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Improving estimates of regional vegetation: Using pre-settlement vegetation data and variable wind speed to quantify pollen dispersal and source area

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1. Introduction

Fossil pollen records from lakes, bogs and mires, provide the main source of information about vegetation responses to climate change and land cover change over timescales of 10^1 to 10^5 years. These records have been used to reconstruct vegetation histories at individual sites and, when aggregated together, have enabled mapping of climate-driven shifts in plant species ranges over 10^2 to 10^3 km during past glacial-interglacial cycles.

However, the pollen found in today's sediment records is not the result of a straightforward process. Taxonomic variability in pollen productivity, physical characteristics of pollen grains, and taphonomic processes all complicate the relationship between pollen and vegetation on the landscape.

2. Motivation

Quantitative reconstructions of past vegetation rely on estimating the transport and dispersal properties of pollen, and thereby estimating the surrounding vegetation. Yet most applications do not account for anisotropies in pollen source area introduced by atmospheric variations. This work uses regional measurements of wind speed and direction in conjunction with settlement era vegetation measurements to better understand their effects on source area.

3.1 Materials and Methods: NARR Wind Records

The North American Regional Reanalysis (NARR) contains near surface records of wind speed and direction for the entirety of North America. This dataset spans 1979-present, with 8x daily records. Each years data were downloaded and subset to the correct 32 km x 32 km grid cell, and then appended together to represent the full 1979-2012 record. The records were then subset to contain only the pollination season, here defined as March through August.

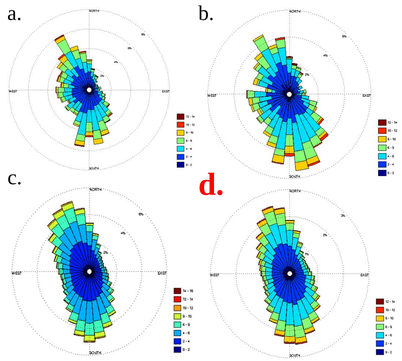
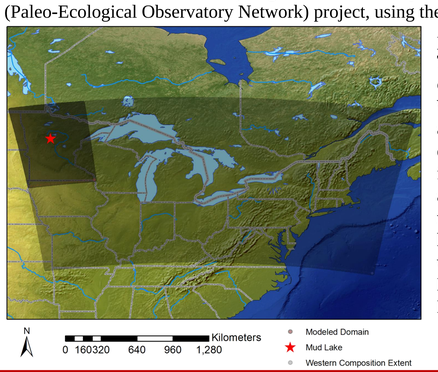


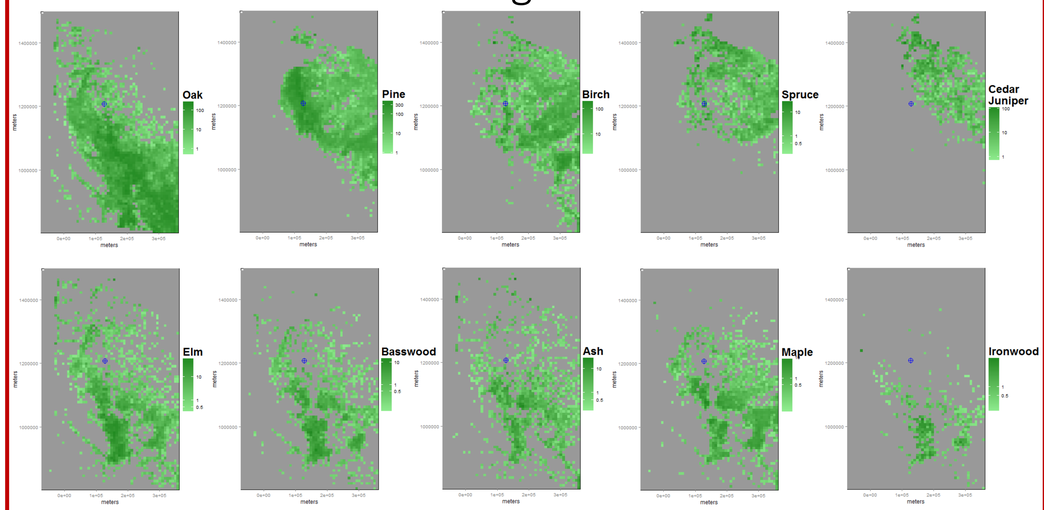
Figure 1. Wind rose diagrams for Mud Lake, MN. (a) Single year, 2012 (b) Single pollination season, 2012 (c) 1979-2012, full years **(d)** 1979-2012, pollination seasons

3.2 Materials and Methods: Pre-settlement Vegetation

Settlement era (ca. 1810-1904) vegetation data was provided by the PalEON (Paleo-Ecological Observatory Network) project, using the western composition product, version 0.3. The domain provides complete data from Wisconsin, Minnesota and N. Michigan, and dispersed samples from Illinois, Indiana, and S. Michigan. For the results shown here, the lake chosen was Mud Lake, in North-Central Minnesota (red star).

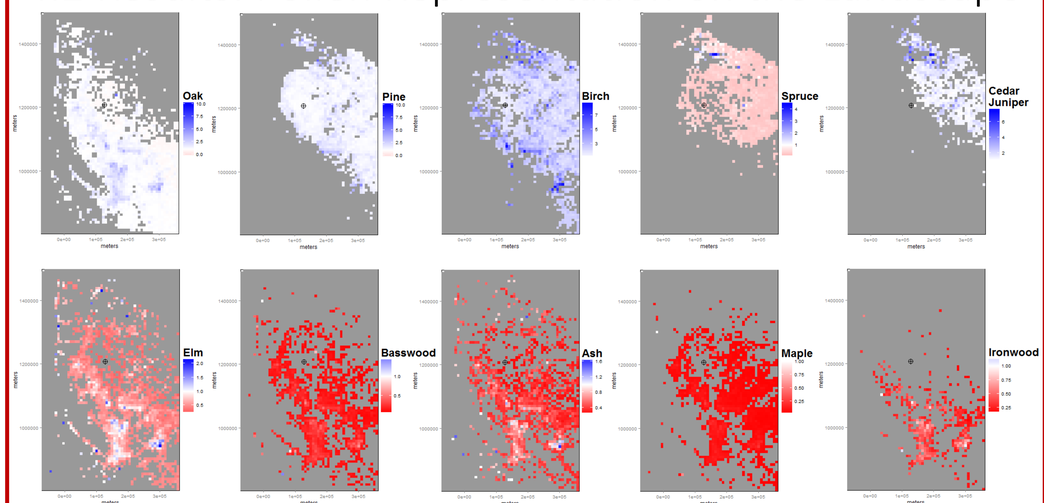


4.1 Results: Pollen Loading Source Area



- **Objective**: Calculate the number of pollen grains per square meter that are deposited on a specific lake surface, on a per taxon basis. Together, these patterns represent the overall source area of pollen for the lake.
- **Results**: Shown above are the source areas for the 10 dominant taxa in this domain. The relative loadings of some taxa compared to others (i.e. oak vs. fir) suggest a differentiable representation in the pollen record. Comparisons of several true pollen counts from lakes in this region to their modeled loading counterparts are shown in 6.1.

4.2 Results: Pollen Representation on the Landscape



- **Objective**: Show how individual taxa are represented in the pollen record when compared to their vegetation abundance.

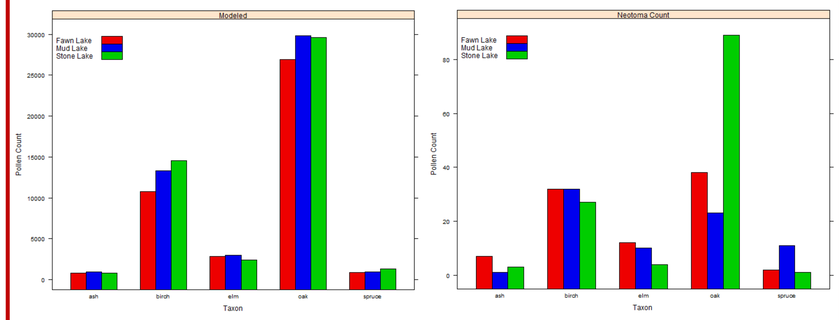
$$Measure\ of\ pollen\ representation_{per\ grid\ cell} = \frac{\left(\frac{Loading\ of\ individual\ taxon}{Total\ pollen\ loading}\right)}{\left(\frac{Number\ of\ tree\ of\ individual\ taxon}{Total\ trees}\right)}$$

- **Results**: Blue areas represent grid cells where pollen loadings are over-represented relative to their vegetation abundance, and red areas represent grid cells that are under represented. These patterns vary highly by taxon, and part of this relationship is explored in 6.2 by looking at the proportions of pollen loading for individual taxa and their relationship with distance traveled.

5. Model Details

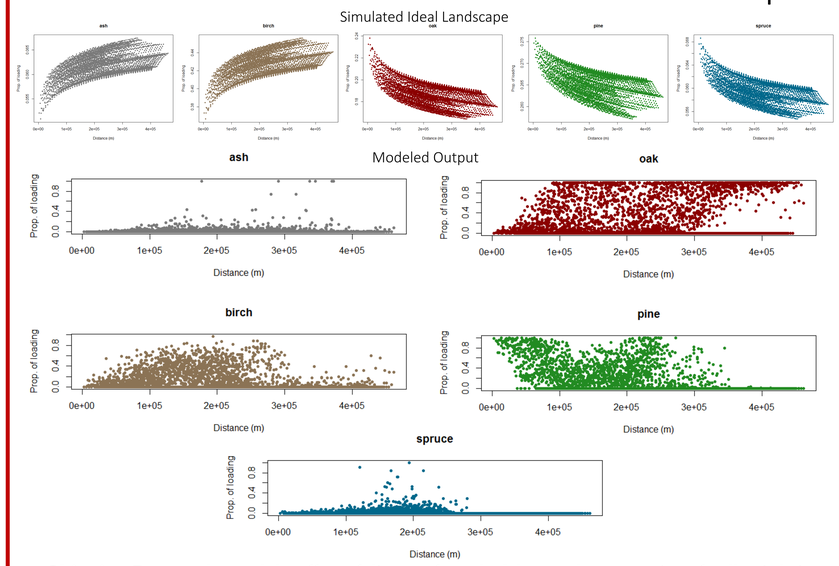
The above modeled results estimate pollen loading of individual taxa on a lake surface. This mechanistic transport model is adapted from the Prentice-Sugita framework. Empirically determined taxon-specific fall speeds determine the proportion of pollen remaining airborne at a distance, z, from vegetation. Relative productivities determine the amount of pollen released by each taxa. The pollen loading on a given lake is estimated on a per-wind-record basis. This means that the pollen loading is integrated across 8 times daily estimates of wind, in a known direction and speed. The direction and speed determine which vegetation (input as gridded raster data) potentially contribute pollen to the lake. If a proportion of emitted pollen remains airborne it is added to the lake's pollen loading.

6.1 Model Validation: Data Comparison



- **Objective**: Compare inter-taxon ratios of real pollen counts from lakes in the Neotoma Paleoecology Database to modeled pollen loadings.
- **Results**: Relative magnitudes of pollen being deposited on lakes matches quite well with true counts

6.2 Model Validation: Distance Relationships



- **Objective**: Better understand the effect of distance from the lake on what proportion of pollen is being deposited on the lake
- **Results**: Some taxa show over representation close to the source, while others are better represented further away from the source

7. Future Work

- Continuing with this work I will expand the number of lakes modeled to better assess the relationship between modeled pollen loadings, true pollen counts, and other quantitative models.
- Beyond these quantitative models, I plan to adapt an existing atmospheric modeling system (Community Multiscale Air Quality model) with realistic sources and characteristics of pollen grains. Pollen is similar to any other biogenic aerosol, and could be used similarly in such a modeling framework.

Acknowledgements

This work is a contribution to PalEON, an interdisciplinary macrosystems research team supported by the National Science Foundation [EF-1241868]. Data were obtained from the Neotoma Paleoecology Database (http://www.neotomadb.org/), and the work of the data contributors and the Neotoma community is gratefully acknowledged. The North American Regional Reanalysis dataset provides a long-term, consistent, high-resolution climate dataset for the North American domain, as a major improvement upon the earlier global reanalysis datasets in both resolution and accuracy, thanks to Fedor Mesinger et. al. Model development was done using MATLAB, and data analysis and figure generation using R and ArcGIS.

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