Continental-scale drivers of lake drainage in permafrost regions

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Lakes and Lake Drainage in Permafrost

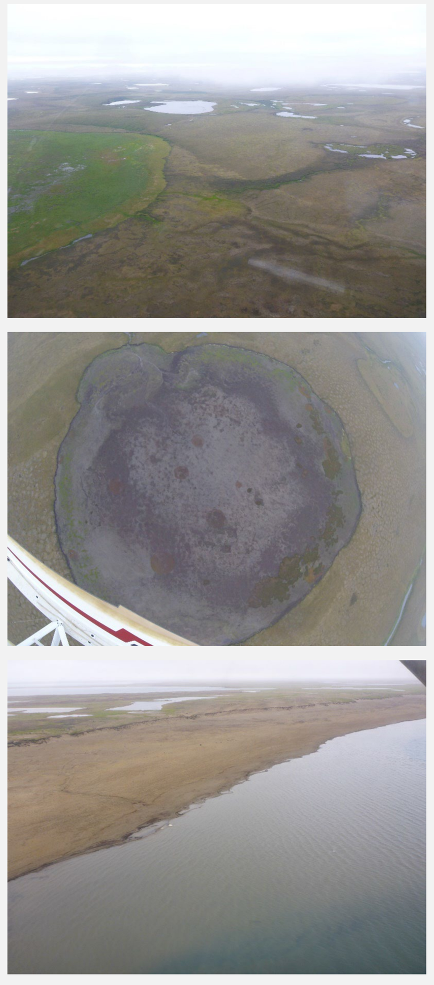


Fig. 1: Oblique photos of drained lakes in western – and northern Alaska.

- Lakes are ubiquitous in high-latitude ecosystems
- Influence on an array of key biogeophysical processes and ecosystem characteristics
- Lakes can be highly dynamic (thermokarst lake cycle)
- Recent decline in lake area observed across permafrost ecosystems
- Prediction of lake persistence for anticipating future carbon-climate feedbacks from arctic ecosystems needed
- Only few studies have systematically analyzed drivers of lake drainage

- What are the main drivers of partial and complete lake drainage?
- Can we correctly predict/recreate lake drainage?
- How will the projected climate change impact spatial patterns of lake drainage?

Data and Study Sites

Four Study Regions
- ~ 600k lakes
- 2.3 M km²
- Lake area changes: 1999-2014
- Lake dataset from Nitze et al, 2018
- Various types of lake formation, climate and ground conditions

Lake Properties
- Lake area, perimeter
- Lake shape (roundness, eccentricity)
- Distance to other lake or drainage

Subdivided into three Drainage Classes
1. Stable lake: <25 % area loss,
2. Drained partial: 25-75 % & >1 ha area loss
3. Drained complete: >75 % & >1 ha area loss

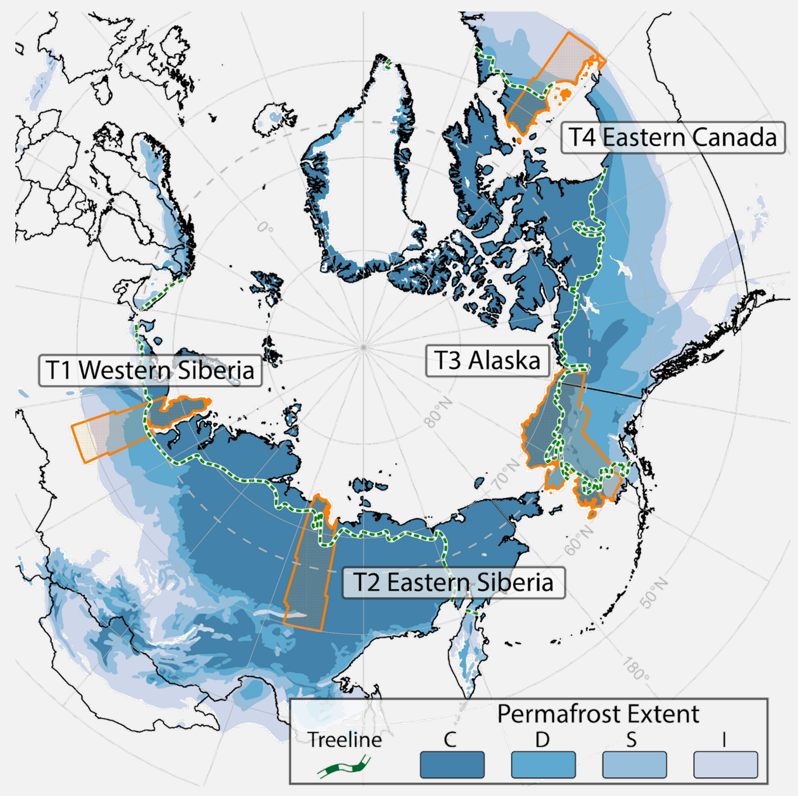


Fig. 2: Study site of lake drainage analysis, adapted after Nitze et al, 2018.

Lake Data Classification

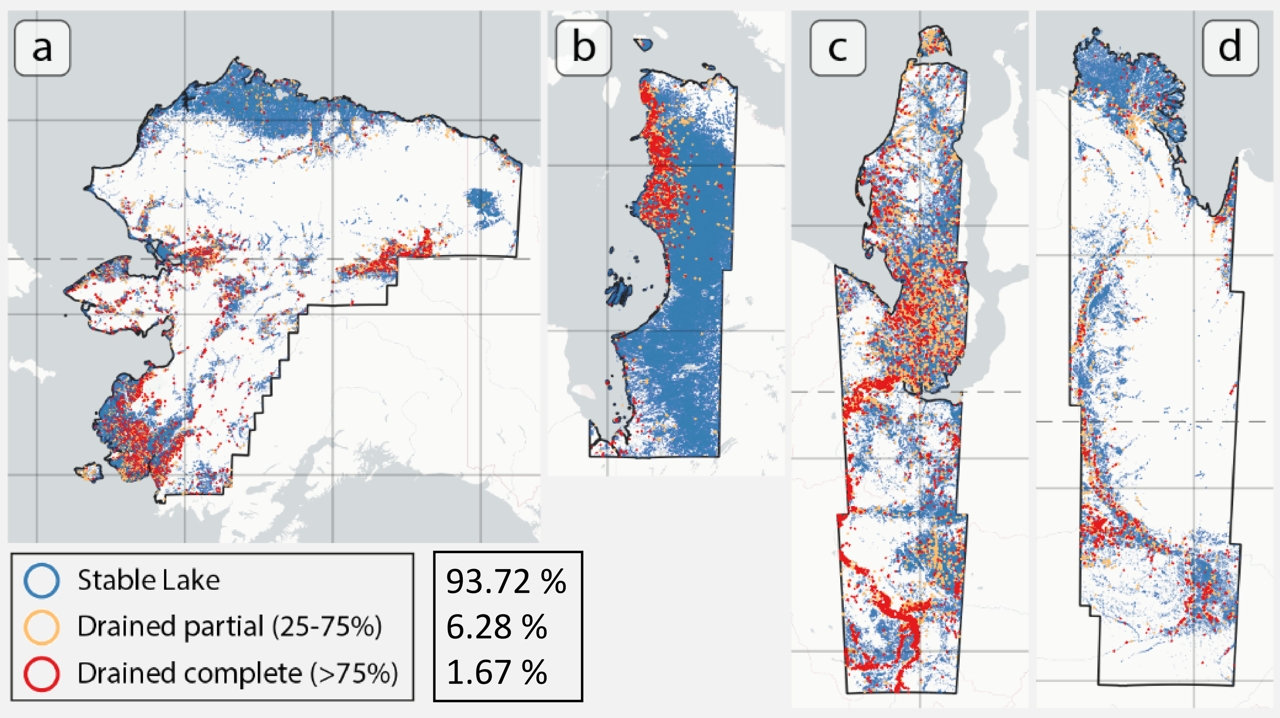


Fig 3: Spatial distribution of lake drainage classification for the period 1999-2014. Drained lakes highlighted for better visibility, due to high class imbalance.

External Datasets

Permafrost
- CCI Ground temperatures v3 (Obu, 2019)
- Thermokarst landscapes (Olefeldt, 2016)
- IPA Permafrost Map: extent, ground-ice

Climate/Weather
- ERA5–Land (mean + trend) (CCCS, 2021)

Geomorphology
- Arctic DEM – elevation (range), slope,
- Distance to drainage

Climate Projections (drainage projection)
- CMIP6 climate ensemble - SSP585 scenario
- mean air temperatures, total precipitation

Key Methods

Data Processing
- Lake classification
- Data assimilation
- Feature engineering

Drainage Prediction

XGBoost + Random Forest
- 1. Observation period (1999-2014)
- 2. Prediction on climate projections

Feature Importances
- Shapley values (XAI)
- Random Forest Feature Importances

Feature Importances

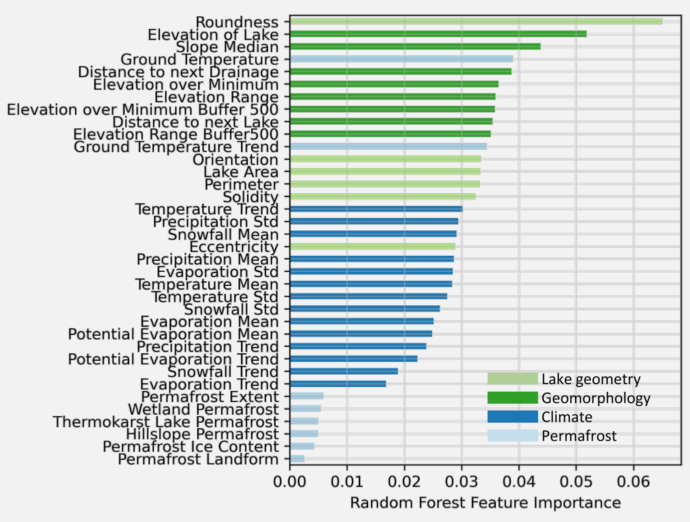


Fig 4: Random Forest Feature Importances (RF-FI) for the complete dataset.

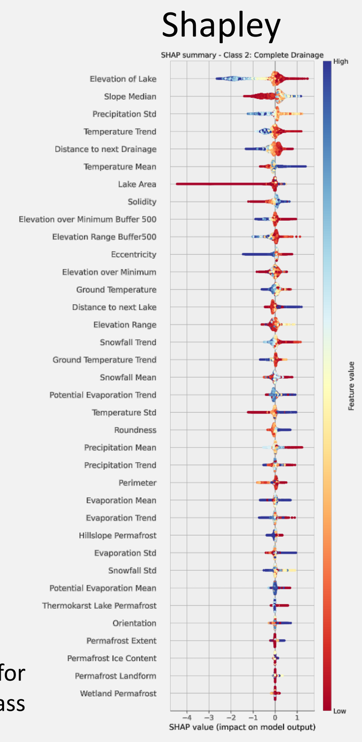


Fig 5: Shapley values for complete drainage class

- Shapley values create FI for each individual lake, RF-FI only for entire dataset
- Lake geometry and geomorphology are most important (local scale)
- Climate + ground temperatures somewhat important, but more dynamic (regional scale)

Drainage Modeling and Prediction

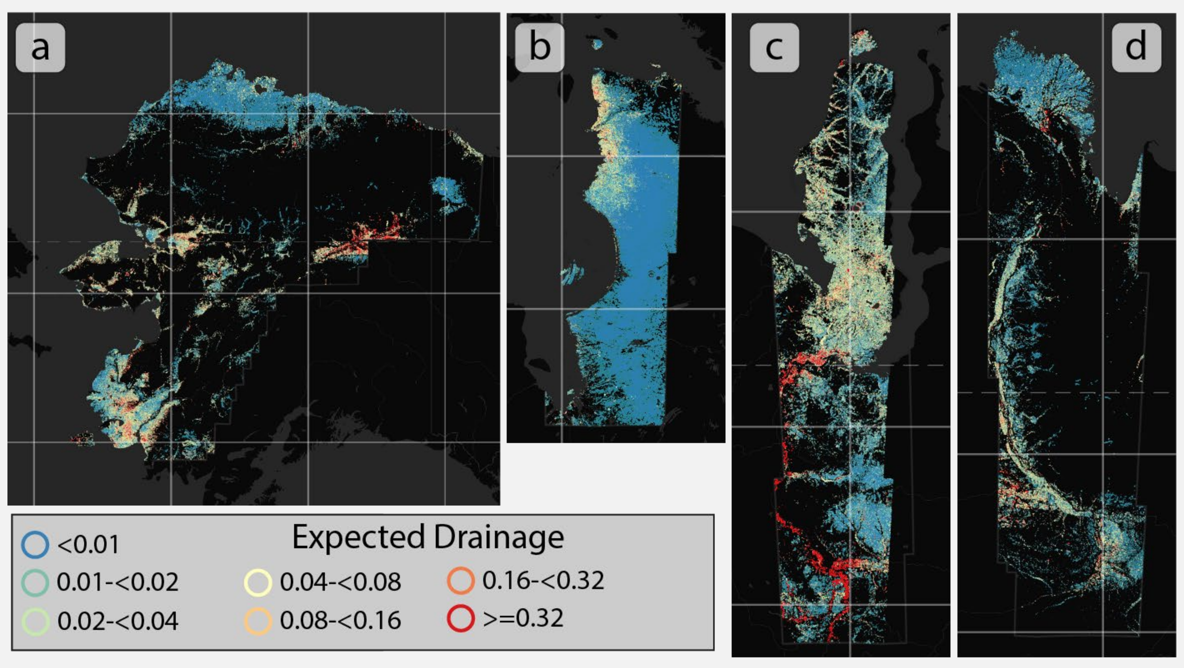


Fig 6: Expected Drainage (xDrain) values (predicted probability values of partial + complete drainage in all four study regions.

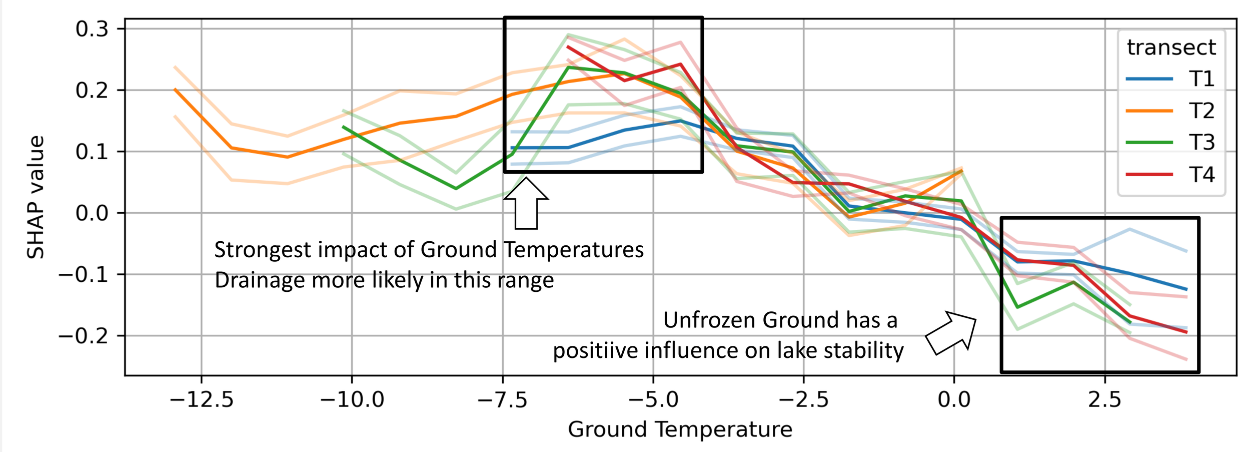
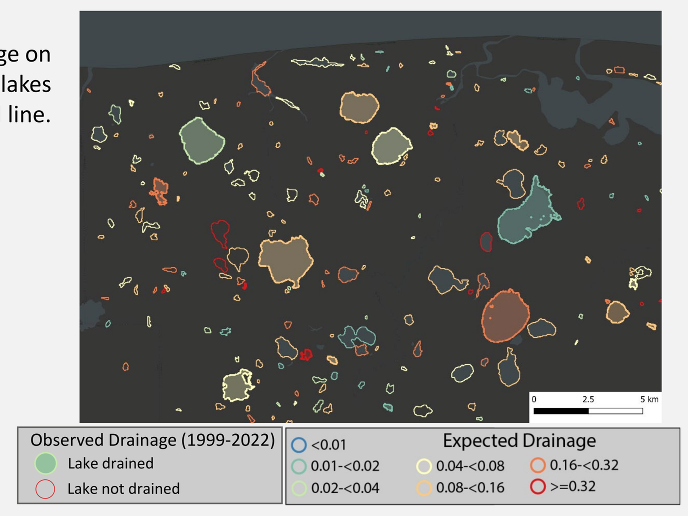


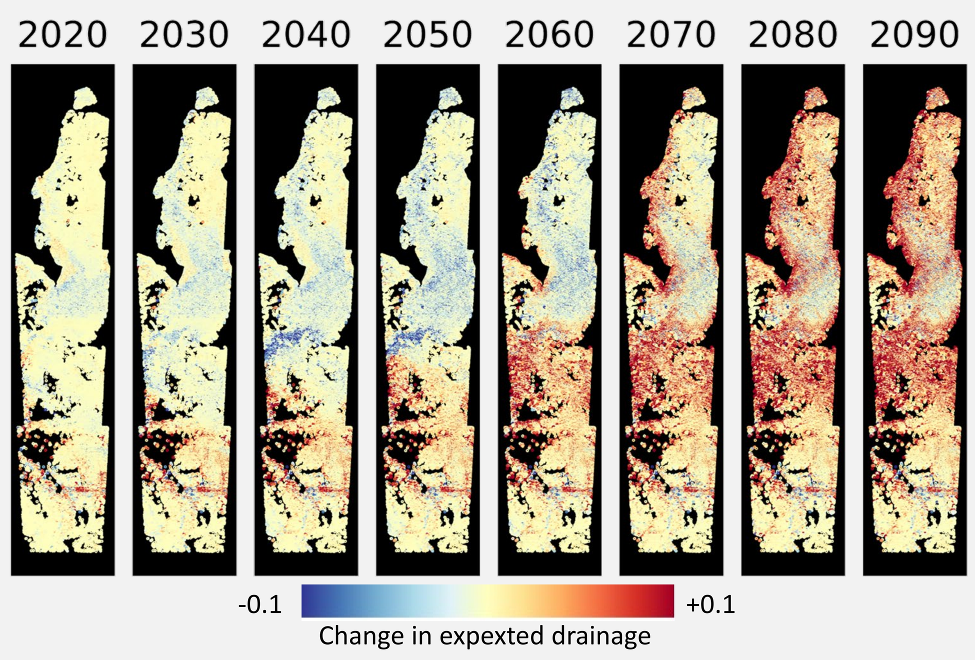
Fig 7: Shapley values (median +- 25th and 75th percentile) of ground temperatures for complete drainage. Ground Temperatures contribute strongest to lake drainage from -8 to -3 °C.

Fig 8: Expected versus observed drainage on the NE Seward Peninsula, Alaska. Drained lakes (1999-2022) in bold dashed line.



- Drainage Events cannot be accurately predicted: BUT likelihood can: eXpected Drainage (xDrain)
- Spatial patterns detected correctly
- XGBoost performs better than Random Forest

Drainage Projection for the 21st Century



- Lake drainage becomes more likely in the future
- Northward shift: today's "stable" cold regions likely affected most
- Unclear if unprecedented future can be predicted on today's data

Fig 9: Projected change in expected drainage in western Siberia (T1) under ssp585 climate change scenario usind CMIP6 climate projections with 2010 decade as baseline. Imputed mean air temperature total precipitation and linear regression of ground temperatures.

Challenges

- Existing data may not cover local geomorphological detail and complexity
- Data homogenization and extraction is challenging
- Lake dataset only trend (not annual) → adding annual data for temporal
- Big data-driven analysis → physics informed AI
- Future climate scenarios are potentially breaking the model

Take Away and Outlook

- Extensive compilation and analysis of lake drainage, provides insight into future patterns of landscape change
- Scaling toward pan-arctic analysis possible
- Integration of further local information might be beneficial

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Get the poster here!

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https://github.com/initze

References:

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