Quantifying Permafrost Thaw and Landscape Hydrology with Graph Theory

A real Big Data challenge for Arctic research

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BACKGROUND

- Large fraction of the lowland permafrost ecosystem characterized by ice-wedge polygons.
- Surface water can accumulate and flow in troughs between polygons.
- Microtopography and topology of trough network determine hydrological drainage patterns.
- Ice-wedge degradation promotes increased network connectivity and thus alters hydrological properties from the sub-meter to the landscape scales.

→ **Monitoring polygon network evolution is important for understanding the transition of permafrost ecosystems under a warming climate.**

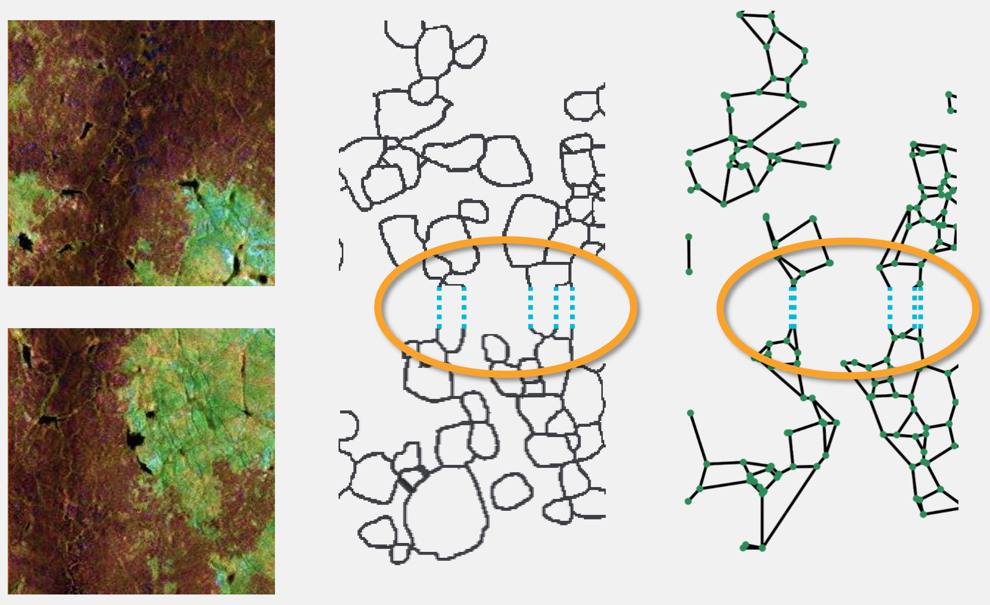
Polygonal ice-wedge landscape with water accumulation in troughs.

TOWARDS A PAN-ARCTIC GRAPH

Methods

Impossible to process pan-Arctic imagery at once.

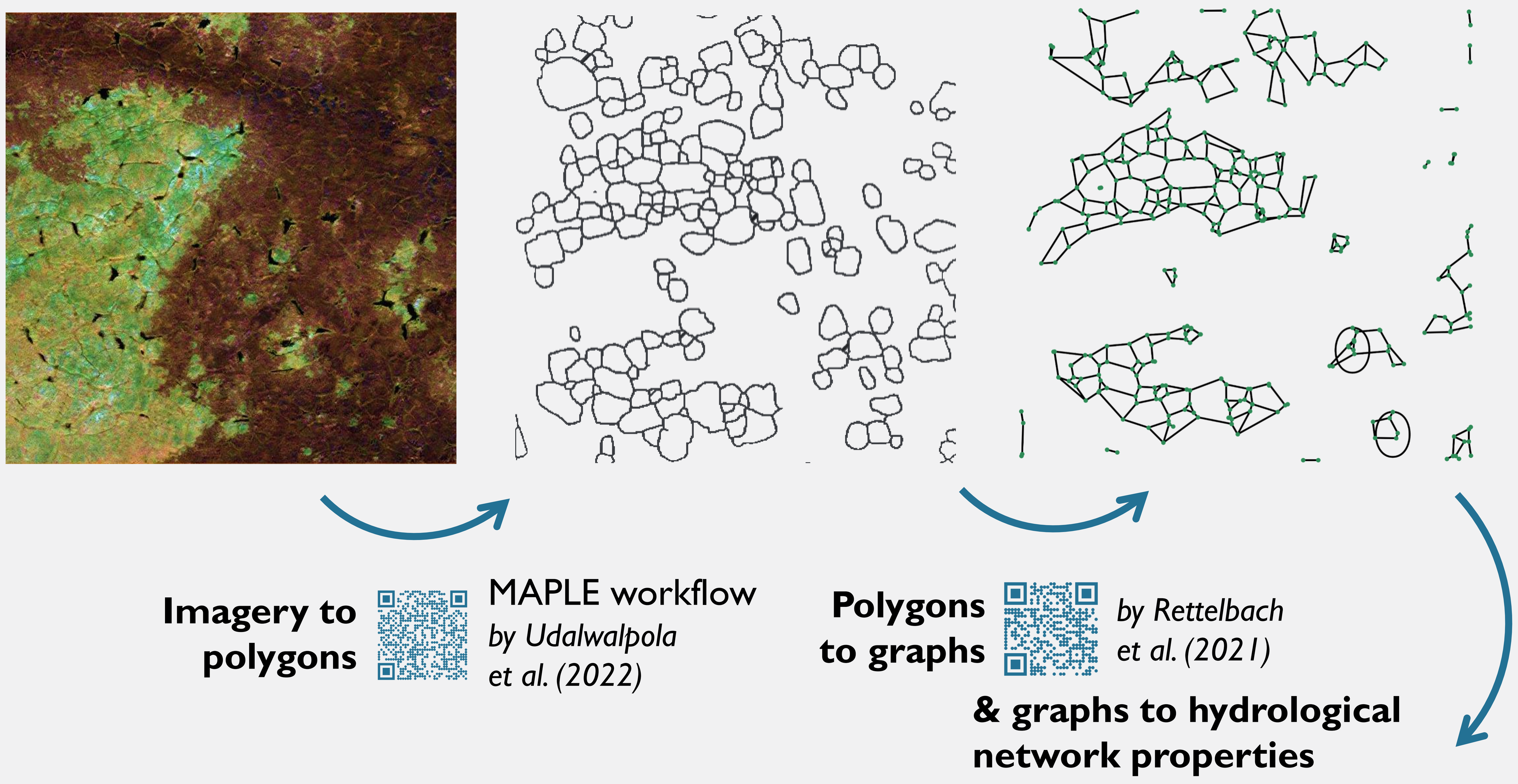
→ **Tile data & reconstruct later**



Spatial information of graph nodes used to recombine correct edges/troughs.

REPRESENTING POLYGONS AS GRAPHS *

Methods



Imagery to polygons — MAPLE workflow *by Udalwalpola et al. (2022)*

Polygons to graphs — *by Rettelbach et al. (2021)*

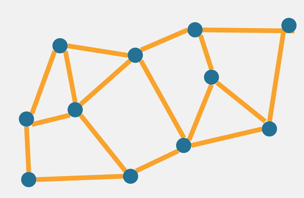
& graphs to hydrological network properties

# nodes	446
# edges	594
avg. node degree	2.66
# connected components	20
network density	0.89
total channel length	9.77 km

Evaluating polygon networks as graphs, allows us to better model surface hydrology.

* Graphs

- Data structure to represent complex networks
- Made up of nodes (elements) and edges (the element's connections)
- Graph metrics allow for describing the networks and their topologies



WORKFLOW AUTOMATION

Methods

→ **with Scientific Workflow Managers**

```
rule select_study_area:
    input: "{AOI}.shp"
    output: "{AOI}.tif"
    shell: "python image_raster_to_aoi.py {AOI}"

rule generate_polygons_maple:
    input: rules.select_study_area.output
    output: "{AOI}_polygons.tif"
    conda: "maple.yaml"
    resources:
        mem_mb=400
    message: "Generating polygons for the area {AOI}."
    shell: "python maple/framework.py {input}"

rule build_graphs:
    input: rules.generate_polygons_maple.output
    output: "{AOI}_graph.edgelist"
    threads: 8
    shell: "python polygons_to_graphs.py {input}"

rule combine_graphs:
    input: "{}_graph.edgelist"
    output: "pan-arctic_graph.edgelist"
    shell: "python combine_multiple_graphs.py {input}"


$ snakemake alaska.shp
```

snakemake
A framework for reproducible data analysis

SWMs support:

- Multiple executions on lists of datasets.
- Parallelism of computation.
- Execution on diversity of platforms.
- Awareness of previous runs.
- Extended logging and tracing of errors.

With SWMs, we achieve *automation*, *scalability*, *portability*, *readability*, *traceability*, and *documentation* of our big geodata analysis.

OUTLOOK

With a pan-Arctic graph, we aim for a comprehensive assessment of the hydrological network in ice-rich permafrost landscapes.

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Geo.X

Main references

Liljedahl, A. K., Boike, J., Daanen, R. P., Fedorov, A. N., Frost, G. V., Grosse, G., ... & Zona, D. (2016). Pan-Arctic ice-wedge degradation in warming permafrost and its influence on tundra hydrology. Nature Geoscience, 9(4), 312-318.

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Udawalpola, M. R., Hasan, A., Liljedahl, A., Soliman, A., Terstriep, J., & Witharana, C. (2022). An Optimal GeoAI Workflow for Pan-Arctic Permafrost Feature Detection from High-Resolution Satellite Imagery. Photogrammetric Engineering & Remote Sensing, 88(3), 181-188.