The Effects of Biochemical Energy Release on Soil

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Heat energy is released into the soil through microbial respiration. The aim of this study is to consider the effect of this energy upon soil temperature and carbon stock.

The Soil Model: The model considers an isolated system in which soil temperature depends on heat produced internally by microbial respiration and heat transfer at the surface.

Model Equations

Soil temperature, T_s, is modelled

$$\mu \frac{dT_s}{dt} = A\, C_s\, r_s(T_s) - \lambda (T_s - T_a)$$

The amount of soil carbon, C_s, depends on the respiration rate and the net primary productivity and is modelled

$$\frac{dC_s}{dt} = \Pi - r_s(T_s) C_s$$

Soil respiration rate $r_s(T_s)$ per unit carbon is often modelled with an exponential Q_{10} function,

$$r_s(T_s) = r_0 \exp\left[\frac{\ln Q_{10}}{10}(T_s - T_0)\right]$$

Equilibria and Stability

Equilibria for soil temperature and soil carbon are

$T_{eq} = T_a + \Pi A / \lambda$ and $C_{eq} = \Pi / r_s(T_{eq})$

Linearising about these equilibria gives the condition for instability in the system,

$$1 + \frac{r_s(T_{eq})\mu}{\lambda} < \frac{A \alpha \Pi}{\lambda}$$

Further inspection of the scales involved shows that $\frac{r_s(T_{eq})\mu}{\lambda}$ is negligible and so the condition can be simplified to

$$1 < \frac{A \alpha \Pi}{\lambda}$$

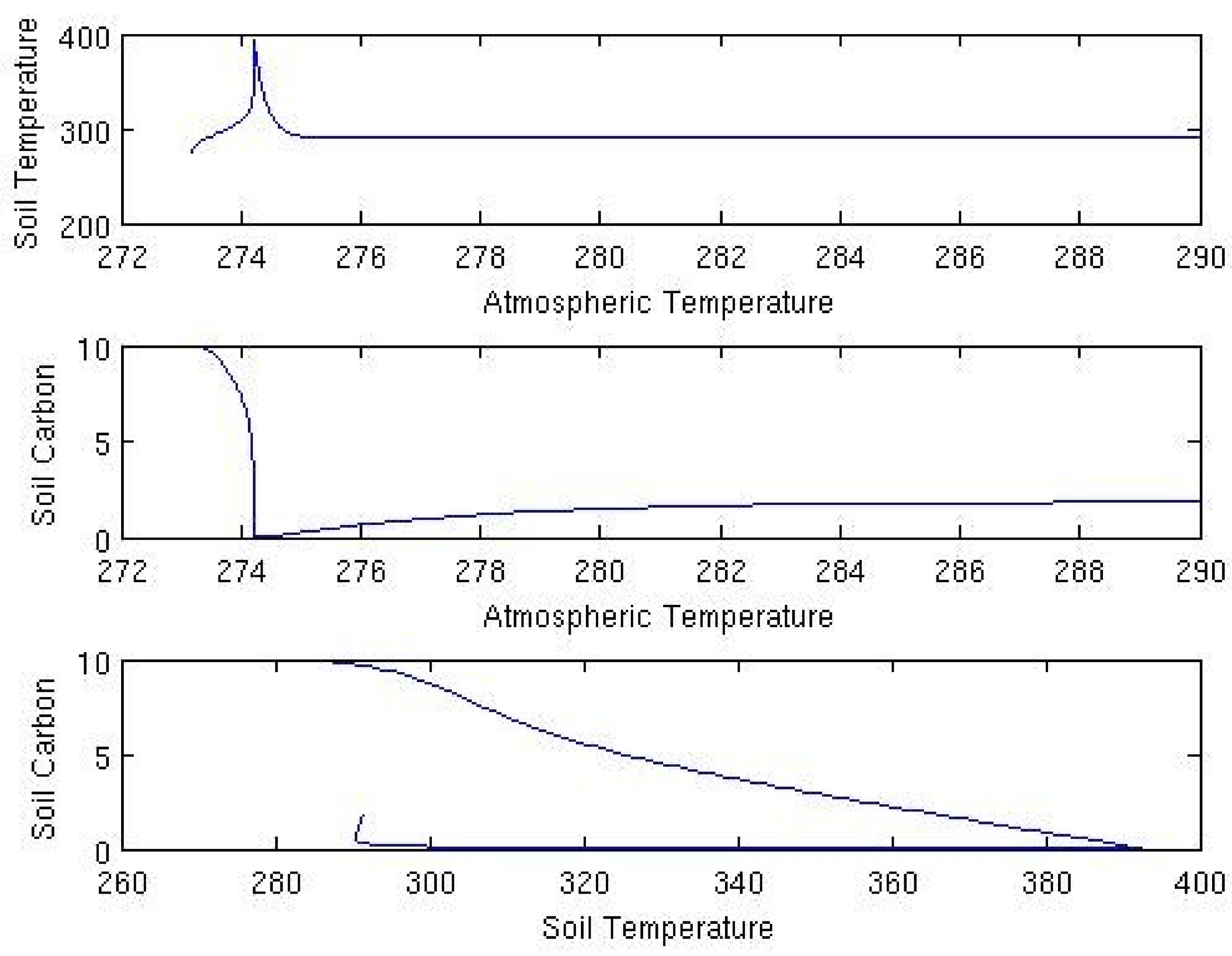
so the stability of the system depends on the ratio between the sensitivities of the soil to heat generated by microbial respiration in the system ($A\Pi\alpha$) and the transfer of heat out of the system (λ).

Parameters

- T_a, atmospheric temperature (K).
- μ, areal soil heat capacity ($Jm^{-2}K^{-1}$).
- λ, areal thermal conductivity or heat transfer coefficient of the soil ($Jy^{-1}m^{-2}K^{-1}$).
- $A = 3.9 \times 10^7\ Jkg^{-1}$, approximate energy produced by respiration per kilogram of carbon emitted.
- $\alpha = (\ln Q_{10})/10$, the fraction increase of specific respiration per unit K of warming.
- r_0, respiration rate at reference temperature T_0.
- Π, net primary productivity ($kgCm^{-2}y^{-1}$).

Model Plot

The plots below have been generated with a Matlab model of the system in which the instability condition is satisfied. Note the peak in soil temperature and drop in soil carbon.



Conclusions and Next Steps

This study shows that for certain soils there is the potential for instability if heat transport is low and respiration rate is high. Potentially important effects of this instability include a sudden increase in soil temperature and a sudden decrease in soil carbon stock. The critical factor in the system is the parameter $\frac{A \alpha \Pi}{\lambda}$ which depends on the areal soil thermal conductivity (λ); the temperature sensitivity of soil respiration, Q_{10}; the net primary productivity (Π). Soils with low λ values combined with high Q_{10} values and a high NPP are most at risk. The model runs exhibiting instability have been produced with parameters for peat soils which have low conductivity and high Q_{10} providing a well insulated environment with high potential for microbial activity.

Future and very recent work includes:

- Examining maximum viable carbon stocks on the stability boundary.
- Investigating the relationship between soil moisture and thermal conductivity to better understand and predict high risk soils.

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