# Poisson-Voronoi Diagrams and the Polygonal Tundra


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## 1. Introduction

- The role played by small-scale features is often fundamental to correctly compute land-atmosphere fluxes (e.g., peatlands and periglacial environments).
- The impact of local heterogeneities is captured only by local mechanistic models, but they are unable to describe regional or global effects.
- A statistical description of such systems may be able to upscale climatic responses and fluxes from local features to large scales.
- Case study to test the approach: polygonal tundra.

## 2. Polygonal Tundra

- Polygonal tundra is a type of patterned ground generated by complex crack and growth processes.
- It mainly consists of elevated dry rims and low wet centres.
- $CH_4$ emissions depend strongly on the position of the water table level (Wt) in respect to the polygon centre surface (S).

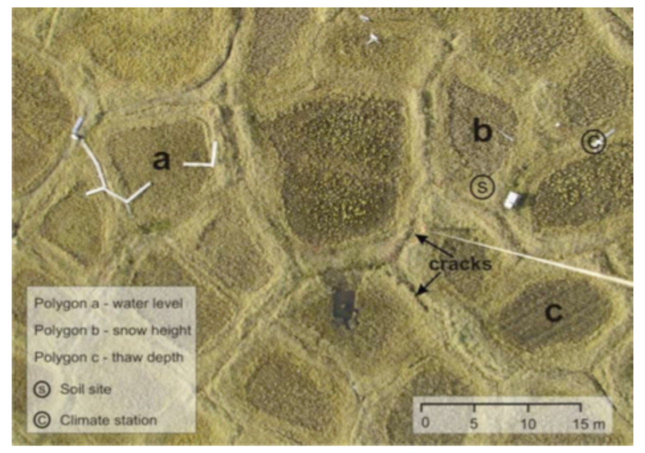
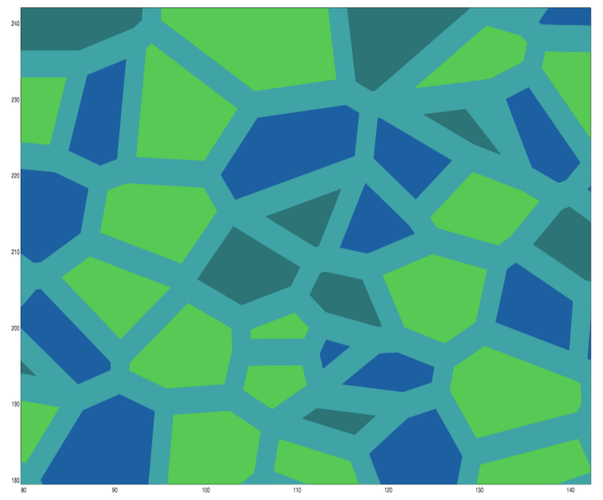



**Figure 1**: Aerial picture of the experimental sites on Samoylov Island, Lena River Delta, Siberia (Boike et al., 2008).

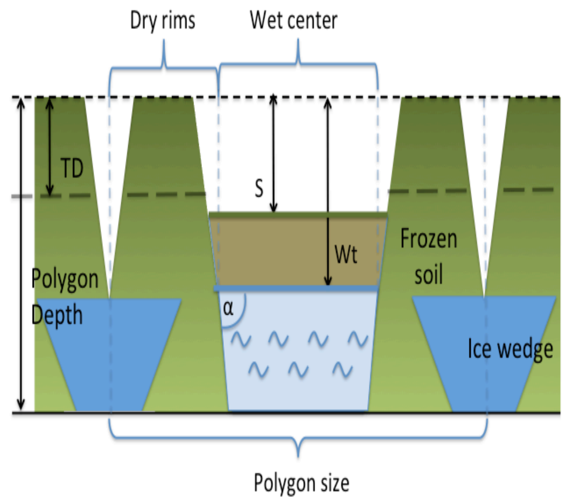
## 3. The model

- **Poisson-Voronoi Diagrams (PVD).** We generate a Poisson point pro-cess and then associate with each point $p_i$ a Voronoi polygon $V(p_i)$.
- Different colours represent different characteristics of the terrain (i.e., humidity).



- **Cross section of a polygon**. To realistically compute greenhouse gas fluxes, we distinguish 3 different terrain types. If:

  a) (S-Wt) >ε → WET centers
  b) |S-Wt|≤ε → SATURATED centers
  c) (S-Wt) <-ε → MOIST centers
  ε = 10 cm




## 4. Results

### Dynamical water table and upscaled methane emissions

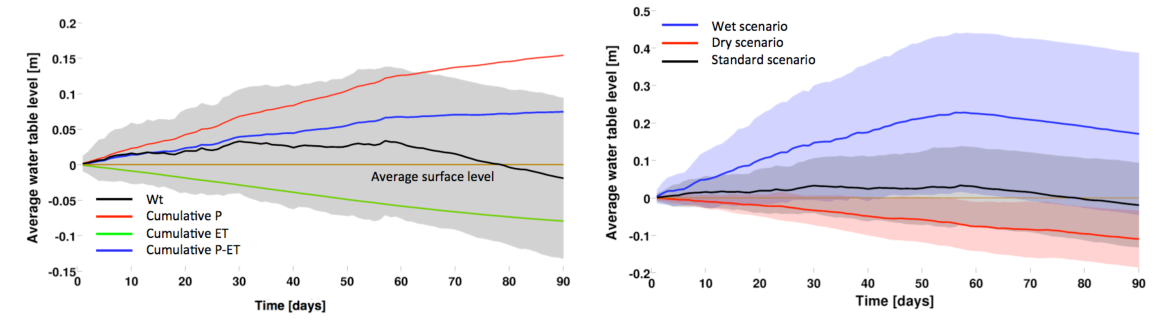



**Figure 2**: Ensemble simulations. Panel (a) displays water table variations over time along with cumulative precipitation and evapotranspiration.
Panel (b) shows water table dynamics in the three simulated scenarios: wet (blue line), dry (red line), and standard (black line).

- Water table level varies with precipitation, evapotran-spiration (climatic forcing) and lateral runoff.
- Lateral runoff takes place if:
  Wt < Thaw Depth
  and it is fundamental in the water balance.
- Very wet summers would lead to significant modifications of the fraction of the landscape covered by saturated centers.
- Different surface types are associated to different emission properties.
- The *wet* scenario leads to a drop in the surface covered by drier tundra, and therefore to higher methane emissions.

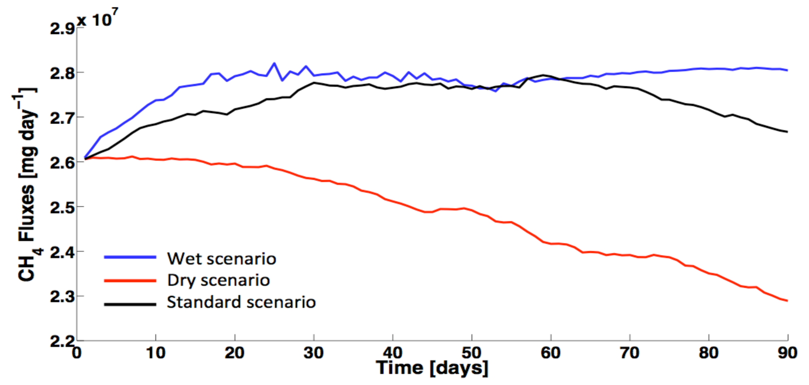



**Figure 3**: Our model shows increased methane emission in the wet scenario because of a drastic drop in the area covered by the relatively drier tundra (moist centers and elevated rims).

### Percolation threshold

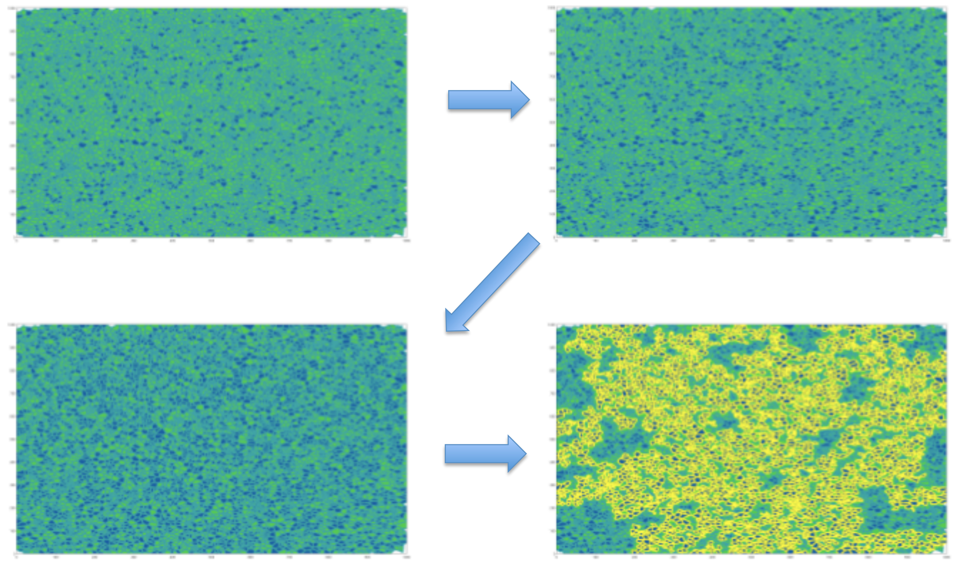


**Figure 4**: Percolation realization. The giant cluster of interconnected polygons is coloured in yellow.

- Interconnections among polygons explain slow drainage.
- Application of percolation threshold theory on PVD.
- Water flows out from the system through a giant cluster of connected polygons.

## 5. Conclusions

- **Statistical properties of the polygonal tundra are well reproduced by the model.**
- **The model is able to upscale land-atmosphere fluxes and to explain shifts in the landscape due to climatic forcing.**
- **Basis for future generalizations of the approach.**

## 6. References and affiliations


- F. Cresto Aleina et al., (2012), A stochastic model for the polygonal tundra based on Poisson-Voronoi Diagrams. *Earth System Dynamics*, in revision.
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- J.Boike, et al., (2008), Climatology and summer energy and water balance of polygonal tundra in the Lena River Delta, Siberia, *Journal of Geophysical Research*.



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