HyspIRI Measurement of Fire Parameters for Climate Change and Carbon Budgets: Fuel, Occurrence, Intensity and Recovery

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Many others (noted on slides)

August 2010

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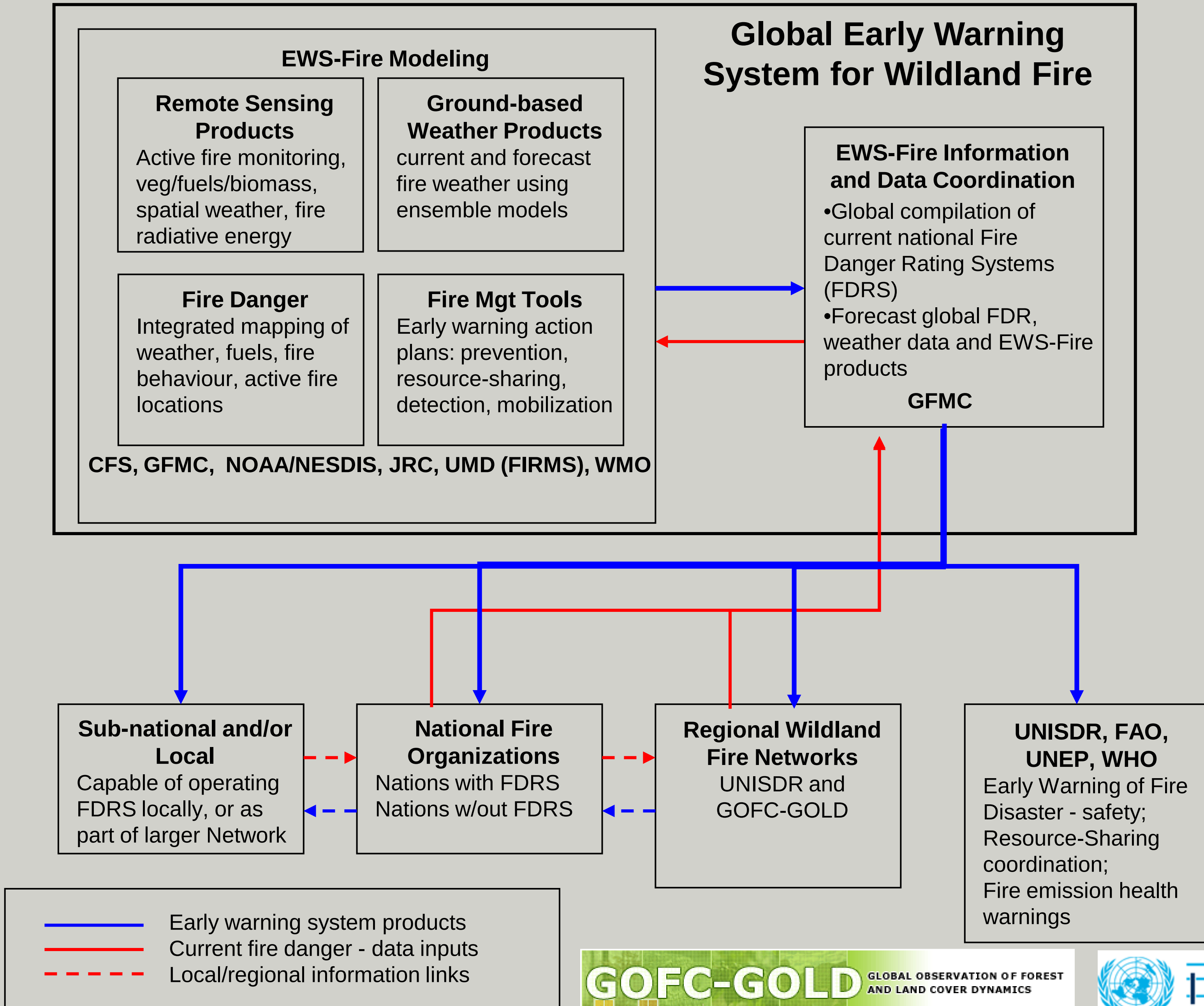
Need for improved global and regional fire monitoring – in plain language

- Societal issues
  - long-term or permanent land cover changes
  - significant contribution to greenhouse gas and particulate emissions
  - smoke from fires is a major health hazard
  - human-fire-climate interactions

- Scientific Issues
  - need to be able to monitor fires and their impacts
  - what vegetation burned
  - how intense and severe was the burning was
  - how much material was emitted into the atmosphere
  - process of vegetation recovery over the burned areas
  - carbon exchange between the land surface and the atmosphere

Needs from the management community – an example



CSIRO PUBLISHING
Review
www.publish.csiro.au/journals/ijwf
International Journal of Wildland Fire **2009**, *18*, 483–507

Implications of changing climate for global wildland fire

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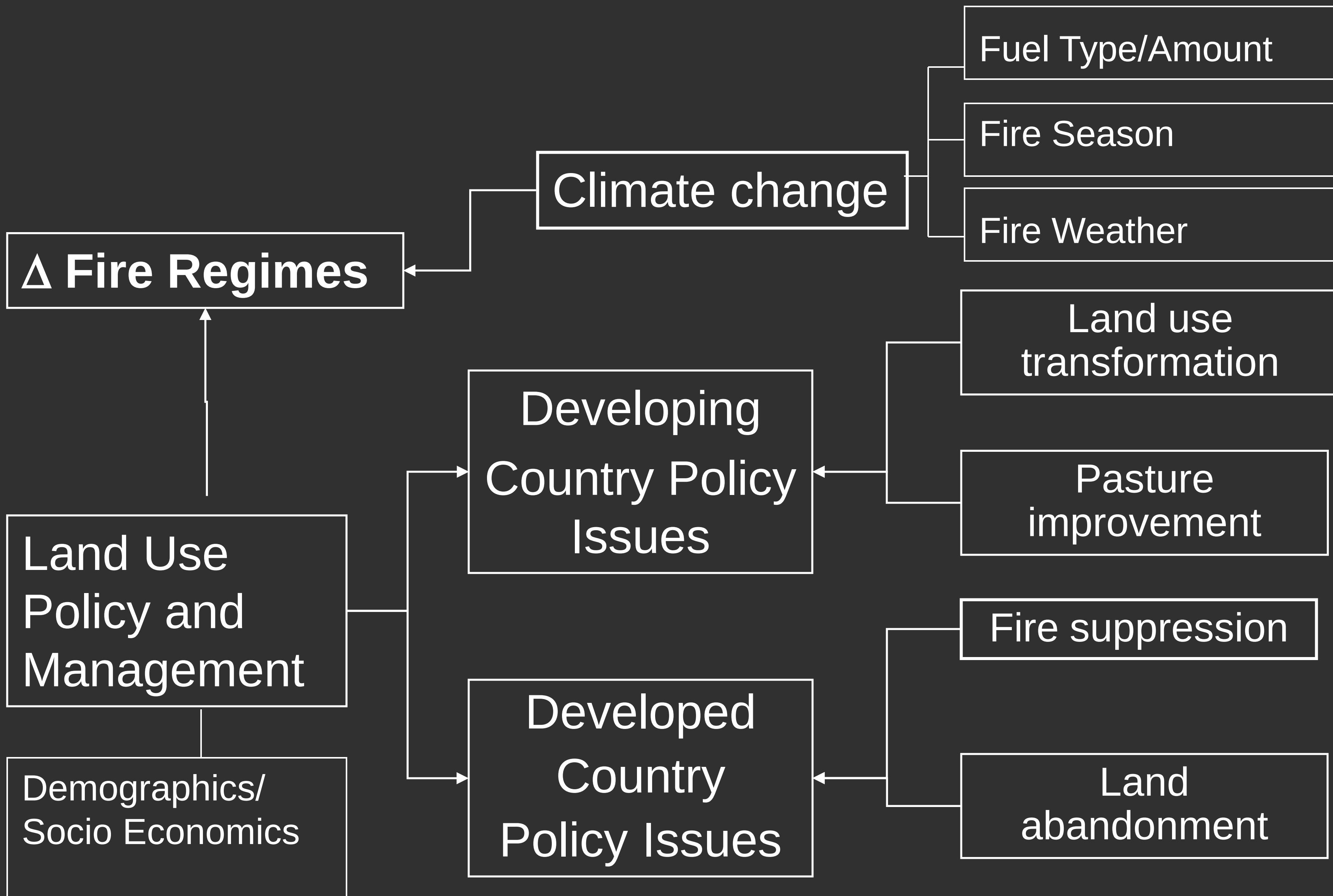
Abstract. Wildland fire is a global phenomenon, and a result of interactions between climate–weather, fuels and people. Our climate is changing rapidly primarily through the release of greenhouse gases that may have profound and possibly unexpected impacts on global fire activity. The present paper reviews the current understanding of what the future may bring with respect to wildland fire and discusses future options for research and management. To date, research suggests a general increase in area burned and fire occurrence but there is a lot of spatial variability, with some areas of no change or even decreases in area burned and occurrence. Fire seasons are lengthening for temperate and boreal regions and this trend should continue in a warmer world. Future trends of fire severity and intensity are difficult to determine owing to the complex and non-linear interactions between weather, vegetation and people. Improved fire data are required along with continued global studies that dynamically include weather, vegetation, people, and other disturbances. Lastly, we need more research on the role of policy, practices and human behaviour because most of the global fire activity is directly attributable to people.

Needs from the fire and climate community – an example

Flannigan et al., 2009

"To date, research suggests a general increase in area burned and fire occurrence but there is a lot of spatial variability, with some areas of no change or even decreases in area burned and occurrence. Fire seasons are lengthening for temperate and boreal regions and this trend should continue in a warmer world. Future trends of fire severity and intensity are difficult to determine owing to the complex and non-linear interactions between weather, vegetation and people. Improved fire data are required along with continued global studies that dynamically include weather, vegetation, people, and other disturbances. Lastly, we need more research on the role of policy, practices and human behavior because most of the global fire activity is directly attributable to people."

Changing fire regimes – complex interactions between climate and society



TQ2. Wildfires

- How are global fire regimes changing in response to, and driven by, changing climate, vegetation, and land use practices? [DS 198]
- Is regional and local scale fire frequency changing? [DS 196]
- What is the role of fire in global biogeochemical cycling, particularly trace gas emissions? [DS 195]
- Are there regional feedbacks between fire and climate change?

CQ2. Wildfires

- How does the timing, temperature and frequency of fires affect long-term ecosystem health?
- How does vegetation composition and fire temperature impact trace gas emissions?
- How do fires in coastal biomes affect terrestrial biogeochemical fluxes into estuarine and coastal waters and what is the subsequent biological response? [DS 198]
- What are the feedbacks between fire temperature and frequency and vegetation composition and recovery?
- How does vegetation composition influence wildfire severity?
- On a watershed scale, what is the relationship of vegetation cover, soil type, and slope to frequency of debris flows?
- How does invasive vegetation cope with fire in comparison to native species?

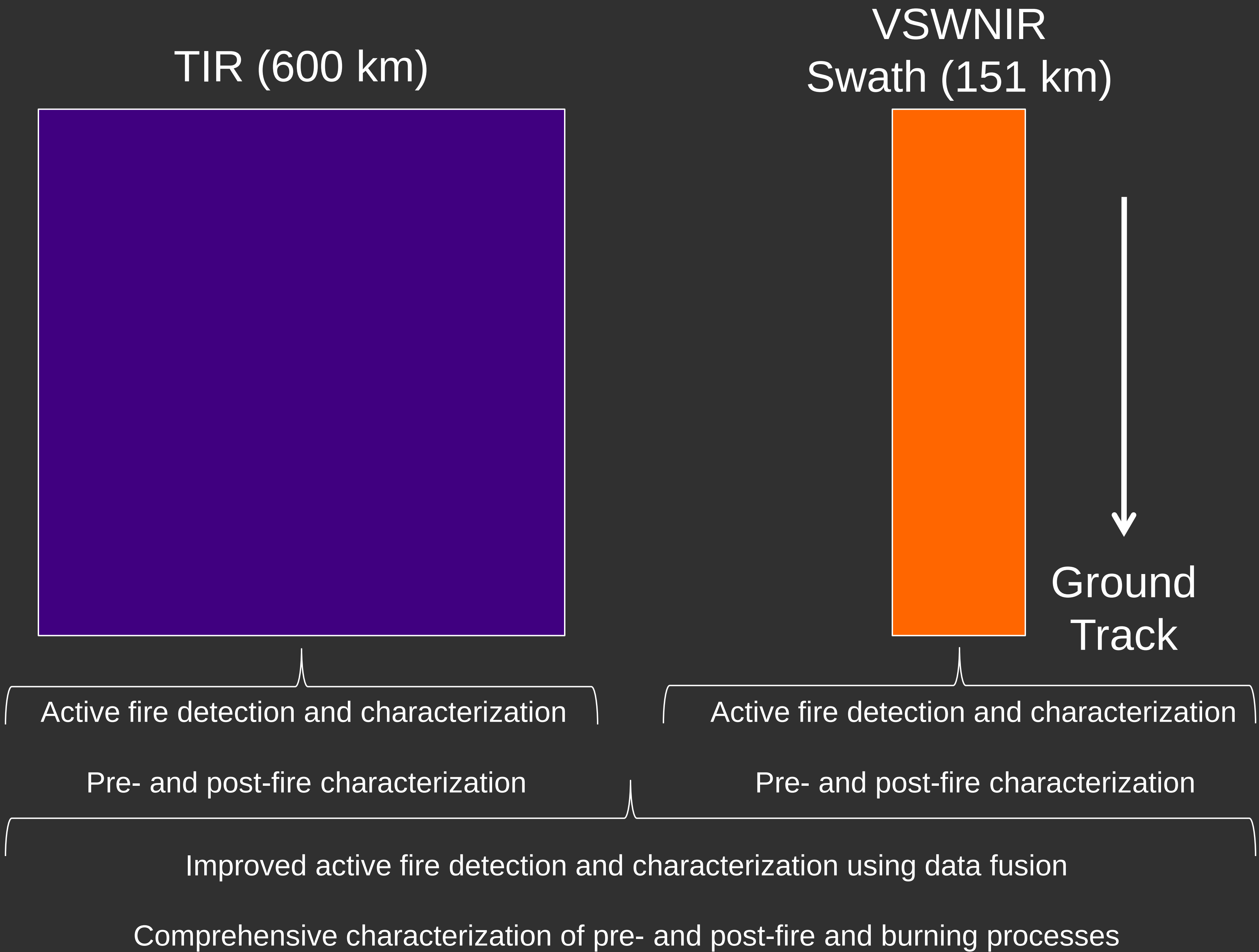
HyspIRI and fire – unprecedented measurement capabilities

- Pre-fire fuel properties, fire weather
  - fuel types, fuel loads
  - live fuel moisture, vegetation stress etc.
  - surface temperature, ET

A prime example for the complementarities between HyspIRI and DESDynI !

- Detection/characterization of the combustion process
  - improved fire characterization
  - improved characterization of smoke emission

- Post-fire impacts
  - fire affected area
  - burn severity
  - amount of material burned
  - hydrophobicity
  - types of ash
  - land cover change
  - nutrient transport


TIR (600 km)
VSWNIR
Swath (151 km)
Ground
Track
Active fire detection and characterization
Active fire detection and characterization
Pre- and post-fire characterization
Pre- and post-fire characterization
Improved active fire detection and characterization using data fusion
Comprehensive characterization of pre- and post-fire and burning processes

Fire Disturbance is an Essential Climate Variable (ECV) of the Global Climate Observing System (GCOS)

For climate-related science questions:

decades-long time series

coarse resolution fire observations
(MODIS, VIIRS, etc.)

+

better understand observations and processes

high resolution fire & fuel observations

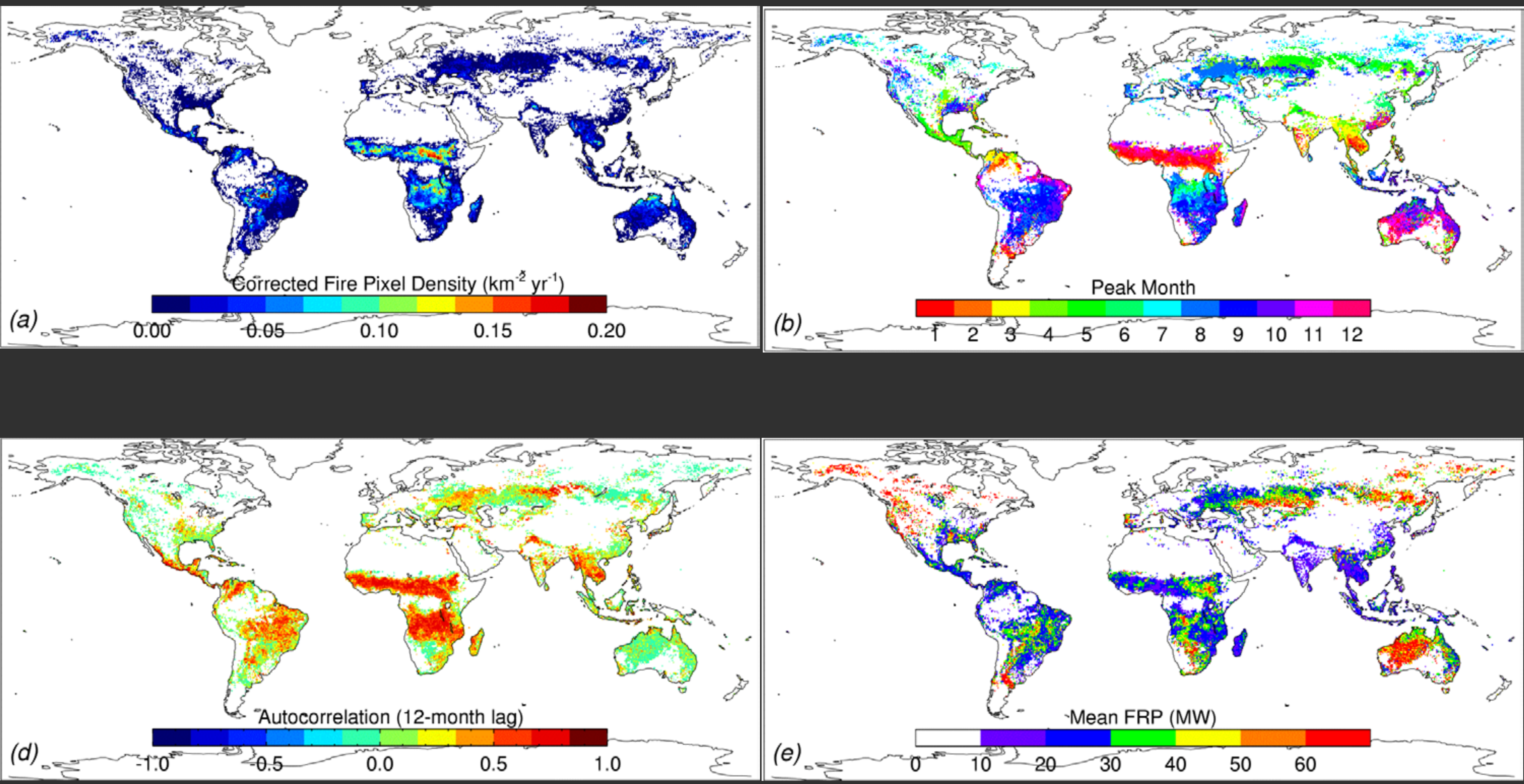
HyspIRI

start of a new, improved data record?

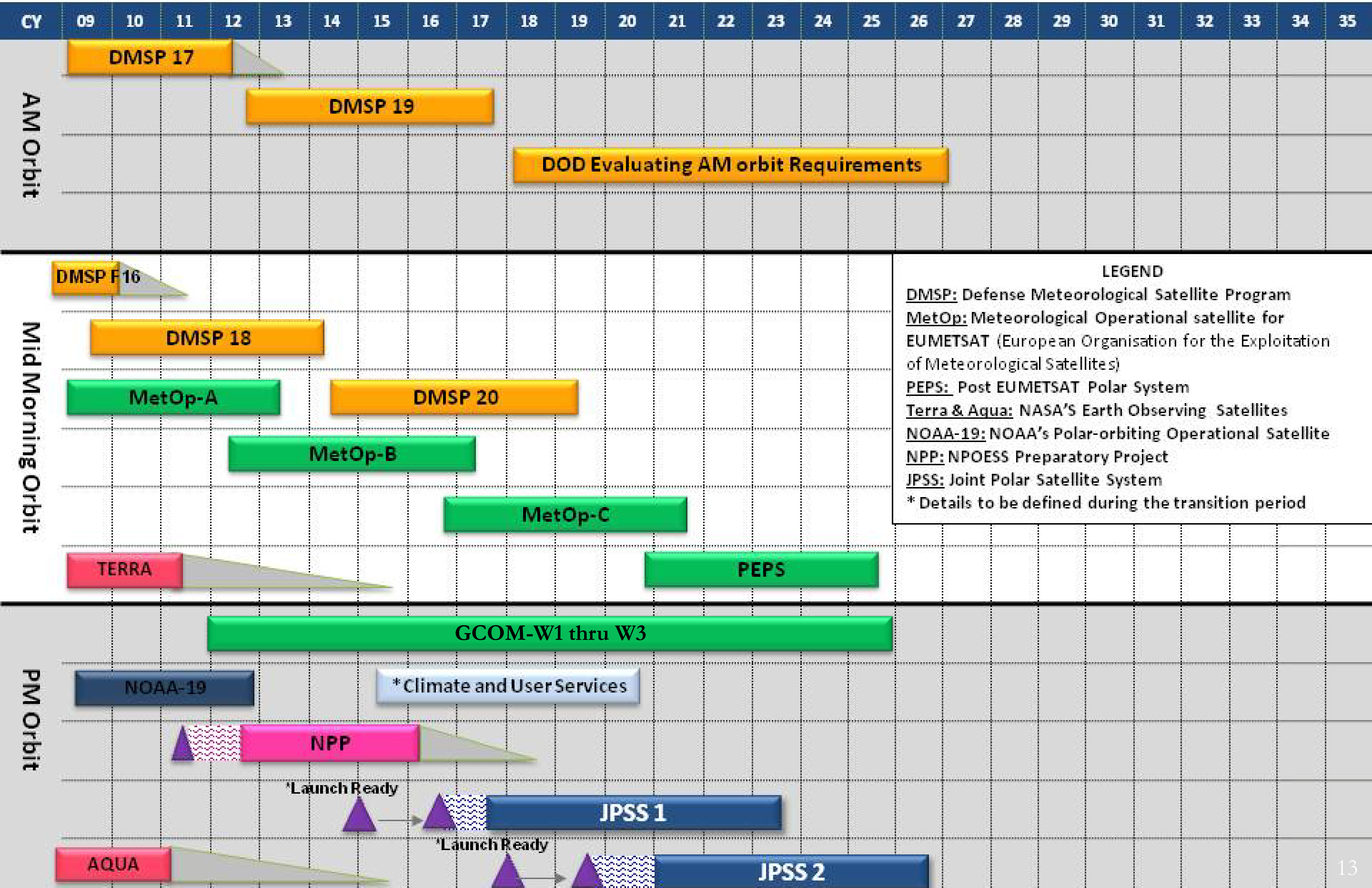
Current and expected capabilities from medium an coarse resolution sensors

- Long-term monitoring of large-scale fire dynamics from medium and coarse resolution sensors
  - fire occurrence
  - Fire Radiative Power and Energy
  - burned areas
- Gradual improvement, but no quantum leap is expected from operational systems

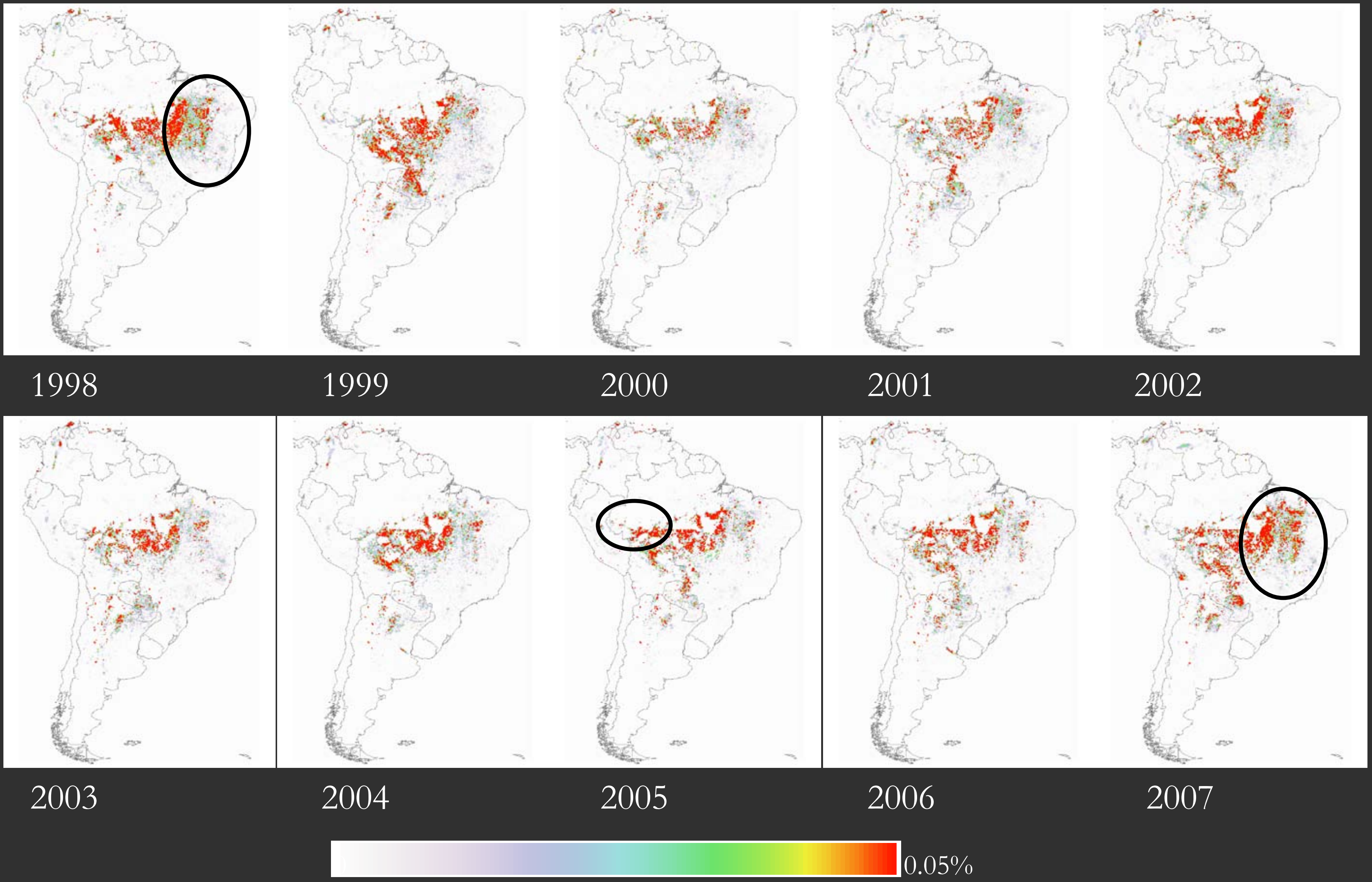
Global fire dynamics from MODIS



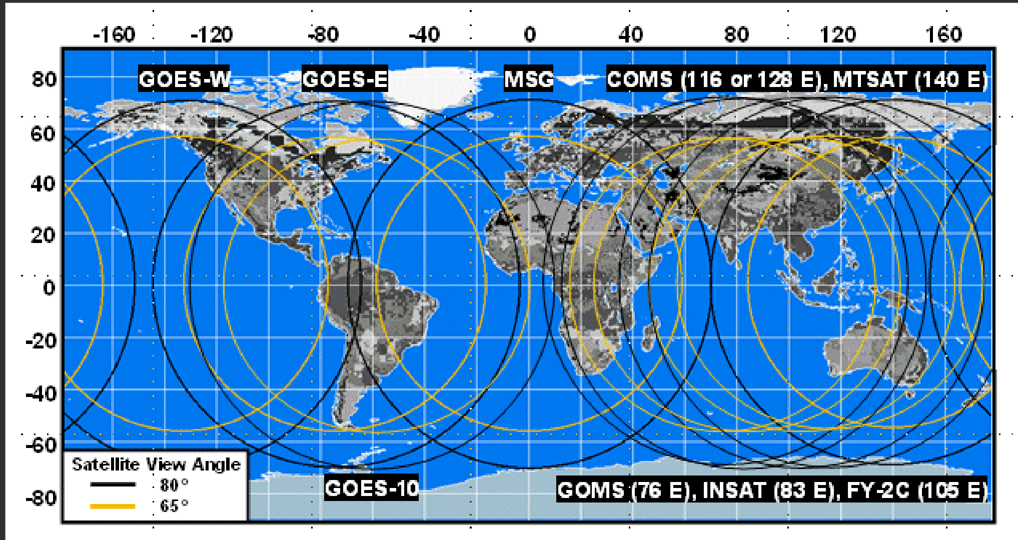
Continuity of Polar Operational Satellite Programs



Fire occurrence in South America from GOES data (JAS)



Global Geostationary Active Fire Monitoring Capabilities



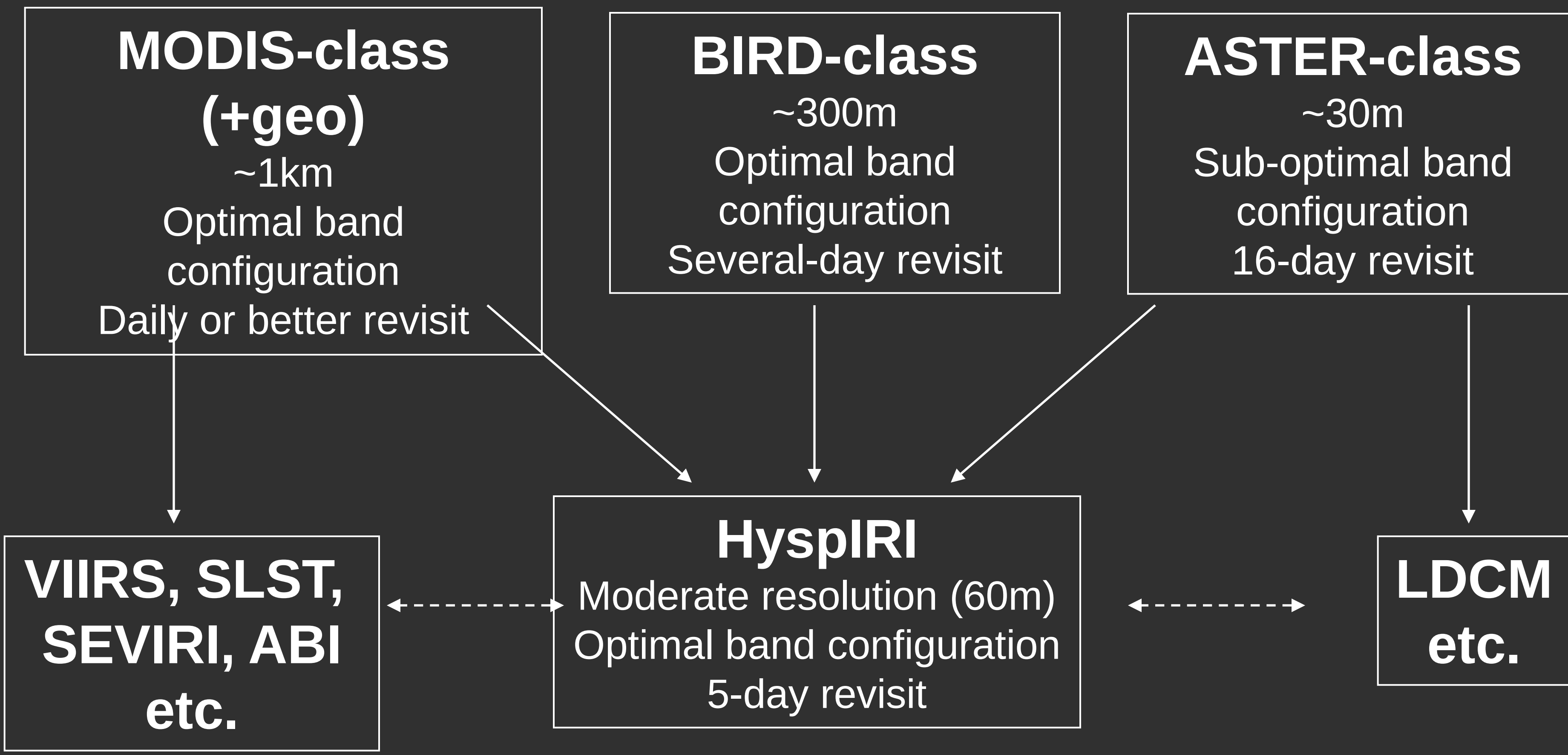
Satellite View Angle

80°

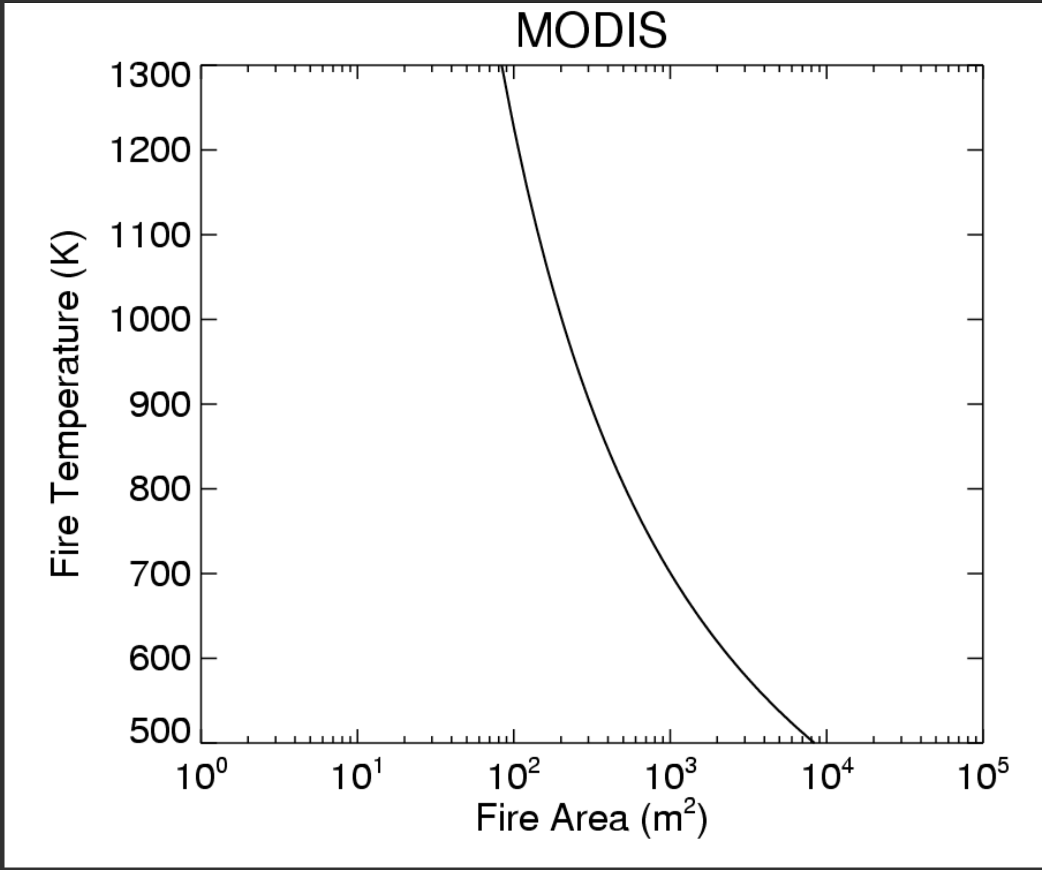
65°

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 (75°W / 135°W)	1 visible 3.9 and 10.7 µm	1.0 4.0	0.57 2.3	3 hours (30 min NHE and SHE)	>335 K (G-11) >335 K (G-12)	0.15
GOES-10 Imager (60°W) (Ceased operation December 2009, replaced with GOES-12 in May 2010)	1 visible 3.9 and 10.7 µm	1.0 4.0	0.57 2.3	3 hours (Full Disk) 15 min (SA)	~322 K (G-10) >335 K (G-12)	0.15
Met-8/-9 SEVIRI (9.5 °E, 0°)	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 °E / 86.5°E)	1 visible, 3.75 and 10.8 µm	1.25 5.0		30 minutes	~330 K	
MTSAT-1R JAMI (140°E) MTSAT-2 (HRIT) (145°E) Operational 2010	1 visible 3.7 and 10.8 µm	1.0 4.0		1 hour	~320 K (MTSAT-1R) ~320 K (MTSAT-2)	0.15
INSAT-3D (83 °E ?, TBD) (Launch 2010)	1 vis, 1.6 µm 3.9 and 10.7 µm	1.0 4.0	0.57 2.3	30 minutes	?	
GOMS Elektro-L N1 (76 °E) (2010) GOMS Elektro-L N2 (14.5 °E) (2011?)	3 visible 1.6, 3.75 and 10.7 µm	1.0 km 4.0 km		30 minutes	?	
COMS (128 °E) (Launch 2010)	1 visible 3.9 and 10.7 µm	1.0 km 4.0 km		30 minutes	~350 K	

Evolving MIR/TIR fire detection capability



Detection envelopes

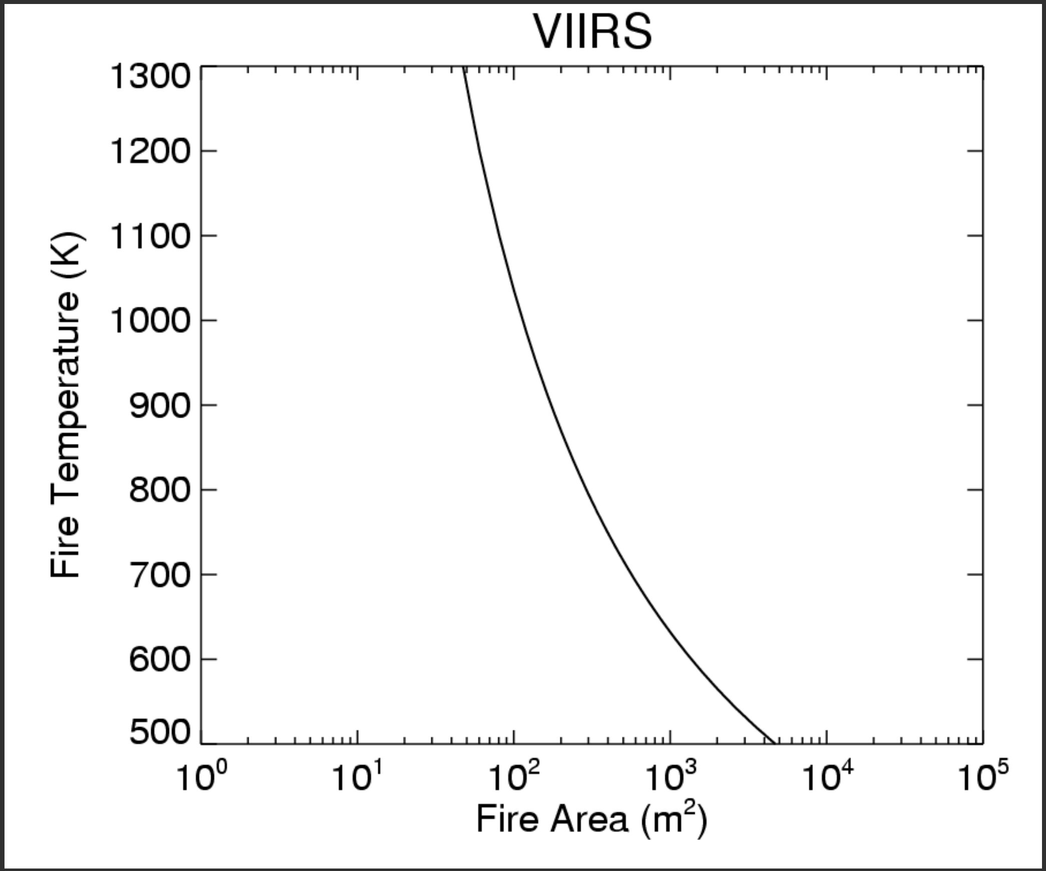


1000 m

90% probability of detection; boreal forest; nadir view

L. Giglio

Detection envelopes

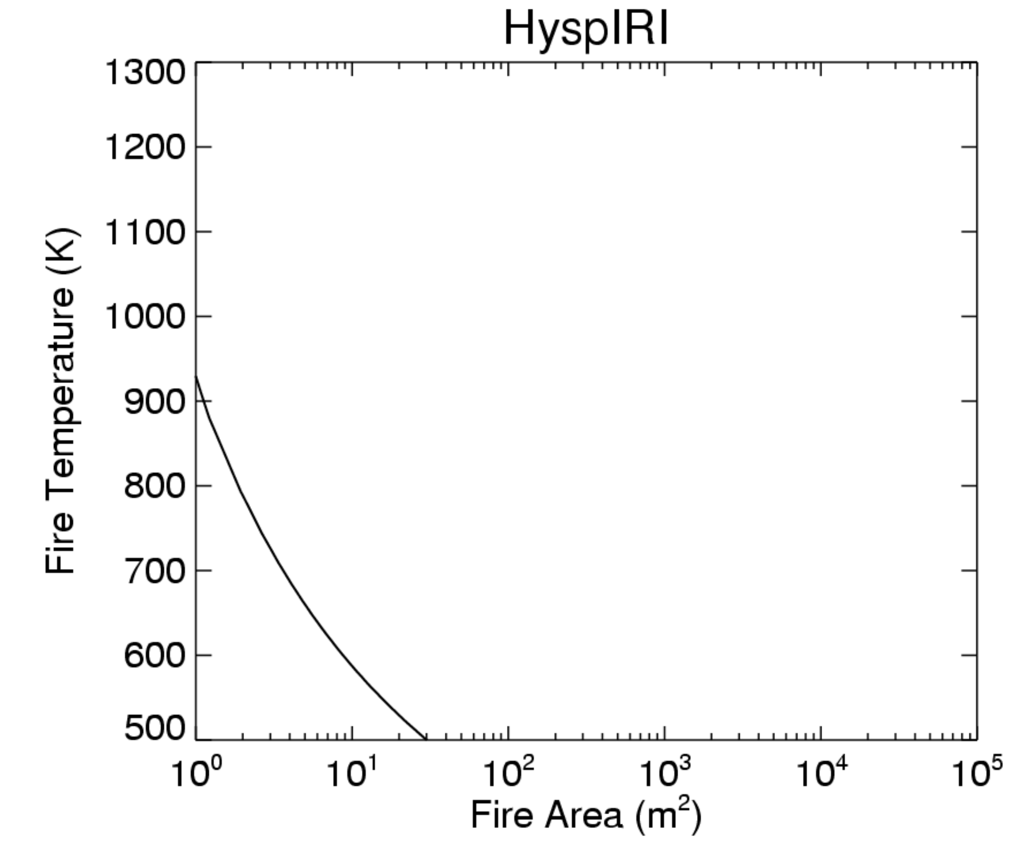


750 m

90% probability of detection; boreal forest; nadir view

L. Giglio

Detection envelopes



60 m

90% probability of detection; boreal forest; nadir view

L. Giglio

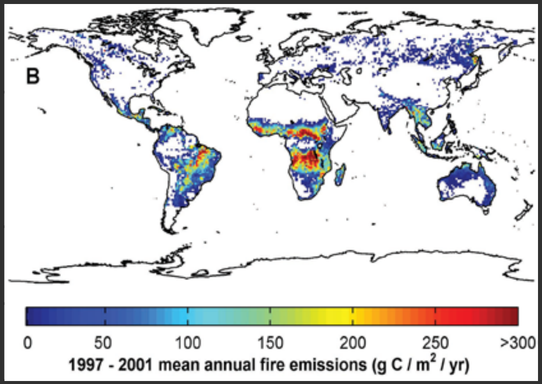
HyspIRI: a changing paradigm

- MODIS-class: multiple sub-pixel fires within footprint, systematic, global observations
  - “fire” often means a fire pixel
- ASTER: detect (but characterize only over a limited range) individual fires on an opportunistic basis
  - cluster size, spatial variability
- HyspIRI: detect and characterize individual fires on a more routine basis
  - cluster size, fire temperature, spatial and temporal variability, size distribution, flaming/smoldering
  - helps us understand what is within the coarse or moderate resolution fire pixel

Global fire emission estimate: 2004

Biomass burning and fossil fuel emissions release ~10^{15} g of carbon (C) to the atmosphere each year. Biomass burning constitutes ~36% of all global C emissions.

Region	Fire emissions 1997-2001 average (10^{15}g C yr^{-1})
Central and northern South America	0.27
Southern South America	0.80
Northern Africa	0.80
Southern Africa	1.02
Southeast Asia	0.37
Boreal (north of 38°N)	0.14
Other	0.13
Global	3.53

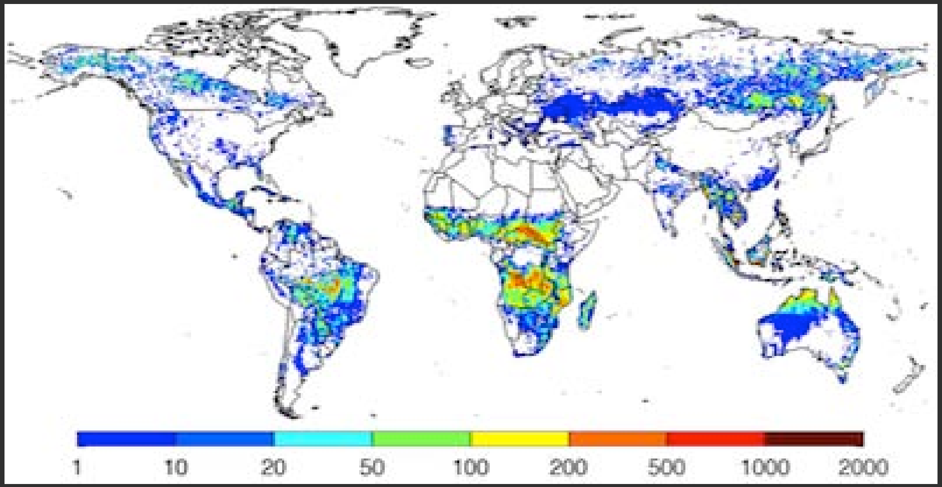


Van der Werf et al., 2004

Global fire emission estimate: 2010

Biomass burning and fossil fuel emissions release ~10^{15} g of carbon (C) to the atmosphere each year. Biomass burning constitutes ~25% of all global C emissions.

Region	Fire emissions 1997-2009 average (10^{15} g C yr^{-1})
Central and northern South America	0.04
Southern South America	0.27
Northern Africa	0.48
Southern Africa	0.27
Southeast Asia	0.04
Boreal (north of 38°N)	0.18
Other	0.73
Global	2.01



Van der Werf et al., 2010

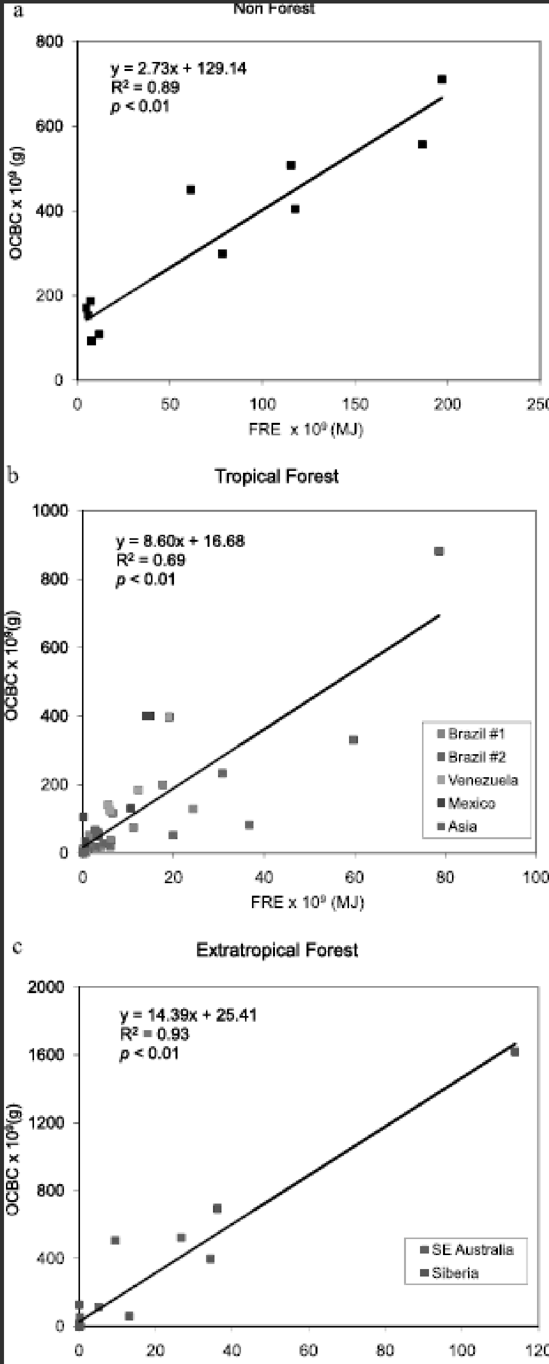
Where does the difference in emission estimates come from?

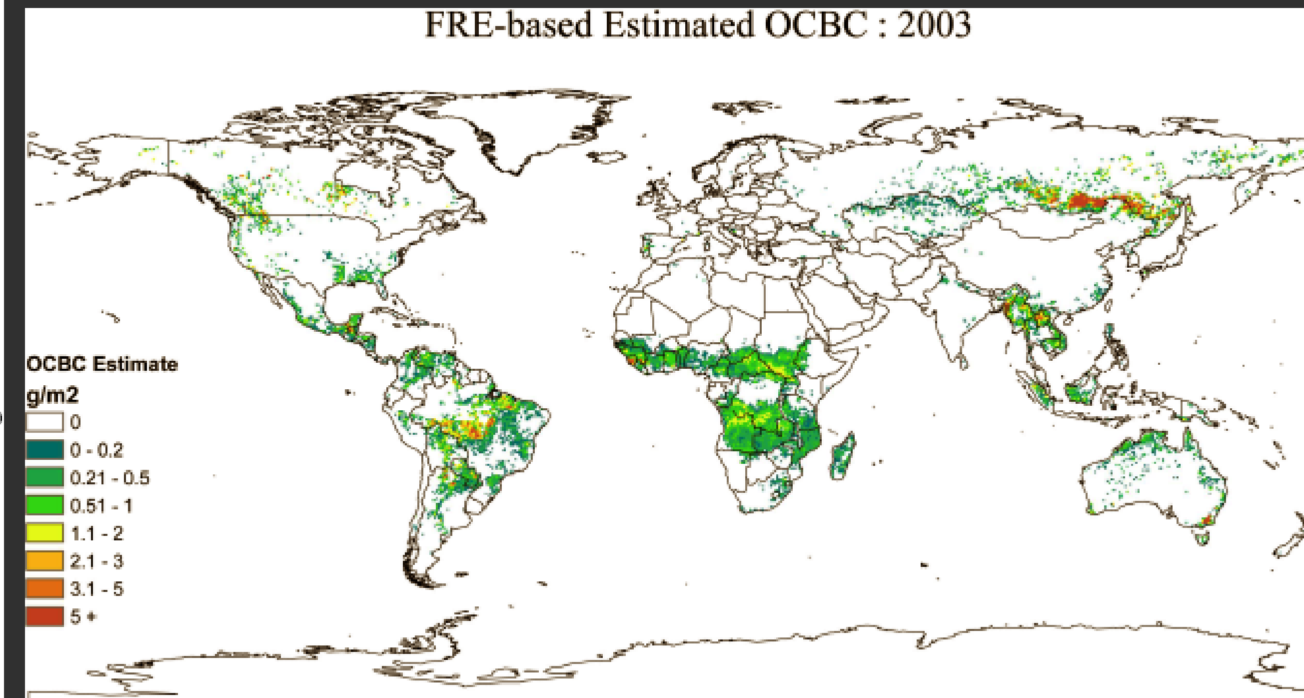
- Longer time period (El Niño/La Niña in 1997/98)
- Updated fuel loads – HyspIRI can help further refine this!
  - Peat is important, but difficult!
- Updated burned area estimates
  - HyspIRI can help only where signal is persistent
  - HyspIRI can help over small scale, fragmented burned areas
- HyspIRI can also help better characterize the combustion, consumption and recovery processes

HyspIRI Burn Mapping Product

- Level 3
- Derived from VSWIR observations
  - Potentially use active-fire observations from TIR sensor to improve fidelity
- Generally requires coincident image pair
  - Large number (but small fraction) of global fires
- Sub-pixel area burned, combustion completeness
  - Mixture modeling (heavily underdetermined system for multi-spectral sensors)
  - Important for pyrogenic emissions estimation

Fire Radiative Energy





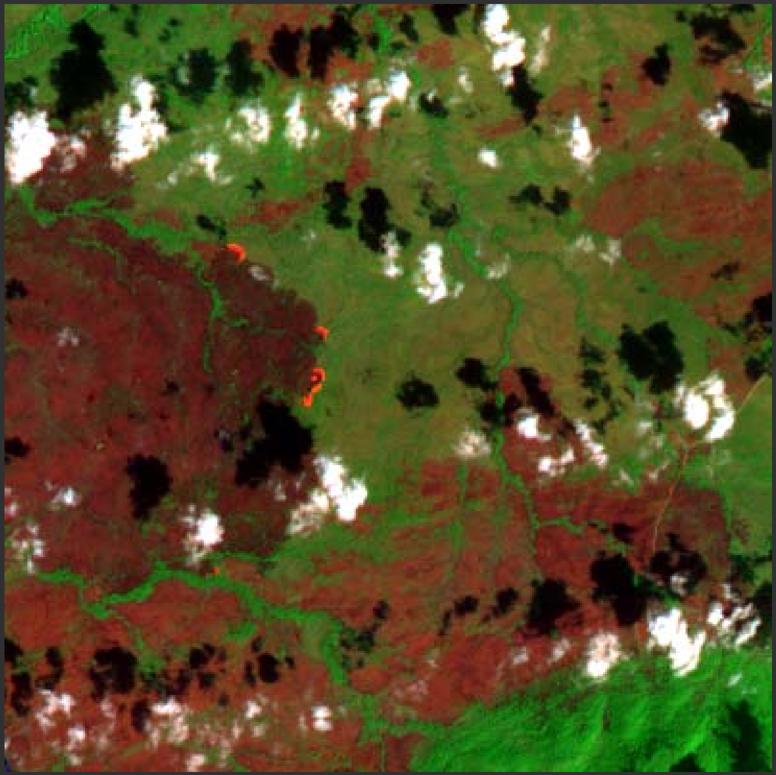
Ellicott et al 2009

HyspIRI Active Fire Product

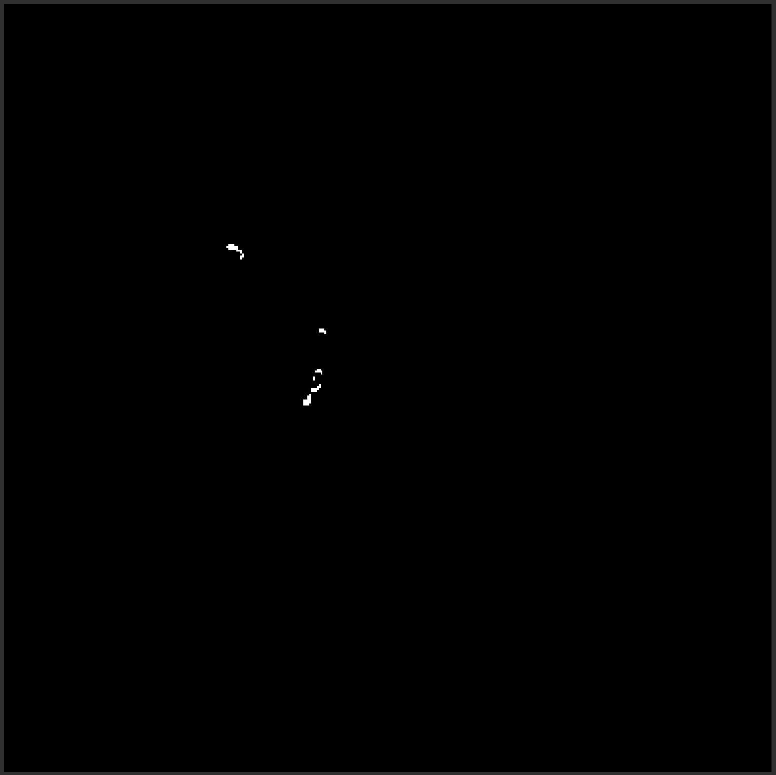
- Level 2
- Fire mask + fire radiative power (FRP)
  - – Produced across 600-km TIR swath
- Improved fire mask + detailed fire characterization
    - Produced within 151-km hyperspectral swath
    - Sub-pixel temperature(s) and area
      - – Minimum of flaming + smoldering + background

Example Fire Mask from ASTER

← 12 km →



ASTER Bands 8 (2.33 µm), 3N (0.82 µm), 1 (0.56 µm)



Active Fire Mask

ASTER saturates for many fires – HyspIRI will allow the “coloring” of the fire mask

HyspIRI MWIR Saturation

- Select TIR MWIR dynamic range so that saturation is extremely rare when observing fires
  - valid radiance measurement essential for fire characterization
    - FRP, sub-pixel temperature and area estimates
  - detailed characterization using hyperspectral sensor possible for only 25% of fires detectable with TIR sensor

MWIR Dynamic Range Comparison

- MODIS (1 km pixels): 500 K
  - based on theoretical worst case
- VIIRS (247 m pre.-agg.): 634 K
  - based on theoretical worst case
- BIRD (370 m): 600 K
- GOES-R ABI (2 km): 400 K
- HyspIRI (60 m): TBD

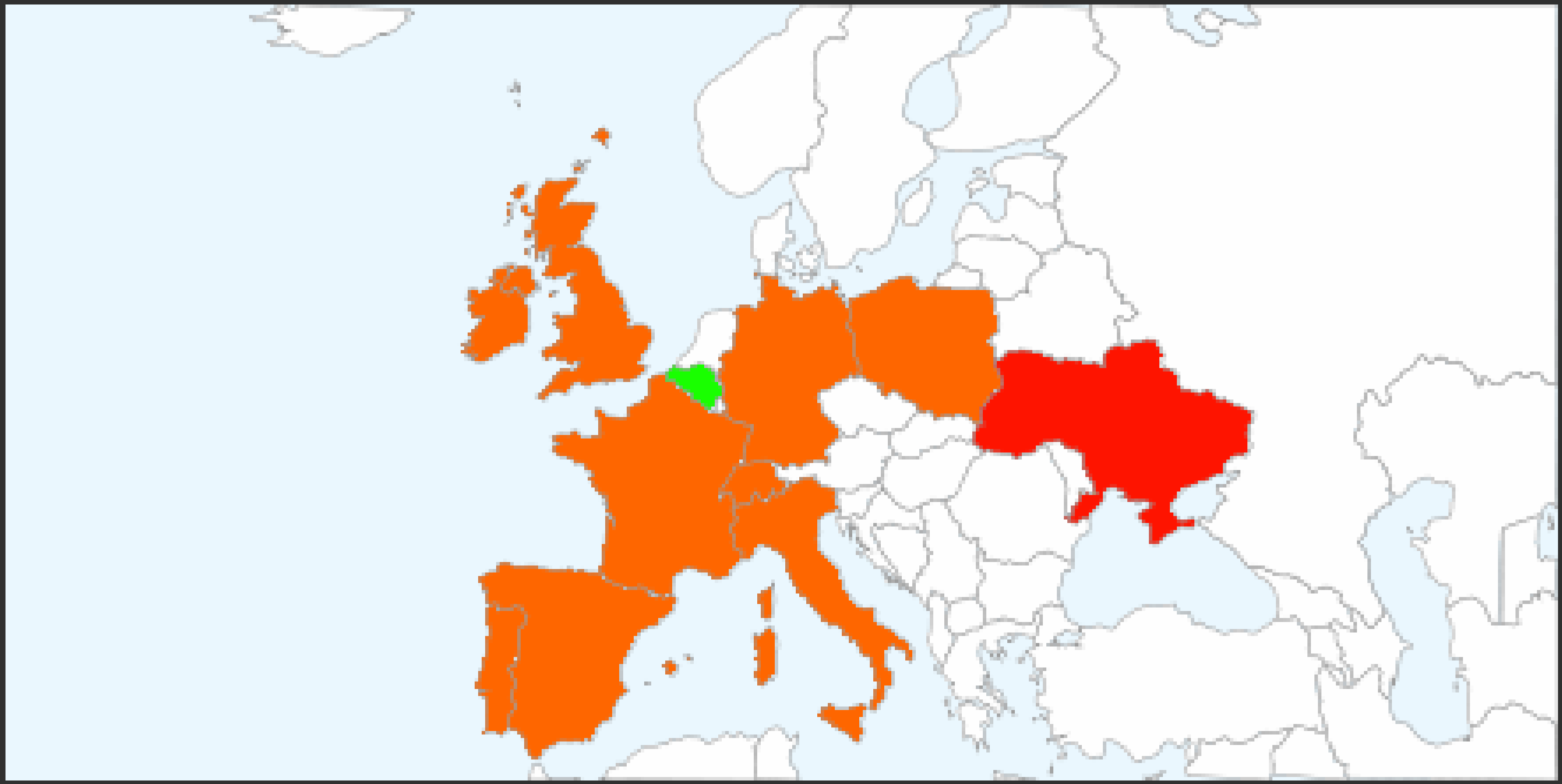
Defining HyspIRI MWIR saturation level - need for regional analysis

- Gao et al. (2007) MODIS Study – statistical analysis
  - Only 0.4% of fire pixels have T_{MWIR} > 450 K
  - Only 1.7% of fire pixels have T_{MWIR} > 400 K
  - For 1-km pixels saturation "*…should be specified at about 450 K or even lower to 400 K in order to make the channels more useful for quantitative remote sensing of fires.*"
- Our own independent analysis shows that from 2003-2009 only 0.02% of all fire pixels saturated MODIS MWIR band 21 (~500K saturation)

Percentage of saturated fire pixels: the Land Surface Temperature analogy

- LST retrieval not possible for saturated land pixels
  - Fire characterization not possible for saturated fire pixels
- Depict Gao et al. (2007) suggested fire-pixel saturation rates as equivalent saturated land surface area confounding hypothetical LST retrieval

1.7% 400 K saturation analog
0.4% 450 K saturation analog
0.02% 500 K saturation analog



1.7% 400 K saturation analog
0.4% 450 K saturation analog
0.02% 500 K saturation analog

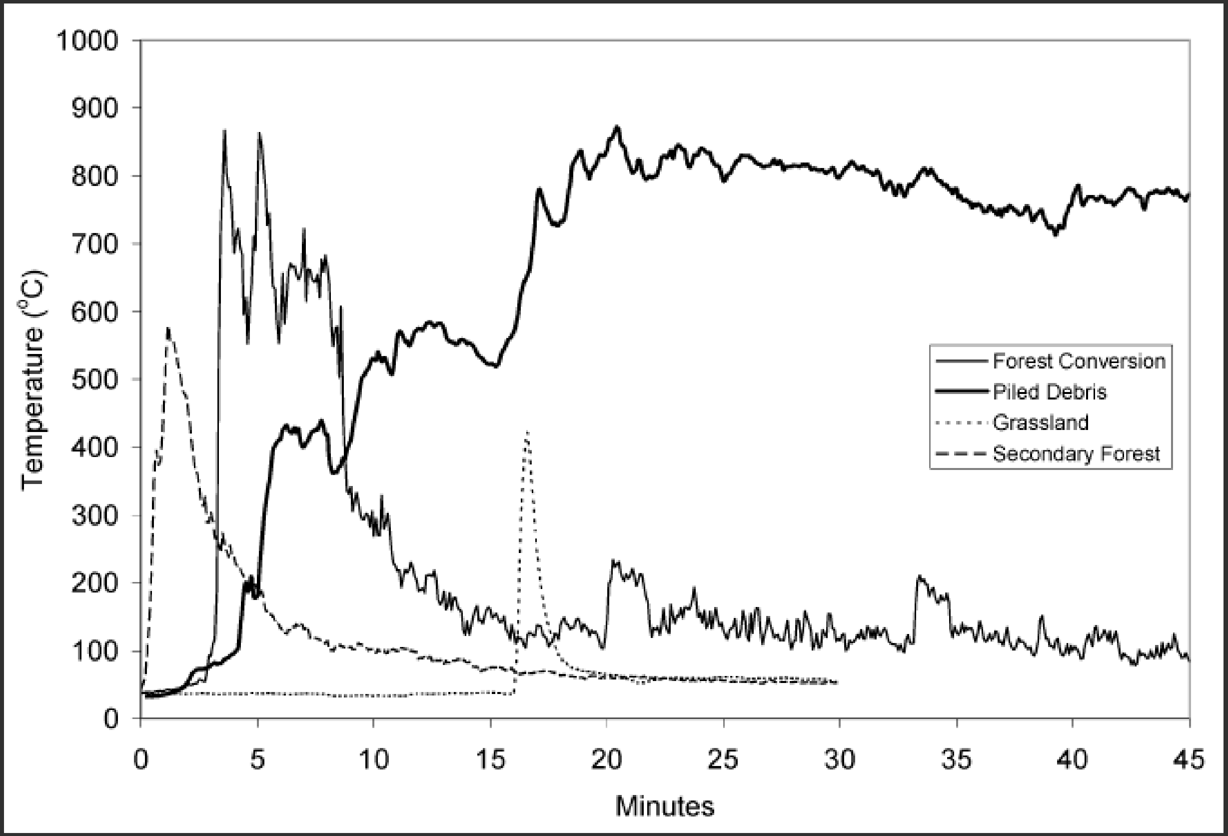
Saturation issues

- What is the expected uncertainty in emission estimates?
- What is the frequency of saturated pixels on a regional basis?
- What are the realistic “extreme” fire characteristics?
  - Up to ~1800K flaming temperature possible for forest (Ward et al., 1992, Lobert et al., 1993)
    - 1200 is a realistic upper end
  - Crown fires on a slope can cover the entire HyspIRI pixel

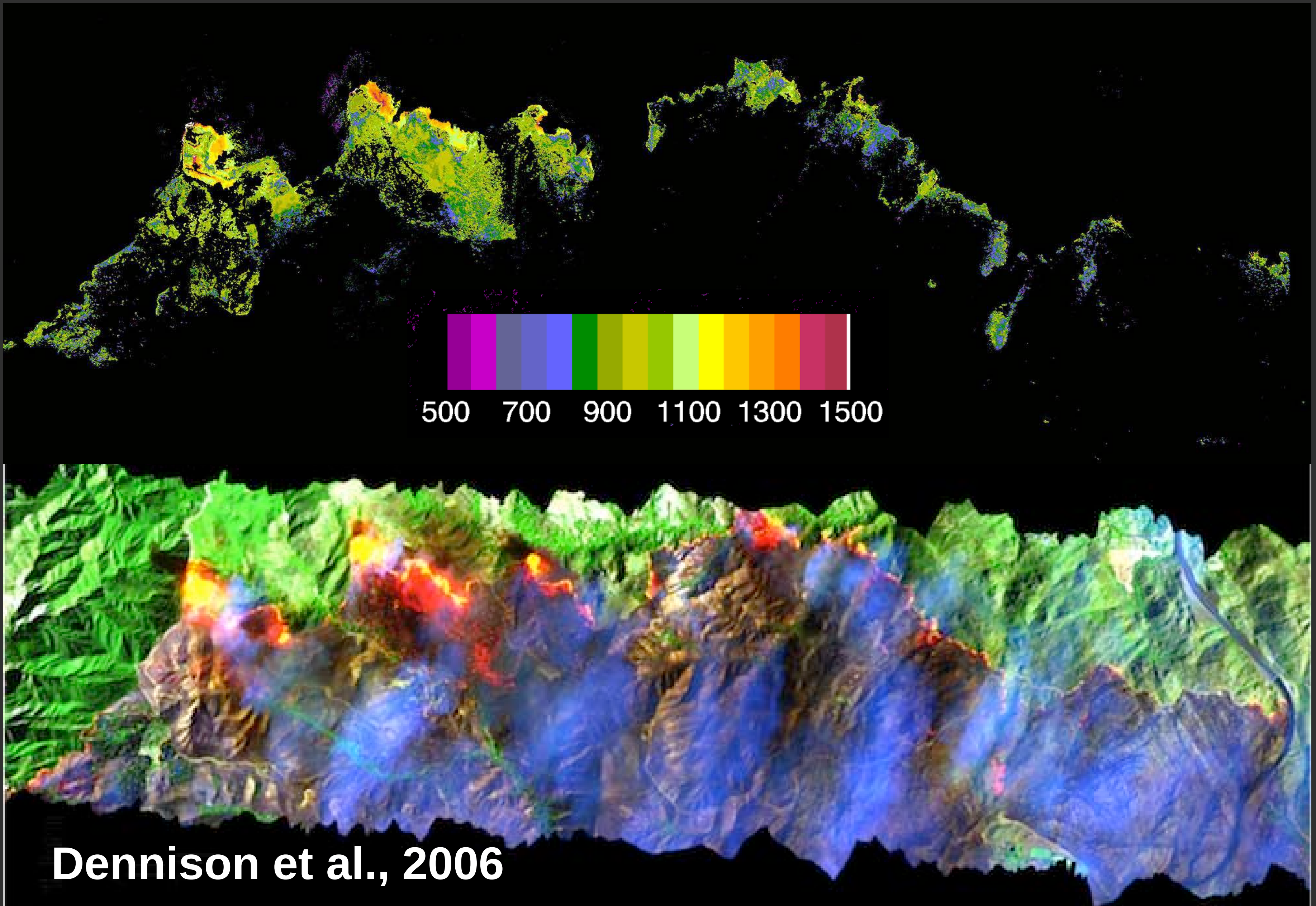
Fire characteristics in Roraima, Brazil

Maintenance

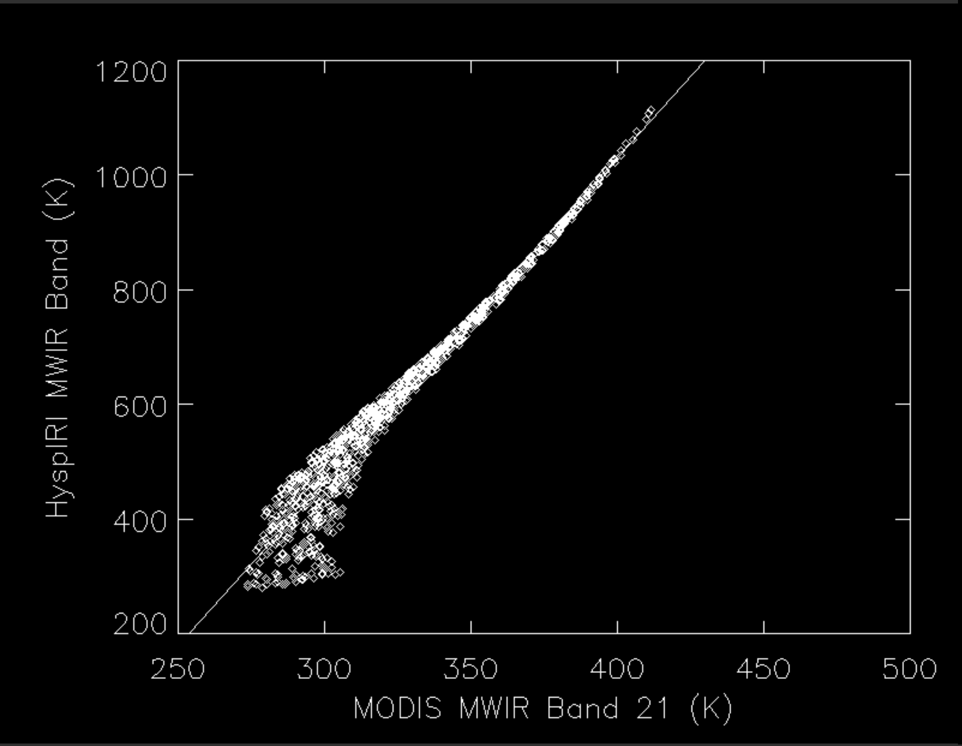
Conversion



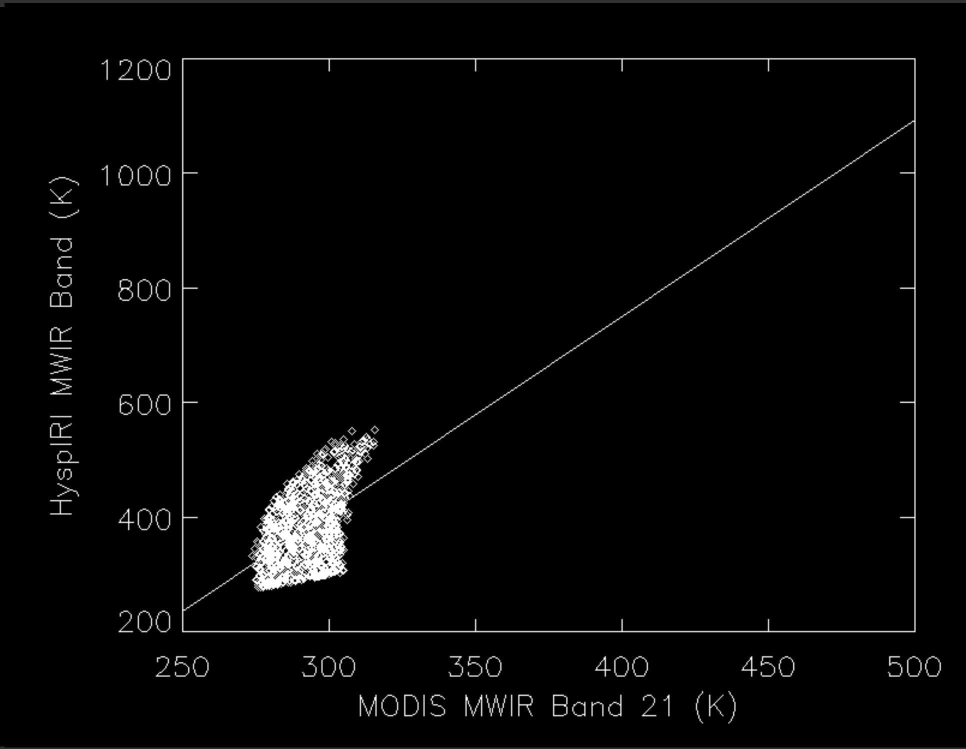
Retrieved Temperature Endmembers



Simulated MWIR brightness temperatures



Up to 1200K, up to 100% fractional area within the HyspIRI pixel



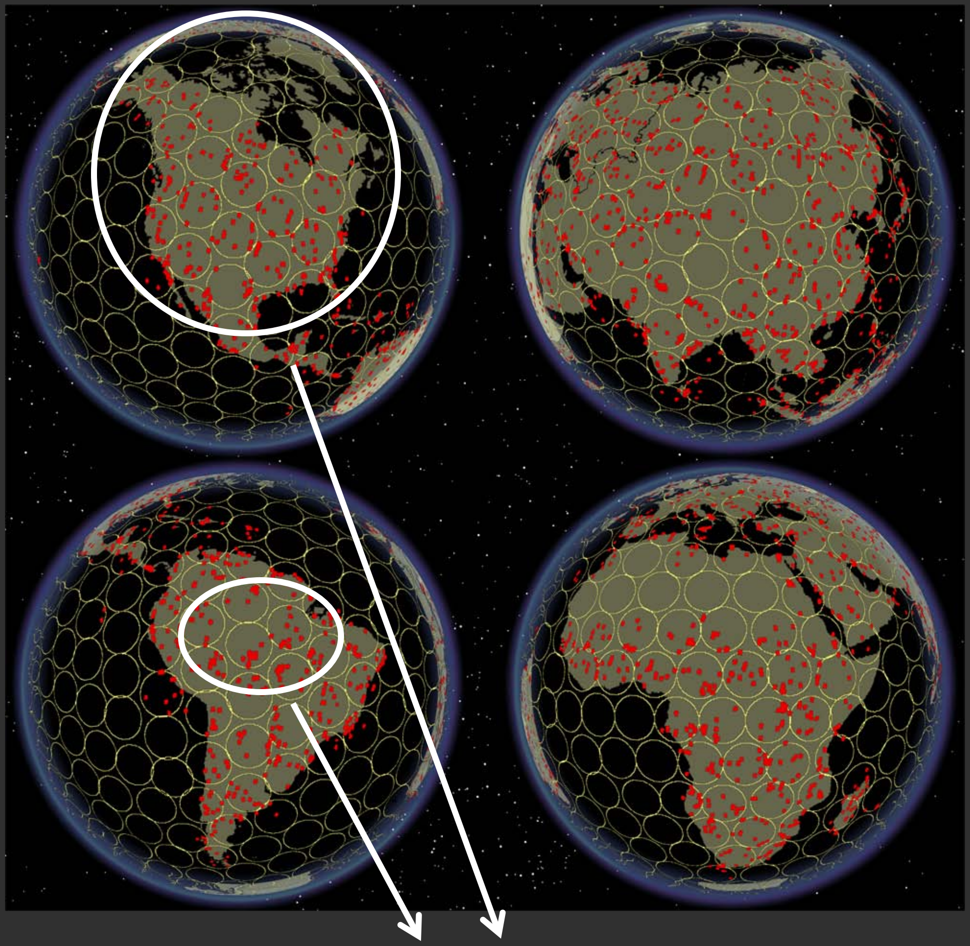
Up to 1200K, up to 20% fractional area within the HyspIRI pixel

Global dataset of ASTER fire masks

- Use of equidistant grid (circular - 900km diameter)
  - 642 cells
  - ~370 over land
  - ~210 in areas with some fire activity (deserts and poles automatically excluded in the process)
- Six years of data represented
  - 2001-2002; 2003-2004; 2005-2006
  - ASTER SWIR data quality issues beginning May 2007
- ~2500 ASTER scenes selected
  - 4 scenes for each grid cell - 2 year period
  - up to 3 scenes represensing highest number of MOD14 fire pixels
  - at least one random scene per cell/period containing fire, no fire, water, clouds, etc.
  - 140 nighttime scenes

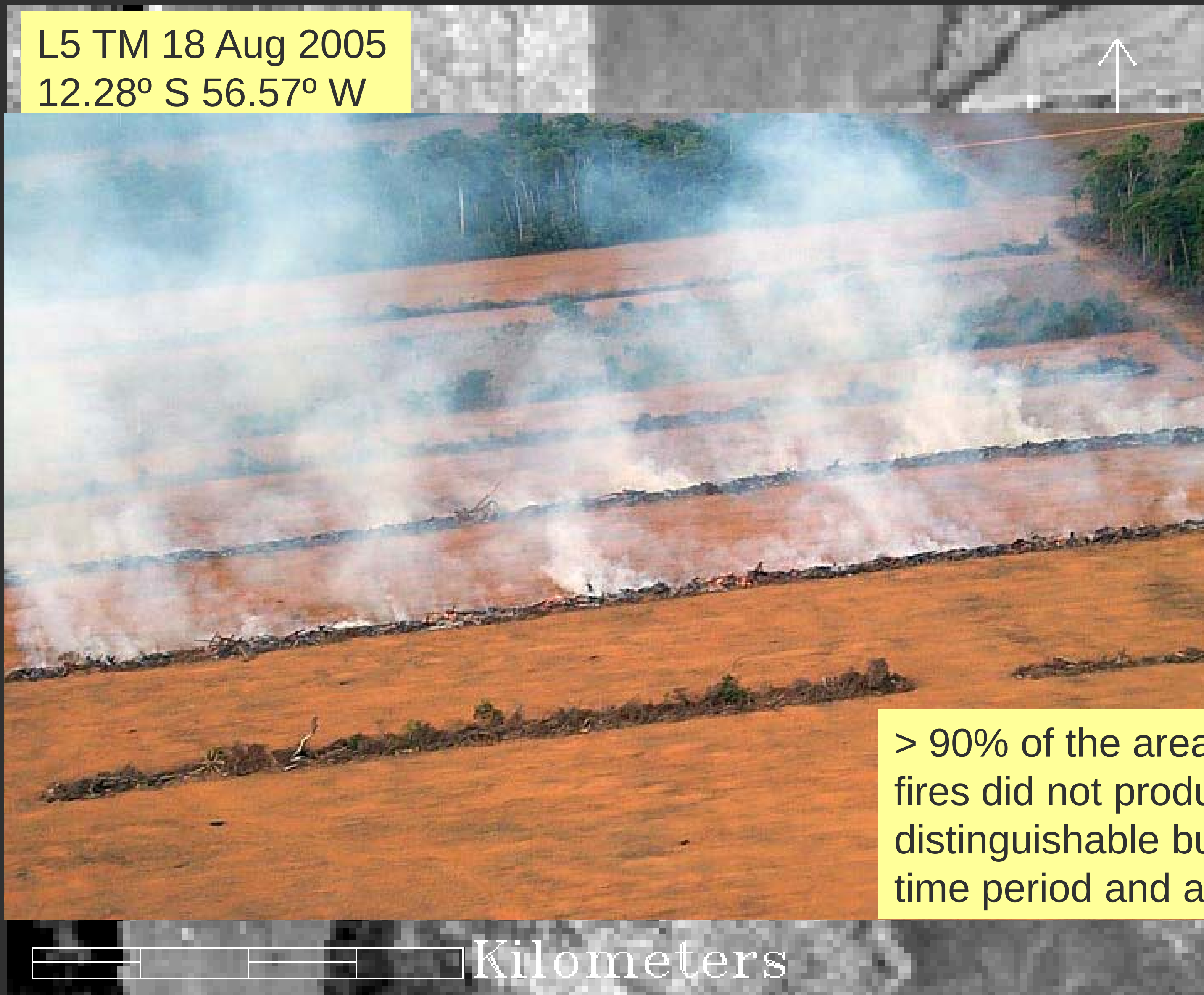
⟹ 16K daytime MOD14 fire pixels sampled

⟹ 700 nighttime MOD14 fire pixels sampled



~30% of fire clusters consist of more than 10 ASTER fire pixels

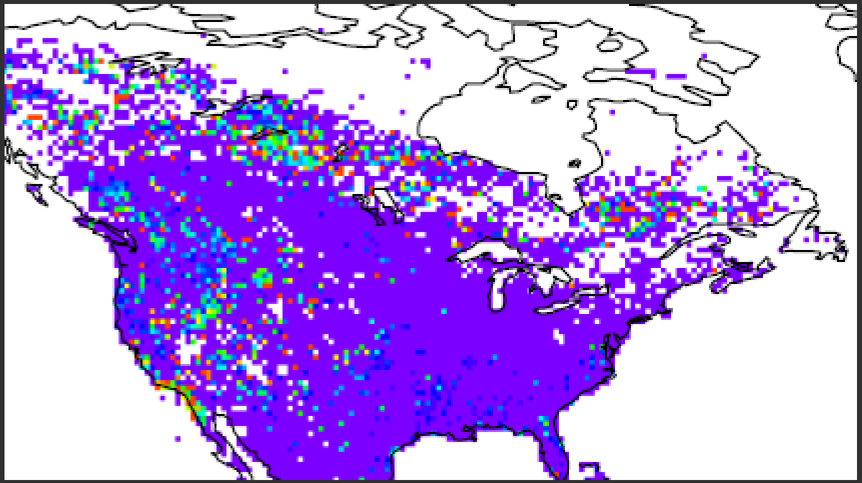
The Case of Central Mato Grosso State in Brazilian Amazonia

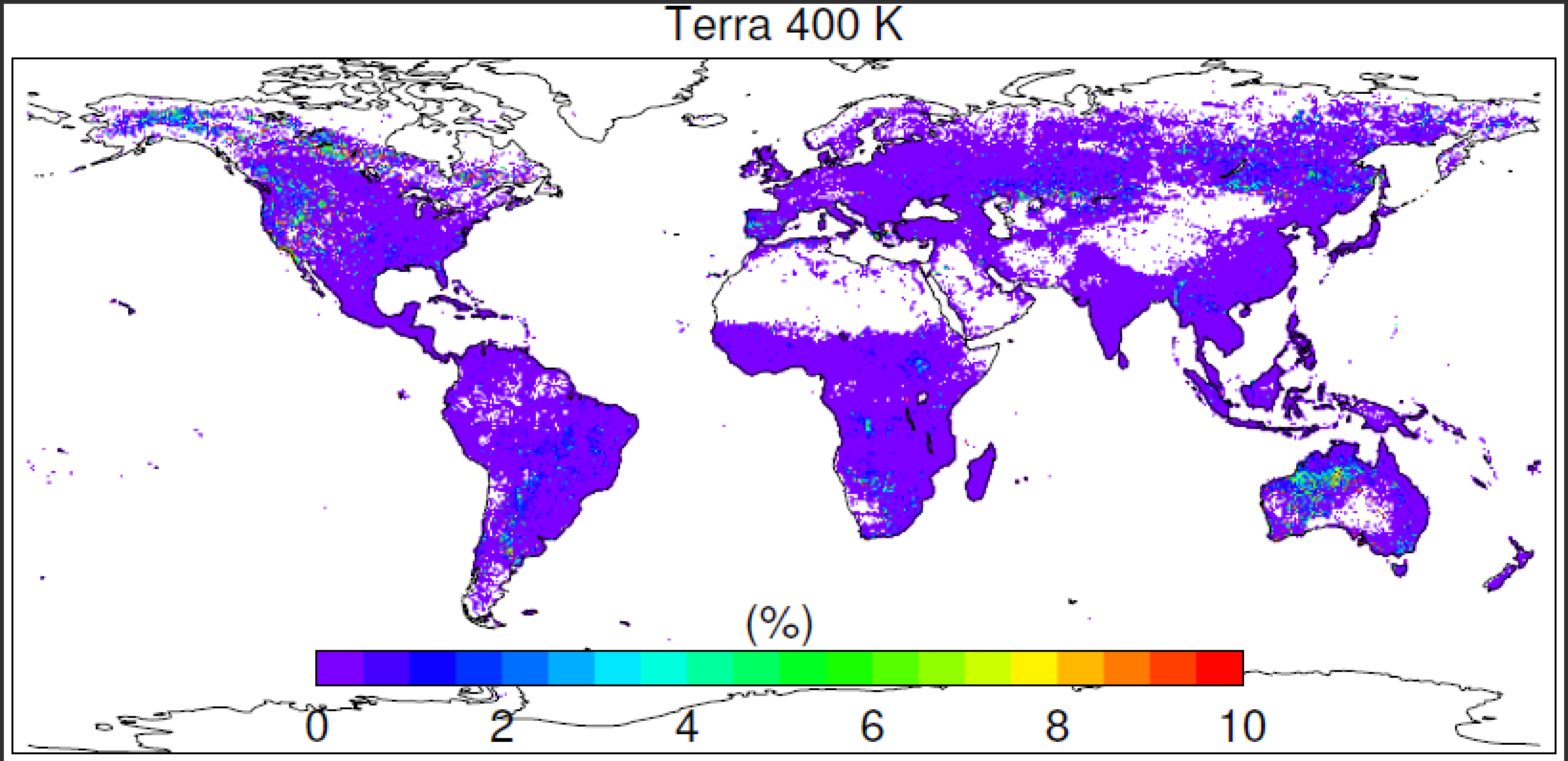


Example of piled debri burning

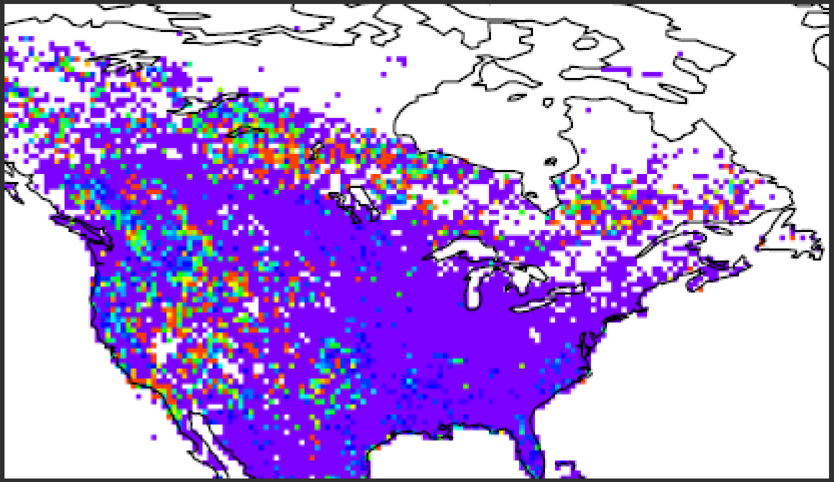
> 90% of the areas with active fires did not produce a distinguishable burn scar for the time period and area analyzed

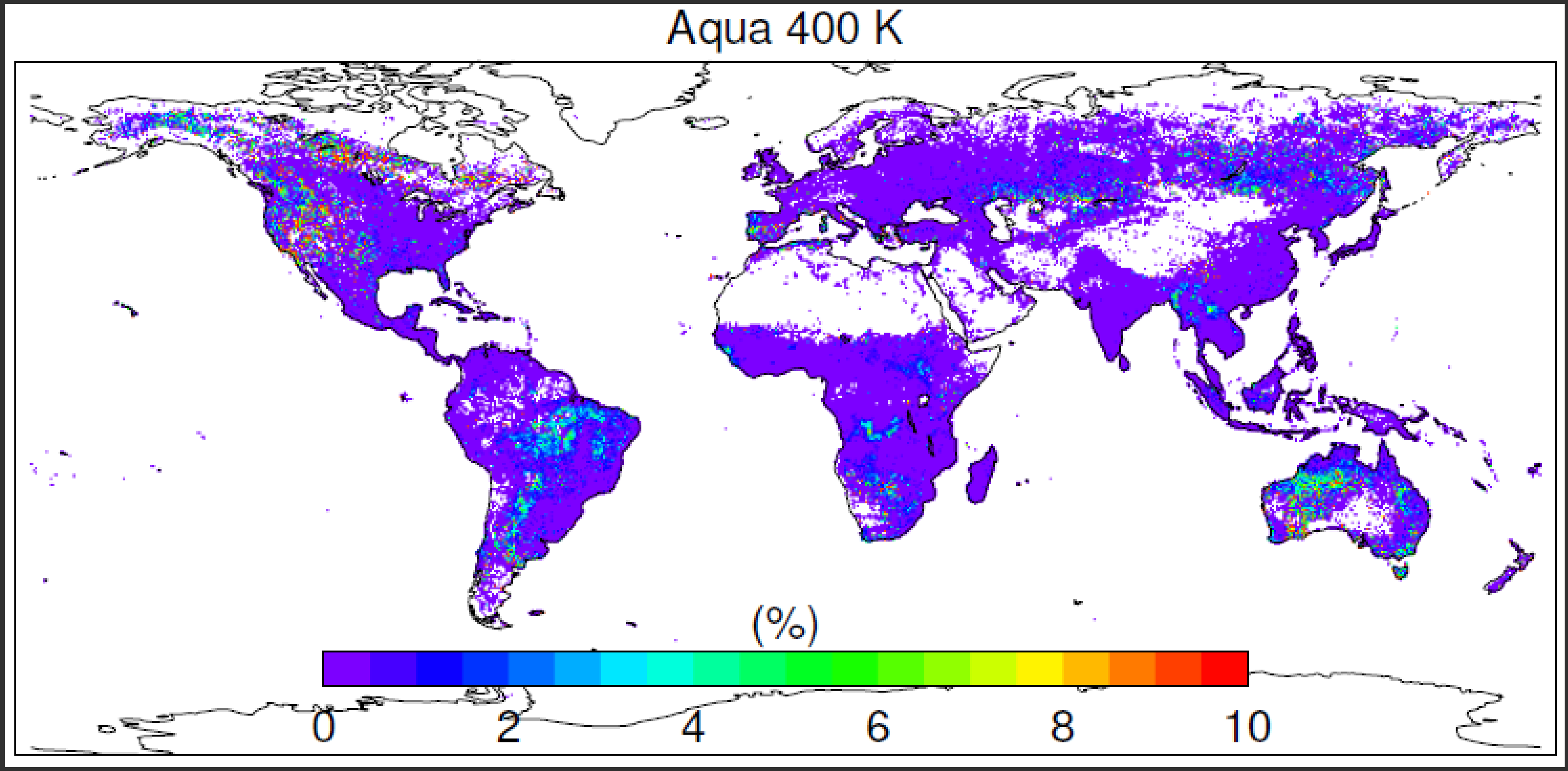
Percentage of MODIS fire pixels with MWIR brightness temperature above the indicated value





Percentage of MODIS fire pixels with MWIR brightness temperature above the indicated value





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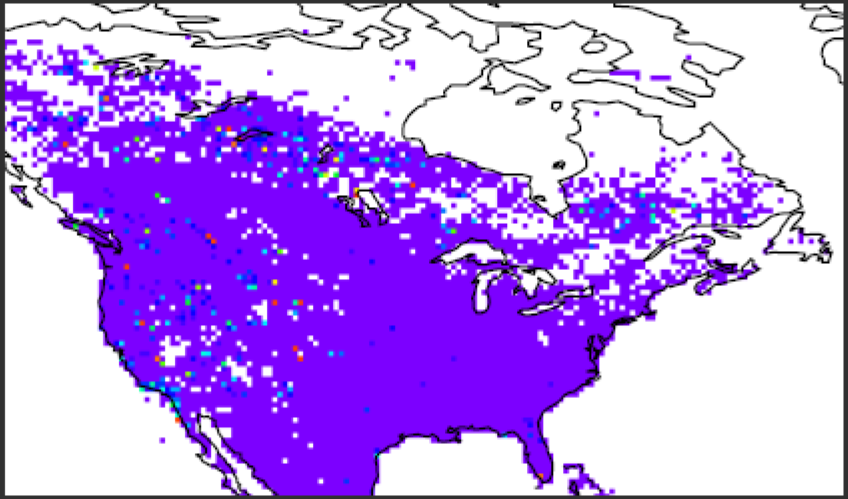

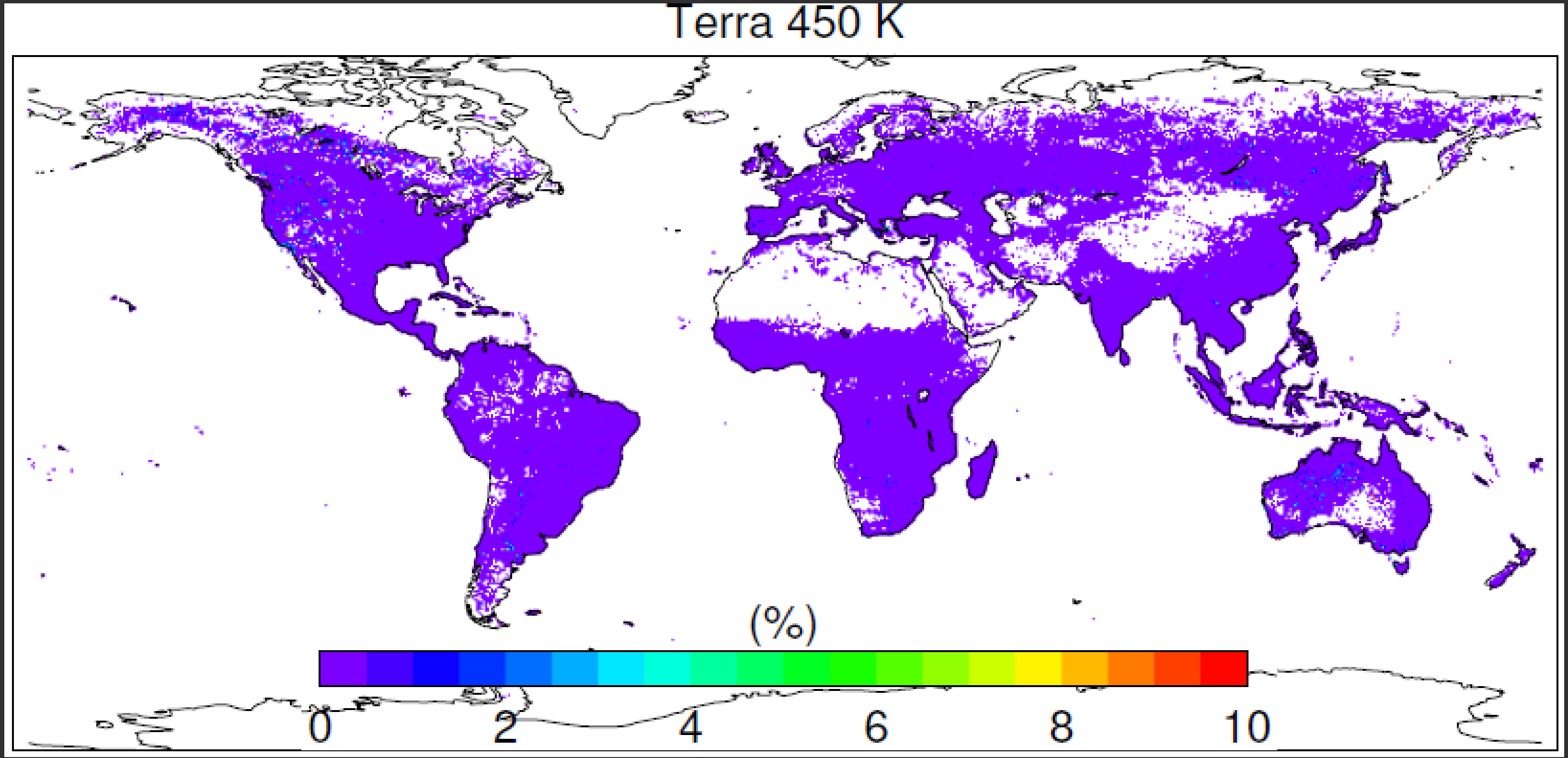

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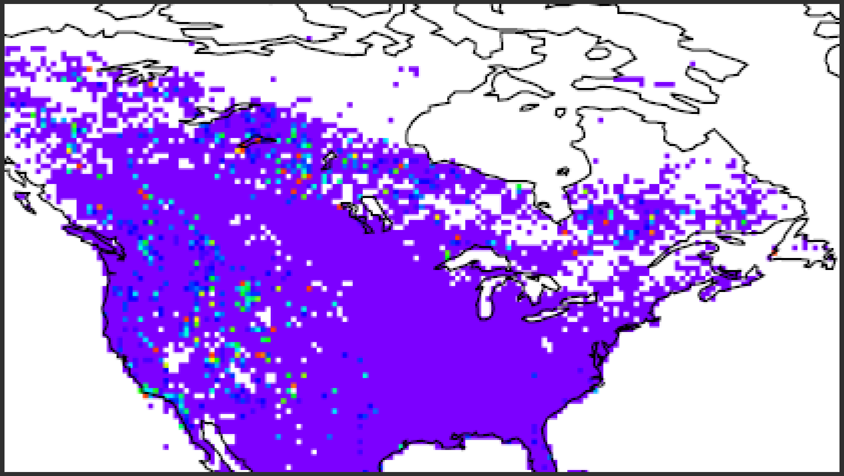

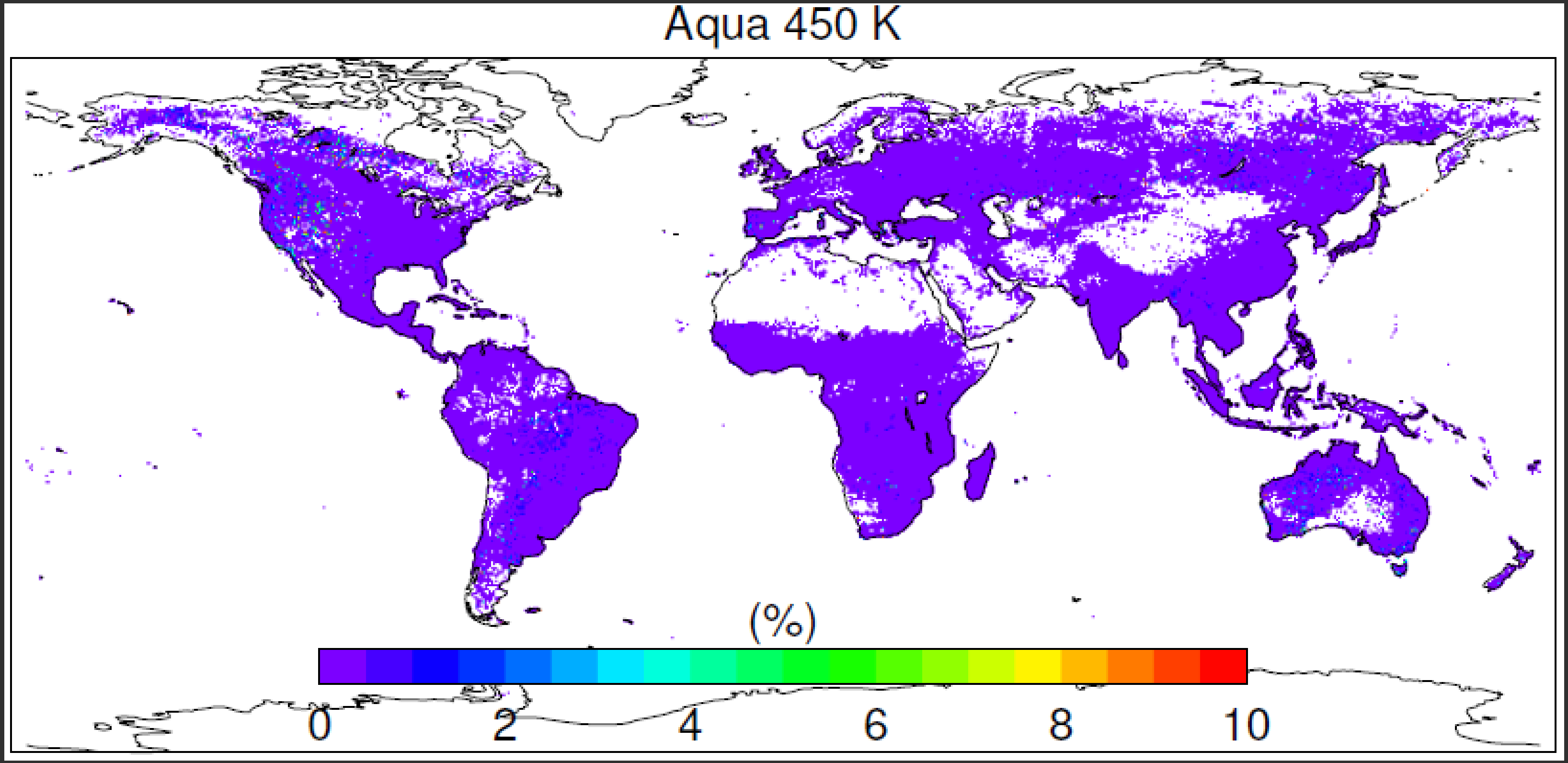

Major benefits of HyspIRI for fire

- Unprecedented capability of global fuel mapping and characterization of the recovery process
- Unprecedented sensitivity to active flaming and smoldering fires
  - can easily detect small agricultural fires (difficult with coarser resolution sensors)
  - fewer false alarms in fire detection
  - straightforward retrieval of fire radiative power
    - single band vs. three or more bands with existing sensors
- Greatly expanded spatial and temporal coverage
  - large samples of detailed fire characteristics useful for statistically modeling fires and their behavior
- Interpretation, calibration and validation of fire observations derived from coarser resolution data