The NACIP Steering Committee prepared this report on short notice in response to the following question from the General Accounting Office (GAO) the to agency program managers.

Are there any significant articles that have been published in recent months (i.e., since the TAR) that address the aerosol Climate forcing and might help reduce uncertainties?

From: M. Prather, V. Ramanathan and S. Schwartz on behalf of the NACIP Steering Committee

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We summarize here the research findings published during 2001 and 2002 that have contributed to: 1) Reducing/Redefining Uncertainties; 2) New Insights; and 3) Underpinnings for quantification of the forcing.

I. Reducing/Redefining Uncertainties

Forcing due to Aerosol modification of Clouds and their albedo (reflectivity): The first indirect effect

The TAR quotes a value of 0 to –2 $W.m^{-2}$ for the forcing due to the first indirect effect; thus this effect is the largest source of uncertainty in estimating human impact on climate. Two major field campaigns (ACE-II and INDOEX) and satellite based studies have provided critical data to help define the mean value and quantify this uncertainty.

Anthropogenic aerosols produce more cloud drops with smaller effective radius: Aircraft measurements during ACE-II in the east Atlantic ocean (subject to pollution from Europe) and during INDOEX in the tropical Indian ocean (subject to pollution from India) have clearly demonstrated that anthropogenic aerosols significantly enhance the number of cloud drops with smaller mean radius in low level clouds. Satellite measurements of aerosol concentration and cloud droplet radii have also shown cloud droplet size to be largest (14 micrometers) over remote tropical oceans and smallest (6 micrometers) over highly polluted continental areas. Small droplets are also present in clouds downwind of continents. Satellite derived clear-sky aerosol number concentration has been shown to exhibit positive correlation with cloud optical depth and negative correlation with cloud drop effective radius, providing additional observational evidence for the first indirect effect over large regions. Cloud liquid water path did not exhibit appreciable dependence on aerosol number concentration (second indirect effect) in contrast to recent model calculations.

McFarquhar, G and Heymsfield A., 2001. Parameterizations of INDOEX microphysical measurements and calculations of cloud susceptibility: Applications for climate studies, J. Geophys. Res., 106, D22, 28,675-28,698.

Pawloska and Berenguier (Tellus, 52B, 868, 2000) for ACE-II

Breon FM, Tanre D, Generoso S, 2002. Aerosol effect on cloud droplet size monitored from satellite, Science, 295: 834-838.

Nakajima, T., Higurashi, A., Kawamoto, K., and Penner, J. E., 2001. A possible correlation between satellite-derived cloud and aerosol microphysical parameters. Geophys. Res. Lett. 28, 1171-1174.

Polluted clouds are also Brighter: Examination of clouds over the North Atlantic subject to the influence of pollution aerosols transported from North America and Europe confirms brightening of clouds by anthropogenic aerosols on synoptic scales. Examination of the dependence of cloud optical depth and spherical albedo on liquid water path derived from AVHRR has permitted detection and quantification of enhancement of cloud reflectance in two episodes over the mid North Atlantic in which chemical transport modeling indicated incursions of continental sulfate. This approach suggests a means of quantifying aerosol indirect forcing globally over the past 15 years using archived satellite data.

Schwartz S. E., Harshvardhan and Benkovitz C. M. Influence of anthropogenic aerosol on cloud optical depth and albedo shown by satellite measurements and chemical transport modeling. Proc. Nat. Acad. Sci. U.S. 99 , 1784-1789 (2002)

Role of Organics in the indirect effect: Present model-based estimates of the first indirect effect of aerosols enhancing the brightness of clouds rely on a classical picture of cloud droplets nucleating on aerosol particles comprised largely of soluble inorganic salts. This picture is insufficient if clouds are formed in the presence of soluble gases such as HNO3 or if the particles contain surfactant organics, which lower the surface tension of the nascent cloud droplets. The further enhancement of cloud drop concentration due to these effects results in an increase in cloud albedo that, if applicable globally, would be of climatological significance.

R. J. Charlson, J. H. Seinfeld, A. Nenes, M. Kulmala, A.Laaksonen, and M. C. Facchini, 2001. Reshaping the Theory of Cloud Formation, Science, 292, 2025-2026.

Anthropogenic Aerosol Forcing Inferred From Climate Record

Several studies have examined the climate record to constrain the climate sensitivity, climate response time, and total forcing from the observational record; from the total forcing the aerosol forcing is inferred by difference. These provide an independent approach to the combined modeling/observation examples noted above.

	Anthropogenic Aerosol Forcing		
Study	Most negative	Central value	Least negative
Andronova and Schlesinger (2001)	-1.3	-0.9	-0.54
Forest et al (2002)	-0.95		-0.3
Wigley and Raper (2001)	-1.9	-1.3	-0.3

Andronova, N. G. and Schlesinger, M. E., (2001): Objective estimation of the probability density function for climate sensitivity, J. Geophys. Res., 106, 22605-22611.

Forest, C. E., Stone, P. H., Sokolov, A. P., Allen, M. R. and Webster, M. D., (2002): Quantifying uncertainties in climate system properties with the use of recent climate observations, Science, 295, 113-117.

Wigley, T. M. L. and Raper, S. C. B., (2001): Interpretation of high projections for global-mean warming, Science, 293, 451-454.

Models are underestimating Direct Forcing: Comparison of aerosol clear-sky forcing calculated by six current aerosol models with satellite observations indicates that the models underpredict (negative) top-of-atmosphere aerosol forcing by 1.7 W m-2 global average. This comparison indicates that climate model calculations using model-based aerosol forcing may be substantially underestimating this forcing.

Penner J. E. et al., A comparison of model- and satellite-derived aerosol optical depth and reflectivity. J Atmos Sci 59 441-460 (2002).

II. New Insights:

Large Reduction in surface solar heating of the ocean and land:

Direct observations of aerosol properties and radiation fluxes have revealed that absorbing anthropogenic aerosols lead to a large reduction in surface solar radiation; and a correspondingly large addition of solar energy to the atmosphere. These changes are factors of 3 (clear skies) to 5 (cloudy skies) or more larger than the change in the radiation fluxes at the top-of-the atmosphere or at the tropopause. The implication is that the Top-of-Atmosphere (TOA) forcing or the tropopause forcing used in IPCC and most global model studies is only a partial or an incomplete indication of the aerosol effects on climate. The TOA forcing used in IPCC is the forcing of the surface-atmosphere system. For the absorbing aerosols, it is necessary to deal also with the forcing at the surface and the forcing within the atmosphere because: The large reduction in surface solar radiation can lead to a net drying of the planet because of the close balance between absorption of solar radiation at the surface and evaporation; and the surface cooling and atmospheric warming can also alter the convective coupling of the oceans and atmosphere and impact regional climate in ways that are difficult to anticipate.

These findings were made from observations during field campaigns in south Asia (INDOEX); East Asia (ACE-ASIA); and the Amazon (LBA); AERONET surface observatories in France, North Africa and Amazon.

For a summary on INDOEX data and discussion of its implication, see:
Ramanathan, V., P.J. Crutzen, J.T. Kiehl and D. Rosenfeld, 2001. Aerosols, Climate and the Hydrological Cycle, Science, Vol 294, 2119-2124.

For findings from surface observatories, see:
Kaufman et al (Journal of Atmospheric Science, 59, 635-646, 2002) ACE-ASIA (Team meeting, Pasadena, Fall, 2001)

Reduction in precipitation efficiency in polluted continental and marine clouds:

Satellite radar and visible data onboard TRMM were used to demonstrate that anthropogenic aerosols was suppressing rain over polluted regions, because of microphysical alteration of the size of cloud drops. Aerosols containing large concentrations of small CCN nucleate many small cloud droplets, which coalesce very inefficiently into raindrops and thus inhibit precipitation. This behavior was shown for polluted clouds in Australia, Asia, Amazon and Israel.

Rosenfeld, Rudich and Lahav, Proc Natl Acad Sci., 98, 5975 ,2001.

Related in situ observations also support this effect for stratus clouds, by observing considerably more drizzle in the maritime clouds than in similar continental ones.

Yum SS, Hudson JG, Maritime/continental microphysical contrasts in stratus, Tellus B, 54: 61-73, 2002

Indirect Effect in the Upper Troposphere: Aerosol processes involving ice clouds in the upper troposphere point out possible new impacts of anthropogenic aerosols on climate by controlling the water vapor in the upper troposphere and tropopause region, e.g.,

Lohmann U., Possible aerosol effects on ice clouds via contact nucleation, J. Atmos. Sci., 59: 647-656, 2002.

Sherwood S , A microphysical connection among biomass burning, cumulus clouds, and stratospheric moisture, Science 295: 1272-1275, 2002.

III. Underpinnings

The use of satellite observations or extensive ground networks in providing a global view of aerosols has grown rapidly during and since the TAR. Some illustrative works are deescribed in

Holben BN, et al., An emerging ground-based aerosol climatology: Aerosol optical depth from AERONET, J. Geophys. Res., 106 (D11): 12067-12097, 2001.

Torres O, Bhartia PK, Herman JR, Sinyuk A, Ginoux, P, Holben B, A long-term record of aerosol optical depth from TOMS observations and comparison to AERONET measurements, JAS, 59: 398-413, 2002

Diner DJ, et al., MISR aerosol optical depth retrievals over southern Africa during the SAFARI-2000 dry season campaign, Geophys. Res. Lett., 28: 3127-3130, 2001.

Zhao TXP, Stowe LL, Smirnov A, Crosby D, Sapper J, McClain CR, Development of a global validation package for satellite oceanic aerosol optical thickness retrieval based on AERONET observations and its application to NOAA/NESDIS operational aerosol retrievals, JAS, 59: 294-312, 2002

The importance of black carbon (soot) as a major element in the radiative forcing by aerosols continues with new studies both theoretical and observational:

Jacobson, MZ, Strong radiative heating due to the mixing state of black carbon in atmospheric aerosols, Nature, 409: 695-697, 2001.

Novakov, T., M.O. Andreae, R. Gabriel, T.W. Kirchstetter, O.L. Mayol-Bracero, and V. Ramanathan, 2000: Origin of Carbonaceous Aerosols over the Tropical Indian Ocean: Biomass Burning or Fossil Fuels? *J. Geophy. Res. Lett*., 27, 4061-4064.

See the Ramanathan et al (Science) paper above for listing of INDOEX papers on black carbon forcing.

Emission studies continue to develop, particularly for black carbon, and provide the basis for interpreting field data and making projections, e.g.,

Streets DG, Gupta S, Waldhoff ST, Wang MQ, Bond TC, Bo YY, Black carbon emissions in China, Atmos. Env., 35: 4281-4296, 2001.

Aircraft and ground-based field campaigns continue to build up our understanding of process that transform and process aerosols over scales of thousands of km. Recent studies have demonstrated that in addition to dust aerosols, biomass burning and pollution aerosols once lofted into the free troposphere can transport across much of the globe.

Browell EV, et al., Large-scale air mass characteristics observed over the remote tropical Pacific Ocean during March-April 1999: Results from PEM-Tropics B field experiment, J. Geophys. Res., 106 (D23): 32481-32501, 2001.