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

- Savannas (3160)
- Domestic fuel (2660)
- Agricultural waste (1190)
- Charcoal prod. & use (200)
- Tropical Forest (1330)
- Extratropical Forest (640)

annual total: 9200 Mio. t

Comparison: worldwide wood trade 2005: ~ 300 Mio. t (600 Mio. m³)

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 km²) burned area
- 25,000 fire fighters were unable to extinguish fires (costs: 120 mio US $)
Open burning comes in many different forms

What is burning?

Trees: branches, stems, crowns

Surface: (dead) leaves, twigs, branches, bushes

Soil: roots, humus
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

http://www.guardian.co.uk/world/gallery/2010/aug/06
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/m$^3$) Virolahti, Finland

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…*

**Fire Weather Index = 17**
- Carbon release: 7.5 t/ha

**Fire Weather Index = 34**
- Carbon release: 19.5 t/ha

Source: W.J. de Groot
Global anthropogenic greenhouse gas emissions 2004

- CO₂ fossil fuel use: 56.6%
- CO₂ (other): 2.8%
- CO₂ (deforestation, decay of biomass, etc): 17.3%
- CH₄: 14.3%
- N₂O: 7.9%
- F-gases: 1.1%
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

VGT              ETM+              “validation”

PREREQUISITES FOR OPEN BURNING
Global fire occurrence

MODIS Land Rapid Response Fire Detections

April 2002

Legend
- MODIS Fire Detections from the Terra Satellite
- World Countries
Global Distribution of Frequency of Open Burning

Globally about 3-4 million km² are burned annually (= land area of India)

Bowman et al., 2009
Conditions for open burning

- Growth
- Fuel structure
- Seasonality
- Ignition source

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
Natural situation:
- Water table close to surface
- Peat accumulation from vegetation over thousands of years

Drainage:
- Water tables lowered
- Peat surface subsidence and CO₂ emission starts

Continued drainage:
- Decomposition of dry peat:
  - CO₂ emission
- High fire risk in dry peat:
  - CO₂ emission
- Peat surface subsidence due to decomposition and compaction

End stage:
- 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 km² of forest burn in Indonesia. 1997/98 about 70,000 km² were burned (=1/4 Germany). By 2006 almost 50% of Indonesian rain forest was converted into plantations.

CO₂ 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

![Graph showing global mean temperature trends from 1860 to 2000.](image)

- **Annual mean**
- **Smoothed series**
- **5-95% decadal error bars**

<table>
<thead>
<tr>
<th>Period</th>
<th>Rate °C per decade</th>
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<tr>
<td>25</td>
<td>0.177±0.052</td>
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<tr>
<td>50</td>
<td>0.128±0.026</td>
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<tr>
<td>100</td>
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<tr>
<td>150</td>
<td>0.045±0.012</td>
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</tbody>
</table>

IPCC, AR4, WG1
Future predictions of global mean surface temperature

- A2
- A1B
- B1
- Year 2000 Constant Concentrations
- 20th century

2.0-6.5 °C
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

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

- Plant regrowth after fire binds carbon from the atmosphere
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

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

(A) Surface air temperature anomaly north of 65°N

(B) Anomaly of sea ice extent (NH)

(C) Anomaly of frozen ground extent (NH)

(D) Anomaly of snow cover extent (NH)

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

Turetsky et al., 2010

2011: 515 gemeldete Feuer in Alaska
Fire impacts change because of different factors

Growth related to changed fire behaviour

Growth because of increased burned area

Annual CO₂ 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 occurrence and fire severity.

• Humans have exerted a noticeable influence on global fire occurrence 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):

- 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.
References (2):

- Marlon et al.: Climate and human influences on global biomass burning over the past two millennia, Nature Geoscience 1, 697–702, 2009.