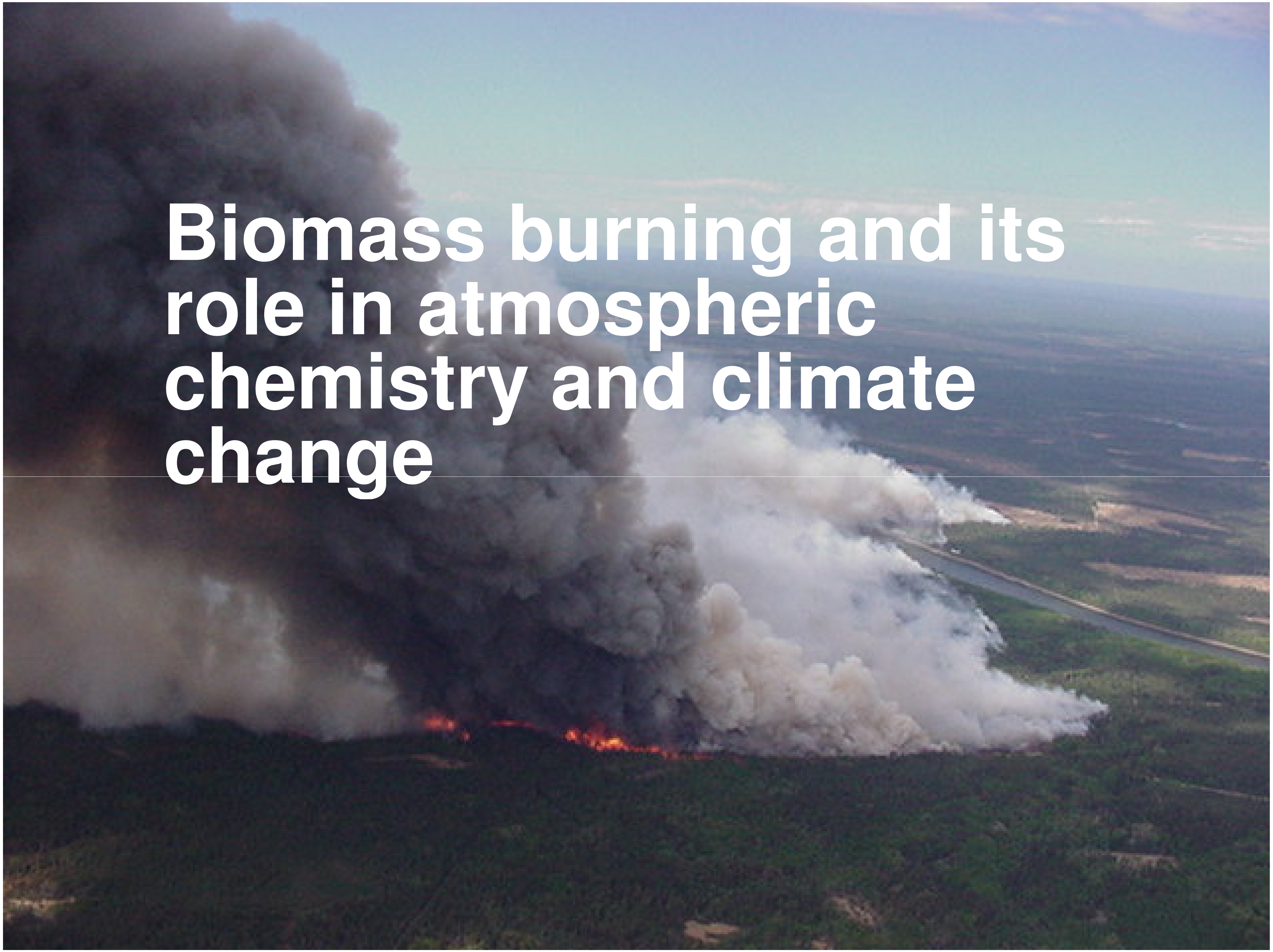
Biomass burning and its role in atmospheric chemistry and climate change



Research Questions

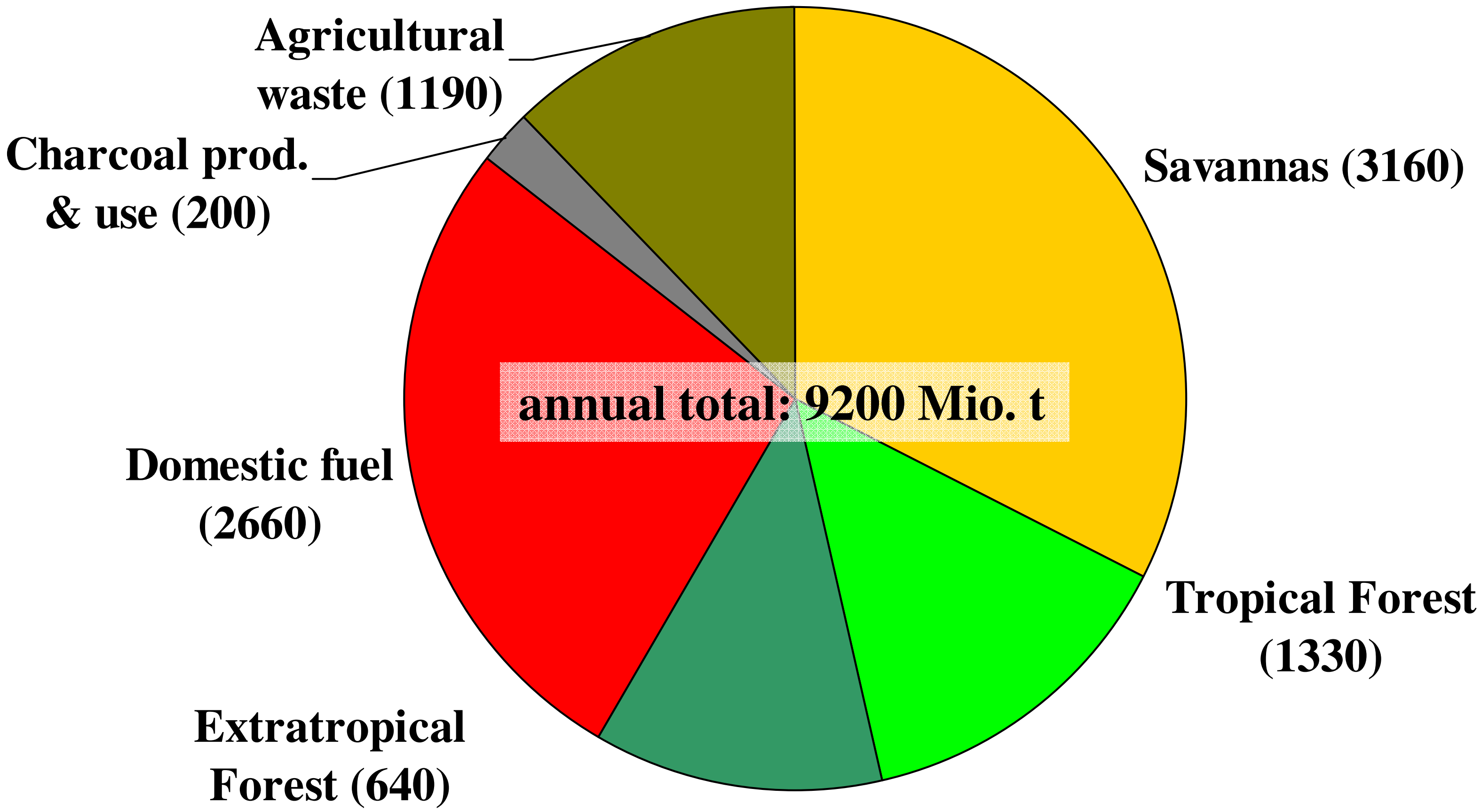
1. What is the role of fires for atmospheric chemistry and in the climate system?

2. How do climate parameters influence fire activity?

3. How will open burning evolve in the future?

INTRODUCTION

Global amount of burned biomass annually



Comparison: worldwide wood trade 2005: ~ 300 Mio. t (600 Mio. m^3)

Source: Andreae and Merlet (2001), Max Planck Institute for Chemistry


Controlled burning of forest litter


Forest fire – ground fire


Smoldering
combustion

Savannah fire

Vegetation fires in India

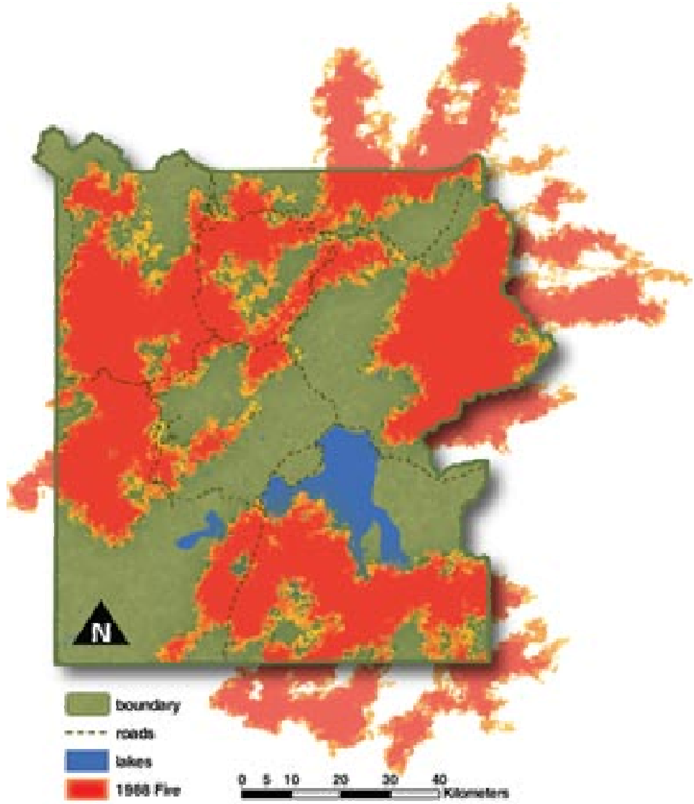
Majority of forest fires in India are man-made
Main causes of fire:

- Deforestation activities: conversion of forestland to agriculture, pasture development etc.;
- Traditional slash and burn/shifting agriculture;
- Grazing land management: Setting of fires in forests by villagers for getting fresh blade of grass, fodder etc.;
- Collection and use of NWFPs: e.g. fires set for the purpose of collection of honey, Sal seeds, flowers of Mahua etc.;
- Forest/human habitation interface: e.g. fire set to burn leaves and other biomass from agriculture fields and fire set to scare the wildlife etc.;
- Conflicts over the land right claims and
- Fire caused by negligence.


Forest fire in India
(Bandipur Nat'l Park)

Forest fire – crown fire
(Yellowstone, 1988)

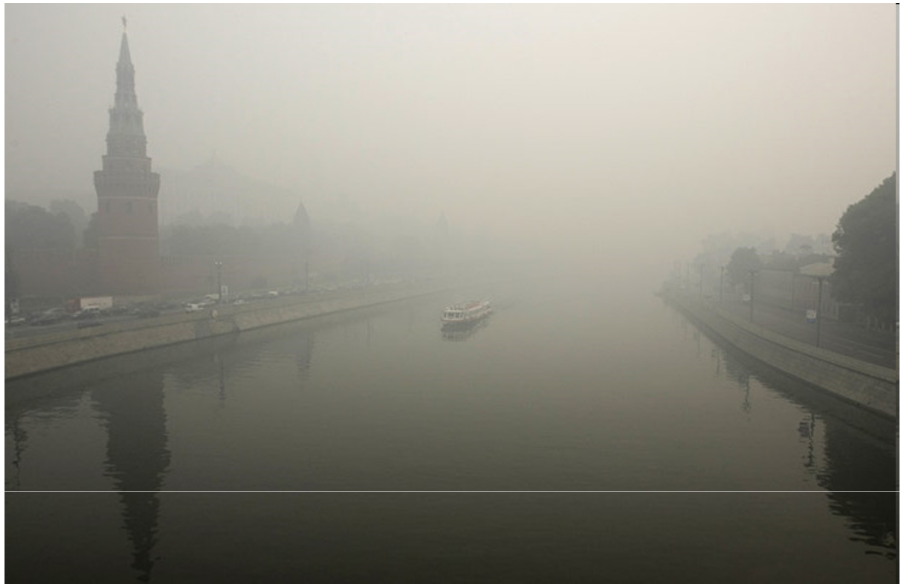
- One of the largest forest fires on record
- More than 1 mio. ha (10.000 km^2) burned area
- 25,000 fire fighters were unable to extinguish fires (costs: 120 mio US $)



Open burning comes in many different forms

Fires cause air pollution

Moscow fires 2010 (early August)



Extreme Heat wave and drought

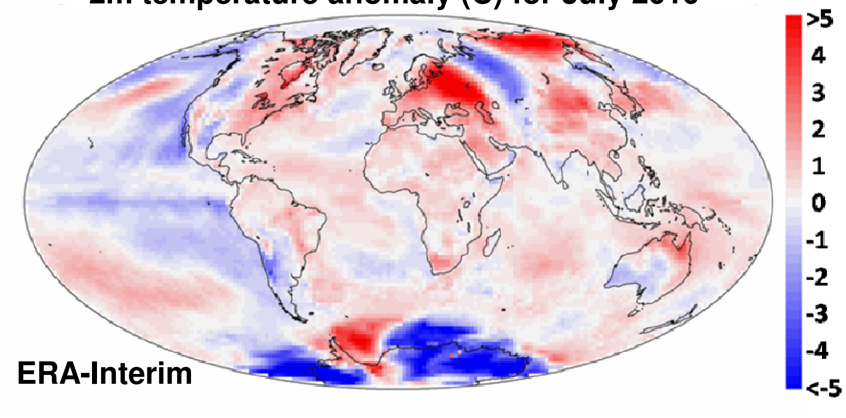
→ Forest and peat fires in the neighbourhood

→ Strong impediments on air quality

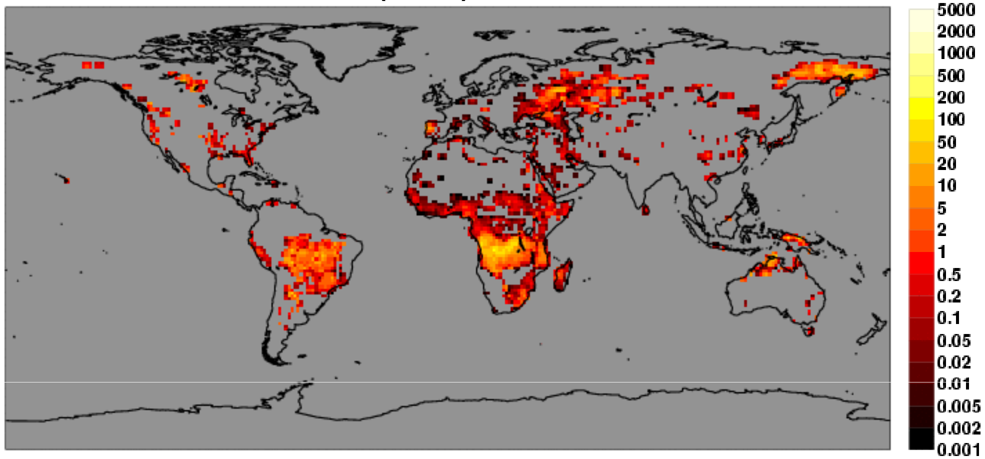
→ Doubling of mortality

Extreme weather may cause extreme fires: 2010 fires in Russia

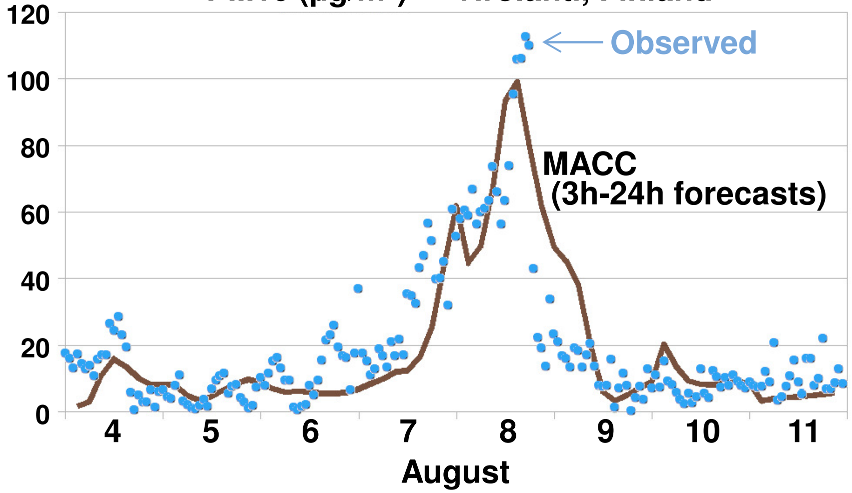
2m temperature anomaly (C) for July 2010



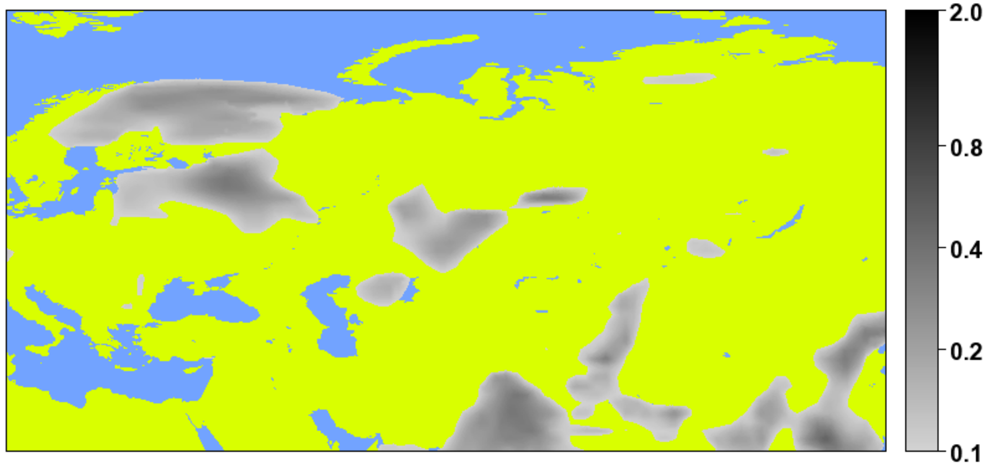
Fire Radiative Power (Wm^{-2}) from SEVIRI and MODIS



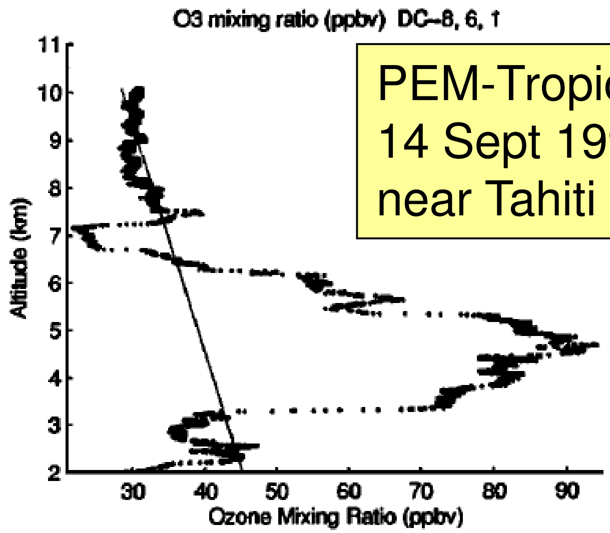
PM10 (μg/m³) Virolahti, Finland

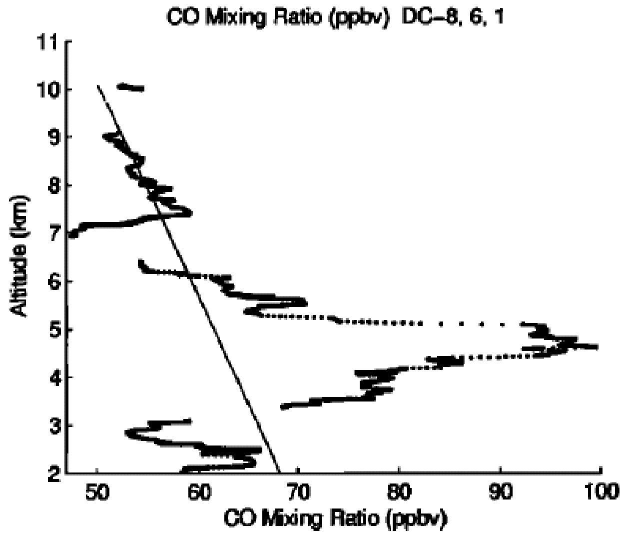


2010072603
Aerosol optical depth due to black carbon and organic matter

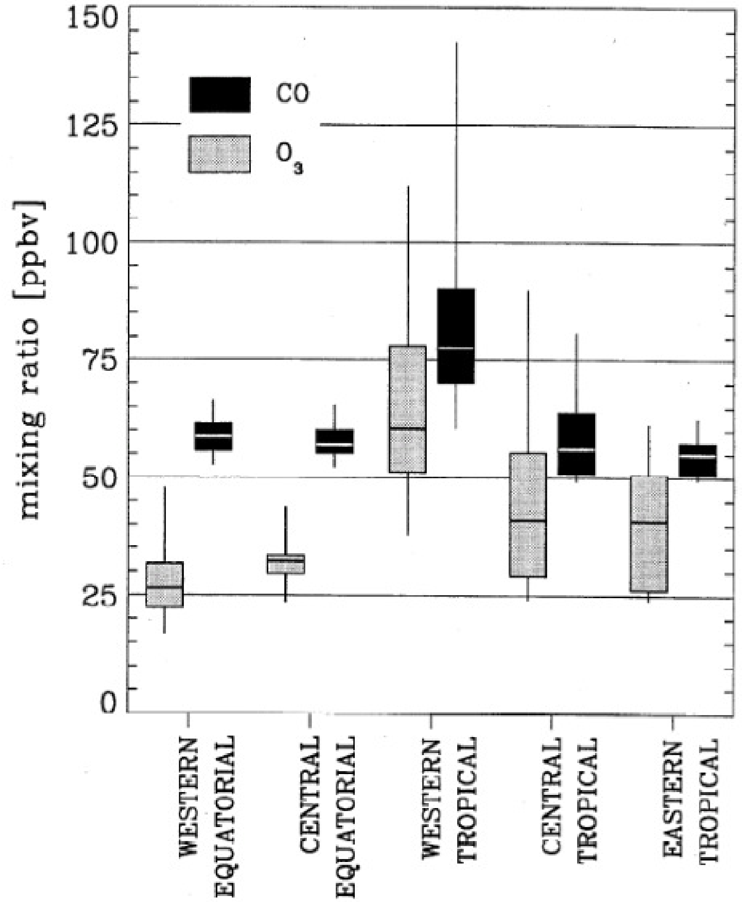


The impact of emissions from fires can sometimes be observed several thousand kilometres away from the sources!





Stoller et al., 1999



Schultz et al., 1999

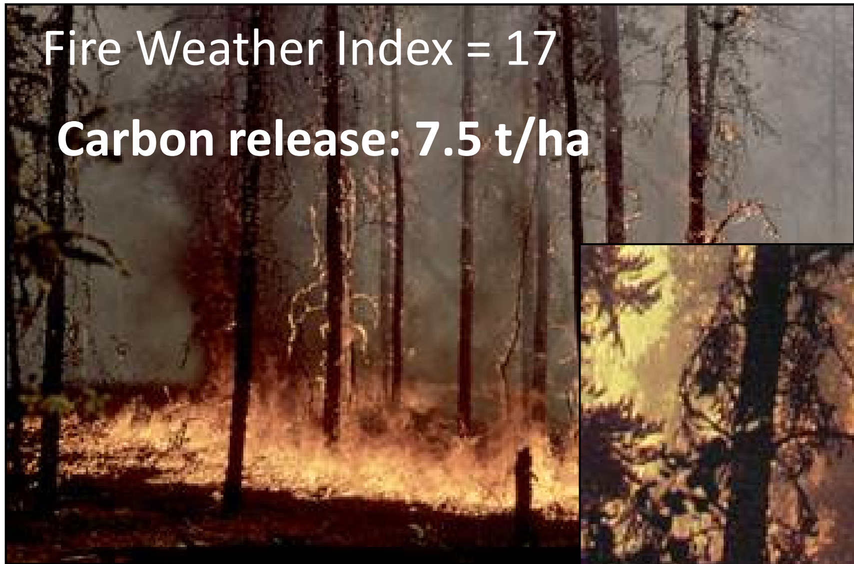
Fire emissions depend on fire type

Wood contains about 47% carbon; most emissions released as CO_2

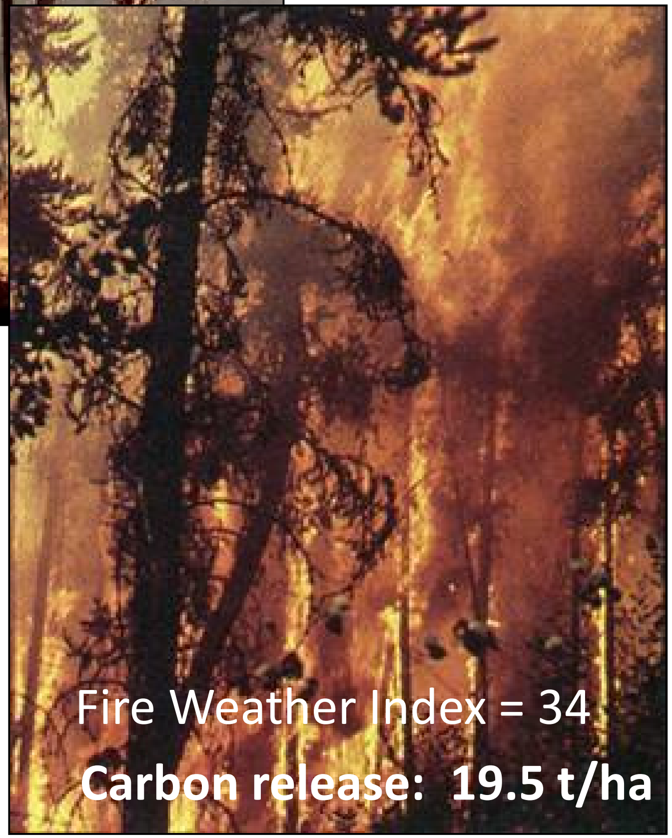
Aerial (crown) Fuels
C storage: 5-85 t/ha
C loss: 0.5-11 t/ha

Surface Fuels
C storage: 2-12 t/ha
C loss: 0.5-8 t/ha

Ground Fuels
C storage: 1.5-42 t/ha
C loss: 0.5-20 t/ha



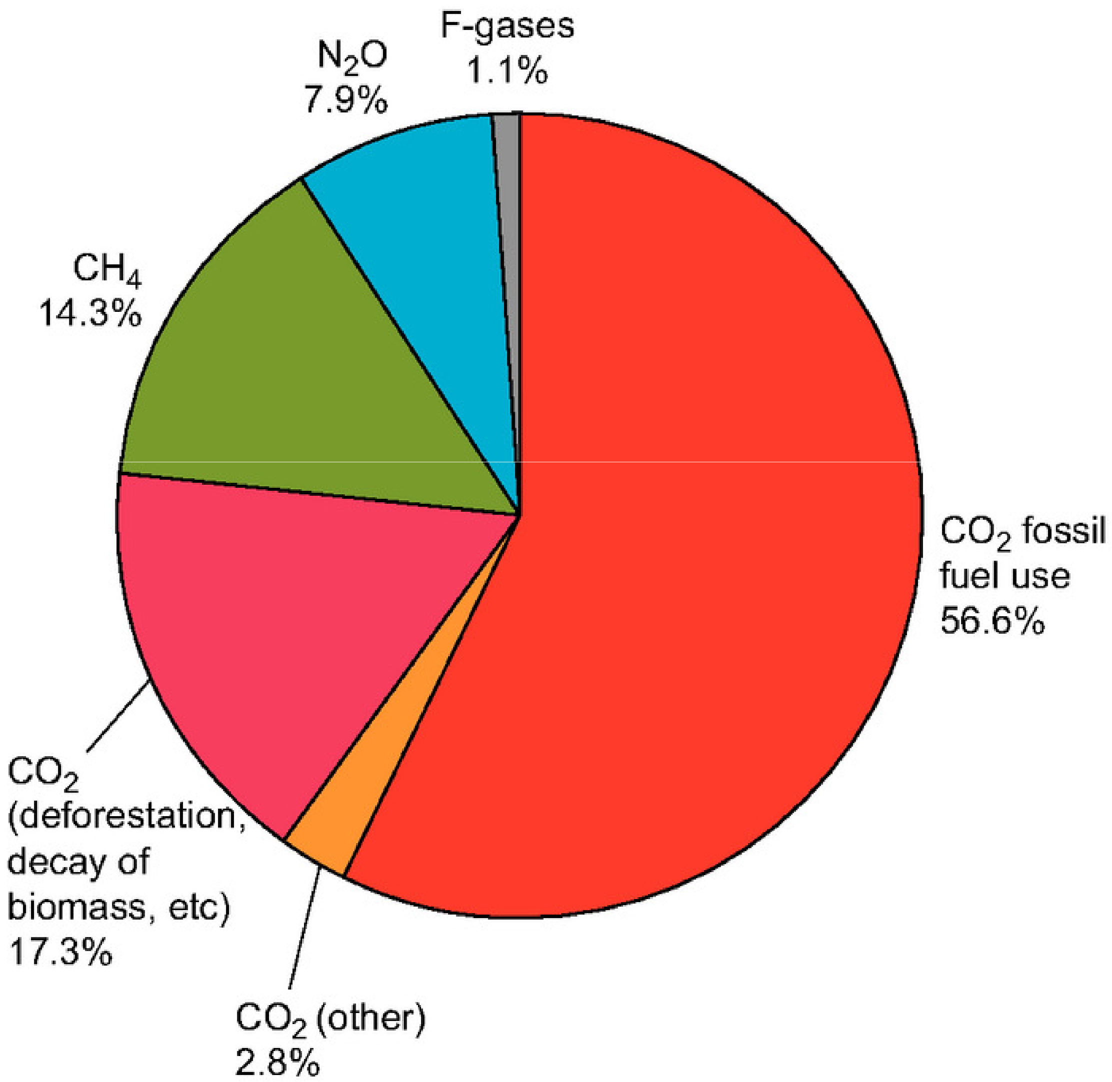
Same forest
2 days later…



Source: W.J. de Groot

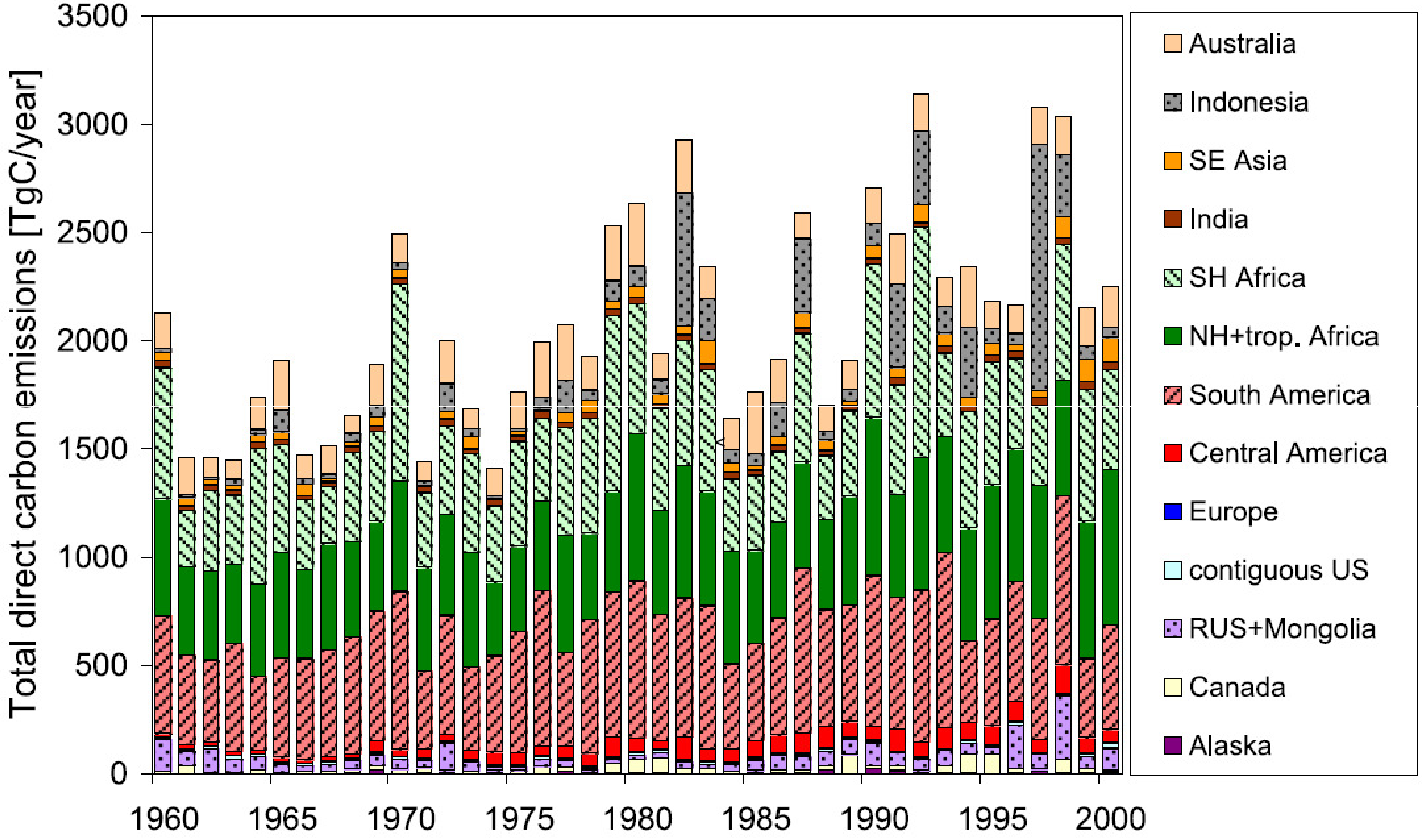
Natural Resources Canada
Ressources naturelles Canada

Global anthropogenic greenhouse gas emissions 2004



IPCC

Carbon emissions from global open burning

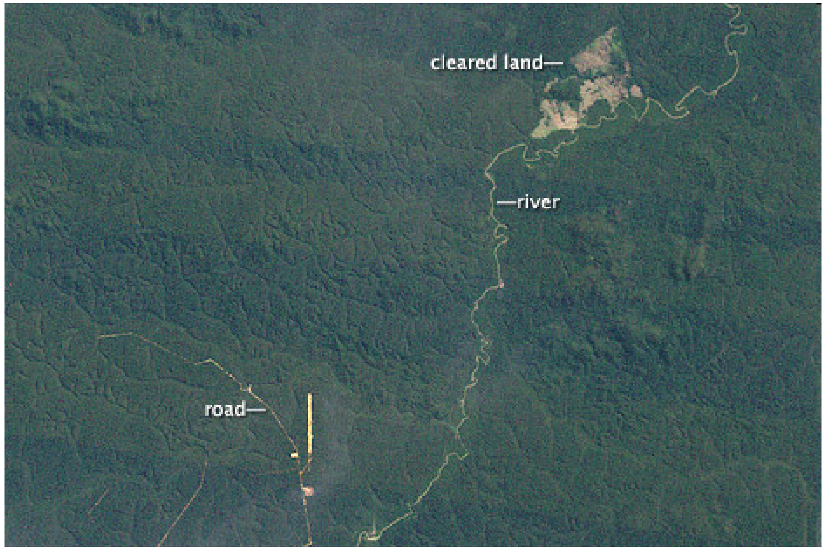


Schultz et al., 2008

Fires influence weather/climate

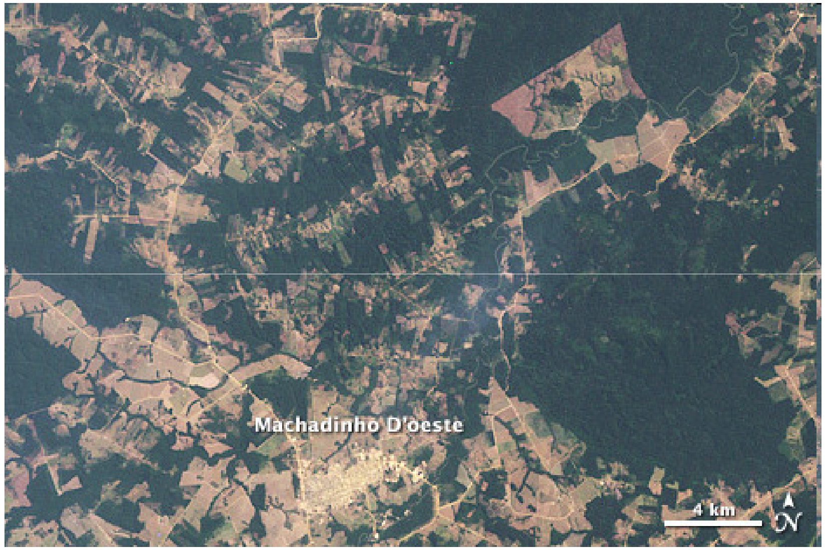
Fires influence weather/climate

Deforestation in Rondonia, Brazil



Landsat TM, 17 June 1984

dark

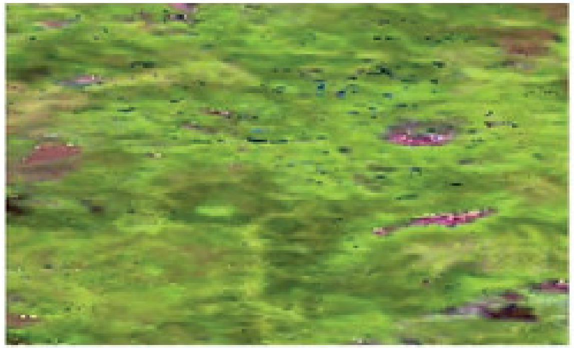


Landsat ETM+, 21 July 2005

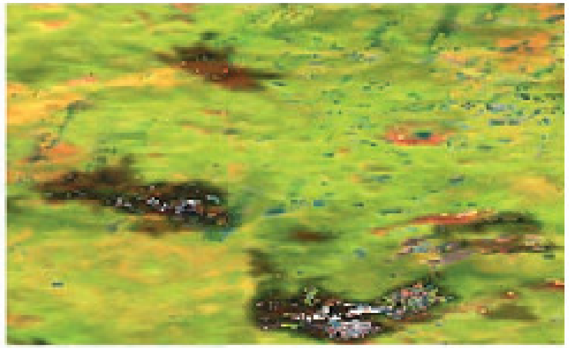
bright

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

Aside: Albedo changes are used to map burned area from space

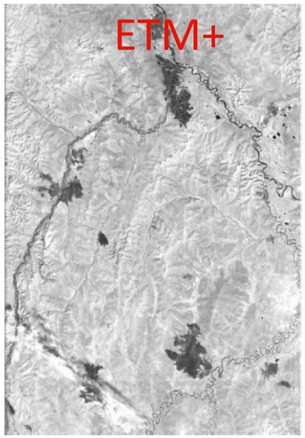


Pre-fire

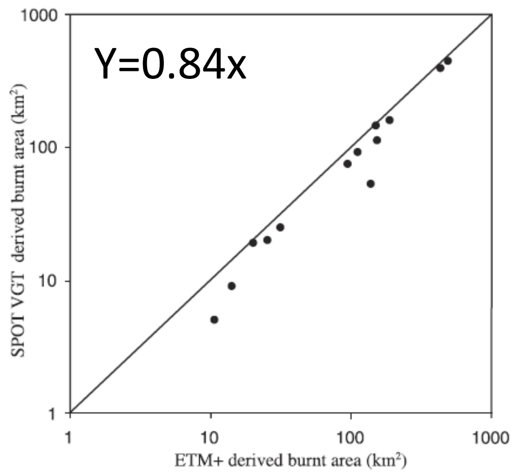


Post-fire

Fire “Scar” Map



“validation”

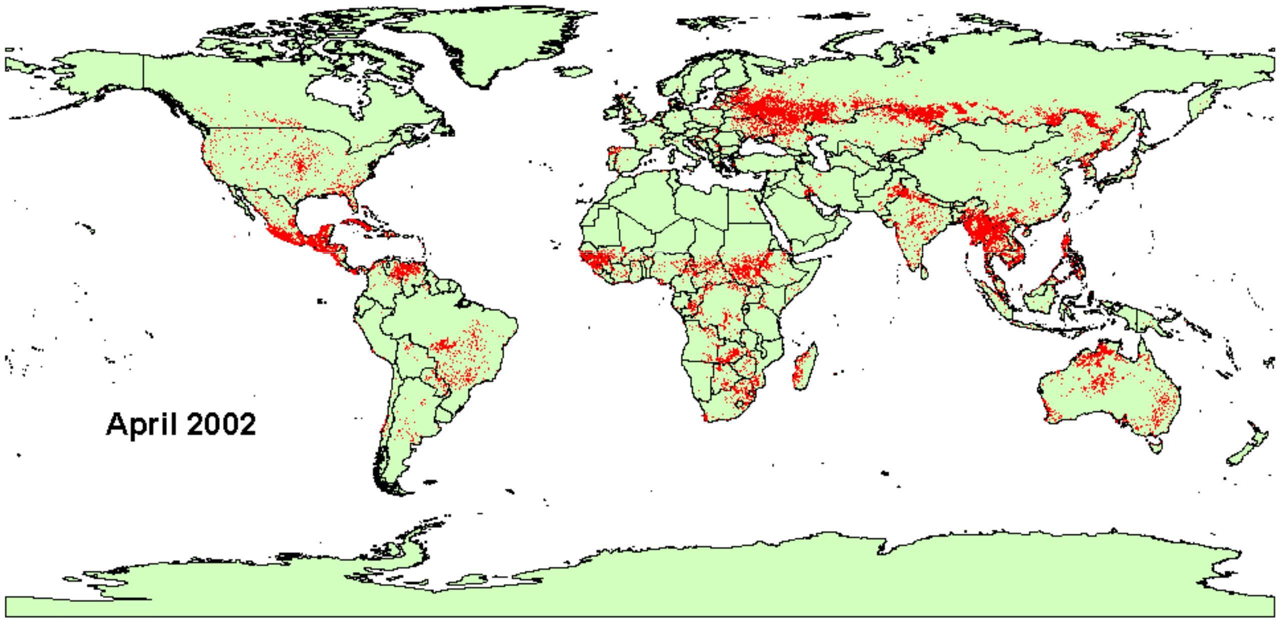


Zhang et al (2003) Monthly burned area and forest fire C emission estimates for the Russian Federation, *Remote Sensing Environ*, 87, 1-15

PREREQUISITES FOR OPEN BURNING

Global fire occurence

MODIS Land Rapid Response Fire Detections

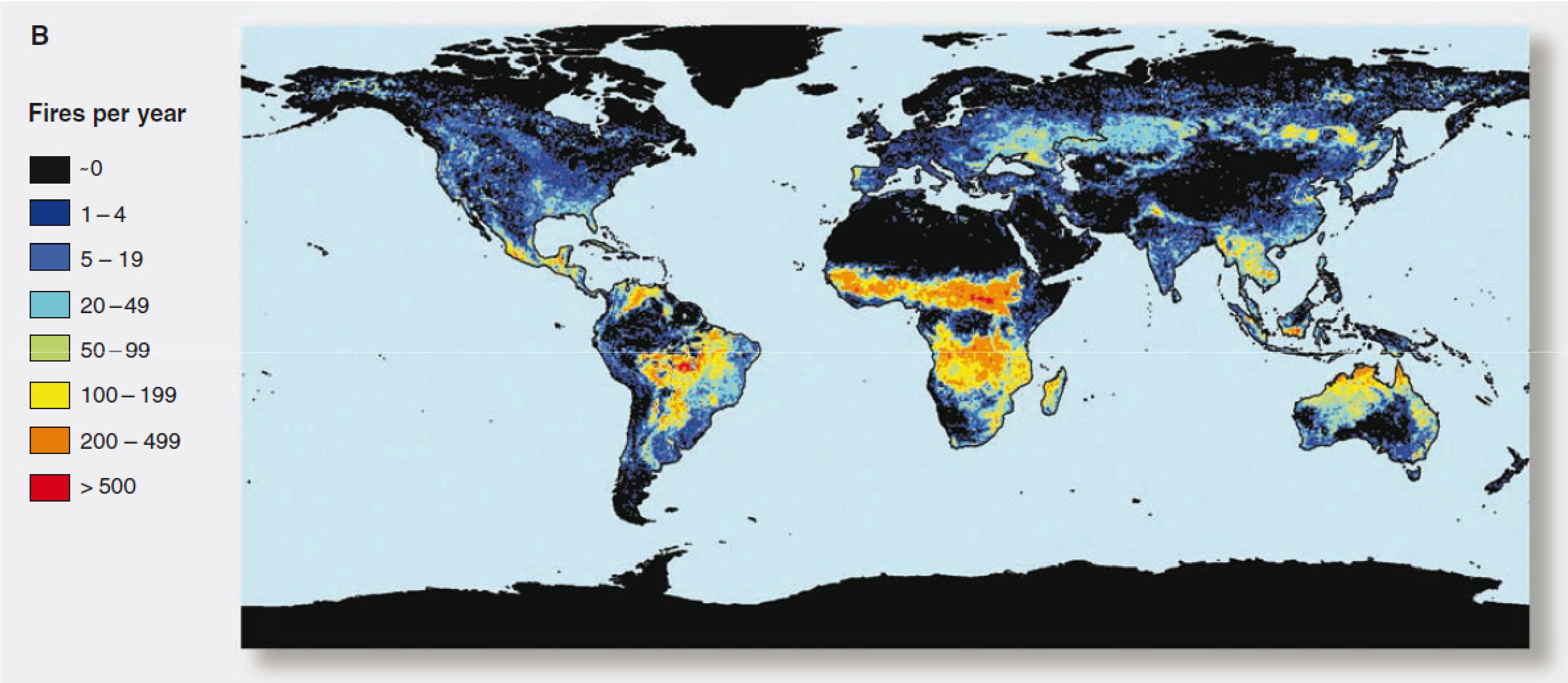


Legend

MODIS Fire Detections from the Terra Satellite

World Countries

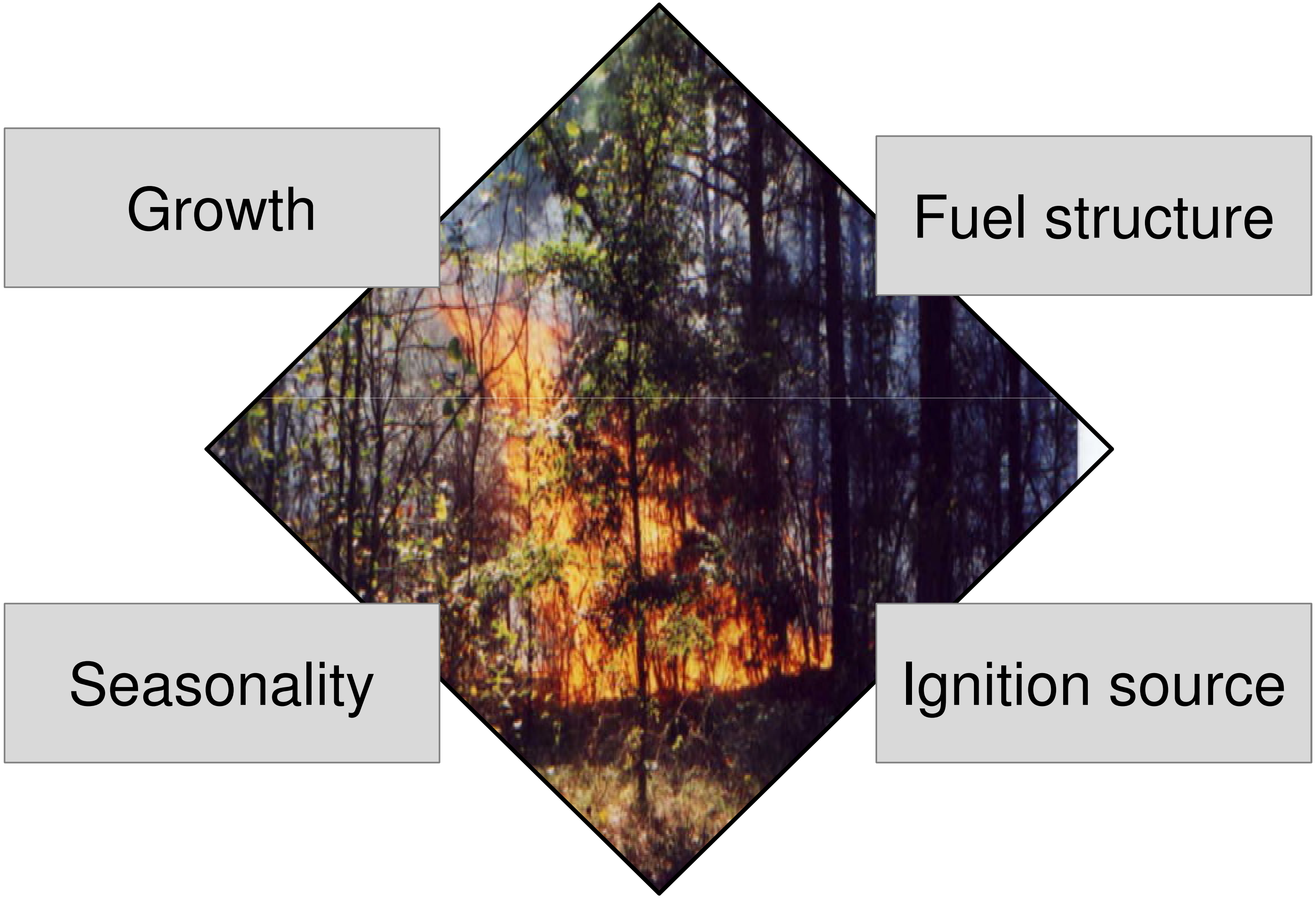
Global Distribution of Frequency of Open Burning



Globally about 3-4 million km^2 are burned annually
(= land area of India)

Bowman et al., 2009

Conditions for open burning



Pausas&Keeley, 2009

Importance of climate seasonality

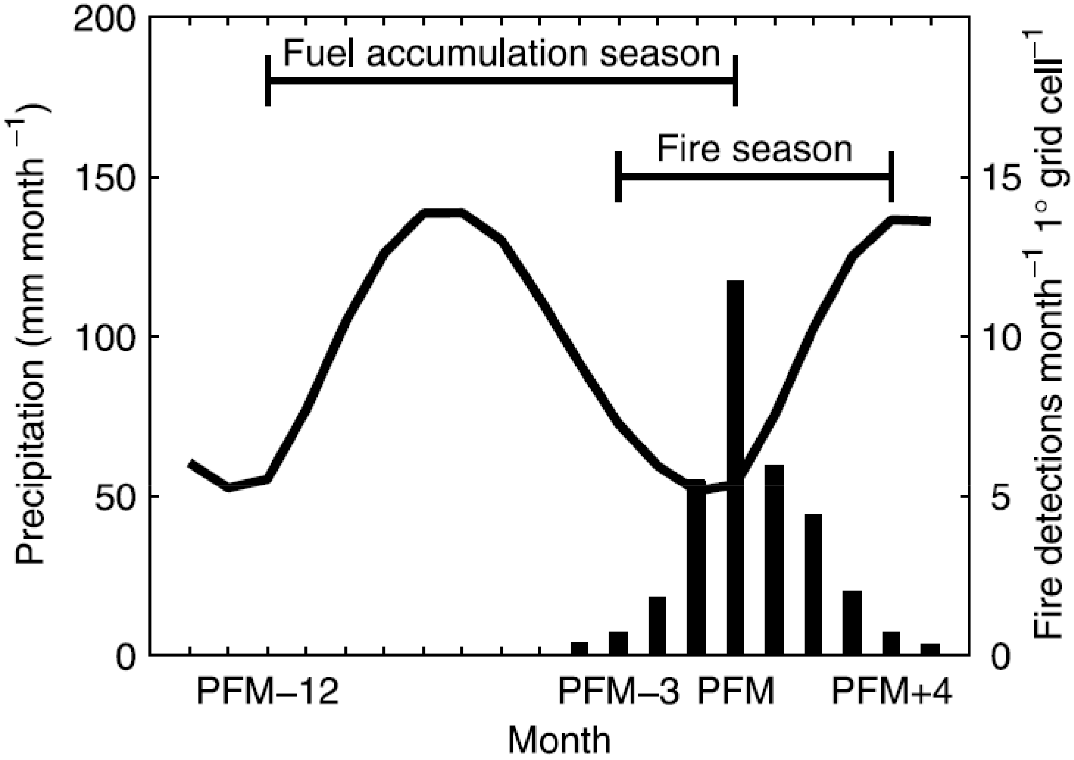
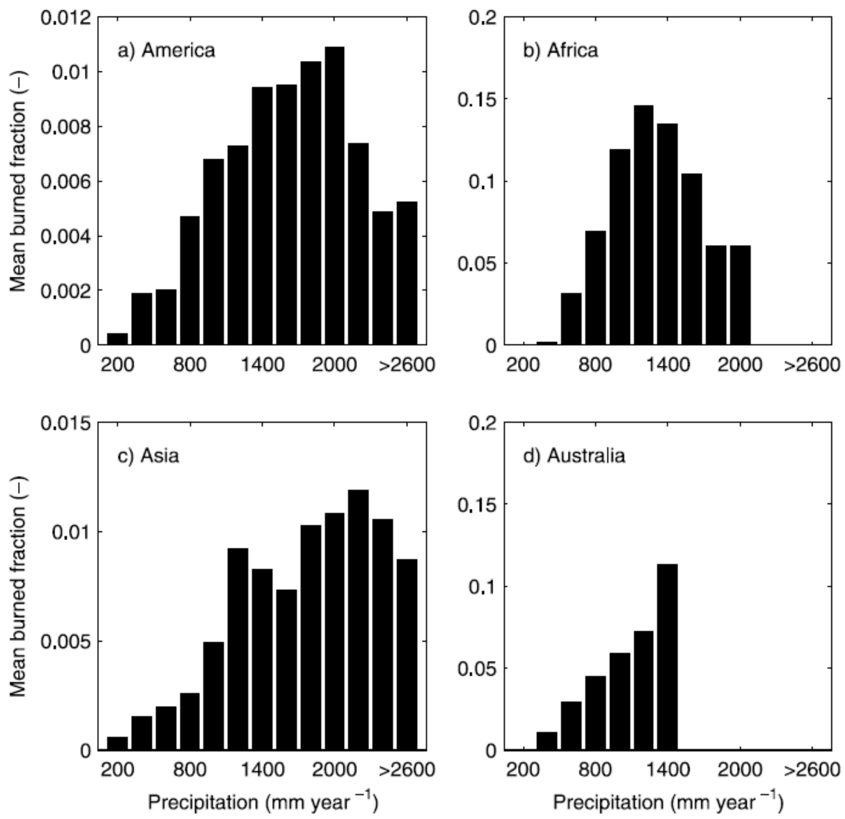
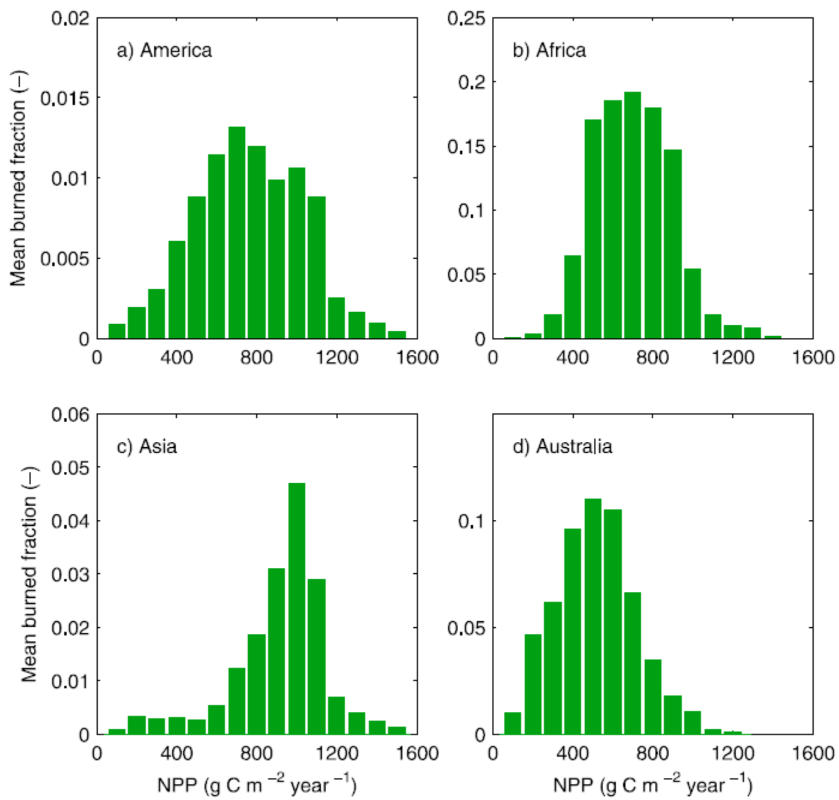


Figure 2. Mean monthly precipitation rates and active fire detections for all grid cells where fire activity was observed. The fire season is defined here as the 8-month period starting 3 months before and ending 4 months after the peak fire month (PFM). The 13-month period preceding and including

van der Werf et al., 2008

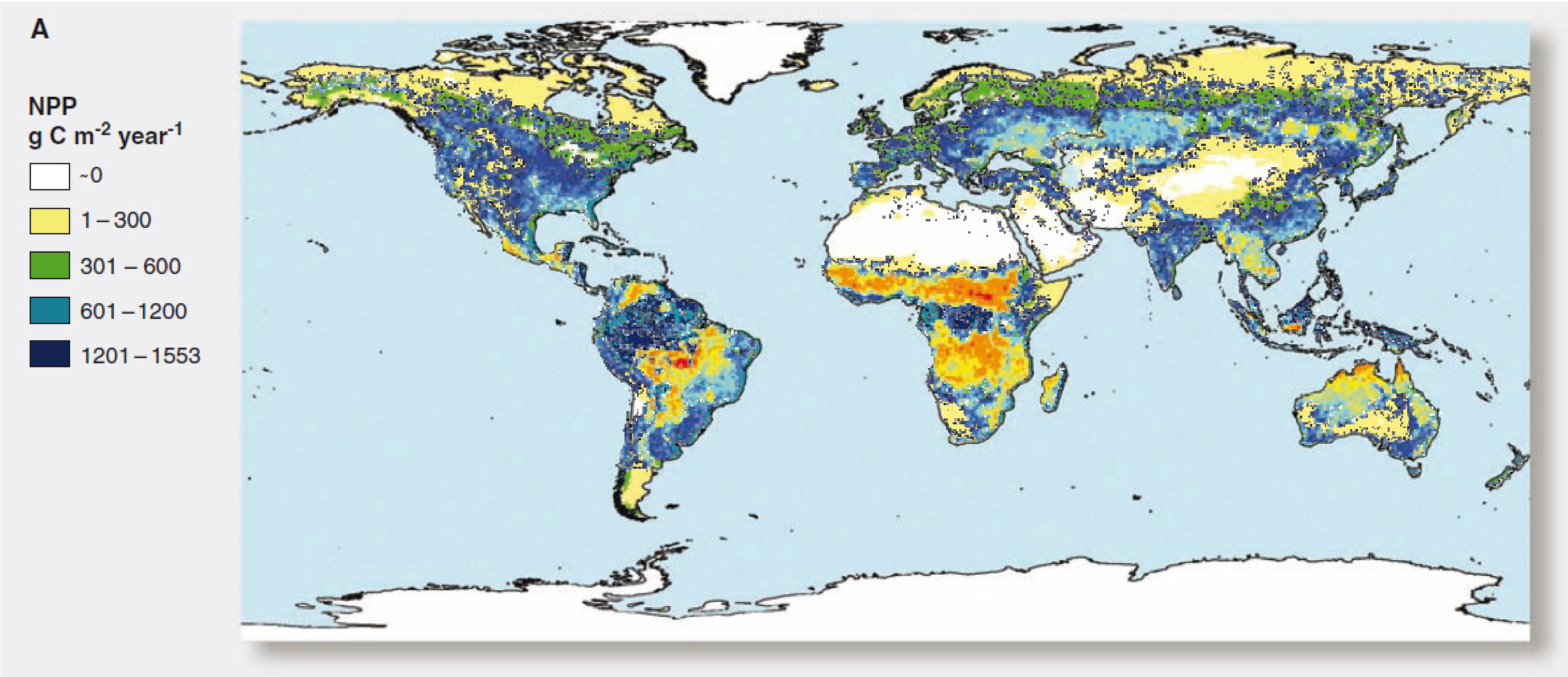
Fire frequency versus precipitation and net primary productivity





van der Werf et al., 2008

Fires generally occur in ecozones of medium productivity

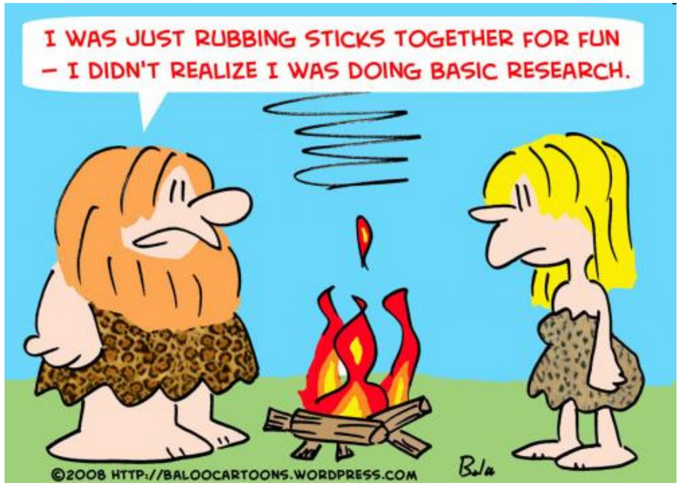


Bowman et al., 2009

HUMAN INFLUENCE ON VEGETATION BURNING (EXAMPLE: INDONESIA)

Co-evolution of human beings and fire

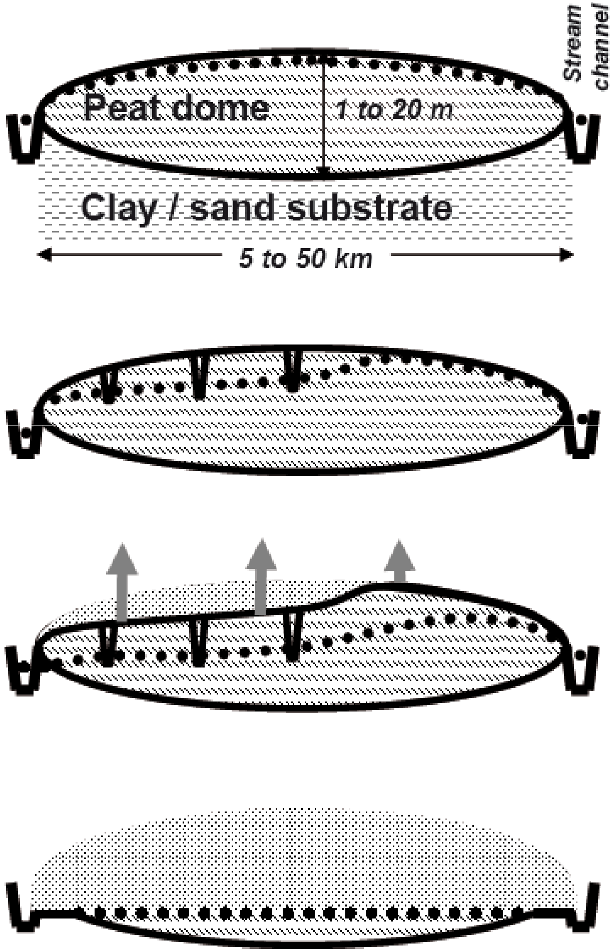
- First evidence for cooked food ~ 1.9 Ma.
- Intentional use of fire since ~ 400 ka.
- Evolution of humans originated in savannah regions which are among most fire-prone regions in the world
- Hunters and gatherers have used fires since ~10 ka to clear land and fertilize soils
- Most fires today (~ 90%) are caused by humans



Bowman et al. (2009)

Drainage of peat areas leads to fire susceptibility of carbon-rich soils

Bild: http://www.wetlands.org



<u>Natural situation:</u>
• Water table close to surface
• Peat accumulation from vegetation over thousands of years

<u>Drainage:</u>
• Water tables lowered
• Peat surface subsidence and CO_2 emission starts

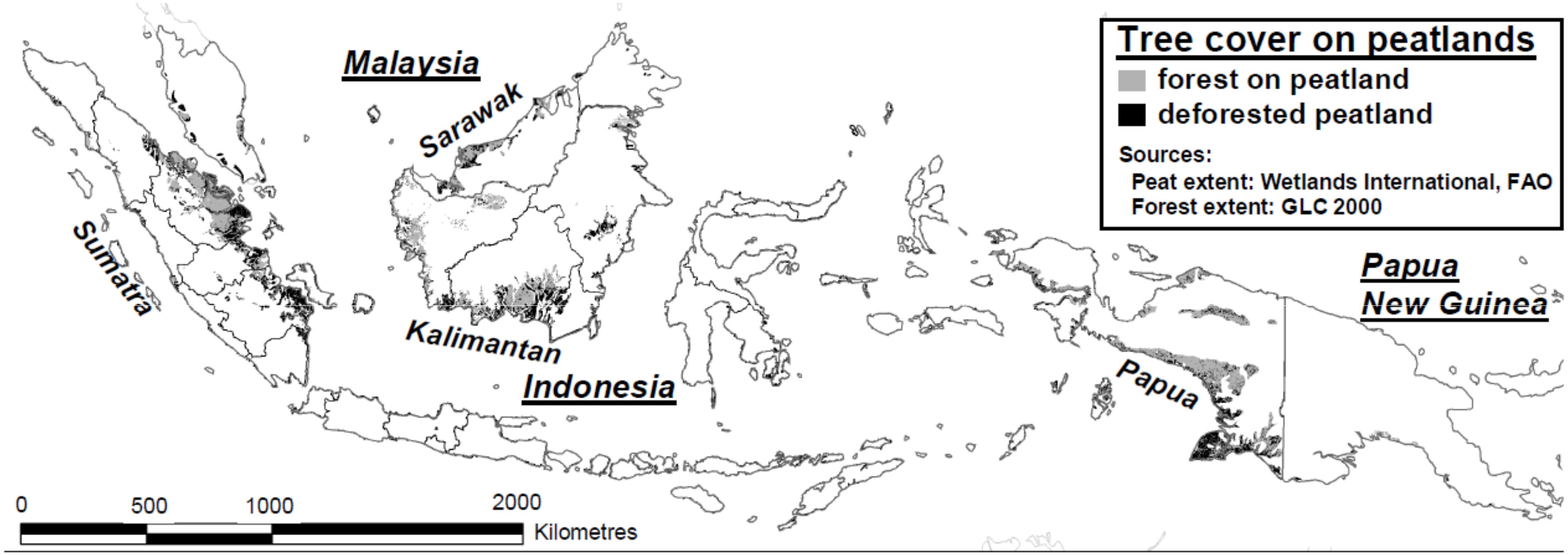
<u>Continued drainage:</u>
• Decomposition of dry peat: CO_2 emission
• High fire risk in dry peat: CO_2 emission
• Peat surface subsidence due to decomposition and compaction

<u>End stage:</u>
• Most peat carbon above drainage limit released to the atmosphere, unless conservation / mitigation measures are taken

Hooijer et al., 2010

Peat fires in Indonesia

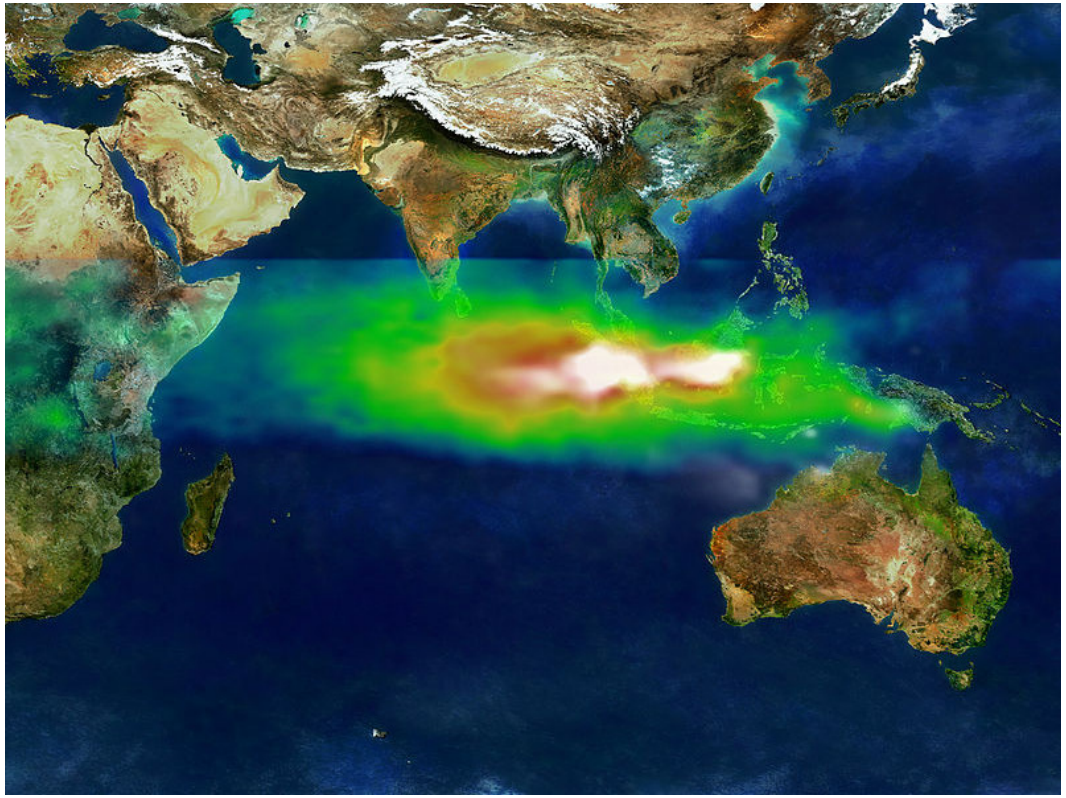
Annually, about 4,500 km^2 of forest burn in Indonesia
1997/98 about 70,000 km^2 were burned (=1/4 Germany)
By 2006 almost 50% of Indonesian rain forest was converted into plantations



CO_2 emissions from Indonesian fires in 1997 (~ 4 weeks) were
about 1/3 of global fire emissions in 1997 (full year) and
about 1/6 of the global emissions from fossil fuel in 1997 (full year)

Hooijer et al., 2010

Peat fires in Indonesia 1997



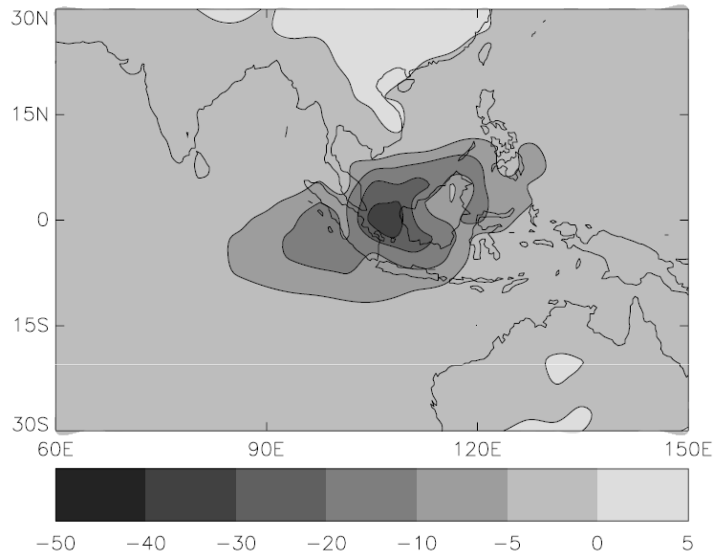
TOMS Aerosol Index

Peat fires in Indonesia 1997

Climate impacts:

Greenhouse gas emissions:
Fires on Sumatra and Kalimantan released about 4000 Mt CO_2

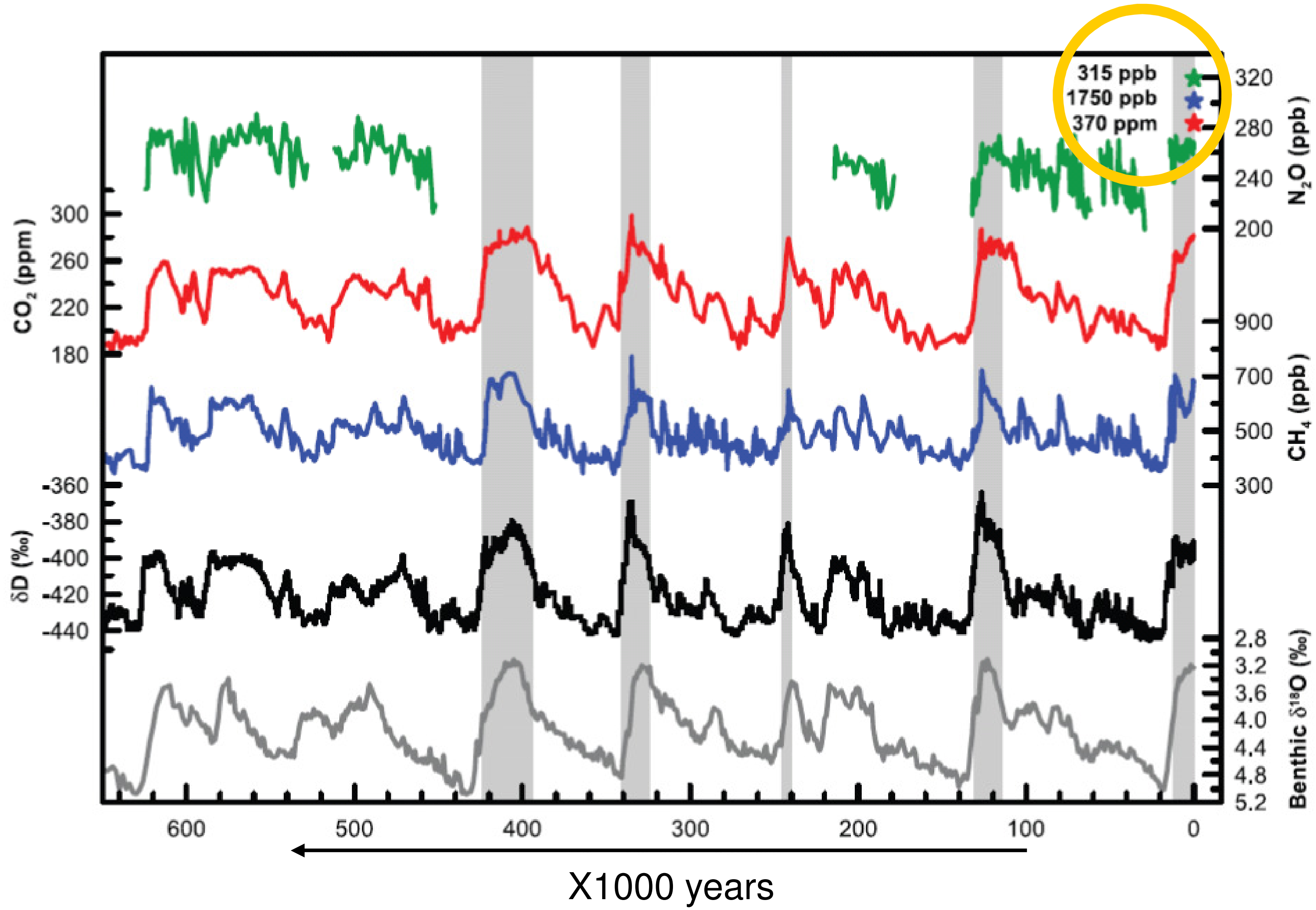
Smoke:
Direct radiative forcing of the smoke plume was up to -40 W/m^2 locally and about -0,3 W/m^2 global average



Top of atmosphere radiative forcing based on model calculations by the UK Met Office (Davison et al., 2004)

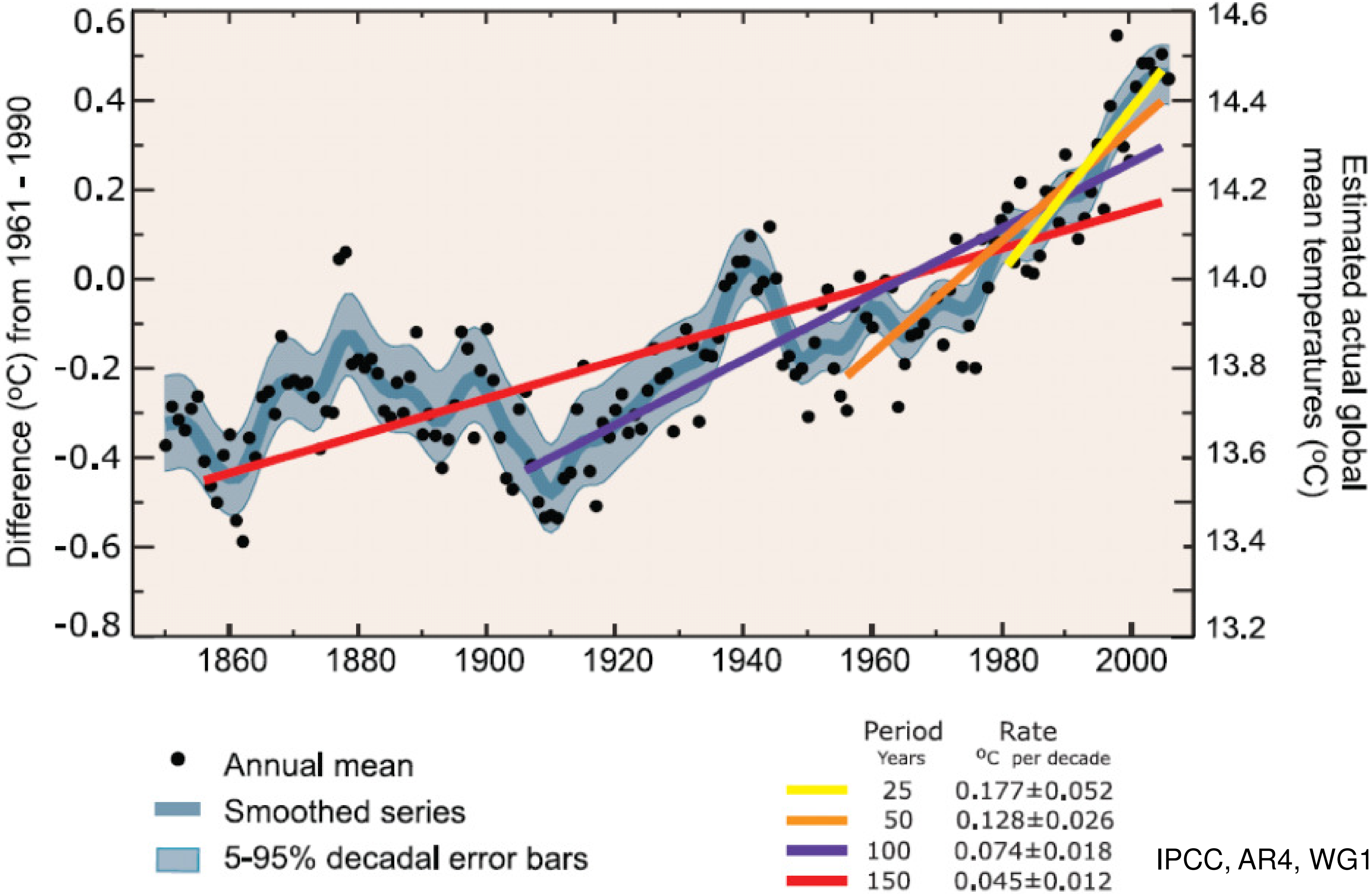
BASIC FACTS ABOUT CLIMATE CHANGE

Greenhouse gases over the past 600,000 years



IPCC, AR4

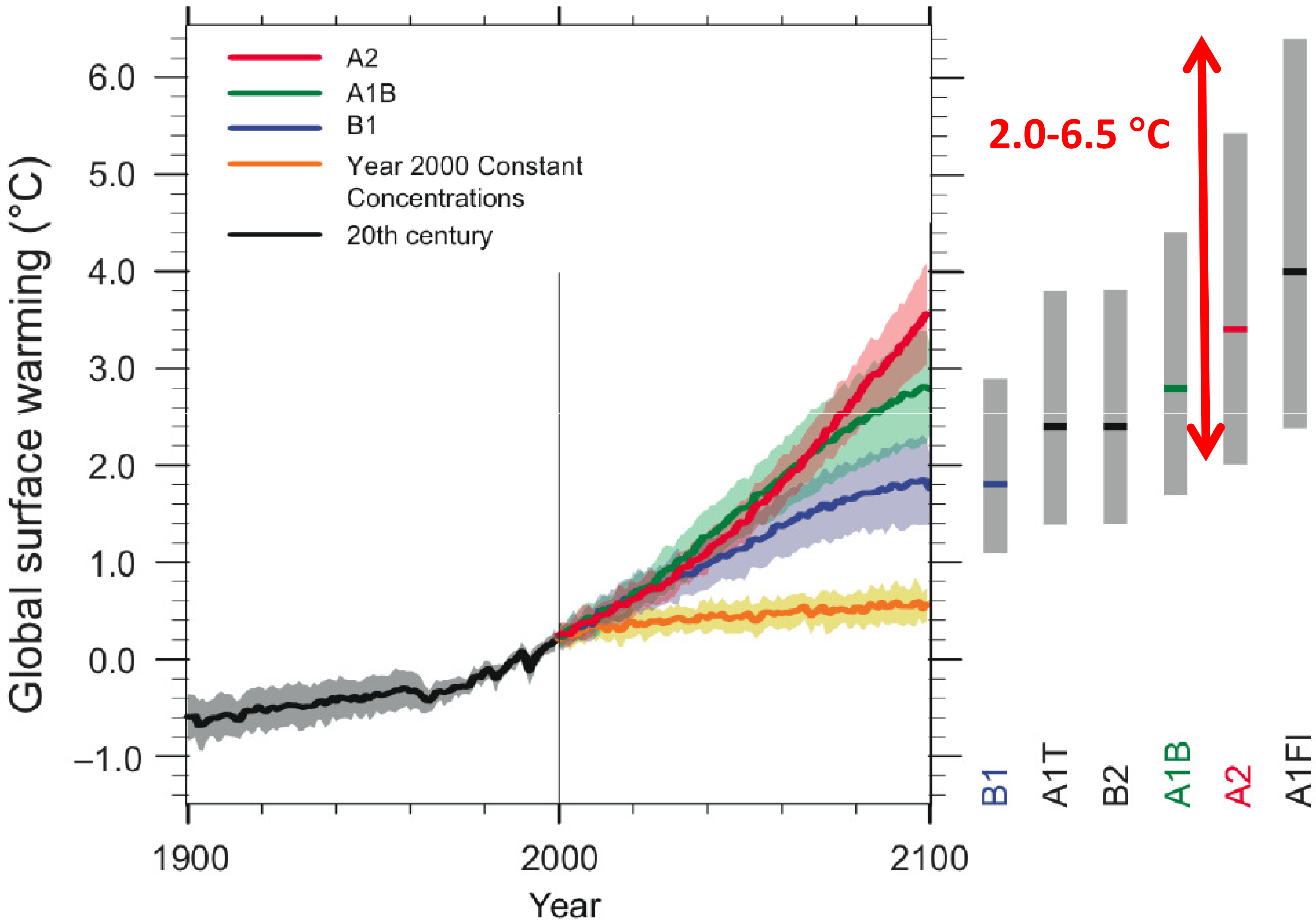
Global mean temperature at the surface



Period Years	Rate °C per decade
25	0.177±0.052
50	0.128±0.026
100	0.074±0.018
150	0.045±0.012

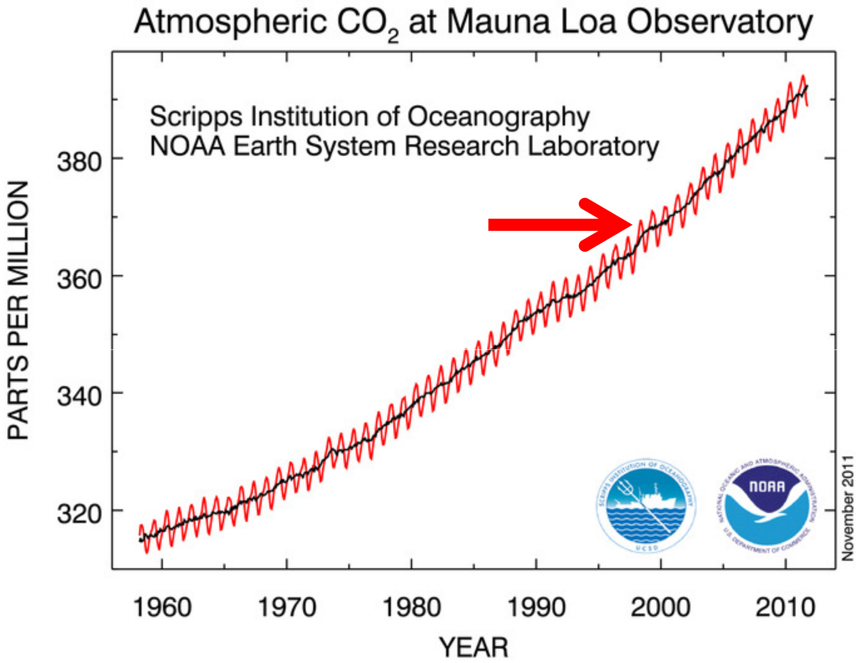
IPCC, AR4, WG1

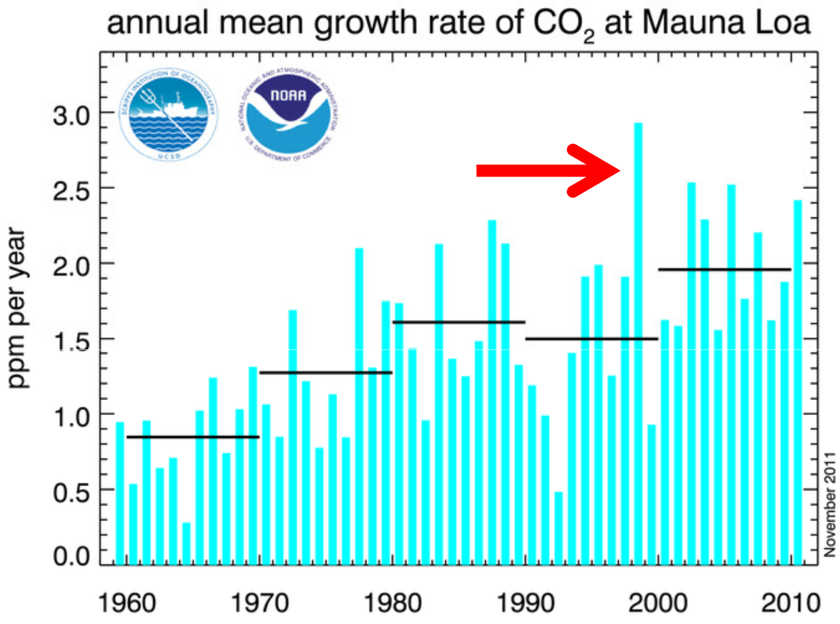
Future predictions of global mean surface temperature



IMPACT OF FIRES ON THE CLIMATE SYSTEM

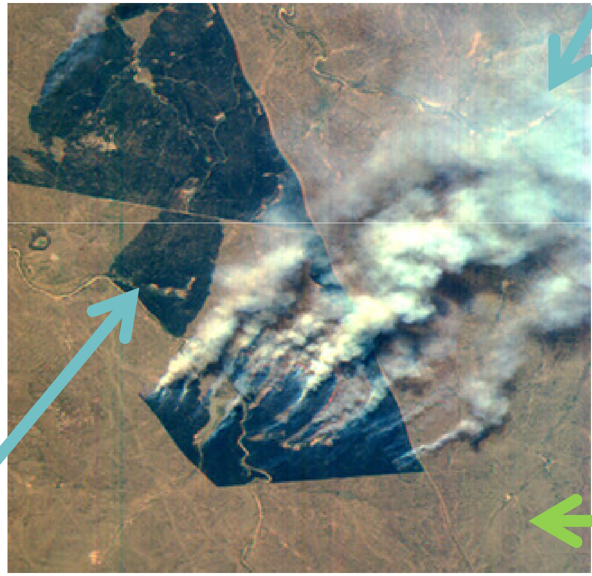
Are fires contributing to the observed increase in atmospheric CO_2?





How do fires impact the climate system?

Smoke plumes (light reflection, scattering); secondary cloud effects; emission of greenhouse gases

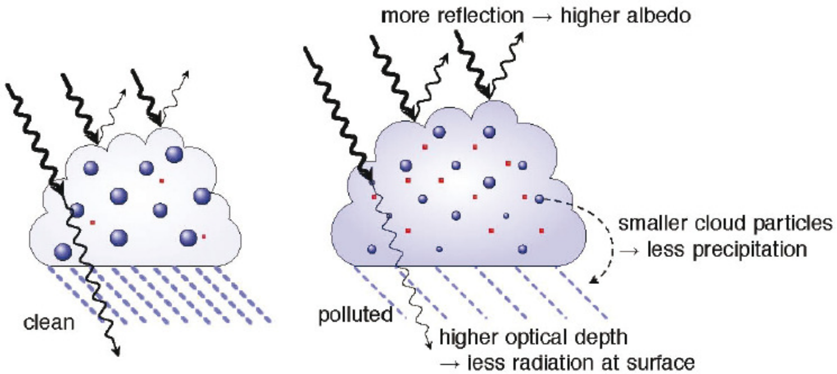


Plant regrowth after fire binds carbon from the atmosphere

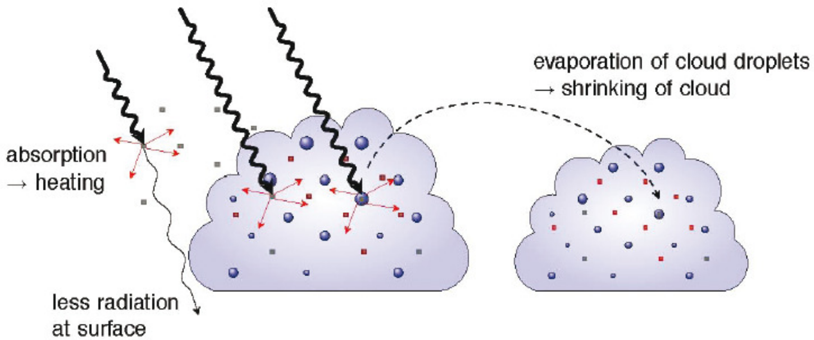
Change in albedo;
release of carbon dioxide;
changes in plant population

Aerosol-Cloud-Effects

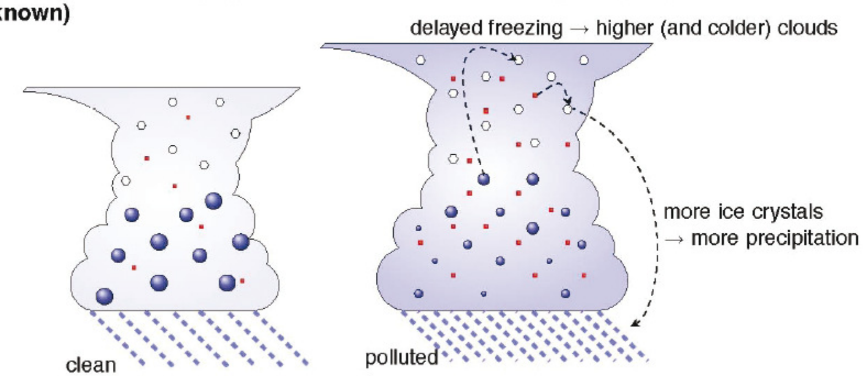
Cloud albedo and lifetime effect (negative radiative effect for warm clouds at TOA; less precipitation and less solar radiation at the surface)



Semi-direct effect (positive radiative effect at TOA for soot inside clouds, negative for soot above clouds)



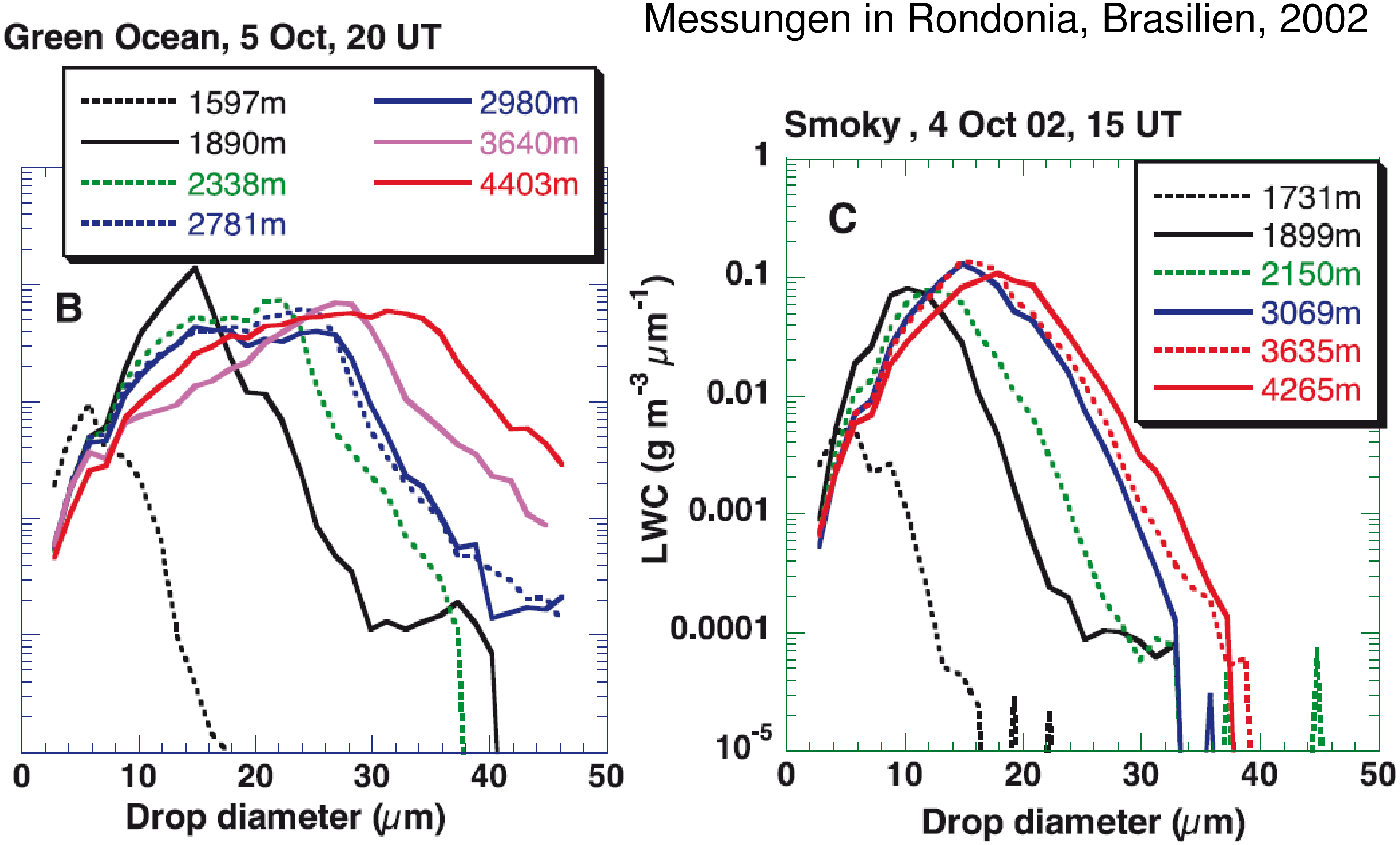
Glaciation effect (positive radiative effect at TOA and more precipitation), thermodynamic effect (sign of radiative effect and change in precipitation not yet known)



IPCC, 2007

Feedbacks Smoke – Clouds - Rain

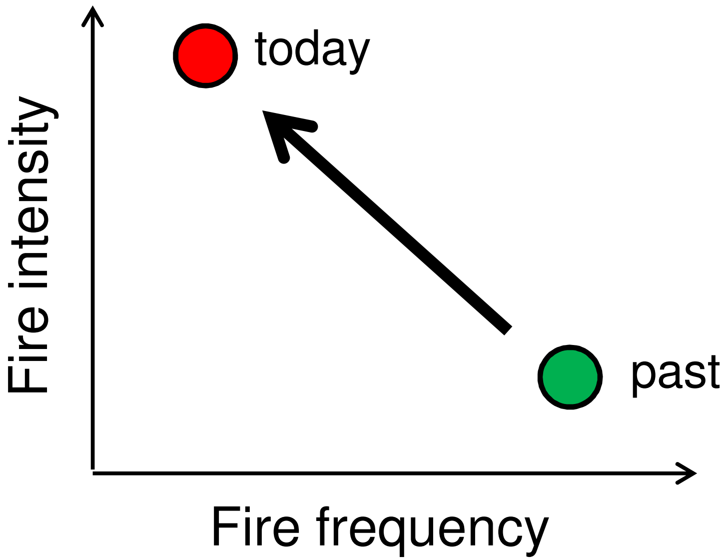
Messungen in Rondonia, Brasilien, 2002



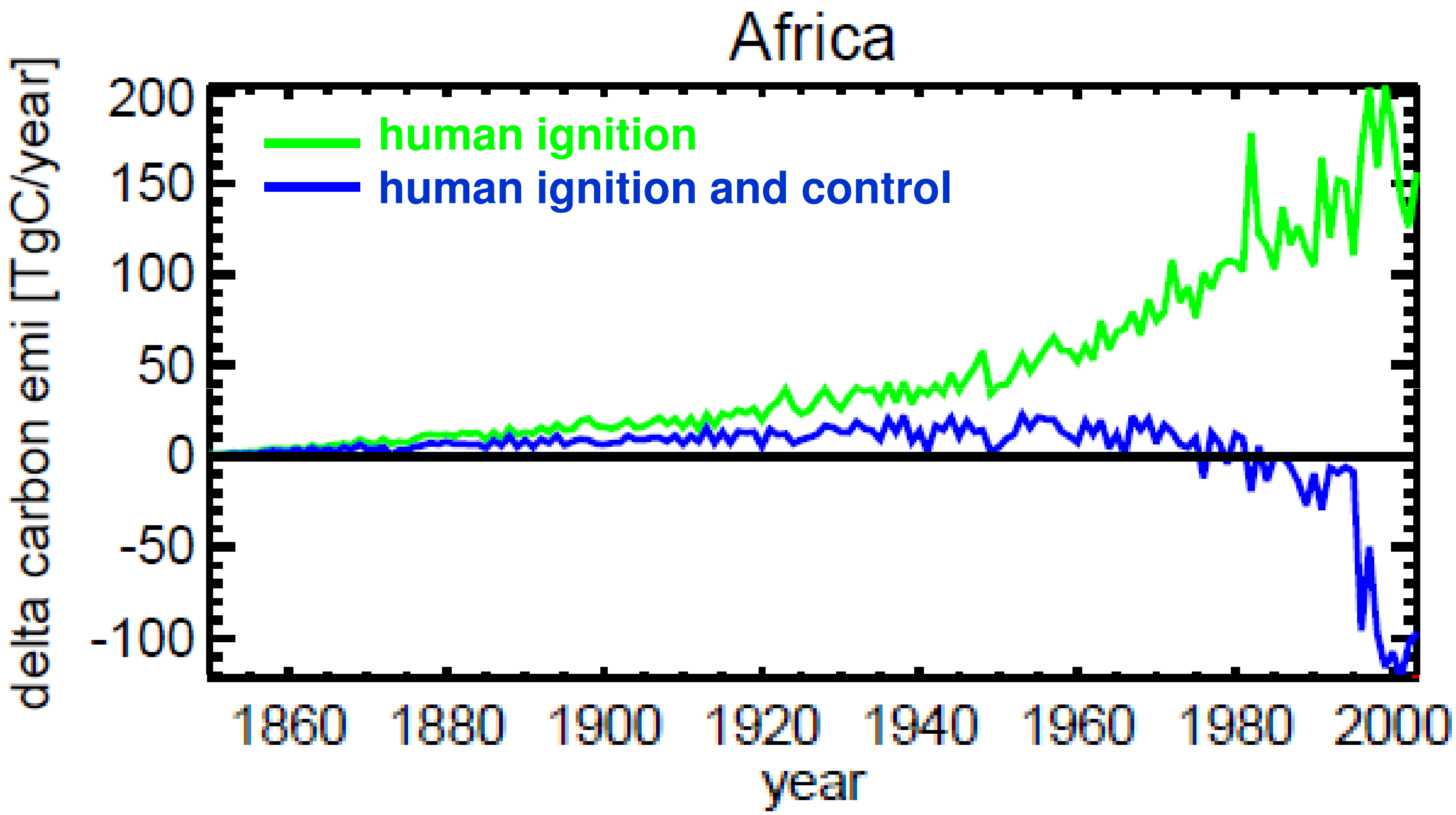
Andreae et al., 2004

HUMAN INFLUENCE ON FIRE ACTIVITY

Forest management impacts on fire frequency and fire severity

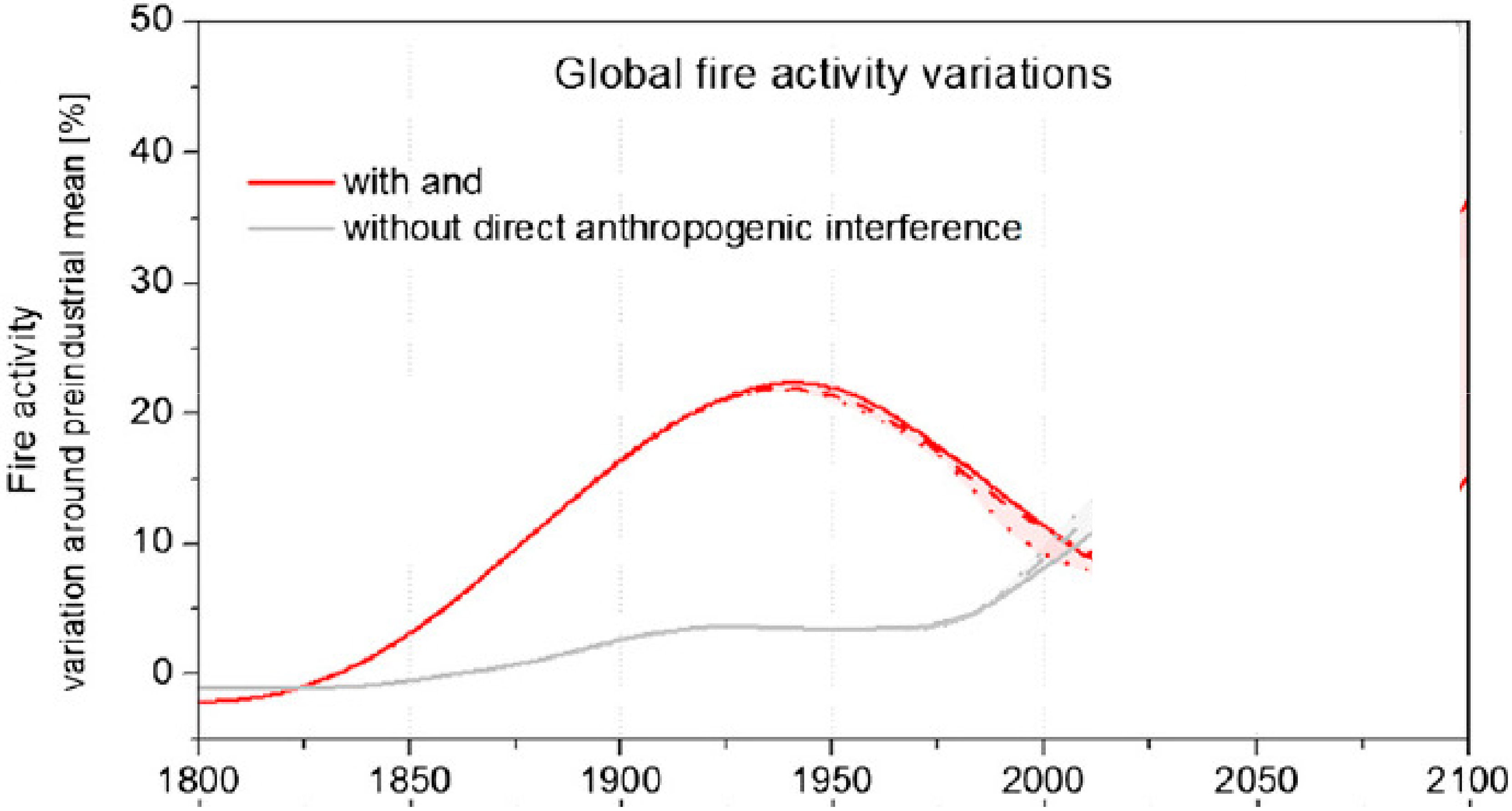


Human ignition and human fire prohibition



Kloster et al., 2010

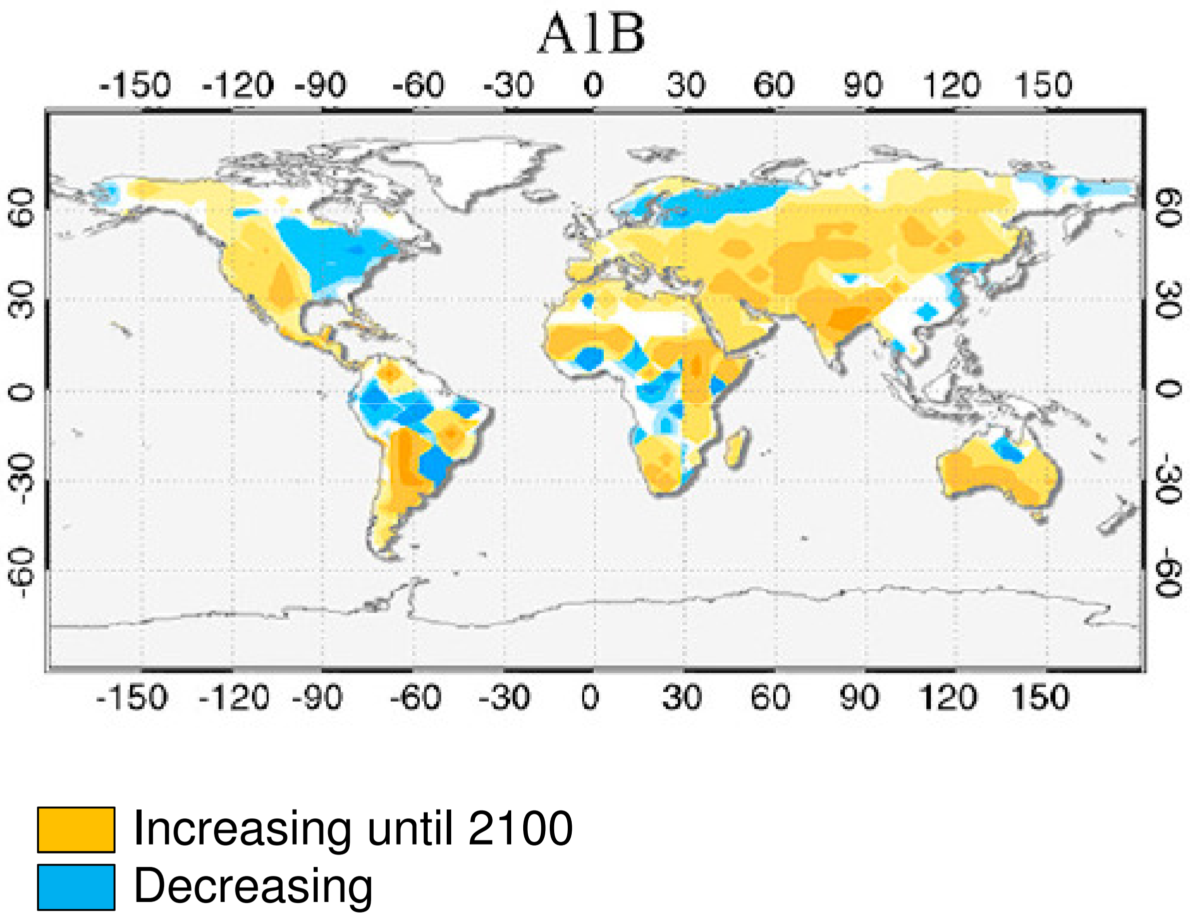
Simulated human influence on fire



Pechony and Shindell, 2010

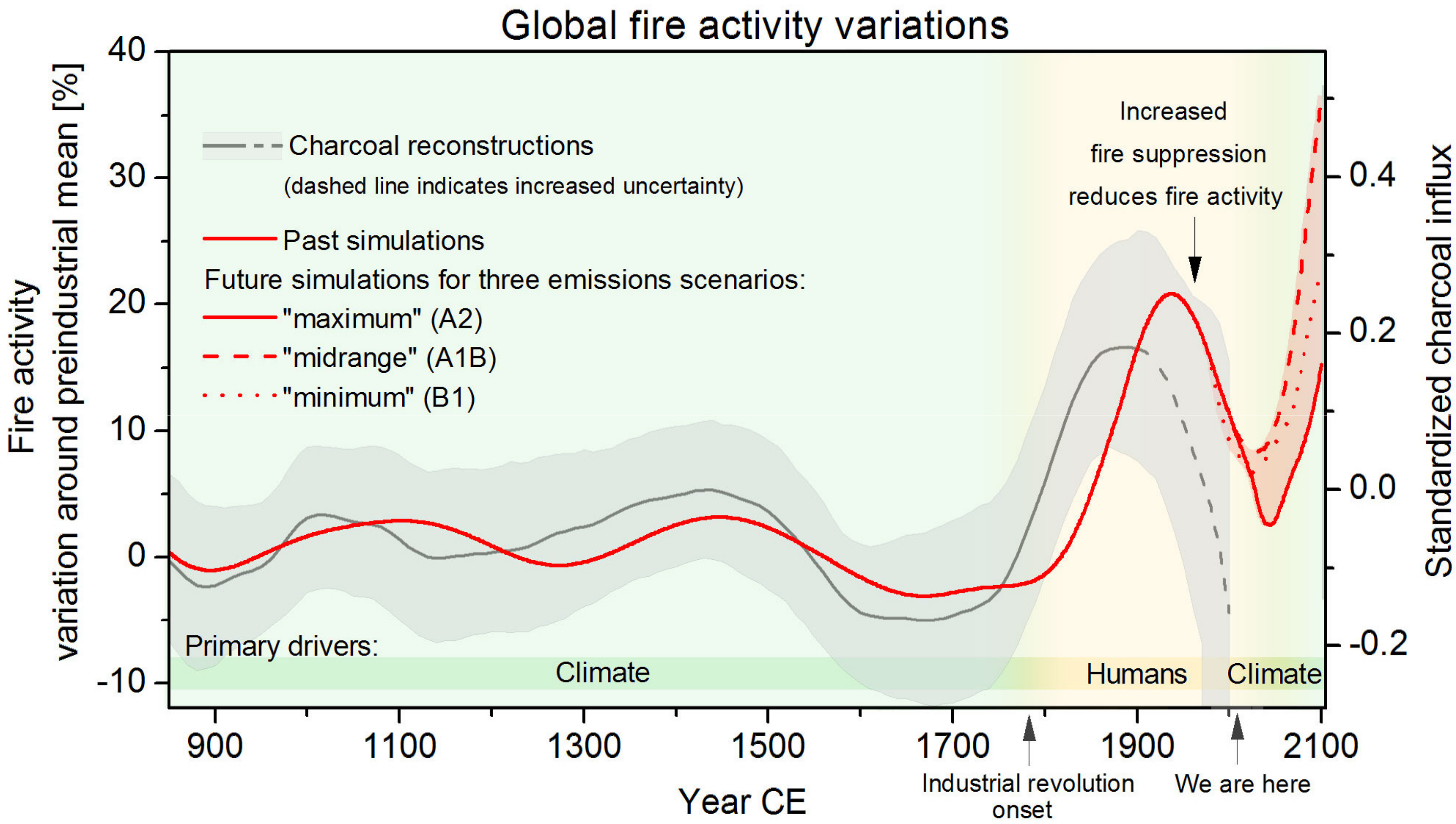
HOW WILL FIRES CHANGE IN THE FUTURE?

Simulated changes in fire frequency



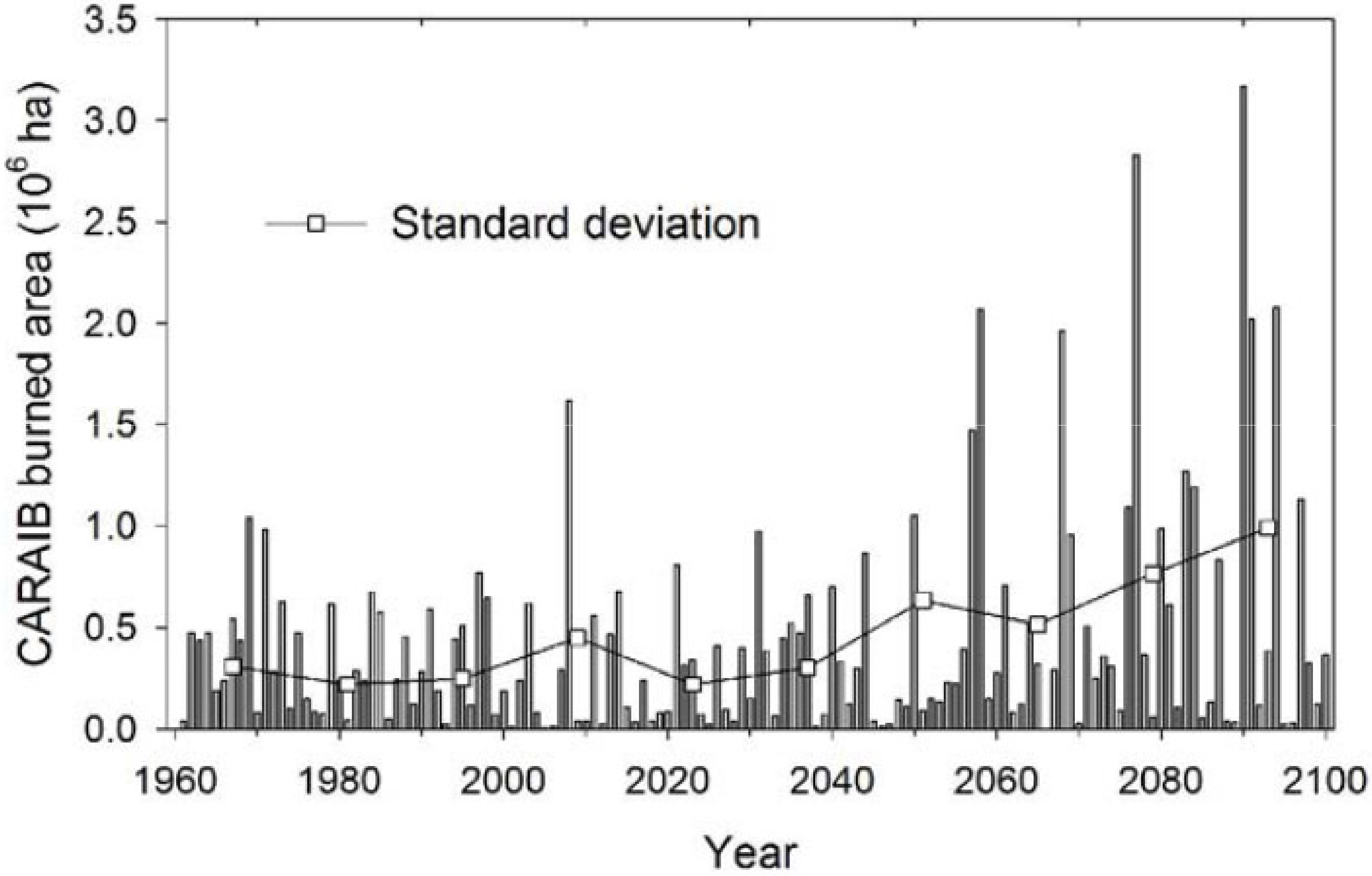
Pechony and Shindell, 2010

Climate will (again) be the main control factor



Pechony and Shindell, 2010

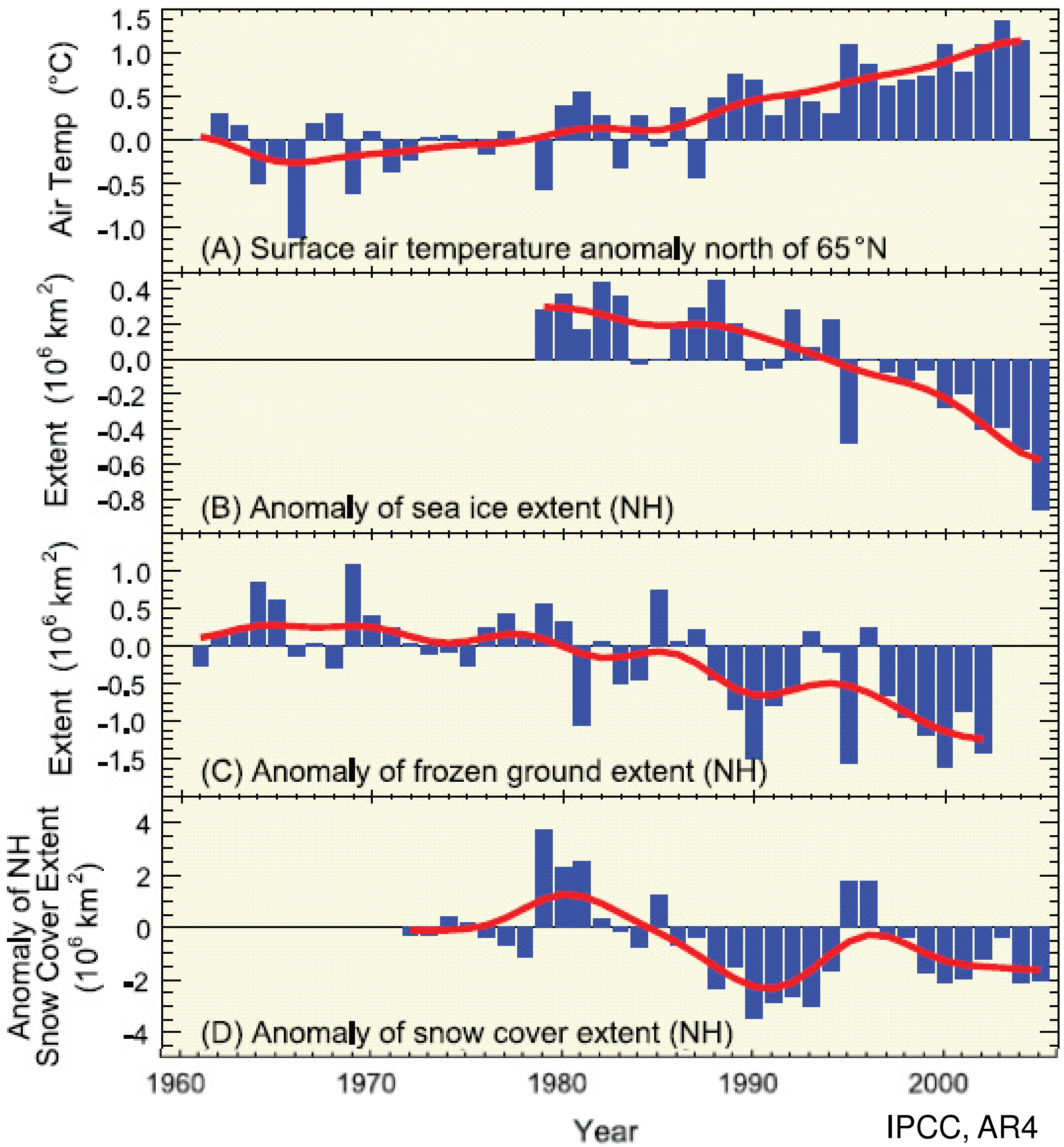
Projected changes in fire activity for the Mediterranean region



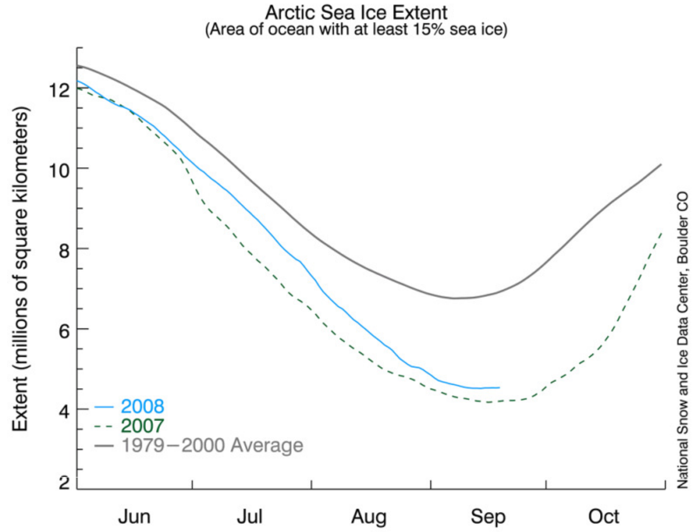
Dury et al., 2011

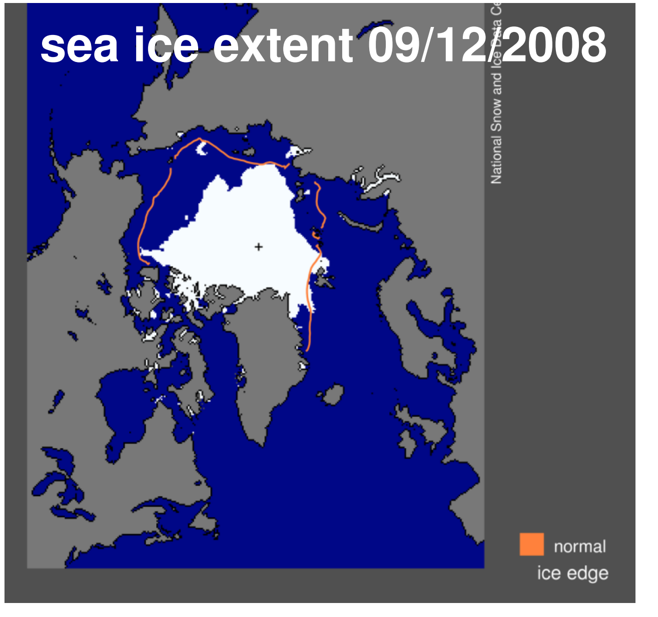
EXPECTED CHANGES IN FIRE REGIME FOR BOREAL FORESTS

Polar areas experience the strongest climate signal

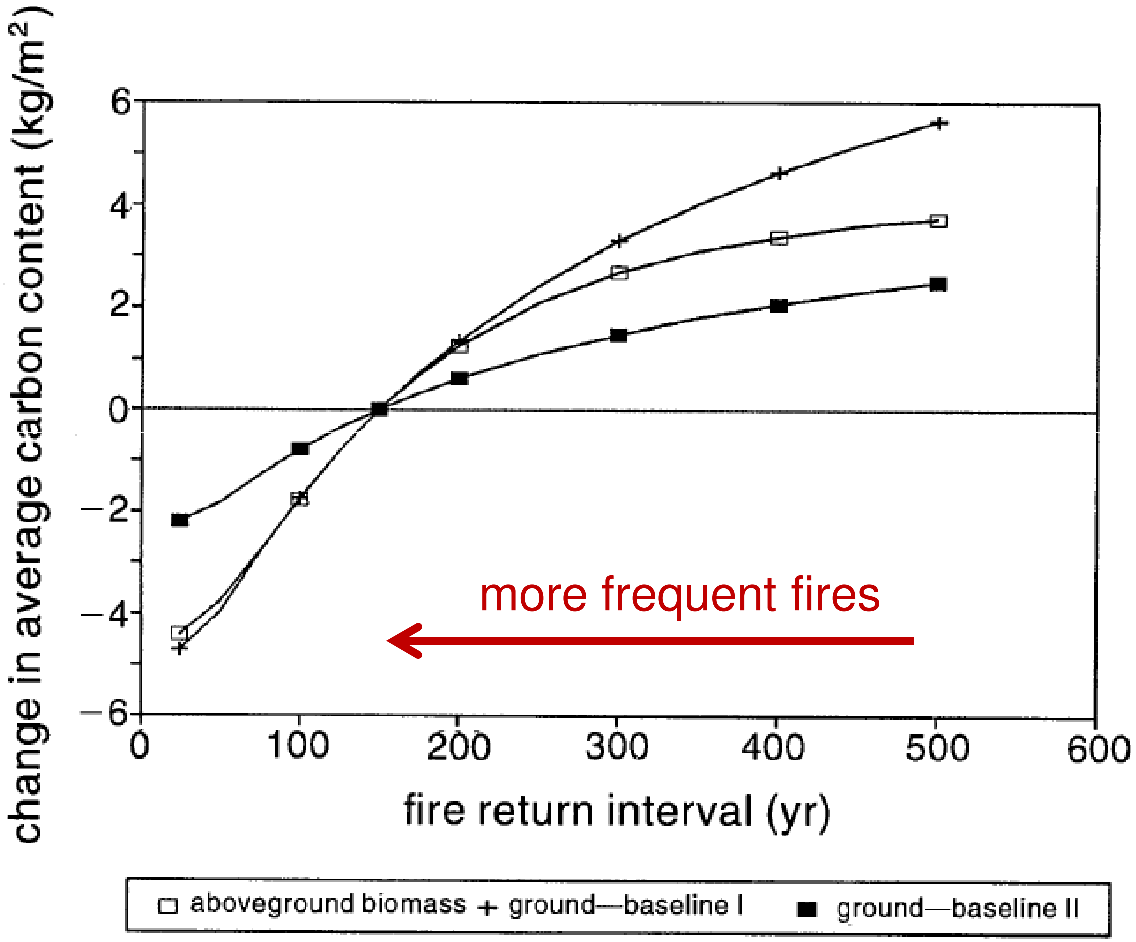


IPCC, AR4





(Boreal) forests will store less carbon when fire frequency increases

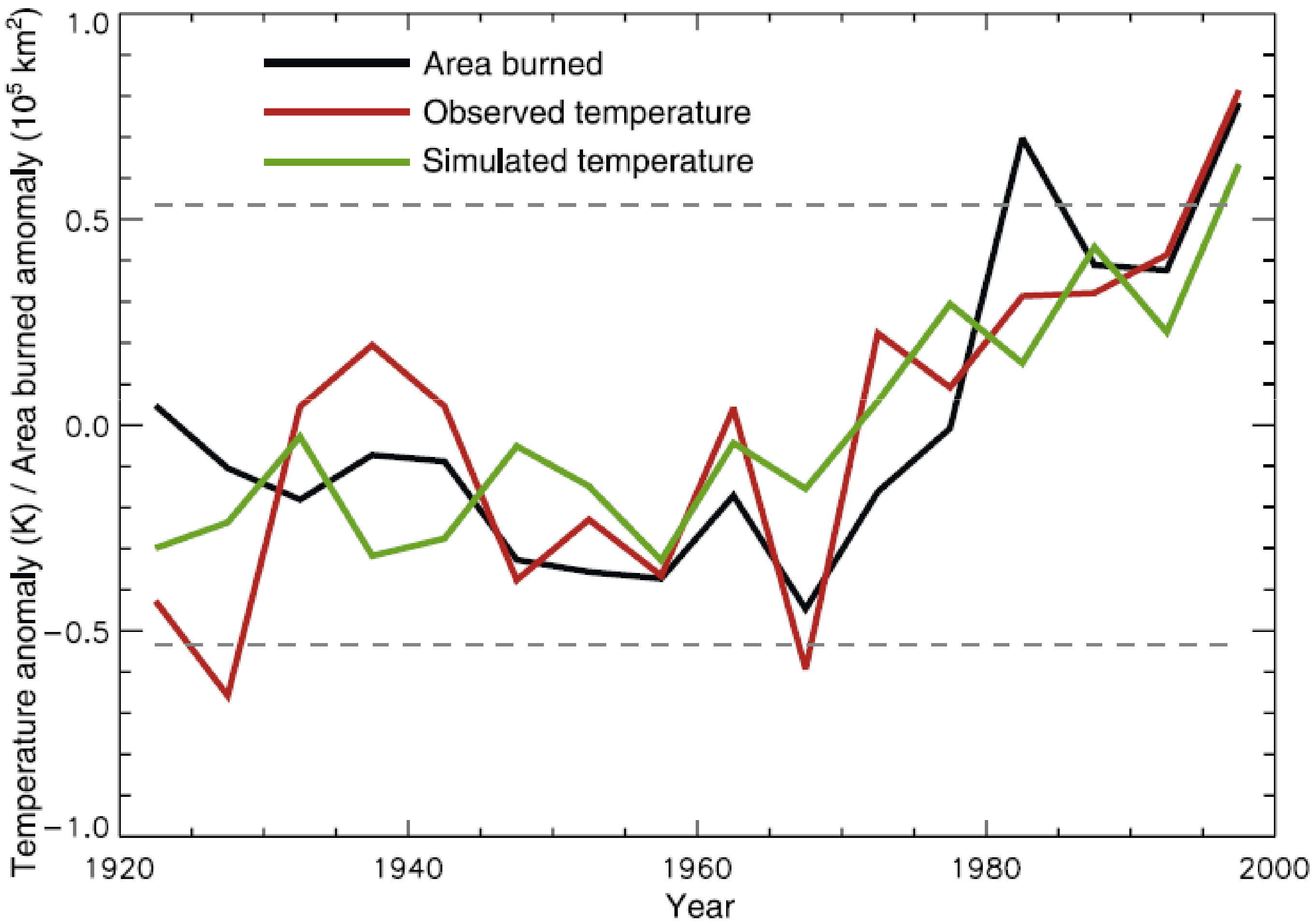


If life expectancy is lower, people will have a younger average age.

If trees are destroyed more frequently, the average age of the trees will be younger!

Kasischke et al., 1995

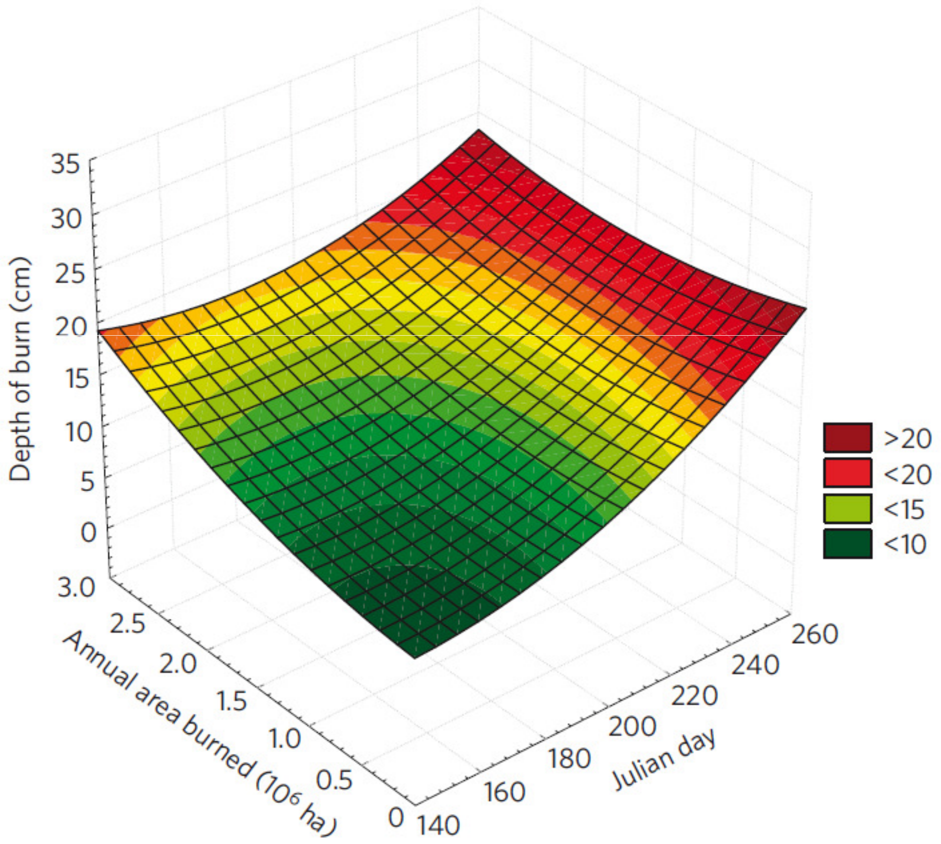
Climate change and boreal fires in Canada

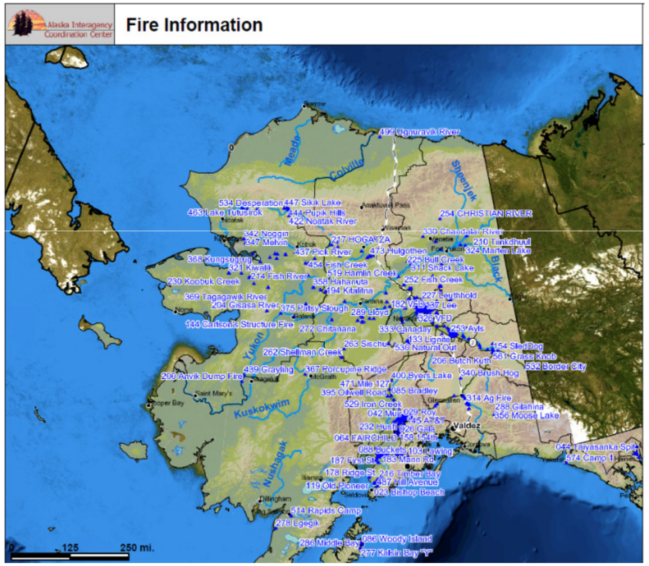


Gillett et al., 2004

Fire changes in the arctic region (Alaska)

Depth of soil burning in relation to burned area and day of fire

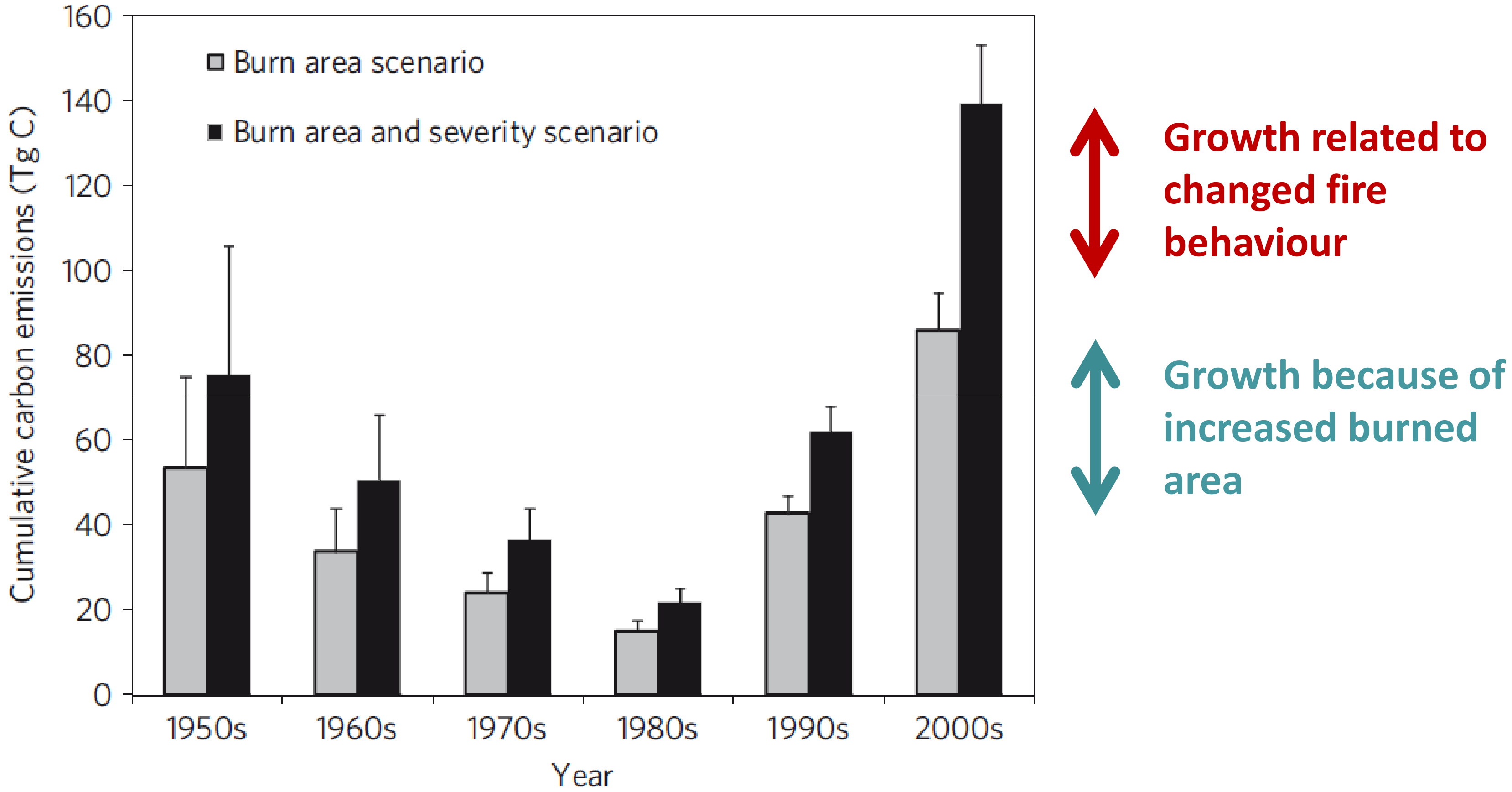




2011: 515 gemeldete Feuer in Alaska

Turetsky et al., 2010

Fire impacts change because of different factors



Annual CO_2 emissions: 1200-2900 Mt

Turetsky et al., 2010; Kaschischke et al., 1995

Conclusions

- Open burning of vegetation plays an important role for global trace gas and aerosol emissions and it influences climate in several ways
- Both natural and anthropogenic factors influence fire occurence and fire sevirity
- Humans have exerted a noticeable influence on global fire occurence during past decades
- Climate change will have serious implications for forest burning – particularly in boreal regions
- Characterization and quantification of fire impact still has very large uncertainties

References (1):

- Andreae, M.O. et al., Smoking Rain Clouds over the Amazon, Science, 303, 1337-1402, 2004.
- Bowman, D.M.J.S., Fire in the Earth System, Science, 324, 481-484, 2009.
- Brown, J.K. and J.K. Smith, Wildland fire in ecosystems: effects of fire on flora, Gen. Tech. Rep. RMRS-GTR-42-vol. 2. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 257 p., 2000.
- Davison, P.S. et al., Estimating the direct radiative forcing due to haze from the 1997 forest fires in Indonesia, J. Geophys. Res., 109, D10207, 2004.
- Dury, M. et al., Responses of European forest ecosystems to 21st century climate: assessing changes in interannual variability and fire intensity, iForest, 4, 82-99, 2011.
- Gillett, N.P. et al., Detecting the effect of climate change on Canadian forest fires, Geophys. Res. Lett., 31, L18211, 2004.
- Hooijer, A. et al., Current and future CO2 emissions from drained peatlands in Southeast Asia , Biogeosciences, 7, 1505–1514, 2010.
- Kasischke, E. et al., Fire, Global Warming, and the Carbon Balance of Boreal Forests, Ecological Applications, 5(2), 437-451, 1995.
- Kehrwald, N. et al., Fire and climate: Biomass burning recorded in ice and lake cores, EPJ Web of Conferences 9, 105–114, 2010.
- Kloster, S. et al., Fire dynamics during the 20th century simulated by the Community Land Model, Biogeosciences, 7, 1877–1902, 2010.
- LePage et al., Global fire activity patterns (1996–2006) and climatic influence: an analysis using the World Fire Atlas, Atmos. Chem. Phys., 8, 1911–1924, 2008

References (2):

- Marlon et al.: Climate and human influences on global biomass burning over the past two millennia, Nature Geoscience 1, 697–702, 2009.
- Moulliot, F. and C.B. Field, Fire history and the global carbon budget: a 1x1 fire history reconstruction for the 20th century, Global Change Biology, 11, 398–420, 2005.
- Pausas, J.G., J.E. Keeley, A Burning Story: The Role of Fire in the History of Life, Bioscience, 59/7, 593-601, 2009.
- Pechony O.; Shindell D. T., Driving forces of global wildfires over the past millennium and the forthcoming century, Proceedings of the National Academy of Sciences of the United States of America, 107, 45, pp. 19167-19170, 2010.
- Power, M.J., Changes in fire regimes since the Last Glacial Maximum: an assessment based on a global synthesis and analysis of charcoal data, Clim Dyn, 30, 887–907, 2008.
- Schultz, M.G. et al., Global wildland fire emissions from 1960 to 2000, Global Biogeochem. Cyc., 22, GB2002, 2008.
- Sommer, J.H. et al., Projected impacts of climate change on regional capacities for global plant species richness, Proc. R. Soc. B, 277, 2271–2280, 2010.
- Thonicke, K. et al., Modeling glacial-interglacial changes in global fire regimes and trace gas emissions, Global Biogeochem. Cyc., 19, GB3008, 2005.
- Turetsky, M.R., Recent acceleration of biomass burning and carbon losses in Alaskan forests and peatlands, Nature Geosciences, 1027, 27-31, 2010.
- van der Werf, G.R. et al., Climate controls on the variability of fires in the tropics and subtropics, Global Biogeochem. Cyc., 22, GB3028, 2008.