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To:	**Dr. Robert Curran**
From:	**Dr. Paul Menzel, Elaine Prins**
Date:	**January 11, 1996**
Subject:	**Annual Summary Report for January - December 1995 Investigation of Biomass Burning and Aerosol Loading and Transport in South America Utilizing Geostationary Satellites (NAGW-3804)**

This report summarizes the objectives of this study and the work performed to date with an emphasis on progress made during the 1995 calendar year. Section 1 includes a review of the objectives of this study and general overview. Algorithm and software development are presented in Section 2 and implementation activities are discussed in Section 3. An overall summary of completed tasks and tentative outline for tasks to be completed in the 1996 calendar year is presented in section 4. Section 5 provides a list of current reports and publications associated with this study. We have also attached a formal request for fourth period (1 January - 31 August 1996) funding, totaling $50,096, and a budget summarizing costs for this period.

1. Objectives and Overview

This study attempts to assess the extent of burning and associated aerosol transport regimes in South America and the South Atlantic using geostationary satellite observations, in order to explore the possible roles of biomass burning in climate change and more directly in atmospheric chemistry and radiative transfer processes. Modeling and analysis efforts have suggested that the direct and indirect radiative effects of aerosols from biomass burning may play a major role in the radiative balance of the earth and are an important factor in climate change calculations. One of the most active regions of biomass burning is located in South America, associated with deforestation in the selva (forest), grassland management, and other agricultural practices. As part of the NASA Aerosol Interdisciplinary Program, we are utilizing GOES-7 (1988) and GOES-8 (1995) visible and multi-spectral infrared data (4, 11, and 12 μm) to document daily biomass burning activity in South America and to distinguish smoke/aerosols from other multi-level clouds and low-level moisture. This study catalogues the areal extent and transport of smoke/aerosols throughout the region and over the Atlantic Ocean for the 1988 (July-September) and 1995 (June-October) biomass burning seasons. The smoke/haze cover estimates are compared to the locations of fires to determine the source and verify the haze is actually associated with biomass burning activities. The temporal resolution of the GOES data (half-hourly in South America) makes it possible to determine the prevailing circulation and transport of aerosols by considering a series of visible and infrared images and tracking the motion of smoke, haze and adjacent clouds. The study area extends from 40 to 70°W and 0 to 40°S with aerosol coverage extending over the Atlantic Ocean when necessary.

Fire activity is estimated with the GOES Automated Biomass Burning Algorithm (ABBA). The GOES ABBA uses the visible, 4 and 11 μm bands to locate fire pixels and provide estimates of subpixel fire size and mean fire temperature. The algorithm was originally developed for the first generation of GOES satellites (GOES 5-7) and has been adapted for the GOES-8 platform in this study. During the 1988 biomass burning season, the ABBA provides estimates of fire activity at 1830 UTC from GOES-7 data. For the 1995 biomass burning season, the ABBA tracks fire trends at 3-hour intervals (0245, 0545, 0845, 1145, 1445, 1745, 2045 and 2345 UTC) with GOES-8 data.

To date, our efforts have focused on GOES-7 and GOES-8 ABBA development, algorithm development for aerosol monitoring, data acquisition and archiving, and participation in the SCAR-C and SCAR-B field programs which have provided valuable information for algorithm testing and validation. Implementation of an initial version of the GOES-8 ABBA on case studies in North, Central, and South America has demonstrated the improved capability for monitoring diurnal fire activity and smoke/aerosol transport with the GOES-8 throughout the Western Hemisphere.

2. Algorithm Development

2a. GOES ABBA

The original GOES ABBA was developed to locate and provide estimates of sub-pixel fire size for a select region of South America (5-15°S, 45-70°W) and was successfully used to determine trends in biomass burning in this region during the 1980's (Prins and Menzel, 1994). The code has been modified to enable monitoring throughout South America. Modifications include an expanded surface vegetation classification scheme (based on the World Ecosystems Map, Olson, 1989-1991) and associated 4 and 11 μm emissivity factors. In addition NMC model estimates of total precipitable water (2.5° by 2.5°) have been incorporated into the algorithm to account for water vapor attenuation in the 4 and 11 μm bands. Data obtained in South America in September 1994 and additional case studies in North and Central America were used to develop the GOES-8 ABBA. The improved radiometric, spatial (4 km on GOES-8 vs. 16 km on GOES-7), and temporal resolution of the GOES-8 provides for much improved fire monitoring capabilities in South America and throughout the Western Hemisphere. An initial version of the algorithm provided diurnal (3-hourly) estimates of fire activity during the SCAR-B field experiment. As a result of fire monitoring efforts during SCAR-B, the GOES-8 ABBA now also incorporates visible data in an effort to screen sub-pixel cumulus cloud contamination for background temperature calculations in the 4 and 11 μm bands.

2b. GOES Smoke/Aerosol Detection

Earlier in this study we analyzed GOES imagery collected over South America during the burning season in 1983, 1988, 1989, and 1991 and found three primary smoke/aerosol transport mechanisms. As an extension of this work we recently reviewed GOES-8 visible and infrared satellite imagery over South America during the dry seasons of 1994, and 1995. An analysis of all 6 years revealed definite patterns for smoke/aerosol transport and extent associated with biomass burning in the selva and cerrado under different meteorological conditions. Four primary transport regimes were identified in sequences of half-hourly visible and infrared data from these 6 years (Prins and Menzel, 1996b). The most common regime (evident in all 6 years) consists of anticyclonic flow throughout the Amazon Basin where easterly winds in the northern portion of the Amazon Basin transport the aerosols westward and the Andes Mountains deflect the smoke to the south-southeast (Figure 1, track a). Typically the smoke pall is limited to the continent. A second regime (evident in 1983, 1988, 1994, and 1995) is an extension of the previous one where a stalled frontal boundary located south of the Amazon Basin extends out over the Atlantic Ocean and acts as a mechanism for channeling the smoke over the Atlantic Ocean (Figure 1, track b). In 1988 and 1995 the smoke pall was tracked across the Atlantic Ocean past the Prime Meridian. A third regime (evident in 1991, 1994, and 1995) consists of transport southward along the Andes Mountains into Bolivia, Paraguay, and Argentina (40-50°S) typically characterized by a lack of cyclonic activity off the coast of Argentina that might otherwise act to channel the emissions east (Figure 1, track c). The fourth regime (evident in all 6 years) consists of flow from the Amazon Basin into the selva regions in the northwestern portion of the Brazilian Amazon extending into Peru and Columbia (Figure 1, track d). This is often accompanied by a large scale convective complex associated with a frontal boundary extending from the front range of the Andes Mountains and across the southern and eastern sections of the Amazon Basin. These examples provide an initial perspective on the extent of aerosol coverage during the dry season in Brazil and typical transport regimes; more quantitative large-scale satellite analyses are needed to better characterize this phenomenon.

An automated GOES multi-spectral aerosol detection algorithm is near completion and will enable more quantitative analyses of GOES satellite data (Prins and Menzel, 1995a). GOES visible and infrared (4, 11, and 12 μm) data have been incorporated into a multi-spectral thresholding scheme. Data collected from 24-29 August 1988 were used to develop a preliminary version of the algorithm. During this time period there was a smoke/aerosol episode that consisted of large-scale aerosol transport and multi-level cloud activity, including semi-transparent cirrus and low-level stratus. In visible imagery smoke often appears as a milky gray haze, but cirrus, low-level moisture, fog and other multi-level clouds can display the same signature. Some of these clouds can be distinguished from smoke/aerosol by investigating brightness temperature limits in the 4 and 11μm bands and considering the 4 minus 11 μm differences. A large positive 4 minus 11 μm brightness temperature difference is often indicative of cirrus and a negative difference on the order of 4 °C can indicate stratus. Since the best conditions for monitoring smoke/aerosols in South America are coincident with a low solar zenith angle, the effect of reflected solar radiation in the 3.9 μm region is minimized. Additionally, the split window (11 and 12 μm) data can be used in conjunction with the visible and 3.9 μm data to create a more robust aerosol detection algorithm. The split window channels have been used extensively to detect low-level moisture and the presence of clouds. They were designed to use differential water vapor absorption across this part of the spectrum to estimate the amount of water vapor in the lower atmosphere; the 12 μm region is more sensitive to water vapor absorption than the 11 μm region. For low visible brightness reflectance values and surface emissivity corrected brightness temperature differences greater than 5 °C, one can assume substantial amounts of low-level moisture. Semi-transparent cirrus which looks very similar to haze in the visible imagery often displays a relatively cold 11 μm brightness temperature and can display a large 11 minus 12 μm brightness temperature difference due to effective emissivity differences in the 11 and 12 μm regions (Inoue, 1985). Table 1 provides a summary outline of the primary components of the algorithm. Additional work is needed to distinguish aerosols from isolated cumulus activity and in identifying smoke in the vicinity of thin cirrus and along gradients between clear and cloud contaminated pixels. Furthermore, solar zenith angle considerations must be included to distinguish aerosols from sun glint.

3. Implementation

3a. Results from SCAR-C and SCAR-B

The Smoke Clouds and Radiation (SCAR-C) experiment based in the Pacific Northwest in the fall of 1994 provided a unique opportunity to monitor diurnal variability in fire intensity and to validate fire size estimates obtained with the GOES-8 ABBA. GOES-8 data were collected for several prescribed burns including the Quinault fire (48 acres), the ITT fire (97 acres) and the Simpson fire (95 acres). The fires were detected in a series of half-hourly GOES-8 4 µm images shown in Figure 2. Half-hourly GOES-8 ABBA estimates of fire size for the Quinault fire were compared with ground observations made by the USFS. The GOES-8 ABBA size estimates were on average within 20% of ground observations at any given time.

During the SCAR-B field program, UW-Madison provided the mission scientists in Brazil with GOES-8 satellite imagery, GOES ABBA fire products, meteorological observations, and NMC model output via the UW-Madison SSEC SCAR-B web site. The web site consisted of three components: GOES-8 imagery loops (3-hourly visible and infrared), GOES-8 ABBA products, and the McWEB forecasting tool. This interactive tool allowed the scientists to access meteorological information as well as satellite imagery and satellite derived fire products from the Mission Operations Center at IBAMA. The web page provided daily plots of fire locations at peak burning times (11:45, 14:45, 17:45, 20:45 UTC) for the region extending from approximately 40 to 70°W and from the equator to 30°S. A text summary of daily peak fire statistics from the GOES-8 ABBA was also available. The page contained a morning (11:45 UTC) and afternoon (17:45 UTC) GOES-8 visible image with outlines depicting the areal extent of smoke/aerosol coverage based on an analysis of visible and infrared imagery.

Preliminary GOES-8 ABBA results obtained during SCAR-B (15 August-15 September 1995) suggest that the peak burning time is in the middle of the afternoon (1745 UTC). The number of fires detected at 1745 UTC is 2 to 4 times greater than that observed 3 hours earlier or later and 20 times greater than that observed at 1145 UTC. Figure 3 provides an example of GOES-8 ABBA diurnal fire monitoring on 24 August 1995, one of the peak burning days during SCAR-B. The red markers indicate the locations of fire pixels processed with the GOES-8 ABBA; yellow markers indicate saturated fire pixels which could not be processed with the GOES-8 ABBA; blue markers represent possible fire pixels which were not processed due to cloud contamination. The majority of the fire activity is concentrated along the perimeter of the Amazon in the Brazilian states of Para, Mato Grosso, Amazonas, and Rondonia. There is also considerable activity in Bolivia, Paraguay, and Northern Argentina. Although the burning pattern is similar to that observed with the GOES-7 ABBA in 1988, the improved spatial resolution available with GOES-8 provides much greater detail concerning fire activity and other surface features (Menzel and Prins, 1995). As in previous years, large smoke palls were identified in the GOES-8 visible imagery. During SCAR-B smoke was evident over a large portion of the continent east of the Andes Mountains. A preliminary summary of the extent of smoke/aerosol coverage as detected by GOES-8 within the SCAR-B study regime is presented in Figure 4. A large smoke pall covering over 4 million km^2 was observed from 21 August through 11 September 1995. At the height of the burning period the smoke pall extended over nearly 7 million km^2. Transport over the Atlantic Ocean was observed on 13 days during the SCAR-B field program. On at least two days, a thin plume of smoke was tracked to the Prime Meridian. The burning practices and meteorological conditions which contributed to this episode are nearly identical to ones which resulted in a similar smoke pall observed during the last week of August 1988.

3b. GOES-8 Diurnal Wildfire Monitoring Capabilities in North and Central America

The enhanced capabilities of the new generation of GOES satellites show dramatic improvements for detecting and characterizing fire activity and aerosol transport for the next decade not only in South America, but throughout the Western Hemisphere. During 1995, several examples in Central and North America demonstrated the capability of the GOES-8 for monitoring diurnal variations in wildfire activity and intensity in these areas. During the third week in May 1995 the GOES-8 4 μm imagery revealed a number of fires in the Yucatan Peninsula in Mexico, Belize and Guatemala. Hourly GOES-8 imagery indicated both large and small fires with definite diurnal patterns. A smoke pall associated with the burning was evident in the visible imagery extending over 1500 km across the Gulf of Mexico to the gulf coast of the United States. During the week of 20 August 1995 fires were observed in the GOES-8 4 μm imagery associated with numerous fire complexes in the Abitibi region of Quebec and Northeast of Wawa, Ontario. The 4 μm imagery indicated numerous fire fronts in both regions. The smoke associated with these fires was evident in the visible imagery. On Tuesday morning, a review of GOES-8 multispectral imagery indicated that the smoke pall extended across the Atlantic Ocean beyond 30°W. Later that week the Long Island fire was monitored in the GOES-8 4 μm imagery. A time series of GOES-8 4 μm imagery showed a strong variation in fire intensity on Thursday night and throughout the day on Friday. A smoke plume extending southeast of Long Island over the Atlantic Ocean was clearly delineated in the visible imagery.

4. Status and Plans

4a. Tasks Completed

Data acquisition:

- GOES-7 multi-spectral imagery for the 1988 fire season (June-September, 1988)
- GOES-8 diurnal multi-spectral imagery representing case studies in North, Central and South America during 1994 and 1995
- Diurnal (3-hourly) GOES-8 multi-spectral imagery for the 1995 fire season (June-October, 1995)
- NMC model output (winds and total precipitable water) for 1988 and 1995.

Algorithm Development:

- Modification of the GOES-7 ABBA, including an expanded surface vegetation classification scheme (Olson World Ecosystems Map) and NMC model output (2.5° by 2.5°) of total precipitable water for water vapor attenuation corrections
- GOES-8 ABBA development based on data collected during the 1994 biomass burning season in South America, SCAR-C and SCAR-B, and numerous case studies involving wildfires in North and Central America
- Multi-spectral GOES aerosol detection algorithm utilizing the visible, 4, 11, and 12 μm imagery

Data Analyses

- Review of GOES visible and infrared satellite imagery in South America during the dry seasons of 1983, 1988, 1989, 1991, 1994, and 1995 reveals four primary transport regimes
- SCAR-C GOES-8 ABBA diurnal fire monitoring and intercomparison with ground truth
- GOES-8 fire detection and smoke/aerosol transport monitoring capabilities demonstrated in North, Central, and South America
- Preliminary fire and aerosol transport results for the 1995 peak burning period in South America

SCAR-C and SCAR-B field programs

- SCAR-C forecasting and fire identification support using GOES-8 multispectral imagery
- SCAR-B Web page support for forecasting, fire identification, and monitoring aerosol transport

4b. Pending Tasks

Fire Statistics

- Produce final fire statistics for the 1988 and 1995 biomass burning seasons (1.0 degree grid)

Aerosol Transport Estimation

- Automate the aerosol detection algorithm and catalogue smoke/aerosol coverage and transport for the 1988 and 1995 biomass burning seasons.
- Catalogue transport for 1988 and 1995 seasons (2.5 degree grid)

5. Reports and Publications Associated with this Study

Bywaters, K.W., and E.M. Prins, 1996: An interactive WWW tool for coupling satellite and meteorological data in real time. 76th AMS Conference, Atlanta, GA. Jan. 28-Feb. 2, 1996, pp (TBD).

Menzel, W.P., and E.M. Prins, 1995: Monitoring biomass burning with the new generation of geostationary satellites. Accepted for publication in the Proceedings of the AGU Chapman Conference on Biomass Burning and Global Change, Williamsburg, VA, March 13-17, 1995.

Prins, E.M., 1995: Biomass Burning, in *Encyclopedia of Environmental Biology*, edited by W. A. Nierenberg, pp. 309-325, Academic Press, San Diego, CA.

Prins, E.M., and W.P. Menzel, 1995a: Investigation of Biomass Burning and Aerosol Loading and Transport Utilizing Geostationary Satellite Data. Accepted for publication in the Proceedings of the AGU Chapman Conference on Biomass Burning and Global Change, Williamsburg, VA, March 13-17, 1995.

Prins, E.M., and W.P. Menzel, 1995b: Monitoring diurnal fire activity and aerosol transport in the Western Hemisphere with GOES-8. Presented at the IGBP-DIS Global Fire Monitoring Workshop, Ispra, Italy, October 17-19, 1995.

Prins, E.M., and W.P. Menzel, 1996a: Monitoring fire activity in the western hemisphere with the new generation of geostationary satellites. 22nd Conference on Agricultural and Forest Meteorology with Symposium on Fire and Forest Meteorology, Atlanta, GA, Jan.28 - Feb.2, 1996, pp (TBD).

Prins, E.M., and W.P. Menzel, 1996b: Monitoring biomass burning and aerosol loading and transport from a geostationary satellite perspective. Seventh Symposium on Global Change Studies, Atlanta, GA, Jan.28 - Feb.2, 1996, pp (TBD).

Table 1. GOES Multi-spectral Smoke/Aerosol Detection Algorithm

Test	Visible Counts	4 μm Temp (K)	11 μm Temp (K)	12 μm Temp (K)	4-11 μm Temp (K)	11-12 μm Temp (K)	Comments
1	60 ↔ 100						Limits the brightness count range to values indicative of haze
2		>285	>285		-4 ↔ +20		Screens for opaque clouds, cirrus, and stratus
3			>285	>280		-4 ↔ +6	Screens for low-level moisture, opaque clouds, and semi-transparent cirrus

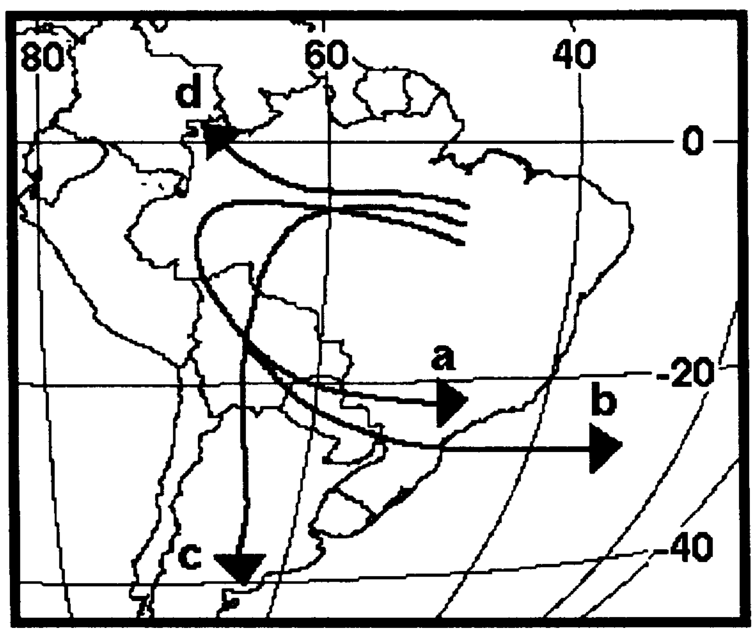

Figure 1. The four labeled trajectories (a, b, c, and d) represent the most common smoke/aerosol transport regimes observed in GOES satellite imagery during six biomass burning seasons (1983, 1988, 1989, 1991, 1994, and 1995) (Prins and Menzel, 1996b).

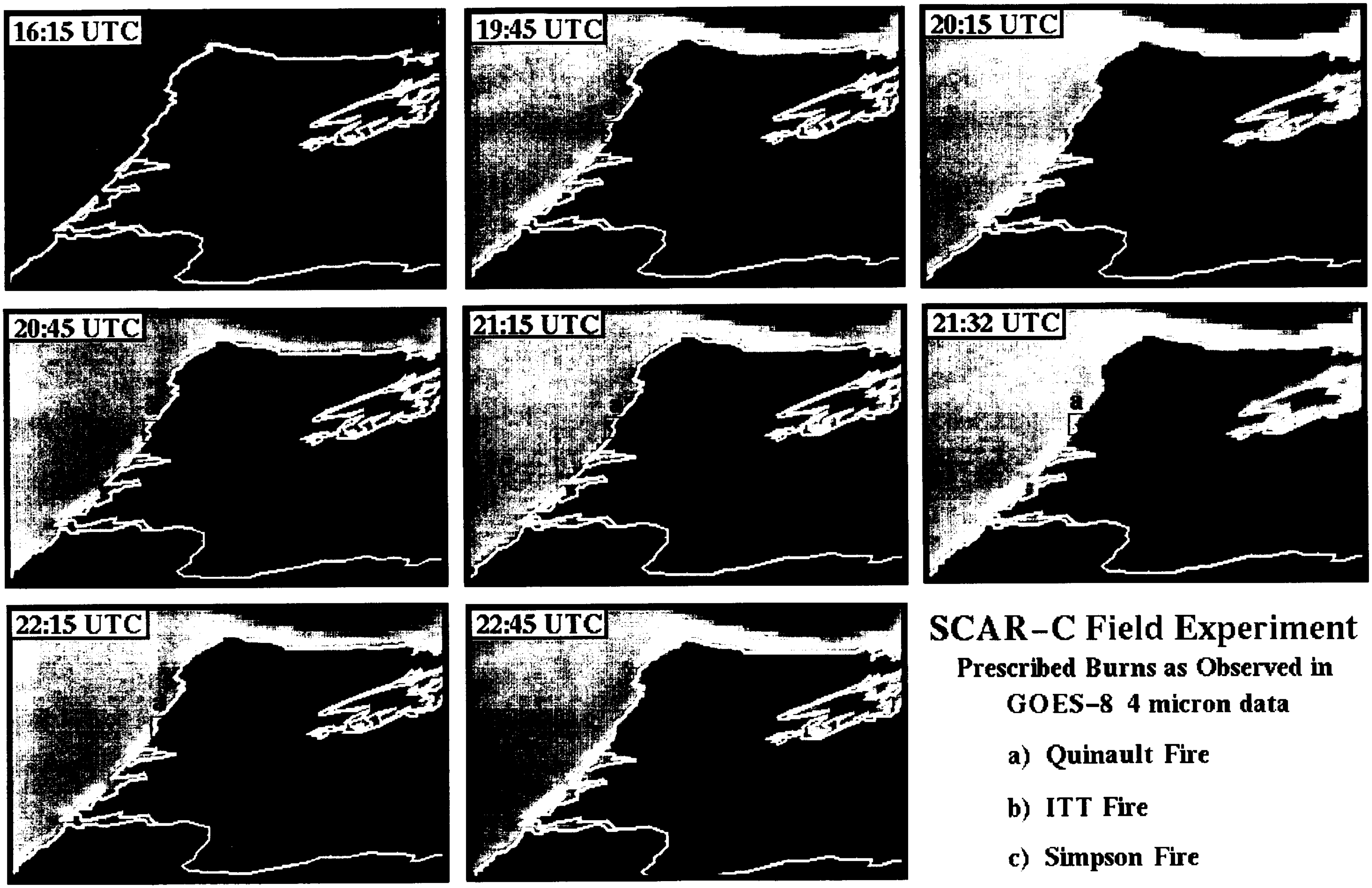

Figure 2. The Quinault, ITT, and Simpson prescribed burns as observed in GOES-8 4 micron imagery on 21 September 1994 during the SCAR-C field program. (Menzel and Prins, 1995)

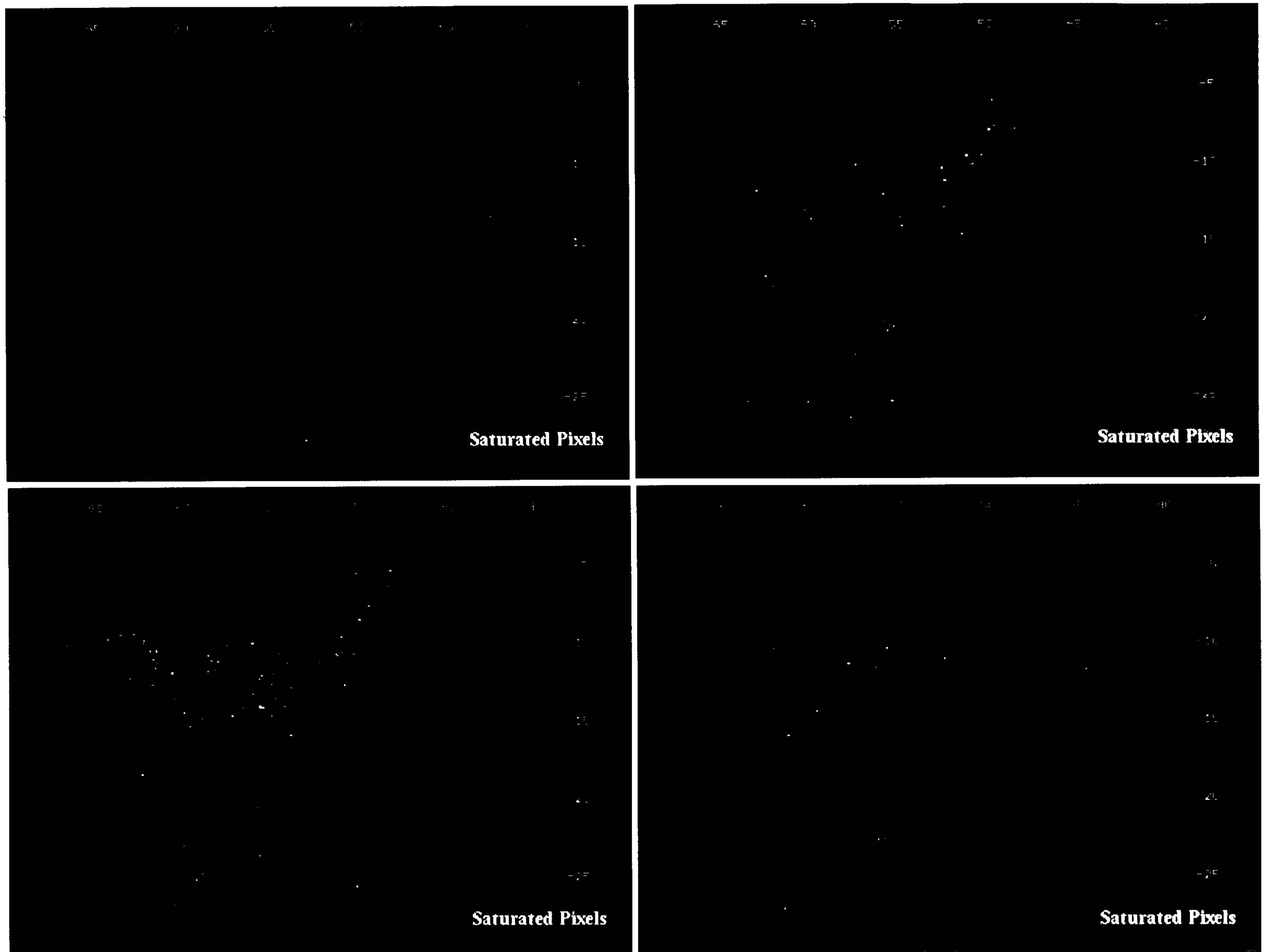

Figure 3. Fires detected by the GOES-8 ABBA on 24 August 1995 at (a) 1145 UTC, (b) 1445 UTC, (c) 1745 UTC, and (d) 2045 UTC. (Prins and Menzel, 1996b)

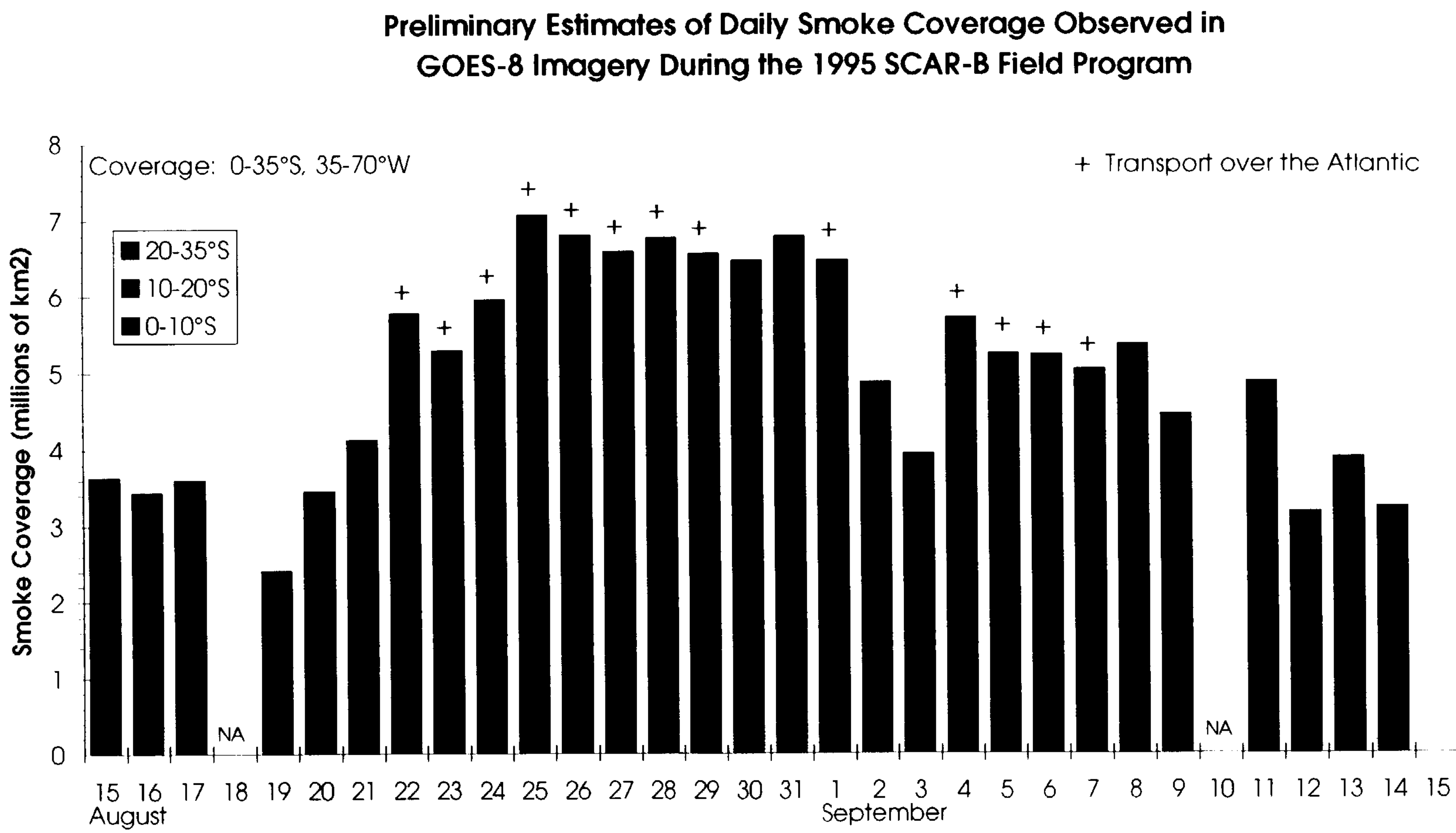

Figure 4. Preliminary estimates of daily smoke coverage observed in GOES-8 imagery during the 1995 SCAR-B field program. The total smoke coverage within the study area is broken down into latitudinal sectors by color. Blue indicates the extent of smoke coverage from 20 to 35°S, green represents smoke coverage from 10 to 20°S, and red indicates coverage from 0 to 10°S. The crosses indicate days where the imagery included smoke transport over the South Atlantic Ocean.

NASA Aerosol Proposal Year 4

1 January 1996 - 31 August 1996

		Hours	Rate	Cost	
I.	Labor and Fringe Benefits				
	a) PI	120	N/A	$ 0	
	b) Program Manager	500	27.51	13,755	
	c) Research Assistant	500	19.93	9,965	
	Subtotal				$23,720
II.	Travel				
	a) 2trips/1person/3days/Wash. DC				1,957
III.	Publications				5,000
IV.	Computing				2,765
V.	SSEC Indirect Cost at 40%				13,377
VI.	Equipment Rental				949
VII.	Tuition Remission (25% of I.c, less fringe benefits)				2,328
	TOTAL				$50,096

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