Progress Report for Proposal entitled " The Direct Radiative Forcing of Biomass Burning Aerosols: Investigations during SCAR-B and ZIBBEE"

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The Direct Radiative Forcing of Biomass Burning Aerosols: Investigations during SCAR-B and ZIBBEE

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I. FORM A

1.1 Abstract

Biomass burning aerosols have a wide spatial distribution that is governed by the geographic distribution of their source regions and tropospheric circulation. Annually, more than 114 Tg of smoke is produced that have residence times ranging from days to weeks depending upon their size and chemical composition. These aerosols reflect the incoming solar directly which is called the "direct effect" and they also modify the reflective properties of clouds which is called the "indirect effect". The direct top of atmosphere (TOA) globally averaged radiative forcing estimates range from -0.2 to -1.1 W/m^2. The uncertainties in this estimate are due to the various assumptions (see Introduction) involved in the calculations. While the TOA radiative forcing estimates provide valuable information on the effects of aerosols on climate, equally important are the downward shortwave irradiances (DSWI) at the surface and the atmospheric heating/cooling rate profiles. For example, the DSWI irradiance calculations show large discrepancies between measurements and calculations in the presence of biomass burning aerosols (Konzelmann et al. 1997) due to the inaccurate characterization of aerosols in radiative transfer models. The DSWI is an important component of the surface radiation balance and the atmospheric effects govern both local and regional circulation patterns. Very few studies have attempted to estimate the surface and atmospheric effects of biomass burning aerosols largely due to the lack of information on the microphysical and chemical properties of biomass burning aerosols.

In 1995 a major field program called the **S**ulfates/Smoke **C**louds **A**nd **R**adiation-**B**razil (SCAR-B) was conducted in Central Brazil to understand the effects of biomass burning aerosols on radiation and climate. In 1997 another field experiment was conducted over Zambia called the **Z**ambian **I**nternational **B**iomass **B**urning **E**xperiment (ZIBBBEE) that among other objectives also studied the effects of biomass burning on climate. A wide range of *insitu* and surface measurements is available from both these field projects that will help reduce the uncertainties in the direct radiative forcing estimates. **The major focus of this proposed effort is to estimate the direct TOA, surface and atmospheric effects of biomass burning aerosols during SCAR-B and ZIBBEE in order to reduce the uncertainties in the aerosol radiative forcing values.**

Using near-coincident coupled measurements from satellites, aircraft, and ground-based measurements from SCAR-B and ZIBBEE, a four-stream radiative transfer model will be used to estimate the direct radiative effects of biomass burning aerosols. Using satellite measurements from the Clouds and the Earth's Radiant Energy System (CERES) instrument from the Tropical Rainfall Measuring Mission (TRMM) platform, this proposed effort will also test and validate the algorithms during the upcoming ***L****arge-Scale* ***B****iosphere-***A***tmosphere Experiment in Amazonia (LBA) experiment over South America. The algorithm and products developed through this*

proposed effort will be directly applicable to the CERES Surface Radiation Budget (SARB) algorithms.

This proposed effort also brings together a team of satellite (Sundar Christopher), ground-based aerosol (Brent Holben), and ground-based flux and calculations (Thomas Eck) researchers to address these issues.

1. 2. Goals:

The long-term research goal is to improve the direct radiative forcing estimates of biomass burning aerosols by using a combination of satellite, insitu, ground-based measurements.

1. 3. Objectives:

Using near-coincident measurements from satellite, insitu and ground-based measurements during SCAR-B and ZIBBEE, the TOA, surface and atmospheric impacts of aerosol radiative forcing will be estimated. The following are the specific objectives of this proposed effort:

a) Using four-stream radiative transfer calculations, compute the instantaneous TOA and surface radiative impact of biomass burning aerosols. To accomplish this task, single scattering albedos from insitu measurements and aerosol optical thickness from ground-based sunphotometer measurements will be used. Vertical profiles of aerosol microphysical properties will be used to estimate the atmospheric radiative heating/cooling rate profiles. Satellite retrievals of AOT from the Advanced Very High Resolution Radiometer (AVHRR) will be performed at selected sites which will serve as input to the radiative transfer model. Once instantaneous values are well validated spatial and temporal averages that correspond to satellite footprints will be performed.
b) Validate the radiative transfer calculations with ground-based broadband pyranometer measurements. During SCAR-B and ZIBBEE, several pyranometers were used to measure the downward shortwave irradiances. These ground-based data sets serve as potential validation tools.
c) Using the CERES/VIRS combination of instruments on the TRMM platform compute and validate the TOA radiative impact of aerosols. During LBA, ground-based sunphotometer measurements along with pyranometer measurements will be available. This provides an exciting opportunity to validate broadband TOA satellite measurements and ground-based shortwave irradiances in the presence of biomass burning aerosols.
d) Document and improve radiative transfer calculations in the presence of biomass burning aerosols. The algorithms will directly be applicable to the SARB algorithms that are currently being developed by the CERES science team.

1. 4. Relevance to NASA's GACP program

Aerosols continue to be one of the largest sources of uncertainty in climate change studies (IPCC, 1995, NRC, 1996). The spatial distribution of aerosols, their chemical composition and microphysical properties are among the important variables that need to be properly measured and modeled before realistic predictions on global climate can be made (NRC, 1996; Wielicki et al, 1995; Hansen et al. 1997; Coakley et al. 1983). NASA's MTPE program is geared towards providing an unprecedented opportunity to measure and understand the earth-atmosphere system in an integrated fashion (Asrar and Dokken, 1993). While satellite remote sensing is the key towards obtaining global estimates of aerosol properties and their associated radiative impacts, the uncertainties in these estimates must be carefully studied through *insitu* and surface measurements. **The major goal of this proposed research effort is to reduce the uncertainties in the direct radiative forcing estimates of biomass burning aerosols by utilizing near-coincident satellite, insitu and ground-based data sets from two field experiments,** 1) SCAR-B in South America, and 2) ZIBBEE in Africa. Using the already launched CERES/VIRS data from the TRMM platform, this proposed effort will also conduct selected intercomparison studies over South America from the upcoming LBA project.

1. 4. Methodology

Two major field campaigns were conducted over biomass burning regimes. The first called the Sulfates/Smoke, Clouds, and Aerosol- Brazil (SCAR-B) was conducted in 1995 in Central Brazil (McDougal et al, 1995) which was joint experiment between NASA and INPE. Several measurements were made as part of this experiment. Figure 1a shows the area of interest along with the ground-based aerosol (AERONET) measurements. Of particular interest to this study is the *insitu* measurements collected by the University of Washington, Convair C131-A measurements (Hobbs, 1997). During SCAR-B, the C131A made twenty nine flights in Brazil (~90hrs) and a wide variety of data were collected. Of particular important to this research effort are 1) vertical profiles of temperature, and water vapor, 2) derived single scattering albedos and asymmetry parameters, and3) vertical profiles of light-scattering and light absorption coefficients of smoke aerosols. Kaufman et al. (1998) provide a thorough review of the various measurements and flight tracks of the C131A during SCAR-B. The downward direct plus diffuse shortwave irradiances (DSWI) were also measured by Eppley Pyranometers (Eck et al. 1998) which serves as a tie-point for the radiative transfer calcuations. Direct sun measurements are also made at seven wavelengths which provide aerosol optical depth (AOT) and precipitable water (PW) from the AERONET program (Holben et al. 1996). Satellite measurements from the AVHRR (Christopher et al. 1998a,b) are also used to map fires and smoke from biomass burning and to also estimate AOT.

During the Zambian International Biomass Burning Experiment (ZIBBEE) AOT along with broadband Eppley pyranometer measurements were also made. Figure 1b shows the region of study during ZIBBEE and the location of the ground-based measurements. Using the methodology described in Eck et al. (1998), where the 6S radiative transfer model is used to obtain single scattering albedos, the four-stream radiative transfer model will be used to compute DSWI in the prewence of aerosols. These values will then be compared with the pyranometer measurements.

A paper titled "Estimation of Downward Shortwave Irradiances in the Presence of Biomass Burning Aerosols During SCAR-B" is attached that details the methodology and the preliminary results.

During LBA, a set of ground-based sunphotometers and Eppley pyranometers will be deployed (Personal communication, Holben and Eck, 1998) in several targets of opportunity over South America (Figure 1c). During this period, the CERES/VIRS instruments will be making routine measurements over South America several times a day (Barskstrom and Wielicki, 1997) that will allow the testing and further development of the radiative transfer algorithm. *This effort does not compete but complements the efforts of the CERES science team algorithm development.*

The Fu-Liou delta-four-stream plane-parallel broadband radiative transfer model (Fu and Liou, 1993) is to used to compute DSWI in the presence of biomass burning aerosols. In previous research, this model has been used to calculate TOA, surface and atmospheric fluxes in clear and cloudy (water and ice clouds) conditions (Fu and Liou, 1993; Alberta and Charlock, 1996). The radiative transfer model is modified to account for biomass burning aerosols by utilizing measured aerosol properties from the C131A and AOT from sun photometer measurements. The delta-four-stream approach agrees with adding-doubling calculations to within 5% for fluxes and improves considerably over the two-stream approach (Liou et al, 1988). The correlated-k distribution technique (Fu and Liou, 1992) is used for gaseous absorption and emission. The gases considered in the model include H_2O, CO_2, O_3, O_2, CH_4, and N_2O. The radiative effects of Rayleigh Scattering, liquid water droplets, ice crystal, continuum absorption of H_2O, and surface albedo are also considered. The shortwave (SW) spectrum (0.2-4.0 μm) is divided into 6 bands : 0.2 - 0.7 μm, 0.7 - 1.3 μm, 1.3 - 1.9 μm, 1.9 - 2.5 μm, 2.5 -3.5 μm, and 3.5 - 4.0 μm while the longwave (LW) spectrum is divided into 12 bands: 2200 - 1900 cm^{-1}, 1900 - 1700 cm^{-1}, 1700 -1400cm^{-1}, 1400 - 1250 cm^{-1}, 1250 - 1100 cm^{-1},1100 - 980 cm^{-1}, 980 - 800 cm^{-1}, 800 - 670 cm^{-1}, 670 - 540 cm^{-1}, 540 - 400 cm^{-1}, 400 - 280 cm^{-1}, 280 - 0 cm^{-1}. For the principal atmospheric gases, the Fu-Liou (1993) code matches a line by line simulation of fluxes to within 0.05% for SW; 0.2% for LW except O_3, and 2% for LW fluxes due to O_3. Only SW calculations are presented in this study. Note that the Eppley PSP measures DSWI values between 0.28-2.8 μm , where as the SW bands in the radiative transfer model extends up to 4.0 μm. Therefore only the first four bands in the radiative transfer model are used in the comparison. The input parameters required for SW calculations include :

1) atmospheric profiles of water vapor, O_3, temperature and pressure.
2) ω_0 and *g* in the six SW bands along with vertical profiles of these aerosol properties,
3) τ_s at these wavelengths,
4) surface albedos for each of the six shortwave bands, and
5) solar zenith angle.

The output parameters include upwelling and downwelling fluxes in each of the prescribed layers from which the radiative fluxes at the TOA and surface along with heating/cooling rate profiles can be calculated. As an example, the spectral albedo for savanna in the six SW bands are as follows : 0.1226, 0.3071, 0.3400, 0.3400, 0.3400, and 0.3400 (Charlock et al. 1989). Vertical profiles of temperature and water vapor are obtained from the C131-A measurements and ozone profiles are from standard tropical McClatchey profiles.

The following is the overall methodology for the proposed research

1. Obtain list of C131A flights over Central Brazil over SCAR-B (Hobbs , 1996).
2. Over collocated sunphotometer sites, perform radiative transfer calculations using *insitu* data and AERONET derived AOT.
3. Compare these values with the ground-based pyranometer values.
4. Perform sensitivity analysis on the different parameters (e.g. AOT, single scattering albedo etc.)
5. Compute daily averages and area averages over specific ecosystems

6. Obtain “average” values of aerosol microphysical properties, their wavelength dependence that can be used in the CERES SARB algorithm. Examine uncertainty over actual measured values.
7. Test algorithms over Africa from the ZIBBEE procedure
8. Where single scattering albedos are not available test and use the values as described in Eck et al. (1998)
9. Use the near-coincident CERS/VIRS data to detect smoke aerosols, intercompare TOA radiative forcing of aerosols, and validate the DSWI’s using ground-based pyranometer data from the upcoming LBA project.
10. Document and evaluate the direct radiative forcing estimates of biomass burning aerosols.

1.5 Tasks Completed

1. Using data from SCAR-B and a four-stream radiative transfer model, the measured downward shortwave irradiances have been compared against calculated values.
2. Fire counts from the 1997-1998 Indonesian fire episodes have been completed.
3. First results from the VIRS/CERES instruments was used to understand the radiative impact of biomass burning aerosols from the Central American fire episode in April-May 1998

1.5 Future plans

1. Construct new Angular Dependence Models for Biomass Burning Aerosols to improve radiative forcing estimates
2. Combine GOES with VIRS/CERES to look at diurnal variation of aerosol radiative forcing
4. Improve techniques for mapping smoke aerosols from space

III. FORM C: FUTURE PLANS

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Research plans for second year:

1. Construct new Angular Dependence Models for Biomass Burning Aerosols to improve radiative forcing estimates
2. Combine GOES with VIRS/CERES to look at diurnal variation of aerosol radiative forcing
5. Improve techniques for mapping smoke aerosols from space

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