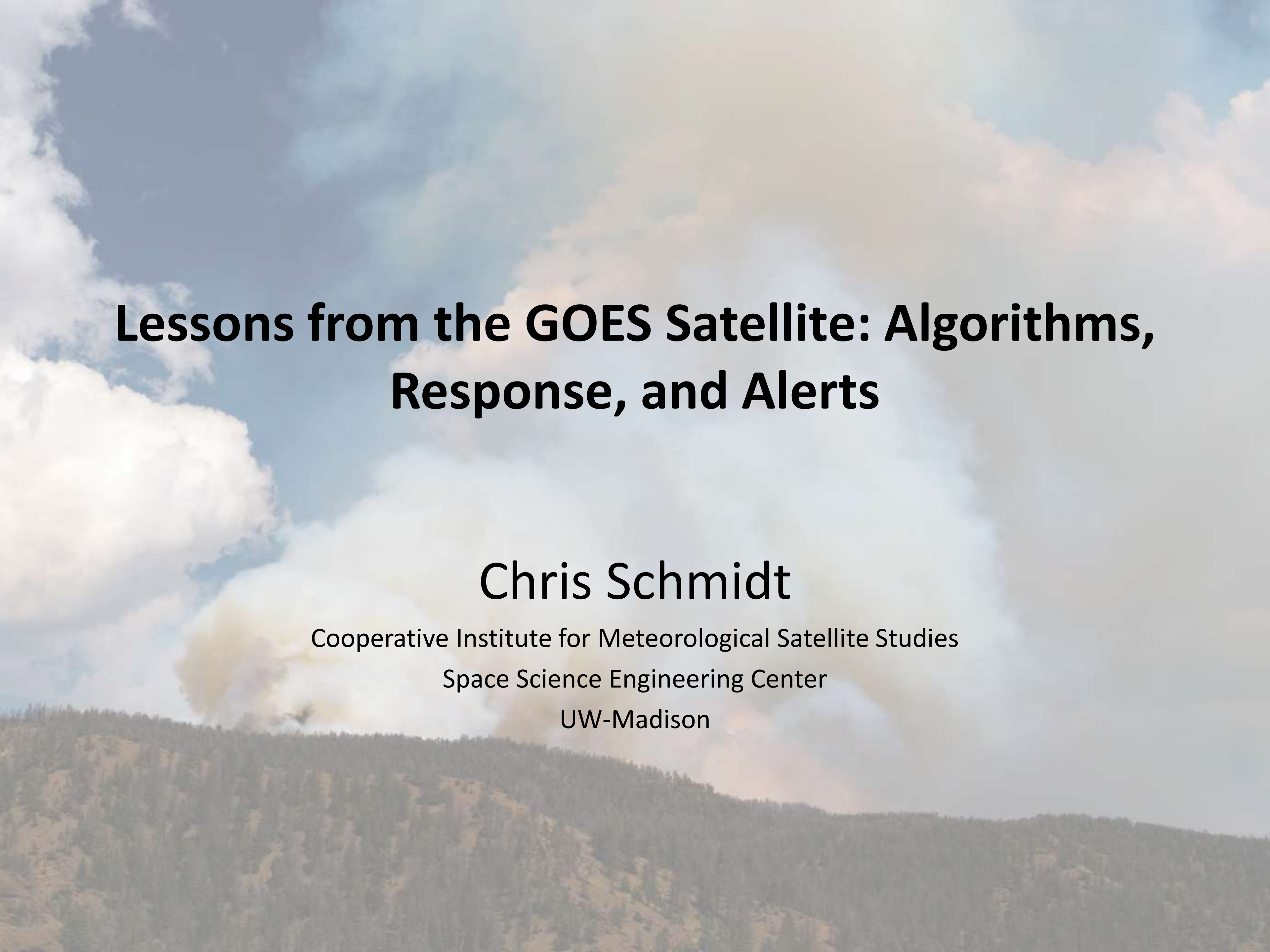
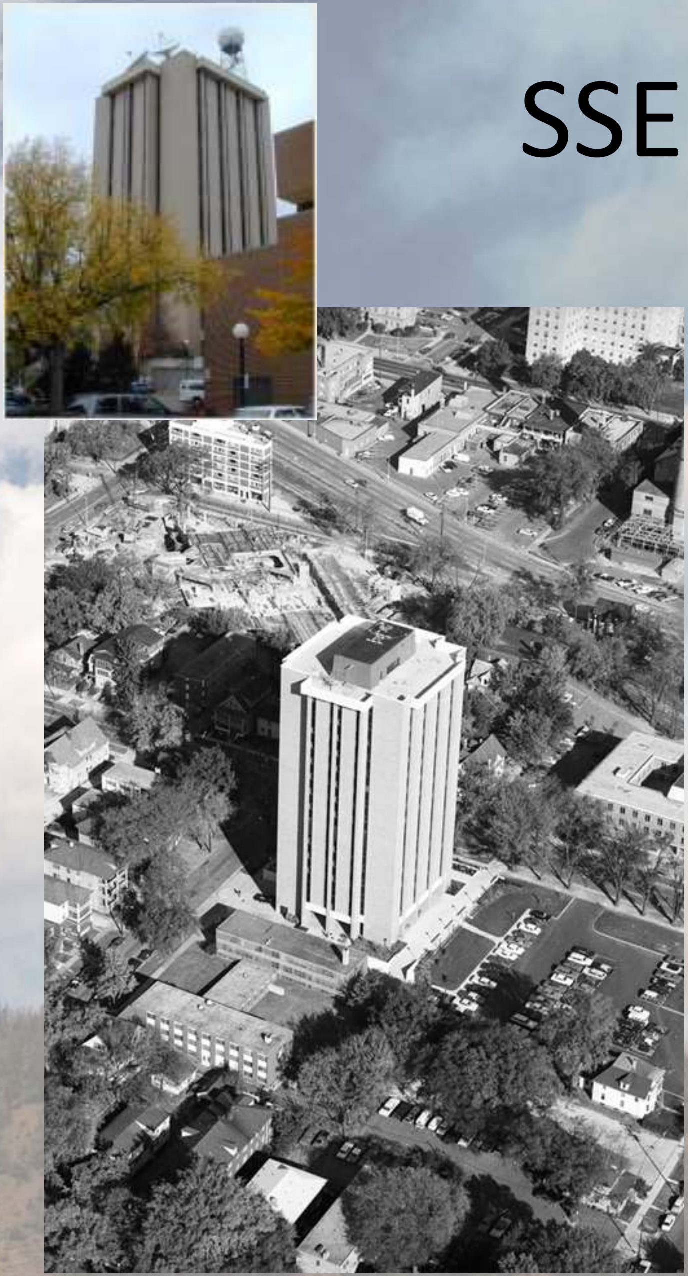


Lessons from the GOES Satellite: Algorithms, Response, and Alerts

Chris Schmidt

Cooperative Institute for Meteorological Satellite Studies
Space Science Engineering Center
UW-Madison

SSEC and CIMSS



AOSS & SSEC building ~1969

In the mid-1960s, Dr. Verner E. Suomi, working with Robert J. Parent, invented the Spin-Scan Cloud Camera. This instrument was the payload of the Applications Technology Satellite series (ATS-I and ATS-III) launched into geostationary orbit in 1966 and 1967, respectively. Launch of the ATS-I into geosynchronous Earth orbit pioneered continuous viewing of weather from space. The ability to obtain continuous satellite imagery of a fixed point on the earth, at 20-minute intervals, allowed scientists to study a synoptic picture of existing meteorological conditions for the first time.

SSEC grew from there, and has played a critical role in the development of NOAA and NASA weather satellites since. The creation of the Cooperative Institute for Meteorological Satellite Studies in 1980 further solidified SSEC's role in the field.

True color ATS-III image from 18 Nov 1967. The US has not had a true color geostationary imager since.

Geostationary Weather Satellites

- Provide multi-spectral data from a (relatively) fixed location
- Currently resolutions are typically 4 km at the sub-satellite point
- The US has launched 8 of the current model and has a new series in development providing higher temporal and spatial resolution
- Individual satellites have typically operated 5 years or longer
- They were designed primarily for cloud tracking, other applications have since been developed

Geostationary Weather Satellite Applications: A partial list

- Hurricane intensity estimates
- Atmospheric profiling (temperature, moisture, ozone)
- Convective initiation detection
- Overshooting top detection (severe thunderstorm development)
- Turbulence detection (water vapor imagery, ozone products)
- Volcanic ash detection
- Cloud-tracked winds
- And many, many more

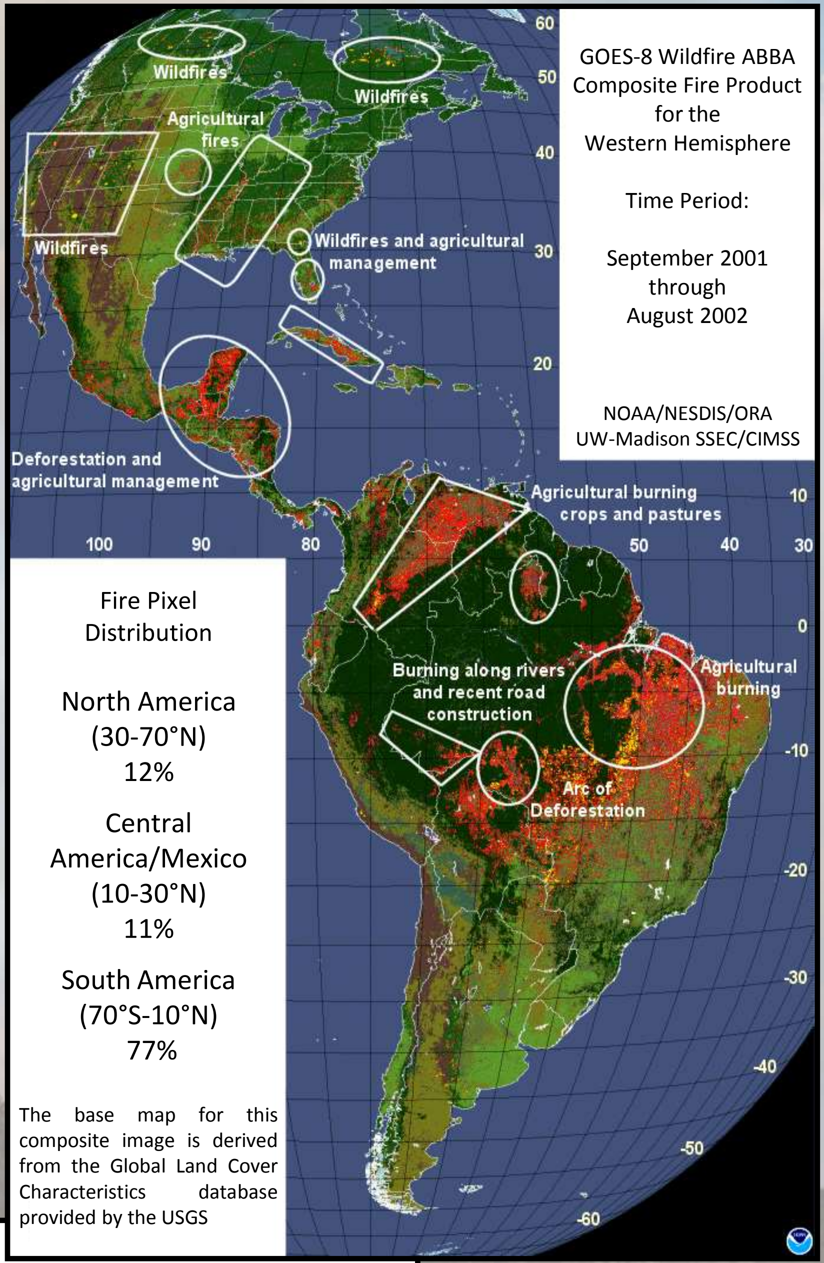
Why do we care about geostationary fire detection and characterization?

- 24/7 monitoring of a hemisphere allows for tracking trends and detecting fires earlier than allowed by polar platforms
- The fire’s radiative power (FRP), size, and temperature can be used to estimate emissions and intensity
  - FRP is related to the mass consumed
  - FRP is proportional to temperature to the fourth power times size
- Knowing what we cannot see is as important and knowing what we do see – with so many more “looks” we know more about what we don’t see
- The large footprint makes early detection of wildfires difficult, but is still useful where human observers are few and far between

Annual Distribution of Fires in the Western Hemisphere

SEPTEMBER 2001 – AUGUST 2002

This WF_ABBA fire product composite was generated from over 15,000 half-hourly GOES-8 images. The composite shows a much higher incidence of burning in Central and South America, primarily associated with deforestation and agricultural management. Approximately 1.67 million fire pixels were identified from September 2001 through August 2002. A 10% increase was observed over the previous year.



GOES-8 Wildfire ABBA Composite Fire Product for the Western Hemisphere

Time Period:

September 2001
through
August 2002

NOAA/NESDIS/ORA
UW-Madison SSEC/CIMSS

Fire Pixel Distribution

North America (30-70°N)	12%
Central America/Mexico (10-30°N)	11%
South America (70°S-10°N)	77%

The base map for this composite image is derived from the Global Land Cover Characteristics database provided by the USGS

WF_ABBA Fire Pixel Category

🟥 Processed 🟨 Saturated 🟪 Cloudy 🟧 High Possibility 🟦 Medium Possibility

Overview of Geostationary Fire Detection at CIMSS

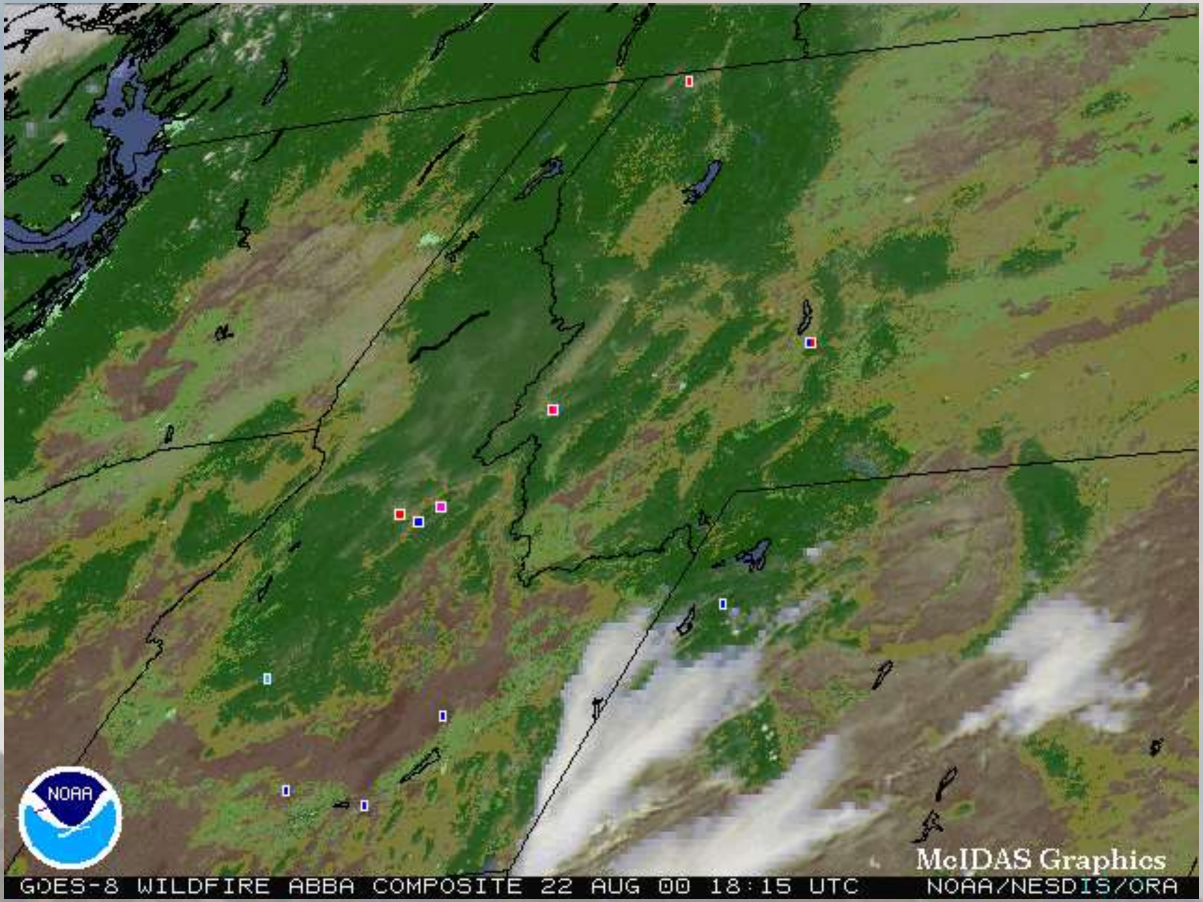
- Elaine Prins, Joleen Feltz, and Paul Menzel started development of the GOES Automated Biomass Burning Algorithm (ABBA) in the mid 1990s
- Research was focused on South America until approximately 2000 when CIMSS started working with NRL-Monterey. This led to development of the Wildfire ABBA (WFABBA).
- In 2002 Version 6.0 of the WFABBA was transferred to NOAA Operations. Data has been processed every half-hour on a fixed schedule since then. Initially the WFABBA supported GOES-8/-10.
- Support has been added for other GOES over time and now includes GOES-8 through GOES-15 and the next generation satellite GOES-R (GOES-16 when it becomes operational).
- In response to requests from the user community, Version 6.5 supports:
  - International geostationary satellites with fire detection capabilities such as Meteosat Second Generation and MTSAT
  - Processing all available data quickly (processing flexibility)
  - Providing enhanced metadata that shows locations of opaque clouds, block-out zones, etc.

Fire Detection and Characterization

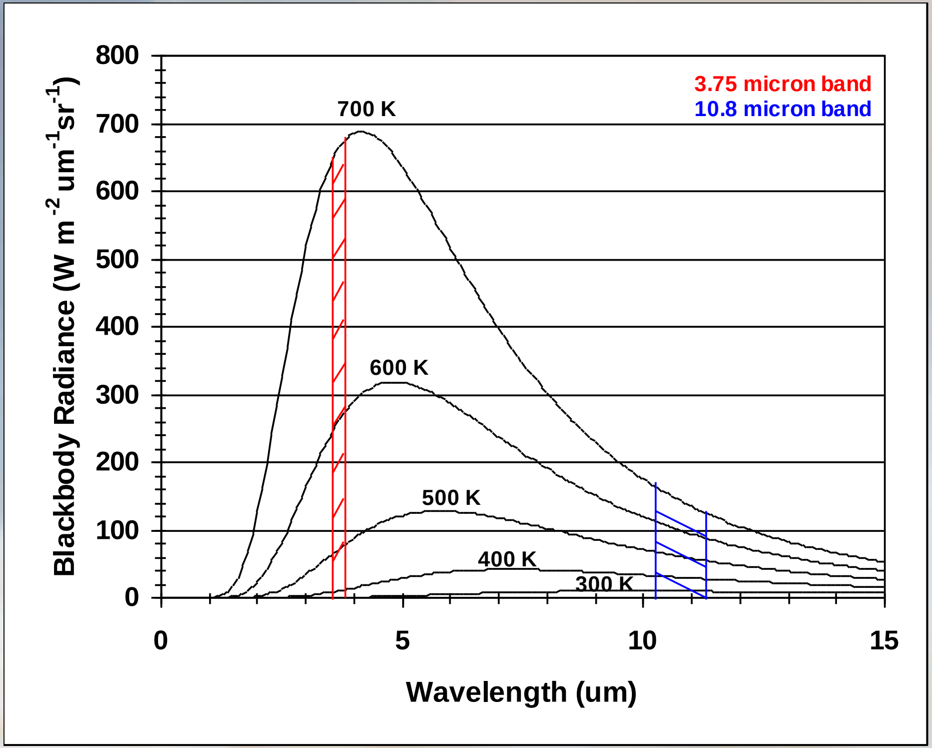
- Works best with at least 2 IR bands: ~4 µm and ~11 µm
- Requires some ancillary data (total precipitable water, surface emissivity, surface type)
- Algorithm is contextual to best handle estimating background surface radiance
- Current hardware can process a full disk image in 5-10 minutes. Best hardware <5 minutes
- Location given is the center of the pixel and subject to navigation error of satellite

WFABBA Example

- 22 August 2000, 18:15 to 23:45 UTC
- Fire complex had started on 14 August
- Loop shows intensification in the afternoon as the winds pick up
- Valley smoke can be seen, as well as a fire induced cloud with a glaciated top



How short and long-wave IR bands are used to detect & characterize fires

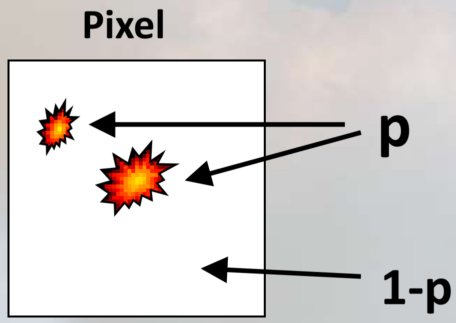


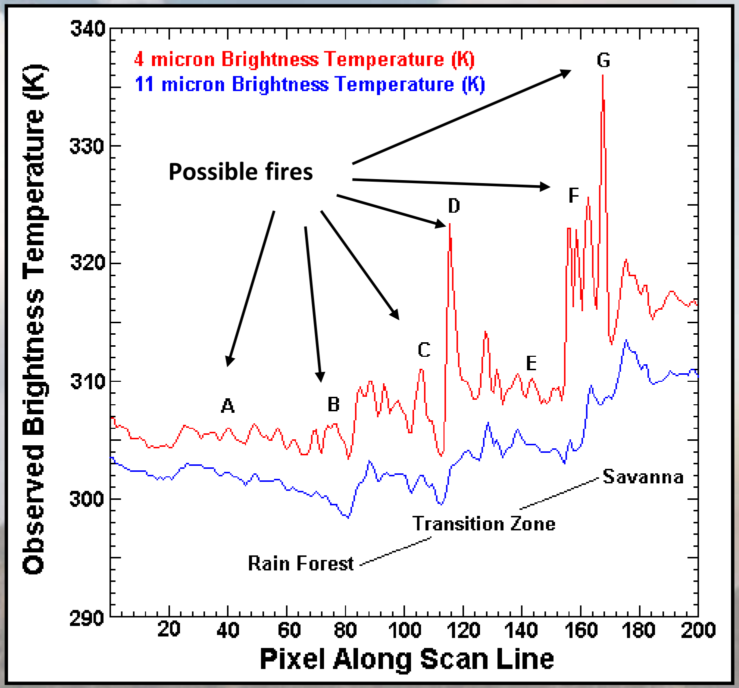
As the surface temperature increases, the peak of the Planck function shifts toward shorter wavelengths, so the radiance increases more rapidly at ~4 µm than ~11 µm. The different brightness temperature responses in these two infrared windows and background conditions can be used to detect fires and estimate sub-pixel fire size, temperature and fire radiative power (FRP).

Fires are sub-pixel entities and IR responses to fires:

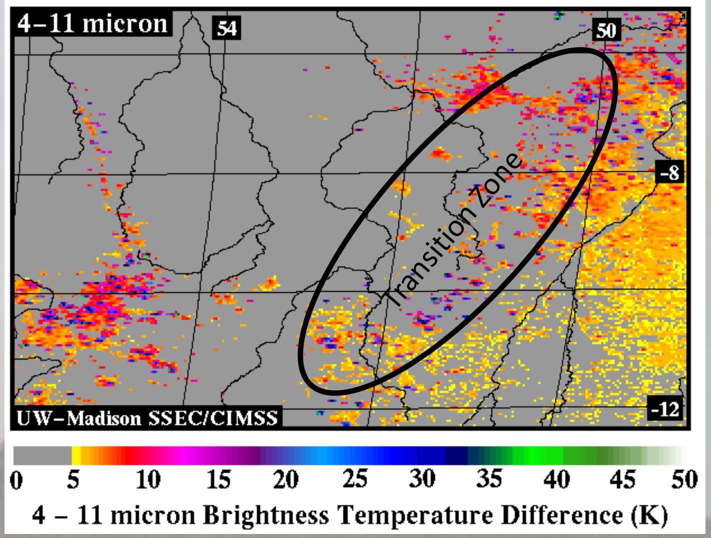
Typically, the difference in brightness temperatures between the two infrared windows at 3.9 µm and 11.2 µm is due to *reflected solar radiation*, *surface emissivity* differences, and *water vapor attenuation*. This normally results in brightness temperature differences of 2-4 K.

Larger differences occur when one part of a pixel (p) is substantially warmer than the rest of the pixel (1-p). The hotter portion will contribute more radiance in shorter wavelengths than in the longer wavelengths.

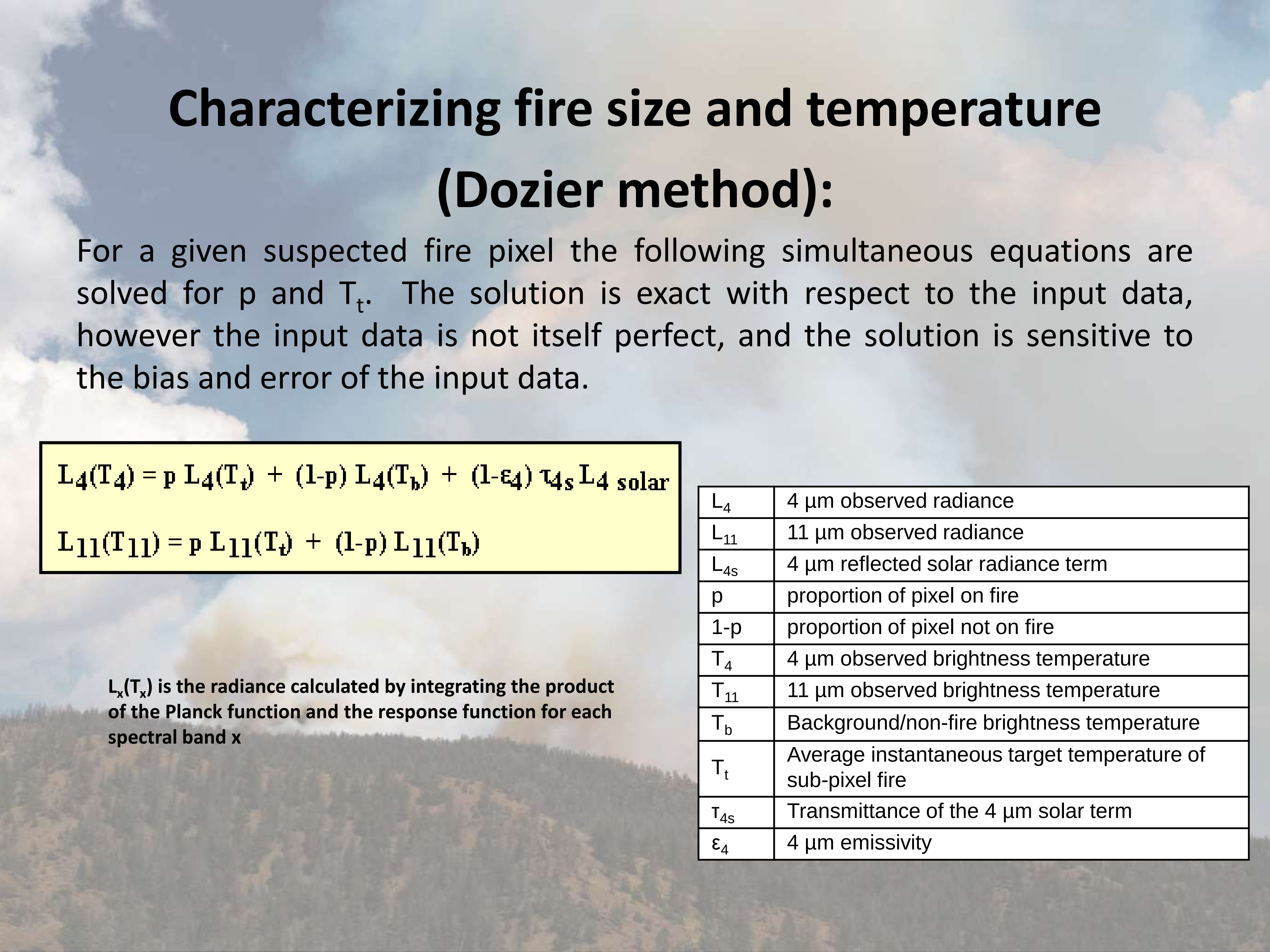




Brightness temperatures along a scan line in NE Brazil



NE Brazil along the transition zone between forest and savanna



Characterizing fire size and temperature (Dozier method):

For a given suspected fire pixel the following simultaneous equations are solved for p and T_t. The solution is exact with respect to the input data, however the input data is not itself perfect, and the solution is sensitive to the bias and error of the input data.

$$L_4(T_4) = p\,L_4(T_t) + (1\text{-}p)\,L_4(T_b) + (1\text{-}\varepsilon_4)\,\tau_{4s}\,L_{4\ solar}$$

$$L_{11}(T_{11}) = p\,L_{11}(T_t) + (1\text{-}p)\,L_{11}(T_b)$$

$L_x(T_x)$ is the radiance calculated by integrating the product of the Planck function and the response function for each spectral band x

L_4	4 µm observed radiance
L_{11}	11 µm observed radiance
L_{4s}	4 µm reflected solar radiance term
p	proportion of pixel on fire
1-p	proportion of pixel not on fire
T_4	4 µm observed brightness temperature
T_{11}	11 µm observed brightness temperature
T_b	Background/non-fire brightness temperature
T_t	Average instantaneous target temperature of sub-pixel fire
τ_{4s}	Transmittance of the 4 µm solar term
ε_4	4 µm emissivity

Fire radiated power (FRP) provides another way to characterize sub-pixel fires:

- Relies on the same 4 and 11 µm data as the Dozier method
- FRP_{DEF} is the definition of FRP
- Can be estimated by applying Dozier solution to FRP_{DEF} or from radiances using FRP_{MIR}. In the range of temperatures and sizes that the Dozier is known to perform well in, the two methods agree well.

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

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

L_{MIR}	4 µm observed radiance
$L_{B,MIR}$	4 µm calculated background radiance
A_{sample}	Area of pixel
a	A constant (function of instrument SRF)
p_k	Instantaneous proportion of pixel on fire
T_k	Instantaneous target temperature of sub-pixel fire
ε	Emissivity of fire (typ. assumed to be 1)
σ	Stefan-Boltzmann constant

Why do we care about FRP? The FRP is the time derivative of the fire radiative energy, which is proportional to the biomass consumed by the fire. This value can be directly applied when calculating emissions.

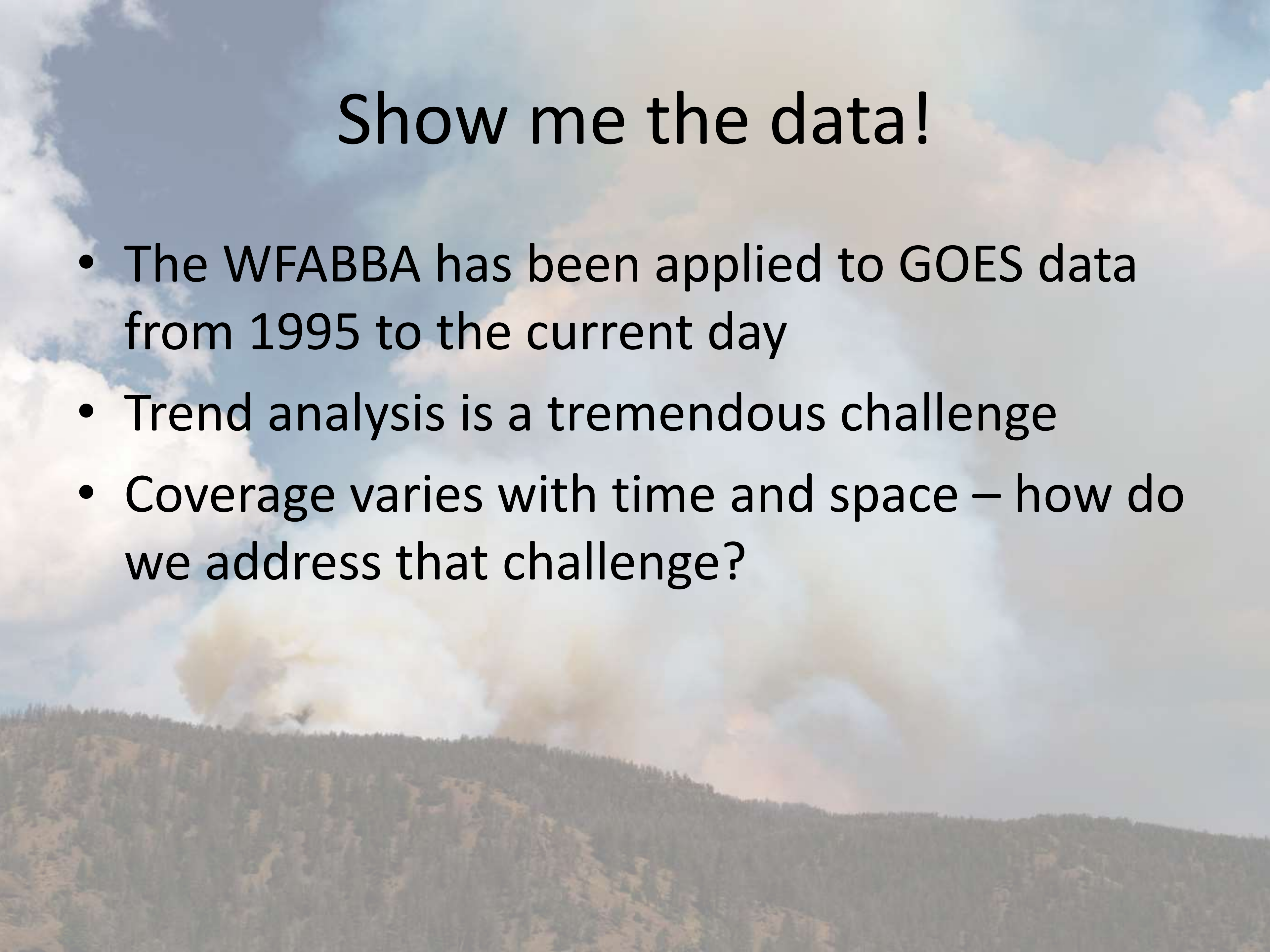
Version 6.5 of the WFABBA added FRP to the fire size and temperature, and also provides a mask describing why a given pixel was rejected as a fire. This provides information critical for adjusting for coverage rates and opaque clouds and also gives us a debugging tool.

Mask Flag	Definition
0	Non-processed region of input/output image
10	Processed fire pixel
11	Saturated fire pixel
12	Cloud contaminated fire pixel
13	High probability fire pixel
14	Medium probability fire pixel
15	Low probability fire pixel
50	Satellite zenith angle block-out zone
60	Reflectance angle or solar zenith angle block-out zone
100	Processed region of image
120	Bad input data (4 or 11 micron)
125	Invalid reflectivity product input. Can be indicative of localized spikes in the reflectivity product/bad data
130	Not currently used
150	Invalid ecosystem type
151	Sea water
152	Coastline Fringe
153	Inland Water and other Land/water mix
155	Not currently used

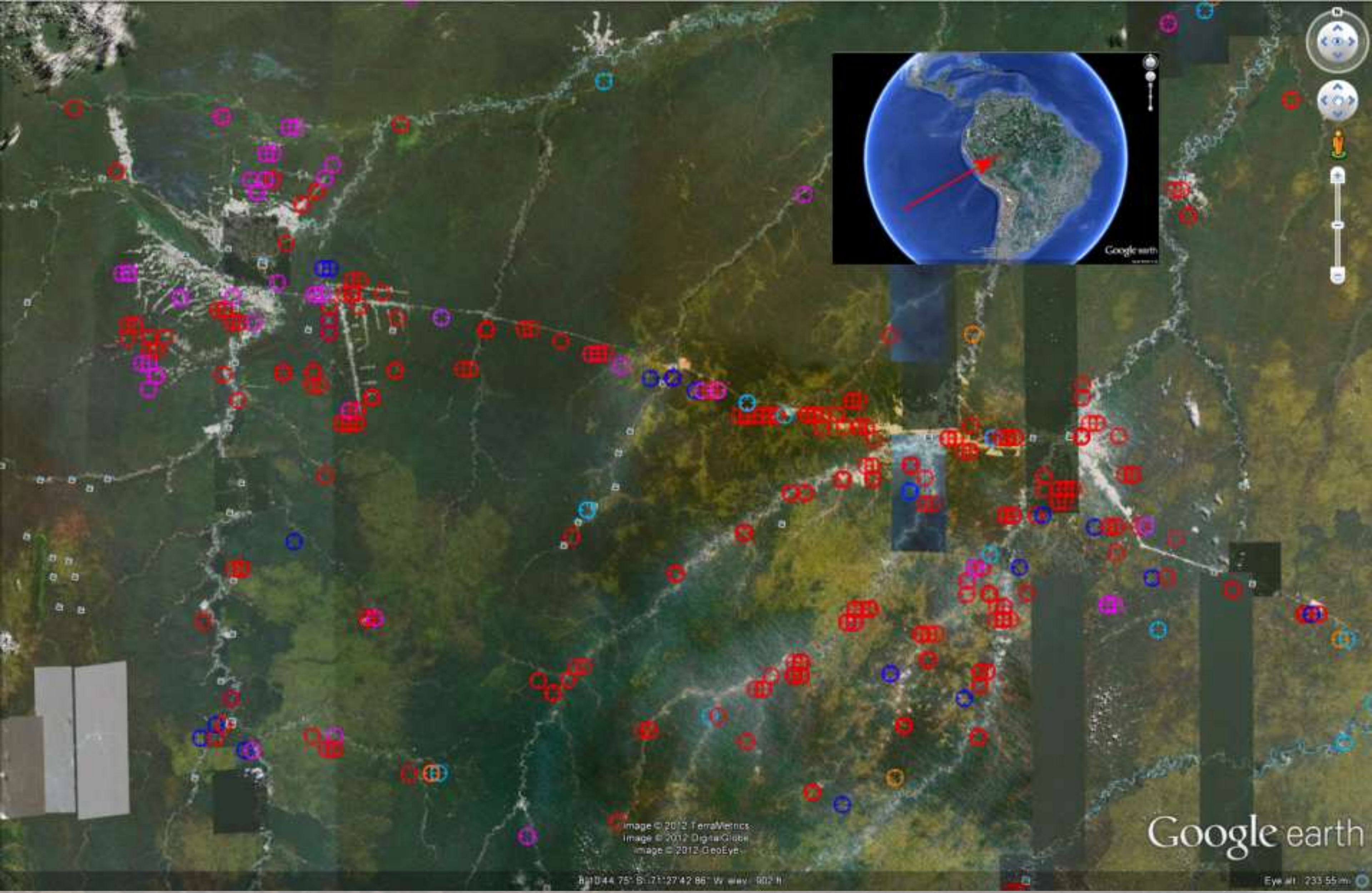
Mask Flag	Definition
160	Invalid emissivity value
170	No background value could be computed
180	Error in converting between temperature and radiance
182	Error in converting adjusted temperatures to radiance
185	Values used for bisection technique to hone in on solutions for Dozier technique are invalid.
186	Invalid radiances computed for Newton’s method for solving Dozier equations
187	Errors in Newton’s method processing
188	Error in computing pixel area for Dozier technique
200	11 micron threshold cloud test
205	4 minus 11 micron negative difference threshold cloud test
210	4 minus 11 micron positive difference threshold cloud test
215	Albedo threshold cloud test (daytime only)
220	12 micron threshold cloud test (only used when data available)
225	11 minus 12 micron negative difference threshold cloud test
230	11 minus 12 micron positive difference threshold cloud test
235	Additional 4 micron minus 11 micron difference cloud test applied under certain conditions.
240	Along scan reflectivity product test to identify and screen for cloud edge used in conjunction with 4 micron threshold
245	Along scan reflectivity product test to identify and screen for cloud edge used in conjunction with albedo threshold

Table is from v6.5.004 for ABI, some changes are present in the most recent update.

Show me the data!

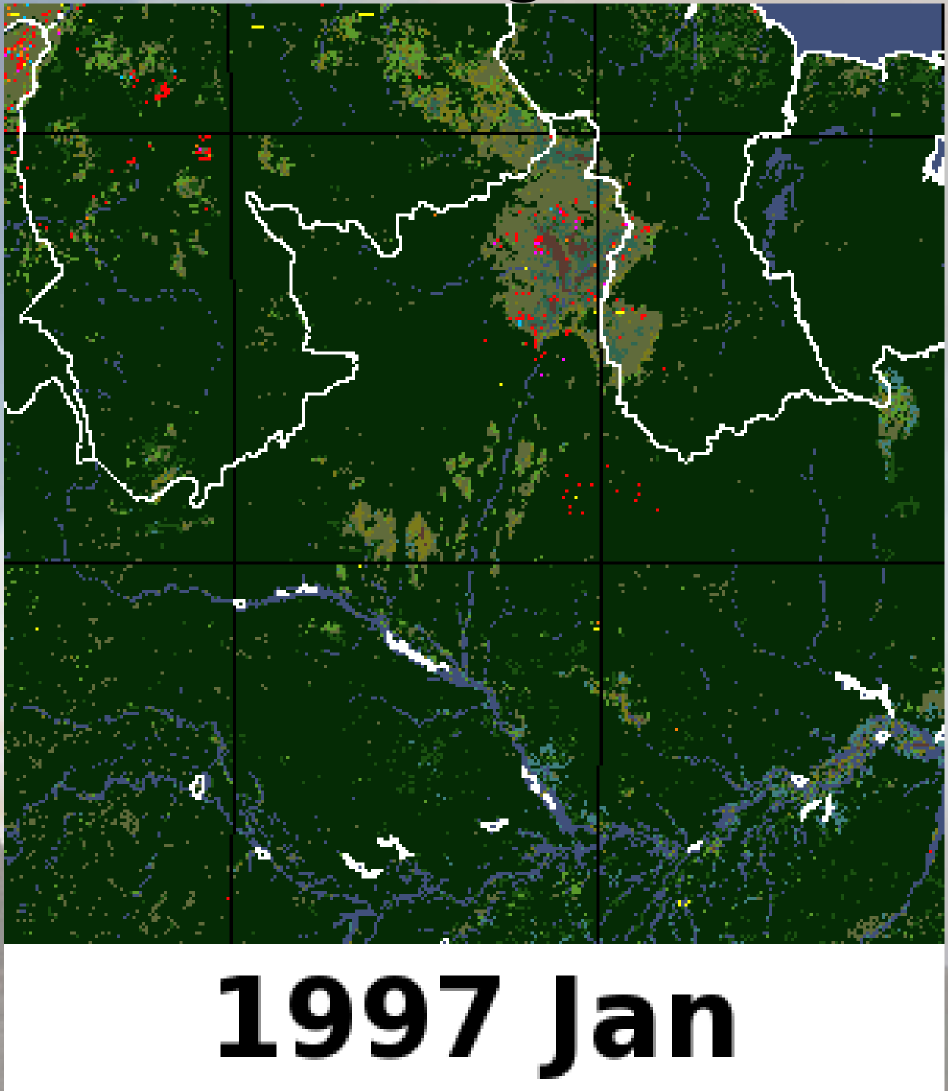


- The WFABBA has been applied to GOES data from 1995 to the current day
- Trend analysis is a tremendous challenge
- Coverage varies with time and space – how do we address that challenge?



GOES-12 composite for 8 September 2010 showing burning in western Brazil. The icons roughly approximate the satellite footprint and not the size of the fire. Red indicates high confidence fires with associated size, temperature, and power. Other colors represent cloud covered fires (purple), saturate pixels (yellow), and other confidence levels. The fires line up along previous clearings and roads, a common pattern for fires in the South American forest.

All GOES WFABBA fire detects over Northern Brazil, Jan 1997 through Oct 2008



Geostationary fire detection’s biggest challenge

Physics does not allow us to escape diffraction

Diffraction is the primary factor in the point spread function (PSF) of a sensor (though not the only one)

The PSF is not uniform and extends beyond the field of view

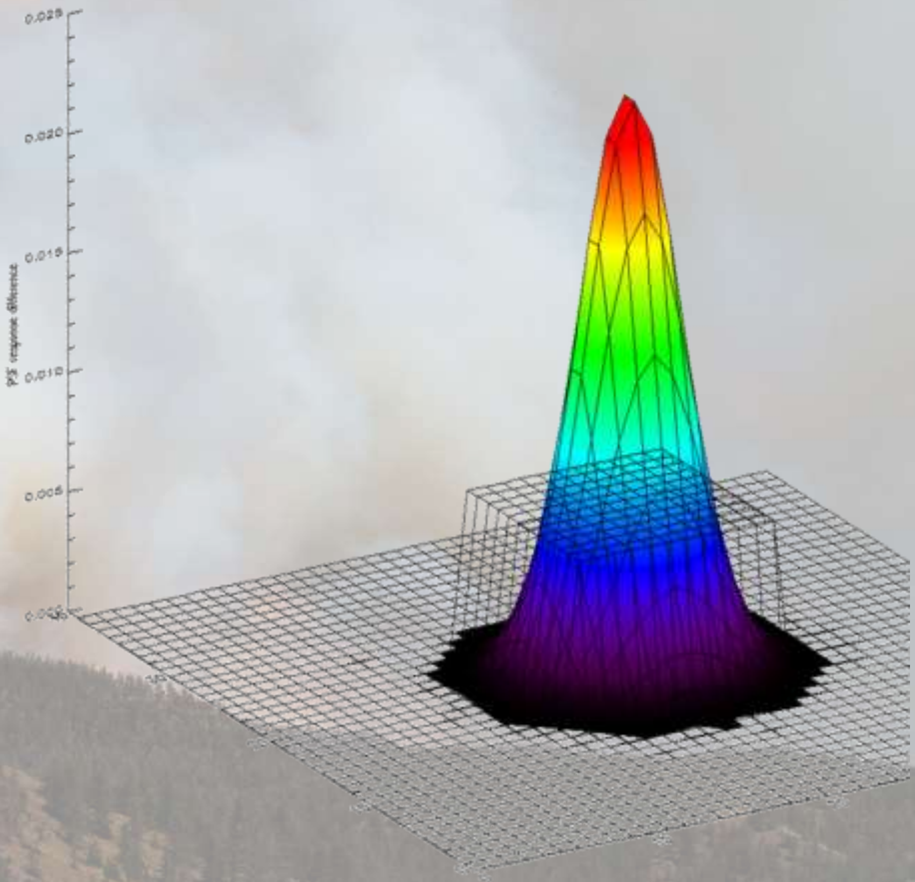
A pixel is calibrated, a sub-pixel is not. Therefore a sub-pixel feature may be magnified or minimized by this effect.

One way to measure the PSF is by the “ensquared energy”, the percentage of the total energy within the nominal footprint. This is how specifications are sometimes written. (in other cases the MTF, the inverse Fourier Transform of the PSF, is specified)

The next slide compares a Gaussian PSF with a step function PSF, both having the same ensquared energy.

Fire detection’s biggest challenge

A “pixel” is not a perfect average of everything within the footprint, it is a more or less Gaussian function (for GOES, at least) that creates unique issues to fire detection. A fire may occupy 1% of a pixel, or less, and its location within the pixel will determine whether it is represented accurately, over-estimated, or under-estimated.



Fire detection's biggest challenge

Most fires will only occupy a very small portion of a pixel, using ABI as an example

A fire cluster is a group of adjacent pixels affected by a single or multi-front fire or complex (e.g. Clusters A, B, and C)

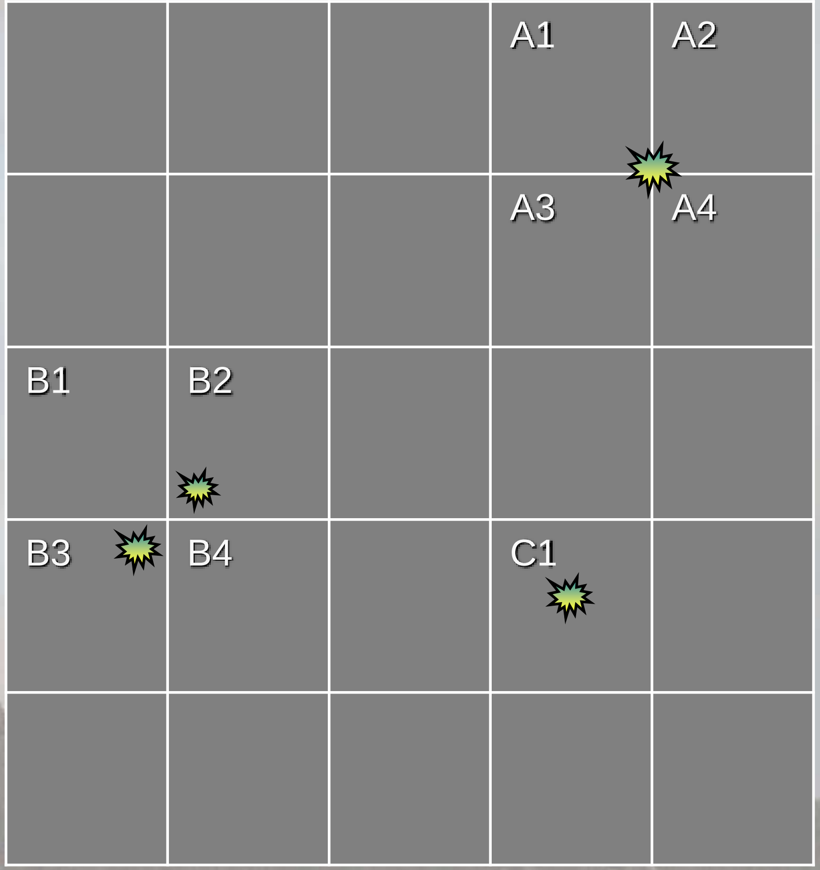
ABI fire pixel refers to each ABI pixel within a cluster that is impacted by any fire activity. (e.g. A1-A4, B1-B4, C1)

In clear sky detectability and characterization of a fire is dependent on size/temperature and location within a pixel.

Fire A is slightly larger than Fire C, but signal is divided among multiple pixels and may not provide a strong enough signal to be accurately characterized, while Fire C is detected and likely over-characterized.

Fires in B2 and B3 may be difficult to distinguish from each other, since they are located on the edge of a pixel impacting surrounding pixels due to diffraction.

GOES-R ABI 3.9 µm pixels



Fire detection’s biggest challenge

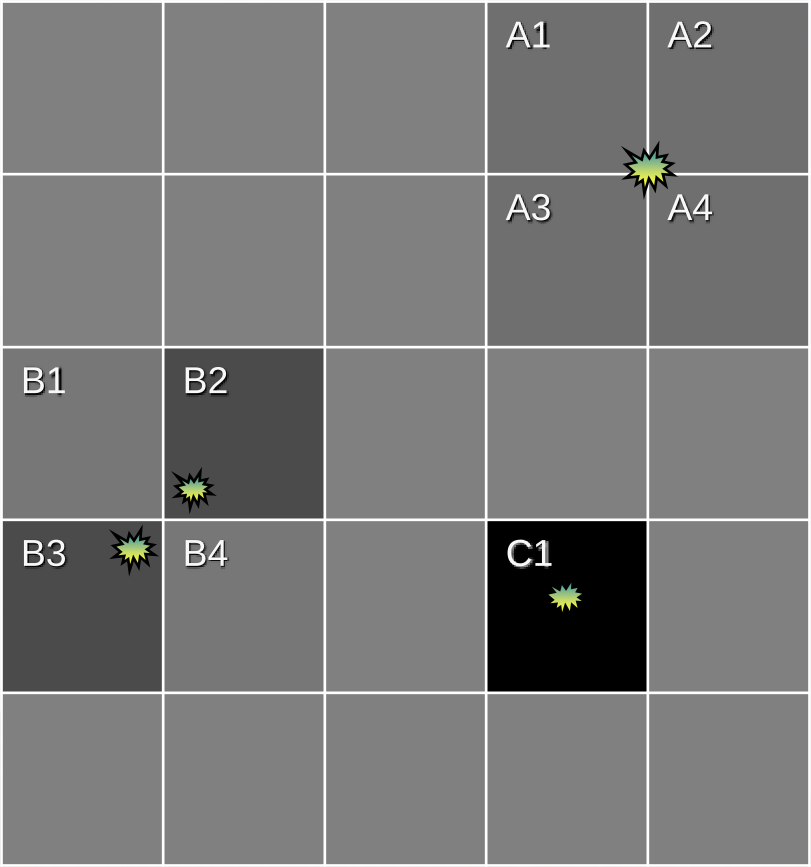
Note:* *Brightness temperatures are simulated here. Assume all fires are the same size and temperature, and that the PSF described above has been applied. Darker represents hotter pixels.

Fire C1 is a saturated pixel, the fire lines up with the peak of the PSF.

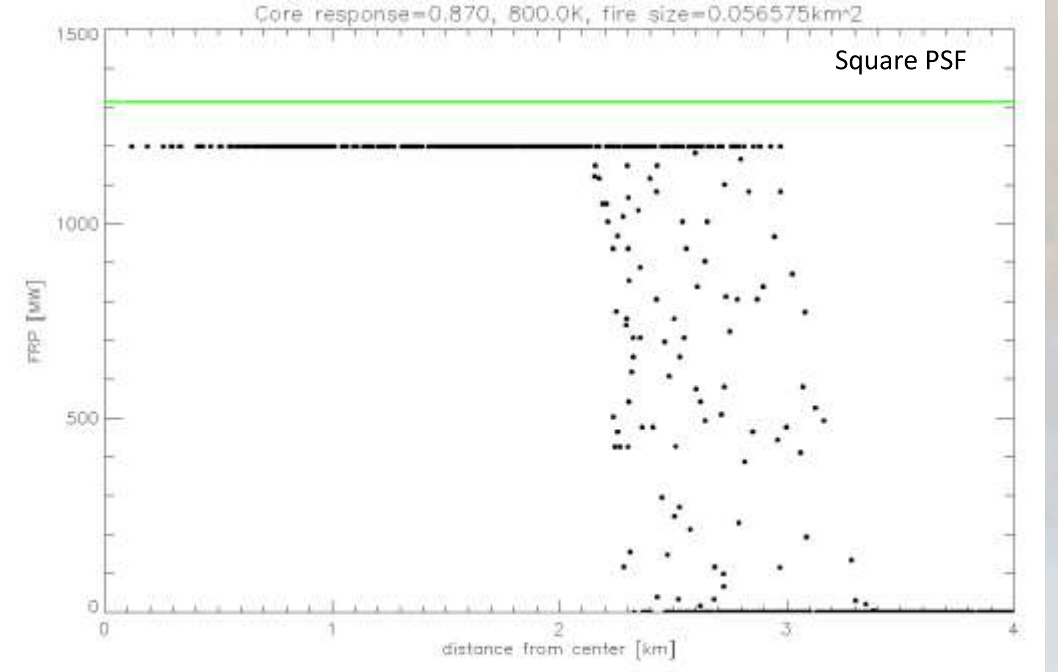
The 2 fires in pixels B2 and B4 impacts 4 pixels.

The one fire between pixels A1-A4 impacts all four pixels, but to a small degree

GOES-R ABI 3.9 µm pixels



Modeling fire detection with different PSFs

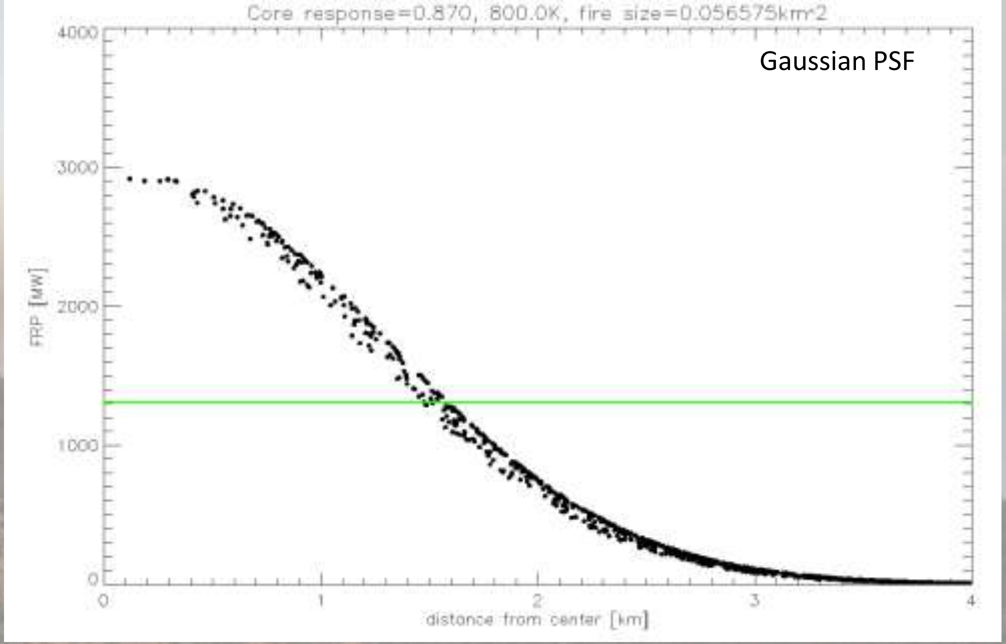


Fire: 800K on a 5m grid, 31x73 grid cells (155m by 365m; following model used by Wilfrid Schroeder)

PSFs: 87% ensquared energy, 4 km footprint (similar to current GOES 4 µm band)

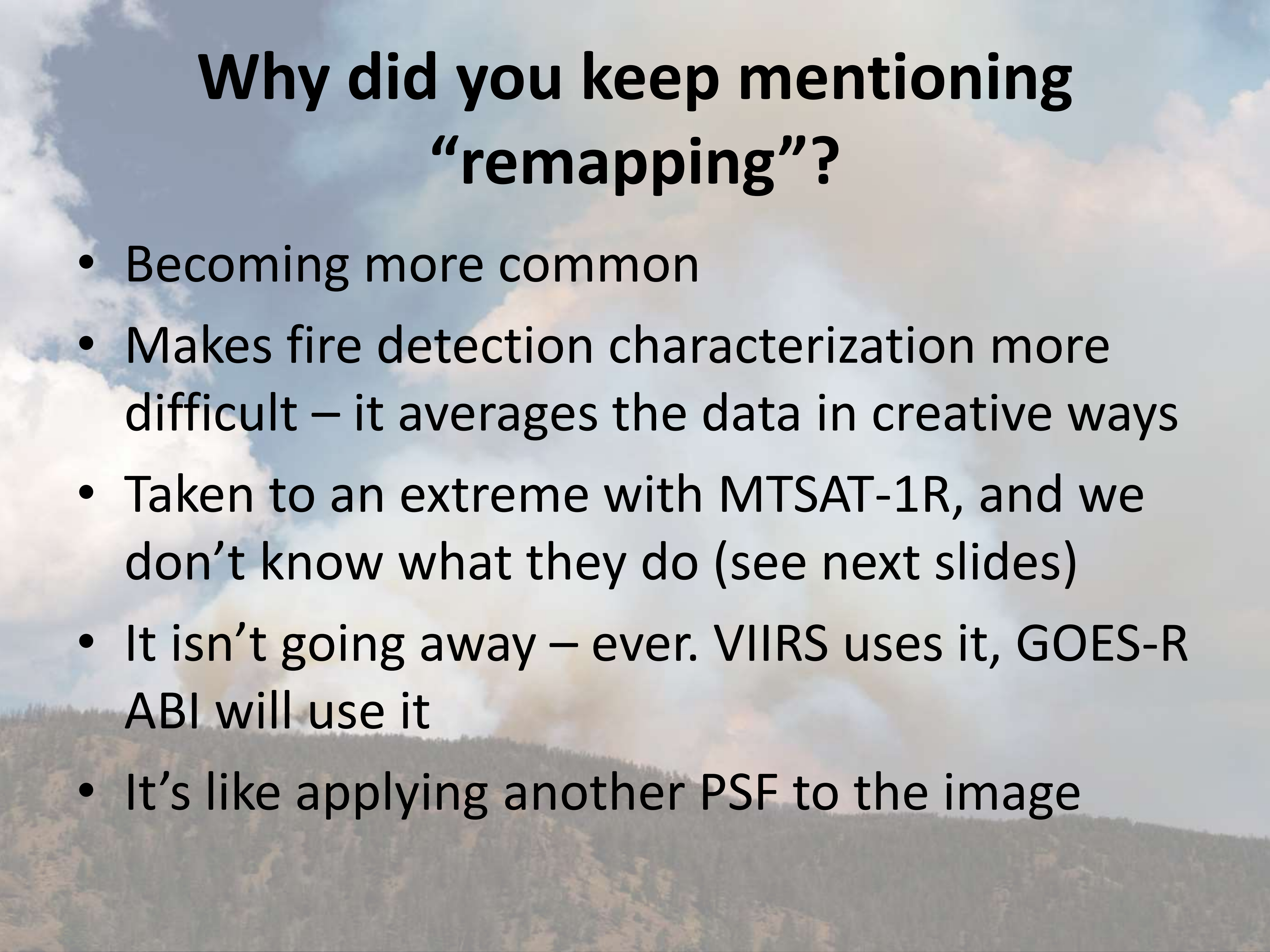
FRP: Calculated using radiance method

Green line is truth, horizontal axis is distance between fire center and pixel center.



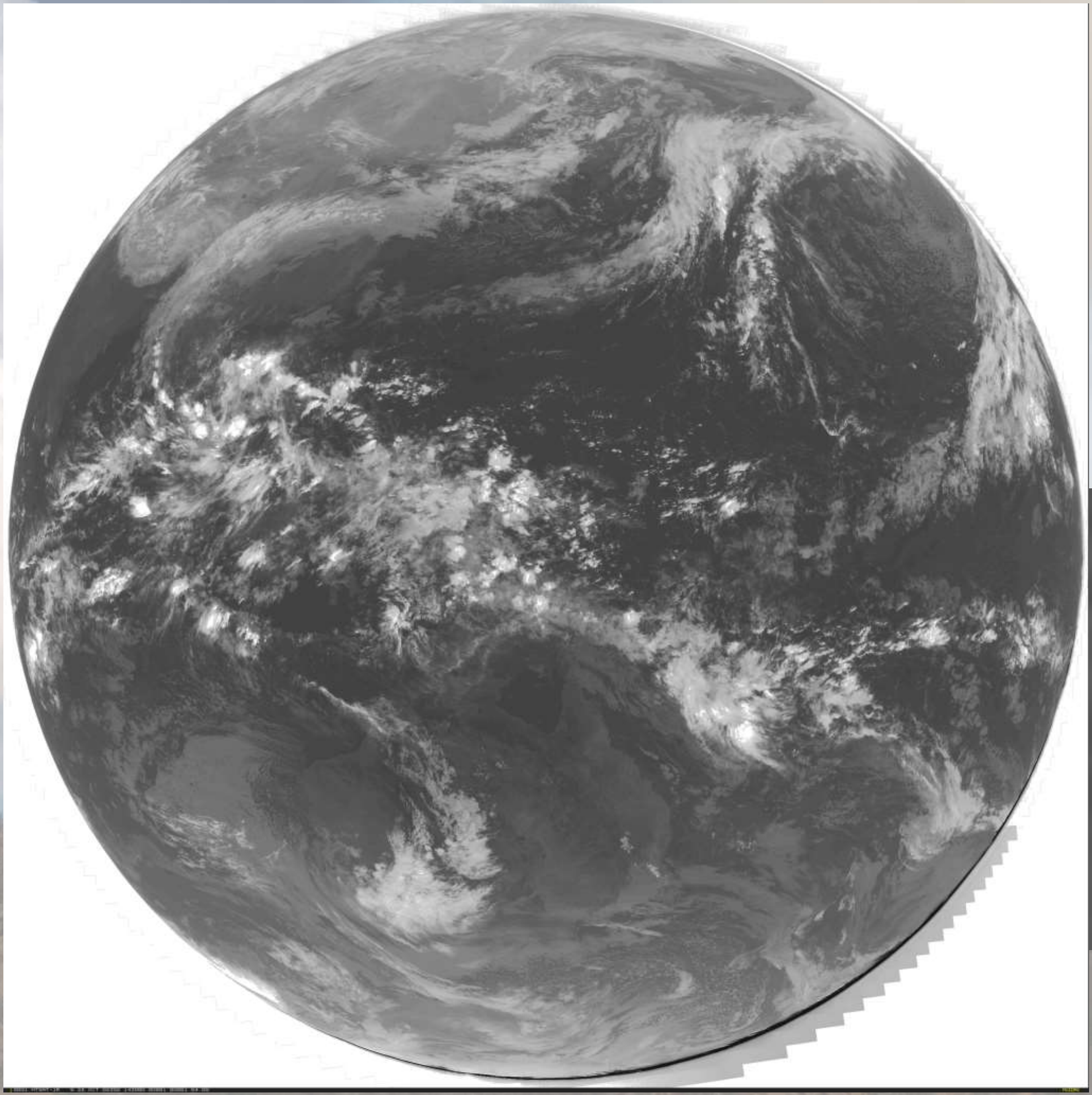
Result: Discomfort for product developers, followed by realization that on average this results in a bias related to the characteristics of the instrument PSF.

Why did you keep mentioning "remapping"?



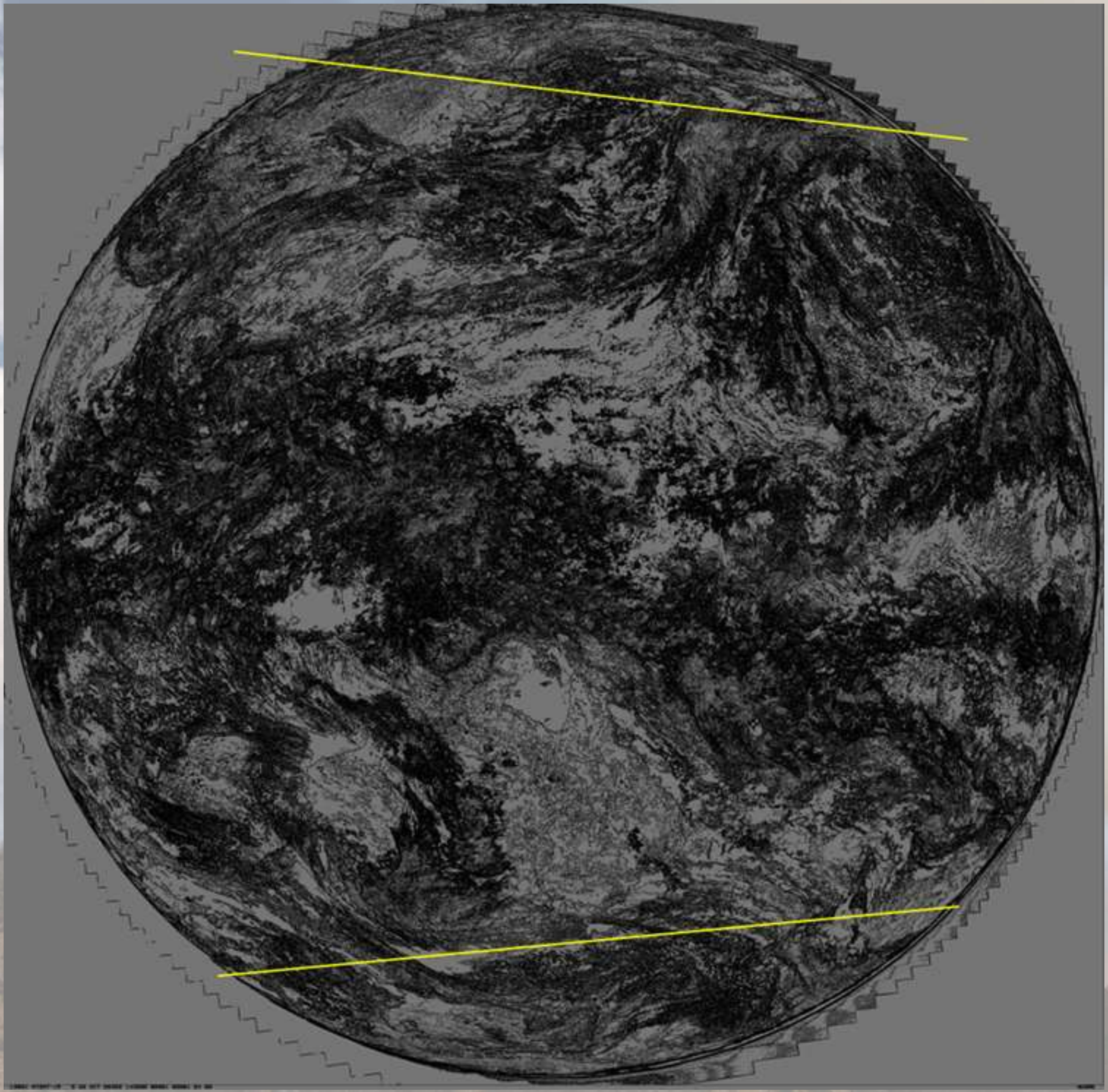
- Becoming more common
- Makes fire detection characterization more difficult – it averages the data in creative ways
- Taken to an extreme with MTSAT-1R, and we don't know what they do (see next slides)
- It isn't going away – ever. VIIRS uses it, GOES-R ABI will use it
- It's like applying another PSF to the image

MTSAT-1R 28 October 2008 14:30 UTC, 4 µm band



Remapping kernel is strong, causes “ringing” around fires (this is not a side-effect of powerpoint). This makes detection and characterization a lot harder.

MTSAT-1R 28 October 2008 14:30 UTC, 4 µm band

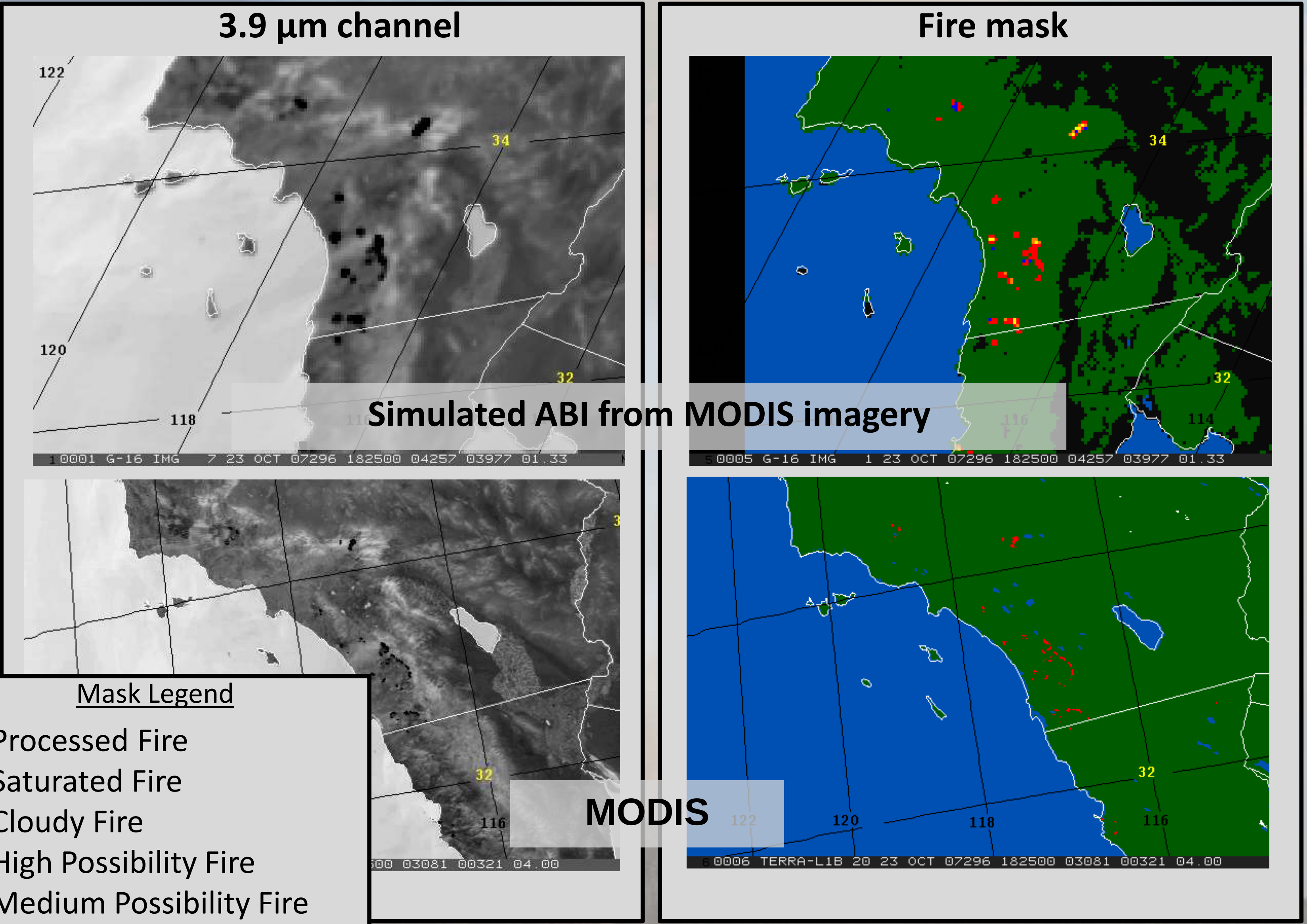


In the original and in this enhanced image the outlines of the scan swaths are visible. Note that they *CHANGE DIRECTION*, converging on a point to the right. This is a characteristic of all tri-axis stabilized geostationary satellites, however on GOES it is minimized. For MTSAT-1R, the solution is to remap the data to a fixed projection.

WFABBA and GOES-R

- GOES-R is the next generation GOES
- The Advanced Baseline Imager (ABI) provides 2 km resolution and a full disk image every 15 minutes, CONUS every 5
- The instrument’s specifications were designed with fires in mind, specifically for the “fire bands”
- Fire detection and characterization will be a “day 1” product
- Development has been underway since ~2004
- Development of proxy data has been a challenge

Proxy Data from MODIS



Simulated ABI from MODIS imagery

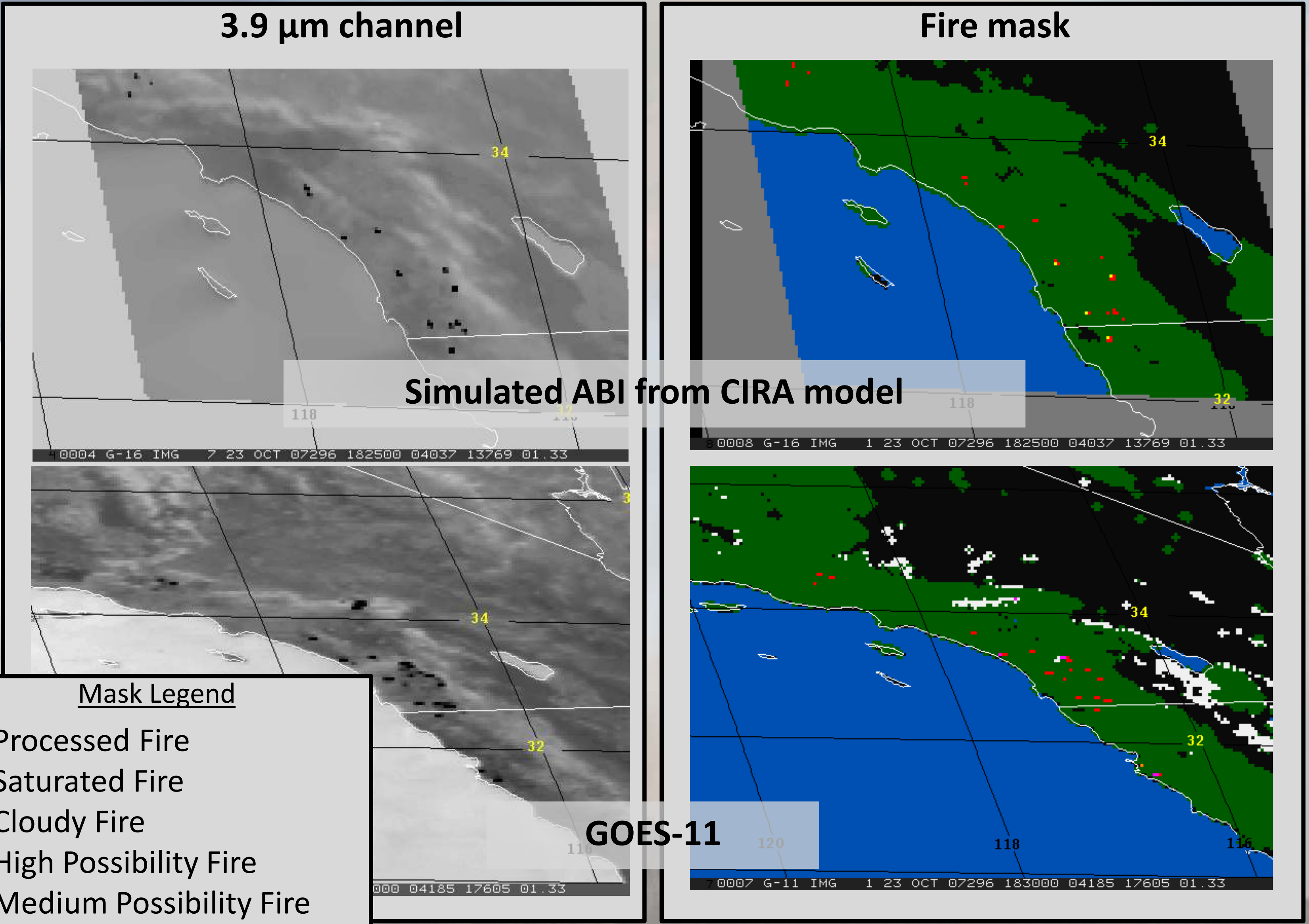
MODIS

Mask Legend

- 🟥 Processed Fire
- 🟨 Saturated Fire
- 🟪 Cloudy Fire
- 🟧 High Possibility Fire
- 🟦 Medium Possibility Fire
- ⬛ Biome Block-out Zone
- 🟩 Processed Region

2007 Oct. Southern California fire outbreak simulation

Proxy Data from a model



3.9 µm channel

Fire mask

Simulated ABI from CIRA model

GOES-11

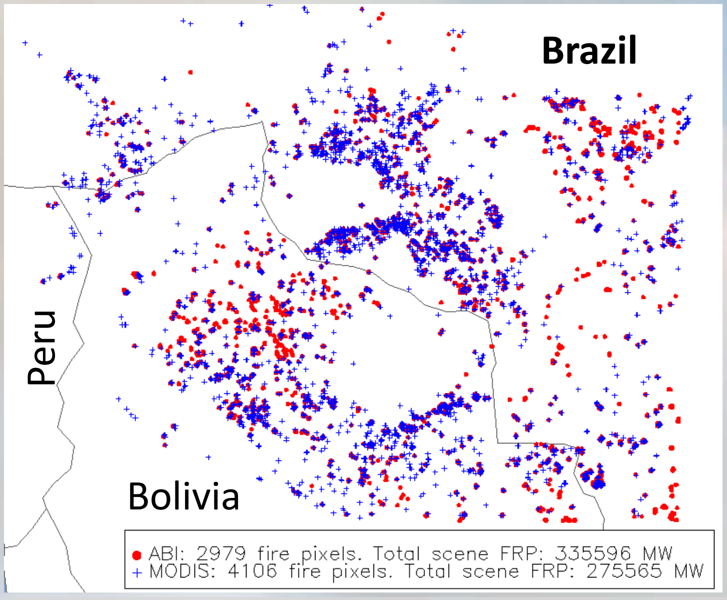
Mask Legend

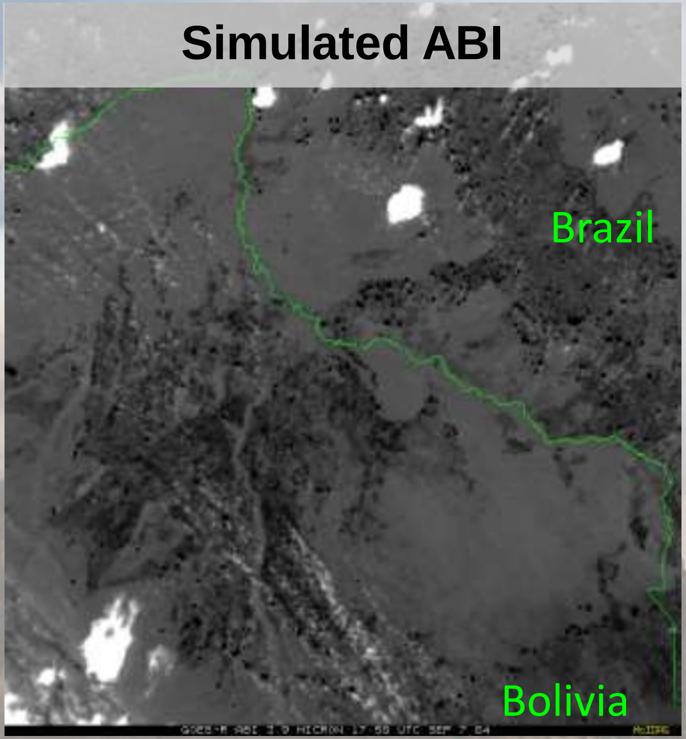
- 🟥 Processed Fire
- 🟨 Saturated Fire
- 🟪 Cloudy Fire
- 🟧 High Possibility Fire
- 🟦 Medium Possibility Fire
- ⬛ Biome Block-out Zone
- 🟩 Processed Region

2007 Oct. Southern California fire outbreak simulation

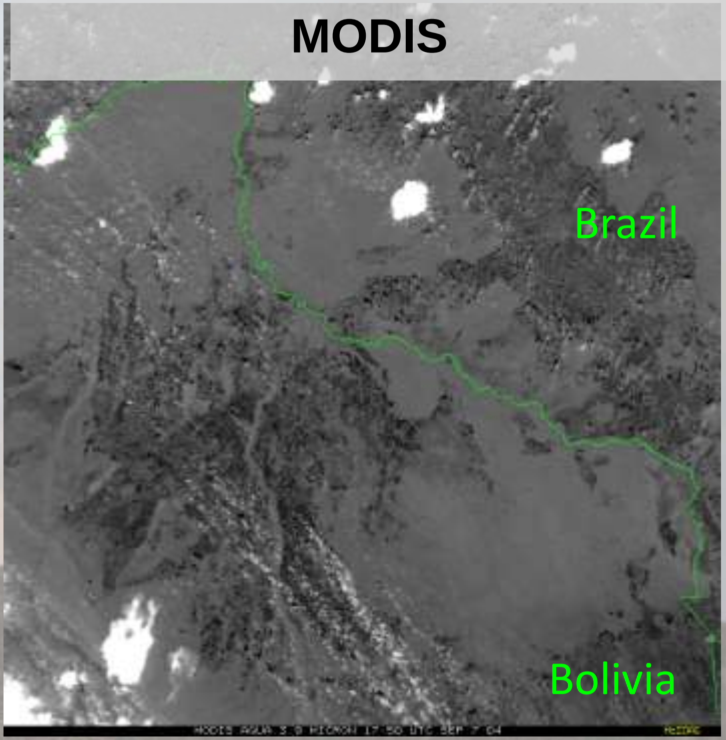
Proxy Data

The ABI from MODIS simulated data for 7 September 2004 involved a remapping using a simulated point spread function. To the right, MODIS fires are blue and ABI simulated fires are red. The differences are in part attributable to that remapping, but also to differences in how the algorithms determine fires.





Simulated ABI

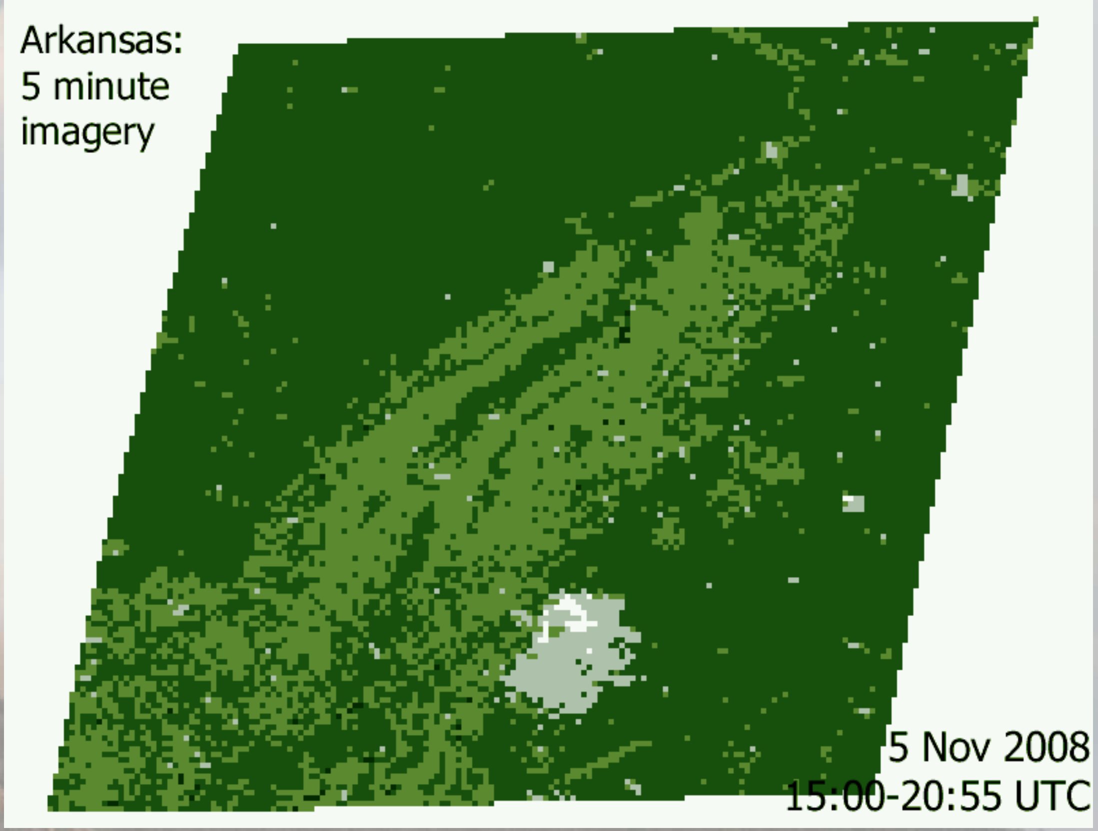


MODIS

ABI Proxy Examples

Example case:

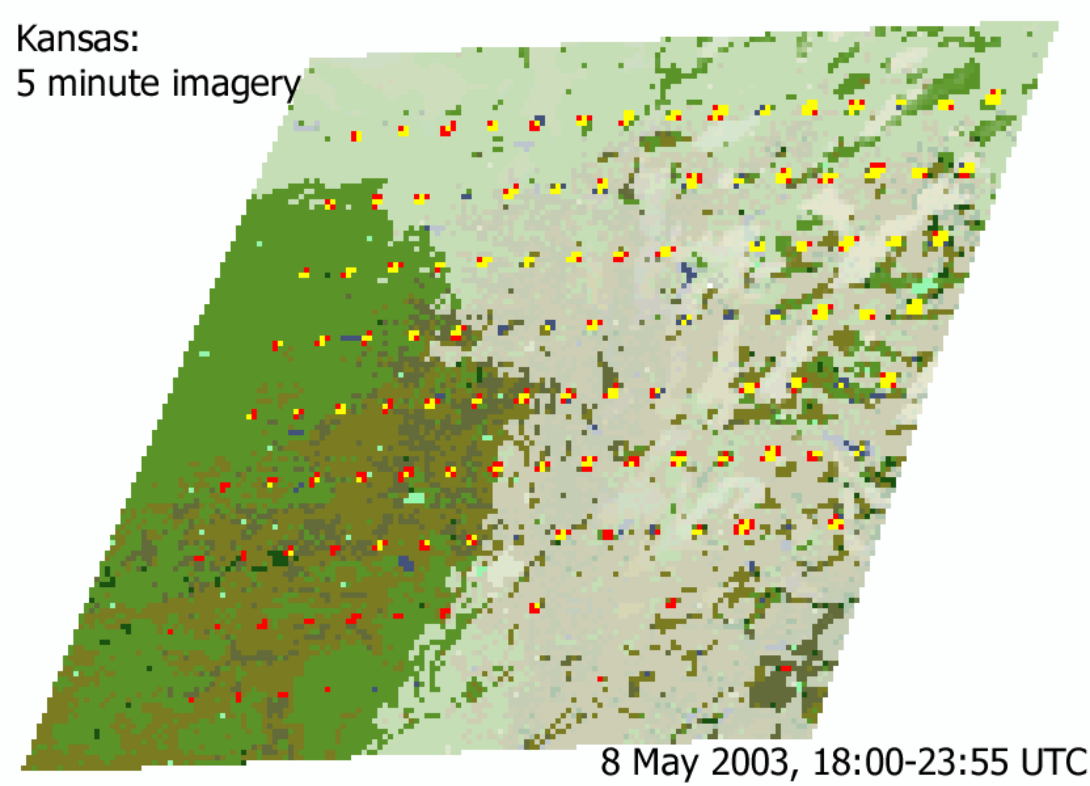
- Model-derived courtesy CIRA
- 5 minute, 2 km imagery
- Fires initialized from GOES-12 WFABBA fire product
- “Alphablended” imagery – ecosystem map used to represent surface, clouds appear in shades of white, fires are predominantly red (processed) in this case



ABI Proxy Examples

Example case:

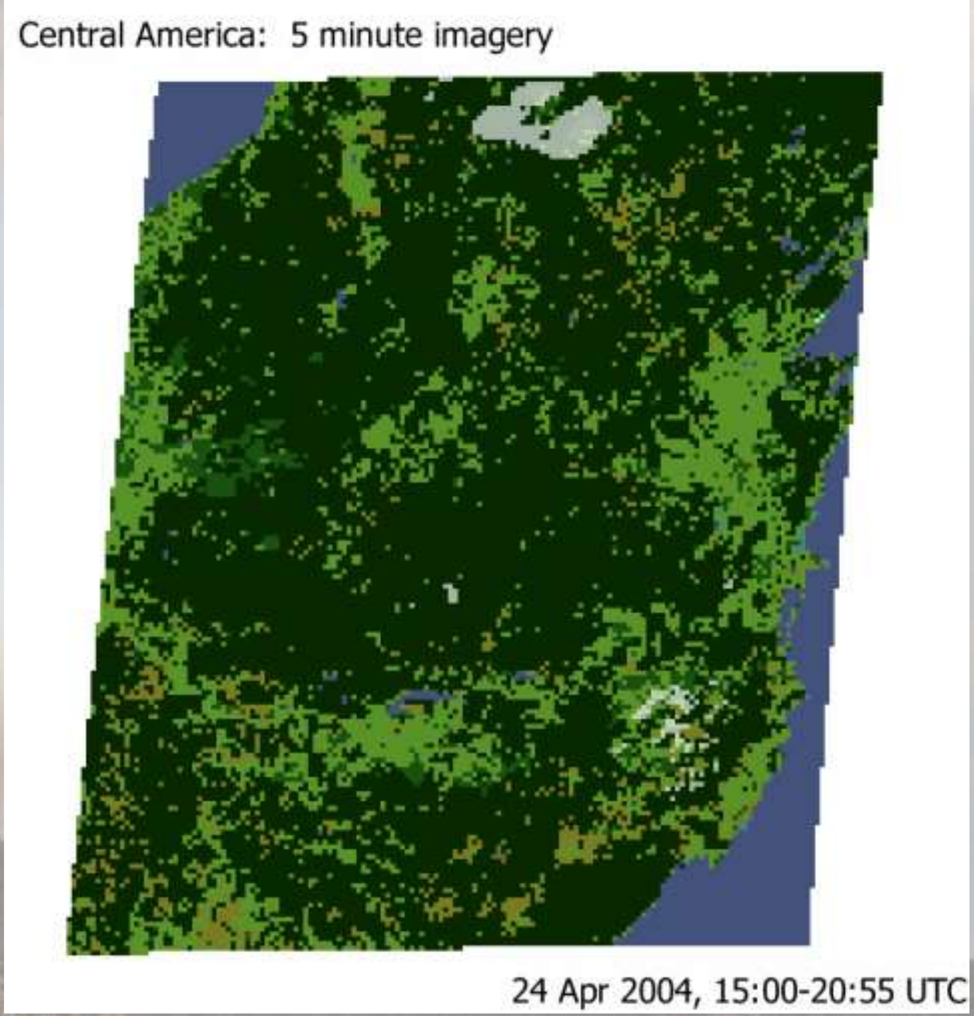
- Model-derived courtesy CIRA
- 5 minute, 2 km imagery
- Fires arranged in a grid: coolest & smallest in bottom left, hottest & largest in upper right
- Yellow fires are saturated pixels; in this case, unrealistically hot and large fires burn through cumulonimbus clouds; this has not been observed in the real world.



ABI Proxy Examples

Example case:

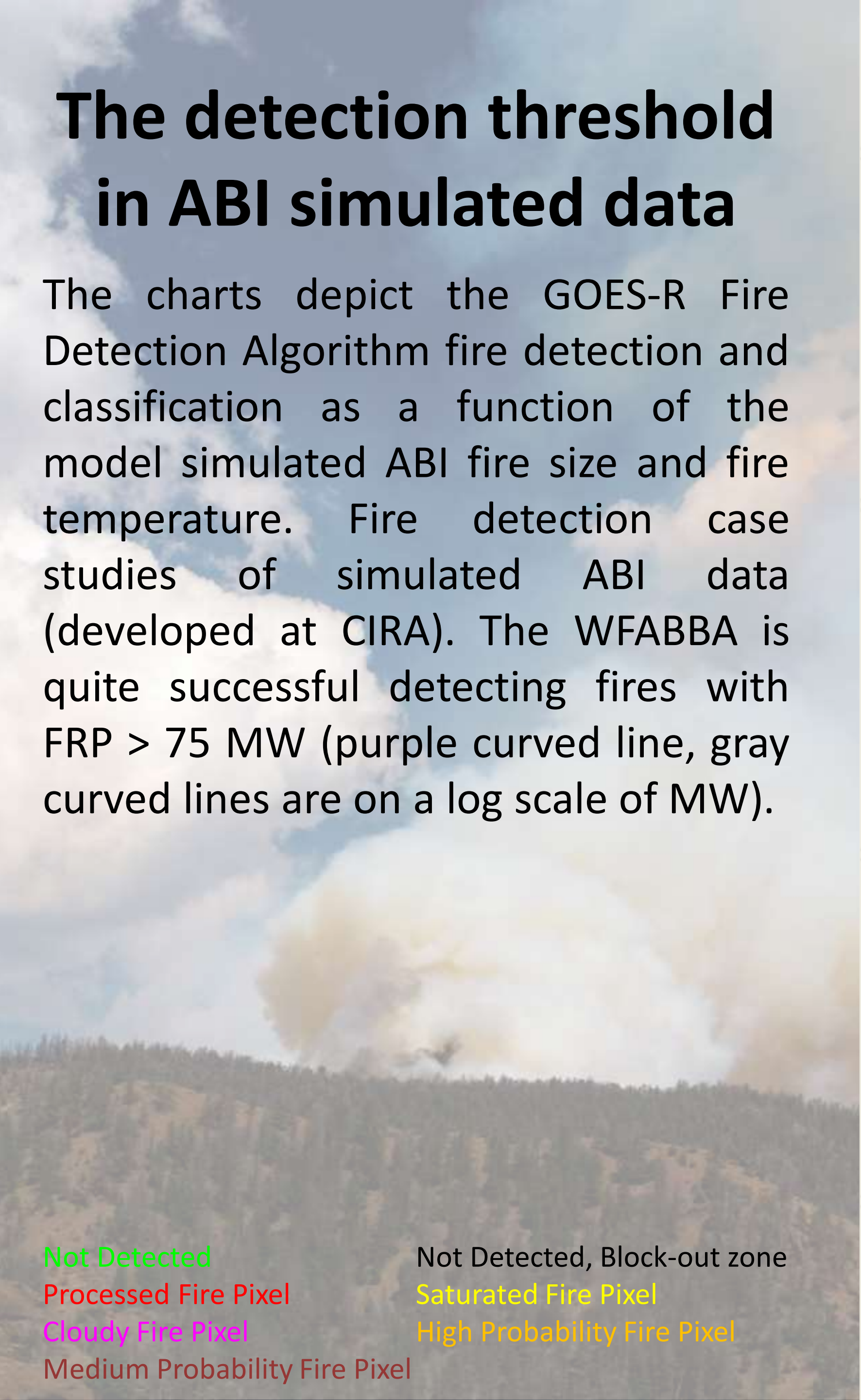
- Model-derived courtesy CIRA
- 5 minute, 2 km imagery
- Fires initialized from GOES-12 WFABBA fire product
- Fires are red (processed) and yellow (saturated)
- Gray region is the solar blockout zone, consisting of two regions of high solar reflection



Model data validation

CIRA Model Simulated Case Studies^								
	CIRA Truth			ABI WFABBA				
	Total # of fire clusters*	Total # of ABI fire pixels*	Total # of ABI fire pixels > FRP of 75 MW*	Total # of detected clusters	% Fire clusters detected*	Total # of fire pixels detected > FRP of 75 MW*	% Fire pixels detected > FRP of 75 MW*	% False postives (compared to model truth, will not be available for routine validation)
Kansas CFNOCLD	9720	63288	52234	9648	99.3%	47482	90.9%	<1%
Kansas VFNOCLD	5723	36919	26600	5695	99.5%	551	80.6%	<1%
Kansas CFCLD	9140	56553	46446	8768	95.9%	39380	84.8%	<1%
Cent. Amer. VFCLD	849	2859	1669	808	95.2%	1424	85.3%	<1%
Oct 23, 2007 California VFCLD	990	4710	2388	989	99.9%	2090	87.5%	<1%
Oct, 26 2007 California VFCLD	120	522	252	120	100%	211	83.7%	<1%

CFNOCLD	Constant Fire No Cloud	^ Limit to ~ 400K minimum fire temperature
VFNOCLD	Variable Fire No Cloud	
CFCLD	Constant Fire with Cloud	* In clear sky regions, eliminating block-out zones
VFCLD	Variable Fire with Cloud	

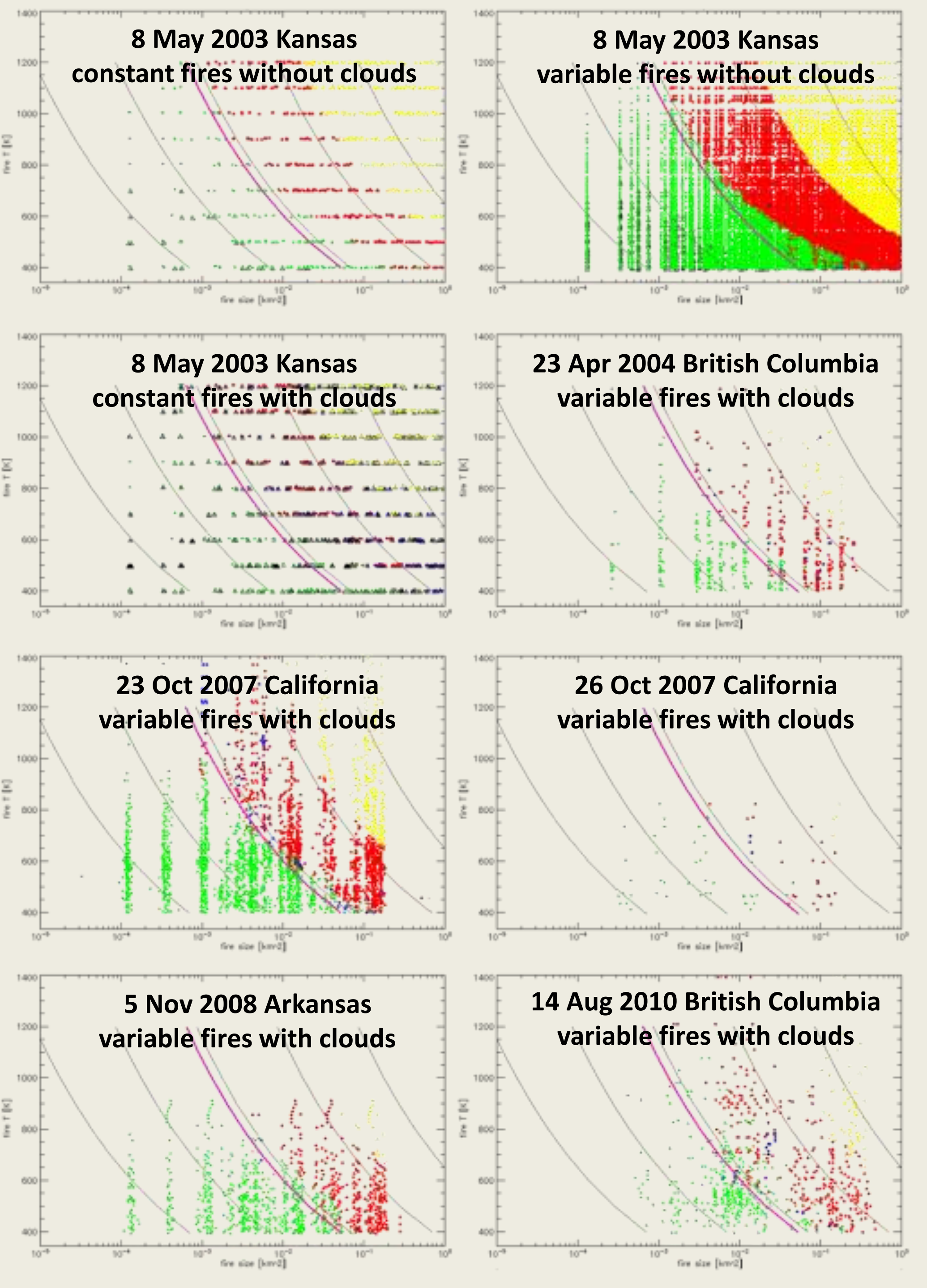


The detection threshold in ABI simulated data

The charts depict the GOES-R Fire Detection Algorithm fire detection and classification as a function of the model simulated ABI fire size and fire temperature. Fire detection case studies of simulated ABI data (developed at CIRA). The WFABBA is quite successful detecting fires with FRP > 75 MW (purple curved line, gray curved lines are on a log scale of MW).

Not Detected
Processed Fire Pixel
Cloudy Fire Pixel
Medium Probability Fire Pixel

Not Detected, Block-out zone
Saturated Fire Pixel
High Probability Fire Pixel



8 May 2003 Kansas
constant fires without clouds

8 May 2003 Kansas
variable fires without clouds

8 May 2003 Kansas
constant fires with clouds

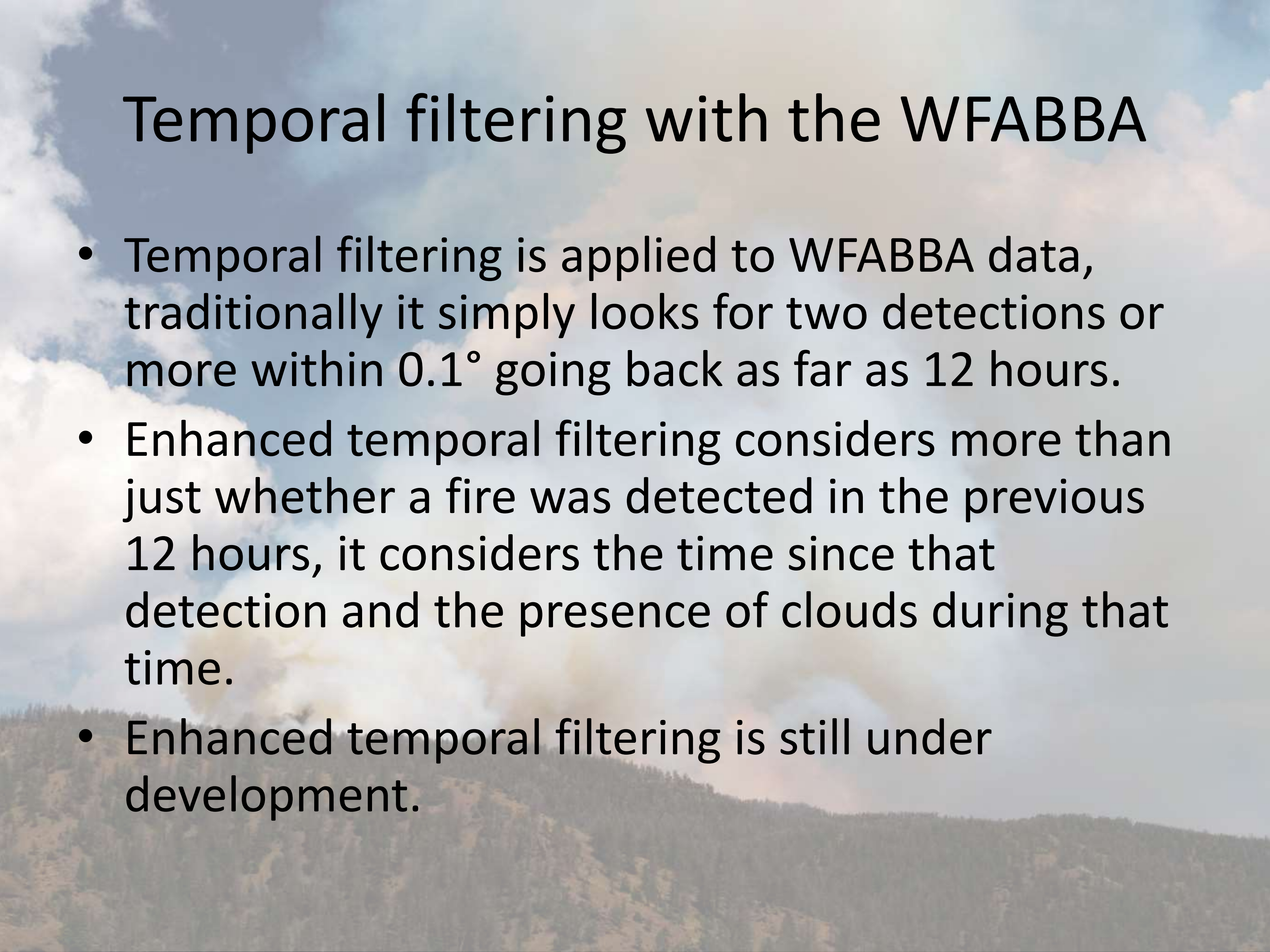
23 Apr 2004 British Columbia
variable fires with clouds

23 Oct 2007 California
variable fires with clouds

26 Oct 2007 California
variable fires with clouds

5 Nov 2008 Arkansas
variable fires with clouds

14 Aug 2010 British Columbia
variable fires with clouds



Temporal filtering with the WFABBA

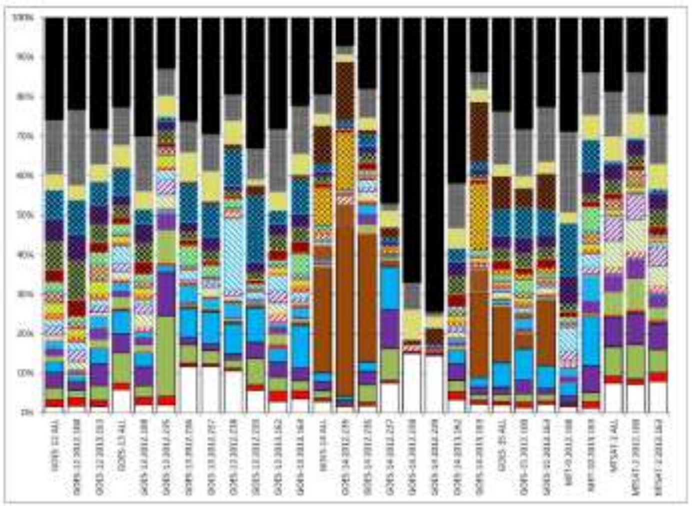
- Temporal filtering is applied to WFABBA data, traditionally it simply looks for two detections or more within 0.1° going back as far as 12 hours.
- Enhanced temporal filtering considers more than just whether a fire was detected in the previous 12 hours, it considers the time since that detection and the presence of clouds during that time.
- Enhanced temporal filtering is still under development.

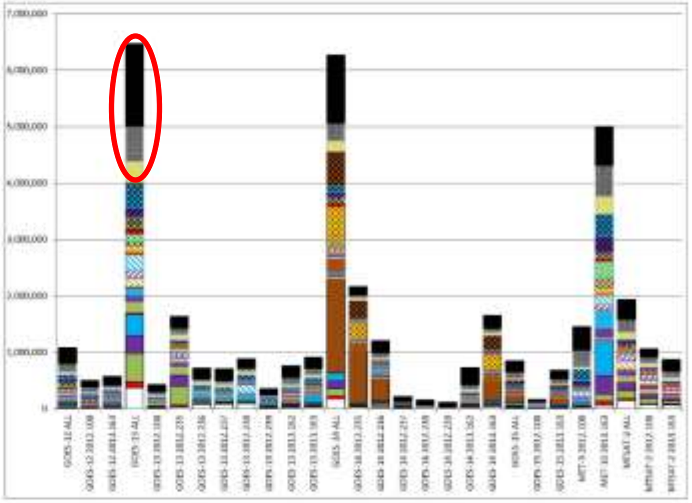
Temporal filtering with the WFABBA

The two plots at right (relative frequency on top, absolute counts below) are the 29 categories analyzed during development of the advanced temporal filtering. The red oval below highlights an example of the three categories (black, gray, light yellow) that were excluded by the original WFABBA temporal filter.

The dates chosen cover some “normal” dates while others cover RSO and SRSO operations for GOES satellites. Data from GOES-12/-13/-14/-15, Met-9, and MTSAT-2 were examined.

The next slide describes the categories in the plot.





Temporal filtering with the WFABBA

Detected fires that will not pass any temporal filtering:

- Black: Single detection fires. Most false alarms fall into this category.
- Gray: Fires detected just once that will eventually be seen for more than 3 hours. Similar to the black fires but much less likely to be false alarms.
- Light yellow: First detection of a series lasting less than 3 hours. Similar to the gray category.

Fires that can pass temporal filtering:

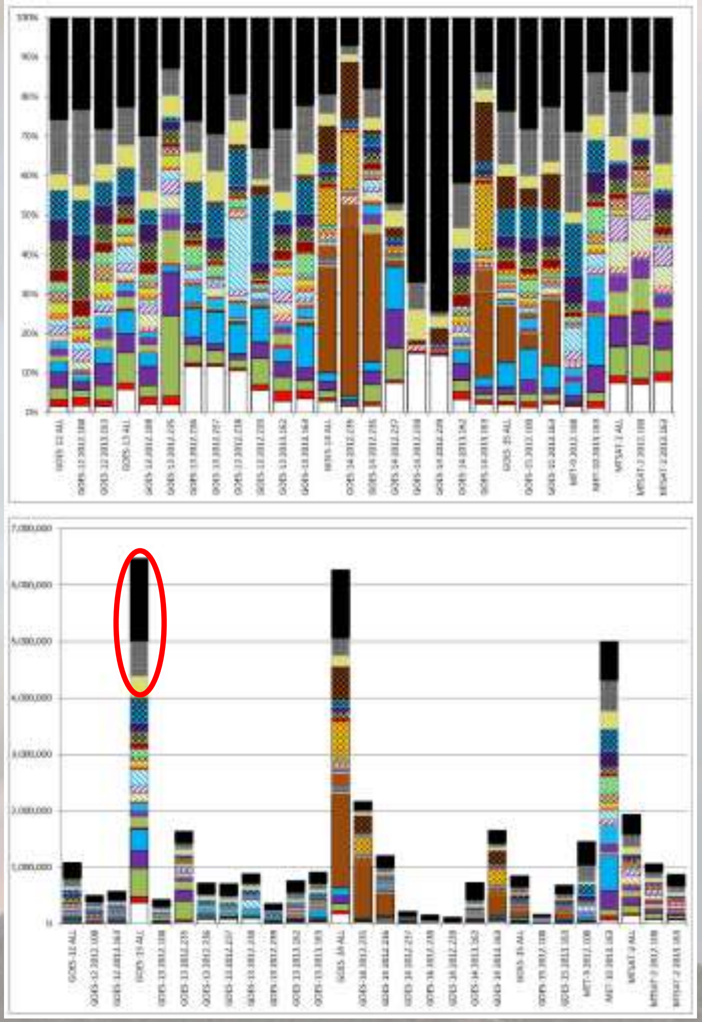
White: Fires with a match 3-12 hours in the past.

Other colors indicate fires lasting at least three hours:

- Brown: Closest match within 5 minutes
- Cyan: Closest match within 5-15 minutes
- Purple: Closest match within 15-30 minutes
- Green: Closest match within 30-60 minutes
- Red: Closest match within 60-180 minutes

The same colors with:

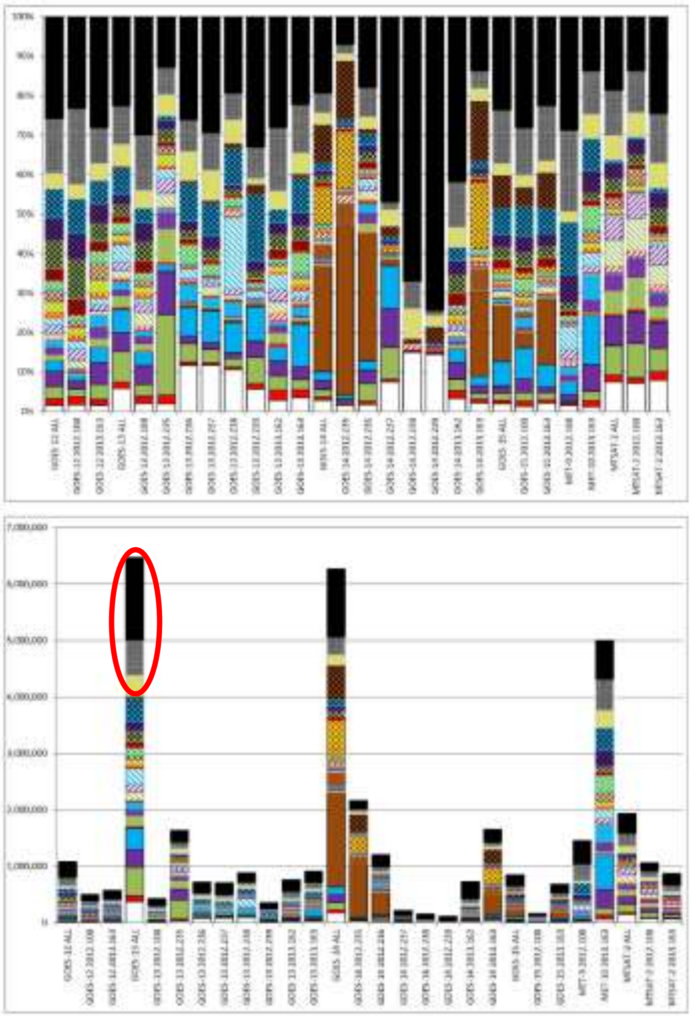
- White dots: The fire has not yet existed for more than 3 hours (but it will in the future) and at least half of the satellite scans met the “clear” criteria. To qualify as “clear” a scan had to have at least one pixel that could have been or was a detected fire in the 7x7 box centered on the pixel being examined.
- Yellow alternating squares: Similar to white dots but less than 50% of the satellite scans met the “clear” criteria.
- White diagonal bars: The fire has not nor will in the future span at least 3 hours and more than 50% of the boxes were clear.
- Black alternating squares: Similar to the white diagonals, except that less than 50% of the boxes met the “clear” criteria.



Temporal filtering with the WFABBA

The take-away:

The temporal filtering does need to be more robust for GOES-R (and current satellites as well). Short term false alarms are common for high temporal resolution data as most are caused by solar contamination, heating of the ground, and/or cloud edges, effects that can persist for 15 or so and thus appear to be persistent fires. Fires that have only been detected for a short time need to be flagged with lower confidence than fires that have been active longer to help the user distinguish between the two categories.

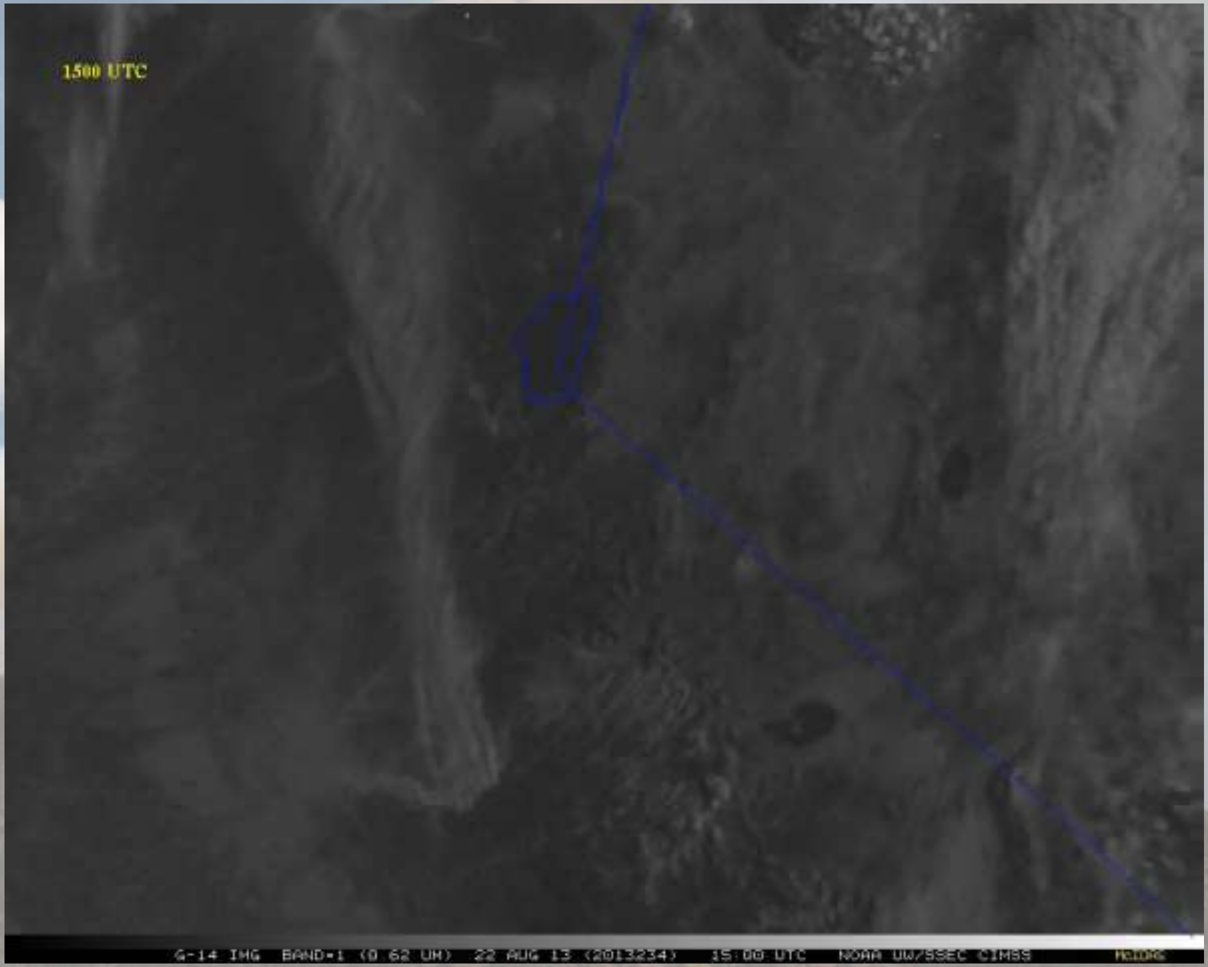


High Frequency GOES Data

- Operational GOES satellites may be run in Rapid Scan Operations(RSO), Super Rapid Scan Operations (SRSO), and Super Rapid Scan Operations for GOES-R (SRSOR)
- SRSOR is a special mode for simulating the GOES-R “mesoscale” coverage mode; data was taken every minute almost continuously
- It was employed with GOES-14, the Operational backup, in August 2013, during the Rim Fire

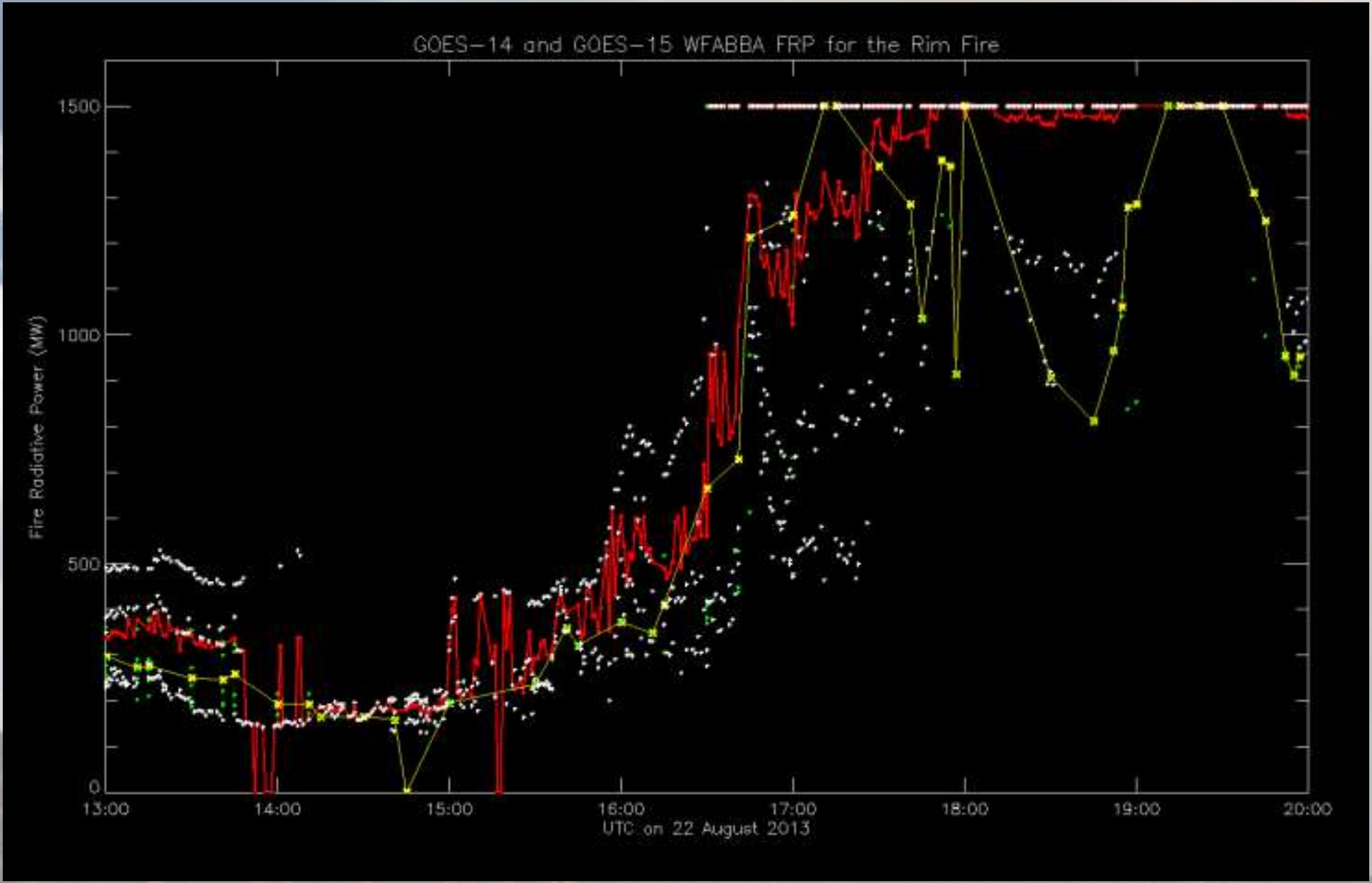
August 22 and 25, 2013

- Loop of GOES-14 visible SRSOR data
- http://cimss.ssec.wisc.edu/goes/srsor2013/800x1000_GOES_B1_RIM_FIRE_animated_2013234_150000_182_2013234_200000_182_X.mp4



Ex 1: GOES-14/-15 WFABBA FRP

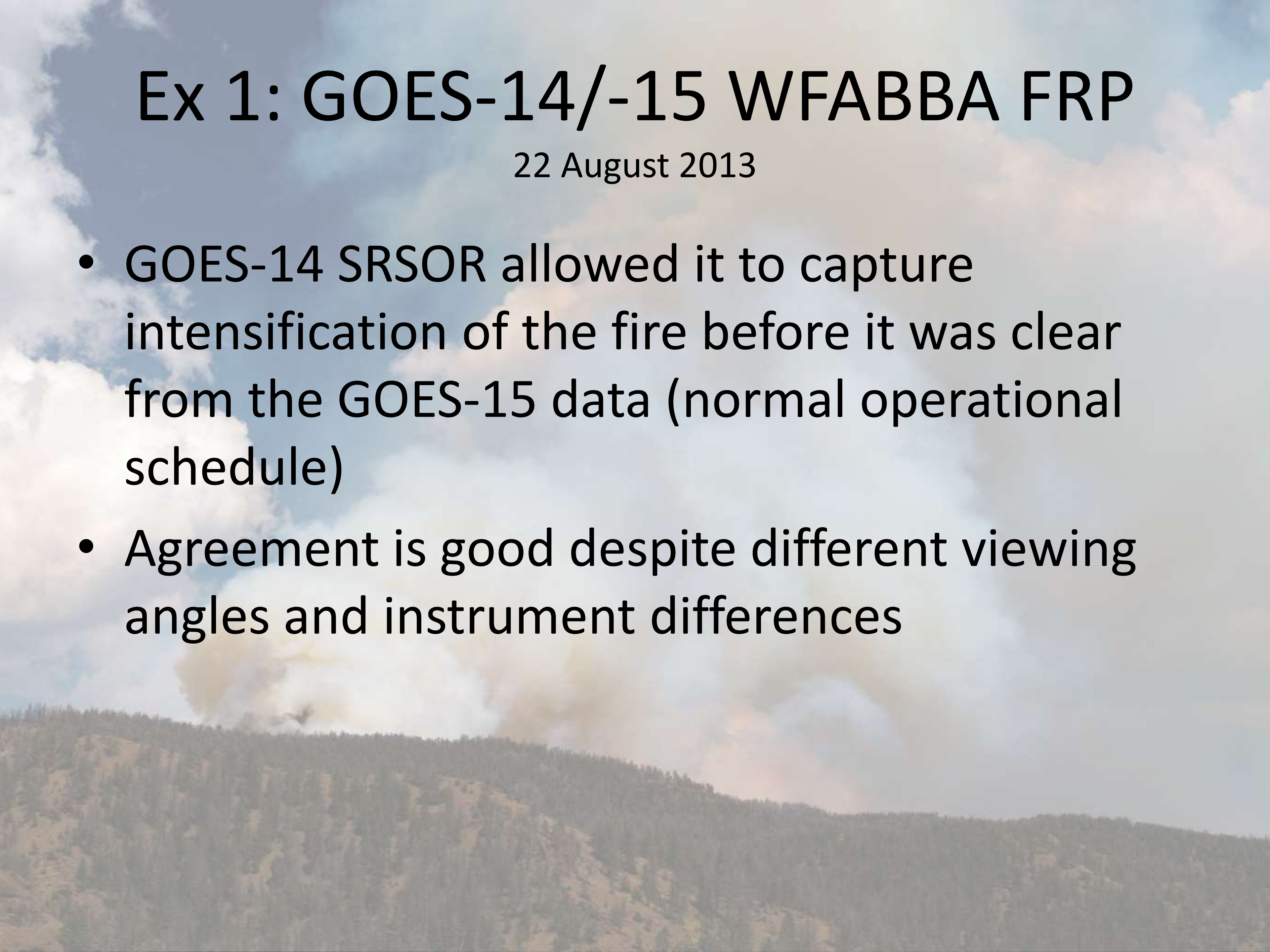
22 August 2013



White dots: GOES-14 per-pixel FRP; Red dots and trendline: GOES-14 FRP averaged over fire pixels, saturated pixels assigned 1500 MW
Green dots: GOES-15 per-pixel FRP; Yellow dots and trendline: GOES-15 FRP averaged over fire pixels, saturated pixels assigned 1500 MW

Ex 1: GOES-14/-15 WFABBA FRP

22 August 2013



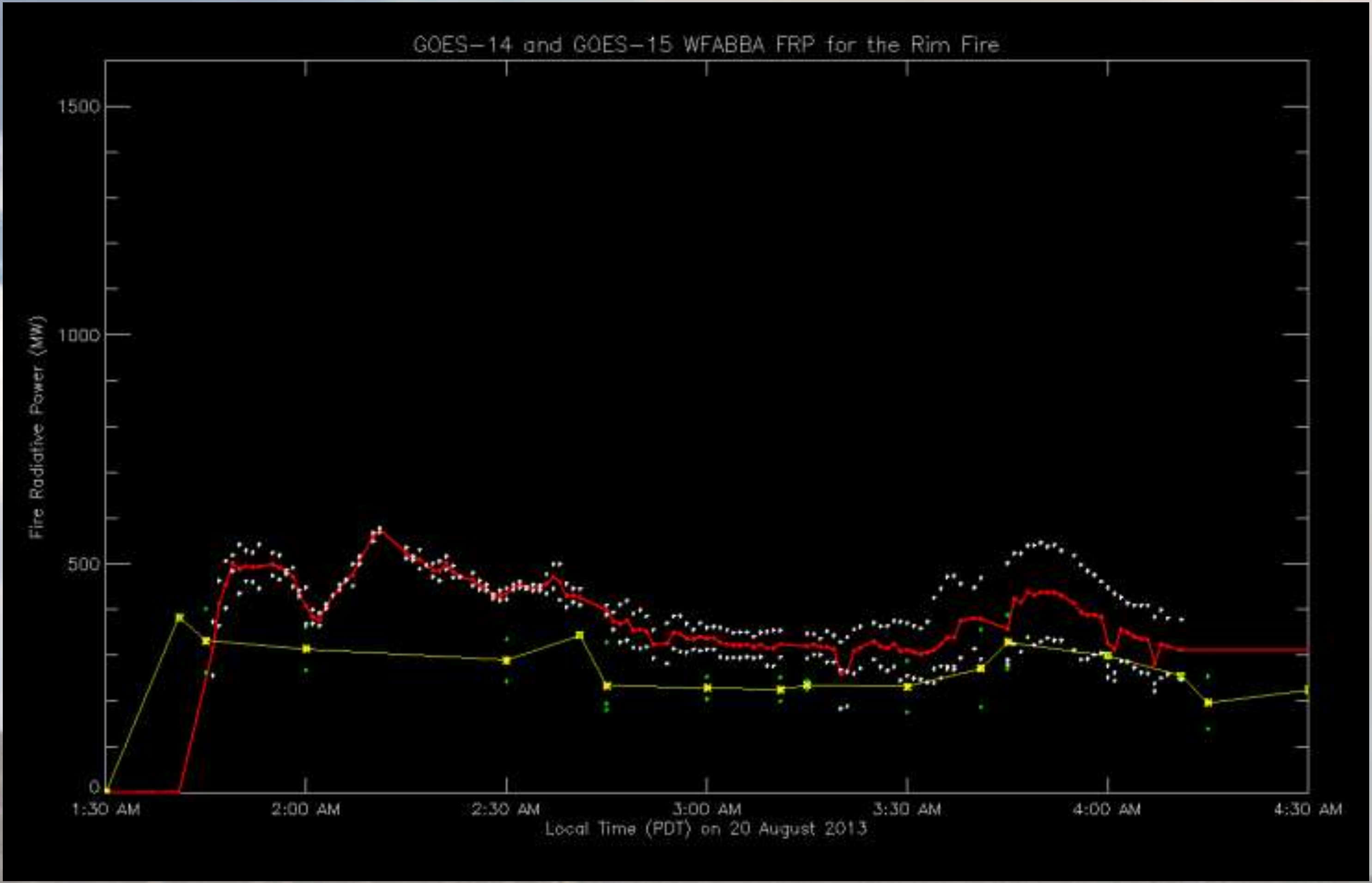
- GOES-14 SRSOR allowed it to capture intensification of the fire before it was clear from the GOES-15 data (normal operational schedule)
- Agreement is good despite different viewing angles and instrument differences

Rim Fire on 22 Aug 2013 at 17:01 PDT

Prototype of new “alphablended” imagery, combines Blue Marble Next Generation with GOES visible (and in next version, 11 µm infrared) band and WFABBA data. Yellow indicates saturated pixels (this is during the peak in Ex 1)

Ex 2: GOES-14/-15 WFABBA FRP

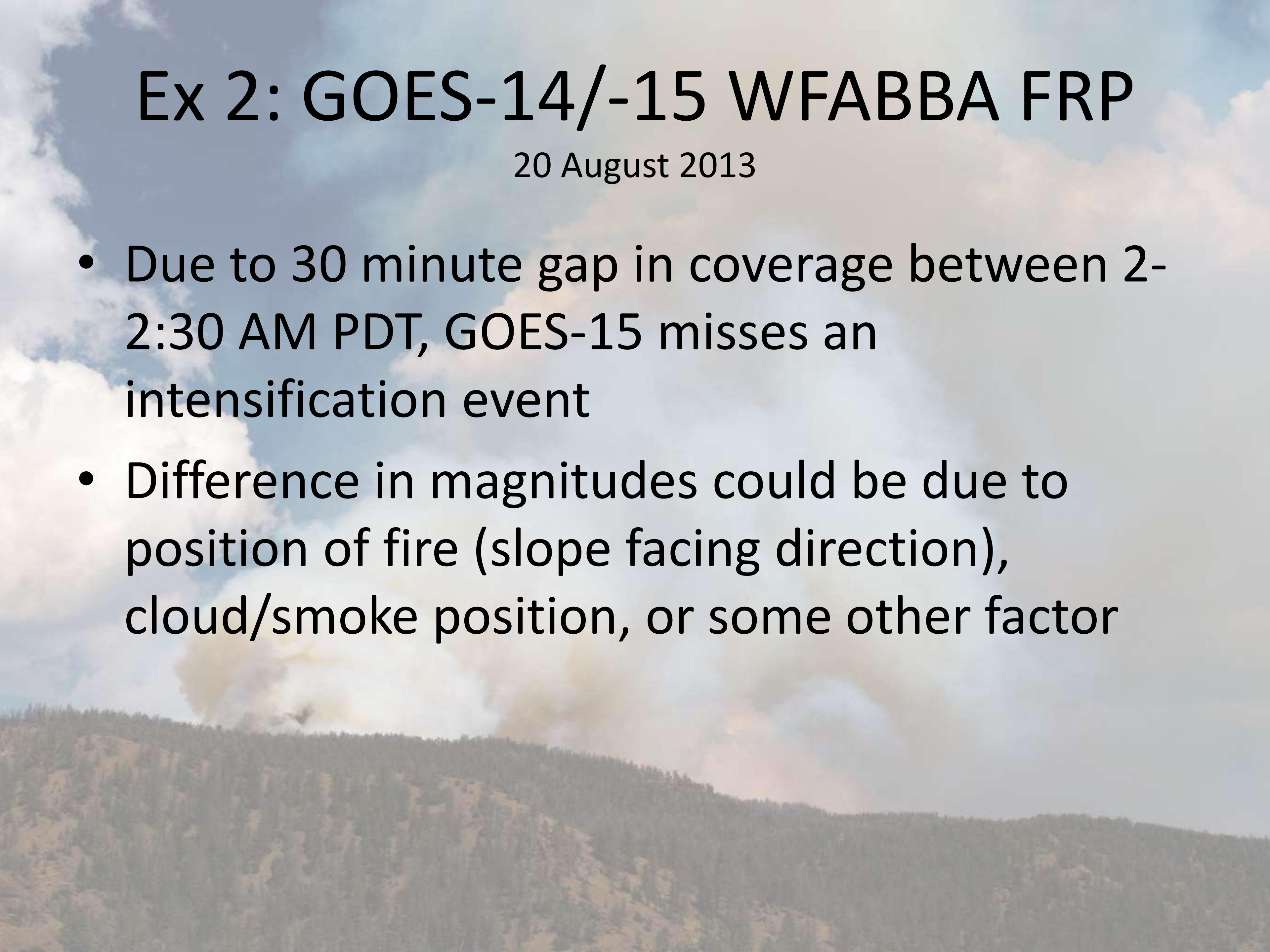
20 August 2013



White dots: GOES-14 per-pixel FRP; Red dots and trendline: GOES-14 FRP averaged over fire pixels, saturated pixels assigned 1500 MW
Green dots: GOES-15 per-pixel FRP; Yellow dots and trendline: GOES-15 FRP averaged over fire pixels, saturated pixels assigned 1500 MW

Ex 2: GOES-14/-15 WFABBA FRP

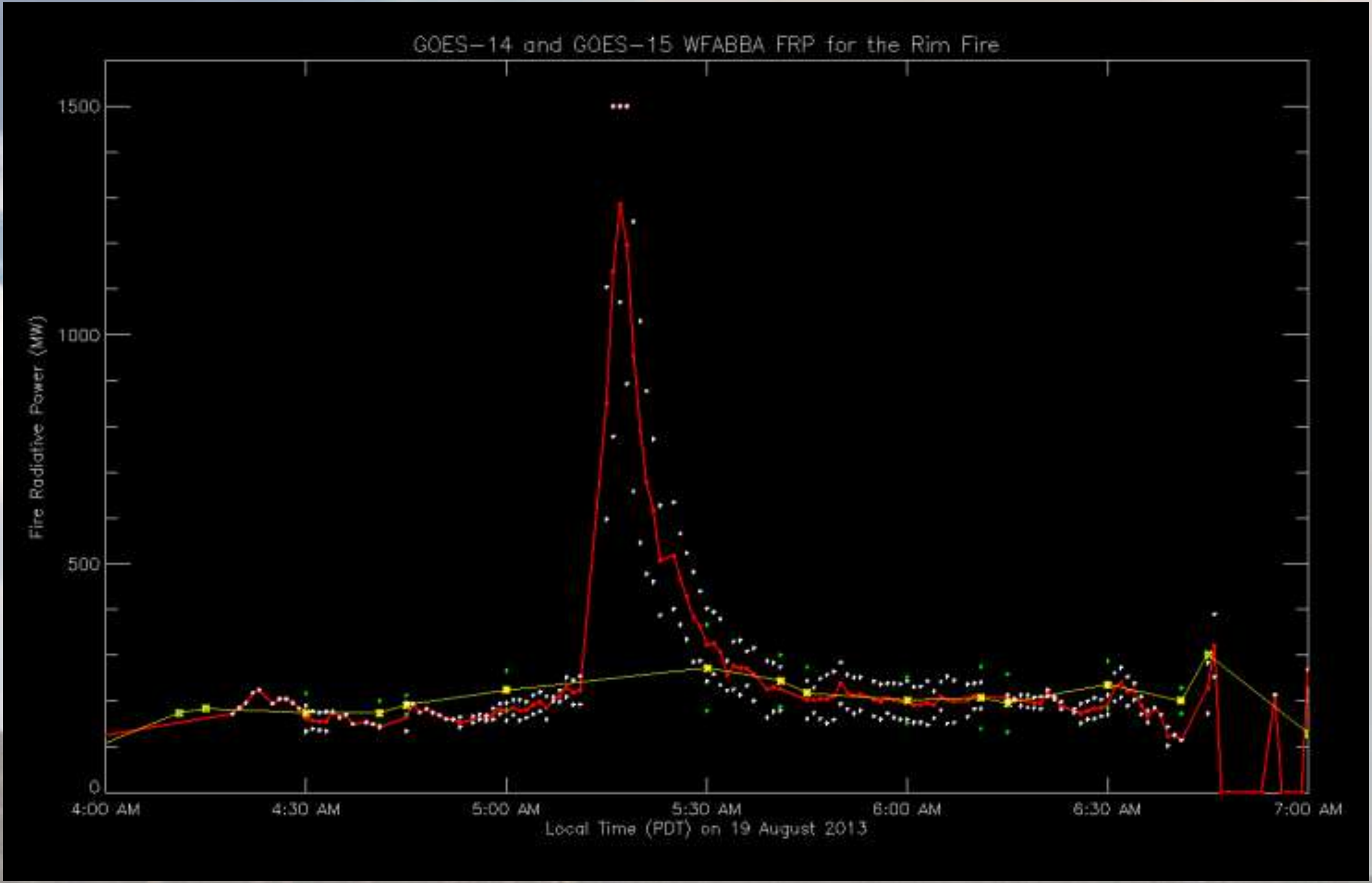
20 August 2013



- Due to 30 minute gap in coverage between 2-2:30 AM PDT, GOES-15 misses an intensification event
- Difference in magnitudes could be due to position of fire (slope facing direction), cloud/smoke position, or some other factor

Ex 3: GOES-14/-15 WFABBA FRP

19 August 2013



White dots: GOES-14 per-pixel FRP; Red dots and trendline: GOES-14 FRP averaged over fire pixels, saturated pixels assigned 1500 MW
Green dots: GOES-15 per-pixel FRP; Yellow dots and trendline: GOES-15 FRP averaged over fire pixels, saturated pixels assigned 1500 MW

Ex 3: GOES-14/-15 WFABBA FRP

19 August 2013

- What looks like an example of intensification captured by GOES-14 that GOES-15 missed is likely due to solar contamination either by light coming into the instrument or an offset in the calibration due to a contaminated space look
- Detection algorithms need to be aware of solar contamination – the WFABBA does account for it but apparently not sufficiently (this type of peaking has been rarely observed but due to its short duration is often missed)

Coverage correction: Why do we need it?

- Satellites scan at different rates over different areas on different schedules
- Current GOES covers the full disk once every three hours, Continental US (CONUS) every 15 minutes – how would you compare detection rates?

Typical GOES-East coverage frequency. GOES-8 28 August 1995 17:45 UTC image shaded by relative frequency of coverage.

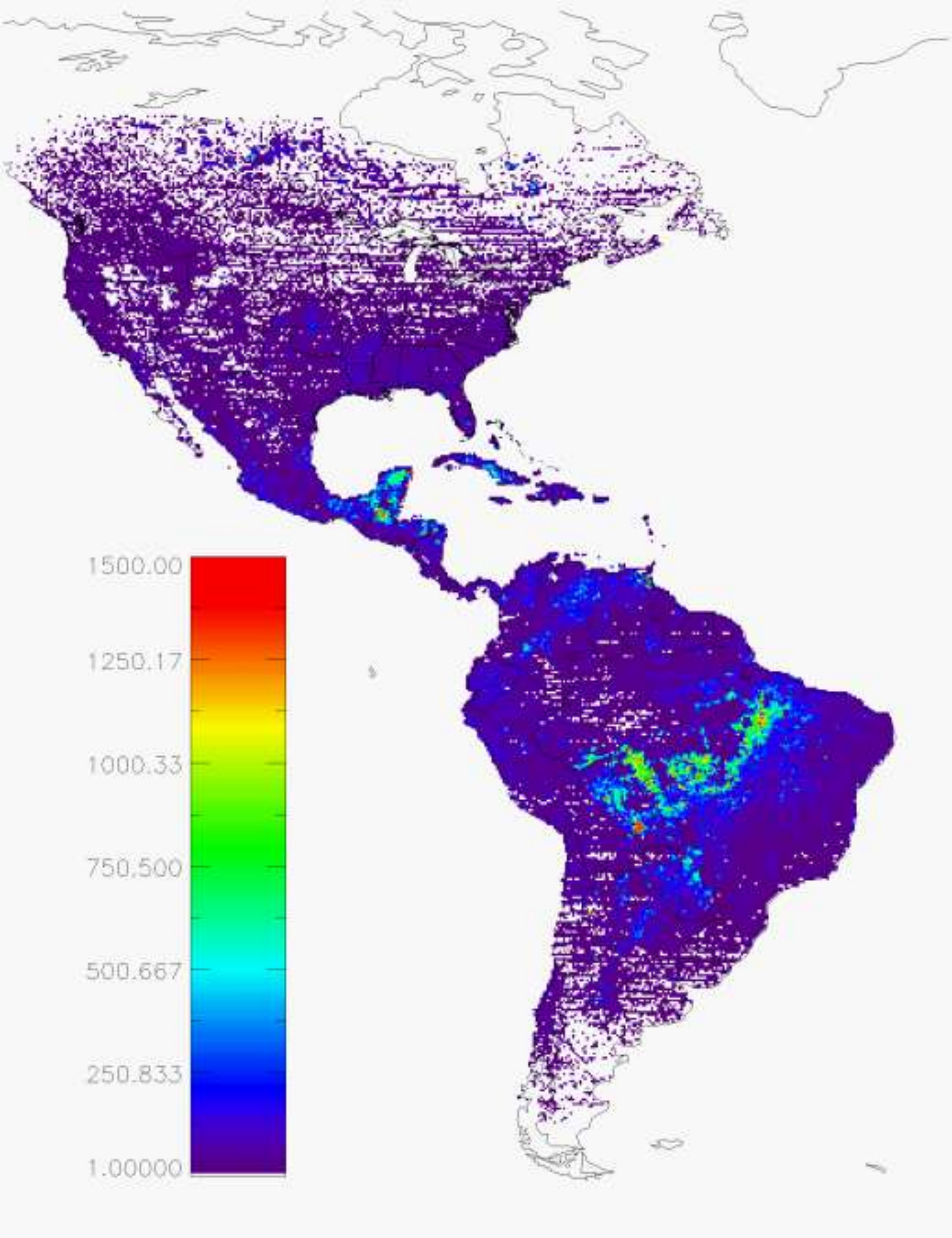
Coverage correction

- Step 1: Create 0.25 X 0.25 degrees latitude/longitude binned mask histogram files. The latitude range is 60 degrees South to 70 degrees North while the longitude range is 30 to 130 degrees West. For each image time the satellite pixels are binned to 0.25 X 0.25 degrees and counts for each mask value code are kept track of in each bin.
- Step 2: Create 0.25 X 0.25 degrees latitude/longitude binned satellite coverage corrected fire files for each image time from the binned mask histogram files. Certain mask code values are grouped together to calculate totals for each category (listed below) for each bin---MV stands for Mask Value
- ***ClearFieldOfView(FOV)Pixels=MV10+MV11+MV12+MV13+MV14+MV15+MV20+MV21+MV22+MV23+MV24+MV25+MV100
- ***CloudyFOVPixels=MV200+MV205+MV210+MV215+MV220+MV225+MV230+MV240+MV245
- ***BlockOutZonePixels=MV50+MV60
- ***ErrantPixels=MV0+MV120+MV125+MV160+MV170+MV180+MV182+MV185+MV186+MV187+MV188
- ***WaterPixels=MV150+MV151+MV152+MV153
- ***SpacePixels=MV40
- ***TotalPixels=SUM OF ABOVE 6 TOTALS OF PIXELS
- ***Number of Non-Coverage Corrected Fire Pixels for each Fire Category = MV10 for processed fires, MV11 for saturated fires, MV12 for cloudy fires, MV13 for high possibility fires, MV14 for medium possibility fires, and MV15 for low possibility fires
- The Total Number of Satellite Coverage Corrected Fire Pixels for each Fire Category (fire category ranges from 0 to 5; 0 is processed fire, 1 is saturated fire, 2 is cloudy fire, 3 is high possibility fire, 4 is medium possibility fire and 5 is low possibility fire) is calculated as follows for each bin:
- Number of Satellite Coverage Corrected Fire Pixels[fire category] = Number of Total Pixels * (Number of Non-Corrected Fire Pixels[fire category] / Number of Clear FOV Pixels)
- The Total Number of Cloud Coverage Corrected Fire Pixels for each Fire Category is calculated as follows for each bin:
- Number of Cloud Coverage Corrected Fire Pixels[fire category] = (Number of Clear FOV Pixels + Number of Cloudy FOV Pixels) * (Number of Non-Corrected Fire Pixels[fire category] / Number of Clear FOV Pixels)

Coverage Corrected WFABBA Fire Counts: 1995

Instrument noise was a problem in the first three years of GOES-8.

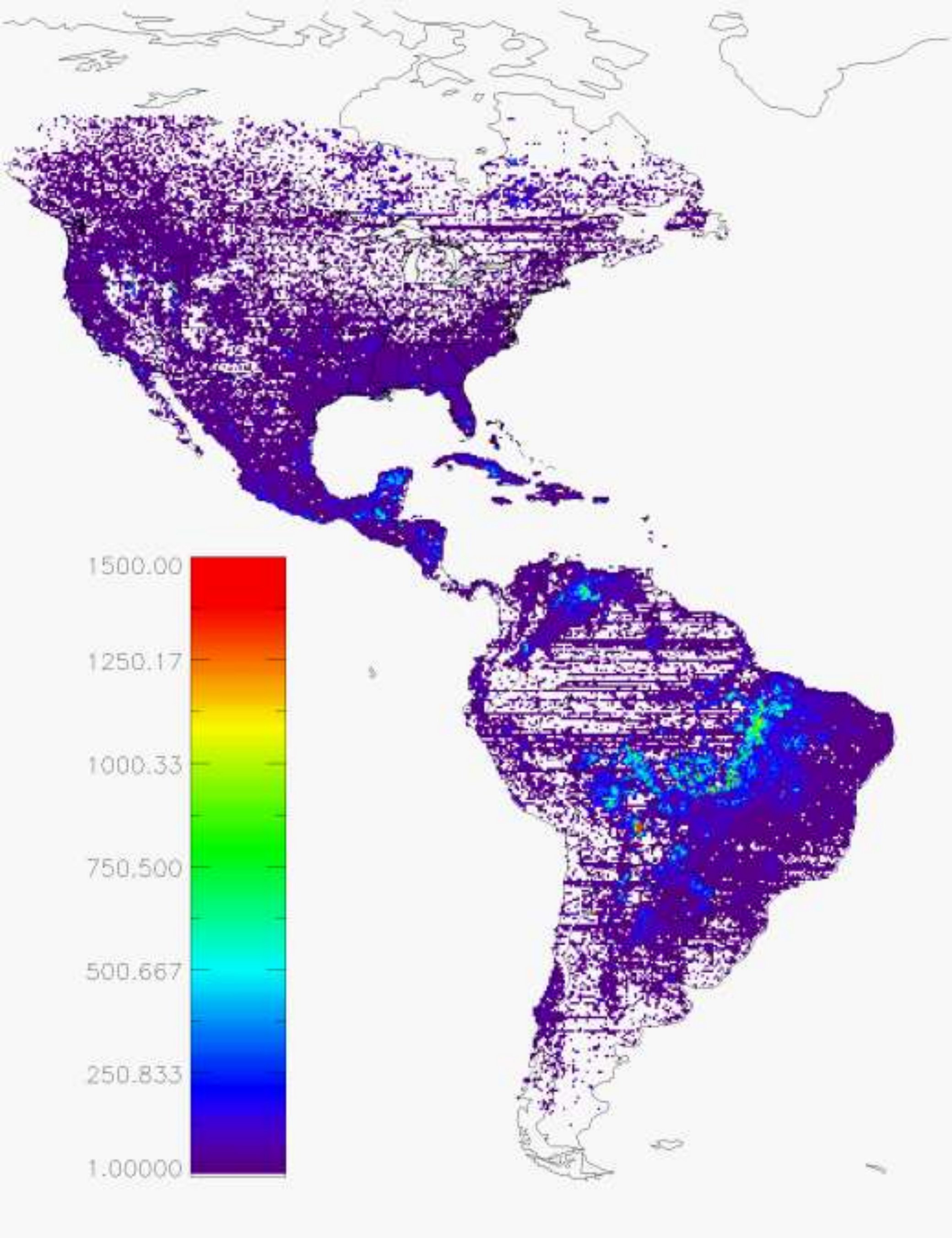
The arc of deforestation shows up clearly.



Coverage Corrected WFABBA Fire Counts: 1996

Instrument noise was a problem in the first three years of GOES-8.

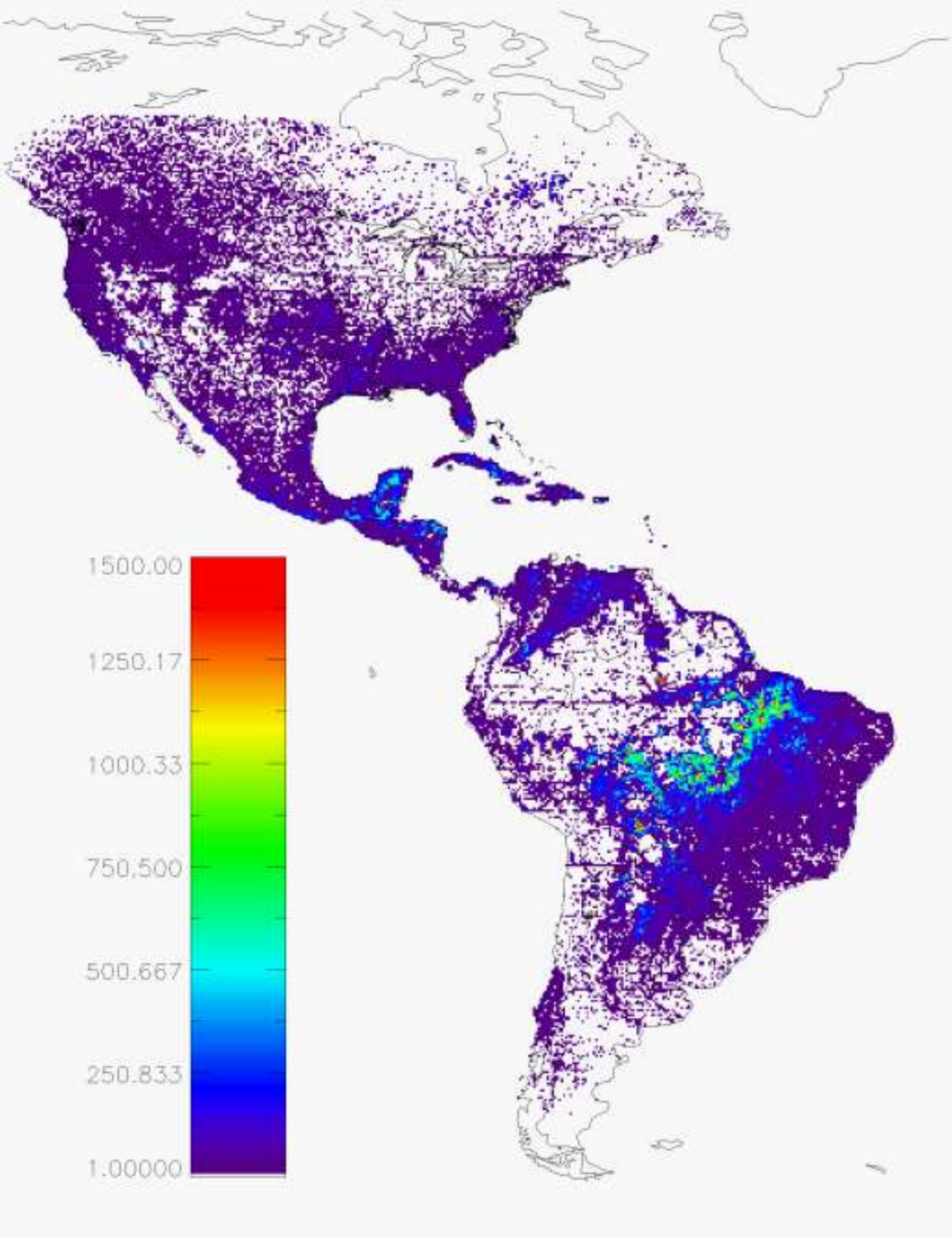
The arc of deforestation shows up clearly.



Coverage Corrected WFABBA Fire Counts: 1997

Instrument noise was a problem in the first three years of GOES-8.

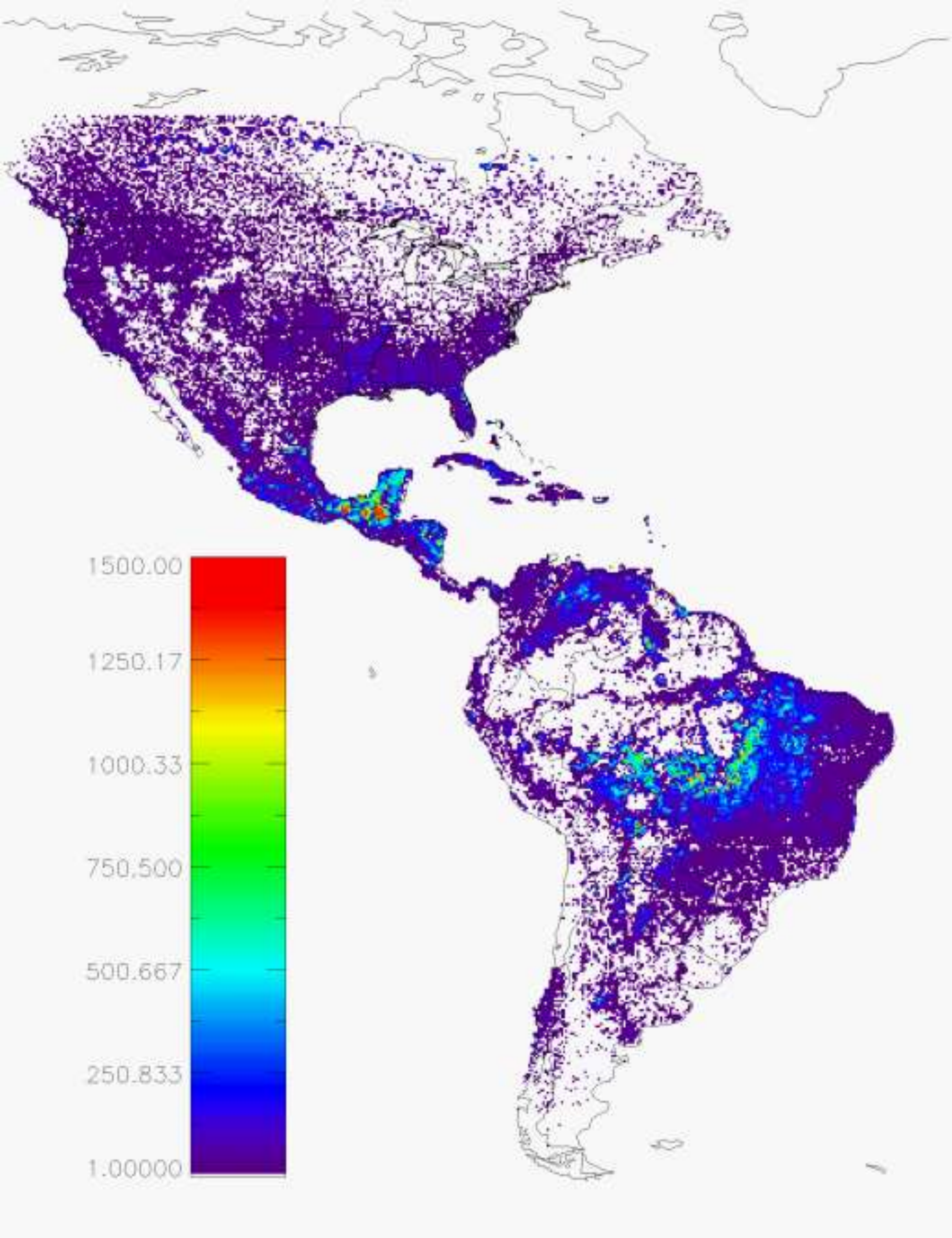
The arc of deforestation shows up clearly.



Coverage Corrected WFABBA Fire Counts: 1998

GOES-8 data.

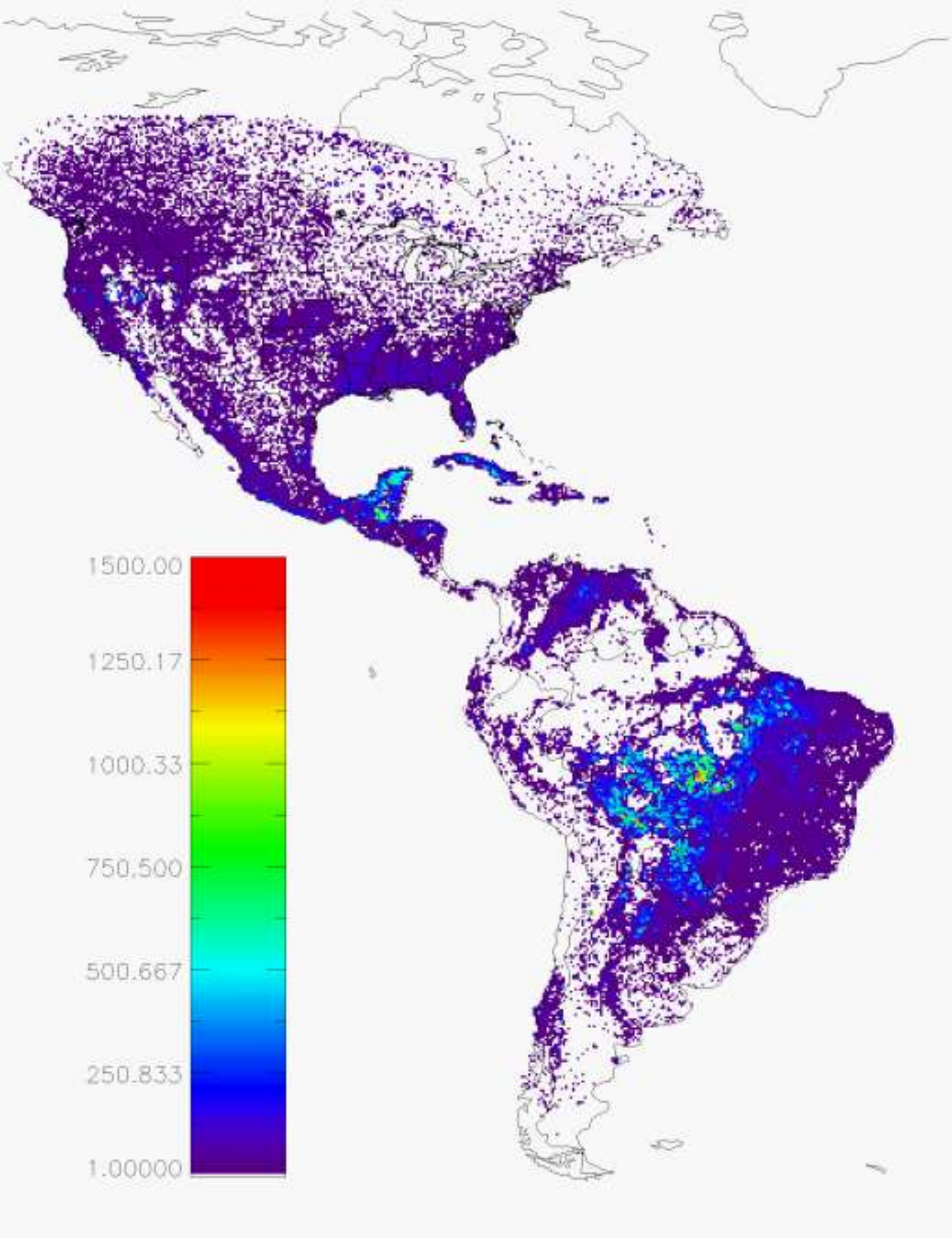
Central America had a busy year, as did Canada.



Coverage Corrected WFABBA Fire Counts: 1999

GOES-8 data.

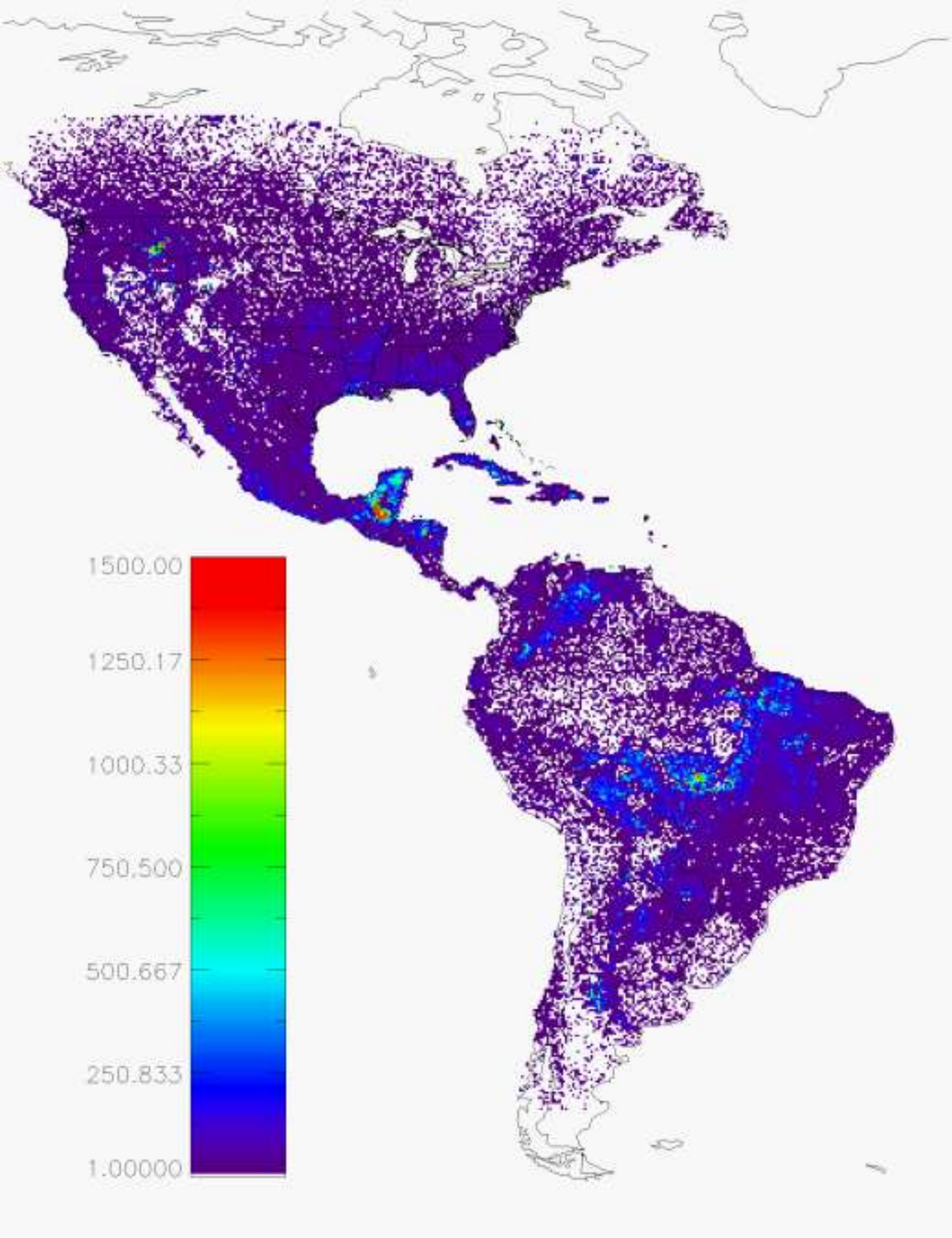
Brazil had a busy year.



Coverage Corrected WFABBA Fire Counts: 2000

GOES-8 data.

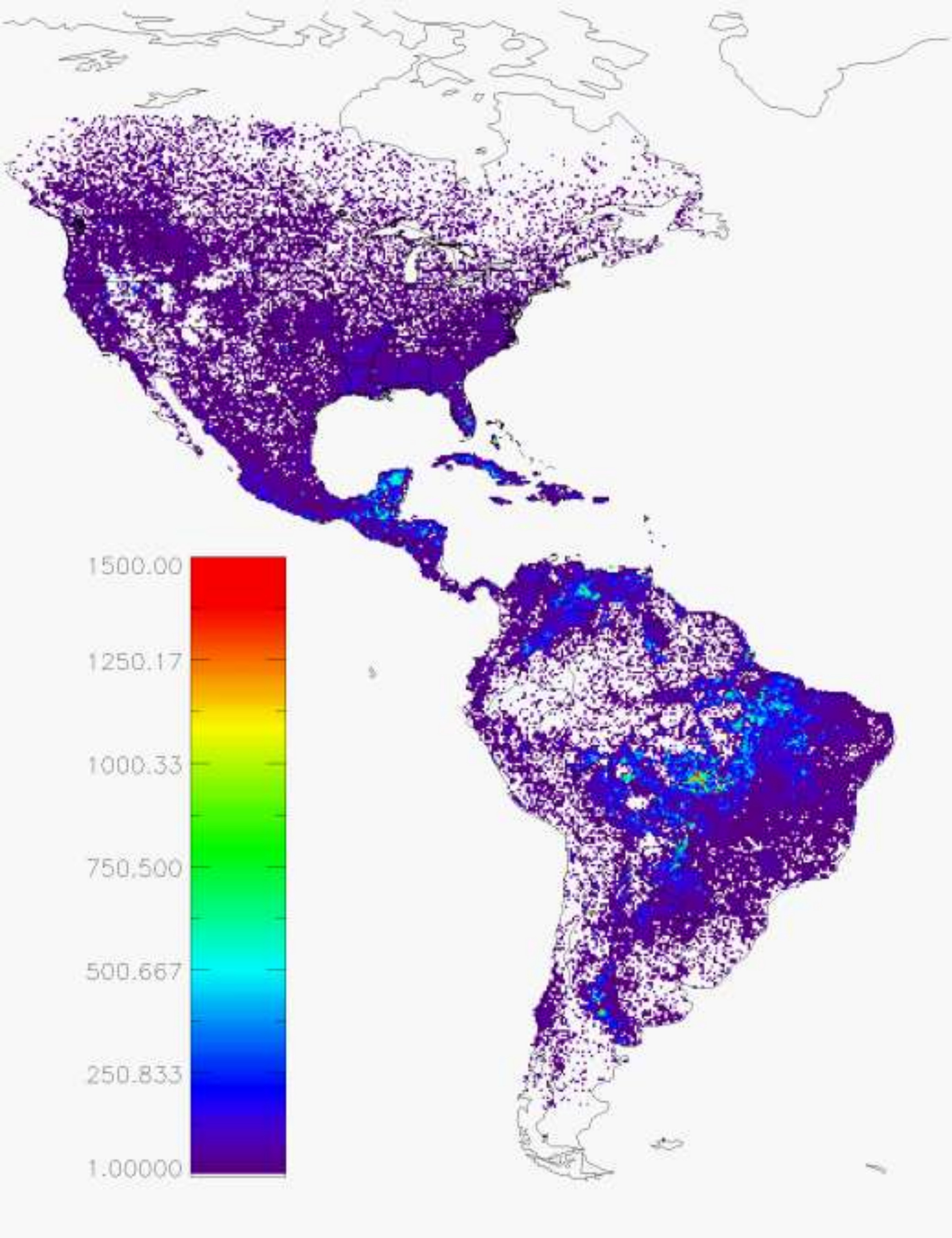
Central America heats up again.



Coverage Corrected WFABBA Fire Counts: 2001

GOES-8 data.

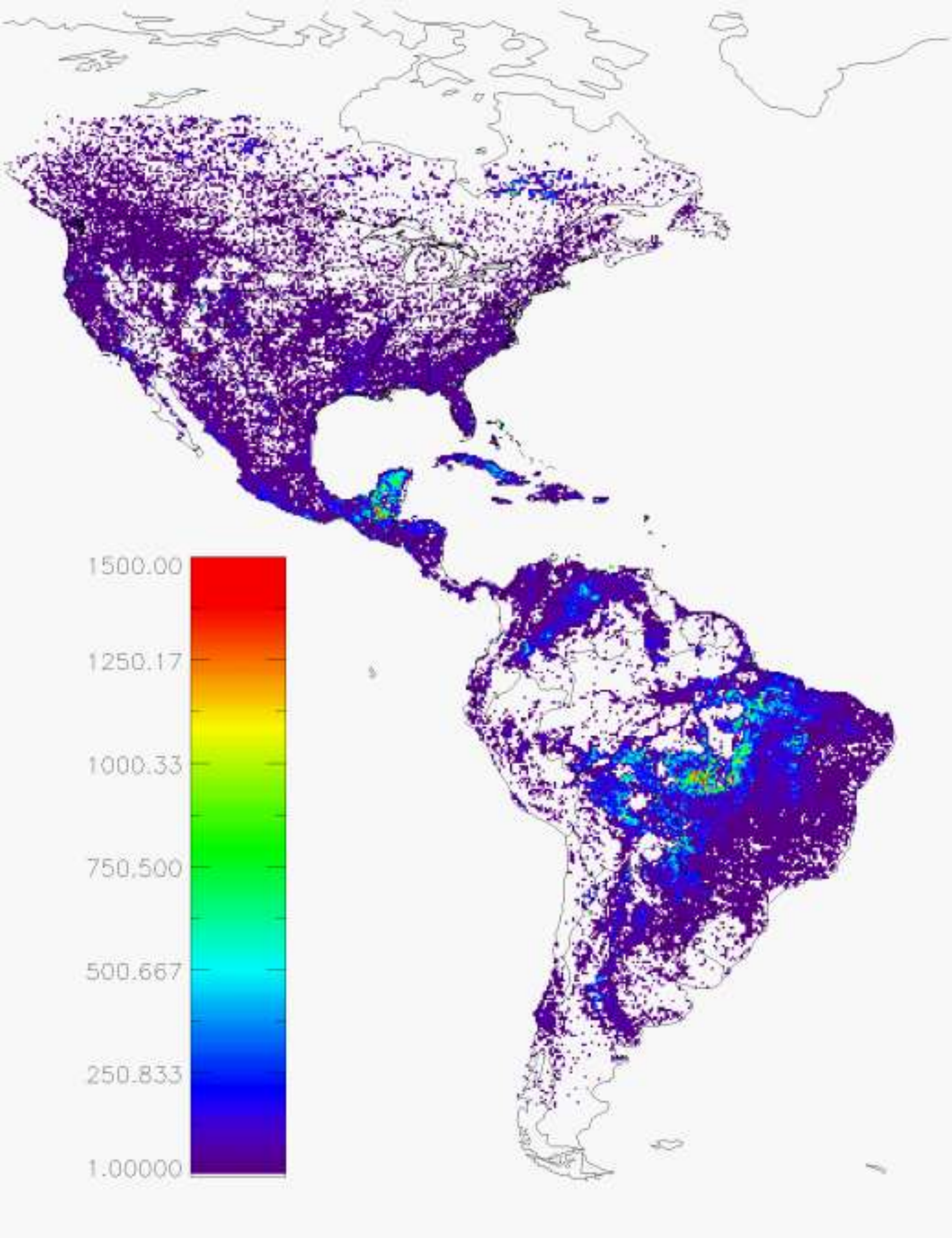
Large fires in the Pampas of Argentina in 2001.



Coverage Corrected WFABBA Fire Counts: 2002

GOES-8 and GOES-12 data.

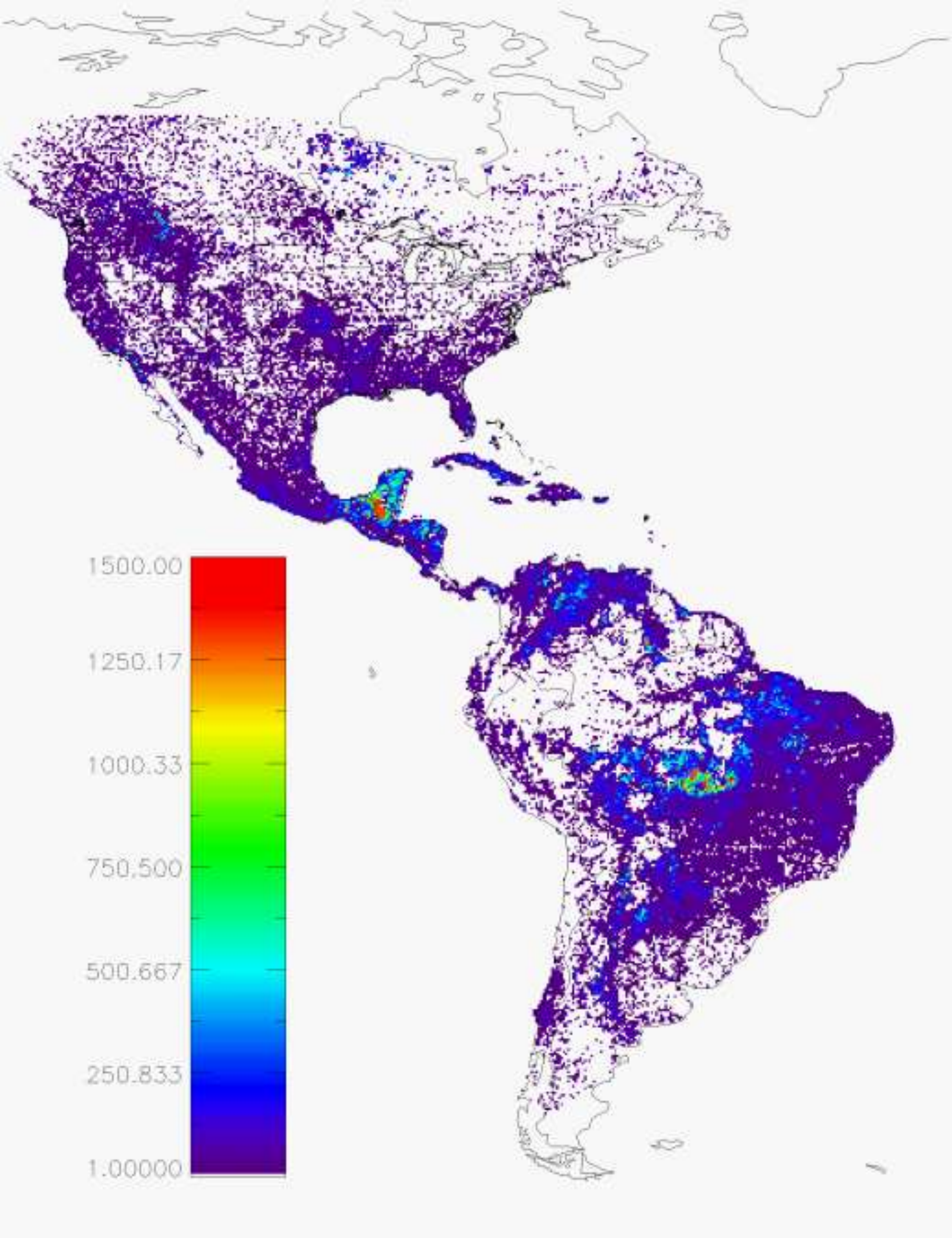
The arc of deforestation
Became more active again.



Coverage Corrected WFABBA Fire Counts: 2003

GOES-12 data.

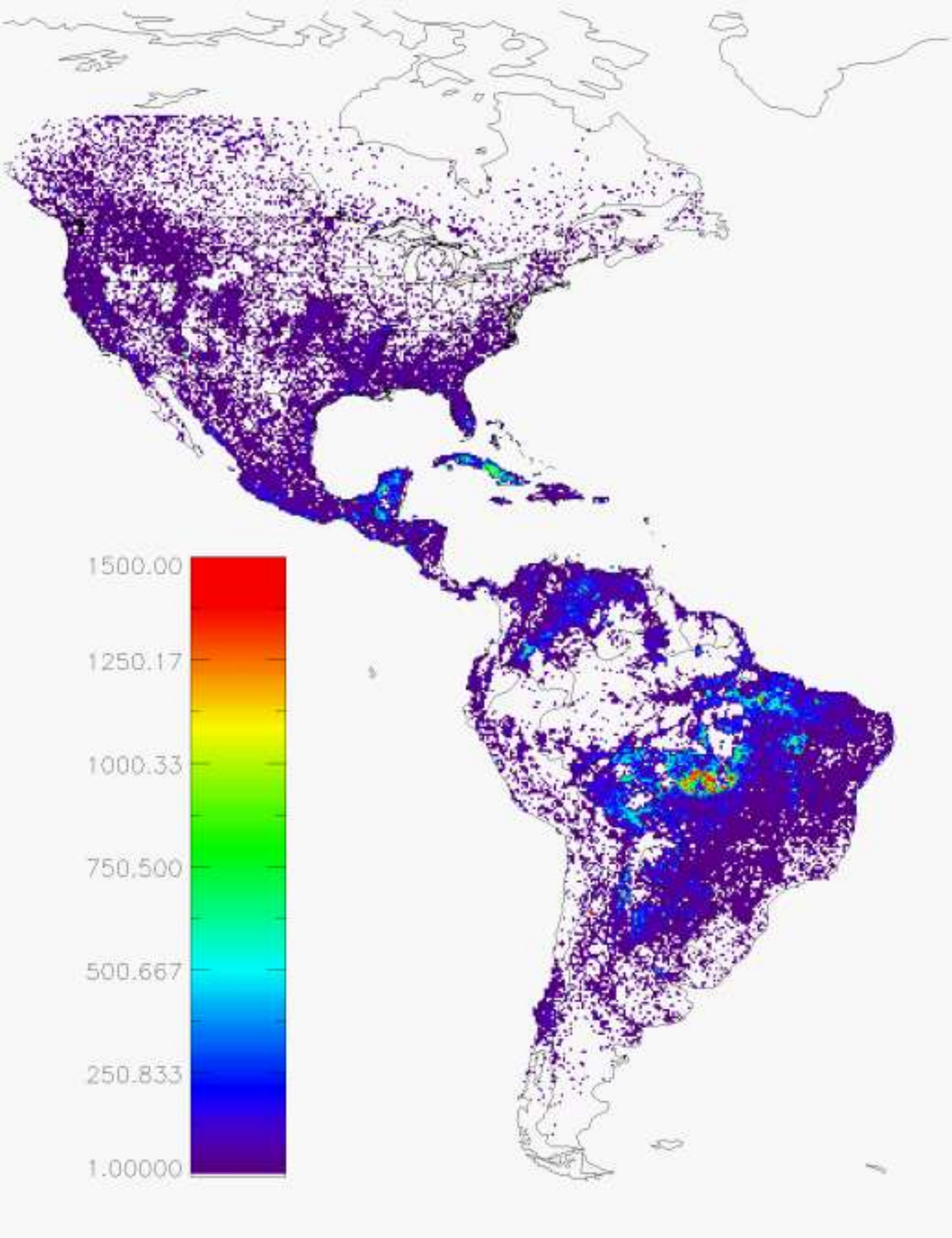
A hot spot of activity in Idaho and Montana, as well as Central America.



Coverage Corrected WFABBA Fire Counts: 2004

GOES-12 data.

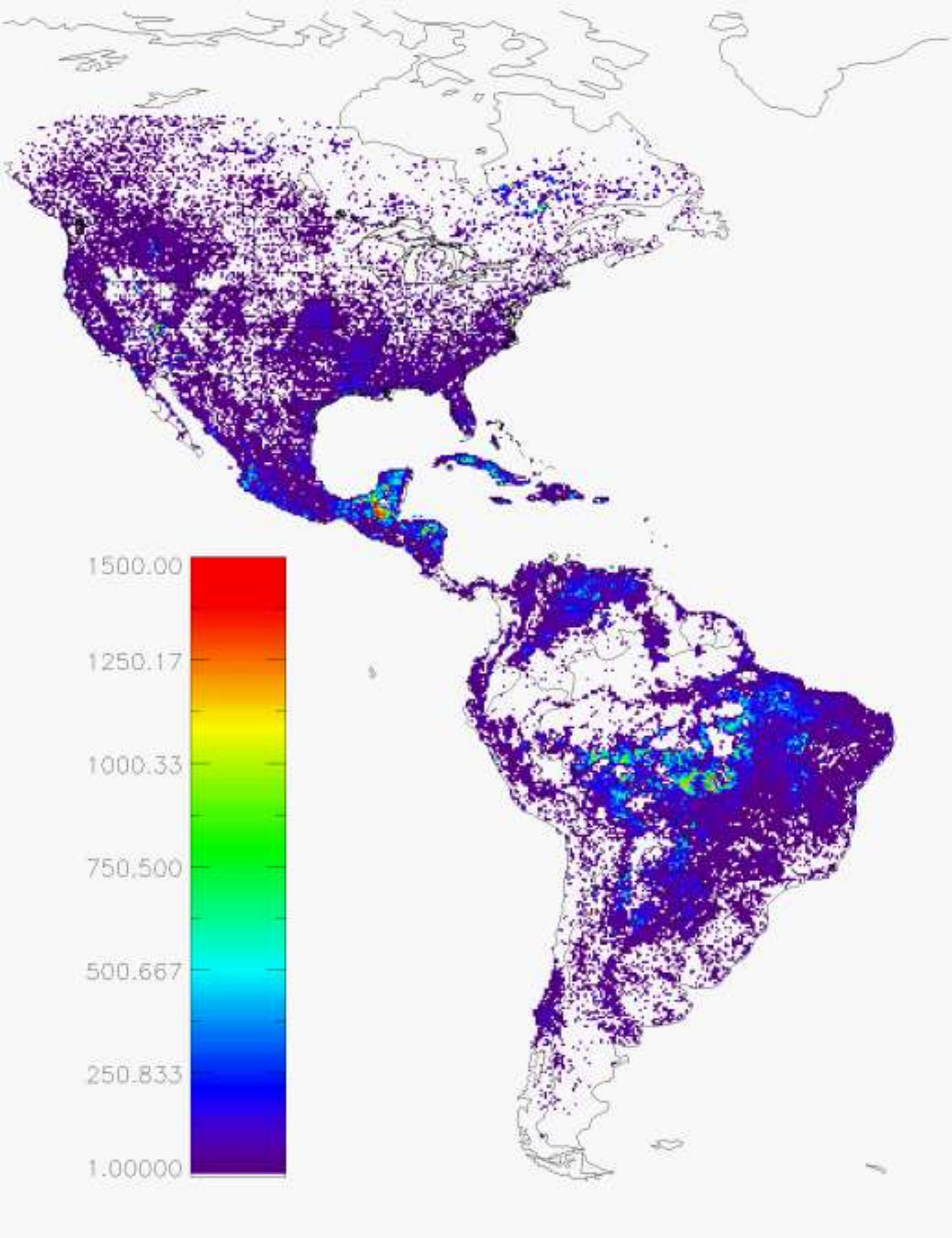
An active year in Cuba.



Coverage Corrected WFABBA Fire Counts: 2005

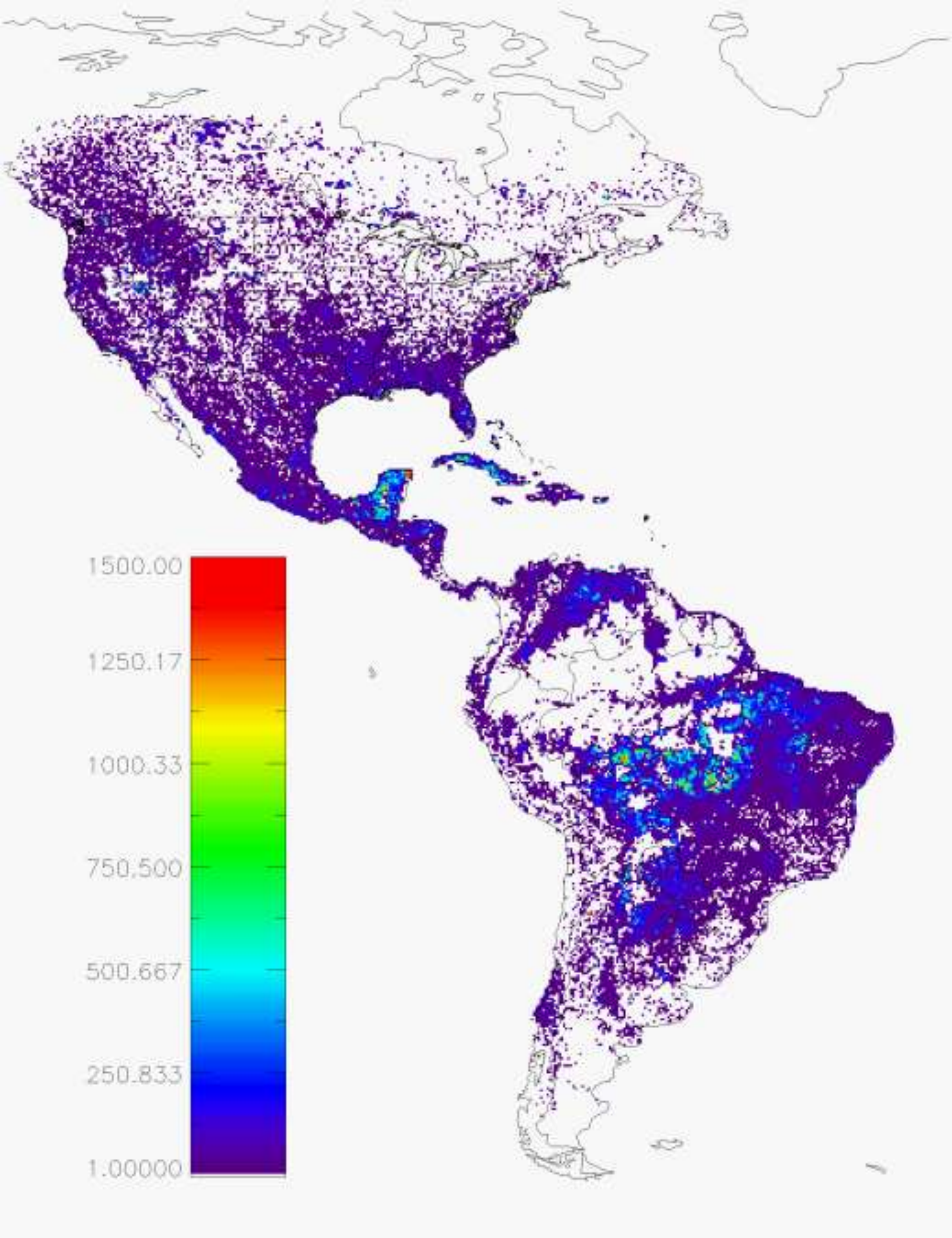
GOES-12 data.

Increased activity in Quebec.



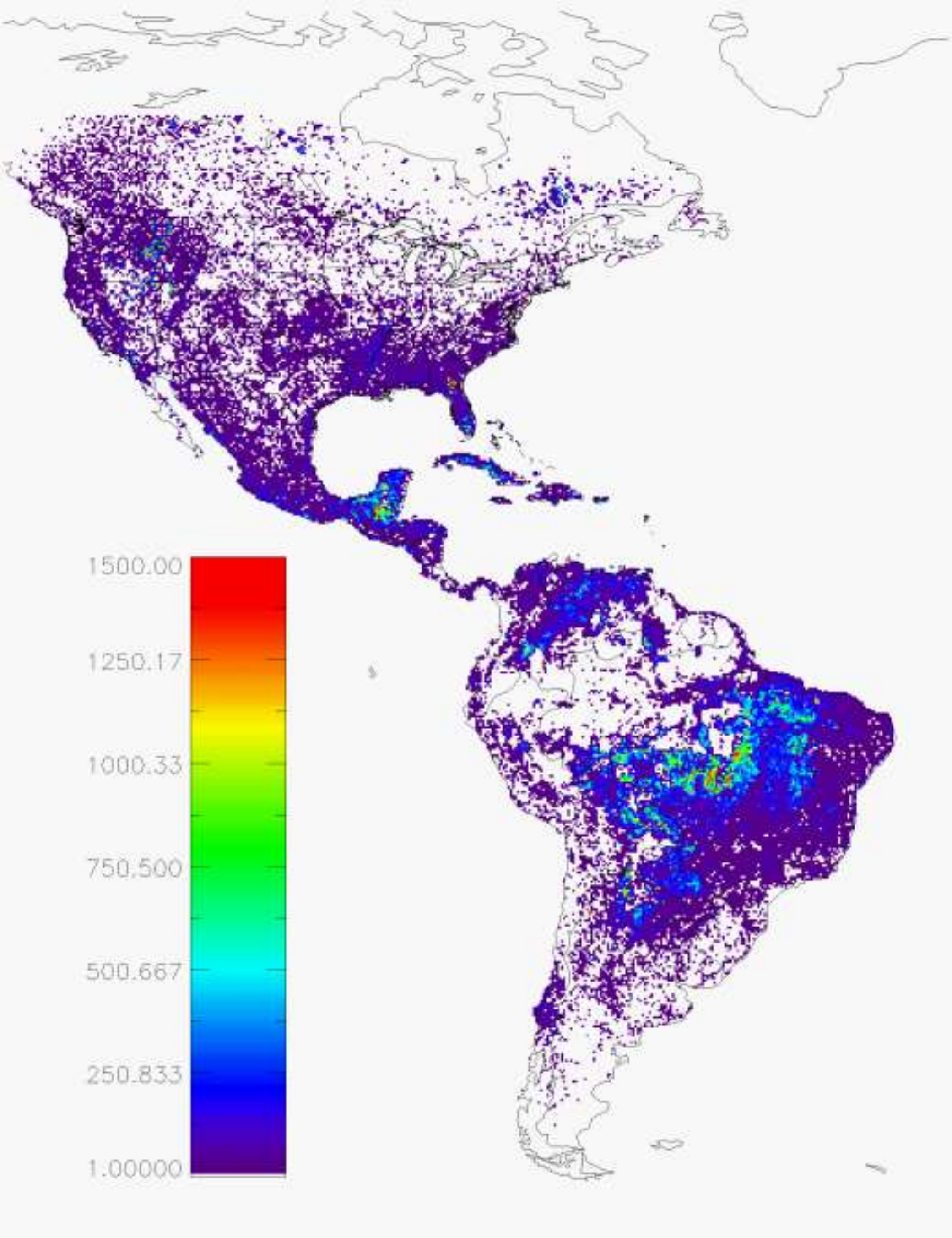
Coverage Corrected WFABBA Fire Counts: 2006

GOES-12 data.



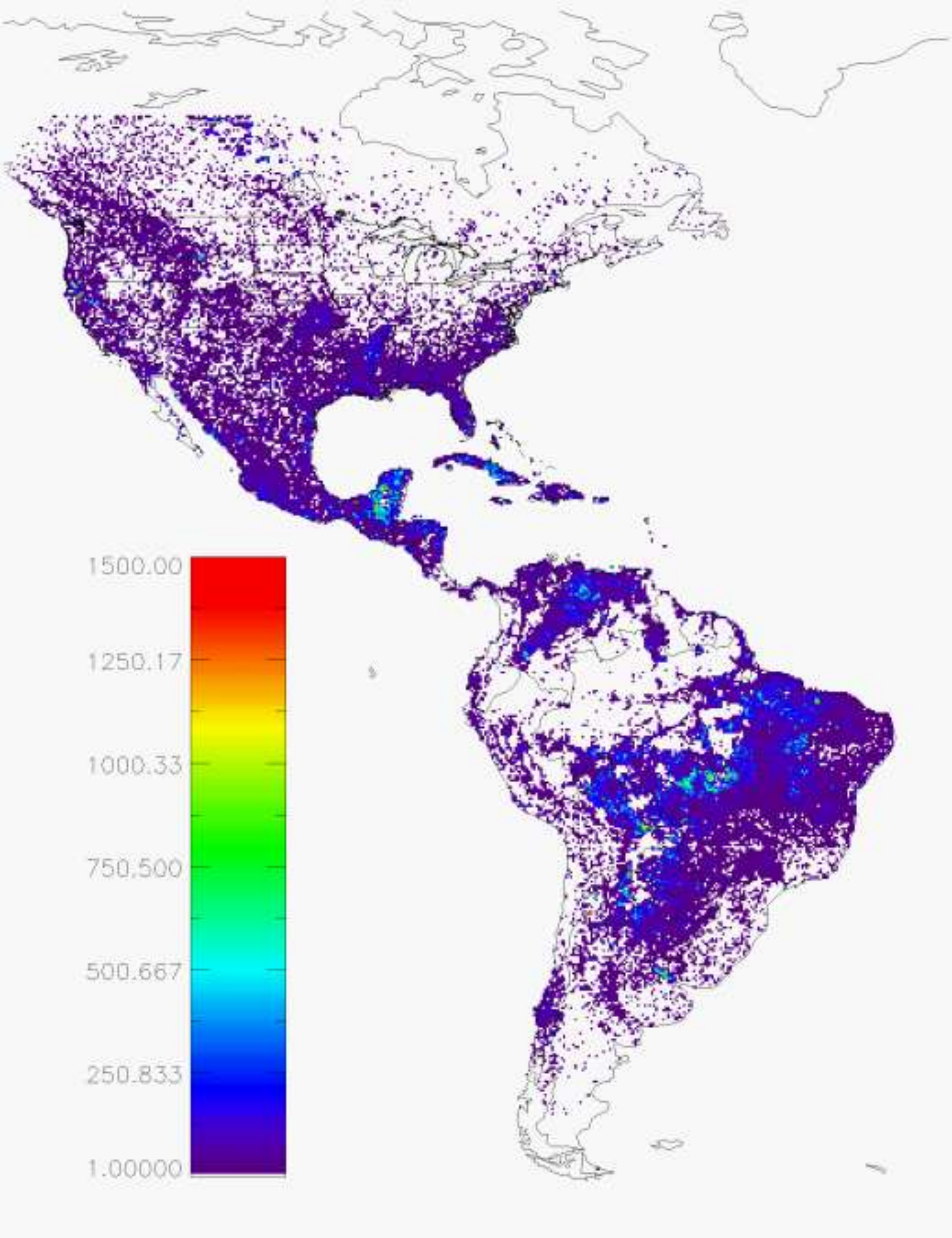
Coverage Corrected WFABBA Fire Counts: 2007

GOES-12 data.



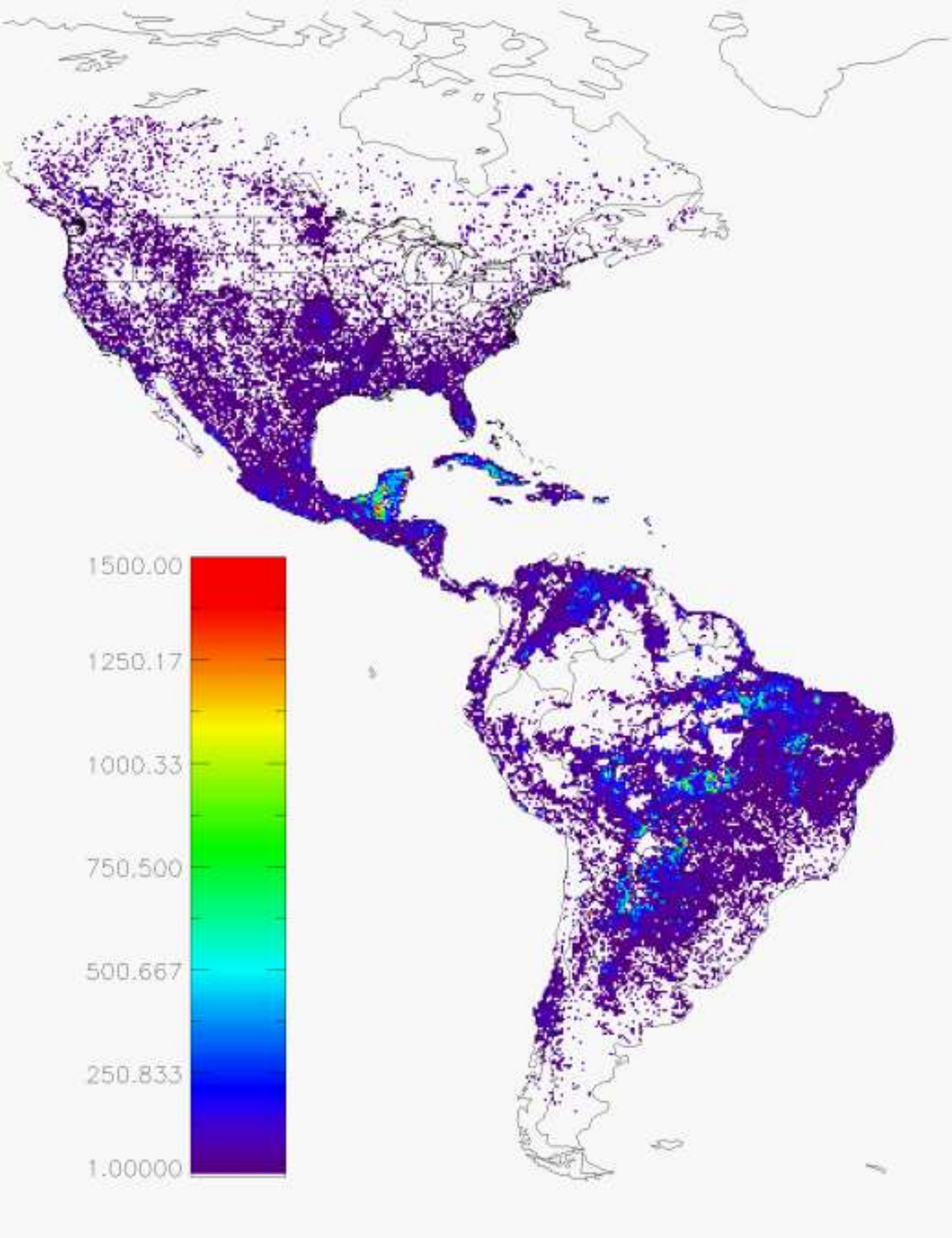
Coverage Corrected WFABBA Fire Counts: 2008

GOES-12 data.



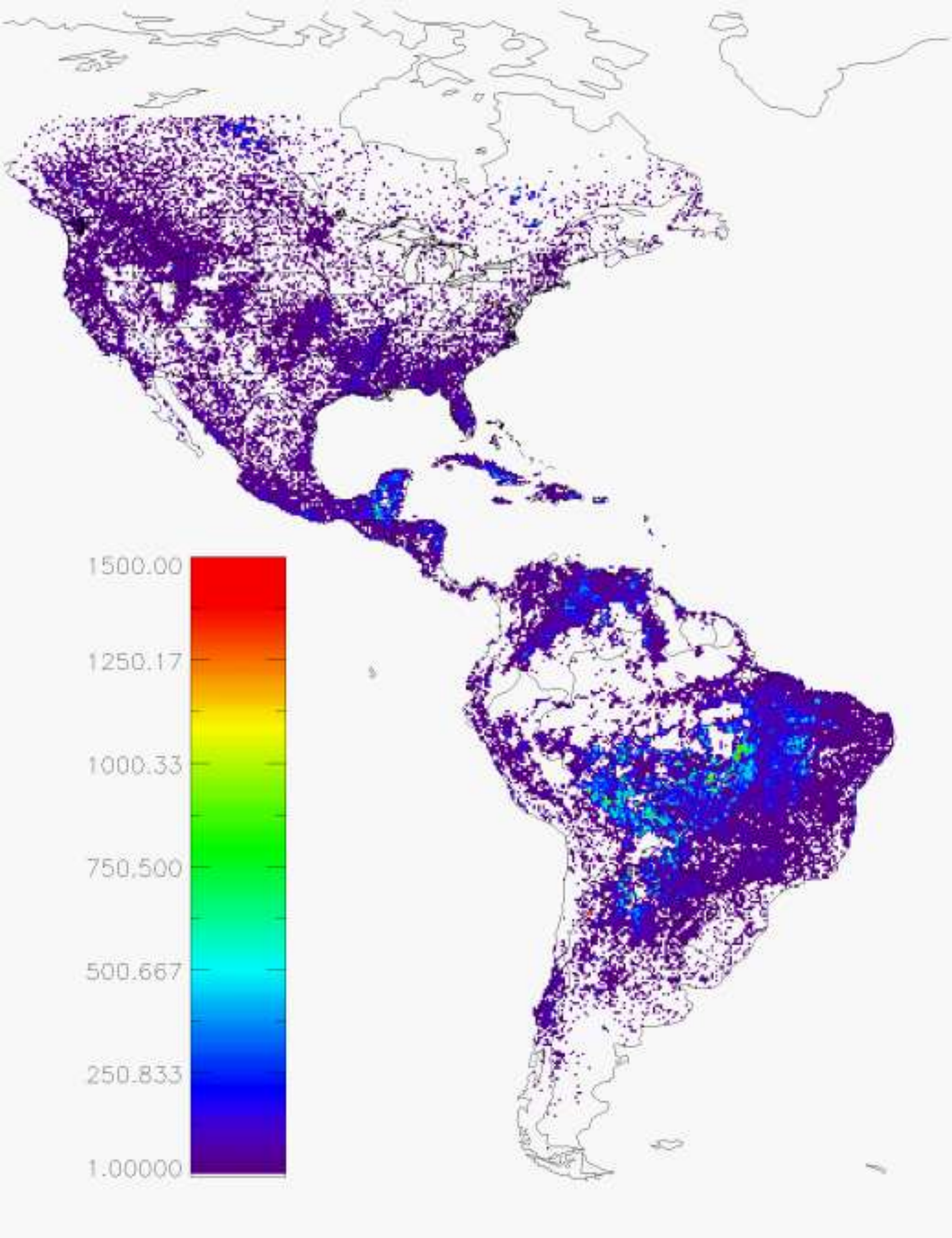
Coverage Corrected WFABBA Fire Counts: 2009

GOES-12 data.



Coverage Corrected WFABBA Fire Counts: 2010

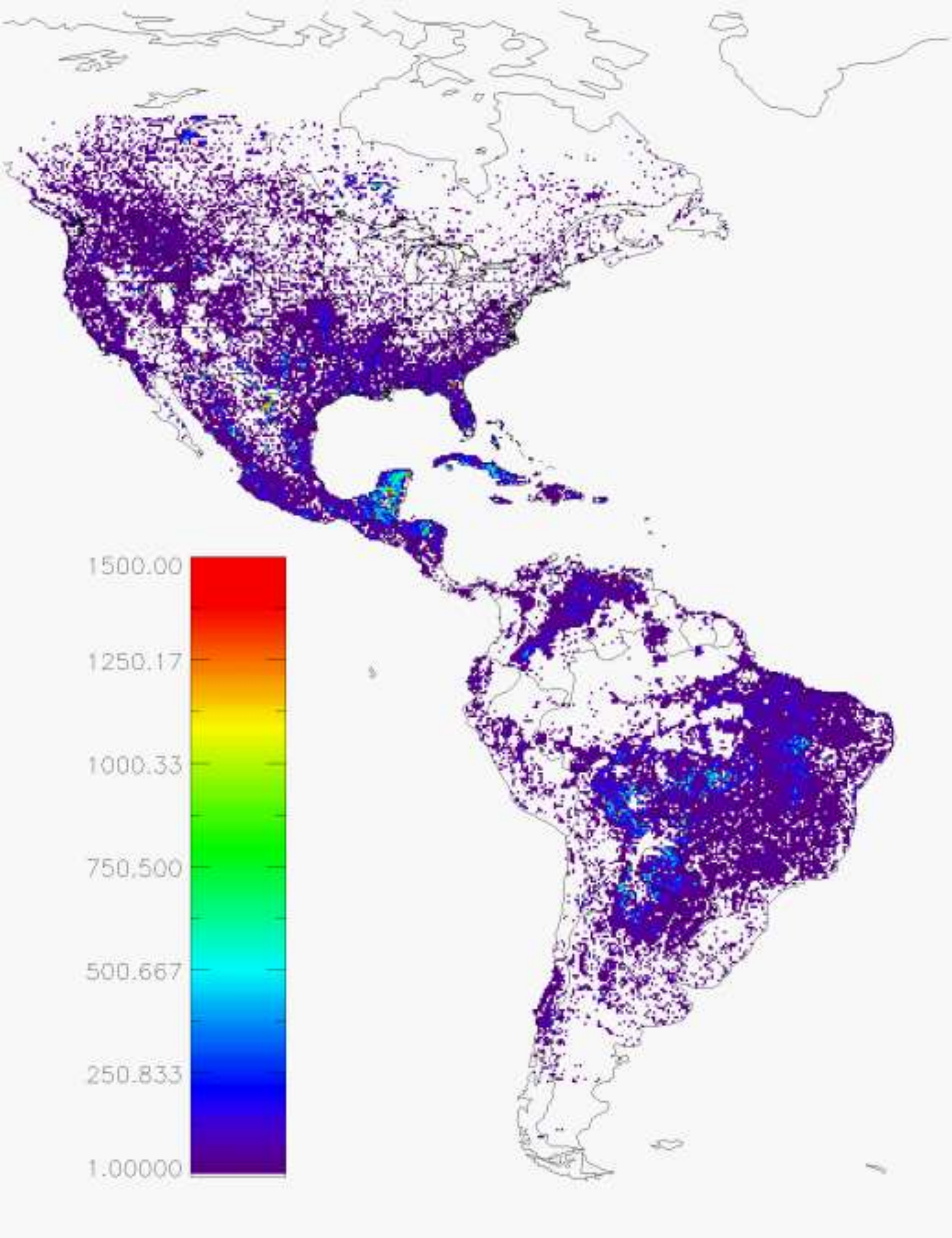
GOES-12 and GOES-13 data.



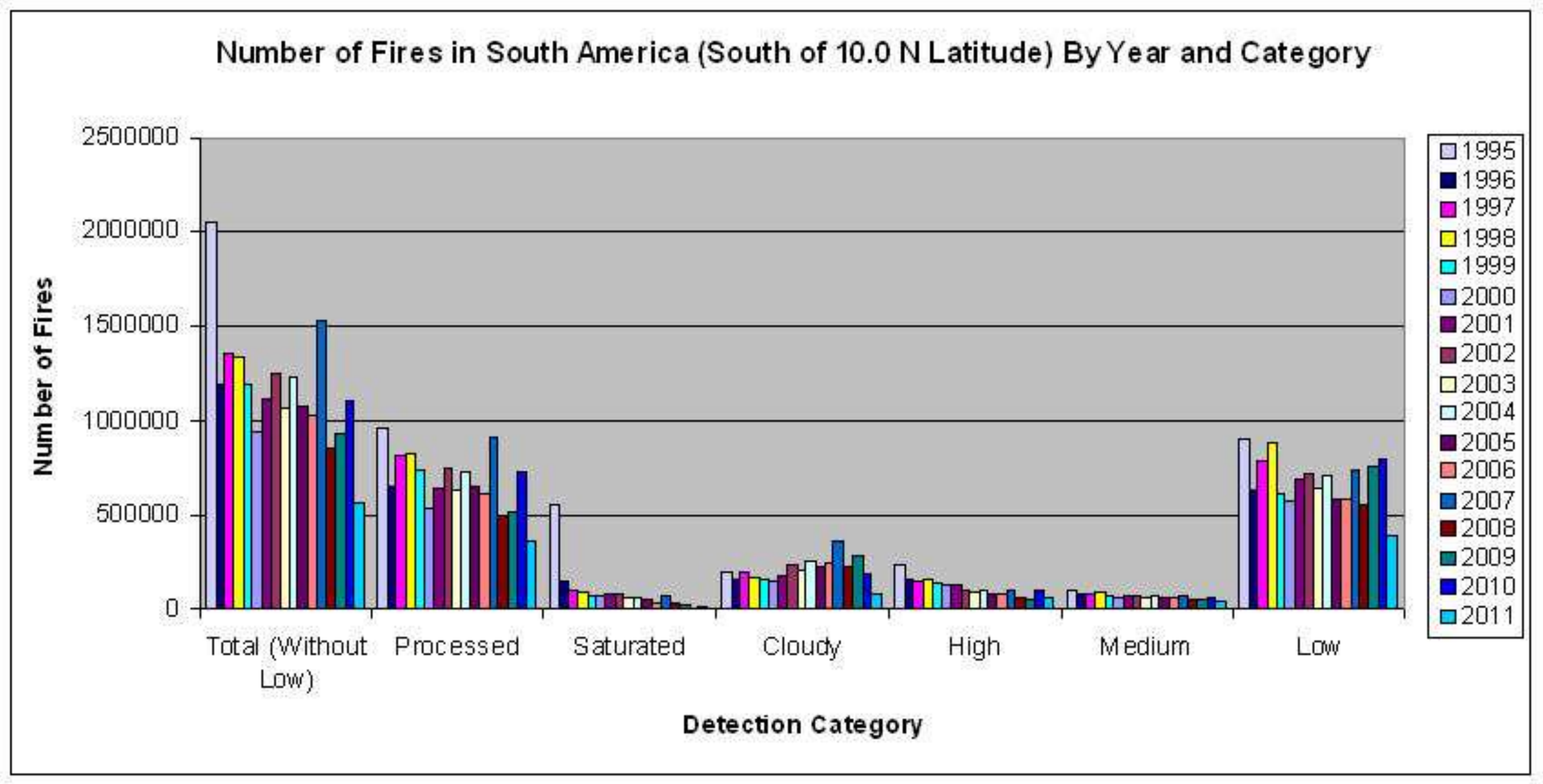
Coverage Corrected WFABBA Fire Counts: 2011

GOES-13 data.

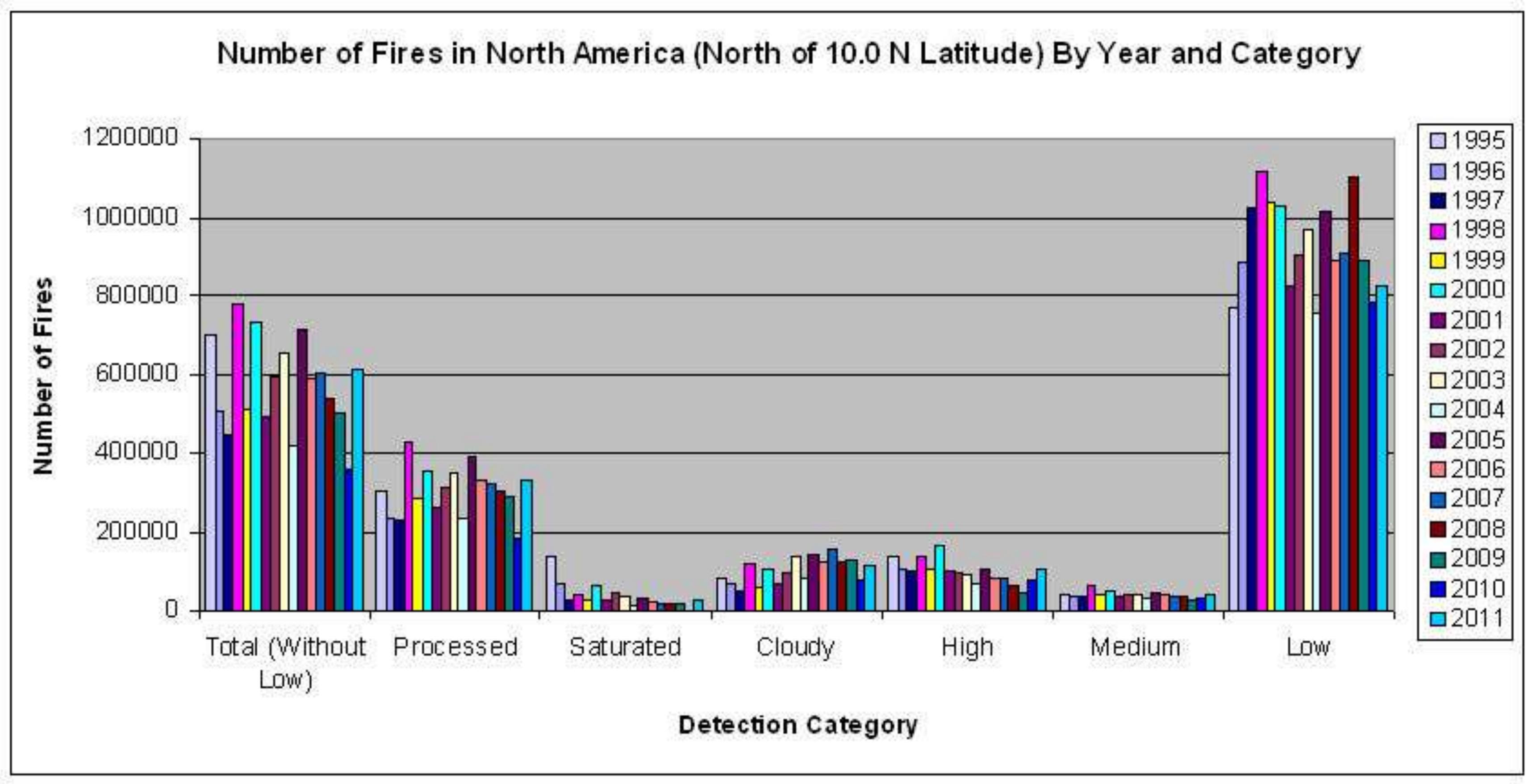
One of the least active years we've had.



Year to Year Trends: South America



Year to Year Trends: North America



Global geostationary fire detection and characterization

On an international level the development and maintenance of a long-term operational global geostationary fire monitoring system is supported by the IGOS GOFC/GOLD Fire Implementation Team[1] and supports Global Earth Observation System of Systems (GEOSS) activities and the Group on Earth Observations (GEO) 2006 work plan

GEO 2006 work plan calls for the initiation of:

- *"a globally coordinated warning system for fire and monitoring for forest conversion, including the development of improved information products and risk assessment models(DI-06-13)" and expanding "the use of meteorological geostationary satellites for the management of non-weather related hazards (DI-06-09)"*

The global geostationary fire monitoring network has also been considered as a CEOS virtual constellation (task DA-07-03) provided long-term agency support is available.

The goal is to create a long-term, consistent geostationary fire product utilizing the capabilities of the unique systems and a common algorithm, the **WFABBA**.

[1] http://gofc-fire.umd.edu/products/pdfs/Events/2nd_GOFC_Geo_Workshop_Report%20final.pdf

Global Geostationary Active Fire Monitoring Capabilities and Limitations

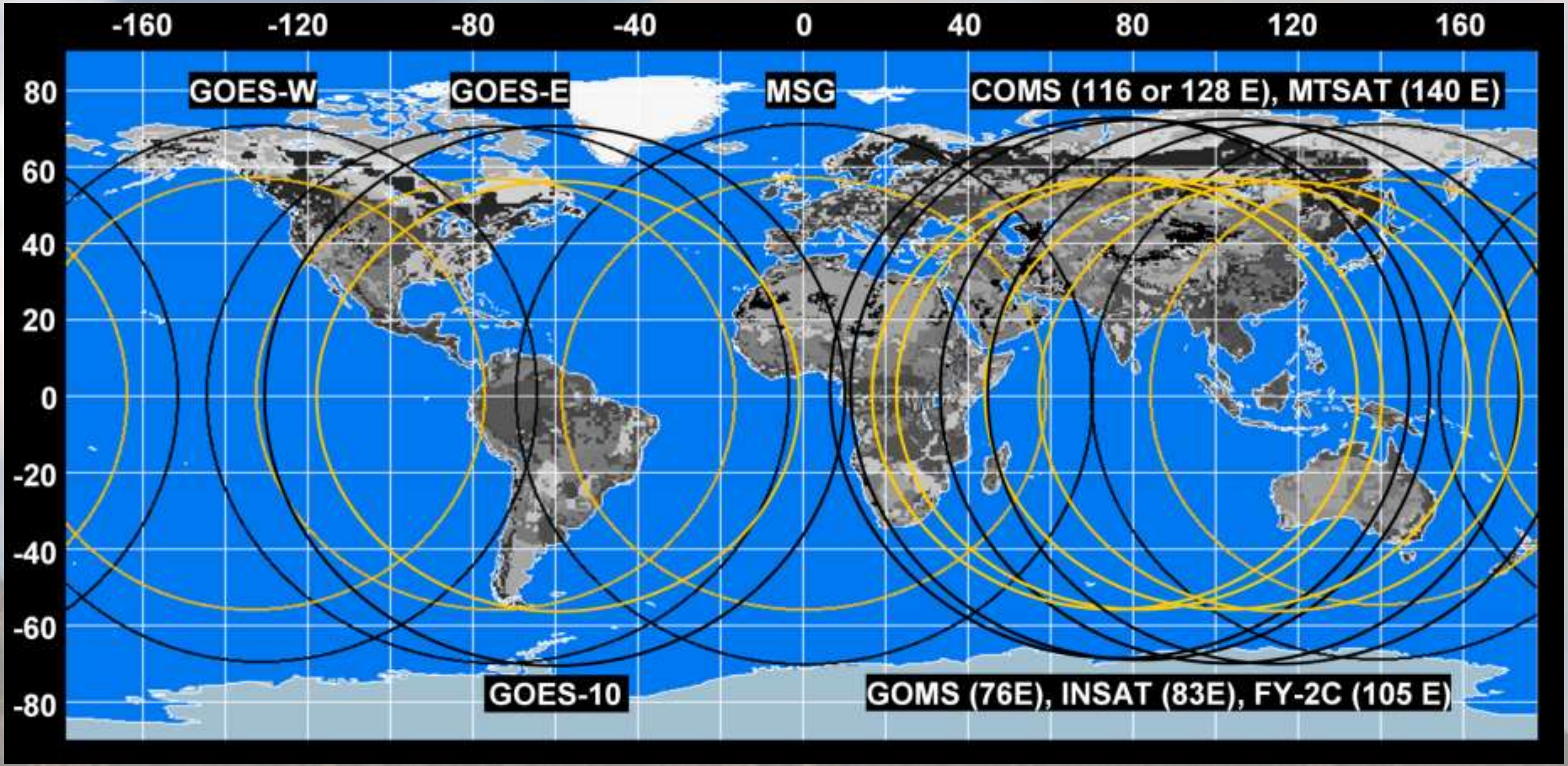
Satellite	Active Fire Spectral Bands	Resolution IGFOV (km)	SSR (km)	Full Disk Coverage	3.9 µm Saturation Temperature (K)	Minimum Fire Size at Equator (at 750 K) (hectares)
GOES-E/-W Imager (75ºW / 135ºW)	1 visible 3.9 and 10.7 µm	1.0 4.0	0.57 2.3	3 hours (30 min NHE and SHE)	~340 K (G-11) ~340 K (G-13)	0.15
GOES-12 Imager (60ºW)	1 visible 3.9 and 10.7 µm	1.0 4.0	0.57 2.3	3 hours (Full Disk) 15 min (SA)	>335 K (G-12)	0.15
Met-8/-9 SEVIRI (9.5 ºE, 0º)	1 HRV 2 visible 1.6, 3.9 and 10.8 µm	1.6 4.8 4.8	1.0 3.0 3.0	15 minutes	~335 K	0.22
FY-2C/2D SVISSR (105 ºE / 86.5ºE)	1 visible, 3.75 and 10.8 µm	1.25 5.0		30 minutes	~330 K	
MTSAT-1R JAMI (140ºE) MTSAT-2 (HRIT) (145ºE) Operational 2010	1 visible 3.7 and 10.8 µm	1.0 4.0		1 hour	~320 K (MTSAT-1R) 330 K (MTSAT-2)	0.15
INSAT-3D (83 ºE ?, TBD) (Launch July 2011)	1 vis, 1.6 µm 3.9 and 10.7 µm	1.0 4.0	0.57 2.3	30 minutes	TBD	
GOMS Elektro-L N1 (76 ºE) (2010) GOMS Elektro-L N2 (14.5 ºE) (2011?)	3 visible 1.6, 3.75 and 10.7 µm	1.0 km 4.0 km		30 minutes	TBD	
COMS (128 ºE) (Launched 2010)	1 visible 3.9 and 10.7 µm	1.0 km 4.0 km		30 minutes	~350 K	

Approximate viewed areas for global geostationary satellites

Satellite View Angle

▬ 80°

▬ 65°



Status of Global WFABBA

Version 6.5 supports:

- **GOES-8/-9/-10/-11/-12/-13/-14/-15** (US; GOES-13 is stationed at 75W, GOES-15 at 135W, and GOES-14 is in storage)
- **Meteosat-8/-9** (Eumetsat)
- **MTSAT-1R/-2** (Japan)
- **GOES-R ABI** (US)
- **COMS** (Korea)

Version 6.5 support is being developed for:

- **INSAT-3D** (India)

And looking further ahead:

- **Meteosat Third Generation** (Eumetsat)
- **MTSAT-3** (Japan; an ABI with slightly different channels)

The WFABBA can support any geostationary satellite for which data is available and that has acceptable instrument characteristics (necessary spectral bands and good overall performance for fire detection).

Composite of 27 September 2011 WFABBA fires

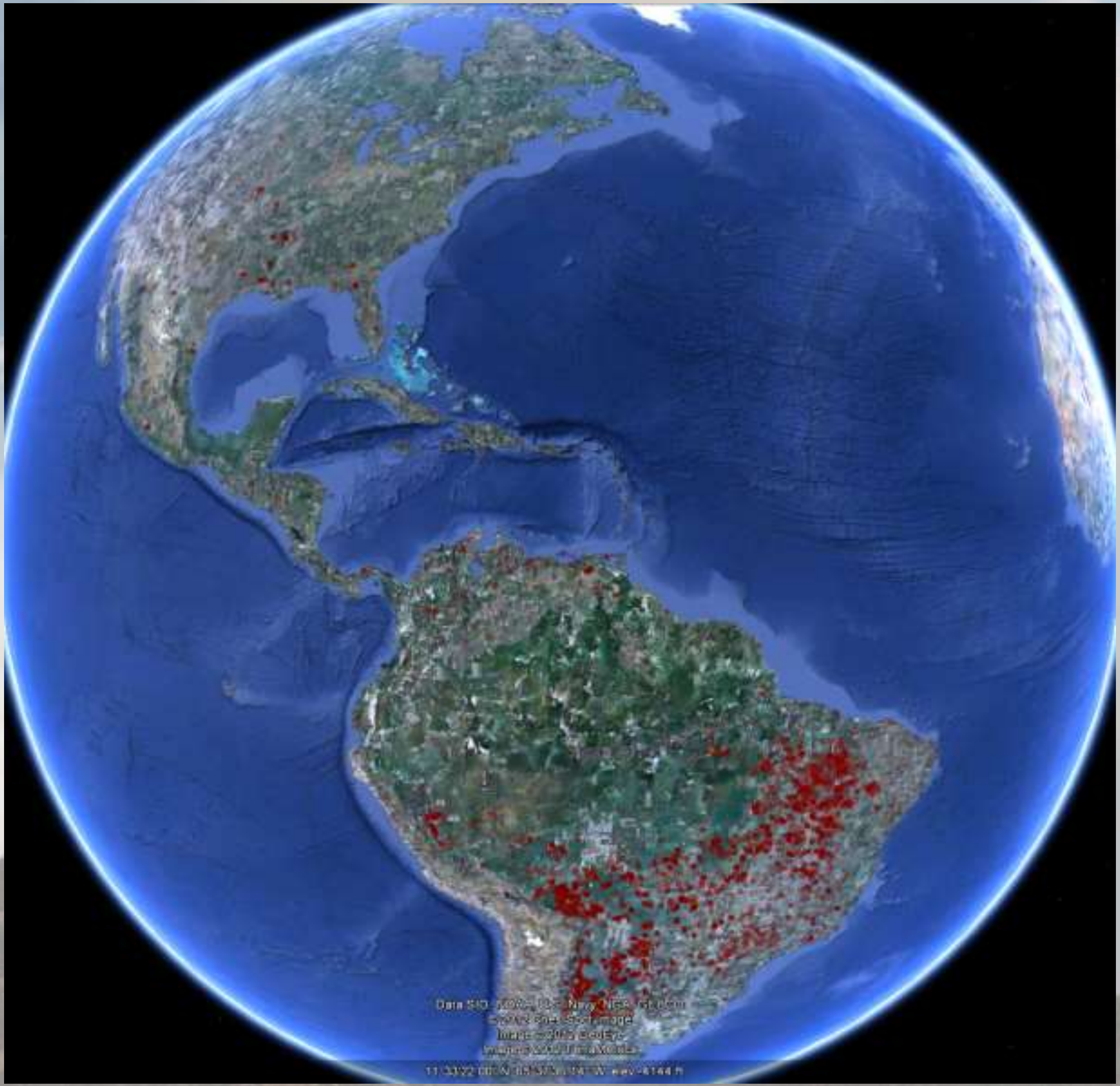
GOES-West

Positioned over the Pacific, GOES-West (GOES-11 in this image, currently GOES-15) sees the least land surface of any of the current geo satellites.

Composite of 27 September 2011 WFABBA fires

GOES-East

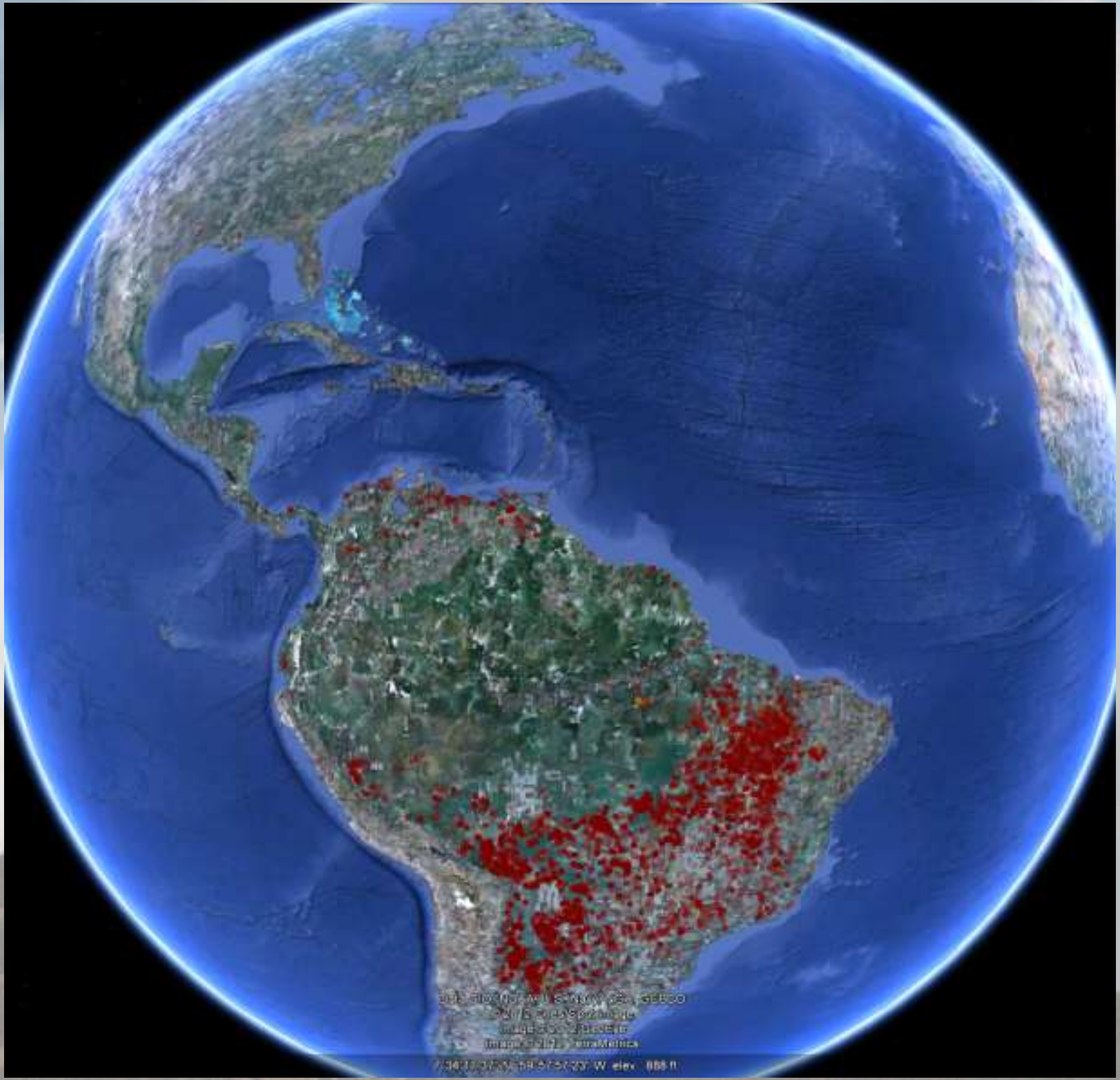
GOES-East (currently GOES-13) provides the best coverage of North America.



Composite of 27 September 2011 WFABBA fires

GOES-SA

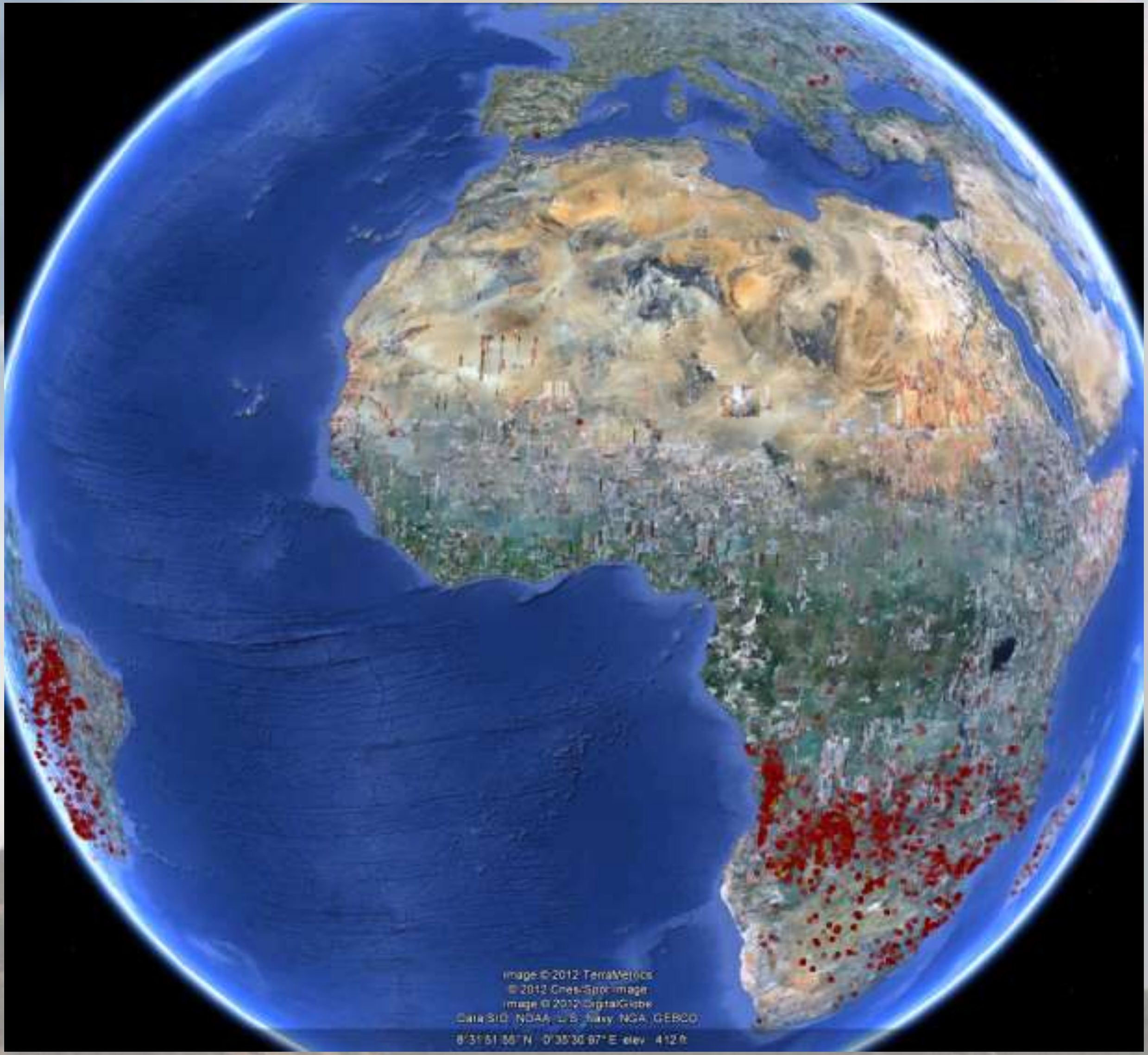
GOES-SA (currently GOES-12) provides additional coverage for South America using an older GOES satellite. Due to the age of the satellite, the data is remapped to a perfect projection to make up for navigation shifts.



Composite of 27 September 2011 WFABBA fires

Meteosat

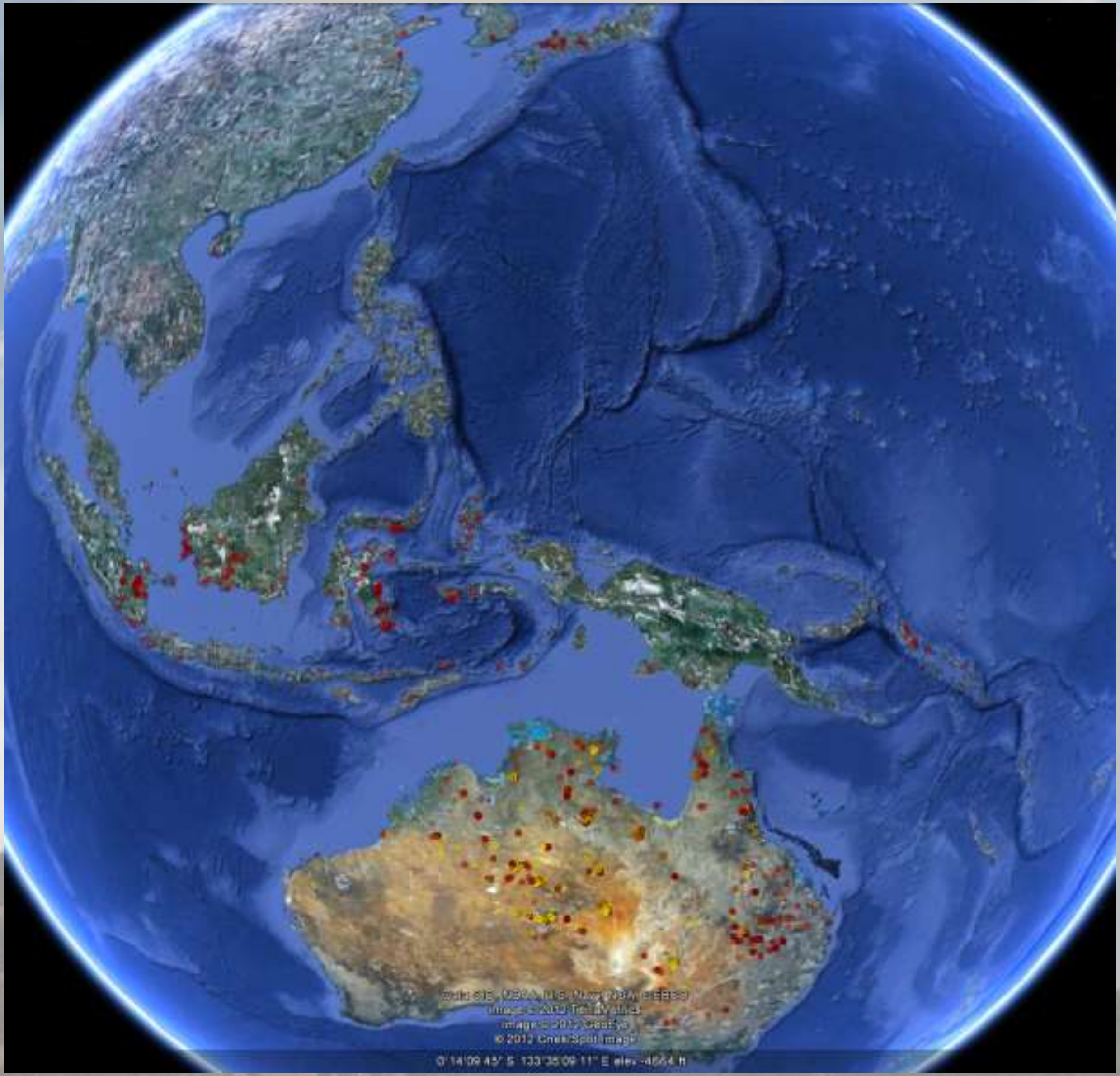
Meteosat (currently Meteosat-9) covers Europe and Africa. Meteosat data is remapped to a perfect projection.



Composite of 27 September 2011 WFABBA fires

MTSAT

MTSAT (currently MTSAT-2) covers Southeast Asia, Australia, Korea, Japan, and part of China. MTSAT data is remapped to a perfect projection.

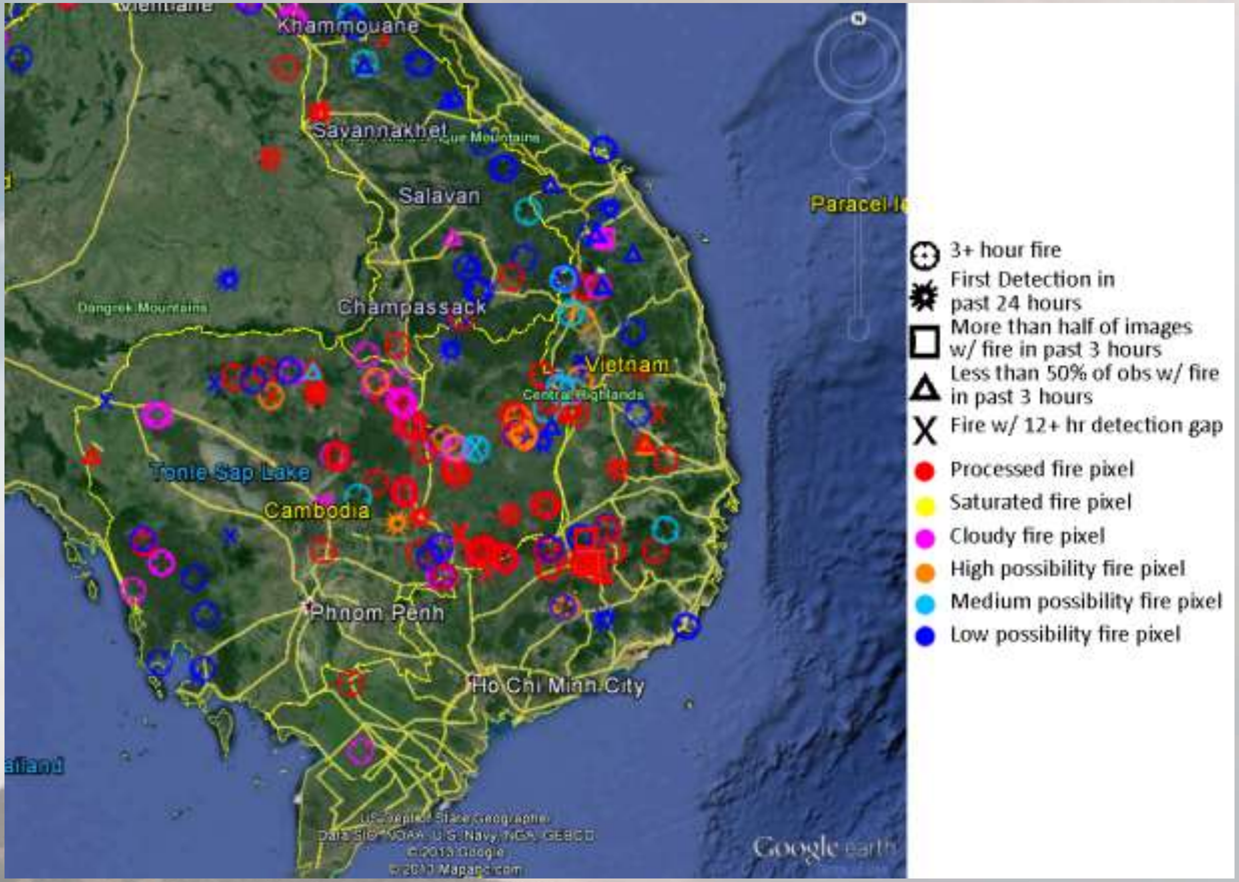


Data from Korea’s COMS

COMS

COMS, like MTSAT, covers Southeast Asia, Australia, Korea, Japan, and part of China. COMS data is remapped to a perfect projection and has some odd artifacts.

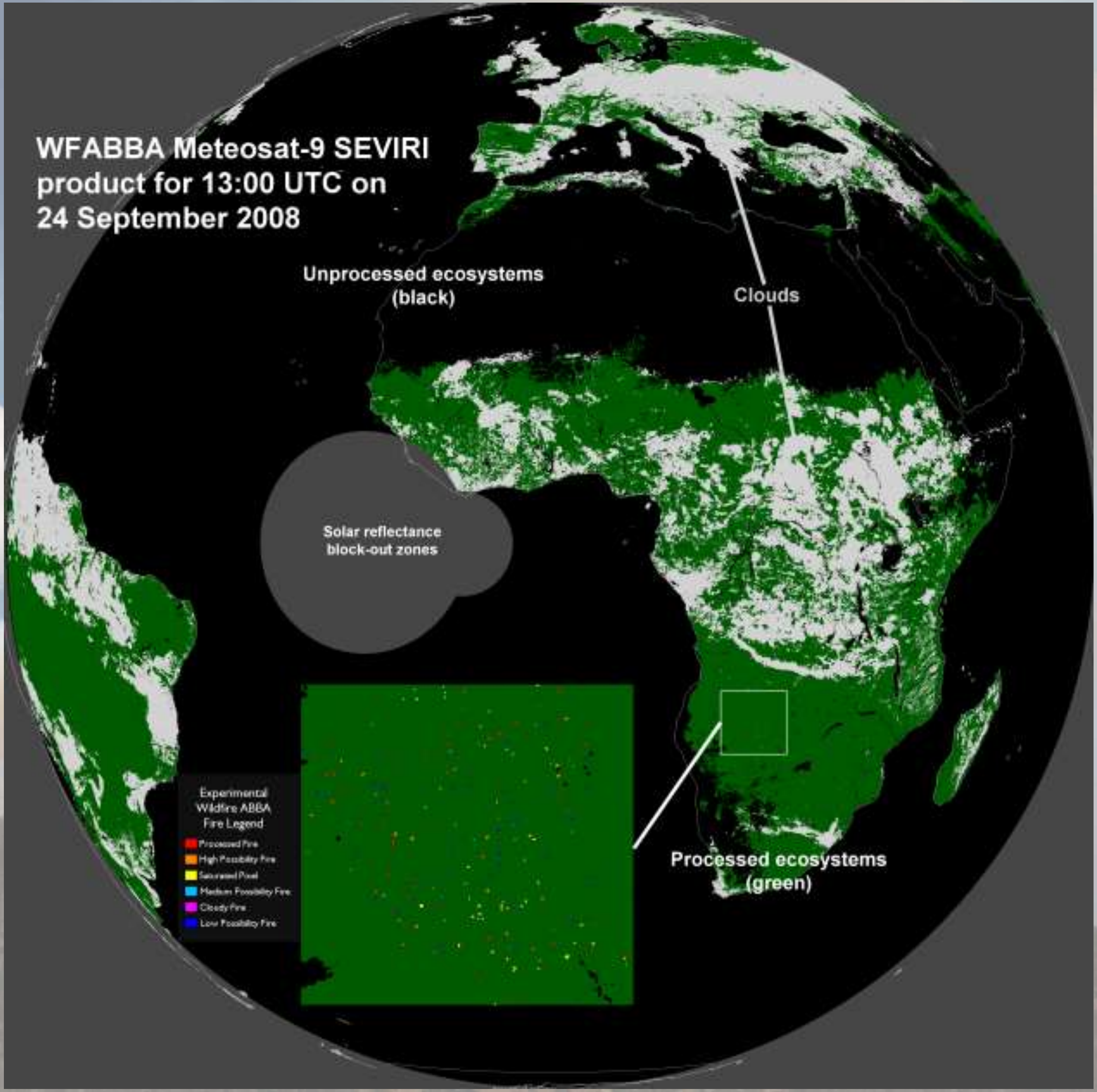
This sample image shows new temporal filtering (under development) applied to COMS.



Performance of satellites in the global system

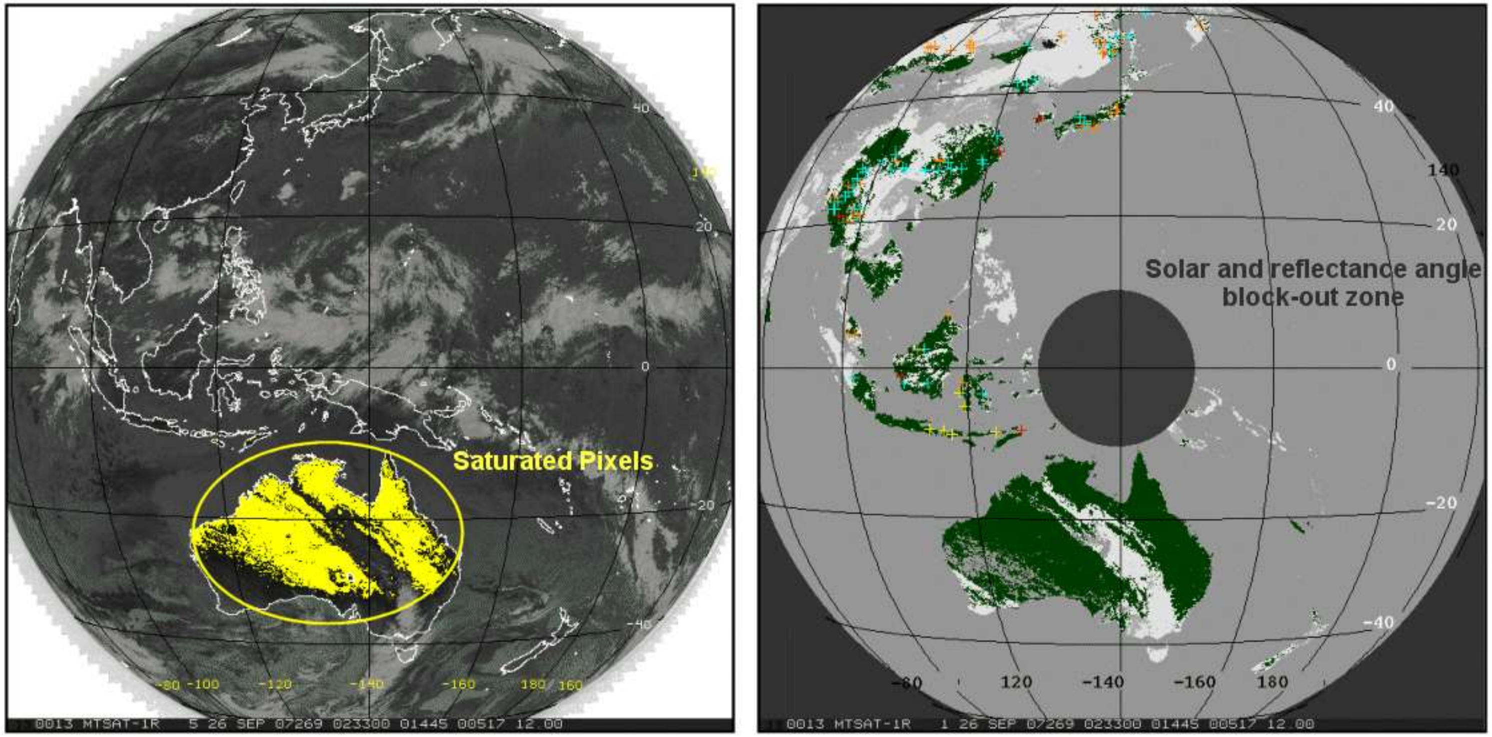
- Each one is different, even within a series like GOES or Meteosat Second Generation.
- And some are more similar than others:
  - GOES, INSAT-3D, COMS, MTSAT-2 are all tri-axis (gyroscopically) stabilized with square aperture scanning imagers modeled after GOES-8
  - MSG (Met-8/-9) are spin-scan instruments (same principle as ATS-I and ATS-III) that employ diamond shaped apertures. The data is remapped before distribution to a fixed navigation centered at 0°, 0°
  - MTSAT-1R is a replacement for the GOES-like MTSAT-1 which was lost upon launch. The imager is a Raytheon unit that employs a CCD array and obtains data at 2 km resolution. The data we receive is 4 km and is remapped with an unknown (to us) remapping kernel
  - FY-2C, FY-2D, and beyond (China) are GOES-like in apparent spectral coverage. However we have had problems using this data, support is not implemented at this time.
  - GOES-12 is the oldest geostationary satellite we use for fires. The data is remapped due to a lack of fuel to correct for high inclination.
  - GOES-13 and beyond employ improved stability features, causing less navigational jitter than we see with current GOES.
  - GOES-9/-10 and MTSAT-1R have 4 µm saturation temperatures that are low for fire detection and characterization purposes. A rule of thumb for determining if a temperature is “low” is to look at how often land surfaces saturate for a given instrument. If deserts, mountains, and even grassy plains saturate the sensor frequently, the temperature is likely too low. Most instruments are now designed with this in mind for fire detection.
  - GOES has 4 km resolution, 4 km N/S spacing, 2 km E/W spacing
  - MSG has 5 km diamond-shaped footprints spaced every 3 km
  - MTSAT-1R has 2 km footprints and presumably 2 km spacing. The data we receive is 4 km footprint, 4 km spacing.

Meteosat-9 WFABBA v65 Example Output



MTSAT-1R WFABBA v65 Example Output

Fire Monitoring with MTSAT-1R JAMI WF_ABBA



MTSAT-1R 3.7 micron data
Date: 26-Sept-2007 Time: 02:33 UTC

MTSAT-1R WF_ABBA Fire Mask
Date: 26-Sept-2007 Time: 02:33 UTC

Experimental Wildfire ABBA Fire Legend

🟥 Processed Fire
🟧 High Possibility Fire
🟨 Saturated Pixel
🟦 Medium Possibility Fire
🟪 Cloudy Fire
🟦 Low Possibility Fire

Comparing WFABBA fire detects and characterizations from different satellites

- Complicated problem, need to account for frequency of viewing, viewing geometry, and satellite properties such as spatial and spectral response functions.
- Most satellites in global system will have some overlap with at least one other satellite.
- Polar orbiting satellites like MODIS provide a standard to compare everything to.
- Eastern Brazil provides a place where we can compare GOES and MSG (specifically GOES-12/-13 and Met-9).
- Overall, the comparisons are promising – when looking at fires in a bulk statistical sense.

End