Conceptualization of Arctic Tundra Landscape Transitions Using the Alaska Thermokarst Model

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I. INTRODUCTION

Thermokarst topography forms whenever ice-rich permafrost thaws and the ground subsides due to the volume loss when excess ice transitions to water. The Alaska Thermokarst Model (ATM) is a large-scale, state-and-transition model designed to simulate landscape transitions between landscape units, or cohorts, due to thermokarst. The ATM uses a frame-based methodology to track transitions and proportion of cohorts within a 1-km^2 grid cell. In the arctic tundra environment, the ATM tracks landscape transitions between non-polygonal ground (meadows), low center polygons, coalescent low center polygons, flat center polygons, high center polygons, ponds and lakes. The transition from one terrestrial landscape type to another can take place if the seasonal ground thaw penetrates underlying ice-rich soil layers either due to pulse disturbance events such as a large precipitation event, wildfire, or due to gradual active layer deepening. The protective layer is the distance between the ground surface and ice-rich soil. The protective layer buffers the ice-rich soils from energy processes that take place at the ground surface and is critical to determining how susceptible an area is to thermokarst degradation. The rate of terrain transition in our model is dependent on the soil ice-content, the drainage efficiency (or ability of the landscape to store or transport water), and the probability of thermokarst initiation. Using parameterizations derived from small-scale numerical experiments, functional responses of landscape transitions will be developed and integrated into NGEE-Arctic climate-scale (CLM) modeling efforts.

II. MODEL DESCRIPTION

The ATM is a state-and-transition model designed to simulate transitions among landscapes caused by thermokarst disturbance. The ATM uses a frame-based methodology to track transitions among landscape units (cohorts).. Although the ATM does not track cohorts in a spatially explicit fashion, initial information on the proportion of each cohort in grid cell is required. The frame logic uses a logical rule set to determine the probability that a cohort will remain in its current landscape unit (parent cohort) and the probability that it will transition to another landscape unit (child cohort) (Figure 3). The probability of initiation and the rate of transition is a deterministic model. The logical rule set considers factors such as climate, topography, fire, land use, hydrology, soil texture and ice content.

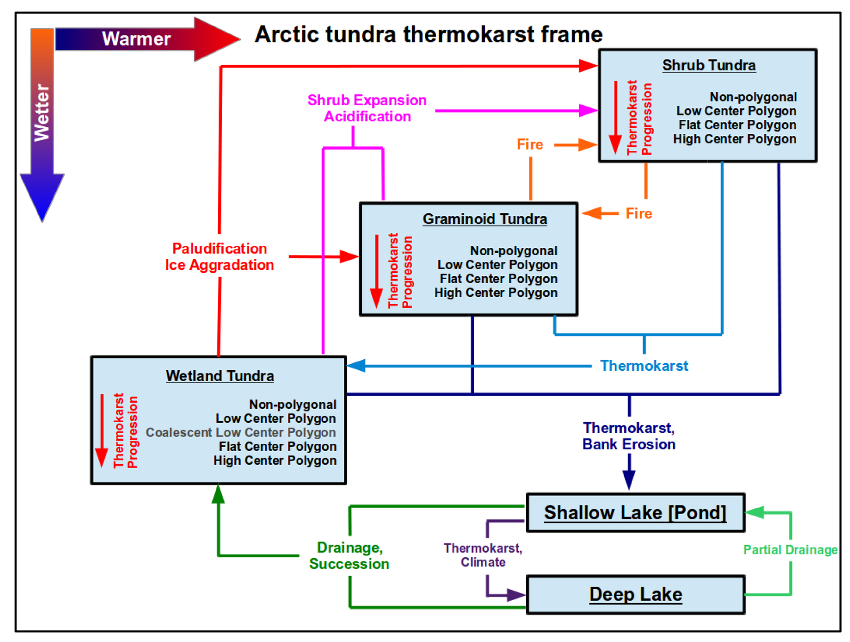


Figure 1. Description of frames and trajectories. The arctic tundra component of the ATM considers landscape transitions due to thermokarst between the following eco-types: wetland tundra, graminoid tundra, shrub tundra, and lakes. Within each terrestrial eco-type, the landscape type defines the state of thermokarst degradation, which is assumed to coincide with the degradation of an ice-wedge polygon.

Figure 2. Examples of landscape types simulated in the ATM.

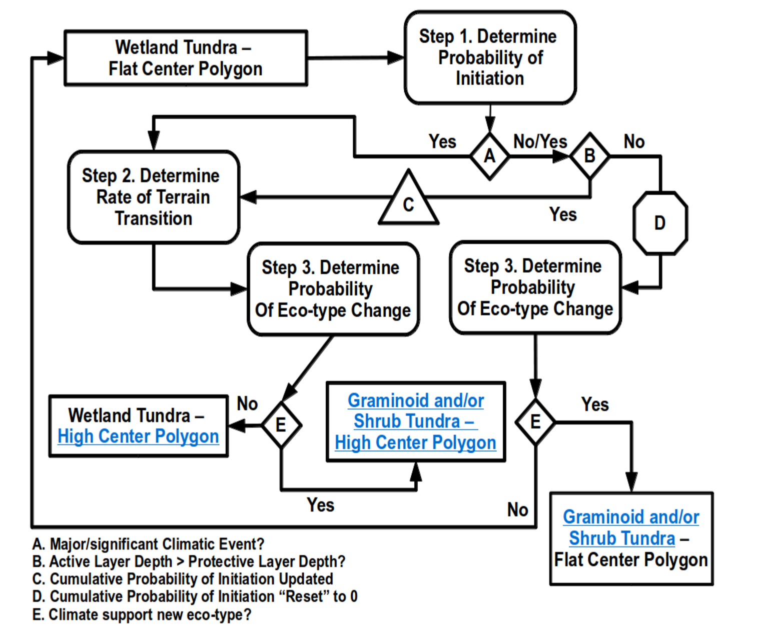
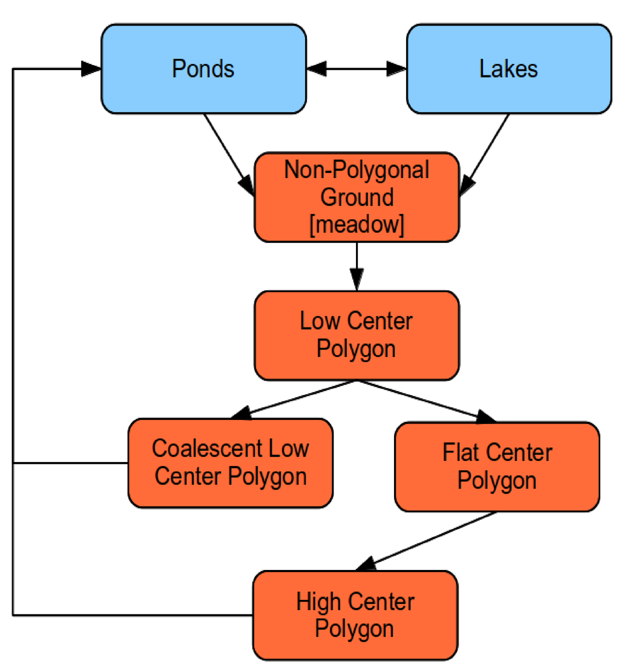


Figure 3. Example of a frame. Frames contain the logic and needed to determine the fate of each cohort present in the simulation domain. At this point in time, the ATM is tracking 15 different cohorts – 13 terrestrial and 2 lake. A unique frame, or decision tree, exists for each cohort.

III. LANDSCAPE TRANSITIONS



Terrestrial Cohorts:

- 1-directional transitions
- Coalescent Low Center Polygon and High Center Polygon cohorts transition to the Pond cohort
- Transition between cohorts occurs when the active layer depth penetrates the protective layer (Figure 4)
- Rate of transition is a function of the ground ice content, the drainage efficiency (landscape ability to store or transmit water, and the degree of active layer penetration into the protective layer)

Pond and Lake Cohorts:

- Permafrost thickness does not allow vertical lake drainage (through the bottom of the permafrost)
- Lakes and Ponds expand vertically and laterally at a prescribed rate
- The difference between lakes and ponds is based upon the presence or absence of liquid water throughout the year (i.e. in deep lakes the lice thickness is less than the lake depth)
- Lateral pond/lake drainage results in the transition from the lake/pond cohort to the Wetland Non-Polygonal Ground cohort (exclusively)

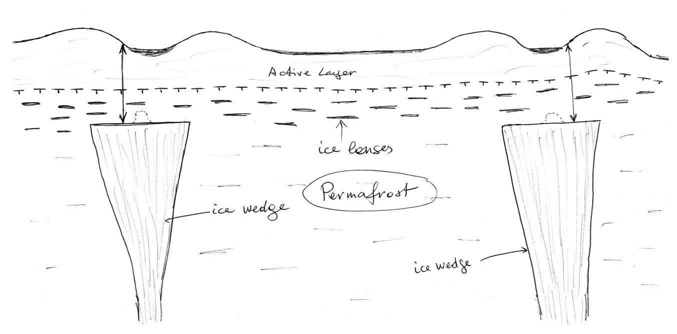


Figure 4. Protective layer illustration. The protective layer is the land surface and the top of ice-rich soils (or massive ice bodies). The protective layer acts as a buffer between surface processes and underlying permafrost.

IV. INITIAL RESULTS

The Barrow Peninsula is the test region for evaluating the dynamics of the tundra thermokarst transitions. The Barrow Peninsula is located in a polygonal tundra landscape under varying degrees of thermokarst degradation. Much of the evaluation of the ATM dynamics will be to compare the simulated expansion rates of thermokarst landscape units to what has been observed. Initial fractional area of each cohort are derived the work of Lara et al (2015).

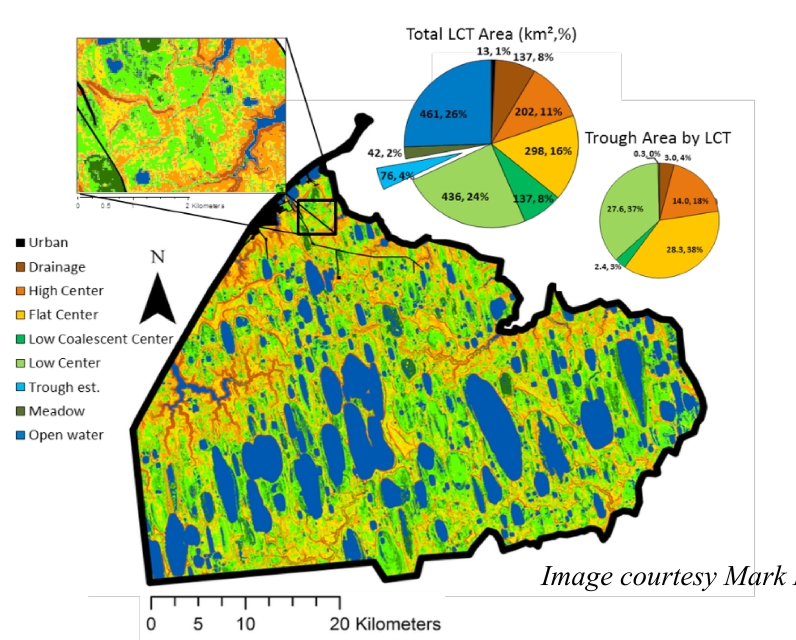


Image courtesy Mark Lara, UAF.

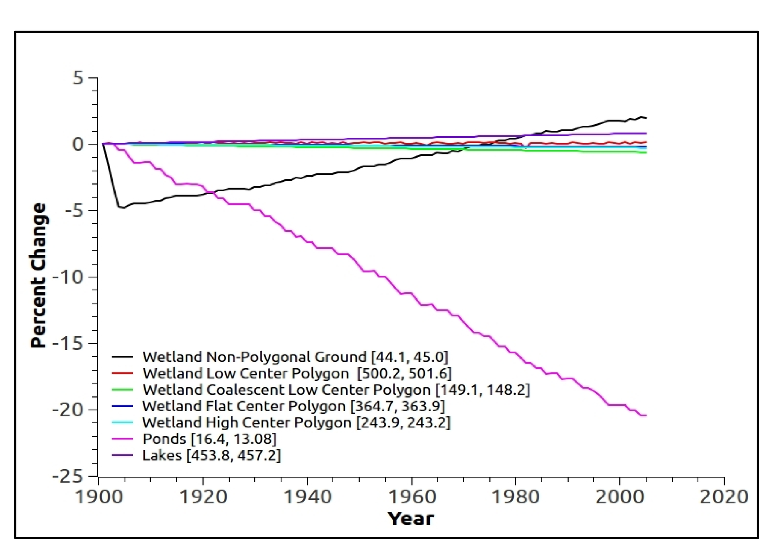


Figure 5A: Percent change in cohort area.

Figure 5B: The Lake cohort.

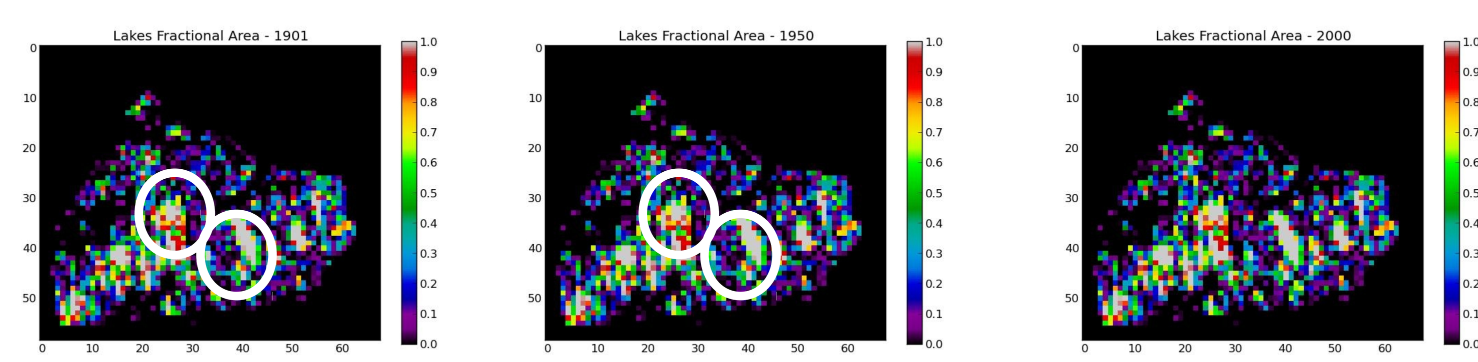


Figure 5B: The Wetland Low-Center Polygon cohort.

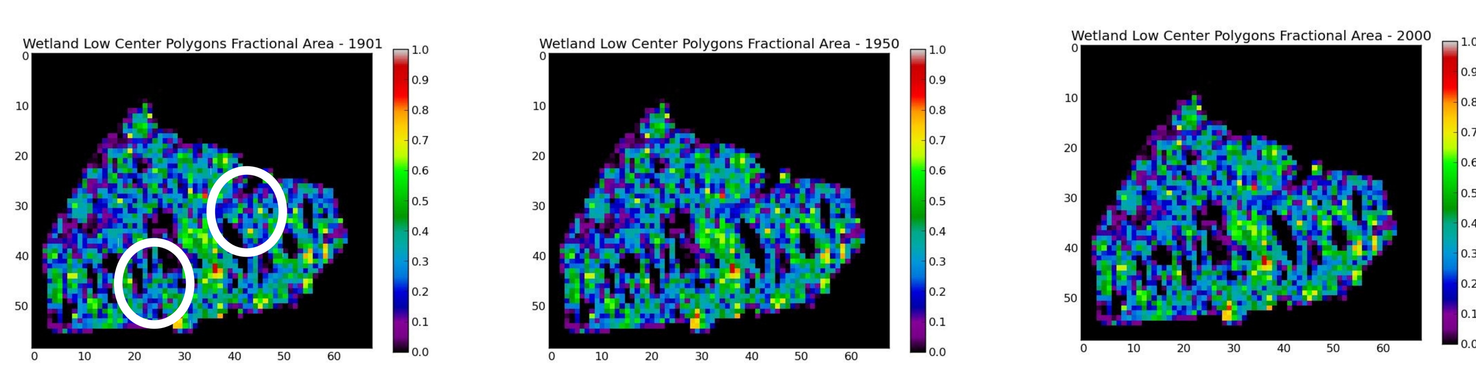


Figure 5C: Dominant Cohort.

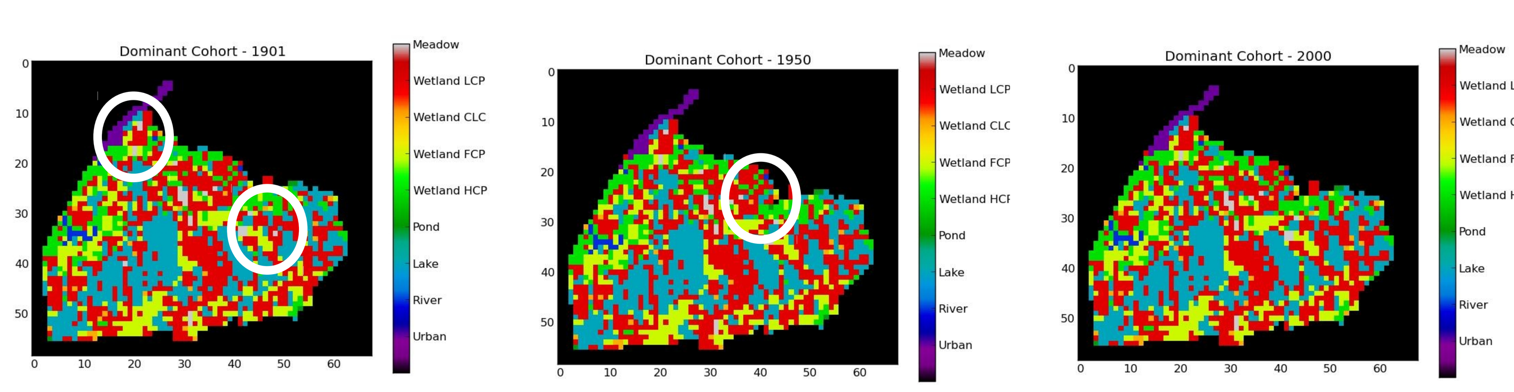


Figure 5. Initial Simulation Results. Results presented here are from the model calibration process. (**A**) Percent change in total cohort area. Values in brackets indicate the cohort area at the beginning and end of the simulation. (**B**) Fractional areas of the Lake and Wetland Low-Center Polygon cohorts for years 1901, 1950, and 2000. (**C**) The dominant cohort (largest fractional area) for the model domain for years 1901, 1950, and 2000. White circles indicate areas of landscape change.

V. FUTURE WORK:

- Function development/parameterization to describe probability of initiation and transition rates from field observation and fine-scale numerical experiments (Figure 6).
- Develop functional responses of landscape transitions to be integrated into climate-scale modeling efforts.
- Robust sensitivity analysis
- Conduct scenario simulations in order to predict future landscape evolution

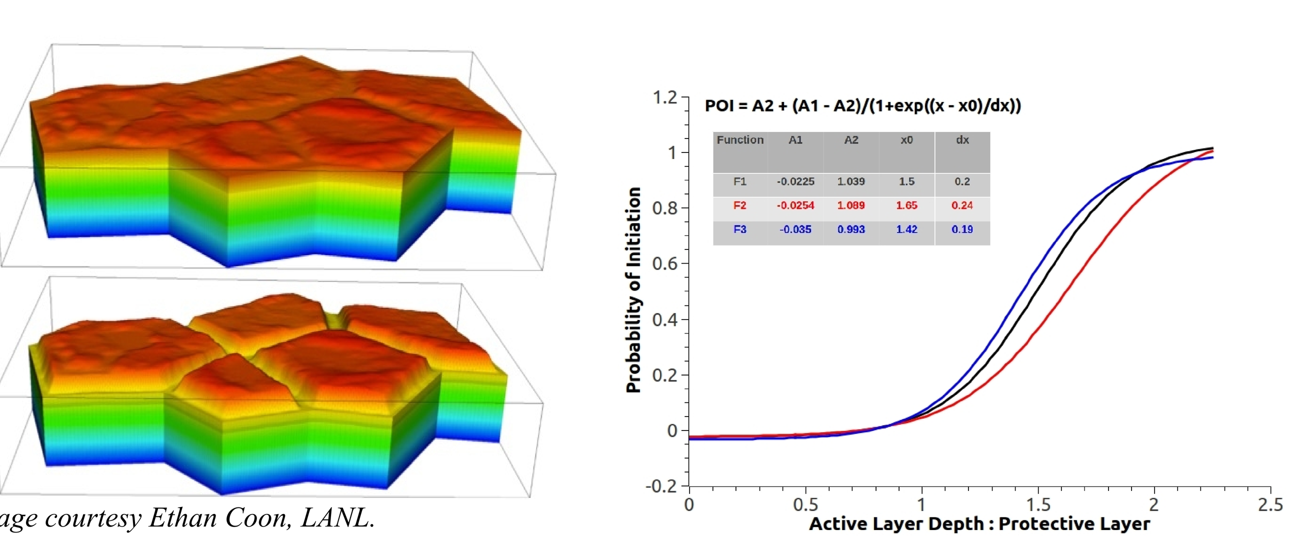


Image courtesy Ethan Coon, LANL.

Figure 6. Fine-scale numerical experiments will be conducted (left panel) to develop probability of initiation (right panel) and rates of landscape transitions for different soil and climatic conditions.

VI. ACKNOWLEDGEMENTS

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