P2.28 A TWO-YEAR ANALYSIS OF FIRE ACTIVITY IN THE WESTERN HEMISPHERE AS OBSERVED WITH THE GOES WILDFIRE AUTOMATED BIOMASS BURNING ALGORITHM

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1. INTRODUCTION

The international environmental monitoring and scientific research communities have recognized the vital role environmental satellites can play in detecting and monitoring active fires for hazards and a wide range of environmental applications. They have also stressed the importance of utilizing operational satellites to produce routine fire products and to ensure long-term stable records of fire activity for applications such as land-use/land-cover change analyses and global climate change research (Dull and Lee, 2001; Gutman, et al., 2001; Justice and Korontzi, 2001; Prins, et al., 2001a). The current series of National Oceanic and Atmospheric Administration (NOAA) operational geostationary satellites provide the opportunity to detect and monitor active fires every half-hour throughout the Western Hemisphere.

In September 2000, the NOAA National Environmental Satellite, Data, and Information Service (NESDIS) Office of Research and Applications (ORA) and the UW-Madison Cooperative Institute for Meteorological Satellite Studies (CIMSS) implemented the GOES Wildfire Automated Biomass Burning Algorithm (WF_ABBA), providing half-hourly fire products in real-time for most of the Western Hemisphere. This on-going activity is part of a collaborative cost-sharing effort with contributions from NOAA NESDIS, UW-Madison CIMSS, the National Aeronautics and Space Administration (NASA), and the U.S. Navy. The user community includes climate change scientists, the aerosol and trace gas transport modeling community, the land-use and land-cover change detection research community, government agencies, resource managers, fire managers, international policy and decision makers, educational institutions, and the general public.

In the United States the primary real-time application of the half-hourly WF_ABBA fire product is diurnal monitoring of fires. Over the past 2 years, the WF_ ABBA has monitored the rapid intensification of a number of wildfires, including the Viejas fire in California, the Thirty Mile Fire in Washington, and conflagrations in Colorado and Arizona during the 2002 fire season. In Canada the WF_ABBA is used to detect and monitor wildfires in northerly and remote locations. In Central and South America the diurnal GOES fire product is primarily used to document burning associated with deforestation and agricultural land management. Much of this activity is concentrated in developing countries where there are few resources to adequately document the extent of burning. In North, Central, and South America the WF_ABBA half-hourly fire products are providing new insights into diurnal, spatial, seasonal and interannual biomass burning activity. This paper focuses on an analysis of fire activity in the Western Hemisphere as observed with the GOES-8 WF_ABBA from September 2000 through August of 2002, including several case study examples. The paper also briefly discusses real-time assimilation of WF_ABBA fire products into the Navy Aerosol Analysis and Prediction System (NAAPS) as part of the Fire Locating And Modeling of Burning Emissions (FLAMBE) project.

2. OVERVIEW OF THE GOES WF_ABBA PROCESSING SYSTEM

The GOES-8/-10 WF_ABBA processing system was developed as a collaborative effort between NOAA/NESDIS/ORA and UW-Madison CIMSS personnel. The WF_ABBA is a modified version of the South American ABBA that has been used to monitor spatial, diurnal, and interannual trends in biomass burning throughout South America since 1995. The WF_ABBA is a dynamic multispectral thresholding contextual algorithm that uses the visible (when available), 3.9 μm, and 10.7 μm infrared bands to locate and characterize hot spot pixels. The algorithm is based on the sensitivity of the 3.9 μm band to high temperature subpixel anomalies and is derived from a technique originally developed by Matson and Dozier (1981) for NOAA Advanced Very High Resolution Radiometer (AVHRR) data. The WF_ABBA incorporates statistical techniques to

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automatically identify hot spot pixels in the GOES imagery. Once the WF_ABBA locates a hot spot pixel, it incorporates ancillary data in the process of screening for false alarms and correcting for water vapor attenuation, surface emissivity, solar reflectivity, and semi-transparent clouds. The AVHRR derived Global Land Cover Characteristics (GLCC) data base (version 2.0) is used to assign surface emissivity and to screen for false alarms (http://edcdaac.usgs.gov/glcc/glcc.html). The National Centers for Environmental Prediction (NCEP) Aviation model total column precipitable water products are utilized to correct for water vapor attenuation. Numerical techniques are used to determine instantaneous estimates of subpixel fire size and average temperature. An in-line temporal filter has been added to the algorithm to screen out false alarms associated with noise in the imagery and cloud edge issues. This is especially important for screening false alarms due to reflection off clouds at extreme view angles and at sunrise and sunset. The temporal filtering technique uses a time series of GOES fire products from previous hours to compare with the current fire product. A fire pixel must appear at least twice (within 0.1 degrees) within the past 12 hours in order to be retained in the final filtered fire product. The filtered fire product can result in delayed identification of a fire start time and eliminates short-lived agricultural management fires. For more information on the algorithm and the determination of subpixel fire characteristics, refer to Prins and Menzel (1992, 1994) and Prins et al. (1998a; b; 2001a; b).

The WF_ABBA is executed every half-hour for both GOES-8 and GOES-10, detecting fires within a satellite zenith angle of 80° (covering the better part of the visible hemisphere). The WF_ABBA fire product is output in ASCII text and Man computer Interactive Data Access System (McIDAS) MD and AREA files. Both temporally filtered and non-filtered fire product ASCII files are placed on an anonymous ftp site at UW-Madison CIMSS. The ASCII files contain information about the detected fire pixels including location, observed 3.9 and 10.7 µm brightness temperatures, estimates of instantaneous sub-pixel fire size and temperature, ecosystem type, and fire classification. The six classification categories are processed pixels (fire pixels that satisfy the criteria to have sub-pixel temperature and size calculated), saturated pixels (the observed 3.9 µm brightness temperature exceeds the maximum temperature that the GOES Imager is capable of quantifying), cloudy pixels (a fire pixel with relatively thin cloud cover), high possibility fire pixels, medium possibility fire pixels, and low possibility fire pixels. The latter category represents the largest number of false alarms as it has the least stringent requirements for fire identification.

A Modified Alpha-Blending (MAB) technique is used to generated composite WF_ABBA fire product imagery (Schmidt and Prins, 2002). The MAB exploits the fact that infrared images tend to highlight clouds high in the atmosphere while the brightest clouds in the visible imagery tend to be the lowest. MAB takes the AVHRR GLCC image and treats it as the surface. It assumes that the visible band from the GOES represents low clouds and blends that on top of the surface. To mimic thin clouds, albedos below 6% are treated as transparent, albedos from 6 to 12% are treated as linearly increasing in opacity, and all albedos above 12% are opaque. The infrared clouds are then blended on top of the first two layers. Temperatures above 280 K are treated as transparent and temperatures below 250 K are considered opaque. To account for the texture in high clouds that can be seen in the visible band but not the infrared, the blending is modified for situations when both the visible and infrared are opaque, allowing the structure of high clouds to be visible. Once this blending is completed, the "mask" output from the WF_ABBA is "burned" on top of the image, showing the detected fires in relation to the cloud data. The MAB code uses 8-bit images as input and outputs three 8-bit images that represent the red, green, and blue components of the fire imagery. These are then combined to form the final product. Alpha-blended WF_ABBA fire product imagery are posted on the Internet at the following URL: http://cimss.ssec.wisc.edu/goes/burn/wfabba.html. Animations of the WF_ABBA fire product for the previous 24 hours are available for both GOES-8 and GOES-10, including 35 "zoomable" regional sectors.

3. ANALYSIS OF FIRE ACTIVITY IN THE WESTERN HEMISPHERE AS OBSERVED IN TWO YEARS OF GOES-8 HALF-HOURLY IMAGERY

Version 5.9 of the GOES WF_ABBA processing system was implemented at UW-Madison CIMSS in September 2000, processing half-hourly GOES-8 and GOES-10 imagery in real time. The resulting 2-year data set is providing unique insights into the diurnal, seasonal, interannual, and spatial variability in fire activity throughout the Western Hemisphere. In this paper we will focus on the GOES-8 fire products. Annual cumulative GOES-8 WF_ABBA fire product composites were created from all available half-hourly GOES-8 WF_ABBA temporally filtered fire pixels identified in the Western Hemisphere from September 2000 through August 2001 and from September 2001 through August 2002. Each composite was generated from over 15,000 half-hourly GOES-8 images. The primary regions of enhanced fire activity in North, Central and South America were similar in both years (Prins, et al., 2001b).

3.1 *Overview of Burning During the Time Period: September 2001 – August 2002*

Figure 1 shows the GOES-8 annual composite of the WF_ABBA filtered fire products for the Western Hemisphere for September 2001 through August 2002. Low possibility fire pixels are not included in the composite. The composite does not include multiple detects of the same fire along a scan line due to oversampling of the GOES Imager in the East/West direction. In cases where a given pixel reported

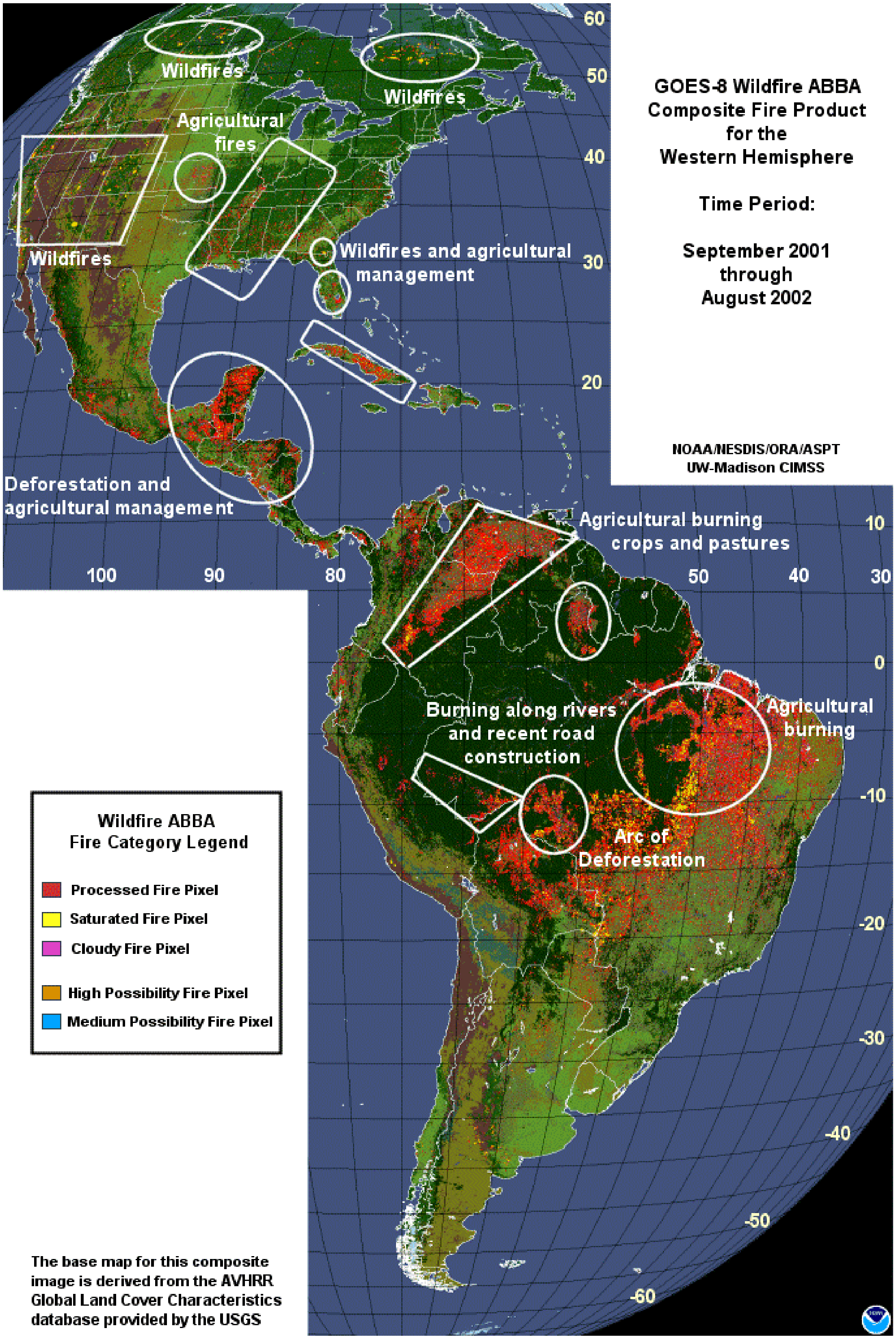

Figure 1. GOES-8 Wildfire ABBA composite of all half-hourly detected fire pixels for the time period 1 September 2001 through 31 August 2002.

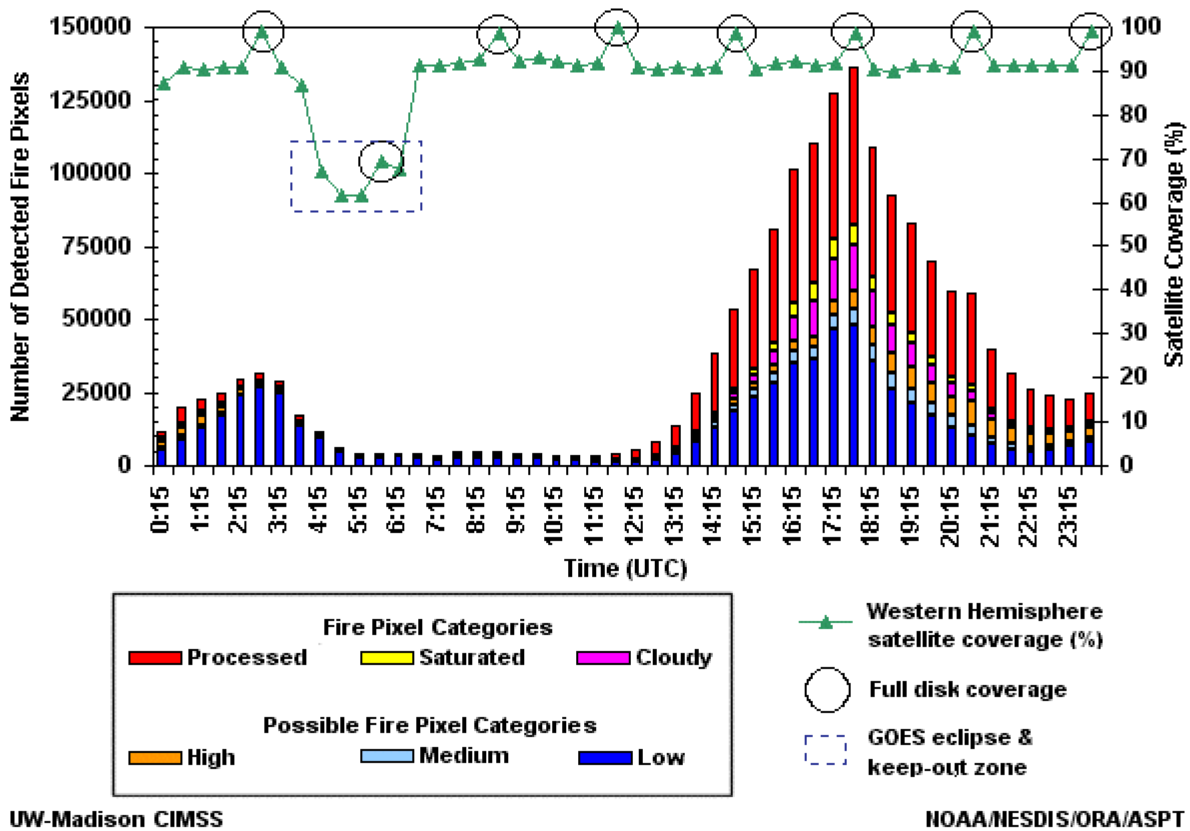

Figure 2. Diurnal distribution of the GOES-8 coverage area and the filtered WF_ABBA fire product for the Western Hemisphere for the time period 1 September 2001 through 31 August 2002.

multiple detects throughout the year, the highest fire confidence level/classification was displayed. In North America fire activity is clearly evident in the western United States and in the Canadian provinces of Alberta, Saskatchewan, Manitoba and Quebec, often in forested/wildland regions. The majority of these fires occurred during the months of June and July in 2002. Clusters of agricultural and grassland fires were observed in the Great Plains states of Nebraska, Kansas, and Oklahoma. Many agricultural fires were also detected in the Mississippi Delta region. Many of these fires are associated with agricultural practices in the fall and spring. The fire pixels detected in Georgia and Florida are associated with both wildfires and agricultural management. In Cuba, Mexico, and Central America, the fires are predominantly associated with agricultural management and deforestation activities and are typically observed during the spring.

The majority of fire activity in the Western Hemisphere occurs in South America. Most of the burning in Brazil, Bolivia, Paraguay, and northern Argentina occurs in the months of August through October. In northern Brazil, Venezuela, Colombia, and Guyana, peak fire activity occurs in the austral spring/summer. In northwestern South America, biomass burning in the countries of Venezuela and Colombia is primarily located in cattle ranching regions, although crops are grown here as well. Some of this fire activity is also located in forested regions. As in the previous year numerous fire pixels were detected in the Guiana Highlands region of Venezuela, Guyana, and northern Brazil. Thousands of fire pixels were located along the arc of deforestation in Brazil with a burning pattern similar to what has been documented by the South American GOES-8 ABBA (Prins et al., 1998a; 1998b; 2001a). The majority of these fires are associated with agricultural applications and deforestation activities. The composite shows distinct burning patterns along rivers and in areas with recent road construction (linear features) (Prins et al., 2001b).

Figure 2 is an overview of the diurnal distribution of temporally filtered GOES-8 WF_ABBA fire products for the time period 1 September 2001 through 31 August 2002. The satellite coverage of the study area for each half-hour time period is also shown. The distributions presented in figure 2 are very similar to what was observed during the first year. The satellite coverage of the entire study area is nearly 100% every 3 hours when the full disk is observed, except at 0545 UTC. At certain times of the year the GOES does not provide imagery from approximately 0415 UTC until about 0615 UTC due to eclipse and solar keep-out-zones. At other times the Northern Hemisphere extended coverage region extends to 20°S, eliminating portions of southern Brazil, Paraguay, Uruguay, Argentina and Chile. Although this region accounts for only 10-15% of the study domain, Paraguay and Argentina have considerable amounts of biomass burning which are not entirely represented in this analysis. The stacked column graph in figure 2 clearly shows that the peak in fire activity occurs around 1745 UTC; primarily due to the South American signature. A secondary peak is centered at 0245 UTC and is primarily associated with fire signals in North America. It is unclear if this peak would extend beyond 0415 UTC if the data coverage was more complete during this time. It is also important to note that from approximately 1145 UTC to 2345 UTC, low possibility fires compose from 20-35% of the total number of fire pixel detections, while from 0015 UTC to 1115 UTC, the percentage of low possibility fires increases to between 40 and 90%. The secondary peak centered at 0245 UTC is primarily composed of low possibility fires and may not represent actual burning. There is also a discontinuity between 2345 and 0015 UTC. This was also observed during the previous year. It is unclear as to why this decrease occurs.

3.2 *A Comparison of Two Years of WF_ABBA Fire Products for the Western Hemisphere*

Although the overall distribution of fire activity is similar for both years, there were significant regional differences. Figure 3 shows fire pixel locations that were only detected during the first year (yellow) or the second year (red). Nothing is plotted for fire pixel locations that were observed in both years. This figure gives an indication of the regional differences in fire activity observed in each year. In North America there was increased fire activity in the western U.S. and northern Canada during the second year. More fire pixels were identified in the Mississippi River valley during the first year. In the Yucatan Peninsula of Mexico and in Guatemala and Belize more fires were reported in the second year. In Nicaragua, the Wildfire ABBA reported more fire activity during the first year. In South America, fire activity along the arc of deforestation in Brazil seems to be quite similar in both years, although there may have been enhanced activity in northeastern Brazil in the second year. In the cerrado regions of eastern Brazil (area highlighted in the white box in figure 3) there appears to be equal amounts of burning in both years, but different pixels are highlighted in each year. This may point to a bi-annual burning signature for the region. In Venezuela and northeastern Colombia, the number of detected fire pixels was greater during the first year. This is also true for western Brazil and central Peru. The large wildfires that burned in south-central Argentina during the 2000-2001 austral summer are clearly outlined in yellow in figure 3 and were not observed during the second year.

Summary statistics were generated for the number of fire pixels detected in North, Central, and South America in each year. In this paper North America includes the region from 30° to 70°N. Central America and Mexico represents the region from 10° to 30°N and South America includes the region from 10°N to 70°S. Approximately 1.51 million filtered fire pixels (all classifications) were observed during the first year (September 2000 – August 2001) and 1.67 million filtered fire pixels were identified during the second year (September 2001 – August 2002). A 10% increase was observed in the second year. Since the processing success rate in the second year only increased by roughly 1% when compared with the previous year, the change in fire activity is probably associated with an actual increase. Some of the difference may also be due to differences in cloud coverage between the two years, although no statistics are available regarding opaque cloud coverage.

During the first year approximately 78% of all filtered fire pixels detected in the Western Hemisphere were located in South America, while 11% were identified in North America, and 12% in Mexico and Central America. During the second year, the statistics were very similar with a breakdown of 77% (South America), 12% (North America), and 11% (Central America and Mexico). This represents a slight relative percent increase in the second year for North America and a slight decrease for South America. Overall, the total number of fire pixels detected in Central and South America increased by 8 and 9%, respectively. It increased by 21% in North America, with a 43% increase in the number of processed fire pixels and a 288% increase in the number of saturated pixels. This primarily reflects the large wildfires that burned in the western U.S. and in Canada in June and July of 2002. It is also interesting to note that when multiple fire detections for the same pixel are not included in the overall annual fire statistics, there is only a 4% increase in fire activity during the second year. This is primarily due to the fact that many of the fires in the western U.S. and Canada burned for many days. In South America, the active agricultural fire signatures for a given pixel are typically only observed for a short time. Even with a record-breaking number of fires in North America during the early summer of 2002, the predominant fire activity remains in South America.

Figure 4 depicts the latitudinal distribution of temporally filtered GOES-8 WF_ABBA detected fire pixels in the Western Hemisphere for each fire category during the first and second years. The distribution is very similar in both years. The greatest number of fire pixels are located in the region from 20°N to 20°S. In North America, although the percentage of fires in the low possible fire category is lower then last year, the true signature of fire activity is masked by the large number of low possibility fires. In fact low possibility fires continue to represent a large percentage of the total detected fire pixels throughout the Western Hemisphere. The significant drop-off in the number of filtered fire pixels south of 20°S is due to the decrease in temporal coverage at these latitudes (every 3 hours instead of every half-hour). When considering all but the low possibility fires, the greatest relative increase in fire activity was observed in the region from 30 to 60°N associated with the wildfires in the western U.S. and Canada and from 0 to 10°S in northeastern Brazil. The largest relative decrease was observed in the region

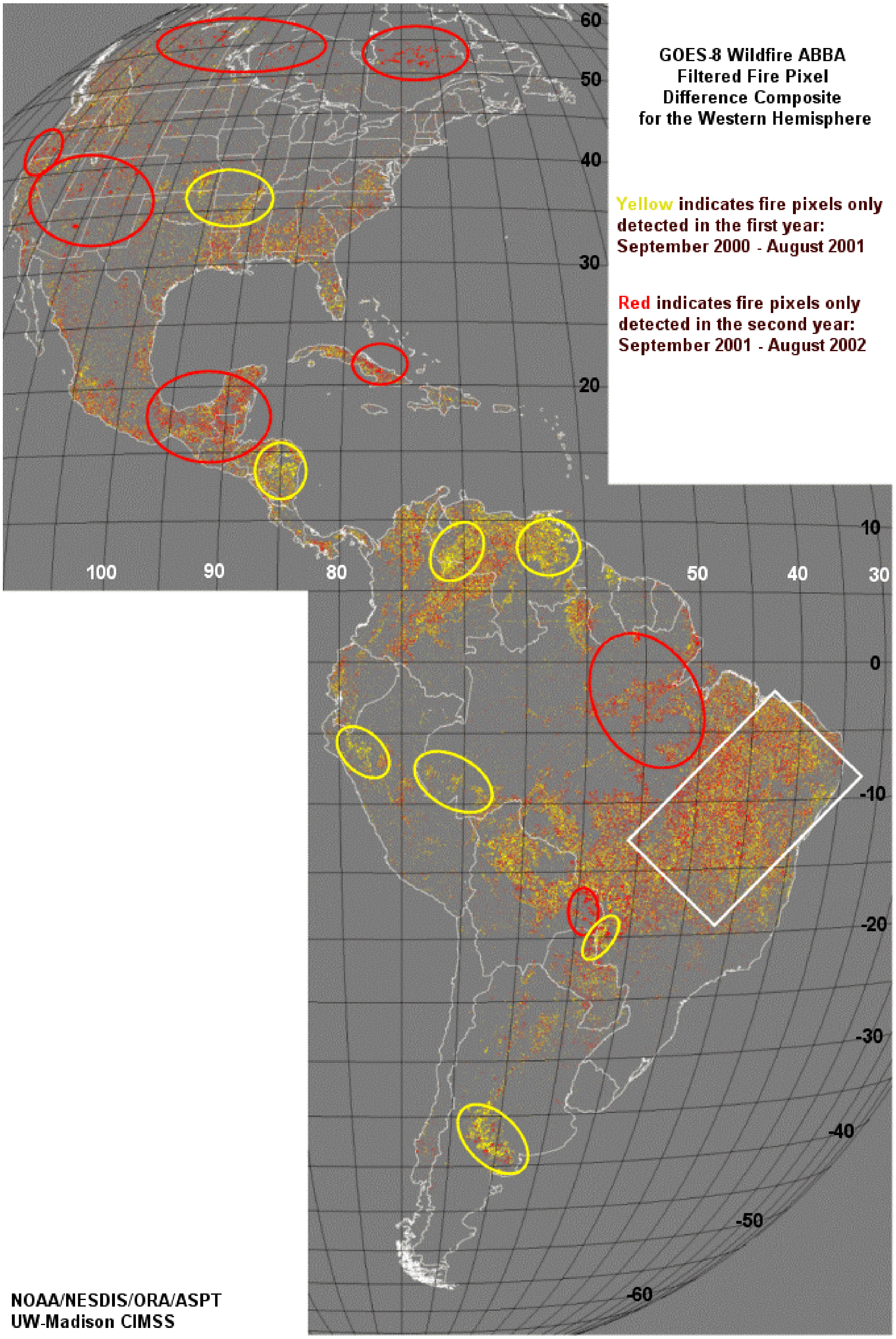

Figure 3. GOES-8 WF_ABBA filtered fire pixel difference composite for the Western Hemisphere. Yellow markers indicate fire pixels that were only detected during the first year and red markers indicate fires that were only detected during the second year.

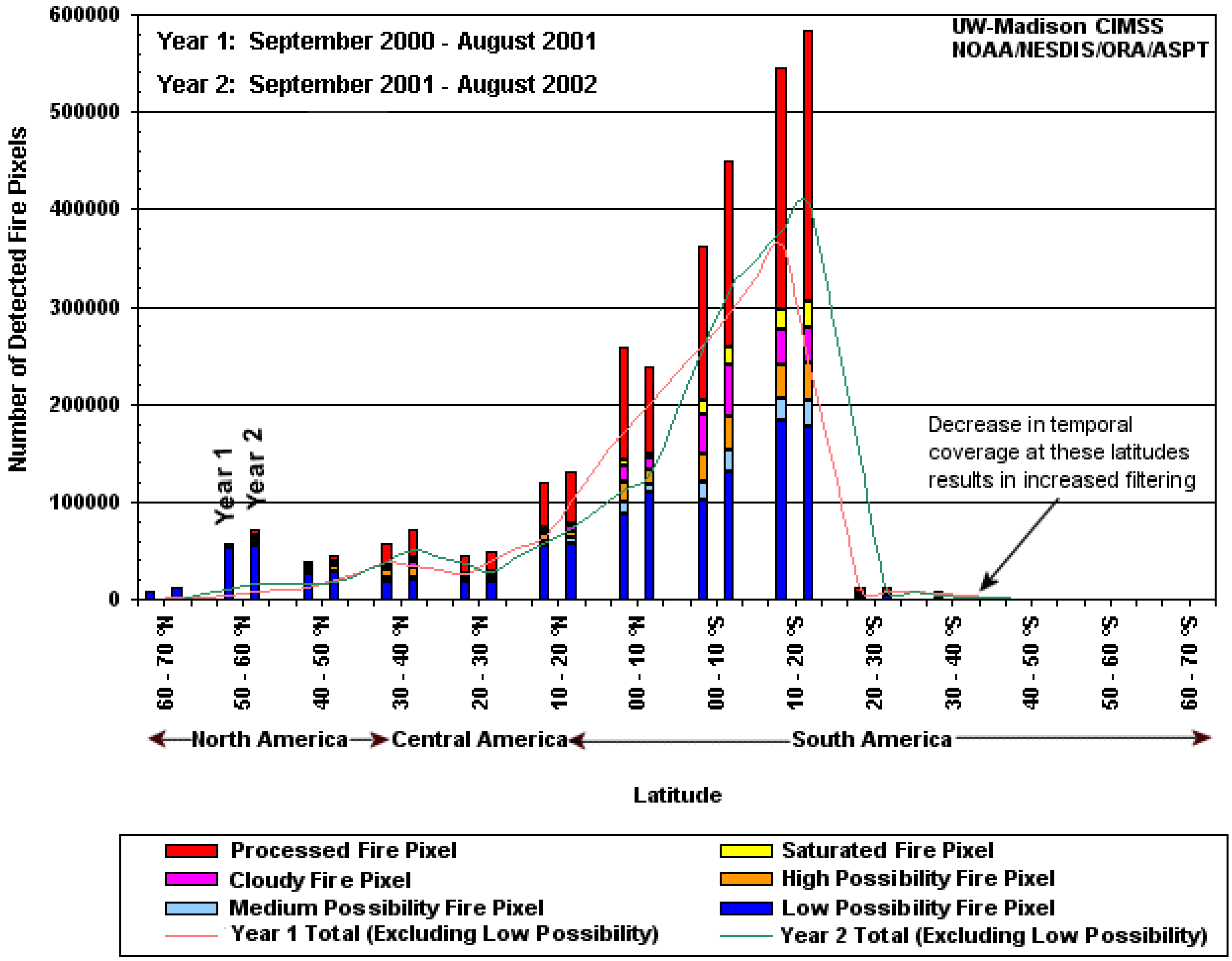

Figure 4. Latitudinal distribution of GOES-8 WF_ABBA fire products for the Western Hemisphere for the first (September 2000 – August 2001) and second year (September 2001 – August 2002).

from 0 to 10°N (Venezuela and Colombia) and 30°S to 50°S (Argentina).

In both years, most of the fire pixels were located in tropical broadleaf seasonal forest, savanna grassland/seasonal woods, and mild/warm/hot grass or shrub ecosystems. The overall ecosystem breakdown is very similar in both years with burning in the temperate and snowy non-boreal forests representing only a small fraction of the total number of fire pixels. The largest relative changes were observed in the temperate broadleaf/conifer forest (+19%) and the snowy non-boreal conifer forest (+56%) ecosystems representing the increased wildfire activity in the western U.S. and Canada in 2002.

4. CASE STUDIES IN THE WESTERN UNITED STATES: AN OVERVIEW OF THE JUNE 2002 WILDFIRES

During the months of June and July 2002, large wildfires raged out of control in the western U.S. and Canada. By June 2002 acreage consumed by wildfires in the western United States was twice the 10-year average for this time of year. A new version of the GOES-8 WF_ABBA (version 6.0) monitored many of these fires in real time and was able to document the rapid intensification of several wildfires. The WF_ABBA also documented the strong diurnal cycle in fire intensity as the fires flared up during the afternoons and diminished at night. Three case studies are featured on the UW-Madison CIMSS

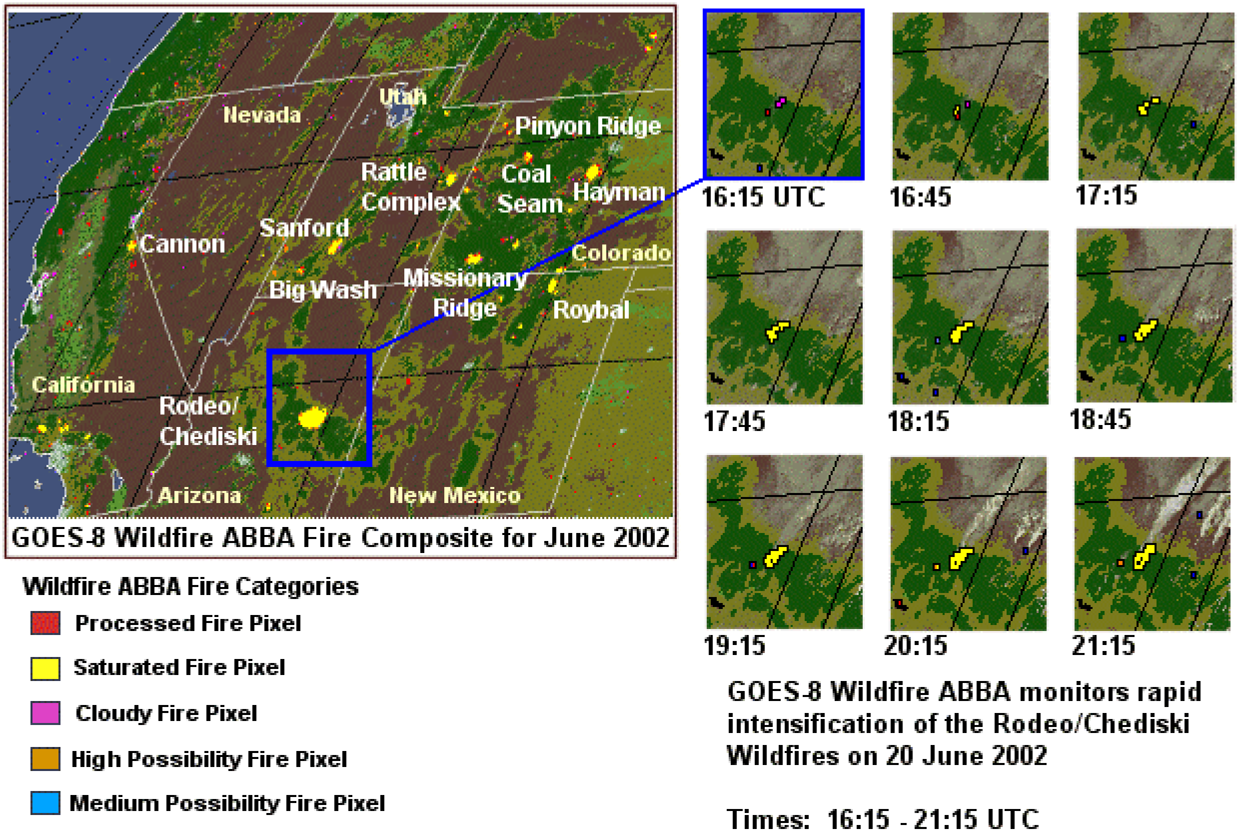

Figure 5. GOES-8 WF_ABBA observations of the June 2002 wildfires in the southwestern U.S.

GOES Gallery and can also be viewed at http://cimss.ssec.wisc.edu/goes/burn/interesting.html, including the Hayman fire in Colorado (~137,000 acres, www.thedenverchannel.com) and the Rodeo/ Chediski complex in Arizona. The Rodeo and Chediski fires combined to form Arizona's largest wildfire in recorded history (469,000 acres, http://www.azdailysun.com). The rapid intensification of the Rodeo/Chediski complex on 20 June 2002 was one of the most extreme examples ever documented with the GOES-8 WF_ABBA. Figure 5 provides a series of half-hourly GOES Wildfire ABBA fire products from 1615 UTC to 2115 UTC. From 1615 UTC to 1745 UTC, the Rodeo fire signature expanded from just a few pixels to numerous saturated fire pixels.

A composite of GOES WF_ABBA half-hourly fire products was created for the month of June 2002 to map the extent of fire activity as observed by GOES-8 (figure 5). The composite clearly shows the extent of the large wildfires that burned throughout the western U.S. Many of the conflagrations were detected as saturated pixels (yellow) in the GOES-8 3.9 µm data reflecting the immense size and intensity of these wildfires.

5. REAL-TIME ASSIMILATION OF THE GOES WILDFIRE ABBA FIRE PRODUCTS INTO THE NAAPS MODEL

For the past two years diurnal GOES Wildfire ABBA fire products have been assimilated into the Naval Research Laboratory (NRL) Aerosol Analysis and Prediction System (NAAPS) in real time as part of the FLAMBE project (http://aerosol.spawar.navy.mil/flambe/flambe_mainmenu.htm). FLAMBE is a joint interdisciplinary effort between the U.S. Navy , National Aeronautics and Space Administration (NASA), National Oceanic and Atmospheric Administration (NOAA), the University of Wisconsin – Madison, and the University of Alabama – Huntsville. It is partially funded by NASA under the Earth Systems Enterprise (ESE) modeling and data analysis research program with cost-sharing from the other agencies. The primary focus of this project is to model biomass burning emissions, transport, and radiative effects using a global prognostic meteorology model. The NAAPS integrates multi-sensor satellite derived fire product information with other aerosol source functions and output from the Navy Operational Global Atmospheric Prediction

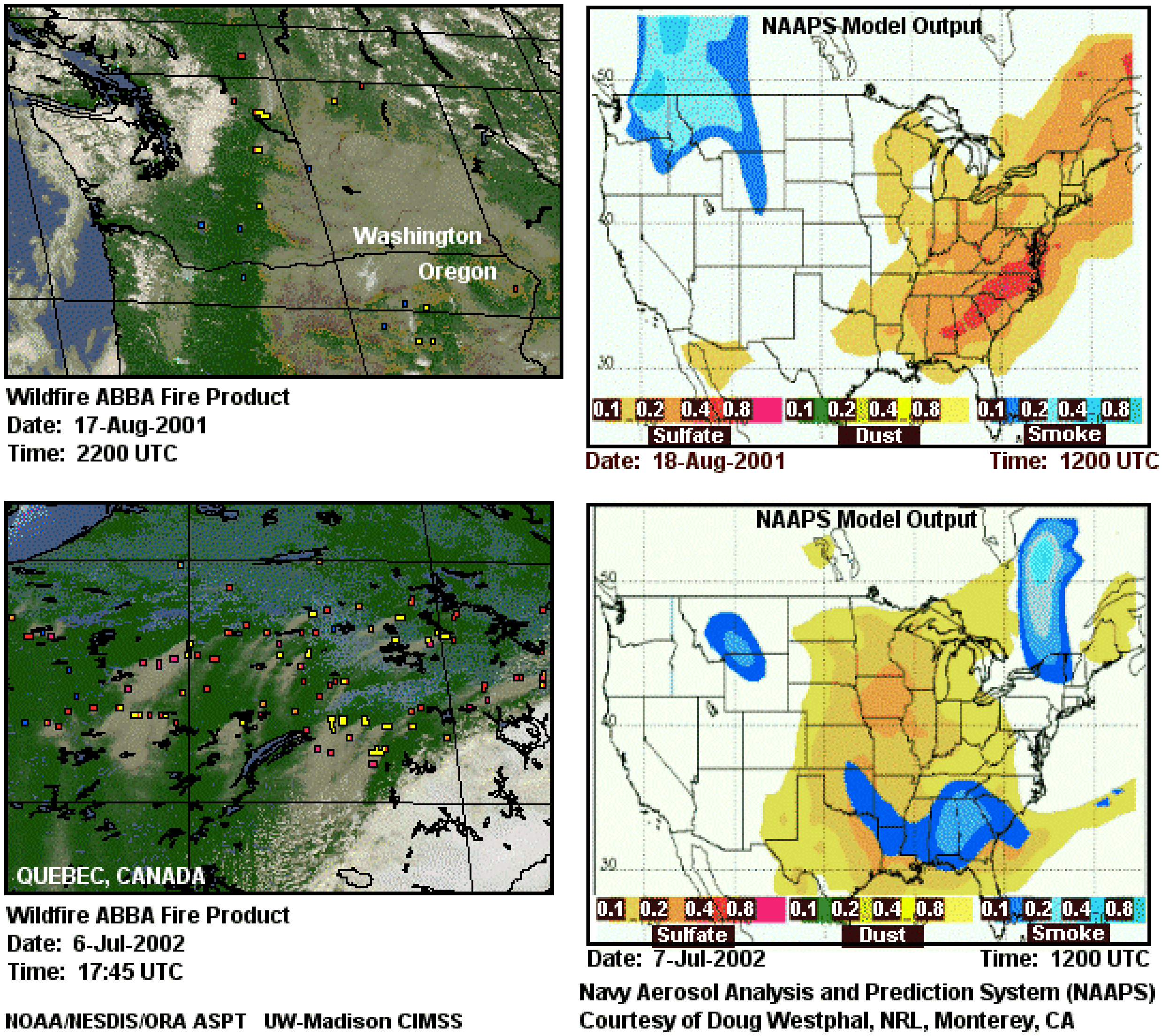

Figure 6. Examples of real-time assimilation of the GOES WF_ABBA fire products into the Navy Aerosol Analysis and Prediction System (NAAPS).

System (NOGAPS) to get a 4-D picture of biomass burning globally.

Figure 6 provides two examples of the GOES WF_ABBA input fire product and the NAAPS aerosol output product for North America. In August 2001 the NAAPS successfully documented the transport of smoke associated with wildfires burning in the western U.S. On 17 August 2001, the GOES WF_ABBA documented several large fires burning in the state of Washington. On 18 August, the NAAPS analyzed a large smoke pall that extended north into Canada and south over the plains of Montana. In early July 2002, the GOES WF_ABBA identified hundreds of fire pixels in Quebec, Canada. Over the next several days a large smoke pall extended over the east coast of the United States reducing visibility and air quality. The NAAPS model output for 1200 UTC on 7 July 2002 correctly depicted the transport of smoke aerosol throughout the region.

6. CONCLUSIONS

Since September of 2000 the UW-Madison CIMSS and the NOAA/NESDIS Office of Research and Applications have provided half-hourly GOES-8/-10 WF_ABBA fire products to the user community in real-time. These products are providing unique insights into the diurnal, seasonal, interannual, and spatial variability in fire activity throughout the Western Hemisphere. Hazard applications include real-time detection of fires in remote locations, diurnal monitoring of rapidly intensifying wildfires, and ongoing monitoring of the diurnal variability in existing fires. The GOES WF_ABBA is also being used to document fires associated with deforestation and agricultural land management. This information is being utilized in climate change research, aerosol and trace gas modeling efforts, and land-use and land-cover change detection studies. Other users include international government agencies, resource managers, fire managers, international policy and decision makers, educational institutions, and the general public. Over the next two years NOAA/NESDIS ORA and the UW-Madison CIMSS plan to adapt the GOES WF_ABBA for application with the European METEOSAT Second Generation (MSG) satellite and the Japanese Multi-functional Transport SATellite (MTSAT-1R) with the goal of implementing a global geostationary fire monitoring network.

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