P4.6 # Global Geostationary Fire Monitoring System

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1. INTRODUCTION

The international environmental monitoring and scientific research communities have emphasized the importance of utilizing operational meteorological satellites to produce routine global fire products and to ensure long-term stable records of fire activity for applications in areas such as land-use/land-cover change analyses, global change research, trace gas and aerosol monitoring, and hazards (Dull and Lee, 2001; Justice and Korontzi, 2001). Since the year 2000, geostationary Wildfire Automated Biomass Burning Algorithm (WF_ABBA) fire products have been produced for the Western Hemisphere in near real-time every half hour. The Geostationary Operational Environmental Satellite (GOES) WF_ABBA was made operational within NOAA NESDIS in 2002 and is currently integrated into the NESDIS Office of Satellite Data Processing and Distribution (OSDPD) Satellite Services Division (SSD) Hazard Mapping System (McNamara et al., 2004). With the launch of the European Meteosat Second Generation (MSG) Spinning Enhanced Visible and InfraRed Imager (SEVIRI) in 2002, the activation of GOES-9 over the western Pacific in spring 2003, and the anticipated launch of the Multi-functional Transport SATellite (MTSAT-1R) Japanese Advanced Meteorological Imager (JAMI) in 2005, it is possible to generate nearly global high temporal resolution fire products (See Figure 1). This paper will provide an overview of the capabilities of each of these platforms for fire monitoring and will discuss future plans for development and implementation of an operational global geostationary fire monitoring system.

2. PLANS FOR A GLOBAL GEOSTATIONARY FIRE MONITORING SYSTEM

Development and implementation of a global geostationary fire monitoring system is being done in cooperation with the Integrated Global Observing Strategy (IGOS) Global Observations of Forest Cover and Land Cover Dynamics (GOFC/GOLD) Fire Mapping and Monitoring program. This project is primarily focused on determining international observation requirements and making the best use of products from existing and future satellite systems for fire management, policy decision-making and global change research. A specific goal of the GOFC/GOLD fire program is to develop and foster the implementation of a near real-time operational global geostationary fire monitoring network using GOES, MSG and MTSAT data to monitor fires as they occur and capture the diurnal signature. The GOFC/GOLD Fire program and the Committee on Earth Observation Satellites (CEOS) Land Product Validation (LPV) Working Group held a joint workshop on *Geostationary Fire Monitoring Applications* to address this goal. The workshop was hosted by the EUropean Organization for the Exploitation of METeorological SATellites (EUMETSAT) in Darmstadt, Germany on 23-25 March 2004. An executive summary can be found online at: http://gofc-fire.umd.edu/products/pdfs/Events/GOFC Geostationary.Workshop.SummaryReport.pdf.

The overall assessment of the workshop was that geostationary systems have an important contribution to make to active fire and smoke detection and characterization with applications in fire management, emissions and air quality studies, and global change research. Geostationary systems can provide valuable diurnal information that is complementary to fire products produced by higher resolution polar orbiting instruments. Workshop participants felt that a global geostationary fire monitoring network is technically feasible, but that it must be supported by the operational agencies in order to sustain the activity and produce standardized long-term data records and fire inventories of known accuracy. In order to demonstrate the science and show the benefits and feasibility of a global geostationary fire monitoring network, a demonstration/feasibility project is planned for 2005 and includes WF_ABBA fire products generated from GOES-9/-10/-12 and MSG. The second phase will incorporate WF_ABBA fire products derived from MTSAT-1R. The focus of the project will be active fire detection, emissions assessment, and intercontinental transport with a strong numerical model data

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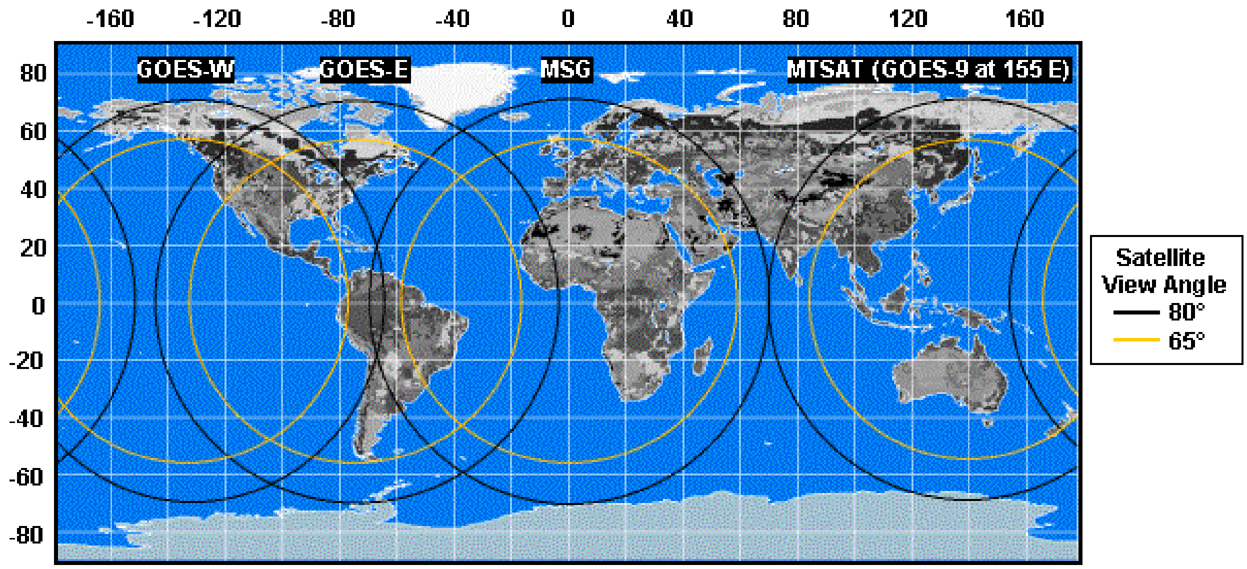

Figure 1. Current/future network of geostationary meteorological satellites with active fire detection capabilities.

assimilation component. In addition, the demonstration phase will be used to identify traditional users and strengthen the input from non-traditional users. Once the demonstration study is completed, the global fire monitoring processing system will be transferred to NESDIS operations where it will be integrated into the OSDPD/SSD Hazard Mapping System (McNamara et al., 2004).

The proposed global geostationary fire monitoring network will include sensors with different spatial resolutions and radiometric characteristics. One of the highest priority items for the GOFC/GOLD Fire Program is to characterize the individual fire monitoring capabilities of the multiple sensors that will be used (GOES Imager, MSG SEVIRI, MTSAT-1R JAMI) and standardize them to create consistent fire products around the globe. The following sections provide some initial insights into the capabilities of the different geostationary sensors for diurnal fire detection and monitoring around the globe.

3. GEOGRAPHICAL COVERAGE OF PROPOSED GEOSTATIONARY FIRE MONITORING NETWORK

For over 20 years multispectral data available from the GOES series have been used to quantitatively monitor diurnal sub-pixel fire activity and smoke transport in the Western Hemisphere. Quantitative geostationary active fire detection and monitoring requires a multispectral approach (using visible, 3.9, and 10.7 µm data) not available on other geostationary platforms until recently. Global geostationary fire monitoring is now possible using GOES-E/-W in the Western Hemisphere, the European MSG satellite, GOES-9 over the western Pacific, and in the near future, the Japanese MTSAT-1R.

Figure 1 depicts the geographical coverage of this suite of geostationary satellites. The current GOES-E and GOES-W platforms are located over the equator at 75°W and 135°W, respectively, providing diurnal coverage of North, Central, and South America. MSG is located over the equator at the Greenwich Meridian providing coverage of Europe and Africa (approximately 60°W to 60°E) with excellent coverage of the African forests. GOES-9 has been positioned at 155°E allowing for some fire monitoring in eastern Asia, and excellent coverage of Australia and portions of Indonesia. MTSAT-1R will be located over the equator at 140°E with active fire and smoke detection capability in the region from approximately 80°E to 160°W with enhanced capabilities for monitoring in Southeast Asia and even portions of India.

In Figure 1 the gold inner circle indicates the areas within a satellite-viewing zenith angle of 65°; the black outer circle represents regions within a satellite-viewing zenith angle of 80°. Fire and smoke detection and monitoring will be limited along the edge of the full disk imagery within the region between the inner and outer circle for each satellite. The figure shows that this suite of geostationary satellites provides excellent coverage of biomass burning in the tropical forests and the mid-latitudes except in Eastern Europe and Western Asia. In boreal regions poleward of 60°, geostationary fire detection capabilities are limited. Polar orbiting instruments such as the Advanced Very High Resolution Radiometer (AVHRR) and the MODerate resolution Imaging Spectroradiometer (MODIS) instrument are better suited for fire detection in northern boreal forests where considerable overlap of successive orbits at high latitudes allows for more frequent observations. For instance, at 80°N/°S the sequential AVHRR swaths overlap by about one-third throughout a day.

Table 1. Overview of Global Geostationary Fire Monitoring Capabilities

Satellite	Active Fire Spectral Bands	Resolution IGFOV (km)	SSR (km)	Full Disk Coverage	3.9 μm Saturation Temperature (K)	Minimum Fire Size at Equator (at 750 K) (hectares)
GOES-12 Imager	1 visible 3.9 and 10.7 μm	1.0 4.0 (8.0)	0.57 2.3	3 hours	~335 K	0.15
GOES-9 & GOES-10 Imager	1 visible 3.9 and 10.7 μm	1.0 4.0 (8.0)	0.57 2.3	1 hour (G-9) 3 hours (G-10)	~324 K (G-9) ~322 K (G-10)	0.15
MSG SEVIRI	1 HRV 2 visible 1.6, 3.9 and 10.8 μm	1.6 4.8 4.8	1.0 3.0 3.0	15 minutes	~335 K	0.22
MTSAT-1R JAMI	1 visible 3.7 and 10.8 μm	0.5 2.0		< 24 minutes	~320 K	0.03

4. GOES, MSG, AND MTSAT FIRE MONITORING CHARACTERISTICS

Table 1 provides a summary of the fire monitoring characteristics for the GOES Imager, MSG SEVIRI, and MTSAT-1R JAMI. The following sections elaborate on the capabilities of each instrument (Prins et al., 2001).

4.1 *GOES IMAGER*

Although diurnal multispectral geostationary fire and smoke detection have been possible in the Western Hemisphere since the early 1980's, the launch of the GOES-8 Imager in 1994 introduced an enhanced capability for diurnal monitoring of subpixel fire activity and aerosol transport providing multispectral imagery every 15 minutes over the continental United States and half-hourly elsewhere. The GOES WF_ABBA utilizes the visible, 3.9, and 10.7 μm data for fire detection and characterization (Prins et al., 2003). The instantaneous geometric field of view (IGFOV) at nadir (sub-satellite point) is 1 km in the visible and 4 km in the infrared window bands. The IGFOVs are oversampled in the east/west direction by a factor of 1.75 in the visible and IR bands providing a sample interval of 0.57 km in the visible band and 2.3 km in the infrared bands at nadir (Menzel and Purdom, 1994). The oversampling in the east/west can be used to enhance the apparent spatial resolution and allows for increased opportunity to capture an entire fire within one field of view.

One of the limiting factors in identifying fires and characterizing subpixel fire activity (e. g., estimates of instantaneous fire size and temperature) is the saturation brightness temperature in the 3.9 μm band. The saturation brightness temperature refers to the maximum brightness temperature that can be derived from the sensor response. For GOES-8 and GOES-12, the 3.9 μm brightness temperature saturation point is elevated above 335 K. For GOES-9 and GOES-10 this value is 324K and 322K, respectively. Less than 10% of the GOES-8/-12 hot spot pixels indicate brightness temperatures of 335 K or greater; thus allowing for sub-pixel fire characterization for over 90% of the detectable fire pixels with GOES-8/-12 (Menzel and Prins, 1996). The number of fire pixels that can be characterized with GOES-9/-10 is less than 20%.

The minimum detectable fire size in clear conditions is bounded by the noise constraints of the GOES Imager, but is primarily determined by factors such as the spatial resolution, satellite viewing geometry, algorithm thresholds, and subpixel fire characteristics. The estimates in this paper do not include atmospheric attenuation and are based on automated fire detection algorithm requirements that the 3.9 μm observed brightness temperature be at least 4 K greater than the average background brightness temperature. This threshold can be reduced to 2 K in homogenous regions allowing for the detection of smaller fires. At the equator, the minimum detectable instantaneous fire size burning at an average temperature of 750 K is 0.15 ha for the GOES Imager; the size increases to 0.32 ha at 50°N. Although the GOES-8 Automated Biomass Burning Algorithm (ABBA) has identified fires in South America estimated to be less than 1 ha in size, ground truth field studies have provided verification for fires on the order of 1 ha in size (Prins et al., 1998). Since the GOES ABBA fire product provides estimates of instantaneous fire size and not total burned area, comparisons were made with ground truth observations and estimates of fire size at the time of the GOES observation in Brazil, the United States and Canada. More studies must be done to validate the GOES ABBA fire product throughout the Western Hemisphere especially in the mountainous regions of the western U.S. where terrain and satellite view angle can influence detection capability.

4.2 *MSG SEVIRI*

MSG is a spin-stabilized satellite and serves as the successor to the European Meteorological

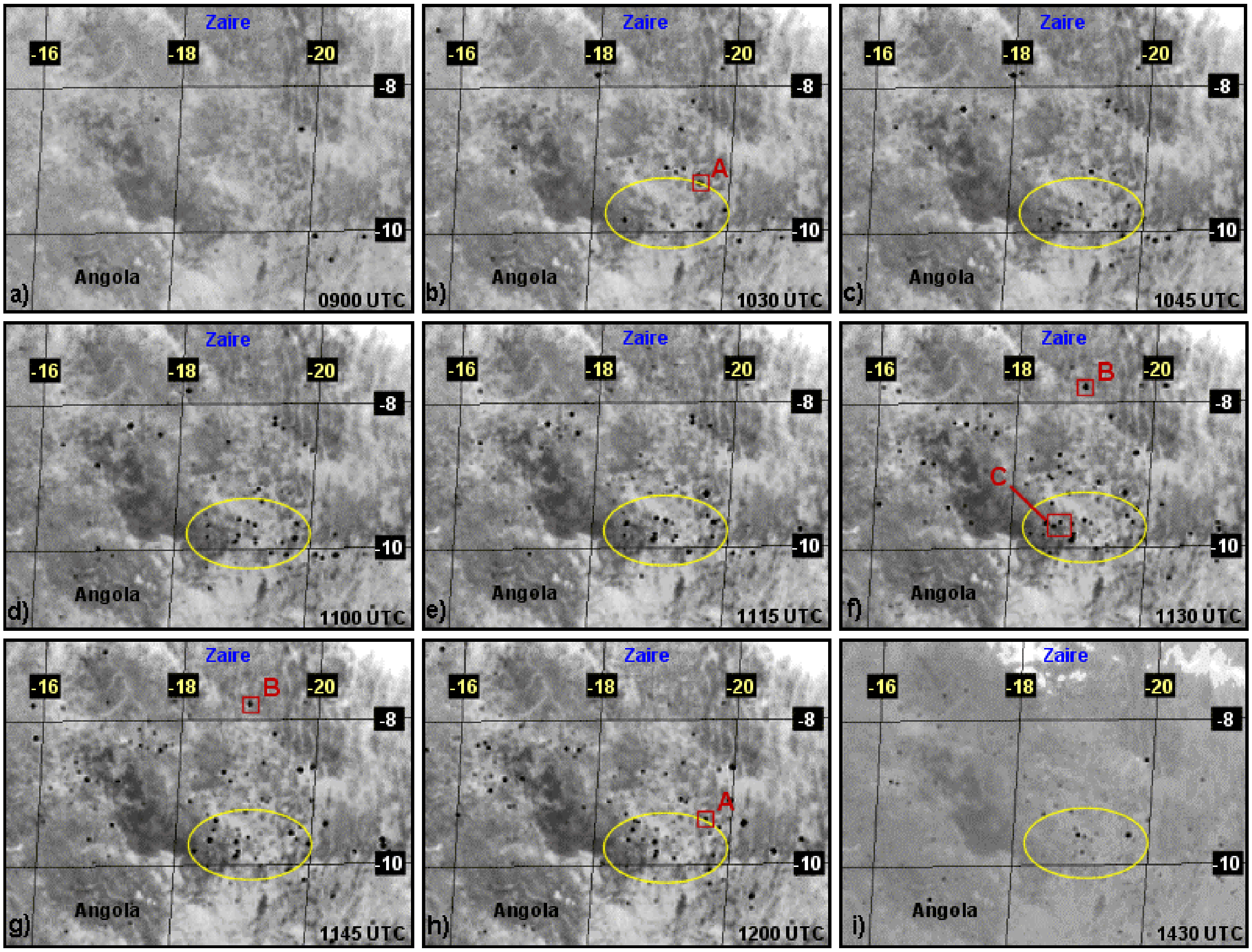

Figure 2. Diurnal variation in African fires as observed in MSG SEVIRI 3.9 µm imagery on 30 July 2004. The dark hot spots are fire pixels.

Satellite (Meteosat) series. The primary instrument on the MSG is the Spinning Enhanced Visible and Infrared Imager (SEVIRI) containing 3 visible bands (broadband centered at 0.75 µm, and bands at 0.63 and 0.81 µm), 1 near-infrared (NIR at 1.6 µm) and 8 infrared bands (3.9, 6.2, 7.3, 8.7, 9.7, 10.8, 12.0, and 13.4 µm). The 3.9 µm band enables subpixel fire monitoring throughout the region. In addition, nighttime measured 1.6 µm radiance can provide quantitative observations of hot spots in the absence of reflected solar radiation contamination during the day, as demonstrated with the Along Track Scanning Radiometer (ATSR) (Wooster and Rothery, 1997). The IGFOV at nadir is approximately 1.6 km in the broadband visible and 4.8 km in the remaining bands, with 10-bit quantization in all bands. All bands are oversampled with a sampled resolution of 1 km in the broadband visible (HRV) and 3 km in the eleven other bands. As mentioned in the previous section, oversampling can be used to enhance the spatial resolution and it increases the opportunity to capture an entire fire within one field of view. Full disk multispectral SEVIRI imagery is available every 15 minutes with shorter repeat cycles possible for selected latitude bands when necessary, although this is at the expense of full disk coverage. For more information regarding MSG SEVIRI please refer to Schmetz et al., 2003.

The elevated saturated temperature (>335 K) in the 3.9 µm band minimizes the impact of saturation and allows for subpixel fire characterization. The shortwave infrared band on MSG is centered at 3.9 µm, which is similar to that on GOES, but it is spectrally wider. The radiometric performance of the 3.9 µm band is very good with a noise-equivalent temperature of 0.24 K at a reference temperature of 300 K. The lower spatial resolution available on MSG and the spectral characteristics of the 3.9 µm band result in a larger minimum detectable fire size compared to GOES and MTSAT-1R. Minimum detectable fire size estimates indicate that MSG will be able to detect a 0.22 ha fire burning at 750 K at the equator and a 0.46 ha fire at 50°N.

Figure 2 shows fire activity in Zaire and Angola on 30 July 2004 as observed in a series of 15-minute

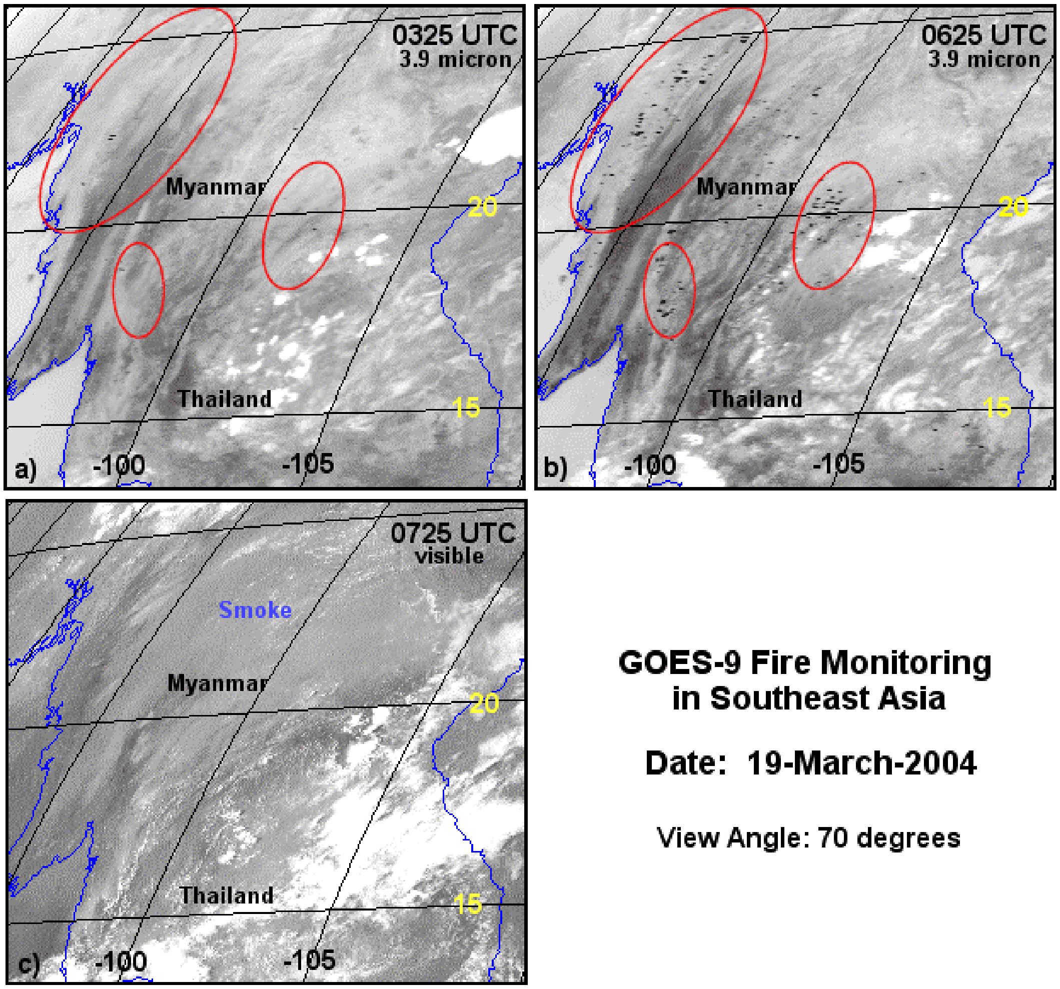

Figure 3. Fires observed in GOES-9 visible and 3.9 µm imagery in southeast Asia on 19 March 2004. The dark hot spots in the 3.9 µm imagery are fire pixels.

MSG 3.9 µm data. The fires appear as dark hot spots. These fires are primarily associated with agricultural management in the savanna and dry tropical woods. The strong diurnal variability in these anthropogenic fires is demonstrated in this series of images. At 0900 UTC (10:00 am local time in Angola) only a few fires are evident in the image (panel a). By 11:30 am local time the fire activity begins to increase (panel b). Over the next several hours numerous fire pixels can be identified in the imagery. A number of the fires are quick burning and can only be identified in one or two images before the signal disappears. Fire pixel A is only observed at 10:30 and 12:00 UTC. Fire pixel B is evident at 11:30 and 11:45 UTC. The fire pixels labeled C only appear in the 11:30 UTC image (panel f). This example clearly shows the importance of high temporal monitoring to capture quick burning or low intensity fires in Africa.

4.3 *MTSAT-1R JAMI*

MTSAT is a multi-functional three-axis stabilized satellite that is being produced by the Japan Meteorological Agency (JMA) and the Japan Civil Aviation Bureau (JCAB) to serve both a meteorological mission as the successor to the Geostationary Meteorological Satellite (GMS) series and an aeronautical mission (JMA, 1997). The initial MTSAT was lost during launch in the fall of 1999. In May 2003, the GOES-9 satellite was activated over the equator at 155°E as part of an agreement with Japan to provide a backup for the aging GMS-5. The loan of GOES-9 to Japan ensures continuous geostationary meteorological coverage in the western Pacific and eastern Asia prior to the launch and activation of MTSAT-1R. It will also enable hourly full disk fire detection and monitoring throughout the region. Figure 3 shows fires observed in GOES-9 3.9 µm and visible imagery in Myanmar and Thailand on 19 March 2004. Even though the satellite view angle is over 70° for this region, numerous agricultural fires are detected in the 3.9 µm image at 06:25 UTC (1:25 pm local time) associated with burning in the croplands and forests. These fires produced large smoke palls as seen in the visible imagery at 0725 UTC (2:25 pm local time). Note that very few fire pixels were detected at 0325 UTC (10:25 am local time).

Preliminary indications are that Japan will launch the replacement satellite MTSAT-1R in the 2005 time frame. The MTSAT-1R will include the Japanese Advanced Meteorological Imager (JAMI), which is similar to the GOES in terms of spectral coverage (Kigawa, 2000). The JAMI includes one visible band (broadband centered at 0.72 μm) and 4 infrared bands (3.75, 6.75, 10.8, and 12.0 μm). The current JAMI design specifies a spatial resolution at nadir of 0.5 km in the visible and 2 km in the infrared bands with 12-bit quantization, although the data may be disseminated to the user community with the reduced resolution of 1 km in the visible and 4 km in the IR. It will be possible to obtain full disk multispectral imagery in less than 24 minutes. The saturation temperature in the 3.75 μm band on MTSAT-1R is expected to be near 320 K, which will hinder subpixel fire characterization due to saturation, but this will still be less of an issue than with historic AVHRR 1 km Local Area Coverage (LAC) data. The spectral width of the 3.75 μm band is significantly wider than the shortwave infrared window band on GOES, extending toward shorter wavelengths and increased solar reflectivity contamination, and spectrally similar to that on AVHRR. The increased spatial resolution of the MTSAT JAMI, spectral differences, and the low saturation temperature will require modifications to the current methodology used to identify and characterize fires with the GOES. MTSAT fire algorithm development will benefit from experiences gained in detecting fires with AVHRR.

The JAMI will offer a unique opportunity to provide early warning in the detection of smaller fires which are not detectable by other geostationary platforms. Minimum detectable fire size estimates suggest that the spectral configuration and 2 km spatial resolution of the 3.75 μm band on MTSAT-1R will allow it to detect significantly smaller fires than with the GOES Imager. With the proposed specifications, the MTSAT-1R will be able to detect a 0.03 ha fire burning at 750 K at the equator. The minimum detectable fire size at 50°N is 0.06 ha. This is 5 times smaller than the GOES minimum detectable fire size.

5. CONCLUSIONS

The suite of current (GOES-9/-10/-12, MSG) and near-term future (MTSAT-1R) operational geostationary satellites offers the capability to generate real-time high temporal resolution fire products and create stable long-term records of diurnal fire activity around the globe. Over the next two years NOAA NESDIS and the UW-Madison Cooperative Institute for Meteorological Satellite Studies (CIMSS) will work in cooperation with the IGOS GOFC/GOLD Fire Program to adapt the GOES WF_ABBA to MSG and MTSAT-1R. Once this task is completed and tested, the global fire monitoring processing system will be transferred to NESDIS Operations where it will be integrated into the OSDPD/SSD Hazard Mapping System (McNamara et al., 2004). The global geostationary fire products will be complementary to those derived from higher spatial resolution polar orbiting instruments (AVHRR, MODIS) providing a more complete picture of global burning with applications in hazards monitoring, climate change research, aerosol and trace gas modeling efforts, land-use and land-cover change detection studies, resource management, and policy and decision-making.

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