Smouldering Mega-fires in peatlands and positive feedbacks to the Climate System

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THE UNIVERSITY OF EDINBURGH

Session on *Impact of Peatland Fires on Ecosystem Function and Feedbacks to Climate*

9th INTECOL INTERNATIONAL WETLANDS CONFERENCE

WETLANDS IN A COMPLEX WORLD

JUNE 3-8, 2012
ORLANDO FLORIDA, USA

NYT "Smoke Shrouds Moscow as Peat-bog fire rages"

@ New York Times, 1972

MOSCOW, Aug. 8 -- Many Muscovites are wiping tears from their eyes these days, not because Boris Spassky is trailing Bobby Fischer in the world chess championship, but because of smoke from a forest and peat-bog fire about 50 miles east of the capital.

Past Errors to Blame for Russia's Peat Fires

James Hill for The New York Times

Firemen and soldiers tried to put out a smoldering fire in a forest planted in a peat field near the town of Elektrogorsk.

The New York Times

By ANDREW E. KRAMER

Published: August 12, 2010

RECOMMEND

TWITTER

ELEKTROGORSK, Russia — For two weeks, soldiers with chain saws felled every tree in sight.

@ New York Times, 2010

1972:

THE MILWAUKEE JOURNAL EDITION

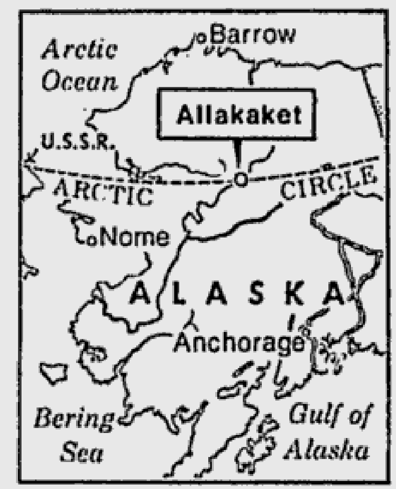
90th Year, Founded 1882 Wednesday, August 9, 1972 © 1972, The Journal Company

Alaska, Russia Battle Blazes

From Press Dispatches

A series of fires caused by lightning burned Tuesday through 250,000 acres of central Alaska wilderness. Flames often disappeared underground to erupt later on the surface.

A spokesman said only 700 men were available and fighting 24 of 45 fires, the largest one covering 200,000 acres just south of the village of Allakaket on the Koyukuk River.



Meanwhile, thousands of Soviet soldiers, firemen and civilians battled peat and forest fires about 80 miles east of Moscow. By Tuesday night, the fires reportedly had engulfed 9,000 acres.

Burning of natural organic soils

Organic soils, Italy

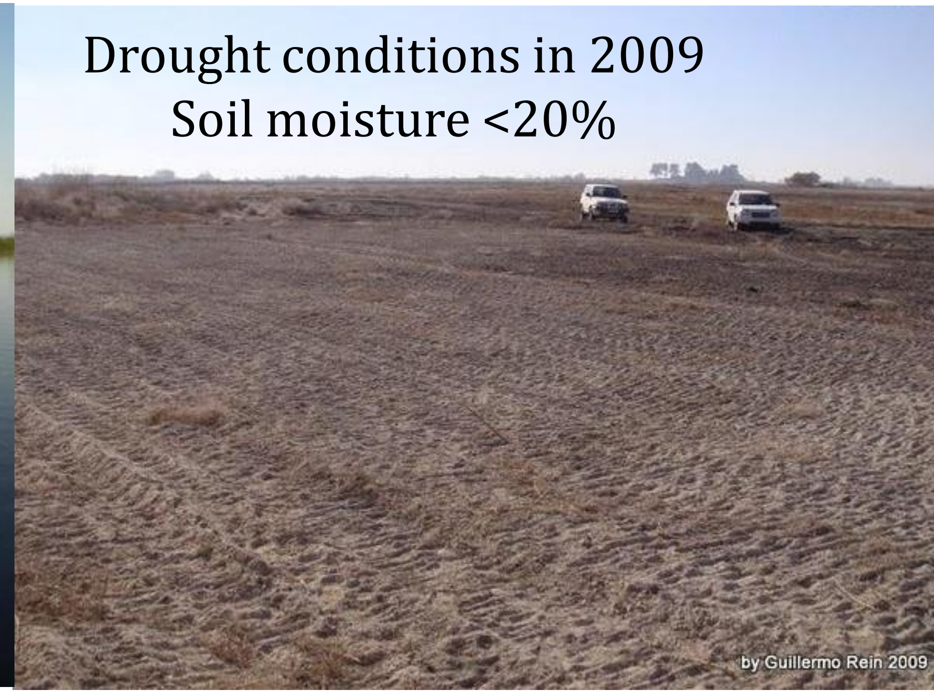
Past Errors to Blame for Russia's Peat Fires

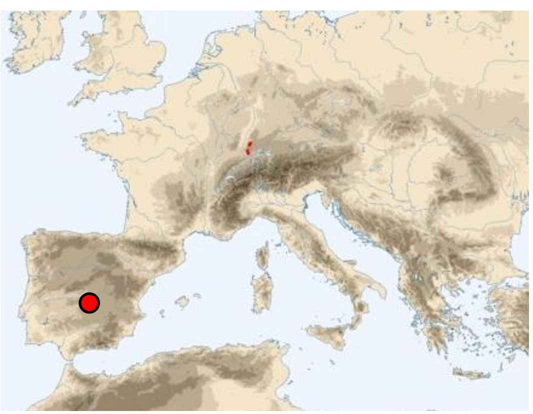

Moscow fires the summer of 2010

Daimiel, Spain


Rothiemurchus, Scotland

Case Study: **2009 Las Tablas de Daimiel National Park, Spain**





- Exceptional case of Southern European wetlands
- Smallest National park in Spain
- Surface area 1,680 ha (11 x 3 km)
- Peat average depth up to 5 m (average 0.91 m)

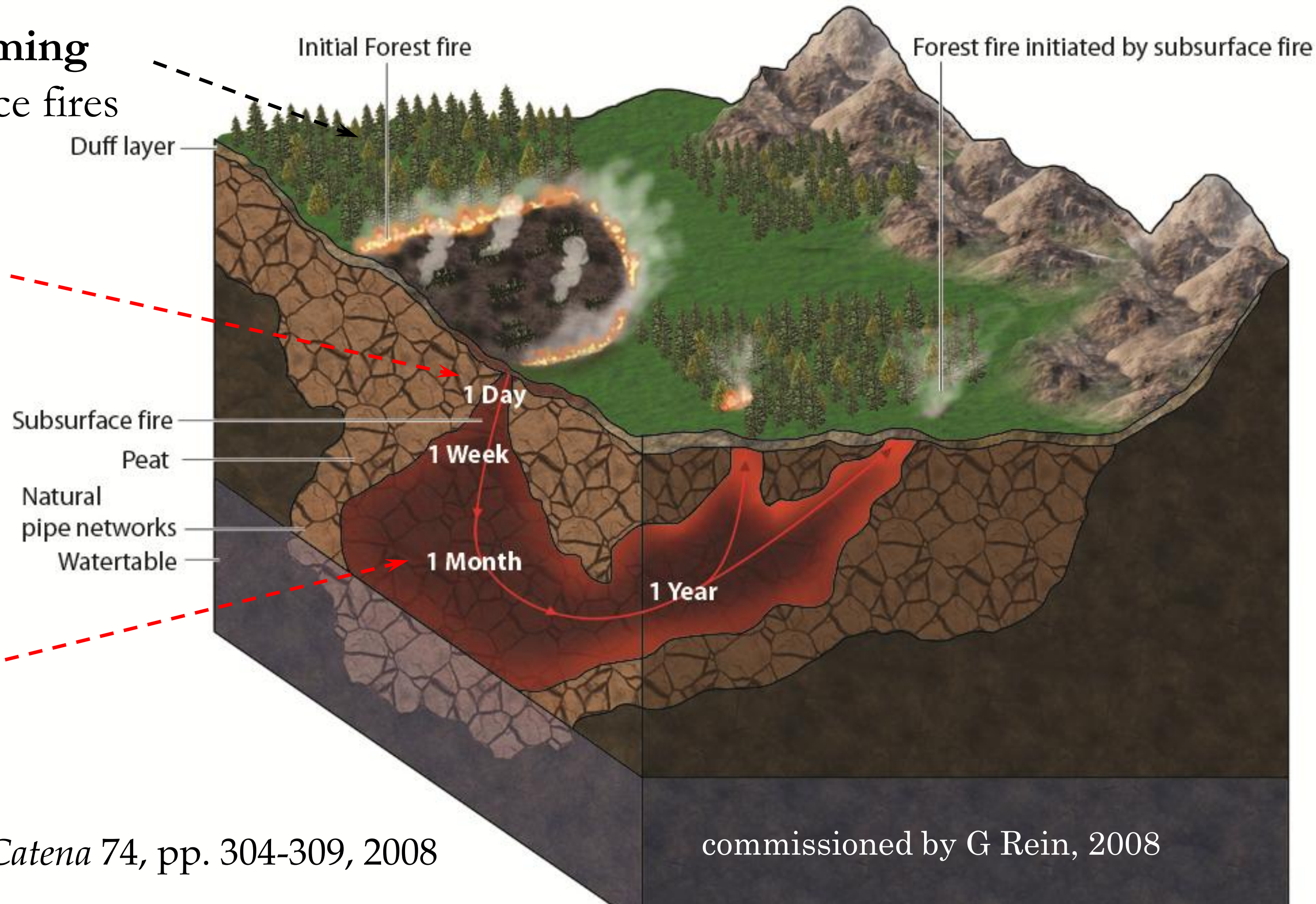
Peat fires – Shallow and Deep

1. Composition – *organic content, water content, inert content*
2. Oxygen availability – *free surface, cracks/channels, galleries*
3. Heat losses – *convection, radiation, conduction, thermal mass*

Flaming surface fires

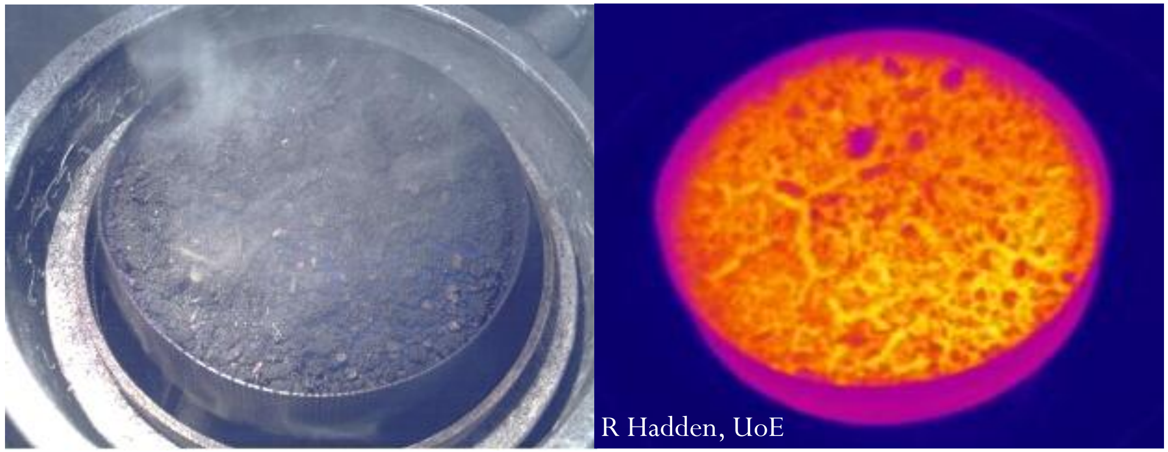
<1m **Shallow** fires

>1m **Deep** fires



Rein et al. *Catena* 74, pp. 304-309, 2008

Smouldering Combustion



- Flameless
- Low peak temperature ~600°C
- Low heat of combustion ~5 kJ/g
- Creeping propagation ~1 mm/min
- Incomplete combustion
- Heterogeneous combustion on fuel surface (pores)
- Fuels: peat, coal, duff, organic soils
- Two-step combustion reaction:

$$Peat \xrightarrow{heat} char + \sum \left(volatiles, CH_4, PAH \right)$$

$$Char + O_2 \rightarrow heat + ash + CO_2 + CO + H_2O$$

Rein, *Int Review Chemical Engineering* 2009

Hadden et al, *Proc Combustion Institute* 2012

Most persistent fires on Earth

- **Smouldering fires are the easiest to ignite**
  - Ignition with much smaller heat sources (8 vs. 15 kW/m^2)
  - Self-heating possible at ambient temperatures (ie, 30 ^{o}C)

- **Smouldering fires are most difficult to suppress**
  - Larger amounts of water (>50% larger kg_{H2O}/kg_{fuel})
  - Lower critical oxygen concentration (10% [O_2] vs. 16%)
  - Much longer smothering holding times (~months vs. min)

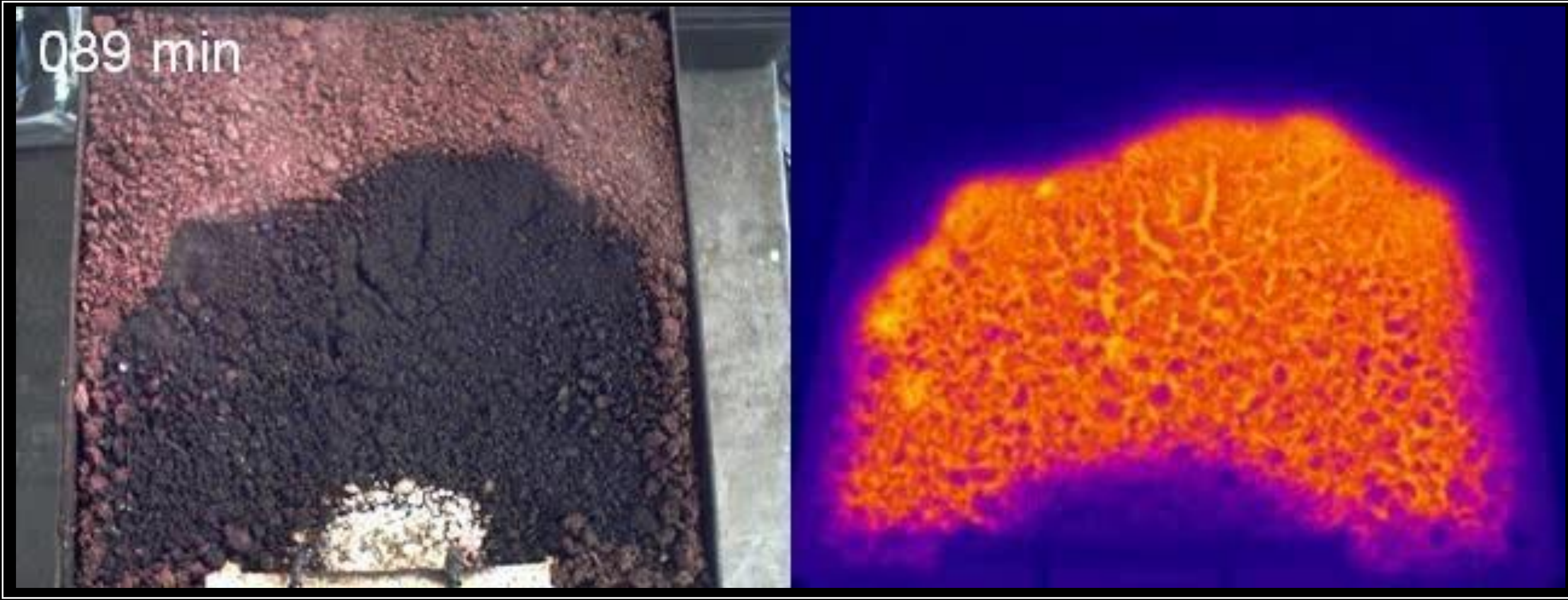
- The **oldest** continuously burning fire on Earth is a smouldering coal seam in Australia ignited >6,000 years old

Rein, *Int Review Chemical Engineering* 2009

Smouldering spread

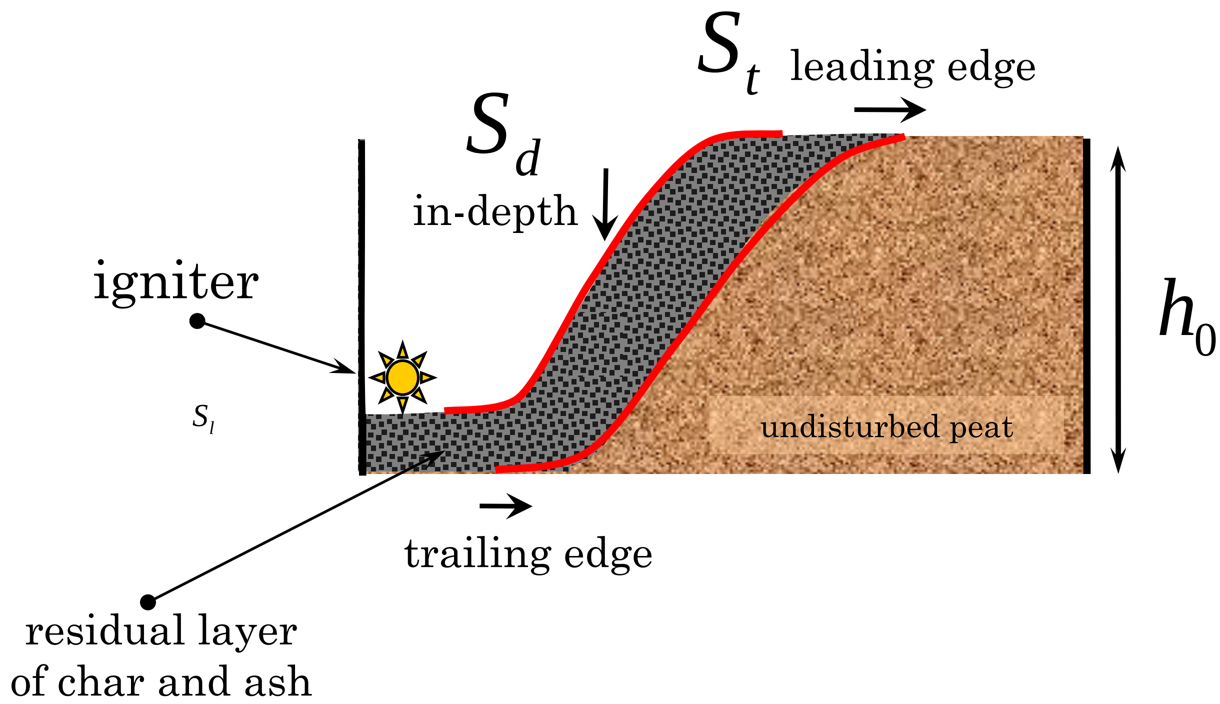
30x30 cm tray setup with 5 cm layer of peat

Top view, Visual camera *Top view, Infrared camera*



video speeded up 600 times
1 s video = 10 min experiment

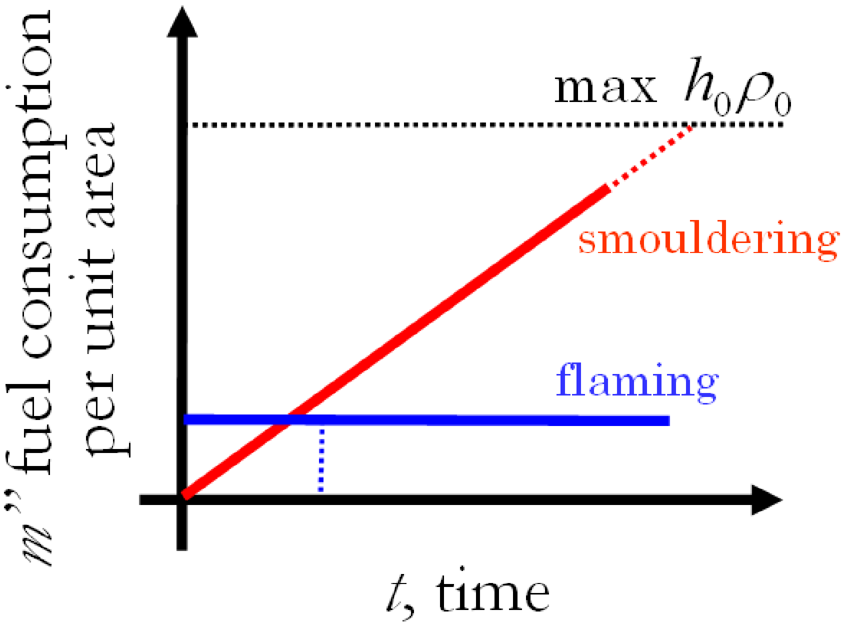
In-depth Spread

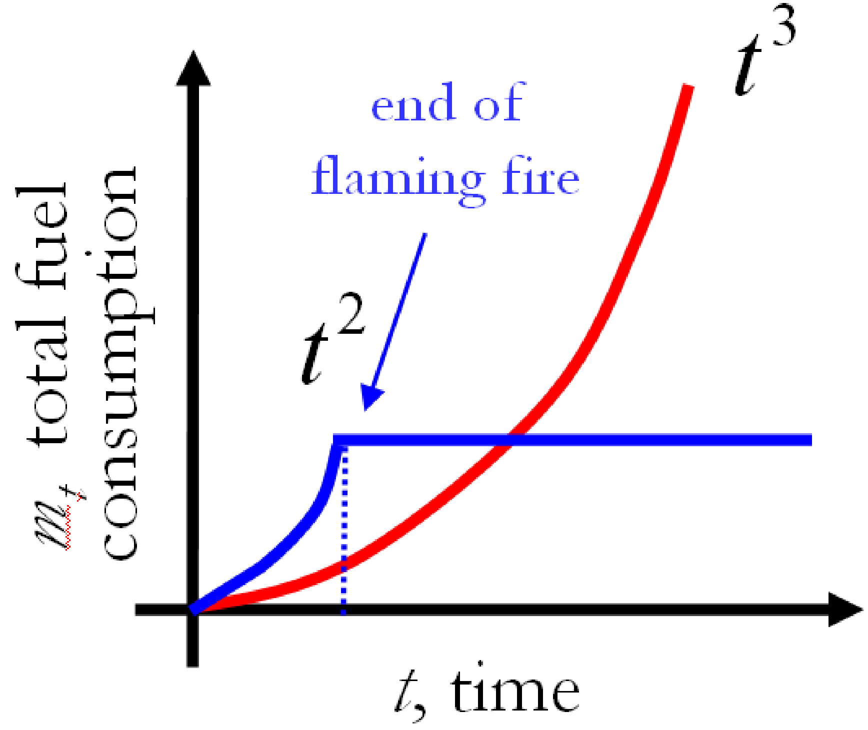


- Smouldering spreads in area and in-depth.
- It is a volumetric phenomenon (flaming is a surface phenomenon)
- Char is simultaneously a product and reactant in pyrolysis and oxidation reactions.

Hadden et al, *Proceedings of the Combustion Institute*, 2012

Mega-fires





$$m''(t) = \int_0^t \dot{m}'' dt = S_d t \rho_0$$

$$m_t(t) = \int_0^t \dot{m}_t dt = \frac{\pi}{3} \rho_0 S_d S_l^2 t^3$$

Smouldering Depth of Burn h_b

2008 Evans Fire, USA

- The depth of burnt h_b increases linearly with time
- Maximum depth h_0 given by
  - ⌘ location of the inert layer or a thick moist layer (>125%MC)
  - ⌘ timing of flooding (heavy continuous rain or firefighting).

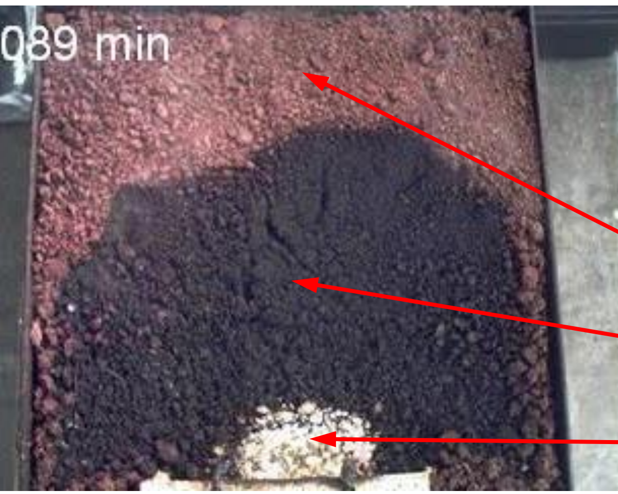
- A shallow fire with a depth of burn of 5 cm (lab experiment) ⬇ fuel consumption $m'' \sim 7$ kg/m^2
- Depth of burns reported in the literature from 0.1 to 5 m, most typically 0.5 m ⬇ $m'' \sim 75$ kg/m^2
- Typical consumption for flaming fires ⬇ $m'' \sim 0.2$ to 5 kg/m^2

- In-depth spread over thick peat layers leads to 50 to 100 times larger fuel consumptions than flaming fires (confirmed by field measurements *Langmann and Heil, ACP 2004*)

Carbon Balance

$$Peat \xrightarrow{heat} char + \sum (volatiles, CH_4, PAH)$$

$$Char + O_2 \rightarrow heat + ash + CO_2 + CO + H_2O$$



Sample	Carbon fraction, %	Hydrogen fraction, %	Nitrogen fraction, %	Density, $kg \cdot m^{-3}$	Carbon density, $kg\text{-}C \cdot m^{-3}$
Peat	50.85±0.34	5.21±0.04	1.13±0.24	151±3	77±2
Char	70.29±12.41	1.65±0.85	2.67±0.34	189±4	133±26
Ash	1.89±0.09	0.10±0.09	0.20±0.06	36±2	0.7±0.1

- Carbon fraction in char is ~1.5 times higher than peat
- Carbon fraction of ash is ~35 times lower than char
- During fires peat soil goes from 77 to 0.7 kg-C/m^3
- >95% of the peat mass is released as gas emissions

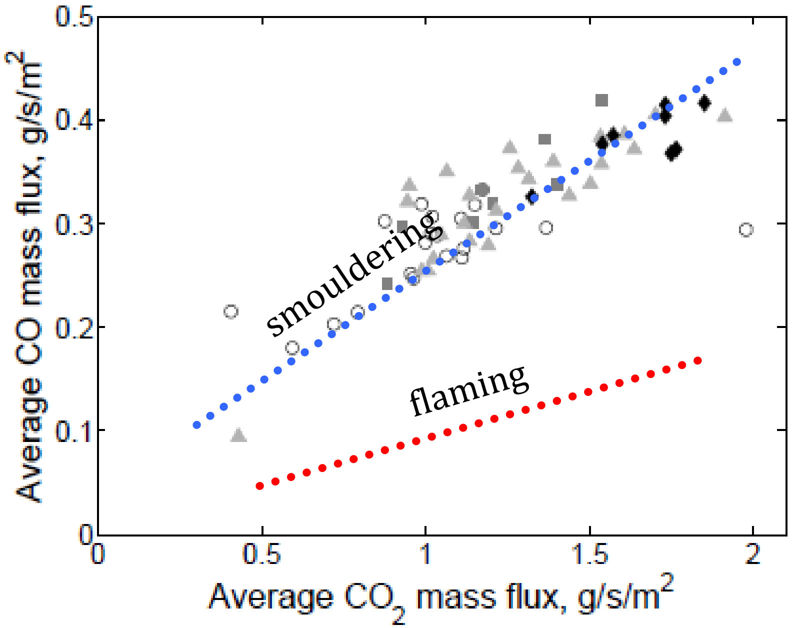
Hadden et al, *Proceedings of the Combustion Institute*, 2012

Gas Emissions

$$Peat \xrightarrow{heat} char + \sum (volatiles, CH_4, PAH)$$

$$Char + O_2 \rightarrow heat + ash + CO_2 + CO + H_2O$$

- Carbon gaseous emissions mostly as CO2 and CO, but also CH4 and PAH
- CO/CO_2 smouldering is 0.43 ± 0.12. vs. typical values for flaming combustion ~0.1



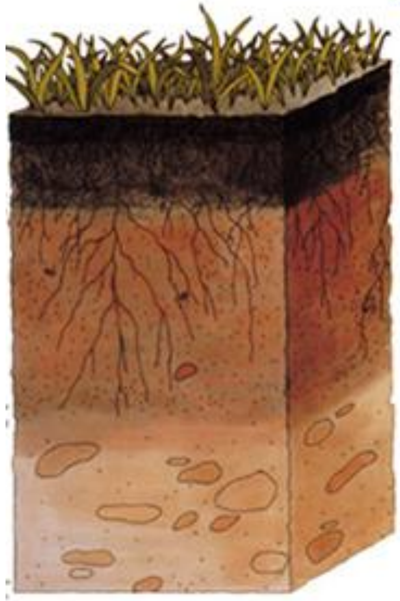
- Carbon emissions from fires are 3,000 times larger the natural respiration flux from peatlands

Rein et al., *Proc. Comb. Inst.*, 2009

Flaming vs. Smouldering

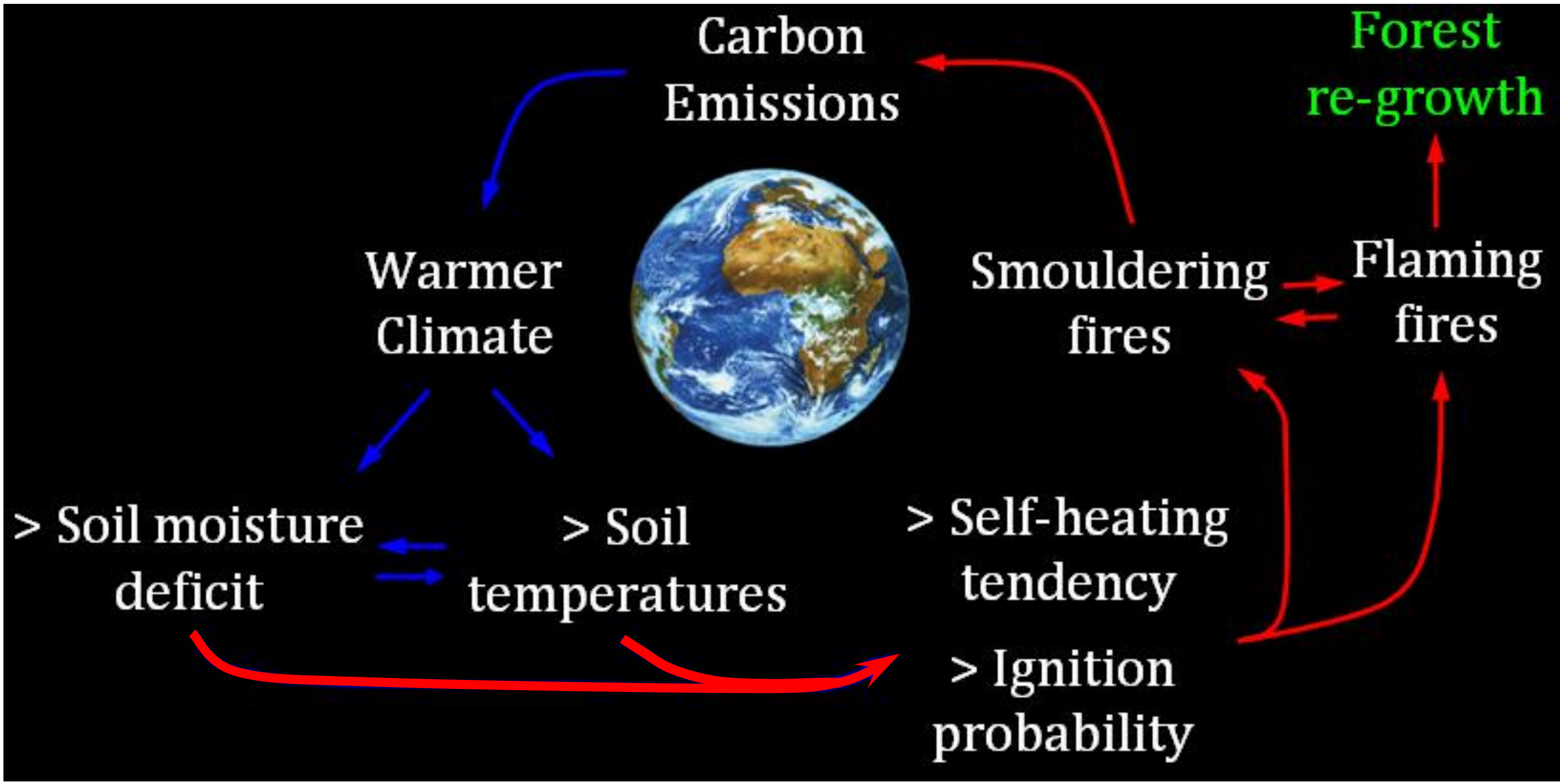
- Flaming fires consume **grasslands**, **shrubs** and **forests**. These take 10-10^2 years to grow back and sequester back the carbon = *Renewable & Carbon Neutral*

- Smouldering fires consume **peat**, organic soils and **coal**. These take 10^4 to 10^9 years to grow again = *Not Renewable & Carbon Positive*



Smouldering fires burn ancient carbon (akin to fossil fuels)

Feedback Mechanism in the Earth System



Permafrost thaw are already resulting in
large smouldering artic fires (e.g., Alaska 2010).

topics I work on

Conclusions

- Smouldering combustion of peatlands leads to the largest fires on Earth
  - ⌘ 100 times higher fuel consumption than flaming fires
- Consume organic matter and release ancient carbon stored deep in the soil (accidental fossil fuel burning)
  - ⌘ Soil goes from 77 to 0.7 kg-C/m^3
- Pose a positive feedback mechanism to climate change via moisture deficit, thaw and self-heating
  - ⌘ Topic of global interest linked to ecosystem perturbation, carbon sequestration and climate change

Geoengineering

- *The Royal Society* defines geoengineering as

  "deliberate large-scale intervention in the Earth's climate system, in order to moderate global warming"

- I propose we start with the simpler task, one with a low level of geointervention:

Deliberate large-scale suppression of smouldering fires on the Earth System

Thanks

- Hadden et al, *Proc Combustion Institute* 2012
- Belcher et al, *PNAS* 2011
- Rein, *Int Review Chemical Engineering* 2009
- Rein et al., *Proc Combustion Institute* 2009
- Rein et al, *Catena* 2008

The Royal Academy of Engineering

The Leverhulme Trust

Met Office

EPSRC
Engineering and Physical Sciences Research Council

International Fire Investigators and Consultants
"Covering the world to prevent, control and investigate fires and explosions."

2009 *Tablas de Daimiel* National Park, Spain

- Lasted from Aug 2009 to Feb 2010 – stopped by heaviest winter rains in 50 years.
- Emitted ~ 10 ton of carbon per day (2 kton in total)

Smouldering Mega-fires in peatlands and positive feedbacks to the Climate System

Dr Guillermo Rein - Imperial College London
Dr Rory Hadden – University of Western Ontario

Smouldering fires, driven by slow, low-temperature, flameless burning, represent the most persistent type of combustion and the longest continuously fires on Earth. Indeed, smouldering mega-fires occur with some frequency in dry peatlands, for example, South East Asia, North America, British Isles, Scandinavia and Russia. Once ignited, fires propagate through organic layers of the ground, and are particularly difficult to extinguish despite extensive rains, weather changes or fire-fighting attempts. They can persist for very long periods of time (months, years), slowly spreading over extensive areas and reaching deep into the soil in the presence of large cracks or natural piping channels. Recent figures at the global scale estimates that on average, smouldering fires account for the equivalent to 15% of the man-made carbon emissions. Because ancient carbon is burning (akin to fossil fuels), a peatland fire is a carbon-positive phenomena. Moreover, soil moisture deficit, thaw and self-heating ignition are enhanced under warmer climates leading to more frequent smouldering fires, thus creating a positive feedback to the climate system. The unprecedented permafrost thaw is leaving large soil carbon pools exposed to fires for the fist time since millennia. It is believed that warmer temperatures at high latitudes could be responsible for the more frequent smouldering fires recently observed in the Artic. Although the role of flaming wildfires on the Earth system is becoming a central topic of research, smouldering peatland fires could be more important, but are receiving very little attention.

Means of Prevention

A. Avoid critical conditions:

1. Store at low temperature
2. Limit size
3. Ventilation
4. Compacting
5. Reduce reactivity - Inertation

B. Avoid ignition during incubation:

1. Turn around
2. Remove/Consume before incubation time

C. Avoid spread after incubation:

1. Wetting
2. Sealing oxygen ingress
3. Comparmentation
4. Compacting

Means for Suppression

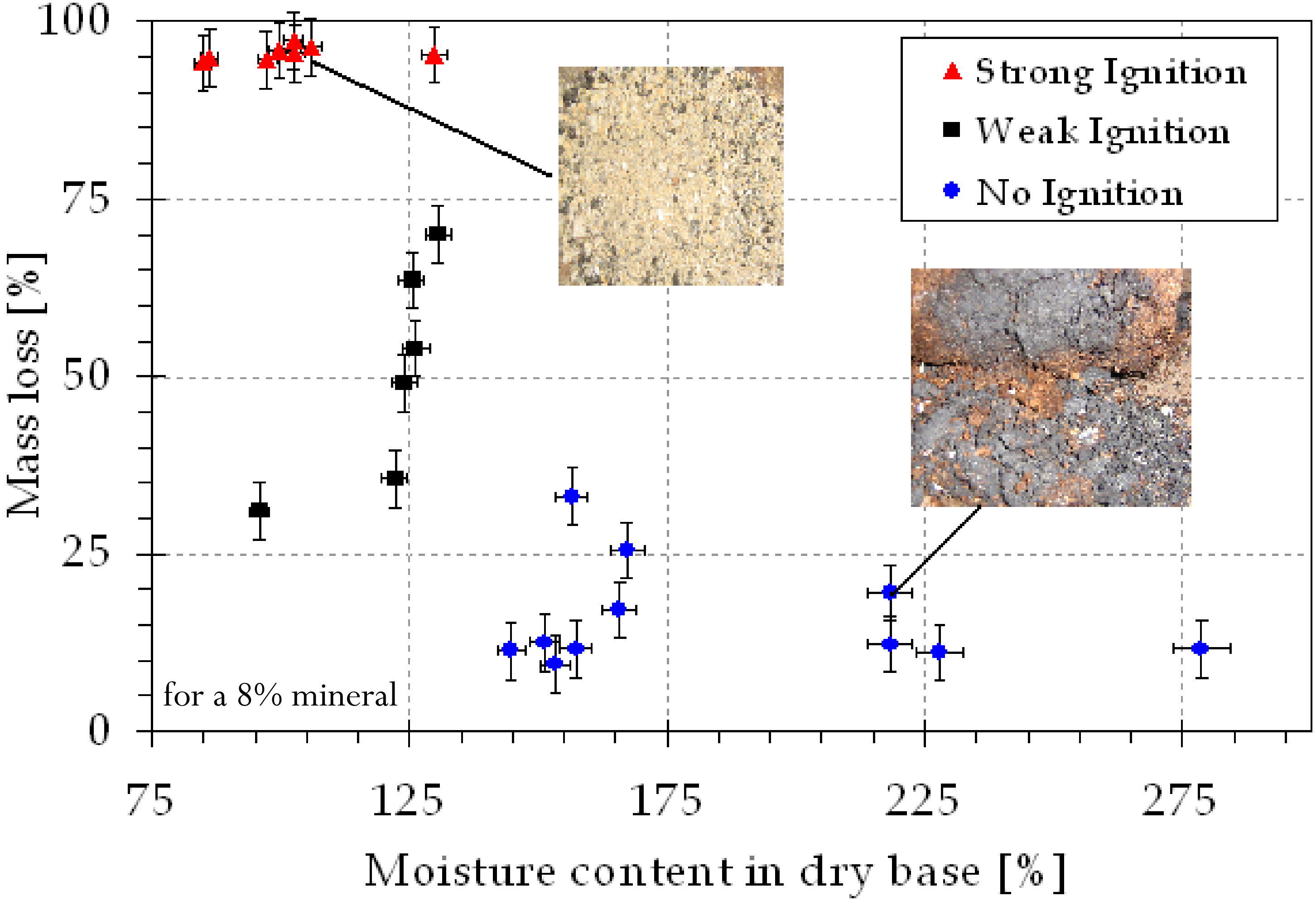
Work best

Most attempted

1. **Remove fuel**
2. Make fuel inert - sand
3. Wetting fuel – agent and additives
4. Sealing – t>100 days
5. Smothering – $[O_2]<16\%$
6. Compaction – reduces spread rate
7. Compartmentation – fire break using any above

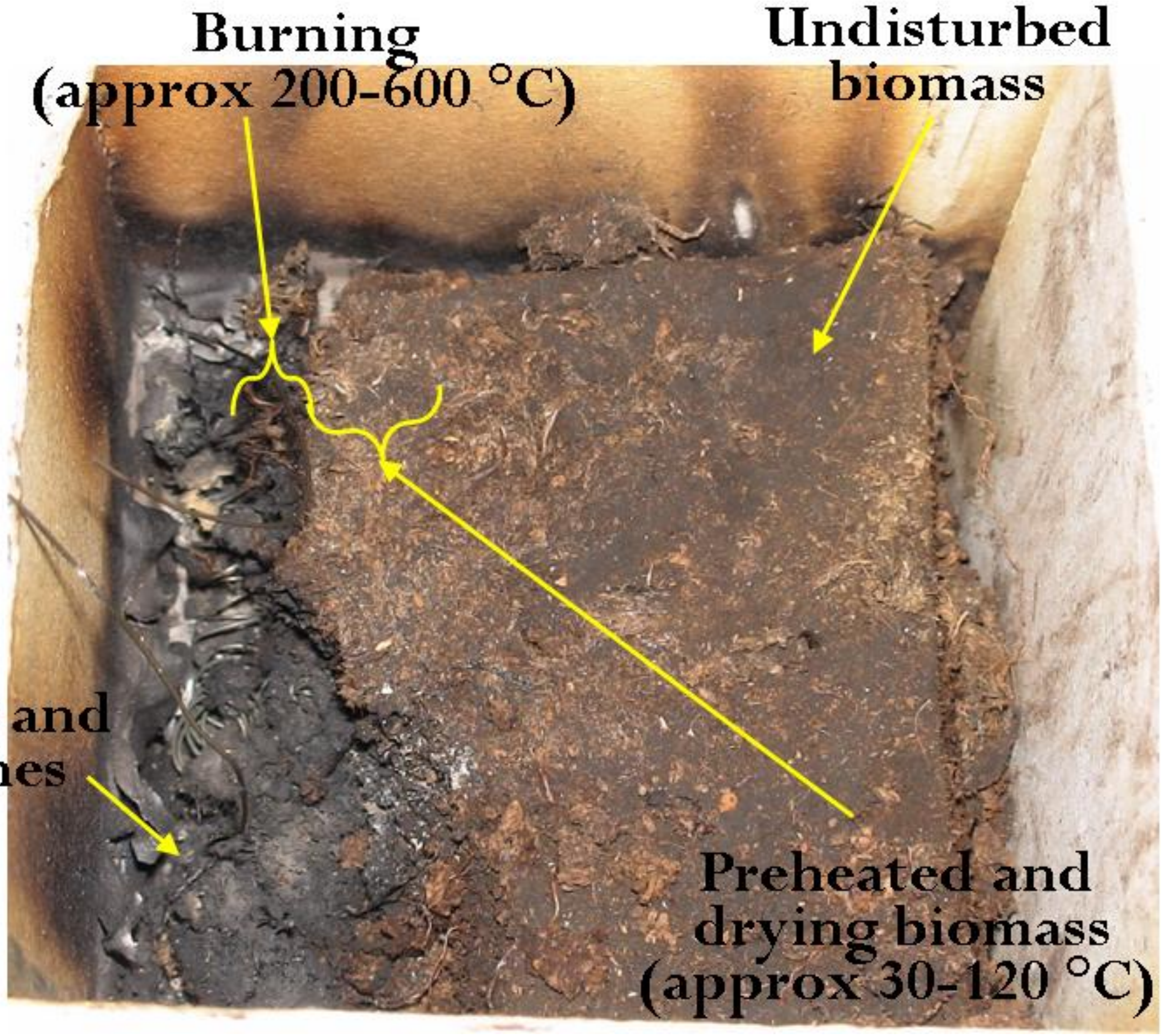
The largest problem is to **detect early** and locate/**mapping** the fire, then deliver technology

Effect of Moisture



Rein et al, *Catena* 2008

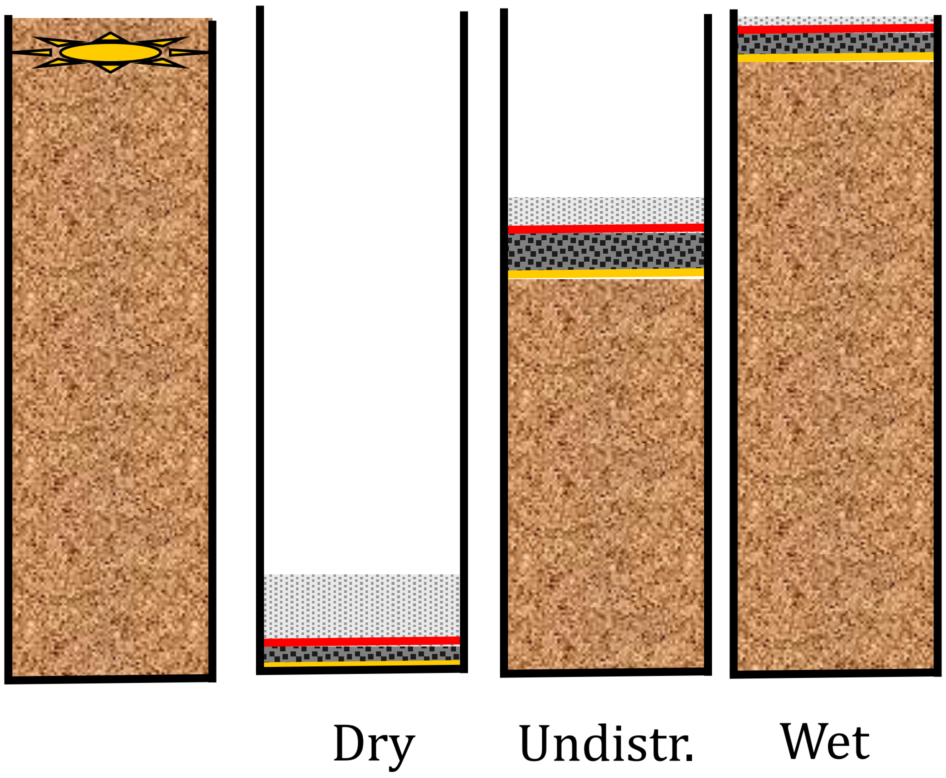
Heterogeneous Reaction Front



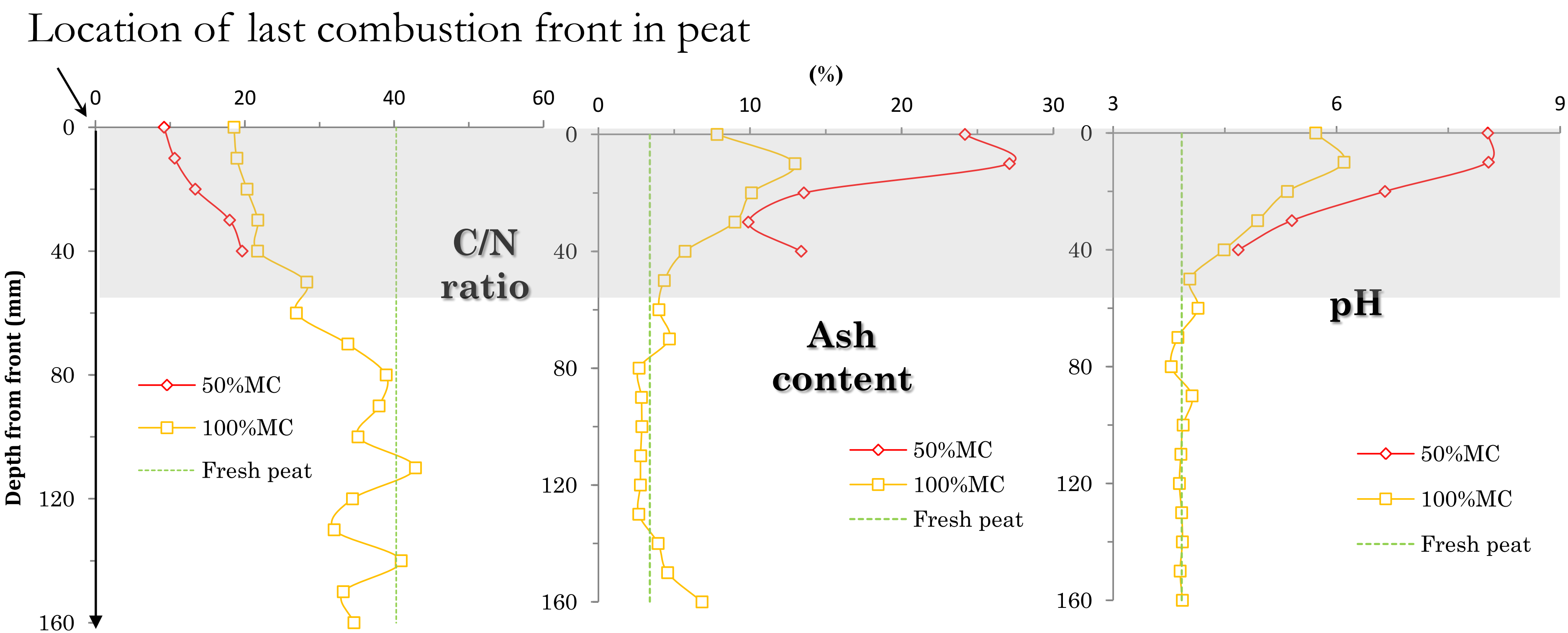
Rein et al, *Catena* 74, pp. 304-309, 2008

Chemical Analysis of the smouldering interface

Smouldering column tests of *Sphagnum* peat at different initial moisture contents (MC) ignited at the top:, dry conditions (**MC50%**), undisturbed conditions (**MC100%**), and wet conditions (**MC200%**).



Chemical Analysis of smouldering residue

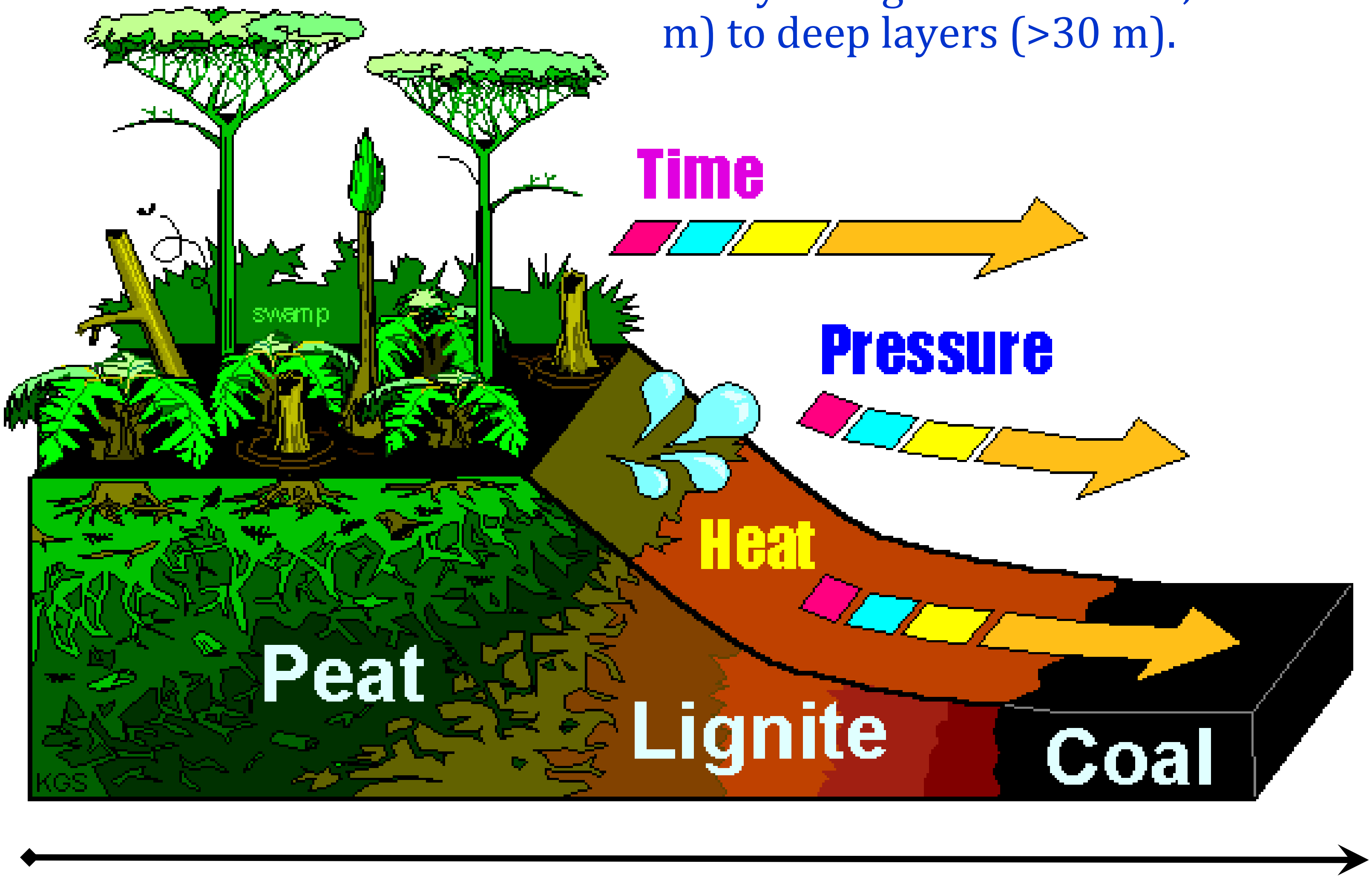


The chemical analysis of the solid residue shows it is a mixture of ash and char with a strong increases of pH, higher C/H and lower C/N ratios relative to the virgin peat

Zaccone et al., *EGU*2012-4795, SSS10.2 Poster XY648

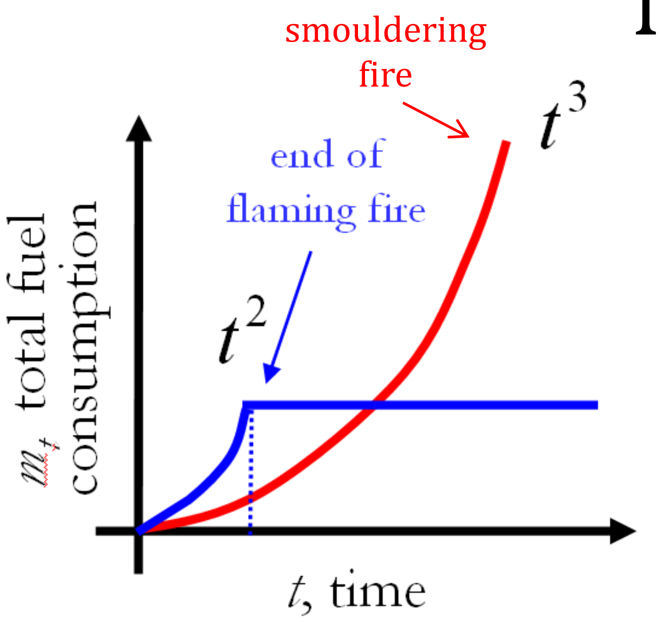
Smouldering Natural Fuels

- Most important: duff, humus, **peat, coal**
- Decayed vegetation matter, from shallow (<0.1 m) to deep layers (>30 m).



10 years   1,000 years   1,000,000 years   300,000,000 years

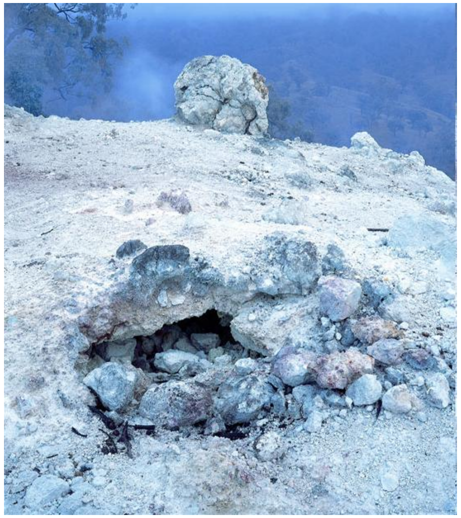
Mega-fires



$$m_t(t) = \int_0^t \dot{m}_t dt = \frac{\pi}{3}\rho_0 S_d S_l^2 t^3$$

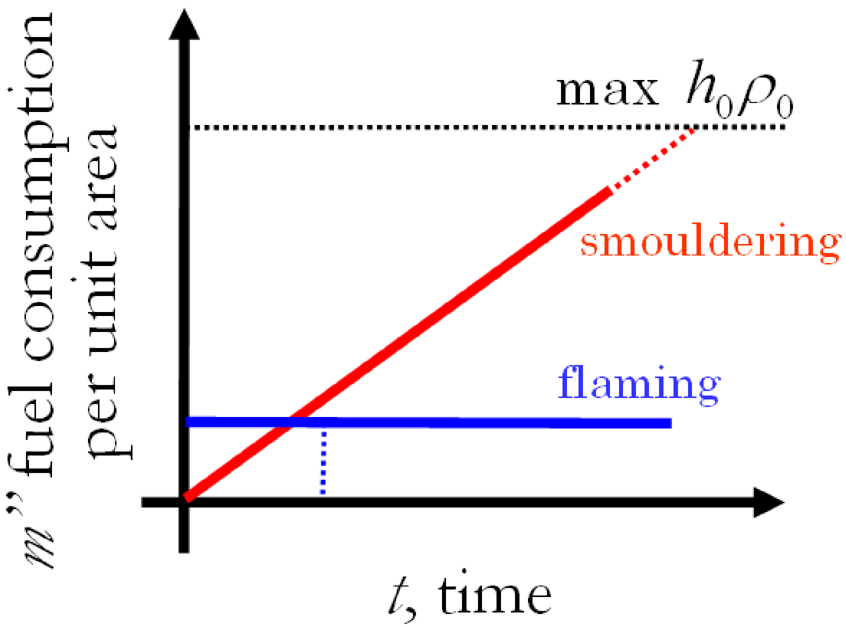
In-depth spread over thick peat layers consumes biomass in the order of 100 kg/m^2, this is **50 to 100 times larger** than flaming fires

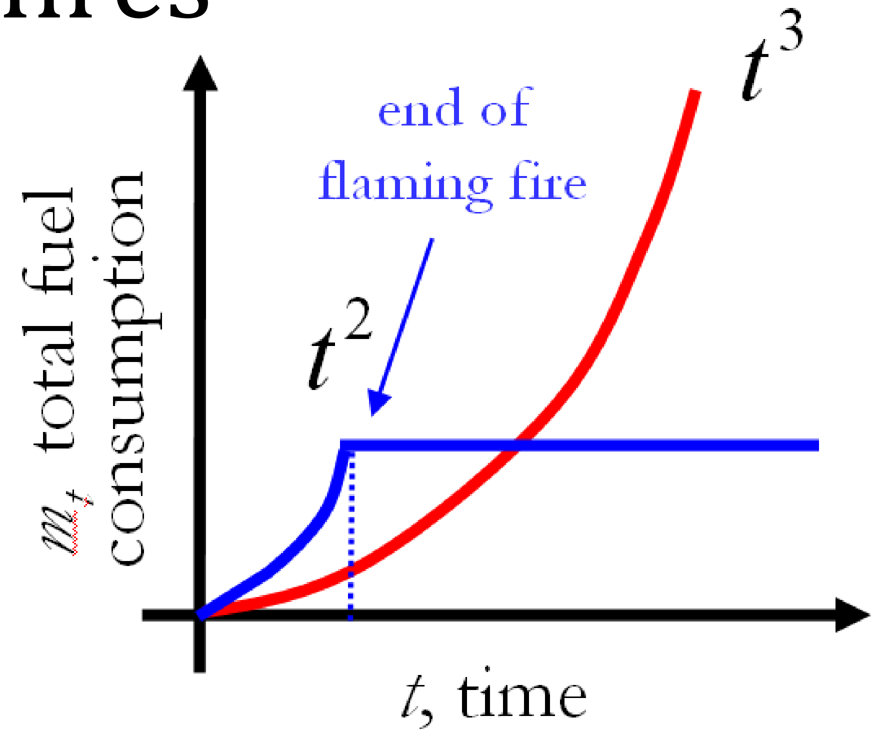
The oldest continuously burning fire on Earth is a smouldering coal seam in Australia ignited **>6,000 years old**



Recent figures at the global scale estimate average greenhouse gas emissions from smouldering peat is **equivalent to >15% of man-made emissions**

Mega-fires





$$m''(t) = \int_0^t \dot{m}'' dt = S_d t \rho_0$$

$$m''(t_b) = S_d t_b \rho_0 = h_b \rho_0$$

$$m_t(t) = \int_0^t \dot{m}_t dt = \frac{\pi}{3} \rho_0 S_d S_l^2 t^3$$

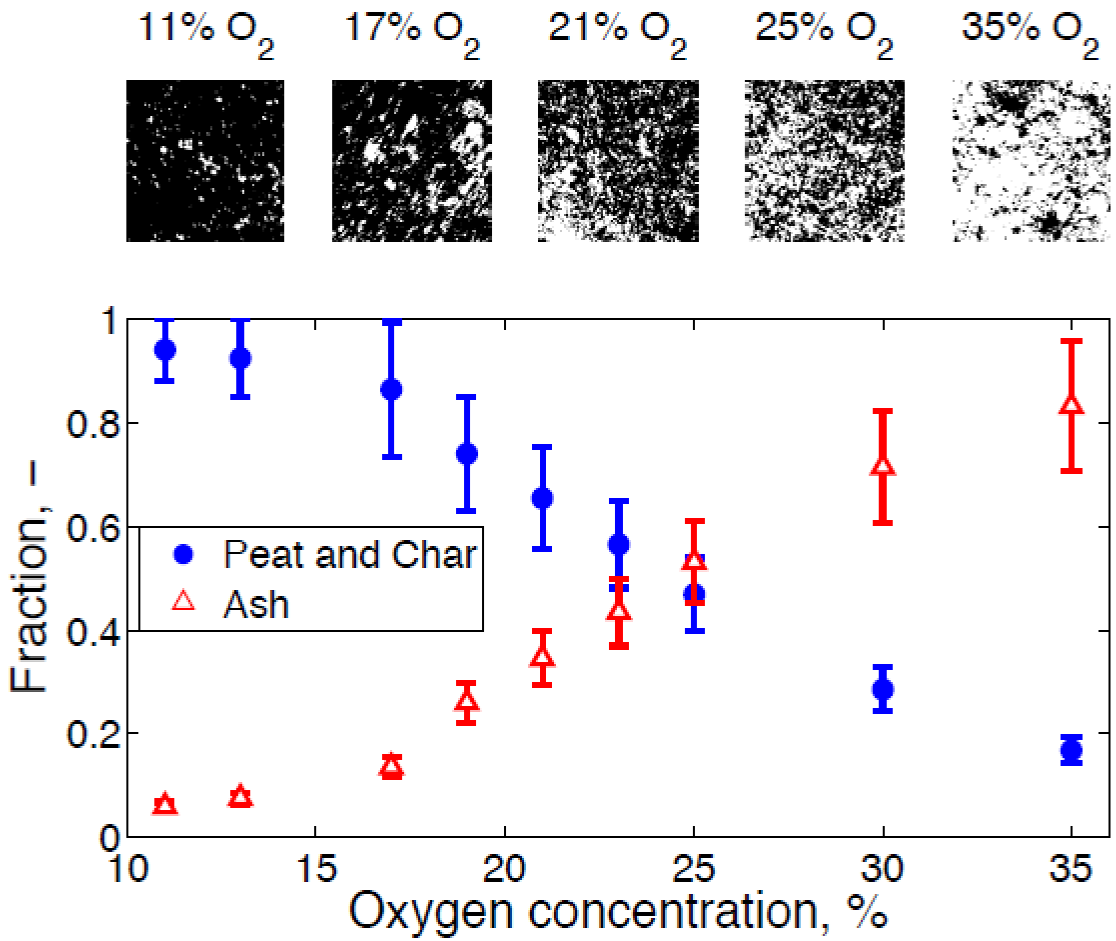
$$m_t(t_b) = \frac{\pi}{3} h_b \rho_0 S_l^2 t_b^2 = \frac{\pi}{3} m'' S_l^2 t_b^2$$

Depth measured in field $\in$[0.1, 5] m, most typical 0.5 m $\Rightarrow$ *m”* ~ 75 kg/m^2

Typical values for flaming fires $\Rightarrow$ *m”* ~ 0.5 to 5 kg/m^2

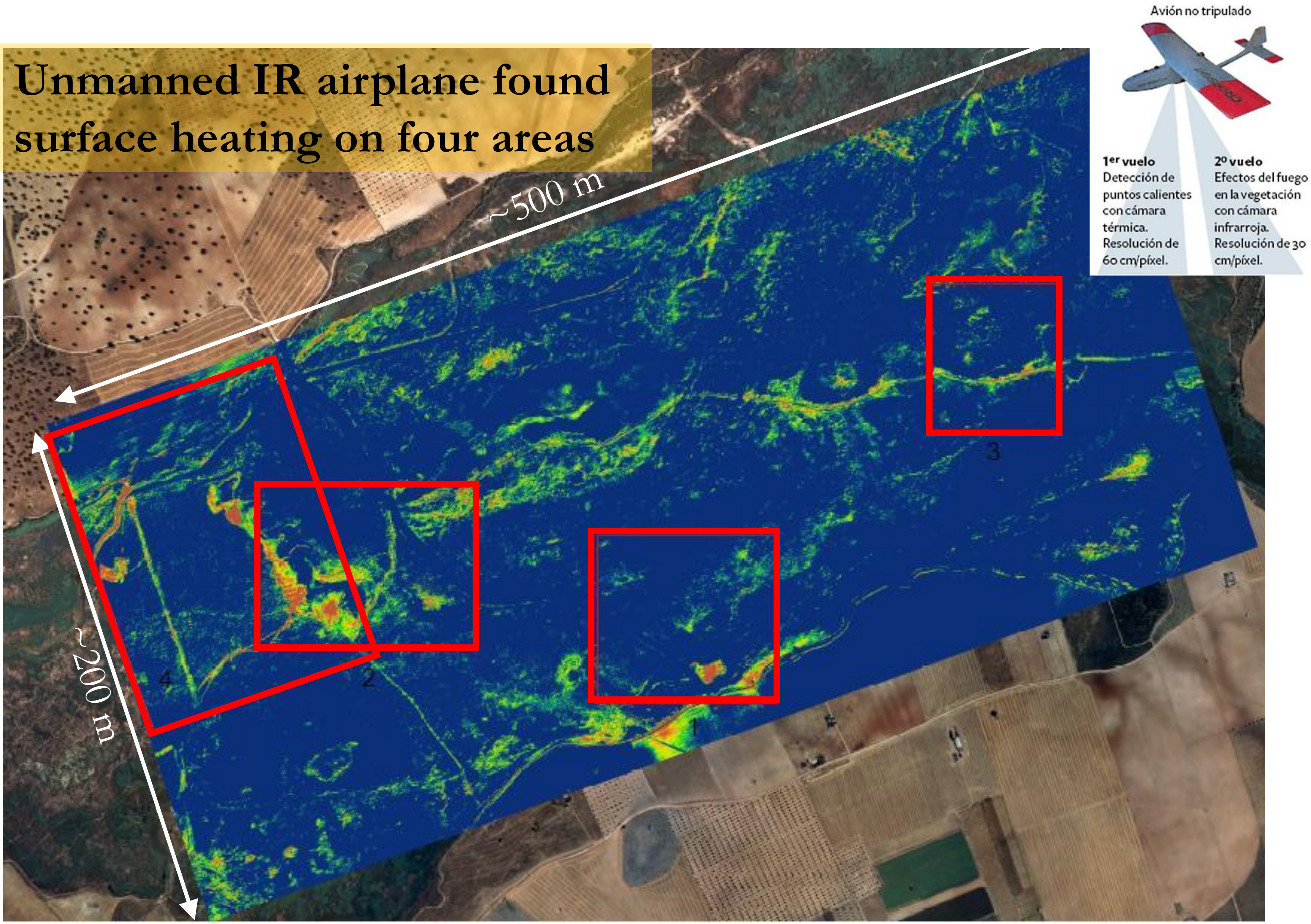
Smouldering fuel consumption >**50 times larger** than in flaming fires

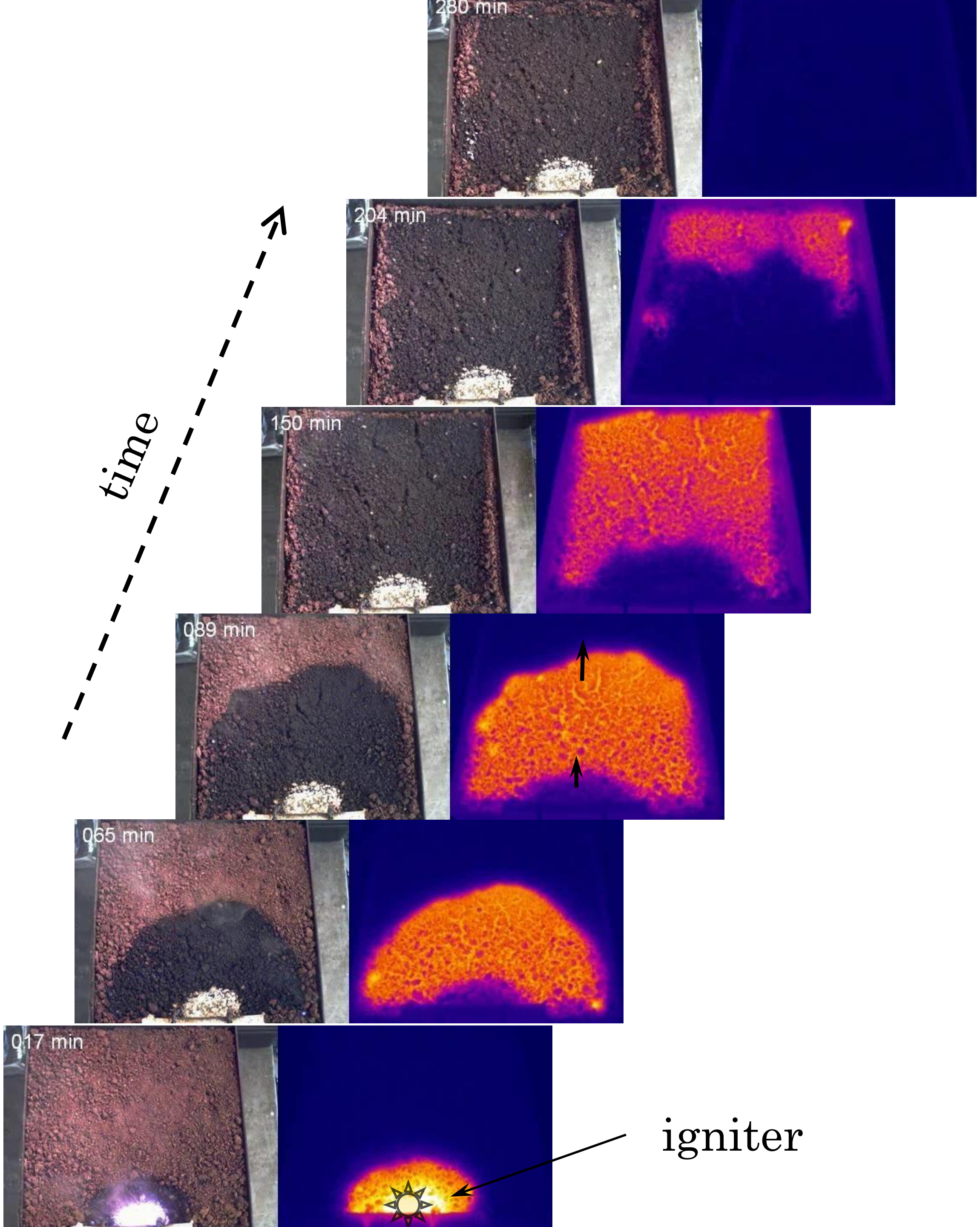
Combustion Dynamics



As the intensity of the fire increases (proxy via increasing oxygen concentration), the fraction of residual char rapidly decreases to zero.

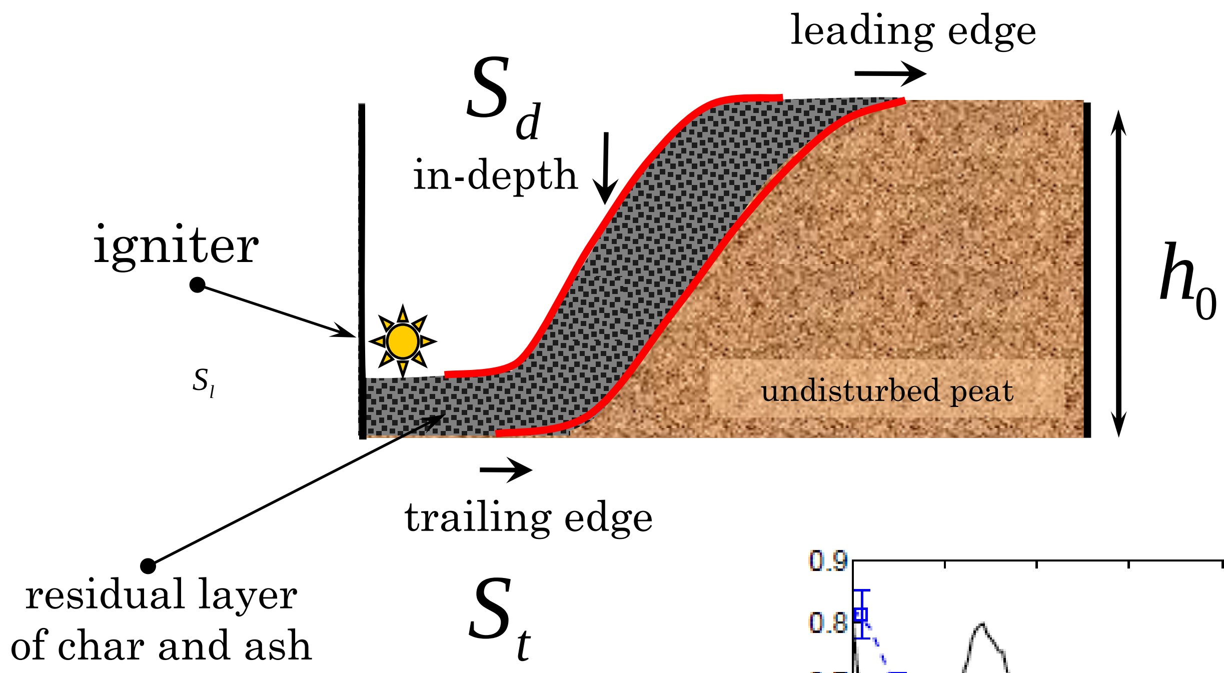
Unmanned IR airplane found surface heating on four areas

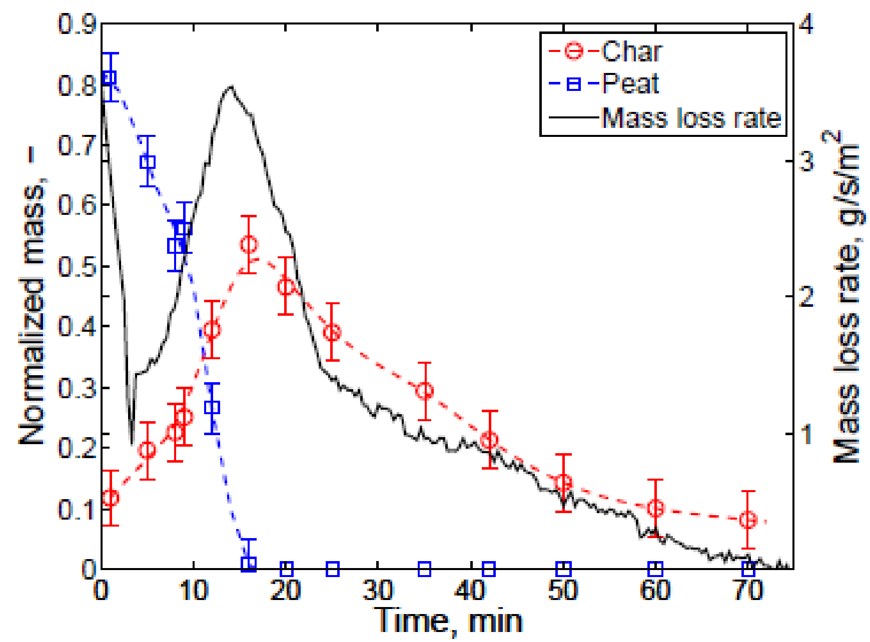




280 min
204 min
150 min
089 min
065 min
017 min
time
igniter

fate of organic matter





Char is simultaneously product and reactant in pyrolysis and oxidation reactions, which **initially results in net char production and later become net char consumption**.

Hadden et al, *Proceedings of the Combustion Institute*, 2012