FORM A
GACP ACCOMPLISHMENT REPORT

Name: Anthony D. Del Genio

Address: NASA GISS, 2880 Broadway, New York, NY 10025

TITLE: An Investigation of the Indirect Effect of Aerosols on Climate: Coupled Chemistry-Climate Modeling and Satellite Validation

GOALS: We will attempt to constrain the indirect effects of aerosols on clouds and climate through a combined modeling and satellite data analysis approach.

OBJECTIVES: A sulfur chemistry model, and eventually interactive source/transport models for other aerosol types, will be coupled to the GISS GCM and the indirect effects (both radiative and microphysical) of anthropogenic aerosols calculated. Available aerosol and cloud in situ and satellite data sets will be analyzed to detect signatures of the indirect effect and used to validate the coupled model. Sensitivity of the model-data agreement to aspects of the cloud parameterization that influence cloud liquid water path and lifetime, and to assumptions linking aerosol chemical and cloud microphysical properties, will be used to estimate the uncertainty in the calculated indirect effects.

APPROACH: We will combine those data sets that measure cloud droplet number concentration directly, rather than inferring it from measured CCN concentrations and supersaturation assumptions, to develop an optimum sulfate-droplet number relationship for the coupled model. We will alter the GISS autoconversion parameterization to admit variable number concentration, test the sensitivity of the microphysical indirect effect to different autoconversion parameterizations, and develop a parameterization suitable for the GCM grid scale to constrain the microphysical effect. We will determine the correlation between sulfate and cloud optical thickness variations in several locations to assess the relative roles of indirect effects, in-cloud production, and wet deposition processes. We will compare model-predicted effective radius, column number concentration, and droplet size - cloud optical thickness correlations to ISCCP estimates. We will analyze aerosol optical thickness climatologies for evidence of regional anthropogenic trends and look for evidence of cloud property changes over the same time period.

TASKS COMPLETED: Cloud droplet number-sulfate regressions have been derived from data sets at three land (Figure 1a) and three ocean (Figure 1b) locations and used to couple the sulfur chemistry model of Koch et al. to the GISS GCM. The autoconversion parameterization in the GCM has been replaced with two number-concentration-dependent parameterizations derived from cloud-scale models. Three-year sulfate direct and indirect effect simulations have been conducted with the coupled model for three different autoconversion parameterizations. Droplet size-optical thickness correlations have been analyzed for different autoconversion assumptions and for clouds at different altitudes. Cloud optical thickness-sulfate correlations have been computed for the model and compared to observed correlations from EMEP and ISCCP. A preliminary version of a complete aerosol model (including sulfate, sea salt, black carbon and organic carbon aerosols) has been used to simulate future aerosol distributions and radiative forcing in an IPCC model intercomparison exercise. NOAA/AVHRR aerosol optical thickness trends over the ocean east of China during the 1980's have been documented and compared to emission trend estimates for China.

RESULTS: The simulated indirect effect (calculated as the cloud forcing difference between three-year runs with anthropogenic and natural sulfur sources) for the GISS coupled model is -1.1, -3.6, and -2.6 W/m^2 for simulations including only the radiative indirect effect, the radiation and microphysics effects using the Beheng autoconversion parameterization, and the radiation and microphysics effects using the Berry autoconversion parameterization, respectively. Comparison of the latter two runs to the first indicates the potential importance of and uncertainty in the microphysical (cloud lifetime and liquid water) component of the indirect effect. In all runs the indirect effect is largest over continental areas near anthropogenic source regions (Figure 2), consistent with the low natural sulfate burden over these regions. The direct forcing in all runs, calculated via offline calls to the radiation subroutine, is -0.7 W/m^2. For the runs that simulate the microphysical indirect effect, cloud liquid water path and cloud cover increase by 13 g/m^2 and 0.9% (Beheng autoconversion) and by 4 g/m^2 and 0.5% (Berry autoconversion), similar to results from several other GCMs. The model generally reproduces the observed switch from positive (for $t<15$) to negative (for $t>15$) r_e-albedo correlations, but only for clouds with tops below the 850 mb level (model levels 1,2); clouds with tops between 700-850 mb (model level 3) exhibit the opposite behavior (Figure 3). Cloud and sulfate optical thicknesses tend to be positively correlated in polluted continental regions but negatively correlated over midlatitude storm tracks when sulfate does not affect cloud properties; when sulfate affects droplet number, the correlation generally increases. The model fails to reproduce the strong negative correlations (at timescales of 7-60 days) between clouds and sulfate that are often observed over polluted regions. AVHRR aerosol optical thicknesses just off the east coast of China show an upward trend from 1984-1990 that is consistent with the magnitude of estimated sulfur emission trends, but only in the autumn season when obscuration by dust aerosols is perhaps least important.

FUTURE PLANS: In the coming year we will add carbonaceous and sea salt aerosols to the coupled model; we will recompute the current vs. pre-industrial indirect effect and will simulate the change in indirect effect from 1950 to the present using estimated emission trends over that time period. We will develop an autoconversion parameterization suitable for the GCM grid scale by combining cloud-scale parameterizations with observed frequency histograms of small-scale liquid water path variability, and use the result to produce a best estimate of the microphysical contribution to the indirect effect. We will also explore ways of incorporating physical processes that introduce variability into the droplet number - sulfate relationship into the model. We hope to examine the vertical variation of the observed r_e-albedo correlation as a possible diagnostic of the fidelity of both the model's cloud occurrence and sulfate vertical distributions. Finally, we will search the ISCCP low cloud climatology for trends in optical thickness over the 1980's in Asia and adjacent ocean regions.

FORM B
GACP SIGNIFICANT HIGHLIGHTS

See the description of project results and Figures 1, 2, 3 above.

FORM C
GACP BIBLIOGRAPHY

A. Papers in refereed journals and books

Koch, D., D. Jacob, I. Tegen, D. Rind and M. Chin, 1999: Tropospheric sulfur simulation and sulfate direct radiative forcing in the GISS GCM. J. Geophys. Res., in press.

C. Oral presentations and posters

Koch, D.M., J.J. Park and A.D. Del Genio, 1999: Global patterns of correlation between clouds and sulfate. AGU Spring Meeting, 1999.

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Del Genio, A.D., 1999: Presentation to Mr. Daniel Goldin on indirect effect simulation and satellite validation at GISS briefing, July 1999.