Form A: GACP Accomplishment Report

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Title: Estimate the Indirect Aerosol Effect and Retrieval of Related Parameters from Satellite Measurement

Abstract:

Aerosol effects on climate change have drawn increased attention in recent years due to the significant uncertainty of the magnitude of its climate forcing and the possible role in feedback mechanisms. Aside from a direct radiative forcing by aerosol changes, there might also be indirect effects because cloud changes are also induced. Due to the lack of observational data, the range of indirect aerosol effect has been remained large and uncertain. In order to narrow the uncertainty in evaluating the indirect aerosol effect, combined efforts from models, field measurements and satellite observations are necessary. In particular, satellite observations can be used to monitor large-scale, long-term variations of aerosols and cloud properties, to suggest specific regions for field campaigns, and to supply parameterization basis and tests for climate models.

Based on the techniques developed in our previous study and using the currently available multi-channel AVHRR and GOES radiance, this proposal focuses on the following scientific questions:

1) How does cloud droplet size changes with aerosol optical thickness? The relation may vary with region because it changes for different sources of aerosols (sulfate, dust, and biomass burning). We can try to observe such relations from satellites and investigate specific cases with field campaigns.

2) What is the relation between cloud albedo and droplet size? Modelers need a quantitative description of this relationship in order to evaluate the indirect aerosol effect.

3) What parameters can satellite observations supply for model studies of the indirect aerosol effect? Limited by the principles of remote sensing and the instrument used, satellite observations have difficulties in providing all desired quantities (such as volume liquid water content and cloud geometrical thickness).

4) What regions appear more susceptible to the indirect aerosol effect? General agreement is that remote ocean areas are more susceptible to the indirect effect. A quantitative estimate will be helpful in determining the place to conduct field experiments.

5) How much is the climate forcing by the indirect aerosol effect? Due to the fact that there is no simultaneous satellite observations for aerosol and cloud properties at the same location, this forcing can only be estimated using an area mean approach. Such an evaluation can supply a lower limit and narrow the range of the uncertainty of its climate impact. We can also try to use models to estimate this effect.

To address the above questions, we plan to analyze twelve years of dataset that relates changes of cloud properties to changes of aerosol abundance and to estimate the indirect aerosol forcing using two different approaches: statistical and trajectory methods. Each method has its own advantages. The results of our analysis will be used in the GISS GCM as a basis for parameterization and validation.

The results of this analysis will be documented and prepared for archival at the NASA Langley DAAC for use by the "aerosol team" and other researchers. The data products will provide the combination of aerosol, cloud and meteorological information used to relate systematic changes of aerosols and clouds.

Goals:

1. One of the important parameters in the research of the aerosol indirect effect is the cloud column susceptibility, which links the change of cloud spherical albedo to the change of column droplet number concentration. Based on the technique of retrieving column droplet number concentration, we plan to develop scheme for the retrieval cloud column susceptibility on a near-global scale.
2. Process twelve years of cloud property data that include optical thickness, column number concentration of water clouds, and column susceptibility. These are properties related to aerosol-cloud interactions.
3. Analyze cloud and aerosol property data to quantitatively relate changes of cloud properties to changes of aerosol abundance. The aerosol property data will be obtained from the products of the science team. This will lead to the estimate of the indirect aerosol forcing.

Objectives:

This investigation is focused upon the following scientific questions:

1) How does cloud droplet size change with aerosol optical thickness? The relation may vary with regions because it changes for different sources of aerosols (sulfate, dust, biomass burning).

2) What is the relation between cloud albedo and droplet size? Modelers need a quantitative description of this relationship in order to evaluate the indirect aerosol effect.

3) What parameters can satellite observations supply for model studies of the indirect aerosol effect? Limited by the principles of remote sensing and the instrument used, satellite observations have difficulties in providing all quantities (such as volume liquid water content and cloud geometrical thickness) that required in current models.

4) What regions are more susceptible to the indirect aerosol effect? General agreement is that remote ocean areas are more susceptible to the indirect effect. A quantitative estimate will be helpful in determining the place to conduct field experiments.

5) How much is the climate forcing by the indirect aerosol effect? Due to the fact that there is no simultaneous satellite observations for aerosol and cloud properties at the same location, this

forcing can only be estimated using an area mean approach. An evaluation can supply a lower limit and narrow the range of the uncertainty of its climate impact.

Approach:

To address the above questions, we plan to perform the following investigations:

1) Retrievals of parameters related to the indirect aerosol effect.

Based on the technology developed in the previous work, we plan to build a cloud property dataset covering 12 years (July 1983 - June 1995) that includes cloud droplet radius, cloud column number concentration, cloud column susceptibility and optical thickness for low-level clouds. These parameters are necessary in narrowing the uncertainty in the estimation of the indirect aerosol effect. The results will be used as input to the GISS GCM to improve the estimate of the indirect aerosol effect by the collaborates of this proposal (Drs. Del Genio and Tselioudes). Working closely with modelers, we can improve the dataset by including other parameters that are necessary for model studies.

2) Retrieval of aerosol distribution

NOAA/NESDIS has been producing aerosol optical thickness product over oceans using AVHRR data (Husar et al. 1997). Weekly or monthly mean fields of aerosol product (presented as 1°x1° grid boxes) can be ordered from NOAA NCDC in Asheville, NC. Starting from March 1995, phase 2 algorithm is used to retrieve aerosol optical thicknesses (Stowe et al., 1997) because the product of phase 1 algorithm underestimates aerosol optical thicknesses (by a factor of 1.5). Other investigators are planning to build new aerosol climatologies based on one channel or two channels method (Nakajima and Higurashi, 1997, 1998).

We will take full advantage of the currently available or future aerosol climatology. However, our study needs results from land areas and from GOES satellite for trajectory approaches (see below) to estimate the indirect aerosol forcing. Based on our previous experience, it is not difficult for us to construct an aerosol distribution dataset covering 12 years (July 1983 - June 1995). For validation, we plan to compare our results with the phase 1 and 2 results from NOAA/NESDIS over ocean areas. This dataset will be on the near-global scale (50°S to 50°N); retrievals in polar regions will be investigated but may not be successful. An assessment of the relative contribution of anthropogenic and natural tropospheric aerosols will be attempted by comparing regional differences of aerosol distributions over ocean areas known to be affected by airmasses from industrial countries (e.g. Atlantic Ocean along North America; Northwest Pacific Ocean along east Asia); by natural sources (mid-Pacific Ocean); by dust storms (areas close to the Sahara desert); and by biomass burning (areas close to the Amazon region and central Africa).

3) Estimation of the indirect aerosol effect on climate

Given the complex relation of aerosol optical thickness and cloud properties and that cloud property variations will depend on other factors, the calculation of the indirect aerosol forcing cannot be straightforward. From the perspective of observation, we plan to use two different methods to estimate the indirect aerosol effect. The first method is the statistical method, which uses zonal mean (e.g., every 1° latitude) values of aerosol optical thickness and fluxes over cloud fields. For each climate zone (e.g., every 10° latitude), choose the 1° zone with the smallest aerosol optical thickness as pristine zone. Then taking differences between fluxes over clouds of other zones and this pristine zone to obtain flux change. This method may underestimate the indirect aerosol effect because the values from pristine zones may includes some effect of pollution. Therefore, the result can be used as a lower limit of the indirect aerosol effect.

The other is the trajectory method, which includes two approaches: fixing location approach and fixing cloud approach.

The fixing location approach will attempt to identify an indirect effect of aerosols on clouds by examining meteorological information (e.g., ECMWF or NCEP reanalysis) at certain location to separate the satellite-based aerosol and cloud observations by wind direction. The idea is to determine, first, whether the aerosol concentration at each location is a systematic function of wind direction, suggesting that the location is either upwind or downwind from an aerosol source region. For such locations, we then examine the cloud properties separated by wind direction to see whether there is any systematic difference. To determine whether changing meteorology plays any role, we will also compare the humidity and temperature differences with wind direction. This approach cannot demonstrate an aerosol effect unambiguously, but it can help select locations for more detailed in situ experiments.

The fixing cloud approach will follow specific cloud cluster to monitor its property change (droplet size, optical thickness, column number concentration, susceptibility) before and after passing a high aerosol concentration region. We need to monitor flux changes for specific cloud parcels. To isolate the effect of aerosol, other dynamical parameters such as wind direction, moisture convergence, vertical velocity have to be obtained from observations. This method has the advantage of the well defined aerosol source and can be used to compare effect from different aerosol sources but requires large amount of observations to estimate mean and standard deviations for certain regions.

Tasks completed during the first year:

The retrieval scheme of cloud column susceptibility has been completed. Two different versions of survey on cloud column susceptibilities (based on and not based on the assumption of constant water content) have been performed. One journal paper is written based on the results and ready to submit.

Future Plans:

1) Retrieval of cloud column susceptibility, column number concentration and aerosol optical thickness using one year (possibly two years) of AVHRR LAC data.

2) Processing twelve years of cloud property data including cloud column number concentration and cloud column susceptibility based on ISCCP data.

3) Analyzing the datasets of cloud and aerosol properties and estimate the indirect aerosol effect on cloud properties.

Results:

Developed the scheme for retrieval of cloud column susceptibility The results have been written into a paper draft "Han, Q., W. B. Rossow, J. Chou, and R. M. Welch, 1999: Near-global survey of column cloud susceptibility of water clouds using ISCCP data". The following is the abstract of this paper.

Abstract This study presents observed results of enhanced cloud droplet concentration on water cloud albedo on a near-global scale using ISCCP data. A new parameter, cloud column susceptibility, is introduced so that no assumption about the value of the liquid water content, which varies in a wide range, is necessary in the retrieval using satellite data. This will greatly reduce the uncertainties. Two approaches are used in retrievals of the relative and absolute cloud susceptibilities. The first approach assumes constant liquid water content and the second approach uses regression technique to avoid this assumption. The retrieved cloud column susceptibilities are compared with case studies in previous investigations and show broad agreement. The results also show that the cloud susceptibility is larger over remote ocean areas than over continents. Actually, cloud column susceptibilities within most continents are already close to saturation so that, on average, cloud albedo is insensitive to changes in cloud droplet concentrations. The values of column susceptibility using regression technique are smaller than those based on the assumption of constant liquid water path. The derived relations such as column susceptibility and column droplet concentration, column susceptibility and cloud albedo, and the distribution of column susceptibility can be used as basis for model studies and guidance for selection of future field campaigns.

Form C: Future Plans

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Plan for the Second year:

- Retrieval of cloud and aerosol properties using one year (two year if the LAC data is available) of AVHRR LAC data. ISCCP data are randomly sampled within 30 x 30 km^2. It has been demonstrated that this sampling does not affect the statistics of cloud properties over global scale (Seze and Rossow, 1991). However, the scale required describing interactions of cloud and aerosol has not been determined. The retrieval using AVHRR LAC data is to compare with those from ISCCP radiance data.
- Retrieval of twelve years of cloud properties using ISCCP data including cloud column number concentration and cloud column susceptibility. This will provide important information for model simulations.

Form B: GACP Significant Highlights

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Title: *Estimate the Indirect Aerosol Effect and Retrieval of Related Parameters from Satellite Measurement*

Among possible radiative forcings that can cause long-term climate change, the effect of changing tropospheric aerosols on cloud properties (called the aerosol indirect effect) is the most uncertain (0 to -1.5 Wm^{-2}) relative to the other known forcings. Furthermore, this is the only forcing without even a mid-range estimate (IPCC, 1996). Recent model study further suggests that the indirect aerosol effect may be playing vital role in global change (Hansen et al., 1997).

One aspect of estimating the aerosol indirect effect is to evaluate the cloud albedo change due to variations of aerosol loading (e.g., Charlson et al., 1987). Twomey (1991) introduced the absolute susceptibility, $\frac{da}{dN}$, which is a very useful parameter in the study of the aerosol indirect effects. However, the approach used to retrieve this parameter from space was based on the assumption of constant water path, which is not supported by many observations (Han et al. 1998). Furthermore, an average value of water content has to be used (Platnick and Twomey, 1994) in the process, which may introduce further uncertainty due to the wide range of water content in real clouds (Pluppacher and Klett, 1998).

We introduce another parameter, ***the column cloud susceptibility,*** $S_c = \frac{da}{dN_c}$, $N_c = N \cdot h$, which is not influenced when liquid water content and cloud geometrical thickness (*h*) change during the aerosol-cloud interactions. It does not require an assumed value of water content and a constant cloud thickness during aerosol-cloud interactions in retrievals from satellite data. This parameter can be easily used in model studies.

Two approaches, one is based on the assumption of constant liquid water path and the other is not, are used to compare the resultant S_c values. Figures 1 and 2 are the first near-global survey of cloud column susceptibilities using these two different methods. The results are in broad agreement with the averaged column susceptibility values of 4.6×10^{-8} cm^2 calculated from the data given by Platnick and Twomey (1994) in the ship-track clouds. These two figures show the similarity of the S_c patterns from these two methods although generally, that S_c values from retrievals not based on the constant liquid water path is smaller than its counterpart. Both figures show a distinct contrast between the column susceptibilities of continental and maritime clouds. Figure 2 also reveals that, if no assumption of constant liquid water path is used, water clouds over most of the continents in July 1987 are close to saturation and further increase of cloud column number concentration will not significantly change the cloud albedo.

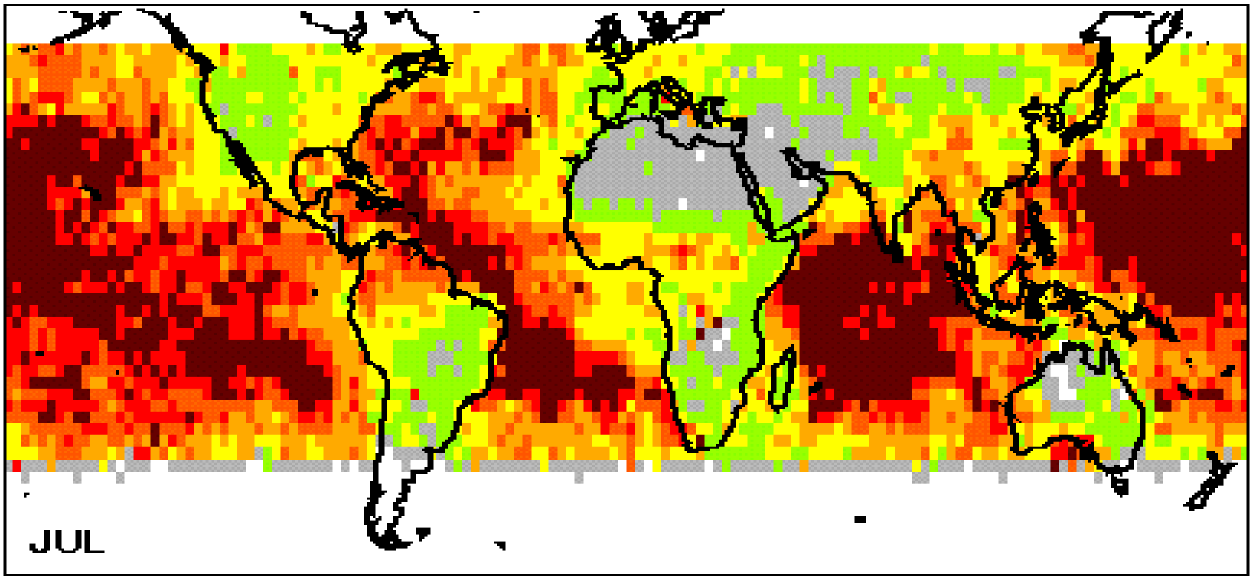

Fig. 1 Cloud column susceptibility of water clouds retrieved from ISCCP data for July, 1987, using the assumption of constant liquid water path.

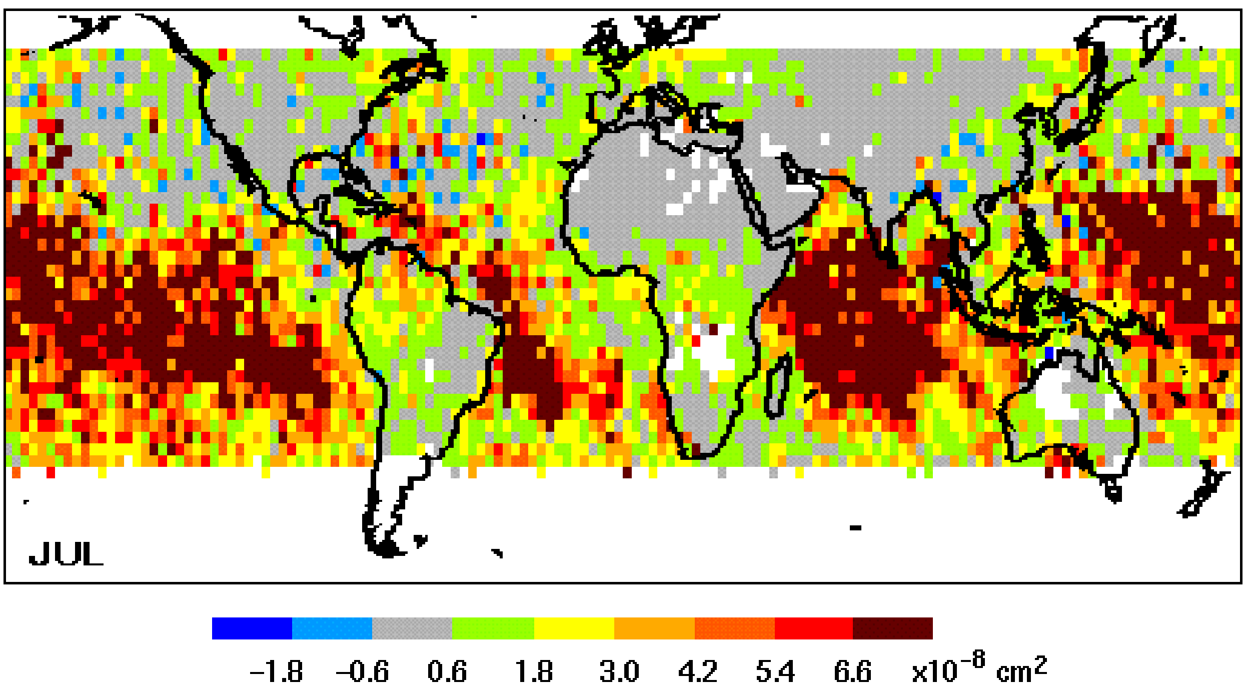

Fig. 2, Same as Fig. 1 but no assumption of constant water path was used