

# Satellite Active Fire Product Validation Using High Spatial Resolution Reference Data

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**Abstract** – Current satellite active fire products provide a snapshot of biomass burning activity at regional to global scales. In order to assess the performance of those products, it is important to: (i) have near-coincident reference data to avoid validation artefacts due to short-term variations in fire conditions; and (ii) to be able to represent the entire active fire line and adjacent smouldering areas, as well as the surrounding fire-free background that will normally be used by contextual fire algorithms in the classification of a fire pixel. In this study, we present the results from the global scale assessment of the EOS/Terra MODIS 1km active fire product (MOD14) based on the use of near-coincident 30m Landsat-class reference data. The validation methodology is also demonstrated for other fire products, with a focus on the next generation NPP/VIIRS and GOES-R/ABI pre- and post-launch active fire validation plans using Landsat-class and airborne reference data.

**Keywords:** active fires, satellites, validation, MODIS, ASTER, Landsat.

## 1. INTRODUCTION

Geostationary and polar orbiting satellites provide a unique view of daily fire activity at continental to global scales. Use of the available active fire data range from near-real time fire monitoring systems, to biomass burning emissions estimation and Earth science applications [Davies *et al.*, 2009; Freitas *et al.*, 2005; Morton *et al.*, 2006]. Consequently, it is important that the performance of those products be fully characterized and documented. Validation of satellite active products demands near-coincident fine resolution reference data in order to describe sub-pixel fire conditions at the time of overpass [Csiszar *et al.*, 2006]. Short-term changes in fire behavior, corroborated by the diurnal cycle of fire activity, result in very stringent requirements for validation, limiting maximum separation between satellite fire and independent reference data sets to approximately 15 minutes [Csiszar and Schroeder, 2008; Giglio, 2007].

The global *Fire and Thermal Anomalies* 1km product derived from the Moderate Resolution Imaging Spectroradiometer (MODIS) aboard the EOS Terra and Aqua satellites was the first of its kind to incorporate a comprehensive validation plan in support of product verification and refinement [Giglio *et al.*, 2003; Justice *et al.*, 2002]. That plan called for routine validation activities implemented at a global scale. Those included inter-comparison analyses with other satellite fire

products and the use of coincident 30m resolution data from the Advanced Spaceborne Thermal Emission and Reflection radiometer (ASTER) aboard the Terra satellite, complemented by field-based validation activities. Use of ASTER active fire reference data to validate the Terra/MODIS fire product (MOD14) evolved from a regionally-adjusted method [Morissette *et al.*, 2005] to a more generic fire algorithm [Giglio *et al.*, 2008] applied to different geographic regions [Csiszar *et al.*, 2006; Schroeder *et al.*, 2008a, b]. Thanks to those initial fire data analyses the MOD14 product could achieve stage 2 validation status (see: <http://landval.gsfc.nasa.gov/>).

In order to further expand the assessment of the MODIS active fire data and continue product refinement, a more comprehensive validation analysis covering a wide range of environmental and observation conditions was needed, including sampling of off-nadir MODIS viewing geometries not covered by ASTER. To meet that requirement and thereby achieve stage 3 validation status, a Terra/MODIS fire validation data set of unmatched size was arranged using approximately 2,500 coincident ASTER scenes complemented by 3,700 near-coincident Landsat-5 TM scenes to allow sampling of off-nadir MODIS pixels. In this study we report on that major accomplishment.

The validation methodology described in this paper is applicable to most satellite fire products, provided that adequate near-coincident Landsat-class or other fine resolution fire reference data sets are available. To demonstrate that, we briefly discuss the fire product validation plans being designed for the next-generation National Polar-orbiting Operational Environmental Satellite System Preparatory Project (NPP) Visible/Infrared Imager/Radiometer Suite (VIIRS) and the Geostationary Operational Environmental Satellite R Series (GOES-R) Advanced Baseline Imager (ABI) active fire data sets.

## 2. MODIS ACTIVE FIRE ASSESSMENT

### 2.1 Data Sets Used

The global validation of Terra/MODIS active fire product analyzed more than 390,000 MODIS pixels with one or more 30m active fire pixels observed by ASTER or Landsat-5, including over 28,000 daytime and 700 nighttime MOD14 fire pixels. The data sets used in the validation are listed in Table 1.

Table 1: Main data sets used in the validation of MOD14 data.

Data Set	Data Type	Main Parameter
MOD14 (C5)	5min swath data (HDF)	Binary fire detection
MOD03 (C5)	5min swath data (HDF)	Pixel lat/lon
ASTER	60×60km L1B (HDF)	30m active fire mask
Landsat 5 TM	180×180km L1G (geotiff)	30m active fire mask
VCF (C4)	10°×10° gridded data (HDF)	500m percent tree cover

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The use of an equidistant global grid and a carefully designed site selection strategy guaranteed homogeneous sampling of a wide range of environmental and observation conditions. As seen in Figure 1, the Terra/MODIS and Landsat 5 TM orbits begin to overlap at approximately  $\pm 25^\circ$  latitude and converge towards the north and south poles, covering a wide range of MODIS scan angles ( $17^\circ$ - $55^\circ$ ). The MOD14 sample spanned 2001-2010. As a result, the product could be validated for both temporal and spatial consistency, while representing different vegetation subsets.

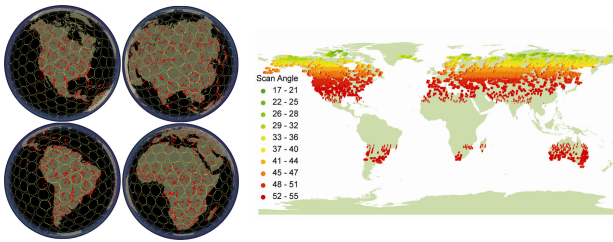


Figure 1: ASTER/MODIS (left) and Landsat5/MODIS (right) data using in the global validation of MOD14. Red shades on left panel indicate  $\sim 60 \times 60$  MODIS pixel clusters sampled by ASTER; superimposed is the circular equidistant grid used. Right panel highlights MODIS pixels sampled by Landsat5 with the color code representing their scan angles.

## 2.2 Results and Discussion

The first analysis performed was the test of temporal consistency to verify product stability over time. Using three subsets of validation data corresponding to 2001-2002, 2003-2004, 2005-2006, we found no statistically significant ( $p < 0.01$ ) difference in product performance over time. Next, omission and commission errors were quantified as a function of percentage tree cover using ASTER reference data, hence representing near-nadir (1km pixel) MODIS viewing conditions. Figures 2a, b show that vegetation density is a key factor influencing the MODIS fire product performance.

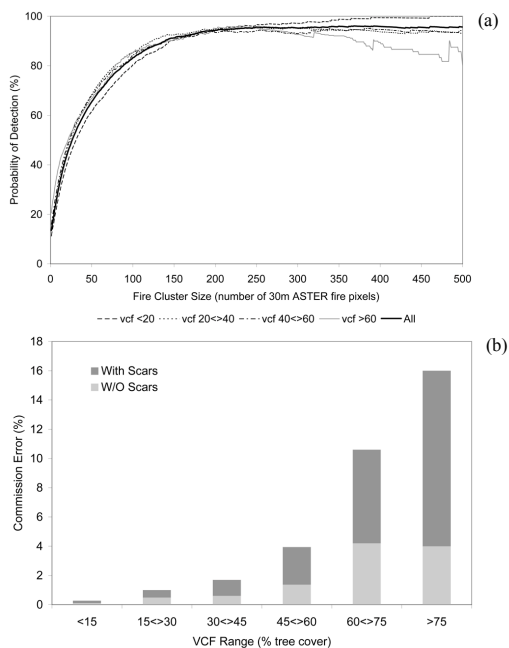


Figure 2: MOD14 probability of detection curves (a) and commission error rates (b) as a function of percentage tree cover. Light (dark) grey in (b) represent fire without (with) coincident burn scars.

Omission errors were found to vary by as much as 10% between sparse and densely vegetated areas, with the latter showing smaller errors. Areas of abnormally high omission errors were found over large fires in densely vegetated areas (see decline in “vcf>60” curve at the high end of fire cluster size in Figure 2a). The decline in detection performance in those cases was found to be caused by heavy smoke contamination leading to omission errors. Conversely, commission errors were small for sparsely vegetated areas, increasing gradually with tree cover. A large percentage of false alarm pixels were found to be spatially coincident with burn scars; false alarms may occur as a result of the high radiometric contrast between those areas and their background.

Similarly, probability of detection and commission error rates were derived for different MODIS scan angle intervals using the Landsat 5 TM reference data. Figures 3 a, b show that product performance responds linearly to pixel area, decreasing the probability of detection and increasing commission error rate as the pixel area increases towards the edge of the scan. In both cases we see a reduction of the fractional area of the pixel occupied by fire leading to a decrease in the spatial contrast between the target pixel and its background, making it progressively more difficult to identify small fires and to discern true fire pixels from false alarms.

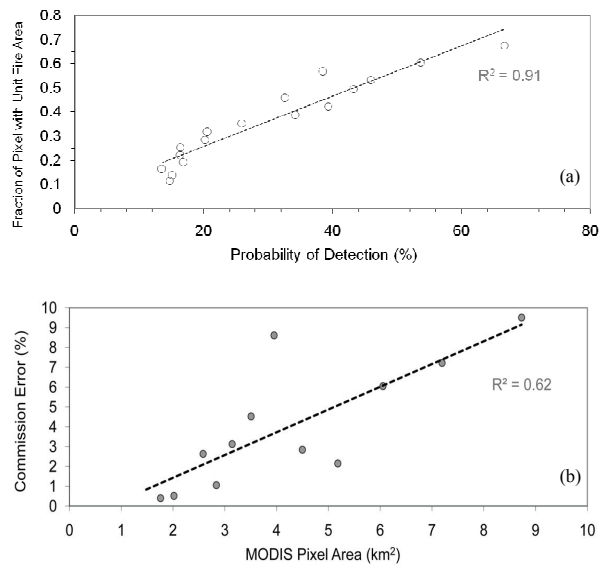


Figure 3: MOD14 probability of detection (a) and commission error rate (b) as a function of pixel area.

## 3. NEXT GENERATION SENSORS

### 3.1 NPP Visible/Infrared Imager/Radiometer Suite

The next generation NPOESS/VIIRS sensor will inherit much of the fire science developed for MODIS, including algorithm architecture and validation approach. As such, it is considered the primary successor of the MODIS global fire data record. Pre-launch assessment of active fire product performance suggests measurable gain in probability of detection of small fires compared to MODIS as a result of improved spatial resolution (750m). Like MODIS, the VIIRS active fire validation plan calls for the use of near-coincident fine resolution data for routine product assessment. The afternoon orbit of the first flight unit (NPP/VIIRS), however, poses major

challenges for the use of Landsat-class data normally acquired around 10am local time. In this case, the time separation between NPP/VIIRS and Landsat-class data sets becomes prohibitively large to allow active fire validation. As an alternative, robust data simulation schemes will be used in combination with airborne fire reference data. While the lack of near-coincident Landsat-class data represents a major drawback for the routine validation of NPP/VIIRS active fire product, the use of airborne data allows investigation of fire characterization parameters that are not usually possible to assess using Landsat-class data primarily as a result of inadequate band configuration and frequent pixel saturation.

Figure 4 shows initial results from the application of robust data simulation techniques to replicate observed MODIS data. In this case, fire and background pixels were derived using ASTER data to constrain the radiance values while accounting for MODIS pixel spectral and spatial responses and atmospheric effects. Similar approach will be used to simulate VIIRS fire and background radiances constrained by airborne reference data.

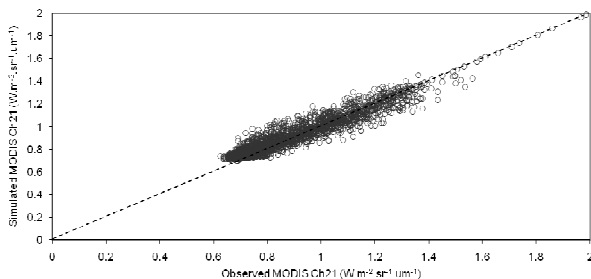


Figure 4: Simulated and observed radiances derived from Terra/MODIS middle-infrared channel 21.

### 3.2 GOES-R Advanced Baseline Imager

The next generation GOES-R/ABI active fire product builds on the Wildfire Automated Biomass Burning Algorithm (WF\_ABBA) developed for the GOES Imager [Prins and Menzel, 1992]. Like their polar orbiting cousins, ABI is expected to deliver improved fire information over its predecessor, GOES Imager, primarily as a result of enhanced spatial resolution (2km), observation frequency (15min), and image navigation stability. Despite nearly 15 years of active fire data archived, there were few validation studies for the GOES Imager WF\_ABBA product [Schroeder *et al.*, 2008a; Prins *et al.*, 1998]. One of the primary reasons for such scarcity of validation studies deals with the navigation errors in the GOES Imager data. These errors can have a major impact on the validation when sub-pixel fires are analyzed at spatial scales of Landsat-class data.

Taking advantage of its improved data quality, the active fire validation plan being implemented for ABI calls for routine assessment of the active fire product using an extensive fire reference data base derived from Landsat-class data. Major reference fire data sets include the Landsat Data Continuity Mission (Landsat 8), the European Space Agency Sentinel-2, and the NASA Decadal Survey Mission HysPIRI sensor. Airborne fire reference data are also expected to play a role in the validation of fire characterization parameters including fire size, temperature, and radiative power (FRP) and energy (FRE).

## 4. CONCLUSION

The gradual increase in active fire data records available from geostationary and polar orbiting satellites has substantially increased the use of those data by both science community and end users. A major effort has been dedicated to the verification and refinement of some of those products, among which the MODIS *Fire and Thermal Anomalies* product is one of the best examples. The favorable EOS Terra platform configuration, which uniquely combines the MODIS and ASTER sensors, was key to allow the implementation of a global validation plan for the 1km MOD14 active fire product. Changes in data policy affecting the United States Landsat program further facilitated access to useful reference data to complement the information available from ASTER. As a result, the MOD14 product achieved stage 3 validation status, an important step towards the creation of stable longer term environmental data records.

One of the most important aspects of any validation work is the need for continued product development. Results from the MODIS fire product validation have been successfully used in support of algorithm modifications and improvement. Building upon the lessons learned from MODIS, the active fire products being designed for the next-generation NPOESS/VIIRS and GOES-R/ABI sensors will incorporate similar validation plans albeit with modifications to adapt to the available reference data at time the time of launch. One major difference concerns the use of airborne data to fulfill the requirements for validation of fire characterization parameters, namely fire size, temperature and radiative power and energy. Fire characterization parameters have largely expanded the use of satellite active fire data by the scientific community, although those data have been poorly validated primarily due to the lack of adequate reference data and protocols. There is great potential though for significant advances in this area as new spaceborne sensors of improved performance and complementary airborne fire data sets become available.

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