Progress Report to NASA for

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Quantifying The Indirect Radiative Forcing of Sulfate Aerosols By a Hybrid Technique

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Form A: GACP Accomplishment Report

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Title: Quantifying The Indirect Radiative Forcing of Sulfate Aerosols By a Hybrid Technique

Abstract: Proposal is made for a three-year study to elicit the degree to which there is large-scale modification of the radiative properties of low-level marine clouds by the presence of sulfate aerosol. Unlike previous studies, such as with ship tracks, the scope of this study is not local but regional and, in principle, global. The analysis will use AVHRR multi-channel radiances to obtain a quantitative measure of effective cloud drop radius and visible optical depth in areas inside and outside the influence of sulfate aerosols. Fields of contemporaneous column sulfate will be obtained from an observed-meteorology driven global chemical model.

The chief advantage of this study is its potentially global coverage. The output of the sulfate model has been compared with *in-situ* measurements over land and further comparisons over oceanic areas are underway. The column sulfate fields will act as surrogates for large-scale *in-situ* observations which are expensive to conduct. An understanding of the conditions under which there is an indirect radiative forcing by sulfate aerosols and an estimate of this effect addresses one of the major objectives of the NRA. In addition, this will be accomplished using a strategy combining satellite data with a global model and will involve investigators with expertise in radiative transfer and tropospheric chemistry.

Goals: The long term research goal of our group is to quantify the radiative forcing of the climate system by clouds and aerosols.

Objectives: Our objective is to quantify the indirect radiative forcing of anthropogenic aerosols. There is the potential for these aerosols to alter cloud microphysics but the uncertainty of this forcing is extremely large based on current knowledge which is based on a limited number of intensive studies. We plan to scale up to global coverage through the use of satellite data.

Approach: The theory underlying the remote sensing of cloud microphysical properties is well established now. We hope to merge cloud microphysical retrievals with knowledge of aerosol distribution over the oceans. Ideally, one would hope for a purely remote sensing endeavor where aerosol information was also obtained from satellite data. However, since the presence of clouds prevents the retrieval of aerosol information, it is not possible to get simultaneous information, except at the edges of cloud fields.

In order to avoid the above problem, we are using a meteorology driven atmospheric chemistry model that simulates sulfate concentrations over the North Atlantic at 6-hour intervals. The relationship between simulated sulfate and retrieved cloud microphysics will quantify the extent of the indirect radiative forcing.

We are using the model described in Benkovitz and Schwartz (JGR, v. 102, p. 25,305-25,338, 1997) and Benkovitz et al. (JGR, v. 99, p. 20,750-20,756, 1994). The model is driven by observation-derived synoptic data obtained from the European Centre for Medium-Range Weather Forecasts (ECMWF), specifically the 6-hour "first guess" data. The horizontal coordinates used are latitude and longitude with 1.125º resolution; the vertical coordinate is the ECMWF eta (η) coordinate, a hybrid system of pressure and terrain-following sigma coordinates, with 15 levels between the surface to 100 mb.

The chemistry portion of the model represents emissions of anthropogenic sulfur dioxide (SO_2) and sulfate and biogenic sulfur species, horizontal and vertical transport, gas-phase oxidation of SO_2 and dimethylsulfide (DMS), aqueous-phase oxidation of SO_2 by hydrogen peroxide (H_2O_2) and ozone (O_3) in precipitating clouds, and wet and dry deposition of SO_2, sulfate, and methanesulfonic acid (MSA).

The cloud microphysical retrieval follows the method of Nakajima and Nakajima (JAS, v. 52, p. 4043-4058, 1995) using AVHRR GAC data over the North Atlantic. We are currently using NOAA-10 data for four months in 1986 and 1987 for which the chemistry model has been run. The retrieval process obtains optical depth and effective radius for 4 km cloudy pixels that pass some screening tests. To avoid ice particles, only pixels with an emission temperature greater than 273K are considered. The retrieval process requires an estimate of the vertical location and geometric extent of the cloud. This is obtained by using the cloud top temperature retrieved from the IR window channel radiance (Ch 4, 11 μm) and the sea surface temperature from the ECMWF archive. Retrievals are only made over the open ocean. This is not a limitation because the indirect radiative forcing is significant only in these regions.

Tasks Completed:

i. acquisition of AVHRR GAC data for the periods March/April 1987.

ii. sulfate column burden simulations for the same time period over the North Atlantic.

iii. retrieval and classification of cloud microphysical quantities for a few selected days and analysis with respect to sulfate column amount.

iv. all programs have been checked and we are in a position to make production runs for other time periods and regions.

Future Plans:

i. acquire three other month-long time periods in 1986-87.

ii. obtain sulfate column amount for the time periods.

iii. analyze the entire data set, stratified by time of year and cloud thickness.

iv. seek corroborative aerosol information from the Pathfinder Project daily aerosol product.

v. relate change in cloud microphysics to a quantitative measure of radiative cloud forcing.

Results: An example of the kind of information that has been obtained to date is shown in the attached figure. Sulfate column amount in $\log_{10}$ (μmoles/m^2) is plotted in Figure 1 over the North Atlantic regions at 1800 UTC on April 21, 1987. Superimposed are three AVHRR images from the NOAA-10 overpass corresponding to the ascending node covering the time period from 1616 UTC (bottom of right image) to 1952 UTC (top of left image) on the same day. The images are shown over the ocean only and for scan angles less than 15° from nadir. Also on the figure are shown the retrieved cloud drop effective radii for cloud tops warmer than 273 K. The analysis further requires a stratification of cloud properties by thickness. Our ultimate goal is to compare gross features of cloud microphysics in the regions under the influence of large sulfate column burdens with those in the cleaner areas as identified by the simulations of the chemistry model.

FORM C: Future Plans

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During the coming year, we plan to accomplish the following:

(i) compare the sulfate column amount from the model simulation with NOAA/NESDIS Pathfinder daily aerosol product (PATMOSA).

(ii) choose days in the four-month period that satisfy the following criteria.

(a) qualitative correspondence between model fields and aerosol optical depth from PATMOSA.
(b) presence of cloudy pixels with brightness temperature greater than 273K.
(c) significant difference in sulfate column amount across regions for which AVHRR retrievals can be obtained.

(iii) the optical depth and effective radius (hence LWP) will be analyzed with respect to the sulfate column amount.

(iv) if model simulations for other time periods become available, then AVHRR data will be acquired and the analysis expanded. Additional model simulations were not part of the original proposal and are being supported by other funding sources.

FORM D: GACP Bibliography

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The following presentation was made by graduate student Jill Zenner at the 1999 Spring AGU Meeting held in Boston, MA, on Tuesday, June 1, 1999.

“Investigation of the aerosol indirect radiative effect using satellite data and analyzed wind fields” by J.M. Zenner, Harshvardhan and Robert Green.

Jill Zenner successfully defended her M.S. thesis on the same subject on July 12, 1999.