Modeling self organization of non-sorted circles

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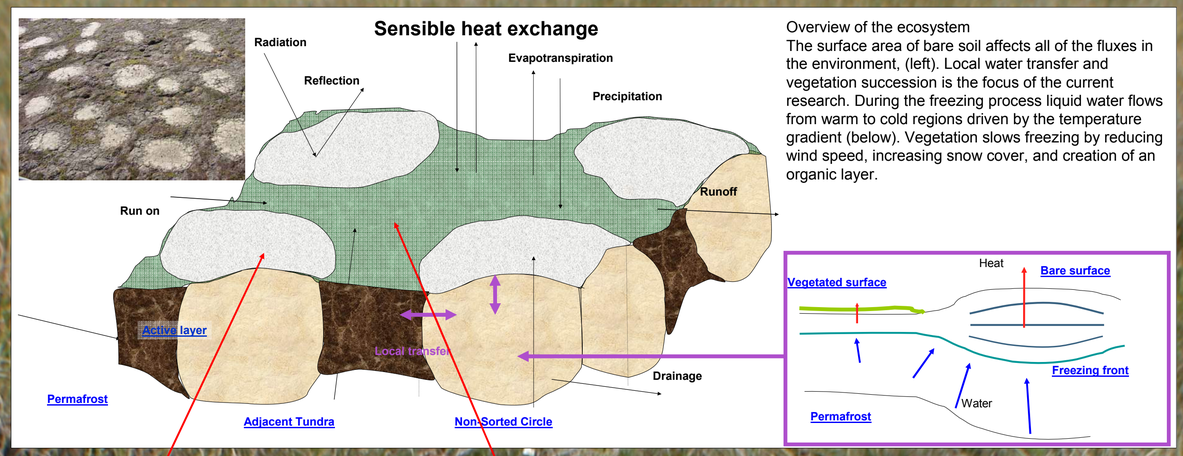
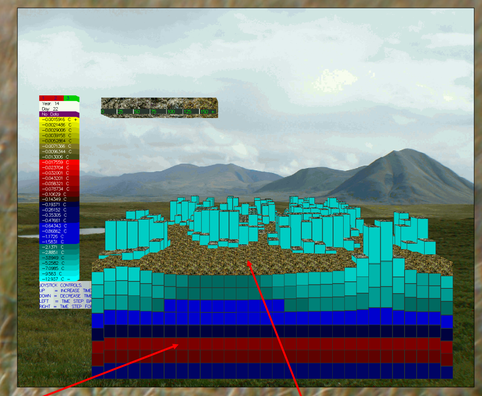
Introduction

Non-sorted circles are an abundant form of patterned-ground with limited vegetation located in the arctic tundra. These features can be found in fine-grained, frost-susceptible, and moist to wet soils, mostly underlain with permafrost. The age of these patterns is estimated to be thousands of years during which the shape and size are maintained. Biological and physical interactions in the non-sorted circle system are balanced. Plant succession drives vegetation toward the center of the circle, where frost heave prevents vegetation development. Insulation due to vegetation and snow creates a temperature gradient in the soil during freezing. This gradient leads to ice lensing (frost heave) which prevent plant roots from developing. Over many years, vegetation is successful in areas with minimal heave, resulting in an accumulation of organic matter, which further stabilizes the system.

This paper focuses on the initial self organization of non-sorted circle systems. Landscapes with non-sorted circles underwent a transformation from barren homogeneous soils without circles to vegetated with circles. We discuss two theories for the initial development of the system: (1) instability of the frost heave process, and (2) initial establishment of random vegetation with redistribution of liquid water.

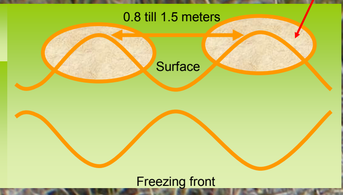


Overview of the ecosystem
The surface area of bare soil affects all of the fluxes in the environment, (left). Local water transfer and vegetation succession is the focus of the current research. During the freezing process liquid water flows from warm to cold regions driven by the temperature gradient (below). Vegetation slows freezing by reducing wind speed, increasing snow cover, and creation of an organic layer.



Differential Frost Heave model

- Governing Equations as pr0posed by Fowler and Krantz (1994)
- Linear stability analysis
- Small perturbations grow if conditions are optimal
- The growth depends on the wavelength of the perturbation



Arctic Vegetation

- Nitrogen limited vegetation development (Epstein 2001)
- Climate influence is determined stochastically
- Frost heave component to reduce plant growth
- Provides insulation to WIT through plant biomass

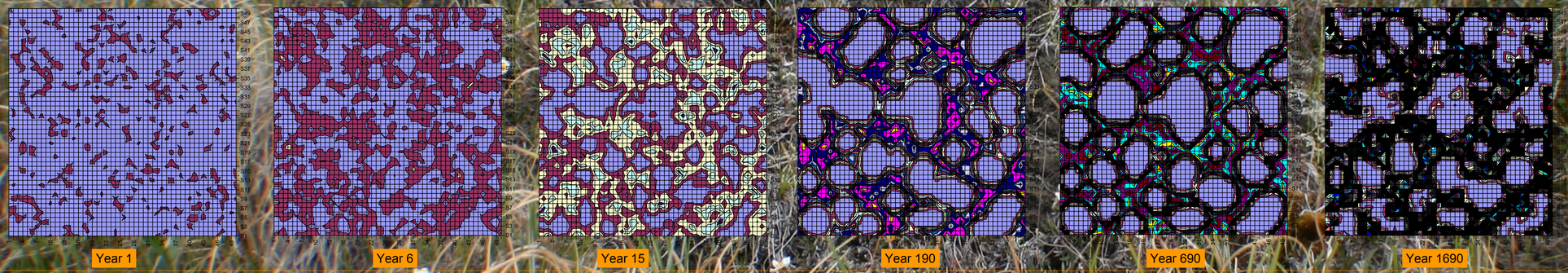
Water Ice Temperature (Daanen and Misra 2006)

- Coupled heat and moisture transfer in 3 D (Daanen and Nieber 2006)
- Phase change according to the general Clapeyron equation to convert temperatures into liquid water pressures and the freezing characteristic curve to determine ice formation
- Insulation at the soil surface drives soil temperature gradients, that leads to preferential ice accumulation

Coupled WIT-ArcVeg

- Ice accumulation as a proxy for the heave parameter in ArcVeg
- Neighboring node heave of 25% added to current node
- Biomass is used to estimate the insulation value for each node
- Soil organic nitrogen is used to adjust the freezing characteristic curve
- Virtual reality tool developed (Daanen et al. 2006)

WIT-ArcVeg pattern development from random vegetation



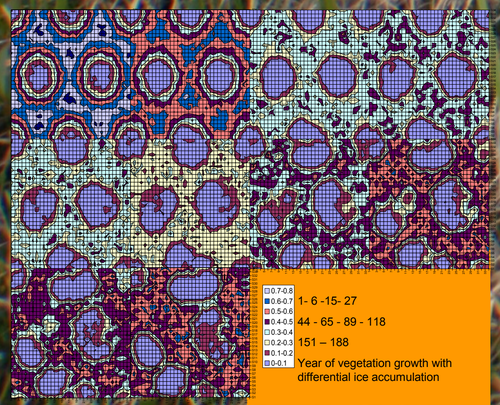
All the pattern views on this poster are top down views of the simulation domain. The colors indicate vegetation density or insulation strength. The values are relative and have no physical meaning.
The blue-purple color indicates minimal vegetation density or non-sorted circles.

Results

The 'Differential Frost Heave model DFH' was applied to simulate the initiation of non-sorted circles from bare soil. The 'WIT3D-ArcVeg model' was applied to simulate pattern formation and identify the stability between heave and growth of the regular pattern initiated by the DFH model. The results show that: (1) Number density of non sorted circles is maintained, (2) Initial pattern is not maintained in the limited initial vegetation case and (3) WIT-ArcVeg pattern is very dynamic.

Discussion

The WIT-ArcVeg model may need more pattern stabilizing relationships. This can be achieved through: (1) Rheology of the soil, (2) Vegetation expansion from the vegetated areas through rhizomes and (3) organic layer root mat on top of heaving mineral soil



DFH and WIT-ArcVeg pattern develpment

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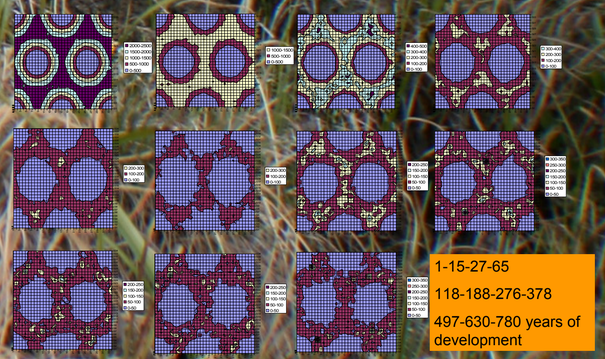
Acknowledgments

Dr. Vladimir Romanovsky for field data. The biocomplexity team for discussion. The Arctic Region Supercomputing Center for computational resources technical and financial support. National Science Foundation Grant No. OPP-0120736.

Stable non-sorted circle ecosystem pattern with DFH and WIT-ArcVeg



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