Module 2.6 Estimation of GHG emissions from biomass burning

Module developer:

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After the course the participants should be able to:

- Understand the strengths and limitation of satellite remote sensing of fire
- Describe a range of fire monitoring approaches and techniques
- Use available fire products to calculate emissions from biomass burning

V1, May 2015

WAGENINGEN UR For quality of life

GOFC-GOLD Global Observation of Forest and Land Cover Dynamics

FOREST CARBON PARTNERSHIP FACILITY

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Background material

- GOFC-GOLD. 2014. *Sourcebook*. Section 2.6.
- IPCC. 2006. *2006 IPCC Guidelines for National Greenhouse Gas Inventories*, vol. 4, ch. 2, "Generic Methodologies Applicable to Multiple Land-use Categories)," with particular regard to section 2.4.
- GFOI. 2014. *MGD* (*Integrating Remote-sensing and Ground-based Observations for Estimation of Emissions and Removals of Greenhouse Gases in Forests: Methods and Guidance from the Global Forest Observation Initiative*).
- GOFC-Fire Implementation Team Portal. http://gofc-fire.umd.edu/

Outline of lecture

1. Fire in the global environment
2. Biomass burning monitoring for REDD+
3. IPCC guidelines for estimating fire-related emissions (CO_2 and non-CO_2)
4. Fire monitoring from satellites:
   - Detection of active fires
   - Mapping of postfire burned areas
5. Available remote sensing fire products (Global burnt areas JRC, MODIS active fires and burned areas, FIRMS, etc.)
6. Calculating GHG emissions from biomass burning
7. Error sources
8. Other potential uses of fire data for REDD+ support

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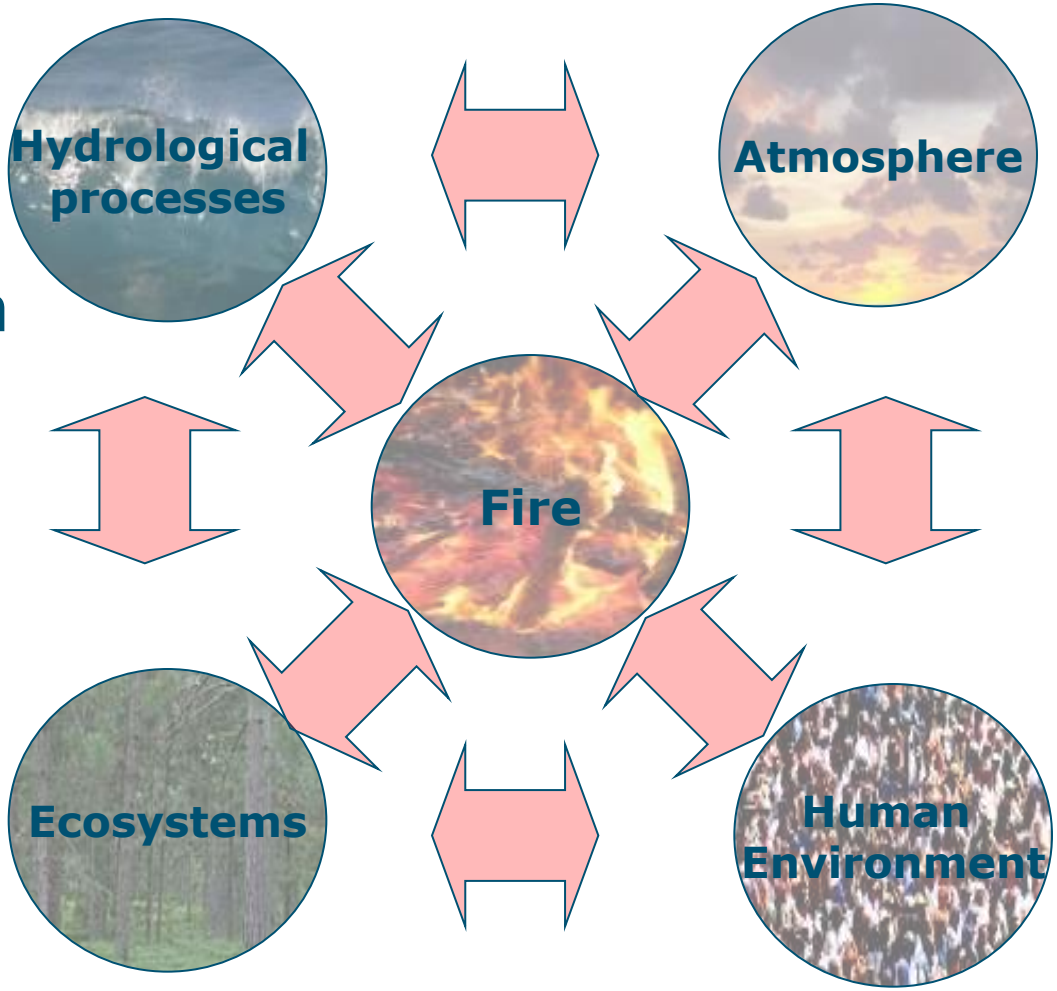
Why is fire important?

- Fire is:
- A global phenomenon (biomass burning)
- An important and poorly understood Earth system process
- A system of multiple loops and feedbacks



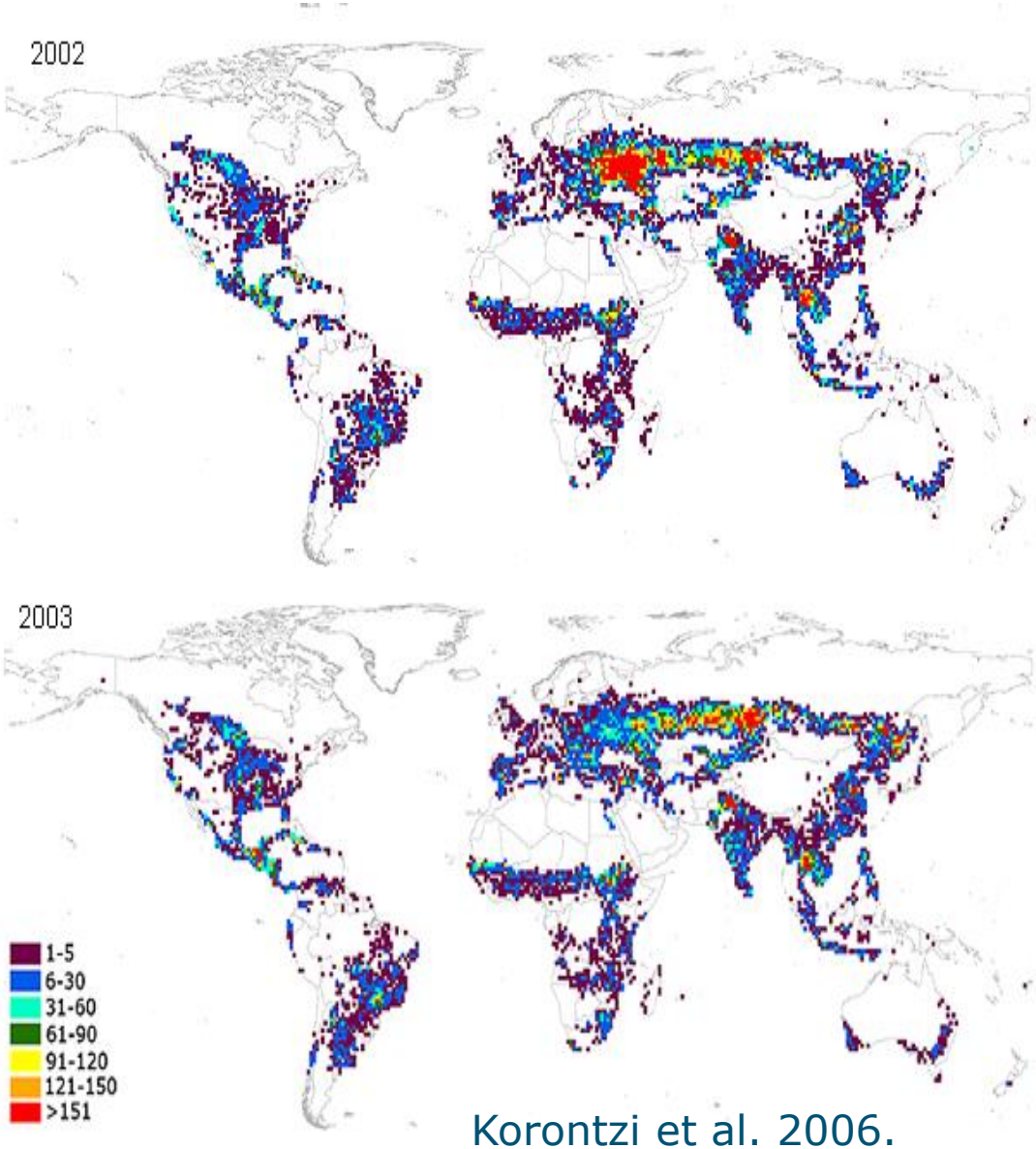
Different fires with different causes

- Natural fires
  - Lightning
  - Volcanoes
- Human-induced fires (>90%, increasing in the past 100 years)
  - Deforestation
  - Important land management tool in tropical and temperate ecosystems
  - Disposing of agricultural wastes
  - Pest control
  - Fuel wood for heating and cooking
  - Production and use of charcoal
  - Arson
  - Cultural ritual

Wildfires and prescribed fires

Agricultural fires

Annual burning of crop Residues a common practice globally

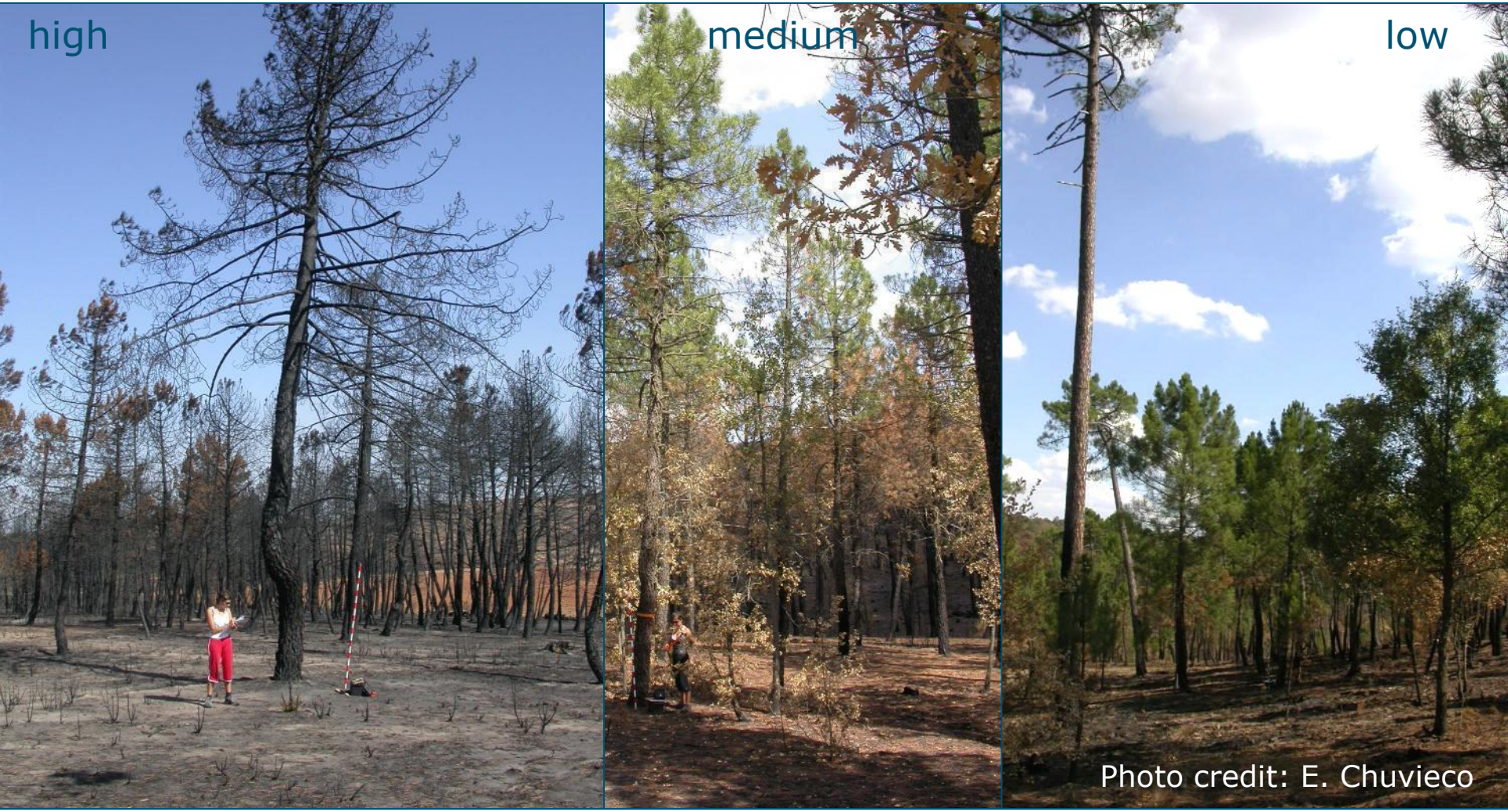


Korontzi et al. 2006.

Impacts of fire:
Wildlife and habitat biodiversity

- Fires have direct mortality on animals.
- Fires may promote and maintain biodiversity.
- Changing fire regimes may pose a threat to biodiversity conservation.
- In several ecosystems, wildfires and invasive species are closely linked.

Impacts of fire: Forest loss and degradation

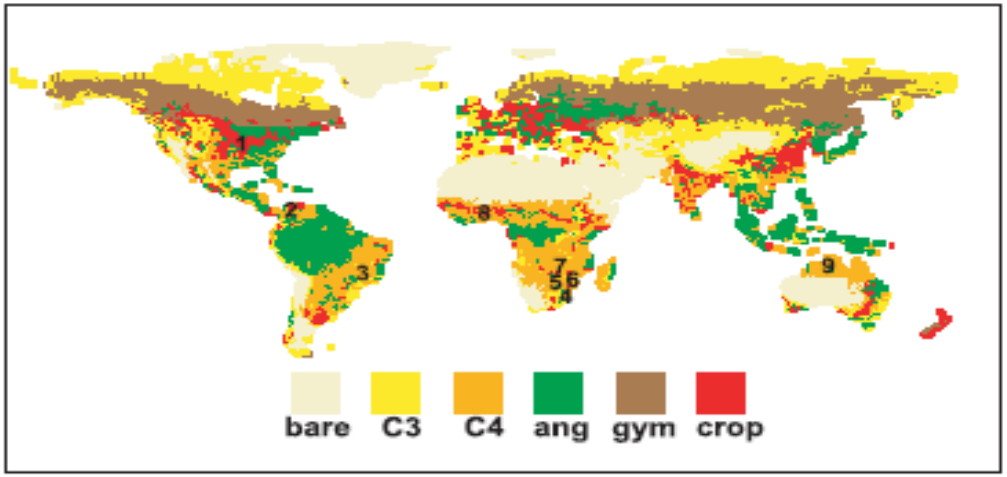


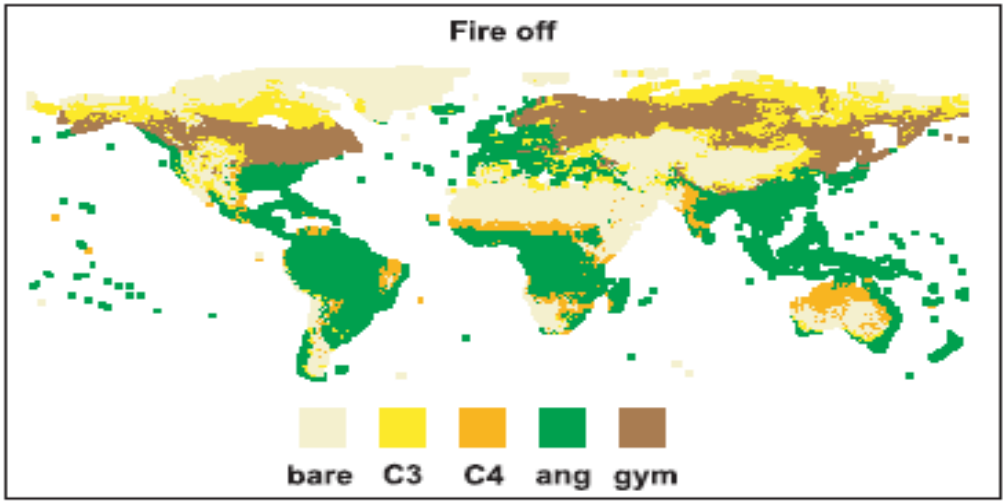
Variations of burn severity

Impacts of Fire: Soils

- Water runoff and soil erosion
- Loss of soil organic carbon
- Need for rapid post fire assessment and treatment

The global distribution of ecosystems in a world without fire

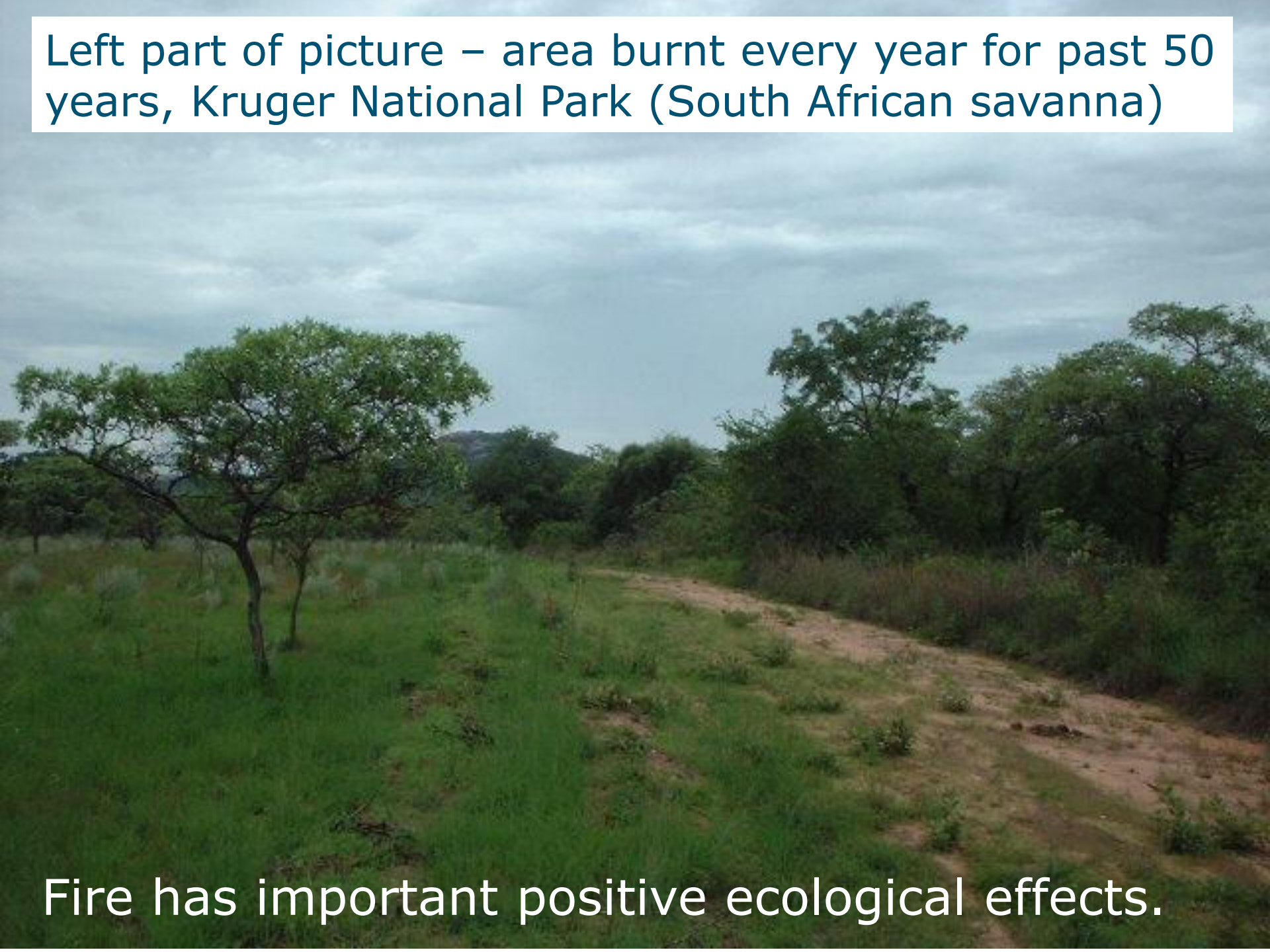




Source: W. J. Bond, *et al*. 2005

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.

Left part of picture – area burnt every year for past 50 years, Kruger National Park (South African savanna)



Fire has important positive ecological effects.

A few global numbers: Why fire matters for REDD+ MRV

- Average global burned area: 3.7 million Km^2 / year (Giglio et al. 2010)
- Fire emissions: not only CO_2, but also significant amounts of trace gases with high greenhouse potential (CO, CH_S, N_2O, NOx), particulate and aerosols
- Average emissions: 2.1 Pg C / year (van der Werf et al. 2010)
- Fires from most biomes contribute to the global fire emissions: savannas (44%), tropical deforestation and degradation (20%), woodland (16%), forest fires (15%), agricultural waste (3%), peatlands (3%) (van der Werf et al. 2010)

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Approaches to monitor fire for REDD+

Approach	Information	REDD+ objective	Suitability
Pre-fire	Early warning system	Protect forest areas at risk and address leakage and permanence	Most suitable for countries with significant amount of wildland fires and known fire regimes
Active fire	Hot spot satellite data	Fire relief and active emissions reduction Support of in-situ actions	Most suitable for countries with large number of small-scale deforestation fires
Post-fire	Burned area estimates	Support estimation of areas of deforestation and degradation	All countries with forest loss due to fire

Fire: A complex biophysical process

- Fire can be seen as:
  - Ecological change agent
  - A disturbance
  - Process associated with land-cover conversion
  - A management tool

- For now, the *Sourcebook* (GOFC-GOLD 2014) covers only emissions from aboveground biomass. More research is needed for monitoring emissions from belowground biomass using standard products and approaches.

REDD+ potential activities related to AFOLU sector and fire monitoring

REDD+ potential activities	**=**	**Forest sector (AFOLU / IPCC)**
Deforestation	=	Forest land converted to other land
Degradation		
SMF	=	Forest land remaining forest land
Conservation		
Enhancement F C S		
Enhancement F C S	=	Other land converted to forest land

REDD+ activities where fire monitoring can be relevant

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IPCC emissions estimation

Bottom up IPCC approach:

$$Lfire = A \times Mb \times Cf \times Gef$$

L = emission for each gas

A = area burned

Mb = fuel load

Cf = combustion factor

Gef = amount of gas released per unit of biomass consumed by the fire

Data needs for emission estimation

For a bottom-up emission estimation, one needs the following, spatially and temporally distributed:

- Burned areas (*available, with caveats*)
- Biomass (*available, with caveats*—models and land-cover maps)
- Combustion completeness (very uncertain)
- Emission factors (*available, with caveats*—temporal variation not well characterized)

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Satellite products

Active fires versus burned areas

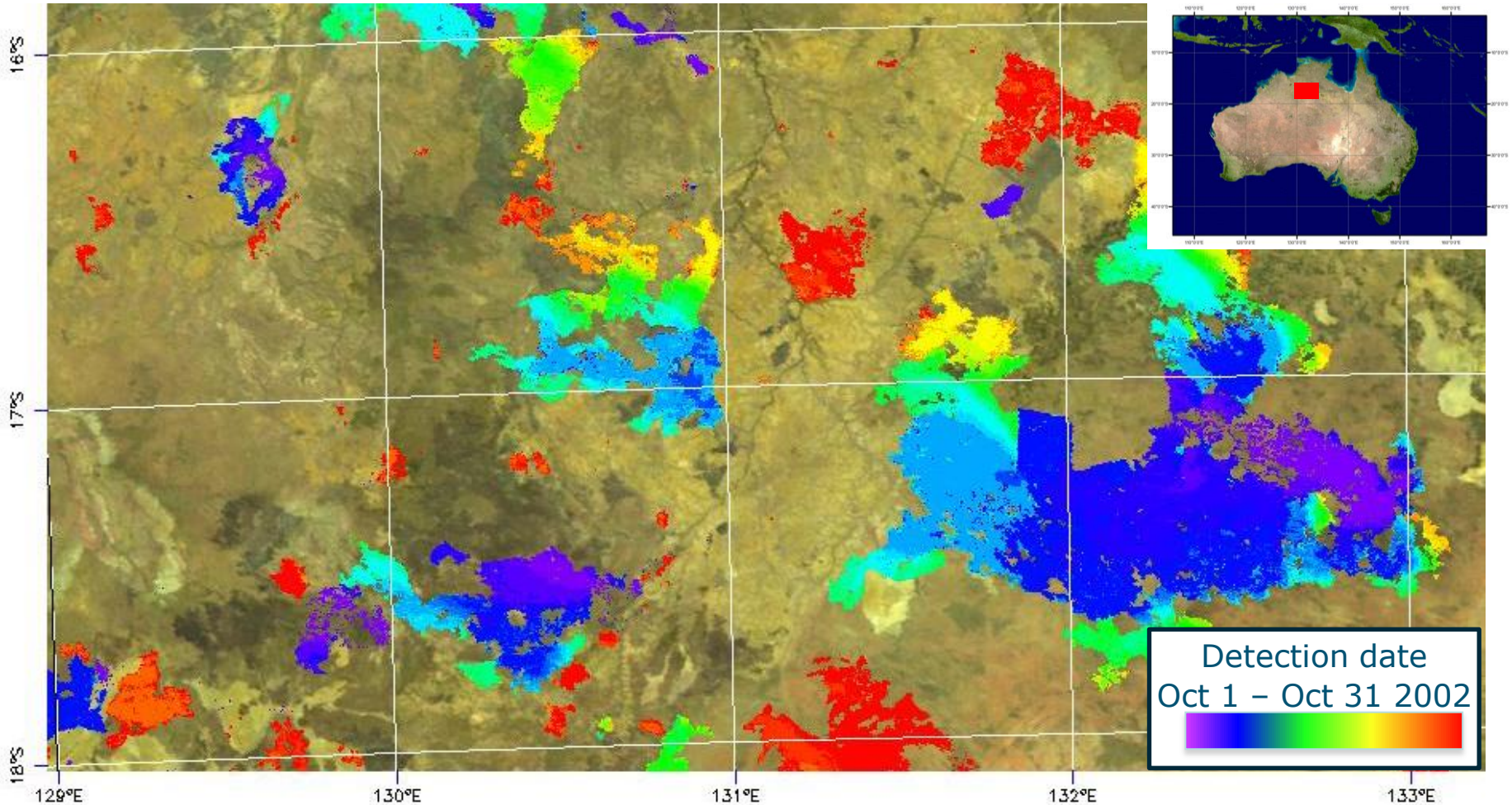
A fundamental distinction!

Satellite products

- Active fires = fires actively burning at the overpass time of the satellite (example: MODIS MOD14 product), detection mostly based on mid-infrared (MIR) and thermal infrared (TIR).

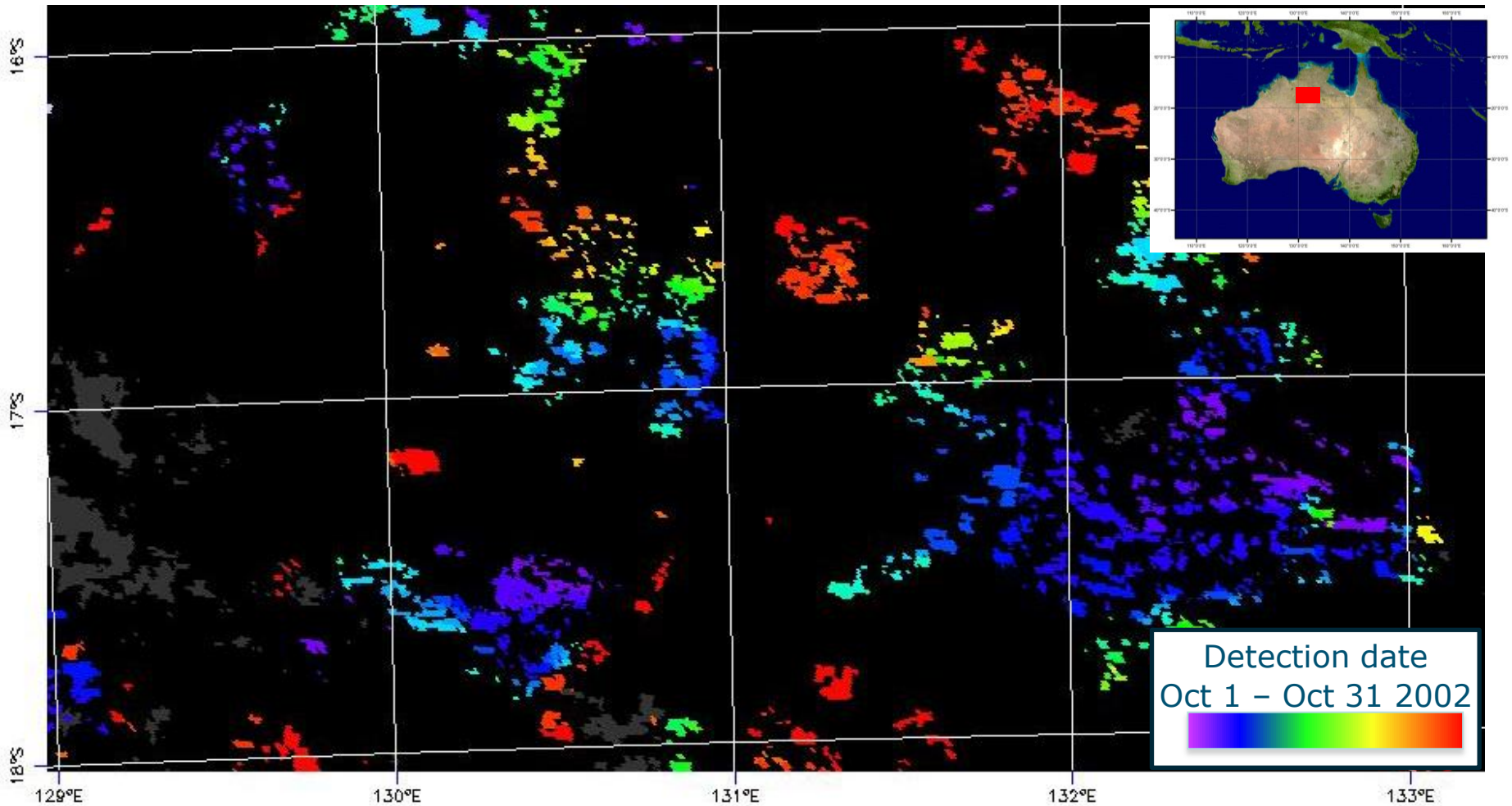
- Burned areas = areas affected by fire within a certain time interval (example: MODIS MCD45, ESA Fire CCI); detection based on time series processing of near- and short-wave infrared optical data, looking for the effects of fire on vegetation.

Australia: Burned areas



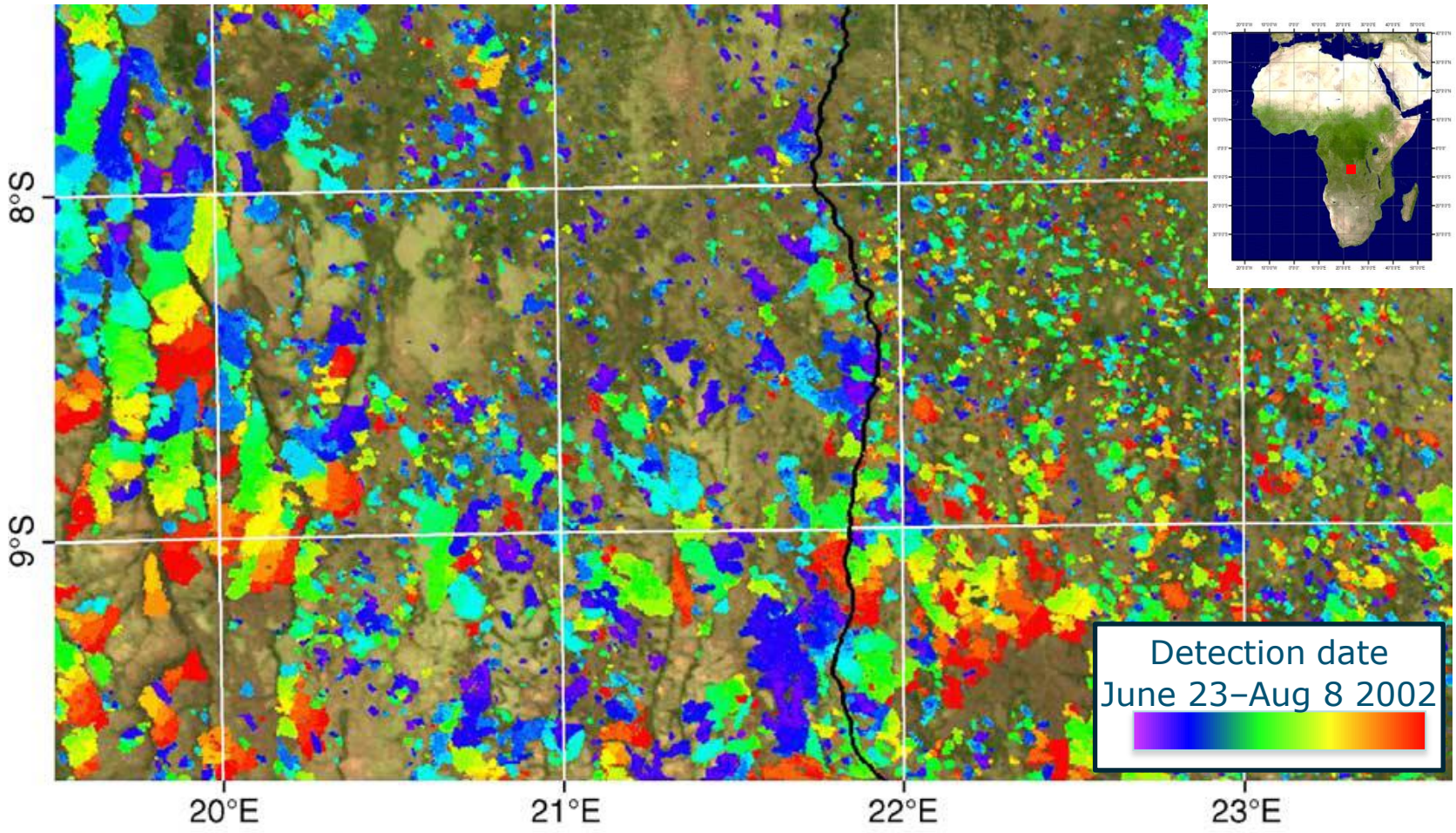
(Roy et al. 2005)

Australia: Active fires



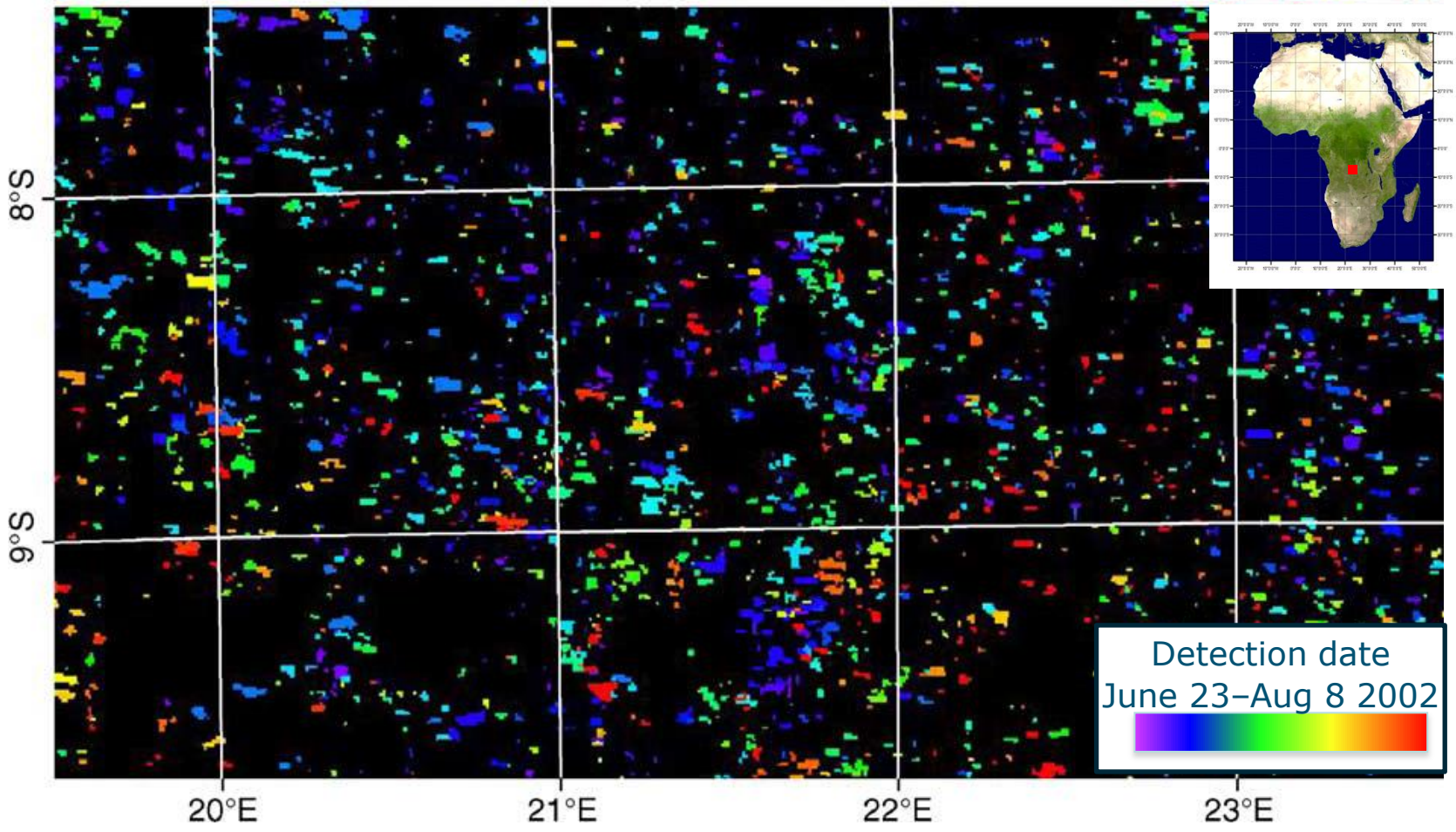
(Roy et al. 2005)

Southern Africa: Burned areas



(Roy et al. 2005)

Southern Africa: Active fires



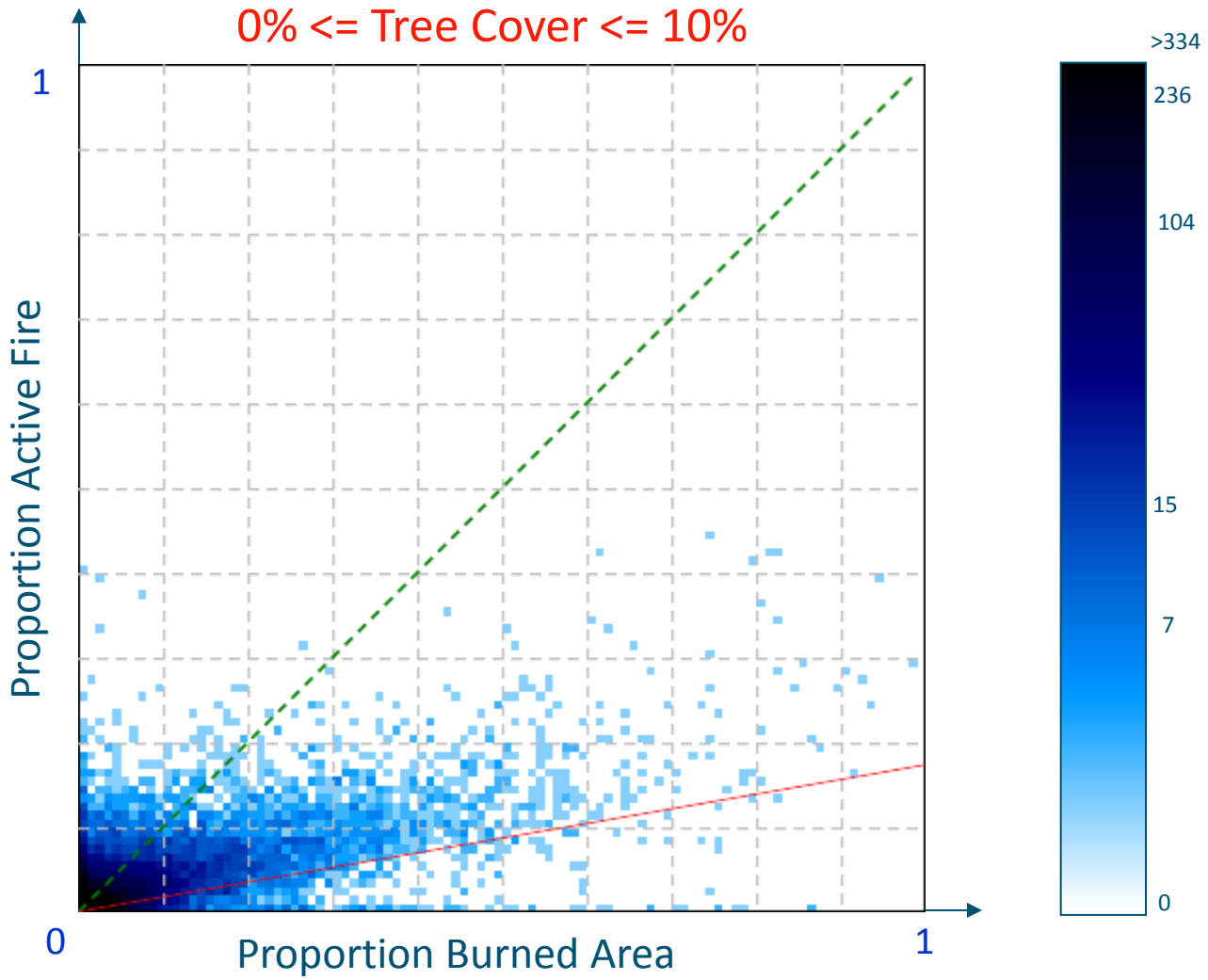
(Roy et al. 2005)

How do active fires and burned areas relate?

- The pattern is confirmed by systematic comparison of the global datasets.

- As the percentage of tree cover increases, **the ratio between active fire and burned area detection changes**, from more burned area detections than active fires in grasslands and savannas, to more active fire detections than burned area detections in very closed forest.

Active fires vs. burned areas in very open Savanna



61,523 cells

mean tree cover = 3.84 %

Slope = 0.173

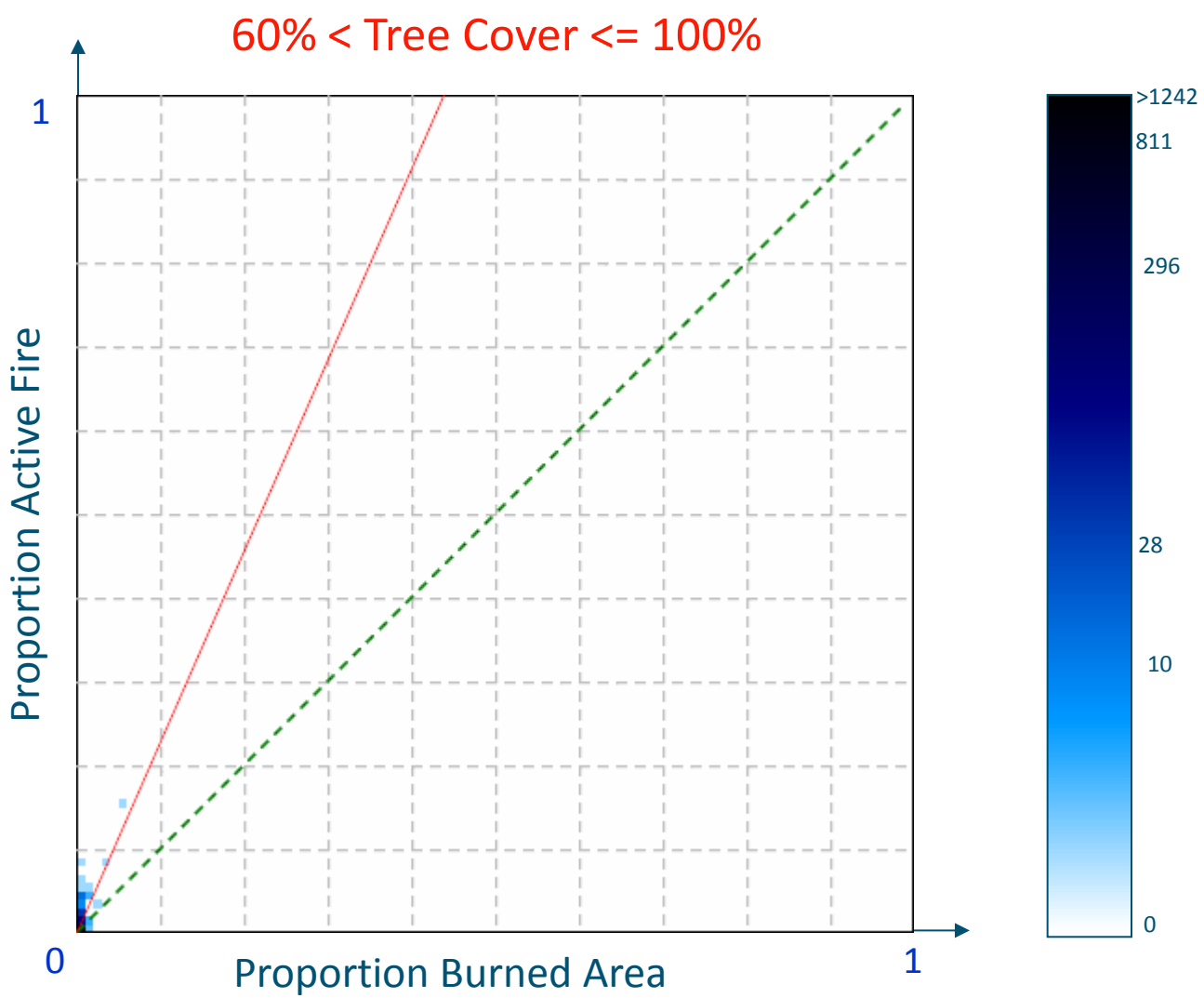
Intercept = 0.002

r = 0.71

Global

2001-2002

Active fires vs burned areas in closed forest



1,403 cells

mean tree cover = 76.2 %

Slope = 2.276

Intercept = 0.002

r = 0.67

Global

2001-2002

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Satellite data

- The nature of fire as nonpermanent land-cover change poses requirements on temporal sampling more strict than for other disturbances.
- Available sensors (tradeoff between spatial and temporal resolution):
  - Hyperspatial: 1 meter–10 meter pixel, available sporadically
  - Moderate / high: 10 meter–30 meter, available weekly/monthly
  - Coarse: over 100 meter, available daily

Satellite products (1/2)

- Updated list of global and regional products

GOFC-Fire Fire Monitoring and Mapping Implementation Team. http://gofc-fire.umd.edu

- Active fire products

MODIS active fires (University of Maryland /NASA / NOAA) 2000–present

http://modis-fire.umd.edu (product information)

http://lance-modis.eosdis.nasa.gov/ (real time web-GIS visualization and distribution)

VIIRS active fires (University of Maryland /NASA / NOAA) 2012–present

http://viirsfire.geog.umd.edu

GOES WF-ABBA (University of Wisconsin/NOAA) 2000–present

http://cimss.ssec.wisc.edu/goes/burn/wfabba.html

Meteosat Second Generation (Eumetsat) 2004–present

http://landsaf.meteo.pt/

TRMM VIRS fire product (NASA) 1998–2005

ftp://disc2.nascom.nasa.gov/data/TRMM/VIRS_Fire/data/

World Fire Atlas (ESA) 1997–2012

http://due.esrin.esa.int/wfa/

Satellite products (2/2)

- Burned area products

  MODIS burned areas (Univ. of Maryland / South Dakota State Univ./ Univ. of Idaho / NASA) 2000-present

  http://modis-fire.umd.edu

  L3JRC (EC Joint Research Center) 1998-2007

  http://bioval.jrc.ec.europa.eu/products/burnt_areas_L3JRC/GlobalBurntAreas2000-2007.php

  Fire CCI (University of Alcala, ESA) under development, currently 2006-2008

  http://www.esa-fire-cci.org

- Emissions

  Global Fire Emissions Database (GFED3) - multi-year burned area and emissions 1997-present

  http://ess1.ess.uci.edu/%7Ejranders/data/GFED3/

  MACC-II (Monitoring Atmospheric Composition and Climate). Global fire analyses and estimates of emissions from fires. 2003-present

  http://www.gmes-atmosphere.eu/about/

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IPCC emissions estimation

Back to bottom-up IPCC approach:

$$Lfire = A \times Mb \times Cf \times Gef$$

L = emission for each gas

A = area burned

Mb = fuel load

Cf = combustion factor

Gef = amount of gas released per unit of biomass consumed by the fire

Implementation of bottom-up approach

The bottom-up approach is linear, and it can easily be implemented in a GIS environment:

$$Lfire_i = A_i \times Mb_i \times Cf_i \times Gef_i$$

Where:

i is a generic burned area pixel, Ai is the area of the pixel, and Mb_i , Cf_i , Gef_i are the biomass load, combustion factor, and emission coefficients for that location.

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Error sources

Bottom-up approach:

$$Lfire = A \times Mb \times Cf \times Gef$$

- All terms of the equation are affected by errors.
- Satellite datasets have greatly reduced the uncertainty on global burned area estimates, but at local scale errors up to 50% have been reported.
- Biomass load and combustion factors are also poorly characterized in the literature.
- Emission factor tables compiled from previous studies often ignore the seasonal changes.

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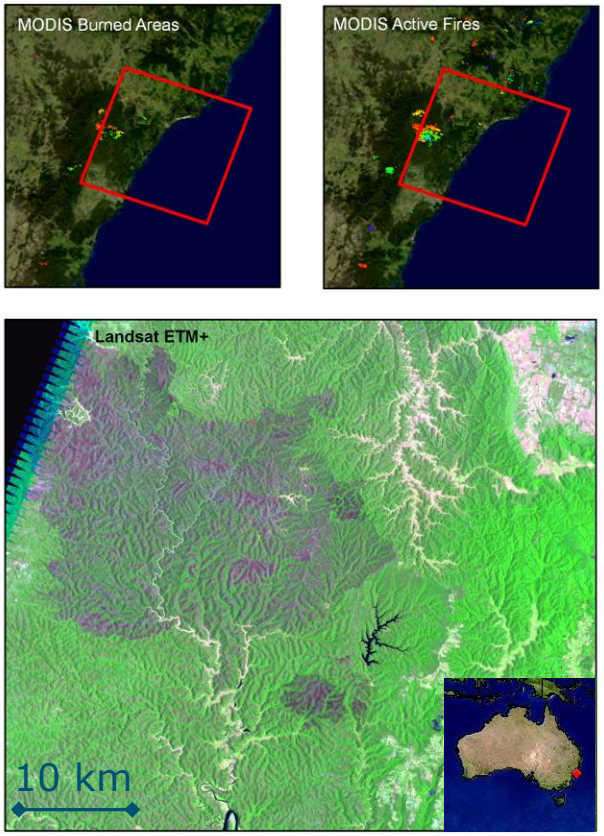
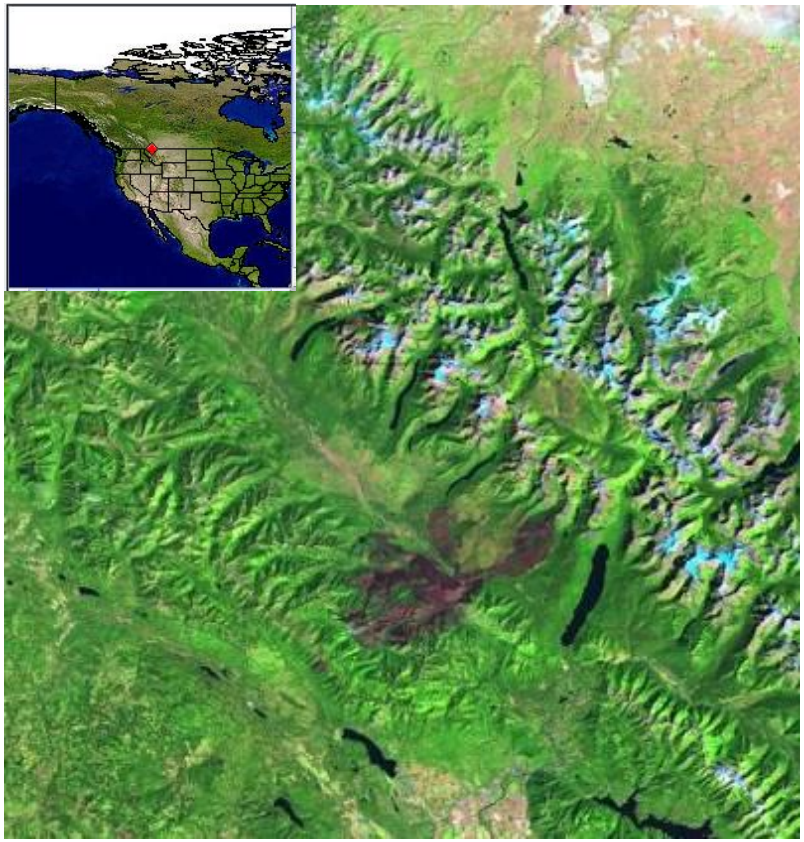
Using fire products for hotspot detection

- Identify areas where forest fires occurred, to guide acquisition of high resolution imagery.
- The mapping is refined in the high resolution imagery.



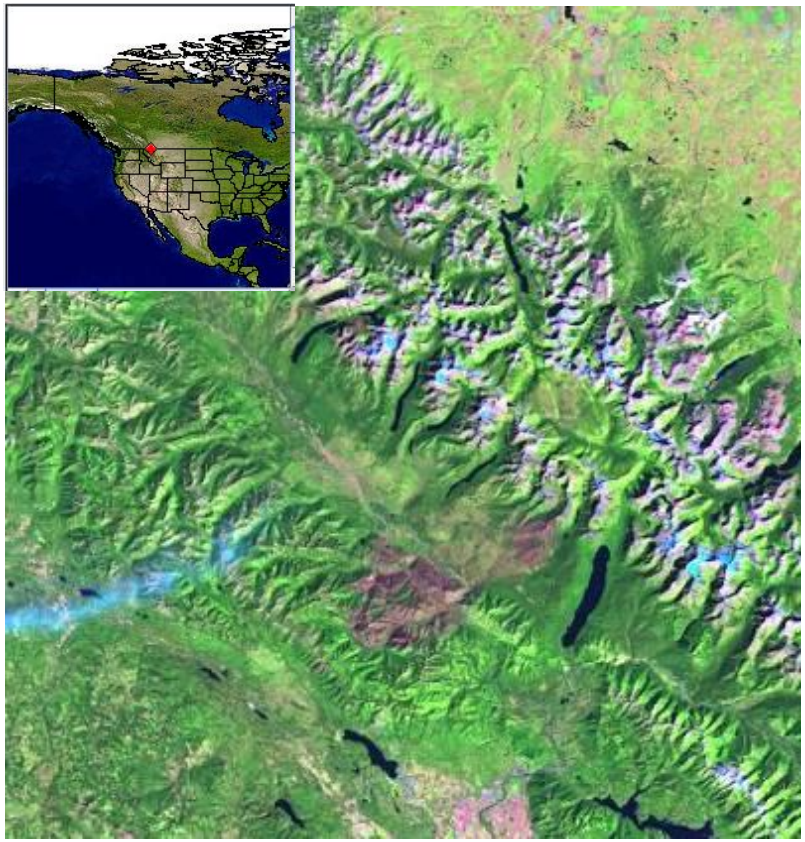
Satellite data for postfire characterization



2001

Conversion from forest to other land use after fire?

Satellite data for postfire characterization

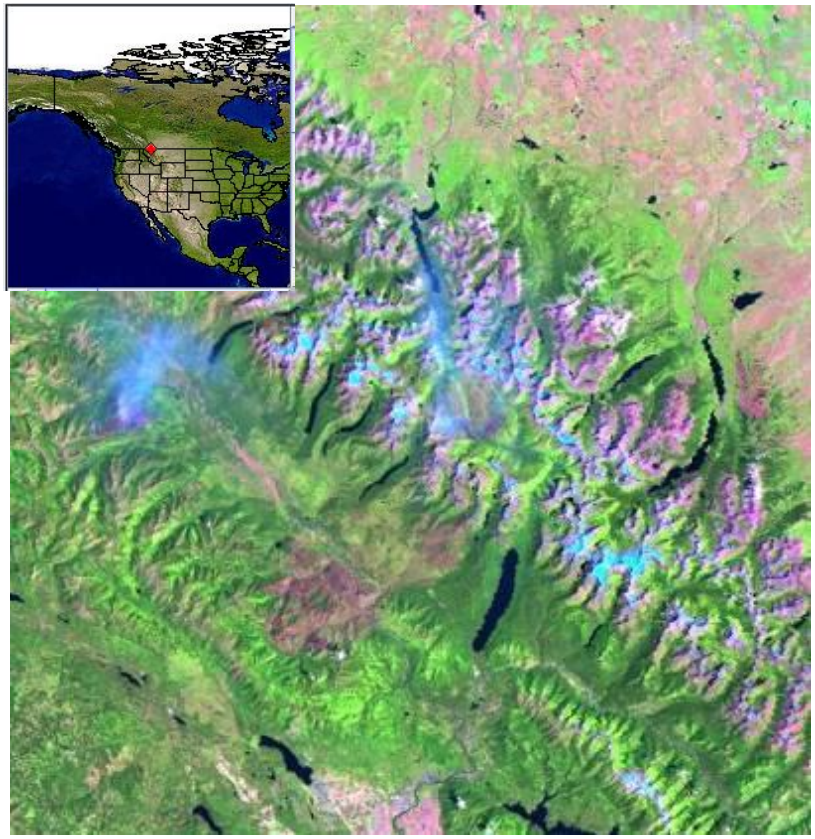


2002

Conversion from forest to other use after fire?

One year later: no.

Satellite data for postfire characterization



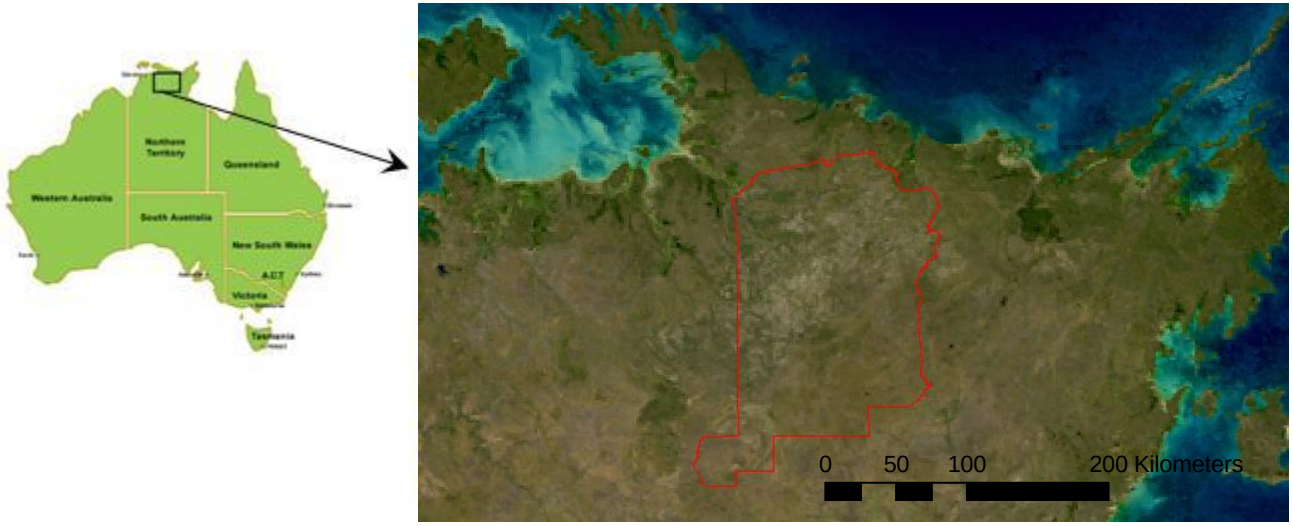
2003

Conversion from forest to other use after fire?

One year later: no.
Two years later: no.

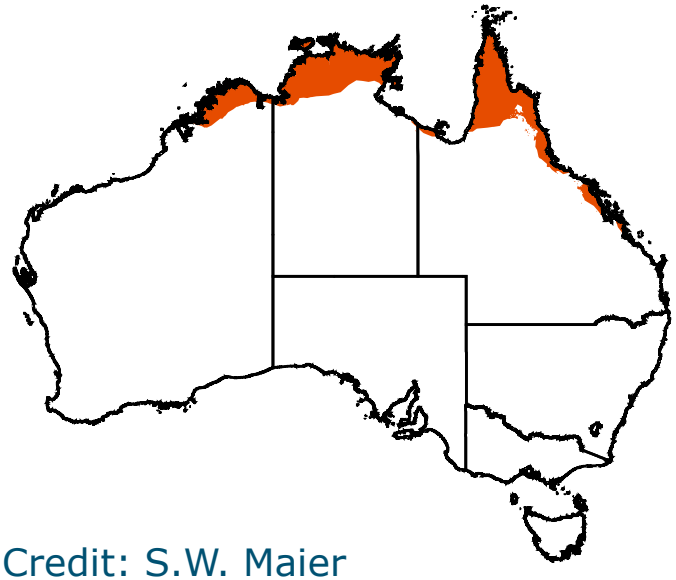
Fire management

- What is forest? Woody Savanna, with tree cover between 10% and 30% can be considered
- Change in total annual emissions by managing fire and changing the seasonality (early versus late fires)
- Example: WALFA in Northern Australia



Carbon farming initiative (CFI)

- Australia introduced a carbon price on 1 July 2012 (fixed at 23 A$/$t_{CO2e}$ for 2012/13).
- The CFI allows farmers and land managers to earn carbon credits by storing carbon or reducing greenhouse gas emissions on the land.
- CFI includes methodology for accounting emissions (non-CO_2) from savanna burning in high rainfall areas (>1000mm/a).



Credit: S.W. Maier

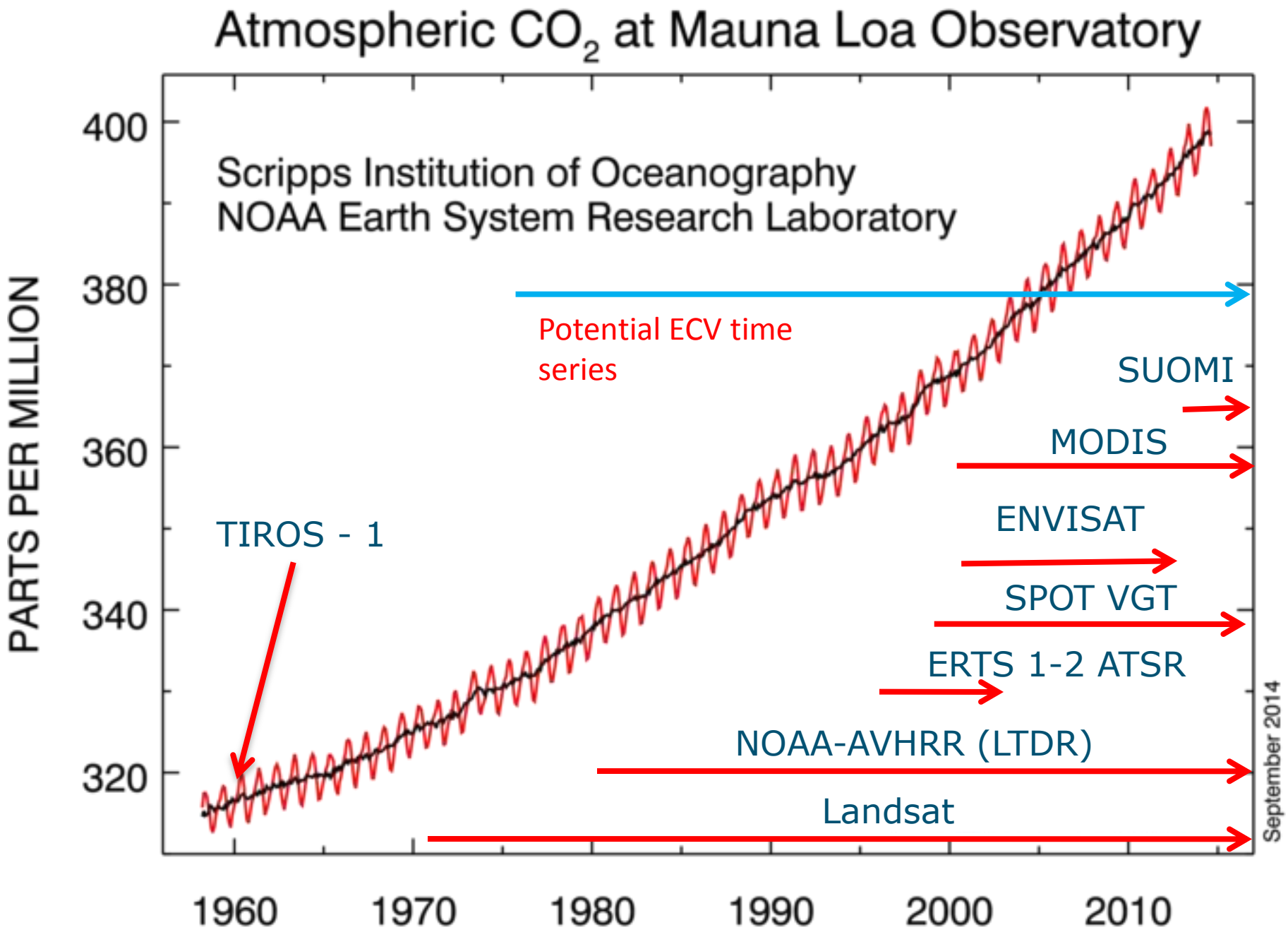
Savanna burning methodology (>1000mm/a)

Objective: Reduce emissions through early dry season (EDS) prescribed burning:

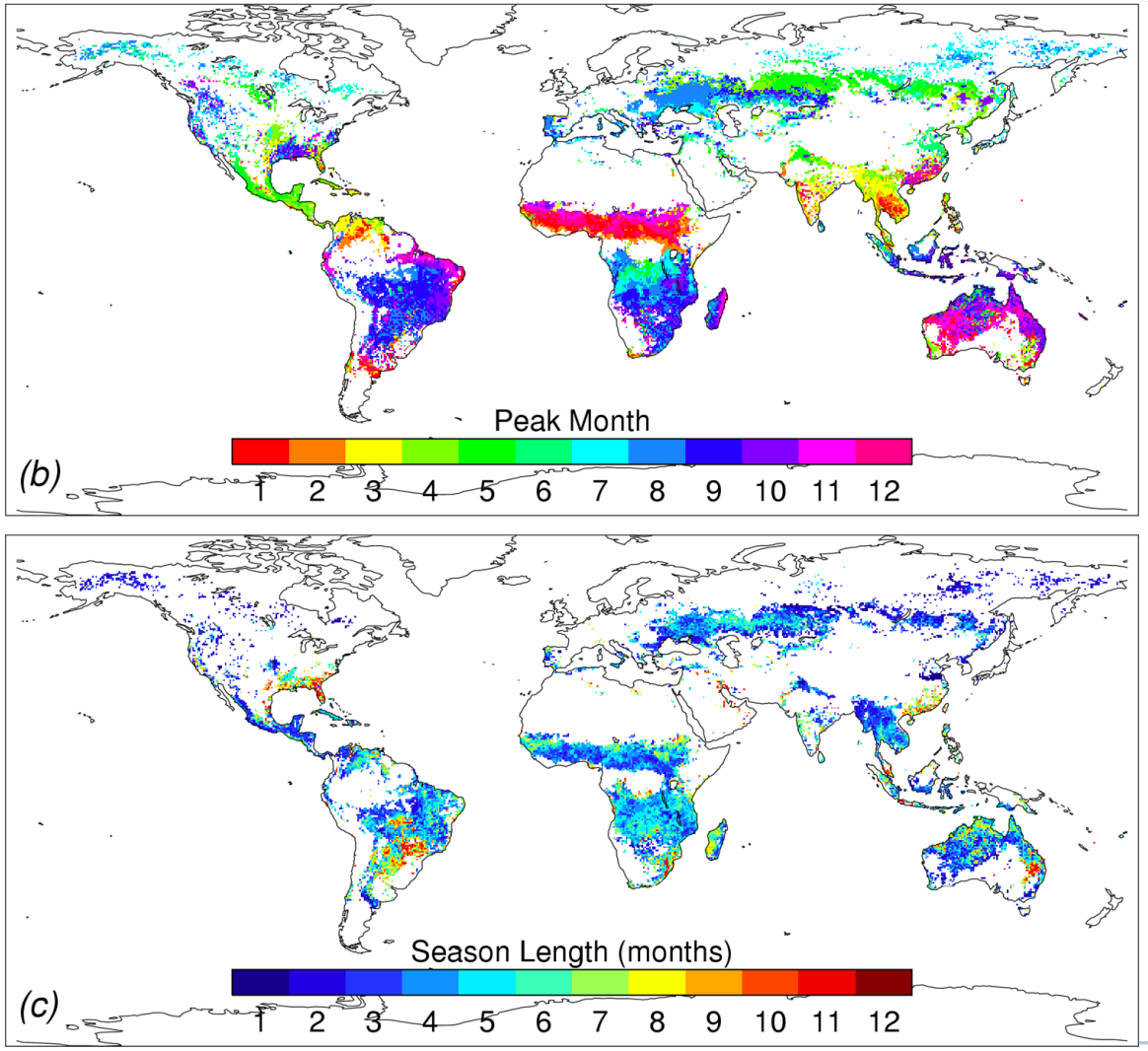
- Vegetation type map ≤ 250m
- Burnt area 5 years prebaseline ≤ 1km
- Burnt area 10 years baseline ≤ 1km
- Burnt area project years ≤ 250m
- Accuracy burnt area > 80%, assessed using (random) aerial observations
- Fuel load derived from time since last fire
- Combustion completeness (EDS vs LDS)
- Emission factors dependent on fuel type only, not season (Maier et al. 2012)

Long-term data records

- Fire can be seen as an essential climate variable (ECV) in support of climate change studies
- Essential climate variables, defined by GCOS (under WMO)
- Integration of existing data sources
- Intercalibration of existing thematic products
- International cooperation for harmonization of future products
- Potential for **series starting in 1980**, with local test dataset with Landsat data from 1970s


Atmospheric CO_2 at Mauna Loa Observatory
Scripps Institution of Oceanography
NOAA Earth System Research Laboratory
PARTS PER MILLION
400
380
360
340
320
1960
1970
1980
1990
2000
2010
Potential ECV time series
SUOMI
MODIS
ENVISAT
SPOT VGT
ERTS 1-2 ATSR
NOAA-AVHRR (LTDR)
Landsat
TIROS - 1
September 2014

Climatological fields



Climatological fields derived from the first five years of Terra MODIS fire observations (November 2000 to October 2005)

(b) Month of maximum climatological fire activity
(c) Fire season length

(Source: Giglio et al. 2006)

In Summary

- Monitoring of fires requires an understanding of the process of fire in forest systems (either as an ecological change agent, a disturbance, a forest management tool, or as a process associated with land cover conversion)
- There are different approaches and objectives to monitor fires in the context of REDD+
  - Pre-fire (early warning systems)
  - Active fire (hotspot satellite data)
  - Post-fire (burned area estimates)
- Calculation of emissions from biomass burning follows the Bottom-up IPCC approach: $Lfire = A \times Mb \times Cf \times Gef$ (IPCC, 2006, AFOLU GL, section 2.4)

Country examples and exercises

Country examples (regions)

- Africa: Burned areas and active fires maps
- Amazonia: Burned areas and active fires maps

Exercise

- Using available fire datasets to estimate GHG emissions from biomass burning in the national contexts for Botswana and Brazil.

Recommended modules as follow-up

- Module 2.7 to continue with estimation of uncertainties
- Module 2.8 to learn more about evolving technologies for monitoring of forest-area changes, carbon stocks, and emissions
- Modules 3.1 to 3.3 to proceed with REDD+ assessment and reporting

References

- Boschetti, L. and Roy, D. Defining a fire year for reporting and analysis of global interannual fire variability. *Journal of Geophysical Research: Biogeosciences,* 113: G3. DOI: 10.1029/2008JG000686.
- IPCC 2006. *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. Volume 4: Agriculture, Forestry and Other Land Use. Prepared by the National Greenhouse Gas Inventories Programme, Eggleston H.S., Buendia L., Miwa K., Ngara T. and Tanabe K. (eds). Published: IGES, Japan. http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.html (Often referred to as IPCC AFOLU GL)
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