3rd Year Progress report and 3 year summary 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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3rd year Highlights

The 3rd year of this project was extremely successful in terms of peer-reviewed papers published.

The following peer- reviewed papers were published in 2000-2001 as part of the GACP. A summary of each paper is provided.

2001

1) **Christopher, S. A., J. Zhang, B. N. Holben, and S-K. Yang: GOES-8 and NOAA-14 AVHRR Retrieval of Smoke Aerosol Optical Thickness during SCAR-B, Int. J. Rem. Sens. March 2001 (in press).**
http://vortex.nsstc.uah.edu/~sundar/papers/ijrs.pdf

Summary. Using the NOAA-14 1-km Advanced Very High Resolution Radiometer (AVHRR) and the Geostationary Operational Environmental Satellite (GOES-8) imager data, smoke aerosol optical thickness (τ) is retrieved over land during the Smoke, Clouds and Radiation-Brazil (SCAR-B) experiment in Brazil during August-September 1995. The satellite-retrieved τ values are then compared against ground-based sunphotometer derived τ values from the Aerosol Robotic Network (AERONET) program. Both the AVHRR and GOES 8 retrieved τ values are in excellent agreement with the AERONET derived τ values with linear correlation coefficients of 0.93. A single scattering albedo of 0.90 (at 0.67 μm) provides the best fit between the measured and retrieved values. The sensitivity of the retrieved τ to assumed surface albedo and aerosol single scattering albedo are also examined. A simple thresholding algorithm is used to separate smoke from other features over land from GOES-8 satellite imagery and regional maps of τ are provided. Our results show that the aerosol properties used in this paper are adequate to characterize biomass-burning aerosols and can be used in studies that model the role of biomass burning on regional climate.

2) **Chan, C. Y.; Chan, L. Y.; Zheng, Y. G.; Harris, J. M.; Oltmans, S. J.; Christopher, S.A., Effects of 1997 Indonesian forest fires on tropospheric ozone enhancement, radiative forcing, and temperature change over the Hong Kong region, 106, 14875-14886, 2001.**

Summary.Tropospheric ozone enhancements were captured over Hong Kong (22.2 ^{o}N, 114.3 ^{o}E) by ECC ozonesondes during the 1997 big forest fire period in Indonesia. The enhancements were with a maximum ozone concentration up to 130 ppbv and an ozone-enhanced layer of 10 km. Tropospheric ozone column deduced from TOMS showed that there was strong ozone enhancement covering the whole of tropical Southeast Asia and subtropical South China of the Western Pacific. Fire and smoke

information deduced from satellite images was used to show that the enhancement was due to photochemical ozone build-up relating to outflow from biomass burning emissions of the Indonesian fires. Back air trajectory showed that ozone-rich air mass was transported over a long distance through the Indo-China region and the South China Sea to Hong Kong following the East Asia local Hadley circulation pattern and an abnormal anticyclonic flow in the tropical Western Pacific. The anticyclonic flow was caused by the high pressure related to the descending motion of the shifted Walker circulation in the strong El Niño event in 1997. A rough estimation on the radiative forcing due to the ozone enhancement was carried out for the two cases using a normalized tropospheric ozone radiative forcing parameter derived from the Unified Chemistry-Climate model (Mickley et al., 1999). The result showed that the ozone enhancements induced an additional radiative forcing of 0.26 and 0.48 W/m^2 compared to the total forcing of 0.48 and 0.39 W/m^2 of the respective months over Hong Kong region. Further estimation on the associated surface temperature change suggested that corresponding ozone enhancement due to the large-scale biomass burning emissions of Southeast Asian forest fire may have important implication on regional surface temperature change.

3) **Christopher, S. A., and J. Zhang, Daytime variation of shortwave direct radiative forcing of biomass burning aerosols from GOES 8 imager. submitted to J. Atmos. Sci. GACP special issue, 2001 (in press)**
http://vortex.nsstc.uah.edu/~sundar/papers/jas_2001_revise.pdf

Summary. Hourly GOES-8 imager data (1344UTC-1944 UTC) from July 20-August 31, 1998 were used to study the daytime variation of shortwave direct radiative forcing (SWARF) of smoke aerosols over biomass burning regions in South America (4-16 S, 51-65 W). Vicarious calibration procedures were used to adjust the GOES visible channel reflectance values for the degradation in signal response. Using Mie theory and Discrete Ordinate Radiative transfer (DISORT) calculations; smoke aerosol optical thickness (AOT) was estimated at 0.67 μm. The GOES retrieved AOT was then compared against ground-based AOT retrieved values. Using the retrieved GOES 8 AOT, a four-stream broadband radiative transfer model was used to compute shortwave fluxes for smoke aerosols at the top of atmosphere (TOA). The daytime variation of smoke AOT and shortwave aerosol radiative forcing (SWARF) was examined for the study area. For selected days, the Clouds and the Earth's Radiant Energy System (CERES) TOA SW fluxes are compared against the model derived SW fluxes.

Our results show that the GOES derived AOT is in excellent agreement with AERONET derived AOT values with linear correlation coefficient of 0.97. The TOA CERES estimated SW fluxes compare well with the model calculated SW fluxes with linear correlation coefficient of 0.94. The daytime diurnally averaged AOT and SWARF for the study area is 0.63±0.39 and –45.8±18.8Wm^{-2} respectively. This is among the first studies to estimate the daytime diurnal variation of SWARF of smoke aerosols using satellite data.

4) **Zhang, J., S. A. Christopher, and B. Holben, Intercomparison of aerosol optical thickness derived from GOES-8 Imager and Ground-Based Sun Photometers, J. Geophysical Res., 106, 7387-7398, 2001.**
http://www.atmos.uah.edu/~sundar/papers/jgr_2000.pdf

Summary. Using high temporal resolution (half-hourly) GOES-8 imager data and radiative transfer calculations, smoke aerosol optical thickness (τ) is retrieved over selected sites in South America and Central America. The degradation of the signal response in the GOES-8 visible channel is estimated and the satellite-retrieved τ values are then compared against ground-based sunphotometer derived values. The satellite-retrieved values are in good agreement with ground-based τ for two sites in South America with mean linear correlation coefficients of 0.97. For Central America the mean correlation coefficient is 0.80. A single scattering albedo of 0.90 (at 0.67 μm) yields the best agreement between ground-based and satellite retrieved values and is consistent with previous studies. However, our results show that the retrieved optical thickness results are sensitive to single scattering albedo and surface reflectance. For example, a 7% change in single scattering albedo (0.87-0.93) yields an uncertainty in τ of 10% for small optical thickness (τ=0.5) and an uncertainty of about 25% for larger optical thickness values (τ=1.5). Although the GOES-8 visible channel has undergone significant degradation in signal response since launch, smoke aerosol optical thickness can be estimated if proper procedures are used to account for this effect.

2000

1) **Christopher, S.A., X. Li, R.M. Welch, P.V. Hobbs, J.S. Reid, and T. F. Eck. Estimation of Downward and top-of-atmosphere Shortwave Irradiances in Biomass Burning Regions during SCAR-B. J. Appl. Meteorology, 39, 1742-1753, 2000.**

Summary. Using *insitu* measurements of aerosol optical properties and ground-based measurements of aerosol optical thickness (τ_s) during the **S**moke, **C**louds **a**nd **R**adiation-**B**razil (SCAR-B) experiment, a four-stream broadband radiative transfer model is used to estimate the downward shortwave irradiance (DSWI) and top-of-atmosphere (TOA) shortwave aerosol radiative forcing (SWARF) in cloud-free regions dominated by smoke from biomass burning in Brazil. The calculated DSWI values are compared with broadband pyranometer measurements made at the surface. The results show that for two days when near-coincident measurements of single-scattering albedo (ω_0), and aerosol optical thickness (τ_s) are available, the root mean square errors between the measured and calculated DSWI, for daytime data are within 30 W m^{-2}. However, for five days during SCAR-B, when assumptions about ω_0 have to be made and also when τ_s was significantly higher, the differences can be as large as 100 W m^{-2}. At the TOA, the SWARF per unit optical thickness ranges from -20 to -60 W m^{-2} over four major ecosystems in South America. Our results show that τ_s and ω_0 are the two most important parameters that affect DSWI calculations. For SWARF values, surface albedos also play an important role. It is shown that ω_0 must be known within 0.05, and τ_s at 0.55 μm must be known to within 0.1, to estimate DSWI to within 20 W m^{-2}. The methodology described in this paper could serve as a potential strategy for determining DSWI values in the presence of aerosols. However, the wavelength dependence of τ_s and ω_0 over the entire shortwave spectrum is needed to improve radiative transfer calculations. If global retrievals of DSWI and SWARF from satellite measurements are to be performed in the presence of biomass-burning aerosols on a routine basis, a concerted effort should be

made to develop methodologies for estimating ω_0 and τ_s from satellite and ground-based measurements.

2) **Li, X., S.A. Christopher, J. Chou, and R.M. Welch, Estimation of shortwave direct radiative forcing of biomass burning aerosols using angular dependence models. J. Appl. Meteor., 39, 2278-2291, 2000.**

Summary. Using a new angular distribution model (ADM) for smoke aerosols, the instantaneous Top-of-Atmosphere (TOA) Shortwave Aerosol Radiative Forcing (SWARF) is calculated for selected days over biomass burning regions in South America. The Visible and Infrared Scanner (VIRS) data is used to detect smoke aerosols and the Cloud and Earth Radiant Energy System (CERES) scanner data from the Tropical Rainfall Measuring Mission (TRMM) is used to obtain the broadband radiances. First, the ADM for smoke aerosols is calculated over land surfaces using a discrete-ordinate radiative transfer model. The instantaneous TOA shortwave (SW) fluxes are estimated using the new smoke ADM and compared with the SW fluxes from the CERES product. The RMS error between the CERES SW fluxes and fluxes using the smoke ADM is 13 Wm^{-2}. The TOA SWARF per unit optical thickness for the 6 surface types range from –29 Wm^{-2} to –57 Wm^{-2}, showing that smoke aerosols have a distinct cooling effect. The new smoke ADM developed as part of this study could be used to estimate radiative impact of biomass burning aerosols.

3) **Christopher, S.A., J. Chou, J. Zhang, X. Li and R.M. Welch, Shortwave Direct Radiative Forcing of Biomass Burning Aerosols Estimated From VIRS and CERES. Geophys. Res. Letters, 27, 2197-2000.**

Summary. Using collocated data from The Visible Infrared Scanner (VIRS) and the Clouds and the Earth's Radiant Energy Budget Scanner (CERES) from the Tropical Rainfall Measuring (TRMM) satellite, observational estimates of the instantaneous Shortwave Aerosol Radiative Forcing (SWARF) of smoke aerosols at the top-of-atmosphere (TOA) are calculated for four days in May 1998 during a biomass-burning episode in Central America. The detection of smoke aerosols is demonstrated using VIRS imagery and using a single scattering albedo (ω_o) of 0.86 (at 0.63 μm) that is representative of absorbing aerosols; smoke optical thickness ($\tau_{0.63}$) is retrieved over ocean areas. The average $\tau_{0.63}$ for these four days was 1.2 corresponding to a SWARF value of -68 Wm^{-2}. The SWARF changes from -24 to -99 Wm^{-2} as $\tau_{0.63}$ changes from 0.2 to 2.2. While this study has provided regional instantaneous values of SWARF, a combination of VIRS and CERES on TRMM and the Moderate Resolution Imaging Spectrometer (MODIS) and CERES on the upcoming "Terra" mission can be used to obtain global estimates of biomass burning aerosol radiative forcing.

Summary of the results obtained during the three year GACP project

The following were the objectives stated in the original proposed effort.

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 that 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.

Completed tasks

Most of the objectives stated in the original proposal have been met.

1) Four stream radiative transfer calculations in the presence of biomass burning aerosols were a challenge because the aerosol properties must be carefully characterized. Our results show that for two days when near-coincident measurements of single-scattering albedo (ω_0), and aerosol optical thickness (τ_s) are available, the root mean square errors between the measured and calculated DSWI, for daytime data are within 30 W m^{-2}. However, for five days during SCAR-B, when assumptions about ω_0 have to be made and also when τ_s was significantly higher, the differences can be as large as 100 W m^{-2} (Christopher et al. 2000, JAM).

2) Satellite retrievals of AOT over biomass burning regions over land were also successful (Zhang et al. 2001, JGR, Christopher et al. 2001, IJRS). Both GOES-8 and NOAA-14 AVHRR data retrievals of AOT over land agreed well with AERONET measurements.
3) The VIRS and CERES instruments were also used successfully to identify smoke aerosols, estimate the TOA direct radiative forcing (SWARF) and quantify this forcing in terms of AOT (Christopher et al. 2000, GRL).
4) An angular dependence model specifically aimed at smoke aerosols was developed (Li et al. 2000; JAM). This ADM could be directly used in CERES estimation of TOA and surface forcing.
5) A preliminary attempt was also made to capture the diurnal variation of SWARF over South America using GOES-8 data (Christopher et al. 2001; JAS, GACP special issue). More work needs to be done in this area to compare the GOES-8 retrievals with the aerosol products from MODIS and MISR.

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