FORM A: GACP ACCOMPLISHMENT REPORT

Name: Joyce E. Penner

Institution: University of Michigan

TITLE: Defining a Climatology and the Effects of Absorbing Aerosols:
Models and Measurements

ABSTRACT: It is crucial to quantify the amount of absorbing aerosol present in the atmosphere because it may lower the single scatter albedo of otherwise mainly scattering aerosol. These absorbing aerosols consist primarily of dust, smoke from biomass burning, and carbonaceous aerosol associated with fossil fuel burning. These aerosols also may act as cloud condensation nuclei, thereby increasing reflection of solar radiation by clouds. In order to estimate the indirect effect, the quantification of the fraction of absorbing, carbonaceous aerosol relative to natural organic aerosol is needed. In this proposal we plan to use our global aerosol model in combination with meteorological fields that have been nudged towards observed or analyzed fields to enable us to compare predicted absorbing aerosols with observed aerosols as derived from the TOMS instrument (Herman et al., 1997). The TOMS instrument is only able to record absorbing aerosol above about 2 km. We intend to use the model/data comparison to improve estimates for the source strengths of aerosol, fill in the gap in data below 2 km, and to improve the aerosol model itself. Other sources of data (i.e. ground-based and aircraft) will also be used to evaluate the model. The technique developed for determining this absorbing aerosol climatology will be applied to develop sources for the entire record of the TOMS data. Furthermore, we will carry out studies with a coupled aerosol/climate model in order to understand whether and to what extent absorbing aerosols warm the atmosphere.

GOALS: The goal of this research project is to quantify the direct and indirect forcing by anthropogenic aerosols, particularly those from biomass burning, and to understand their climate impact. We will also summarize recent literature to understand work related to the radiative effects of aerosols and evaluate model capability to assess the climate forcing by anthropogenic aerosols.

OBJECTIVES: One of the largest sources of uncertainty in estimates of the climate impact of biomass aerosols is the magnitude of the total source strength of aerosols from biomass burning. Our present ability to test the model's representation of biomass aerosols and their source strength is unsatisfactory. In Liousse et al. (1996) we found reasonable agreement between our predicted aerosol concentrations and measurement of absorbing aerosols at Amsterdam Island, but our concentrations at the South Pole were underestimated for the time period October - February. Tegen et al. (1997) showed that the optical depths from our smoke aerosols were considerably smaller than those measured locally at several sites in South America (possibly due to an overestimate of the grid-averaged optical depth by a localized measurement); but the model-predicted optical depths were higher than measured off the Western South Atlantic. Another example of

the uncertainty in biomass-burning source strengths derives from the comparison of model-predicted CO concentrations and measurements. Saylor and Easter (1996) compared model-predicted CO (which is primarily from biomass burning in Africa and South America) with data from the MAPS instrument and found that their inventory for burning may be substantially under predicted.

Quantifying the radiative forcing by anthropogenic aerosols is one of the most important tasks in the assessment of climate change since this radiative forcing is one of the most uncertain factors affecting climate. The NASA Aerosol Climatology Project has the potential to significantly increase our understanding of the effects of aerosols on climate over the historical past by defining a climatology of aerosols through model/satellite intercomparison and through comparison of a variety of historical data sets. One purpose of our project is to help coordinate the activities of the NASA Aerosol Program science team members and to act as Coordinating Lead Author for Chapter 5 of the forthcoming IPCC Third Assessment Report.

APPROACH: Satellite-derived aerosol optical depths are available from the AVHRR instrument on the NOAA satellites (Nagaraja Rao et al., 1988). However, this data does not distinguish absorbing aerosols from non-absorbing aerosols. Further, it is only available over ocean surfaces. Herman et al. (1997) derive an absorbing aerosol index using a technique which is able to distinguish absorbing aerosol from non-absorbing aerosol and cloud. They define the difference

$$\Delta N_l = -100\left\{\log_{10}(I_{340}/I_{380})_{meas} - \log_{10}(I_{340}/I_{380})_{calc}\right\}$$

where $(I_{340}/I_{380})_{meas}$ is the ratio of the measured irradiances at 340 and 380 nm and $(I_{340}/I_{380})_{calc}$ is a model calculated ratio of irradiances. Because of the separate wavelength dependence of absorbing aerosols compared to scattering aerosols, $\Delta N_l > 0$ when absorbing aerosols are present and $\Delta N_l < 0$ when mainly scattering aerosols and clouds are present. This dual capability of detecting clouds and absorbing aerosols at the same time, gives us a unique ability to test a model-predicted climatology of absorbing aerosol.

The comparison of predicted absorbing aerosol with the presence of measured absorbing aerosol for specific days in regions where cloud does not occur is a measure of the accuracy of the sources of absorbing aerosol at the surface, assuming the transport and removal of aerosols between the location of burning and detection by TOMS is sufficiently accurate. The TOMS data from the Nimbus 7 satellite extend from November 1978 to May 1993 and similar data are available again beginning July 1996. TOMS data from the non-Sun-synchronous Russian Meteor 3 satellite are available from August 1991 to December 1994, but because the quality of the data is only good when its orbit is close to the near-noon orbit of the Nimbus 7 satellite, there are periods of time for which no model/satellite comparisons are possible. Thus, the use of these data for developing an understanding of biomass burning sources would be less than optimum. We intend to begin our study and the design of our method for improving aerosol sources for biomass and dust using model-generated aerosol concentration fields which use the Hamburg-

model nudged meteorological fields. These fields are presently available for 1993. We will examine the time period January to May 1993 to find instances when absorbing aerosol is available. Data on fire occurrence is also available for this time period and will be used to refine our source estimates.

TASKS COMPLETED: We have developed estimates of the temperature change expected from including biomass and fossil fuel black carbon in a climate model. We are proceeding to analyze these results to understand whether the inclusion of black carbon in the model can significantly alter cloud cover and/or the vertical temperature structure in the atmosphere. In particular, we have compared the model-predicted temperature difference anomalies for the surface and mid-troposphere and the column black carbon concentration. Absorption by black carbon appears to significantly alter the vertical structure of temperature. The change in vertical structure appears to depend on the vertical structure of the distribution of aerosol. Thus, biomass aerosols, injected into the model near 500 mb tend to cool the surface while warming the mid troposphere, and fossil fuel black carbon, injected into the model boundary layer, tends to warm the surface relative to the mid troposphere. We hope to use these results to examine further the appropriate vertical distribution of absorbing aerosol. This should aid us in interpreting the TOMs data which are sensitive to the vertical structure of absorbing aerosols.

We also conducted a model intercomparison exercise where, for the first time, models for dust, sea salt, organic carbon and black carbon as well as for sulfate, were compared. We are continuing to analyze the results of this intercomparison and hope to report on it at the next NASA Aerosol Program meeting.

FUTURE PLANS: We expect to complete our model intercomparison exercise and a draft chapter on aerosols for the IPCC Third Assessment Report. In addition, we will continue our analysis of the effects of absorbing aerosol on vertical temperature structure. Furthermore, we will continue our work to refine the estimates of the total biomass burning source which are based on satellite estimates of burned area. Our work to compare model-predicted biomass aerosol with measurements by the TOMs satellite have only just begun since we only recently obtained access to the TOMs level 2 data. However, with this data in hand, we expect to proceed with a detailed comparison of model-predicted and measured biomass aerosols.

RESULTS: We have developed estimates of the change in vertical temperature structure associated with black carbon aerosols. These results show that the vertical temperature structure is quite sensitive to the vertical structure of the aerosol distribution. We are proceeding with a similar analysis for dust aerosols and plan to compare our model predictions with observations.

FORM C: FUTURE PLANS

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The Hamburg modeling group developed a version of their model in which a four-dimensional assimilation technique is used to relax the meteorological fields of vorticity, divergence, temperature, and surface pressure towards the European Center for Medium-Range Weather Forecasts (ECMWF) global meteorological analyses (Jeuken et al., 1996). This makes available meteorological fields that are close to observed fields for a given time period together with precipitation rates at each model grid and level. The global meteorological analysis fields could also be used to develop meteorological fields for a given time period, but precipitation is not available from these fields (except at the surface). Thus, some means of developing a description of the vertical structure of precipitation is needed in order to use such fields with a chemical transport model.

We intend to begin our study and the design of our method for improving aerosol sources for biomass and dust using model-generated aerosol concentration fields which use the Hamburg-model nudged meteorological fields. These fields are presently available for 1993. We will examine the time period January to May 1993 to find

instances when absorbing aerosol is available. Data on fire occurrence is also available for this time period and we are using these data to help refine our estimates of biomass smoke sources.

The NCAR modeling group have developed a version of their model that uses the ECMWF analyzed fields or the NCEP analyzed fields to develop estimates of the vertical moisture fields. Thus, these meteorological fields could also potentially help in describing aerosol concentrations for a particular time period. We expect to obtain meteorological fields from the NCAR model to also test our biomass source inventory against the TOMs measurements.

FORM D: GACP BIBLIOGRAPHY

Name:

Institution:

BIBLIOGRAPHY:

Papers, reports, and presentations refer to those published during GACP by the principal investigator, co-investigators, and other researchers supported by your agency for aerosol research. Include those in progress or planned.

a. List of publications (including books, book chapters, and refereed papers), using AMS bibliographic citation form.

Grant, K.E., C.C. Chuang, A.S. Grossman, and J.E. Penner, Modeling the spectral optical properties of ammonium sulfate and biomass burning aerosols; Parameterization of relative humidity effects and model results, 1999: *Atmos. Env.*, 33, 2603-2620.

Penner, J.E., Aerosols, 1998: invited article for the Encyclopedia of Global Change, Ed. A.S. Goudie, Oxford University Press, New York.

Lohmann, U., J. Feichter, C.C. Chuang, and J.E. Penner, 1999: Prediction of the number of cloud droplets in the ECHAM GCM, *J. Geophys. Res.*, 104, 9169-9198.

Lohmann, U., J. Feichter, C.C. Chuang, and J.E. Penner, 1999: Erratum, *J. Geophys. Res.*, in press, 1999.

Lohmann, U., J. Feichter, J.E. Penner, and R. Leaitch, 1999: Indirect effect of sulfate and carbonaceous aerosols: A mechanistic treatment, submitted to J. Geophys. Res.

Penner, J.E., Chuang, C.C., and K. Grant, 1999: Climate Change and Radiative Forcing by Anthropogenic Aerosols: Research Findings During the Last 5 Years, La Jolla International School of Science, submitted, The Institute for Advanced Physics Studies, La Jolla, CA 92038-2946, March 29-30, 1999.

Penner, J.E. Encyclopedia article, Aerosols, effect on the climate, in preparation, 1999.

Schlesinger, M.E. S. Malyshev, E.V. Rozanov, F. Yang, N.G. Andronova, B. de Vries, K. Jiang, T. Masui, T. Morita, N. Nakicenovic, J.E. Penner, W. Pepper, A. Sankovski, and Y. Zhang, 1999: Geographic distributions of temperature change for the SRES scenarios of greenhouse gas and sulfur dioxide emissions, submitted to Special Issue of *Technological Forecasting and Social Change* May, 1999.

b. List of printed technical reports and non-refereed papers.

Penner, J.E., 1999: Climate change and radiative forcing by anthropogenic aerosols: A summary of current understanding, 10th Conference on Atmospheric Radiation, 28 June—2 July 1999, Madison, WI, 507-509.

c. List of oral presentations or posters at professional society meetings and conferences.

Climate Change and Radiative Forcing by Anthropogenic Aerosols: A Summary of Current Understanding: PAOS/NOAA-CDC/CIRES Distinguished Lecturer Series, December 4, 1998, University of Colorado, Boulder.

Climate Change and Radiative Forcing by Anthropogenic Aerosols: Research Findings During the Last 5 Years, La Jolla International School of Science, The Institute for Advanced Physics Studies, La Jolla, CA 92038-2946, March 29-30,1999.

Climate Change and Radiative Forcing by Anthropogenic Aerosols: A Summary of Current Understanding, AMS 10th Conference on Atmospheric Radiation, Madison, Wisconsin, June 28 - July 2, 1999.

Climate Change and Radiative Forcing by Anthropogenic Aerosols: A Summary of Current Understanding, International Union of Geodosy and Geophysics, University of Birmingham, Birmingham, United Kingdom, July 19 - 30, 1999.
