Temperature Anomaly Reemergence in Seasonally Frozen Soils

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Background

Land Memory is the persistent feedback of soil temperature & moisture on surface energy fluxes. Land memory can vanish for several months and reappear at a later date [*Lo and Clark*, 2002; *Robock et al.*, 2003; *Wang and You*, 2004]. This land memory storage mechanism is unexplained.

Hypothesis

Soil temperature anomalies are stored as variations in the amount of frozen ground water and released when the soil thaws. Variations in the amount of ground ice and associated latent heat of fusion isolate energy from diffusion processes. After the frozen soil completely thaws, energy diffusion resumes and the temperature anomaly reemerges.

Conclusions

We saw reemergence in observed soil temperatures and model simulations. Reemergence occurs in seasonally frozen soils just after thaw in late spring. Reemergence strength increases with soil water/ice content.

Data and Methods

1) **Observed reemergence**

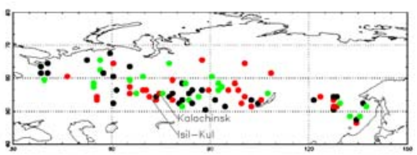

Figure 1: Meteorological stations in the former Soviet Union with soil temperature records used in this study [*Barry et al*., 2001]. Strong secondary peaks in autocorrelation function indicate reemergence [*Desser et al*., 2003] Red is statistically significant reemergence; green is not statistically significant reemergence; black is no reemergence.

2) **Simulated reemergence**

We used a soil thermodynamic model with phase change based on Community Climate Model [*Bonan*, 1996]. Soil water and texture determine thermodynamic properties [*Bonan*, 1996]. Heat capacity is mass weighted average of ice, water, soil, and latent heat of fusion:

$$C_a = C_m f_m + C_w f_w + C_i f_i + f_w L_f \frac{\partial f_w}{\partial T}$$

heat capacity — mineral — water — ice — latent heat

Assume constant soil moisture and seasonally sinusoidal ground heat flux (*G*). 50 year spin up to steady state and introduce *G* perturbation. Subtract steady state to get temperature anomaly vs. time. Strong secondary peaks in temperature anomaly indicate reemergence.

3) **Reemergence Strength**

Vary average temperature and soil water content to determine required conditions for reemergence. Reemergence strength (*S*) relates temperature anomalies (T') to a anomalies of reference case for diffusion only without freezing (T'_{ref}).

$$S = \max\left(\frac{T'}{T'_{ref}}\right) - 1$$

S = 0: No reemergence: T' no greater than expected for diffusion alone

S > 1 for reemergence

1) Observed Reemergence

2) Simulated Reemergence

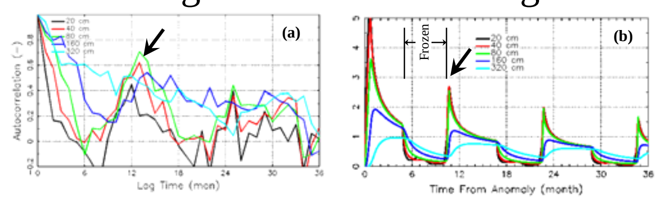

Figure 2: (a) Observed autocorrelations as a function of lag time June soil temperature anomalies at Kalachinsk and (b) simulated temperature anomalies as a function of time from perturbation for a June ground flux perturbation. Secondary peaks (arrows) indicate reemergence.

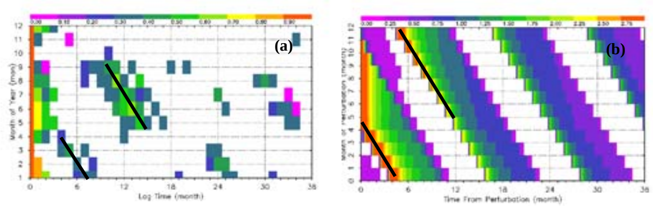

Figure 3: (a) Statistically significant autocorrelations at 40 cm at Kalachinsk as a function of lag time and month of year and (b) simulated temperature anomalies at 40 cm as a function of time from ground flux perturbation and month of perturbation. Tilted secondary peaks (lines) indicate reemergence is synchronized to soil thaw.

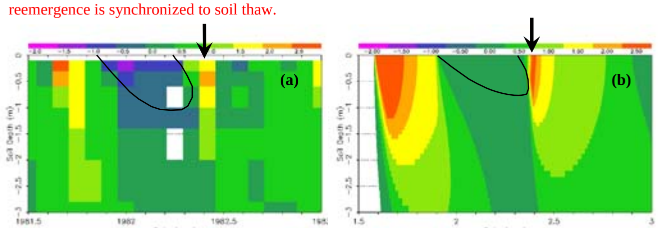

Figure 8: (a) Observed temperature anomalies for 1981-2 showing reemergence at Isil-Kul and (b) simulated temperature anomalies showing reemergence for an August ground flux perturbation. Black lines are freeze lines and arrows show reemergence.

3) Reemergence Strength

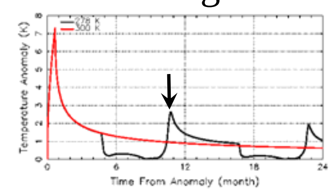

Figure 5: Simulated T' at the surface for soils that freeze each year (black) and soils that never freeze (diffusion only, red). Arrow indicates temperatures used to define reemergence strength (*S*).

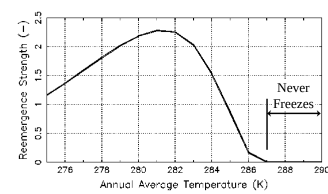

Figure 6: *S* increases to an optimal value with annual average temperature. Reemergence does not occur when the soil does not freeze.

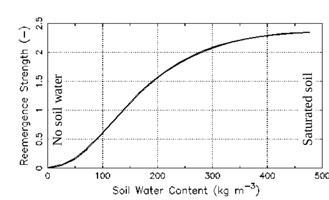

Figure 7: *S* increases with soil water content and reemergence does not occur without soil water.

References:
Bonan, G. B. (1996), A Land Surface Model (LSM Version 1.0) for Ecological, Hydrological, and Atmospheric Studies: Technical Description and Users Guide, NCAR Technical Note NCAR/TN-417+STR, Boulder Colorado.
Lo, F. and M. Clark (2002), Relationships between Spring Snow Mass and Summer Precipitation in the Southwestern United States Associated with the North American Monsoon System, J. Clim., 15, 1378-1385.
Robock A, Mu MQ, Vinnikov K, Robinson D (2003), Land surface conditions over Eurasia and Indian summer monsoon rain, J. Geophys. Res.: Atmos., 108(D4), Art. No. 4131.
Wang GL, You LZ (2004), Delayed impact of the North Atlantic Oscillation on biosphere productivity in Asia, Geophys. Res. Lett., 31(12), Art. No. L12210.

Acknowledgements: This research was funded by the National Academy of Sciences postdoctoral fellowship program through the Earth System Research Laboratory, Climate Monitoring Division, National Aeronautics and Space Administration (NASA) grant NNG05GD15G, and NASA grant NNX06AE65G.