Water and Land-surface Feedbacks in a Polygonal Tundra Environment

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I. INTRODUCTION:

The Arctic, including Alaska, is currently experiencing an unprecedented degree of environmental change with increases in both the mean annual surface temperature and precipitation. These observed changes in the climate regime has resulted in a permafrost condition that is particularly sensitive to changes in both Changes in the surface energy balance and water balances and is susceptible to degradation. Thermokarst topography forms whenever ice-rich permafrost thaws and the ground subsides into the resulting voids. Extensive areas of thermokarst activity are currently being observed throughout the arctic and sub-arctic environments. The important processes involved with thermokarsting include surface ponding, surface subsidence, changes in drainage patterns, and related erosion. In this research, we are applying the land-surface evolution model, ERODE (http://csdms.colorado.edu/wiki/Model:Erode), to an area dominated by low-center, ice-wedge polygons. We are modifying the ERODE model to include land surface subsistence in areas where the maximum active layer depth exceeds the protective layer – the layer of soil above ice-rich soils that acts as a buffer to surface energy processes. The goal of this modeling study is to better understand and quantify the development of thermokarst features in the polygonal tundra environment, emphasizing the resulting feedbacks and connections between hydrologic processes and a dynamic surface topography. Further, we are working on understanding the balance between thermal and mechanical processes with regard to thermokarst processes. This unique application of a landscape evolution model may provide valuable insight related to the rates and spatial extent of thermokarst development and the subsequent hydrologic responses to degrading permafrost in a changing climate.

II. MODEL DESCRIPTION:

The model used in this research is the ERODE model, a rast-based, fluvial landscape evolution model that describes how the weathering, erosion, and sediment transport processes alter the landscape over time. The basic formulations the ERODE model uses are: 1) continuity of mass; 2) runoff generation and routing of surface water; 3) erosion transport laws for hillslope sediment; and 4) erosion transport laws for river sediment. The continuity of mass equation is:

$$\frac{dz}{dt} = \left(\left(Q_{s_i} - Q_{s_o}\right) / dxdy\right) dt \qquad (1)$$

where dz/dt is the change in elevation over time [L/T]; Q_{si} and Q_{so} are the sediment transport rates into and out of a model element [L^3/T]; and dx and dy are the dimensions of the model element [L]. The runoff equation is:

$$Q = RA^P \qquad (2)$$

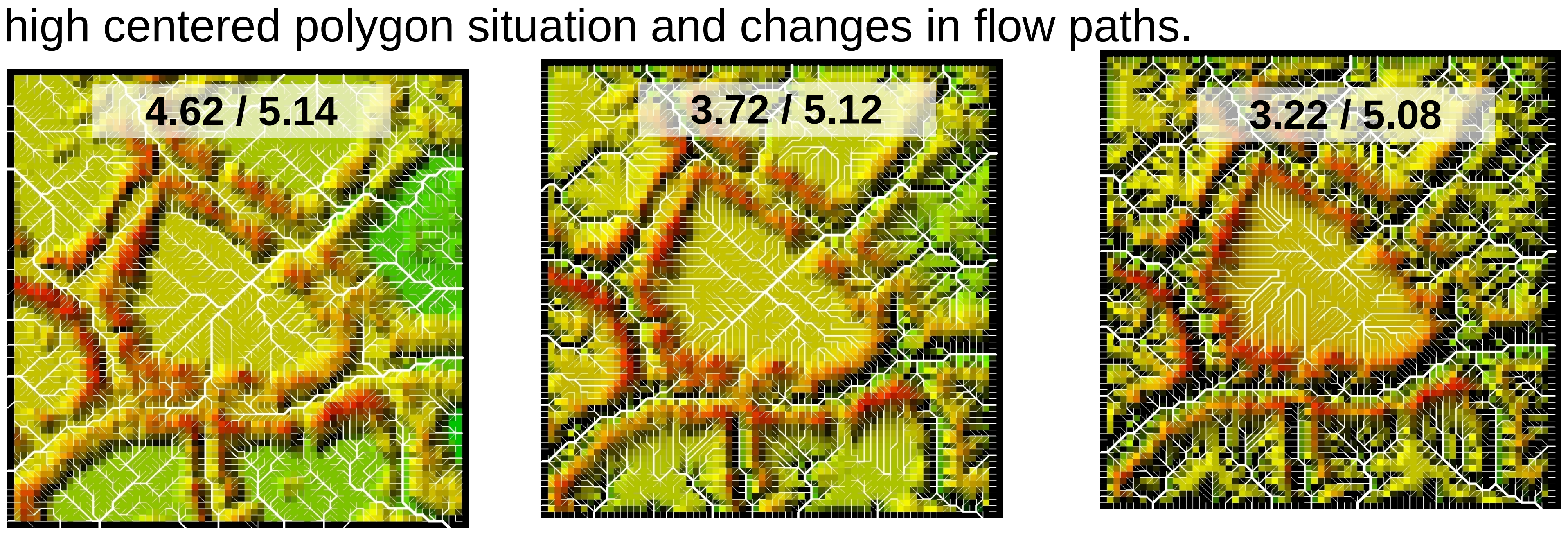
where Q is the runoff rate [L^3/T]; R is the rain rate [L/A]; A is the contributing area [L^2]; and P is the Q-A coefficient. The sediment transport rate is:

$$Q_s = KQ^m S^n \qquad (3)$$

where K is the erodibility factor []; S is the slope [L/L]; and m & n are the discharge and slope coefficients.

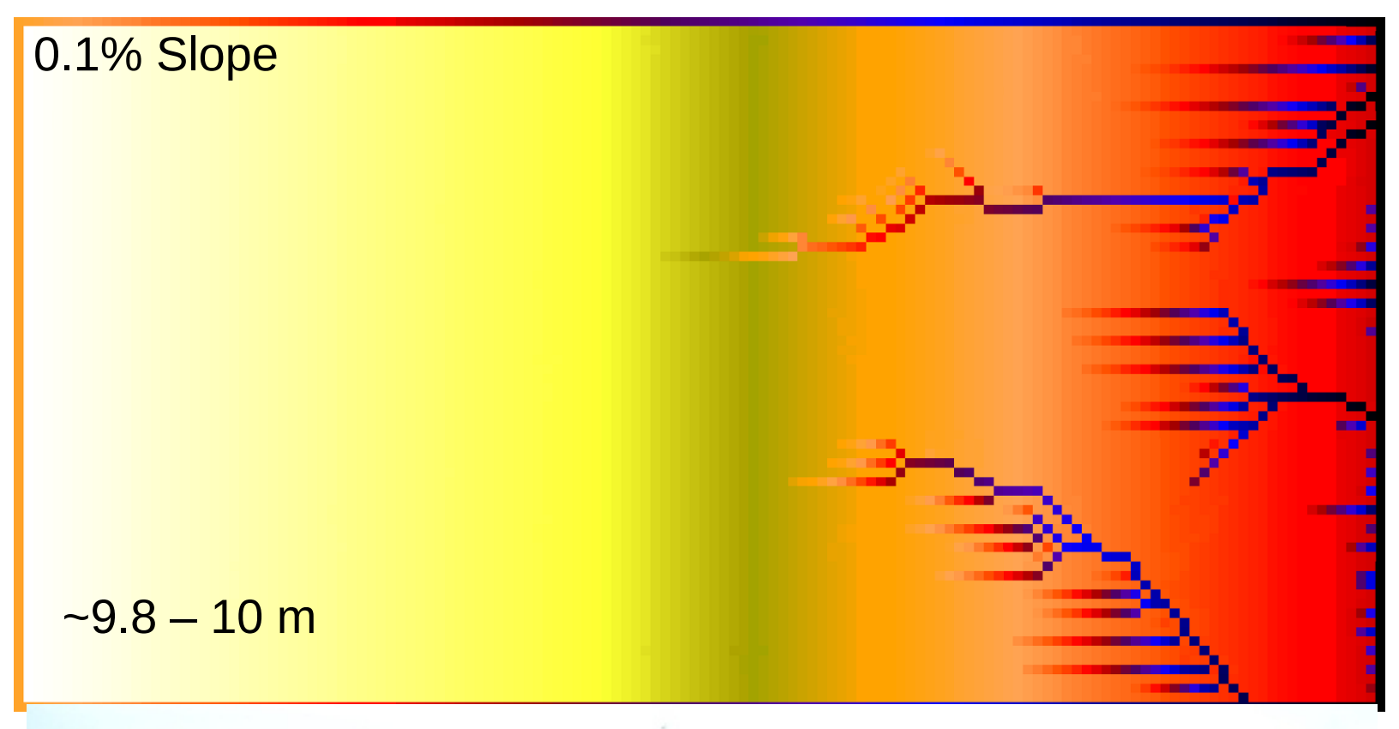
III. APPROACH AND RESULTS:

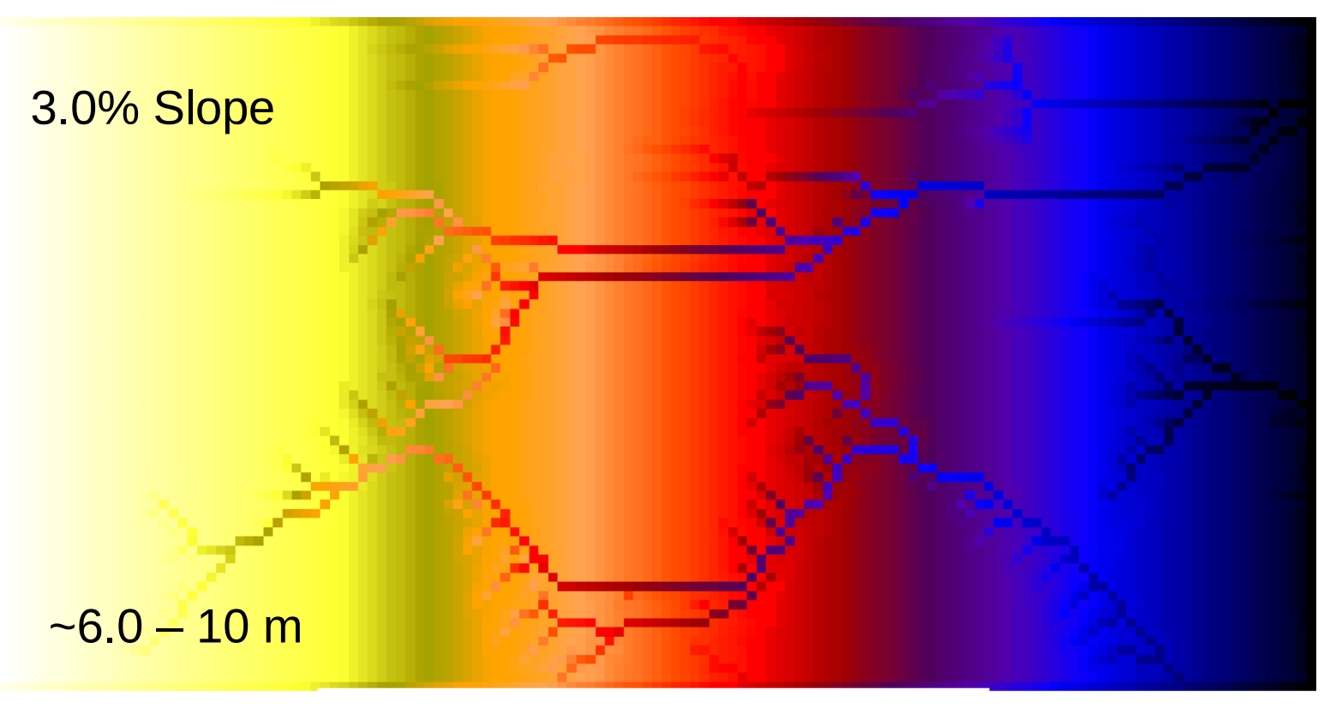
The ERODE model was modified to accept spatially variable erodibility factor [K in Equation 3] and applied to a low centered polygon. A mask was used to identify areas underlain with ice-wedges (troughs) and areas without massive ice (polygon centers). Areas underlain with ice wedges are assumed to have a much higher erodibility [potential] than polygon centers (non-ice wedge areas). As the model progresses, the troughs deepen as expected leading to a more high centered polygon situation and changes in flow paths.



The left, center and right panels display the polygon at time 0 and future states of time depending upon the degree of warming. The numerical values inside each panel indicate the minimum/maximum elevations, in meters, of the model domain. White lines indicate the direction of water flow. If climate warming is included in the analysis, ice melt and permafrost thaw will greatly accelerate the landscape evolution.

The role of topography was also explored by applying the mask to a plane (140 m x 73m) with different slopes and over a 1000 year time period. Results indicate that on flat areas (like the Arctic Coastal Plain), topography is not likely to be an important factor in the landscape evolution. However, slight increases in the slope (or topography) can result in a very different landscape.





IV. FUTURE DIRECTION:

We are currently working on implementing a modified Stefan equation into the ERODE model in order to calculate the maximum active layer depth each year. If the maximum active layer exceeds the protective layer, the land surface elevation will be reduced by the void space between the two active layers (previous and current maximums). These modifications will allow us to better understand the balance between mechanical and thermal processes in thermokarst development.

V. ACKNOWLDEGMENTS:

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