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From local to global assessments

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Editors

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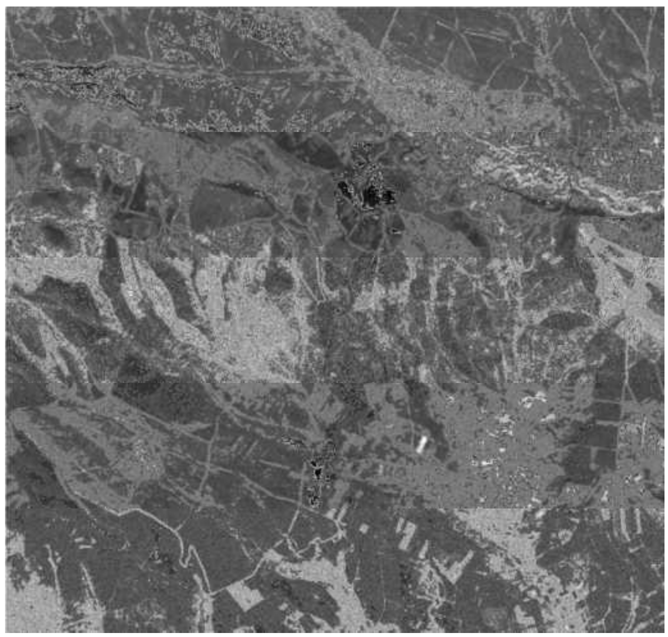

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NASA'S AIRBORNE AUTONOMOUS MODULAR SCANNER (AMS) – WILDFIRE SENSOR: INSTRUMENTATION SUPPORTING FIRE INTENSITY, RADIANT ENERGY MEASUREMENTS, AND DISASTER MANAGEMENT

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Abstract

The NASA Autonomous Modular Scanner (AMS) – Wildfire sensor is an airborne, 16-channel line scanner with bands in the VIS-IR-MIR-TIR spectral region. Four AMS thermal channels replicate the spectral bandpass region of two of the proposed NPOESS VIIRS channels and allow improved discrimination of wildfire conditions over other airborne wildfire sensor systems. The AMS has operated on a range of manned and unmanned aircraft, including the NASA Ikhana UAS, and more recently the NASA Beechcraft B-200 King-Air manned aircraft. On-board processors allow near-real-time Level 2 products to be derived from the spectral data and sent through a satellite link to investigators on the ground. The AMS processing algorithms can be modified in flight to allow derivation of various fire property indices to be calculated. Real-time, on-board processing includes terrain / geo-rectification procedures that allow generation of standard Open Geospatial Consortium (OGC) – qualified data. The AMS-Wildfire instrument has been flown extensively in the western U.S. since 2006, supporting disaster managers with real-time fire products such as the CCRS hot spot / temperature threshold detection algorithm, a Normalized Burn Ratio (NBR) product for post-fire burn assessment and a Burn Area Emergency Response (BAER) data set to allow rapid post-fire burn area / fire intensity assessment. The data sets were routinely delivered to fire incident management teams to support operational mitigation efforts, as a demonstration of new sensor technologies, utility of UAS platforms, and autonomous processing capabilities. The AMS data processing is being further modified to provide additional fire-related products that support the wildfire science community and support calibration / validation of current and future earth observation satellite systems, such as MODIS and NPOESS - VIIRS. The AMS has supported satellite calibration and validation efforts with collections over wildfire events simultaneously with MODIS data collections during campaigns in 2007-2010. These measurements have led to improved understanding of the satellite observations and allowed a renewed focus on the AMS sensor as an instrument capable of deriving critical fire parameters to allow improved estimation of wildfire thermal properties. With high spatial, temporal and radiometric measurement capabilities of the AMS instrument, improved discrimination of fire properties are achieved. The "lingering" capabilities afforded by airborne platforms, allow temporal observations of fire properties, rather than the single observations provided by satellite systems. A new fire radiative power (FRP) algorithm is being added to the suite of on-board, autonomous-generated, real-time image processing capabilities, to allow cross-referencing with the MODIS-derived FRP product for coincident wildfire observations. Additionally, the airborne AMS FRP measurements will allow assessment of the future NPOESS VIIRS FRP product, and can also be used to support validation efforts of the GOESS-R ABI Active Fire Product parameters. The AMS operations, successful missions, and plans for future use to support both the fire science community and the disaster management community are described here.

Keywords: wildfire, AMS, Fire Radiative Power (FRP), TIR, MODIS, VIIRS, GOES-R ABI

Background

The National Aeronautics and Space Administration (NASA) Autonomous Modular Sensor (AMS) – Wildfire scanner, is a 16-channel airborne instrument imaging in the visible / near-infrared / mid-infrared / thermal-infrared (VIS-IR-MIR-TIR) electromagnetic regions. Between 2006 and 2011, the AMS was employed on manned / unmanned platforms, to support imaging science capabilities and provide near-real-time, on-board-processed, Level 2 data products to wildfire incident management teams. The products included near-real-time geo-rectified imagery, fire detection shapefiles, Normalized Burn Ratio (NBR), and Burn Area Emergency Response (BAER) imagery [*Ambrosia, et al. 2011a; Ambrosia, et al. 2011b*]. In 2011, an on-board processed, real-time FRP algorithm was added to the product delivery suite.

While the AMS-Wildfire sensor is useful for wildfire mapping at local scales, satellite data represent the primary source of information for mapping of biomass burning activity at regional to global scales [e.g., *Freitas et al*. 2005; *Davies et al*. 2009; *Ichoku et al*. 2008; *Kahn et al. 20*08*; Reid et al*. 2009; *van der Werf et al*. 2010]. The Moderate-resolution Imaging Spectro-radiometer (MODIS) aboard the NASA Terra and Aqua satellites was the first satellite-borne sensor capable of measuring fire radiative energy (FRE) release rate, or power (FRP), quantitatively on a global scale [e.g. *Kaufman et al*. 1998a; *Justice et al*. 2002; *Giglio et al*. 2003, *Ichoku et al. 20*08]. Subsequently, FRP is being derived from a few other satellite sensors [e.g., *Wooster et al*. 2003; *Xu et al*. 2010]. Planned satellite systems, including the polar orbiting Visible / Infrared Imager Radiometer Suite (VIIRS) and the geostationary GOES-R Advanced Baseline Imager (ABI) will provide enhanced spatial resolution and temporal observations of fire events and require validation of their fire products to ascertain their effectiveness for fire detection using airborne sensors such as the calibrated AMS [*Schroeder et al. 2010*, *Giglio et al. 2008; Schroeder et al. 2008*]. Deriving airborne AMS-Wildfire FRP measurements coincident with satellite-derived measurements (MODIS, VIIRS, etc.) will improve both regional and global estimates of fire radiative properties.

AMS Sensor Characteristics

The NASA AMS-Wildfire scanner has operated on-board both manned and UAV platforms and is a 16-channel (12 discrete VIS-IR-MIR-TIR bands) airborne multi-spectral imaging line scanner. Table 1 indicates the sensor specifications for the AMS.

Table 1. AMS-WILDFIRE 16-channel Scanner Specifications. Channels replicating the equivalent Landsat Thematic Mapper (TM) and VIIRS Moderate resolution (M) bands are identified.

Spectral Band	Wavelength µm
1	0.42- 0.45
2	0.45- 0.52 (TM1)
3	0.52- 0.60 (TM2)
4	0.60- 0.62
5	0.63- 0.69 (TM3)
6	0.69- 0.75
7	0.76- 0.90 (TM4)
8	0.91- 1.05
9	1.55- 1.75 (TM5) (high gain)
10	2.08- 2.35 (TM7) (high gain)
11	3.60- 3.79 (VIIRS M12) (high gain)
12	10.26-11.26 (VIIRS M15) (high gain)
13	1.55- 1.75 (TM5) (low gain)
14	2.08- 2.35 (TM7) (low gain)
15	3.60- 3.79 (VIIRS M12) (low gain)
16	10.26-11.26 (VIIRS M15) (low gain)
Total Field of View: 42.5 or 85.9 degrees (selectable) **IFOV:** 1.25 mrad or 2.5mrad (selectable) **Spatial Resolution:** 3 – 50 meters (variable based on alt)	

On-Board, Real-Time Sensor Data Processing

The AMS provides a series of Level 2 products directly from the aircraft, through a satellite communications link, to investigators on the ground. To derive the Level 2 products, the selected raw digital data counts are converted to at-sensor radiance for visible and near-infrared wavelength channels, and bright-

ness temperature for the thermal channels. Radiometric correction is performed using pre-flight (labor-atory) calibration coefficients. Two on-sensor black-body calibration reference source temperature readings provide a linear digital count-to-radiance conversion which is then used in an approximate inverse Planck's equation to produce a brightness temperature for each pixel in the thermal channels. This on-board pre-processing calibration step allows data to be spectrally and thermally consistent from mission to mission.

AMS-Derived Fire Hot-Spot Detection Algorithm

A fire hot-spot detection algorithm based on the satellite-derived hot spot detection algorithm developed by the Canadian Center for Remote Sensing (CCRS) [*Li, et al. 2000a, Li, et al. 2000b, Flasse and Ceccato 1996, and Cahoon, et al. 1992*], was implemented using the representative AMS thermal channels. The fire hot-spot detection algorithm uses the AMS-Wildfire 3.6µm channel to define a fire temperature threshold, and two or more additional channels to refine the classification and eliminate fire commission errors. The fire detection algorithm uses a difference-minimum between a temperature threshold from AMS channels 11 and 12, and a shortwave IR reflectance maximum in channel 7 (to screen high-reflectance commission errors), to derive a pixel-based fire hot-spot data set. The hot spot pixel data are then aggregated / produced as shapefiles (*.SHP), geo-rectified and provided as a near-real-time Level 2 product.

AMS –Derived Fire Radiative Power (FRP) Algorithm

In 2011, a FRP algorithm was added to the AMS on-board processing suite to derive finer spatial and temporal scale FRP estimates over wildfires [*Ichoku, et al. 2010*]. FRP is a measure of the radiant energy liberated per-unit-time from burning vegetation. The MODIS FRP is estimated as:

$$R_{fre} = \ a\ (T_4^{\ 8} - T_{4b}^{\ 8})$$

Where:
a *is* a constant used for MODIS (4.34 x 10^{-19});
R_{fre} (in MW or MJ/s for MODIS) is the pixel fire radiative power;
T_4 (in K) is the fire pixel brightness temperature at the 4-µm channel;
T_{4b} is the 4-µm brightness temperature of the background surrounding the fire pixel [*Kaufman, et al. 1998*].
The same FRP measurements are made from MODIS fire observation data daily for the US, and improvements can be made to those satellite measurements with coincident, higher spatial and temporal resolution AMS airborne measurements. The MODIS FRP algorithm is being adapted with AMS data by using the radiance to temperature calibration for the MIR region covered by the AMS channel 11 (3.60- 3.79 µm). The AMS FRP equation is then the same as the MODIS FRP equation above, but with units of W/m^2/pixel. This method was first tested on the Eagle Fire, collected in July 2011 during an AMS sensor operational check flight and provided as a post-processed data product of planned on-board-derived FRP measurements (Figure 1).

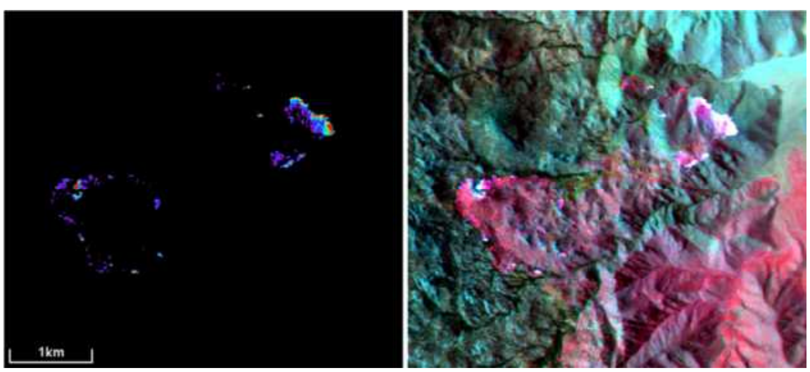

Figure 1. AMS FRP measurement for the Eagle Fire, California, 26 July 2011 (left). The colors range from purple (150W/m2) to red (3000+W/m2. Values below 150 are non-fire. The three-channel color composite of the Eagle Fire (right) (AMS channels 12, 9, 10) vividly show the hottest regions of the burning.

Discussion

The AMS-Wildfire airborne instrument, in operation since 2006 on both manned and unmanned aircraft, has been shown to be an effective sensor for deriving and delivering near-real-time Level 2 fire-related data products to fire incident management teams and scientists. Recent modifications to the sensor improve the quantification of wildfire indices, calibration and validation of current and planned satellite observation systems, and also improve active- and post-fire information for wildfire incident teams. In 2011, the AMS was flown to support both the wildfire management community and the fire science community with improved, higher spatial- and temporal-resolution data collection campaigns. Those missions included testing of a new AMS-derived FRP product to help validate / calibrate the MODIS FRP product. Additionally, the sensor can /will serve as a test-bed for validating the NPOESS VIIRS satellite fire detection capabilities, and the NOAA GOES-R ABI sensor. The airborne AMS validation efforts will undoubtedly improve the satellite-based regional / global estimates of fire properties, thereby improving measurement of fire impacts on global climate change.

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