Satellite and Airborne Fire Sensor Systems for Arctic Wildfire Observations

A Report for the:

Interagency Arctic Research and Policy Committee (IARPC): Wildfire Implementation Team (WIT)
V5 (11-7-14)

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1.0 OBJECTIVES

This report details orbital and sub-orbital (airborne) imaging / sensing system assets that have applicable uses for the wildfire observations. The imaging assets are research or operational systems operated by a variety of agencies and international groups including NASA, NOAA, ESA, JAXA, DLR and others. The accompanying table and systems descriptions are provided to support the Interagency Arctic Research and Policy Committee (IARPC), Wildfire Implementation Team (WIT) The WIT is a multi-agency sub-committee chartered with investigating the frequency and severity of wildfires in the arctic as a component of understanding high latitude terrestrial ecosystem process, ecosystem services and climate feedbacks. The Wildfire initiative is identified in section 3.2: Research Initiatives, of the draft *IARPC Arctic Research Plan: FY2013-2017*. This report is also responsive to the five-year plans for federally-sponsored research in the arctic region, where the IARPC identified seven over-arching categories to form the basis of a national policy for Arctic research and that will especially benefit from interagency collaboration; one of those categories is the "Observing Systems" category. This report supports that beneficial-needs assessment.

As part of the IARPC WIT, a key element for informing the arctic research community on the impact of wildfires in the arctic was identified in Milestone 3.2.4e:

> *"Identify existing knowledge and quality of data on wildfire frequency, extent, and severity in the Arctic. If needed, develop strategies/projects to improve data to monitor changes in wildfire frequency, extent, and severity in the Arctic."*

This ensuing report is directly responsive to that milestone element.

2.0 INTRODUCTION

The following sections detail the orbital and sub-orbital (airborne) remote sensing systems which can provide fire information, particularly active fire observation capabilities. The sensor systems are highlighted with references to their spectral characteristics, orbit frequency, spatial coverage and any fire detection algorithm capabilities. The airborne systems identified in this document highlight the imaging capabilities of both operational and "research" sensors used by the fire communities and the fire research community. The final section of this document highlights the various agencies that have web services that provide operational fire monitoring.

3.0 SENSOR SYSTEMS

This report primarily considers the U.S. national orbital asset systems for applicability to wildfire observations. Secondarily, the report further identifies national asset airborne sensor systems that can be employed for more localized studies on the impact of wildfires. Thirdly, the report highlights non-U.S. sensor systems that are currently operational or planned for operation in the coming years. In this report, we have only considered land-imaging sensor systems which include spectral observation capabilities in the visible, near-infrared, middle-infrared and thermal infrared (emitted energy) portions of the electro-magnetic spectrum. In-situ or orbital atmospheric sensors that discriminate constituents from wildfire events / plumes were not identified in this report.

The sensor systems identified in the following table, highlight the current operational sub-orbital and orbital assets available to the arctic wildfire research and applications community. The table highlights the pertinent instrumentation capabilities, responsible / managing agency, the viable spectral / radiometric configurations to enable wildfire observations, the sensor saturation temperature (pertinent for identification of wildfire "hot-spots" and as a false-target discriminator), the instrument / sensor imaging characteristics, such as imaging area swath width (FOV), spatial ground resolution (IFOV) and temporal coverage (collection frequency). Additional information includes the sensor system supporting website URL address, the capability of supporting near-real-time data delivery, and a concluding "notes" section, which highlights some pertinent information on the sensor / instrument.

Table 1. Satellite and Airborne Fire Sensor Systems For Arctic Wildfire Observations.

INSTRUMENT	RESPONSIBLE AGENCY	SYSTEM	VIABLE MWIR CHANNELS	SATURATION TEMPERATURE	FOV	IFOV (mrad)	COLLECTION FREQUENCY	WEBSITE	Deliver R/T Data	NOTES
AMS	**USFS, on loan from NASA**	Airborne	Band 11 (3.60 - 3.79 µm)	628K (355 C°)	86 deg	1.25 / 2.5	variable / operational by USFS	http://nirops.fs.fed.us/ams	Yes	Operates on USFS aircraft (2013)
MASTER (NASA)			Band 30 (3.7 µm)	568K (295 +/- 10 C°)	86 deg	2.5				
"	**NASA**	Airborne	Band 26 (4.0 µm) Low Gain	640K (367C°)	"	"	requested through NASA Airborne Science Program office	http://airbornescience.nasa.gov/instrument/MASTER	Possible (with mods)	NASA research instrument, not operational; can be ordered for scientifc collection missions. Operates on NASA ER-2 and other platforms.
"			Band 32 (4.0µm) High Gain	560K (290 C°)	"	"				
eMAS (NASA)		Airborne	M1 (3.637 - 3.655 µm)	??	86 deg	2.5	same as MASTER	http://mas.arc.nasa.gov/index.html	Yes, with mods	NASA research instrument, not operational; can be ordered for scientifc collection missions.
AVIRIS (NASA)		Airborne	None	N/A	34 deg	1.00	same as MASTER	http://aviris.jpl.nasa.gov/index.html	N/A	AVIRIS contain hyperspectral data (224 bands) can be used for post-fire vegation analysis
WAI (NASA SBIR; XIOMAS, LLC)	**NASA-Ames Research Center**	Airborne	(4.4 - 5.4 µm)	Temperature threshold has not been measured	90 deg.	0.33	to be operational with USFS in 2014		Possible	Ijuly 2013, in fire imaging testing for USFS on aircraft.
MODIS (NASA)	**NASA**	Satellite	Band 21 (3.929 - 3.989µm)	335K (61.85 C°)	2330 km	1000m spatial	2-4 times a day over globe	http://modis.gsfc.nasa.gov/about/	R/T Fire info at: http://activefiremaps.fs.fed.us/	Operates on two platforms (AQUA and TERRA), allowing multiple collections per day
VIIRS	**NOAA / NASA / DoD**	Satellite	Band M13 (4.05 µm)	380K (107 C°) (High Gain)	3040 km	~750m spatial	2 times daily	http://viirsfire.geog.umd.edu/index.html	R/T Fire info at: http://activefiremaps.fs.fed.us/	Operational fire product delivered to USFS; DR version based on MODIS C6 delivered to USFS
ALI	**NASA / USGS**	Satellite	None	N/A	37km x 42km	10m Pan; 30m multispectral	16-day, but more frequent with multiple look angles	http://eo1.usgs.gov/sensors/ali	Yes, underr equest	ALI: Advanced Land Imager; Flies on EO-1 Satellite; testbed / sensor technology demonstrator for LDCM (Landsat 8); Has "pointing-mode" for frequent revisit coverage
Landsat 8 (OLI / TIRS)	**NASA / USGS**	Satellite	None; though TIR at: 10.9 & 12.0 microns can serve fire data	N/A; 360K in TIRS	185km	15m Pan; 30m multispectral; 120m TIR	16-days	http://www.nasa.gov/content/landsat-8-instruments/#.UfBQJm3lc5c	NRT from acquisition	Instruments that compose the Landsat 8 satellite system; ALI: Operational Land Imager; TIRS: Thermal Infrared Sensor
OLS (DMSP)	**DoD / A.F. Space and Missle System Center**	Satellite	None (has LWIR Band)	310K in LWIR	3000km	560m-1.1km	2-4 times daily coverage	http://ngdc.noaa.gov/eog/dmsp.html	Special acquisitions / permissions	"Night lights" satellite imaging system, capable of fire imaging
GOES Imager	**NOAA**	Satellite	Band 2 (4µm)	337 K in MIR	Full disk	4km	Every 15 minutes (7.5 minutes in rapid scan mode)	://noaasis.noaa.gov/NOAASIS/ml/imager.l	Yes	Polar imagery, well off-nadir, and minimally useful
AVHRR	**NOAA**	Satellite	3B (4µm)	320 - 331 K in MIR	3000km	1100m	Up to 10 times daily	http://noaasis.noaa.gov/NOAASIS/ml/avh	Yes, direct broadcast capable	Next launch on MetOp-C (2017)
HyspIRI (planned 2022 launch)	**NASA**	Satellite	H1 (4µm)	400 K in LWIR; 1200 - 1400 K in MIR	600km	60m	5 days	http://hyspiri.jpl.nasa.gov	Yes, direct broadcast capable	Launch 2022?
GOES R/S Advanced Baseline Imager	**NOAA**	Satellite	Band 7 (4µm)	400 K in MIR	Full disk	2km	Up to 12 times hourly	p://www.goes-r.gov/spacesegment/abi.ht	Yes	First launch in 2015
Sentinel-3 SLSTR	**ESA**	Satellite	F1 (4µm)	?	1400km	1km	2 days	t/Our_Activities/Observing_the_Earth/Cop	?	Launch in 2014
GCOM-C SLGI	**JAXA**	Satellite	None; though TIR at 10.8 µm can serve fire detection data	?	1150km	500m	2 days	'www.jaxa.jp/projects/sat/gcom_c/index_	Yes	First launch in 2014

3.1 <u>Orbital Remote Sensing Sensor Assets for Wildfire Observation</u>

Fire properties from orbital and sub-orbital imaging systems can be measured in three ways: instantaneous fire size, instantaneous fire temperature, and fire radiative power (FRP). Fires produce a stronger signal in the mid-wave infrared (MWIR) bands (around 4 microns) of the electromagnetic spectrum than they do in the long-wave infrared bands (LWIR; such as ~11.0 microns). That differential response forms the basis for most Fire Detection and Characterization (FDC) algorithms (Figure 1).

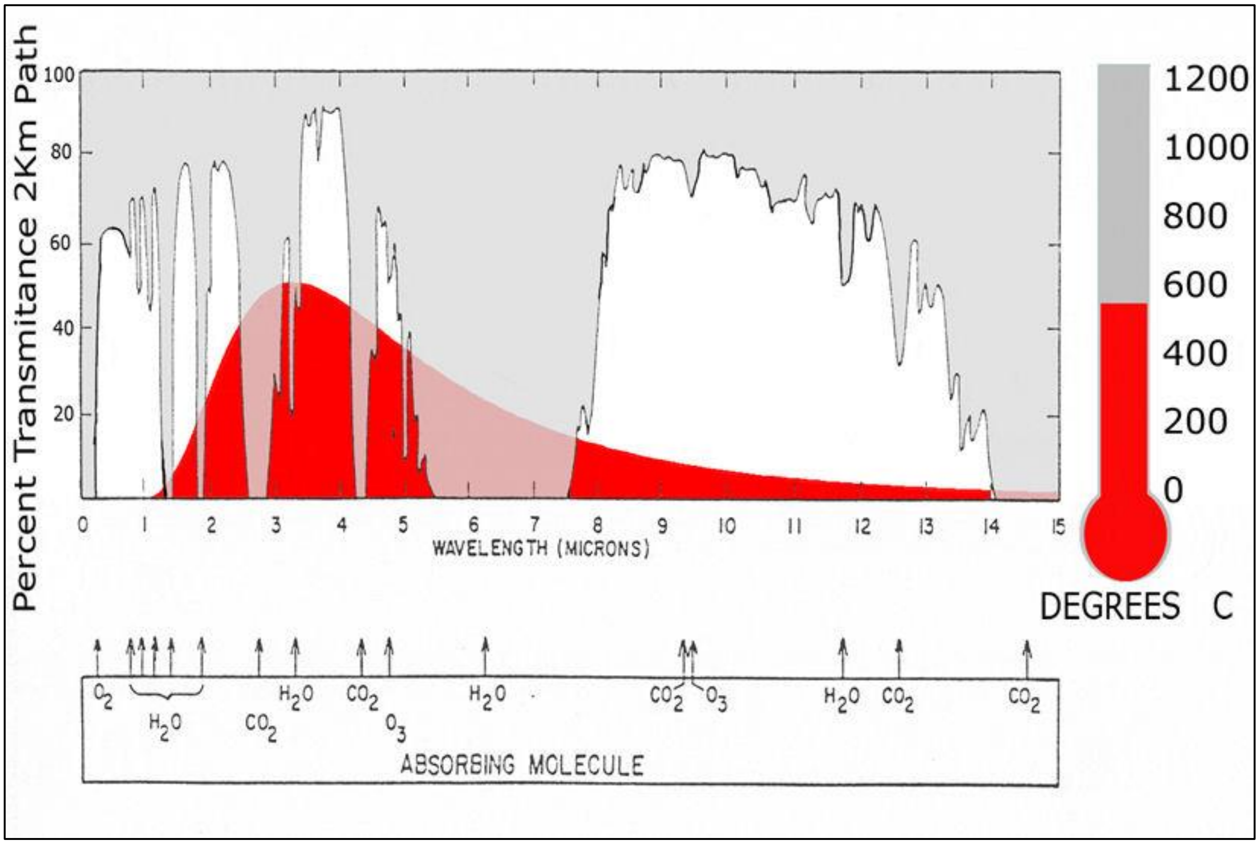

Figure 1. *Electromagnetic spectrum wavelength region appropriate for hot object detection (~600°C), showing peak response at ~3.7 µm-4.0 µm. Figure courtesy of J. Green, Xiomas, Inc.*

A number of the satellite imaging assets include the characteristic "fire-channels" to allow fire detection / discriminations. Other orbital assets have spectral characteristics that allow post-fire burn area assessment or fire intensity assessment to allow determination of burn-affected areas. The U.S. national-asset orbital, earth-observation satellite systems that have variable utility for active fire observation include the following:

- MODIS (on NASA Aqua and Terra orbital platforms)
- VIIRS (NPP Suomi; NOAA / NASA)
- ALI (EO-1 platform; NASA)
- Landsat 8 (OLI / TIRS; USGS / NASA)
- OLS (DMSP; DoD)
- GOES Imager (NOAA)
- AVHRR (NOAA)

In addition to these systems, there are U.S. and non-U.S. orbital sensors, near-term / planned launches of the following assets with potential fire observation capabilities, including:

- TET-1 (DLR; Launched in July 2012)

- GMES SENTINEL-2 MSI (ESA; Launch in late 2014)
- GMES SENTINEL-3 SLSTR (ESA; Launch in 2014)
- GCOM-C1 SLGI (JAXA; launch in 2014)
- JPSS-1 VIIRS (Launch in 2016)
- GOES-R / S Advanced Baseline Imager (ABI) (NOAA; first launch in 2015)
- HyspIRI (NASA; 2019-2022 tentative launch date)
- INSAT-3D (India; 2014?)
- CMA FY-4A AGRI (2015)
- MTG-I FCI (>2017)
- GEO-KOMPSAT-2A AMI (>2017)
- Russia Elektro-M MSU-GSM (2017)

Most of the satellite observation systems highlighted in this report are in a near-polar orbit configuration, where their observation period and return frequencies vary significantly from "staring" geo-synchronous satellite observation systems. Conversely, the polar-orbiting systems have the advantage of finer spatial resolution due to their earth-proximal orbit altitudes. Additionally, with most polar-orbiting satellite systems on a slight (~8-degree) offset from the North Pole on their orbit track, their potential for increased observation capabilities on adjacent swath paths is heightened at more northerly latitudes. This provides for a potentially higher revisit rate / overlap for observation of temporal phenomenon, such as arctic or boreal fire events. These adjacent swath path "overlaps" are particularly pronounced and advantageous for satellite sensor systems with wide swath width profiles, such as MODIS and VIIRS.

For the geo-synchronous satellite systems identified in this document (GOES, GOES-R, SEVIRI, etc.), there is limited observation capabilities for high-latitude regions given their equatorial stationary position and consequent low-view angles at Earth's near-polar extremes. The full-disk imaging makes arctic- / boreal-region fire observations of more limited value and accuracy, although their temporal frequencies of observations are improved over lower earth orbit systems.

3.1.1 Accessing Resource Information on Orbital Fire Sensor System Capabilities:

The World Meteorological Organization (WMO) has developed a resource, Observing Systems Capability Analysis and Review Tool (OSCAR) that supports Earth observation applications, studies and global coordination (http://www.wmo-sat.info/oscar/). OSCAR contains quantitative user-defined requirements for observation of physical variables in application areas of WMO and also provides detailed information on all earth observation satellites and instruments, and expert analyses of space-based capabilities. OSCAR targets all users interested in the status and the planning of global observing systems as well as data-users looking for instrument specifications at platform level. Users can select one of the following modules: Observation Requirements, Satellite Capabilities, Surface-based Capabilities. By doing a satellite gap analysis by the variable “Fire temperature”, the tool will build a searchable list (and relevancy listing) of ALL operational or planned (out to year 2030) satellite sensor systems capable of fire mensuration (http://www.wmo-sat.info/oscar/gapanalyses?view=62). Specific sensor attributes are provided for each system, and ranked by capability to make necessary observations (n this case, fire temperature mensuration / observation) (Table x). Some of the sensor systems below have been discontinued or are not operating currently.

Table x. Satellite instruments for fire measurements. Adapted from WMO (http://www.wmo-sat.info/oscar/gapanalyses?view=62).

Satellite Instruments for Measuring Fire Temperature			
Instruments	**Relevance of Measurement**	**Processing Maturity**	**Operational Limitations**
MODIS	very high	Consolidated methodology	Clouds
MERSI-2	very high	Consolidated methodology	Clouds
VIIRS			
MSU-MR-MP	very high	Consolidated methodology	Clouds
MetImage			
AATSR	very high	Consolidated methodology	Clouds
ATSR-2			
SLSTR			
GLI	very high	Consolidated methodology	Clouds
MVISR	high	Consolidated methodology	Clouds
VIRR (FY-3)			
AVHRR/3	high	Consolidated methodology	Clouds
MSU-MR			
ABI	high	Consolidated methodology	Clouds
AHI			
FCI			

AMI MSU-GSM			
SEVIRI	high	Consolidated methodology	Clouds
OCTS	high	Consolidated methodology	Clouds
AVHRR/2	high	Consolidated methodology	Clouds
ATSR	high	Consolidated methodology	Clouds
VIRS	high	Consolidated methodology	Clouds
AGRI	high	Consolidated methodology	Clouds
ISR	high	Consolidated methodology	Clouds
MSU-GS MSU-GS/A	high	Consolidated methodology	Clouds
NIRST	high	Consolidated methodology	Narrow-swath. Clouds
CIRC	high	Consolidated methodology	Narrow-swath. Clouds
AVHRR	fair	Consolidated methodology	Clouds
IMAGER (GOES 8-11) IMAGER (MTSAT-2) JAMI MI IMAGER (GOES 12-15) S-VISSR (FY-2C/D/E) S-VISSR (FY-2F/G/H)	fair	Consolidated methodology	Clouds
IMAGER (INSAT)	fair	Consolidated methodology	Clouds
SGLI	marginal	Consolidated methodology	Clouds
HRMX-TIR	marginal	Consolidated methodology	Clouds
HSRS	marginal	Consolidated methodology	Narrow-swath. Clouds

The following section highlights the various fire imaging capabilities of the aforementioned satellite imaging systems and identifies the capabilities and the access points for fire-related operational products from those systems.

3.1.2 MODIS

The Moderate Resolution Imaging Spectroradiometer (MODIS) instrument is a sensor system onboard the Terra (EOS AM) and Aqua (EOS PM) polar-orbiting satellites that is used operationally by US agencies to identify wildfire occurrences on a daily basis. The Terra's orbit around the Earth is timed so that it passes from north to south across the equator in the morning, while Aqua passes south to north over the equator in the afternoon. Terra MODIS and Aqua MODIS are viewing the entire Earth's surface every 1 to 2 days, acquiring data in 36 spectral bands, or groups of wavelengths (Tables x and x). Due to orbit and swath width of the sensor system, the MODIS sensor(s) can observe the same feature on the ground from 2-4 times per 24-hour period. Because of the polar-orbit configuration and swath width (2330 km), observation capabilities are increased for far northern (or southern) latitudes, and can afford more frequent observations of fire events during adjacent orbits for arctic regions of the earth.

Table x. MODIS satellite sensor specifications.

Orbit:	705 km, 10:30 a.m. descending node (Terra) or 1:30 p.m. ascending node (Aqua) at equator, sun-synchronous, near-polar, circular
Scan Rate:	20.3 rpm, cross track
Swath Dimensions:	2330 km (cross track) by 10 km (along track at nadir)
Quantization:	12 bits
Spatial Resolution:	250 m (bands 1-2); 500 m (bands 3-7); 1000 m (bands 8-36)

Table x. MODIS Spectral Band Configuration.

Band	Wavelength(μm)	Sat. Temp. (K°)
1	620 - 670	
2	841 - 876	
3	459 - 479	
4	545 - 565	
5	1230 - 1250	

6	1628 - 1652	
7	2105 - 2155	
8	405 - 420	
9	438 - 448	
10	483 - 493	
11	526 - 536	
12	546 - 556	
13	662 - 672	
14	673 - 683	
15	743 - 753	
16	862 - 877	
17	890 - 920	
18	931 - 941	
19	915 - 965	
20	3.660 - 3.840	0.45(300K)
21	3.929 - 3.989	2.38(335K)
22	3.929 - 3.989	0.67(300K)
23	4.020 - 4.080	0.79(300K)
24	4.433 - 4.498	0.17(250K)
25	4.482 - 4.549	0.59(275K)
26	1.360 - 1.390	6.00
27	6.535 - 6.895	1.16(240K)
28	7.175 - 7.475	2.18(250K)
29	8.400 - 8.700	9.58(300K)
30	9.580 - 9.880	3.69(250K)
31	10.780 - 11.280	9.55(300K)
32	11.770 - 12.270	8.94(300K)
33	13.185 - 13.485	4.52(260K)
34	13.485 - 13.785	3.76(250K)

35	13.785 - 14.085	3.11(240K)
36	14.085 - 14.385	2.08(220K)

Highlighted in the above table are the key Thermal Infrared (TIR) channels which are employed to derive fire / hot spot detections from MODIS data (Channels 21/22 and channel 31). MODIS fire detection is performed using a contextual algorithm (Giglio et al., 2003) that exploits the strong emission of mid-infrared radiation from fires (Dozier, 1981; Matson and Dozier, 1981). The algorithm uses brightness temperatures derived from the MODIS 4 µm and 11 µm channels (Figure x).

Figure X. *MODIS scene of western Alaska USA, collected on 26 May 2002. The red polygons represent hot-spot algorithm-detected regions. Associated smoke plumes can be seen, as well as snow-covered regions, and areas of sea ice.*

Various organizations provide web-based, geospatial wildfire observation maps / data derived from the MODIS sensor system. The most common service is provided by the USDA-Forest Service, which provides wildfire information for the lower US and Canada (http://activefiremaps.fs.fed.us/) (Figure x). The other MODIS channels, particularly the Visible and Near-infrared (NIR) channels can be used to derive historical burn scar information, fire intensity information (Fire radiative energy) (Figure x), vegetation regrown following burns and plant health / vigor using various operational spectral channel indices. Additional information about MODIS can be derived from: http://modis.gsfc.nasa.gov/about/.

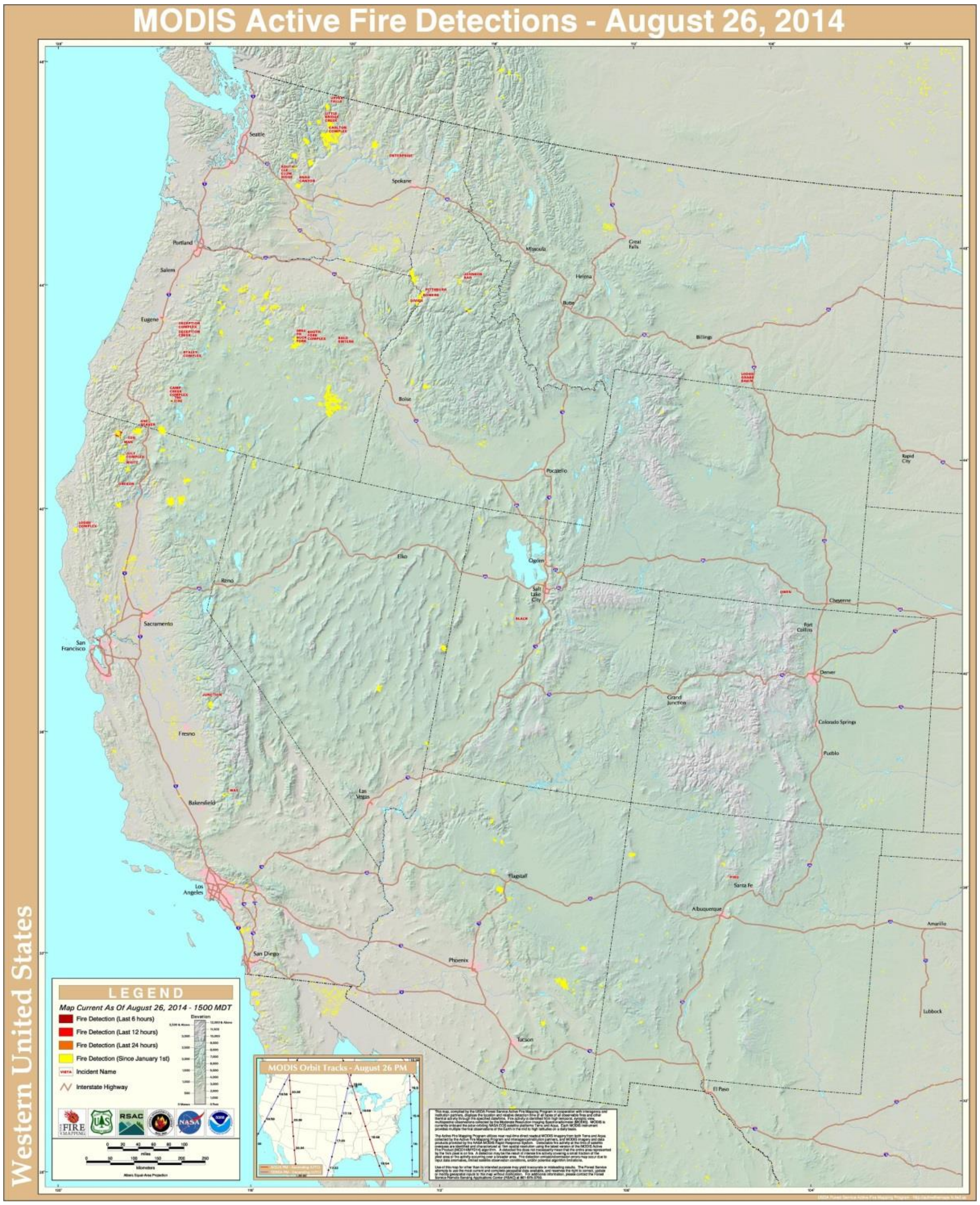

Figure x. *Geospatial data of western U.S. wildfires on 26 August 2014 as derived from MODIS satellite hot-spot detection algorithms. The data are web-served by the USDA Forest Service Remote Sensing Applications Center Active Fire Mapping Program and updated with every Aqua and Terra MODIS overpass.*

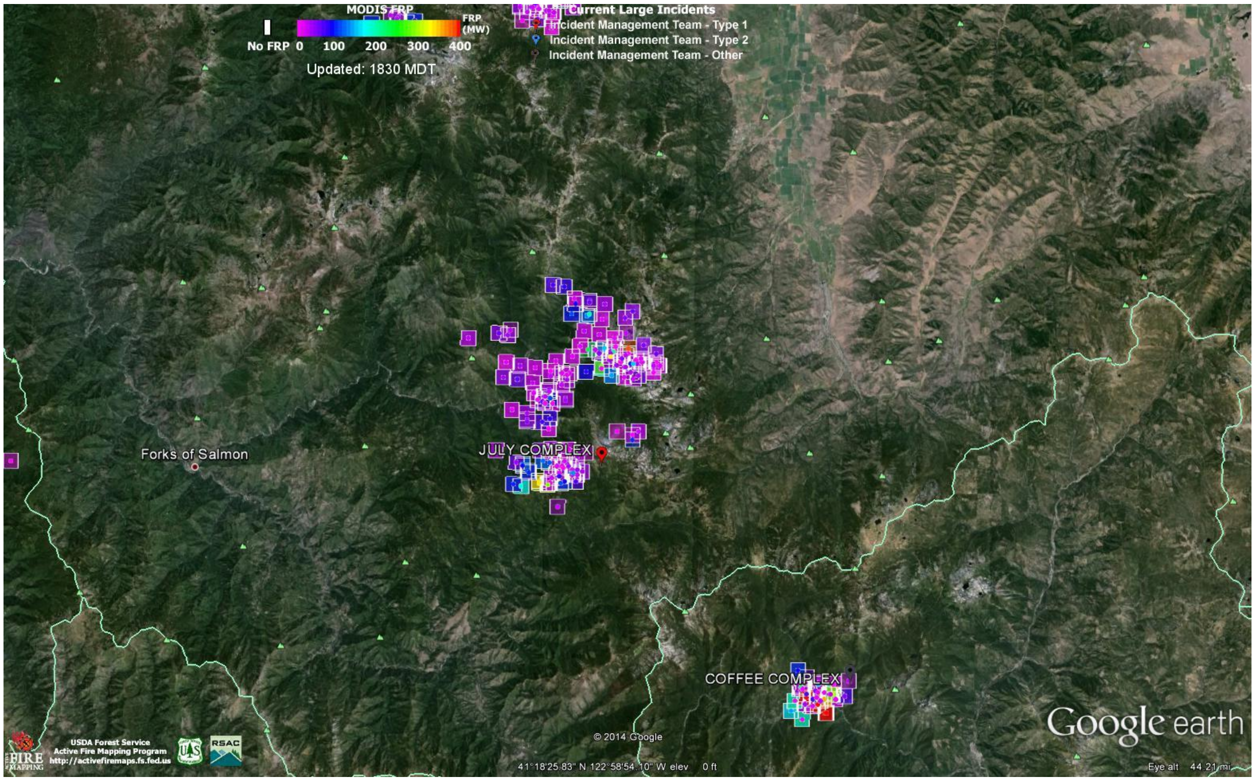

Figure X. *MODIS-derived Fire Radiative Power (FRP) estimated product collected over the July and Coffee Complex Fires in Northern California on 13 August 2014. The FRP values for each pixel are overlain on a GoogleEarth background image.*

3.1.3 VIIRS

The Visible Infrared Imaging Radiometer Suite (VIIRS) aboard the Suomi-NPP satellite is a polar-orbiting system that was launched in October of 2012 and provides a follow-on, improved spatial resolution to MODIS fire detections (http://npp.gsfc.nasa.gov/viirs.html). The VIIRS is currently in the same orbit as the Aqua satellite (with MODIS aboard), and therefore provides 1-2 observations per 24-hour period of fire occurrences throughout the globe. The VIIRS data is currently being configured to provide similar operational fire detections and is being served as a daily fire product for the US from the same USFS Fire website indicated above (http://activefiremaps.fs.fed.us/). VIIRS represents a continuation of high quality active fire monitoring capabilities started with MODIS on the NASA EOS Terra and Aqua satellites, and also a significant improvement of the current capabilities of the Advanced Very High Resolution

Radiometer (AVHRR) on the current NOAA operational polar satellites. Initial evaluation, following the activation of the thermal bands on January 18, 2012, has provided empirical evidence of the good quality of the VIIRS fire observations.

VIIRS provides operational and research users with spectral coverage from 412 nm to 12 µm in 22 bands; image data at ~375 m nadir-resolution in 5 bands and moderate resolution (~750 m at nadir) in the TIR channels. The swath width of VIIRS is 3040 km. The VIIRS satellite sensor specifications and spectral channels are shown in Table x.

Table x. VIIRS Spectral Band Configuration.

Band	Wavelength(µm)	Spatial Res (m)	Sat. Temp (on Orbit) (K)
DNB	0.5 - 0.9	750	
M1	0.402 - 0.422	750	
M2	0.436 - 0.454	750	
M3	0.478 - 0.498	750	
M4	0.545 - 0.565	750	
M5	0.662 - 0.682	750	
M6	0.739 - 0.754	750	
M7	0.846 - 0.885	750	
M8	1.230 - 1.250	750	
M9	1.371 - 1.386	750	
M10	1.580 - 1.640	750	
M11	2.225 - 2.275	750	
M12	3.660 - 3.840	750	357°
M13	3.973 - 4.128	750	362° (High gain)
M14	8.400 - 8.700	750	352°
M15	10.263 - 11.263	750	370°
M16	11.538 - 12.488	750	368°
I1	0.600 - 0.680	375	
I2	0.846 - 0.885	375	
I3	1.580 - 1.640	375	
I4	3.550 - 3.930	375	357
I5	10.500 - 12.400	375	377

Highlighted in the above table are the key Thermal Infrared (TIR) channels which are employed to derive fire / hot spot detections from VIIRS data (Channels M13 and M15). VIIRS fire detection is performed using a contextual algorithm similar to the algorithm used for the MODIS fire detection process, which exploits the strong emission of mid-infrared radiation from fires (Dozier, 1981; Matson and Dozier, 1981). The algorithm uses brightness temperatures derived from the VIIRS 4 µm (M13) and 11 µm (M15) channels.

Additional applications research is indicating that the VIIRS I-Band data can be quite useful for fire observations, given the enhanced spatial resolution. The VIIRS 375m active fire algorithm builds on the heritage MODIS *Fire and Thermal Anomalies* product (MOD14 & MYD14), using a contextual approach based on all five imager (i-band) channels to detect active fires during daytime, and on the middle- and thermal-infrared channels to detect active fires burning at night. Visible and shortwave infrared channel daytime data are used to screen for clouds and water bodies, and to help separate active fires from other fire-free bright pixels characterized by high solar reflection. At night, the sources of confusion are by and large eliminated, therefore the night fire detection is primarily driven by channel I4 and I5 input data (Figure x).

Additional VIIRS information can be found at: http://www.jpss.noaa.gov/viirs.html. Further VIIRS wildfire sensing information can be found at: http://viirsfires.tumblr.com/ or http://npp.gsfc.nasa.gov/viirs.html.

Figure x. *VIIRS I-Band (375m spatial resolution) fire detection for a wildfire at Great Slave Lake, NW Territories, Canada collected on 14 July 2014. Note the improved spatial detail of the I-band data.*

3.1.4 ALI (EO-1 Platform)

The Advanced Land Imager (ALI) instrument on NASA's polar-orbiting Earth Observing (EO-1) satellite was used to validate and demonstrate technology for the Landsat Data Continuity Mission (LDCM / Landsat 8). The original EO-1 Mission was successfully completed in November 2001. Since the end of the mission, the high interest in continued acquisition of image data from EO-1, allowed continued operations through an agreement between NASA and the USGS as an Extended Mission. The EO-1 Extended Mission is chartered to collect and distribute ALI multispectral and Hyperion hyperspectral products in response to Data Acquisition Requests (DARs). Under the Extended Mission provisions, image data acquired by EO-1 are archived and distributed by the USGS Center for Earth Resources Observation and Science (EROS) and placed in the public domain. Because of this configuration, the ALI data cannot readily support near-real-time request acquisitions for fire observations, but can supplement Landsat 8 observations for post-fire assessment for small areas. The ALI has a small swath width (37x42 km) and a spatial resolution of 10m for the single panchromatic channel, and 30m for the multispectral channels (Table x). Because the ALI has a steerable sensor mechanism, the sensor can operate in "pointing-mode", allowing multiple looks (albeit, off-nadir) for the same feature on adjacent orbit passes. Further information on the ALI instrument on EO-1 can be found at: http://eo1.usgs.gov/sensors/ali.

Table x. ALI Spectral Band Configuration.

Band	Wavelength(µm)	Spatial Res. (m)
Pan	0.48 - 0.69	10
MS - 1'	0.433 - 0.453	30
MS - 1	0.45 - 0.515	30
MS - 2	0.525 - 0.605	30
MS - 3	0.63 - 0.69	30
MS - 4	0.775 - 0.805	30
MS - 4'	0.845 - 0.89	30
MS - 5'	1.2 - 1.3	30
MS - 5	1.55 - 1.75	30
MS - 7	2.08 - 2.35	30

3.1.5 Hyperion (EO-1 Platform)

The Hyperion instrument is part of the EO-1 satellite (in conjunction with ALI) and serves as an "on-request acquisition hyperspectral instrument. The Hyperion provides a high resolution hyperspectral imager capable of resolving 220 spectral bands (from 0.4 to 2.5 µm) with a 30-meter spatial resolution. The instrument can image a 7.5 km by 100 km land area per image, and provide detailed spectral mapping across all 220 channels with high radiometric accuracy (Table x).

Table X. Hyperion Spectral Band Configuration.

Spatial Resolution	30 m
Swath Width	7.75 km
Spectral Channels	220 unique channels; VNIR (70 channels, 356 nm - 1058 nm); SWIR (172 channels, 852 nm - 2577 nm)
Spectral Bandwidth	10 nm (nominal)
Digitization	12 bits
Signal-to-Noise Ratio (SNR)	161 (550 nm); 147 (700 nm); 110 (1125 nm); 40 (2125 nm)

The EO-1 Hyperion Extended Mission Page, where more information is available, can be found at: http://eo1.gsfc.nasa.gov/new/extended/.

Examples of wildfire imagery collected simultaneously from the ALI and Hyperion instrument aboard the EO-1 platform can be seen in Figure X.

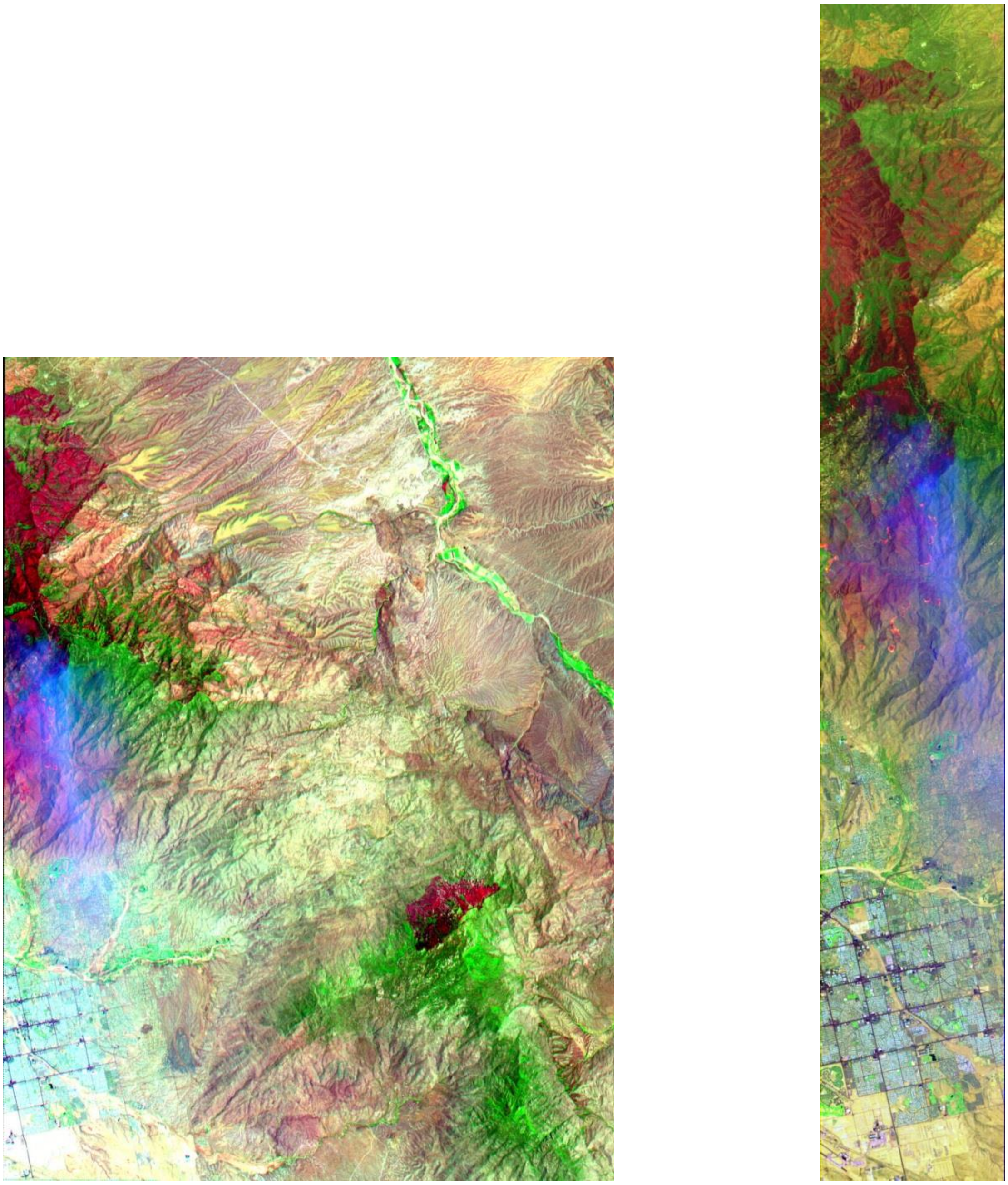

Figure x. *ALI (left) and Hyperion (right) image taken on the Aspen Forest Fire, near Tucson, Arizona. Note that neither the ALI nor the Hyperion contain MWIR channels, therefore the sensors are of limited utility for fire discrimination, and only useful in regions with a small smoke plume covering the burning area. The two instruments can prove useful for post-fire assessment of burn severity.*

3.1.5 Landsat 8 (OLI / TIRS)

The polar-orbiting Landsat 8 satellite imaging system was launched in February 2013 to replace the aging Landsat 7 and Landsat 5 systems. The Landsat 8 satellite images the entire Earth every 16 days in an 8-day offset from Landsat 7. Landsat 8 carries two instruments: The Operational Land Imager (OLI) sensor includes refined heritage bands, along with three new bands: a deep blue band for coastal/aerosol studies, a shortwave infrared band for cirrus detection, and a

Quality Assessment band. The Thermal Infrared Sensor (TIRS) sensor provides two thermal bands. These sensors both provide improved signal-to-noise (SNR) radiometric performance quantized over a 12-bit dynamic range (Table x). The Landsat 8 OLI instrument has a single panchromatic channel at 15m spatial resolution and multispectral bands (eight channels) at 30m spatial resolution. The two TIRS bands are collected at 100m spatial resolution, but resampled to 30m to match the OLI multispectral bands. The swath width is the 'standard" Landsat coverage of 185x185 km.

Table x. Landsat 8 OLI and TIRS Spectral Band Configuration.

Band	Wavelength (µm)	Spatial Res. (m)
Band 1	0.43 - 0.45	30
Band 2	0.45 - 0.51	30
Band 3	0.53 - 0.59	30
Band 4	0.64 - 0.67	30
Band 5	0.85 - 0.88	30
Band 6	1.57 - 1.65	30
Band 7	2.11 - 2.29	30
Band 8 - Panchromatic	0.50 - 0.68	15
Band 9	1.36 - 1.38	30
Band 10 (TIRS) 1	10.60 - 11.19	100
Band 11 (TIRS) 2	11.50 - 12.51	100

The Landsat 8 TIRS instrument is not readily suitable for direct fire mapping, due to the spectral channels that compose the thermal sensor. The 2 channels, centered at 10.9 and 12.0 um are not optimum for measuring high temperature sources such as wildfires. The temperature saturation point for these channels (~360°K) is not sufficient for fire / false detection separation. The channels can be used to highlight and identify hot spots, but without sufficient temperature discrimination to differentiate other nominally-detected hot spots (false positives). The 16-day orbit cycle also does not allow for "active fire mapping" from repeat coverage of active fire. The OLI instrument is useful for post-fire burn assessment and fire severity measurements, although, given the 16-day repeat orbit cycle and the high cloud cover presence in the arctic region, acquiring cloud-free data over burned areas can be problematic. A Landsat 8 OLI image of the 2014 King Fire (California) can be seen in Figure X. Further Landsat 8 OLI and TIRS information can be found at: http://landsat.usgs.gov/landsat8.php.

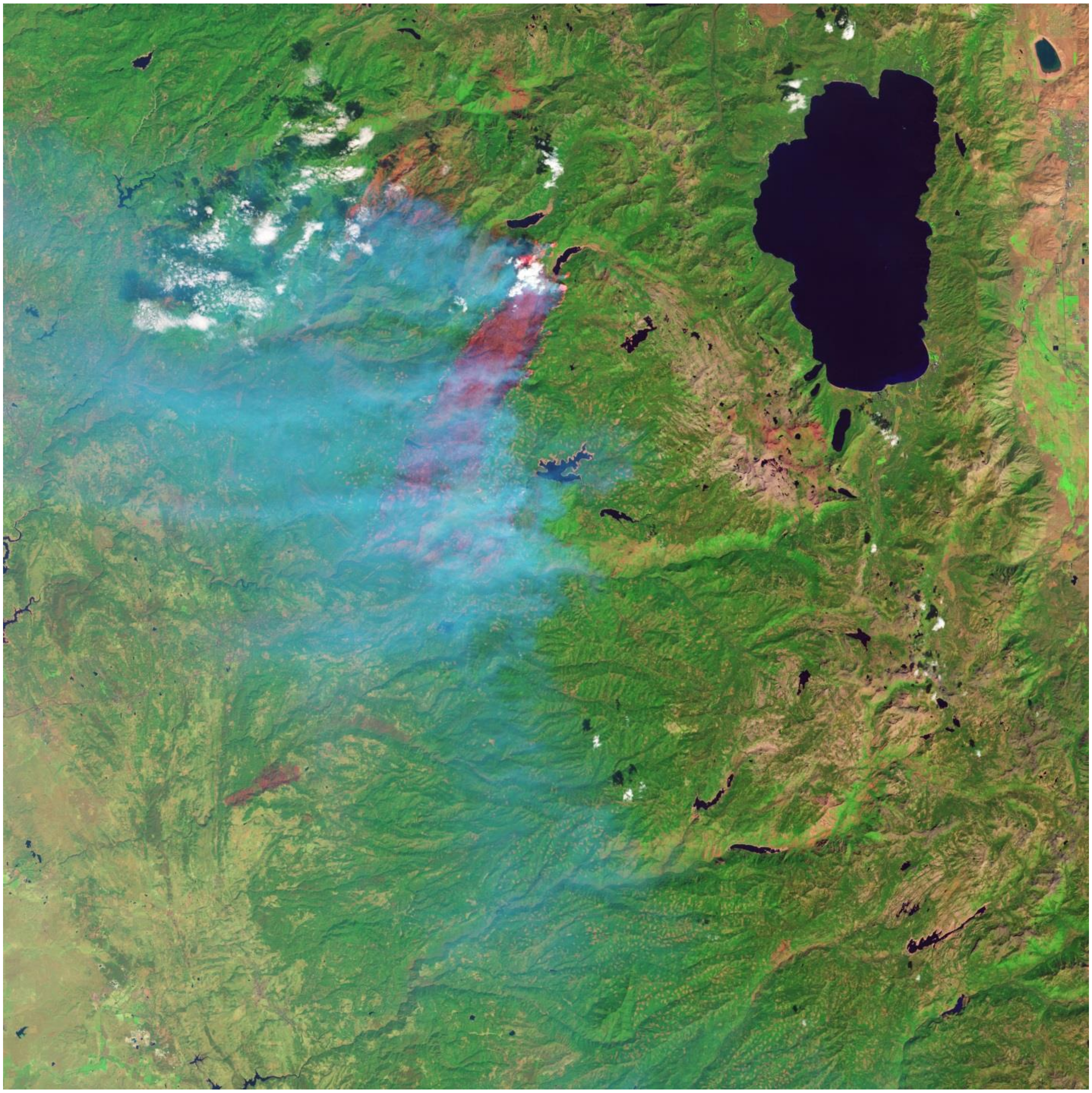

Figure X. *Landsat 8 OLI image of the King fire in Eldorado National Forest. In the false-color image, burned forest appears red; unaffected forests are green; cleared forest is beige; and smoke is blue. Lake Tahoe can be seen on the right side of the image.*

3.1.7 Operational Line Scanner (OLS) DMSP

The DMSP is a long-term USAF effort in space to monitor the meteorological, oceanographic and solar-geophysical environment of the Earth in support of DoD operations. All spacecraft launched have had a tactical (direct readout) and a strategic (stored data) capacity. In December 1972, DMSP data were declassified and made available to the civil and scientific communities. The USAF maintains an operational constellation of two near-polar, sun-synchronous satellites. Each DMSP satellite has a 101 minute, sun-synchronous near-polar orbit at an altitude of 830km above the surface of the earth. The visible and infrared sensors (OLS) collect images across a 3000km swath, providing global coverage twice per day. The combination of day/night and dawn/dusk satellites allows monitoring of global information such as clouds every 6 hours. Visible and infrared imagery from DMSP Operational Linescan System (OLS) instruments are used to monitor the global distribution of clouds and cloud top temperatures twice each day. The archive data set consists of low resolution global and high resolution regional, imagery recorded along a 3,000 km scan, satellite ephemeris and solar and lunar information. Infrared pixel values correspond to a temperature range of 190 to 310 Kelvins in 256 equally spaced steps. This calibrated temperature measurement does not allow finite discrimination of wildfires from other warm sources in that temperature range. The OLS is an oscillating scan radiometer with two broad spectral bands: the Visible Near-Infrared (VNIR, .58 to .91 µm) and Thermal Infrared (TIR, 10.3 to 12.9 µm). There are two spatial resolutions of night-time images: “fine” resolution data have a nominal spatial resolution of 0.56 km, while “smooth” data have a nominal spatial resolution of 2.7 km with 5 × 5 block averaging.
The data are sent to the National Geophysical Data Center's Solar Terrestrial Physics Division Earth Observation Group (NGDC/STP/EOG) by the Air Force Weather Agency (AFWA) for creation of an archive. Currently, data from 4 satellites (3 day/night, 1 dawn/dusk) are added to the archive each day. Further information on the DMSP OLS can be found at https://catalog.data.gov/dataset/dmsp-ols-operational-linescan-system and at http://ngdc.noaa.gov/eog/dmsp.html.

3.1.8 GOES Imager

The Geostationary Satellite system (GOES), operated by the United States National Environmental Satellite, Data, and Information Service (NESDIS), supports weather forecasting, severe storm tracking, and meteorology research. Spacecraft and ground-based elements of the system work together to provide a continuous stream of environmental data Like many weather satellites, GOES was developed and launched by NASA, but once operational GOES was turned over to NOAA for day-to-day administration. The provision of timely global weather information, including advance warning of developing storms, is the primary function of the GOES. There are four GOES satellites in geostationary position (35,790 km (22,240 statute miles above the earth); two of those satellites (GOES-EAST and GOES-WEST cover the U.S. GOES-13, also known as GOES-EAST sits above the equator at 75° West Longitude, while GOES-WEST (GOES-15) is in geostationary orbit at the equator and 135° West Longitude.

There are two payload instruments on GOES, the Imager and the Sounder. The Imager is a multichannel instrument that senses infrared radiant energy and visible reflected solar energy from the Earth's surface and atmosphere. The Sounder provides data for vertical atmospheric temperature and moisture profiles, surface and cloud top temperature, and ozone distribution. The GOES I-M Imager is a five channel (one visible, four infrared) imaging radiometer designed to sense radiant and solar reflected energy from sampled areas of the earth. The Imager's multispectral channels can simultaneously sweep an 8-kilometer (5 statute mile) north-to-south swath along an east-to-west/west-to-east path, at a rate of 20 degrees (optical) east-west per second. This translates into being able to scan a 3000 by 3000 km (1864 by 1864 miles) "box" centered over the United States. The spectral band and spatial resolution configuration for the GOES Imager are shown in Table x.

Table x. GOES Imager Sensor Specifications and Spectral Band Configuration.

Band	Wavelength (μm)	Spatial Res.
1 (Visible)	0.55 - 0.75	1 km
2 (MWIR)	3.80 - 4.00	4 km
3 (Moisture)	6.50 - 7.00	8 km
4 (IR 1)	10.20 - 11.20	4 km
5 (IR 2)	11.50 - 12.50	4 km

GOES Imager data have been used to highlight wildfires using the band 2 MWIR (3.80-4.00 μm) data at 4 km spatial resolution. Further GOES information is also available at: http://noaasis.noaa.gov/NOAASIS/ml/imager.html. The NOAA National Environmental Satellite, Data, and Information Service (NESDIS), Office of Satellite and Products Operations (OSPO) produces fire products operationally and serves them at the following website address: http://www.ospo.noaa.gov/Products/land/hms.html. The 4km GOES fire detection data for the current year are accessible from the NOAA/NESDIS website: http://www.firedetect.noaa.gov/viewer.htm. The GOES Imager daily wildfire detection data are also served on the web by the USFS, and can be accessed at the following website address: http://activefiremaps.fs.fed.us/current.php?sensor=avhrr&extent=conus.

3.1.9 AVHRR

The Advanced Very High Resolution Radiometer (AVHRR) is a NOAA polar-orbiting weather satellite system which provides daily coverage of the entire planet at moderate resolution (~1.1 km). The thermal channel included on AVHRR satellites provides sufficient wildfire detection capabilities with a MWIR (Channel 3B) saturation temperature of 320-331° K. The AVHRR satellite data has an FOV of 3000 km (swath width), and an FOV of 1100m (1.1 km) spatial pixel resolution. Although the spatial resolution is considered 'coarse", small fires can be detected when their emitted energy is sufficient enough to saturate a 1.1km pixel, allowing for events smaller than the FOV to be detected (Table x).

Table x. AVHRR Satellite Sensor Specifications and Spectral Band Configuration.

Band	Wavelength (μm)	Spatial Res.
1	0.58 - 0.68	1.09 km
2	0.725 - 1.00	1.09 km
3A	1.58 - 1.64	1.09 km
3B	3.55 - 3.93	1.09 km
4	10.30 - 11.30	1.09 km
5	11.50 - 12.50	1.09 km

The AVHRR Fire Detects from the Fire Identification, Mapping and Monitoring Algorithm (FIMMA) product is an automated algorithm to detect fires from the NOAA polar-orbiting AVHRR satellites. The FIMMA product was originally developed by Dr. I. Csiszar while he was a member of the Cooperative Institute for Research in the Atmosphere, working at the NOAA/NESDIS Office of Research and Applications (ORA) in Camp Springs, Maryland. The latest version of FIMMA uses geo-corrected High Resolution Picture Transmission (HRPT) AVHRR data over the US (including Alaska and Hawaii) received from the NOAA/NESDIS CoastWatch group and uses the SeaSpace Terascan software to correct for known AVHRR navigation errors. The FIMMA product is running in operational mode within the Satellite Services Division (SSD). Products are currently being made from available NOAA-15 (~7:30 am and pm, local time), NOAA-16 (~1:30 am, local time) and NOAA-17 (~10:30 am and pm, local time) passes, which have 3.7 micron (MWIR) measurement capabilities. The orbital data are available near-real-time, typically 3-6 hours after satellite overpass. The AVHRR fire product is generated by an automated algorithm and is placed on the web page as soon as available. The FIMMA algorithm uses AVHRR channels 2 (.9 micron), 3b (3.7 micron), 4 (10.8 micron) and 5 (12 micron).

The AVHRR daily wildfire detection data are also served on the web by the USFS, and can be accessed at the following URL: http://activefiremaps.fs.fed.us/current.php?sensor=avhrr&extent=conus. AVHRR and GOES fire detection data are not provided for download by the USFS Active Fire Mapping Program. The 1km AVHRR fire detection data for the current year are accessible from NOAA/NESDIS website: http://www.firedetect.noaa.gov/viewer.htm

3.1.10 SEVIRI

The European Organization for the Exploration of Meteorological Satellites (EUMETSAT) Meteosat satellite is in geostationary orbit 36,000 km above the equator, the Meteosat satellites — Meteosat-7, -8, -9 and -10 — operate over Europe and Africa. Meteosat-10 (launched from the Guiana Space Centre in Kourou in 2012) is the prime operational geostationary satellite, positioned at 0 degrees longitude and providing full disc imagery every 15 minutes. Meteosat-9 (launched on 2005) provides the Rapid Scanning Service, delivering more frequent images every five minutes over parts of Europe, Africa and adjacent seas. Meteosat-8 (launched in 2002) serves as a back up to both spacecraft. Meteosat-7 (launched in 1997) is the last of the first generation of Meteosat satellites and operates over the Indian Ocean, filling a data gap over the region until it is de-orbited in 2017.

The MSG satellites carry a pair of instruments — the Spinning Enhanced Visible and InfraRed Imager (SEVIRI), which observes the Earth in 12 spectral channels and the Geostationary Earth

Radiation Budget (GERB) instrument, a visible-infrared radiometer for Earth radiation budget studies. The satellites continually return detailed imagery of Europe, the North Atlantic and Africa every 15 minutes, for operational use by meteorologists. The SEVERI instrument is the most useful for fire detection, although it is of limited utility for high latitude fire discrimination to its geo-synchronous orbit location (over the equator), with high limb-look angles for near-polar regions. The image repeat cycle for SEVIRI is every 15-mintes and the spatial resolution varies by spectral band as is shown in Table x.

Table x. METEOSAT SEVIRI Sensor Specification and Spectral Band Configuration.

Band	Wavelength (μm)	Spatial Res. (km)
HRV	Broadband (peak within 0.6 – 0.9)	1 km
VIS 0.6	0.56 – 0.71	3.0 km
VIS 0.8	0.74 – 0.88	“
IR 1.6	1.50 – 1.78	“
IR 3.9	3.48 – 4.36	“
IR 8.7	8.30 – 9.10	“
IR 10.8	9.80 – 11.80	“
IR 12.0	11.00 – 13.00	“
IR 6.2	5.35 – 7.15	“
IR 7.3	6.85 – 7.85	“
IR 9.7	9.38 – 9.94	“
IR 13.4	12.40 – 14.40	“

Information on the METEOSAT SEVIRI fire detection capabilities and data is provided at: http://ocean.space.noa.gr/seviri/fend_new/, where current detections as well as archival data are available in a web map server framework. Other fire related SEVIRI information (Fire FRP) is available at: http://badc.nerc.ac.uk/view/neodc.nerc.ac.uk__ATOM__DE_df857e66-1d71-11df-bc75-00e081470264.

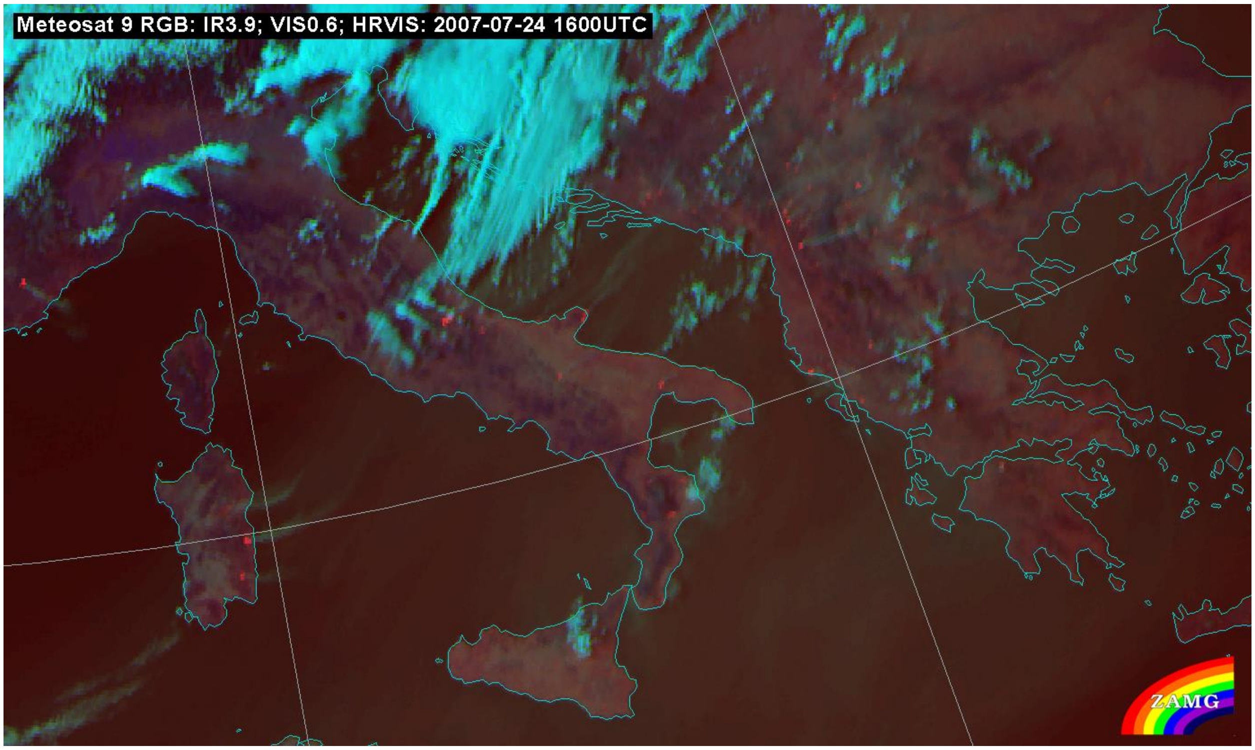

***Figure x**. Meteosat SEVIRI data collected 24 July 2007 over fires in the southern EU Mediterranean region. The image is a composite of the visible, MWIR and HR visible data channels. Fire locations are identified in red, while associated smoke plumes are seen in blue-white emanating from the fires.*

3.1.11 DLR FireBird Mission (TET-1 and BIROS)

The DLR FireBird mission consists of the two constructed DLR spacecraft TET-1 and BIROS. The main goal of this mission is the development of small satellite systems for detection and monitoring of high temperature events (HTE), e.g. forest fires or other hot spots. TET-1 was launched in summer of 2012, and in the first year of operation the spacecraft was used by the OOV (On-Orbit Verification) mission of the DLR Space Administration. After that first year in space, the objectives changed to the goals of the FireBird mission, supported by the R&D program of the DLR Directorate Space. The BIROS (Berlin Infrared Optical System) spacecraft, with a launch expected in 2015, is the second satellite of the two satellite constellation FireBird. BIROS is also supported by the R&D program of the DLR Directorate Space. The constellation phase of FireBird is expected to last one year, ending in December 2015, but if the satellites are still working, the mission may be continued. BIROS has the same size as TET-1 (but with a mass of 140 kg) and an IR payload for fire detection.

TET-1 (Technologie Erprobungs Träger-1) is a German technology demonstration microsatellite of DLR (German Aerospace Center). The overall goals of TET-1 is to provide industry and research institutes with adequate means for the in-flight validation of space technology. The satellite is in a sun-synchronous orbit altitude of ~510 km, with a Local-Time-On-Ascending-

Node pass at 11:27 UTC. The optical payload, designed and developed at DLR, consists of an assembly of three push-broom cameras, one in the VNIR (Visible Near Infrared) range and two imagers in the infrared region (MWIR and LWIR) (Table x).

Table X. TET-1 Sensor Specification and Spectral Band Configuration.

Band	**Wavelength (µm)**	**Spatial Res. (m)**
B1	.460-.560	42.4m
B2	.565-.725	"
B3	.790-.930	"
MWIR	3.4 - 4.2	356m
LWIR	8.5 - 9.3	"

The TET-1 mission objective is the detection and quantitative analysis of HTE (High Temperature Events) like wildfires and volcanoes. The optical concept of the TET sensor is to follow-on to the BIRD system, launched in 2001. The fire detection and analysis extraction of fire attributes includes:

- Background classification for threshold adaptation: land, water, clouds, sun glints;
- Hotspot detection (based principally on the BIRD algorithm);
- Consolidation of hot pixels in hot clusters;
- Extraction of attributes of hot clusters, such as coordinates, FRP (Fire Radiative Power) and, optionally, fire line strength, effective fire temperature and area.

The TET-1 was planned for short-mission operational validation and verification of a microsat concept, weighing less than 12kg for the sensor package. The BIROS (Berlin InfraRed Optical System) is a follow-on fire detection mission of DLR with a planned launch in 2015. BIROS will be based on the satellite bus as developed for TET-1. The BIROS sensor system is nearly identical to the optical payload of TET-1. The TET-1 was still operating in May 2014. The two systems (TET-1 and BIROS) were not designed to be operational fire sensing instruments, nor have a wide distribution of data. The intent is to develop and evaluate technologies for improved fire mapping with an eventual goal of operationalizing future systems based on the proven technology components. Additional information on the system can be found at: https://directory.eoportal.org/web/eoportal/satellite-missions/t/tet-1.

3.1.12 SENTINEL-2 Multispectral Imager (MSI)

SENTINEL-2 is a multispectral operational imaging mission within the GMES (Global Monitoring for Environment and Security) program, jointly implemented by the EC (European Commission) and ESA (European Space Agency) for global land observation (data on vegetation, soil and water cover for land, inland waterways and coastal areas, and also provide atmospheric absorption and distortion data corrections) at high resolution with high revisit capability to provide enhanced continuity of data so far provided by SPOT-5 and Landsat-7. The Multispectral Imager (MSI) instrument is based on push-broom concept. The equivalent swath width for the coverage area is 290 km. The MSI is planned as having 10 m, 20 m, and 60 m spatial resolution (in the VNIR to SWIR spectral range), and an accurate geolocation of < 20 m (without GCPs) and shall be produced automatically to meet the timeliness requirements. The system will have very good radiometric image quality (combination of onboard absolute and on-ground vicarious calibration). Since the MSI will not have a MWIR or a LWIR, the system will have limited utility for direct wildfire observations, but will be valuable for post-fire assessment and for continuity with Landsat 8 observations.

Table X. SENTINEL-2 MSI Sensor Specification and Spectral Band Configuration.

Band	**Center Wavelength (µm)**
B1	0.443
B2	0.49
B3	0.56
B4	0.665
B5	0.705
B6	0.74
B7	0.775
B8	0.842
B8a	0.865
B9	0.94
B10	1.375
B11	1.61
B12	2.19

A launch date for the SENTINEL-2 is planned for the first half of 2015. A ground receiving station is planned for Alaska, U.S. Further information on the SENTINEL-2 can be found at: https://directory.eoportal.org/web/eoportal/satellite-missions/c-missions/copernicus-SENTINEL-2.

3.1.13 SENTINEL-3 SLSTR

The European Space Agency's (ESA) SENTINEL-3 polar-orbiting mission's main objective is to measure sea-surface topography, sea- and land-surface temperature and ocean- and land-surface color with high-end accuracy and reliability in support of ocean forecasting systems, and for environmental and climate monitoring. SENTINEL-3 builds directly on the ERS-2 and Envisat heritage. The instrument package includes the Sea and Land Surface Temperature Radiometer (SLSTR), which is based on Envisat's Advanced Along Track Scanning Radiometer (AATSR), to determine global sea-surface temperatures to an accuracy of better than 0.3 K. The SLSTR improves the along-track-scanning dual-view technique of AATSR and provides advanced atmospheric correction. The SLSTR has a swath width in the nadir view of >1400 km, and in the oblique view of >740 km. With one satellite in orbit, the global coverage revisit time for the polar-orbiter is 1.9 days, while a revisit time of 0.9 days is expected for a two-satellite system (when launched / operational), and up to a 0.5 day revisit time for a two satellite, nadir view revisit time. The SLSTR spatial resolution is expected to be 0.5 km (500m) for the visible and SWIR bands, and 1.0 km (1000m) for the MWIR and LWIR fire channels. SLSTR will measure in nine spectral channels and two additional bands optimized for fire monitoring (duplicated spectral range with increased fire temperature measurement saturation capabilities). The SLSTR has a spatial resolution in the visible and shortwave infrared channels of 500 m, and 1 km in the thermal infrared channels (Table x). A pair of SENTINEL-3 satellites will enable short revisit times of less than one day for the SLSTR at the equator.

Table x. SENTINEL-3 SLSTR Sensor Specification and Spectral Band Configuration.

Band	Wavelength (μm)	Spatial Res. (km)
1 (VIS)	0.55 (center)	0.5
2 (VIS)	0.659	"
3 (IR)	0.865	"
4 (SWIR)	1.375	"
5 (SWIR	1.61	"
6 (SWIR)	2.25	"
7 (MWIR)	3.74	1.0
8 (LWIR)	10.85	1.0
9 (LWIR)	12.0	1.0

The key fire detection channels that will be employed for the algorithm are highlighted in red in the table above. The ESA plans to implement a fire detection algorithm for the SLSTR data and provide near-real-time fire locations to the community following launch and sensor shake-down operations. The fire characterization for the SENTINEL-3 SLSTR can be found at: https://SENTINEL.esa.int/web/SENTINEL/SENTINEL-3-slstr-wiki/-/wiki/SENTINEL+Three+SLSTR/Fire+characterisation.
The first SENTINEL-3 satellite is expected to be launched in the 2014 / 2015 timeframe, followed by the second satellite shortly thereafter. Further SENTINEL-3 information can be found at: http://www.esa.int/Our_Activities/Observing_the_Earth/Copernicus/SENTINEL-3.

3.1.14 GCOM-C SLGI

The Japan Aerospace Exploration Agency (JAXA) Global Change Observation Mission (GCOM) project consists of two satellites; the GCOM-C will carry the Second Generation Global Imager (SGLI). The GCOM-C is scheduled for launch in 2016 with a planned mission life of five years.. The SGLI on GCOM-C1 is an optical sensor capable of 19-channel observation at wavelengths from near-UV to thermal infrared wavelengths (380nm to 12μm). SGLI also has polarimetry and forward / backward observation functions at red and near infrared wavelengths. SGLI will be in a sun-synchronous orbit at 798km, and will obtain global observation data once every 2 or 3 days, with resolutions of 250m to 1km, with a nominal swath width of 1150-1400 km (Table x).

Table x. The JAXA GCOM-C SLGI Sensor Specification and Spectral Band Configuration.

Band	Wavelength (μm) Center	Spatial Res. (km)
VN1	0.380	250
VN2	0.412	"
VN3	0.443	"
VN4	0.490	"
VN5	0.530	"
VN6	0.565	"
VN7	0.6735	"
VN8	0.6735	"
VN9	0.763	1000
VN10	0.8685	250
VN11	0.8685	250
P1 (Polarized Channel)	0.6735	1000
P2 (Polarized Channel)	0.8685	"
SW1	1.050	"
SW2	1.380	"
SW3	1.630	250
SW4	2.210	1000
T1 (TIR)	10.8	500
T2 (TIR)	12.0	500

The JAXA GCOM-C SLGI sensor will not have a MWIR channel (~4.0 μm) to allow discrete fire observations, although the LWIR channels, particularly the T1 (10.8 μm) channel may prove useful for fire discrimination. A proposition has been made to develop a fire detection algorithm using the SLGI by Miura and Moriyama (2010). Further information on the GCOM-C SGLI satellite platform / sensor can be found at: http://suzaku.eorc.jaxa.jp/GCOM_C/presen/SPIE2014_SGLI_IRS_20141026.pdf and http://www.jaxa.jp/projects/sat/gcom_c/index_e.html.

3.1.15 JPSS-1 and JPSS-2 VIIRS (planned early 2017 launch)

Building on the success of Suomi NPP, NOAA and NASA are on track, on budget, and on schedule for the launch of the second satellite in the JPSS program in early 2017, called Joint Polar Satellite System-1 (JPSS-1). JPSS-1 is the second spacecraft within NOAA's next generation of polar-orbiting satellites. It is scheduled to launch in early 2017. JPSS-1 spacecraft will have five similar instruments to Suomi NPP: (1) VIIRS, (2) CrIS, (3) ATMS, (4) OMPS-N, and (5) CERES-FM6, taking advantage of the successful technologies developed through the Suomi NPP satellite. JPSS-1's design life is seven years, and it is scheduled to launch aboard a Delta-II Mission Launch Vehicle.

JPSS-2 will provide operational continuity of satellite-based observations and products for NOAA Polar-Orbiting Environmental Satellites (POES) and S-NPP satellite and ground systems. The baseline plan for JPSS Ground System will be to support JPSS-2, similar to JPSS-1. The JPSS-2 spacecraft will host the following instruments: (1) VIIRS, (2) CrIS, (3) ATMS, and (4) OMPS. The two platforms (JPSS-1 and JPSS-2), with the same VIIRS configuration will allow long-term mission science continuity. Further JPSS-1 and JPSS-2 information can be found at: http://www.jpss.noaa.gov/satellites.html#JPSS2. The VIIRS spectral configuration can be found in the table located in the VIIRS instrument description section of this document. It is not known at this time if the spatial resolution will remain the same as the current Suomi NPP VIIRS.

3.1.16 GOES-R / S Advanced Baseline Imager (ABI) (planned early 2016 launch)

The Geostationary Operational Environmental Satellite-R Series (GOES-R) is the next generation of National Oceanic and Atmospheric Administration (NOAA) geostationary Earth-observing systems planned for launch in early 2016. The Advanced Baseline Imager (ABI), a sixteen-channel imager with two visible channels, four near-infrared channels, and ten infrared channels, will provide three times more spectral information, four times the spatial resolution, and more than five times faster temporal coverage than the current system (Tables x and x). Other advancements over current GOES capabilities include total lightning detection (in-cloud and cloud-to-ground flashes) and mapping from the Geostationary Lightning Mapper (GLM), and increased dynamic range, resolution, and sensitivity. This should enable enhanced, early fire detection (on 5-minute interval data collection) and improved detection through increased spatial resolution. Because the GOES-R ABI system will be operational from a geostationary "parked" orbit, centered over the equator, there is limited high latitude coverage for north / south regions. The slant-angle for the sensor at the high latitudes makes accurate fire detections problematic and reduces their effectiveness for discriminating fire events. The off-angle view also increases the effective Ground Sampling Distance (spatial resolution) of the system, reducing the detectability of fire / hot spot events (Figure x).

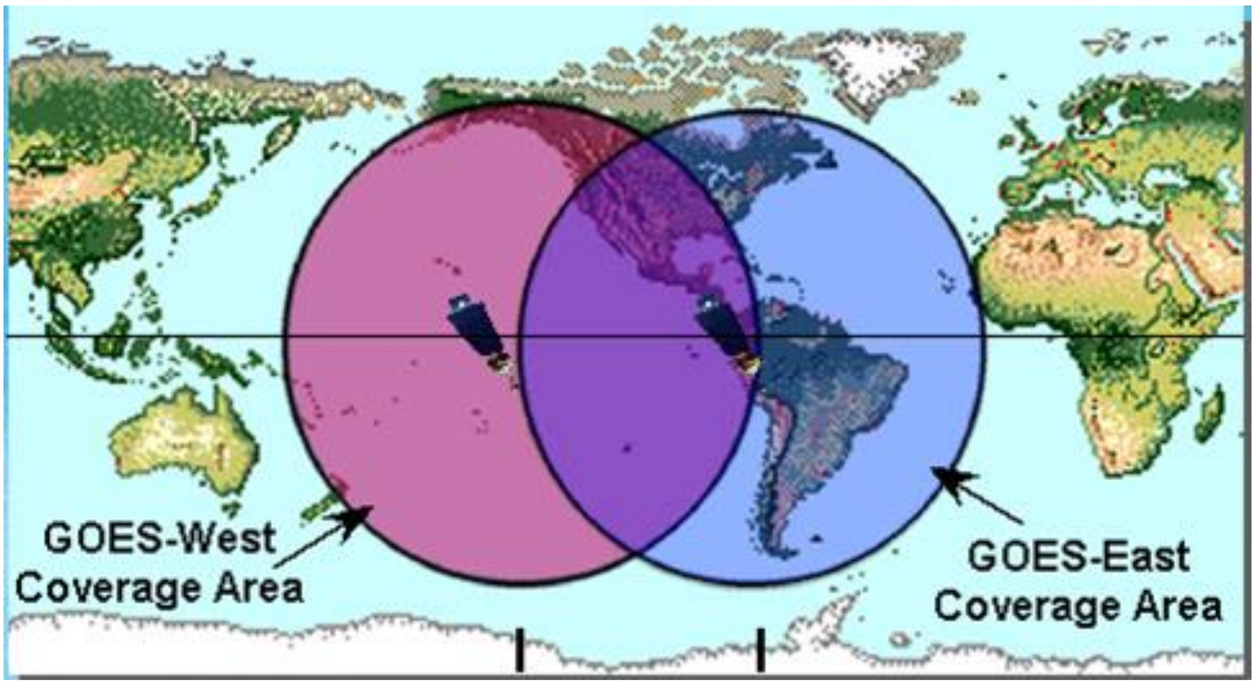

Figure x. *U.S. GOES Imager Coverage. With two geostationary orbit platforms (GOES-West and GOES-East) positioned above the equatorial Pacific and equatorial Columbia, SA, a large swath of North and South America as well as the eastern Pacific and much of the Atlantic Ocean can be imaged. The high northern latitudes are precluded from coverage.*

Table X. The GOES-R ABI Planned Configuration.

Spectral Coverage:	16 bands
Spatial Resolution:	
0.64 µm Visible (band 2) Other visible/near-IR bands Bands (>2.0 µm)	0.5 km 1.0 km 2 km
Spatial Coverage:	

Full Disk CONUS Mesoscale	4 per hour 12 per hour Every 30 sec

Table X. GOES-R ABI Planned Spectral Band Configuration.

GOES-R ABI Band	Wavelength (μm)	Spatial Res. (km)
1	0.45 - 0.49	1
2	0.59 - 0.69	0.5
3	0.846 - 0.885	1
4	1.371 – 1.386	2
5	1.58-1.64	1
6	2.225 – 2.275	2
7	3.8 - 4.0	2
8	5.77 – 6.6	2
9	6.75 – 7.15	2
10	7.24 – 7.44	2
11	8.3 – 8.7	2
12	9.42 – 9.8	2
13	10.1 – 10.6	2
14	10.8 – 11.6	2
15	11.8 – 12.8	2
16	13.0 - 13.6	2

The GOES-R ABI will be capable of detecting heat signature with improved time and space resolution, including smaller fires, compared to the current GOES Imager. GOES-R will represent a step forward in the ability of the hazards and air quality monitoring communities to detect fires and their properties. The algorithm used for GOES-R data was taken into account when creating the specifications of the 3.9 micron band on ABI (band 7; highlighted in red), allowing GOES-R to exceed the Fire Detection and Characterization (FDC) performance seen with current GOES satellites. The FDC algorithm is a contextual algorithm that looks for hot spots, attempts to determine the background temperature without fire present, corrects for solar contamination and water vapor attenuation, and in cases where confidence is high, provides fire characteristics for the detected fires. The algorithm screens out surfaces that are not usable, such as water, tundra, deserts, and sparsely vegetated mountains. Such surfaces either do not see fires or are prone to false alarms due to extreme daytime heating. Regions where solar reflection is an issue are screened out based on the viewing geometry. The algorithm also screens out clouds that are opaque for ~4 micron radiation. This is different than a typical cloud mask since fires are often detected through thin clouds such as cirrus or stratus decks.

The GOES ABI instrument on GOES-R will scan about five (5) times faster than the current GOES imager, allowing for more frequent coverage of earth full-disk views. There are two anticipated scan modes for the ABI: Full-disk images collected every 15 minutes, plus 5-minute CONUS images and mesoscale images, or the collection of the full disk every 5-minutes (Figure x). The GOES-R ABI instrument will have limited / no coverage over the high arctic region as noted in the figure of the GOES East and West coverage area, as well as in the full-disk figure below. This will make it of limited value when trying to observe fire events in the tundra and arctic regions of North America.

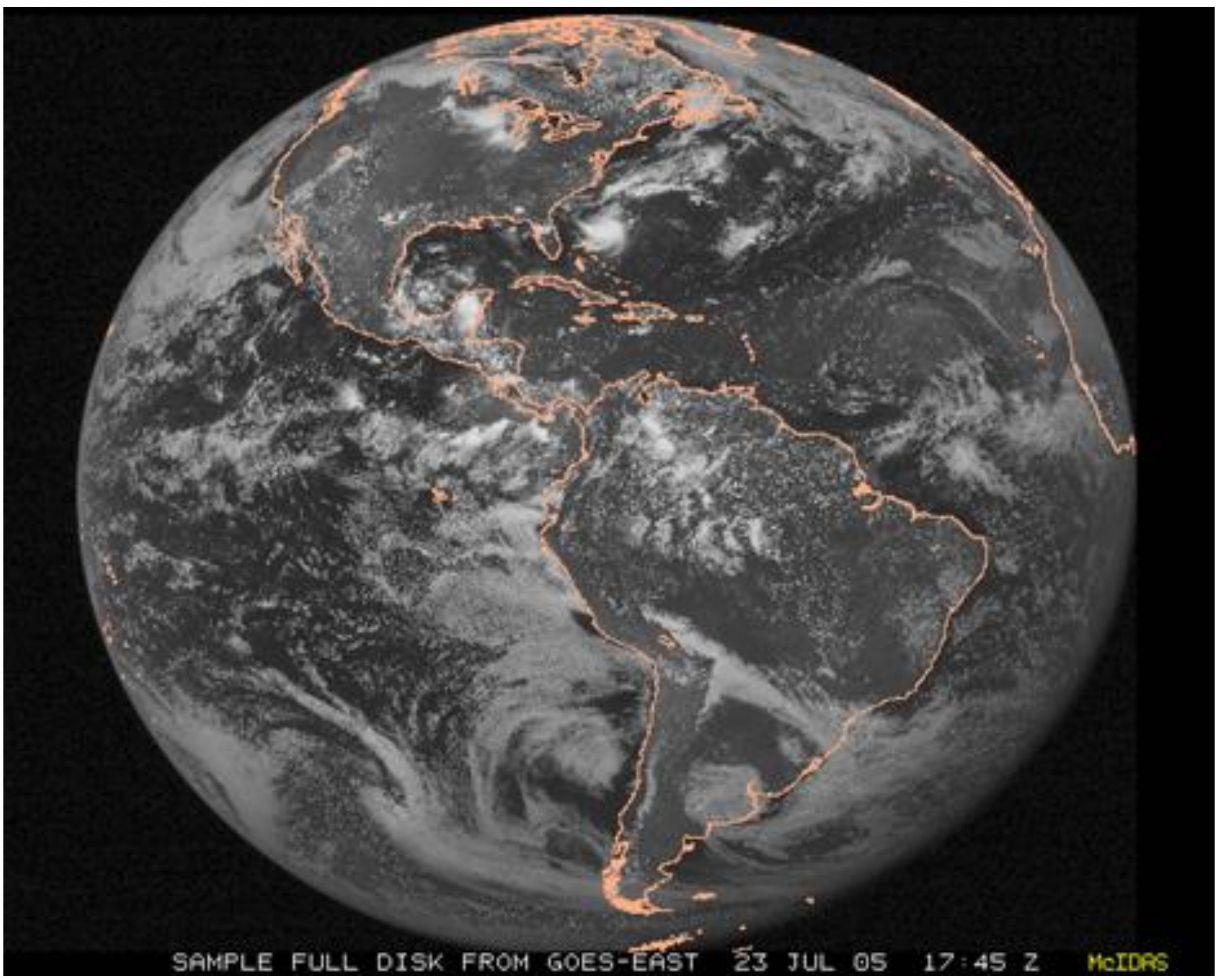

***Figure x**. Full disk image example of the GOES east coverage expected to be acquired on a 5x faster rate on GOES-R. Note the minimal coverage (and slant-angle look) for boreal and arctic regions*

Further information on the GOES-R system and fire detection capabilities can be found at: http://www.ssd.noaa.gov/PS/FIRE/Layers/ABBA/abba.html and http://cimss.ssec.wisc.edu/goes/burn/wfabba.

3.1.17 HyspIRI (~2022 launch)

The Hyperspectral Infrared Imager (HyspIRI) mission will study the world's ecosystems and provide critical information on natural disasters such as volcanoes, wildfires and drought. The mission will also assess the pre-eruptive behavior of volcanoes and the likelihood of future eruptions as well as the carbon and other gases released from wildfires. The HyspIRI mission includes two instruments mounted on a satellite in Low Earth Orbit. There is an imaging spectrometer measuring from the visible to short wave infrared (VSWIR: 380 nm - 2500 nm) in 10 nm contiguous bands and a TIR multispectral imager measuring from 3 to 12 um in the mid and long-wave thermal infrared (MWIR and LWIR). The VSWIR and TIR instruments both have a spatial resolution of 60 m at nadir. The VSWIR will have a revisit of 19 days and the TIR will have a revisit of 5 days. HyspIRI also includes an Intelligent Payload Module (IPM) which will enable direct broadcast of a subset of the data.

The mission was recommended in the recent National Research Council Decadal Survey requested by NASA, NOAA, and USGS. The mission is currently at the study stage of mission planning / development and if costing objectives are met, it will be slated for launch in the early 2020's.

3.1.18 INSAT-3D

The INSAT-3D is an advanced weather satellite of India configured with an improved Imaging System and Atmospheric Sounder. INSAT-3D is designed for enhanced meteorological observations, monitoring of land and ocean surfaces, generating vertical profile of the atmosphere in terms of temperature and humidity for weather forecasting and disaster warning. The INSAT-3D carries four payloads -

- 6 channel multi-spectral Imager
- 19 channel Sounder
- Data Relay Transponder (DRT)
- Search and Rescue Transponder

The payloads of INSAT-3D will provide continuity and further augment the capability to provide various meteorological as well as search and rescue services. The INSAT-3D was launched into a geo-synchronous orbit on 26 July 2013 and is currently operational, providing full disk imagery with the satellite centered at 93.5 degrees East. The system provides images in Visible, Near-Infrared, Shortwave Infrared, Water Vapor and Thermal Infrared bands. The MWIR and LWIR bands, although in the range of fire spectral channels, are calibrated for low-temperature saturation points to make observations low clouds and fog, and estimates of sea surface temperatures. The Imager generates images of the earth disk from geostationary altitude of 36,000 km every 26 minutes and provide information on various parameters, namely, outgoing long-wave radiation, quantitative precipitation estimation, sea surface temperature, snow cover, cloud motion winds, etc. (Table x).

Table X. INSAT-3D Planned Spectral Band Configuration.

Band	Wavelength (µm)
VIS	0.55 - 0.75
SWIR	1.55 - 1.70
MWIR	3.8 - 4.0
TIR 1	10.3 - 11.3
TIR 2	11.5 - 12.5
Water Vapor	6.5 - 7.1

Since the INSAT-3D is a geo-synchronous satellite, centered with full disk imaging over the equator, it is not well suited for arctic environment imaging, due to the off-nadir angular imaging at the sensor limbs (northern and southern polar regions). Further information on the INSAT-3D can be found at: http://www.isro.org/insat-3d/mission.aspx.

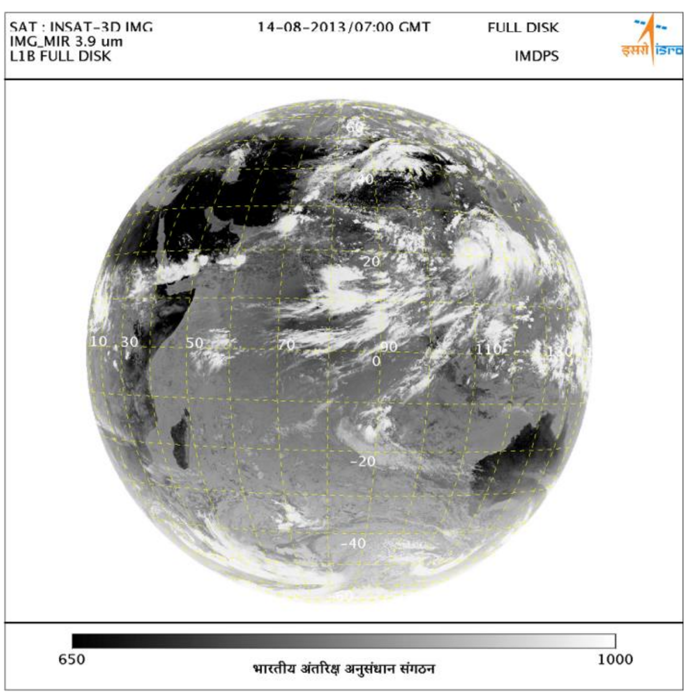

Figure x. *INSAT-3D Full Disk Image of the MWIR band centered over the central Indian Ocean (93.5 degrees East over the equator).*

3.1.19 CMA Feng-Yun-4 AGRI (planned 2017 launch)

The China Meteorological Administration (CMA) Feng-Yun-4 (Wind-Cloud 4) will be China's second series of geostationary meteorological satellites. They are similar to the USA's GOES-13/15 3-axis stabilized satellites built by the Boeing Corp. in the USA. The FY-4 plans for 3-axis stabilization, 14-channel imagery with 5-minute scans of China, a FTIR sounder, a lightning mapper, and a solar imager. The current plans are for the FY-4A to be launched in 2017, with 6 more follow-on at 2- to 3-year intervals. The FY-4 imager is called the Advanced Geosynchronous Radiation Imager (AGRI), and resembles the Advanced Baseline Imager (ABI) being constructed for GOES-R/S. AGRI uses an off-axis telescope, two scan mirrors, 216 detectors in 14 spectral bands, and full-path on-orbit calibration. Since the system will focus as a weather satellite with coverage over China, it will have limited coverage of the north polar regions. There is a channel identified as a fire detection channel in the MWIR and a LWIR channel that can be used to develop a kA-b fire detection algorithm. Those channels are identified in the table below (Table x).

Table X. Feng-Yun-4 Planned Spectral Band Configuration.

Band	Wavelength (µm)	Spatial Resolution (km)
1	0.45-0.49	1
2	0.55-0.75	0.5-1
3	0.75-0.90	1
4	1.36-1.39	2
5	1.58-1.64	2
6	2.10-2.35	4-Feb
7	3.5-4.0 (high)	2
8	3.5-4.0 (low)	4
9	5.8-6.7	4
10	6.9-7.3	4
11	8.0-9.0	4
12	10.3-11.3	4
13	11.5-12.5	4
14	13.2-13.8	4

Further information on the CMA Feng-Yun-4 and the AGRI sensor can be found at the following locations: http://www.cma.gov.cn/en/ or http://goes.gsfc.nasa.gov/text/geonews.html#FENGYUN2.

3.1.20 MTG-I FCI (planned for launch in 2019)

The EUMETSAT's METEOSAT Third Generation (MTG) mission will consist of satellite pairs in geostationary orbit, one carrying a multispectral imager (MTG-I), the other a hyperspectral sounder (MTG-S). The imaging satellite will carry a 16-channel scanning imager, and a high-resolution 4-channel mesoscale imager. The sounding satellite will carry an infrared instrument for temperature-moisture profiling, a lightning mapper, and a reflected sunlight instrument for pollution tracking over Europe. When ESA contracted for the MTG instrument payload with Astrium in mid-2011, the atmospheric mission was called "Sentinel-4".

The MTG-I Flexible Combined Imager (FCI) will have eight 1-km resolution channels using reflected sunlight at 0.4, 0.5, 0.6, 0.8, 0.9, 1.3, 1.6, and 2.2 microns. The scanning imager will also have eight 2-km resolution channels using thermal emission at 3.8, 6.2, 7.3, 8.7, 9.7, 10.5, 12.3, and 13.3 microns (Table x). The MTG FCI requirements call for Full Disk Scan (FDS), with a basic repeat cycle of 10 minutes, and a European Regional-Rapid-Scan (RRS) which covers of one-quarter of the full disk with a repeat cycle of 2.5 minutes.

The METEOSAT MTG has a MWIR (centered at 3.8 µm and a LWIR (centered at 10.5 µm) channel that can be employed to map hot targets (fires). The calibration / saturation point of these channels (particularly the 3.8 µm channel) has not been established yet.

Table x. METEOSAT MTG Planned Spectral Band Configuration

Band	**Center Wavelength (um)**	**Spatial Res. (km)**
VIS 0.4	0.444 µm	1.0 km
VIS 0.5	0.510 µm	1.0 km
VIS 0.6	0.640 µm [TBC]	1.0 km; 0.5 km*
VIS 0.8	0.865 µm [TBC]	1.0 km
VIS 0.9	0.914 µm [TBC]	1.0 km
NIR 1.3	1.380 µm [TBC]	1.0 km
NIR 1.6	1.610 µm	1.0 km
NIR 2.2	2.250 µm [TBC]	1.0 km; 0.5 km*
IR 3.8 (TIR)	3.800 µm	2.0 km; 1.0 km*
WV 6.3	6.300 µm	2.0 km
WV 7.3	7.350 µm	2.0 km
IR 8.7 (TIR)	8.700 µm	2.0 km
IR 9.7 (O3)	9.660 µm	2.0 km

IR 10.5 (TIR)	10.500 µm	2.0 km; 1.0 km*
IR 12.3 (TIR)	12.300 µm	2.0 km
IR 13.3 (CO2)	13.300 micron	2.0 km

For more information on the METEOSAT Third Generation (MTG) multispectral imager and Flexible Combined Imager (FCI) see: http://www.eumetsat.int/website/home/Satellites/FutureSatellites/MeteosatThirdGeneration/index.html and http://goes.gsfc.nasa.gov/text/geonews.html#MTG.

3.1.21 GEO-KOMPSAT-2A AMI (planned for launch in 2018)

The Geostationary Korea Multi-Purpose Satellite-2A (GEO_KOMPSAT-2A) being developed by the Korean Meteorological Administration (KMA) is a planned operational meteorological satellite to be in geostationary orbit at 35,786 km altitude at 128.2 degrees East. The satellite will contain the Advanced Meteorological Imager (AMI), which is a moderate-resolution multi-purpose imager designed primarily for tracking clouds and water vapor features. The AMI is based on the GOES-R ABI sensor with similar spectral capabilities. There are sixteen (16) VIS/NIR/SWIR/MWIR/LWIR channels planned for the AMI (Table x). The AMI will replace the MI flown on the COMS-1 satellite and will provide 0.5, 1.0, or 2.0 km spatial resolution (dependent on band number). The imaging frequency will be less than 10 minutes for full disk, and considerably less for limited areas.

Table x. GEO-KOMPSAT-2A AMI Planned Spectral Band Configuration.

Band	Wavelength (µm)	Bandwidth	Spatial Res. (km)
1	0.455	48 nm	1.0 km
2	0.511	15 nm	1.0 km
3	0.642	35 nm	0.5 km
4	0.86	21 nm	1.0 km
5	1.38	10 nm	2.0 km
6	1.61	18 nm	2.0 km
7	3.85	0.22 µm	2.0 km
8	6.24	0.36 µm	2.0 km
9	6.95	0.12 µm	2.0 km
10	7.34	0.17 µm	2.0 km
11	8.6	0.32 µm	2.0 km
12	9.63	0.17 µm	2.0 km
13	10.43	0.36 µm	2.0 km

14	11.2	0.24 µm	2.0 km
15	12.3	0.30 µm	2.0 km
16	13.3	0.18 µm	2.0 km

For more information on the GEO-KOMPSAT-2A platform and AMI multispectral imager see: http://goes.gsfc.nasa.gov/text/geonews.html#COMS, http://www.wmo-sat.info/oscar/instruments/view/285 or http://eng.kari.re.kr/sub01_01_02_09.

3.1.22 Russia Elektro (Artika) M MSU-GSM (planned for launch in 2017)

Russia is developing a unique satellite network dedicated to monitoring the Arctic. With territory stretching thousands of kilometers along the Arctic Ocean, Russian Federation faces many challenges such as communications and weather forecasting satellite observations at high latitudes. Russian engineers proposed a multi-purpose constellation dubbed Arktika (Arctic). The Arktika network will be employed to perform a variety of remote-sensing tasks, such as monitoring of environmental conditions, and also provide reliable communications and navigation across the arctic region.

A pair of Arktika-M satellites fully funded from the Russian space budget would be focused on meteorology and emergency communications. Each spacecraft will carry a multi-spectral imager, known as MSU-GSM, along with transmitters for meteorological and rescue systems. An apogee (highest point) of their orbit would be 40,000 kilometers above the Earth surface and a perigee 1,000 kilometers. Such orbital parameters would enable frequent overflies of the polar regions with practically uninterrupted view of the northern hemisphere. In contrast, most civilian meteorological satellites deployed in the geostationary orbit can see little or no useful details beyond the 60th parallel, due to curvature of the Earth, while the satellites in traditional polar orbits do not have continuous view of all polar regions. The first Arktika-M was expected to fly in 2013, but slipped to 2014. The launch of Arktika-M No. 3 was planned in 2018 and No. 4 in 2019.

The sensor package will be a moderate resolution system (1.0-4.0 km spatial resolution), with the VIS channels at 1.0 kilometers and the MWIR and LWIR channels at 4.0 km (Table x). With a MWIR (3.5 – 4.0 µm) and a LWIR (10.2 – 11.2 µm), the sensor system can be useful for fire detection, although its main purpose is to support weather observations in the arctic regions.

Table x. **Russia Elektro (Artika) M MSU-GSM** ***Planned Spectral Band Configuration.***

Band	Wavelength (um)	Resolution (km)
1	0.50 - 0.65 µm	1.0
2	0.65 - 0.80 µm	1.0
3	0.80 - 0.90 µm	1.0
4	3.50 - 4.00 µm	4.0
5	5.70 - 7.00 µm	4.0
6	7.50 - 8.50 µm	4.0
7	8.20 - 9.20 µm	4.0
8	9.20 - 10.2 µm	4.0
9	10.2 - 11.2 µm	4.0
10	11.2 - 12.5 µm	4.0

Further information on the system can be found at: http://www.russianspaceweb.com/arktika.html and at: http://www.wmo-sat.info/oscar/instruments/view/324.

3.2 Sub-Orbital (Airborne) Remote Sensing Assets for Wildfire Observation

Selected US agencies operate sub-orbital (airborne) earth-observation sensor systems with capabilities for wildfire observations. The airborne sensor systems that have utility for active fire observation include the following:

- AMS (USFS / NASA)
- MASTER (NASA)
- eMAS (NASA)
- AVIRIS (NASA)
- PHOENIX (USFS)
- WAI (NASA SBIR / USFS)
- TMAS (NASA SBIR / USFS; in development, scheduled for 2016 operations)

Each of these systems is identified in the following section.

3.2.1 AMS

The Autonomous Modular Scanner (AMS) - WILDFIRE Sensor is a multi-use NASA–developed airborne platform (manned and UAS-capable) sensor system now operated by the U.S.D.A. Forest Service. The AMS is a well-calibrated instrument capable of wildfire measurements with unique spectral capability in the MWIR and TIR spectral region. The AMS scanner is composed of a Daedalus AADS-1268 scanning system with a Thematic Mapper Simulator (TMS) scan-head configuration which was used for land-cover studies and wildfire imaging. This configuration flew primarily on the NASA ER-2, high-altitude aircraft platform from the 1980's forward. The new AMS was reconfigured into a fully functional UAS-compatible airborne sensor with a configured for wildfire observations (Ambrosia, et. al, 2011).

The 16-channel WILDFIRE Scanner was developed at the NASA-Ames Research Center Airborne Sensor Facility (ASF; http://asapdata.arc.nasa.gov/) for operations on-board both manned and UAV platforms. The instrument has been modified to fulfill scientific requirements for fire imaging, with four new MWIR and LWIR channels (two each of high gain / low gain MWIR and LWIR) to allow measurement of fire (and other hot sources) (Table 1). The MWIR and LWIR channels have been calibrated for accurate (~0.5° C) temperatures discrimination of hot targets, up to ~650°C. The MWIR and LWIR channels simulate those found on the Visible/Infrared Imager/Radiometer Suite (VIIRS instrument.

Table X. AMS-WILDFIRE 16-Channel Scanner Specifications.

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)	

Modifications to the AMS-WILDFIRE scanner include the addition of a wireless remote interface control capability to allow operations on UAS platforms for remote operations and real-time data processing. These sensor developments allow autonomous or remote operations of the sensor package aboard a manned / UAS platform during missions. Other major enhancements include the inclusion of 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. The system can provide real-time, fully geo-rectified images of any spectral channel combinations, and provide autonomous algorithm processed data as well. This feature makes the AMS a versatile sensor to support both active and post-fire analysis. Data can be shared real-time through an interface to the USFS data telemetry system (AirCell), enabling the fire and scientific community to acquire processed data during mission collections.

The AMS-Wildfire instrument is currently operated by the U.S. Forest Service aboard a Cessna Citation Bravo (Tail No. 144Z) jet aircraft to support wildfire imaging, post-fire assessment and various resource inventory projects. Mission development is currently being guided by the USDA-Forest Service Remote Sensing Applications Center (RSAC) in Salt lake City, Utah (http://www.fs.fed.us/eng/rsac/).

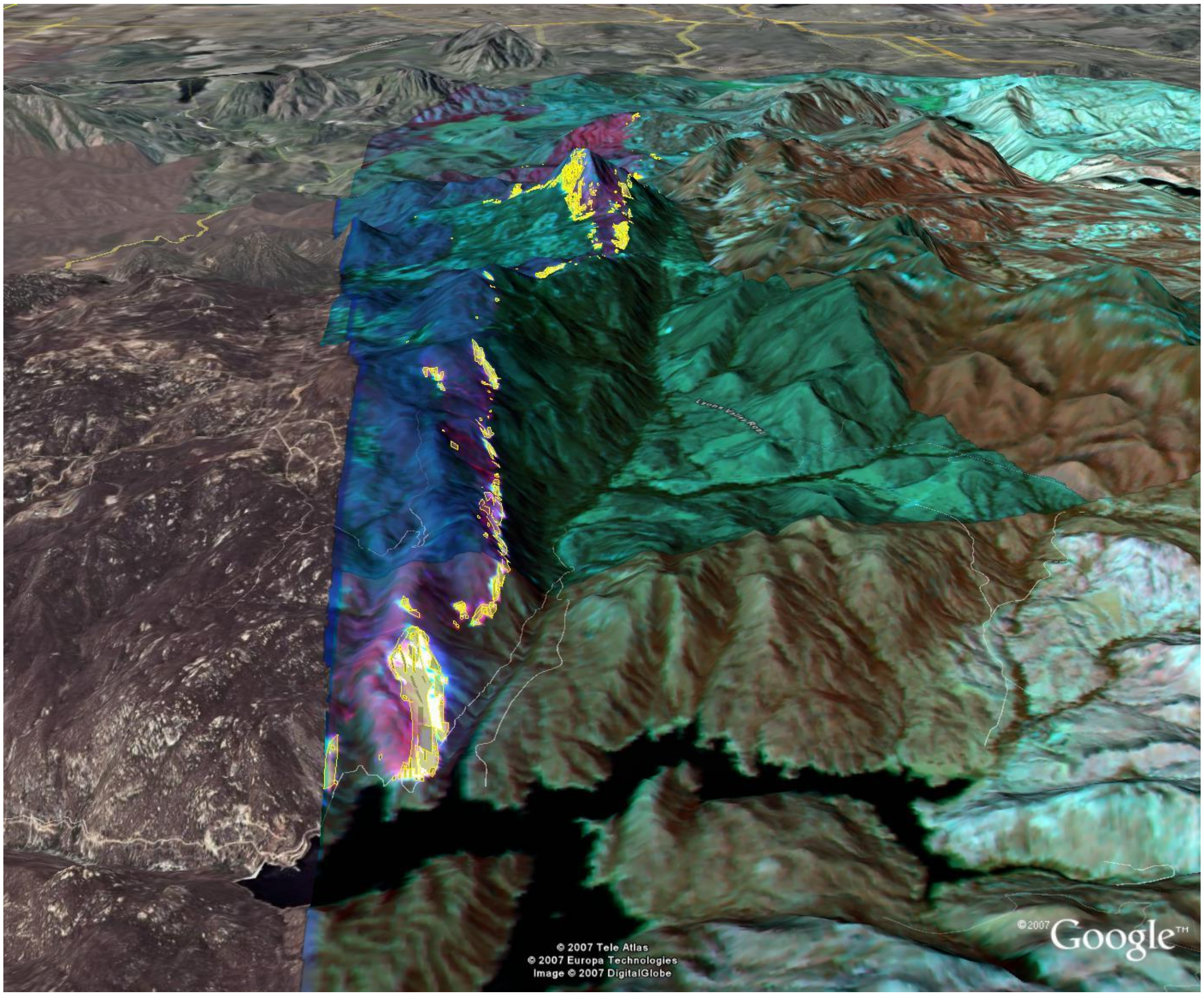

Figure X. *USFS AMS onboard-processed image collected over the Harris Fire, San Diego County, California on 23 October 2007. The imagery is overlain on a GoogleEarth background and shows burned areas in greens and blues, and the active fire areas, determined from a temperature thresholding algorithm, shown in shades of red, yellow and white.*

3.2.2 MASTER

The MODIS/ASTER (MASTER) airborne simulator is a joint development instrument involving the Airborne Sensor Facility at the NASA Ames Research Center, the Jet Propulsion Laboratory and the EROS Data Center. The primary objective of the MASTER activity is to support the ASTER and MODIS instrument teams in the areas of algorithm development, calibration and validation. MASTER is essentially a clone of the MODIS Airborne Simulator (MAS), with changes in the spectral band positions in order to better simulate both ASTER and MODIS. The MASTER collects in 50 spectral channels ranging from 0.4 to 13.0 micrometers. The Instantaneous Field of View is 2.5 milliradians, and the Total Field of View is 85.92 degrees. The sensor has been fitted and flown on a variety of aircraft, including a Beechcraft B200 KingAir, a C208, a DC-8, a WB57 and an ER2, with various spatial resolutions dependent on platform altitude. The MWIR channel 32 (center: 4.07µm) has a low (for fire discrimination uses) thermal saturation level of 483°K. The two useful MWIR and LWIR channels for fire detection are highlighted in the table below. Unlike the NASA-developed AMS sensor, the MASTER does not have onboard processing capabilities; therefore all acquired data must be post-mission-processed to derive imagery and fire-related products. Further information on the MASTER airborne instrument can be found at: http://asapdata.arc.nasa.gov/dscrptns.htm#MASTER and at https://airbornescience.nasa.gov/instrument/MASTER. The MASTER is currently (2014-beyond) being flown to support a HyspIRI airborne testbed campaign.

Table X. MASTER Scanner Specifications.

Band	Wavelength (µm)	Band	Spectral Range (µm)
1	0.440-0.480	**26**	3.075-3.225
2	0.480-0.520	**27**	3.225-3.375
3	0.520-0.560	**28**	3.375-3.525
4	0.560-0.600	**29**	3.525-3.675
5	0.630-0.690	**30**	3.675-3.825
6	0.690-0.730	**31**	3.825-3.975
7	0.730-0.770	**32**	3.975-4.125
8	0.780-0.820	**33**	4.125-4.275
9	0.845-0.885	**34**	4.300-4.450
10	0.885-0.925	**35**	4.425-4.575
11	0.925-0.965	**36**	4.575-4.725
12	1.600-1.650	**37**	4.725-4.87 5
13	1.650-1.700	**38**	4.875-5.025
14	1.700-1.750	**39**	5.025-5.175
15	1.750-1.800	**40**	5.175-5.325
16	1.800-1.850	**41**	7.70-8.10
17	1.850-1.900	**42**	8.10-8.50
18	1.900-1.950	**43**	8.50-8.90
19	1.950-2.000	**44**	8.90-9.30
20	2.050-2.100	**45**	9.50-9.90
21	2.135-2.185	**46**	9.90-10.30
22	2.185-2.235	**47**	10.30-10.95
23	2.235-2.285	**48**	10.95-11.65
24	2.297-2.362	**49**	11.80-12.30
25	2.362-2.427	**50**	12.50-13.00

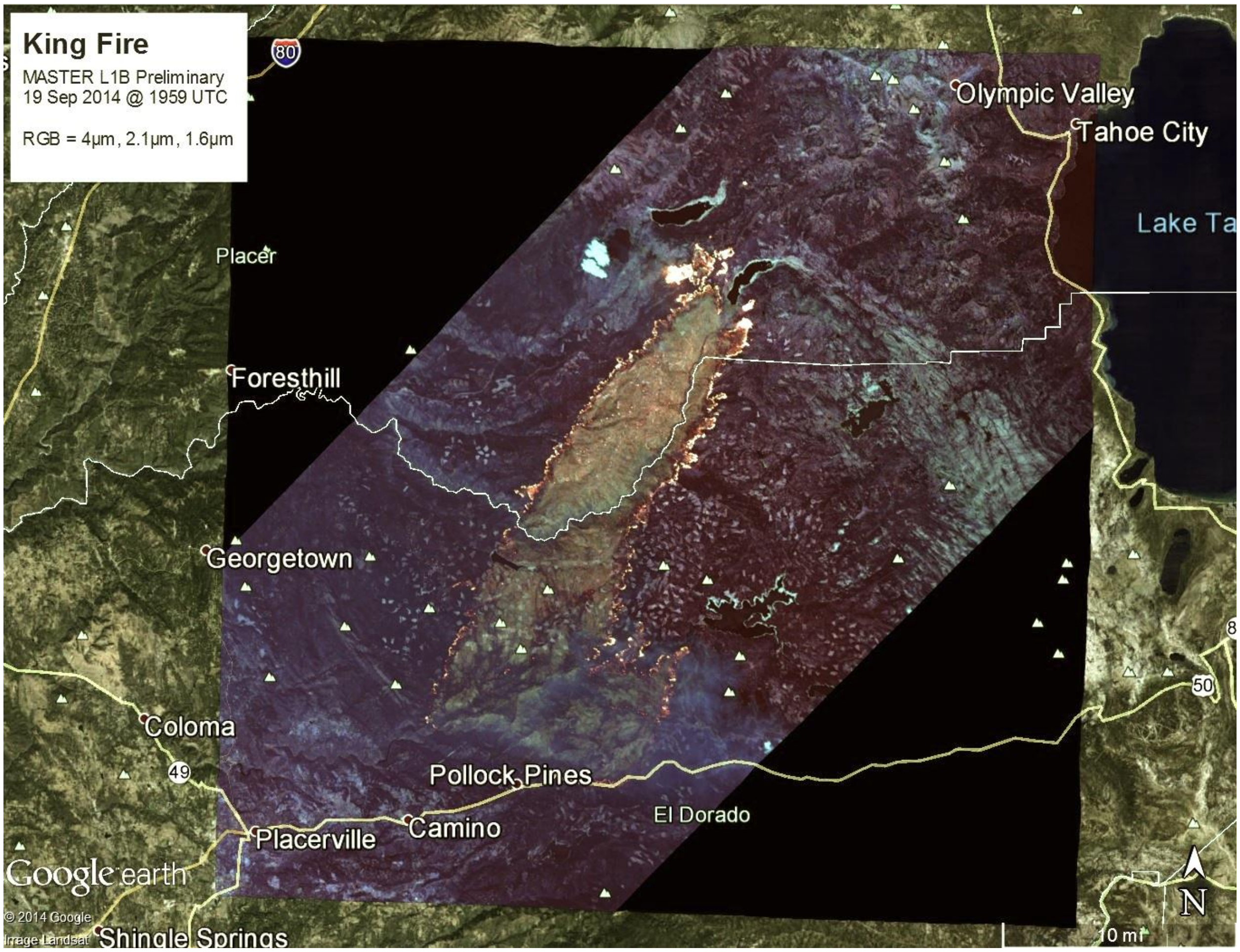

***Figure x**. NASA MASTER airborne sensor data collected over the King Fire, California on 19 September 2014, overlaid on a GoogleEarth background. The fire line hot spots can be seen on the east and west flanks of the fire, with the most intense fire growth in the NW corner of the fire. The multispectral composite image is composed of MASTER channels 32, 21 and 12.*

3.2.3 eMAS

The Enhanced MODIS Airborne Simulator (eMAS) is an airborne scanning spectrometer that acquires high spatial resolution imagery of cloud and surface features from its vantage point on-board a NASA ER-2 high-altitude research aircraft. The eMAS was developed from the MODIS Airborne Simulator (MAS), which had originated as the NASA Wildfire scanned, developed by Daedalus Corp. in the 1990s to serve as a highly-calibrated multiband thermal scanner for wildfire and high-temperature (volcanos, etc.) event measurements. The eMAS has 38 channels that range from the Visible (0.465 µm) to the LWIR (~14.0 µm). With 2-3 channels for wildfire detection (channels 26, 32 and 33) highlighted in the table.

Data acquired by the eMAS are helping to define, develop, test, and refine algorithms for the Moderate Resolution Imaging Spectroradiometer (MODIS). The eMAS instrument is maintained and operated by the Airborne Sensor Facility (ASF) at NASA Ames Research Center in Mountain View, California, under the oversight of the EOS Project Science Office at NASA Goddard. Instrument scheduling is coordinated by the NASA Airborne Science Program (ASP), with formal arrangements made via the NASA Airborne Science Program Flight Request System.

The eMAS has a 2.5 mrad detector capable of 50m spatial resolution from ER-2 nominal altitudes (~65,000') altitude. Further information on the eMAS instrument can be found at: http://mas.arc.nasa.gov/index.html.

Table X. eMAS Scanner Specifications.

Band	Center Wavelength (µm)	Band	Center Wavelength (µm)
1	0.465	20	2.13
2	0.549	21	2.179
3	0.655	22	2.229
4	0.703	23	2.279
5	0.743	24	2.328
6	0.825	25	2.378
7	0.867	26	3.732
8	0.908	27	6.73
9	0.947	28	7.31
10	1.619	29	8.251
11	1.675	30	8.542
12	1.727	31	9.728
13	1.779	32	10.197
14	1.832	33	11.034
15	1.882	34	12.025
16	1.932	35	12.603
17	1.982	36	13.354
18	2.032	37	13.639
19	2.081	38	13.957

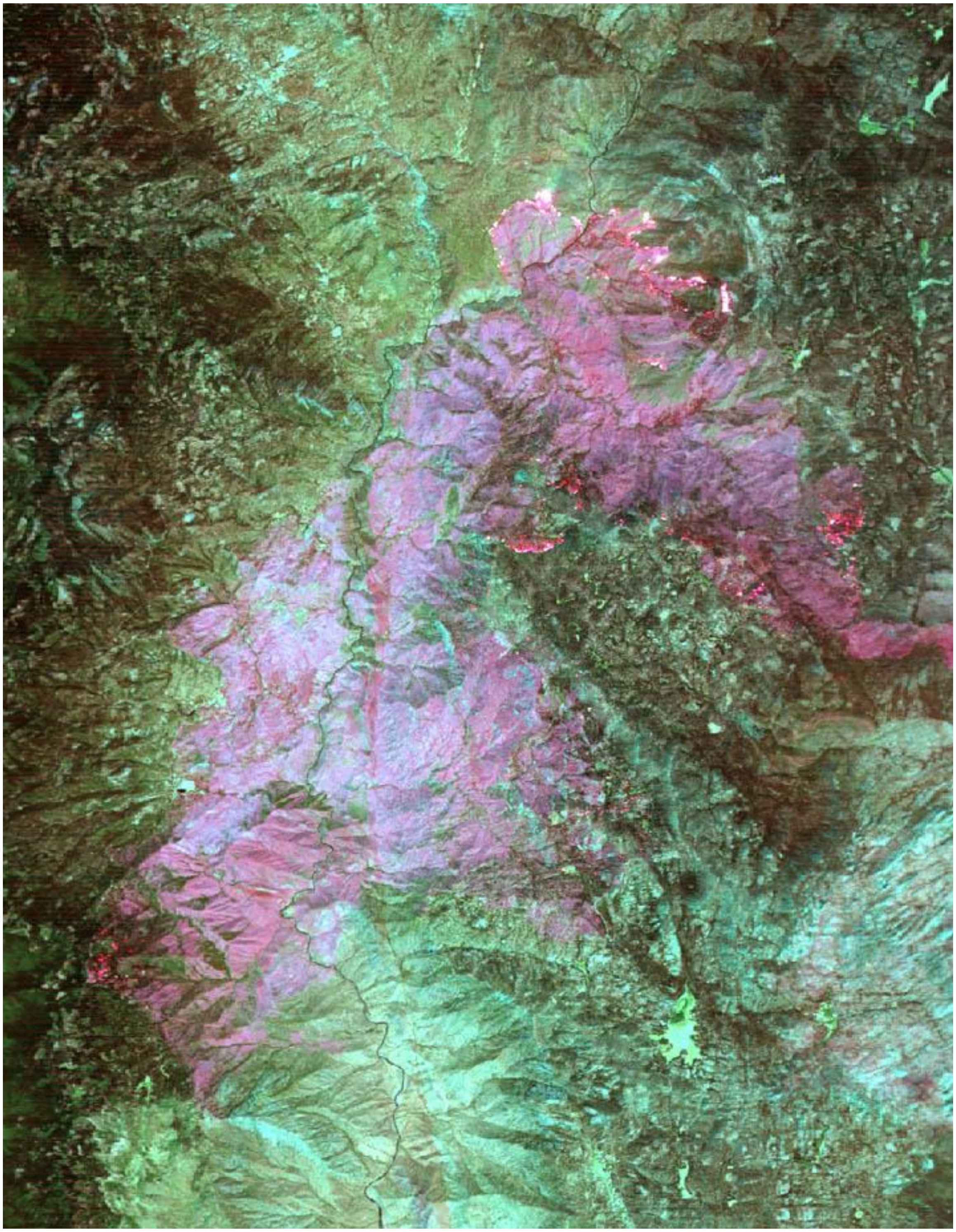

Figure x. *eMAS data collected over the McNally Fire, California on 6 August 2002 The burned area can be seen in light red hues, while the active fire front is seen in the upper right edges of the burned area as yellow and white areas. This composite is composed of the following spectral channels: 21, 10 and channel 2.*

3.2.4 AVIRIS

The Airborne Visible InfraRed Imaging Spectrometer (AVIRIS) is a hyperspectral airborne optical sensor that delivers calibrated images of the upwelling spectral radiance of the Earth in 224 contiguous spectral channels (bands) with wavelengths from 400 to 2500 nanometers. AVIRIS has been flown on four aircraft platforms: NASA's ER-2 jet, Twin Otter International's turboprop, Scaled Composites' Proteus, and NASA's WB-57. The system is used primarily to support NASA remote sensing research operational missions. The main objective of the AVIRIS project is to identify, measure, and monitor constituents of the Earth's surface and atmosphere based on molecular absorption and particle scattering signatures. The AVIRIS is a whisk-broom scanning devise with 720-pixels collected in the cross-track direction, and continuous lines in the along-track direction, with 10nm nominal channel bandwidth, calibrated to within 1nm. The system has a 1.0 milliradian IFOV, providing ~20m spatial resolution from ER-2 platform altitudes of ~65K feet. Since the AVIRIS does not contain any MWIR or LWIR channels, it is of limited use for fire detection, although hot sources (fire fronts) can be observed with the longer wavelength regions of the system (~2500 nanometers), especially in regions with lesser amounts of smake pall, which would obscure viewing in SWIR channels (Figure x). The sensor has been used for post-fire burn area assessment and subtle changes in vegetation health given the spectral sensitivities and radiometric integrity of the hyperspectral information in the visible and SWIR channels. Further information on the Daedalus system can be found at: http://aviris.jpl.nasa.gov/index.html.

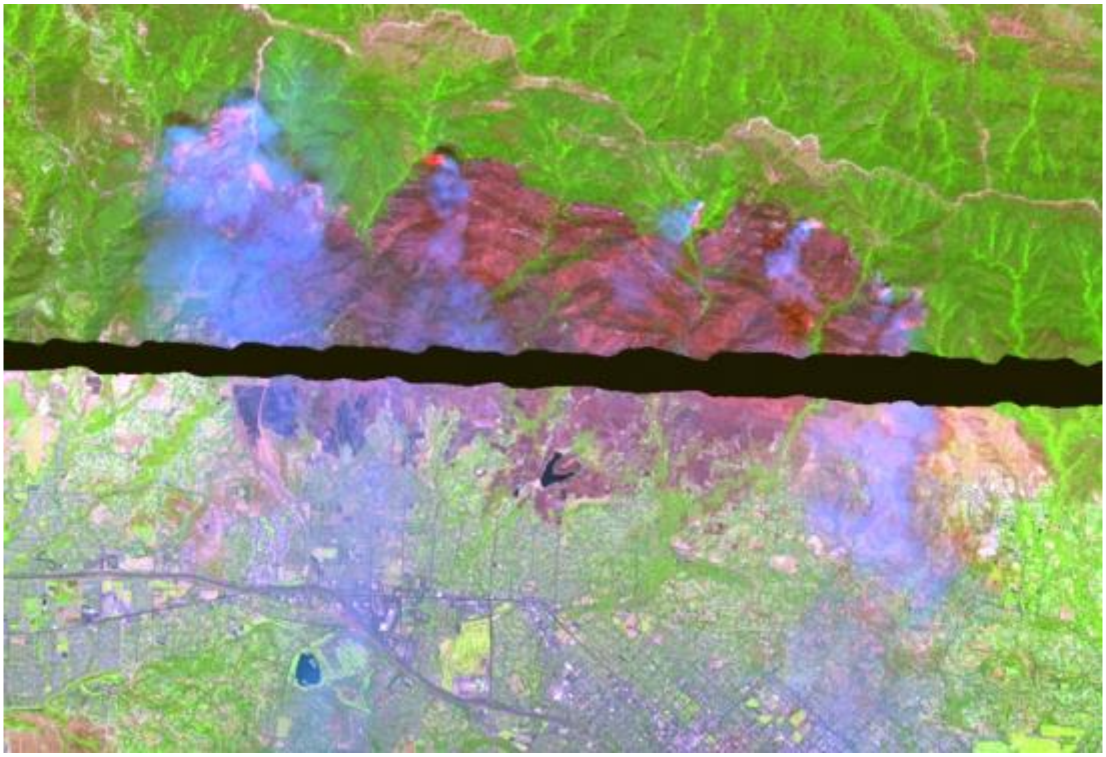

***Figure x**. AVIRIS spectral band data collected in May 2009 over the Jesusita Fire, Santa Barbara, California. Although the AVIRIS does not contain the MWIR and LWIR channels for accurate fire detection, the Visible, NIR and SWIR channels can be used to identify fire areas where small amounts of smoke are present, as is the case in this fire scene. This scene is composed of two AVIRIS flight line passes (gap between adjacent flight lines noted in center). Active fire is seen as bright red on northern perimeters of the fire, with smoke blowing over the city of Santa Barbara, CA. Image courtesy of D. Roberts, UCSB.*

3.2.5 PHOENIX

For several years, the USDA Forest Service has been making advances to the airborne thermal infrared imaging capabilities for wildland fire detection and mapping. The USFS operates two line scanner systems aboard national asset aircraft to support wildfire imaging in the United States. The two systems, named "Phoenix" has been in development and use since 1998 with cooperators from NASA-Ames Research Center, the US Army Aviation and Missile Command, the National Infrared Operations (NIROPS), USFS - Remote Sensing Applications Center (RSAC), and USDA Fire & Aviation Management. The Phoenix system is maintained at the National Interagency Fire Center (NIFC) in Boise, Idaho. The Phoenix systems are flown on two aircraft: a Cessna Citation jet platform and a Beechcraft B200 KingAir. The sensor system and data telemetry system (AirCell) on-board the two aircraft provide near-real-time thermal imagery and fire detections to fire managers on the ground. The Phoenix output includes navigation data, aerial platform attitude information (provided by an Applanix POS/AV 210), and 2 channel ortho-rectified image data. All data can be readily ingested into GIS package. The sensor system is performance characteristics are identified in Table X.

Table X - Phoenix Performance

Total Field-of-View	Ground Coverage	Detect ability	Fire Location Method	Aerial Platform	Pixels/Scan Line
120°	6.5 Statute Miles at 10,000 Ft AGL	8" 600° Hot Spot @ 14,000 Ft AGL	Edge Marks	King Air B200 King Air B90 Citation Jet Lear 35/36 (with modifications)	1680

At the core of the Phoenix system are two thermal infrared detectors that are utilized to provide thermal hot spot (fire) detectability. With one detector in the 3-5 µm band and the second in the 8-14 µm band, thermal imaging for wildland fire can be realized. As described by the Planck function, the shorter wavelength detector is more sensitive to radiation of higher temperatures and the longer wavelength detector is more sensitive to lower temperatures. This latter band is used to generate the background imagery, while the former detector typically sees the heat associated with wildland fire. It is the combination of these bands together that determines whether a single spot exceeds a user-defined threshold to be identified as fire. The digital processing of the *kA-B* fire detection algorithm analog function used in similar fashion to other sensors, such as the AMS, and orbital asset sensor systems as well, and was developed for use on GOES and subsequent satellite systems. Figure X is an example of fire data captured from the Phoenix system.

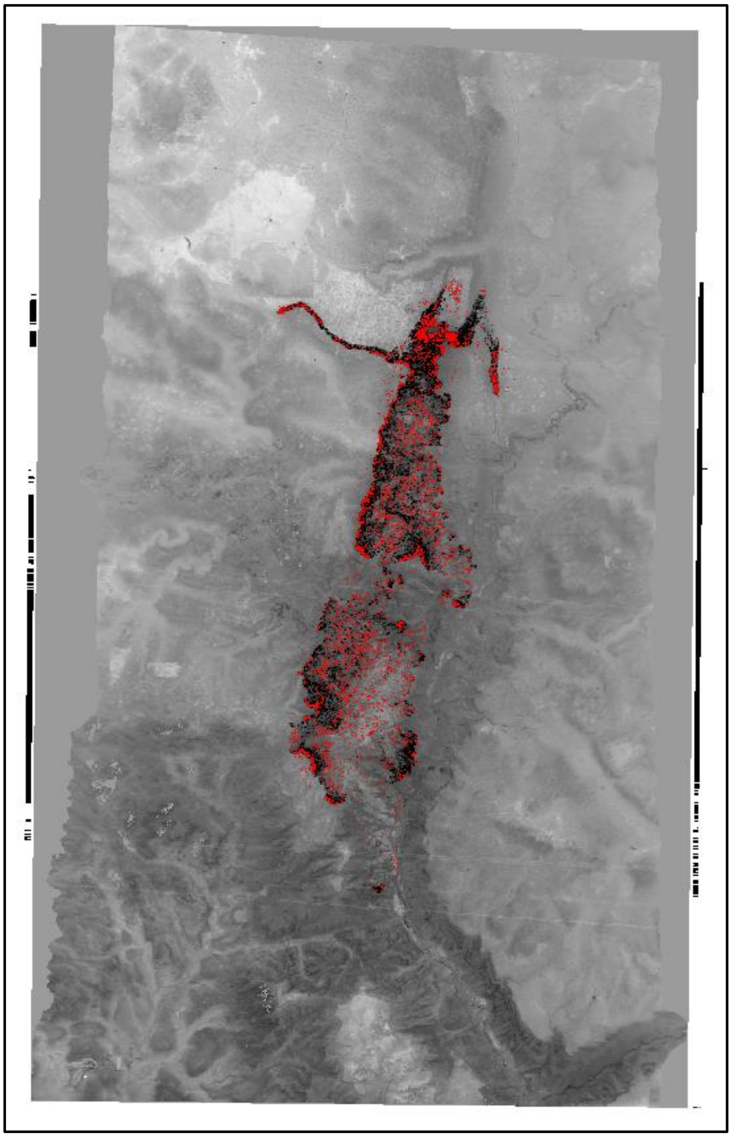

Figure X. *Phoenix data captured 21 May 2014 over the Slide Fire near Sedona, Arizona. On this day, high winds pushed the fire several miles to the north towards Sedona (top). The long finger pointing to the W is a burnout along a forest road. This images shows the algorithm-developed hot spots in red on a gray-scale thermal background image base. Black marks along image sides indicate fire pixels in scene scan line. Image courtesy of USDA-Forest Service RSAC and NIFC-NIROPS.*

3.2.6 WAI

The Wide Area Imager (WAI) was developed under a NASA-administered Small Business Innovative Research (SBIR) program grant to Xiomas, LLC, starting in 2009 (SBIR 07-PH 1 NNX08CA75P). The instrument was selected for each phase of the SBIR development process (Phase I (development of an instrument feasibility effort), Phase II (development of a working prototype system), and Phase III (commercialization / operational maturation)). The WAI was developed with the intent of supporting fire science and applications with an innovative new design for a wide-area-coverage MWIR and LWIR system, coupled with visible spectral channels in an airborne instrument configuration capable of on-board and remote operations. The unique instrument design focuses on a “step-stare” optical configuration that combines a high resolution camera with a wide field-of-view scanning mirror assembly. The system is designed with an IFOV of 400 µRadians which yields a 4m pixel GSD from an aircraft altitude of 10,000 m. The FOV of the system is 90 degrees, which yields an 15.15 mile (80,000 ft.) swath width at 10,000 m. Operating on an aircraft at 300 mph (260 kts.), at these altitude and sensor specifications, the system can image 2.9 million acres per hour of flight. The system was originally planned with six (6) spectral channels (Table x), on-board processing for real-time image classification and algorithm development and geo-rectification through autonomous / remote operations, with a data transmission system via a wireless data link to ground or satellite. The WAI goal was to develop a system to detect a 10-inch fire square at 600°C, cover three times the areal extent of the current USFS airborne fire imaging systems, with the same / less amount of time, have map location accuracies of <10m, and to measure fire temperatures to +/- 10% accuracy up to 1000°C.

Table x. Wide Area Imager (WAI) Airborne System Spectral Band Configuration

<table>
<tr><th>Band</th><th>Wavelength (um)</th><th>Sensor Sensitivity</th></tr>
<tr><td>1</td><td>Green</td><td>VIS (Camera)</td></tr>
<tr><td>2</td><td>Red</td><td>VIS (Camera)</td></tr>
<tr><td>3</td><td>Near Infrared</td><td>NIR (Camera)</td></tr>
<tr><td>4</td><td>3.0 - 5.0</td><td rowspan="2">2- Band QWIP (MWIR and LWIR)</td></tr>
<tr><td>5</td><td>8.8 - 10.5</td></tr>
</table>

The WAI has flown operational evaluation / comparison missions over prescribed fire aboard a USFS Beechcraft B200 KingAir aircraft in 2013 and 2014, in conjunction with the USFS Phoenix system (Figure x). The two systems were comparable in identifying fire, with the WAI able to cover a larger area than the Phoenix system.

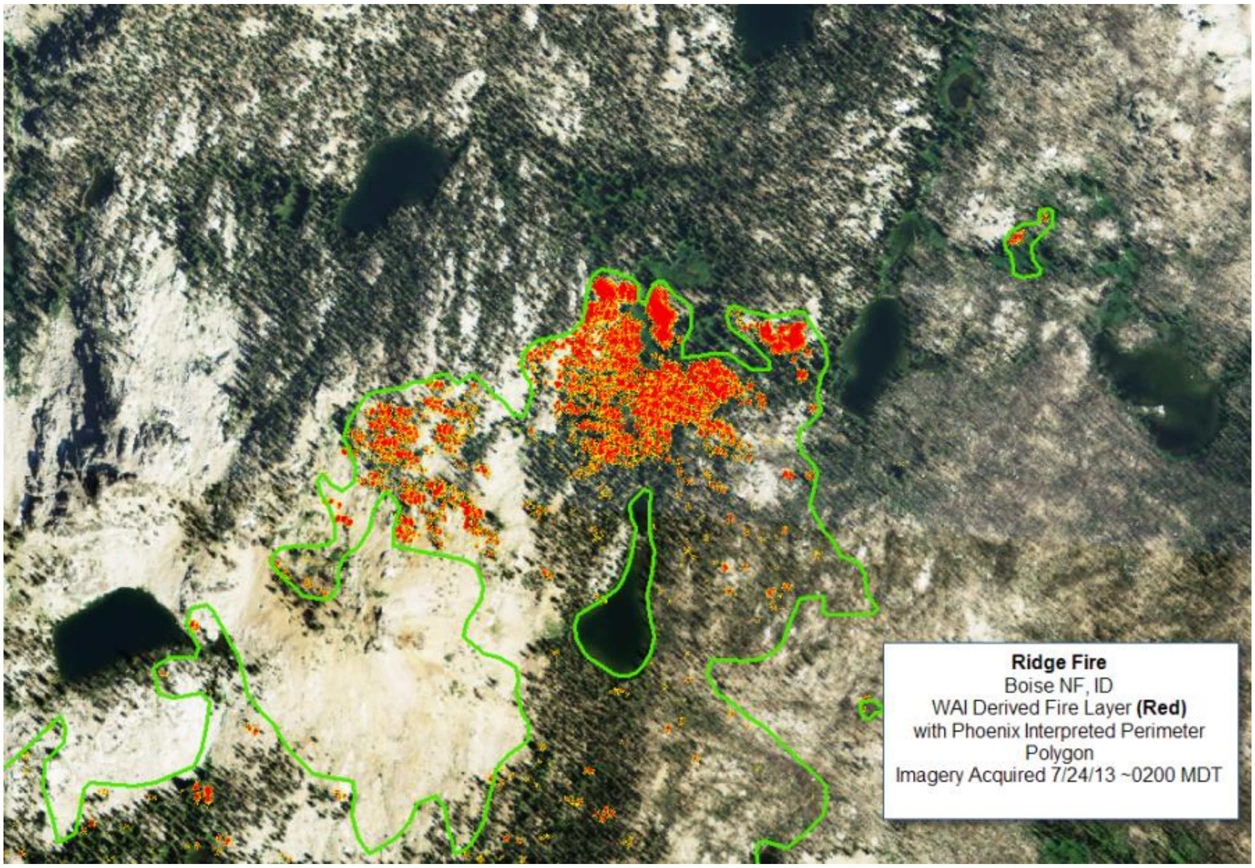

***Figure x**. Xiomas, Inc. WAI imagery collected over the Ridge Fire, Idaho on 24 July 2013 at 2:00 AM local time. The fire hot spot detections are shown in red, overlain on a GoogleEarth background image. The fire perimeter polygon, derived from the co-flown Phoenix imagery, is shown as a green line around the fire burned area.*

The WAI will be in operational use within the USFS (on loan from NASA-Ames Research Center in 2015 and beyond on a call-up basis to support "surge" capabilities during multiple fire events in the US. The point of contact at the USFS is; Brad Quayle, USFS-RSAC, bquayle@fs.fed.us. Further information can be found at: http://xiomas.com/news, and http://sbir.gsfc.nasa.gov/content/xiomas-technologies-llc, and http://nirops.fs.fed.us/docs/upload/Green-XiomasWAIPhaseIIINov2012TFRSACUpdateCompressed.pdf.

3.2.7 TMAS

The Thermal Mapping Airborne Simulator (WAI) was developed under a NASA-administered Small Business Innovative Research (SBIR) program grant to Xiomas, LLC, starting in 2009 (SBIR Contract No. NNX13CA58C). The instrument is currently in Phase II of development (development of a working prototype system)

4.0 FIRE AND SMOKE RELATED WEB LINKS

Operational fire monitoring web links are provided by a number of US agencies including the USDA-Forest Service, NOAA and USGS. The following links provide access to the various satellite data fire services provided by those organizations.

Table X. Operational, satellite-derived, wildfire-related data web-links.

Fire	Air Quality
NIFC Fire Information	NWS Air Quality Forecast Guidance
NIFC Large Fire Incident Map	The Smog Blog
Canadian Wildfire Map	Kilauea Volcano Daily Status Report
SPC Fire Weather Forecast	OMI SO2
GEOMAC Wildfire Viewer	NASA data portal
Alaskan Fire GIS display	NRL Aerosol page
Alaska Interagency Coordination Center	NRL Aerosol links
MODIS Rapid Response	NOAA Earth System Research Lab
WFABBA at CIMSS	RAMSDIS G-11 Blowing Dust Product
INCIWEB	CIMSS Saharan Dust Graphic
	http://www.ijis.iarc.uaf.edu/cgi-bin/fire-monitor.cgi?lang=e

5.0 TERMINOLOGY / ACRONYM LIST

ABI: Advanced baseline Imager; aboard the National Oceanic and Atmospheric Administration (NOAA) geostationary Earth-observing Geostationary Operational Environmental Satellite - R Series (GOES-R) planned for launch in early 2016.

ALI: Advanced Land Imager; Flown on EO-1 as an instrument design testbed for the planned OLI on Landsat 8; Does not have a MWIR "fire" band, but can be used for fire assessment or post-fire assessment; Real-time data can be acquired through arrangement with NASA (GSFC).

AMS: Autonomous Modular Sensor (NASA-developed airborne imaging instrument, operated by USFS).

AVIRIS: Airborne Visible / Infrared Imaging Spectrometer (NASA airborne imaging instrument. No thermal channels, but hyperspectral capabilities from VIS through mid-wave IR (2.5 um).

Deliver R/T Data (real-time): This applies primarily to airborne data, where data on fire parameters or imagery is available immediately upon collection from platform sensor.

eMAS: Enhanced MODIS Airborne Simulator (NASA airborne imaging instrument)

FOV: Field of View; expressed as angular (swath width) viewing geometry, which defines areal coverage. Dependent on platform altitude for coverage swath width.

GCOM-C SLGI: Japan Aerospace Exploration Agency (JAXA) Global Change Observation Mission (GCOM) satellite with the Second Generation Global Imager (SGLI) sensor.

IFOV: Instantaneous Field of View; expressed in milliradians, and defines spatial resolution of sensor system; Dependent on platform altitude for spatial (pixel) resolution.

LWIR: Long-Wave Infrared; Spectral wavelength region described as having a spectral range of 8.0 to 15.0 µm. This region is referred to as a thermal or emitted infrared region.

MAS: MODIS Airborne Simulator (NASA Airborne Imaging Instrument)

MODIS: Moderate Resolution Imaging Spectroradiometer; hyperspectral orbiting sensor (on Aqua and Terra platforms), allowing large area coverage (2330 kilometers swath width) but at 1km pixel resolution discrimination. Multiple observations / day with each platform.

MWIR: Mid-Wave Infrared; spectral wavelength region described as having a spectral range of 3.0 to 8.0 µm, where fire temperature discrimination is maximized (generally centered at wavelength region around 4.0 µm).

NIR: Near-infrared. Spectral region encompassing wavelengths longer than those of visible light, extending from the nominal red-edge of the visible spectrum at 0.75 µm to 1.4 µm. Sometimes referred to as “reflected infrared”.

NRT: Near-Real-Time from acquisition and through ordering process…not "on-demand".

OLI: Operational Land Imager, multispectral scanner system operating on Landsat 8; No MWIR "fire" channel.

OLS: Operational Linescan System on the DMSP satellite. Multiple looks per day at earth surface; fire detection possible; no operational fire observations.

SENTINEL-2 MSI: European Space Agency's (ESA) SENTINEL-2 polar-orbiting mission's Multispectral Imager (MSI) sensor.

SENTINEL-3 SLSTR: European Space Agency's (ESA) SENTINEL-3 polar-orbiting mission's Sea and Land Surface Temperature Radiometer (SLSTR) sensor.

TIRS: Thermal Infrared Sensor; Two channel LWIR sensor operating on Landsat 8; 120m spatial resolution, can be used for rudimentary fire detection.

VIIRS: Visible Infrared Imaging Radiometer Suite (VIIRS); multispectral weather satellite with a MWIR "fire" band (M13 (4.05 µm), higher spatial resolution than MODIS (750m vs. 1000m), slightly higher temp saturation point (380°K vs. 334°K.

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