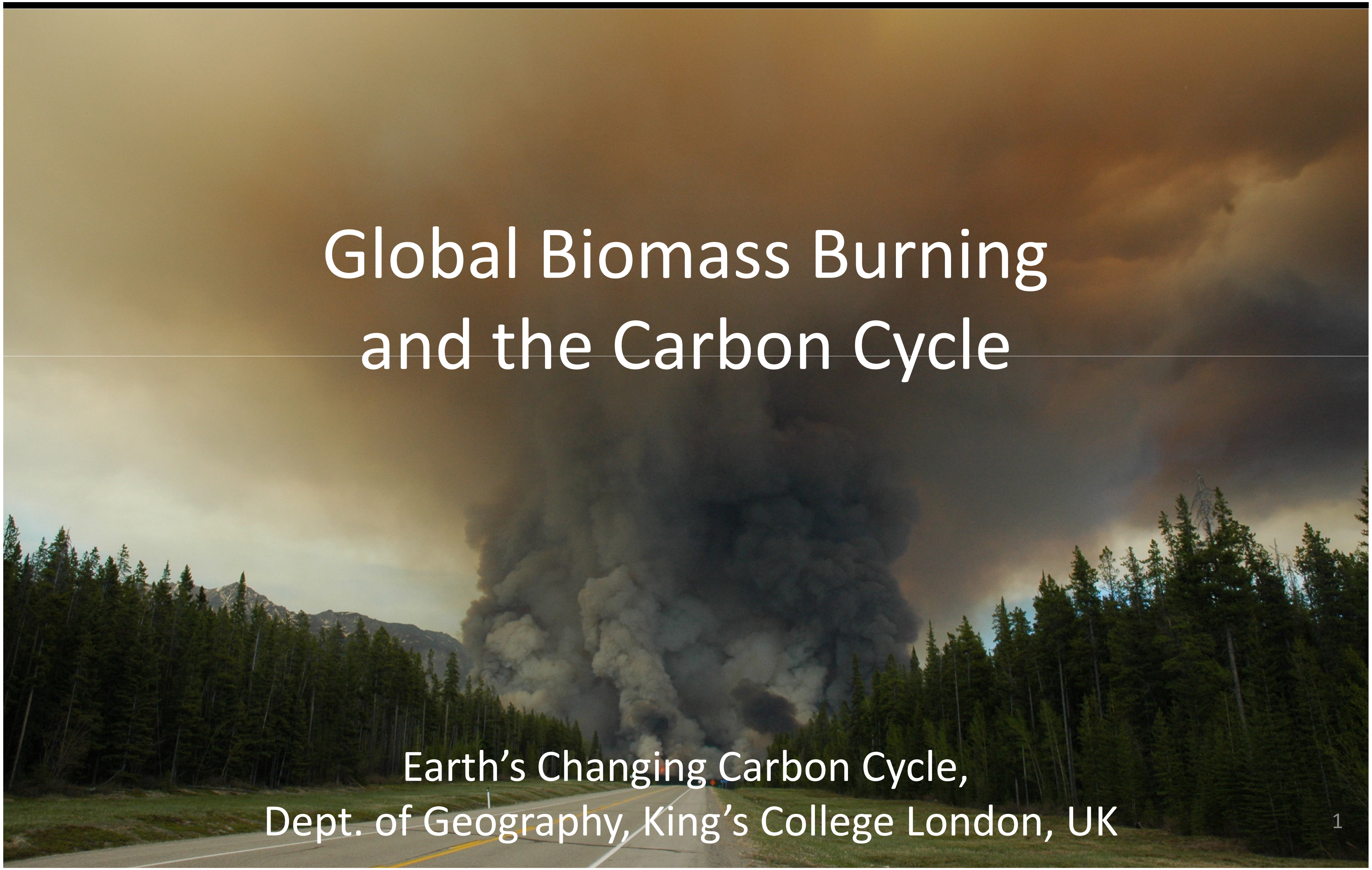


Global Biomass Burning and the Carbon Cycle

Earth's Changing Carbon Cycle,

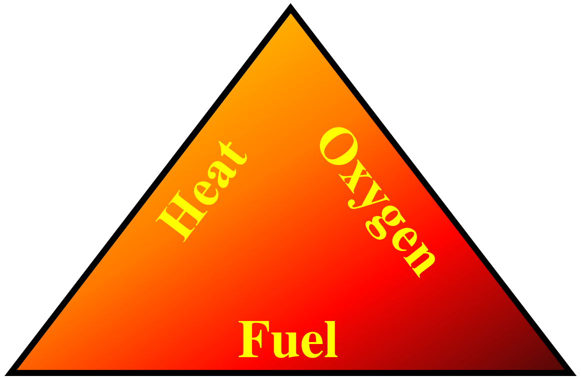
Dept. of Geography, King's College London, UK

Lecture Outline

I. Some Figures about Fires
II. Physical Process
III. Fire Monitoring
IV. Fire Modelling

Biomass Burning

Required for Fire



"Fire Triangle"

http://www.flickr.com/photos/pedrosz/3876517126/

Observed Geostationary FRP [W/m^2] (red)

Modelled BC+OM AOD [-] (blue)

:ncyclopaedia of Southern Fire Science: http://www.forestencyclopedia.net/p/p4

Fire Emissions Equation

$$M_x = EF_x \times A \times \beta \times AFL$$

M_x : amount of species X emitted (kg)

EF_x : emission factor for species X per fire ($kg.kg^{-1}$)

A_i: burnt area (m^2)

β_k: combustion completeness (0 to 1.0)

AFL_k: available fuel load ($kg.m^{-2}$)

Crutzen, P.J., L.E. Heidt, J.P. Krasnec, W.H. Pollock and W. Seiler, 1979: Biomass burning as a source of atmospheric gases CO, H_2 , N_2O, NO, CH_3Cl and COS. *Nature*, **282**, 253-256.

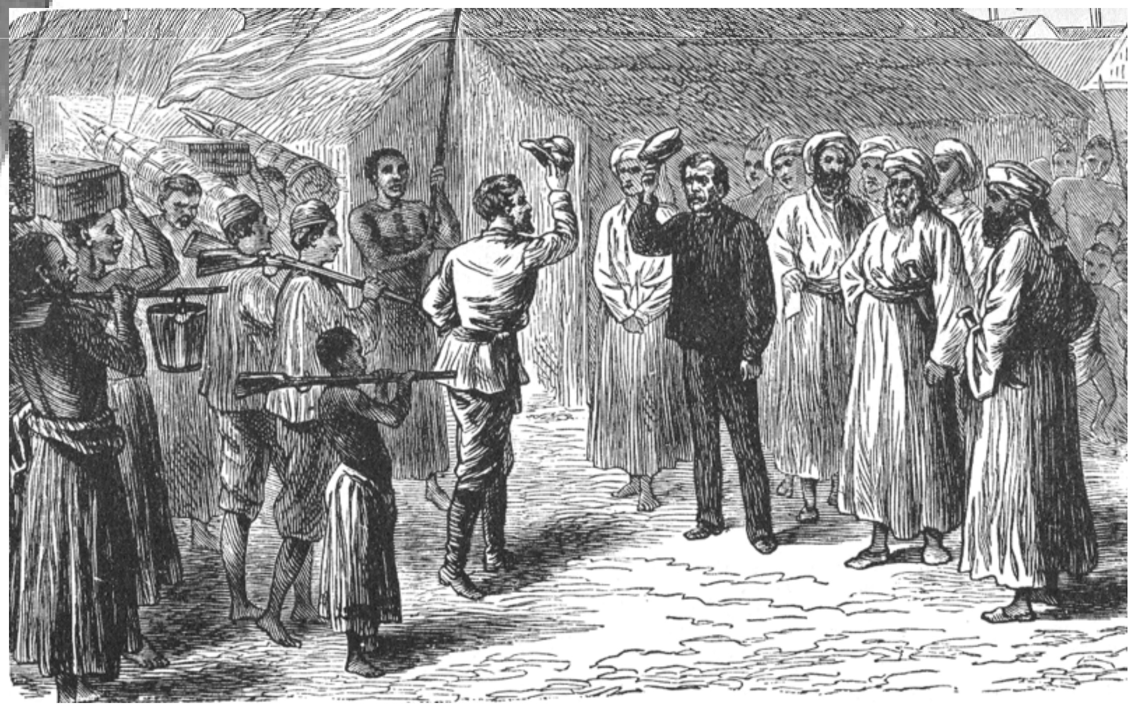
$$\textbf{\textit{Emissions}} = \textbf{\textit{BA}} \times \textbf{\textit{FL}} \times \textbf{\textit{CC}} \times \textbf{\textit{EF}}$$

Seiler, W. and P.J. Crutzen, 1980: Estimates of gross and net fluxes of carbon between the biosphere and the atmosphere from biomass burning. *Climatic Change*, **2**, 207-247

Crutzen, P.J. and M.O. Andreae, 1990: Biomass burning in the tropics: impact on atmospheric chemistry and biogeochemical cycles. *Science*, **250** , 1669-1678.

Victorian Era (1874)

“Dr Livingstone I presume?”



Alexander von Danckelman

weighed the dry grass

standing on a square meter

fraction of land covered by

savannah

Estimated that 20 % of the area of tropical Africa south of the equator burned each year…► 0.6 Gt/yr

Contemporary estimates of global coal burning 0.3 Gt/yr

Current GFED V3.1 S.A fuel consumption……**1.0 Gt/yr**

Alexander von Danckelman

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Impact factor 2010
1.402

According to the 2008 Journal Citation Report the impact factor of the Meteorologsiche Zeitschrift has increased to 1.257 and the immediacy factor has risen to 1.1171.
Regarding the immediacy factor in the rankings categories of 'Meteorology and Atmospheric Sciences' the Meteorologische Zeitschrift peaked at position 1.

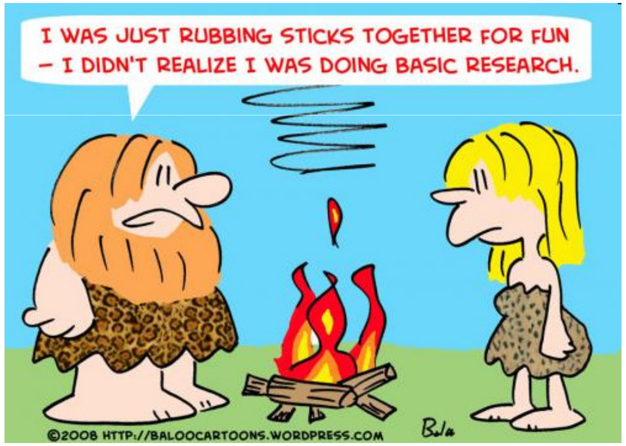
Description

Meteorologische Zeitschrift (originally founded in 1866) is the joint periodical of the meteorological societies of Austria, Germany and Switzerland. It accepts high-quality peer-reviewed manuscripts on all aspects of observational, theoretical and computational research out of the entire field of meteorology, including climatology. Meteorologische Zeitschrift represents a natural forum for the meteorological community of Central Europe and

VON DANCKELMAN, A. (1884a) Die Bewölkungsverhältnisse des südwestlichen Afrikas [Cloud-conditions in Southwest Africa]. *Meteorological Zeitschrift,* 1, 301–311

History of Anthropogenic Biomass Burning

- Humans evolved in savanna environments, and these are still amongst Earth's most fire-prone ecosystems.
- In the archeological record, cooked food appears ~ 1.9 Ma.
- Human control of fire ~ 400 ka.
- Hunter-gatherers used fire to reduce fuels and manage wildlife and plants >> 10 ka.

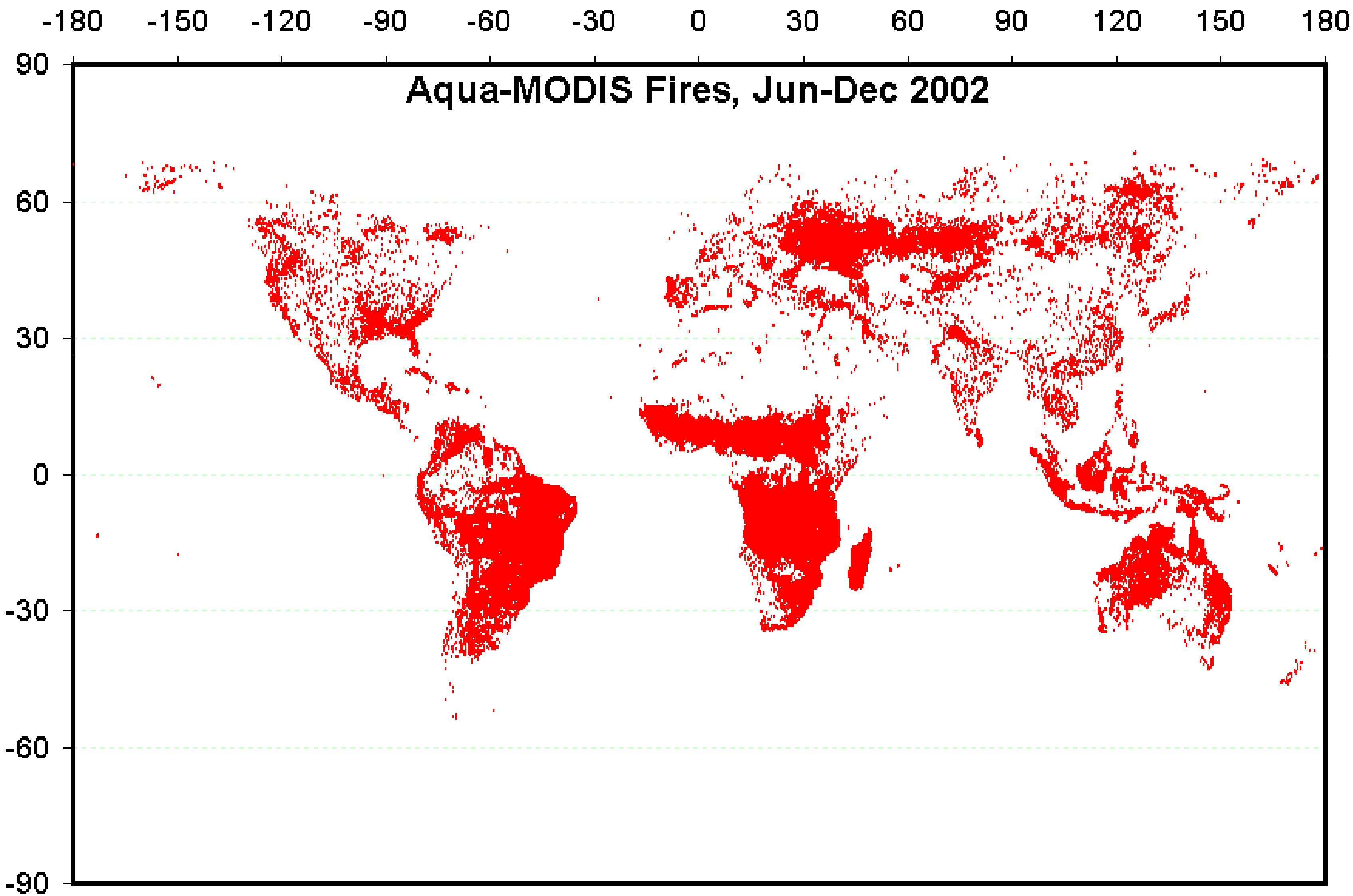


- In addition to "accidental" fires, such activities still dominate savanna fire today – most initiated by man.

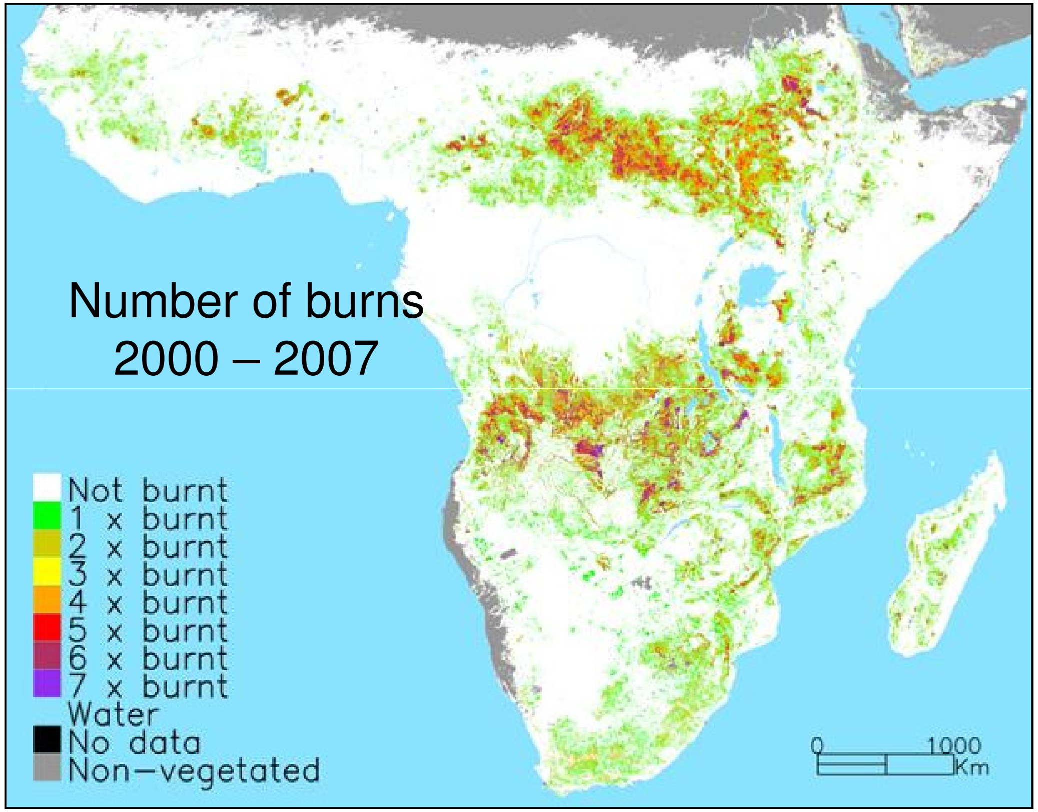
Bowman et al. (2009)

Global Scale?

Global Fire Occurrence



Savannah Fire ~ Neutral C Balance



- Partially burnt fuel ("char")
  (combustion completeness < 100%)
- Senesced unburned vegetation
- White 'mineral' ash
- Post-burn vegetation regrowth

- Africa site of ~ 30 – 50 % of total annual fuel consumption in fires
- IPCC only include CO_2 emissions from landuse change fires, here only other GHG's

Tansey, K., et al. (2007) A new, global, multi-annual (2000–2007) burnt area product at 1 km resolution GRL, 35, L01401 doi:10.1029/2007GL031567

Ecology and Fire - Canadian Jack Pine

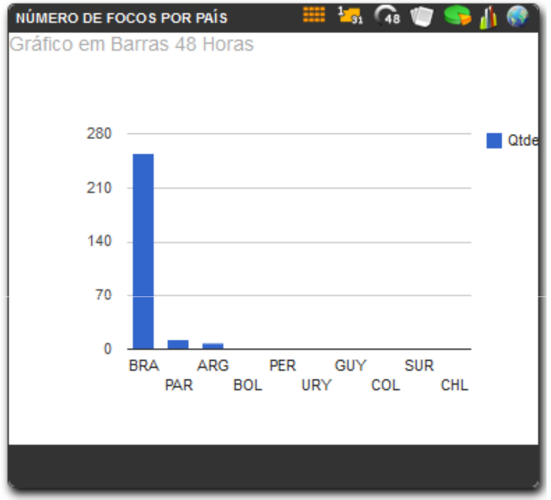
Prescribed burn in Alberta Canada 2009

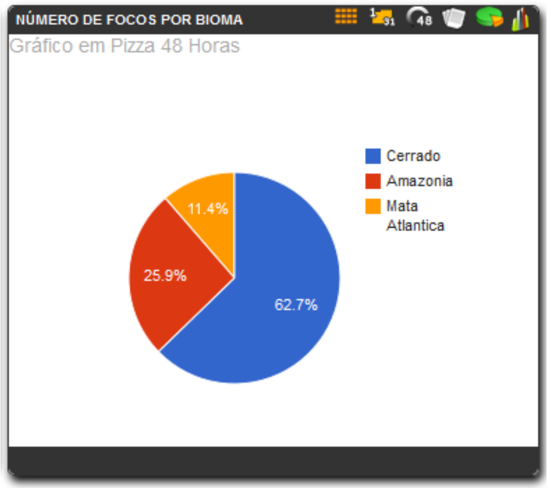
The cones remaining closed for many years, until a forest fire kills the mature trees and opens the cones, reseeding the burnt ground.
The cones on mature trees open when exposed to intense heat, greater than or equal to 50 ℃.

Fire in South America

KING'S College LONDON
University of London

Fire statistic for the 26th of July 2011



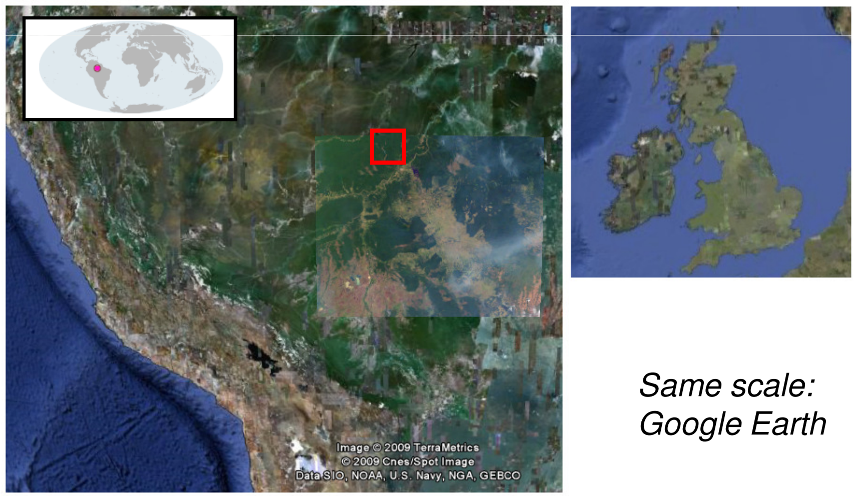


Deforestation and Land degradation

•Transition from subsistence to industrial economies is associated with forest conversion to agricultural or pastoral landscape usually via use of fire.

- During the past 30 yrs, around 1/3rd of Rondônia's original forest (208,000 km²) was cleared.

- This is ~ 3x area of Wales !
  [http://www.simonkelk.co.uk/sizeofwales.html]



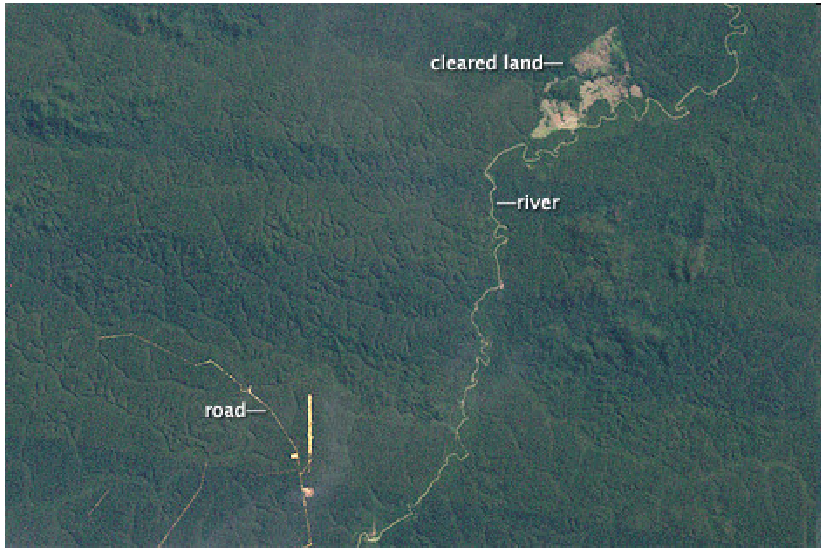
Same scale: Google Earth

http://earthobservatory.nasa.gov/Features/AmazonFire/

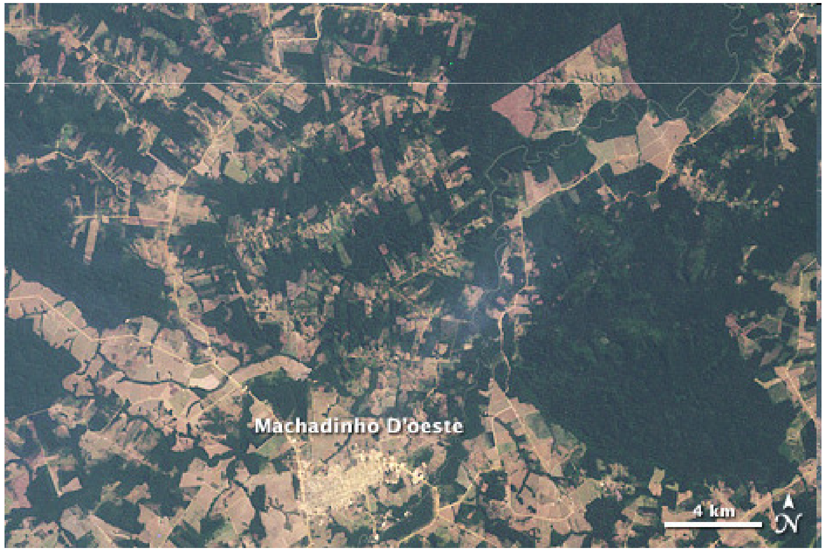
Deforestation and Land degradation

Deforestation and Land degradation

Over the longer-term changes have been even more dramatic. Landsat TM and ETM+ allow change detection over decades….



Landsat TM, 17 June 1984



Landsat ETM+, 21 July 2005

http://earthobservatory.nasa.gov/Features/WorldOfChange/deforestation.php

Deforestation and human activities

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28 January 2011 Last updated at 14:52

308 Share

Amazon road set to give Brazil and Peru new trade route

By Dan Collyns
BBC News, Puerto Maldonado

The road is making long isolated parts of Peru and Brazil more accessible

What better way to celebrate the opening of a road than by racing cars on it?

Related Storie

"More than development, the road has brought us problems," says Luis Aguirre, just a month into his new job as governor of Madre de Dios.
"It was supposed to bring progress but instead it's brought us more crime, more drug-addiction, more deforestation, more ecological destruction and more unchecked migration."

Suleyde Ochoa left Inapari 23 years ago. Now married to an Iranian and with two daughters, she has returned to set up a roadside restaurant.
"I see a real future here now, that's why I've come back with my family".

Current Biomass Burning Impacts

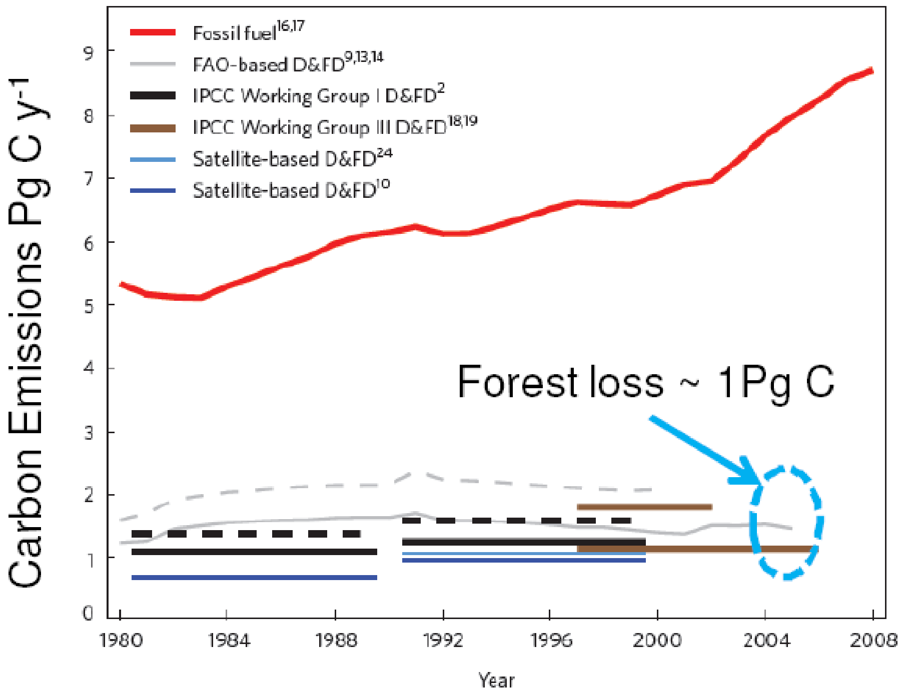
CO_2 emissions from forest loss

G. R. van der Werf, D. C. Morton, R. S. DeFries, J. G. J. Olivier, P. S. Kasibhatla, R. B. Jackson, G. J. Collatz and J. T. Randerson

Deforestation is the second largest anthropogenic source of carbon dioxide to the atmosphere, after fossil fuel combustion. Following a budget reanalysis, the contribution from deforestation is revised downwards, but tropical peatlands emerge as a notable carbon dioxide source.

NATURE GEOSCIENCE | VOL 2 | NOVEMBER 2009 | www.nature.com/naturegeoscience

1. Stopping deforestation / degradation could save up to ~12% of emissions (~15% if peat included)
2. Unlikely that this can be reduced to zero
3. Reducing other emissions very important



Fire Intensity

Fire Line Intensity (FLI; $kW.m^{-1}$) = rate of heat release per unit time per unit length of fire front, regardless of depth of flaming zone

$$FLI = h.w.r$$

h = heat of combustion ($kJ.kg^{-1}$)
w = fuel consumed in flames ($kg.m^{-2}$)
r = rate of spread ($m.s^{-1}$)

Australian eucalyptus:
In the dry Australian bush, eucalyptus developed a thick bark to protect from higher fire intensities.

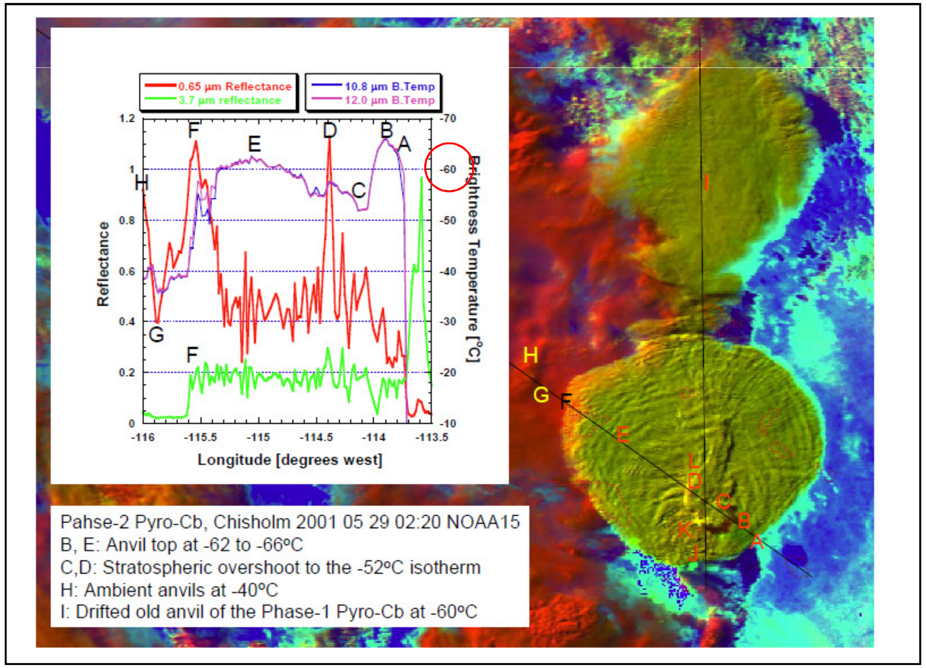
The Chisholm Firestorm

King's College London
University of London

- FLI values range from 10's to ~ 100,000 $kW.m^{-1}$
- Greatest in high intensity "crown" fires
- $H = 18{,}600\ kJ.kg^{-1}$ $W = 2\ kg.m^{-2}$ $r = 0.5\ m.s^{-1}$

  $\rightarrow$ FLI = 18,600 $kW.m^{-1}$

- Chisholm fire (Alberta) - burned 500,000 ha (500 km^2) in 7 hrs.
- First atomic bomb ~ 80 x 10^{12} J
- Fuel heat yields of 18,600 $kJ.kg^{-1}$
- Energy ~ 3-5 atomic explosions per min
- Smoke lofted into stratosphere (>12 km)



Rosenfeld et al (2007) http://www.atmos-chem-phys.net/7/645/2007/acp-7-645-2007.pdf

Lecture Outline

I. Some figures about Fires

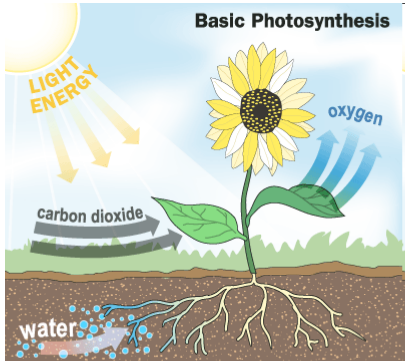
II. Physical Process

III. Fire Monitoring

IV. Fire Modelling

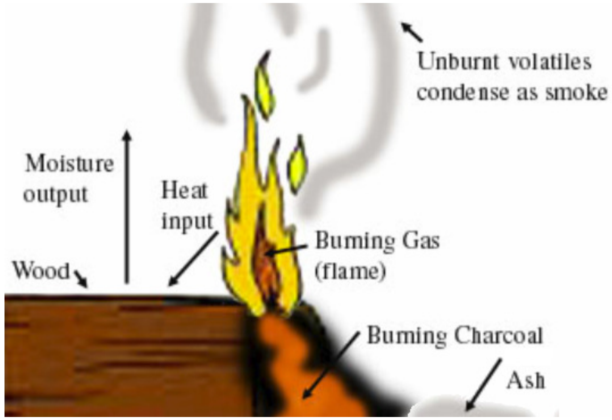
Fire: A Chemical/Physical Reaction

Energy stored in biomass via photosynthesis released as heat:



Photosynthesis:

$6CO_2 + 6H_2O + \text{solar energy} \rightarrow C_6H_{12}O_6 + O_2$



Combustion:

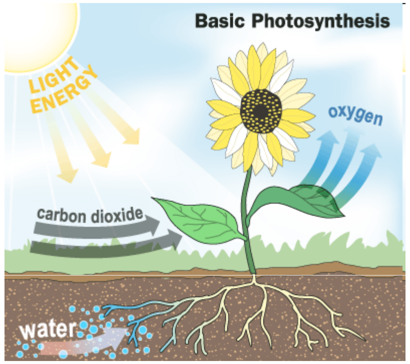
$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + \text{heat energy}$

- Heat yield of vegetation ~ 20 x 10^3 kJ/kg
- Takes 419 kJ for 1 kg of water from 0 ° to 100 ℃…

Whelan (1995) The Ecology of Fire, Cambridge University Press, Chapter 2

Fire: A Chemical/Physical Reaction

Energy stored in biomass via photosynthesis released as heat:



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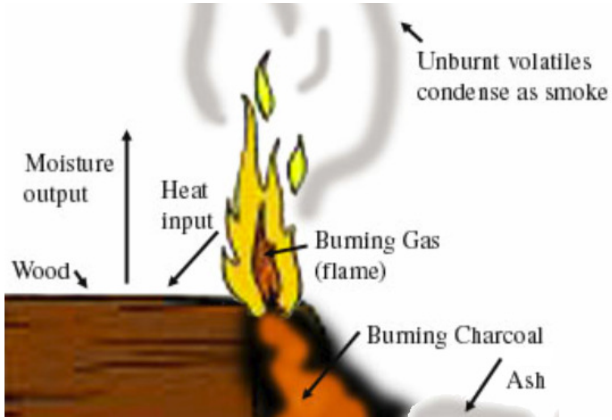


convection

radiation

conduction

Combustion:

$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + \text{heat energy}$

Biomass is more complex than this simple sugar, having more complex organic compounds and trace amounts of silica, magnesium, potassium, calcium, phosphorus etc..so produces a variety of products

Whelan (1995) The Ecology of Fire, Cambridge University Press, Chapter 2

Physics of Fire - Energy Balance

Fire behavior

Relation between Consumption, Radiation and Convection

[Parent et al 2010]

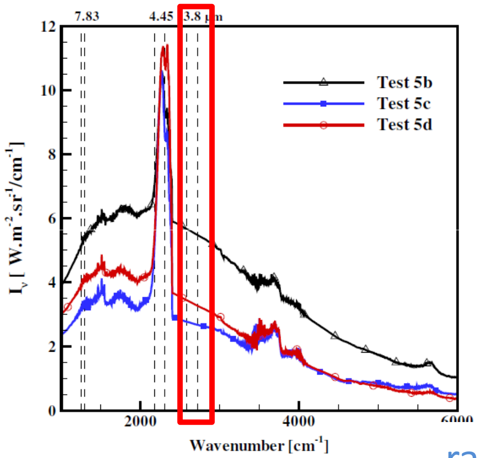
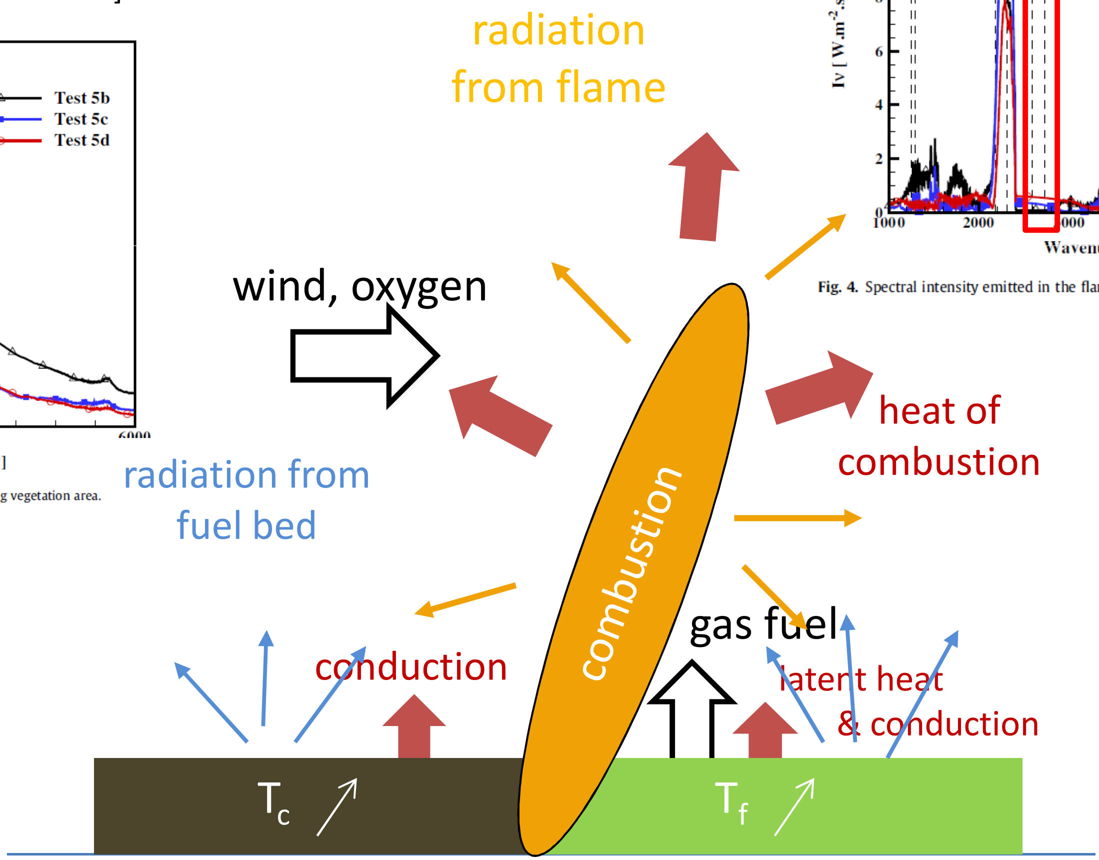


Fig. 6. Spectral intensity emitted by the burning vegetation area.

MIR



- char oxydation
- drying
- pyrolisys

[Parent et al 2010]

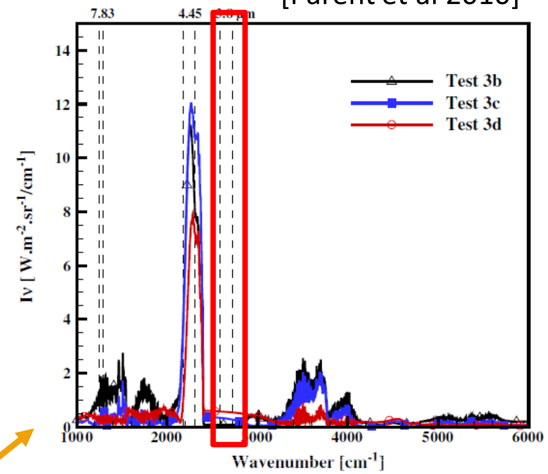
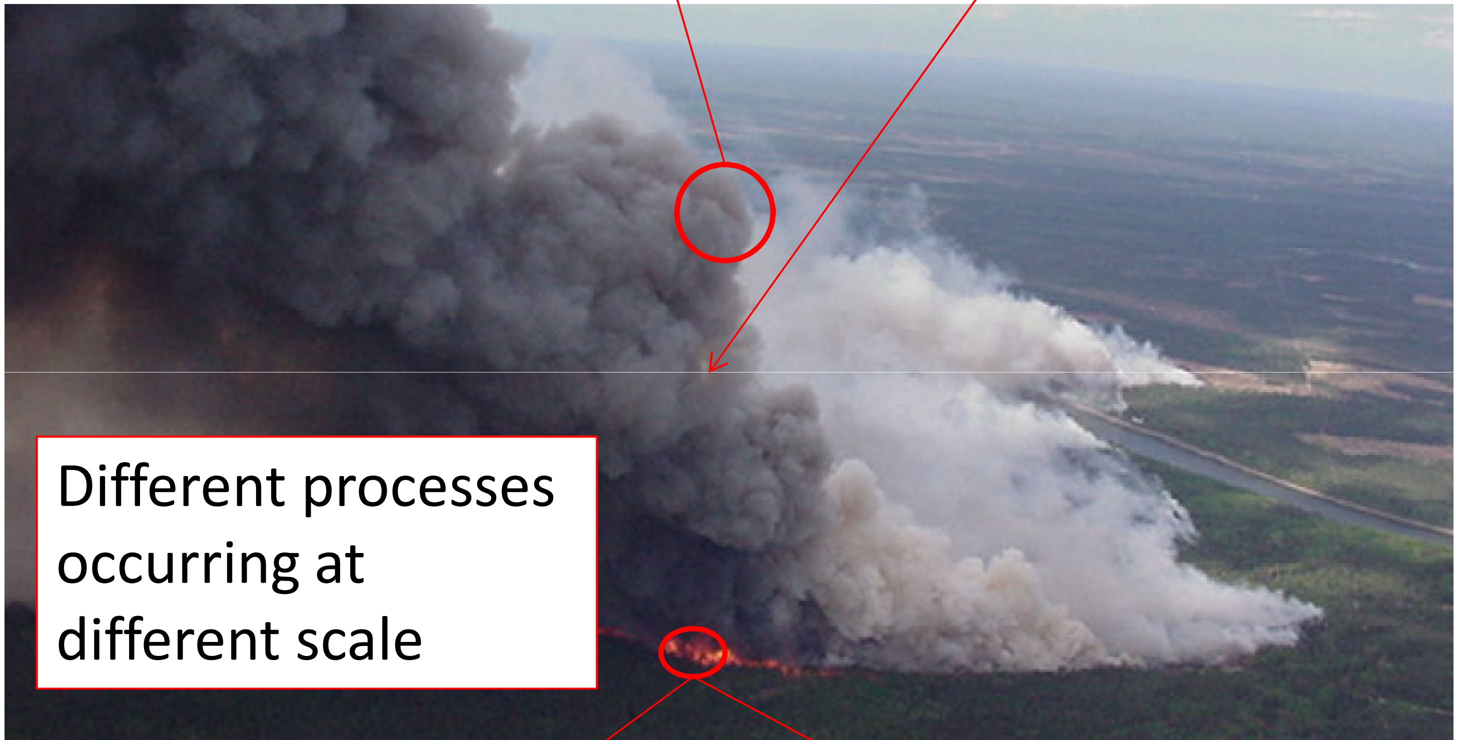


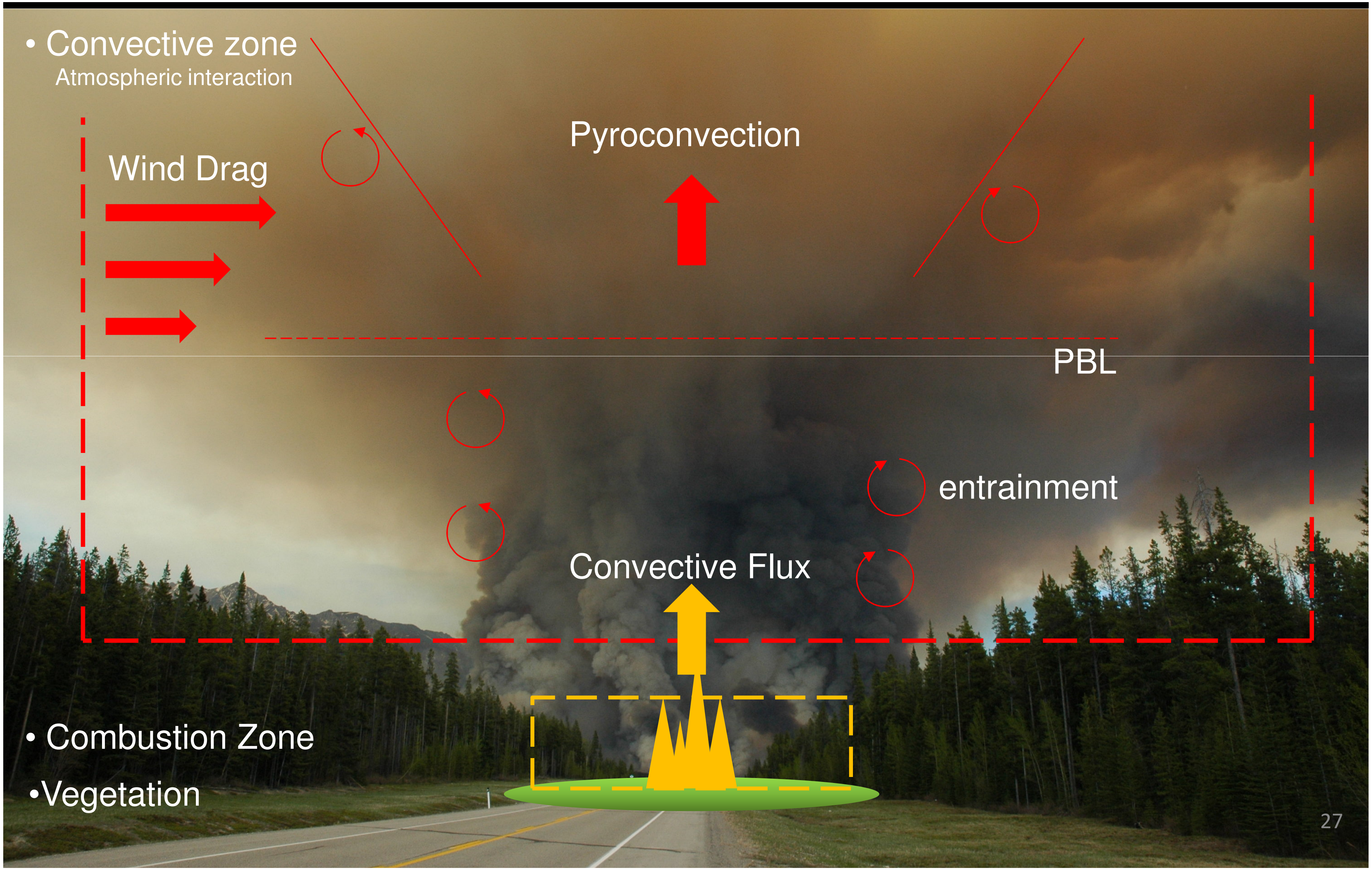
Fig. 4. Spectral intensity emitted in the flame 10 cm above the burning vegetation.

Biomass Burning Processes



- Vegetation fires release large amounts of carbon (vegetation is ~ 47% C)

Physics of Fire - Convective Plume



outline

I. Some figures about Fires

II. Physical Process

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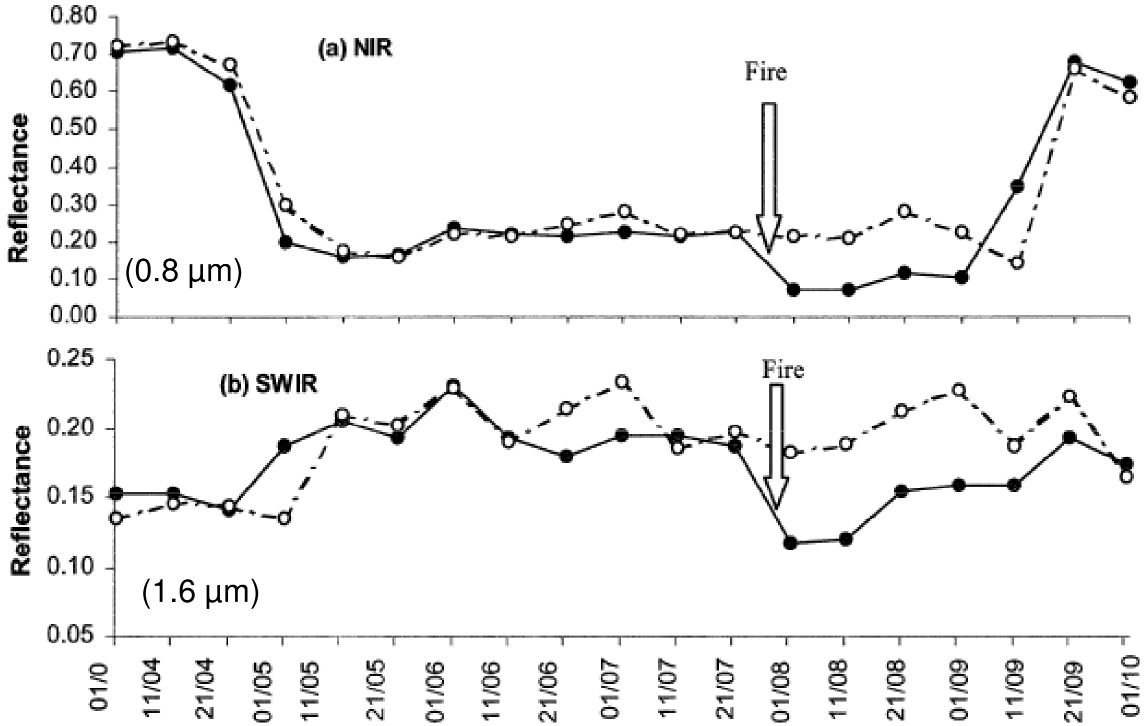
IV. Fire Modelling

Burned Area Mapping from Earth Observation



$$\mathrm{NDVI} = \frac{(\rho_{\mathrm{NIR}} - \rho_{\mathrm{red}})}{(\rho_{\mathrm{NIR}} + \rho_{\mathrm{red}})}$$

$$\mathrm{SWVI} = \frac{(\rho_{\mathrm{NIR}} - \rho_{\mathrm{SWIR}})}{(\rho_{\mathrm{NIR}} + \rho_{\mathrm{SWIR}})}$$

Burned Area Mapping Approaches

King's College London
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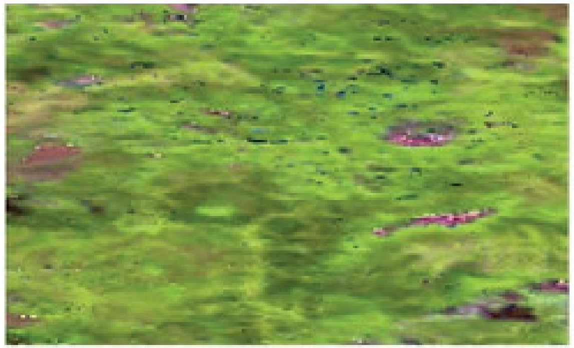
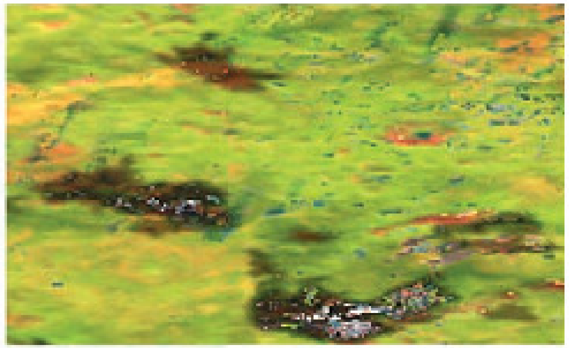
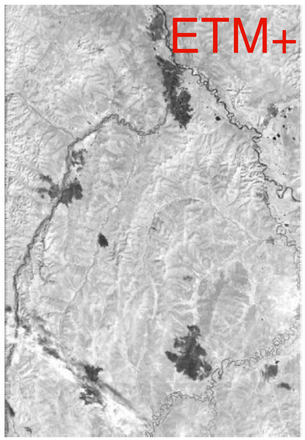


Pre-fire

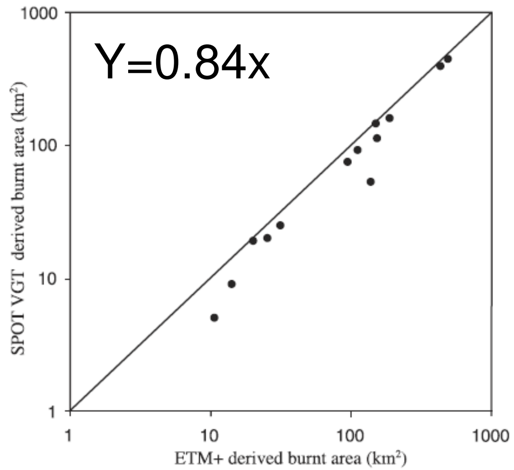


Post-fire

Fire “Scar” Map

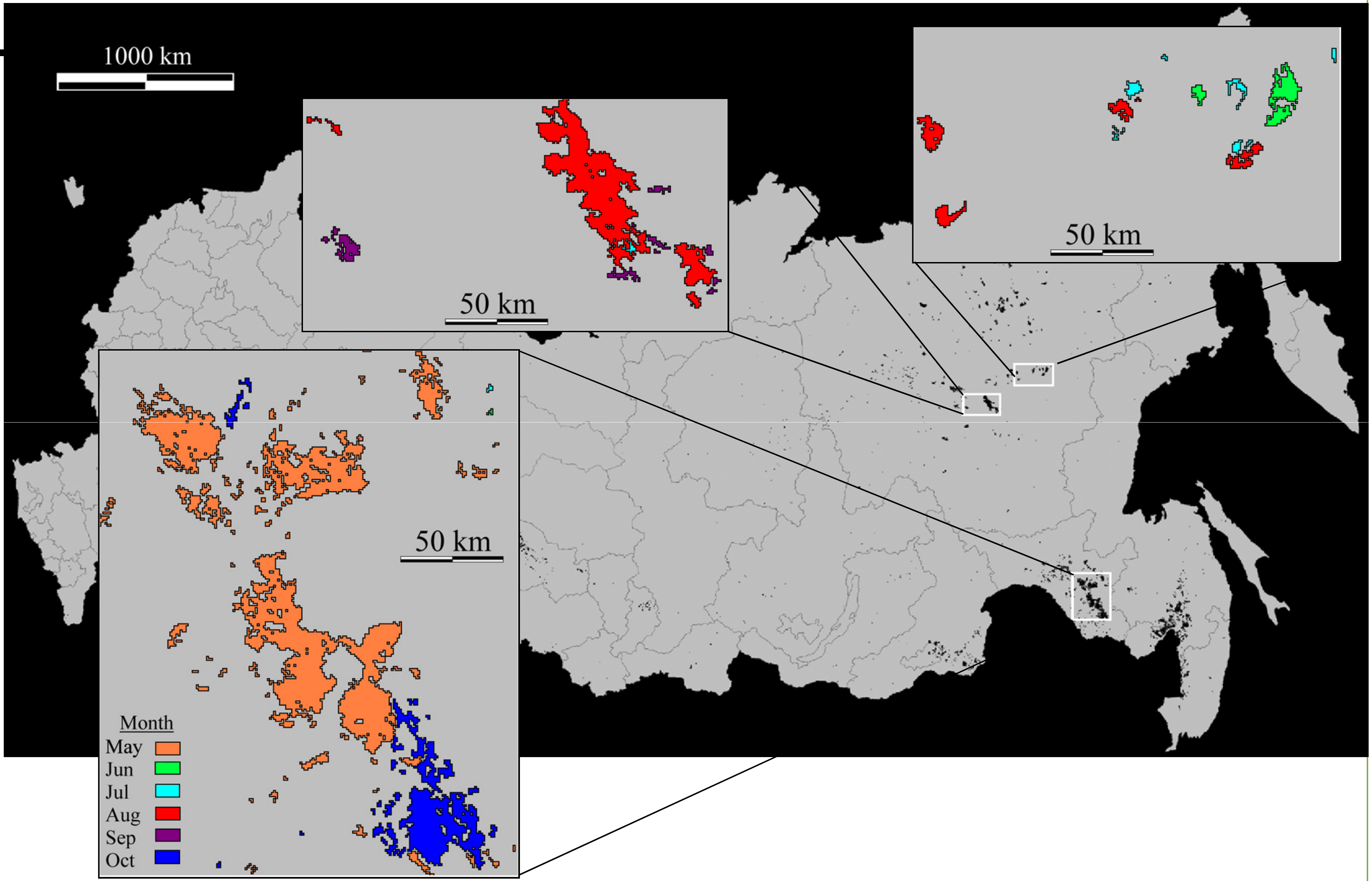


“validation”



Zhang et al (2003) Monthly burned area and forest fire C emission estimates for the Russian Federation, *Remote Sensing Environ*, 87, 1-15

Burning in the Russian Federation (2001)



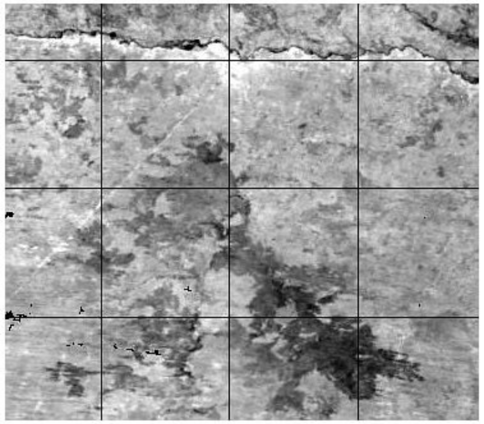
Total = 51,500 km² (±15% based on comparisons to Landsat ETM+)

Burning in the Russian Federation (2001)

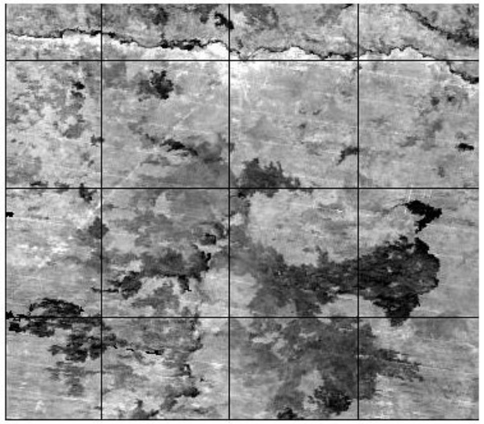
- Mapped 41,700 km² of Russian fires (2001) – twice the area of Wales!
- A total of 31,200 km² of burns in forest and 10,600 km² in other landuse classes

Zhang et al (2003) Monthly burned area and forest fire C emission estimates for the Russian Federation, *Remote Sensing Environ*, 87, 1-15

Change Detection of Burned Areas

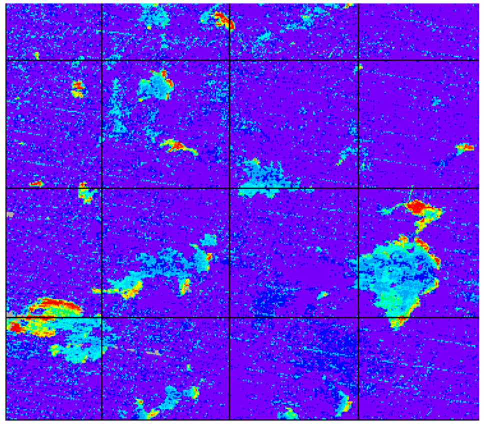

BRDF predicted 1.24 micron reflectance (500m) day 275

Predicted Refl.

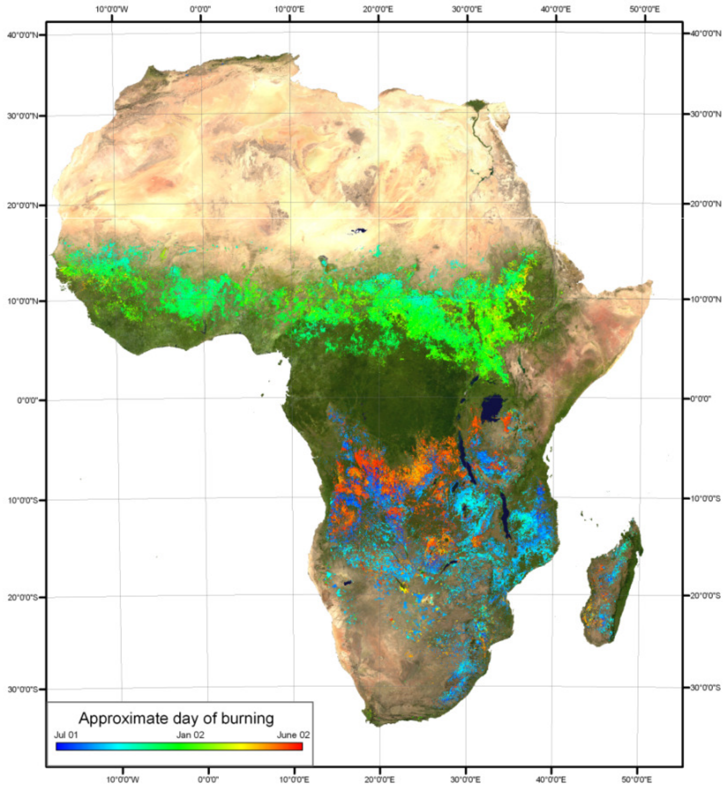

Observed 1.24 micron reflectance (500m) day 275

Observed Refl.

Difference


Z-score 1.24 micron reflectance (500m) day 275

Official MODIS "Burned Area" product (MCD45A1) based on this approach



Roy et al. (2002) Burned area mapping using multi-temporal moderate spatial resolution data, Remote Sensing Environ, 83, 263-28

BRDF Change Detection of Burned Areas

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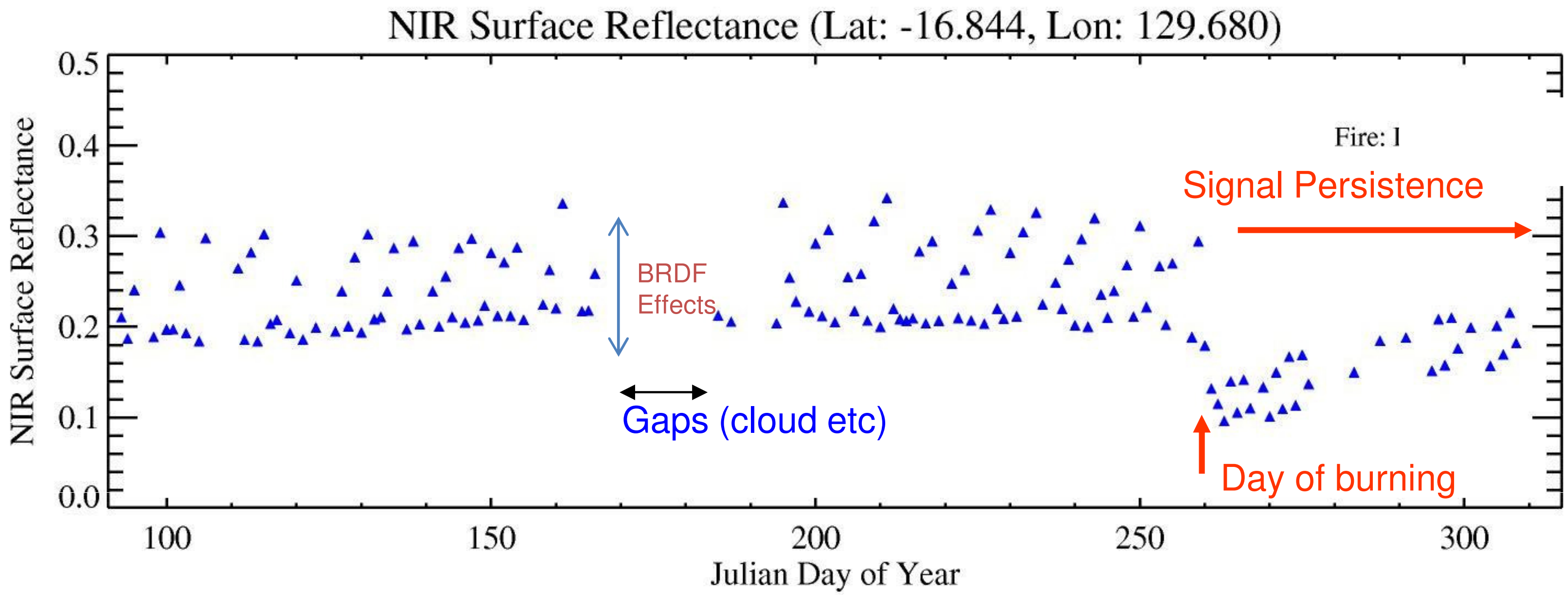
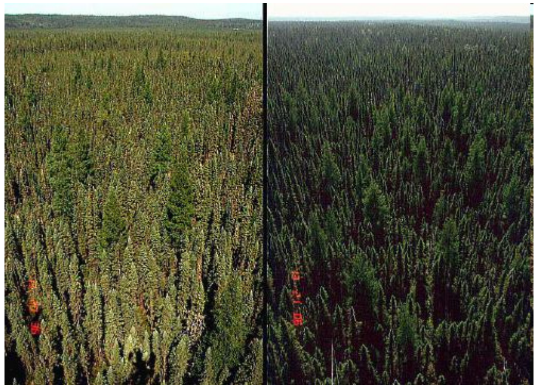


Bidirectional Reflectance Distribution Function (BRDF)

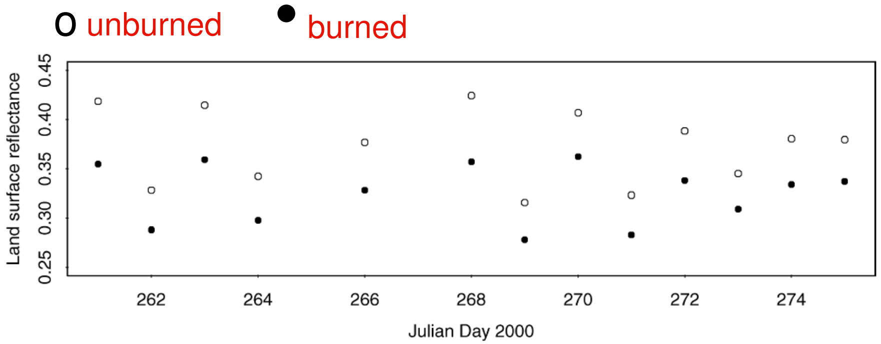


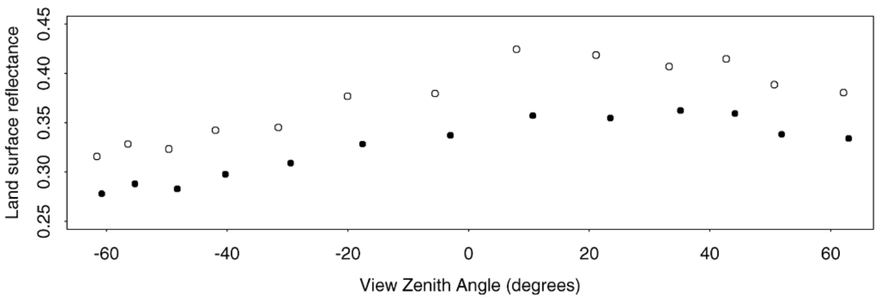
Wavelength dependent BRDF depends on shadow-casting, mutiple scattering, transmission, reflection, etc

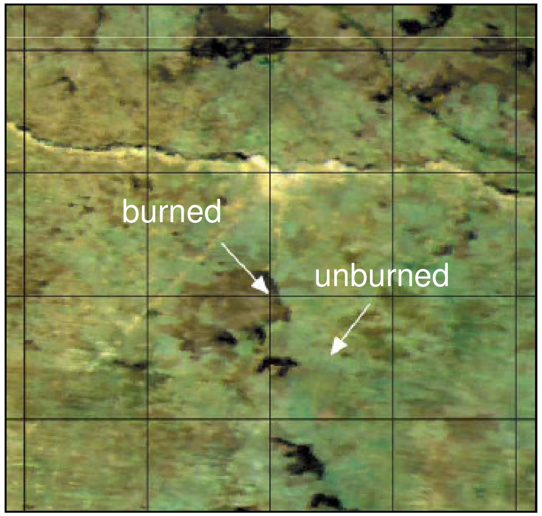
Photos: Don Deering

Roy et al. (2002) Burned area mapping using multi-temporal moderate spatial resolution data, Remote Sensing Environ, 83, 263-286.

Change Detection of Burned Areas

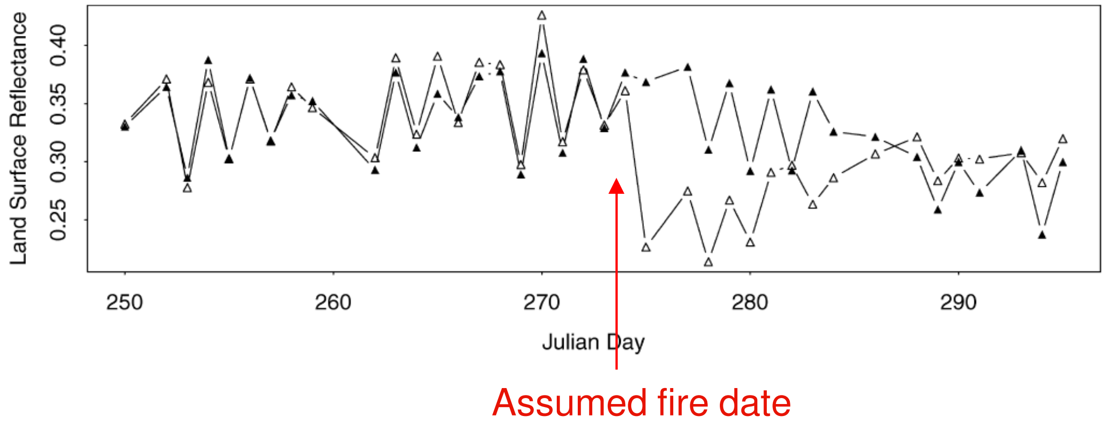






MODIS image
Angolan-Namibian Border

BRDF model predicted vs observed reflectance



Roy et al. (2002) Burned area mapping using multi-temporal moderate spatial resolution data, Remote Sensing Environ, 83, 263-286.

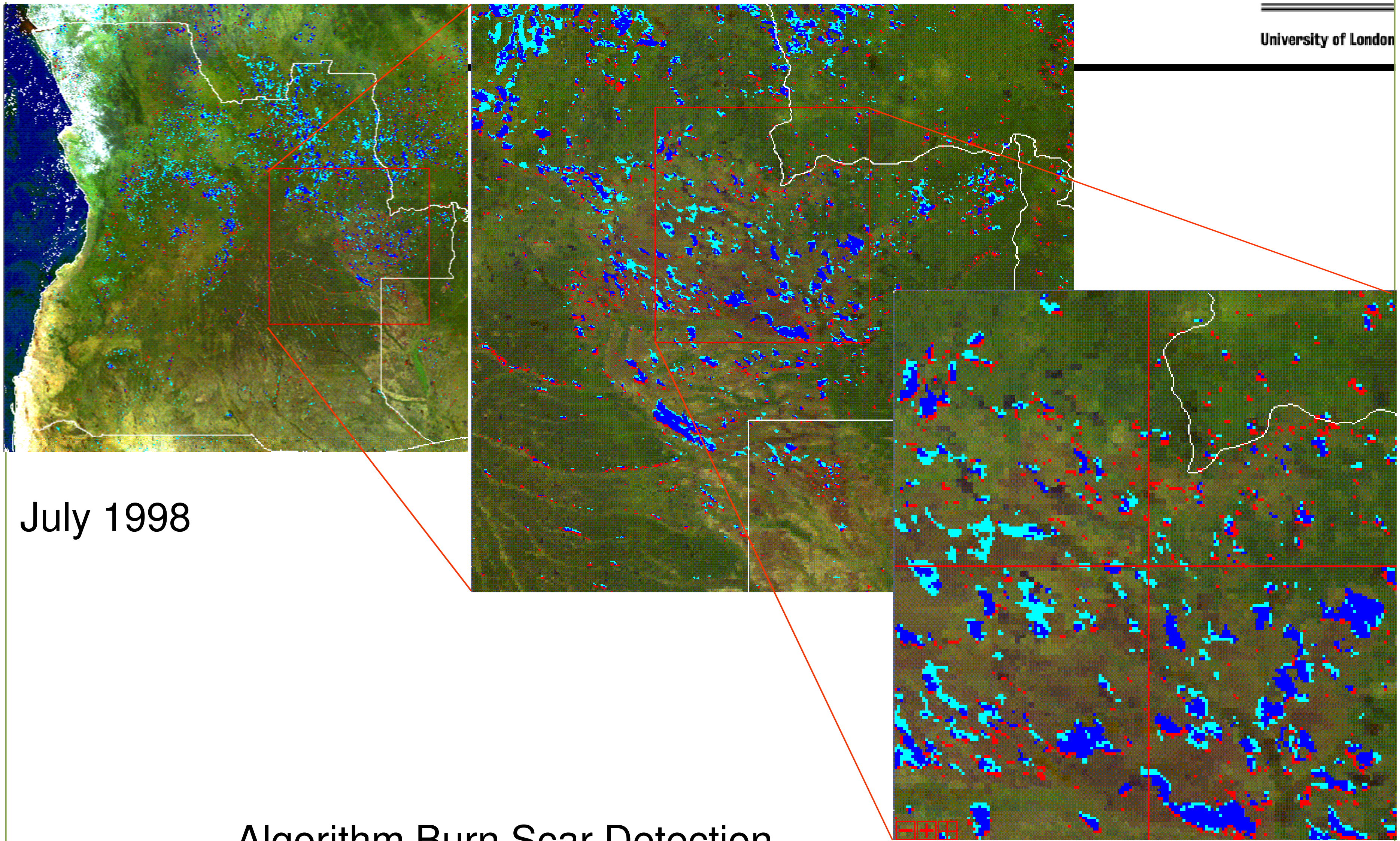
Burned Area Product Intercomparisons

Table 5. Comparison of burned areas and carbon emissions from African fires

Year	Burned Area [Mha]	Comments	Reference
whole continent			
2000	$\boxed{227}$	GBA2000	Boschetti et al., 2004
2000	$\boxed{121}$	GLOBSCAR	Boschetti et al., 2004
2000	2.3	World Fire Atlas	Boschetti et al., 2004
1981-83, 1985-91	547	AVHRR fire counts	Barbosa et al., 1999
northern hemisphere			
2000	126	GWEM 1.4	Hoelzemann et al., unpublished
1981-83, 1985-91	362	AVHRR fire counts	Barbosa et al., 1999
1998-2001	167	TRMM-VIRS fire counts	van der Werf et al., 2003
1960-2000	27	Reg-FIRM	this study(1)
southern hemisphere			
2000	111	GWEM 1.4	Hoelzemann et al., unpublished
1981-83, 1985-91	185	AVHRR fire counts	Barbosa et al., 1999
climatology	399		Scholes et al., 1996
1998-2001	116	TRMM-VIRS fire counts	van der Werf et al., 2003
1960-2000	52	Reg-FIRM	this study[a]

[a] For the calculation of emissions, these values are scaled

Burned Area Product Intercomparison



July 1998

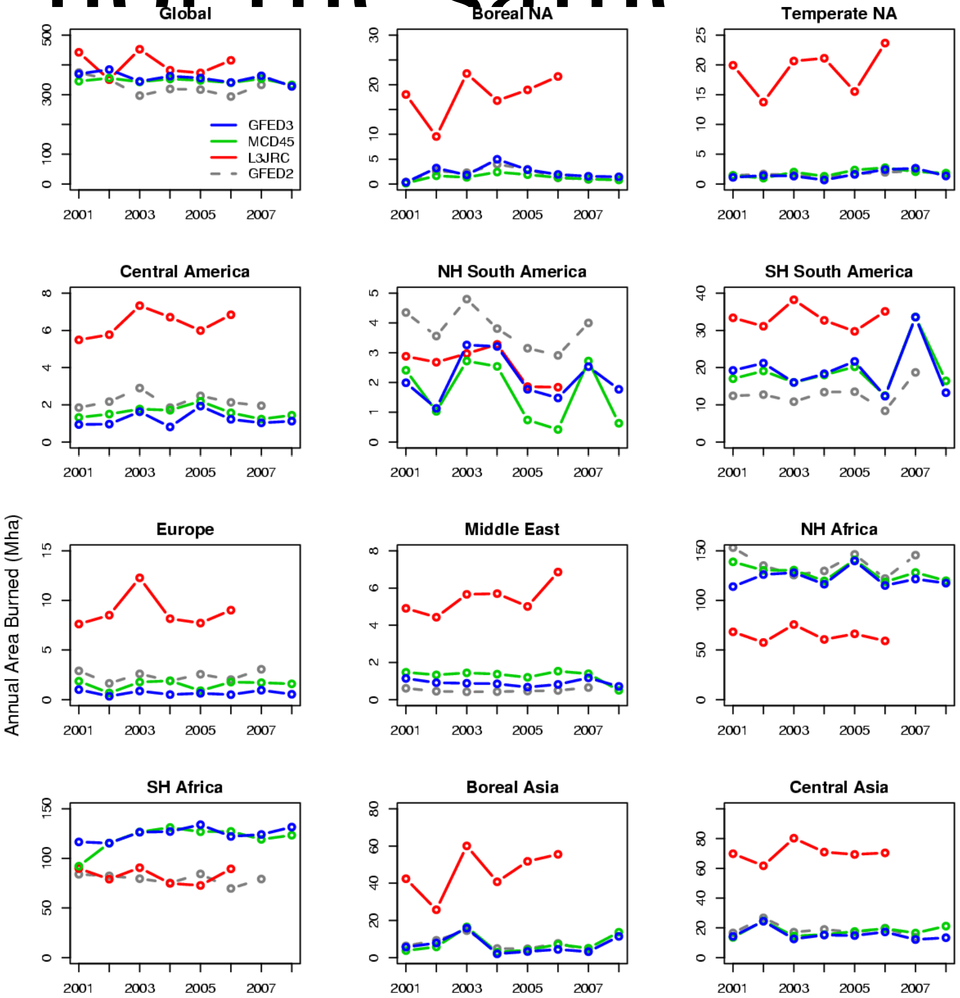
Algorithm Burn Scar Detection

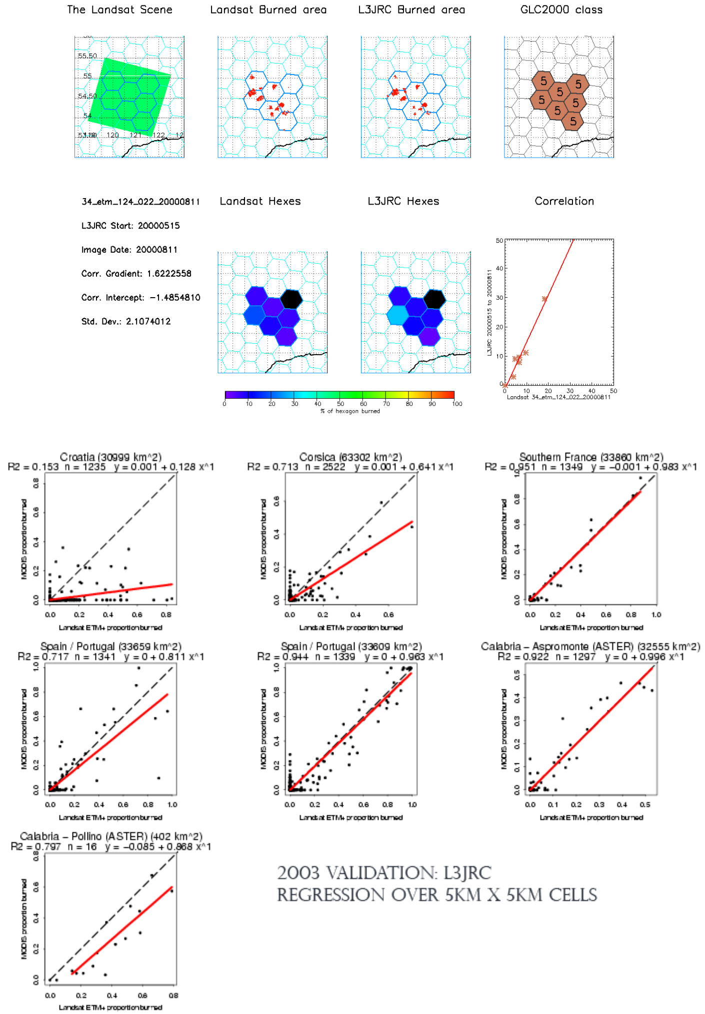
GLOBSCAR only

GBA only

Both algorithms

Burned area products clearly not the same

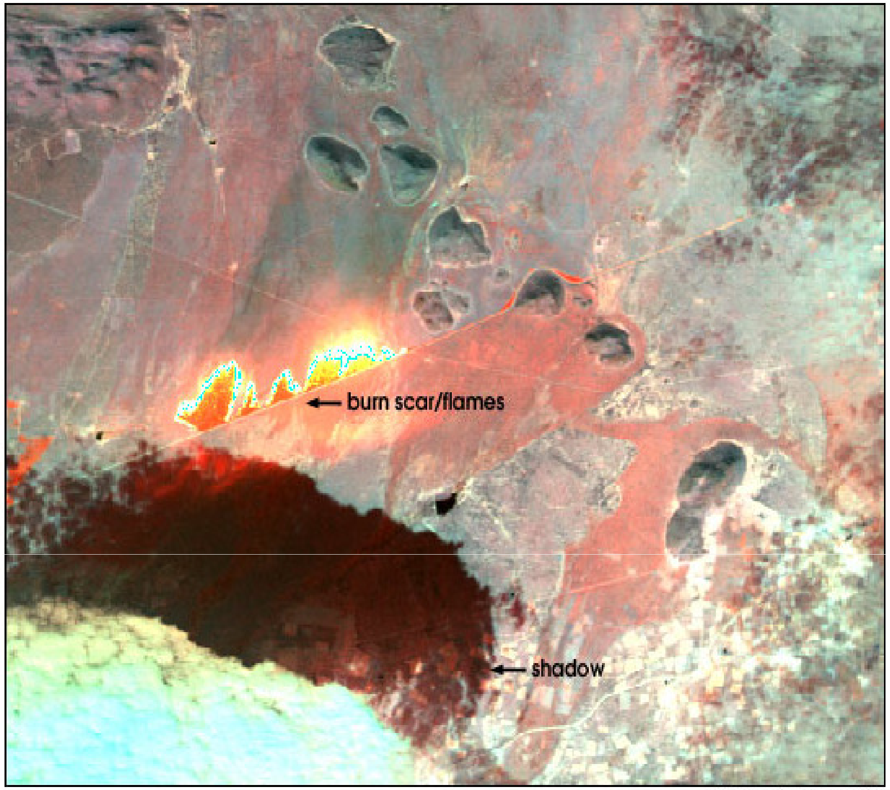




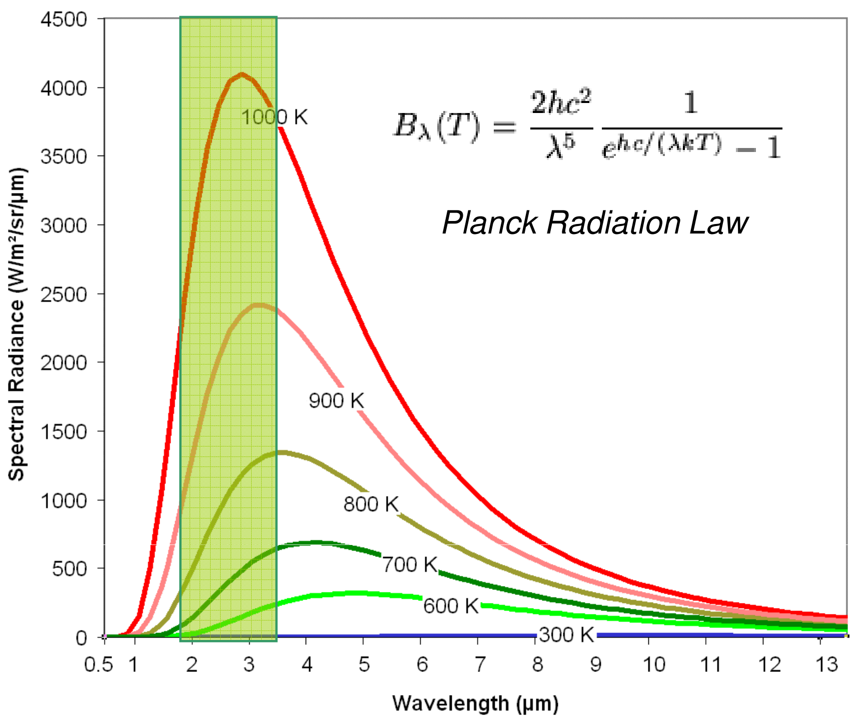
2003 VALIDATION: L3JRC
REGRESSION OVER 5KM X 5KM CELLS

Tansey, K., et al. (2007) A new, global, multi-annual (2000–2007) burnt area product at 1 km resolution GRL, 35, L01401 doi:10.1029/2007GL031567

Active Fire Products



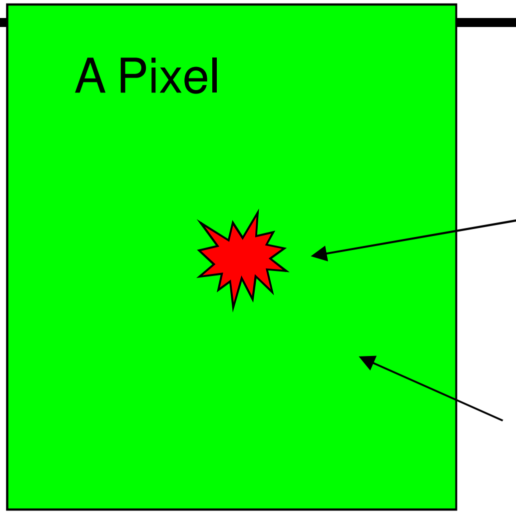
infrared composite



- Identify fires via their intense thermal emissions.
- Particularly strong in the SWIR – MIR region, optimum ~ 3 – 4 µm
- Also smoke is largely transparent at these wavelengths
- Signal so strong that fires filling fraction of a pixel can be detected

Fuller et al (2000) Satellite remote sensing of biomass burning with optical & thermal sensors, Progress in Phys.Geog., 23,543-561

Bi-spectral Model (Dozier, 1981)



Fire: "Temperature" = T_{fire}
pixel proportion = p

Background: Temperature = T_{back}
pixel proportion = (1-p)

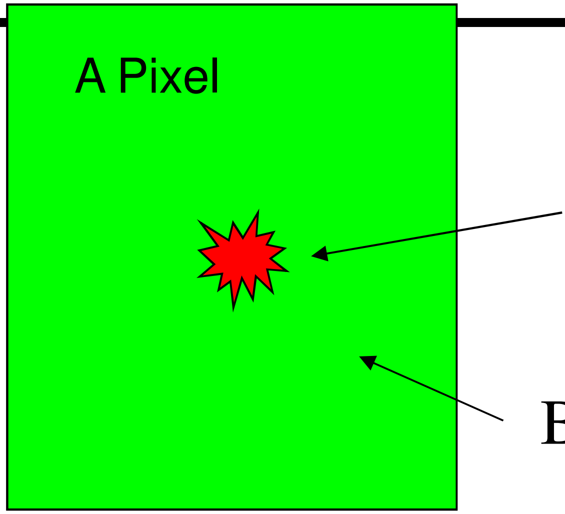
$$L_{obs}(\lambda) = pB_{fire}(\lambda, T_{fire}) + (1-p)B_{back}(\lambda, T_{back})$$

(ignoring any atmospheric effects on the signal)

- Then using L_{obs} you invert Planck Radiation Law to get a "brightness temperature"
- BT dependent upon wavelength due to differing radiance vs temp relationships
- Where $BT_{3.7}$ and BT_{11} differ substantially, liklihood of a fire within pixel is high.

Wooster et al (2003) Fire radiative energy for quantitative study of biomass burning: Derivation from the BIRD experimental satellite and comparison to MODIS fire products. Remote Sensing Environ, 86: 83-107.

Bi-spectral Model (Dozier, 1981)



Fire: "Temperature" = T_{fire}
pixel proportion = p

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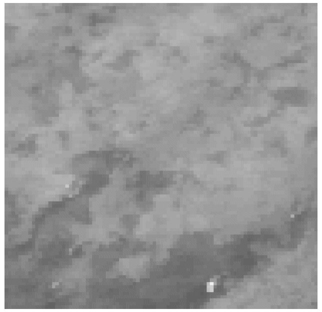
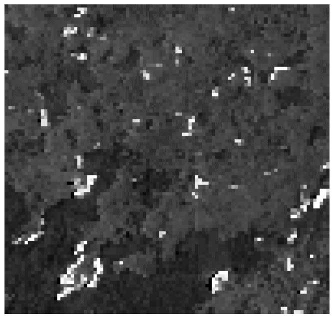
pixel proportion = (1-p)

Example AVHRR BT Imagery

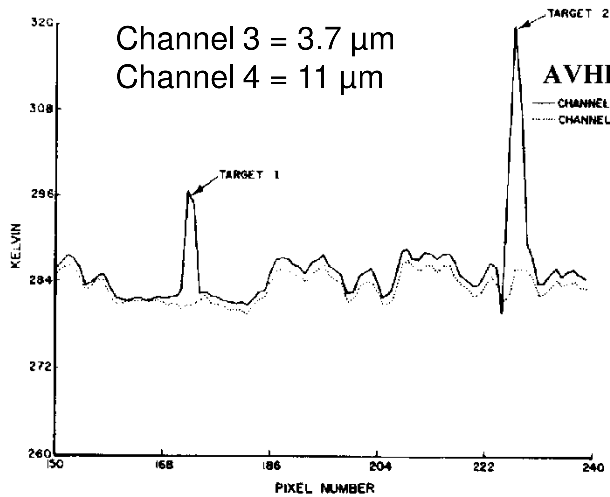


BT @ 11 µm

BT @ 3.7 µm



BT difference



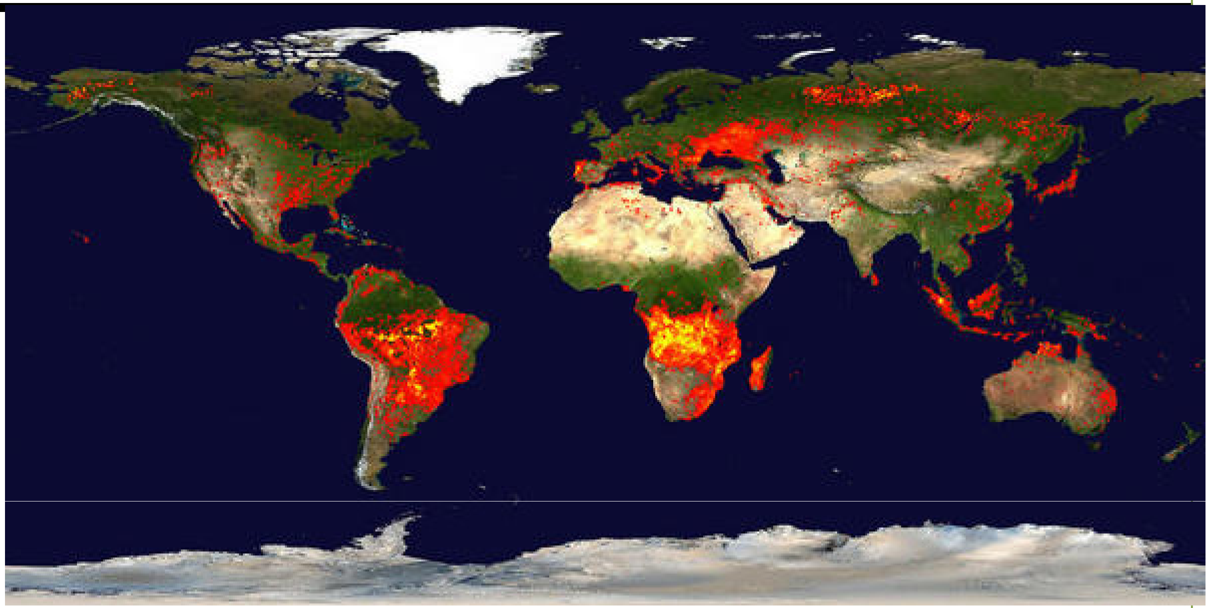
Wooster et al (2003) Fire radiative energy for quantitative study of biomass burning: Derivation from the BIRD experimental satellite and comparison to MODIS fire products. Remote Sensing Environ, 86: 83-107.

Active Fire 'Hotspot' Products

King's College London
University of London

MODIS Global Fires

http://rapidfire.sci.gsfc.nasa.gov/



Advantages: ~ global 1 km spatial resolution
focused product validation
NRT production, should be continued with VIIRS
can also measure fire radiative power (see later)

Disadvantages: temporal resolution limited to at best ~ 6 hrs at equator (more at high latitudes)

African Fire Diurnal Cycle