Detection and characterization of biomass burning in the GOES-R era

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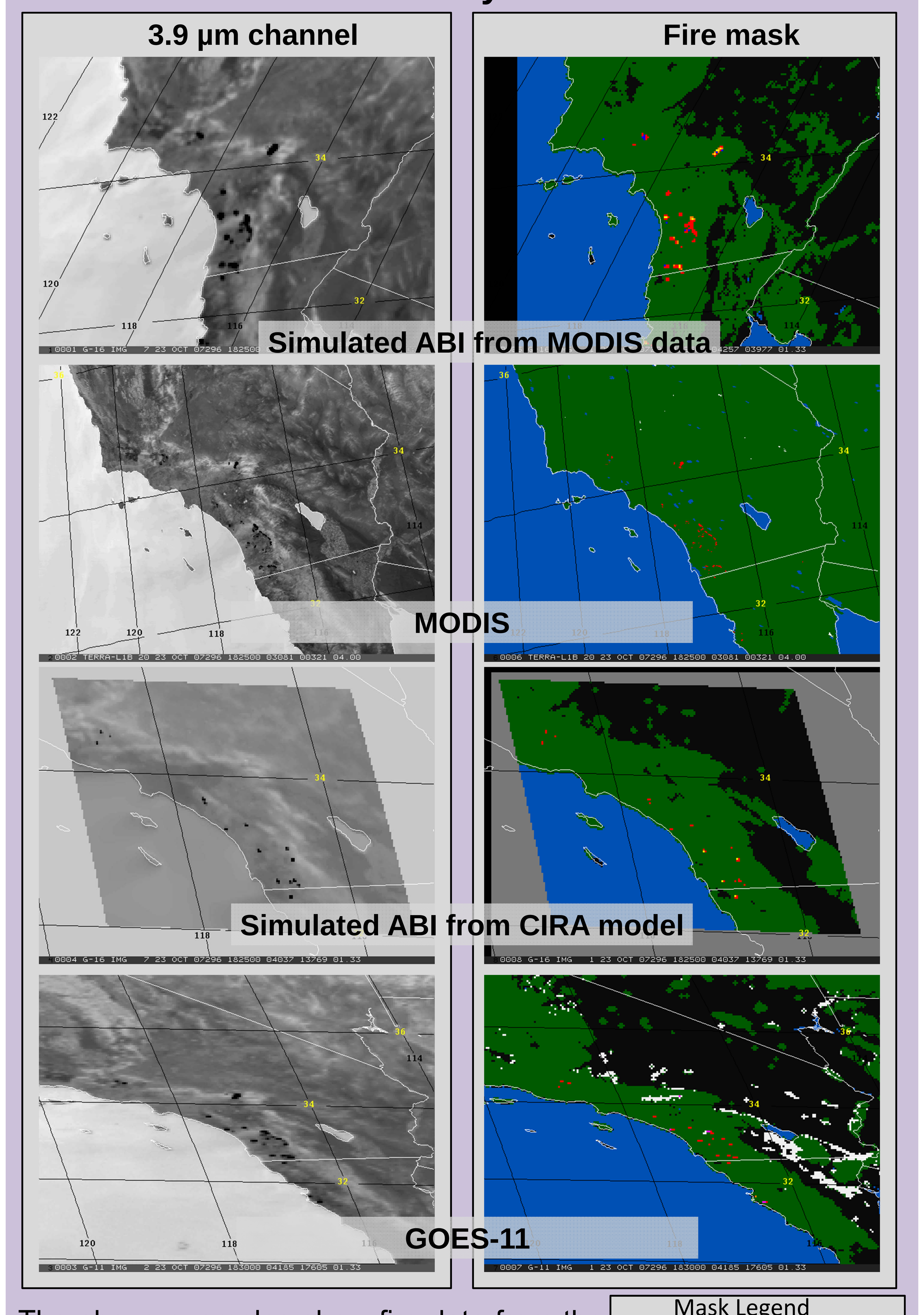
Detection of Fires with Geostationary Satellites

Geostationary weather satellites have been used operationally to detect and characterize wildfires and anthropogenic biomass burning for the last decade. The Wildfire Automated Biomass Burning Algorithm (WF_ABBA) developed at the Cooperative Institute for Meteorological Satellite Studies (CIMSS) at UW-Madison has been used with data from GOES-8 through GOES-15, Meteosat-8/-9, and MTSAT-1R/-2, with support for other satellites in the international geostationary constellation in development. The increased spatial and temporal resolution afforded by GOES-R ABI, as well as the additional infrared channels, makes the GOES-R Fire Detection and Characterization product a substantial step forward in the development of geostationary fire detection and characterization. This fire data finds use in aerosol and smoke modeling as well as real-time monitoring of active fires; both sets of users will see benefits from the higher data rate and low latency provided by ABI, improving detection confidence and the quality of derived characteristics. Additionally, research is underway to utilize the new capabilities of ABI for fire detection and characterization, including the use of additional, previously unavailable channels in the algorithm. Development of the algorithm has led to pioneering work in the modeling of satellite fire detection, primarily with respect to understanding how sub-pixel fires with their high-contrast against the background are measured by a sensor whose footprint is much larger than the fires being detected as well as how resampling of satellite data changes the quality of fire detection and characterization. Both producers and users of satellite detected and characterized fire data benefit from this enhanced understanding of how the observations themselves drive the error budget for fire detection and characterization.

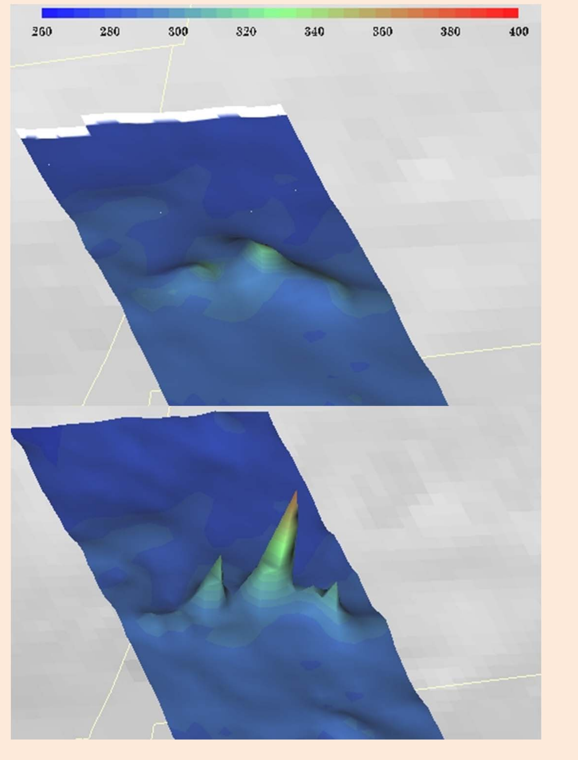
Proxy Data



Mask Legend
- Processed Fire
- Saturated Fire
- Cloudy Fire
- High Possibility Fire
- Medium Possibility Fire
- Biome Block-out Zone
- Processed Region

The above examples show fire data from the October 2007 Southern California fire outbreak. Simulated ABI data and the corresponding MODIS source data are presented in the images above. CIRA's model simulated ABI data is also shown with the GOES-11 data from the corresponding time in the bottom two image sets.

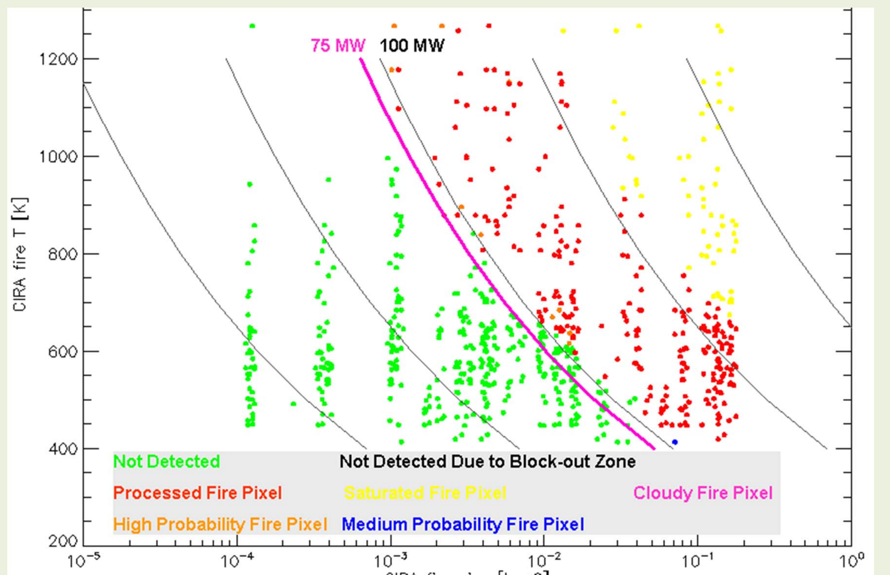
Improved ABI Resolution



Fire detection and characterization will benefit from the improved spatial, spectral, and temporal resolution provided by GOES-R ABI. The influence of spatial resolution of the 3.9 micron brightness temperature is illustrated to the right. 4km GOES-12 data from October 27, 2003, is shown above the corresponding 2km simulated ABI 3.9 micron brightness temperature. The improved spatial resolution results in greater contrast between fire and background pixels.

WF_ABBA Performance with Simulated ABI Data

	Simulated Conditions				WF_ABBA Performance			
	Fire clusters	Fire pixels	Fire area (km²) non-saturated	Total FRP (MW) non-saturated	% of fire clusters detected	% of fire pixels detected	% of fire area detected	% of FRP detected
May 8, 2003 Kansas constant fires without clouds	9720	52234	$4.2x10^3$	$2.0x10^7$	99.3%	90.9%	98.8%	91%
May 8, 2003 Kansas variable fires without clouds	5723	26600	$4.8x10^3$	$1.6x10^7$	99.5%	80.6%	77.4%	66%
May 8, 2003 Kansas constant fires with clouds	9140	46446	$3.1x10^3$	$6.2x10^7$	95.9%	84.8%	81.6%	25%
Apr 23, 2004 Cent. Amer. variable fires with clouds	849	1669	86.0	$5.8x10^5$	95.2%	85.3%	56.3%	69%
Oct 23, 2007 California variable fires with clouds	990	2388	100.0	$9.1x10^5$	99.9%	87.5%	125.9%.	105%
Oct 26, 2007 California variable fires with clouds	120	252	12.7	$8.1x10^4$	100%	83.7%	57.1%	100%
Nov 5, 2008 Arkansas variable fires with clouds	282	520	34.7	$1.8x10^5$	93.3%	78.1%	69.0%	84%



The above chart illustrates WF_ABBA fire detection and classification as a function of the CIRA model simulated ABI fire size and fire temperature. This example is from the Oct 23, 2007 California case. The WF_ABBA is quite successful detecting fires with fire radiative power (FRP) > 75 MW.

The above table depicts the WF_ABBA detection statistics for multiple case studies of simulated ABI data (developed at CIRA). The algorithm is able to detect nearly 100% of the fire clusters (groups of individual fire pixels). The performance is not quite as good for the detection of individual fire pixels or fire characteristics in large part due to sub pixel fire detection and characterization issues related to instrument effects and the quality of input radiances.

Subpixel Fire Detection and Characterization

The need to systematically and reliably generate diurnal biomass burning information led to the development WF_ABBA processing system. With inputs consisting of geostationary satellite data, total precipitable water from numerical forecast models, and an ecosystem map, the WF_ABBA is able to detect and characterize fires in near real-time, providing users such as NOAA and the hazards community with high temporal and spatial resolution fire data. Current Geostationary Operational Environmental Satellite (GOES) data allows for fire detection at a spatial resolution of 4 km, and the WF_ABBA runs on all GOES data, detecting fires within a satellite zenith angle of 80° (covering the better part of the visible hemisphere). The WF_ABBA algorithm can be extended to any geostationary satellite platform that possesses 3.9 µm and ~11 µm bands which meet certain requirements.

IR fire detection from satellites takes advantage of the fact that as target temperature increases radiance increases faster at the shortwave end of the spectrum as opposed to the longwave end. The WF_ABBA can estimate the radiance due to the fire itself, within limits determined by viewing conditions and satellite characteristics. That fire radiance can be split into instantaneous size and temperature via the Dozier method or converted into fire radiated power (FRP). The key to successfully estimating any of those quantities is to have good radiance information, which requires correcting for atmospheric attenuation, accurately estimating the background temperature, and having good instrument performance (such as low NEDT at high temperatures and a sufficiently high saturation temperature).

Fire Size and Temperature

To solve fire size and temperature, a system of two equations with two unknowns can be solved for numerically.

$$L_4 = pL_4(T_t) + (1-p)L_4(T_b)$$

$$L_{11} = pL_{11}(T_t) + (1-p)L_{11}(T_b)$$

FRP

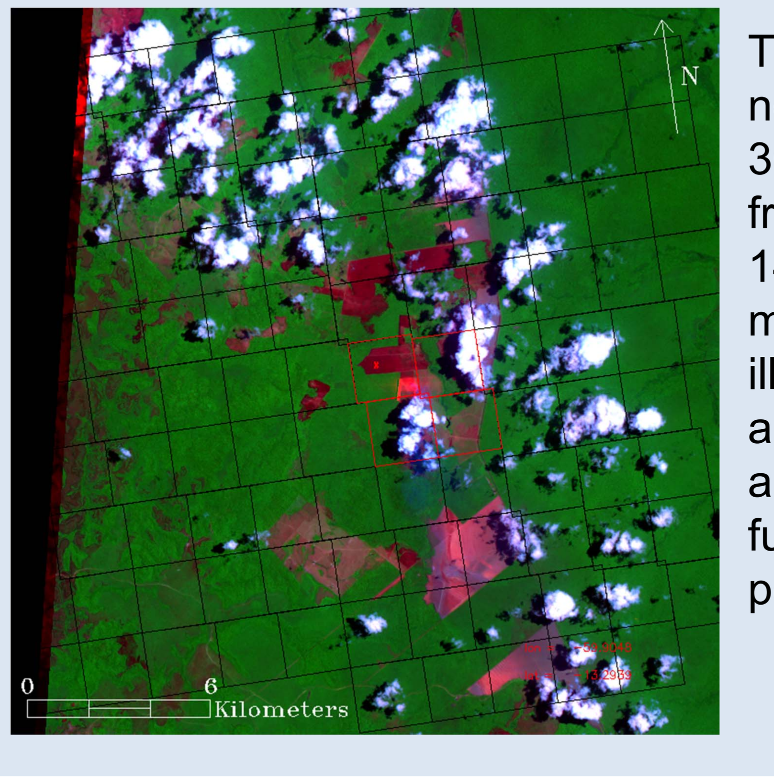
Fire radiative power (FRP) can be calculated two ways. FRP_{DEF} requires knowledge of the fire size and temperature. FRP_{MIR} only requires one middle IR channel, however the solution is only valid for fire temperatures that fit the L≈T⁴ approximation:

$$FRP_{DEF} = A_{pixel}\varepsilon\sigma\sum_{k=1}^{n} p_k T_k^4$$

$$FRP_{MIR} = \left(\frac{A_{pixel}\sigma}{a}\right)\left(L_{MIR} - L_{B,MIR}\right)$$

$$L_{f,MIR} = \varepsilon B(\lambda, T) \approx \varepsilon a T^4$$

Modified Dozier equation terms	
Term	**Definition**
$L_x(T_x)$	Radiance calculated by integrating the product of the Planck function and the response function for each spectral band x
L_4	3.9 µm adjusted radiance
L_{11}	11.2 µm adjusted radiance
p	Proportion of pixel on fire
1-p	Proportion of pixel not on fire
T_4	3.9 µm adjusted brightness temperature
T_{11}	11.2 µm adjusted brightness temperature
T_b	Background/non-fire brightness temperature
T_t	Average instantaneous target temperature of sub-pixel fire
FRP equation terms	
A_{pixel}	Area of pixel
ε	Emissivity of the fire (typically assumed to be 1)
σ	Stefan – Boltzmann constant [5.67 x 10^{-8} $Wm^{-2}K^4$]
p_k	Instantaneous sub-component area on fire within the pixel where the number of sub-components ranges from 1 to n
T_k	Instantaneous temperature of the sub-component area on fire within the pixel where the number of sub-components ranges from 1 to n
$B(\lambda,T)$	The monocrhomatic irradiance of a blackbody at a specific temperature and wavelength
a	An empirically derived , instrument specific constant typically around 3.0 x 10^{-9} [$Wm^{-2}sr^{-1}\mu m^{-1}K^{-4}$]



The image to the left shows GOES-R ABI nominal pixels (grid) overlaid on a coincident 30m resolution ASTER image (RGB composite from bands 8-3-1) acquired 19 Oct 2002 at 14:21:59 UTC. WF-ABBA fire pixels are marked in red (credit: Wilfrid Schroeder). This illustrates how subpixel hotspot features can appear in multiple full-resolution pixels as an artifact of the shape of the imager response function (which is not square) and relative postion of the subpixel feature.

WF_ABBA on the web: