TQ2 - Wildfires

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and contribution by many others (see slides for credit)

Outline

- Overarching question
- Science traceability matrix
- Decadal Survey relevance
- Sub-questions and associated science
- Level 2 and Level 3 products
- Validation approach

Overarching question

- What is the impact of global biomass burning on the terrestrial biosphere and atmosphere, and how is this impact changing over time?

- Observational needs:
  - biogeochemical and earth system processes and interactions
    - (e.g. vegetation – fire – emissions)
  - monitoring of Earth System processes
    - local, regional, global scales

Thematic subquestions

- TQ2a: How are global fire regimes (fire location, type, frequency, and intensity) changing in response to changing climate and land use practices?
- TQ2b: Is regional and local fire frequency changing?
- TQ2c: What is the role of fire in global biogeochemical cycling, particularly trace gas emissions?
- TQ2d: Are there regional feedbacks between fire and climate change?

Science traceability matrix

Science Objectives	Measurement Objectives	Measurement Requirements	Instrument Requirements	Other Mission and Measurement Requirements
TQ2. Wildfires: What is the impact of global biomass burning on the terrestrial biosphere and atmosphere, and how is this impact changing over time?				
How are global fire regimes (fire location, type, frequency, and intensity) changing in response to changing climate and land use practices? [DS 198] (feedbacks?)	Fire monitoring, fire intensity	Detect flaming and smoldering fires as small as ~10 sq. m in size, fire radiative power, fire temperature and area, 4-10 day repeat cycle	Low and normal gain channels at 4 and 11 µm (possible dual gain for 11 um). Low-gain saturation at 1400 K, 1100 K, respectively, with 2-3 K NEdT; normal-gain NEdT < 0.2 K. Stable behavior in the event of saturation. 50-100 m spatial resolution. Accurate inter-band coregistration (< 0.25 pixel). Opportunistic use of additional bands in 8-14 µm region.	Daytime and nighttime data acquisition, direct broadcast and on-board processing, pre-fire and post-fire thematic maps, opportunistic validation. Low Earth Orbit.
Is regional and local fire frequency changing? [DS 196]	Fire detection	Detect smoldering fires as small as ~10 sq. m in size, 4-10 day repeat cycle over the duration of the mission	8-12 µm normal gain. normal-gain NEdT < 0.2 K. Stable behavior in the event of saturation. 50-100 m spatial resolution. Accurate inter-band coregistration (< 0.25 pixel)	Daytime and nighttime data acquisition. Requires a historical context from other sensors with measurement intercalibration, establishes a baseline. Low Earth Orbit. Daytime and nighttime data acquisition (Thermal inertia)
What is the role of fire in global biogeochemical cycling, particularly trace gas emissions? [DS 195]	Fire detection, fire intensity, fire monitoring, burn severity, delineate burned area	Detect flaming and smoldering fires as small as ~10 sq. m in size, fire radiative power, 4-10 day repeat cycle; fire temperature and area.	Low and normal gain channels at 4 and 11 µm (possible dual gain for 11 um). Low-gain saturation at 1400 K, 1100 K, respectively, with 2-3 K NEdT; normal-gain NEdT < 0.2 K. Stable behavior in the event of saturation. 50-100 m spatial resolution. Accurate inter-band coregistration (< 0.25 pixel). Opportunistic use of additional bands in 8-14 µm region.	Daytime and nighttime data acquisition, pre-fire vegetation cover, condition and loads for fuel potential. Requires fuel fire modeling element.
Are there regional feedbacks between fire and climate change? [DS 196]	Extent of fire front and confirmation of burn scars	Detect flaming and smoldering fires as small as ~10 sq. m in size, fire radiative power, 4-10 day repeat cycle; fire temperature and area.	Low and normal gain channels at 4 and 11 microns. Low-gain saturation at 1400 K, 1100 K, respectively, with 2-3 K NEdT; normal-gain NEdT < 0.2 K. Stable behavior in the event of saturation. 50-100 m spatial resolution. Accurate inter-band coregistration (< 0.25 pixel).	Daytime and nighttime data acquisition, pre-fire vegetation cover, condition and loads for fuel potential. Requires fuel fire modeling element.

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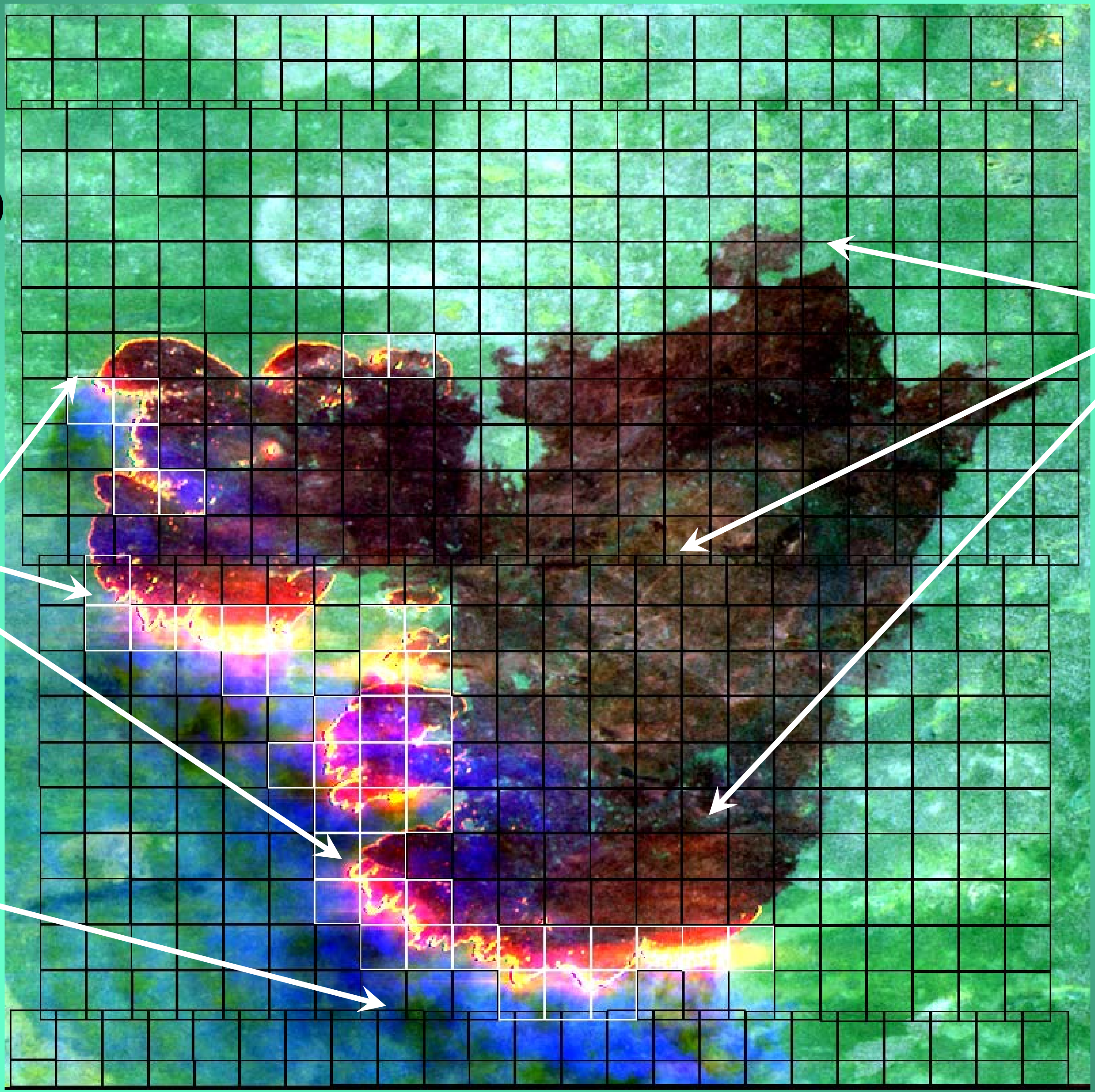
HyspIRI MIR/TIR active fire detection and characterization capabilities

- 60m resolution, high saturation level
- low detection limit
  - early detection
- Quantitative information for fire characterization
  - Fire Radiative Power
  - Fire Area/Temperature
- Better spatial and temporal coverage for this class of observations than before

TERRA MODIS Fire Detections over an ASTER image
(Simultaneous High Resolution Acquisition with MODIS)

Aug 17 2001
09:08 UTC
18.8S 19.9 E
(NE Namibia)

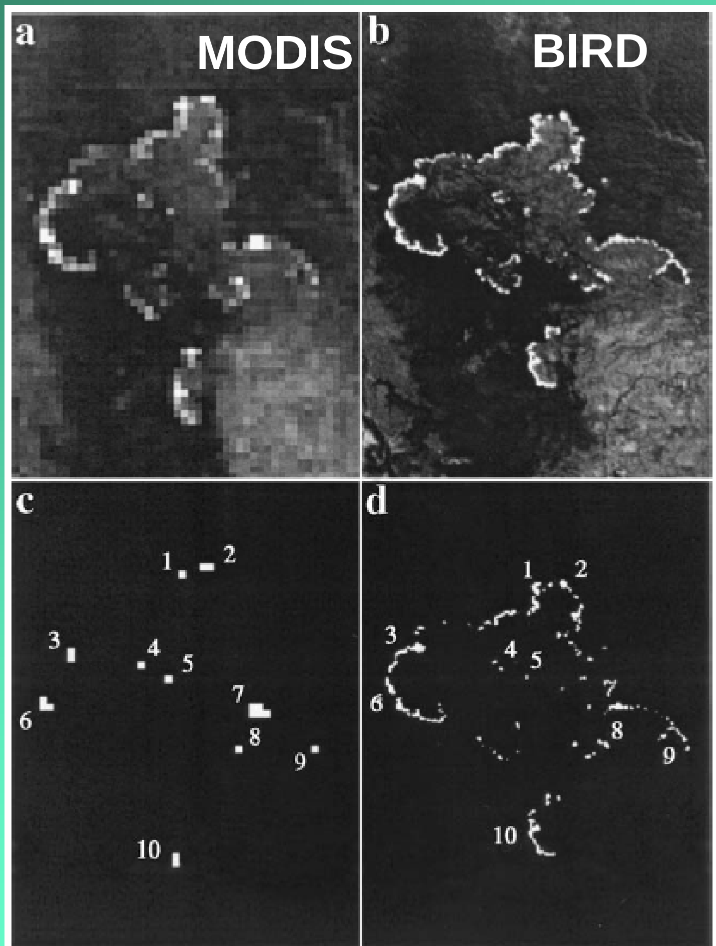


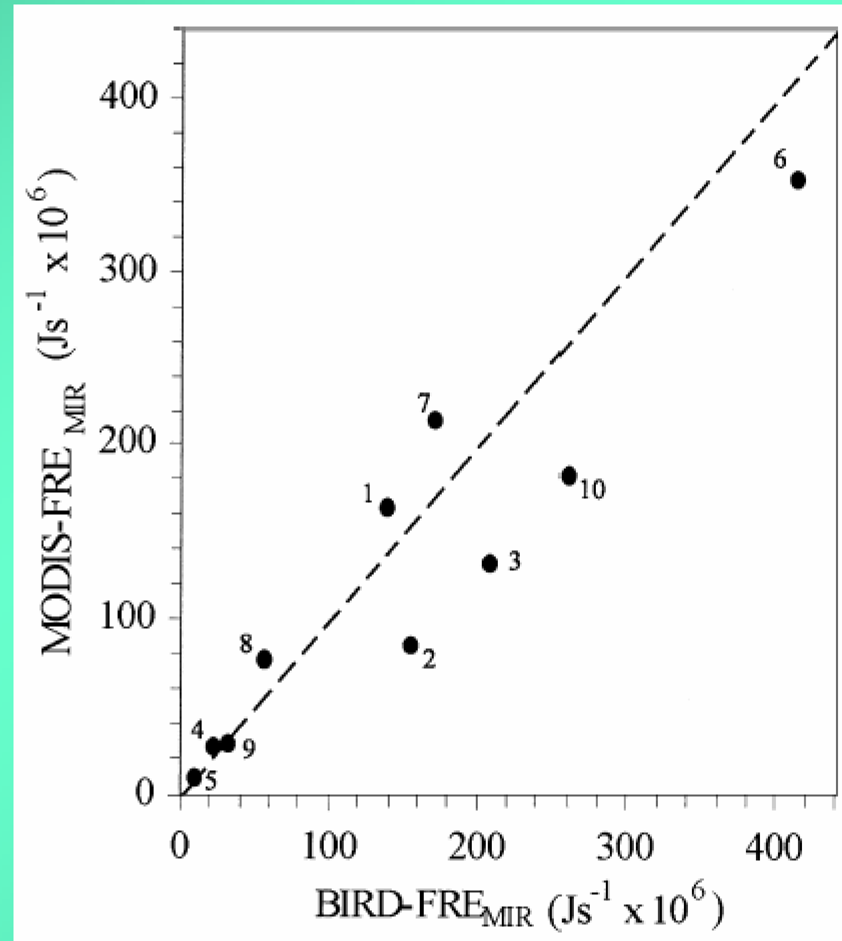
White squares: MODIS fire pixels

R: 2.16 μm
G: 1.65 μm
B: 0.56 μm

(Csiszar, Giglio)

Fire Radiative Energy – MODIS vs. BIRD





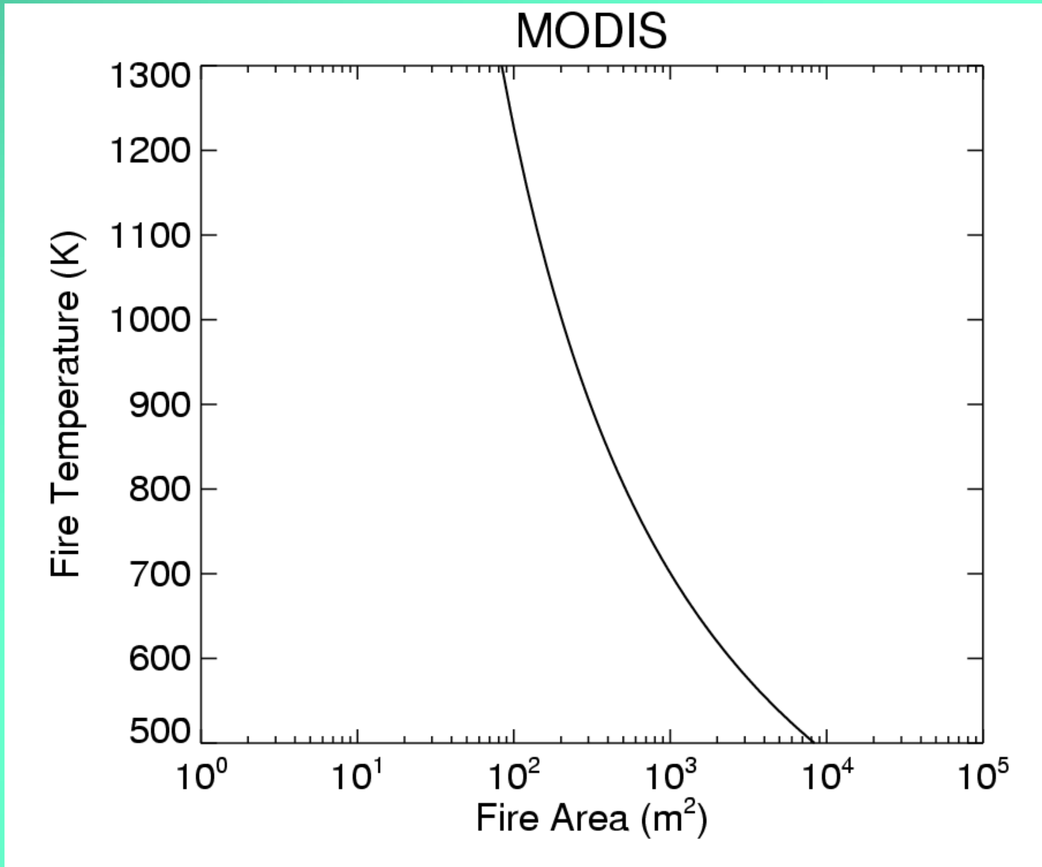
from D. Oertel
DLR, Germany

BIRD satellite

spacesensors.dlr.de/SE/bird/

Wooster et al 2003

Detection envelopes

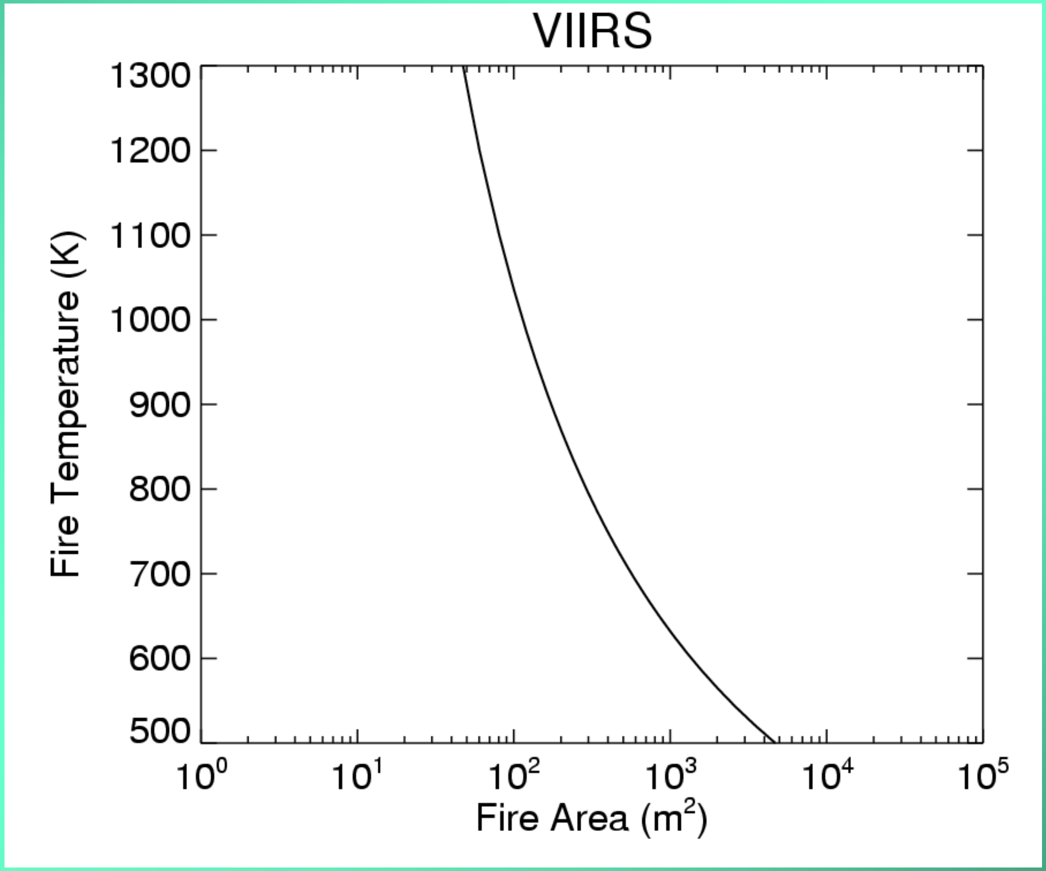


1000 m

90% probability of detection; boreal forest; nadir view

L. Giglio

Detection envelopes

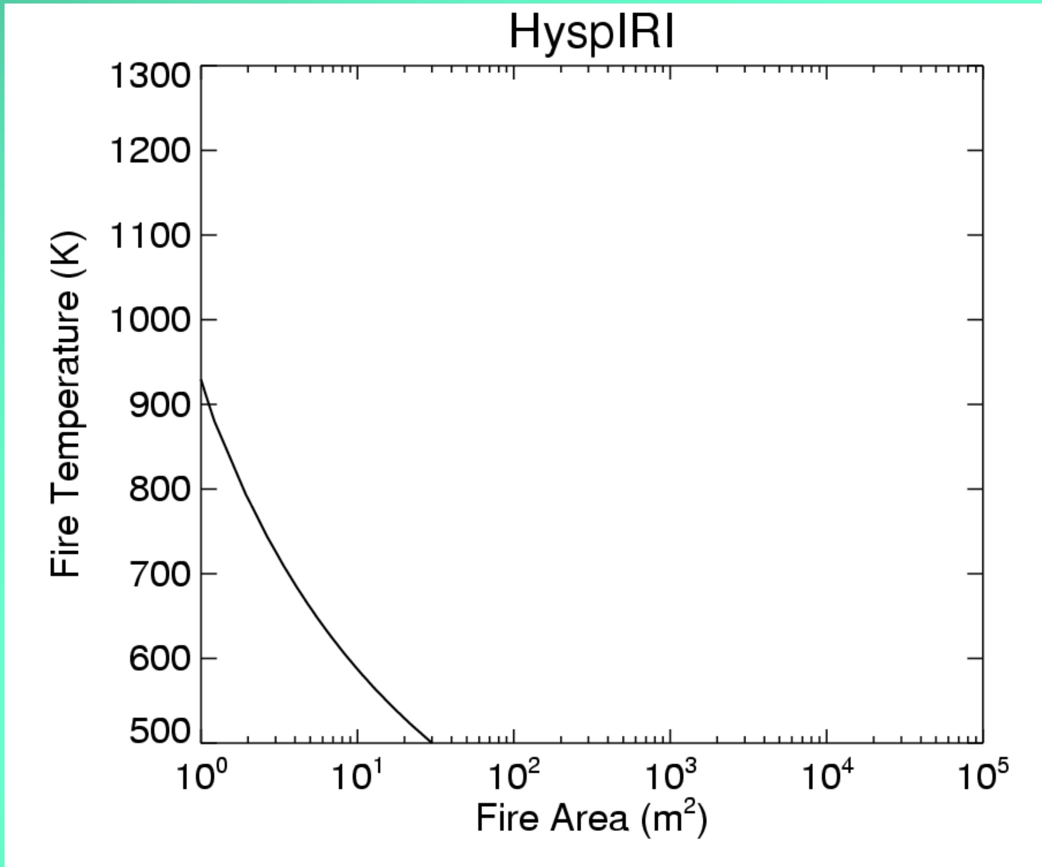


750 m

90% probability of detection; boreal forest; nadir view

L. Giglio

Detection envelopes

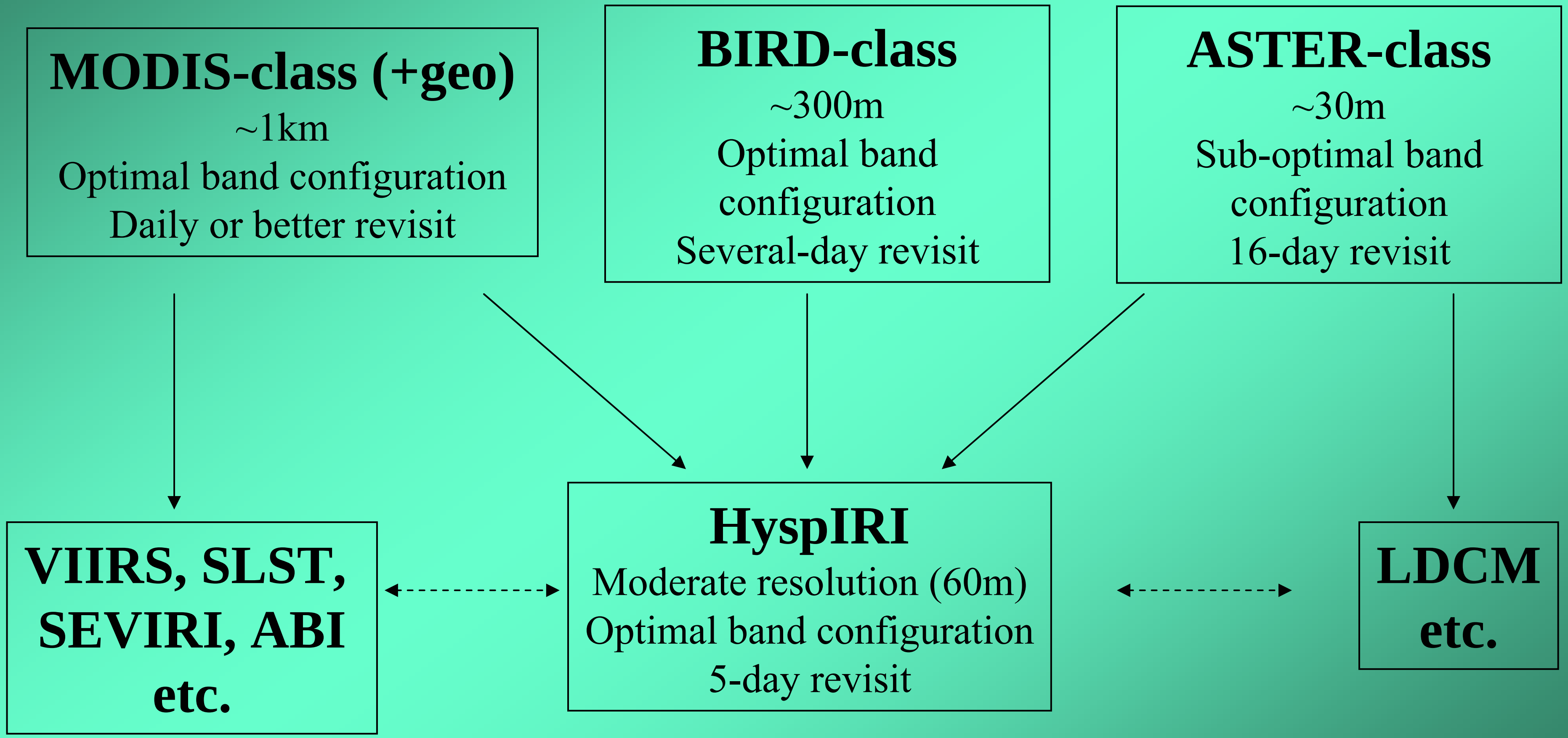


60 m

90% probability of detection; boreal forest; nadir view

L. Giglio

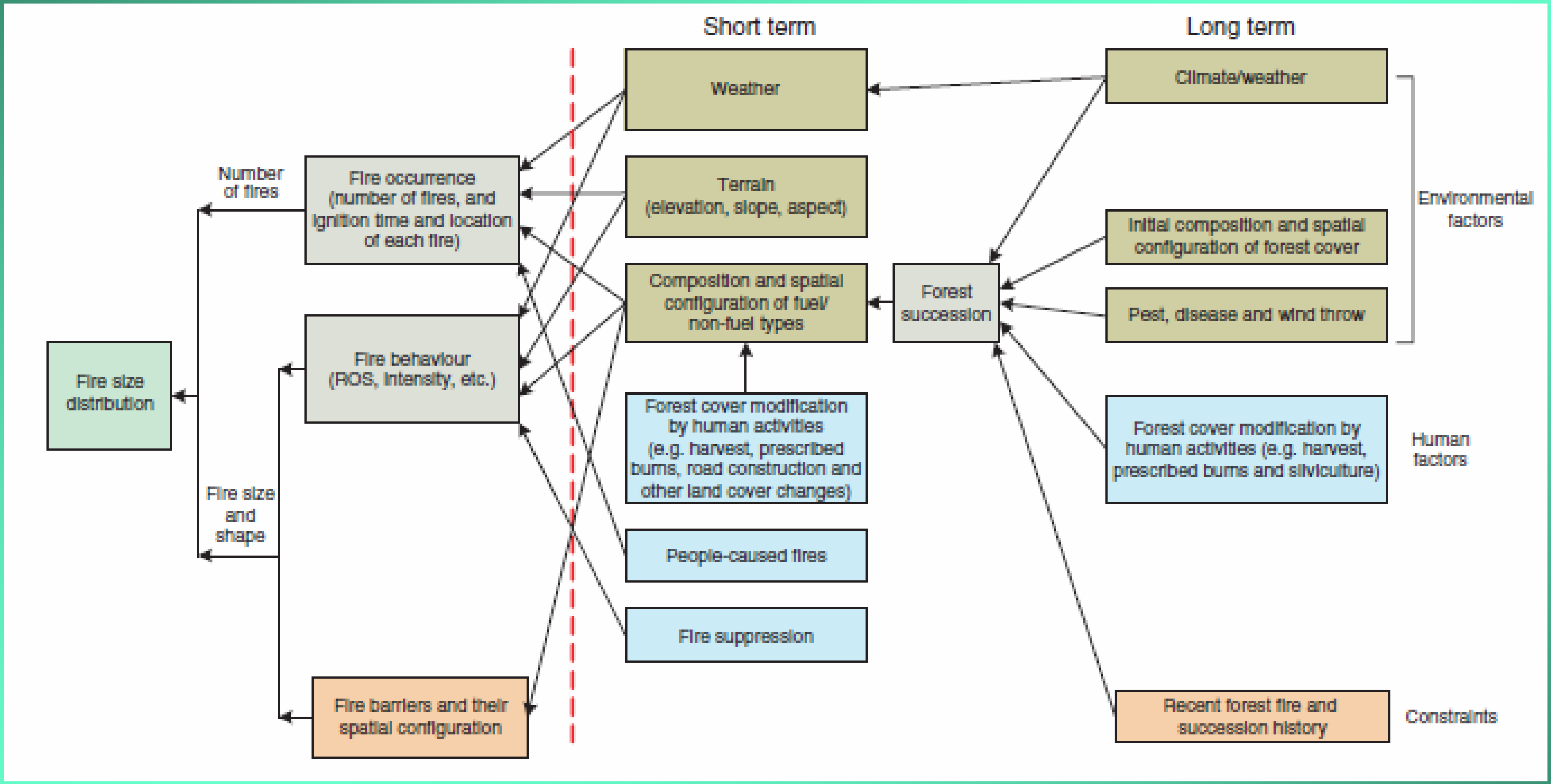
Evolving MIR/TIR fire detection and monitoring capability



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

Fire size distribution



Cui and Pereira, 2008

Fire in the Decadal Survey panel reports

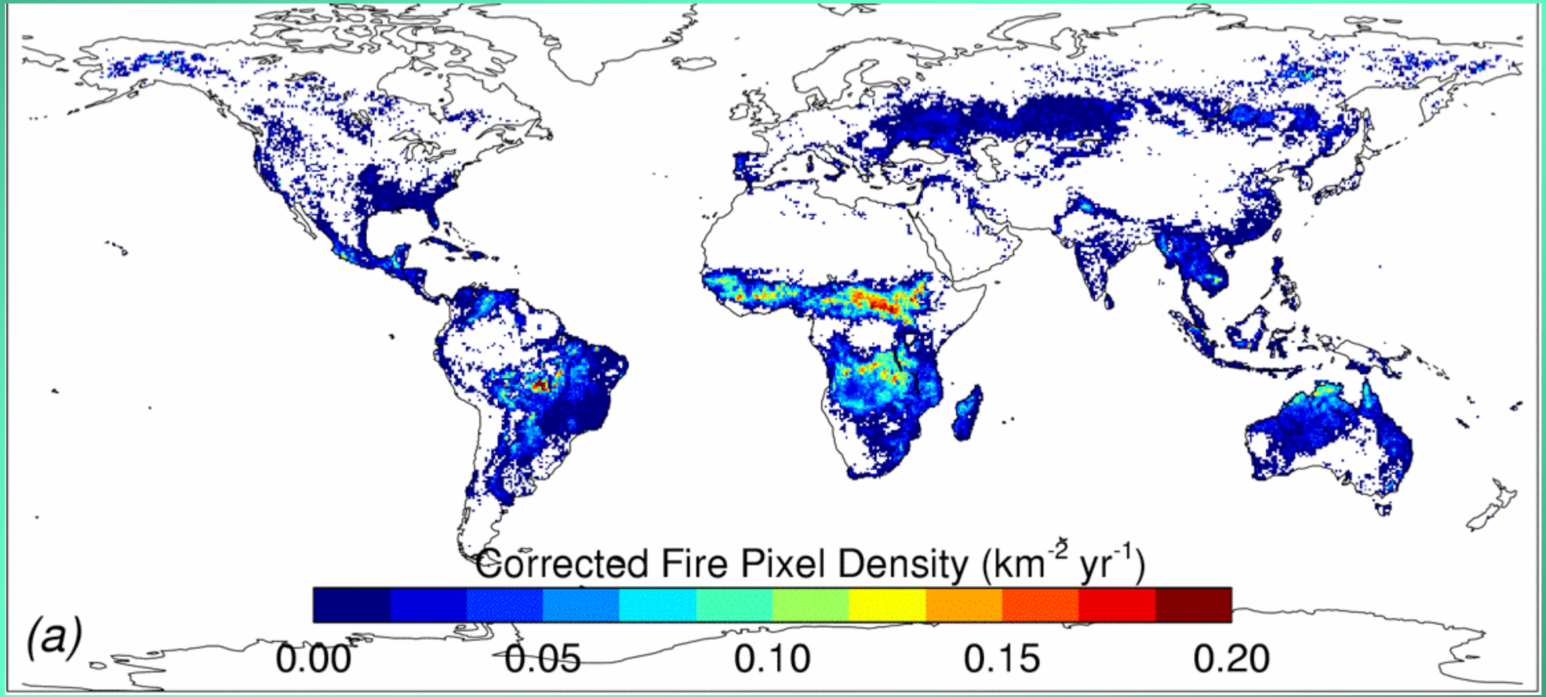
HyspIRI

- Land-use change, ecosystem dynamics and biodiversity
  - distribution and changes in ecosystem function
    - disruption in carbon cycles
    - early detection of such events
  - changes in disturbance cycles
    - related to climate change and changes in water cycle
- (Solid earth hazards, natural resources and dynamics)
  - (relevance through post-fire effects (e.g. debris flow))
- Climate variability and change
  - Fire Disturbance: "major climate variable"; GCOS Essential Climate Variable – CEOS, GTOS, GOFC-GOLD relevance
  - "Will droughts become more widespread in the western United States, Australia, and sub-Saharan Africa? How will this affect the patterns of wildfires?"

TQ2a: How are global fire regimes (fire location, type, frequency, and intensity) changing in response to changing climate and land use practices?

MODIS: Mean Fire Pixel Density

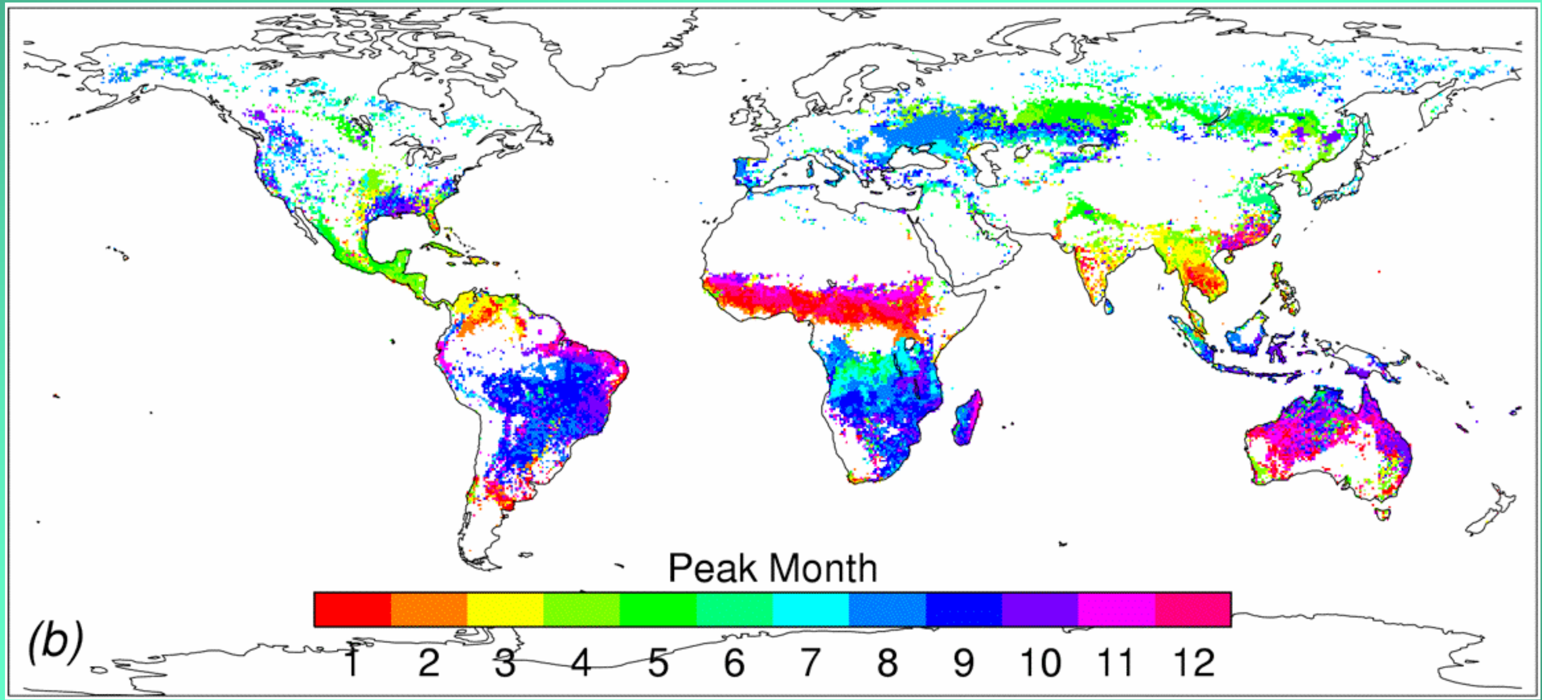
"fire location"



5-year mean (Nov. 2001 - Oct. 2005)

MODIS: Peak Fire Month

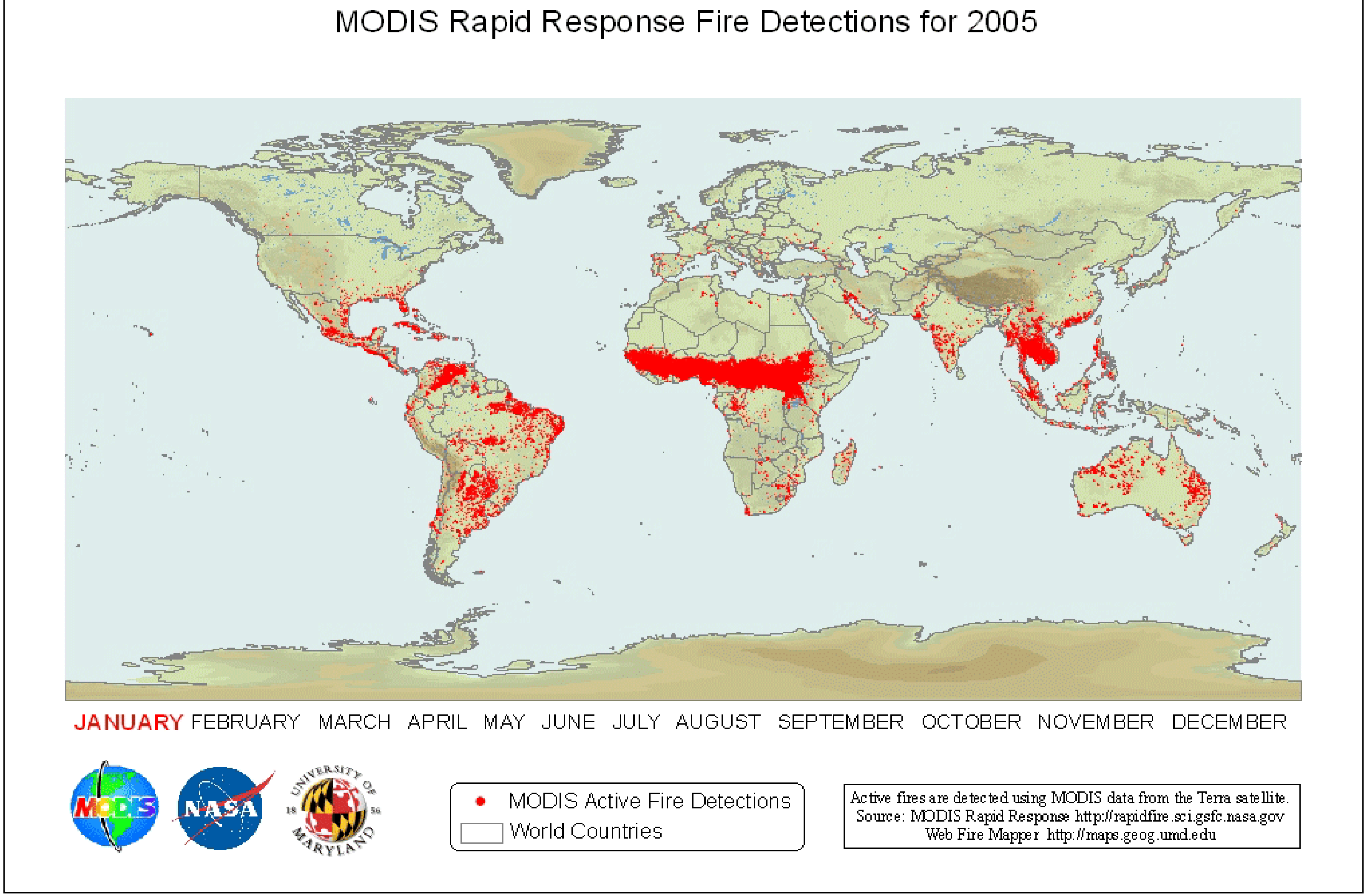
"fire location"



Giglio et al. (2006)

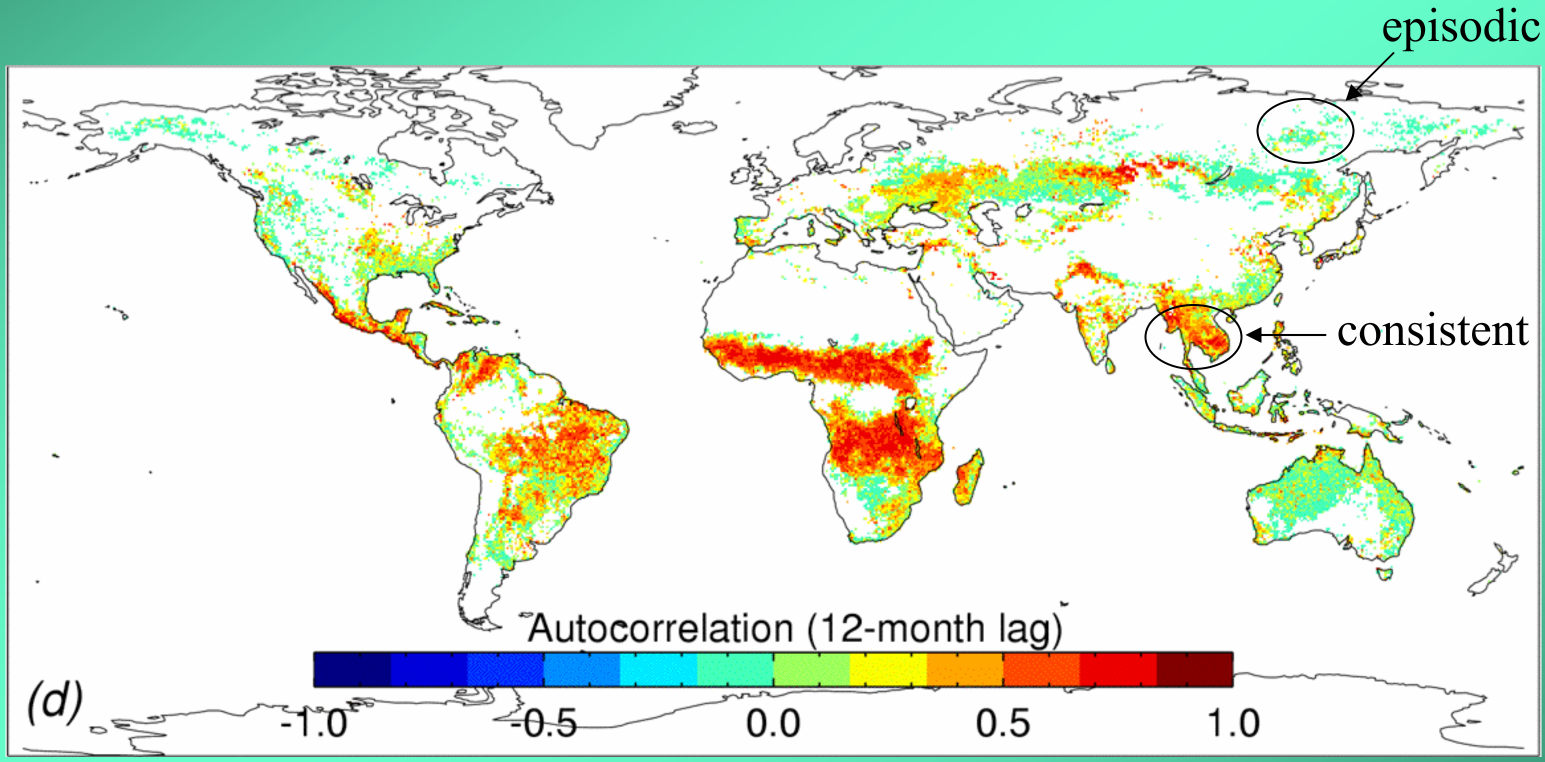
MODIS: Seasonal Variability (2005)

"fire frequency"



MODIS: Autocorrelation

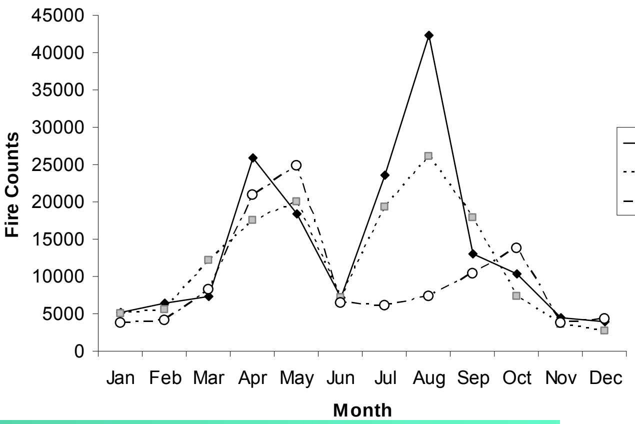
"fire type"

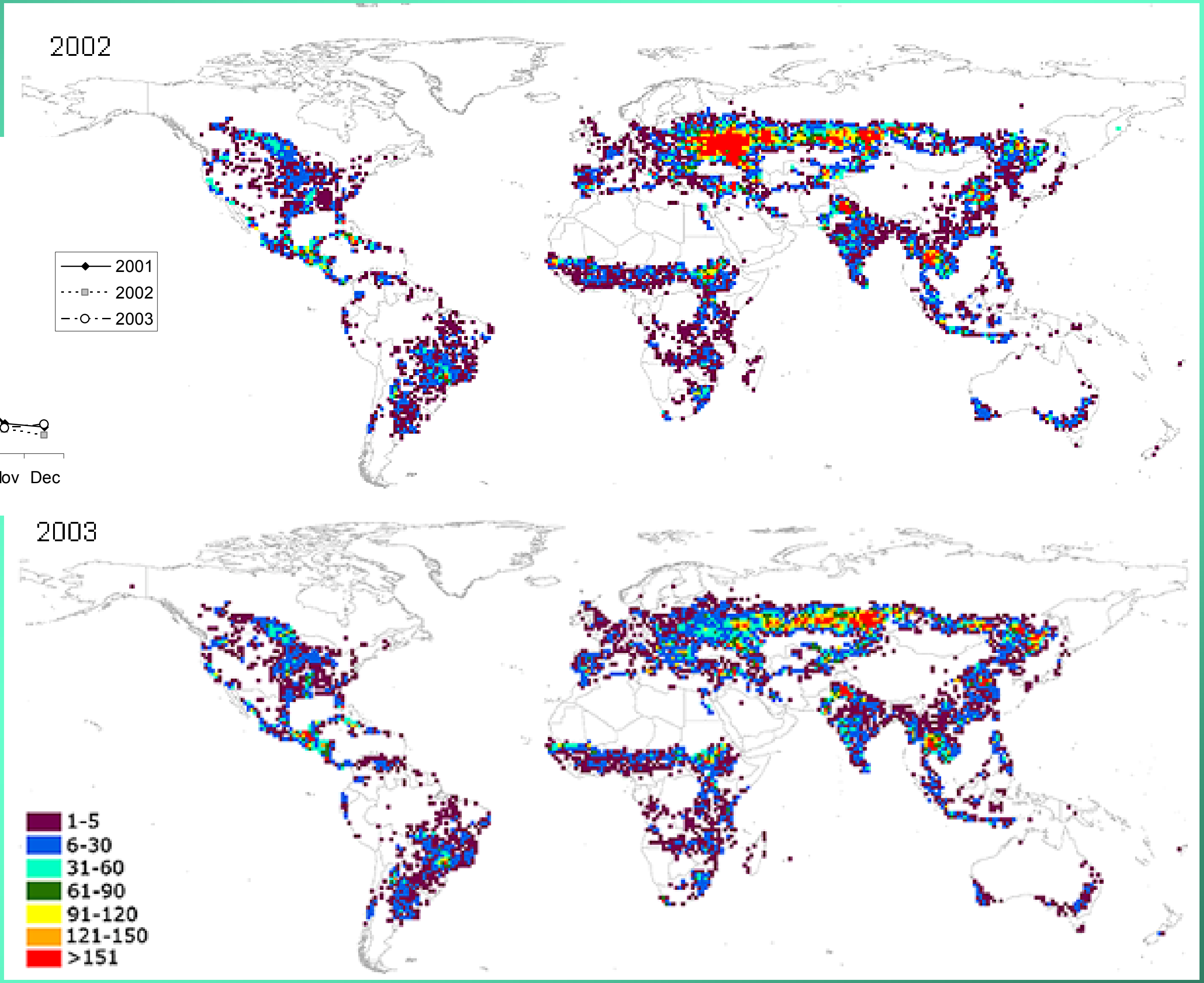


Giglio et al. (2006)

Land Use Fires: Global Agriculture

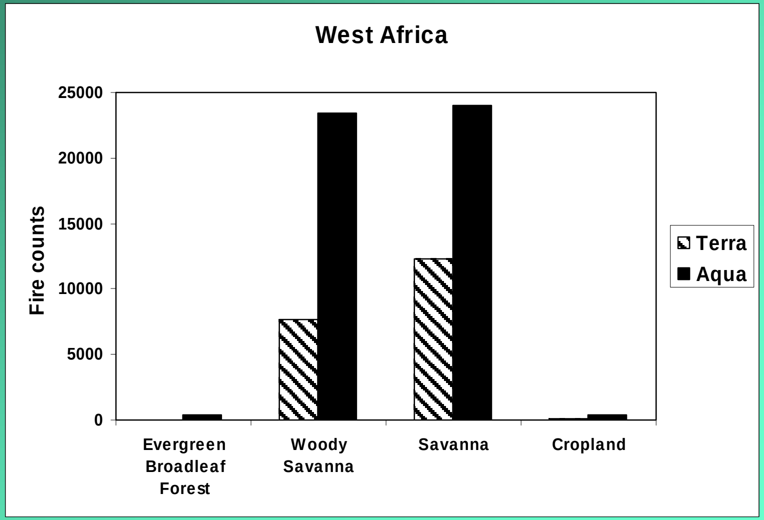
"fire type"

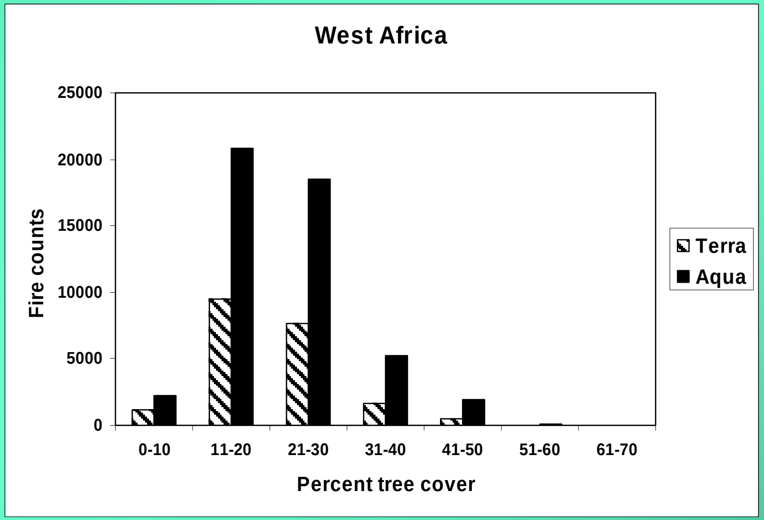




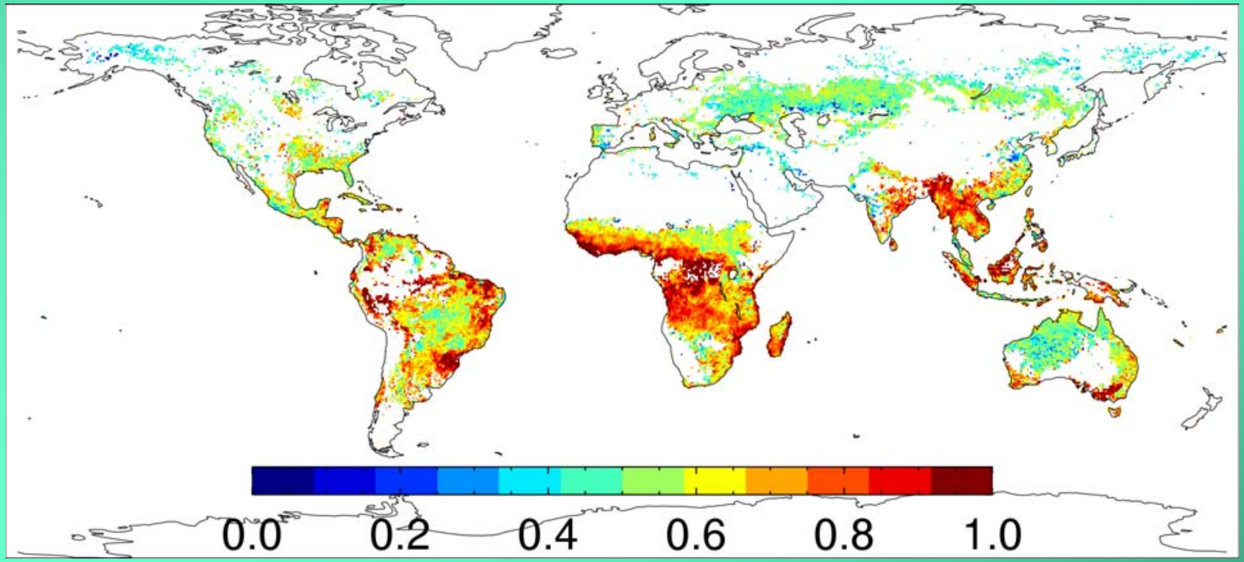
Korontzi et al.

Diurnal cycle of fire activity





Csiszar et al., 2005



STRONGER **WEAKER** **STRONGER**

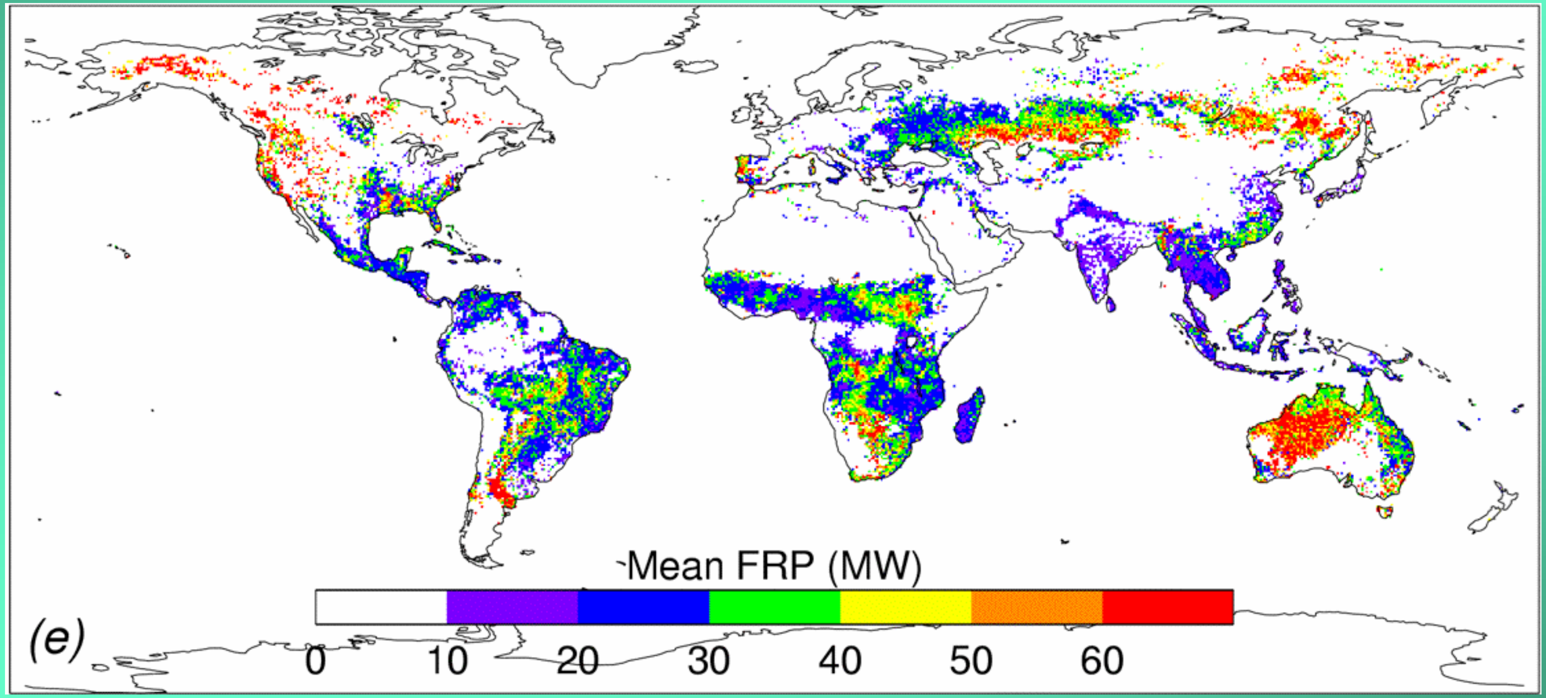
"fire type"

Aqua fire fraction

Giglio et al., 2006

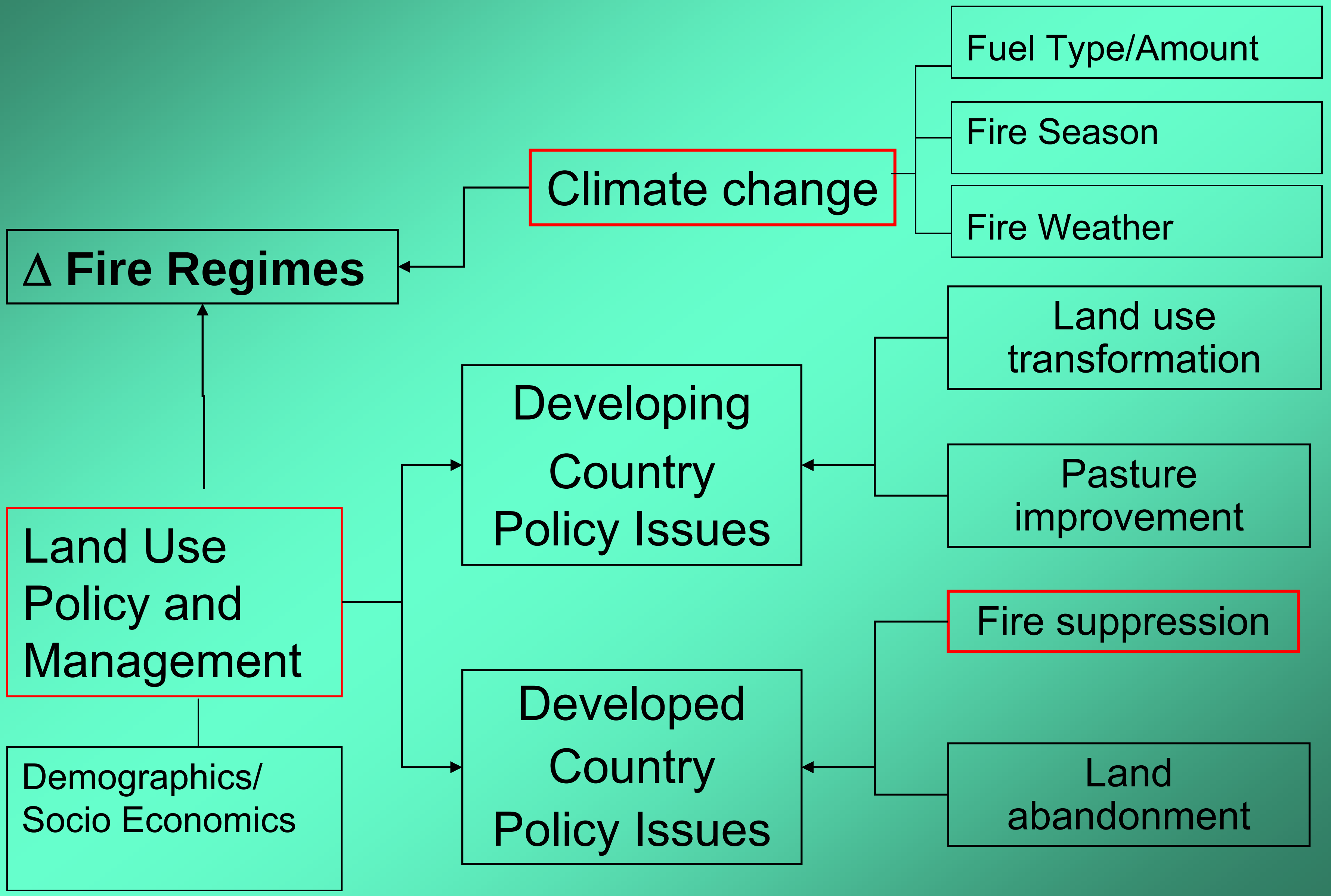
MODIS: Mean Fire Radiative Power

"fire intensity"



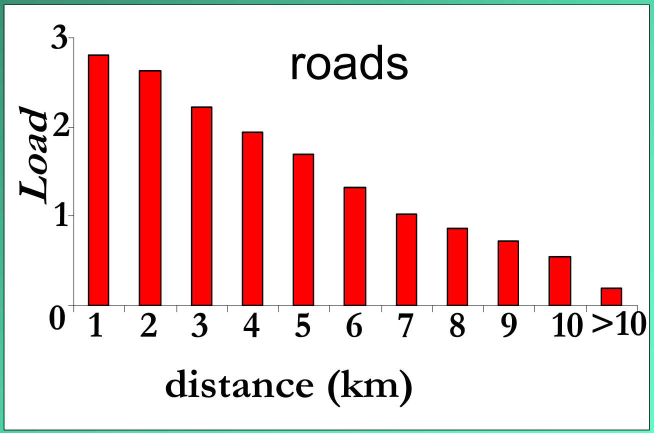
Giglio et al. (2006)

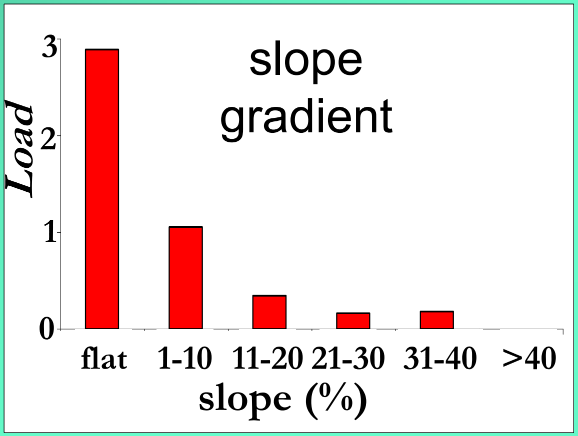
Changing fire regimes

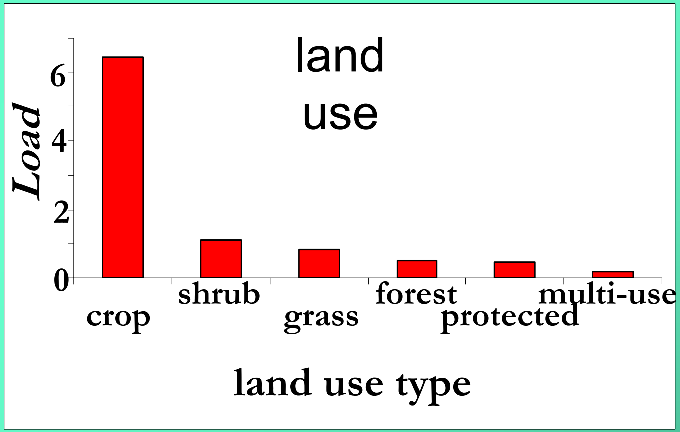


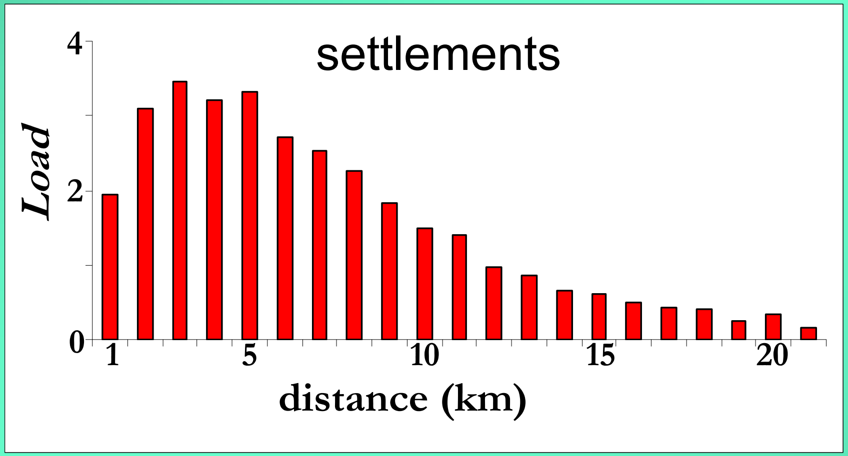
Quantifying fire ignition in the RFE

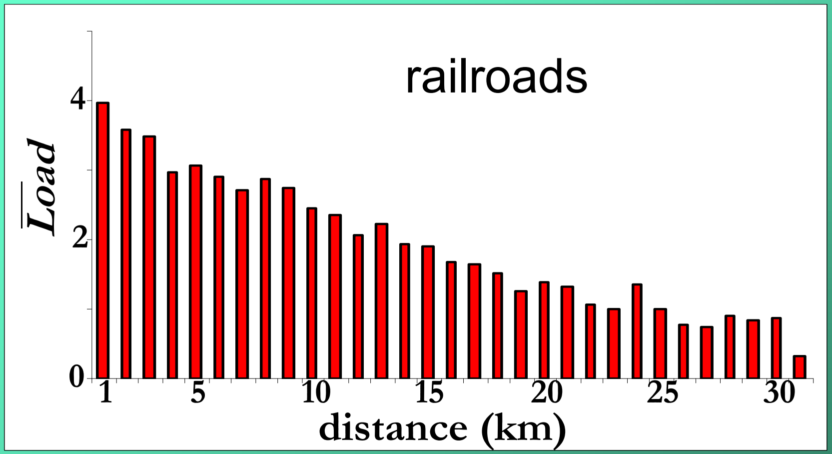
$$\textit{Ignition Load} = \frac{\text{average relative frequency of ignition}}{\text{\% area occupied by a zone from total area of the region}}$$











Loboda et al 2009

Predicted changes in fire occurrence

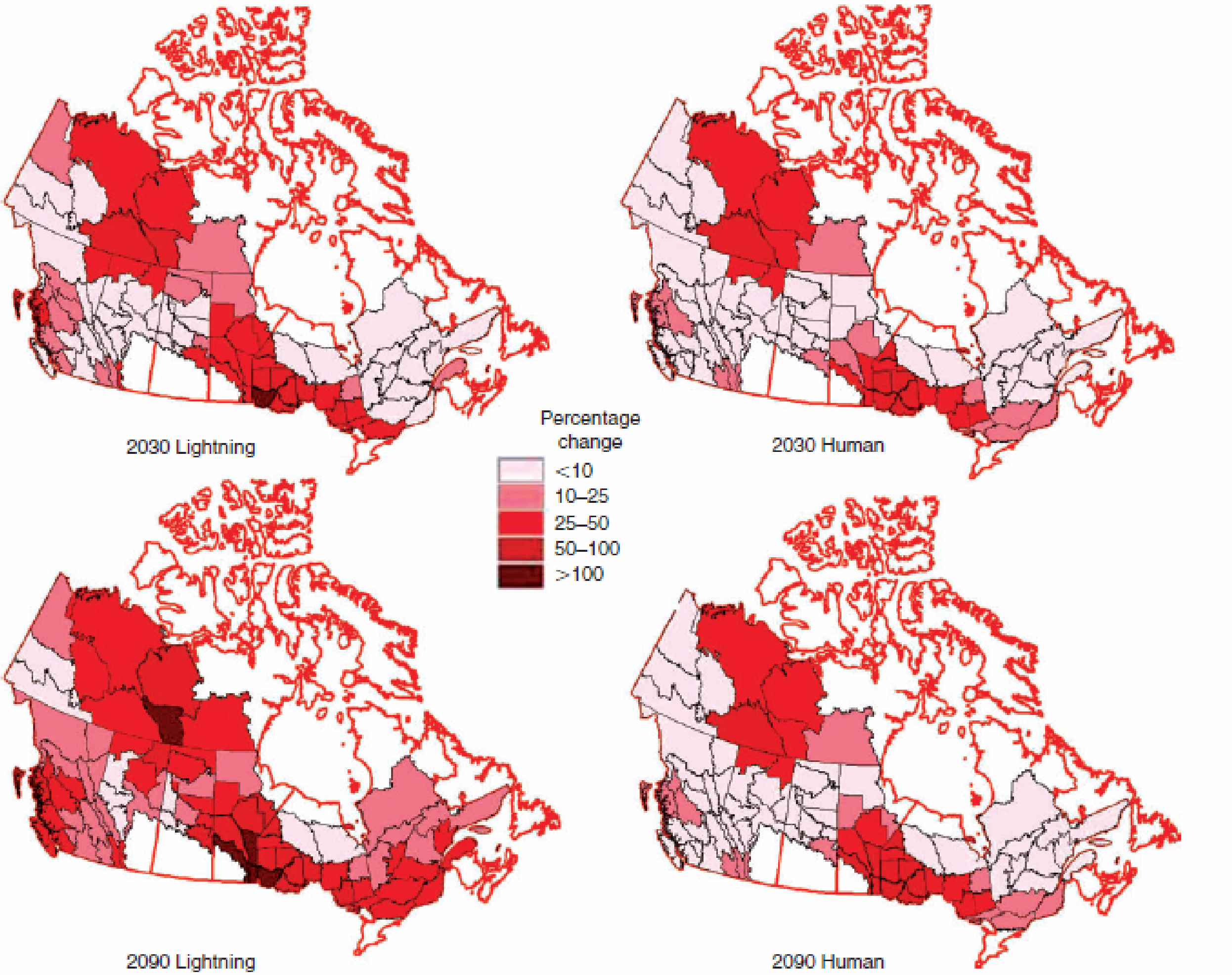
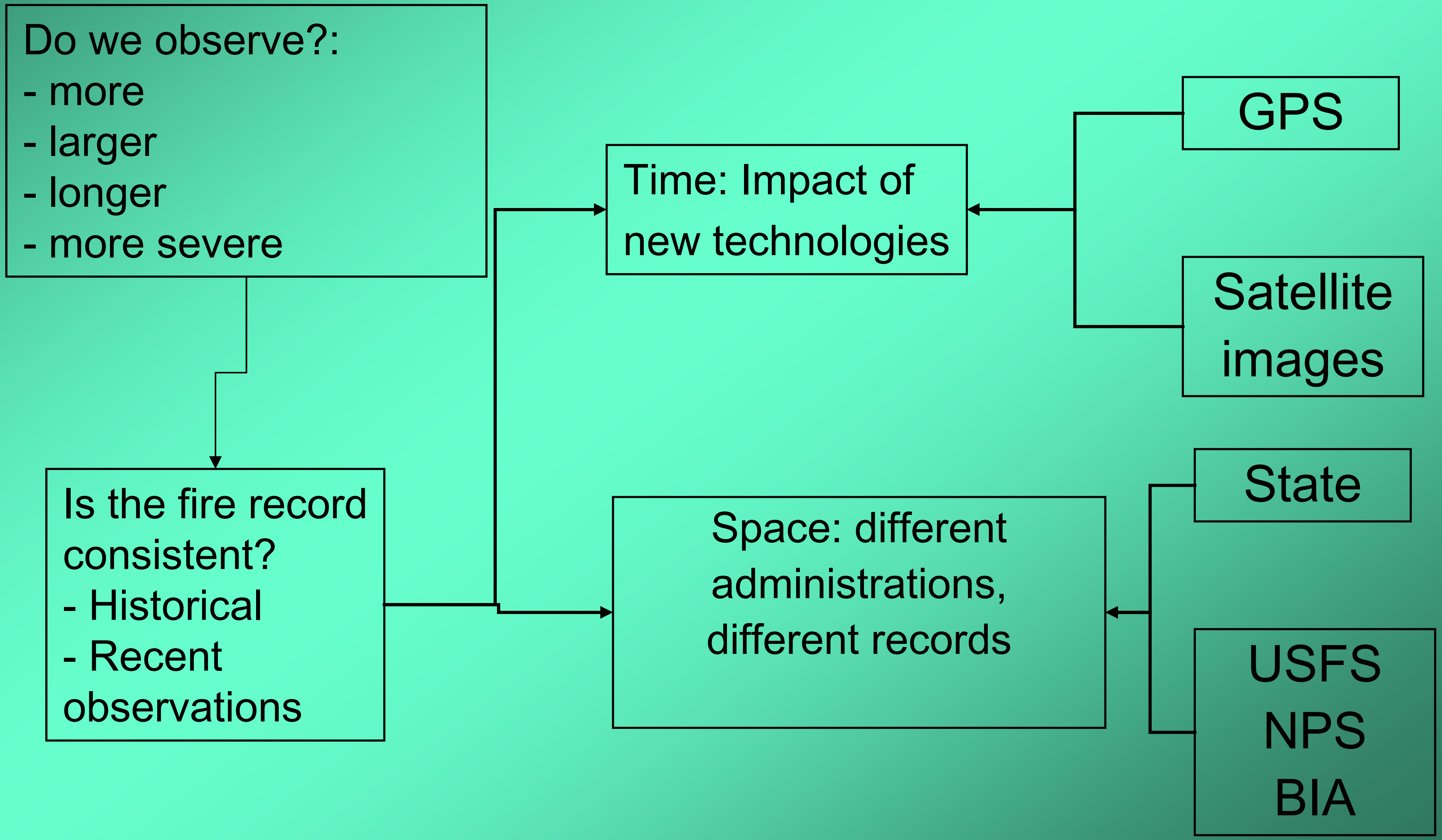


Fig. 4. Relative change (percentage increase) in fire occurrence between future and baseline scenarios for the Canadian Climate Centre GCM (global circulation model). Relative change is given as the percentage increase in number of fires predicted by the GCM (future scenario minus baseline scenario) divided by the total number of fires in the baseline scenario (i.e. $(n_{2020-40} - n_{1975-95})/n_{1975-95}$); 'no data' is shown in white.

Flannigan et al., 2009

TQ2b: Is regional and local fire frequency changing?

Are Fire Regimes Changing?



Available Fire Data Records to Study Trends

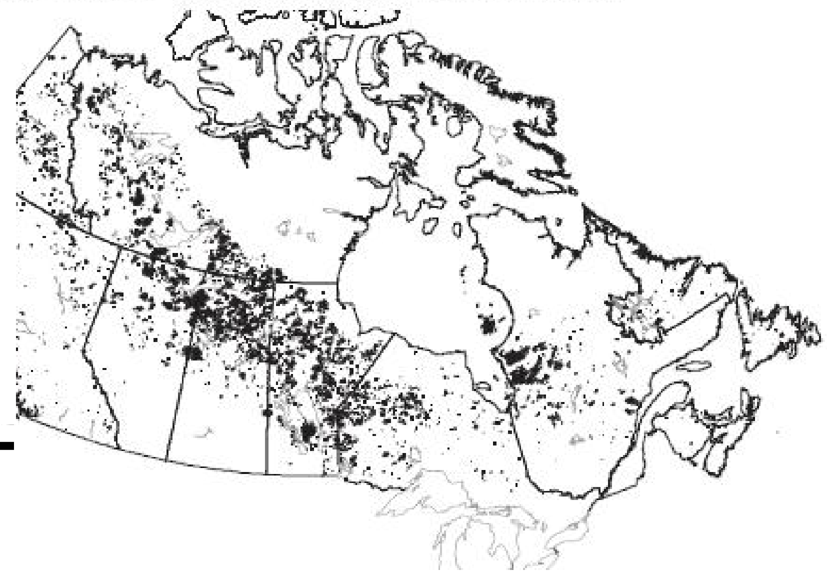
JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 108, NO. D1, 8149, doi:10.1029/2001JD000484, 2003

Large forest fires in Canada, 1959–1997

B. J. Stocks,[1] J. A. Mason,[1] J. B. Todd,[2] E. M. Bosch,[1] B. M. Wotton,[1] B. D. Amiro,[2] M. D. Flannigan,[2] K. G. Hirsch,[2] K. A. Logan,[1] D. L. Martell,[3] and W. R. Skinner[4]

Received 8 February 2001; revised 22 August 2002; accepted 28 August 2002; published 20 December 2002.

Fig. 1. Map of large fires in Canada, 1980–1994. Each solid polygon shows an area burned.



Program for Climate, Ecosystem and Fire Applications

Coarse Assessment of Federal Wildland Fire Occurrence Data

Report for the National Wildfire Coordinating Group

Timothy J. Brown
Beth L. Hall
Charlene R. Mohrle
Hauss J. Reinbold

DRI
Desert Research Institute
Division of Atmospheric Sciences

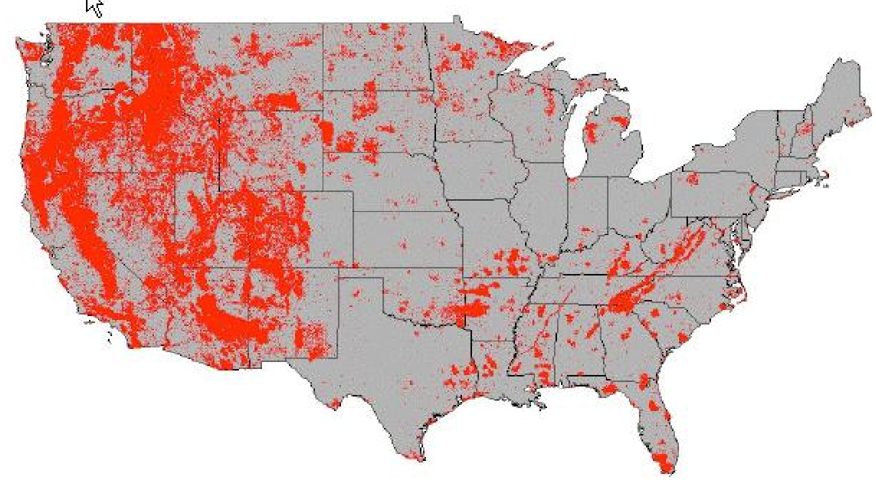
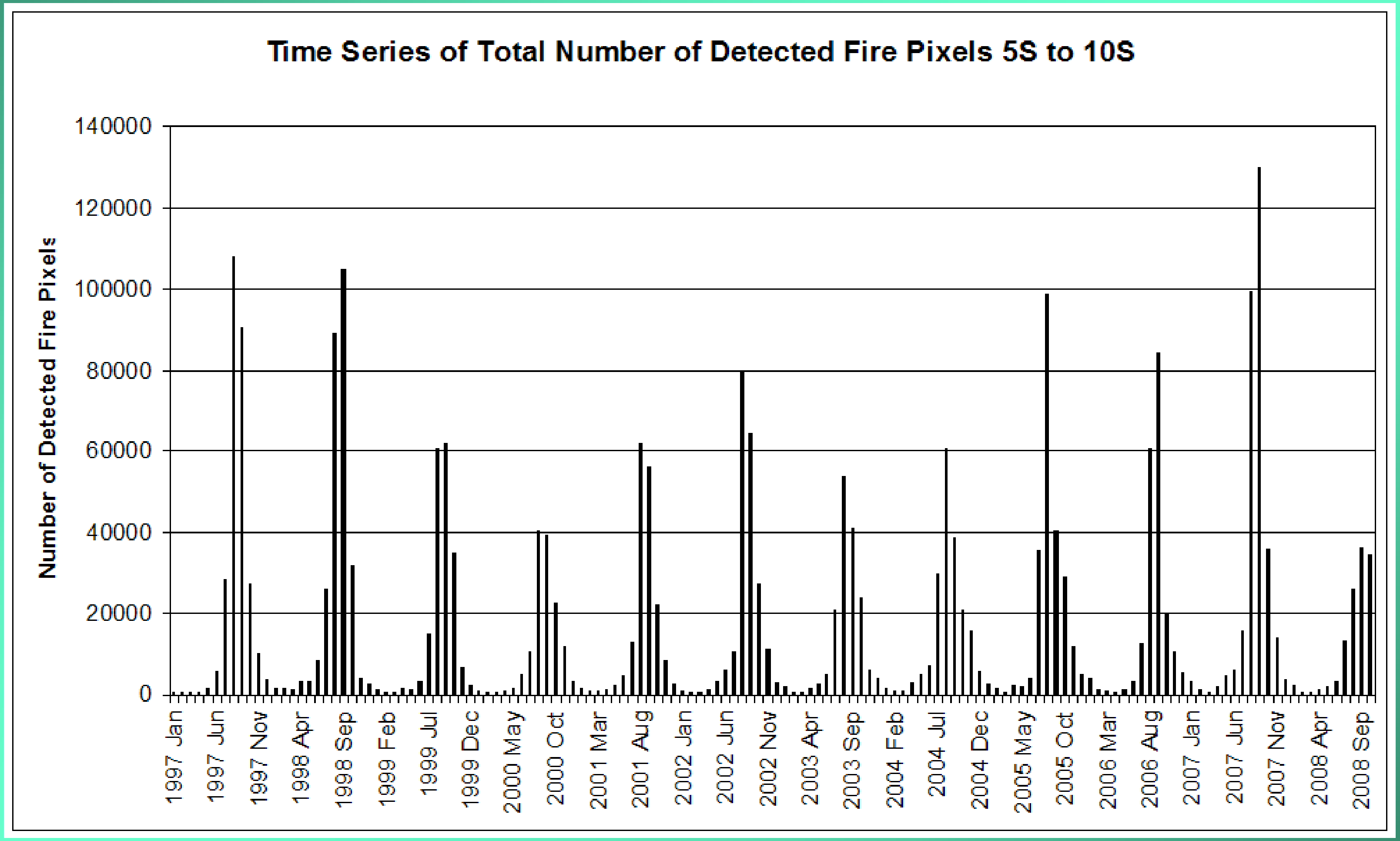


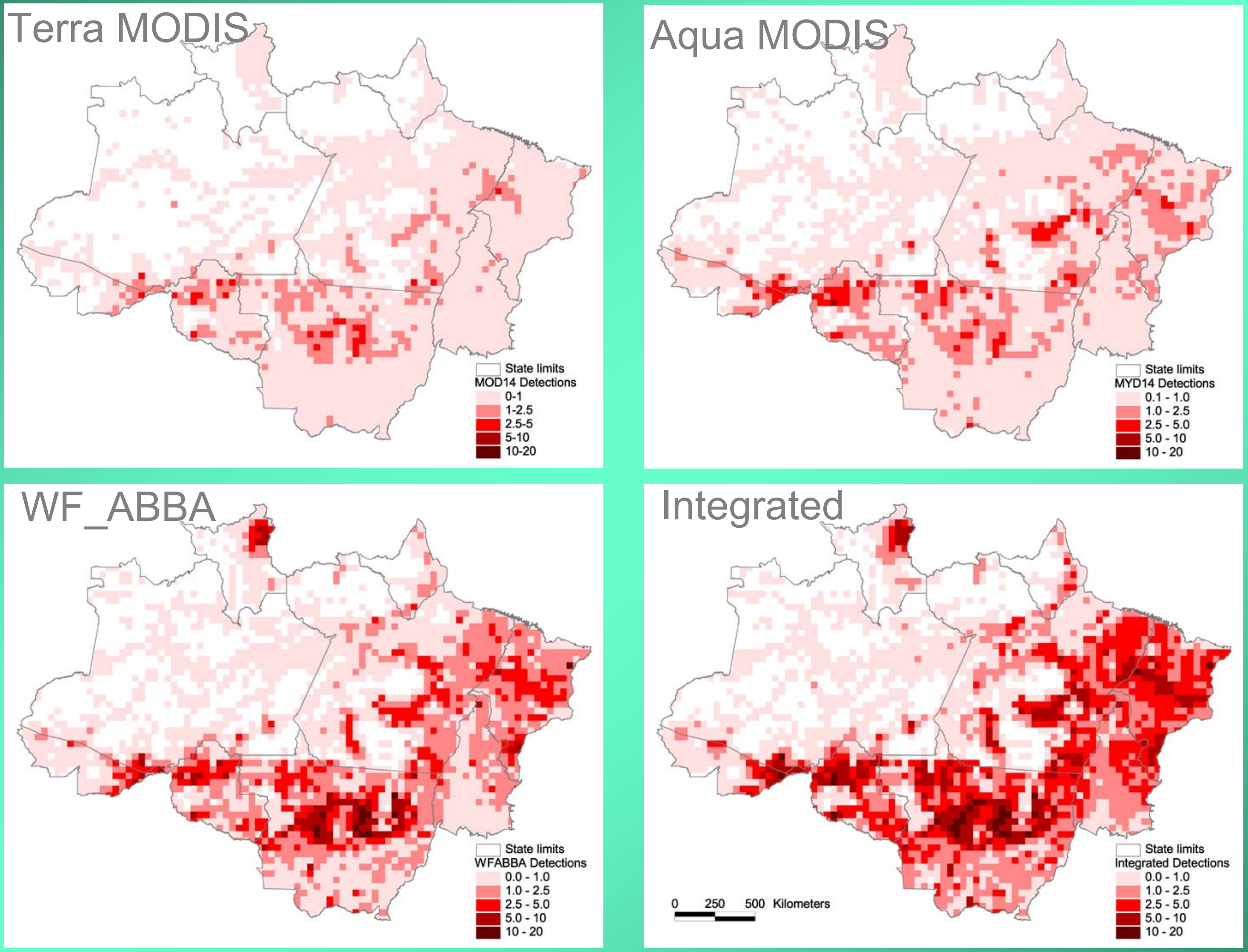
Figure 1. Point locations of coarse quality controlled U.S. wildland fires (red symbols) from the federal fire occurrence database for the period 1970-2000.

Time series of GOES detections in South America



Schmidt et al.

Fire product integration



Yearly detections

Integrated product:

correction for

cloud obscuration

and

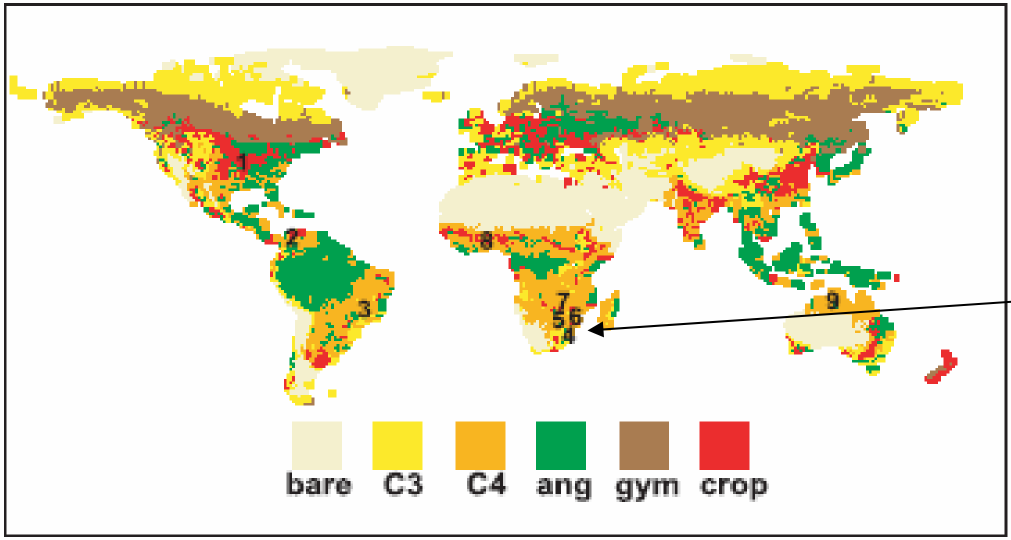
commission errors

Schroeder et al., 2008

TQ2c: What is the role of fire in global biogeochemical cycling, particularly trace gas emissions?

The global distribution of ecosystems in a world without fire

W. J. Bond, F. I. Woodward and G. F. Midgley –
New Phytologist 2005, 165, 525

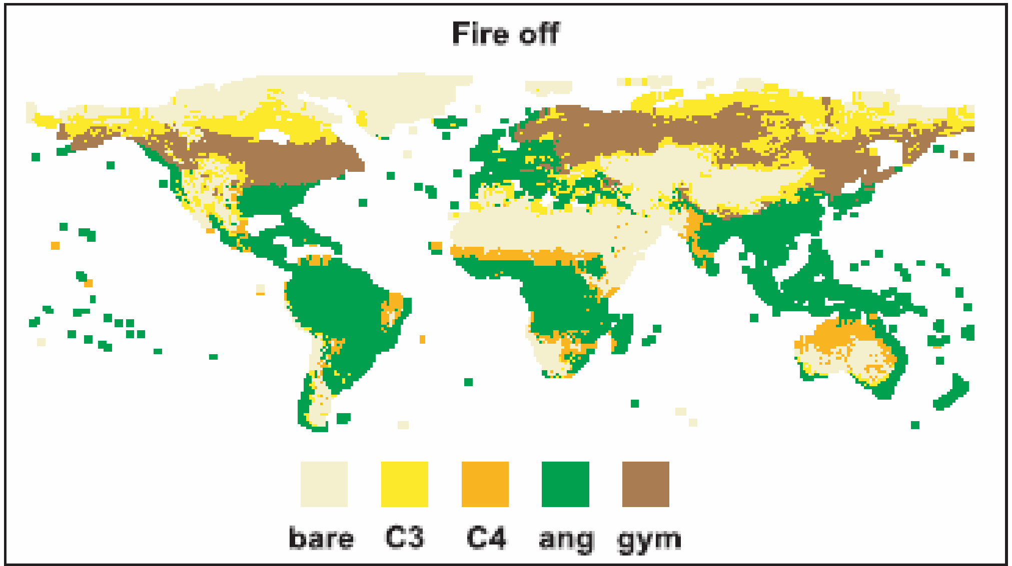


Without fire, closed forests would double from 27% to 56% of vegetated grid cells, at the expense of C4 plants but also of C3 shrubs and grasses in cooler climates.

Long term Fire Trials

Fig. 3 ISLSCP Landcover according to dominant functional types. See Table 1 for conversion of landcover classes to dominant functional types. Squares indicate the location of long-term fire exclusion studies listed in Table 2. Source: ftp://daac.gsfc.nasa.gov/data/inter_disc/biosphere/land_cover

ang: angiosperm; gym: gymnosperm



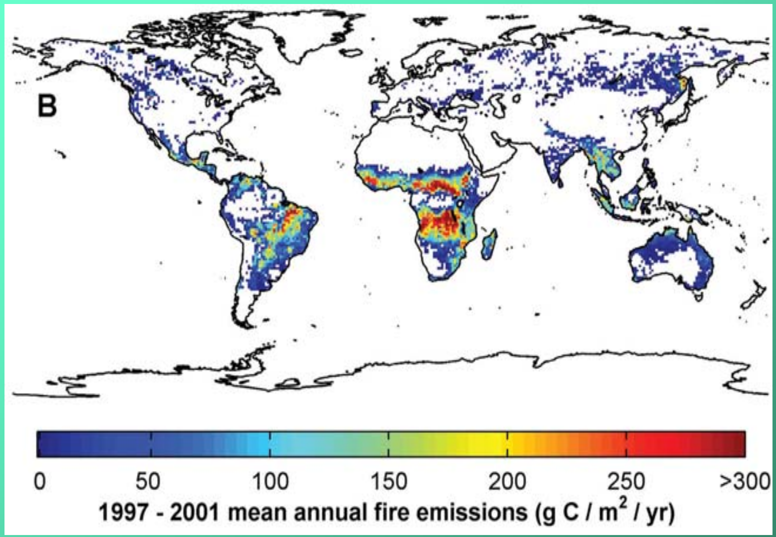
C4 grasses began spreading 6-8 Ma, long before human influence on fire regimes. Results suggest that fire was a major factor in C4 grass spread into forested regions, splitting biotas into fire tolerant and intolerant taxa.

Fig. 4 Distribution of dominant functional types measured by cover and simulated with 'fire off'.

Fire and the Atmosphere

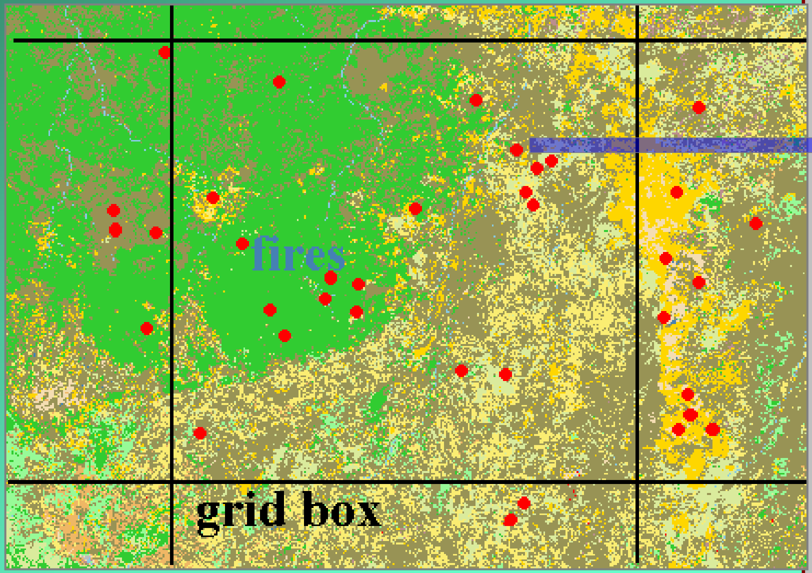
- Biomass burning and fossil fuel emissions release ~10^{15} g of carbon (C) to the atmosphere each year. Biomass burning constitutes ~36% of all global C emissions.

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

Source Emission Parameterization for biomass burning



- **Mass of the tracer emitted:**

$$M_{[\eta]} = \alpha_{veg} . \beta_{veg} . \mathrm{E}f_{veg}^{[\eta]} . a_{fire},$$

α : aboveground biomass density (dry matter basis, kg m^{-2})

β : combustion factor (%)

E_f : emission factor (g[η] / kg): gives the total amount of the tracer emitted in terms of the total biomass consumed

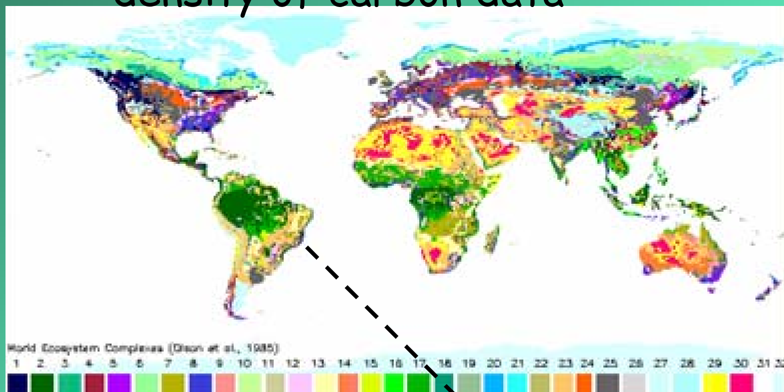
a_{fire}: burnt area

K. Longo and S. Freitas, INPE

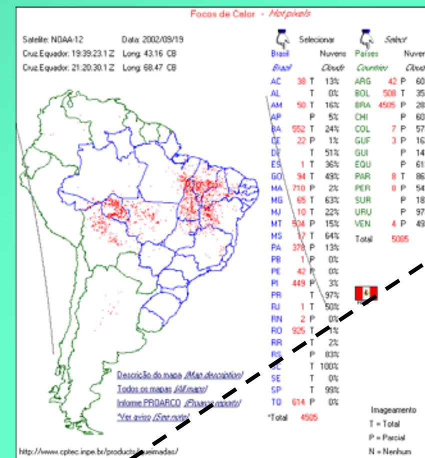
Biomass burning emissions inventory

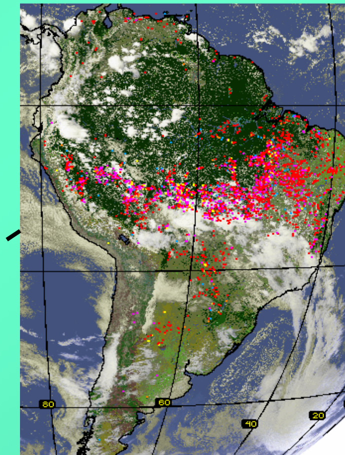
Regional scale – daily basis

density of carbon data

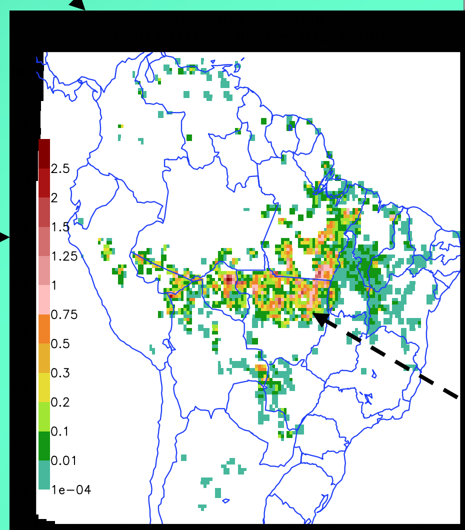


near real time fire product





land use data



CO source emission (kg m^{-2}day^{-1})

emission & combustion factors

Biome category	Emission Factor for CO (g/kg)	Emission Factor for PM2.5 (g/kg)	Aboveground biomass density (α, kg/m^2)	Combustion factor (β, fraction)
Tropical forest[1]	110.	8.3	20.7	0.48
South America savanna[2]	63.	4.4	0.9	0.78
Pasture[3]	49.	2.1	0.7	1.00

[1] Average values for primary and second-growth tropical forests, [2] Average values for campo cerrado (C3) and cerrado sensu stricto (C4), [3] value for campo limpo (C1). All numbers are from Ward et al.,

mass estimation

$$M_{[\eta]} = \alpha_{veg} . \beta_{veg} . Ef_{veg}^{[\eta]} . a_{fire} .$$

K. Longo and S. Freitas, INPE

Fire temperature and area

Dozier retrieval (1981)

$L_{MIR}=fB(\lambda_{MIR},T_{fire})+(1-f)B(\lambda_{MIR},T_{background})$

$L_{TIR}=fB(\lambda_{TIR},T_{fire})+(1-f)B(\lambda_{TIR},T_{background})$

L: radiance
B: Planck function
f: fire fractional area

Two equations, three unknowns (f, T_{fire}, $T_{background}$).

If one estimates $T_{background}$ independently, the above set of equations can be solved for f and T_{fire}.

Limitations and sources of error:

- pixel co-registration
- non-unit emissivities
- atmospheric effects
- sensor saturation

Fire radiative power

Physical basis

- Estimate total radiative energy emitted by the fire from spectral radiances
- Stephan-Boltzmann law
- Planck Law

Algorithms

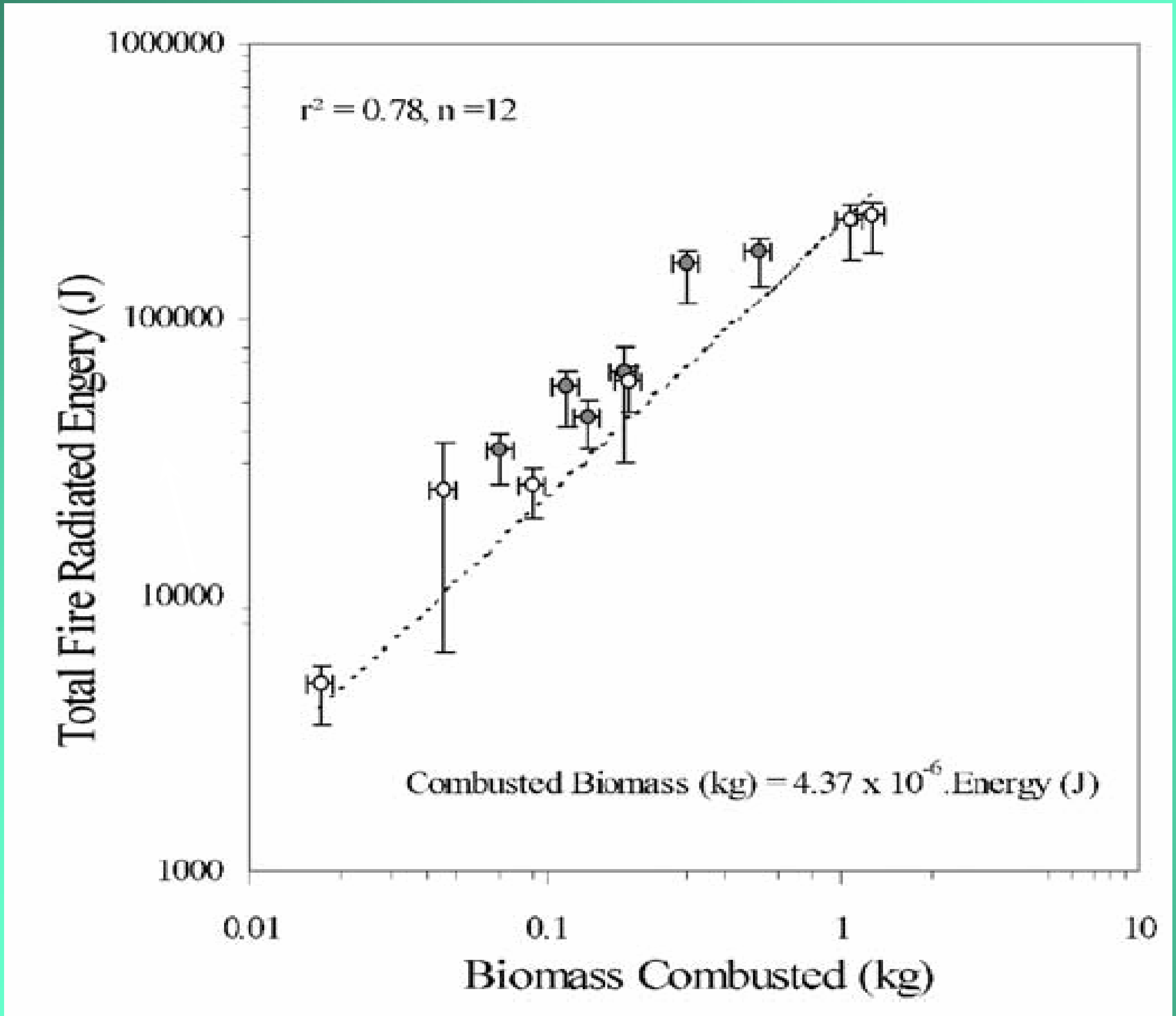
MODIS: $FRE=4.34x10^{-19}(T^8_{MIR}-T^8_{MIR,bg})$ (Kaufman)

MODIS: $FRE=1.89x10^{7}(L_{MIR}-L_{MIR,bg})$ (Wooster)

BIRD: $FRE=5.93x10^{5}(L_{MIR}-L_{MIR,bg})$ (Wooster)

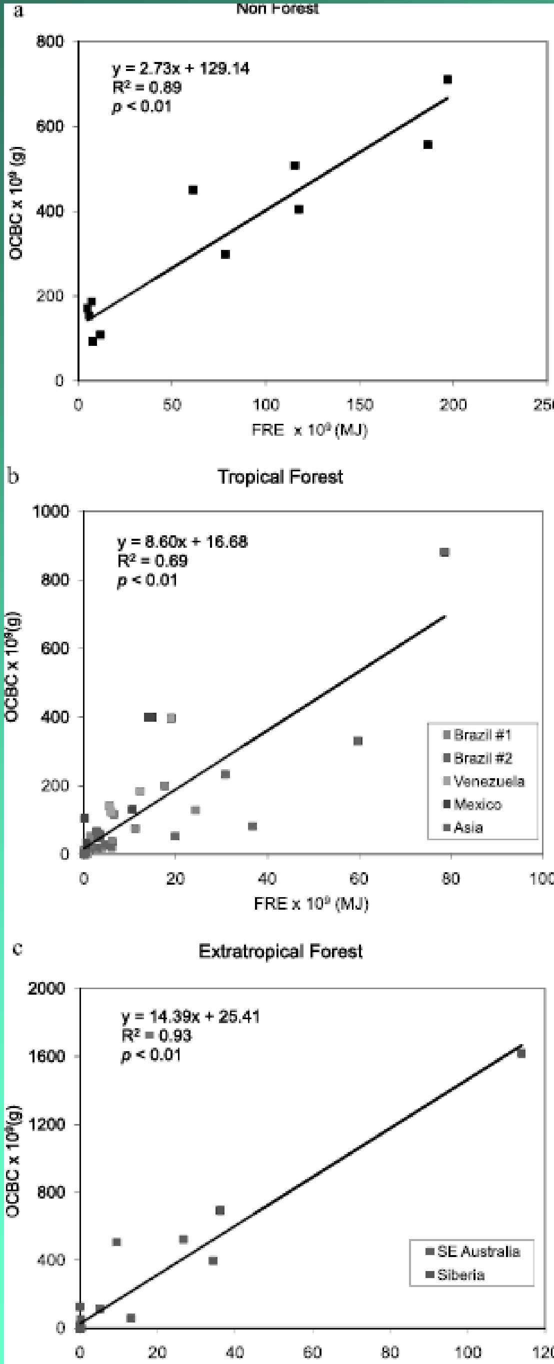
Wooster et al 2002 and 2003

Fire Radiative Energy

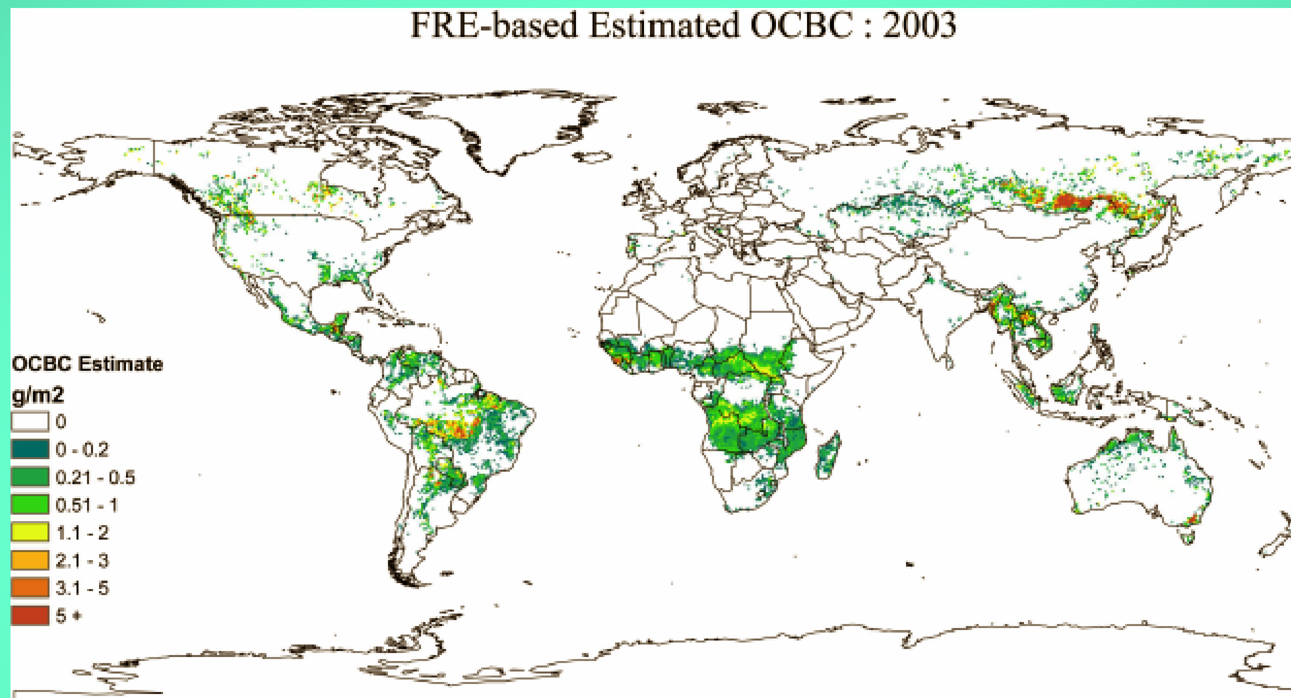


alternative approach for estimating fire emissions

Wooster et al 2002 and 2003



Fire Radiative Energy



(consider FRP temporal dynamics to derive FRE)

Ellicott et al 2009

TQ2d: Are there regional feedbacks between fire and climate change?

Fire Regimes and Climate

GEOPHYSICAL RESEARCH LETTERS, VOL. 33, L09703, doi:10.1029/2006GL025677, 2006

Recent changes in the fire regime across the North American boreal region—Spatial and temporal patterns of burning across Canada and Alaska

Eric S. Kasischke[1] and Merritt R. Turetsky[2]

Received 16 January 2005; accepted 29 March 2006; published 3 May 2006.

Doubling of Annual Burned Area and increase in frequency of large fire events

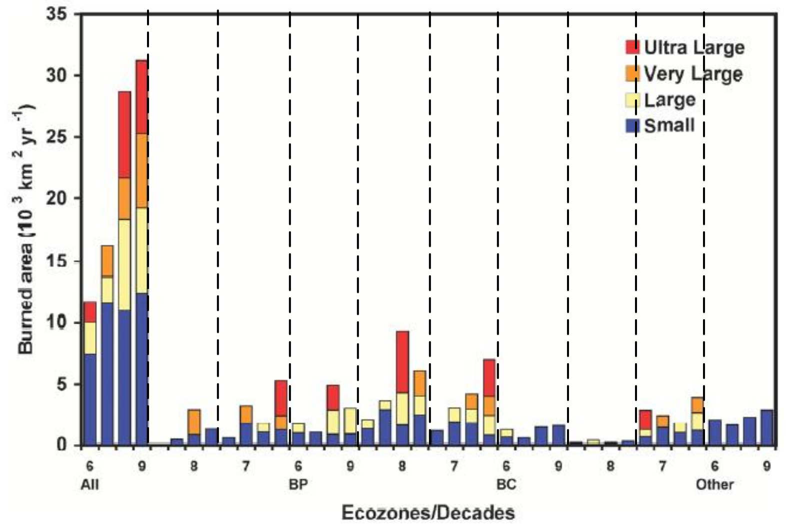
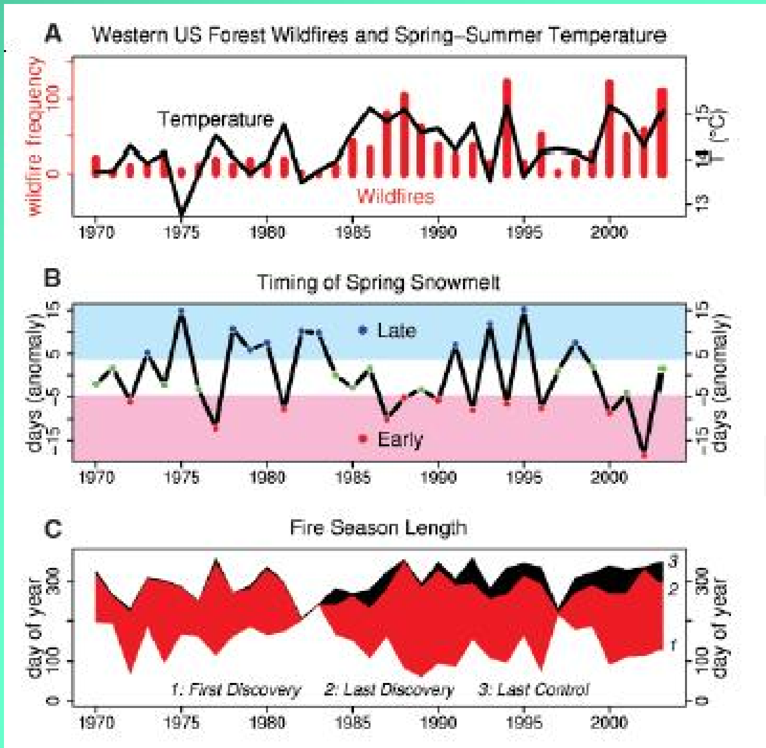


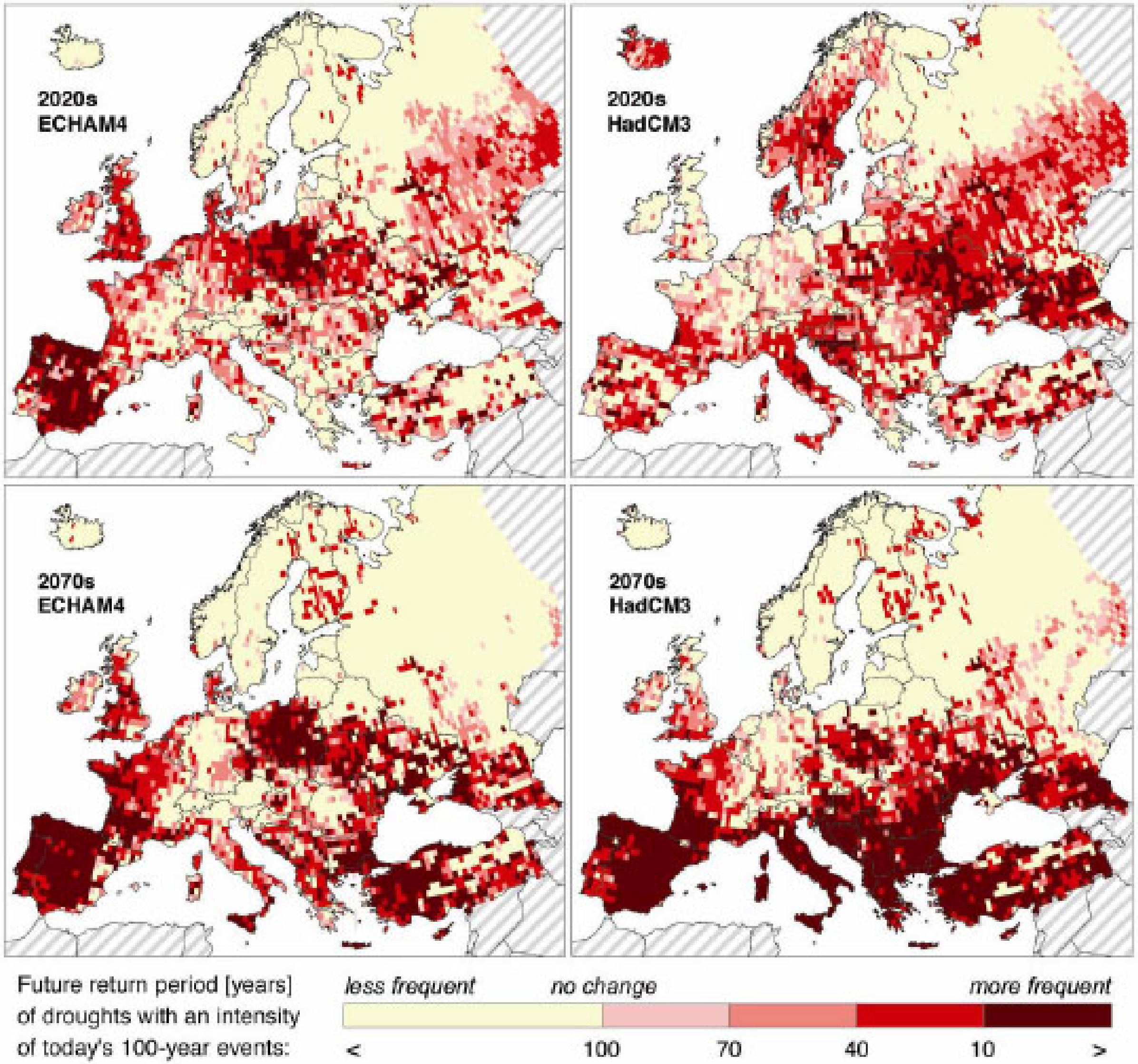
Figure 1. Decadal patterns in burned area across the NABR and in individual ecozones (on the x-axis, 6 = 1960s, 7 = 1970s, etc.; see Table 2 for the key to the ecozones).



18 AUGUST 2006 VOL 313 SCIENCE www.sciencemag.org

Warming and Earlier Spring Increase Western U.S. Forest Wildfire Activity

A. L. Westerling,[1,2*] H. G. Hidalgo,[1] D. R. Cayan,[1,3] T. W. Swetnam[4]



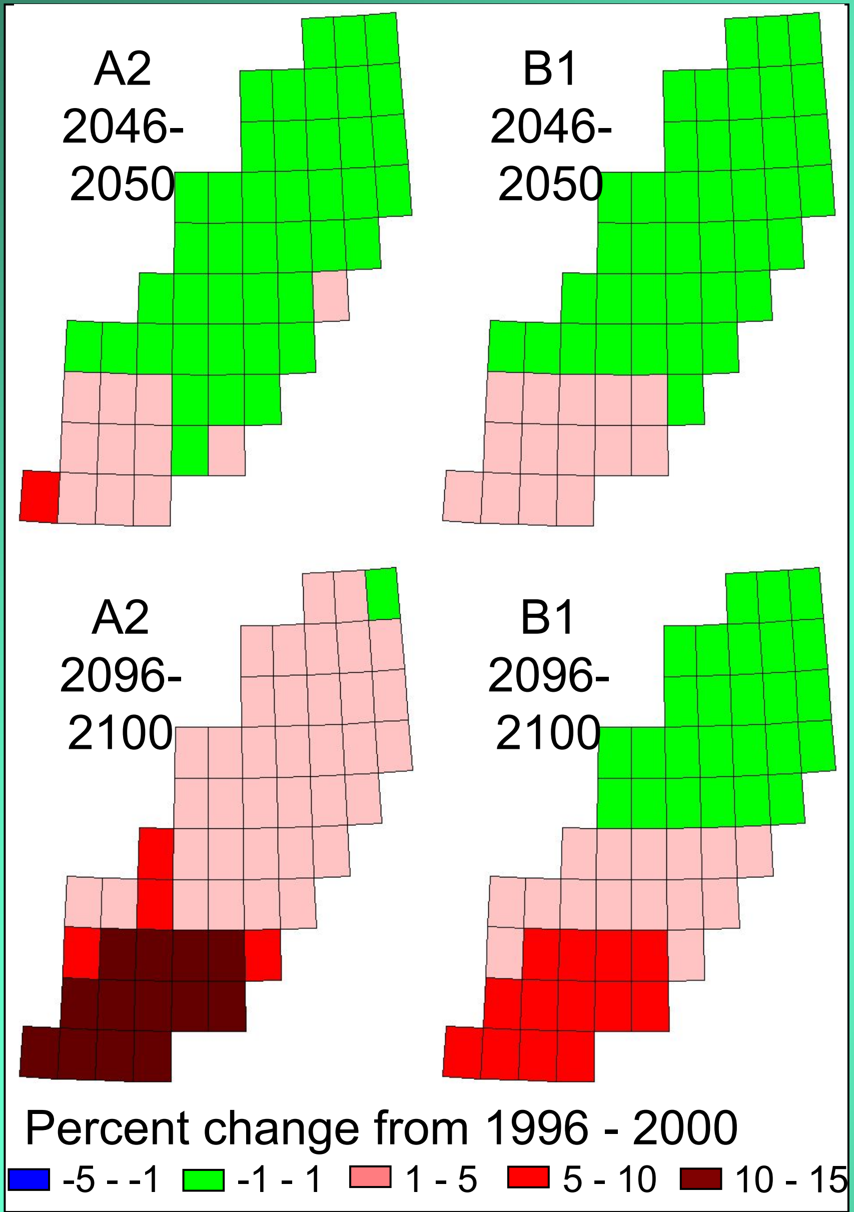
Change in 100-year drought occurrence: 2020s and 2070s compared to 1961-90 (ECHAM4 and HadCM3 GCMs; IS92a emissions; business-as-usual water use). (Lehner et al., 2005).

Long-term changes in fire weather

WMO

UNEP

Spatial Variability of Potential Fire Danger change in the RFE



Monthly mean Fire Danger by 1-degree cells is variable:

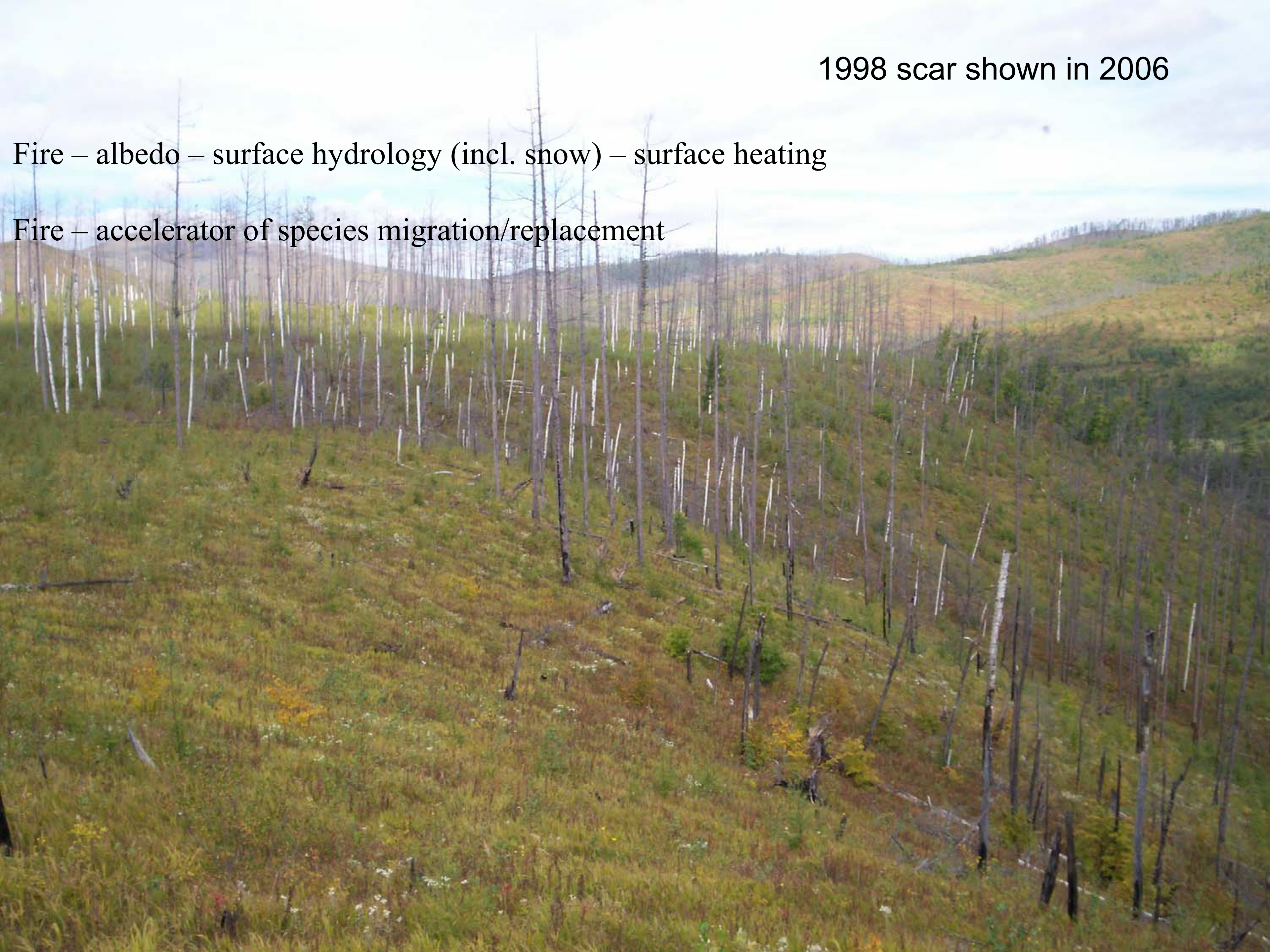
- negligible increase or decrease in Fire Danger during March-April
- up to 37% increase in July – August
- over 10% increase in Fire Danger during July - November

Loboda et al 2009

1998 scar shown in 2006

Fire – albedo – surface hydrology (incl. snow) – surface heating

Fire – accelerator of species migration/replacement


1998 scar shown in 2006
Fire – albedo – surface hydrology (incl. snow) – surface heating
Fire – accelerator of species migration/replacement

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.

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."

Product specifications

- Level 2
  - orbital mask
  - fire characteristics (FRP, area/temperature)
- Enhanced products from Level 2
  - cluster size
  - cluster shape
  - cluster mean temperature and variability
  - statistical distributions
- Level 3
  - spatially aggregated (grid size/aggregation period TBD)
  - seasonal (?) temporal composite
    - fire pixel density
    - gridded mean fire temperature
    - gridded mean FRP

Validation

What is validation?

- Validation is defined as the process of assessing by <u>independent means</u> the quality of the data products derived from system outputs

- Active fire product accuracy is a function of
  - observing conditions (i.e. satellite view angle)
  - environmental conditions (non-fire background)
  - sensor conditions (i.e. degradation of sensitivity)

Validation data needs

- Primary: simultaneous (much) higher resolution information on the thermal conditions over the entire HypIRI pixel
  - less critical issue because of 60m resolution (reconnaissance OK?)
  - high resolution satellite and aircraft imagery
  - prescribed burns
- Secondary: post-fire confirmation by burned area etc.

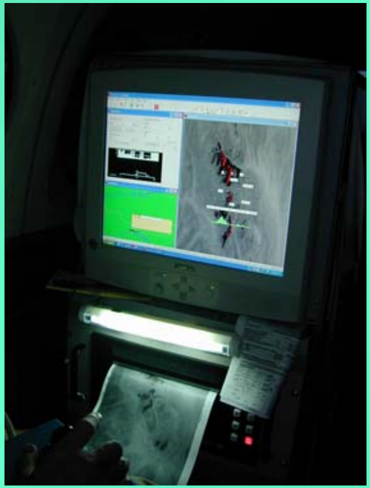
Hyperspatial Resolution Data
Quickbird

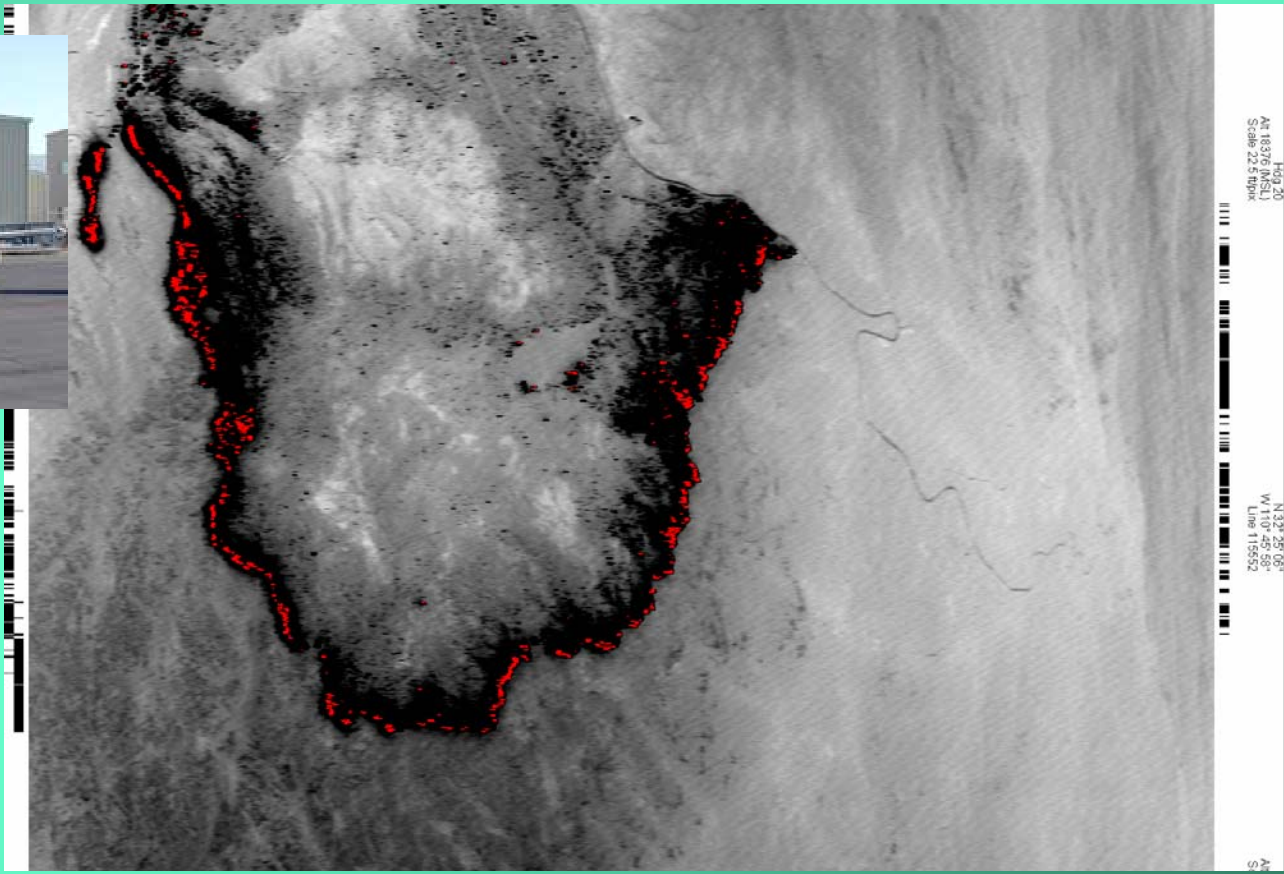
60cm Resolution Imagery of the Esperanza Fire, Twin Pines, Ca
October 2006

(courtesy Digital Globe)

Forest Service Thermal Infrared System

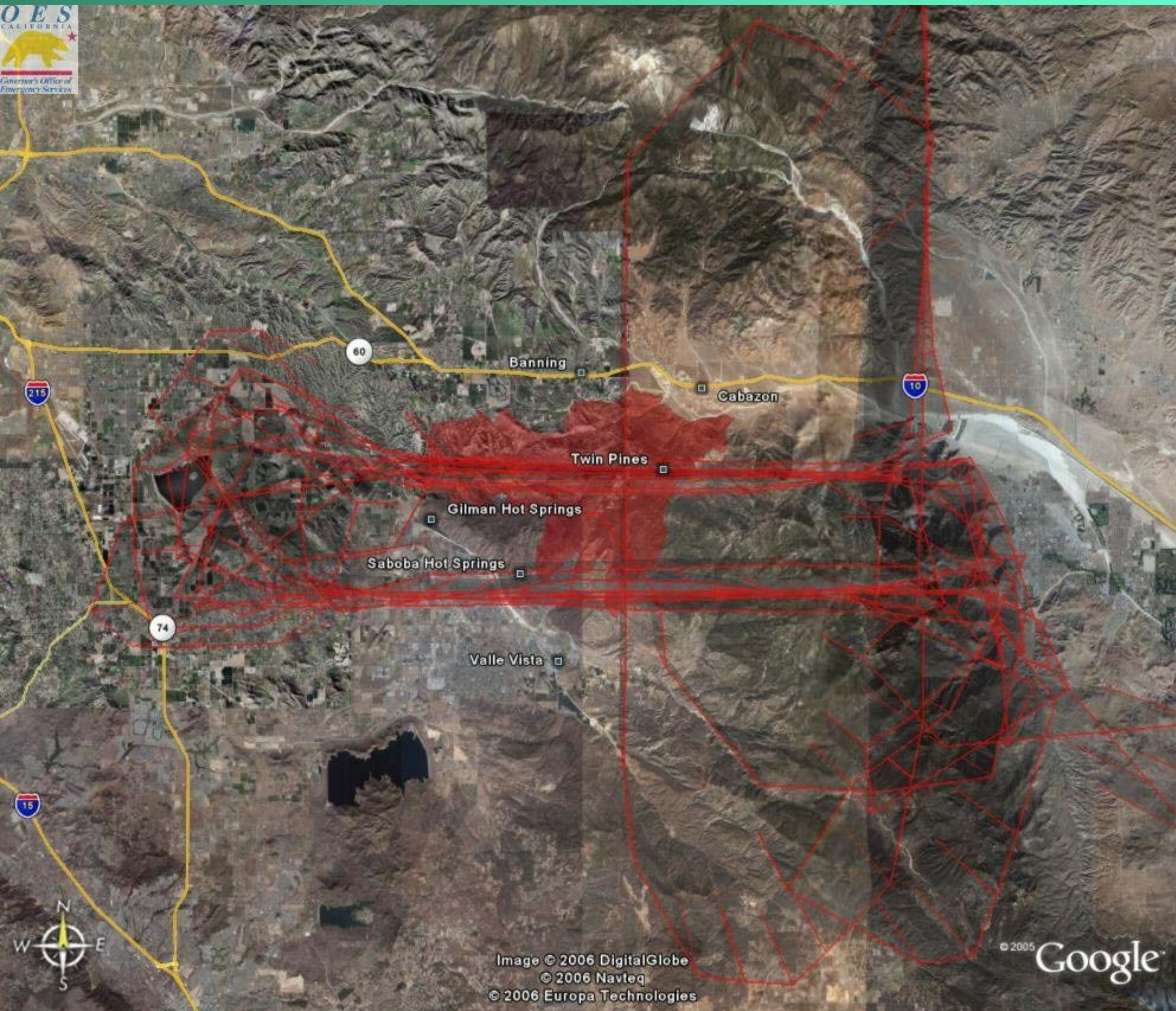
Type 1 High Resolution Airborne Thermal Infrared Line Scanner





Night Image – Red is active fire

T. Bobbe



Close up of the ALTAIR flight lines with the Esperanza Fire perimeter displayed (also in red).

Altair

S. Ambrosia

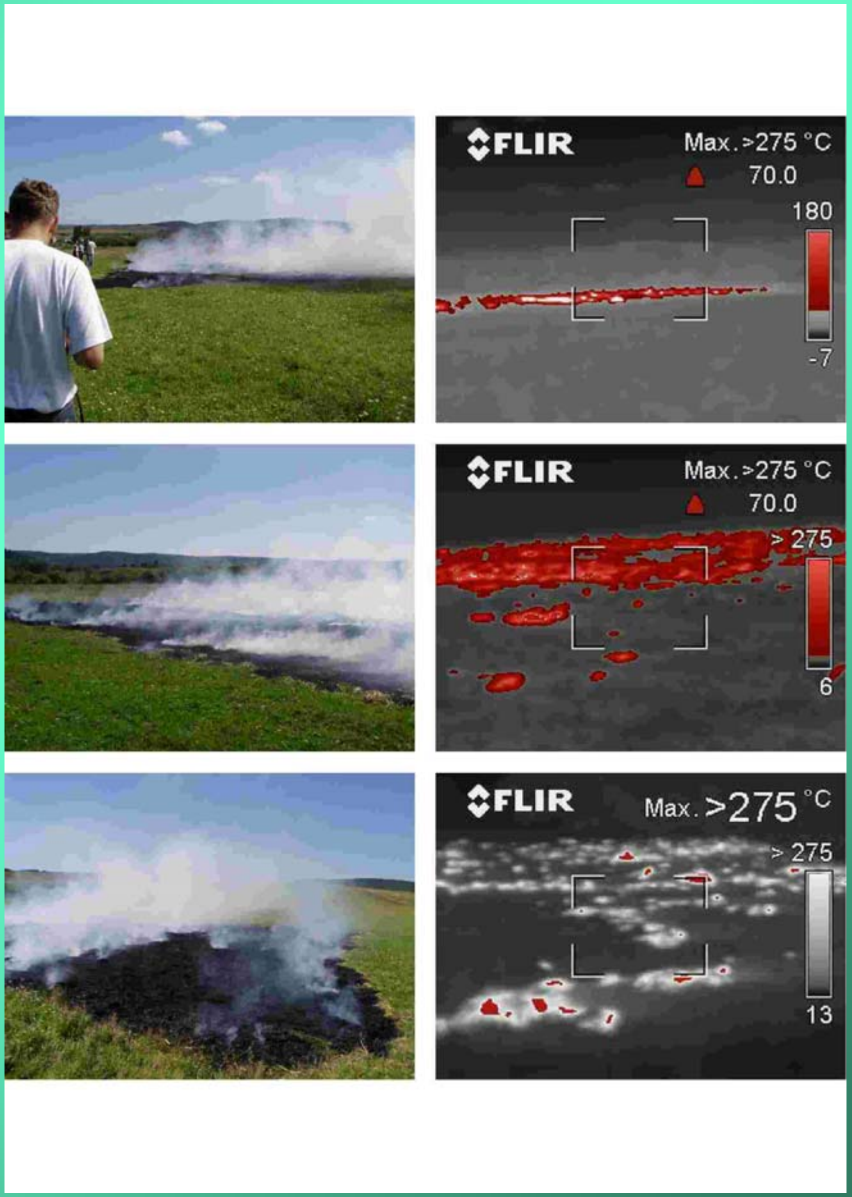
Airborne Active-Fire Detection: Reconnaissance

Aerial Surveys

- Fixed wing aircraft surveys
- Flights are conducted during moderate to high fire danger levels
- Targeted to areas of recent lightning activity
- Fire information is relayed directly to local dispatch centers

T. Bobbe USFS

Prescribed burns

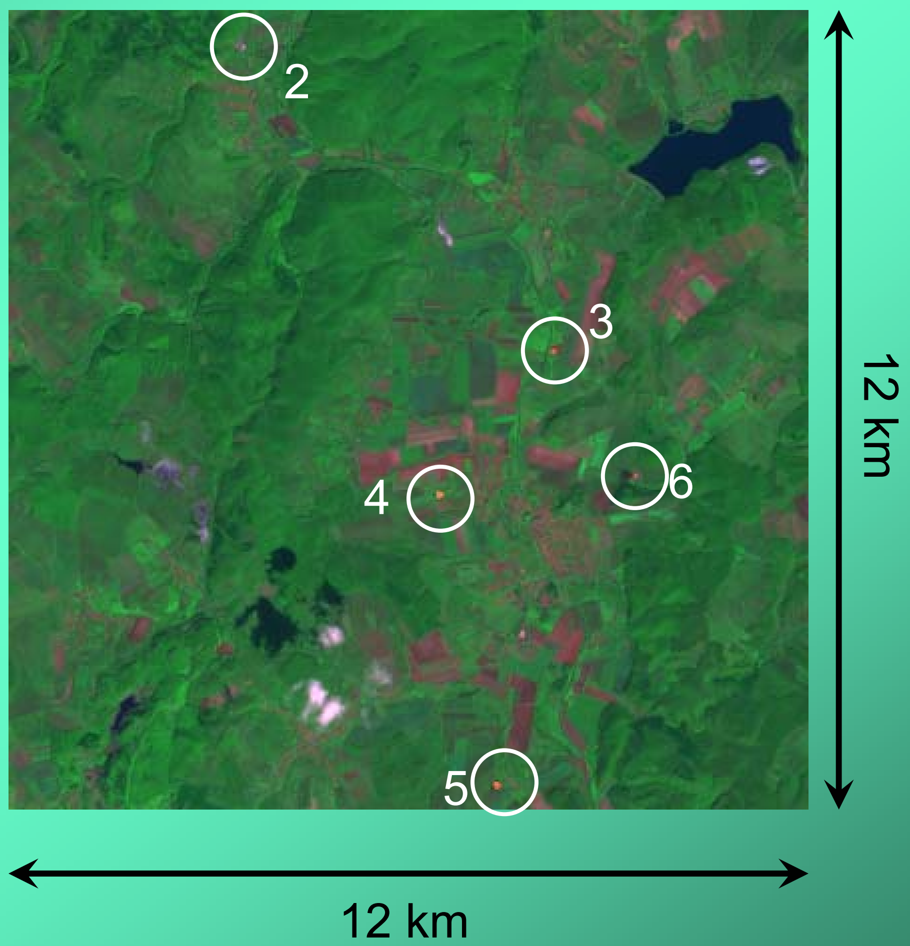


Prescribed burns

Location	*Coordinates*	*Area*	*Material*	*Temperature*
1. Bódvaszilas	**N 48˚30’.88.9” E 20˚42.42.2”**	**2 m^2**	**Diesel oil /5l Gasoline /1l**	**N/A**
2. Perkupa	**N 48˚28'16.7” E 20˚41'35.3”**	**10 m^2**	**Straw (5 bales)**	**N/A**
3. Szendrő Csehipuszta	**N 48˚25'83.6” E 20˚44'53.8”**	**50 m^2**	**Straw (15 bales)**	**max: 388˚C**
4. Szendrő	**N 48˚24'57.2” E 20˚43'02.4”**	**500 m^2**	**Straw**	**max:420˚C**
5. Szendrő Büdöskút- puszta	**N 48˚22'40.1” E 20˚42'67.5”**	**100 m^2**	**Straw**	**max: 420˚C**
6. Galvács	**N 48˚24'33.1” E 20°44'53.5”**	**10 m^2**	**Tire**	**max:893˚C**

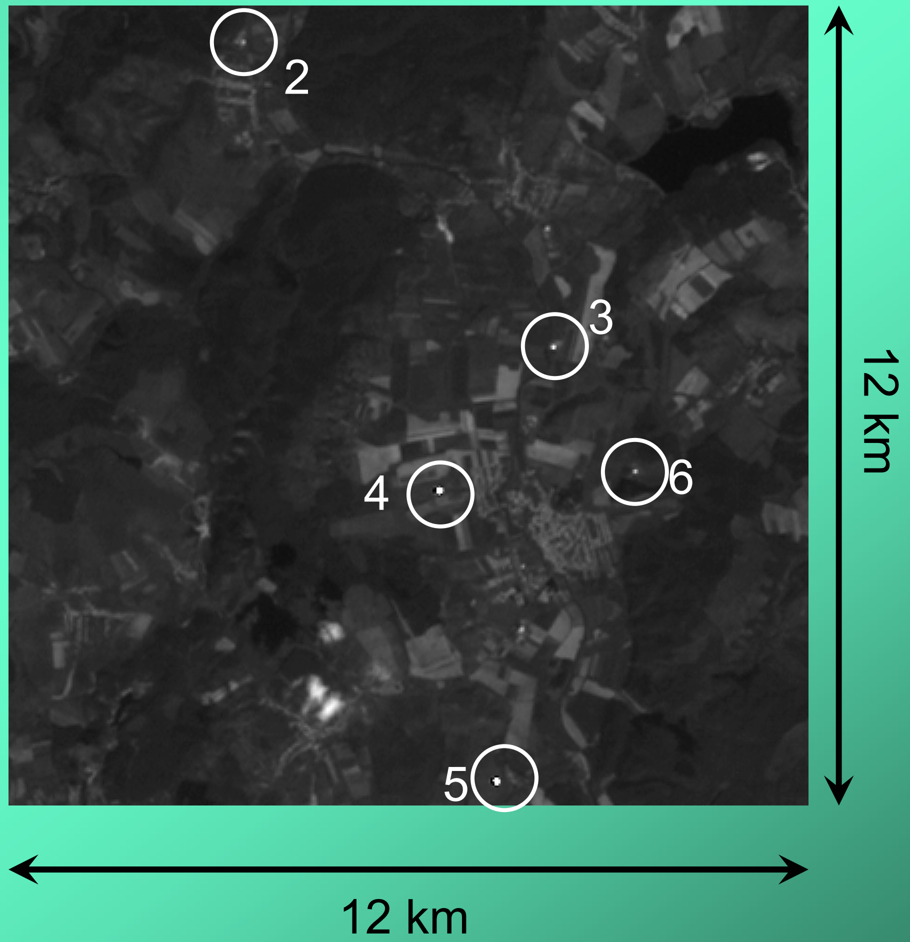
ASTER RGB image

Fire	*Area*	*Temperature*
1.	**2 m^2**	**N/A**
2.	**10 m^2**	**N/A**
3.	**50 m^2**	**max: 388˚C**
4.	**500 m^2**	**max:420˚C**
5.	**100 m^2**	**max: 420˚C**
6.	**10 m^2**	**max:893˚C**



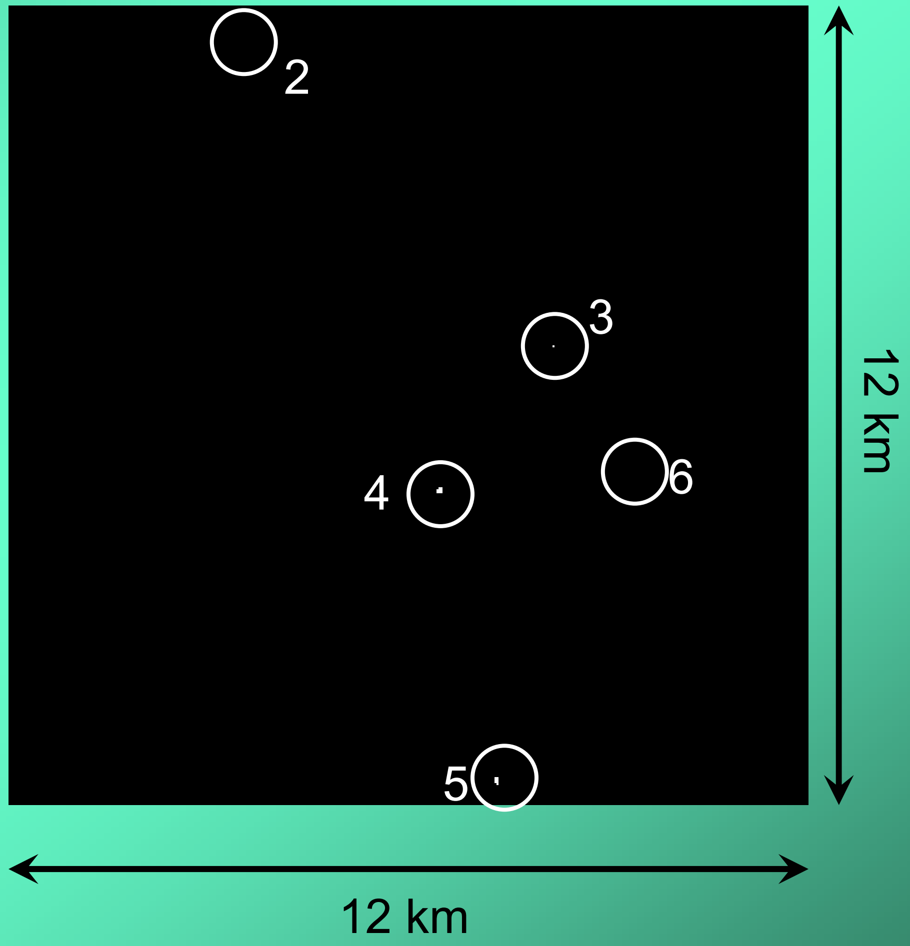
ASTER band 8 reflectance

Fire	*Area*	*Temperature*
1.	**2 m^2**	**N/A**
2.	**10 m^2**	**N/A**
3.	**50 m^2**	**max: 388˚C**
4.	**500 m^2**	**max:420˚C**
5.	**100 m^2**	**max: 420˚C**
6.	**10 m^2**	**max:893˚C**



ASTER fire mask from algorithm

Fire	*Area*	*Temperature*
1.	**2 m^2**	**N/A**
2.	**10 m^2**	**N/A**
3.	**50 m^2**	**max: 388˚C**
4.	**500 m^2**	**max:420˚C**
5.	**100 m^2**	**max: 420˚C**
6.	**10 m^2**	**max:893˚C**



Summary

- HyspIRI alone
  - representative sample of global fire occurrence
    - spatial and temporal aggregation necessary
  - characterize fire regimes
    - new paradigm, new variables
- HyspIRI for quantifying and characterizing the combustion process
  - vital ingredient for understanding the role of fire in the Earth System
- HyspIRI to enable other sensors
  - bridging and improving time series from medium and coarse resolution sensors
    - e.g. MODIS – VIIRS
- Multi-level product hierarchy is needed for these areas of applications
  - build on MODIS experience, but expand range of derived variables