# NASA's Autonomous Modular Scanner (AMS) – Wildfire Sensor: Improving Wildfire Observations From Airborne Platforms

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**Abstract -** The NASA Autonomous Modular Scanner (AMS) – Wildfire sensor is an airborne, 16-band line scanner with channels 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. The AMS has operated on a range of manned and unmanned aircraft, including the NASA Ikhana UAS. 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-Wildfire instrument has been flown extensively in the western U.S. since 2006, supporting disaster managers with real-time fire products that define hot-spots, active fire, smoldering and post-fire conditions. 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 extrapolation of wildfire thermal properties. With high spatial, temporal and radiometric measurement capabilities of the AMS instrument, improved discrimination of fire properties can be made. The "lingering" capabilities afforded by airborne platforms, allow temporal observations of fire properties, rather than the single observations provided by satellite systems. The AMS operations, successful missions, and plans for future use to support both the fire science community and the disaster management community will be highlighted.

**Keywords:** NASA, AMS, UAS, wildfire, VIS-IR-MIR-TIR

## 1. INTRODUCTION

The Autonomous Modular Scanner (AMS) - WILDFIRE Sensor is a multi-use NASA facility sensor system and modular UAS-capable system for use by the science and applications community. The AMS scanner is composed of a Daedalus AADS-1268 scanning system that had three configuration optical heads. One of the configurations was the Thematic Mapper Simulator (TMS) which was used for land-cover studies, and also for wildfire imaging. This configuration flew primarily on the NASA ER-2, high-altitude aircraft platform. The new AMS was reconfigured into a fully functional UAS-compatible sensor with a similar variety of scan-head

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configurations, including the WILDFIRE configuration. The sensor characteristics and composition of the AMS-Wildfire instrument is described in the following section.

## 2. AMS WILDFIRE SENSOR

The 16-channel WILDFIRE Scanner was developed at the NASA-Ames Research Center Airborne Sensor Facility for operations on-board both manned and UAV platforms. The instrument has been modified to fulfill scientific requirements for fire imaging, with four new mid-IR and TIR channels (two each of high gain / low gain mid-IR and TIR) to allow measurement of fire (and other hot sources). The AMS-Wildfire scanner subsystems include the scan head, digitizer/data system, Applanix navigation system enclosure, Trimble DGPS / storage subsystem enclosure, power distributor, blackbody control subsystem, GPS antenna and assorted cabling (Figure 1).
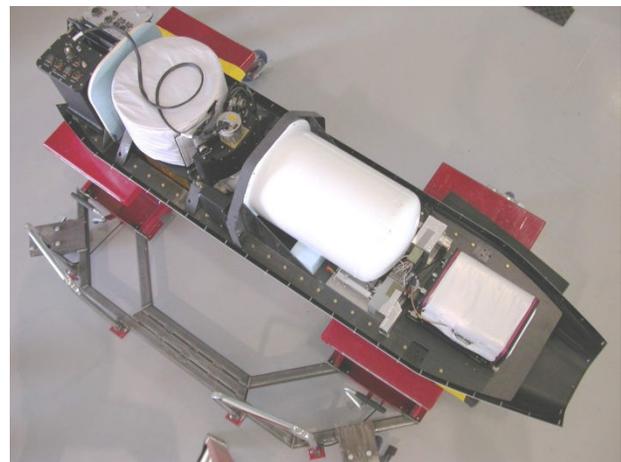


**Figure 1.** The AMS-Wildfire sensor system in the pod payload tray, prior to integration on the under-wing mount of the NASA Ikhana UAS platform. The scan-head is located under the cylindrical pressure "can" on the left, while the digitizing electronics are located in the central white, horizontally mounted pressure vessel. Various power supplies and Applanix DGPS inertial navigation systems are also included in the configuration.

### 2.1 Sensor characteristics

The AMS wildfire instrument is an airborne multi-spectral imaging line scanner. It builds an image by raster-scanning across its direction of travel and accumulating lines of pixels as

it moves. By interchanging optical components (primary apertures), it can support pixels sizes of either 1.25mR or 2.5mR. The swath width is always 716 pixels across, giving total angular widths of roughly 43° or 86° respectively. There are three spectrometers which can be interchanged on the scan head, each providing a different selection of spectral channels. The table below shows the approximate spectral bands (in µm) for each spectrometer. Scan rates are infinitely adjustable from 2-scans/sec to 33-scans/sec, depending on the specific configuration. Spatial resolution is determined by altitude and the primary aperture size.

Table 1. AMS-WILDFIRE 16-channel Scanner Specifications.

| 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)

The TIR channels have been calibrated for accurate (~0.5° C) temperatures discrimination of hot targets, up to ~800°C. The TIR channels simulate those found on the proposed Visible/Infrared Imager/Radiometer Suite (VIIRS) instrument, scheduled for orbital operations aboard the National Polar-orbiting Operational Environmental Satellite System (NPOESS) satellite series. These two TIR channels replace the original AADS-1268 channels 11 and 12, which were wide-band (8.5-14µm) low- and high-gain TIR channels.

Modifications (in 2005) to the AMS original configuration also include a pressurized electronics housing, 16-bit Digitizer w/ Auxiliary CPU, New Scanning Optics Module, Solid State Storage Media, and long-duration autonomous operation capabilities. These sensor developments allow autonomous or remote operations of the sensor package aboard a UAS platform during missions. An additional major enhancement includes more spectral channels in the short-wave IR and visible portion of the spectrum. The scanning optics is also improved, allowing for a more robust system with improved imaging capabilities which allow long-duration missions aboard UAS platforms to demonstrate wildfire observations and real-time data delivery to incident management teams.

## 2.2 On-Board, Real-Time Sensor Data Processing

On-board processing of the AMS has been developed to provide 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 apparent radiance for visible and near-infrared wavelength channels, and brightness temperature for the thermal channels. The most recent sensor laboratory calibration information is employed for deriving apparent radiance from those spectral channels. 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.

**2.2.1 Fire Hot-Spot Detection Algorithm**. A fire hot-spot detection data set based on that developed by the Canadian Center for Remote Sensing (CCRS), was implemented (Li, et al., 2000a, Li, et al., 2000b, Flasse and Ceccato, 1996, and Cahoon, et al. 1992). The fire hot-spot detection algorithm uses the AMS-Wildfire 3.6µm channel to define fire via a temperature threshold, and two or more additional channels to further refine this classification and to remove fire commission errors. The fire hot-spot detection algorithm is calculated as:

*If:*
*Band 11 (3.60- 3.79 µm) > Band 11minimum temperature (e.g. 380° K) and*
*Band 12 (10.26-11.26µm) > Band 12 minimum temperature (e.g. 240° K) and*
*Band 11 – Band 12 > Difference minimum (e.g. 14° K),*
*And (if available),*
*Band 7(0.76- 0.90µm) < Reflectance maximum (e.g. 0 .3) (to screen high-reflectance commission errors),*
*Then, Pixel is classified as a fire hot-spot*

**2.2.2  Normalized Burn Ratio (NBR)**. A normalized burn ratio (NBR) index algorithm was also implemented to derive post-fire vegetation burn condition classes. The NBR algorithm discriminated  between photosynthetically healthy and burned vegetation (Howard, *et al.* 2002). The Normalized Burn Ratio Index algorithm is calculated as:

$$\frac{AMS\ Band\ 7 - AMS\ Band\ 10}{AMS\ Band\ 7 + AMS\ Band\ 10}$$

The AMS-acquired post-fire NBR values can be compared to pre-burn satellite data (such as Landsat Thematic Mapper) to derive a Differenced Normalized Burn Ratio (dNBR), where the difference is determined as: *pre – post NBR* to derive the *dNBR*.

**2.2.3  Data Geo-Rectification.** An on-board geo-rectification process utilizes an Applanix Position and Orientation System for Airborne Vehicles (POS AV) model 310 system to provide real-time and post-processed measurements of the position, roll, pitch and heading of each scanline of the AMS. Photogrammetric projective transformation equations are used to determine the position of each pixel in the scanline as projected to the ground, with "ground" being determined by the

on-board digital elevation model (DEM) data for the area being over-flown. The DEM, consisting of a composite data set of one-arc-second, 30-meter posting, Shuttle Radar Topographic Mission (SRTM) elevation "tiles" of the western US is served on the on-board processor and employed to accurately geo-reference the AMS sensor data Level 2 products, generated on-board and sent through the data telemetry system to the ground.

**2.2.4 Data Telemetry System.** The NASA *Ikhana* UAS over-the-horizon (OTH) data telemetry system is used for bi-directional command and control (C&C) of the UAS as well as for bi-directional control of the AMS-Wildfire sensor system. The link allows imagery and Level 2I data products, developed on the payload processors to be sent from the UAS to the UAS ground receiving station and then redistributed through the Internet to scientists and customers. The OTH telemetry system on the NASA *Ikhana* allows 3.0 Mb/s data throughput rates.

## 3.    WILDFIRE MISSIONS – 2006-2008

### 3.1  2006 AMS-Wildfire Missions
On 28 October 2006, the AMS-Wildfire sensor, operating aboard the Altair UAS (*Ikhana* UAS predecessor), collected sensor data over the Esperanza Fire in southern California, providing real-time wildfire hot spot detection to the on-site Incident Command Team (Ambrosia, et al., 2009).

### 3.2  2007 AMS-Wildfire Missions
In 2007, the AMS-Wildfire was integrated on the new NASA *Ikhana* UAS, and eight fire observation missions occurred between August and October. The first four missions where operated over fires in eight western states. Mission operations over 27 fires were between 10-22 hours long and extended for 1400-3200 mile ranges. Real-time fire data were relayed to Incident Command Centers (ICC) through the W-CDE.

**3.2.1 Southern California Firestorm AMS Missions** – In late October 2007, a series of Santa Ana wind-driven fires erupted in the Los Angeles and San Diego regions of Southern California. The NASA *Ikhana* UAS / AMS-Wildfire sensor flew the first four mission-days over 11 major wildfire complexes in the region. Real-time hot spot data were provided to the individual Incident Command Centers, the various County Emergency Operations Centers and the state of California Emergency Center.

### 3.3 2008 AMS Missions
In late June 2008, lightning ignited hundreds of fires in northern California and the AMS, operating aboard the *Ikhana* UAS, flew a series of four mission-days over the various complexes, completing the mission series in mid-September. Each of the fire management teams were provided near-real-time, on-board-derived fire LEVEL 2 data, as defined earlier in section 2.2.

### 3.4  2009-2010 AMS Missions
During the 2009 fire season, the NASA Ikhana UAS was unavailable to support missions until November. An AMS-Wildfire post-fire NBR data collection mission was flown over the Station Fire in Southern California on 19 November 2009.

In 2010, again due to the unavailability of the Ikhana UAS, the AMS team initiated installation on a NASA manned platform (Beechcraft B200 King Air). No wildfires were flown in the 2010 period.

A summation of the AMS-Wildfire sensor missions is shown in Table 2.

| YEAR | AIRCRAFT | FLIGHTS | HOURS | FIRES FLOWN |
|------|----------|---------|-------|-------------|
| 2006 | Altair | 4 | 68 | 2 |
| 2007 | Ikhana | 12 | 89 | 37 |
| 2008 | Ikhana | 4 | 21 | 16 |
| 2009 | Ikhana | 2 | 11 | 2 (post-fire) |
| TOTAL | | 35 | 207 | 60 |

## 4.    AMS SUPPORTING FIRE SCIENCE

In addition to supporting the wildfire management community with observations, the AMS-Wildfire has supported the wildfire science community with radiometrically calibrated wildfire data since 2006. In 2006, 2007 and 2008, the team supported AMS-Wildfire (on-board *Ikhana* UAS) data collections with simultaneous AQUA and TERRA MODIS satellite observations. The objective was to demonstrate the capabilities of the UAS to collect coincident spectral data over a dynamic wildfire at increased spatial resolution and providing a similar fire "hot-spot" product to that derived from the MODIS Rapid Response System (RRS) product. An example of a coincident data collection is shown in Figure 2.
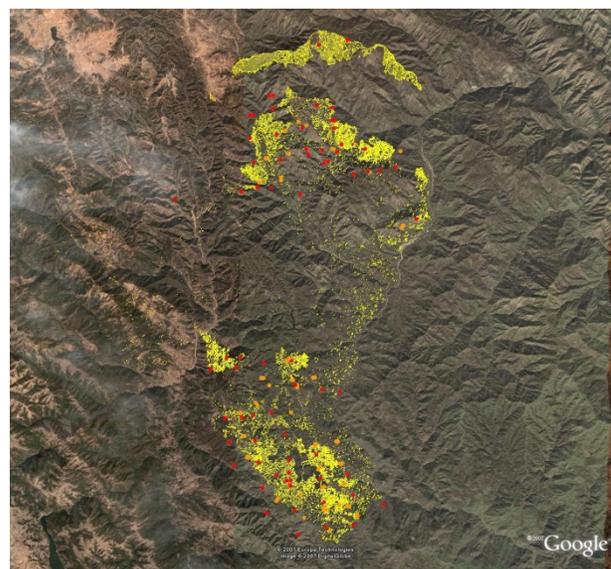


Figure 2.    AMS-Wildfire hot-spot algorithm-derived data (yellow pixels) and coincident overpass time MODIS satellite hot-spot algorithm-derived data (red and orange dots) collected over the Lick Fire, California at 2:25 PM (local) on 7 September 2007.

## 4.1 AMS Future Operations

In 2010, plans were initiated to develop AMS-Wildfire missions supporting satellite calibration / validation efforts and derive Fire Radiative Power (FRP) estimates of wildfires in differing ecosystem regimes (Ichoku, et al., 2010). Fire Radiative Power is a measure of the radiant energy liberated per-unit-time from burning vegetation. FRP varies with vegetation composition and drives other fire-related conditions such as carbon combustion fraction, smoke plume generation, energetics, and injection properties. The FRP is measured as:

$$R_{fre} = 4.34 \times 10^{-19} \, (T_4^8 - T_4^{8b})$$

Where:

$R_{fre}$ (in MW or MJ/s) 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 measurement with coincident, higher spatial and temporal resolution AMS airborne measurements. Time series AMS FRP measurements, made from an on-station airborne platform over a fire event offer improved measurements of the critical fire-related properties such as rapidly changing spatial composition of the pixel fractional area of flaming, smoldering and unburned vegetation. By "lingering" over an event, a longer time-scale measurement can be made, improving the estimate derived from the "snap-shot" observation of the satellite systems.

The AMS data can therefore be used to improve the MODIS-derived FRP estimates and also be useful for determining the future FRP measurement capabilities of the NPOESS VIIRS sensor system. The AMS-derived FRP algorithm will be integrated into the on-board processing steps of the system in 2011, to facilitate near-real-time measurements over fire regimes in the western US.

## 5.    DISCUSSION

The AMS-Wildfire airborne instrument, operating on both manned and unmanned aircraft has been shown to be an effective sensor for deriving and delivering near-real-time Level 2 data products of fires from calibrated spectral measurements in the VIS-IR-MIR-TIR electromagnetic region. The sensor has been in operation since 2006, supporting both wildfire disaster incident management organizations and the scientific community with real-time fire-related intelligence. Recent modifications to the sensor will improve the scientific usefulness to support the measurement of wildfire indices, calibration and validation measurements in support of current and planned satellite observation systems, and also to support wildfire management agencies with new, and more accurate active- and post-fire intelligence data. In 2011 and beyond, we will employ the AMS to support both the wildfire management community and the fire science community with improved, higher spatial- and temporal-resolution data collection campaigns.

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