NASA/CR-97- 207215

NAGW-3740
IN-43-CR
061460

Satellite Remote Sensing of Fires, Smoke and Regional Radiative Energy Budgets

Sundar A. Christopher, Min Wang, Kristine Barbieri, and Ronald M. Welch
Institute of Atmospheric Sciences, South Dakota School of Mines and Technology
501 East Saint Joseph Street, Rapid City, SD 57701-3995

Shi-Keng Yang
Climate Prediction Center/NCEP
W/NMC53
World Weather Building, 5200 Auth. Road, #805
Washington, DC, 20233

Abstract -- Using satellite imagery, more than five million square kilometers of the forest and cerrado regions over South America are extensively studied to monitor fires and smoke during the 1985 and 1986 biomass burning season. The results are characterized for four major ecosystems, namely: (1) Tropical Rain Forest [TRF], (2) Tropical Broadleaf Seasonal [TBS], (3) Mild/Warm/Hot Grass/Shrub [MGS], and (4) Savanna/Grass and Seasonal Woods [SGW]. Using collocated measurements from the instantaneous scanner Earth Radiation Budget Experiment [ERBE] data, the direct regional radiative forcing of biomass burning aerosols are computed. The results show that more than 70% of the fires occur in the MGS and SGW ecosystems due to agricultural practices. The smoke generated from biomass burning has negative net radiative forcing values for all four major ecosystems within South America. The smoke found directly over the fires have mean net radiative forcing values ranging between -25.6 to -33.9 W/m^2 for 1985 and between -12.9 to -40.8 W/m^2 for 1986. These results confirm that the regional net radiative impact of biomass burning is one of *cooling*.

INTRODUCTION

Each year in the tropics, extensive areas of the forests and savannas are burned for agricultural purposes and to accommodate the needs of the expanding population [1]. The permanent removal of forests are replaced with grazing or crop land, while the land cleared for agricultural purposes is primarily used for shifting agriculture. Although burning takes place whenever there is plant material that is dry, biomass burning is concentrated between July and October in the Southern hemisphere, and between December and April in the northern hemisphere. In recent years, the effect of biomass burning on a global and regional scale has received due attention because of its effect on atmospheric chemistry, radiation budget, increasing greenhouse gases, loss of biodiversity, decreasing evapotranspiration and rainfall from altered general circulation patterns; increasing surface albedo and runoff; and spread of plant and human diseases via colonization. The wide variety of satellite data from current and future instruments can be used to address these issues.

Although it has been well established that aerosols play a significant role on the radiation balance of the earth-atmosphere system, no comprehensive picture has yet emerged on how to obtain the radiative effects of aerosols on a global scale. The radiative effects of aerosols are often classified into two categories, namely, the "*direct effect*" [2] where the atmospheric aerosols scatter the incoming solar radiation, thereby reducing the amount of solar insolation to space and causing a "cooling effect", and the "*indirect effect*" [3] where the aerosols act as cloud condensation nuclei and modify the shortwave reflective properties of clouds. This effect could cause either "cooling" or "warming" depending upon the optical properties of clouds. Current estimates of the global direct effect of biomass burning range from -0.8 W/m^2 [2] to -0.2 W/m^2 [4].

We take a different approach to obtain the radiative forcing of aerosols which is similar to the cloud radiative forcing concept. In this method, narrowband measurements from the AVHRR are used to identify the smoke from biomass burning. Then, collocated measurements from the ERBE scanner are used to determine the TOA fluxes for both clear sky and aerosol regions. The difference between the clear and aerosol regions in the shortwave and longwave parts of the spectrum provide the "shortwave aerosol radiative forcing" and "longwave aerosol radiative forcing" respectively. These values are called "instantaneous radiative forcing values" because they are obtained during the time of the satellite overpass. In order to obtain a global mean value, sufficient spatial and temporal sampling must be available. The CERES/VIRS combination of instruments that will be available in the near-future from the TRMM platform is especially suited for obtaining global means of aerosol radiative forcing because the tropical regions will be sampled several times during any given day.

Acknowledgments: This research was supported by NASA Grant NAGW-3740 managed by Dr. Robert J. Curran, and by NASA New Investigator Program Grant NAGW-5195, managed by Dr. Ghassem Asrar.

DATA SETS, PREPROCESSING METHODS, AND REGION OF STUDY

The AVHRR LAC images from NOAA-9 are used in this analysis to map fires and smoke as a function of four major ecosystems. The period of study is between August to October, 1985 and July to October, 1986. Only daytime images during the ascending orbit (14:30 local solar time (LST)) are used. The ERBE scanner, which was operational between February 1985 and January 1987 on NOAA-9, are used to obtain the radiative fluxes at the top of atmosphere (TOA). The spatial resolution at nadir of the AVHRR and ERBE are about 1.1 x 1.1 km^2 and 35x35 km^2 respectively.

The region of study shown in Figure 1 in the enclosed rectangle between 10N to 30S and 40W to 80W encompasses four major ecosystems within South America. The four ecosystems [5] are: (1) Tropical Rainforest (TRF), (2) Tropical Broadleaf Seasonal (TBS) with dry or cool season, (3) Savanna/grass and seasonal woods (SGW), and (4) Mild/warm/ hot grass shrub (MGS).

METHODOLOGY

The detection of fires from AVHRR imagery is a well-established procedure. The physical principle behind the detection of fires from AVHRR imagery is the increased 3.7 µm channel response to fires when compared to the background. *Robinson* defines the amplification factor as the ratio of fire irradiance to the background irradiance. Calculations show that at 3.7 µm, amplification factors of about 3200 and 20000 are predicted for cool (1000K) and hot fires (1800K) which makes the detection of fires possible from satellite imagery.

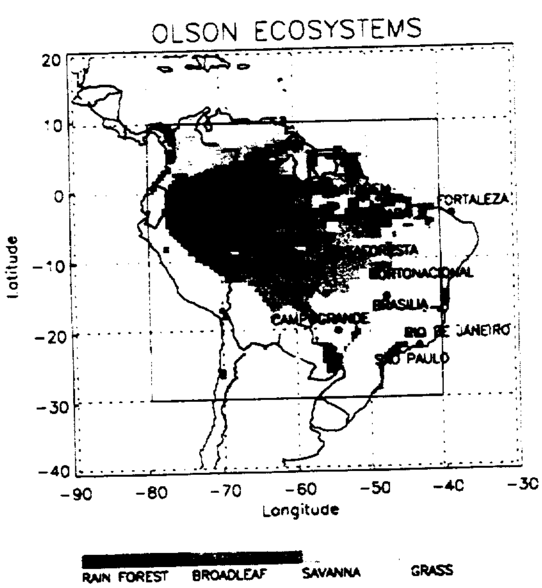

Fig. 1: Major ecosystems over South America.

Smoke pixels are identified by first locating fires within a collocated ERBE pixel. Within an ERBE pixel if fire and/or fires are present, then each AVHRR pixel is checked to ensure if the channel 4 temperatures are warmer than 273K. If this criteria is satisfied, then the ERBE pixel is classified as a "smoke pixel." This method captures the smoke directly above the fires that are wamer than 273K. Although it is possible to include clouds in this method, a visual examination of several images shows that directly above the fires, smoke predominates, as opposed to low level water clouds.

RESULTS

During August, September, and October 1985, a total of 211,580 fires were detected in all four ecosystems. Out of these, less than 1% of the fires were detected in the TRF. The percentage of fires detected by the TBS, MGS, and SGW ecosystems were 27%, 32%, and 40%, respectively. These results indicate that the majority of the fires are related to agricultural practices.

Figure 2 shows the temporal distribution of fires along with percent cloud cover values for July through October 1986. Peak fire activities are in late August and early September with more than 1500 fires detected for all ecosystems. A total of 9, 17, 17, and 22 images were used in this analysis for July, August, September, and October, and the number of fires detected were around 8851, 9622, 6253, and 11,548 respectively. There appears to be a well-defined relationship between the total number of fires and the clouds over this area which shows the difficulty in obtaining exact fire counts over the South American region.

Table 1 shows the SWARF, LWARF, and NETARF values for the four ecosystems. The SWARF values for all four ecosystems are negative, ranging from -25.3 to -40.6 W/m^2. The TRF results should be

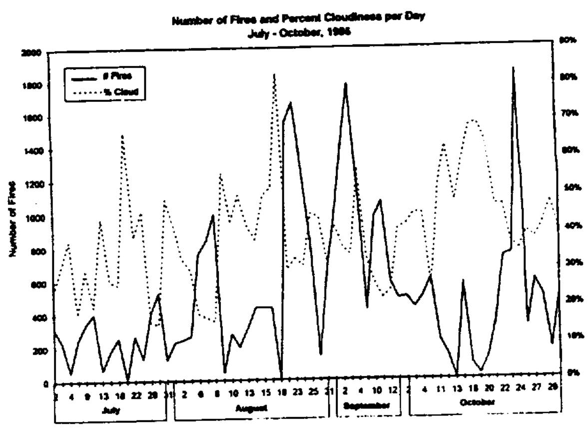

Fig. 2: Fire counts and percent cloud cover for the 1986 biomass burning season.

interpreted with caution because very few smoke pixels were identified during the period of study. The negative values indicate that the smoke pixels on the average reflect more of the incoming solar radiation as opposed to clear sky regions. These values are consistent with our previous study [7]. The mean LWARF values range from -0.3 to 6.7 W/m^2, with the MGS ecosystem having the only negative LWARF value. The NETARF, which is the sum of the SWARF and LWARF terms, therefore, shows the predominant effect of the reflective properties of smoke aerosols. The instantaneous net radiative forcing values are negative for all four ecosystems, with the TBS ecosystem having the largest NETARF values of about -35.3 W/m^2. Similar results are shown for 1986. These results show that the net radiative impact of aerosols for all four major ecosystems in South America is one of cooling.

Table 1
Mean shortwave, longwave, and net radiative forcing [W/m^2] for four ecosystems for 1985 and 1986.

1985	TRF	TBS	MGS	SGW
SWARF	-40.6	-36.0	-25.3	-35.8
LWARF	6.7	0.7	-0.3	5.3
NETARF	-33.9	-35.3	-25.6	-30.5

1986	TRF	TBS	MGS	SGW
SWARF	-47.2	-36.16	-30.8	-32.6
LWARF	6.4	4.2	17.9	8.3
NETARF	-40.8	-32.4	-12.4	-24.3

SUMMARY

Collocated narrowband and broadband measurements are very useful in evaluating the direct radiative forcing of biomass burning aerosols on a regional scale. In this study, the 1985 and 1986 biomass burning season between July through October has been studied to monitor fires and smoke and to estimate the direct regional radiative impact of aerosols in four major ecosystems over South America. The AVHRR LAC data are used to detect fires and smoke. The broadband ERBE measurements are used to compute the instantaneous SW, LW and net radiative forcing of biomass burning aerosols. The majority of the fires occur in the SGW and MGS ecosystems, which are broadly called the cerrado regions. The TRF ecosystem (selva) has less than 1% of the total fires that were detected. The smoke from biomass burning, which often spreads throughout the Amazon Basin, has a significant impact on the regional radiative balance. The average instantaneous radiative forcing of smoke for the four ecosystems that are studied are negative and range between -25.6 to -33.9 W/m^2 for 1985 and between -12.9 to -40.8 W/m^2 for the 1986 biomass burning season.

References

[1] Andreae, M.O., Biomass burning: Its history, use, and its distribution and its impact on environmental quality and global climate, *In Global Biomass Burning*, J. S. Levine, ed., 1-21, 1991.

[2] Penner, J.E., R.E. Dickinson, and C.A. O'Neill, Effects of aerosol from biomass burning on the global radiation budget, *Science*, *256*, 1432-1434, 1992.

[3] Schwartz, S.E., Are global albedo and climate controlled by marine phytoplankton, *Nature*, *336*, 441-445, 1988.

[4] Hobbs, P.V., J.S. Reid, R.A. Kotchenruther, R.J. Ferek, and R. Weiss, Direct radiative forcing by smoke from biomass burning. *Science*, *275*, 1776-1778.

[5] Olson, J.S., World Ecosystems (WE1.3 and WE 1.4) Digital Raster data on global Geographic (LAT/lon) 180X360 and 1080X2160 grids. Available from NOAA National Geophysical Data Center. Boulder, Colorado, 1991.

[6] Robinson, J.M., Fire from space: Global fire evaluation using infrared remote sensing. *Int. J. Rem. Sens.*, *12*[1], 3-24, 1991.

[7] Christopher, S.A., D.V. Kliche, J. Chou, and R.M. Welch, First estimates of the radiative forcing of aerosols generated from biomass burning using satellite data, *J. Geophys. Res.*, *101*, D16, 21265-21273, 1996.