Insights from two decades of developing satellite-based fire climate data records and their use and abuse

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6th SALGEE Workshop
Darmstadt, Germany
October 2019

Presentation Structure

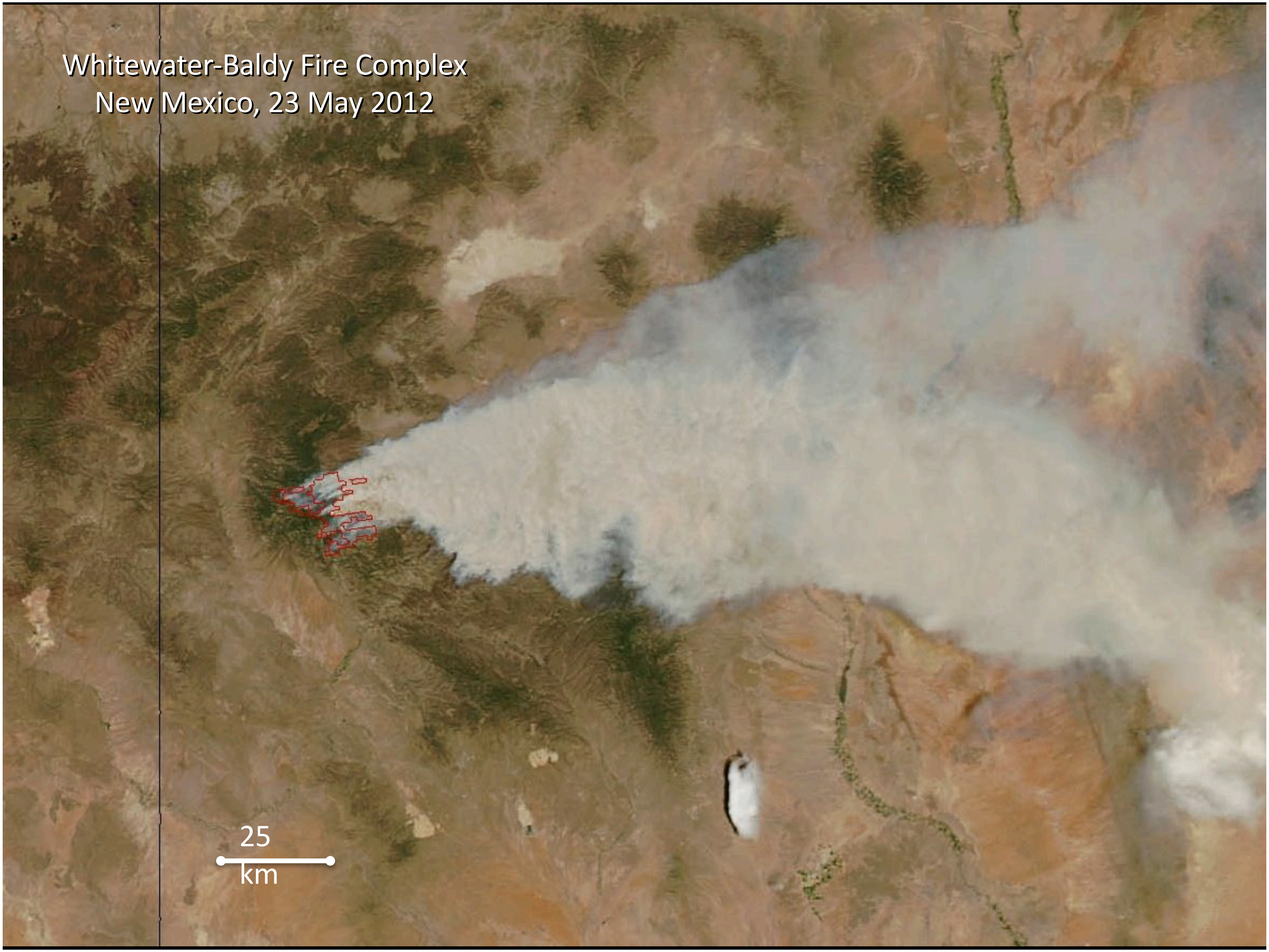
- History/Introduction
  - Emphasis on long-term fire monitoring sensors
    - MODIS
    - VIIRS
  - Active Fire + Burned Area
- Use and Misuse

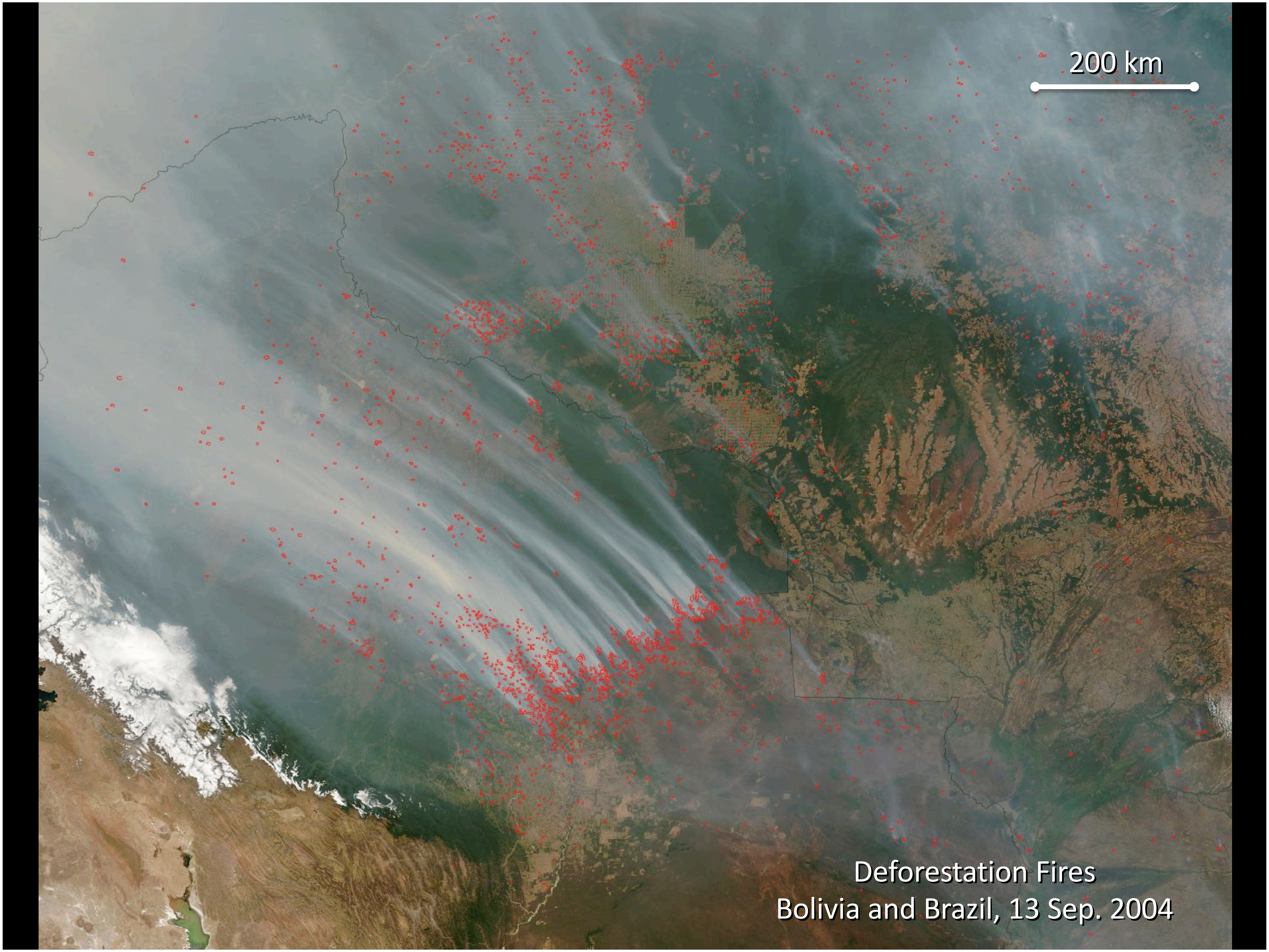
Satellite-Based Fire Products

- Active Fire
- Burned Area

Active Fire Products

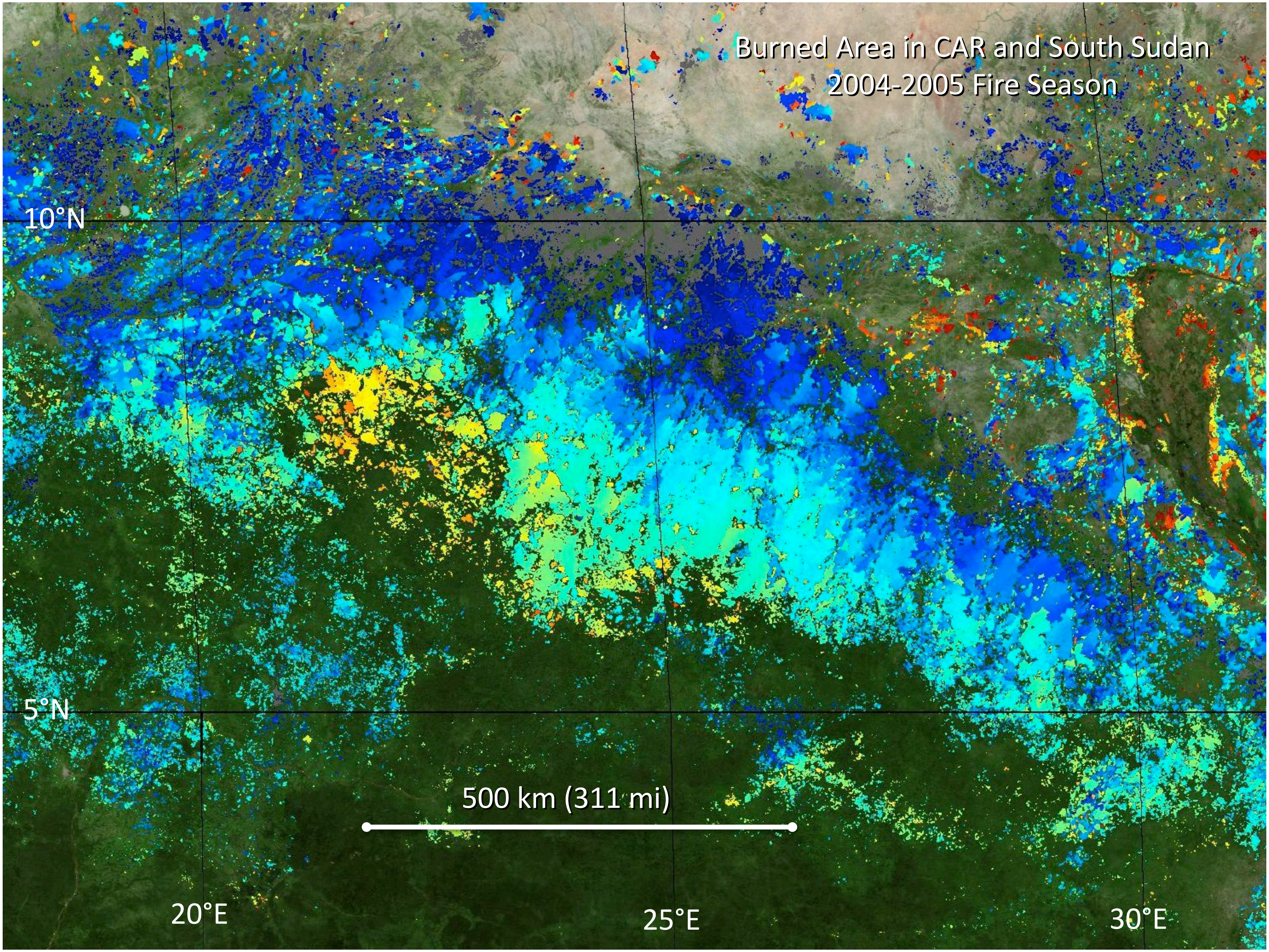
- Identify **where** fires are actively burning at time of satellite overpass (and implicitly **when** they are burning)
- Possibly provide **additional information** about fires at time of satellite overpass
  - Intensity, average temperature, instantaneous size, rate of combustion, injection height, etc.


Whitewater-Baldy Fire Complex
New Mexico, 23 May 2012
25
km


200 km
Deforestation Fires
Bolivia and Brazil, 13 Sep. 2004

Burned Area Products

- Map **spatial extent** of post-fire burn scars over a particular time period
  - Approximate date of burn
- Potentially provide **additional information** about the area that burned
  - Combustion completeness

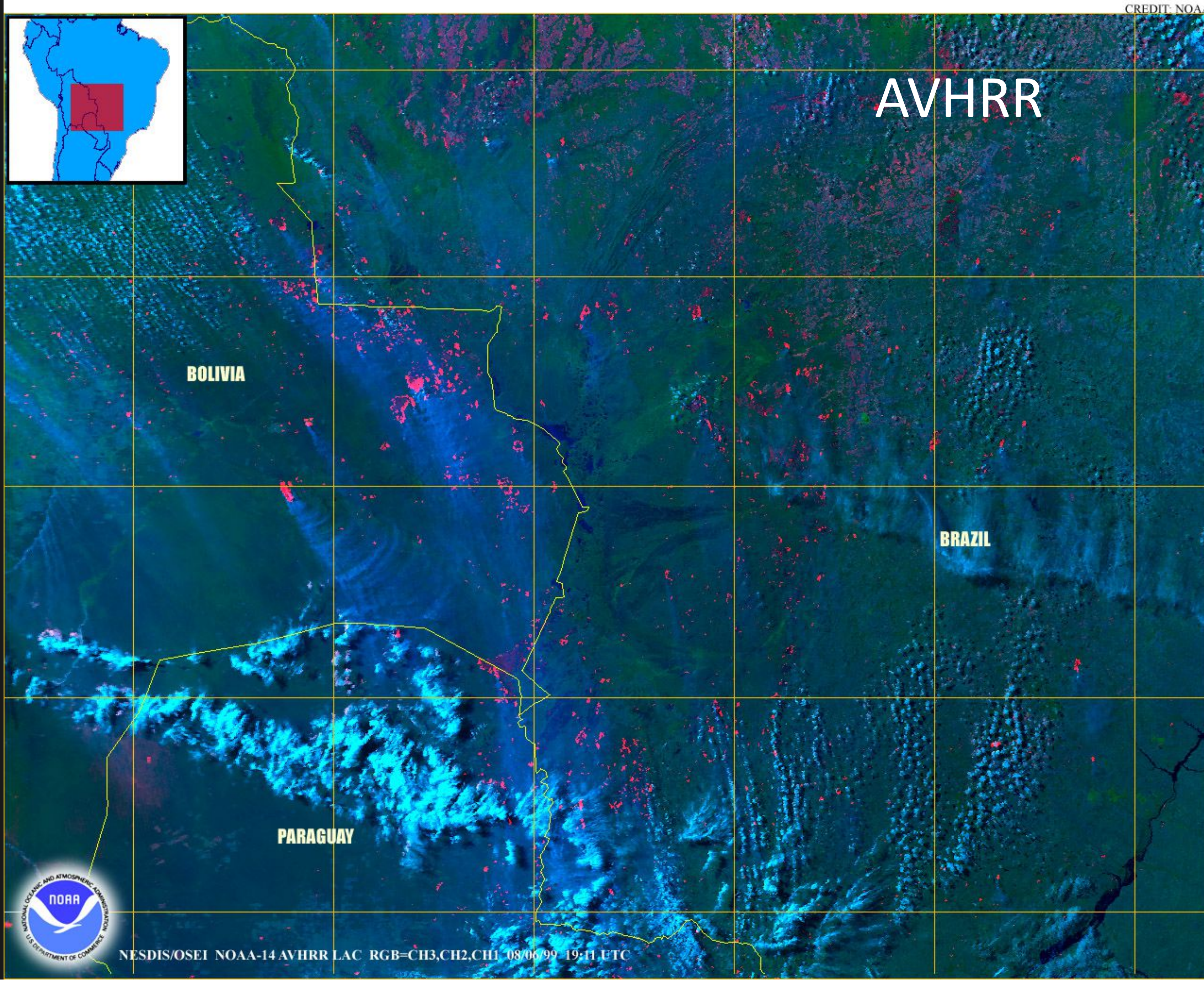


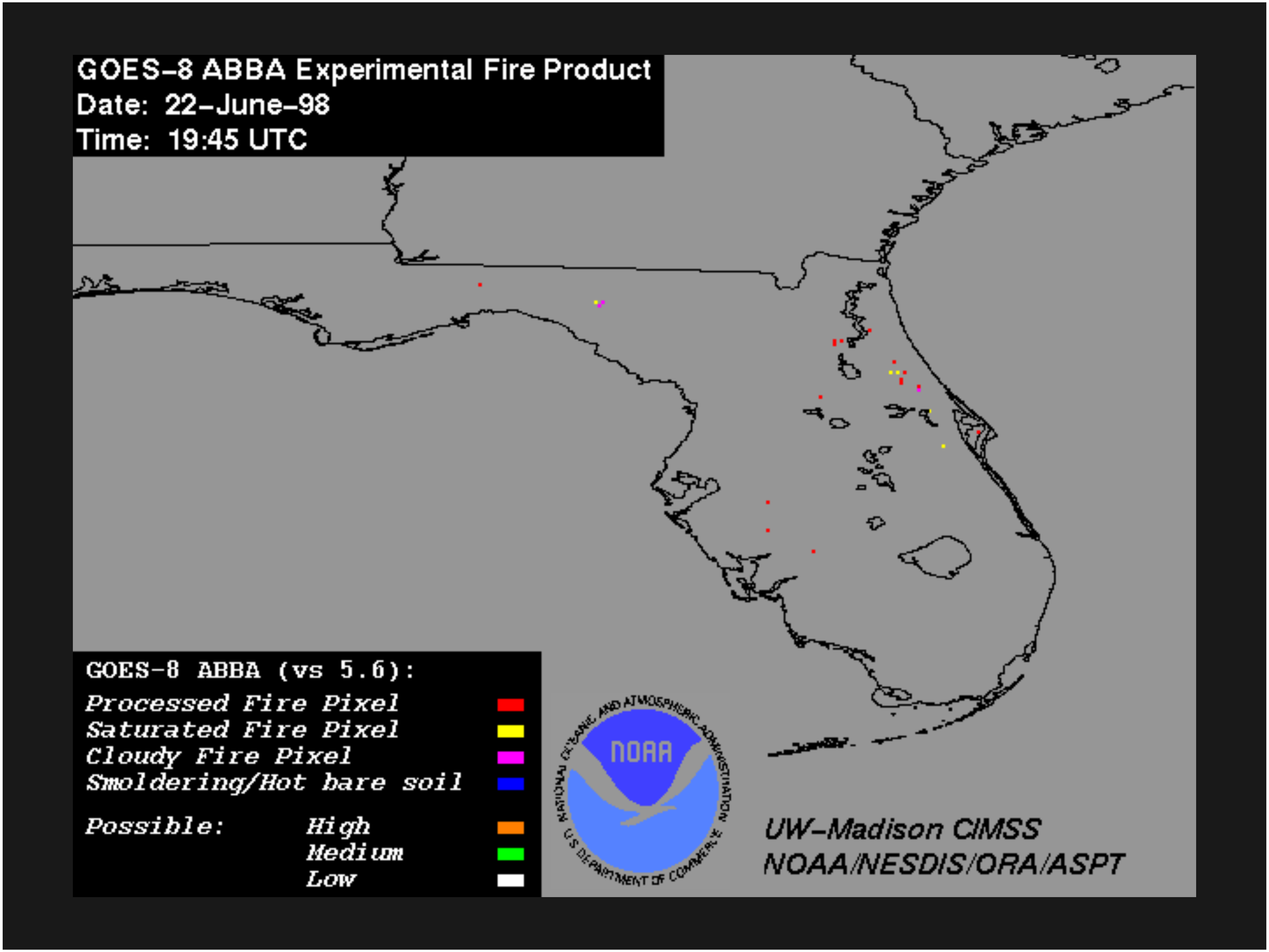
Burned Area in CAR and South Sudan
2004-2005 Fire Season
10°N
5°N
500 km (311 mi)
20°E
25°E
30°E

Some History

- Before MODIS, focus was largely on active fire detection
- Many different satellite sensors
  – AVHRR, ATSR, VIRS, DMSP, GOES
- Decent fire detection requires very specialized sensors
  – Exploit differential increase of black body radiance at 4 μm and 11 μm
  – Annoy other users not interested in fire!
  – Fire not "on the radar"

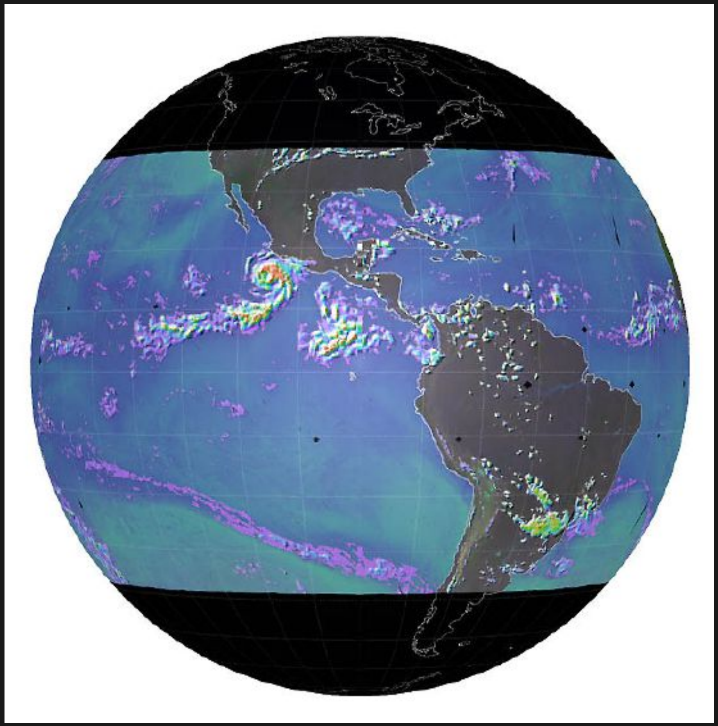
Heat signatures (red) and smoke (blue haze) from many areas of fire burning in Bolivia, Brazil and Paraguay.




GOES-8 ABBA Experimental Fire Product
Date: 22-June-98
Time: 19:45 UTC
GOES-8 ABBA (vs 5.6):
Processed Fire Pixel
Saturated Fire Pixel
Cloudy Fire Pixel
Smoldering/Hot bare soil
Possible: High
Medium
Low
NOAA
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
U.S. DEPARTMENT OF COMMERCE
UW-Madison CIMSS
NOAA/NESDIS/ORA/ASPT

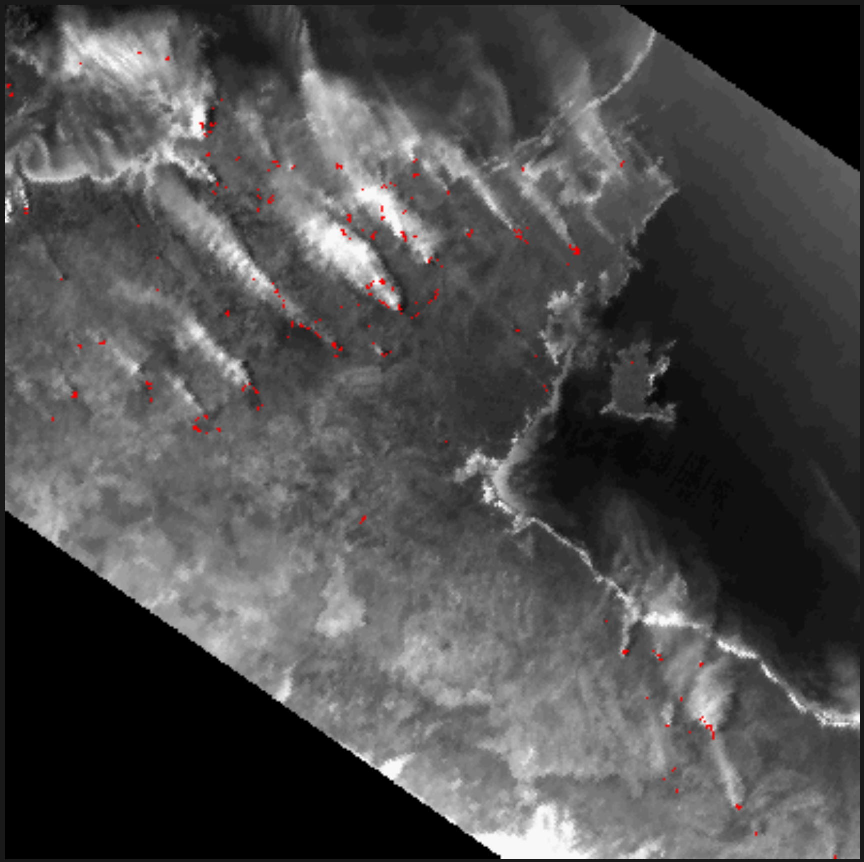
Tropical Rainfall Measuring Mission

- Nov. 1997 – June 2015
- Orbit precesses to capture diurnal variability of tropical rainfall
- Visible and Infrared Scanner (VIRS)
  - 5 channels (0.63, 1.6, 3.8, 10.8, 12.0 μm)
  - 2.1 km resolution



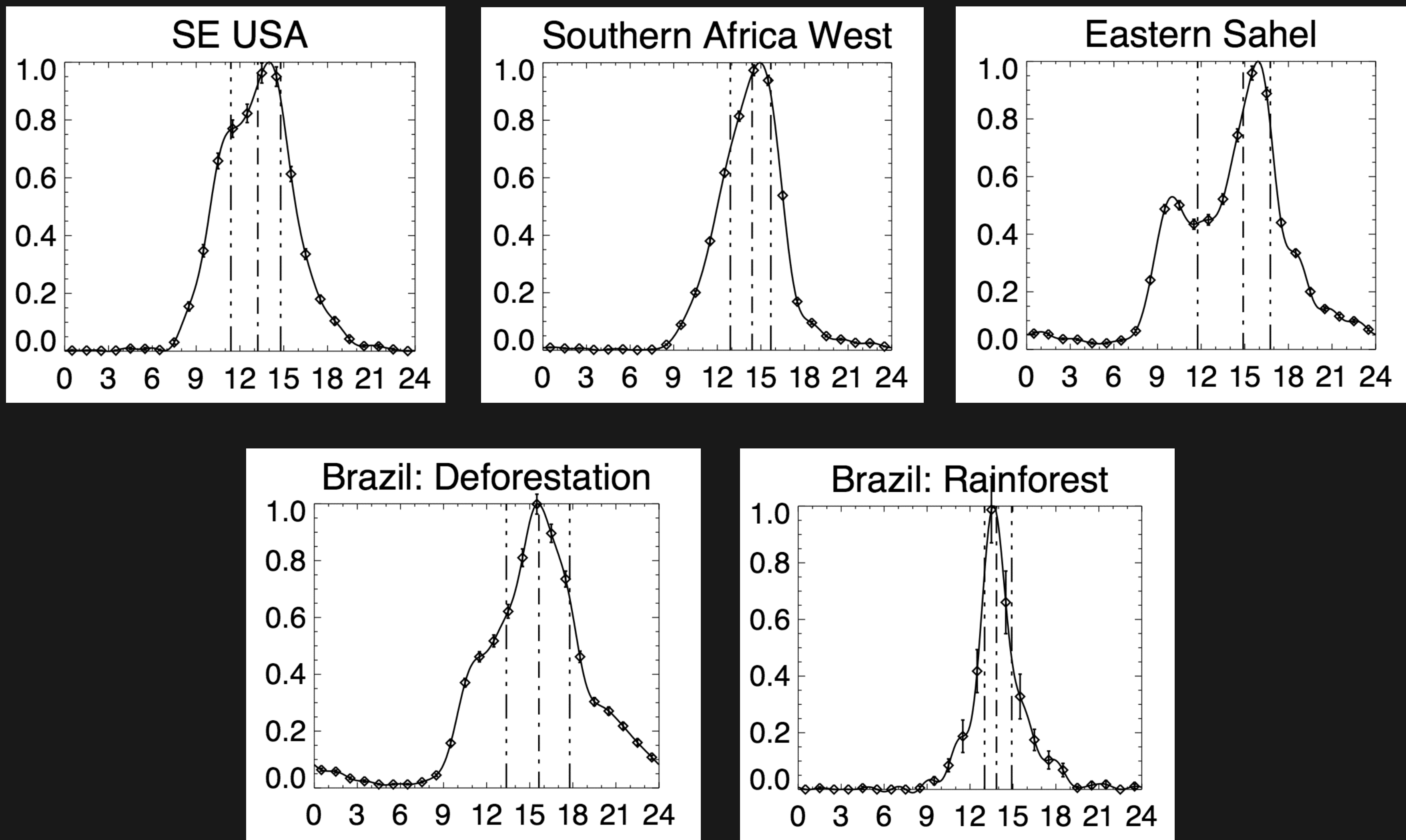
Two-Day Coverage

TRMM VIRS Fire Detection



VIRS 0.63 µm channel with active fire mask overlaid in red.

Northern Australia
29 August 1999



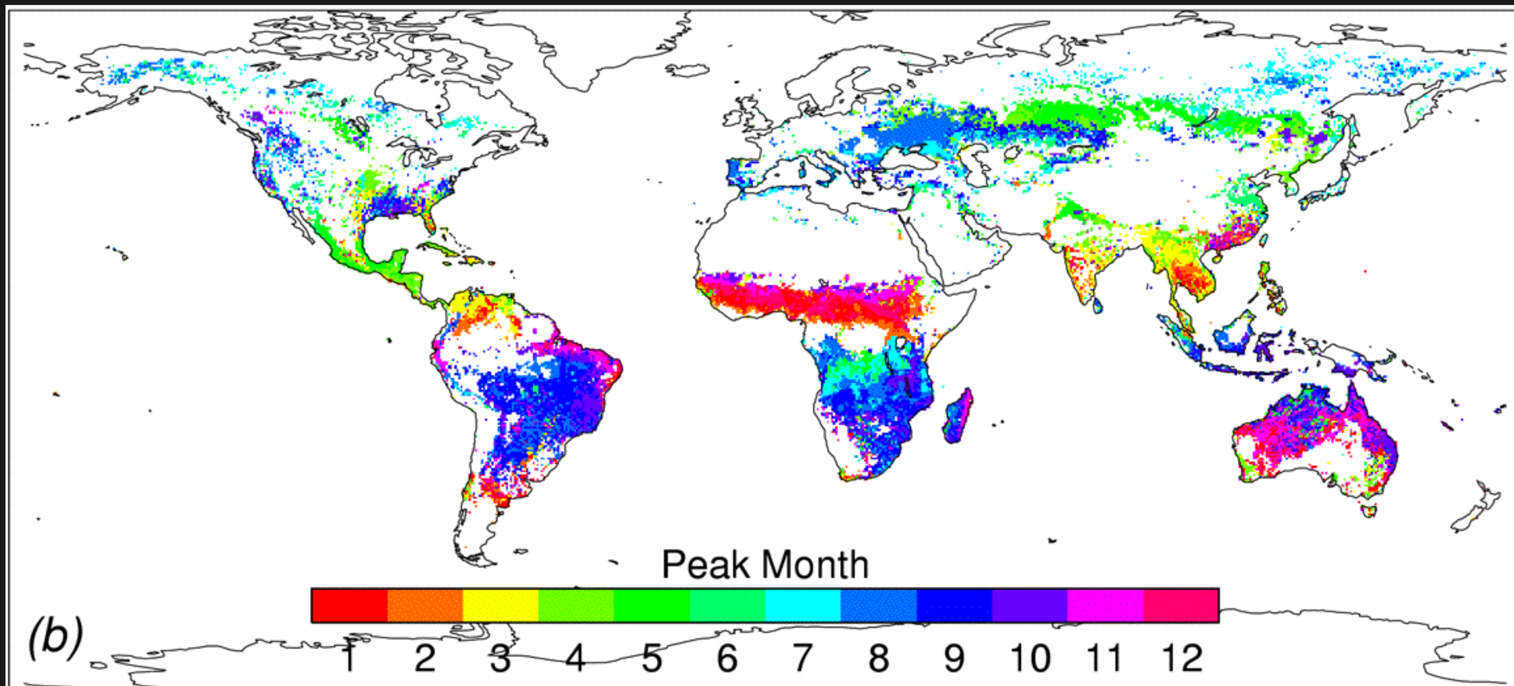
Local Hour   Local Hour

Giglio (2008)

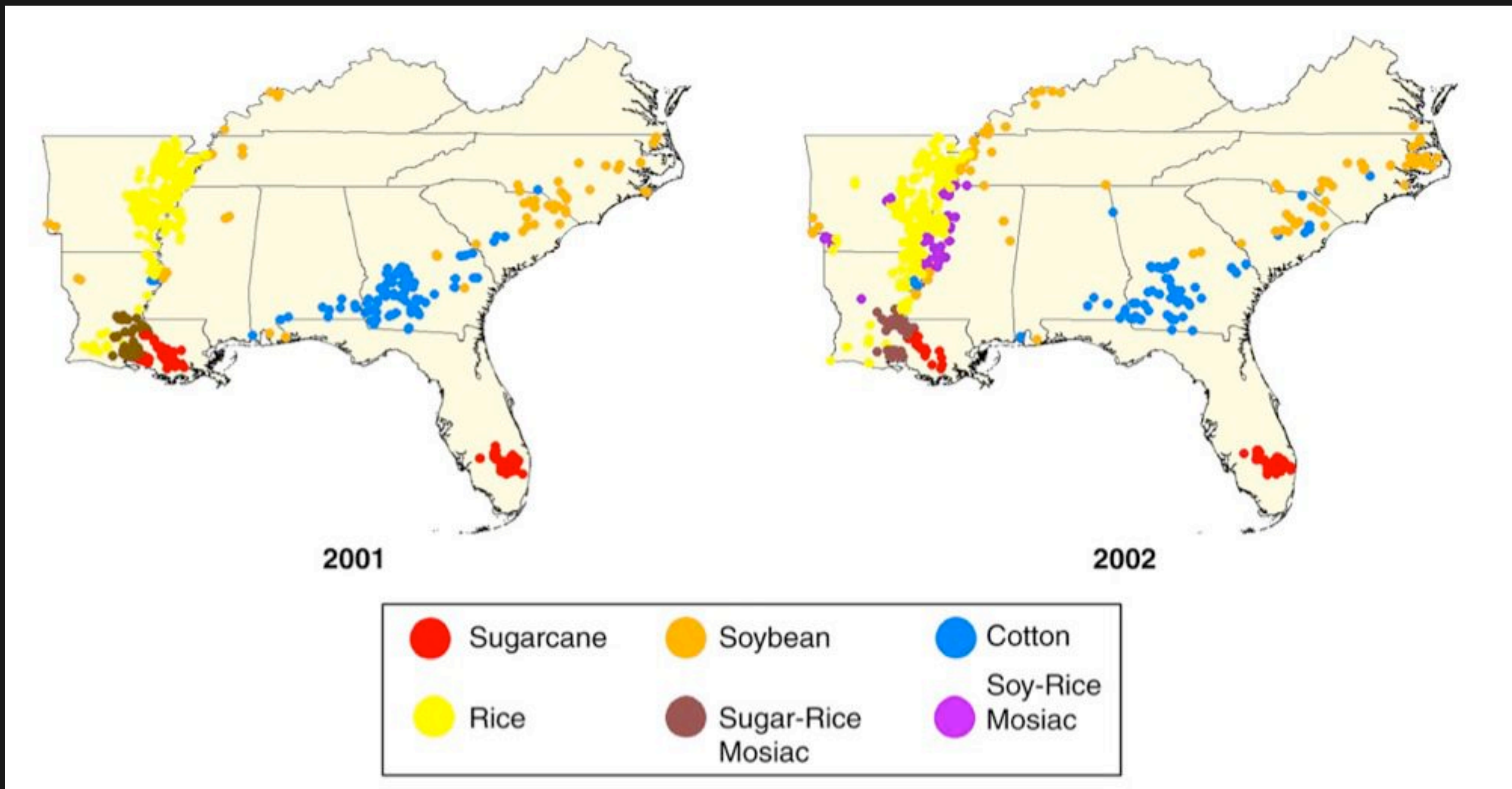
MODIS

- One of the few Earth Observation sensors built with fire observation capabilities
  - Spectral bands
    - specifically for observing active fires
    - useful for observing burned areas
  - Accurate and reliable calibration & geolocation
- Dedicated 1 km fire bands
  - Channel 21: 3.96 µm, ≈ 500 K saturation
  - Channel 22: 3.96 µm, ≈ 330 K sat. (multi-purpose)
  - Channel 31: 11.0 µm, ≈ 400 K saturation

Terra MODIS
Peak Fire Month



Giglio et al. (2006)



McCarty et al. (2007)

Fire Radiative Power (FRP)

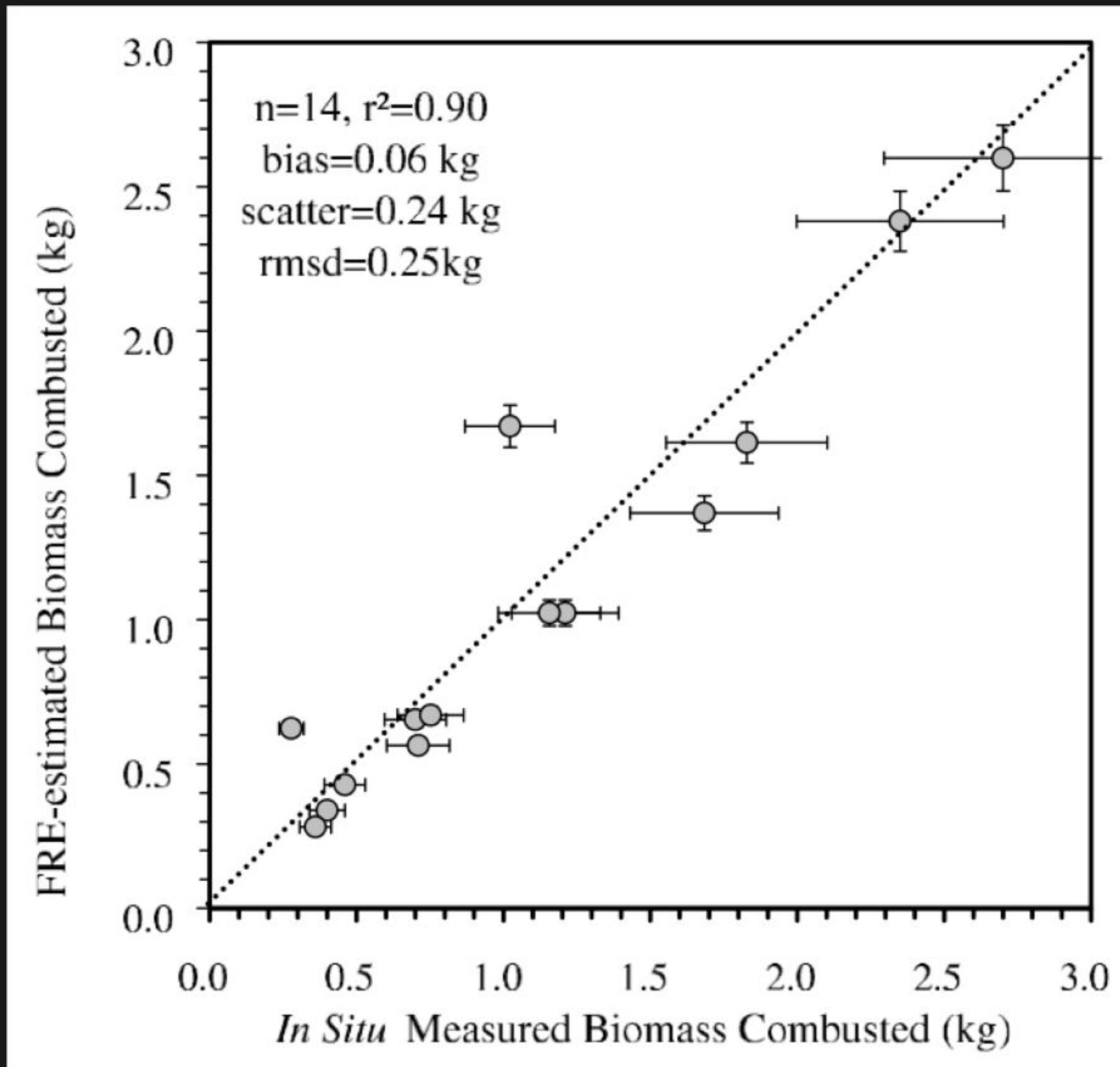
- Instantaneous rate of emission of electromagnetic energy released by combustion
  - Not all fire energy is released through this way
- Can be retrieved via remote sensing using a single ~4 µm channel
  - Exploits serendipitous characteristics of the Planck function
  - Kaufman et al. (1998), Wooster et al. (2003)

FRP Rationale

- Measure of fire intensity
  - This in itself has some value
- Proportional to rate of combustion (MT^{-1}) of fuel
- Integrating FRP over time yields *fire radiative energy* (FRE)
- FRE is proportional to the total mass of fuel consumed during combustion

FRP Rationale

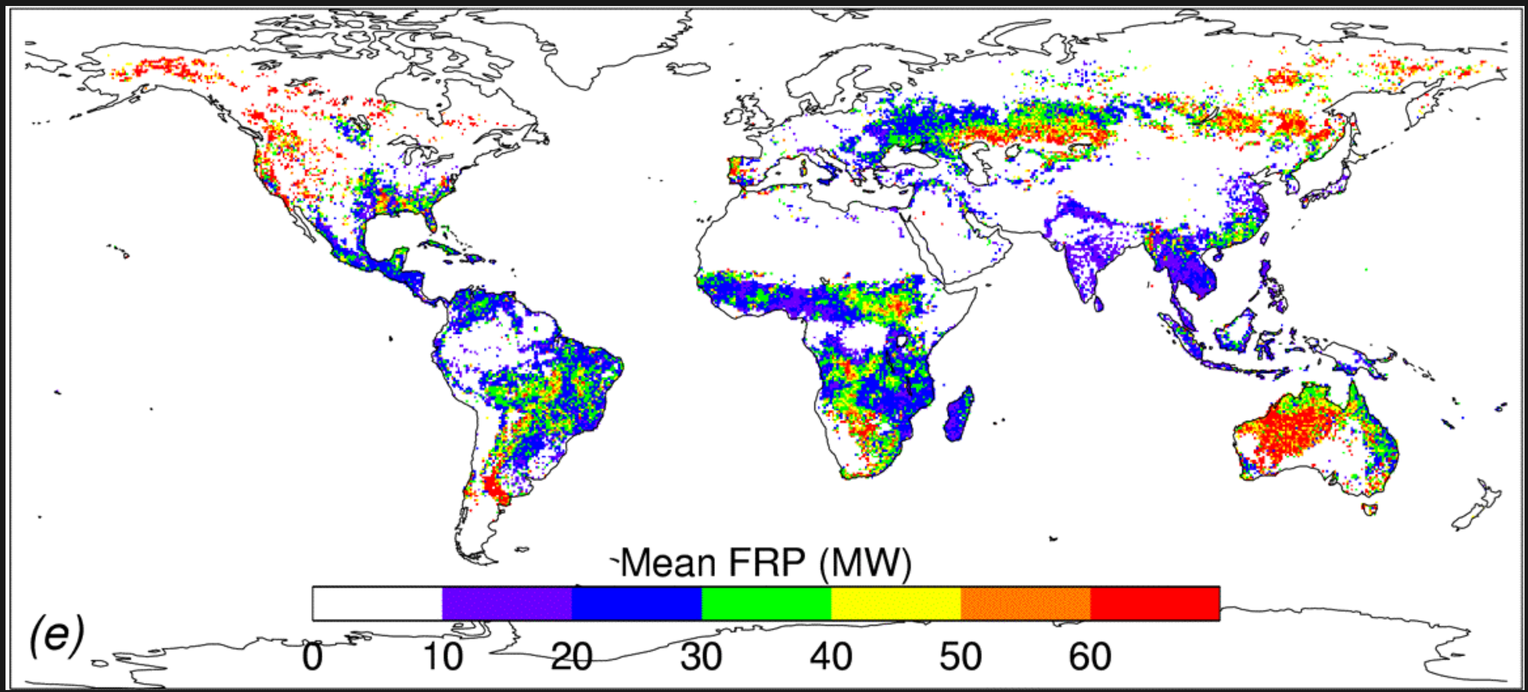
- FRE offers an appealing alternative to inventory-based methods for estimating fire emissions
  - Inventory-based methods require spatially-explicit maps of fuel load and combustion completeness



Small grassland test fires observed with ground-based mid-infrared camera.

Roberts et al. (2005)

Terra MODIS
Mean Fire Radiative Power

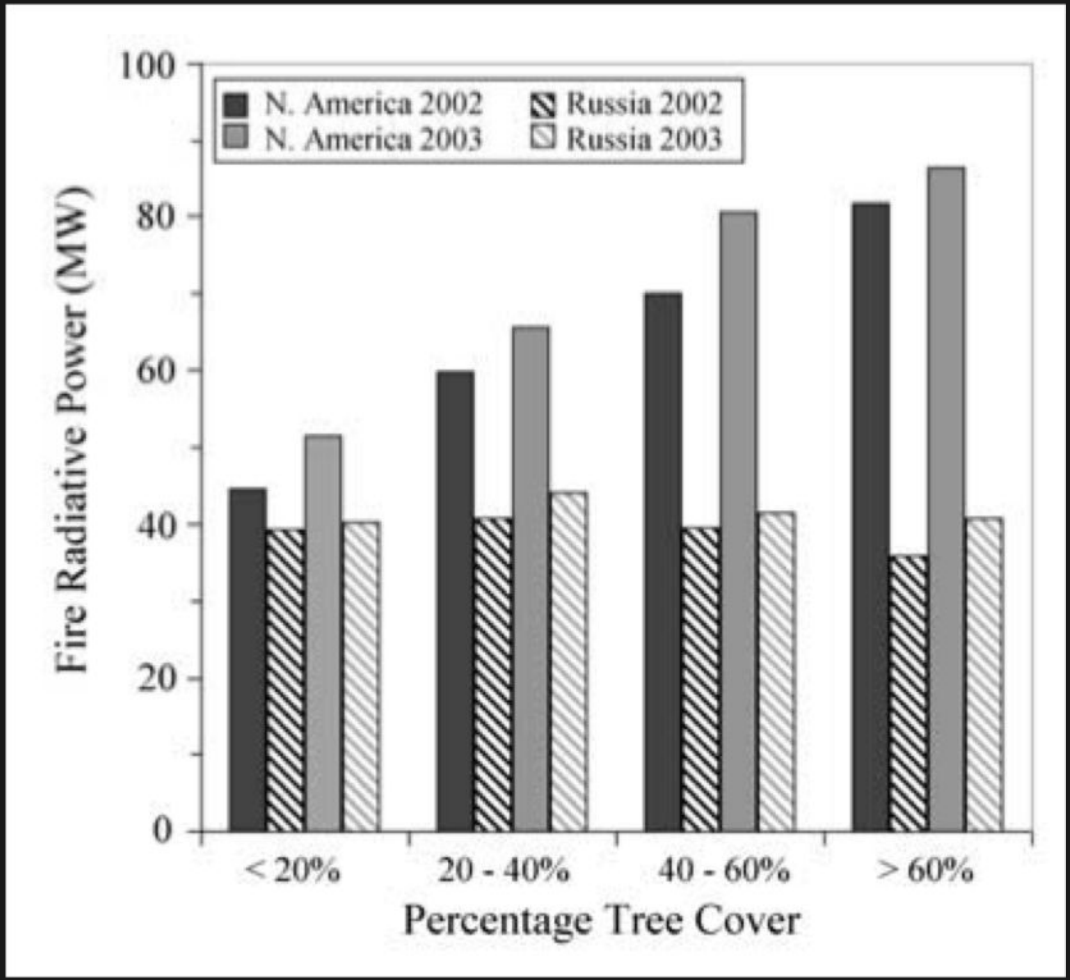


Giglio et al. (2006)

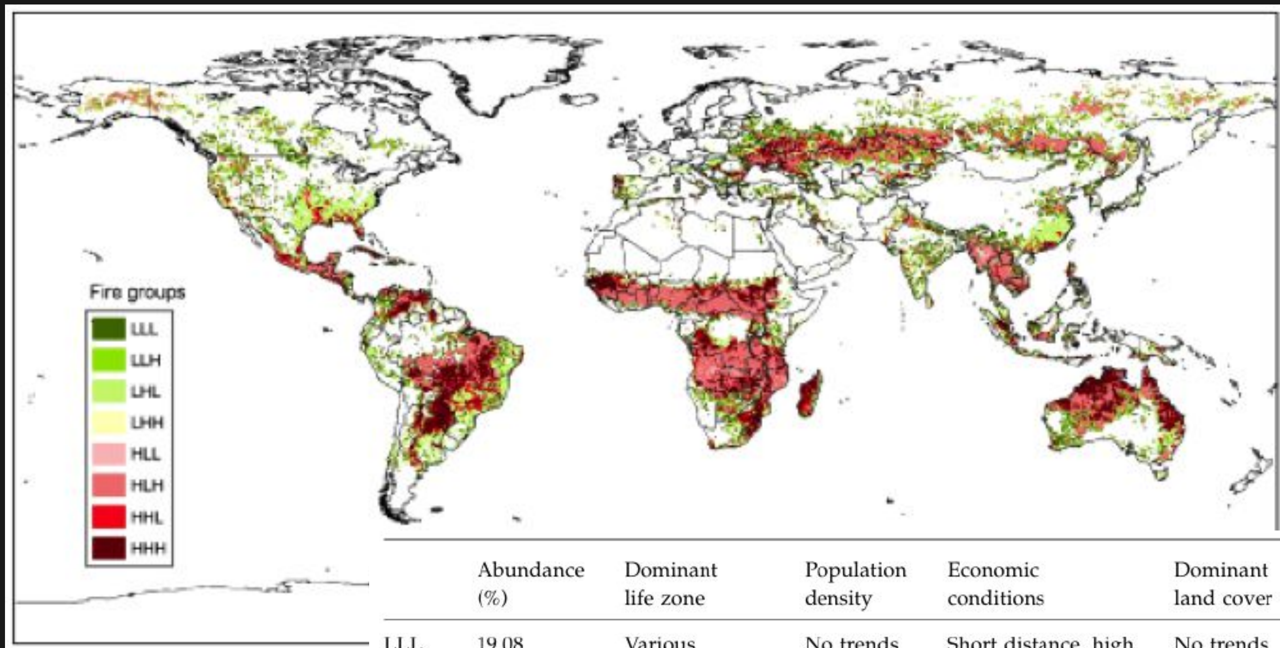
Boreal forest fires burn less intensely in Russia than in North America

M. J. Wooster[1] and Y. H. Zhang[1,2]

Received 22 June 2004; revised 18 August 2004; accepted 10 September 2004; published 26 October 2004.



Global Fire Regimes



	Abundance (%)	Dominant life zone	Population density	Economic conditions	Dominant land cover	Interpretation
LLL	19.08	Various	No trends	Short distance, high investment	No trends	Various fires in developed regions
LLH	6.16	Boreal	Low density	Long distance, low investment	Low crops Low grass	Boreal fires
LHL	20.64	Temperate and tropical wet	High density	Short distance, high investment	High crop	Agricultural fires in developed regions
LHH	1.27	Temperate	No trends	No trends	No trends	Various temperate
HLL	3.16	Various	No trends	No trends	No trends	Residual
HLH	24.17	Boreal and tropical	Lower densities	Long distance, low investment	Low crops, high grass	Boreal and savannas fires in low developed regions
HHL	5.98	Tropical wet	Higher densities	No trends	High crops and grass	Periodic tropical fires, agricultural and savannas
HHH	19.54	Tropical dry	Various	Long distance, low investment	High grass	Savannas and deforestation fires

Chuvieco et al. (2008)

VIIRS

- Visible Infrared Imaging Radiometer Suite (VIIRS)
- On Suomi-NPP and JPSS satellites
  – S-NPP launch 25 October 2011
- 22 bands
  – 750 m and 375 m spatial resolution
- Multi-agency JPSS legacy
  – $$$
  – complicated development and uptake of products

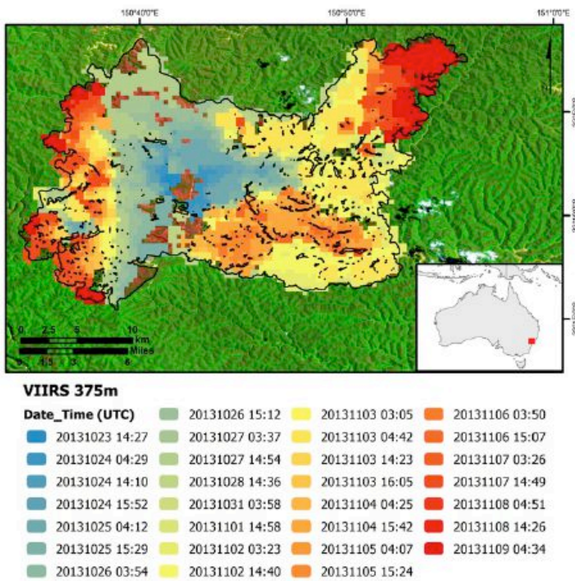
VIIRS Active Fire Data Status

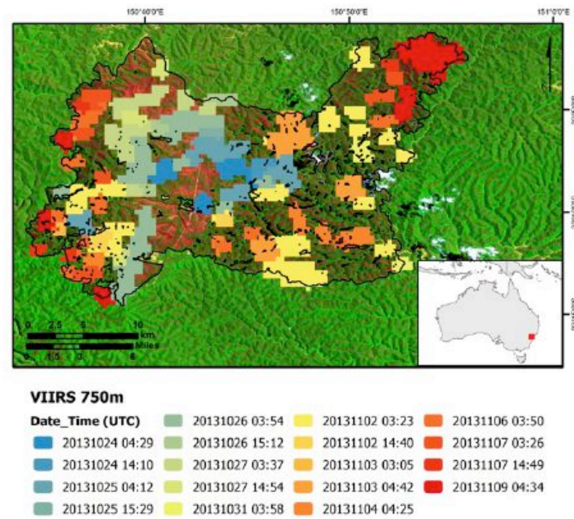
- NASA 750m product
    - Based on C6 MODIS fire algorithm
    - Running at Land SIPS (≈12h latency), incomplete/inconsistent record due to changes in input data and data retention
    - Available through NASA (**VNP14** product) and NOAA (**AF_v1r0_npp** product)
    - Also available through IPOPP direct readout data processing package

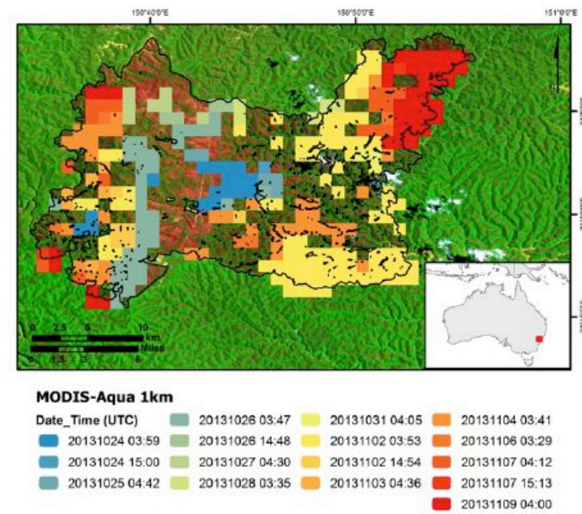
- NASA 375m product
    - Builds on MODIS fire product, customized for VIIRS 375m data characteristics
        - Running at Land SIPS (≈12h latency), incomplete/inconsistent archive due to changes in input data and data retention
        - Available through NASA (**VNP14IMG** product)
        - Running at LANCE, feeding FIRMS/Worldview since Dec 2015
        - Also available through through IPOPP direct readout data processing packages

- Data reprocessing tasks being implemented at NASA and NOAA
    - Should provide complete/consistent data record

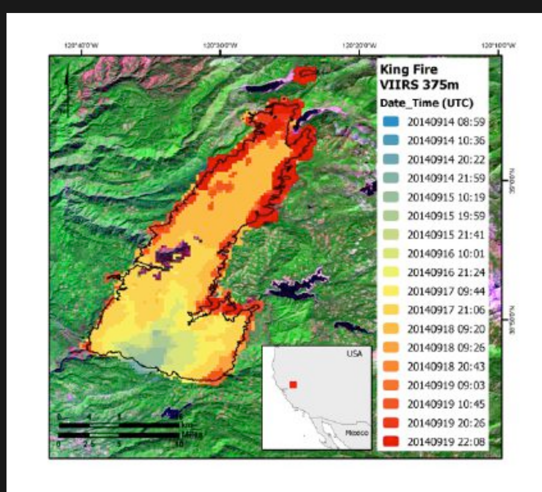
S-NPP/VIIRS 375 x 750m x Aqua/MODIS 1km Fire Detection Data Quick Comparison



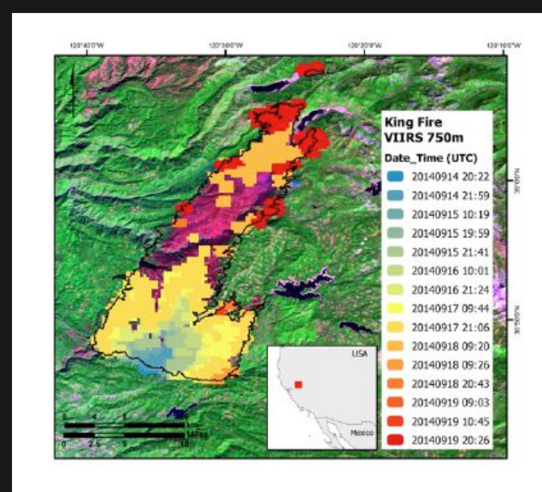




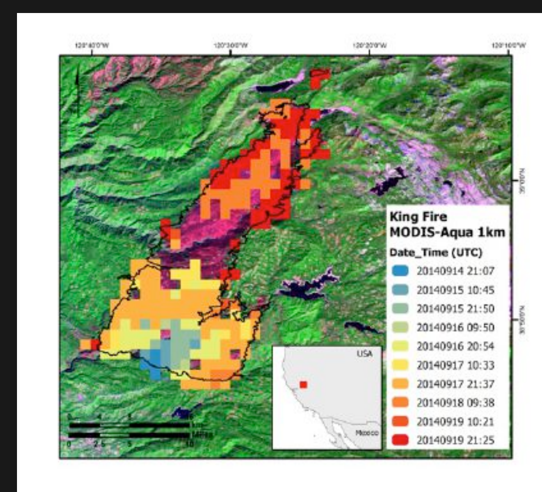
S-NPP/VIIRS 375 m



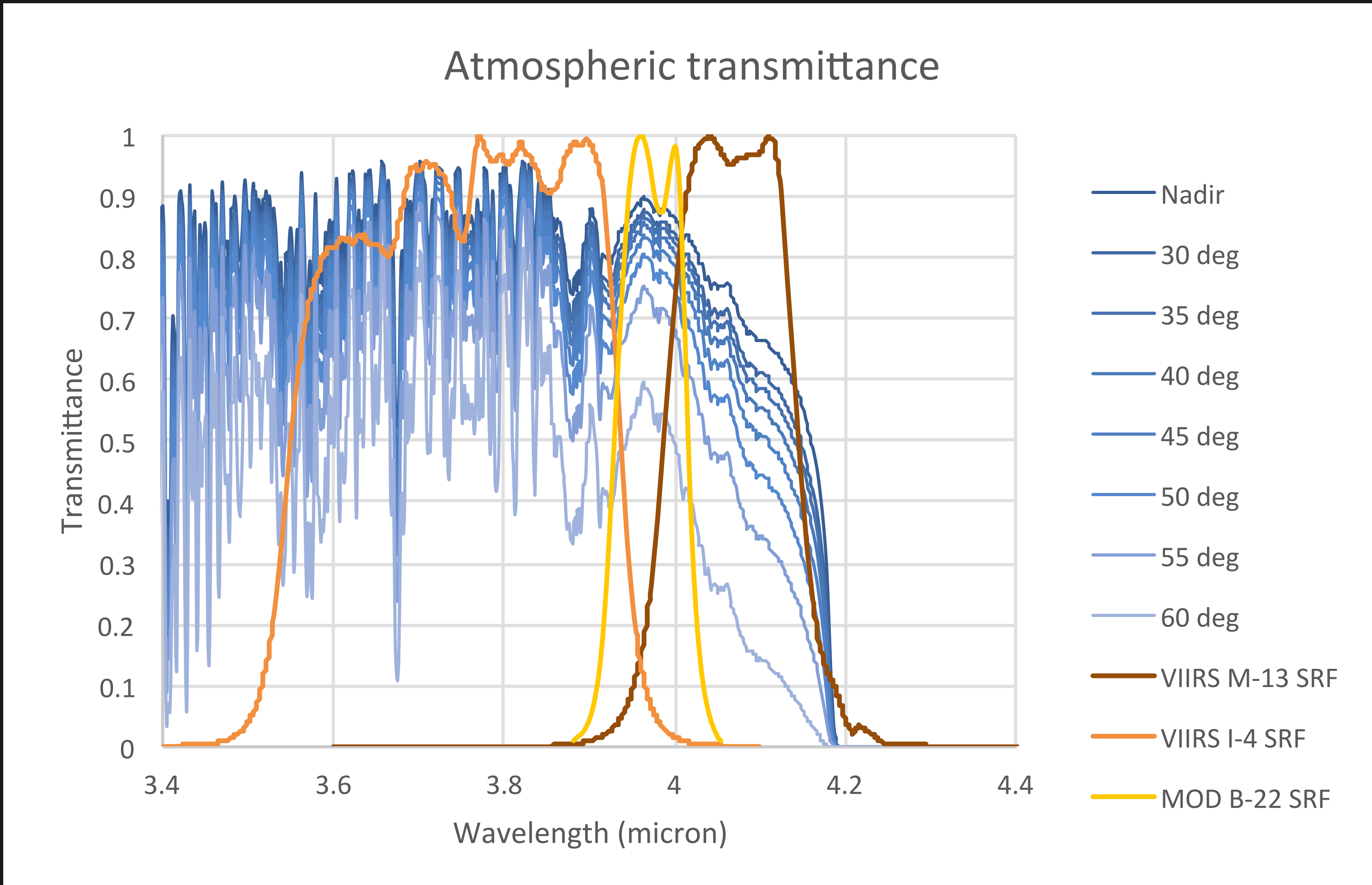
S-NPP/VIIRS 750 m



Aqua/MODIS 1 km



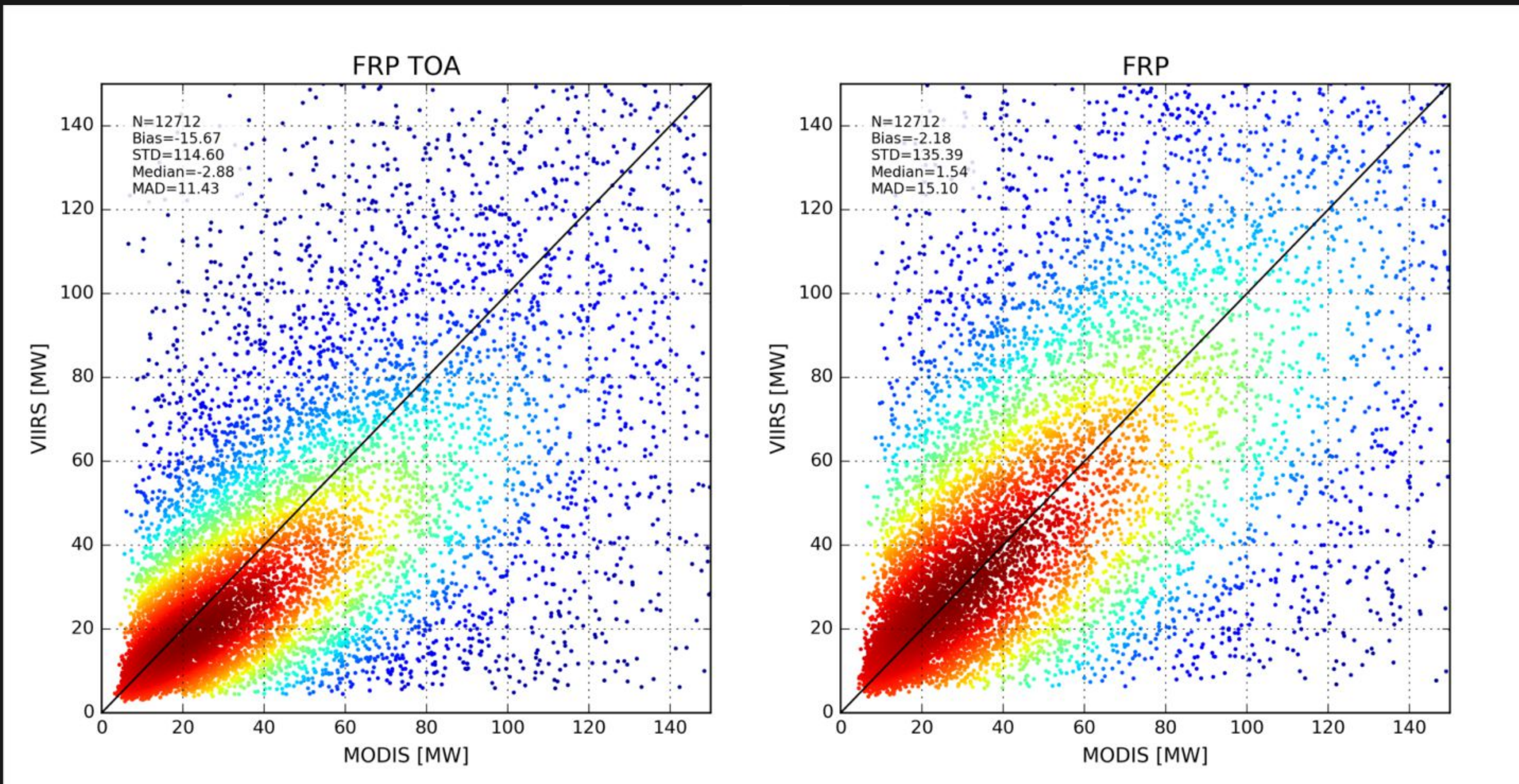
MODIS x VIIRS Mid-IR
Spectral Responses & Atmospheric Transmittance



W. Schroeder

Atmospheric Correction of MODIS and VIIRS

Implementing approach to correct Level 2 , 3, 4 products in support of data continuity
Currently running MODTRAN + MERRA-2 (0.625° x 0.5°)



Before atmospheric correction

After atmospheric correction

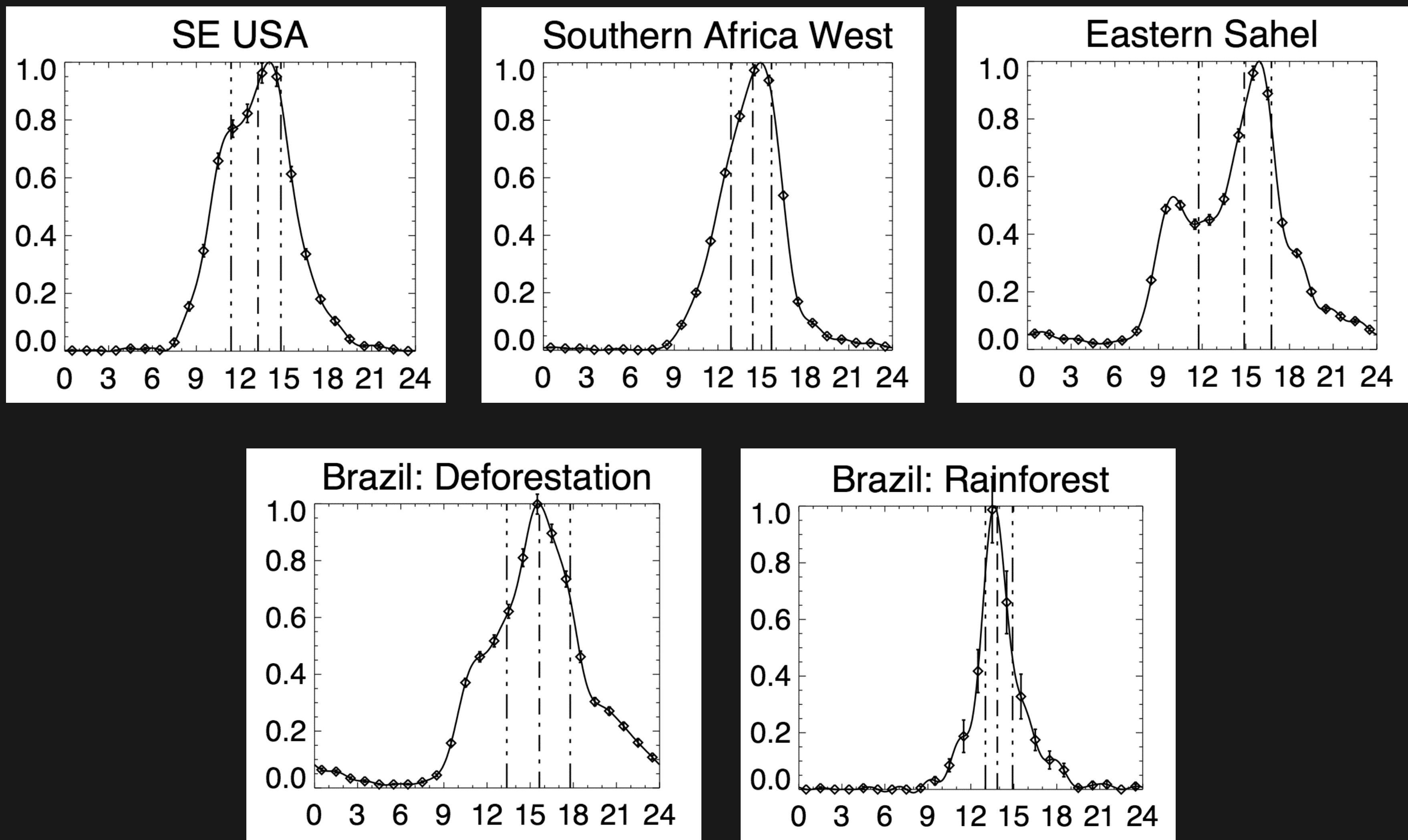
W. Schroeder

Long-Term ("Climate") Studies

- Often necessitate multiple satellite sensors
- Active fire signal generally sensitive to even small differences
  - Spatial resolution + temporal sampling
- Potentially FRP
  - Record commences with MODIS (late 2000)
- Burned area data often most appropriate
  - Continuity + Consistency
  - Cross-calibration generally more straightforward

Active Fire Detections (Millions)

Year	Terra + Aqua MODIS 1 km	S-NPP VIIRS 750 m	S-NPP VIIRS 375 m
2018	4.21	9.22	38.26
2017	4.48	9.78	40.02
2016	4.44	10.01	40.60
2015	4.77	10.48	42.79
2014	4.46	9.90	40.20
2013	4.25	9.56	38.64



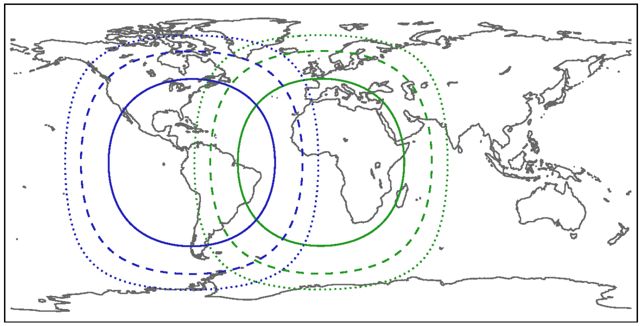
Local Hour Local Hour

Giglio (2008)

Geostationary Satellite Active Fire Products

- **Advanced Baseline Imager (ABI)** on board NOAA GOES-16 (launched November 2016)
- **Spinning Enhanced Visible and Infra-Red Imager (SEVIRI)** on board ESA Meteosat Second Generation (MSG) satellite series (multiple launch dates)

	GOES-16 ABI	MSG SEVIRI
Product	Fire Detection and Characterization (FDC; Schmidt et al., 2012)	Fire Radiative Power (FRP-PIXEL; Wooster et al., 2015)
Spatial Resolution	2km at nadir	3km at nadir
Temporal Resolution	Full Disk: 15 minutes CONUS: 5 minutes	Full Disk: 15 minutes Europe: 5 minutes
Active Fire Product Values	10(30) = processed 11(31) = saturated 12(32) = cloudy 13(33) = high prob. 14(34) = med prob. 15(35) = low prob.	Fire Confidence (0 – 100%)



Solid, dashed, dotted lines indicate the boundaries at which the area of the pixel footprint grows to a factor of 2, 4, and 8 times larger than at the sub-satellite point.

Geostationary Fire Product Validation Summary

14,032 LS8 images were coincident* with MSG

5,760 LS8 images were coincident* with GOES-16

* Within 5 (or 6) minutes separation from mid-scan

	GOES-16 ABI FDC	**MSG SEVIRI FRP-PIXEL**
Validation Date Range	18 Jul 2018 – 30 Sep 2018 (87 days)	1 Nov 2017 – 28 Feb 2018 (120 days)
Total number of pixels sampled (includes fire/non-fire/land/water/clouds)	43,113	300,945
Total number of non-fire pixels with coincident reference fire activity (omissions)	36,384 (84%)	295,227 (98%)
Pixels flagged as fire with coincident reference fire activity (true positives)	1527 (23%)	5,261 (92%)
Pixels flagged as fire without coincident reference fire activity (false positives)	5214 **(77%)**	457 **(8%)**

Geostationary Fire Product Validation Summary

Int J Appl Earth Obs Geoinformation 83 (2019) 101928

Contents lists available at ScienceDirect

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Int J Appl Earth Obs Geoinformation

journal homepage: www.elsevier.com/locate/jag

Validation of GOES-16 ABI and MSG SEVIRI active fire products

J.V. Hall[a,*], R. Zhang[a], W. Schroeder[b], C. Huang[a], L. Giglio[a]

[a] University of Maryland, Department of Geographical Sciences, College Park, MD, USA
[b] NOAA/NESDIS/OSPO Satellite Analysis Branch, College Park, MD, USA

coincident reference fire activity (**omissions**)	36,384 (84%)	295,227 (98%)
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Long-Term ("Climate") Studies

- Often necessitate multiple satellite sensors
- Active fire signal generally sensitive to even small differences
  - Spatial resolution
  - Temporal sampling
- Burned area data records generally more appropriate
  - Continuity + Consistency
  - Cross-calibration generally more straightforward

Geophysical Research Letters

RESEARCH LETTER
10.1029/2019GL083469

Key Points:
- Burned area in Africa declined by 18.5% (51.9 Mha) from 2002–2016
- The majority of the decline (35.4 Mha) occurred in noncropland areas
- 71.2% of the decline in noncropland burned area can be explained by changes in effective rainfall

Supporting Information:
- Supporting Information S1
- Table S1
- Table S5
- Table S6

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Changes in Fire Activity in Africa from 2002 to 2016 and Their Potential Drivers

Maria Zubkova[1], Luigi Boschetti[1], John T. Abatzoglou[2], and Louis Giglio[3]

[1]Department of Natural Resources and Society, University of Idaho, Moscow, ID, USA, [2]Department of Geography, University of Idaho, Moscow, ID, USA, [3]Department of Geographical Sciences, University of Maryland, College Park, MD, USA

Abstract While several studies have reported a recent decline in area burned in Africa, the causes of this decline are still not well understood. In this study, we found that from 2002 to 2016 burned area in Africa declined by 18.5%, with the strongest decline (80% of the area) in the Northern Hemisphere. One third of the reduction in burned area occurred in croplands, suggesting that changes in agricultural practices (including cropland expansion) are not the predominant factor behind recent changes in fire extent. Linear models that considered interannual variability in climate factors directly related to biomass productivity and aridity explained about 70% of the decline in burned area in natural land cover. Our results provide evidence that despite the fact that most fires are human-caused in Africa, increased terrestrial moisture during 2002–2016 facilitated declines in fire activity in Africa.

GLOBAL FIRE ACTIVITY

A human-driven decline in global burned area

N. Andela,[1,2]* D. C. Morton,[1] L. Giglio,[3] Y. Chen,[2] G. R. van der Werf,[4] P. S. Kasibhatla,[5] R. S. DeFries,[6] G. J. Collatz,[1] S. Hantson,[7] S. Kloster,[8] D. Bachelet,[9] M. Forrest,[10] G. Lasslop,[8] F. Li,[11] S. Mangeon,[12] J. R. Melton,[13] C. Yue,[14] J. T. Randerson[2]

Fire is an essential Earth system process that alters ecosystem and atmospheric composition. Here we assessed long-term fire trends using multiple satellite data sets. We found that global burned area declined by 24.3 ± 8.8% over the past 18 years. The estimated decrease in burned area remained robust after adjusting for precipitation variability and was largest in savannas. Agricultural expansion and intensification were primary drivers of declining fire activity. Fewer and smaller fires reduced aerosol concentrations, modified vegetation structure, and increased the magnitude of the terrestrial carbon sink. Fire models were unable to reproduce the pattern and magnitude of observed declines, suggesting that they may overestimate fire emissions in future projections. Using economic and demographic variables, we developed a conceptual model for predicting fire in human-dominated landscapes.

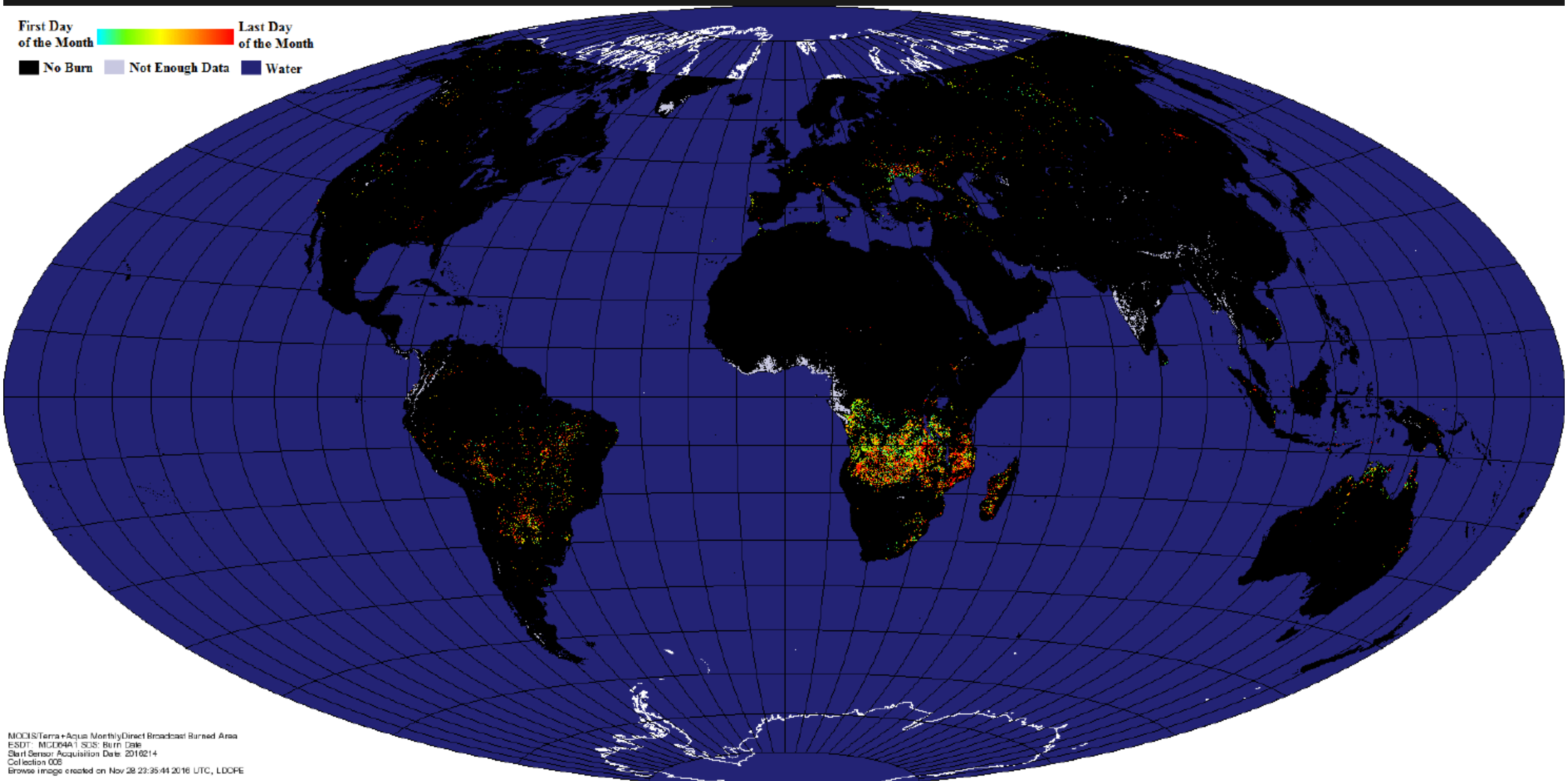
MODIS Burned Area Product

- MCD64A1
  - 500 m, daily
  - MODIS collection 5.1 and 6
  - Maps burns using surface reflectance + active fire information
  - November 2000 - present

MODIS Collection 6 Burned Area Products

MCD64A1	500-m Monthly
MCD64A1-based GIS Products (SCF)	Shapefiles + 500-m GeoTIFF
MCD64CMQ (SCF)	0.25° Monthly

August 2016 C6 MCD64A1 Global Browse



http://landweb.nascom.nasa.gov/cgi-bin/browse/browseMODIS.cgi

VIIRS Collection 1 Burned Area Products

VNP64A1	500-m Monthly
VNP64A1-based GIS Products (SCF)	Shapefiles + 500-m GeoTIFF
VNP64CMQ (SCF)	0.25° Monthly

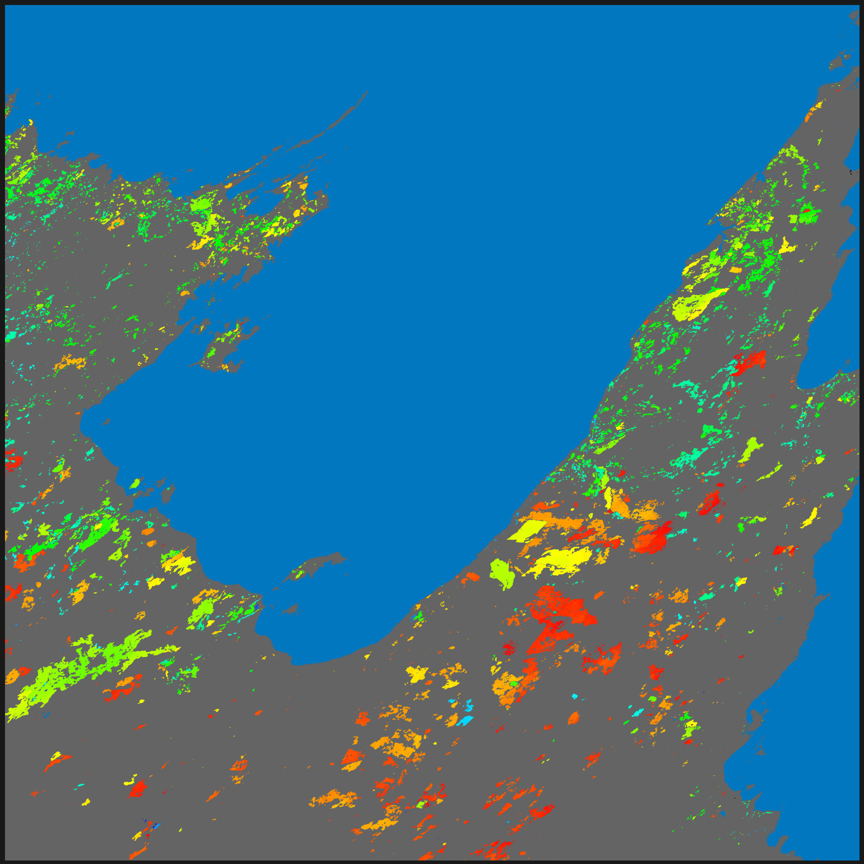
VIIRS Burned Area Product Status

- Adapted MCD64 production code to use VIIRS data
  - 750-m versus 375-m bands
- Retained 500-m grid for MODIS compatibility
- Tuned* operational code finally running in NASA land production system
  - Collection 1 product generated September 2019
- Collection 2 reprocessing imminent

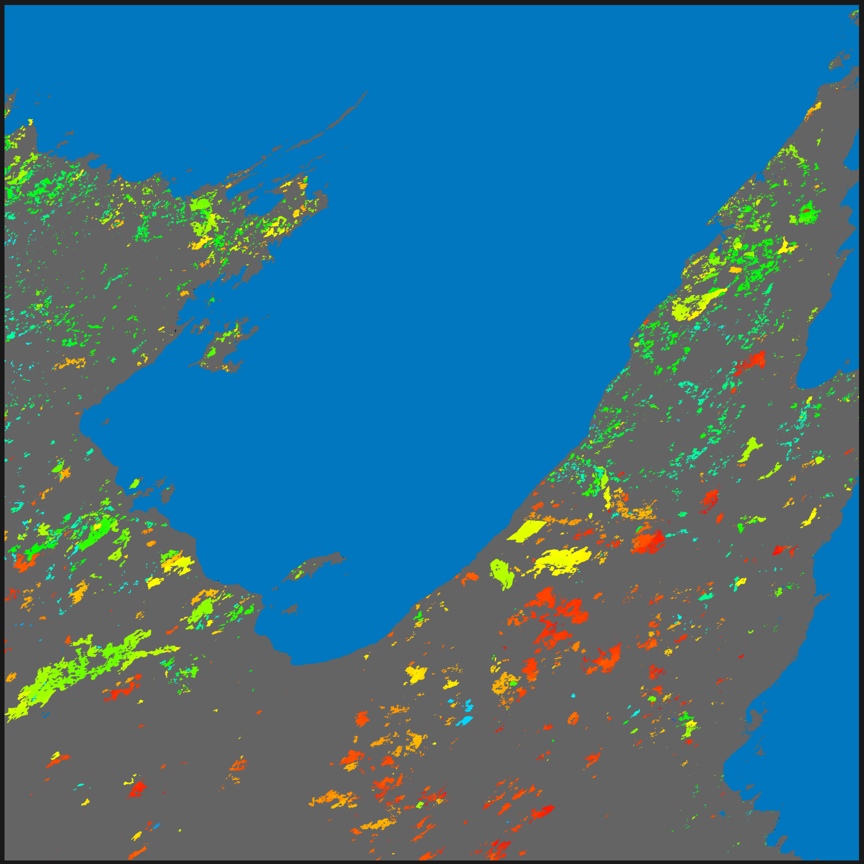
2017 Cumulative Burned Area

MODIS Tile h31v10 (Northern Australia)

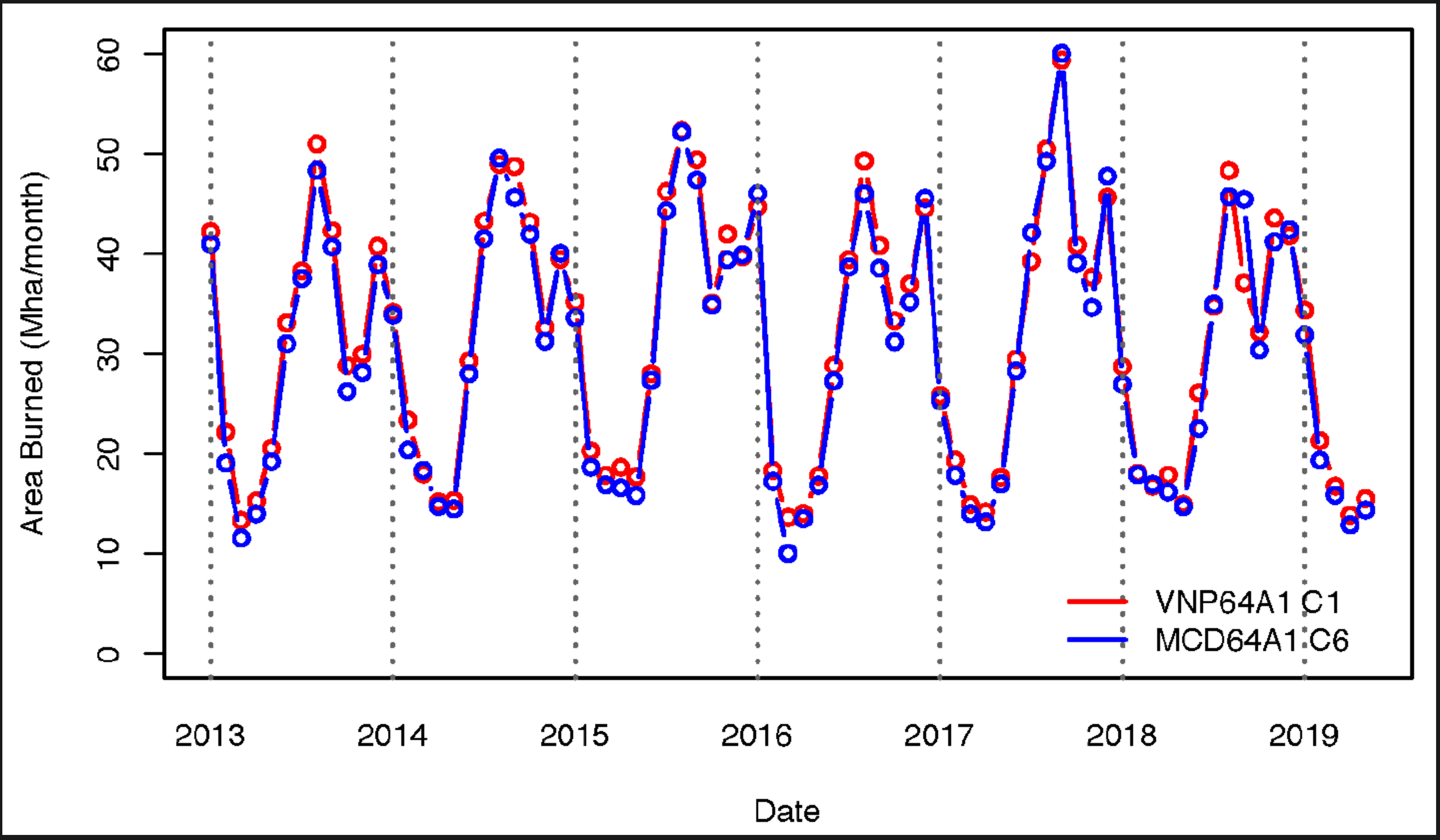
MODIS



VIIRS

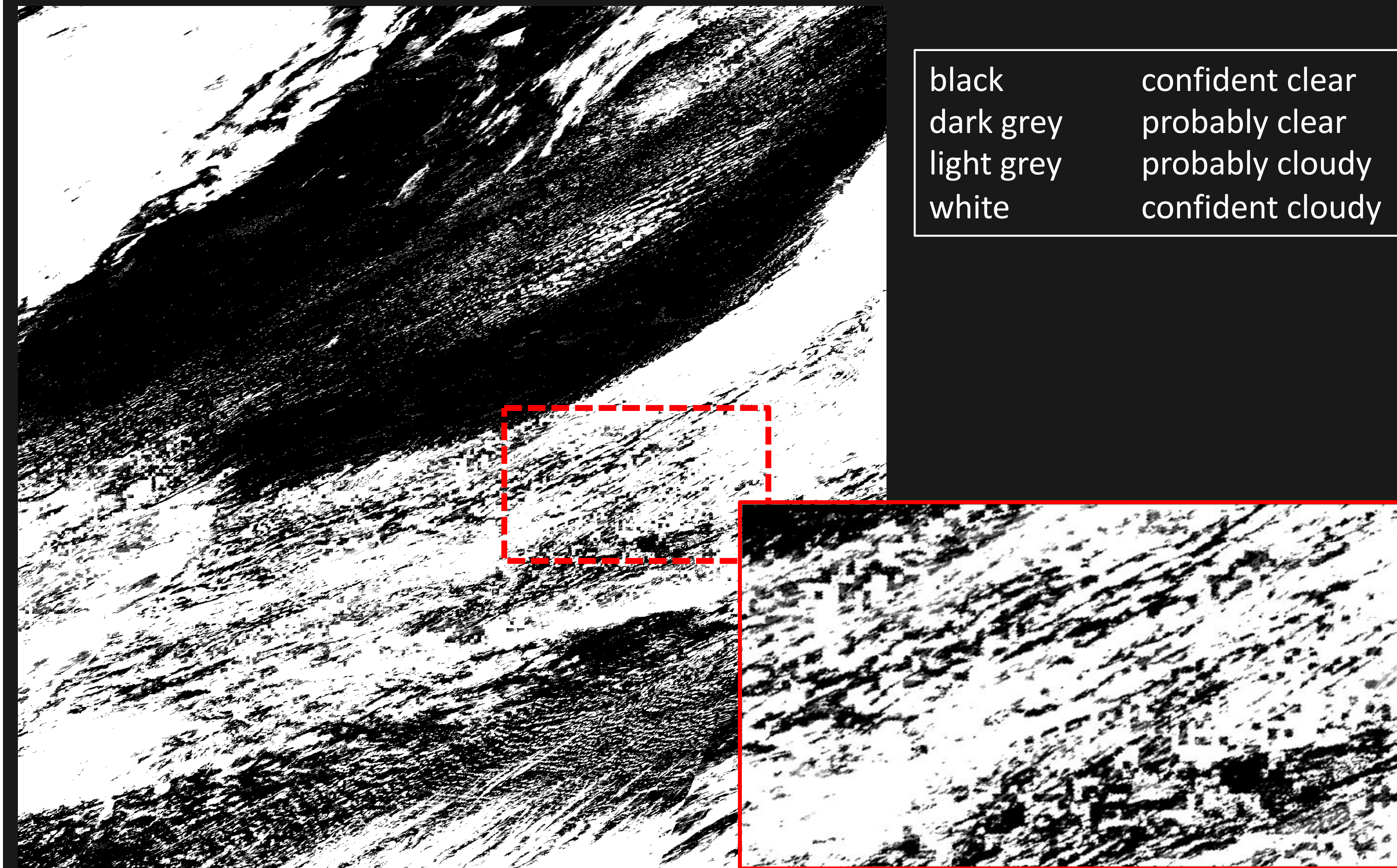


Monthly Global Burned Area



Cloud Mask Example

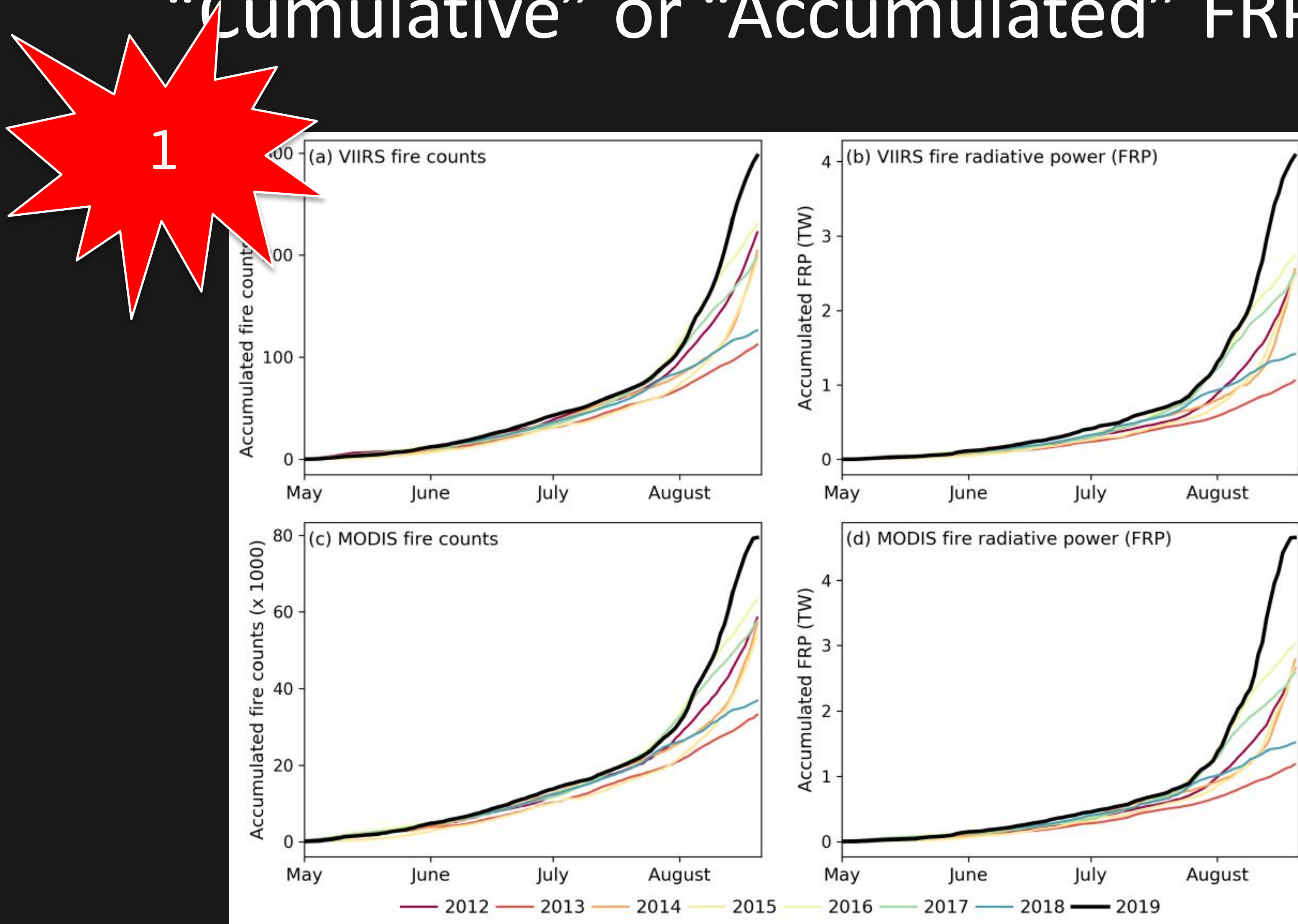
VNP09GHKM.A2016232.h12v03.001.2019133144101



black	confident clear
dark grey	probably clear
light grey	probably cloudy
white	confident cloudy

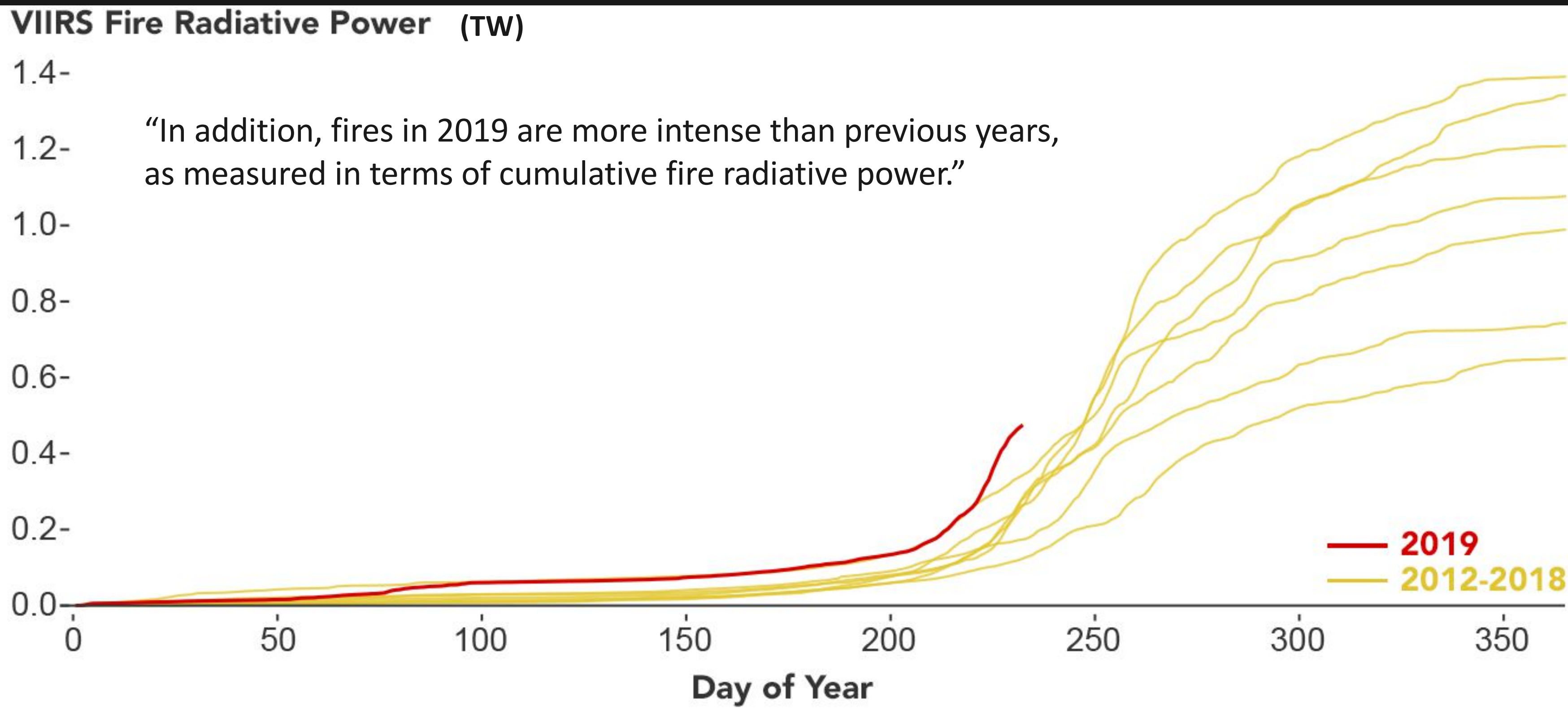
"...Use and Abuse"

“Cumulative” or “Accumulated” FRP



https://www.globalfiredata.org/forecast.html

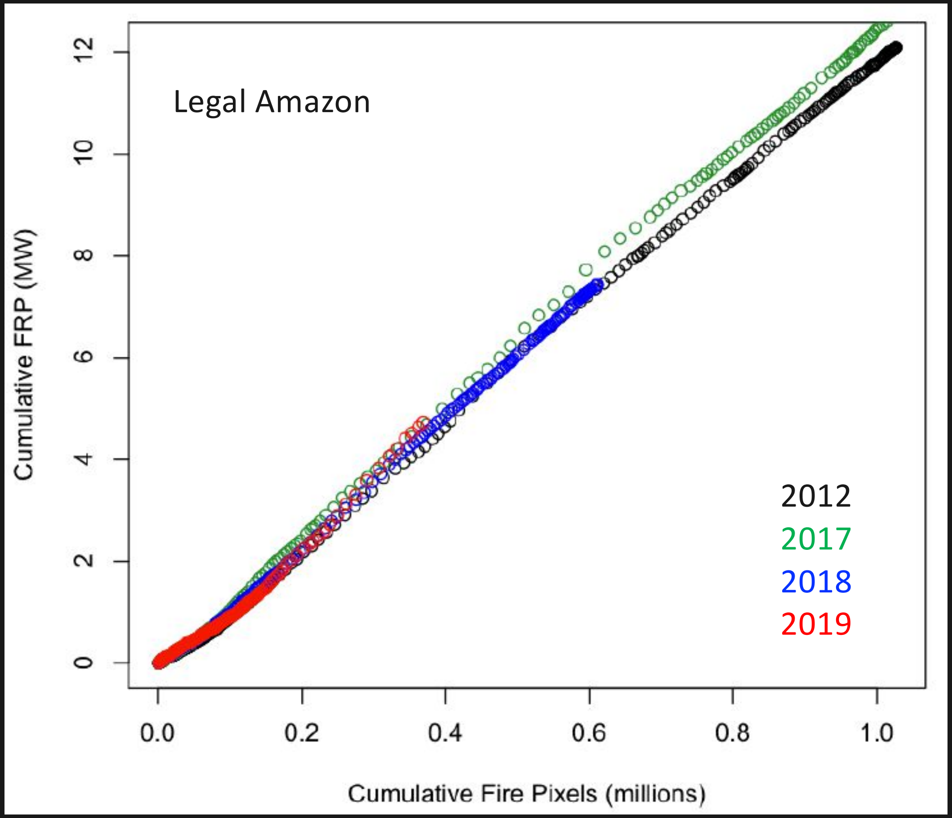
https://www.earthobservatory.nasa.gov/images/145498/uptick-in-amazon-fire-activity-in-2019



“In addition, fires in 2019 are more intense than previous years, as measured in terms of cumulative fire radiative power.”

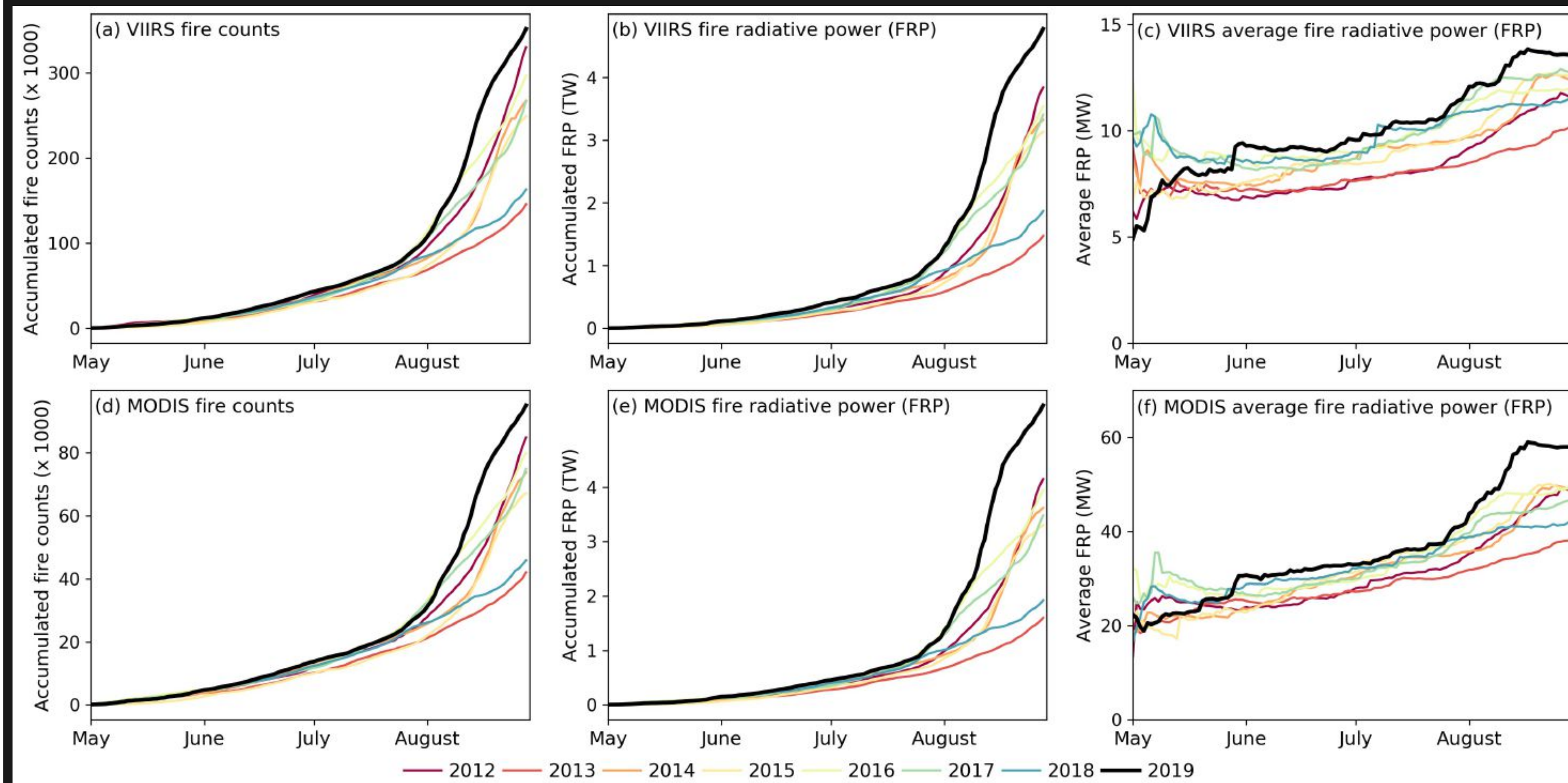
https://www.earthobservatory.nasa.gov/images/145498/uptick-in-amazon-fire-activity-in-2019

"Cumulative" or "Accumulated" FRP



Plot: Cumulative FRP vs.
Cumulative Fire Pixels

- No meaningful physical interpretation
  - Analogous to "cumulative speed"
- Largely duplicates information provided by cumulative fire pixel counts



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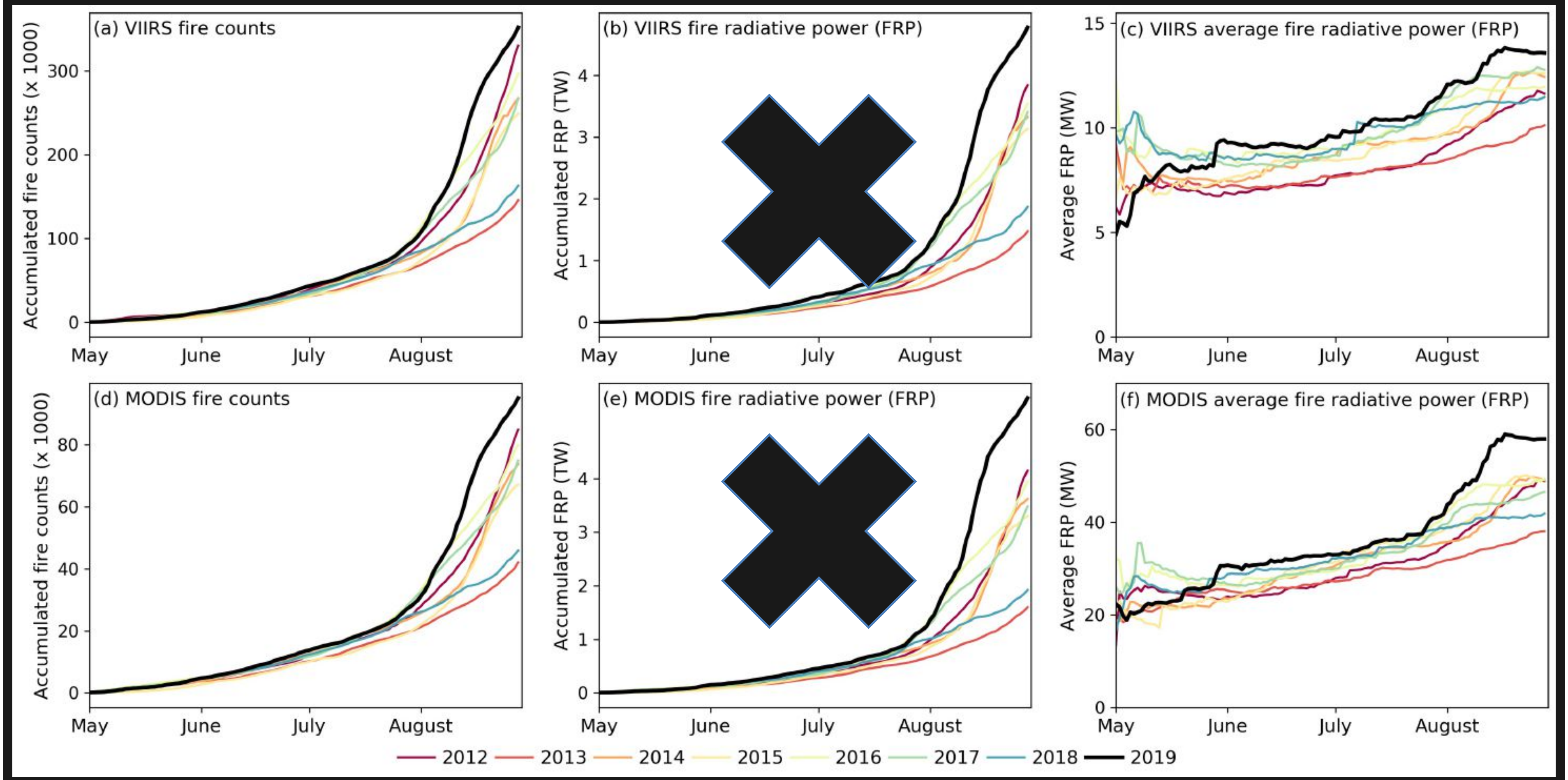

https://www.globalfiredata.org/forecast.html

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RNAL OF GEOPHYSICAL RESEARCH, VOL. 117, G04012, doi:10.1029/2012JG002128, 2012

Global burned area and biomass burning emissions from small fires

J. T. Randerson,[1] Y. Chen,[1] G. R. van der Werf,[2] B. M. Rogers,[1] and D. C. Morton[3]

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[1] In several biomes, including croplands, wooded savannas, and tropical forests, many small fires occur each year that are well below the detection limit of the current generation of global burned area products derived from moderate resolution surface reflectance imagery. Although these fires often generate thermal anomalies that can be detected by satellites, their contributions to burned area and carbon fluxes have not been systematically quantified across different regions and continents. Here we developed a preliminary method for combining 1-km thermal anomalies (active fires) and 500 m burned area observations from the Moderate Resolution Imaging Spectroradiometer (MODIS) to estimate the influence of these fires. In our approach, we calculated the number of

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Global fire emissions estimates during 1997–2016

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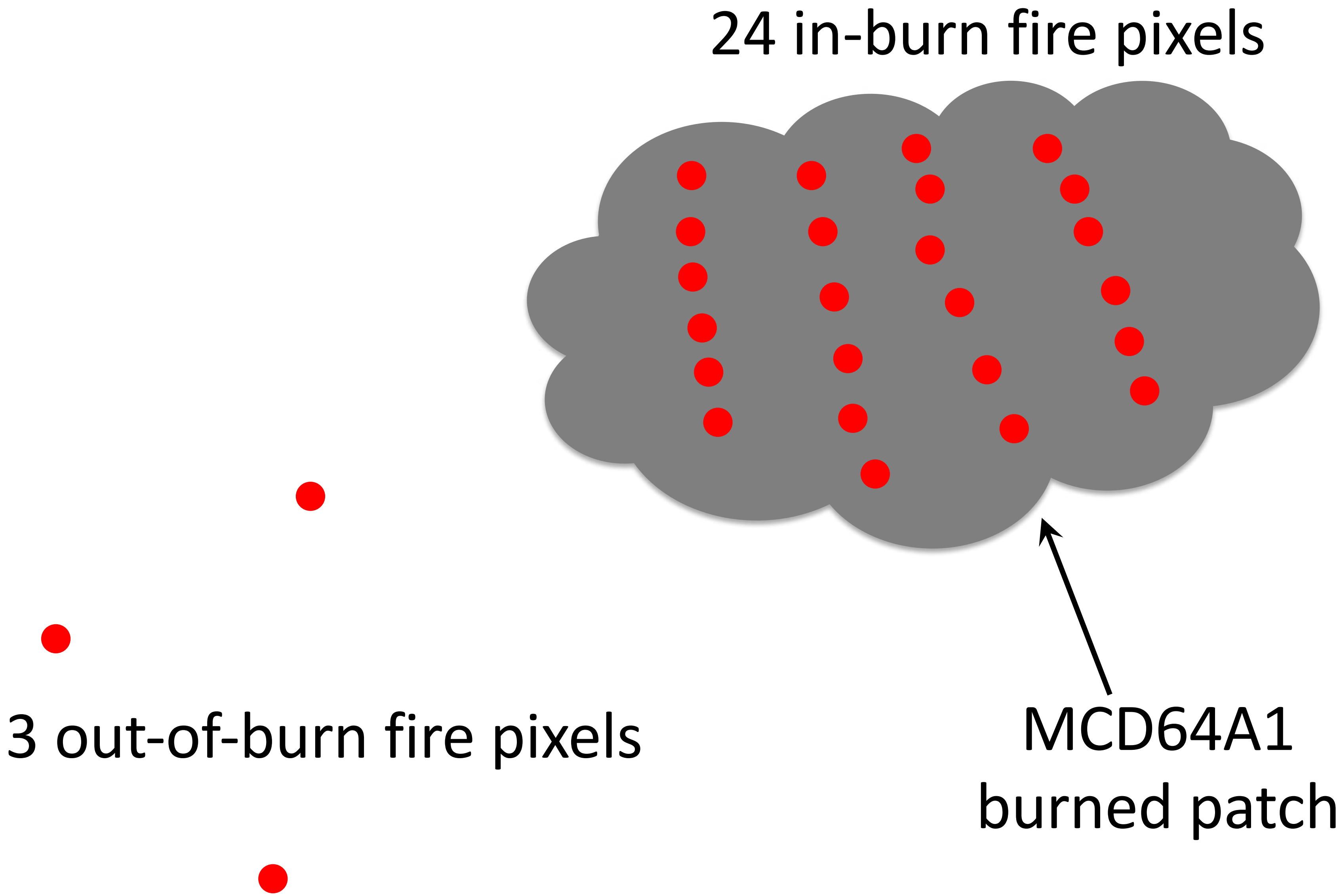
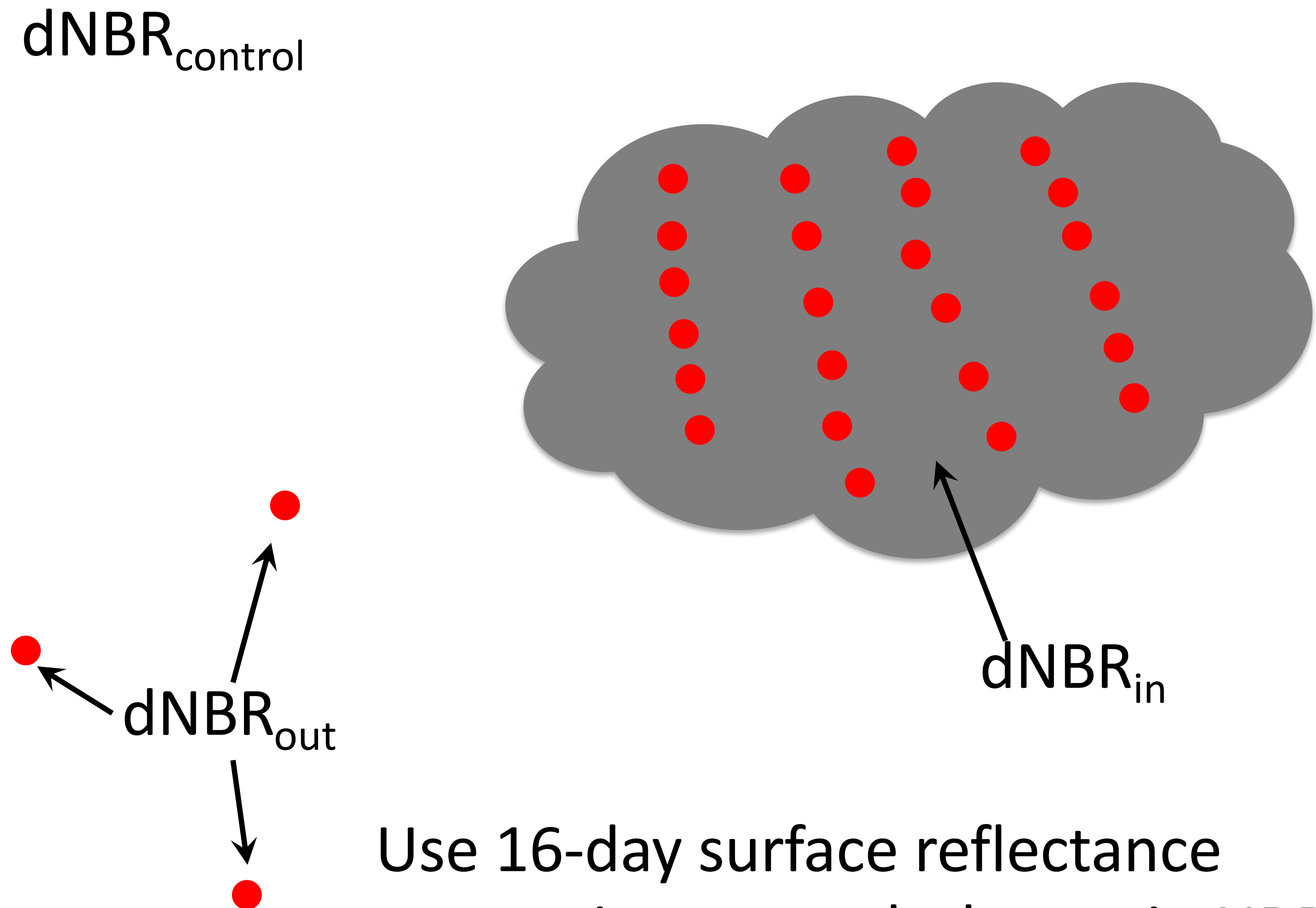

24 in-burn fire pixels
3 out-of-burn fire pixels
MCD64A1
burned patch



Use 16-day surface reflectance composites to track change in NBR.

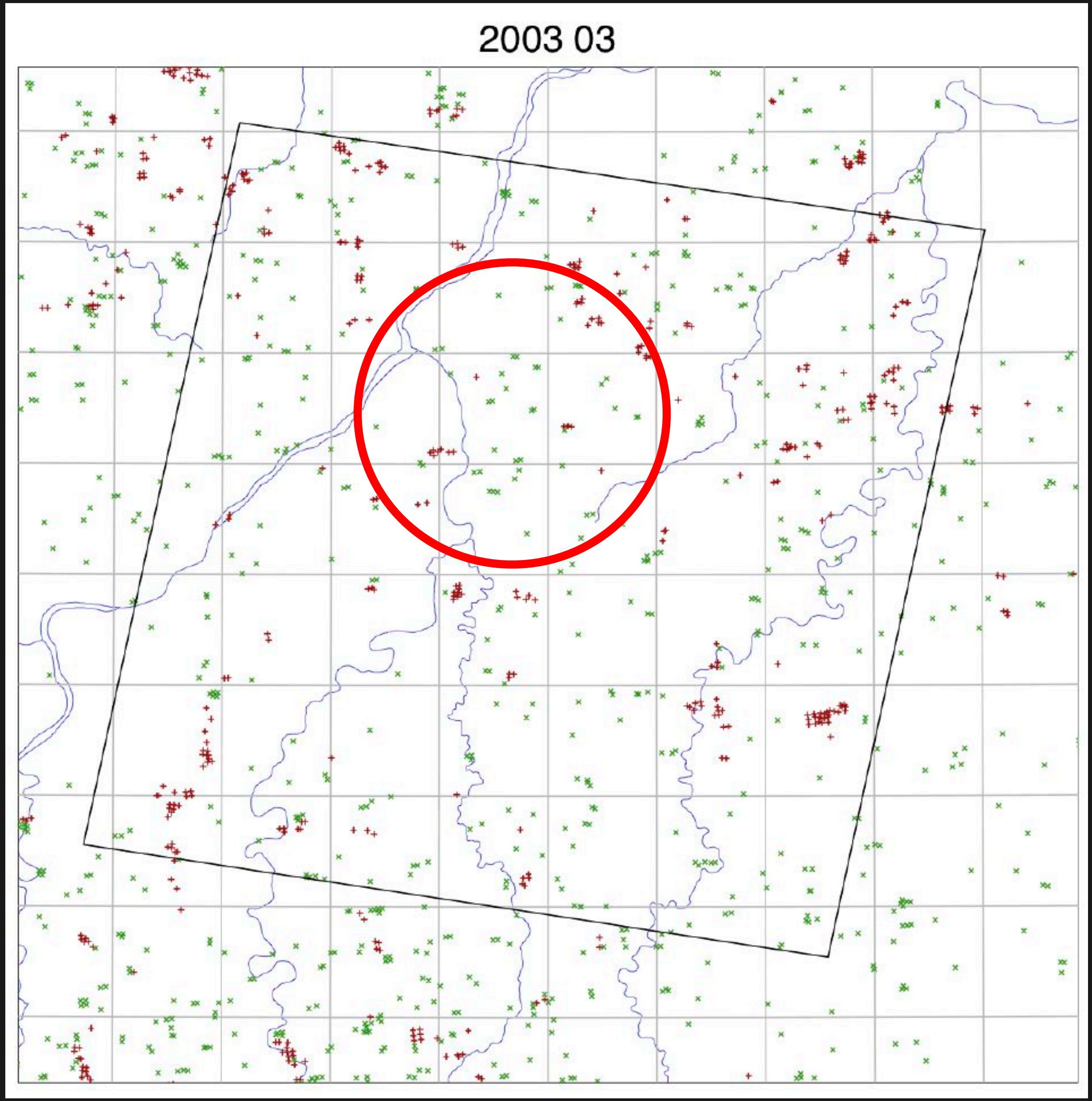
Problems

- Ignores impact of MODIS triangular response
- Ignores impact of resampling error associated with MODIS sinusoidal grid
  - Moves edges and small features, alters shapes
- Ignores impact of compositing
  - Can move, shrink, expand features
- Others
  - Particularly applicable to cropland

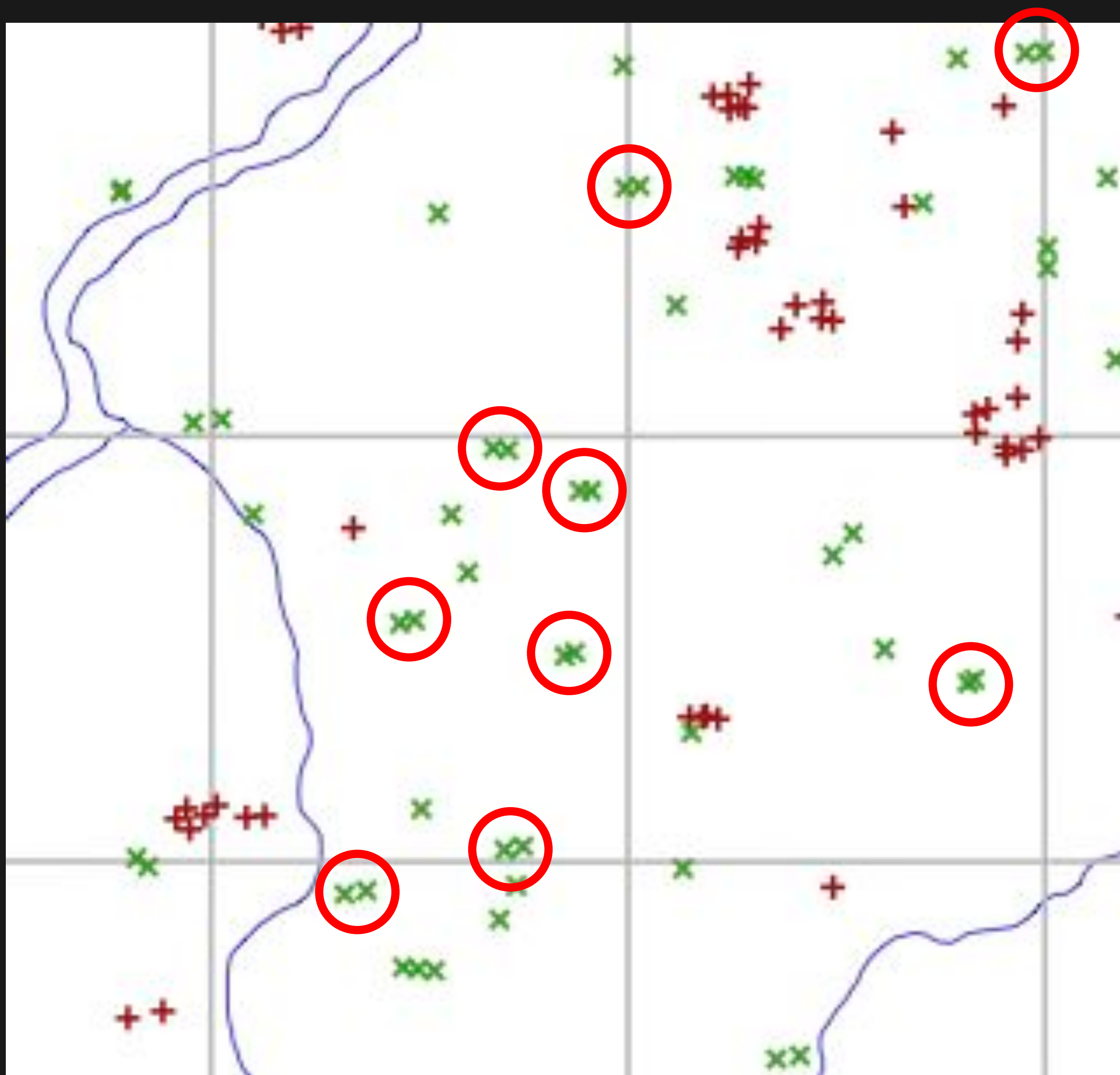
Effect of MODIS Triangular Response

- MODIS triangular response boosts out-of-burn fire counts much more significantly than in-burn fire counts
- ~20% of out-of-burn fire pixels are “doublets”

Mali



red = in-burn MODIS fire pixel, green = out-of-burn MODIS fire pixel



Effect of MODIS triangular response.

GFED4s Burned Area

$$A_{4\mathrm{s}}(i,t,v) = A_{\mathrm{MCD64A1}}(i,t,v) + \mathrm{FC}_{\mathrm{out}}(i,t,v) \times \alpha_{r,s,v,y} \times \gamma_{r,s,v,y}$$

0.25° grid cell i, month t, vegetation class v, region r, year y, season s

$\alpha_{r,s,v,y}$ = area burned per "in-burn" fire pixel

$$\gamma(r,s,v,y) = \frac{dNBR_{out}(r,s,v,y) - dNBR_{control}(r,s,v,y)}{dNBR_{in}(r,s,v,y) - dNBR_{control}(r,s,v,y)}, \qquad (4)$$

GFED4s Burned Area

$$A_{4s}(i,t,v) = A_{MCD64A1}(i,t,v) + FC_{out}(i,t,v) \times a_{r,s,v,y} \times \gamma_{r,s,v,y}$$

0.25° grid cell i, month t, vegetation class v, region r, year y, season s

$\alpha_{r,s,v,y}$ = area burned per "in-burn" fire pixel

$$\gamma(r,s,v,y) = \frac{dNBR_{out}(r,s,v,y) - dNBR_{control}(r,s,v,y)}{dNBR_{in}(r,s,v,y) - dNBR_{control}(r,s,v,y)}, \quad (4)$$

Strongly affected by resampling error!

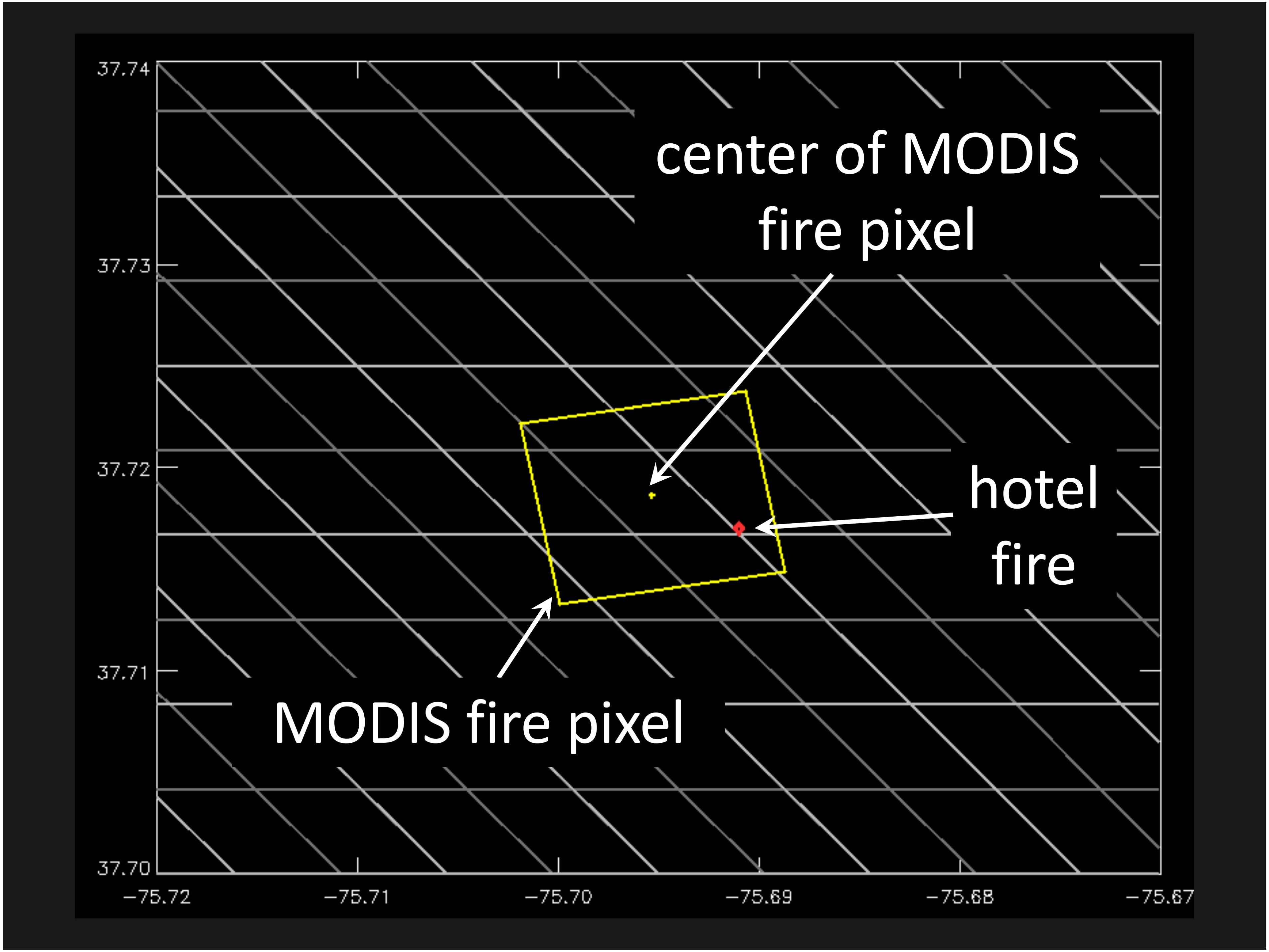
“Clean” Small-Fire Test Case (Rare)

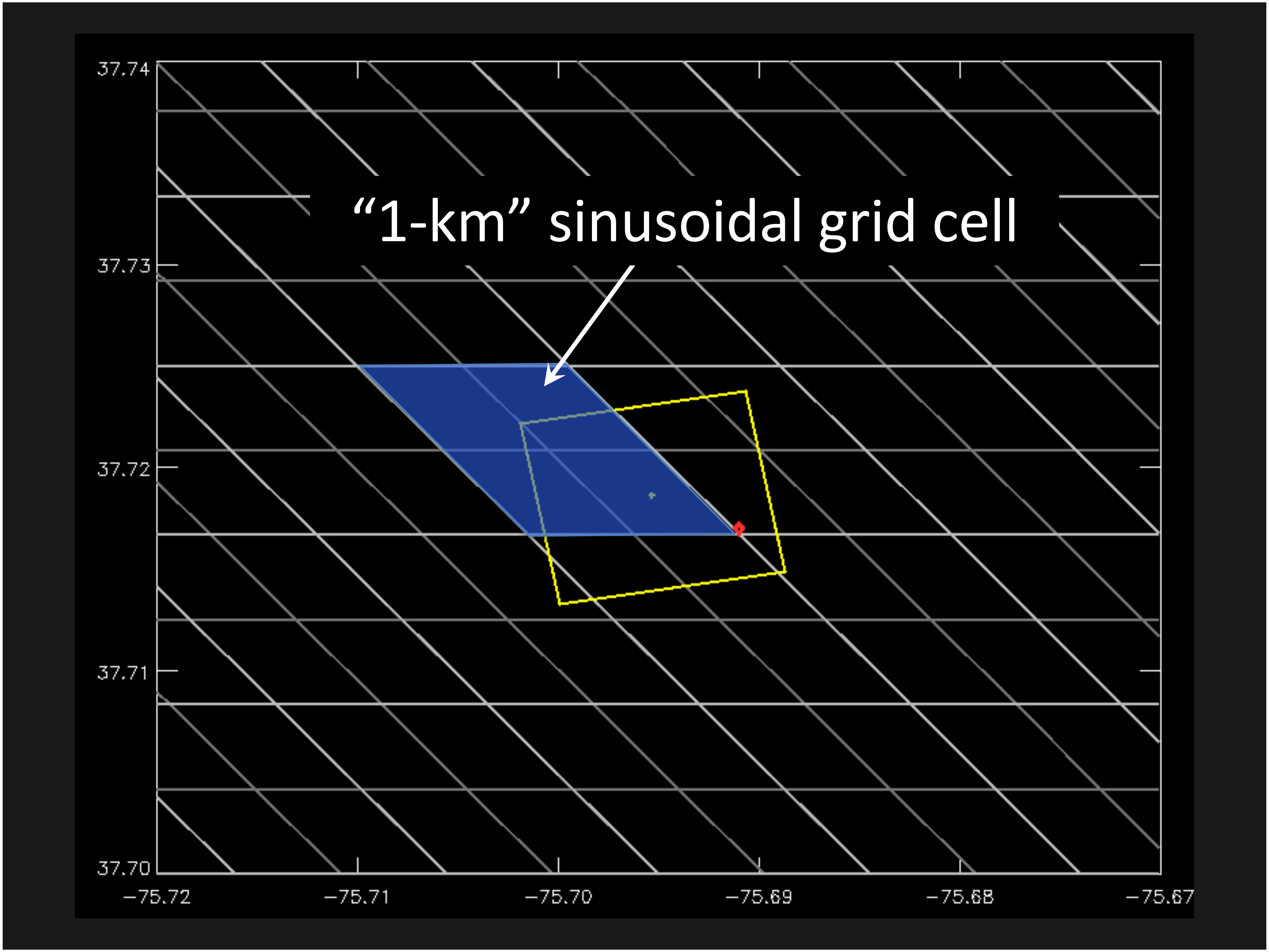
Burned evening of 12 March 2013.

http://wamu.org/news/13/08/06/suspects_indicted_in_dozens_of_eastern_shore_arson_cases

Whispering Pines Hotel Fire

- Detected by Terra MODIS
  - 1 fire pixel
- Croplands, cropland/natural mosaic
- Actual area burned ~460 m^2 (0.046 ha)
- GFED4 (MCD64A1): 0 ha
- GFED4s: 45.09 ha ➞ 980× too high

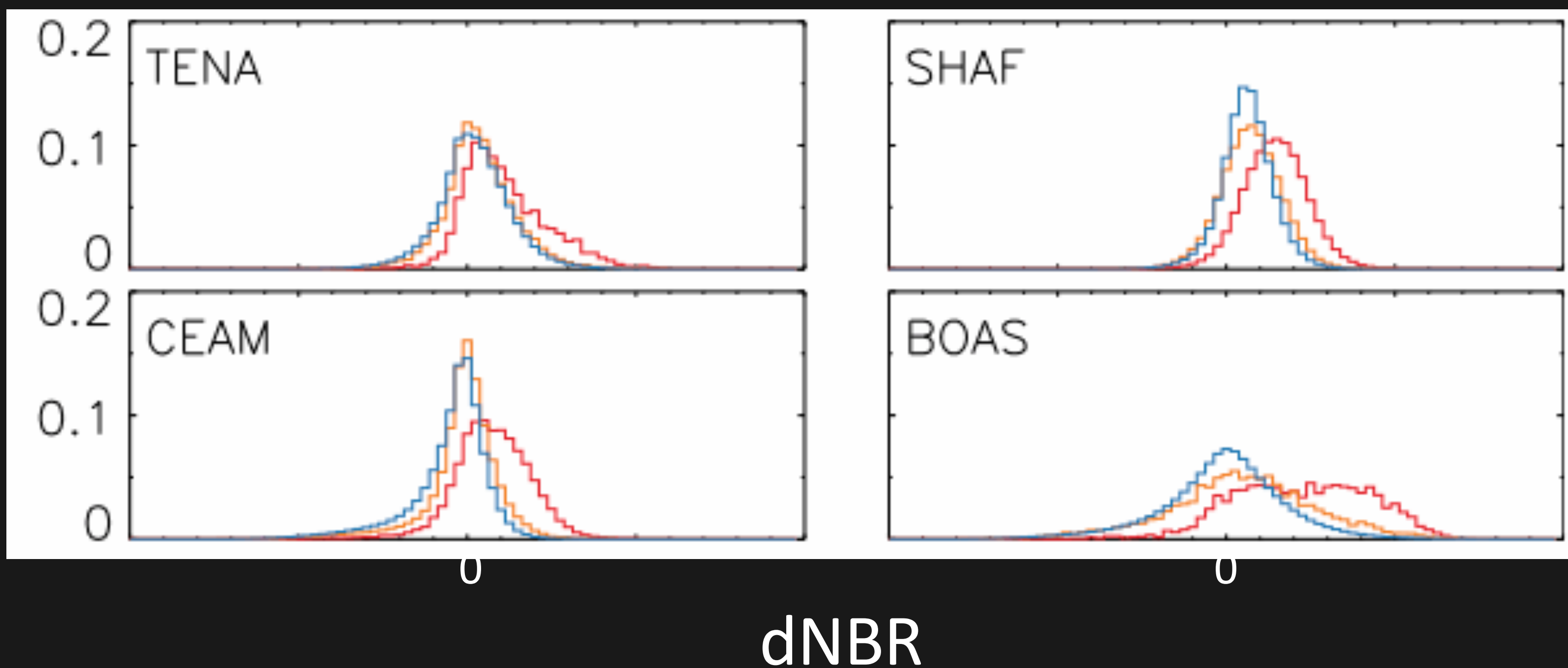

37.74
37.73
37.72
37.71
37.70
−75.72
−75.71
−75.70
−75.69
−75.68
−75.67
center of MODIS fire pixel
hotel fire
MODIS fire pixel



"1-km" sinusoidal grid cell
37.74
37.73
37.72
37.71
37.70
−75.72
−75.71
−75.70
−75.69
−75.68
−75.67

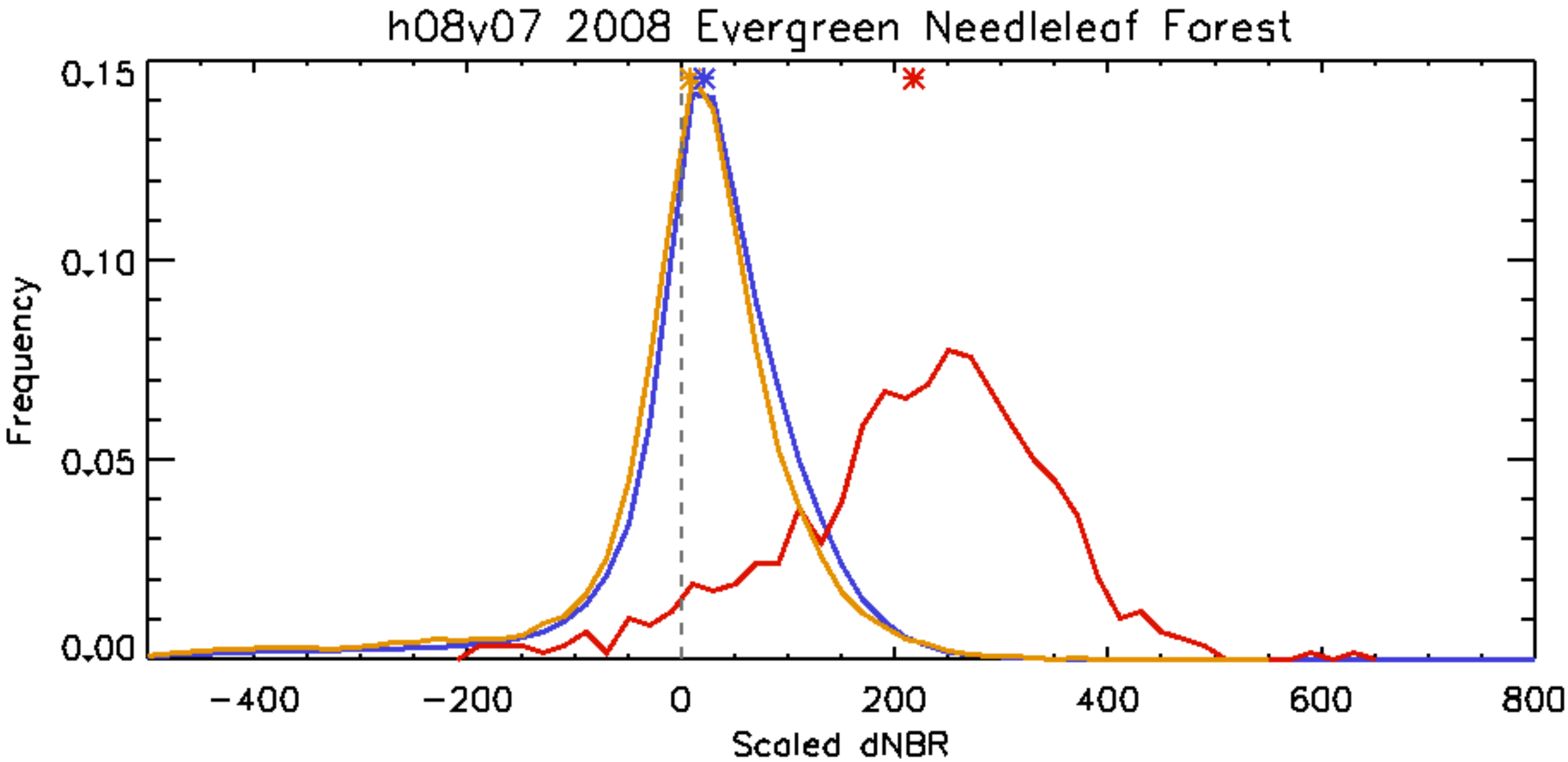
dNBR PDFs:

red: active fires within burns
orange: active fires outside of burns
blue: unburned/no fires



Randerson et al. (2012)

1-year sample from a single MODIS tile.



(CEAM)

Simulated Small-Fire Location "Blur"

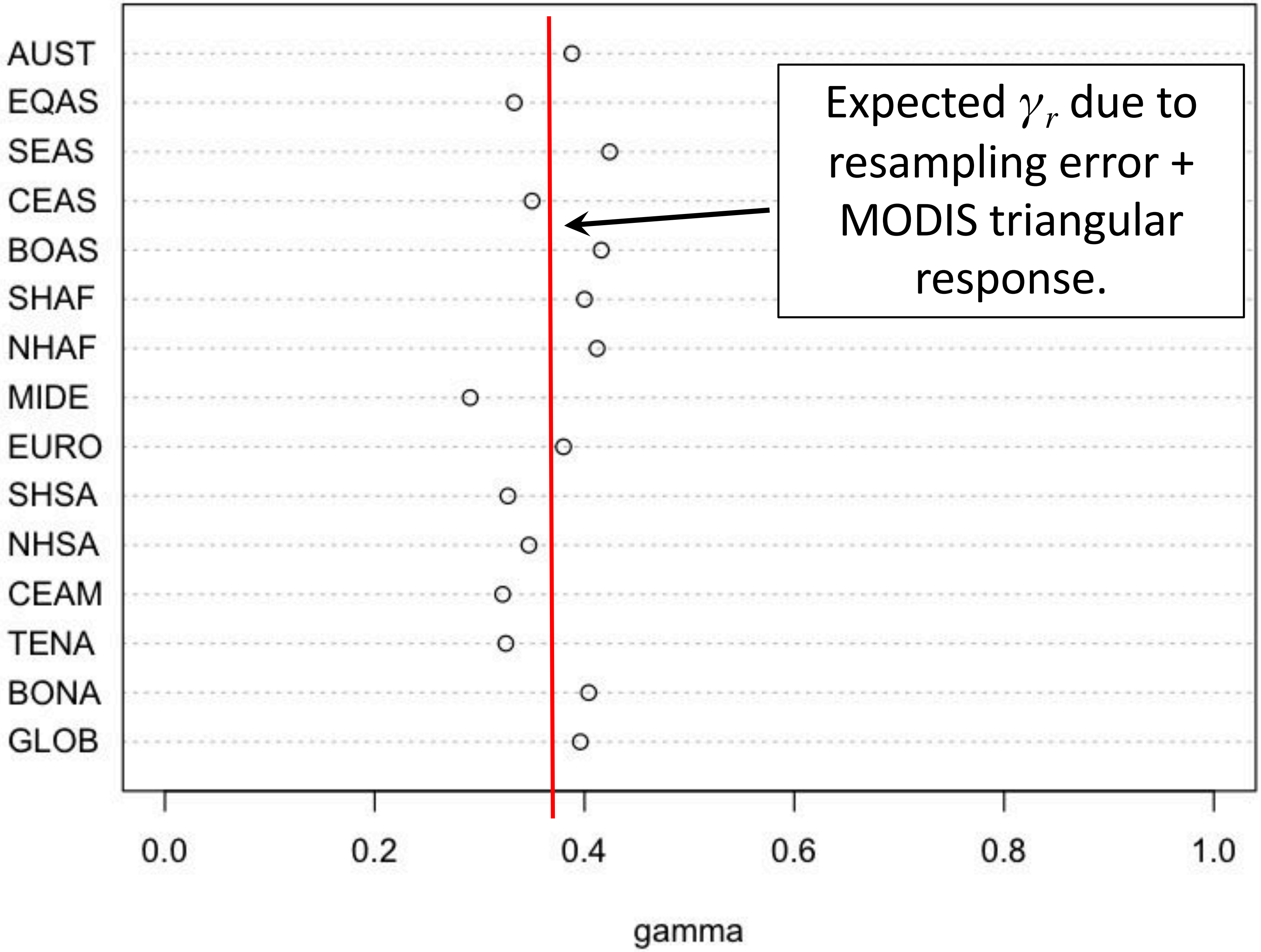
0.00	0.00	0.00	0.00	0.00
0.00	0.03	0.12	0.03	0.00
0.00	0.10	0.44	0.10	0.00
0.00	0.03	0.12	0.03	0.00
0.00	0.00	0.00	0.00	0.00

500 m

Only a 44% chance that center grid cell will contain the small fire located within a 1-km fire pixel.

Regional Gamma Values

(i.e., these are the critical small-fire correction factors)



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Global fir 997–2016

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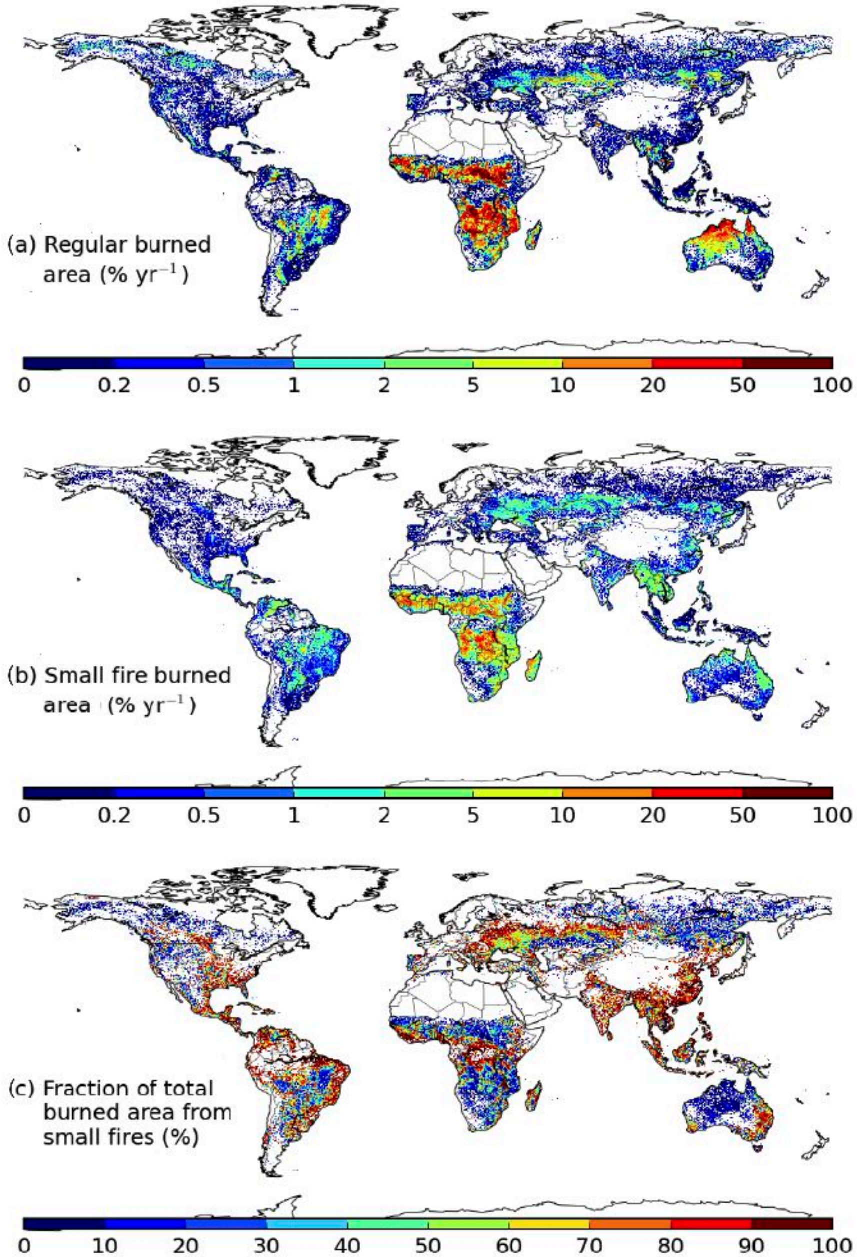

Figure 1. Average burned area over 2003–2016 from **(a)** MODIS surface reflectance imagery (MCD64A1) and **(b)** small fire burned area. Panel **(c)** shows the small fire percentage of total burned area.

3

Release	Burned Area Data Set	Global/Regional
TBD	Fire CCI OCLI+SLSTR	G
7/2019	Fire CCI MODIS v5.1	G
3/2019	Fire CCI LT v1.0	G
11/2018	Fire CCI SFD v1.1 (Africa)	R
10/2018	Fire CCI SA v1.0 (South America)	R
3/2018	Fire CCI MODIS v5.0	G
2018	GABAM Long et al.	G
2018	RAPT Mithal et al. (Tropical Forest)	R
2017	USGS BA ECV	R
2017	Fire CCI (Indonesia)	R
2017	NASA MODIS MCD64A1 C6	G
2016	Fire CCI v4.1 MERIS	G
2015	GFED4.1s	G
2014	Fire CCI v3.1 MERIS	G
2013	NASA MODIS MCD45A1 C5.1	G
2012	NASA MODIS MCD64A1 C5.1 / GFED4	G
2010	GFED3	G
2008	NASA MODIS MCD45A1 C5	G
2008	GIO-GL1	G

Contributing Factors

- Google Earth Engine
- Machine Learning
- Rise of rapid-publication journals
  - MDPI
  - Peer review often compromised

SHARE

Open-access journal editors resign after alleged pressure to publish mediocre papers

By Jop de Vrieze | Sep. 4, 2018 , 3:45 PM

All 10 senior editors of the open-access journal *Nutrients* resigned last month, alleging that the publisher, the Multidisciplinary Digital Publishing Institute (MDPI), pressured them to accept manuscripts of mediocre quality and importance.

The conflict is familiar for many commercial open-access publishers: Because authors pay fees per published article (about $1800 in the case of *Nutrients*), the publisher has an incentive to publish as many as possible. On the other hand, scientists prefer to publish in choosy, reputable journals, and academic journal editors want to maintain this quality.

On 15 August, the editor-in-chief of the journal, Jon Buckley, of the University of South Australia in Adelaide, received an email from MDPI announcing his replacement at the end of the year by someone who would “bring different ideas on board.” Buckley says this was an excuse to push him aside because of his strict editorial policy. He resigned immediately, and nine other senior editors followed.

remote sensing

MDPI

Article

[illegible]

[illegible]

Received: 12 August 2019; Accepted: 1 September 2019; Published: 3 September 2019 remote sensing

MDPI

Article

[illegible]

[illegible]

[illegible]

Received: 29 July 2019; Accepted: 16 August 2019; Published: 30 August 2019

check for updates

fire

Article

Received: 15 August 2019; Accepted: 24 August 2019; Published: 2 September 2019 *fire*

MDPI

Editorial

[illegible]

[illegible]

[illegible]

Received: 13 November 2018; Accepted: 14 November 2018; Published: 21 November 2018

check for updates

Summary

- Users
  - Avoid cumulative FRP
  - Consider resampling error when focusing on sub-pixel phenomena
- Product Developers
  - Exercise restraint
  - Consistency is critical for long term studies
  - Eschew questionable journals