of optical thickness, refractive index, and size retrievals.[5,6]

The respective objectives[‡] include the retrieval of the vertical distribution of all aerosol characteristics.

2. Indirect effect

The aerosol effect on the cloud albedo can be detected and quantified from space by means of long-term global measurements of the change in the number concentration of aerosol particles acting as cloud condensation nuclei (CCNs) and the associated change in the cloud albedo. Other measurable manifestations of the indirect effect include the change in the cloud droplet size and number concentration and changing liquid water path.[7,8] Since the droplet generation efficiency of aerosols depends on their size and hygroscopicity,[7,8] the measurement of the aerosol number concentration must be accompanied by the determination of the aerosol effective radius and chemical composition.

The left column of Table 2 lists the cloud and aerosol characteristics that are required for a reliable monitoring of the indirect aerosol effect on climate and its anthropogenic component, whereas the right column lists the minimum set of retrievable quantities that can be used to determine the required cloud and aerosol characteristics. The respective minimum proposed measurement requirements (thresholds) include the retrieval of the average column cloud droplet size distribution (4.1.6.3.3) as well as the column aerosol optical thickness (4.1.6.2.1) and the average column values of the effective radius and effective variance of the aerosol size

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[†] The IORD defines thresholds as minimum requirements below which utility of the system becomes questionable.

[‡] The IORD defines objectives as operationally significant increments above the respective thresholds.

distribution (4.1.6.2.2) and the real part of the aerosol refractive index (4.1.6.2.2a) for each mode of a bimodal aerosol population. The respective objectives include the measurement of the vertical distribution of all cloud and aerosol characteristics.

Table 2. Quantification of the indirect aerosol effect

Required cloud and aerosol characteristics	Retrieved quantities	
Cloud albedo $A_c(\lambda)$ Cloud particle effective radius $r_{e,c}$ Cloud particle number concentration N_c Liquid water path	$\tau_c(\lambda)$ $r_{e,c}$ $v_{e,c}$	
Aerosol particle number concentration N_a Aerosol particle effective radius $r_{e,c}$ Aerosol chemical composition	$\tau_a(\lambda)$ $r_{e,a}$ $v_{e,a}$ $m_a(\lambda)$ shape	for two modes

Note that the cloud and aerosol particle number concentrations listed in the left column of Table 2 must be deduced from the column optical thickness and the particle extinction cross section (a function of size distribution, refractive index, and particle shape). The accuracy with which they must be determined is 15–20% for clouds and 20–30% for aerosols.[9,10] This accuracy is very difficult to achieve and necessitates the retrieval of the cloud droplet and aerosol size distributions and the aerosol refractive index with precision unattainable with instruments based on radiometric measurements alone.[11] Assuming rather than retrieving the effective variance of the cloud droplet and aerosol size distributions and the aerosol refractive index as well as retrieving the aerosol Angstrom exponent rather than the aerosol effective radius, as implied by the current version of IORD, can lead to even larger errors in the retrieved number concentrations.

3. Required measurement accuracies

The criteria for specifying measurement accuracy requirements must be based on the desire to detect plausible changes of the aerosol radiative forcing estimated to be possible during the next 20 years and to determine quantitatively the contribution of this forcing to the planetary energy balance. A significant global mean flux change can be defined as 0.25 W/m^2 or greater based on the consideration that anticipated increases of greenhouse gases during the next 20 years will cause a forcing of about 1 W/m^2. The estimated plausible 20-year change of the global mean aerosol optical thickness is 0.04, whereas the global mean optical thickness change required to yield the 0.25 W/m^2 flux change is 0.01.[2] These numbers justify the proposed threshold accuracy and precision for the aerosol optical thickness measurement (4.1.6.2.1).

The threshold accuracy and precision indicated for the aerosol size distribution measurement (4.1.6.2.2) are dictated by the requirement to measure the aerosol number concentration with an accuracy good enough for detecting the effect of increasing CCN concentration on cloud properties. The latter should be at least 30% or better.[9,10] The strong dependence of the extinction cross section on the effective radius and effective variance makes the retrieval of aerosol number concentration very difficult and necessitates high-accuracy measurements of the size distribution.[11] Accurate retrievals of the aerosol particle size are also needed in order to determine the cloud condensation efficiency of aerosols.[7,12]

The threshold measurement accuracy and precision indicated for the real part of the aerosol refractive index (4.1.6.2.2a) are determined by the need to identify the aerosol chemical composition. The latter is required in order to identify hygroscopic aerosols and discriminate between natural and anthropogenic aerosol species.

The threshold measurement accuracy and precision for the cloud particle size distribution (4.1.6.3.3) are dictated by the need to detect a flux change of 0.25 W/m^2 or greater,[2] reliably detect a change of cloud particle size caused by increasing CCN concentrations,[7,8] and determine the cloud droplet number concentration with an accuracy of at least 20%.[9,10]

4. Proposed aerosol and cloud measurement requirements

4.1.6.2.1 Aerosol Optical Thickness (DOC/DoD). Aerosol Optical Thickness (AOT) is defined as the extinction (scattering+absorption) vertical optical thickness of modes 1 and 2 of the bimodal aerosol size distribution at multiple wavelengths within the 0.4 – 2.4 micron spectral range (# – applies to total column optical depth of each mode). The requirements below apply only under clear conditions.

Systems Capabilities	**Thresholds**	**Objectives**
a. Vertical coverage	Surface to 30 km	Surface to 50 km
b. Horizontal Cell Size	10 km	1 km
c. Vertical Cell Size	Total column	
1. from 0 to 2 km		0.25 km
2. from 2 to 5 km		0.5 km
3. >5 km		1 km
d. Mapping Accuracy #	4km	1 km
e. Measurement Range #	0 to 5	0 to 10
f. Measurement Precision #	0.01 over ocean/0.03 over land	0.005 over ocean/0.02 over land
g. Measurement Accuracy #	greater of 0.02 or 7% over ocean greater of 0.04 or 10% over land	greater of 0.01 or 5% over ocean greater of 0.03 or 7% over land
h. Refresh	6 hours	4 hours
i. Long Term Stability	0.01	0.005

4.1.6.2.2 Aerosol Particle Size Distribution (DOC/DoD). Measurement of the bimodal size distribution of the aerosol population in terms of the effective radius r_e and effective variance v_e of each mode. The effective radius is the ratio of the third moment of the aerosol size distribution to the second moment. The effective variance characterizes the width of the size distribution. The requirements below apply only under clear conditions (# – applies to the average column size distribution; ‡ – applies only to sub-satellite pixels).

Systems Capabilities	**Thresholds**	**Objectives**
a. Vertical coverage	Surface to 30 km	Surface to 50 km
b. Horizontal Cell Size	10 km	1 km
c. Vertical Cell Size	Total column	
1. from 0 to 2 km		0.25 km
2. from 2 to 5 km		0.5 km
3. >5 km		1 km
d. Mapping Accuracy #	4km	1 km
e. Measurement Range #	0 to 5 µm for r_e	0 to 10 µm for r_e
	0 to 3 for v_e	0 to 5 for v_e
f. Measurement Precision #	greater of 0.05µm or 10% for r_e	greater of 0.05µm or 5% for r_e
	greater of 0.1 or 40% for v_e ‡	greater of 0.1 or 20% for v_e
g. Measurement Accuracy #	greater of 0.1µm or 10% for r_e	greater of 0.05µm or 5% for r_e
	greater of 0.3 or 50% for v_e ‡	greater of 0.2 or 30% for v_e
h. Refresh	6 hours	4 hours
i. Long Term Stability	greater of 0.05µm or 10% for r_e	greater of 0.05µm or 5% for r_e
	greater of 0.2 or 40% for v_e ‡	greater of 0.1 or 20% for v_e

4.1.6.2.2a Aerosol Refractive Index, Single-Scattering albedo, and Shape (DOC) (applies only to sub-satellite pixels). Measurement of the real part of the refractive index m and the single-scattering albedo ϖ of each mode of the bimodal aerosol size distribution at multiple wavelengths within the 0.4 – 2.4 micron spectral range and determination whether aerosol particles are spherical or nonspherical. Non-sphericity is detected when the value $S = (L_{max}/L_{min} - 1) > 0.3$, where L_{max} is the maximum length of the particle and L_{min} is the minimum length of the particle. The value of S can be inferred from multi-angular measurements of the departure of scattered radiation from that expected from spherical aerosol particles. The requirements below apply only under clear conditions (# – applies to the average column size distribution).

Systems Capabilities	**Thresholds**	**Objectives**
a. Vertical coverage	Surface to 30 km	Surface to 50 km
b. Horizontal Cell Size	10 km	1 km
c. Vertical Cell Size	Total column	
1. from 0 to 2 km		0.25 km
2. from 2 to 5 km		0.5 km
3. >5 km		1 km
d. Mapping Accuracy #	4km	1 km
e. Measurement Range #	1.3 to 1.7 for m 0 to 1 for ϖ	1.3 to 1.8 for m 0 to 1 for ϖ
f. Measurement Precision #	0.01 for m 0.02 for ϖ	0.005 for m 0.01 for ϖ
g. Measurement Accuracy #	0.02 for m 0.03 for ϖ	0.01 for m 0.01 for ϖ
h. Refresh	6 hours	4 hours
i. Long Term Stability	0.01 for m, 0.02 for ϖ	0.005 for m 0.01 for ϖ

4.1.6.3.3 Cloud Particle Size Distribution (DOC/DoD). The effective radius r_e and effective variance v_e of a single mode particle size distribution. The effective radius is the ratio of the third moment of the size distribution to the second moment. The effective variance characterizes the width of the size distribution (‡ – applies only to sub-satellite pixels).

Systems Capabilities	**Thresholds**	**Objectives**
a. Horizontal Cell Size	15 km	5 km
b. Vertical Reporting Interval	1 km	0.3 km
c. Mapping Uncertainty	4 km	1 km
d. Measurement Range	0 to 50 µm for r_e 0 to 2 for v_e	0 to 80 µm for r_e 0 to 3 for v_e
e. Measurement Precision	greater of 0.5µm or 5% for r_e greater of 0.04 or 40% for v_e ‡	greater of 0.3µm or 3% for r_e greater of 0.03 or 30% for v_e
f. Measurement Accuracy	greater of 1µm or 10% for r_e greater of 0.05 or 50% for v_e ‡	greater of 0.5µm or 5% for r_e greater of 0.04 or 40% for v_e
g. Refresh	6 hours	4 hours
h. Long Term Stability	greater of 0.5µm or 5% for r_e greater of 0.04 or 40% for v_e ‡	greater of 0.3µm or 3% for r_e 0.03 or 30% for v_e

5. Proposed changes in the IORD Requirements Correlation Matrix

Atmospheric Parameters (Para 4.1.6.2.x.)

Parameter 1 – Aerosol Optical Thickness (DOC/DoD). (USAF) AWS Report establishes aerosol optical thickness threshold values required to provide useful measurements to support PGM employment.

(DOC) This EDR is derived from imagery and multi-angle photopolarimetry. The threshold values are consistent with or better than values specified in the imagery parameter and ensure the detection and quantification of a global mean flux change due to increasing aerosol load of 0.25 W/m^2 or greater.

Parameter 2 – Aerosol Particle Size Distribution (DOC/DoD). (USAF) AWS Report establishes aerosol particle size information at the specified values crucial to precision guided munitions (PGM) support.

(DOC) This EDR is derived from imagery and multi-angle photopolarimetry. The threshold values are consistent with or better than values specified in the imagery parameter and ensure the measurement of the aerosol column number density with an accuracy of 30% or better.

Parameter 2a – Aerosol Refractive Index, Single-Scattering Albedo, and Shape (DOC). (DOC) This EDR is derived from multi-angle photopolarimetry for sub-satellite pixels only. The threshold values ensure reliable identification of the aerosol chemical composition and morphology.

Cloud Parameters (Para 4.1.6.3.x.)

Parameter 3 – Cloud Particle Size Distribution (DOC/DoD). (USAF) … [The first two paragraphs as in the current version of IORD].

(DOC) This EDR is derived from imagery, multi-angle photopolarimetry, atmospheric sounding data, and/or microwave observations. NOAA threshold requirements are consistent with and justified by values specified under the atmospheric Vertical Moisture Profile, Atmospheric Vertical Temperature Profile, Imagery, Sea Surface Winds, and Soil Moisture. They ensure reliable detection and quantification of the indirect aerosol effect on clouds and the measurement of the cloud droplet column number concentration with an accuracy of 20% or better.

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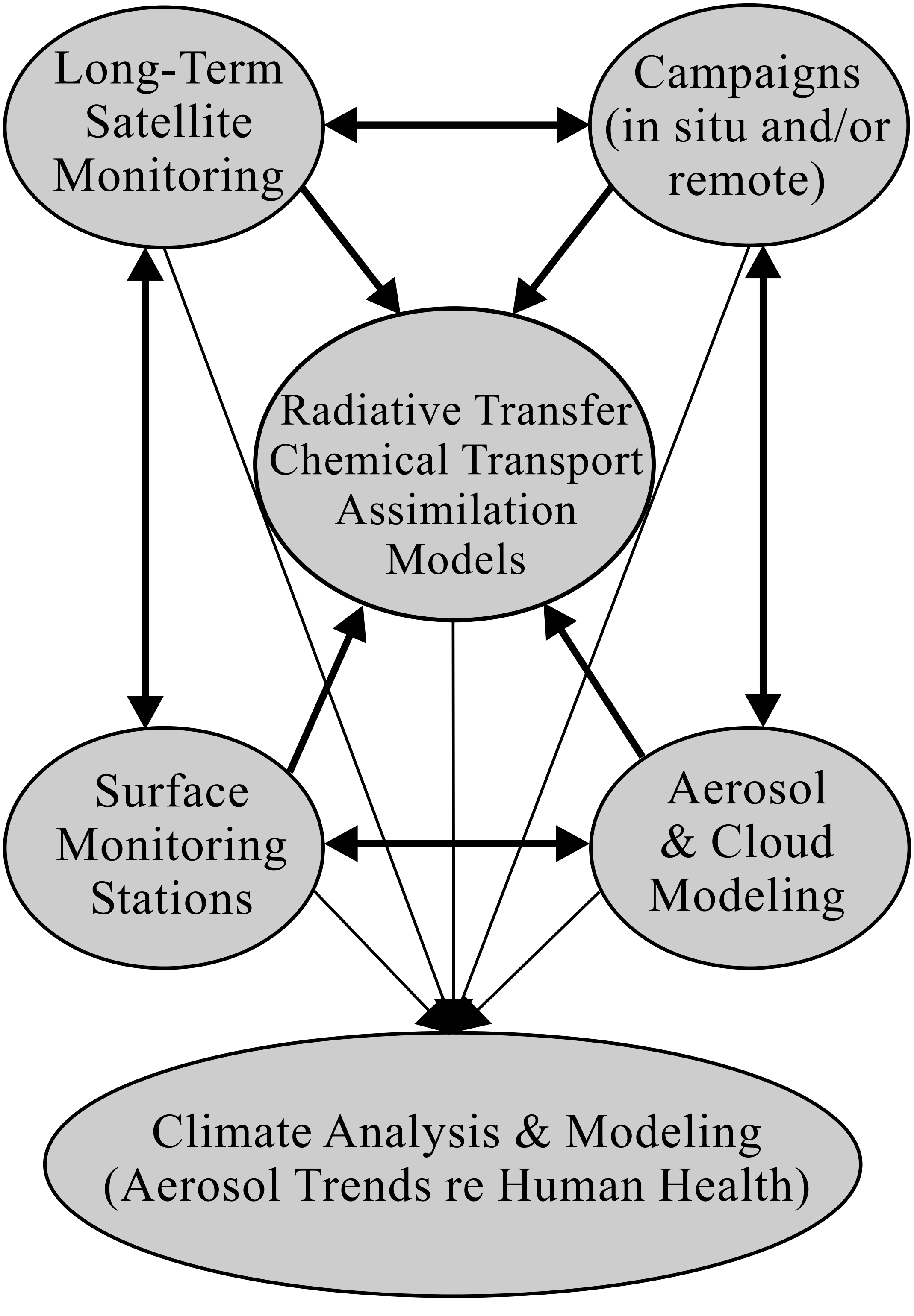
Enclosure C

SATELLITE INSTRUMENT CAPABILITIES

INSTRUMENT	MASS (kg)	POWER (W)	DATA RATE	SPECTRAL RANGE (µm)	TECHNIQUE	AEROSOL PRODUCT*
AVHRR				0.63 and 0.83	imager	‣ optical thickness (±0.07 or 40%) ‣ Angstrom exponent (±0.4)
MISR	149	72	3.3 Mbps	0.45–0.87	multi-angle imager	‣ optical thickness (±0.05 or 20%) ‣ 2–4 size/composition groups ‣ nonsphericity
MODIS	229	163	6.1 Mbps	0.4–2.2	imager	‣ optical thickness (±0.04 or 10%) ‣ effective radius
PICASSO	178	232	279 Kbps	0.532 and 1.064	nadir-pointing depolarization lidar	‣ vertical profile of backscatter ‣ nonsphericity ‣ rough estimate of size
TRIANA				0.32–0.87	imaging camera	‣ optical thickness (20–30%) ‣ estimate of size
POLDER	33	42	882 Kbps	0.44–0.91	multi-angle imaging polarimeter	‣ optical thickness (±0.05 or 10%) ‣ Angstrom exponent (±0.3) ‣ refractive index (3 classes: 1.33, 1.4, 1.5)
EOSP-Lite	20	15	60 Kbps	0.41–2.25	high-precision along-track scanning photopolarimeter	‣ two aerosol modes ‣ optical thickness (±0.02 or 6%) ‣ effective radius (10%) ‣ effective variance (±0.05 or 50%) ‣ refractive index (±0.015) ‣ number density (30%) ‣ nonsphericity
VIIRS	158	238	=8 Mbps	0.4–2.4	imager	‣ optical thickness (±0.03 over ocean, ±0.2 over land) ‣ effective radius (±0.3 µm over ocean, ±1.0 µm over land)

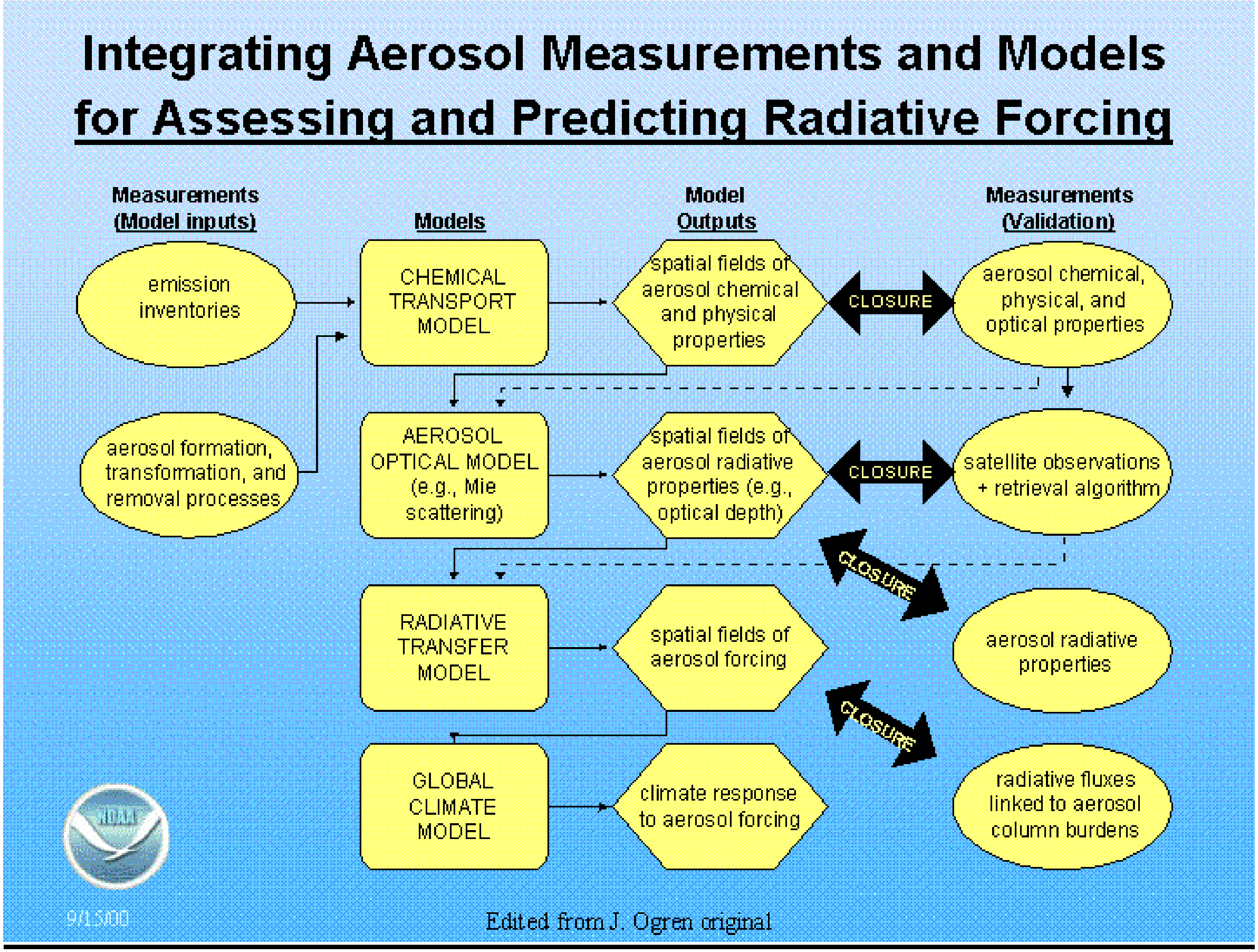
*Accuracy estimates are provided by instrument teams and in some cases may represent expected rather than actual performance

Instrument characteristics and expected products. The products and expected accuracies are those provided by instrument representatives. They may contain some subjectivity or refer to capabilities under special conditions.



Heuristic sketch of the principal components of an integrated program to determine the aerosol climate forcing. Directed laboratory measurements are also needed, primarily as an input to the modeling. It is noted that information obtained on aerosol properties and their trends also may have relevance to human health issues.

Enclosure E



Integrating Aerosol Measurements and Models for Assessing and Predicting Radiative Forcing

Measurements (Model inputs)

Models

Model Outputs

Measurements (Validation)

emission inventories

CHEMICAL TRANSPORT MODEL

spatial fields of aerosol chemical and physical properties

CLOSURE

aerosol chemical, physical, and optical properties

aerosol formation, transformation, and removal processes

AEROSOL OPTICAL MODEL (e.g., Mie scattering)

spatial fields of aerosol radiative properties (e.g., optical depth)

CLOSURE

satellite observations + retrieval algorithm

CLOSURE

RADIATIVE TRANSFER MODEL

spatial fields of aerosol forcing

aerosol radiative properties

CLOSURE

GLOBAL CLIMATE MODEL

climate response to aerosol forcing

radiative fluxes linked to aerosol column burdens

9/15/00

Edited from J. Ogren original

Schematic flowchart integrating aerosol measurements and models to assess and predict aerosol radiative forcing (presented at workshop by John Ogren).

Enclosure F

(a) Aerosol Optical Depth (# of sites)

- NOAA/CMDL (4+)
- NASA/AERONET (~100)
- DOE/ARM (3)
- WCRP/BSRN (12-20, new)
- WMO/GAW (12, new)

Global

- NOAA/SRRB (3)
- GISS (6) +SUNY/Albany (10)
- USDA/UV (30)

Cont. U.S.

- ACE I-III, TARFOX, SAFARI, INDOEX...

Episodic

(b) Surface Solar Irradiance

(current instantaneous accuracies under ideal conditions, BSRN specifications)

- Direct beam reference accuracy to 0.001%
- Direct beam operational accuracy to 0.3%
- Diffuse (4 W m^{-2})
- Total (6 W m^{-2})
- Optical Depth ~0.01

Current surface networks for monitoring (a) aerosol optical depth, and (b) solar irradiance (presented at workshop by Ellsworth Dutton).

Enclosure G

A. Network of ground-based measurements:

- **Sun photometer - T_{AP}**
- **Ground-based aerosol chemistry**
- **Physical & optical properties**

B. A set of measurements to determine vertical profile climatology at selected locations.
- **In a downwind of major source regions: Europe, North America, Asia, soil dust, biomass, sea salt**
- **Background rites**

C. <u>Process studies</u> to determine what processes establish the size distributed & size-segregated chemistry of aerosols for selected locations:
- **Continental**
- **Marine**
- **Upper troposphere**
- **Regions dominated by dust, sea salt, biomass**
- **Models**

D. <u>Process studies</u> in variety of locations (cloud systems)

- **Microphysical properties:**
  $\Delta N_c / \Delta N_{AP}$
- **Macrophysical properties:**
  $\Delta LWC / \Delta N_{AP}$
  $\Delta \text{precip.} / \Delta N_{AP}$
  $\Delta_{\alpha c} / \Delta N_{AP}$

E. Closure studies to characterize
$\Delta F_c / \Delta N_{AP}$

F. Studies to determine how to scale from individual clouds (1-10km) to (100-500km) model parameterization scales. Cloud-resolving models to single-column models to GCM aerosol models.

G. Large-scale (spatial global) comparison of aerosol and cloud parameters
$\Delta N_c / \Delta N_{AP}$
$\Delta LWC / \Delta N_{AP}$
$\Delta \alpha_c / \Delta N_{AP}$

H. Models vs. satellites observations
Checks on overall understanding
$\Delta F / \Delta N_{AP}$

End-to-end summary of modeling and data requirements for analyzing aerosol climate forcing (presented at workshop by Joyce Penner).

Enclosure H

Aerosol Indirect Effect

(a) Presentation (Del Genio):

- **Indirect effect will never be defined by observations alone**
- **Uncertainty in background → need long time record of observed changes**
- **Details of low cloud and aerosol vertical structure important**
- **Weather variability masks small aerosol signal in cloud properties**
- **ΔLWC<O sometimes → 3rd indirect effect due to evaporation?**
- **Cloud height, droplet size distribution changes?**

Needs:

- **High vertical resolution, realistic cloudy PBL parameterizations needed in GCMs**
- **Large ensembles of CRM simulations**
- **Systematic studies of analysis products to separate AIE from natural variability**

(b) Summary Discussion (Harshvardhan)

- **Indirect effect will never be defined by observations alone**
- **Satellites cannot measure aerosol properties when there is cloud obscuration**
- **Vertical structure of aerosol and low cloud are needed → can satellites do this?**
  CLOUDSAT (cloud radar)
- **Need to measure cloud geometrical height →can we find cloud base? → CLOUDSAT (?)**
- **Need liquid water path → microwave measurements (but resolution is very coarse)**
- **Chemistry/transport models should be used synergistically with satellite observations**
- **Detailed process studies of cloud microphysics are needed**

Analysis of aerosol indirect effects as presented at workshop by Anthony Del Genio (a) and in summary at workshop by Harshvarden (b).