NSF Arctic Data Center

Scalable and Computationally Reproducible Approaches to Arctic

September 22, 2022

Billions of Ice Wedge Polygons

Transforming of BIG imagery into Arctic Science ready products

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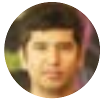
UCONN NATURAL RESOURCES AND THE ENVIRONMENT

Permafrost Discovery Gateway (PDG)

Navigating the new Arctic tundra through big data, artificial intelligence, and cyberinfrastructure

[Award #s:1927872, 1927723, 1927729, 1927720 & 1927920]

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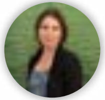
Arctic Data Center

Ben Jones & Jennifer Moss
University of Alaska Fairbanks


Jason Cervenec & Aaron Wilson
Ohio State University

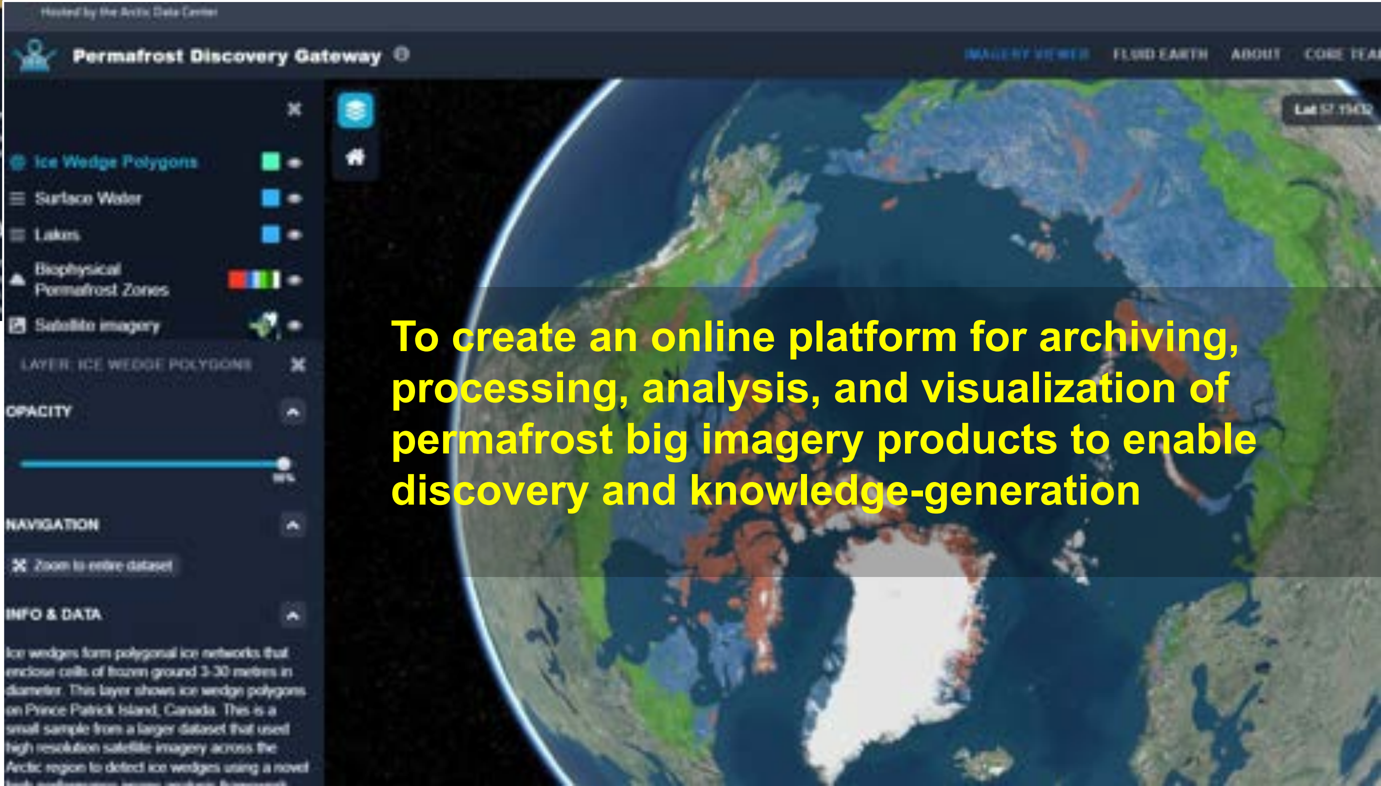
Gala Wind
NASA

Michael Brubaker
Alaska Pacific University

Chandi Witharana
University of Connecticut


Guido Grosse & Ingmar Nitze
Alfred Wegener Institute

Permafrost Discovery Gateway



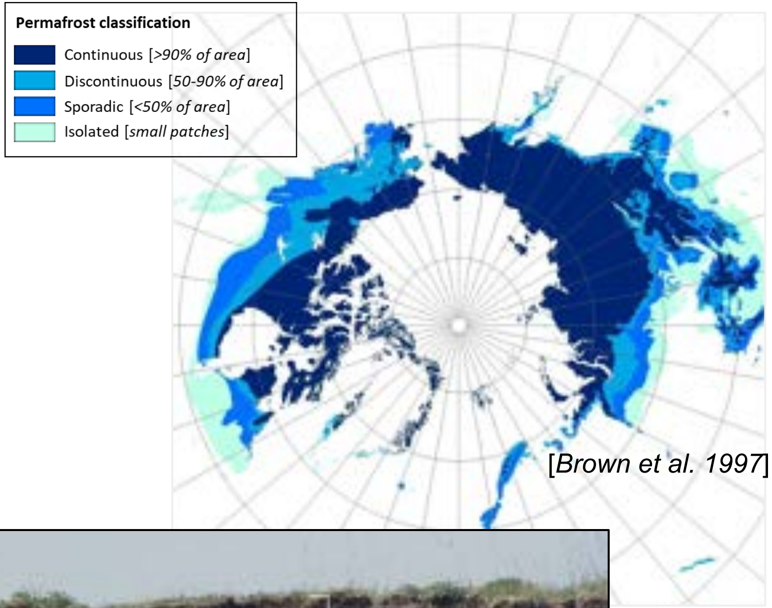
To create an online platform for archiving, processing, analysis, and visualization of permafrost big imagery products to enable discovery and knowledge-generation

https://arcticdata.io/catalog/portals/permafrost

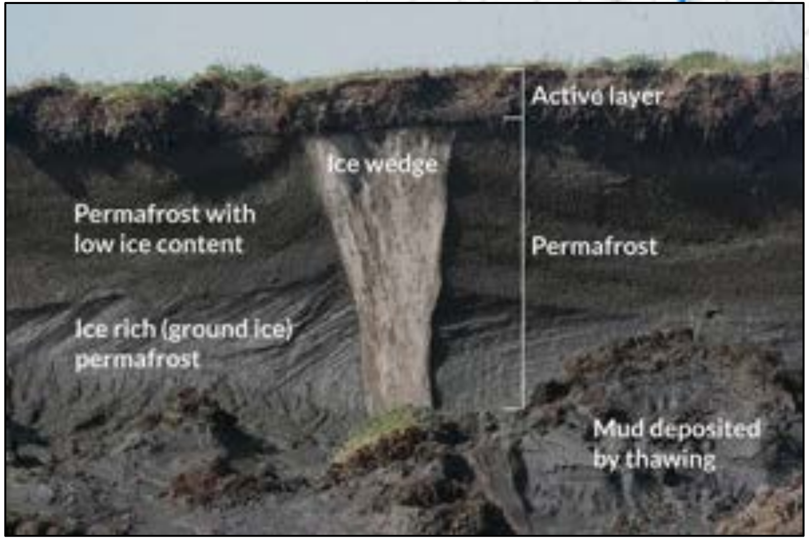
Arctic Permafrost

- **Sub-surface earth materials that stay below 0°C for at least 2 years in a row**
- 23 million km^2 of northern hemisphere land mass
- A critical component of the coupled atmosphere-ocean-land system
- **~14%** Earth's carbon tied to permafrost
- Controls many ecological process as ground ice supports the surface and affects topography.
- Permafrost affects the outcome of climate-induced changes

[*Jorgensen and Grosse 2016, Schuur et al. 2015, Grosse et al. 2011*]



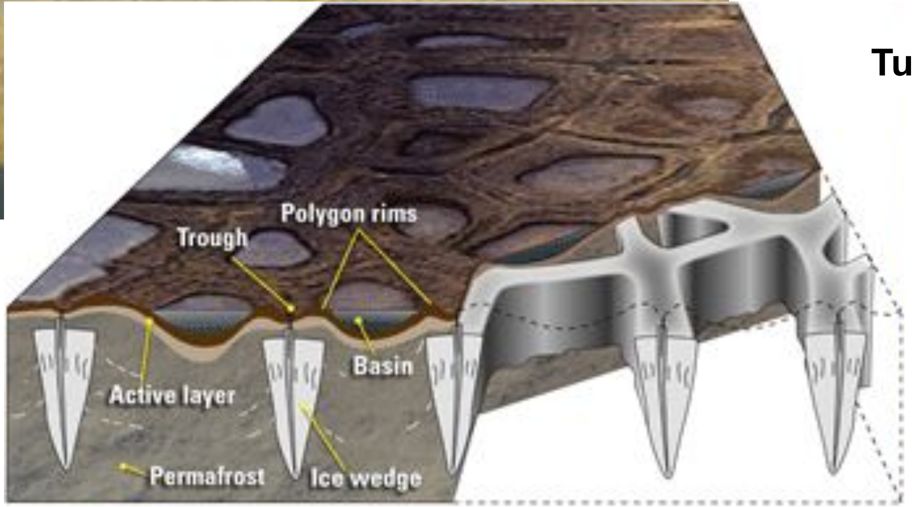
[*Brown et al. 1997*]



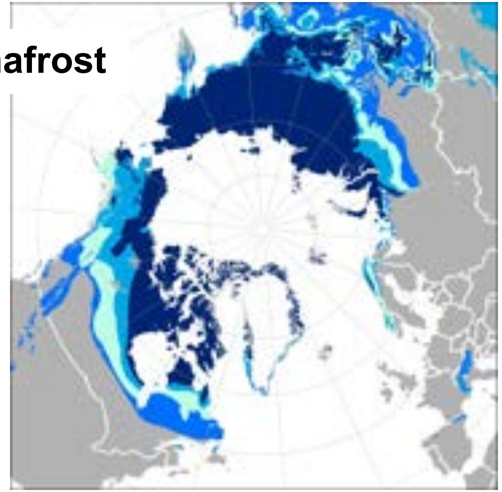
Patterned ground

A network of small polygonal ponds and patches of wet/dry tundra

-Archetypal polygonal pattern-



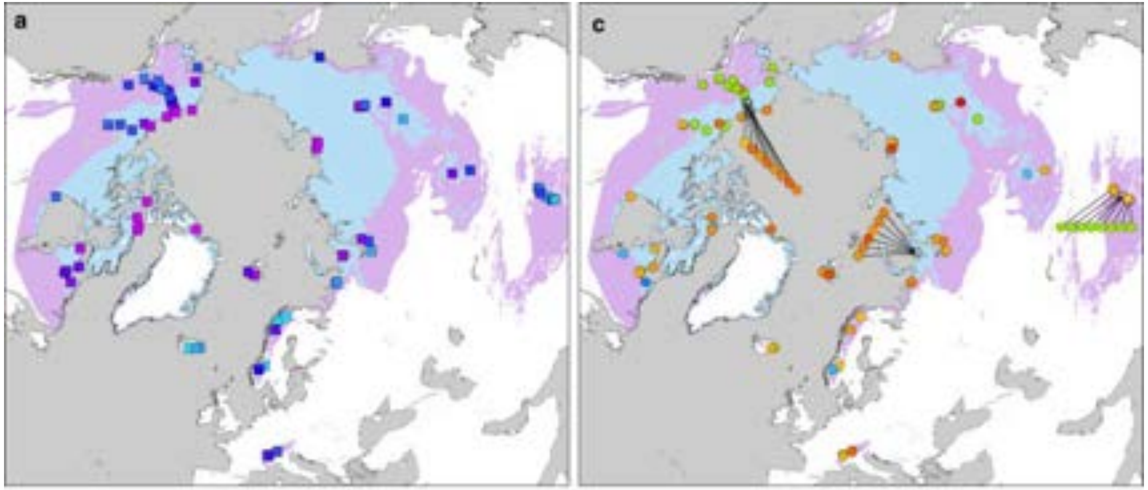
Permafrost

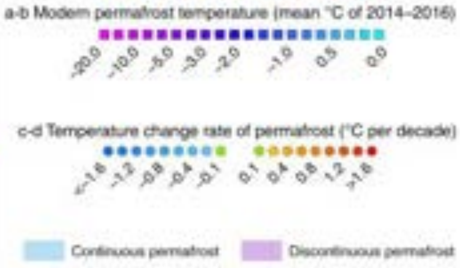


Tundra

Peramfrost is Warming at a Global Scale

- Continuous permafrost zone - 0.4°C warming per decade
- Discontinuous permafrost zone - 0.2°C warming per decade





[Biskaborn et al., 2019]

Response of permafrost tundra to climate change

- Re-organizes hydrological flow paths, soil processes, biogeochemical cycling, vegetation dynamics
- Compositional shift/biomass changes of vegetation due to altered nutrient availability and competitive interaction among species
- Shoreline erosion and differential ground subsidence
- Flipping carbon sink to carbon contributor

[*Myers-Smith et al. 2011, Jones et al. 2011, Walvoord et al. 2012, Jorgenson et al. 2013, Potter et al. 2013; Lousada et al. 2018*]

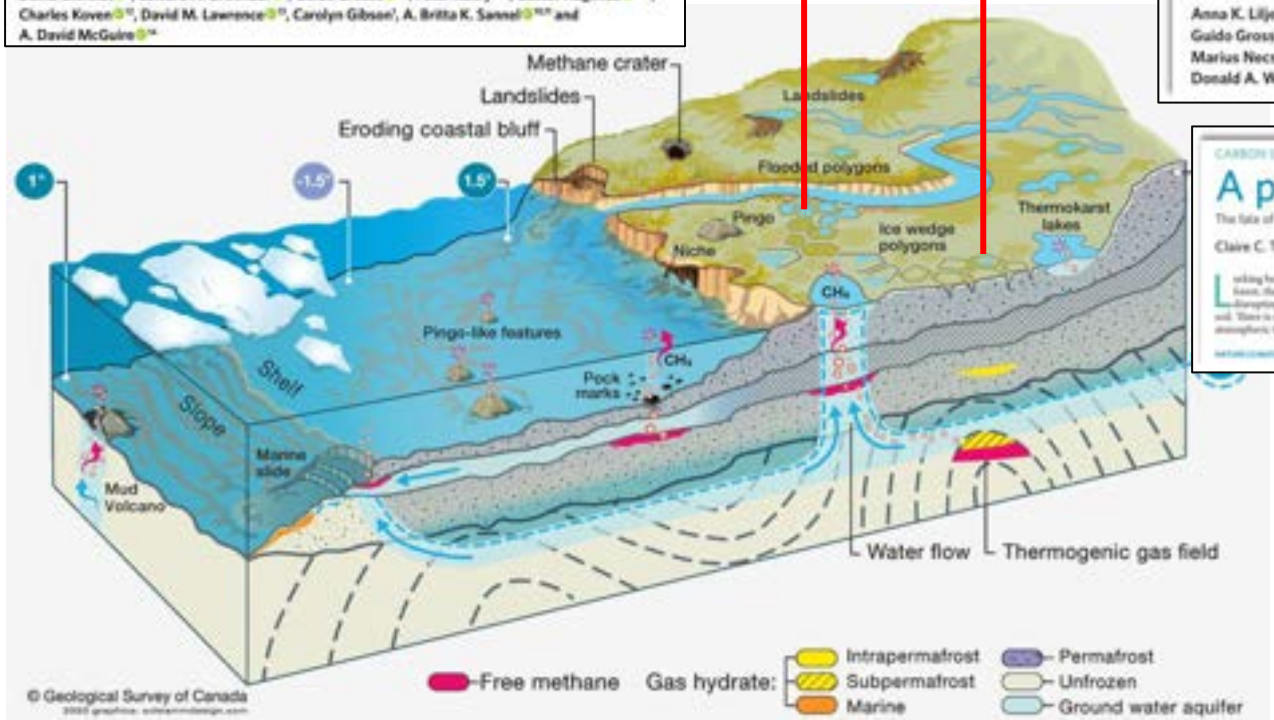
Wake up calls…..

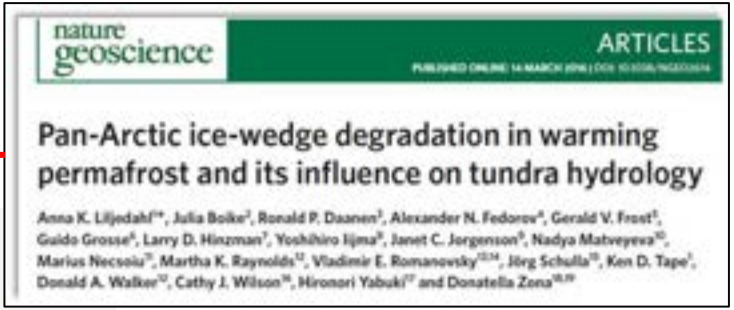

ARTICLES

nature geoscience

Carbon release through abrupt permafrost thaw

Merritt R. Turetsky, Benjamin W. Abbott, Miriam C. Jones, Katey Walter Anthony, David Olefeldt, Edward A. G. Schuur, Guido Grosse, Peter Kuhry, Gustaf Hugelius, Charles Koven, David M. Lawrence, Carolyn Gibson, A. Britta K. Sannel and A. David McGuire




nature geoscience

ARTICLES

PUBLISHED ONLINE: 14 MARCH 2016

Pan-Arctic ice-wedge degradation in warming permafrost and its influence on tundra hydrology

Anna K. Liljedahl, Julia Boike, Ronald P. Daanen, Alexander N. Fedorov, Gerald V. Frost, Guido Grosse, Larry D. Hinzman, Yoshihiro Iijima, Janet C. Jorgenson, Nadya Matveyeva, Marius Necsoiu, Martha K. Raynolds, Vladimir E. Romanovsky, Jörg Schulla, Ken D. Tape, Donald A. Walker, Cathy J. Wilson, Hironori Yabuki and Donatella Zona


CARBON STORAGE

A permafrost carbon bomb?

The fate of permafrost soil carbon following thaw depends on hydrology

Claire C. Treat and Steve Frolking


nature

Letter | Published: 28 May 2009

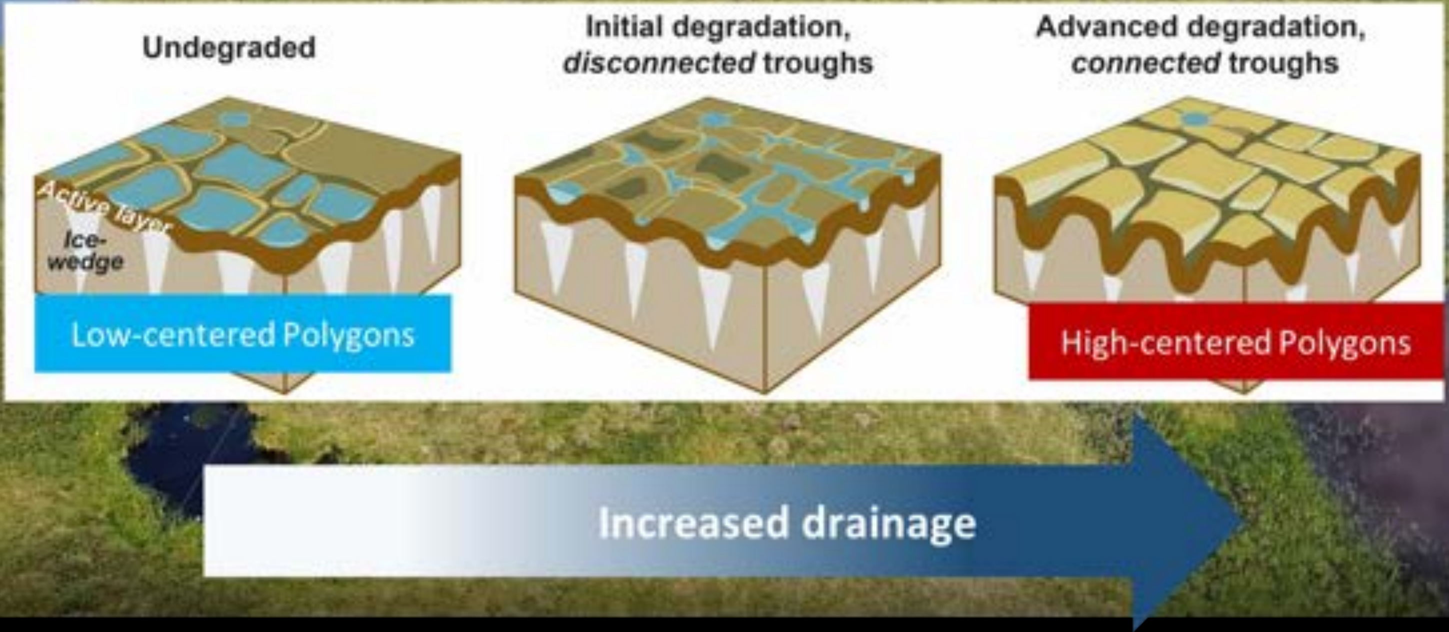
The effect of permafrost thaw on old carbon release and net carbon exchange from tundra

Edward A. G. Schuur, Jason G. Vogel, Kathryn G. Crummer, Hanna Lee, James O. Sickman & T. E. Osterkamp

Source: https://www.grida.no/publications/512

Is topography stationary against climate change?

[Liljedahl et al., Nature Geoscience 2016]

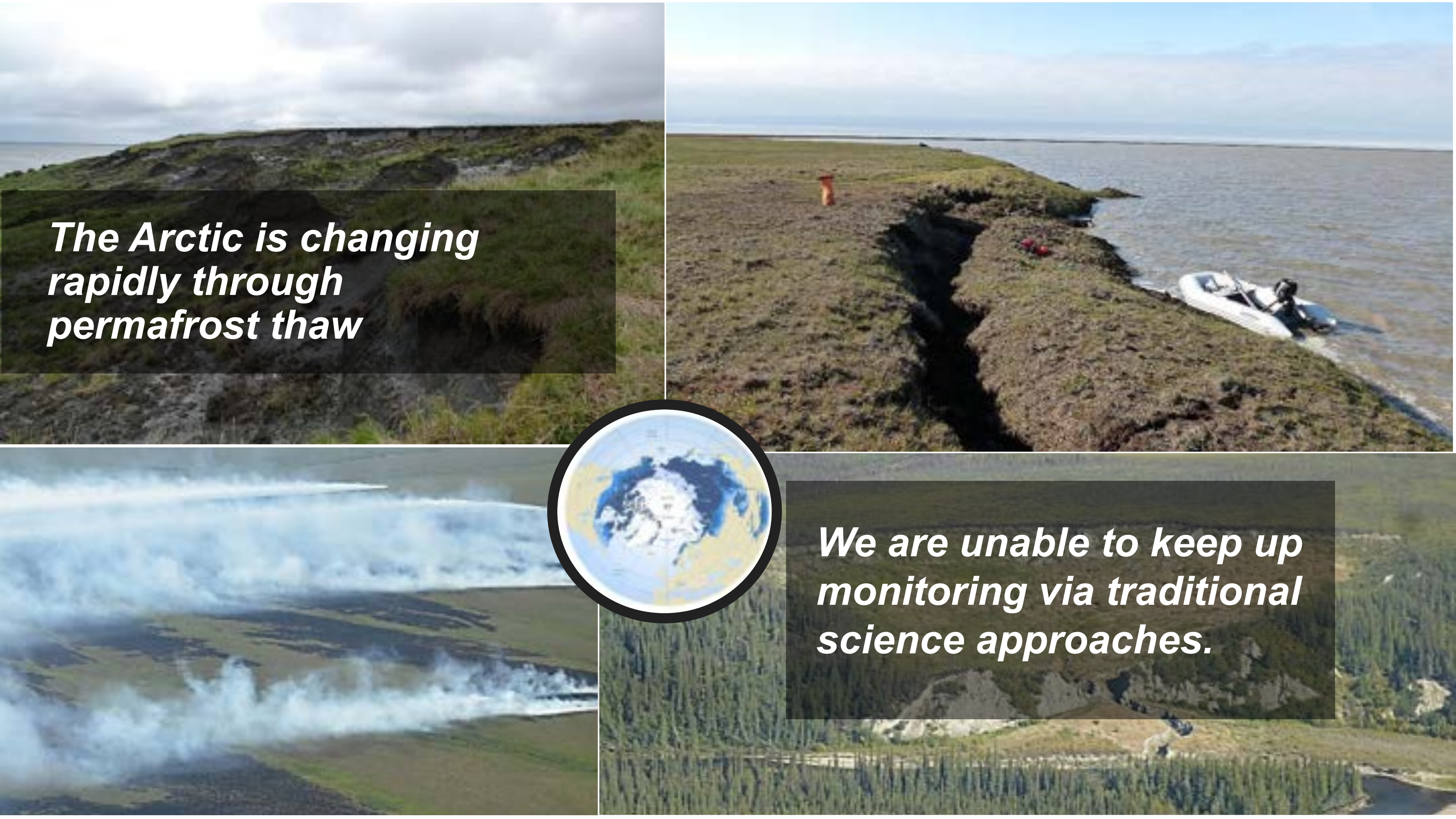


Ground subsidence over degraded ice-wedges, resulting in high-centered polygons

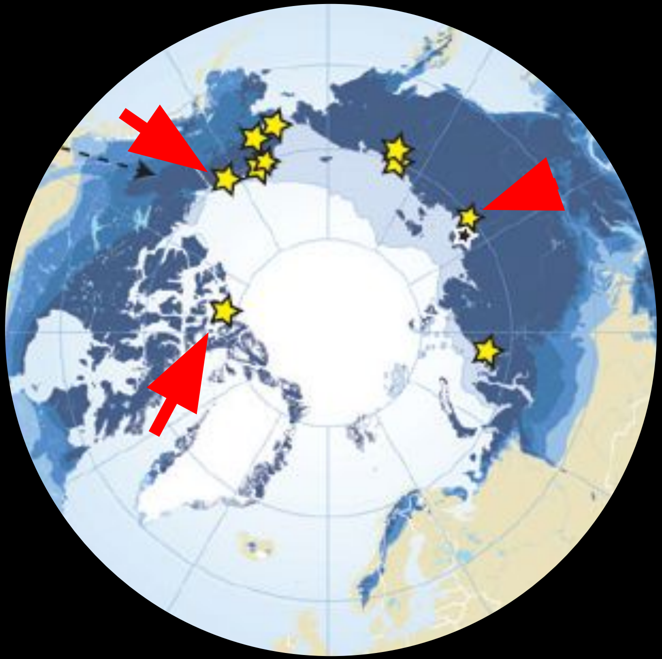
Water is not draining away so the ground subsidence results in trough-ponds

Water is draining away as runoff. The cracks on the sides of the troughs indicate actively degrading ice-wedges below the trough

Prudhoe Bay, Alaska | July 2019 |Photo: *Anna Liljedahl*


The Arctic is changing rapidly through permafrost thaw
We are unable to keep up monitoring via traditional science approaches.

What happens, When, Where ???...



Observed landscape-wide ice-wedge degradations

[*Liljedahl et al., Nature Geoscience 2016*]

Ice-wedge polygon extent is largely unknown.

… what are the current extents of ice-wedge polygon landscape ?

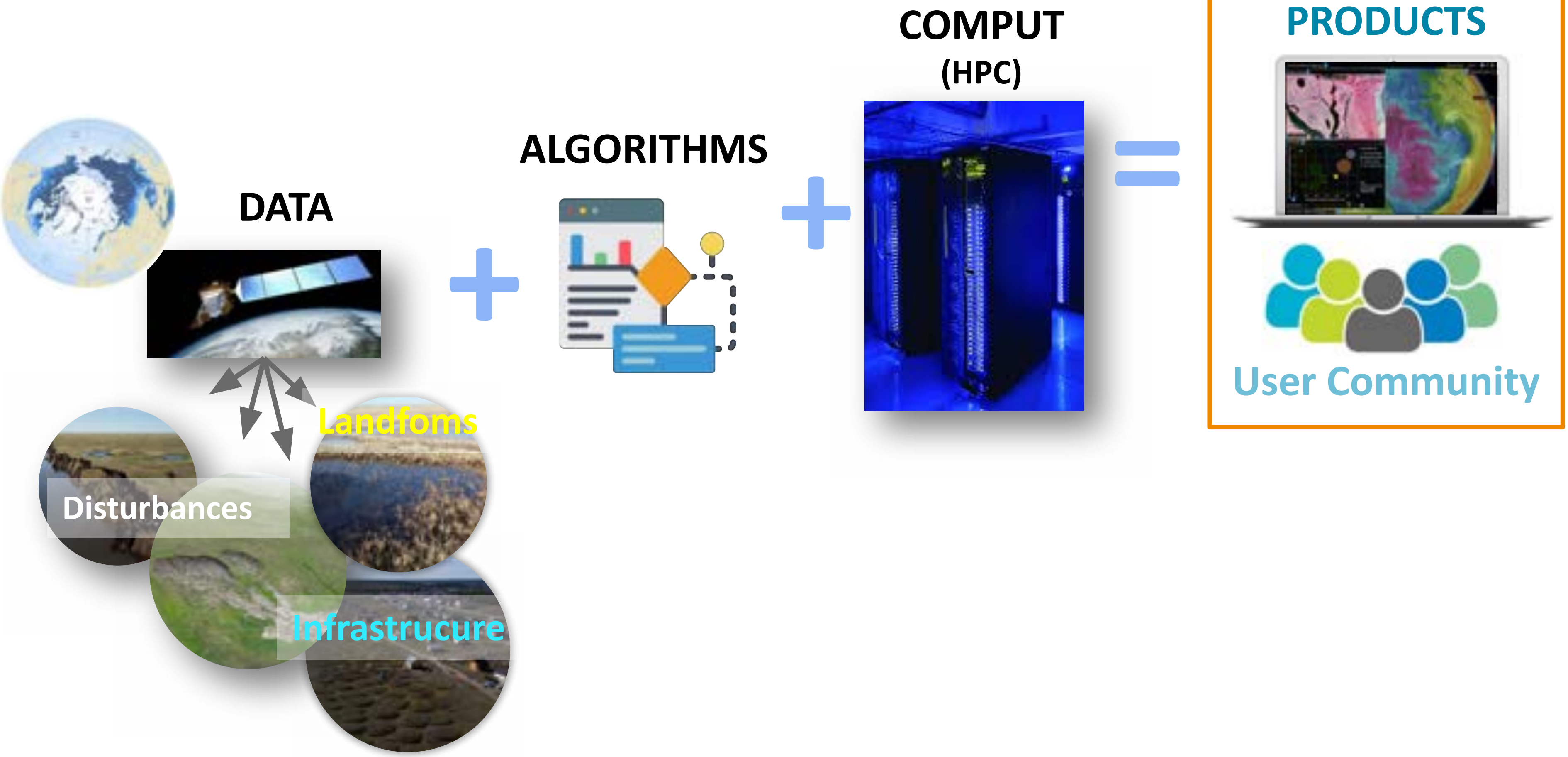
Documentation of pan-Arctic permafrost degradation is patchy both spatially and temporally.

….what are successional stages of ice-wedge polygons across Arctic tundra ?

Commercial satellite [*BIG*] imagery to rescue.

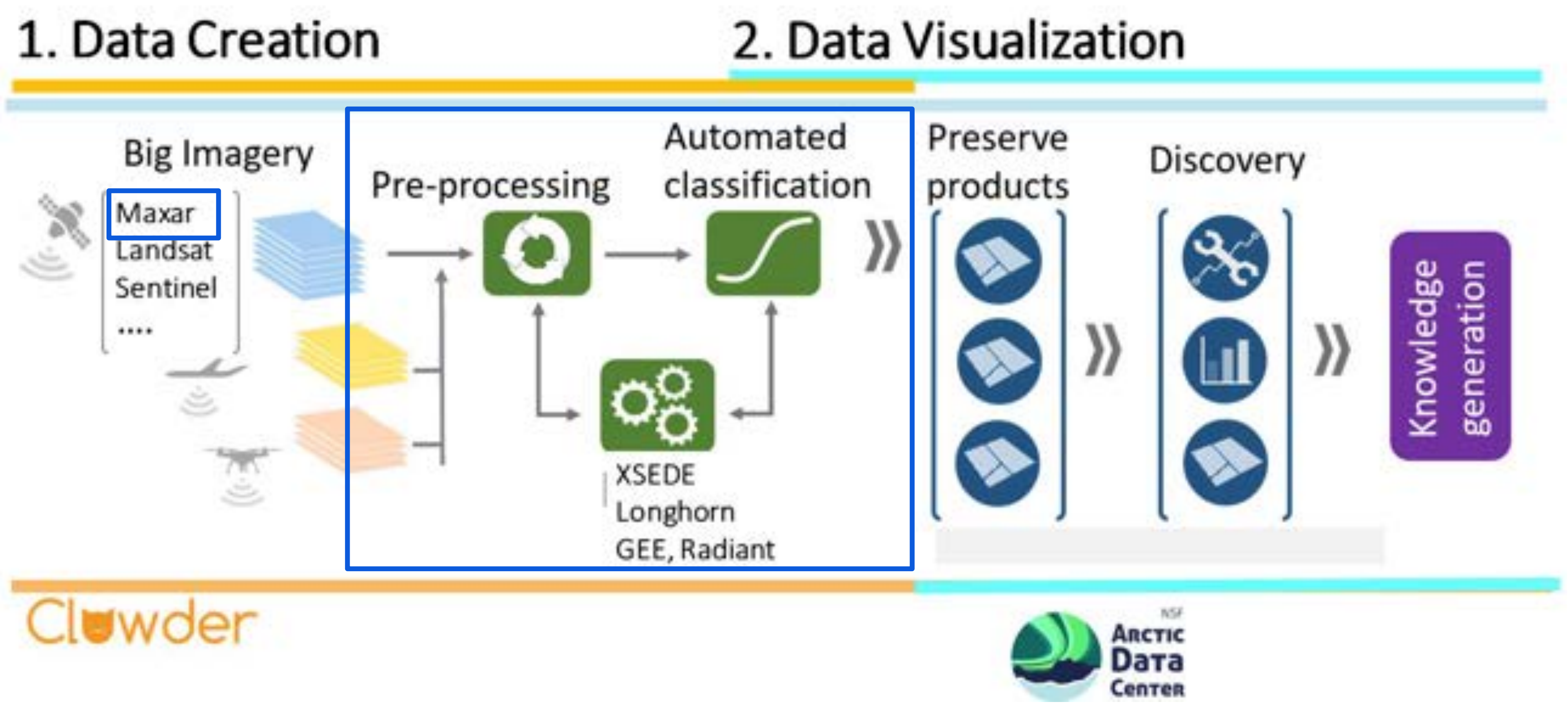
….Can we produce an ice-wedge polygon map for the pan-Arctic polygonal tundra ?

Big Idea........



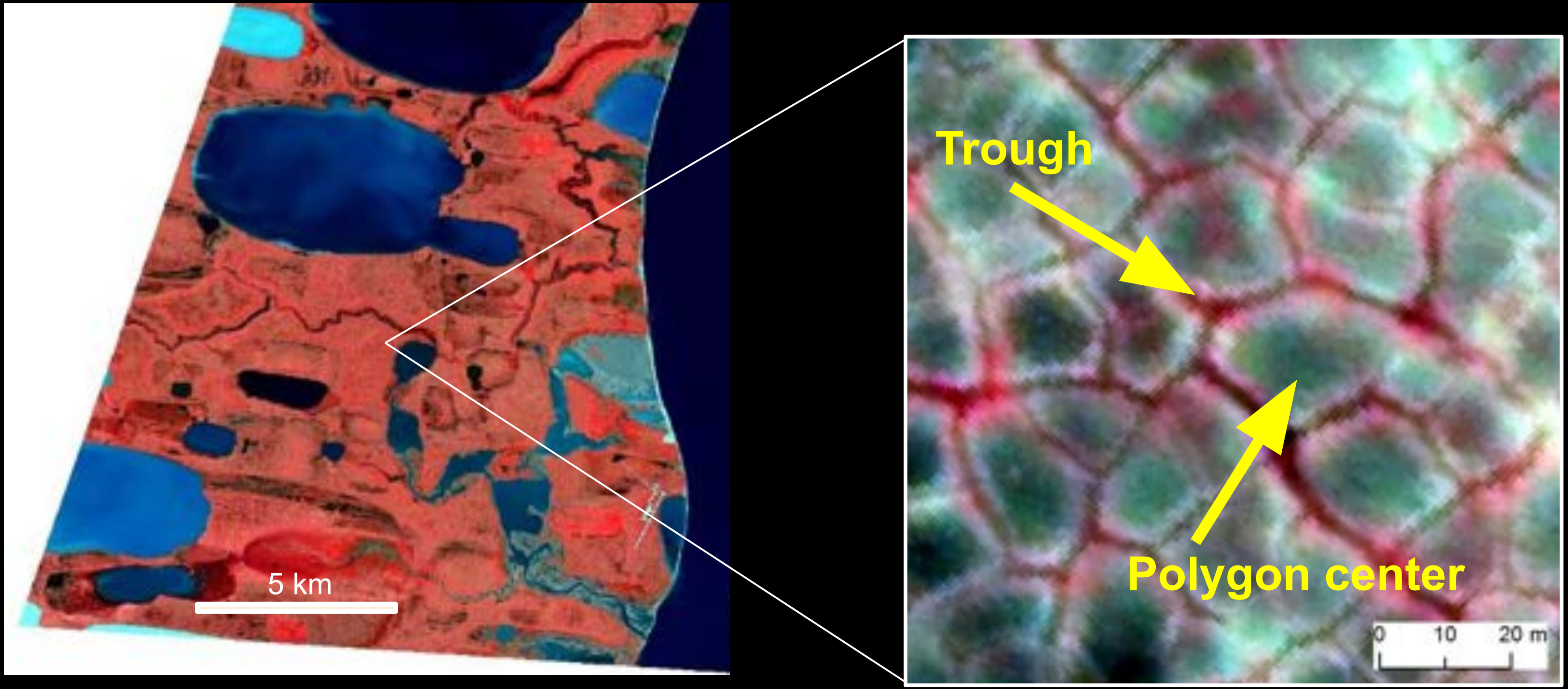
DATA
Landfoms
Disturbances
Infrastrucure
+
ALGORITHMS
+
COMPUT
(HPC)
=
SCIENCE-READY
PRODUCTS
User Community

PDG Framework



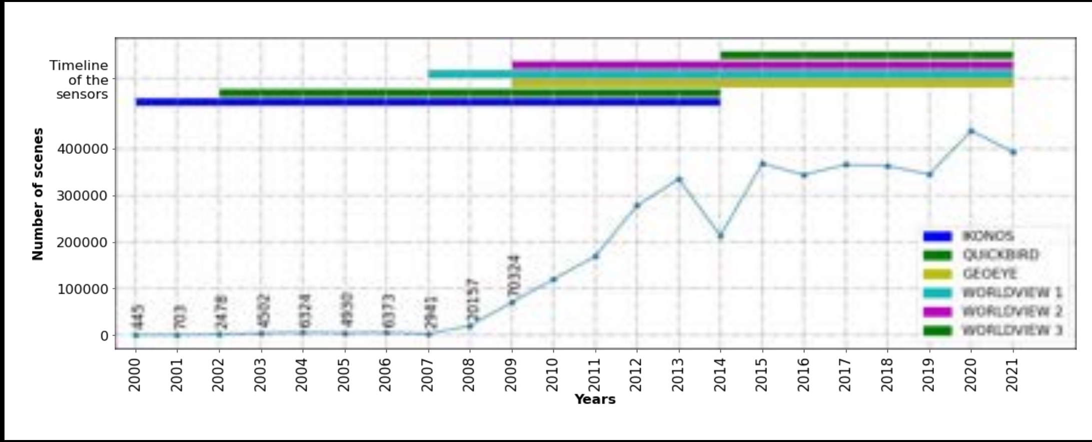
WorldView-2 commercial satellite image [0.5m resolution, July 2016]

Ice-wedge Polygons seen in High-res Satellite Imagery



[*Image copyright DigitalGlobe*]

Maxar Commercial Satellite Imagery Coverage (2000 – 2021)

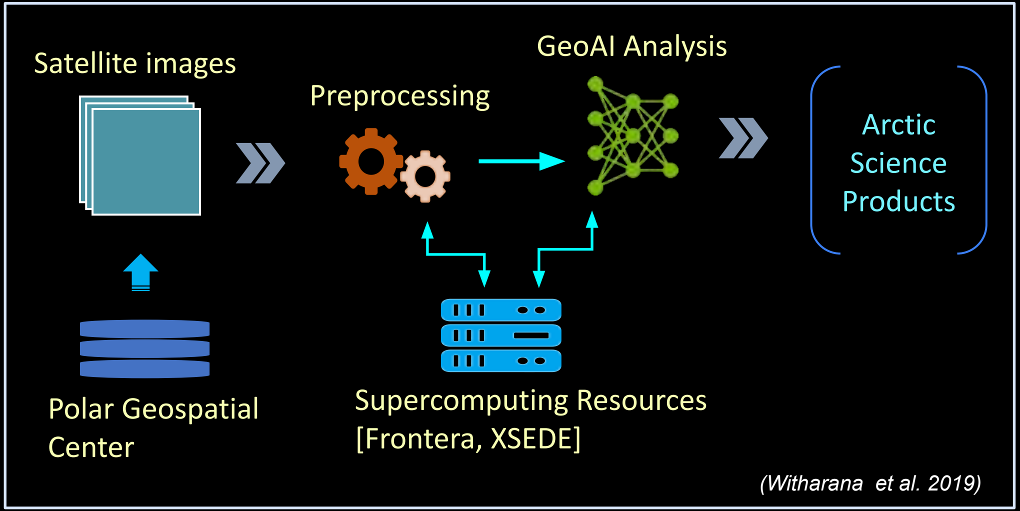


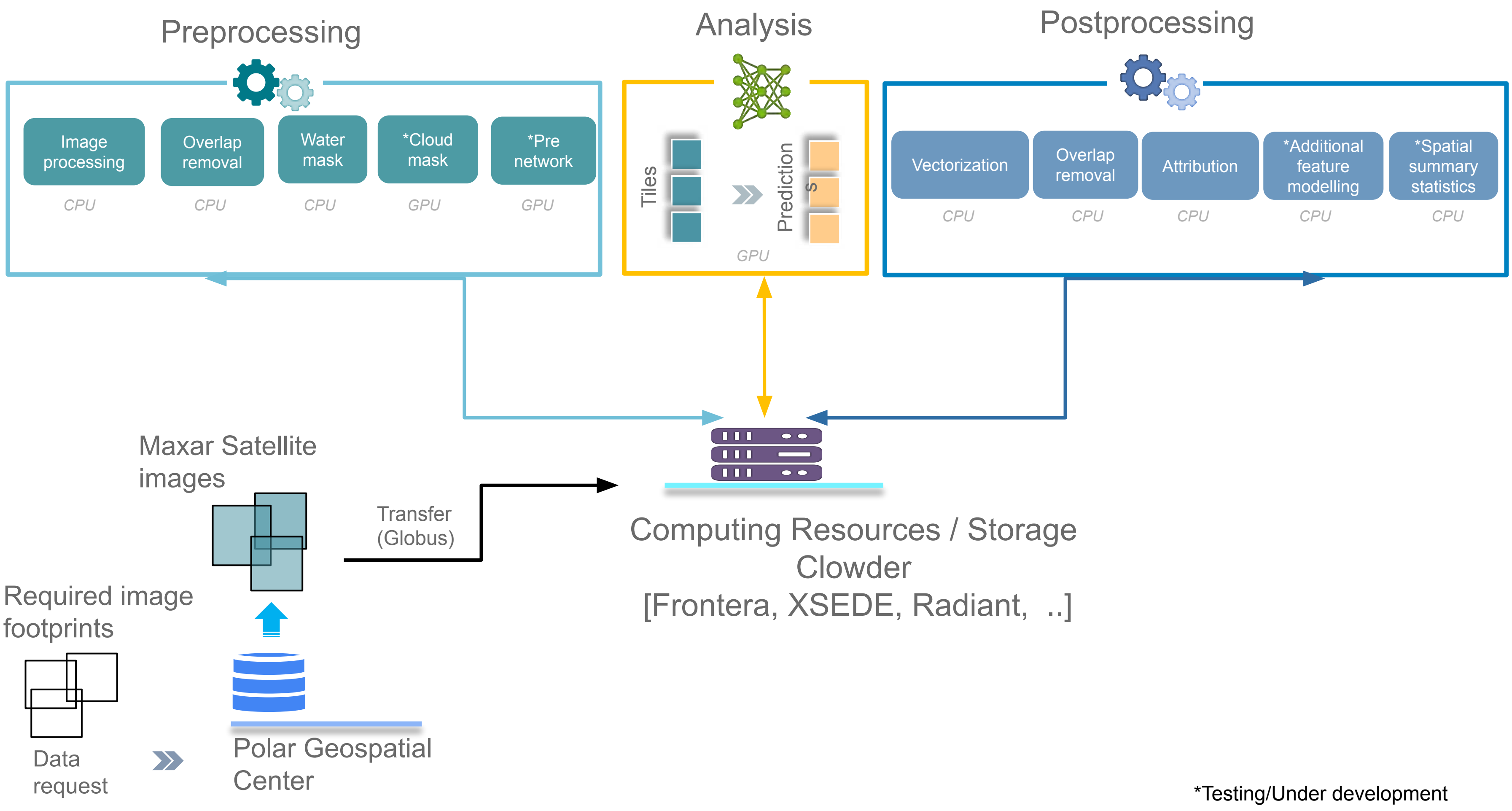
0.5 m resolution
> 5 million image scenes
> 2 PB data
Pan-Arctic coverage (60º N)
Can access via Polar Geospatial Center

(Plots and maps produced based on the satellite image footprints provided by the Polar Geospatial Center, University of Minnesota)

Mapping application for **A**rctic **P**ermafrost **L**and **E**nvironment - **MAPLE**

- Operational-scale GeoAI pipeline
- Translation of ***big*** commercial imagery into science-ready products
- Production of first pan-Arctic ice-wedge polygon map
- Transferability across image data and targets of interest
- Scalability and interoperability across heterogenous computing resources





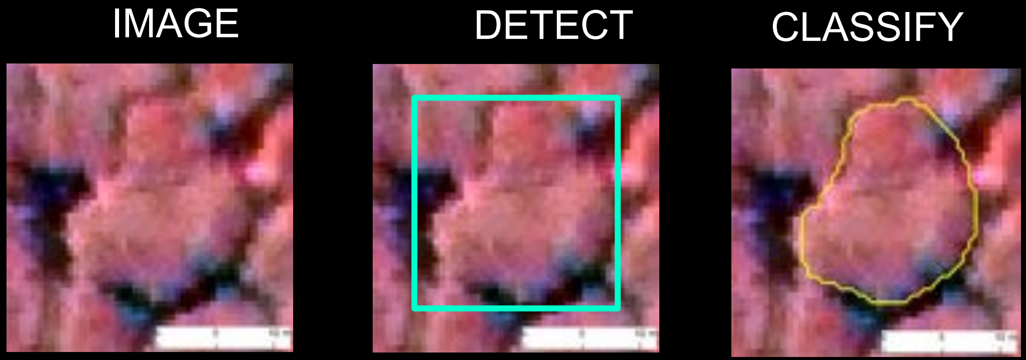
Preprocessing
Image processing
CPU
Overlap removal
CPU
Water mask
CPU
*Cloud mask
GPU
*Pre network
GPU
Analysis
Tiles
Predictions
GPU
Postprocessing
Vectorization
CPU
Overlap removal
CPU
Attribution
CPU
*Additional feature modelling
CPU
*Spatial summary statistics
CPU
Maxar Satellite images
Transfer (Globus)
Computing Resources / Storage
Clowder
[Frontera, XSEDE, Radiant, ..]
Required image footprints
Data request
Polar Geospatial Center
*Testing/Under development

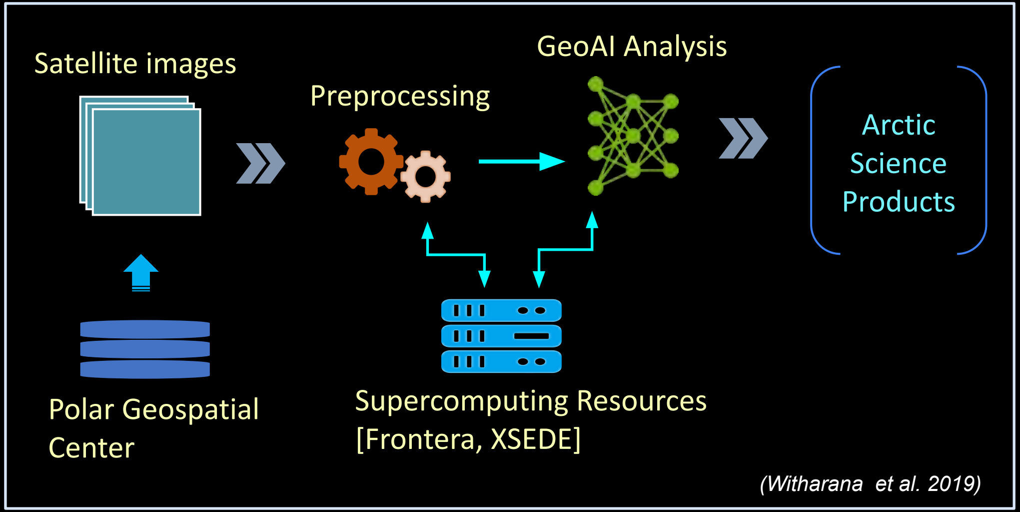
Deep Learning Convolutional Neural Nets (CNNs)

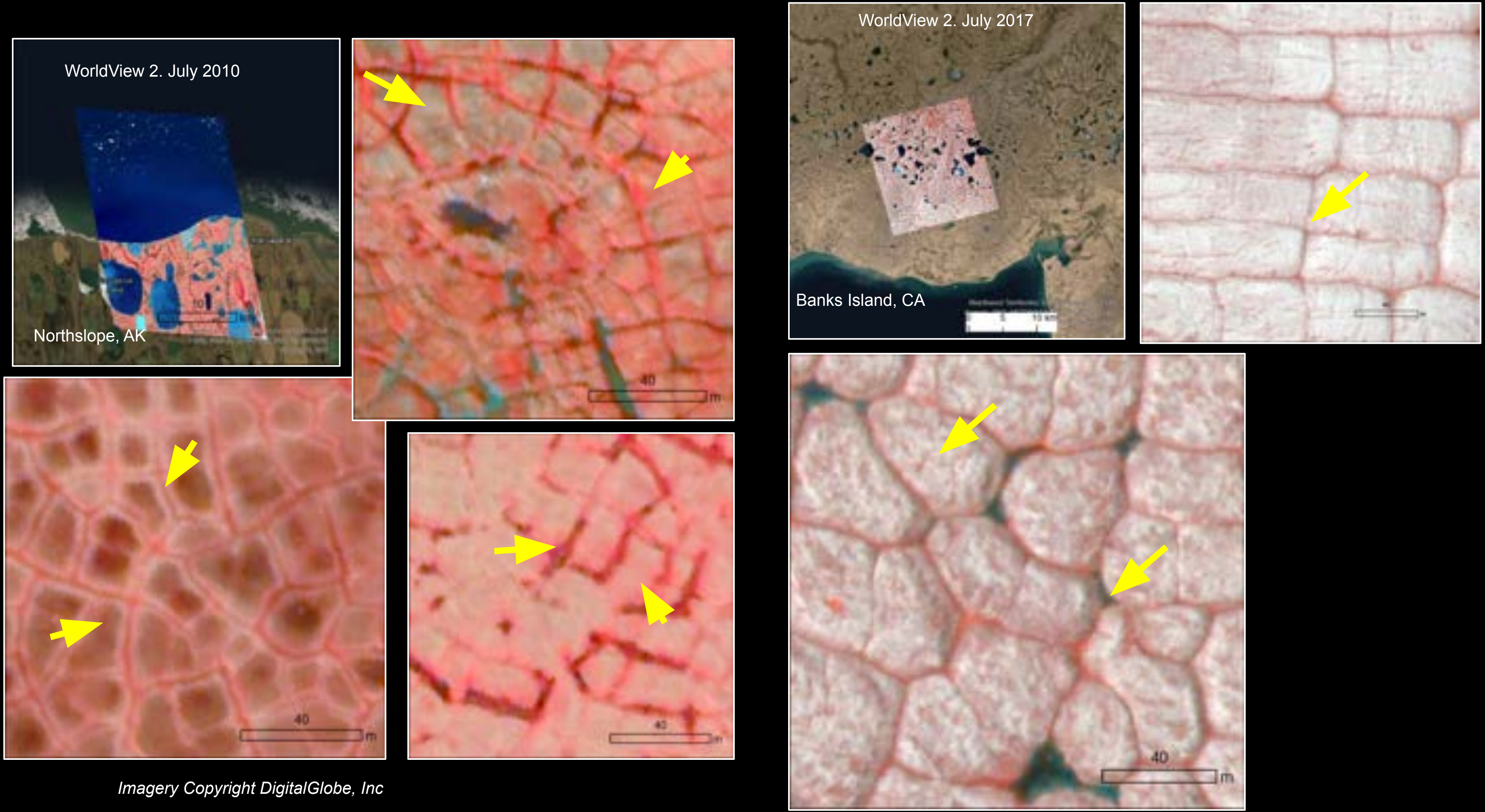
Semantic object instance segmentation

Process of associating each pixel of an image with a class label, (such as *flower*, *person*, *road*, *sky*, *ocean*, etc.).

Example CNN architectures:
Mask RCNN, U-Net





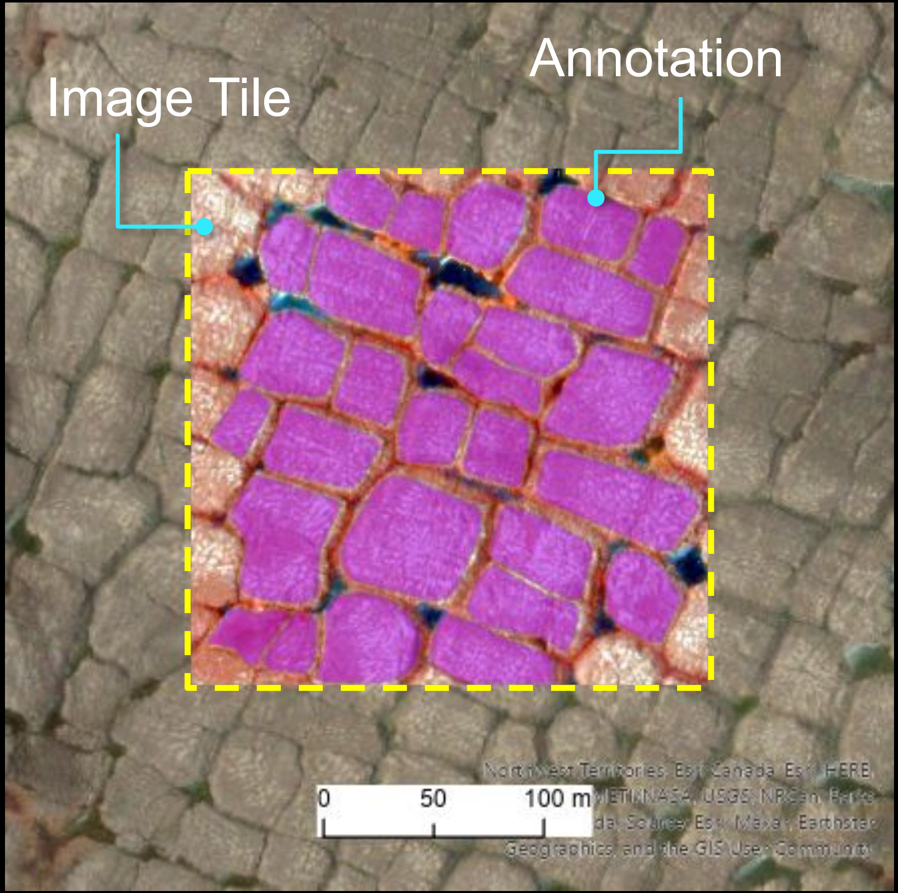


Imagery Copyright DigitalGlobe, Inc

Manual Annotation

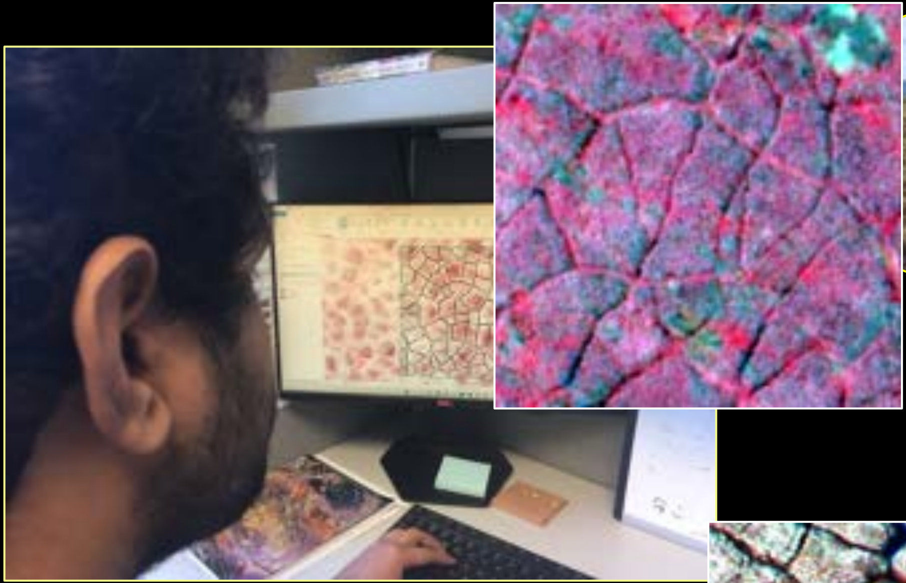
Average # of targets per Tile: 55
Average annotation time per tile: 20 minutes

Tiles	Individual targets
743	41,018



Imagery Copyright DigitalGlobe, Inc

Manual Annotation



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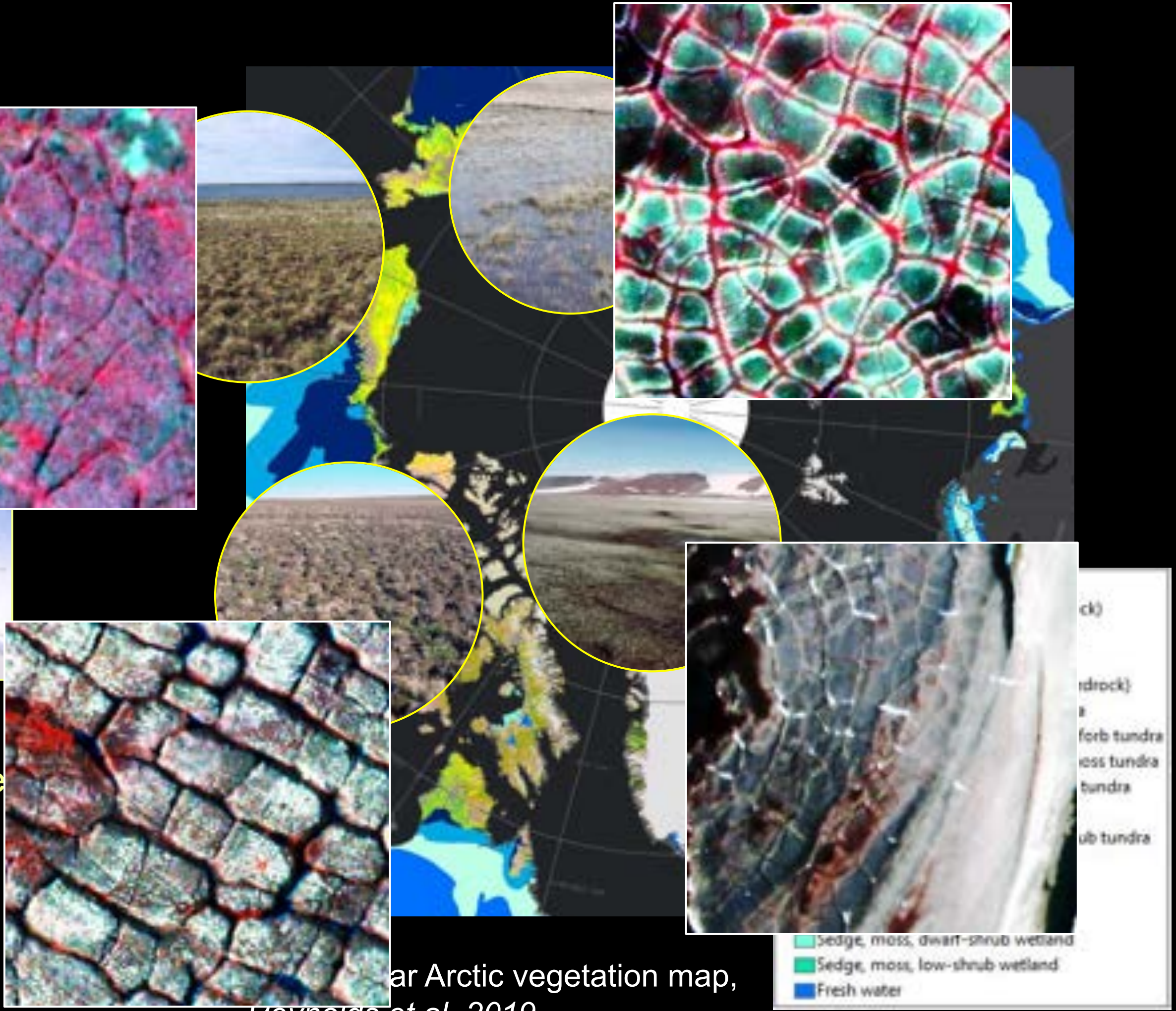
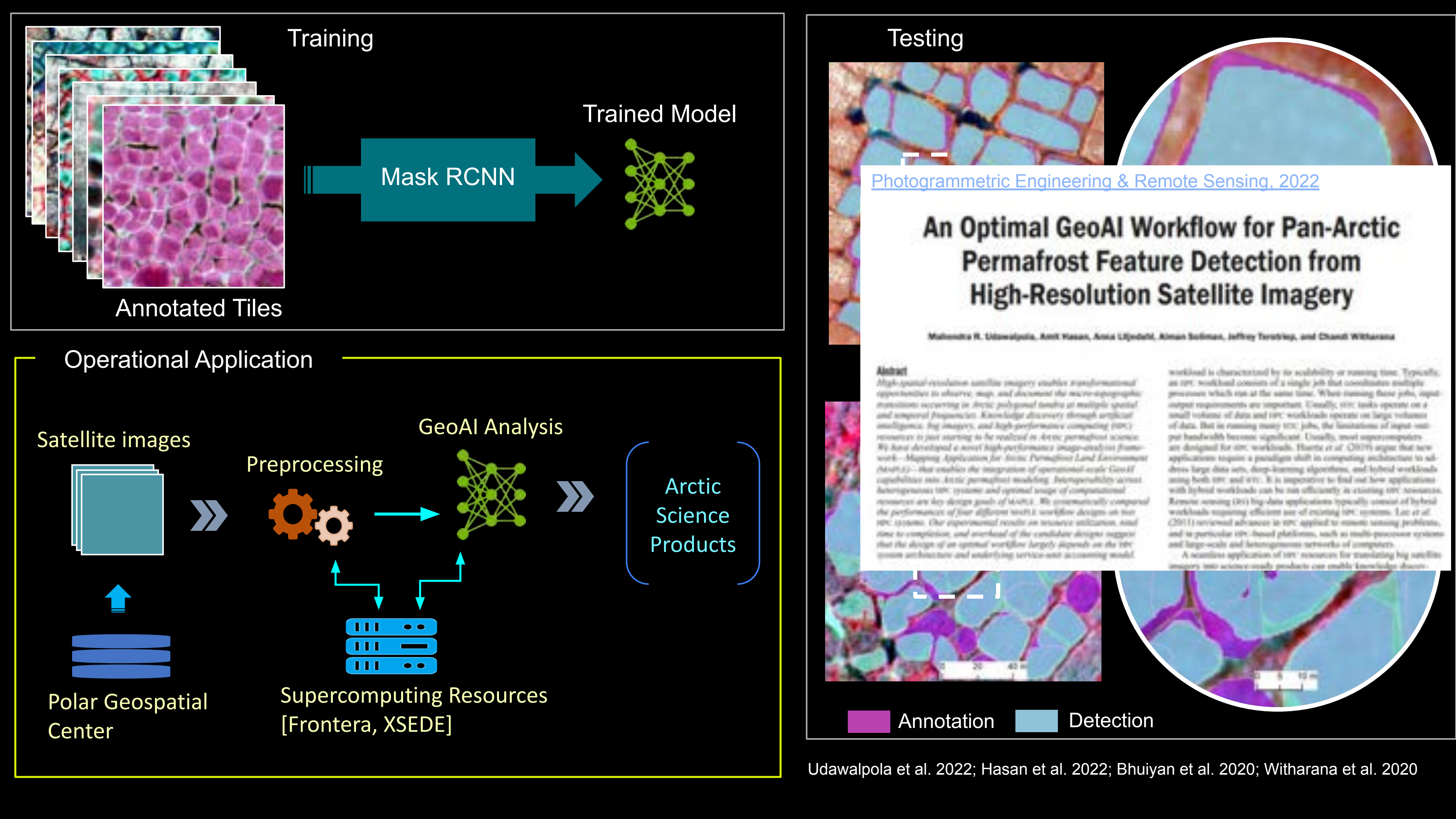


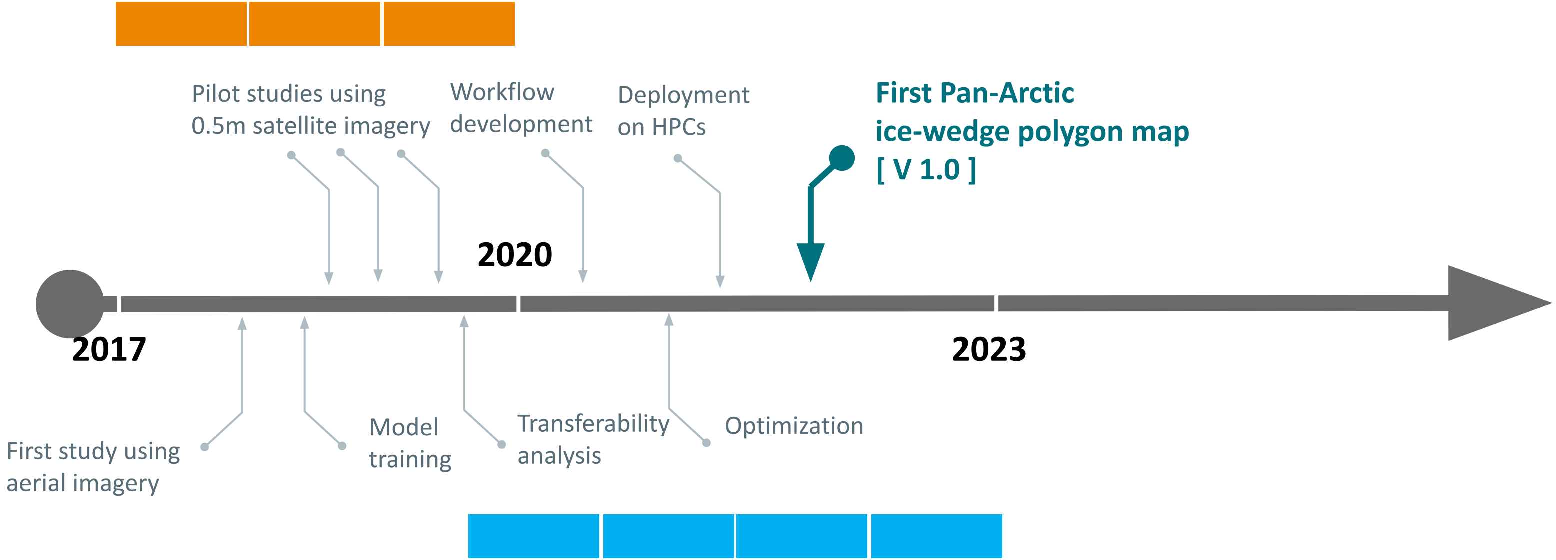
ar Arctic vegetation map, *Reynolds et al. 2019*


Training
Trained Model
Mask RCNN
Annotated Tiles
Testing
Photogrammetric Engineering & Remote Sensing, 2022
An Optimal GeoAI Workflow for Pan-Arctic Permafrost Feature Detection from High-Resolution Satellite Imagery
Mahendra R. Udawalpola, Amit Hasan, Anna Liljedahl, Aiman Soliman, Jeffrey Terstriep, and Chandi Witharana
Abstract
Operational Application
Satellite images
Preprocessing
GeoAI Analysis
Arctic Science Products
Polar Geospatial Center
Supercomputing Resources [Frontera, XSEDE]
Annotation
Detection
Udawalpola et al. 2022; Hasan et al. 2022; Bhuiyan et al. 2020; Witharana et al. 2020

Timeline of MAPLE

ARCSS

Patterns, Dynamics, and Vulnerability of Arctic Polygonal Ecosystems: From Ice-Wedge Polygon to Pan-Arctic Landscapes



NNA

The Permafrost Discovery Gateway: Navigating the new Arctic tundra through Big Data, artificial intelligence, and cyberinfrastructure

Automated Recognition of Ice-wedge Polygons from Maxar Imagery

So far, we have mapped

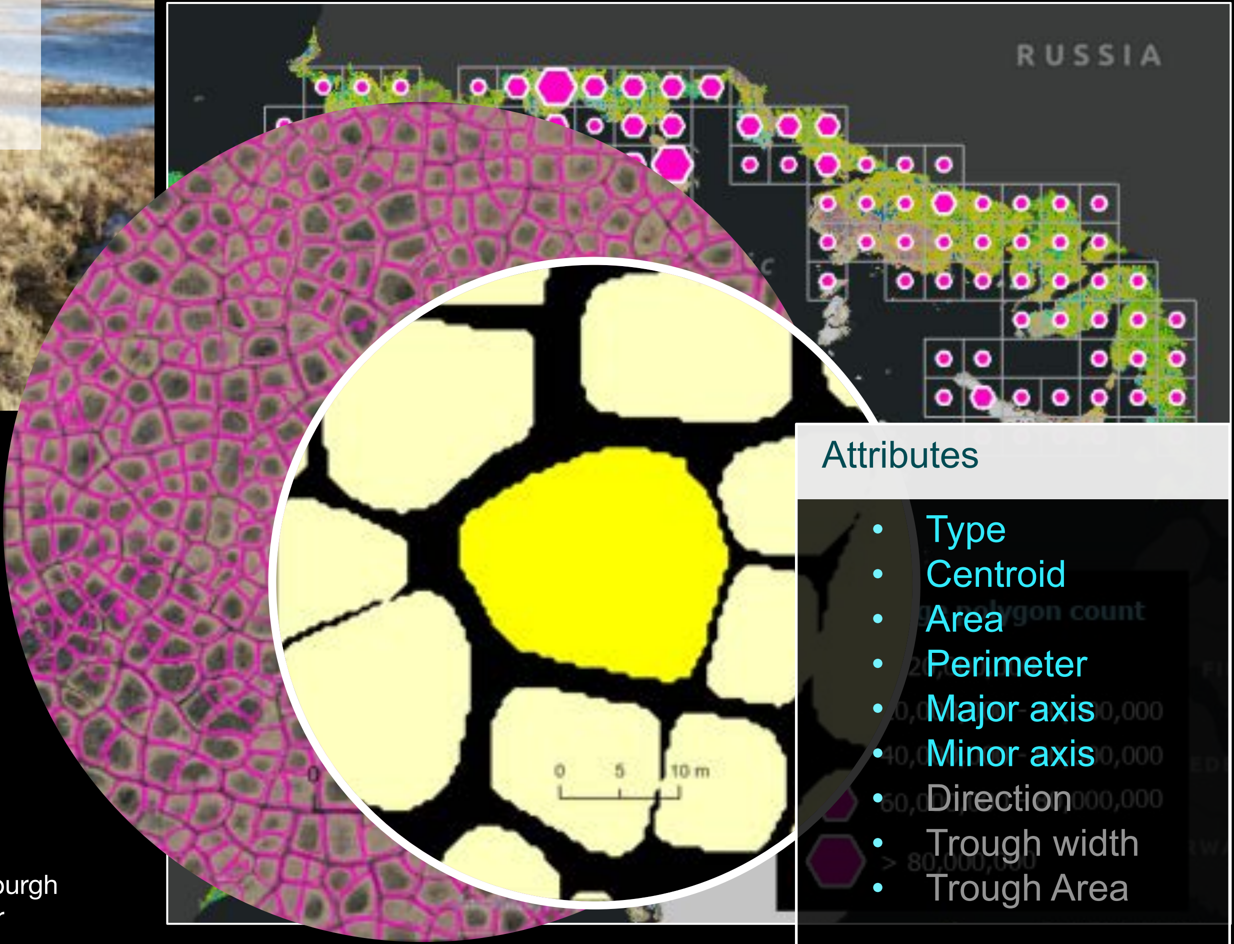
> 1 billion

individual ice-wedge polygons …

- Over 3 million km^2 of Tundra
- > 30,000 Maxar image scenes
- > 250 TB of image data

Frontera supercomputer at the Texas Advanced Computing Center (TACC)

XSEDE Bridges-2 Pittsburgh Supercomputing Center



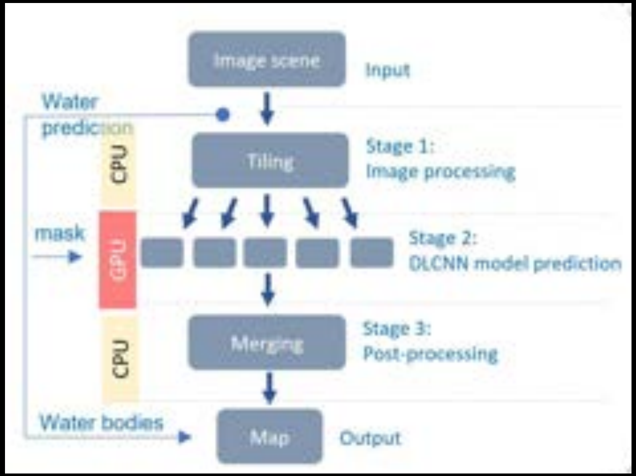
Attributes

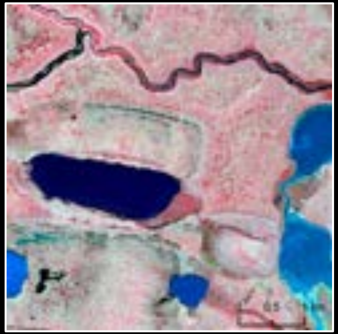
- Type
- Centroid
- Area
- Perimeter
- Major axis
- Minor axis
- Direction
- Trough width
- Trough Area

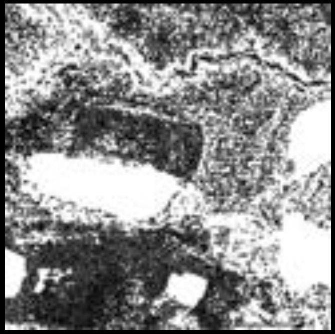
Surface water extraction from Maxar imagery

remote sensing
Monitoring the Transformation of Arctic Landscapes: Automated Shoreline Change Detection of Lakes Using Very High Resolution Imagery

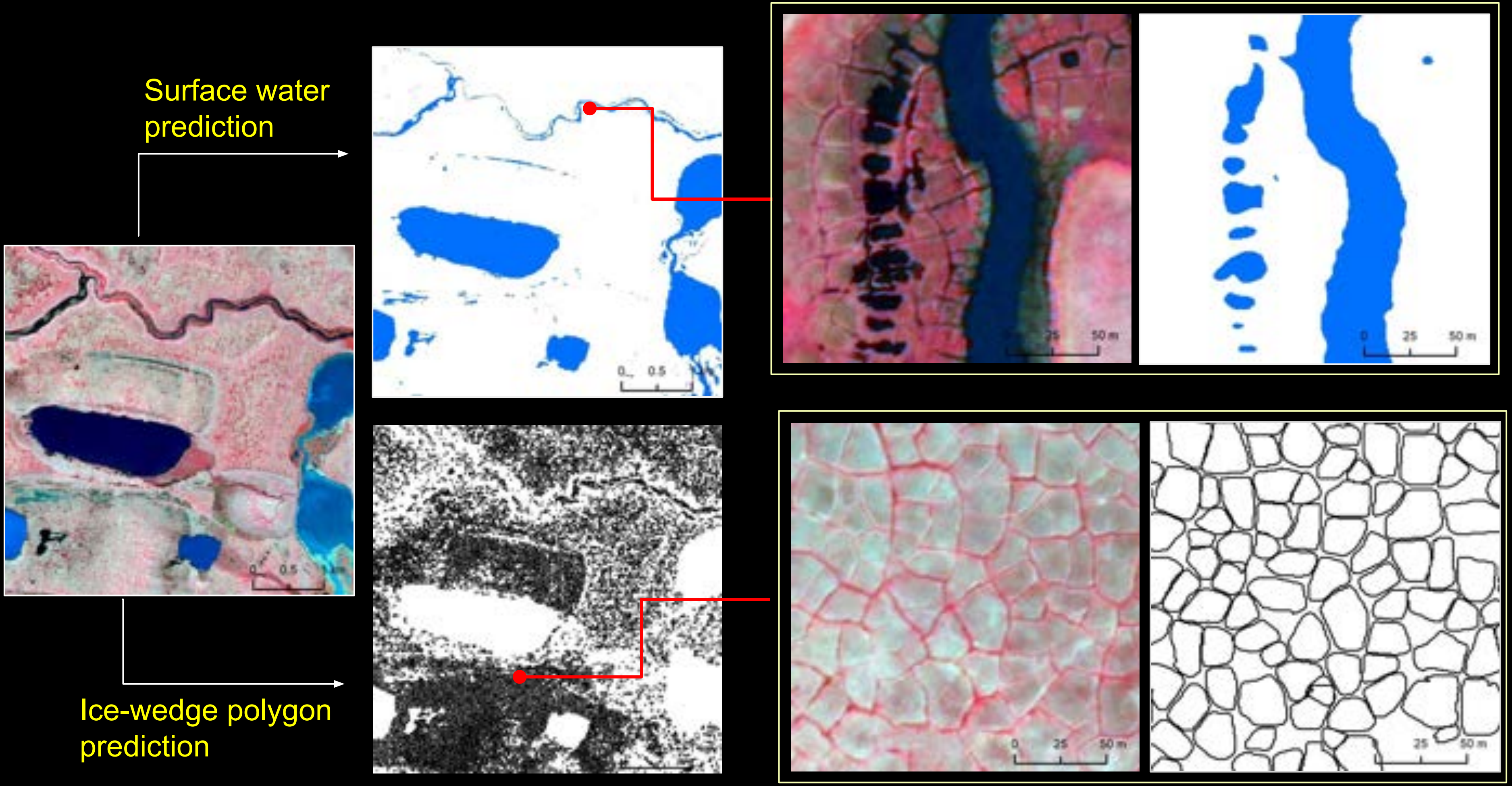
Kaiser et al. 2021






Ice-wedge polygons


Water bodies

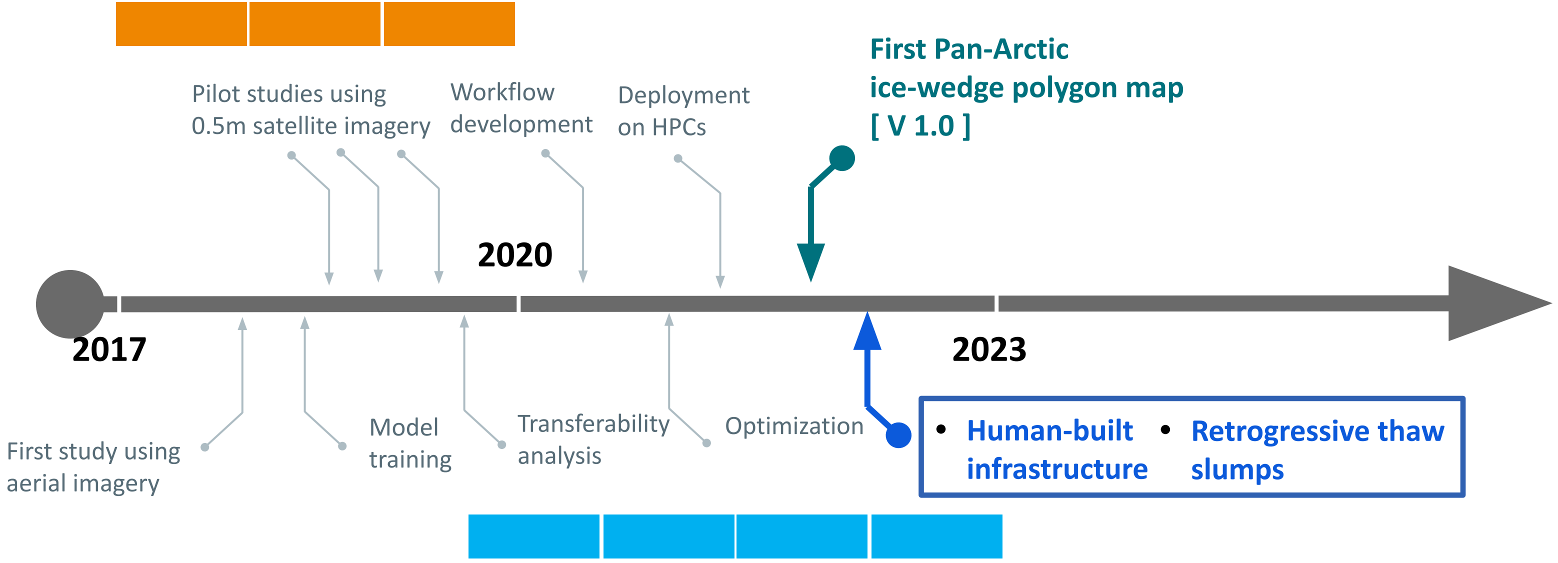


Udawalpola et al. 2021, Udawalpola et al. 2022 (in-press)

Ongoing additions to MAPLE

ARCSS

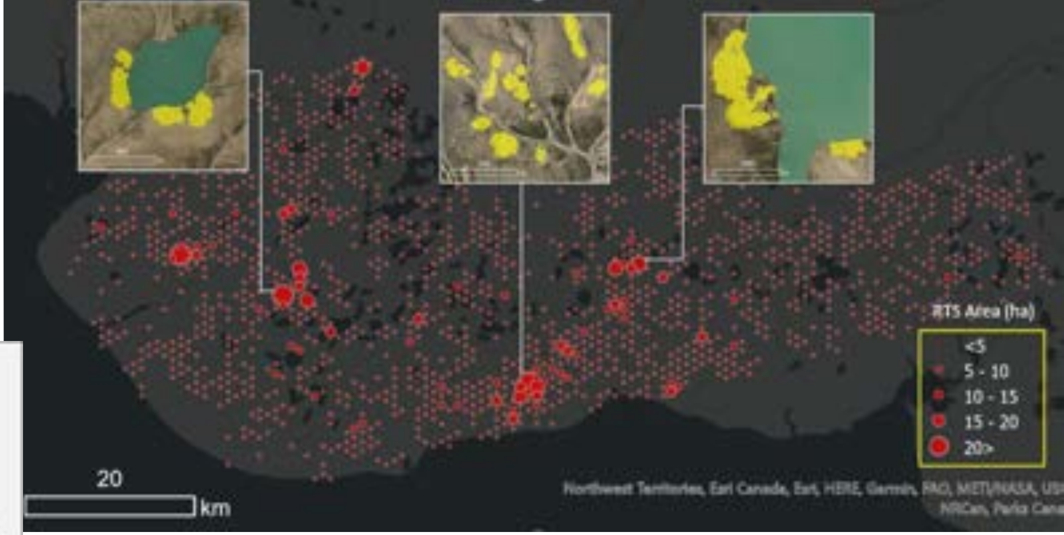
Patterns, Dynamics, and Vulnerability of Arctic Polygonal Ecosystems: From Ice-Wedge Polygon to Pan-Arctic Landscapes



NNA

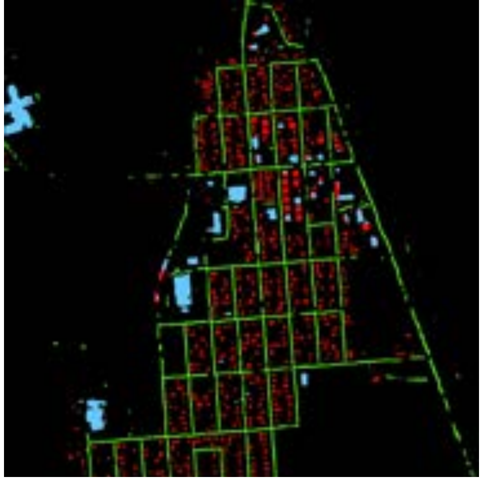
The Permafrost Discovery Gateway: Navigating the new Arctic tundra through Big Data, artificial intelligence, and cyberinfrastructure

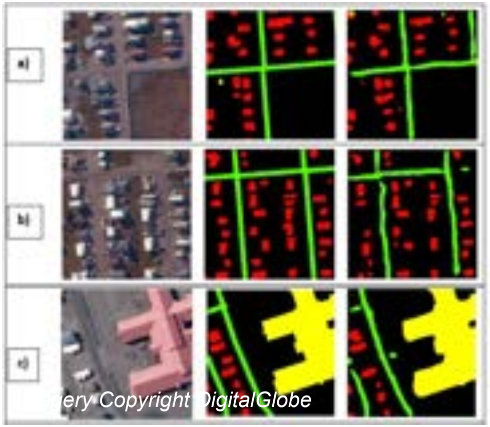
Automated Recognition of Retrogressive Thaw Slumps from Maxar Imagery

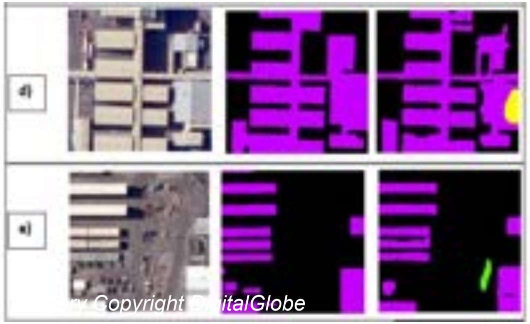


Witharana et al. (2022)

Automated Recognition of Human-Built Infrastructure from Maxar Imagery







Selected model predictions on the testing dataset from Barrow and Prudhoe Bay sites. (a-d) each contain the input image tile, annotated image tile showing true output, and output predicted by model.

Class

- Background
- Road
- Residential/Commercial
- Public
- Industrial

Manos et al. (2022)

NSF Arctic Data Center

Scalable and Computationally Reproducible Approaches to Arctic

September 22, 2022

Billions of Ice Wedge Polygons

Transforming of BIG imagery into Arctic Science ready products

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