The Compost Bomb

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Background

- Soils contain around 1000 Pg of carbon, and so will play a critical role in climate change.
- Carbon enters the soil through NPP, Π, and leaves the soil through decomposition caused by soil respiration.
- Respiration increases with temperature and is exothermic.
- Possibility of a runaway feedback leading to an explosive release of carbon.
- Occurs in compost heaps and so has been termed the compost bomb.
- Does this happen in nature, and will it become more common as the Earth warms?

Model respiration using a Q_{10} function, which is the factor the rate increases by for every 10 degrees of temperature increase.
$Q_{10} \sim 2.0$.

$$\mu \frac{\mathrm{d} T_s}{\mathrm{d} t} = -\lambda \left(T_s - T_a \right) + A C_s r_0 Q_{10}^{\frac{1}{10} \left(T_s - T_{\mathrm{ref}} \right)} \tag{1}$$

$$\frac{\mathrm{d} C_s}{\mathrm{d} t} = \Pi - C_s r_0 Q_{10}^{\frac{1}{10} \left(T_s - T_{\mathrm{ref}} \right)} \tag{2}$$

Here T_s is the soil temperature, T_a is the air temperature, A is the specific heat of respiration, C_s the soil carbon. The heat capacity and the conductivity are given by μ and λ.[1]

[1] C. M. Luke and P. M. Cox. "Soil carbon and climate change: From the Jenkinson effect to the compost-bomb instability". In: *European Journal of Soil Science* 62.1 (2011), pp. 5–12.

- This model is dynamically excitable and susceptible to rate-dependent tipping.
- The system will tip if the air temperature increases fast enough
  - Unlike conventional bifurcation tipping which happens if a parameter exceeds some critical value.

With rapid enough warming the system tips and a compost bomb goes off after 15 years.

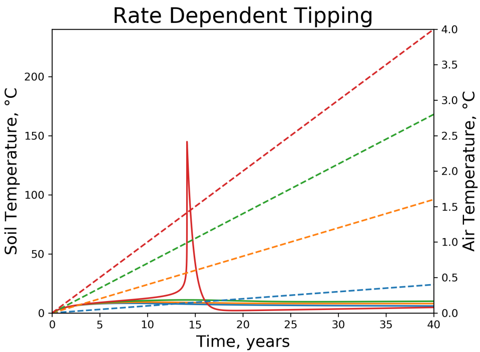

Figure: Dashed lines give the air temperature, solid lines the soil temperature

Problems

- This is a very idealised model
- It neglects processes like hydrology and diffusion which might suppress the compost bomb
- It assumes respiration is controlled only by temperature and the quantity of soil carbon
- The value of λ depends on the vertical discretization of the soil column.

This motivates studying more complicated setups. To make things tractable, we examine the case where $\dot{C}_s = 0$ which leads to a traditional saddle node bifurcation at a critical air temperature.

Modelling the Effect of Diffusion

We consider a column of soil, depth H, which has respiration and heat diffusion

$$\mu \frac{\partial T_s}{\partial t} = \kappa \frac{\partial^2 T_s}{\partial z^2} + \frac{A C_s r_0}{H} e^{\alpha (T_s - T_{\mathrm{ref}})} \tag{3}$$

Despite its nonlinearity, the steady state has an exact solution!

$$T_s(z) = T_0 + \frac{1}{\alpha} \ln \left(\mathrm{sech}^2 \sqrt{e^{\alpha T_0} \frac{\kappa}{\kappa_0} \frac{(z+H)^2}{4H^2}} \right) \tag{4}$$

with $\kappa_0 = \alpha A r_0 C_s H e^{-\alpha T_{\mathrm{ref}}}$

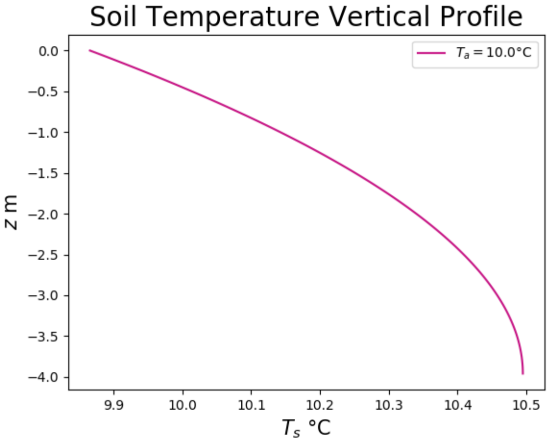

Figure: Vertical Temperature Profile of the Soil

The upper boundary condition gives a critical T_a above which the solution does not exist — a compost bomb.

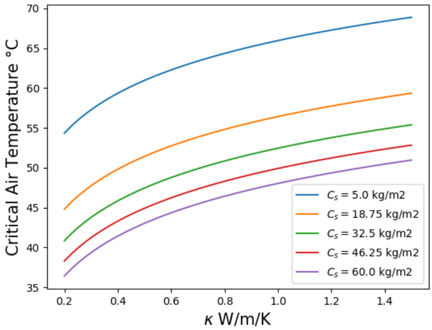

Figure: Critical Air temperature dependence on κ

JULES

JULES is a sophisticated land surface scheme, which presently does not account for the effect of respiratory heating on soil temperature. We added a respiratory heating term and managed to get compost bombs to go off.

This is an example of a compost bomb going off just before the year 2000 in the JULES model.

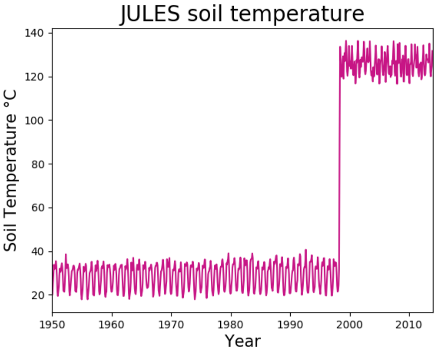

Figure: Soil temperature of one grid box from a JULES run with historical temperature forcing.

Conclusions

Compost bombs can go off in more complicated systems, and we have derived a relationship between the critical air temperature for a compost bomb and in principle measurable parameters.

Future work will work out *where* we might see a compost bomb and under which conditions. We will also investigate candidate compost bomb events, such as the 2010 Russian wildfires.

Further Reading

- S. Wieczorek et al. “Excitability in ramped systems: The compost-bomb instability”. In: *Proceedings of the Royal Society A: Mathematical, Physical and Engineering Sciences* 467.2129 (2011), pp. 1243–1269.
- Andrew J. Wiltshire et al. “JULES-GL7: The Global Land configuration of the Joint UK Land Environment Simulator version 7.0 and 7.2”. In: *Geoscientific Model Development* 13.2 (2020), pp. 483–505.
- C. M. Luke and P. M. Cox. “Soil carbon and climate change: From the Jenkinson effect to the compost-bomb instability”. In: *European Journal of Soil Science* 62.1 (2011), pp. 5–12.