Challenges in long-term historical fire reconstruction and modelling

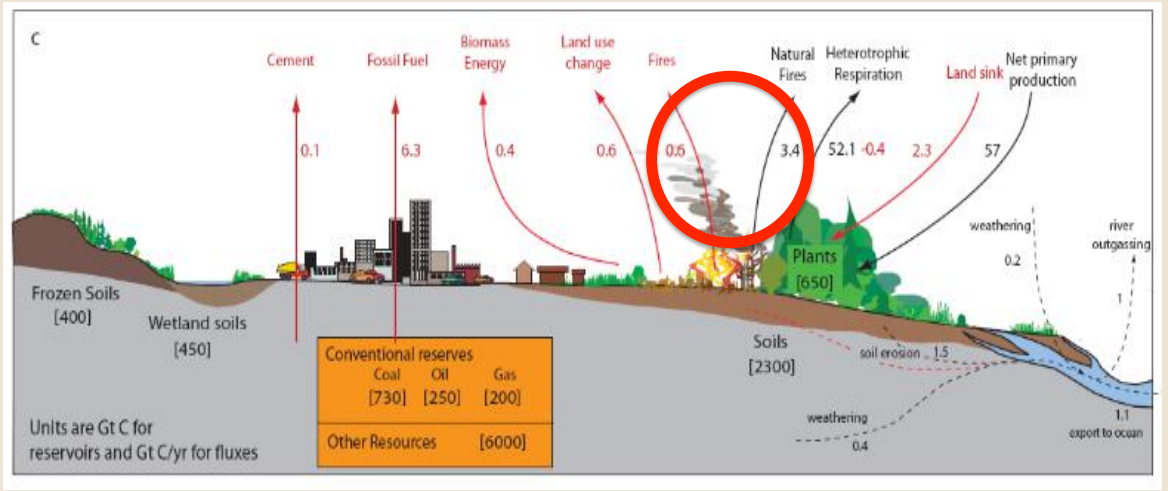
Photo : Loic Fossard

Florent MOUILLOT
IRD, UMR CEFE 5175, Montpellier France

www.ird.fr
florent.mouillot@ird.fr

Global burned Area : 300 – 450 Mha.year-1

Carbon emissions from fires: 3-4 GtC.year-1
=> 50% of Fossil Fuel emissions



How to estimate fire emissions to the atmosphere?

A simple equation…

Emissions = S . B . C

Burnt Area (m2) Biomass (gC.m-2) Combustion efficiency (%)

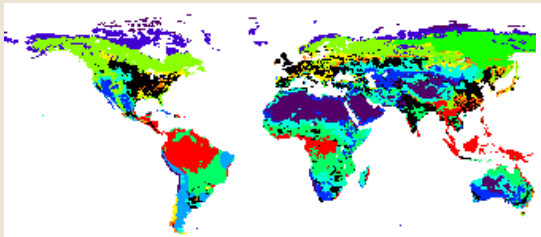
… with high uncertainties

Challenges for estimating the global burned area

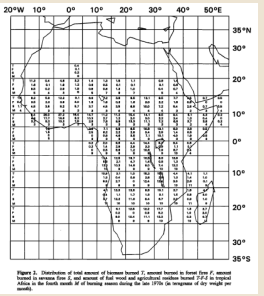
First approach: fire return interval in major biomes

Hao and Liu 1996
Seiler & Crutzen 1980

Fire return interval x



Global biome map



FAO, 2000. the global fire assessment Report:
compilation of national fire statistics

Challenges for estimating burned areas:

From 2000: the Emergence of global burned area products from remote sensing

Eva and Lambin 1998
Barbosa et al. 1999: continental scale approaches
Dwyer et al. 2000: global estimate from remote sensing

Limits:
=> Continental scale

=>1 year of data

2000-present: global Burned area products
Mouillot et al. 2014

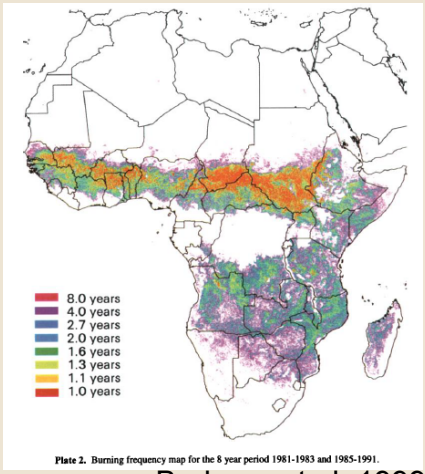


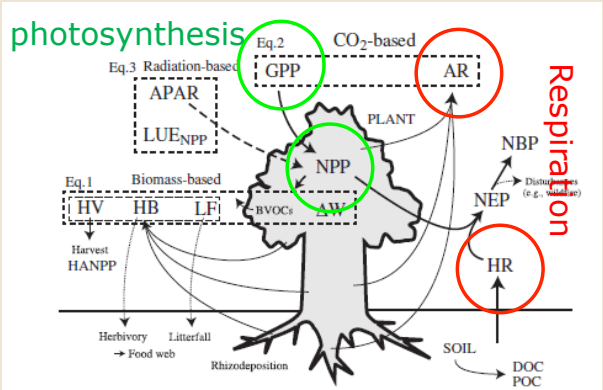
Plate 2. Burning frequency map for the 8 year period 1981-1983 and 1985-1991.

Barbosa et al. 1999

Challenges for Biomass estimates

Biogeochemical models or Dynamic Global Vegetation Models (DGVM)

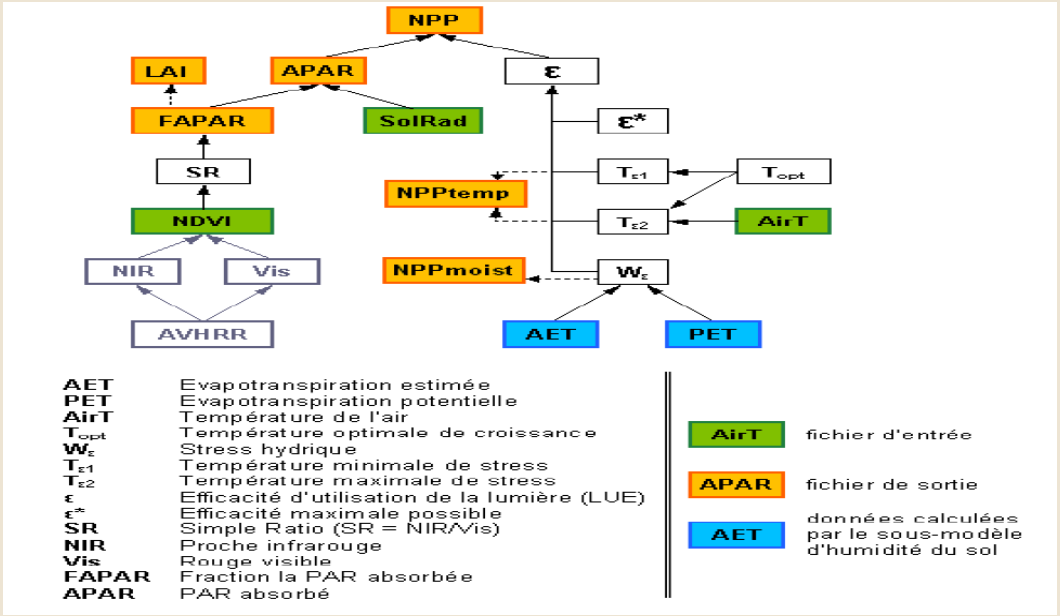
Major carbon fluxes in ecosystems



A biogeoechemical model used for global fire emissions (GFED)

CASA (Potter al. 1993, Field et al. 1995)

Main assumption:
C assimilation is driven by climate and Leaf Area Index from remote sensing



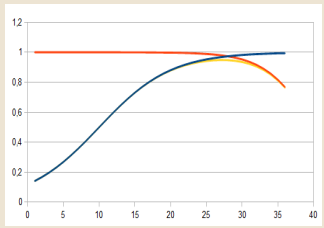
$$NPP(x,t) = IPAR(x,t) * \varepsilon(x,t)$$

$$IPAR(x,t) = FPAR(x,t) * solrad(x,t) * solarconversion$$

$$\varepsilon(x,t) = E_{\max} * NPP_{temp} * NPP_{moist}(x,t)$$

Light use efficiency: gC.MJ^{-1}

$$NPP_{temp} = T_{\varepsilon 1} * (1.1919 * T_{\varepsilon 2low} * T_{\varepsilon 2high})$$



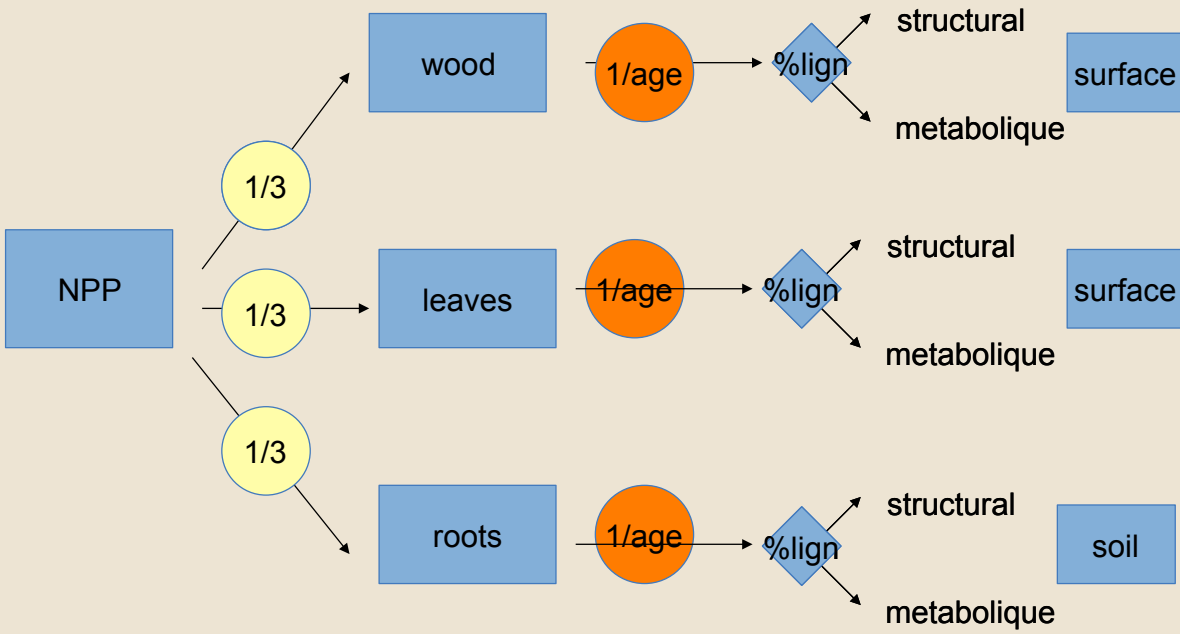
$$T_{\varepsilon 1} = 0.8 + (0.02 * T_{opt}) - (0.0005 * (T_{opt}^{\ 2}))$$

$$T_{2low} = \frac{1}{(1 + \exp(0.2 * (T_{opt} - 10 - T_{air}(x,t)))}$$

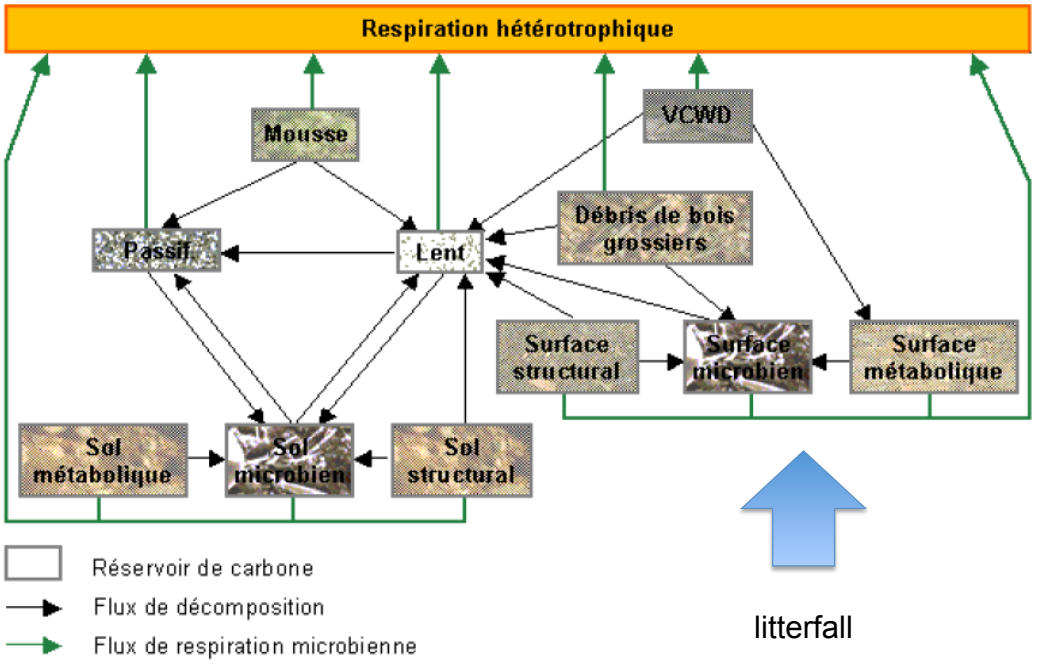
$$T_{2high} = \frac{1}{(1 + \exp(0.3 * (T_{air}(x,t) - 20 - T_{opt})))}$$

$$NPP_{moist}(x,t) = 0.2 + (0.8 * \frac{EET(x,t)}{PET(x,t)})$$

Carbon allocation to leaving biomass



Soil decomposition pools and heterotrophic respiration
CENTURY Model *Parton et al. 1992*



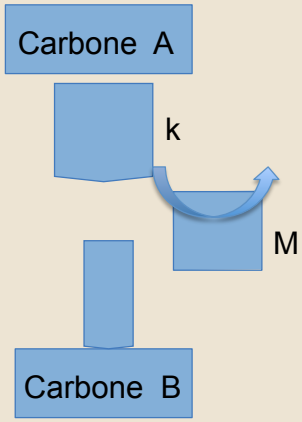
Climate control on soil respiration

C Stock

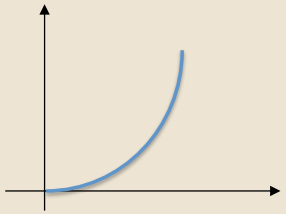
micro-organisme efficiency

$$R_h = \sum_{1}^{i} C_i * k_i * T_{Rh} * W_{Rh} * M_{ei}$$

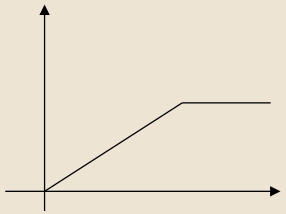
Constant
Decomposition rate



$$T_{Rh} = Q_{10}^{(tair-30)/10}$$



Wrh= RWC/PET



Main Challenges for modelling C emissions to atmosphere

1. **Present C emissions:**

   How accurate/reliable are global Burned area products

2. **Past C emissions:**

   Can we go further (backward) than the remote sensing era?

3. **Future C emissions:**

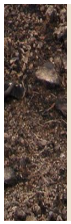
   Can we go beyond deterministic C emissions and identify processes to project future fire regimes?

Part 1: Present Global Burned Area

Since 2000, the emergence of remotely sensed global BA products

Table 1
Overview of global burned area dataset from spaceborne remote sensing.

Name of dataset	Time span	Satellite	Spatial resolution	Temporal resolution	Status	Development purpose	Source
GFED3	1996.07–present	MODIS 500 m, TRIM/VIRS, ATSR	0.5 d × 0.5 d	Monthly	Operational	Atmospheric and bio-geochemical models	Giglio et al. (2010)
MCD45A1	2000–2009	MODIS 500 m	500 m	Monthly	Operational	General purpose	Roy et al. (2008)
L3JRC	2000–2007	SPOT VEGETATION	1 km	Daily	Finished	General purpose	Tansey et al. (2008a,b)
Globcarbon	1998.04–2007.12	SPOT VEGETATION, ATSR-2, AATSR	1 km, 0.25 or 0.5 degree	Monthly	Finished	Targeted for global carbon cycling and climate modelling use	Plummer et al. (2006)
GBS	1982–1999	NOAA-AVHRR GAC 8 km data	8 km	Weekly	Finished	Globally consistent records of global fire activity.	Carmona-Moreno et al. (2005)
GLOBSCAR	>2000	ERS2-ATSR2	1 km	Monthly	Finished	Producing global incremental monthly maps of burned areas	Simon et al. (2004)
GBA2000	2000	SPOT VEGETATION	1 km	Monthly	Finished		Tansey et al. (2004)

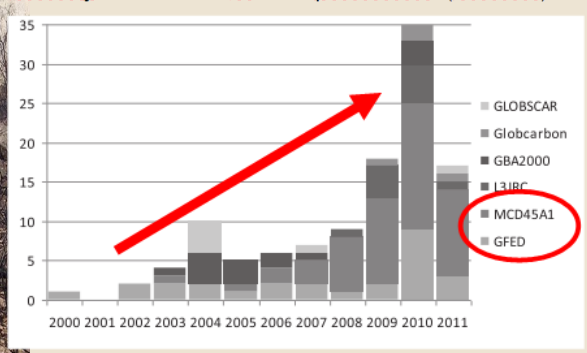


Mouillot et al. 2014, *Int. J. Earth Obs. and Geoinf*

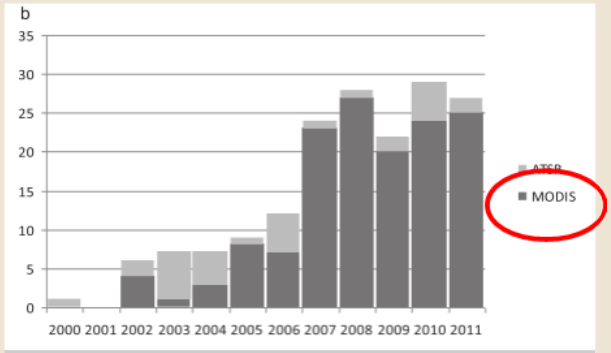
GFED 4 Giglio et al. 2013
ESA fire Cci: 2006-2008, MERIS, 1km / 0.5°, Daily, operational , Alonso et al. 2015
http://www.esa-fire-cci.org/

BA from MODIS sensor increasingly used as the reference dataset

Yearly citations of BA products (isiweb)



Yearly citations of fire activity (isiweb)



Mouillot et al. 2014

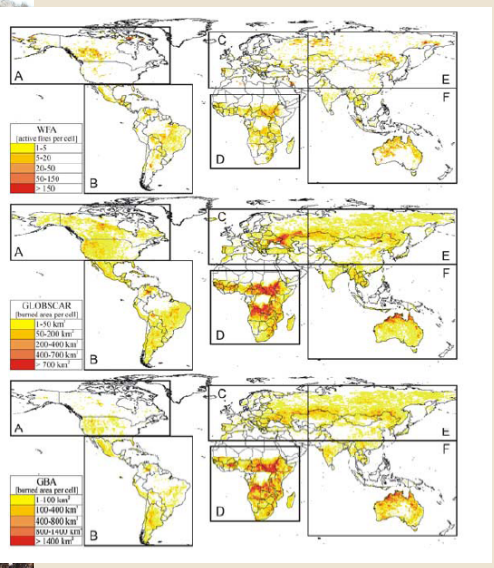
How reliable and consistant are burned are products?

From 211 .10^4 $km^2.yr^{-1}$ to 503 .10^4 $km^2.yr^{-1}$

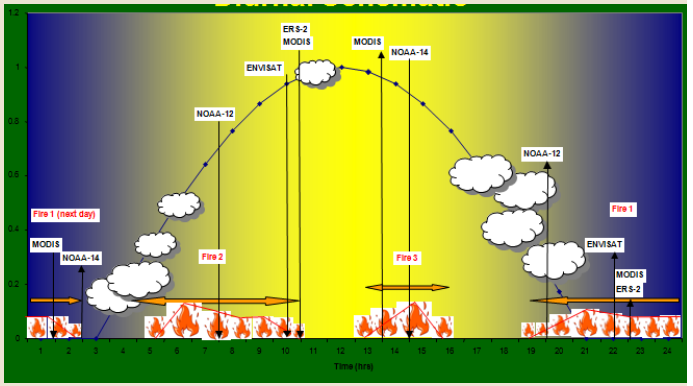
Table 3. Annual Global Burned Area Estimated by Different Studies

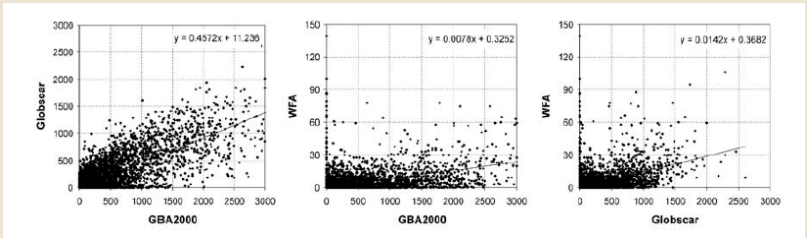
Source	Study Period	Annual Burned Area ($10^4 km^2 yr^{-1}$)	Study Approach
GFED4 [*Giglio et al.*, 2013]	1997–2011	348	multiple satellite observations
GFED3 [*Giglio et al.*, 2010]	1997–2010	363	multiple satellite observations
GFED2 [*van der Werf et al.*, 2006]	1997–2004	329	multiple satellite observations
MCD45A1 [*Roy et al.*, 2008]	2002–2010	338	satellite observation
L3JRC [*Tansey et al.*, 2008]	2000–2007	392	satellite observation
GBA2000 [*Tansey et al.*, 2004]	2000	350	satellite observation
GlobScar [*Simon et al.*, 2004]	2000	211	satellite observation
[*Randerson et al.*, 2012]	2001–2010	464	satellite observation
[*Kloster et al.*, 2010]	1997–2004	300	process-based fire model
[*Li et al.*, 2012]	1997–2004	330	process-based fire model
[*Schultz et al.*, 2008]	1960–2000	383	hybrid of official statistics and process-based fire model
[*Mouillot and Field*, 2005]	1900–2000	503	hybrid official statistics and satellite observation
This study	1901–2007	442	hybrid of process-based fire model and satellite observation

Yang et al. 2014



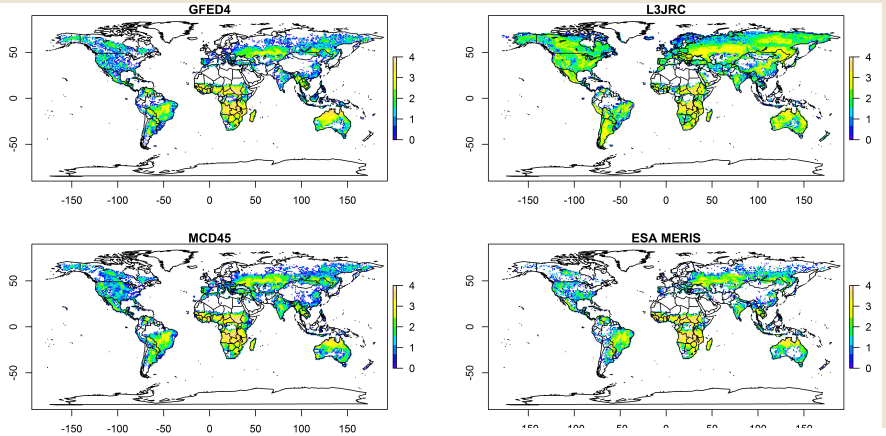
Pixel to pixel Inter-product discrepancies:
Due to Different timing



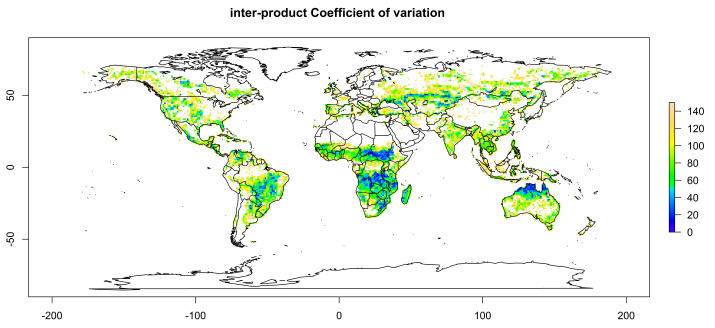


Boschetti et al. 2005

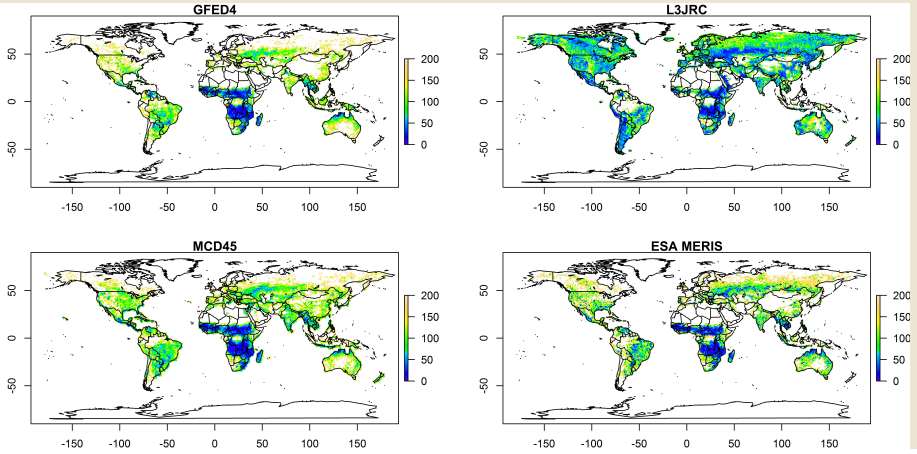
Global BA product intercomparison: burned area



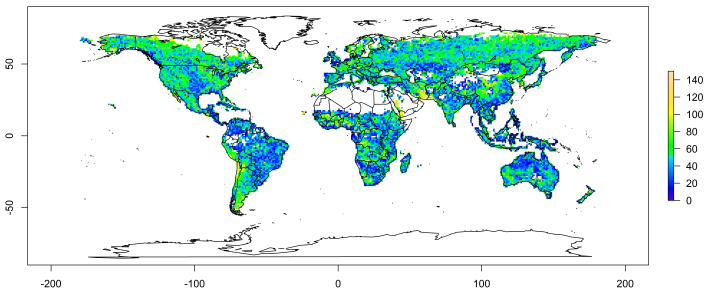
Hantson et al. Subm.
Fire MIP initiative



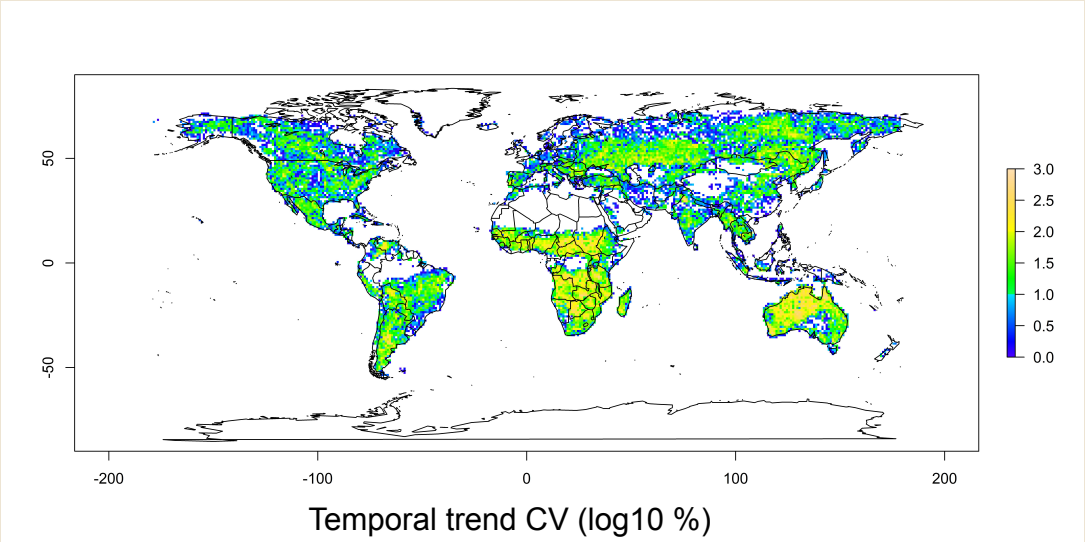
Global BA product intercomparison: interannual Coeff. Var.



Hantson et al. Subm.
Fire MIP initiative



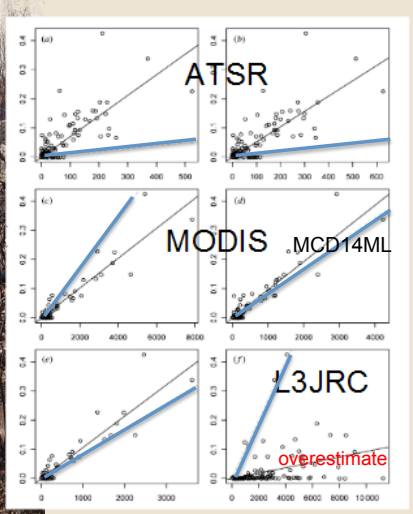
Global BA product intercomparison: temporal trend 2000-2007



Hantson et al. Subm.
Fire MIP initiative

How do global BA product compare with national statistics?

EUROPE



Loepfe et al. 2012

North America

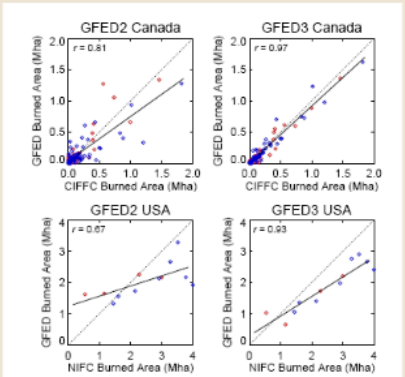
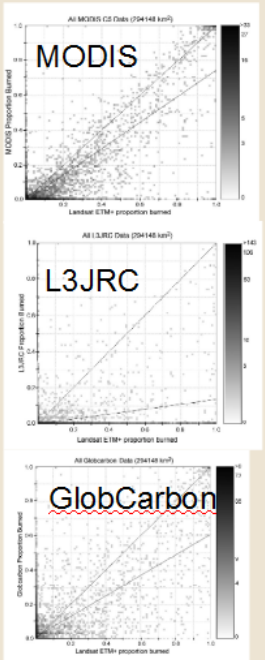


Fig. 15. 1997–2008 GFED2 (left column) and GFED3 (right column) annual burned area totals versus independent annual totals compiled by the Canadian Interagency Forest Fire Centre (http://www.ciffc.ca/) for nine Canadian provinces (top row) and the National Interagency Fire Center (http://www.nifc.gov/fire_info/fire_stats.htm) for the United States (bottom row). Totals from the pre-MODIS era are shown in red; totals from the MODIS era (2001 onward) are shown in blue.

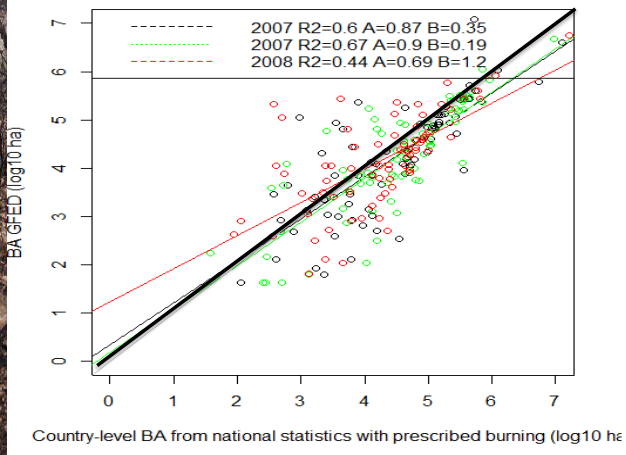
Giglio et al. 2010



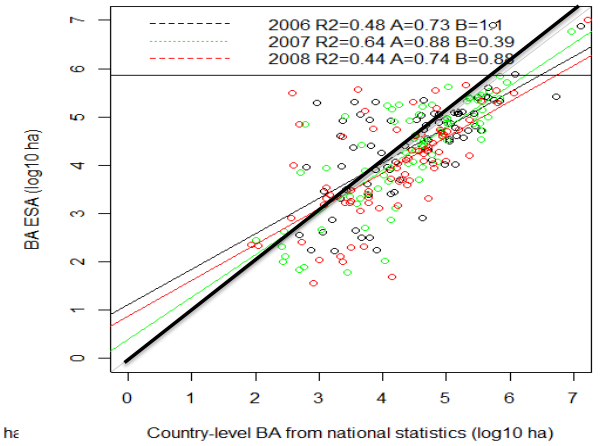
Roy & Boschetti 2009

A generic agreement for an underestimation of BA compared to national statistics

GFED4



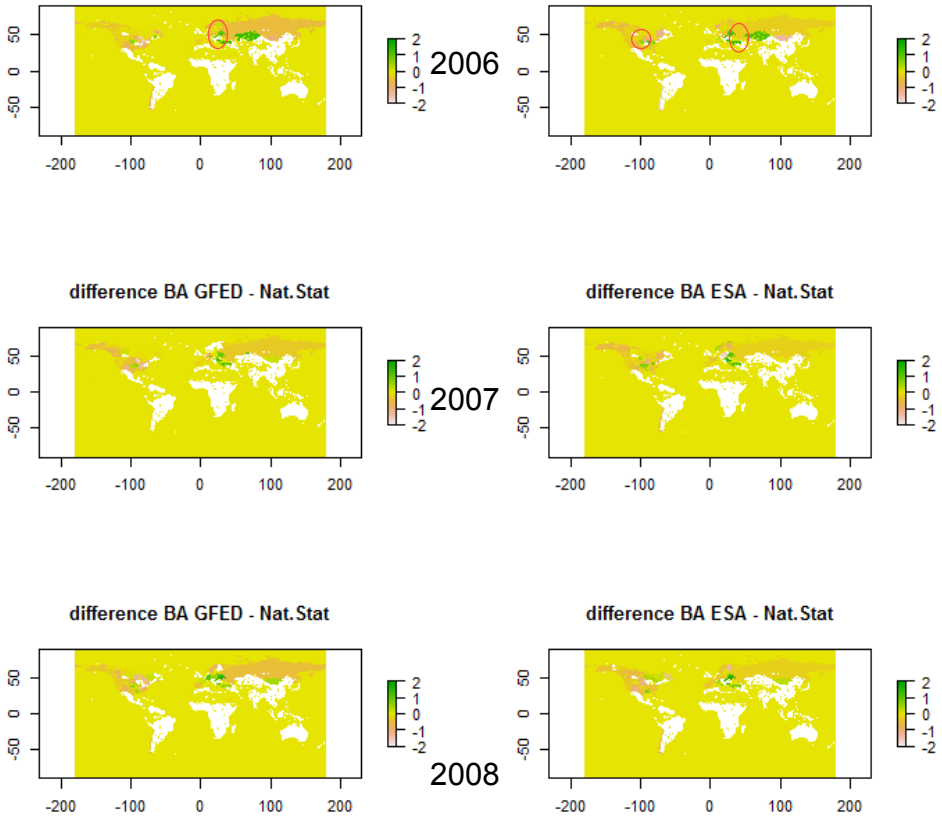
ESA Fire CCi



ESA fire Cci climate assessment Report

GFED

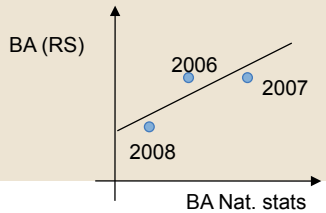
ESA

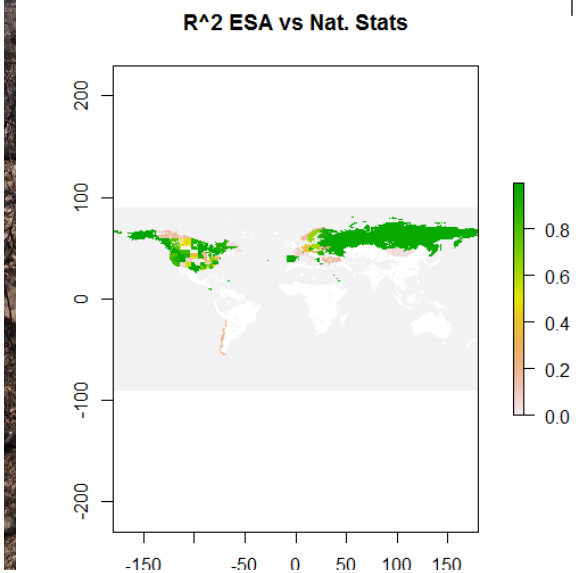


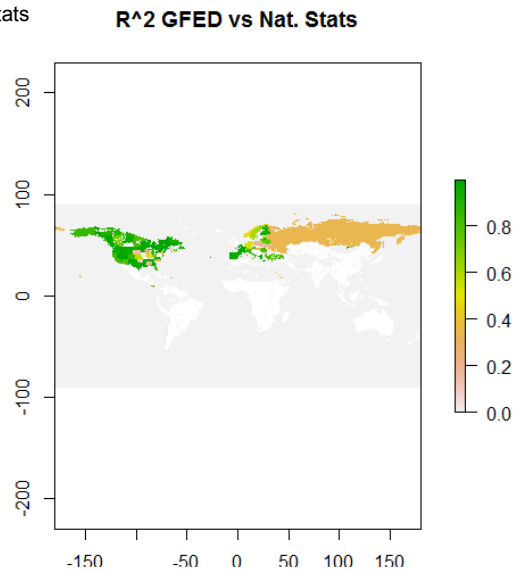
RS > Nat. Stat

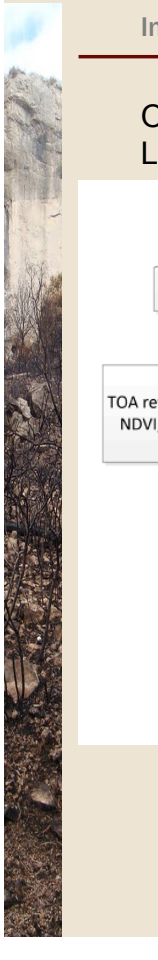
Nat Stat>RS

Temporel trend agreement between national statistics and GFED/ESA

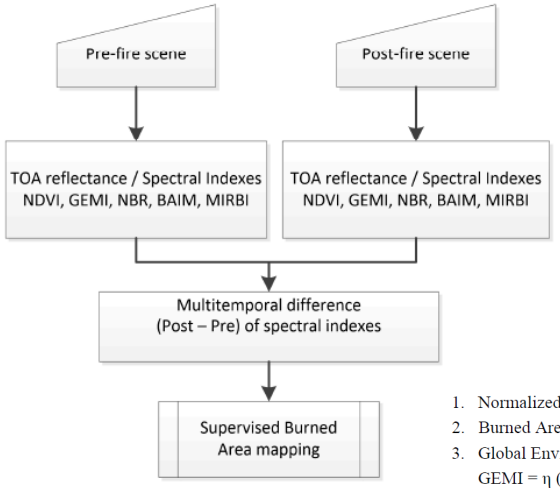








Other burned area assessment tools: local high resolution remote sensing data
Landsat 30 m, 15 days



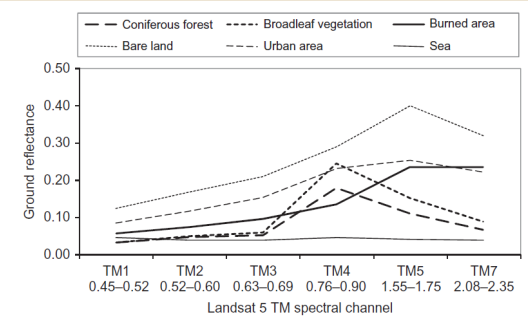
BAMS software
Bastarrika et al. 2014, Remote Sensing

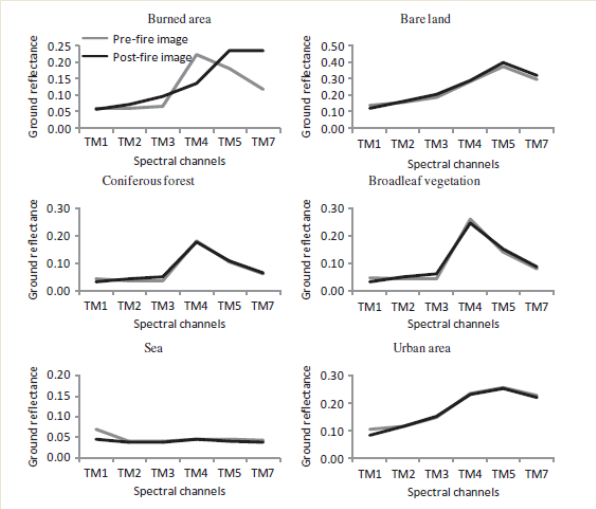
1. Normalized Difference Vegetation Index (NDVI) [34], $NDVI = (\rho_{NIR} - \rho_{RED})/(\rho_{NIR} + \rho_{RED})$
2. Burned Area Index Modified (BAIM) [35], $BAIM = 1/((\rho_{NIR} - 0.05)^2 + (\rho_{SWIRL} - 0.2)^2)$
3. Global Environmental Monitoring Index (GEMI) [36],
   $GEMI = \eta\,(1 - 0.25\,\eta) - (\rho_{RED} - 0.125)/(1 - \rho_{RED})$
4. Normalized Burned Ratio (NBR) [37], $NBR = (\rho_{NIR} - \rho_{SWIRL})/(\rho_{NIR} + \rho_{SWIRL})$ and
5. Mid-Infrared Burned Index (MIRBI) [38], $MIRBI = 10\,\rho_{SWIRL} - 9.8\,\rho_{SWIRS}$

where

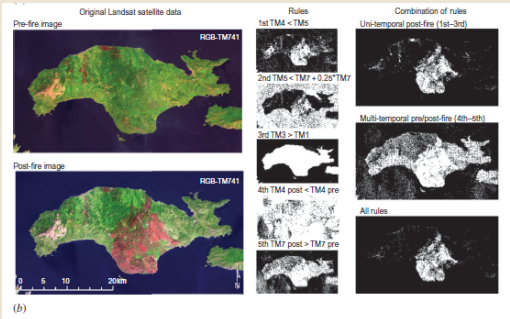
$\eta = (2\,(\rho_{NIR}^2 - \rho_{RED}^2) + 1.5\,\rho_{NIR} + 0.5\,\rho_{RED})/(\rho_{NIR} + \rho_{RED} + 0.5)$
ρ_{RED} = Red reflectance
ρ_{NIR} = Near Read Infrared reflectance
ρ_{SWIRS} = Short Wave Infrared Short reflectance (approximately wavelength center in 1.6 μm)
ρ_{SWIRL} = Short Wave Infrared Long reflectance (approximately wavelength center in 2.2 μm)

Other burned area assessment tools: local high resolution remote sensing data
Landsat 30 m, 15 days

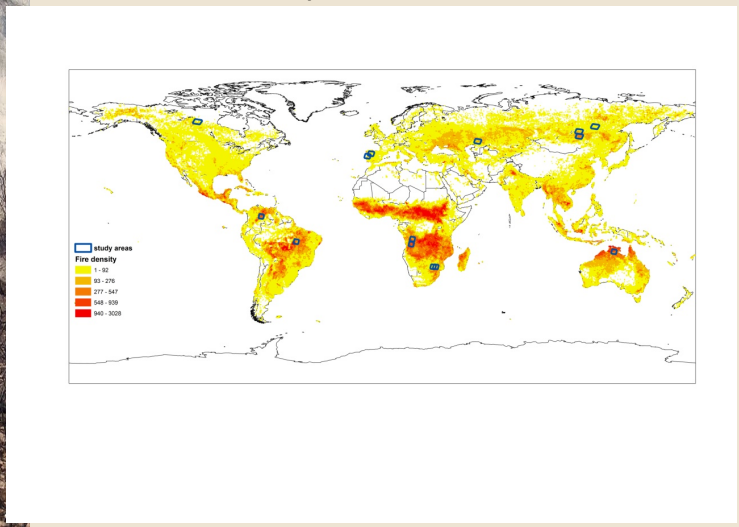


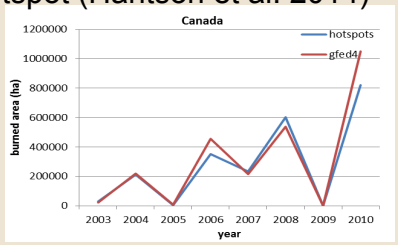


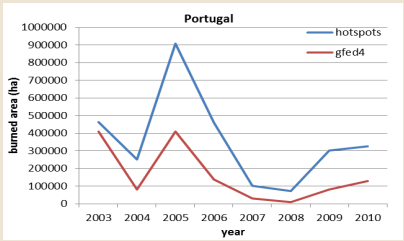
Koutsias et al. 2013

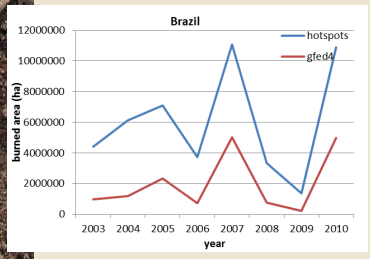


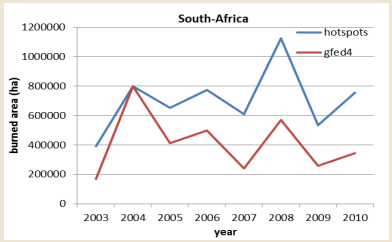
GFED comparison with landsat data/MODIS hotspot (Hantson et al. 2014)



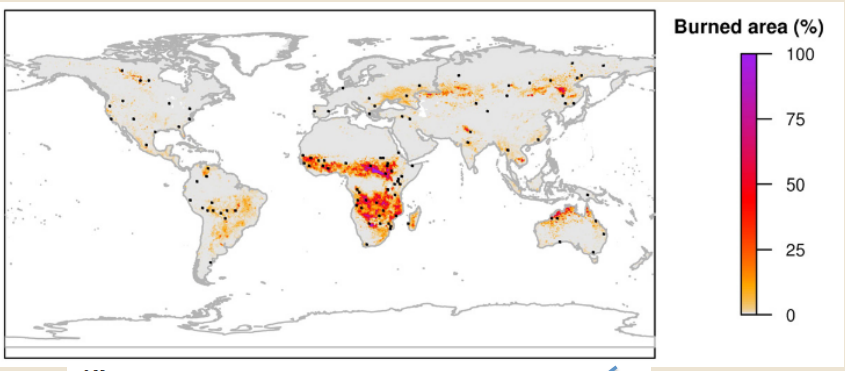








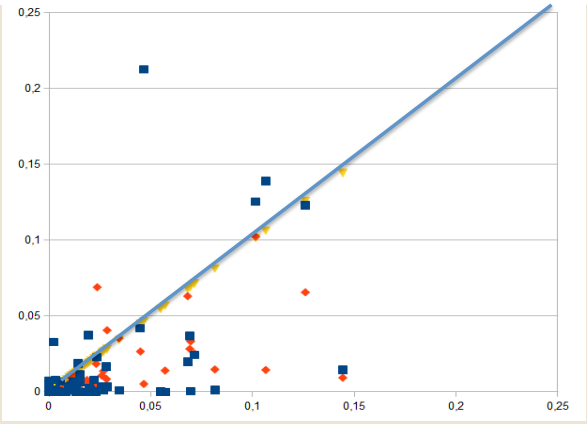
Global comparison (Landsat 151 test sites vs GFED, Padilla et al. 2015)



Global BA

MERIS

MCD45



Landsat BA

Part 2: Can we go further than the remote sensing era?

Why do we need to go further back in time for Burned area?

1. Identify long term processes

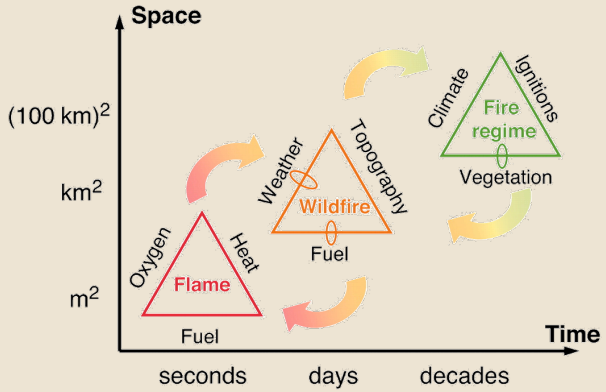
2. Improve climate models

3. Long feed backs on post fire carbon sequestration

Part 2: Can we go further than the remote sensing era?

Why do we need to go further back in time for Burned area?

1. **Identify long term processes**
2. Improve climate models
3. Long feed backs on post fire carbon sequestration



Moritz et al. 2005

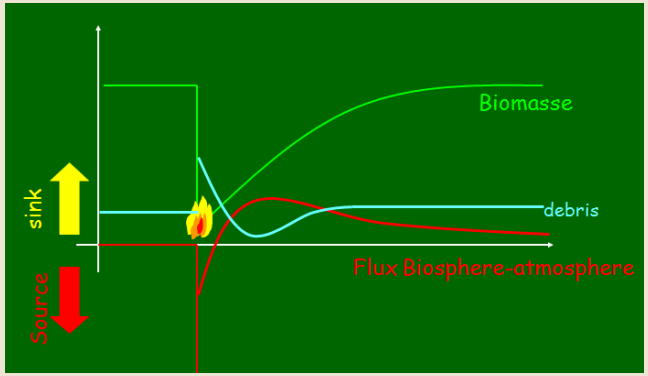
Part 2: Can we go further than the remote sensing era?

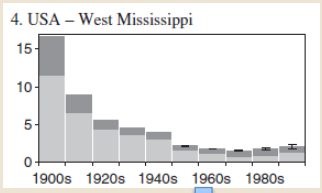
Why do we need to go further back in time for Burned area?

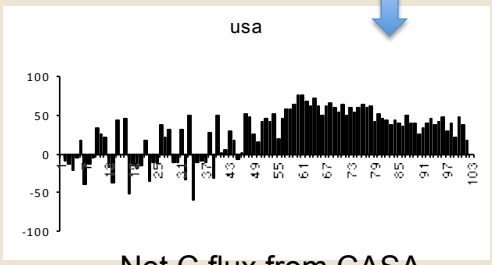
1. Identify long term processes

2. Improve climate models

3. Long feed backs on post fire carbon sequestration

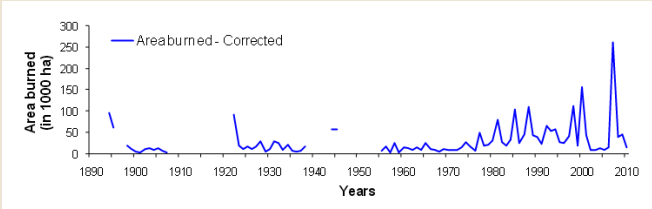






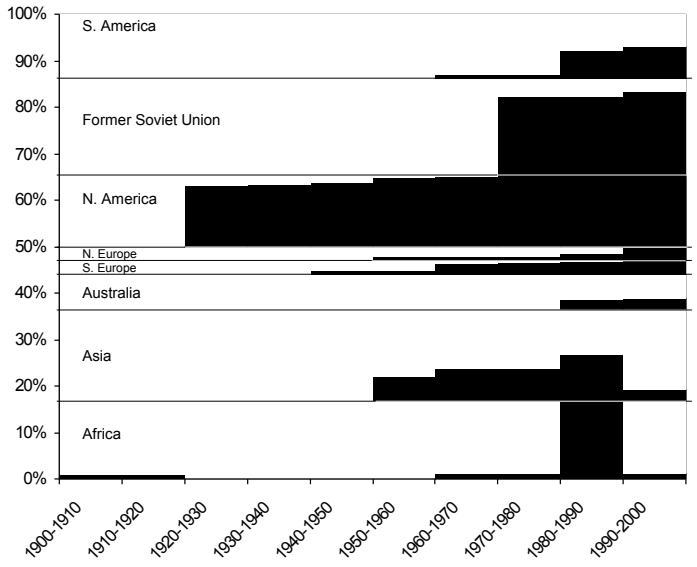
Net C flux from CASA

Major source of information: national fire statistics…with significant gaps



Greece: Koutsias et al. 2012

Synthesis of available data
For the 20th century
Used in *Mouillot & Field (2005)*



How reliable are national statistics?

Warning: Inter-country Discrepancies in the defition of a ‘fire’…

Wildfires:
Forest fires
What is a forest (FAO: >10% tree cover, other: >30%)

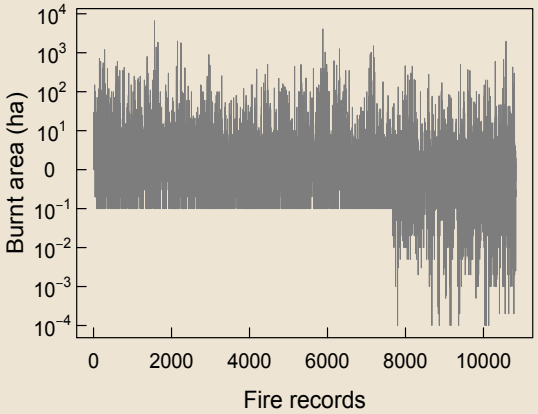
Other lands

Anthropogenic fires:
Prescribed burning
Agricultural fires
Deforestation fires

Fire types:
Crown fires
Surface fires
Smoldering combustion

How reliable are national statistics?

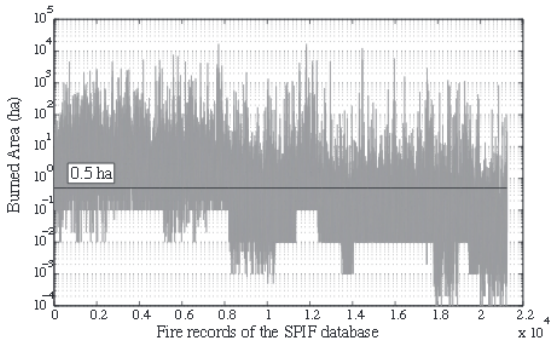
France



Ruffault and Mouillot, Ecosphere, in press

Changes in reporting fire size thresholds along time

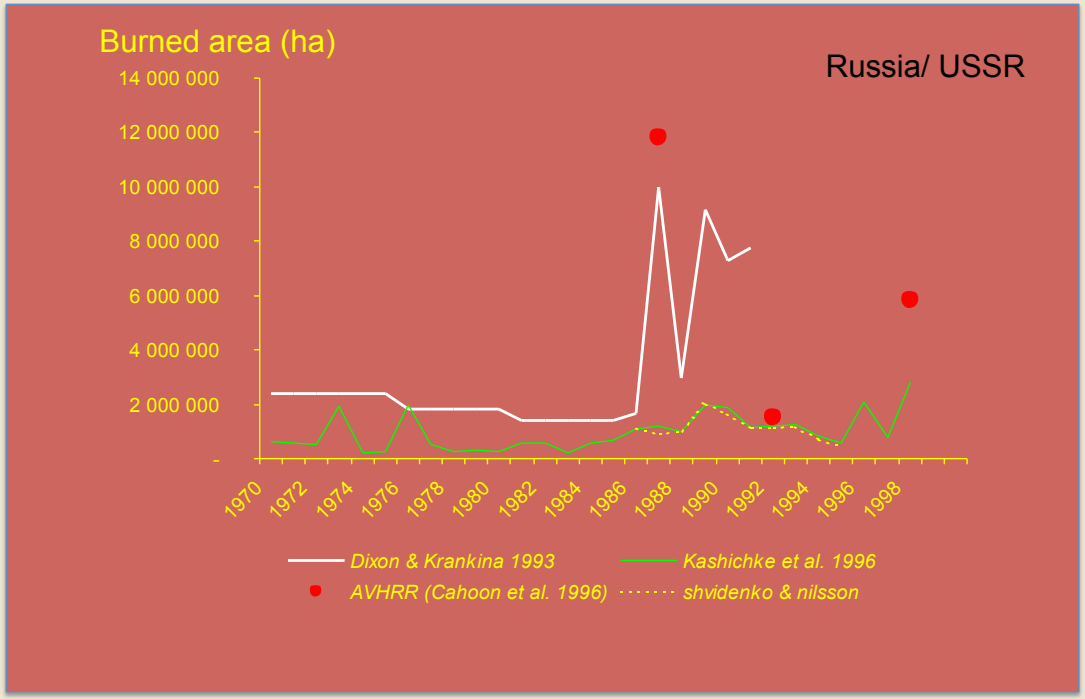
Spain



Turco et al. 2013

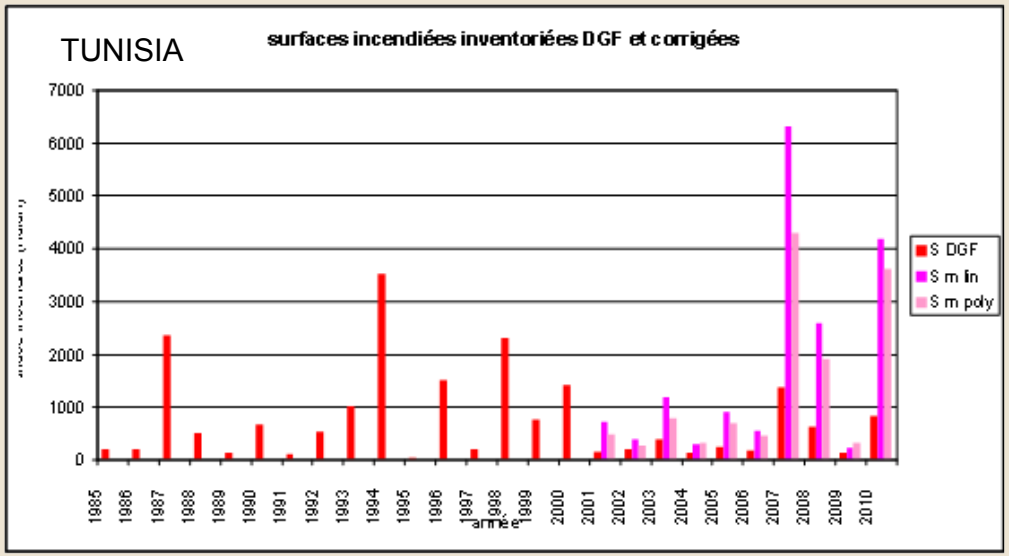
How reliable are national statistics?

Evident Misreporting : political or social issues



How reliable are national statistics?

Evident Misreporting : political or social issues



A ‘best guess’ global fire history map for the 20th century

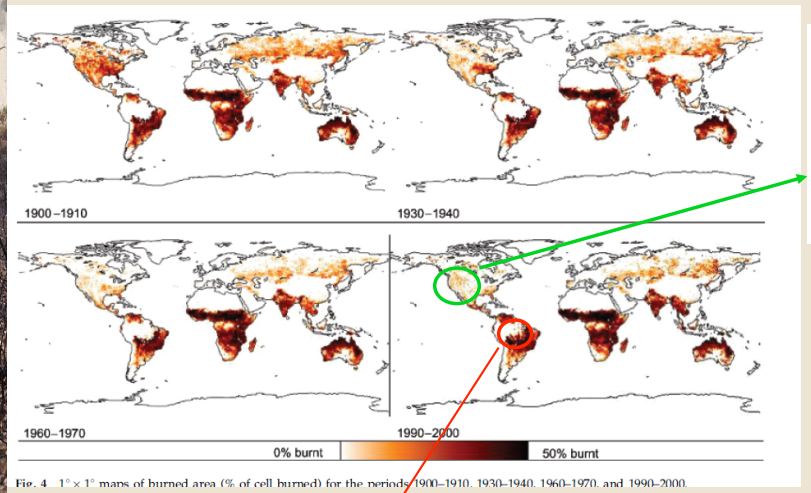
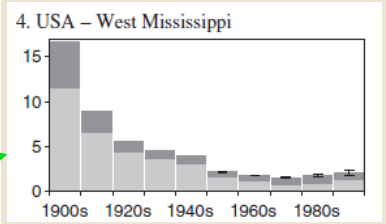
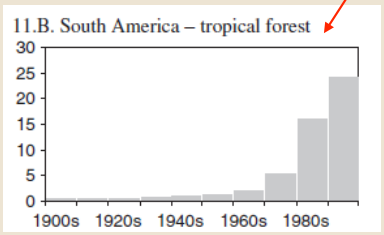
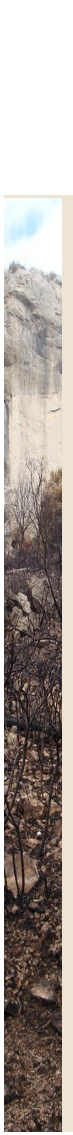


Fig. 4. 1° × 1° maps of burned area (% of cell burned) for the periods 1900–1910, 1930–1940, 1960–1970, and 1990–2000.

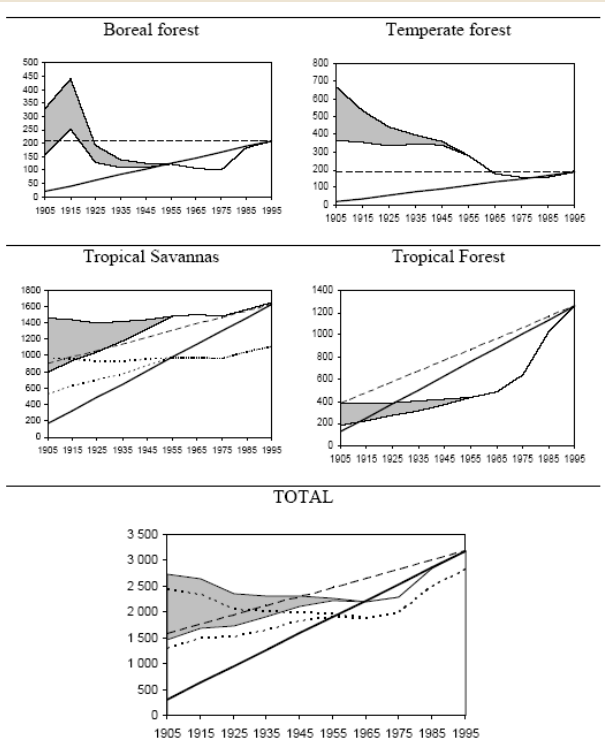




Mouillot & Field 2005, Glob. Change Biol.



Historical fire emissions along the 20th century
Hypothesis have changed since the 1990's…



[Crutzen and Zimmermann, 1991]

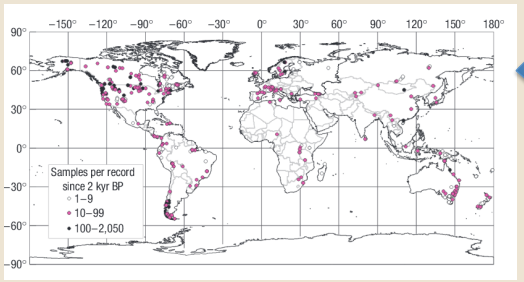
EDGAR-HYDE [Van Aardenne et al., 2001]

Mouillot et al. 2006

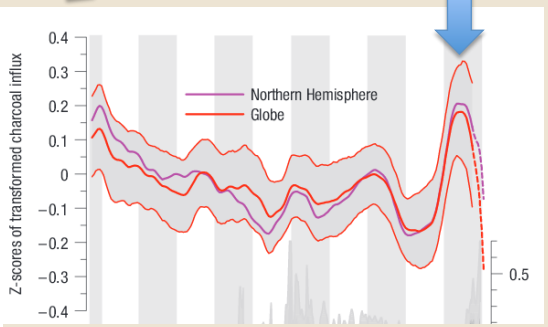
Soil Charcoal as a qualitative source of information:

A New hypothesis: a high fire peak at the end of the 19th century

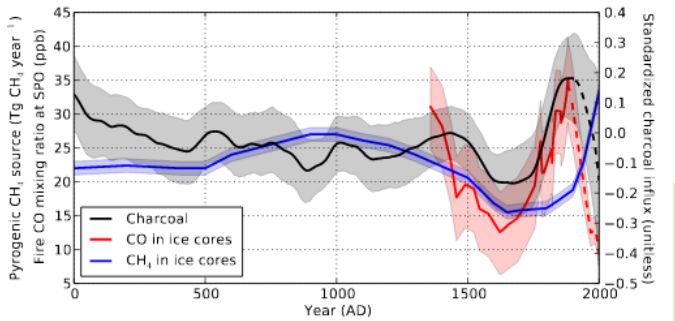
A global database



1850-1900

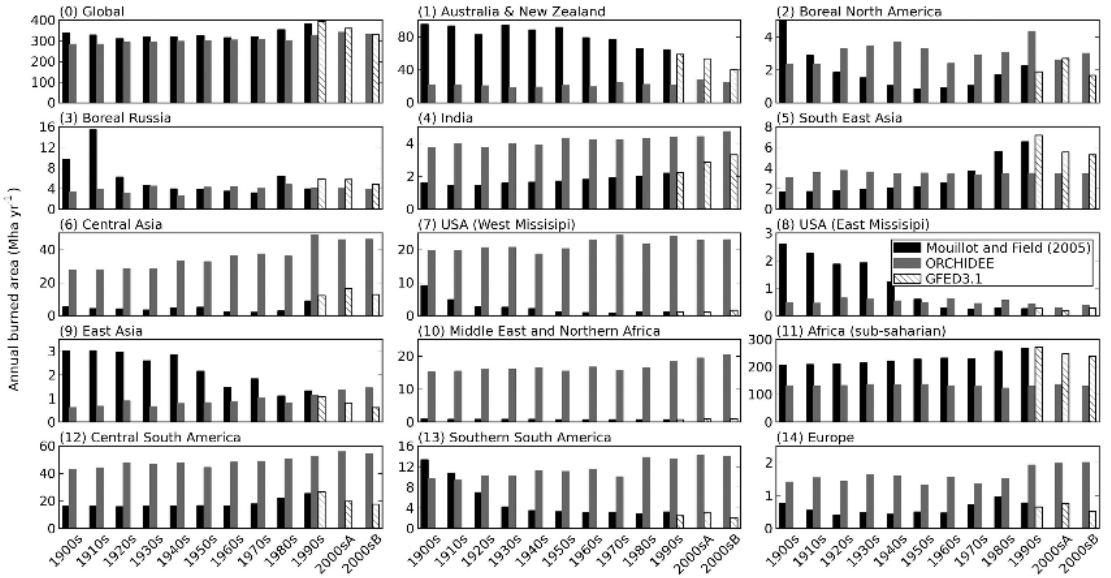


Marlon et al. 2008, nature geoscience

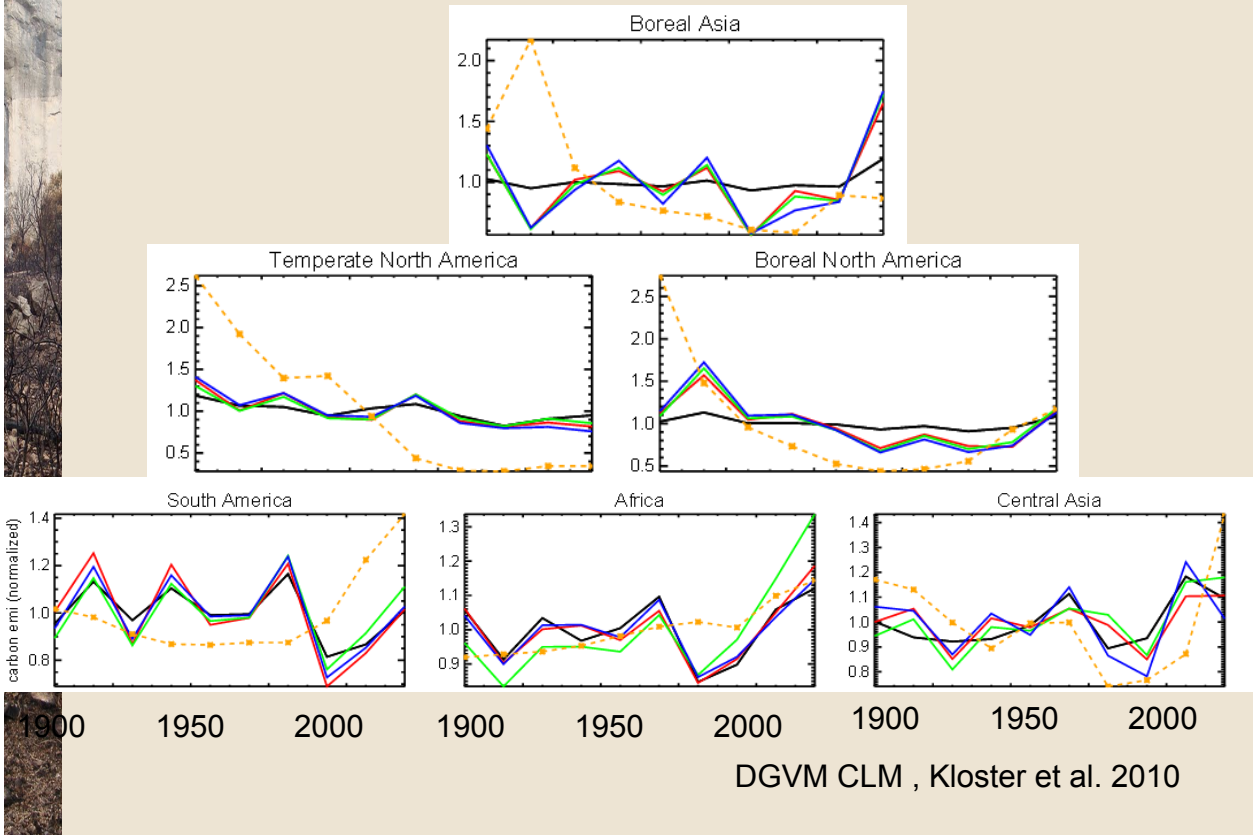


Van der Werf et al. 2013

Are we getting close to historical trends with fire models?.... Not that much



DGVM ORCHIDEE – SPITFIRE, *Yue et al. 2014*



DGVM CLM , Kloster et al. 2010

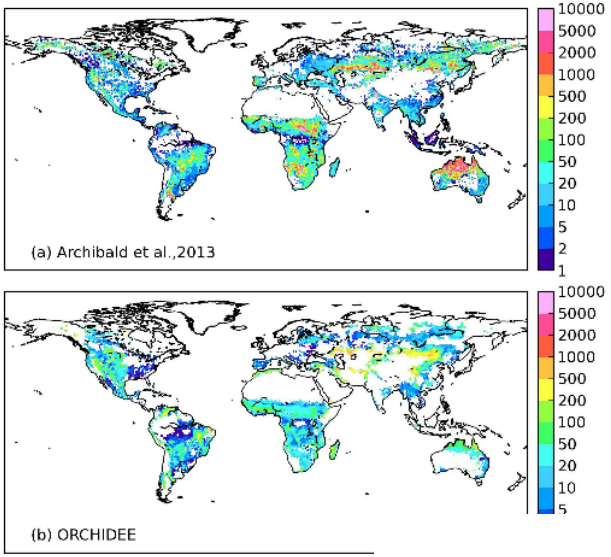
Part 3: Projecting future fire regimes

Future Modelling needs:

refining processes of fire spread and size distribution

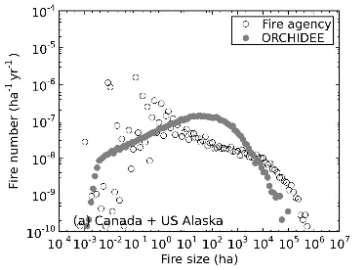
How to account for abrupt non climatic changes: *Pausas and Keeley 2014, ecosystems*

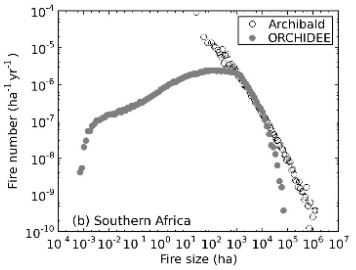
Invasive
Fauna
Policy



Beyond burned area:

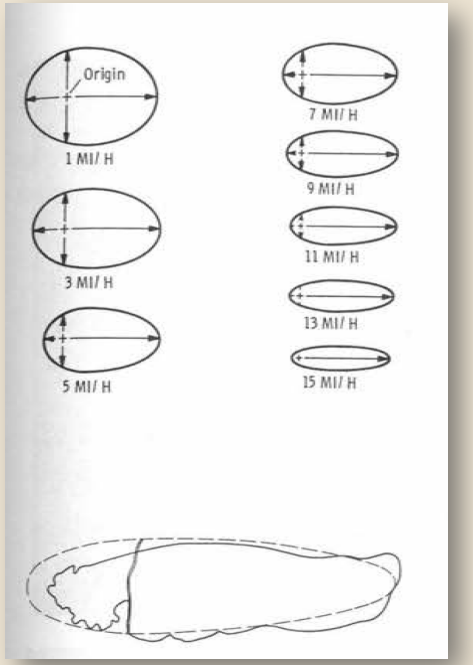
Fire patch size in DGVMs
ORCHIDEE SPITFIRE
Yue et al. (2014)





Toward fire patch morphology with mid resolution burned area

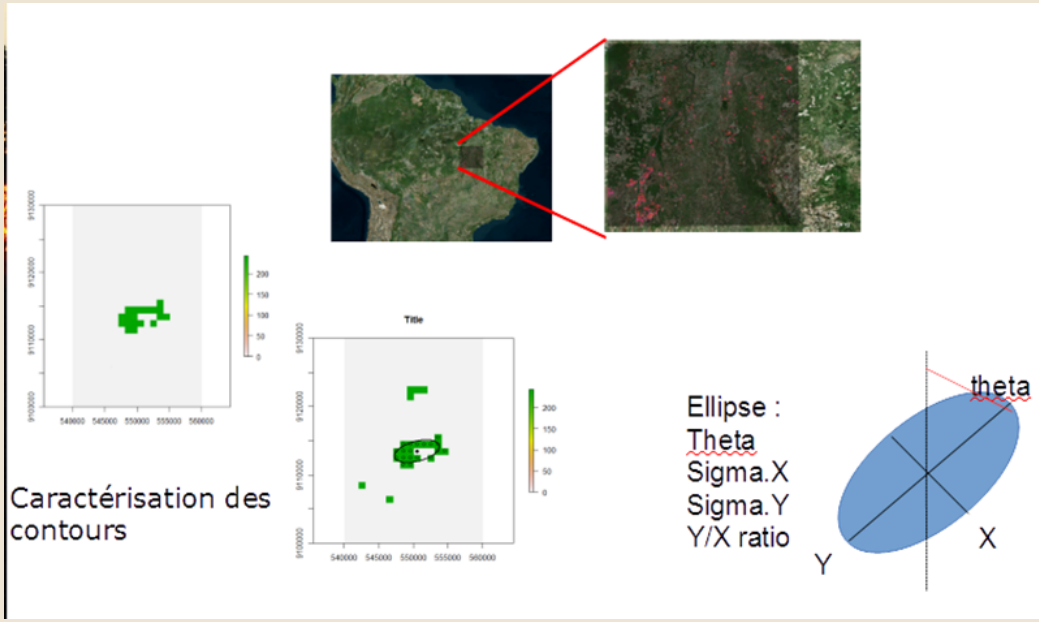
Pyne et al. 1996

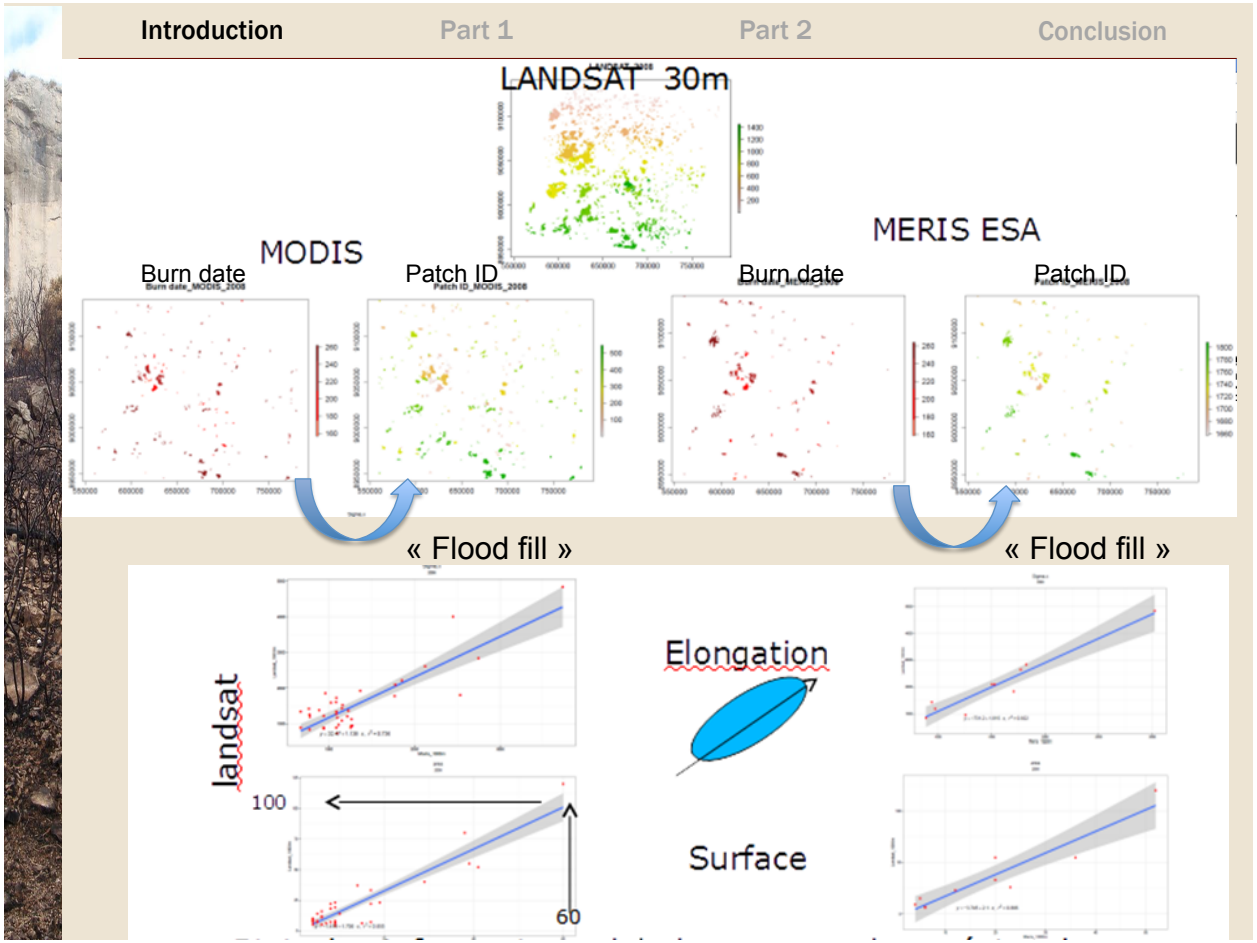


Fire elongation as a response to wind

Fire elongation simulated by DGVM fire module

Temptative fire patch analysis with ESA 1km fire data




LANDSAT 30m
MODIS
MERIS ESA
Burn date
Patch ID
Burn date
Patch ID
« Flood fill »
« Flood fill »
Elongation
landsat
100
60
Surface

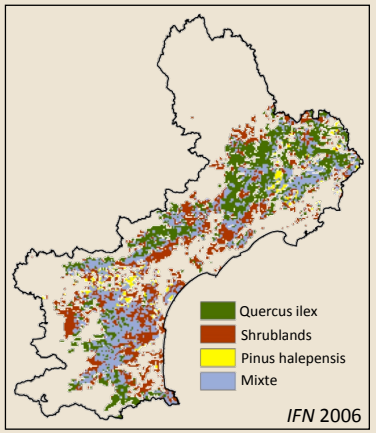
Human impact on fire regime…
Exemple in southern France:
How changes in fire policy can abruptly reshape the fire weather relationship

Ruffault & Mouillot, Ecosphere in Press

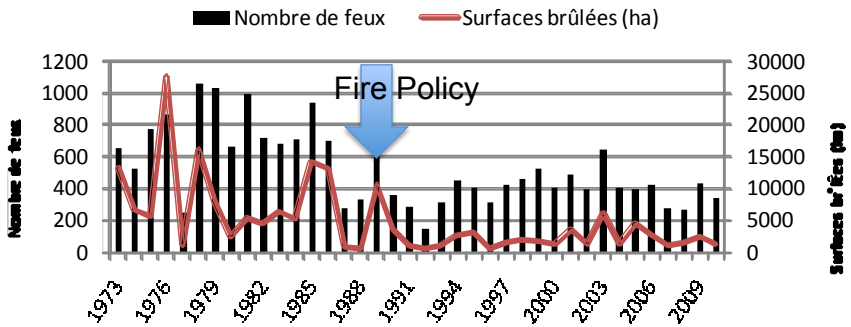
Study area : Languedoc-Roussillon (LR) region

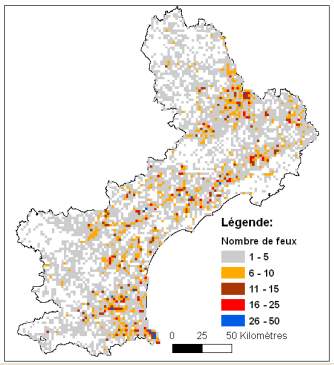
DEM of LR region

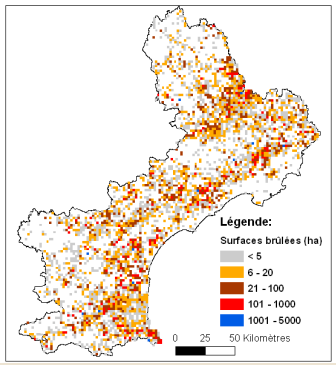
Mediterranean type ecosystems



Historical fire regime and regional distribution

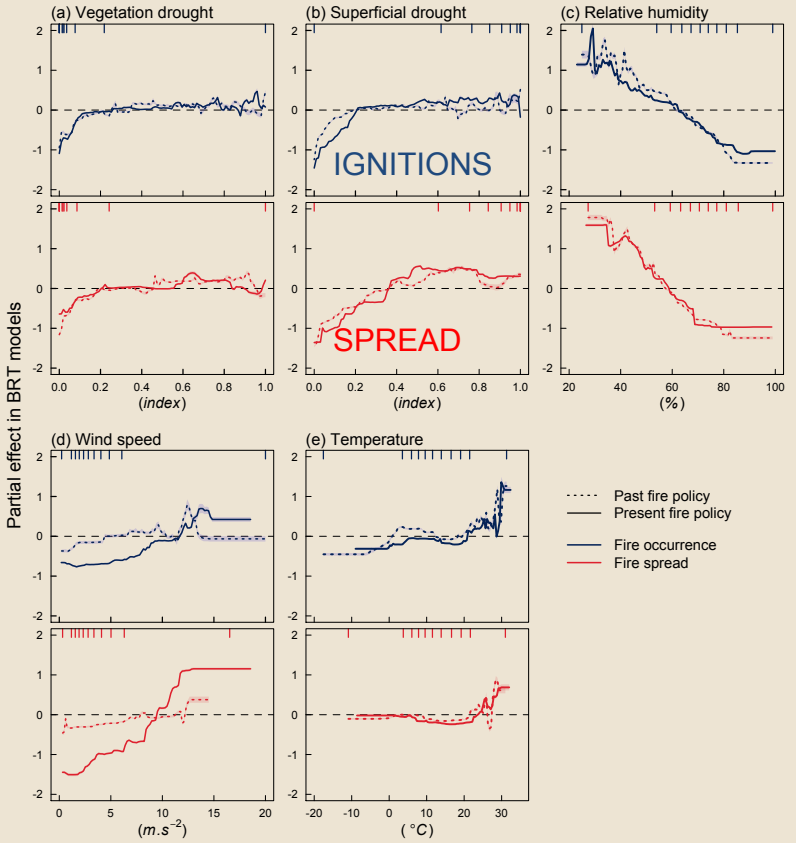




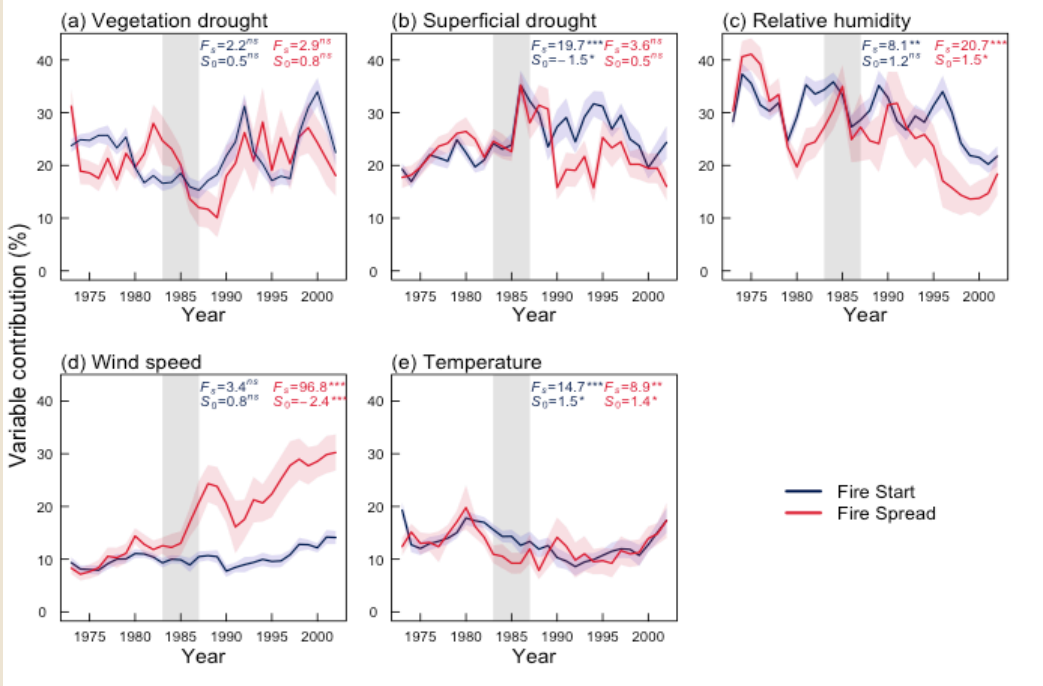


Statistical assessment
Of the fire weather

Boosted Reg. Trees

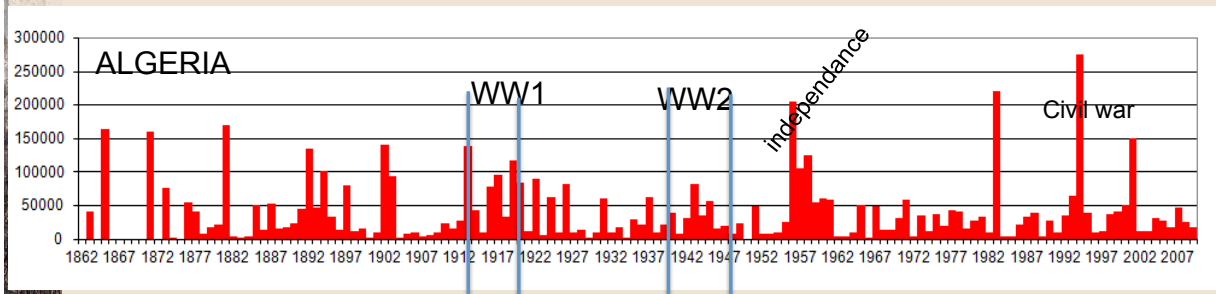


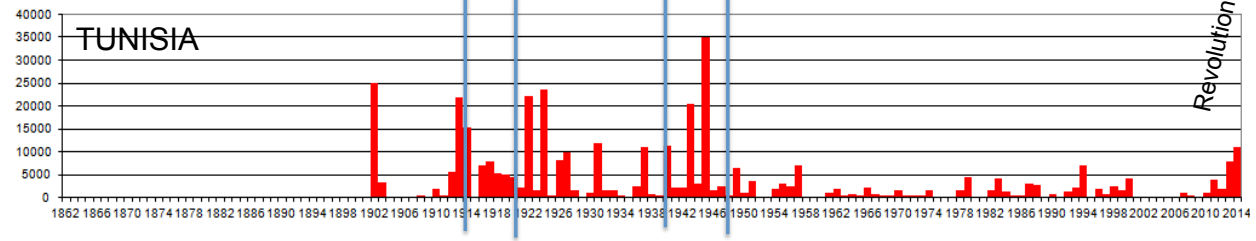
Temporal trend of variable contribution on a 5-year moving window
=> Detection of an abrupt change in 1987 for wind speed



Humans can reshape the fire weather by modifying fire policies…
=> Implication for future projections under socio economic changes

Human impacts: History matters…
Exemple in North Africa





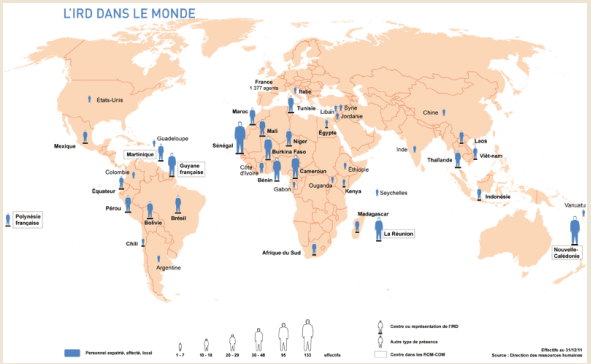
How to model ????

European Space Agency Climate Change Initiative

www.esa-fire-cci.org

Institut de Recherche pour le Développement

www.ird.fr



florent.mouillot@ird.fr