Smouldering Subsurface Fires in the Earth System

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1. SUBSURFACE FIRES

When a layer of organic soil ignites, it burns steadily without a flame, propagating slowly through layers of the forest ground. Dry soil conditions are the main trigger. Large smouldering fires are locally rare but globally frequent, and can last for long periods of time (weeks or years), causing the loss of natural and energy resources. The oldest continuously burning fire on Earth is the smouldering coal deposit at The Burning Mountain, Australia, dated to be active since 4000 BC.

2. SMOULDERING COMBUSTION

Smouldering [1] is the flameless form of combustion of a solid fuel where the oxidation reaction occurs on the surface of the solid (Fig 1). The characteristic temperature (500-700°C) , spread rate (1-50mm/h) and heat release rate (~8 kJ/g) are significantly lower than in flaming.

Figure 1 – Flaming vs. smouldering [3].

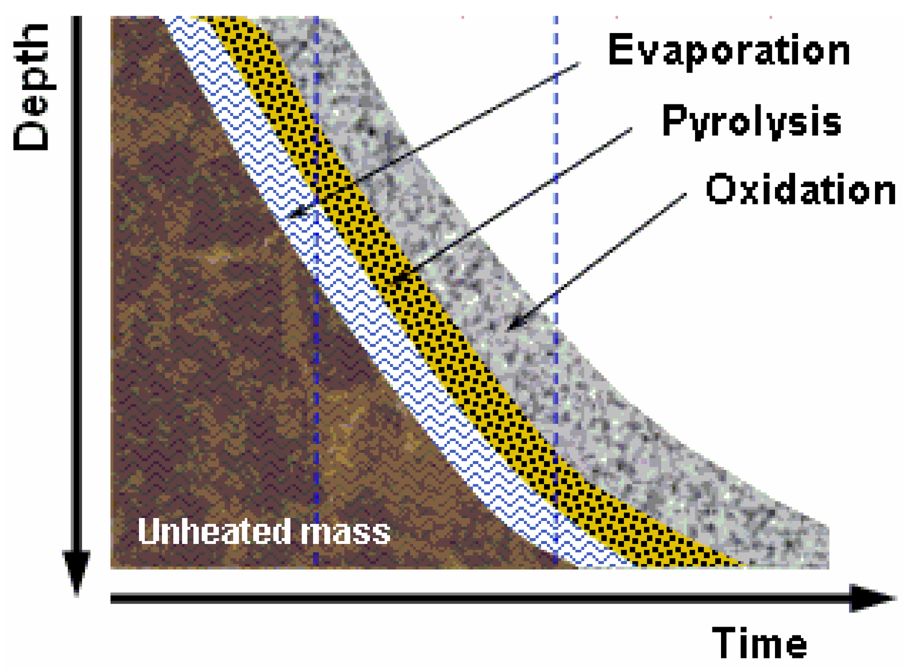

Figure 2 – Sketch of a downward spread smouldering front and its reaction structure [2].

3. DAMAGE *to the* SOIL

Physical, chemical and biological changes on the soil are caused by the fire. As fires spreads (Fig. 3), mass losses reaches up to 90% resulting in the destruction of the soil layers. The measured thermal severity in terms of temperature threshold vs. residence time shows that smouldering leads to soil sterilization (Fig. 4).

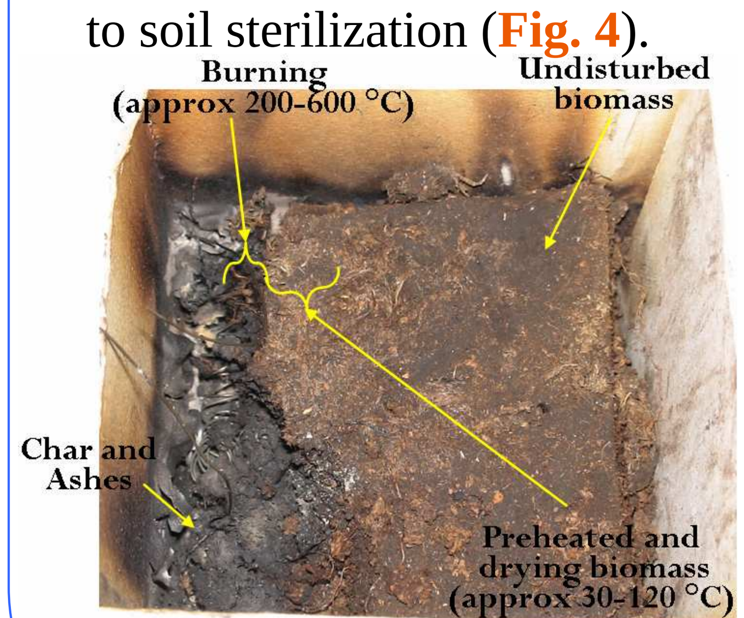

Figure 3 – Flaming vs. smouldering [3].

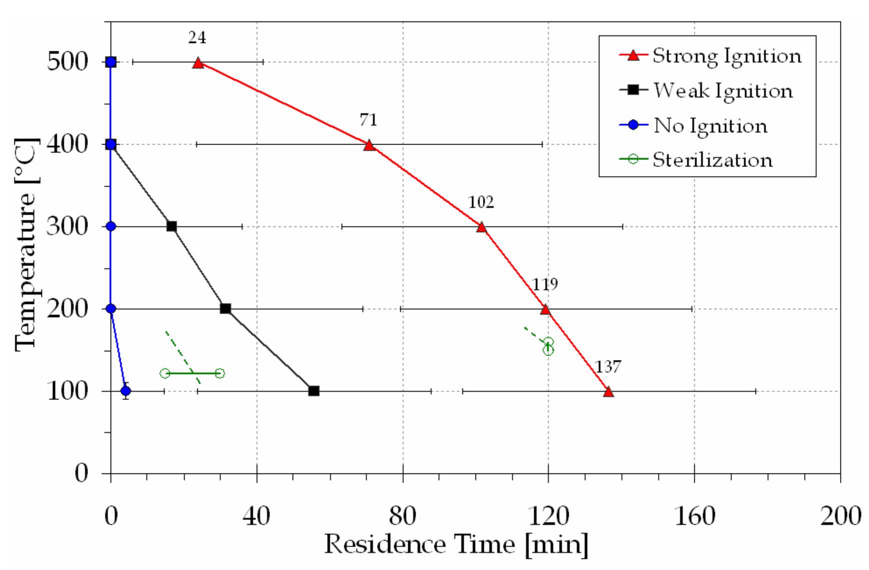

Figure 4 – Flaming vs. smouldering [3].

4. EARTH SYSTEM

Smouldering soils are made of partially decayed vegetation matter, mainly duff, humus, peat and coal, and represent more terrestrial carbon than the forests and the atmosphere. These fires are a large perturbation to the global atmospheric chemistry, and contribute with 10 to 40% of the global greenhouse gas emissions. Recent unprecedented permafrost thaw is leaving large soil carbon pools exposed to fire.

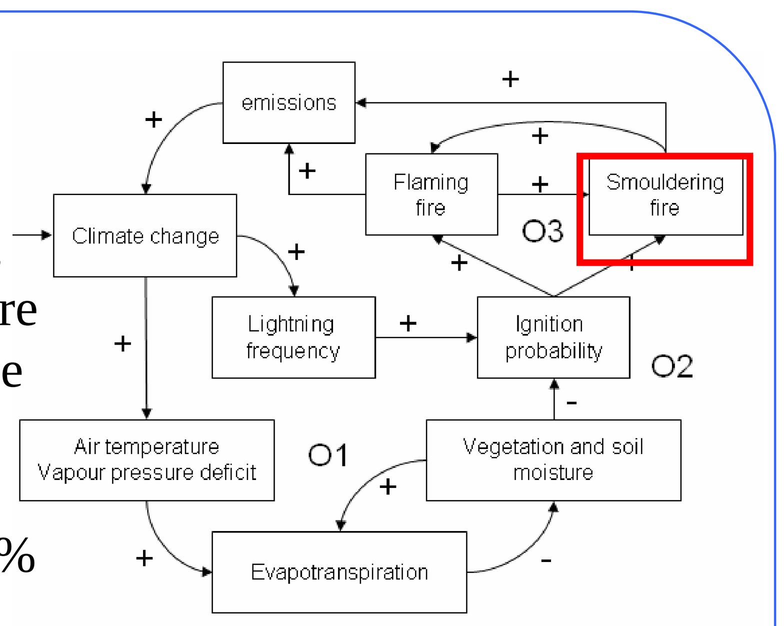

Figure 5 – Feedback loop between Earth atmosphere and fires, via moisture. by M Williams

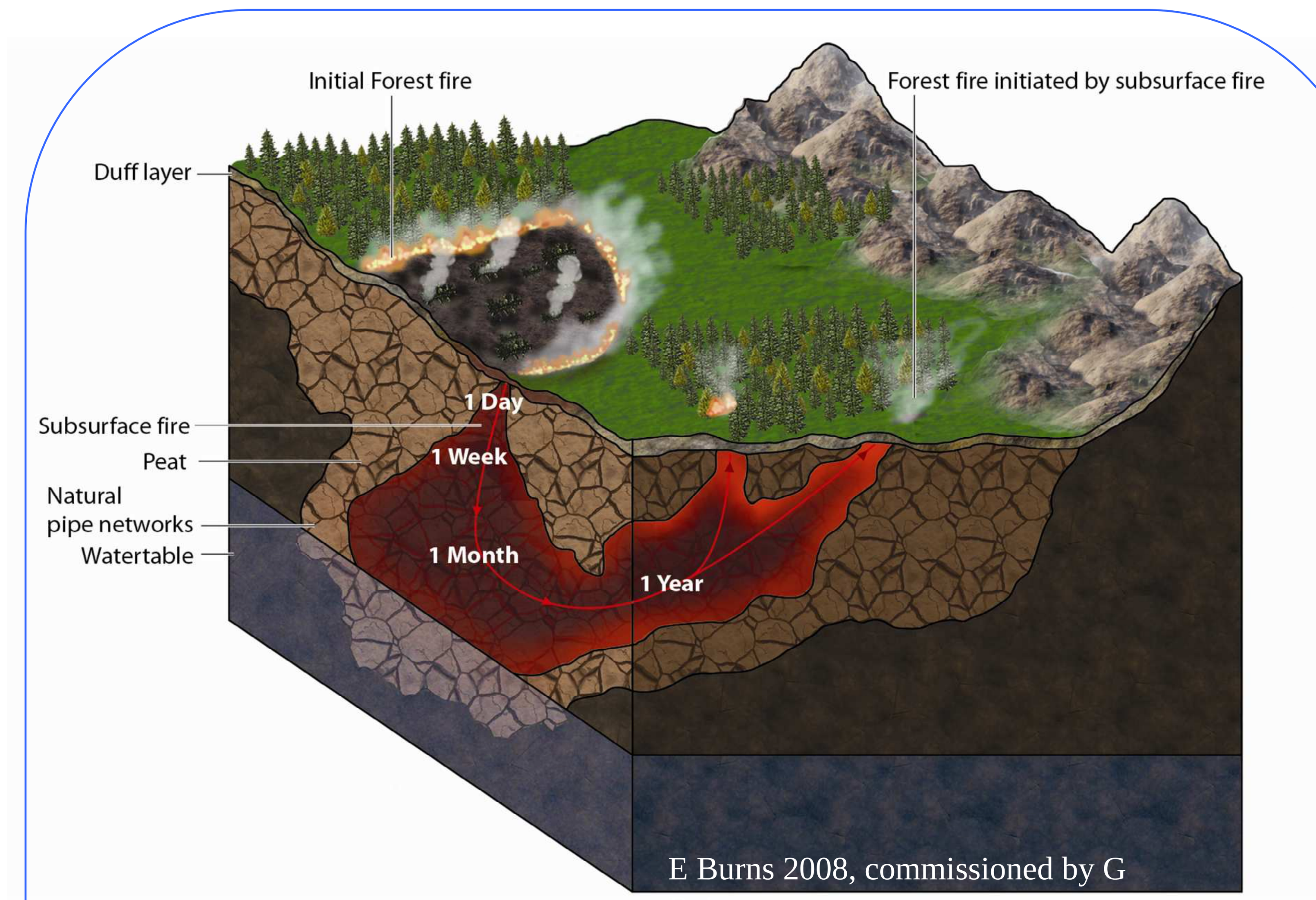

Figure 6 – Illustration of a subsurface fire initiated at the surface that propagates into the ground and emerges months later [1].

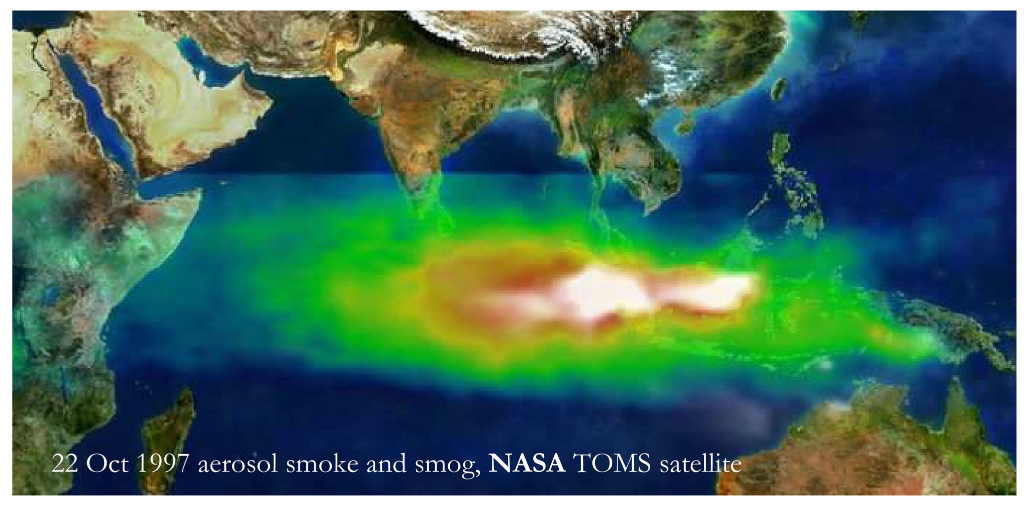

Figure 7 – Smoky haze covering South-East Asia released by the 1997 Indonesia peat fires during the El Niño climate event.

Figure 8- Adjacent forest stands at 2006 Rothiemurchus peat fire in Scotland [3]. Left) Not affected by the fire; Right) ~0.5 m peat layer removed by smouldering fire.

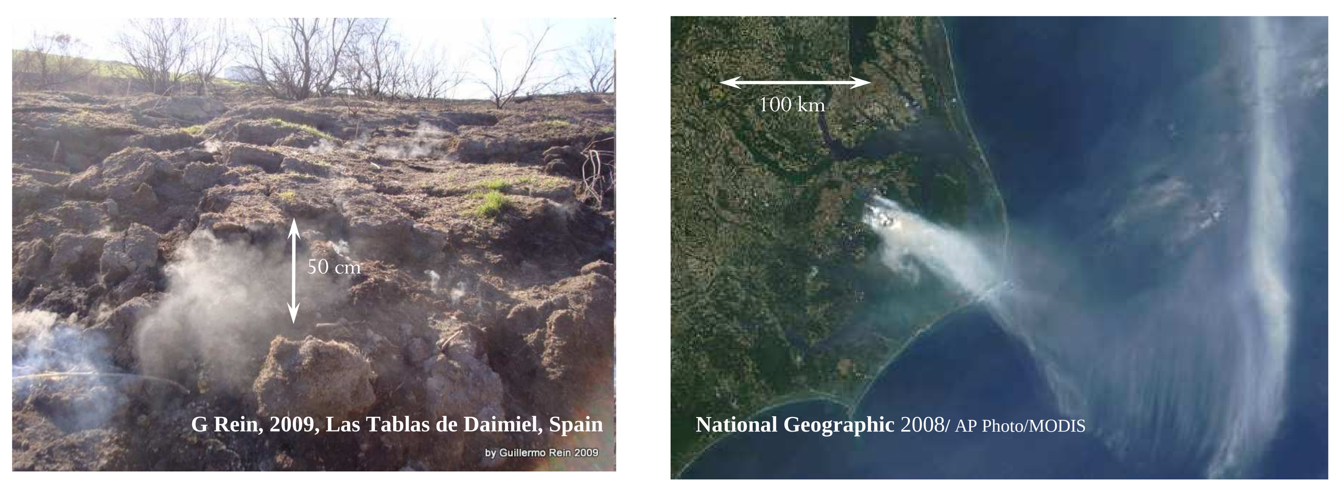

Figure 9- Smouldering peat fires. Left) The 2009 Las Tablas de Daimiel National Park in Spain, burned for 5 months. Right) The 2008 Pocosin Lakes National Wildlife Refuge in USA burned for 3 months.

5. CARBON EMISSIONS

Emissions measured in peat samples smouldering under realistic and steady-state burning regimes (Fig. 7) show that total CO and CO2 flow rate is equivalent to 3,000 times the natural flux in peatlands. Carbon yield is of 59±15% g/g. The CO/CO_2 ratio was 0.43±0.12, a distinctive signature of smouldering peat and twice the value in flaming fires [2].

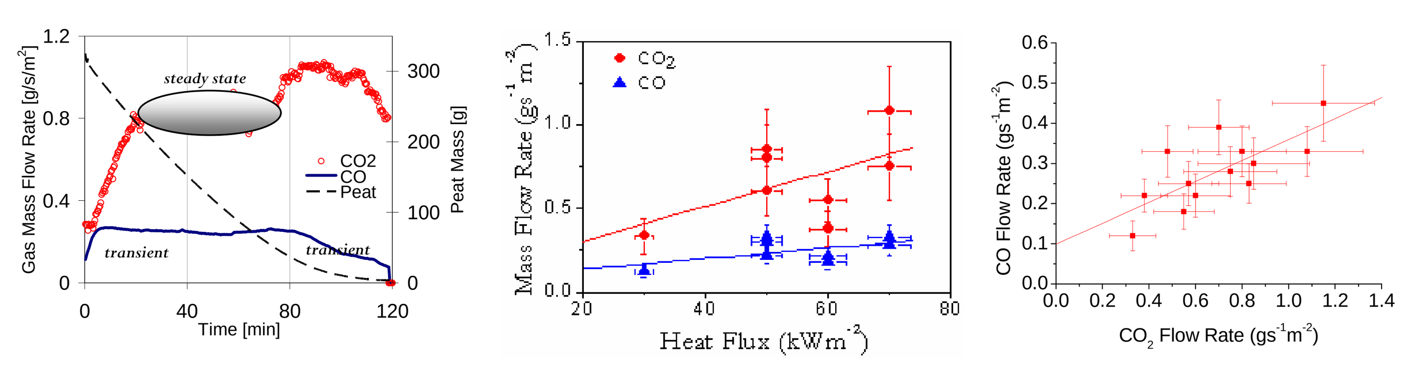

Figure 7 – Left) Evolution of CO and CO2 mass flow and peat mass loss rates. Center) Mass flows. Right) CO/CO_2 ratio [2]

[1] Rein, **Smouldering Combustion Phenomena in Science and Technology**, International Review of Chemical Engineering 1, pp 3-18, 2009 http://hdl.handle.net/1842/2678

[2] Rein et al., **Carbon Emissions from Smouldering Peat in Shallow and Strong Fronts**, *Proceedings of the Combustion Institute* 32, pp. 2489-2496, 2009

[3] Rein et al., **The Severity of Smouldering Peat Fires and Damage to the Forest Soil**, Catena 74 (3), pp. 304-309, 2008