

Evolution of Active Fire Monitoring Capabilities from the US Geostationary and Polar Orbiting Satellite Series

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Abstract – Fire products from the Geostationary Operational Environmental Satellite (GOES) series now constitute over ten years of consistent time series and preparations are underway for the improved fire mapping capabilities from the Advanced Baseline Imager (ABI) sensor on board the new generation GOES-R satellites. On the polar platforms, initial fire monitoring from the Advanced Very High Resolution Radiometer (AVHRR) on the operational NOAA series was followed by improved observations from the advanced Moderate Resolution Imaging Spectroradiometer (MODIS) sensor on the NASA Terra and Aqua Satellites. Current research and development activities focus on the continuity and transition from AVHRR and MODIS to fire observations from Visible Infrared Imager Radiometer Suite (VIIRS) on the upcoming NPOESS Preparatory Project (NPP) and Joint Polar Satellite System (JPSS) systems. In addition to the emergence of improved sensors, there have been advances in algorithm development, testing and validation, establishing data continuity among the various sensors, and coordination with compatible international missions.

Keywords: fire detection, satellites, sensors

1. OVERVIEW OF SENSOR DEVELOPMENT

1.1 Geostationary Platforms

The Geostationary Operational Environmental Satellite (GOES) series provide good temporal coverage and an opportunity to monitor daily fire dynamics with consistent observing geometry. Since GOES-8 was made operational in 1995, the 4km resolution Imager on the GOES series has been used to detect and characterize biomass burning (Prins et al., 1998). The Wildfire Automated Biomass Burning Algorithm (WF_ABBA) was under development for several years before being run operationally by NOAA/NESDIS, starting in 2002. Since that time, the WF_ABBA has been improved with expanded detection abilities, including characterization of instantaneous fire size, instantaneous fire temperature and fire radiative power (FRP). Recently the WF_ABBA was modified providing improved metadata that allows for tracking why individual pixels were not labeled as fires, such as opaque cloud cover and block-out zones associated with sun glint, viewing conditions, various biome types, and data issues.

The next generation imager on the operational GOES-R series will be the Advanced Baseline Imager, which will have a 2km resolution, 4 μm band suitable for the improved detection and characterization of active fires in four principal ways. First, the

smaller pixel size will allow for the detection of smaller fires. Second, the increased saturation level will enable the characterization of fires with the wider range of size and intensity. Third, the more frequent observations will reduce the loss of information due to cloud obscuration and will enable more accurate calculation of time-integrated Fire Radiative Energy (FRE). Finally, the improved geolocation will improve the identification of burning areas as well as the accuracy of FRE calculations. The first satellite of the GOES-R series is planned for launch in 2015.

1.2 Polar Platforms

The 1km AVHRR has been used worldwide for operational fire monitoring and for research purposes since at least the early 1990s (Justice and Tucker, 2009). The increased thermal signal in the 3.7 μm channel, together with radiometric measurements in the longwave and shortwave channels, enable the detection of thermal anomalies from AVHRR for a wide range of environmental and observing conditions. (Starting with NOAA-15, the 3.7 μm channel, or channel 3B, has operated according to a channel switching schedule with the 1.6 μm channel 3A.) A number of operational fire monitoring systems around the world have been using AVHRR as one of the primary sensors. Examples include the NOAA Hazard Mapping System, or INPE's (Brazil) operational fire monitoring system.

Over a decade of routine global active fire observations is now available from the 1km resolution MODIS instruments aboard the EOS Terra and Aqua satellites. MODIS represented a major advance in fire observations, allowing the production of 1km global fire detection product with fewer saturated pixels, improved geolocation and orbit stability compared to its predecessors (Justice et al., 2011). Production of routine fire characterization parameters, namely FRP, created new possibilities for direct application of the data towards biomass burning emissions and air quality studies. A major effort was designed to comprehensively assess and validate the quality of the data produced, which in turn allowed the continuous refinement of the *Fire and Thermal Anomalies* algorithm (Giglio et al., 2003). As a result, the product has achieved maturity which is evidenced by the large number of data downloads and data applications found in the literature.

The next generation operational medium resolution imager, the VIIRS (Visible/Infrared/Imager/Radiometer Suite) instrument will provide radiometric measurements that offer useful information for the detection of active fires. The baseline algorithm for the VIIRS Active Fire Mask Application Related Product (ARP), building on the MODIS algorithm, uses

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primarily the M13 (4.05 μm) and M15 (10.76 μm) bands, aggregated from the native resolution measurements into 750m medium resolution pixels according to a scheme aimed at reducing the decrease of resolution towards the edges of the scan line. The first VIIRS sensor will be flown on the NPP (NPOESS Preparatory Project) satellite, to be launched in late 2011, with planned subsequent operational VIIRS sensors on JPSS (Joint Polar Satellite System) and Defense Weather Satellite System (DWSS) satellites (Justice et al. 2011).

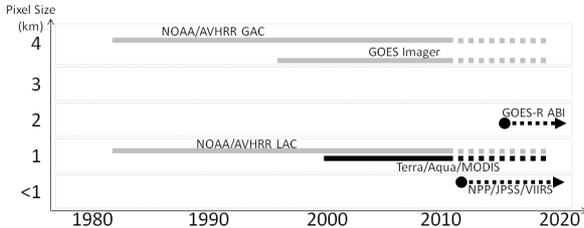


Figure 1. Timeline of long-term US satellite missions with coarse resolution sensors applicable for fire detection. Black lines indicate sensors with dedicated channels for hot spot detection. Grey lines correspond to sensors with suboptimal saturation levels in the 4 μm band.

2. PREPARATION FOR THE NEXT GENERATION OF OPERATIONAL SENSORS

An important element of the current algorithm development and verification efforts is the convergence and leveraging of activities between the geostationary and polar orbiting platforms. These activities are coordinated by the GOES-R and JPSS Algorithm Working Groups and the NASA NPP Science Team.

2.1 Algorithm Development

Both the ABI and VIIRS fire detection algorithms follow the principles of the thresholding-contextual approaches previously implemented within the GOES Imager and MODIS processing systems. Algorithm improvements include modifications to account for the different sensor characteristics and the inclusion of advanced tests as a result of prior experience. For example, detailed evaluation of MODIS fire detections in the Amazon revealed increased false alarms at forest clearings with sizes compatible with the MODIS pixel size. A new test to reduce such false alarms was implemented in the latest version (Collection 6) of the MODIS active fire algorithm and is proposed to be included in the VIIRS algorithm.

2.2 Product Validation

The validation plans for ABI and VIIRS build on the use of fine resolution near-coincident imagery for fire detection and characterization assessment. The validation approach is similar to the method developed for the Terra MODIS *Fire and Thermal Anomalies* product (Justice et al., 2002), which was based on the use of Landsat-class data including coincident 30m resolution ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) imagery (Morisette et al., 2005; Csiszar et al., 2006), and near-coincident 30m resolution Landsat-5 TM imagery.

Due to the transient nature of active fires, the above methodology is applicable only if simultaneous Landsat-class observations are available (Csiszar and Schroeder, 2008). This is less an issue for geostationary sensors with frequent observations (Schroeder et al., 2008). However, it is not possible to directly use Landsat-class data, normally collected during the local morning hours (~10am) to validate NPP VIIRS

data collected at the early afternoon overpass. Alternative reference data sets are limited in this case, to those derived from airborne instruments with fire-dedicated bands. Additionally, the limited reference data can be used to verify the accuracy of theoretical radiative transfer simulations to estimate the detection capabilities from medium resolution sensors.

3. TOWARDS A LONG-TERM ACTIVE FIRE DATA RECORD

3.1 Data Continuity and Compatibility

Fire Disturbance is an Essential Climate Variable (ECV) defined by the Global Climate Observing System (GCOS, 2010). Within the Fire Disturbance ECV, active fire occurrence is one of the supplementary variables. General requirements for long-term satellite-based data records for ECVs are articulated in the GCOS Climate Monitoring Principles for satellite measurements, which specify requirements both for observing systems and for product generation and distribution (GCOS, 2006).

The GOES fire data record, now spanning over a decade, albeit for the Western Hemisphere, allows the creation of long-term consistent datasets that also characterize the diurnal cycle of fire activity. For example, this capability was utilized by a project within the Large-scale Biosphere-Atmosphere Experiment in the Amazon (LBA) to derive a 10-year (1998-2007) active fire data record for South America from GOES imager data, using a refined fire detection algorithm within the system.

The long data record of AVHRR makes it an essential part of a long-term, multi-sensor record of fire activity. For AVHRR major sensor-related challenges include the relatively low saturation level of the 3.7 μm channel, the orbital drift of the early NOAA satellites and pixel geolocation inaccuracies. Additionally, detection of most fires requires full resolution observations and therefore the globally and systematically available 4km Global Area Coverage (GAC) data are inadequate for global active fire monitoring. While regional-scale long-term reprocessing (e.g. Pu et al., 2007), as well as global-scale data collection and processing for limited time periods (e.g. Dwyer et al., 2000) have taken place, the reprocessing of the complete 1-km AVHRR archive remains a challenge.

The availability of several years of global MODIS fire data series allows for the analysis of the spatial and temporal dynamics of fire activity (Csiszar et al., also Giglio et al.). Fire detections from the latest reprocessing of the MODIS data record have been processed into Terra and Aqua MODIS monthly Climate Modeling Grid (CMG) fire products at 0.5° spatial resolution (Giglio et al., 2006). The MODIS CMG fire products are primarily intended to facilitate the incorporation of the MODIS active fire products into global climate, emissions, and chemical transport models. Data layers in this product include fire pixel counts (corrected for geometric effects, missing observations, and variable cloud cover), FRP, mean fire detection confidence and land use and land cover information.

3.2 International Coordination

Global Observation of Forest Cover/Global Observation of Landcover Dynamics (GOF-C-GOLD) is a panel of the Global Terrestrial Observing System (GTOS) and also part of the project of the Integrated Global Observing Systems (IGOS)

(Townshend et al., 2011). The GOF-C-GOLD Fire Mapping and Monitoring theme is aimed at providing the necessary coordination to improve fire data access and use, and to secure long-term fire observing systems. The GOF-C-GOLD Fire program addresses the needs of resource managers, policy makers and the scientific community, covering such topics as fire danger rating, fire detection and characterization, fire affected area mapping, post fire recovery and fire emissions. The goals include summarizing fire management and research information needs for the data providers, improving improved access to and use of fire data and information, standardizing satellite products and determining their accuracy, promoting research and development to improve information provision, and securing long term global operational monitoring of fires.

One of the specific goals of GOF-C-GOLD fire is the development of an operational global geostationary fire network providing observations of active fires in near real time from satellites operated by multiple agencies (Prins et al., 2001). In response to this goal, NOAA/NESDIS has implemented an extended WF_ABBA processing system that now includes, in addition to GOES, data from the Meteosat Second Generation (MSG) SEVIRI (Spinning Enhanced Visible Infra-Red Imager) and the MTSAT-1R/-2 sensors, forming a near-global operational system. Planning is underway for the inclusion of additional sensors, such as that of the Communication, Ocean, and Meteorological Satellite (COMS) of the Korea Geostationary Satellite Program and the Indian geostationary satellite, INSAT-3D.

GOF-C-GOLD, in coordination with the Committee on Earth Observation Satellites (CEOS), also articulates the need for the compilation and reprocessing of full resolution AVHRR measurements from on-board Local Area Coverage (LAC) data and direct-readout High Resolution Picture Transmission (HRPT) receiving stations. This activity would build on similar efforts such as the International Geosphere Biosphere Program (IGBP), Global Land 1km AVHRR Project by the US Geological Survey (Teillet et al., 2000).

As fire detection capabilities strongly depend on the observing system, establishing a continuity is also needed among AVHRR, MODIS, VIIRS as well as non-US sensors such as the (Advanced) Along-Track Scanning Radiometer ((A)ATSR), and the upcoming Sea and Land Surface Temperature Radiometer (SLSTR) on the ESA GMES Sentinel-3 satellite. Such continuity can be established by improved understanding of detection capabilities through systematic product validation and simulations. This could include geostationary fire observations as a reference to account for differences in satellite overpass times and the consequent different sampling of the diurnal cycle of fire activity from polar orbiters. For inter-comparison and inter-use of products from international satellite systems, it will be important to have accepted standards for products and protocols for product validation.

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