

# The Fun and Frontiers of AI in Arctic Science



Wenwen Li and Anna Liljedahl

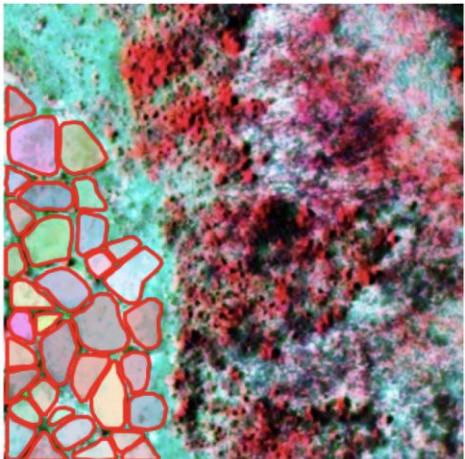


Woodwell Climate  
Research Center

# AI's two big subfields

## Image analysis/Computer vision

- Image classification
- Object detection and recognition
- Facial recognition
- Medical imaging



Segmenting IWP from Maxar imagery

## Natural language processing

- Chatbots and virtual assistants
- Text and sentiment analysis (search)
- Language translation
- Content generation

A screenshot of a Google search results page. The search query "AI in Arctic science" is entered in the search bar. Below the search bar, there are several search results:

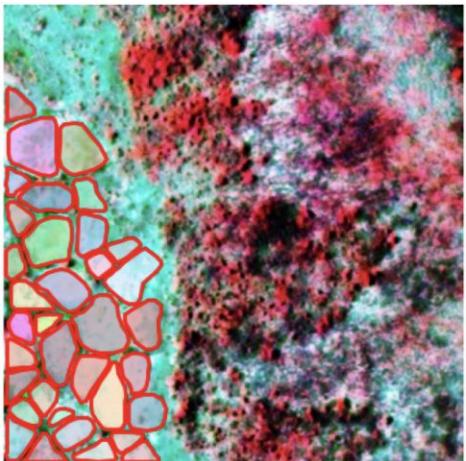
- Google** AI in Arctic science
- Artificial Research Consortium of the United States | ARCUS**  
<https://www.arcus.org/witness-the-arctic-highlight>  
Artificial Intelligence and Machine Learning Tools for Arctic ...  
by F Huettmann — AI is a wide and evolving field that combines computer science and datasets—robust or new—to enable problem-solving. It also encompasses the established sub- ...
- Ted Stevens Center**  
<https://tedstevenscenter.org/2024/01/18...> [PDF] ...  
Arctic Climate Data Science: The Role of Artificial ...  
by K Frazier — This paper delves into the role of AI in Arctic Climate Data Science, emphasizing its transformative impact in assimilating and analyzing ...
- MIT News**  
<https://news.mit.edu/2023/dataset-arctic-images-will-spur-artificial-intelligence-research> ...  
A new dataset of Arctic images will spur artificial ...  
Jul 24, 2023 — A new dataset of Arctic Images will spur artificial Intelligence research. The dataset, being collected as part of a US Coast Guard science ...
- LinkedIn - British Antarctic Survey**  
130+ reactions · 11 minutes ago  
How is AI being used for good in the Arctic?  
From sea ice prediction to wildlife conservation, AI is making a positive impact in the Arctic, offering hope for a more sustainable and resilient future.
- ASU News**  
<https://news.asu.edu/2023/07/28/solutions-asu-research...> ...  
ASU research to use AI to advance Arctic science  
Jul 28, 2023 — A new, open-access resource that will use satellite data and artificial intelligence

Google search for “AI in Arctic science”

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Thawing permafrost is a result of climate change and can have severe impacts on the environment and people.

### Infrastructure damage

Thawing permafrost can cause roads, buildings, and pipes to crack, shift, or break.

### Landslides and erosion

Thawing permafrost can make soil more unstable, especially along coasts.

### Changes to ecosystems

Thawing permafrost can create temporary shallow ponds. It can also alter the landscape and impact aquatic wildlife.

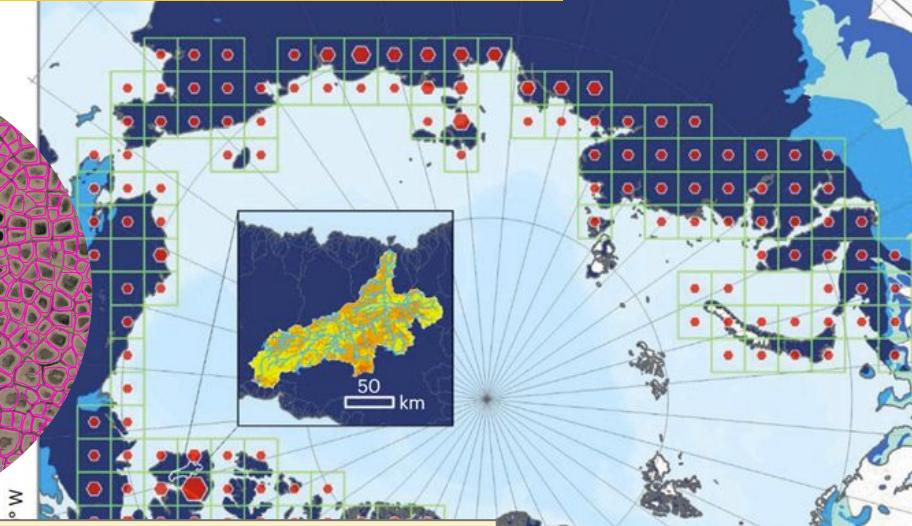
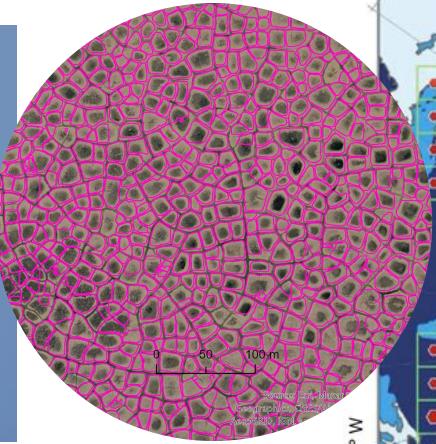
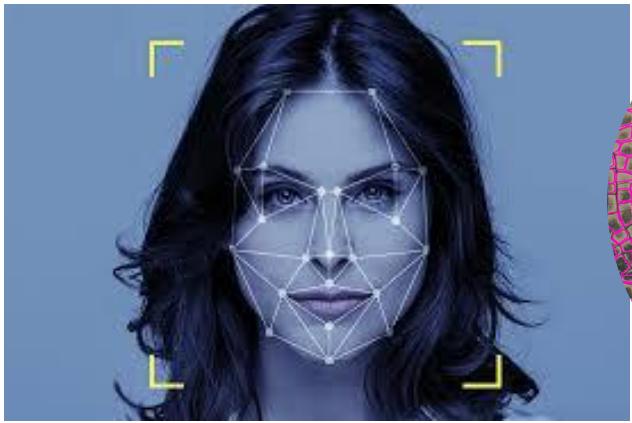
### Release of greenhouse gases

When permafrost thaws, microbes decompose the organic carbon in the soil, releasing carbon dioxide and methane into the atmosphere. These greenhouse gases trap heat in the atmosphere, which can lead to further thawing of permafrost. This creates a feedback cycle called the permafrost carbon feedback cycle.

**KNOWLEDGE  
GRAPH**

Text understanding and knowledge representation

# What attracted me to use AI in Arctic research?



1. AI can help me detect things that traditional remote sensing methods are unable to
  2. AI can help me distill stories in the big data
  3. AI can help me keep up with the changing landscape
  4. AI can help me make connections with data/people
- AI is my new tool in the toolbox, not my creative partner.*

Ice wedge polygon count

- <25,000,000
- 25,000,001-50,000,000
- 50,000,001-75,000,000
- 75,000,001-100,000,000

# What attracted me to use AI in Arctic Research?



A visit to Fairbanks, AK in August 2009  
for IPY GeoNorth 2009



# Cyberinfrastructure and big data

Data to knowledge production pipeline



# Cyberinfrastructure and big data

PolarHub: large-scale web crawler for distributed polar data

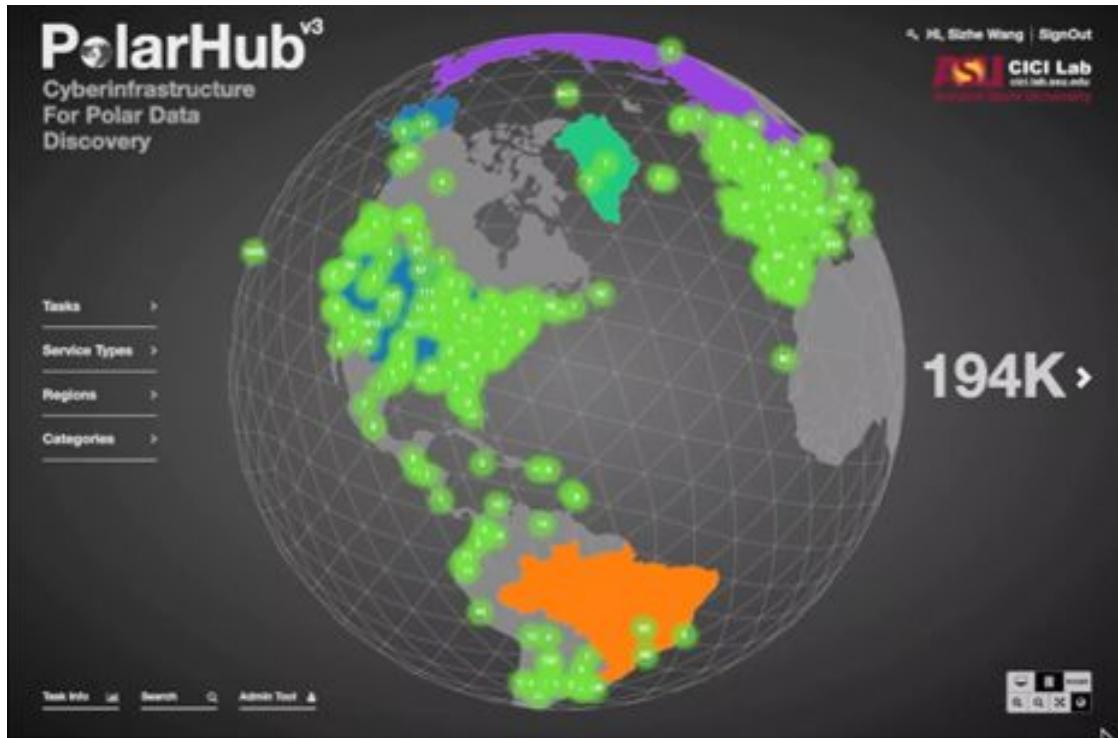
## Metrics:

- No. of datasets: 194,000
- 7 types of data
- 1,730,000 unique data layers
- from 150+ countries
- Access from 27 countries

## Significance:

- Support polar science
- Spatial decision support consortium
- Wildfire, water quality, biodiversity conservation communities

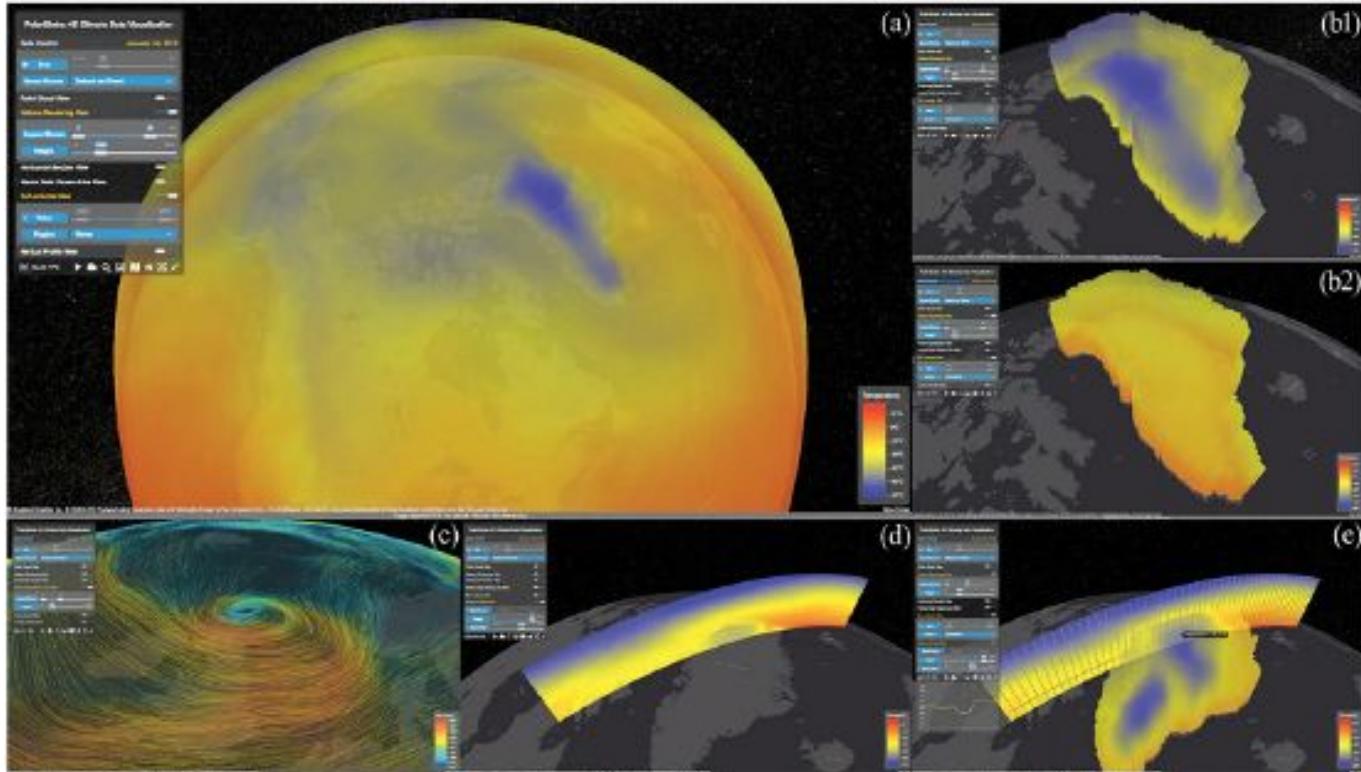
<https://cici.lab.asu.edu/polarhub3>





# Cyberinfrastructure and big data

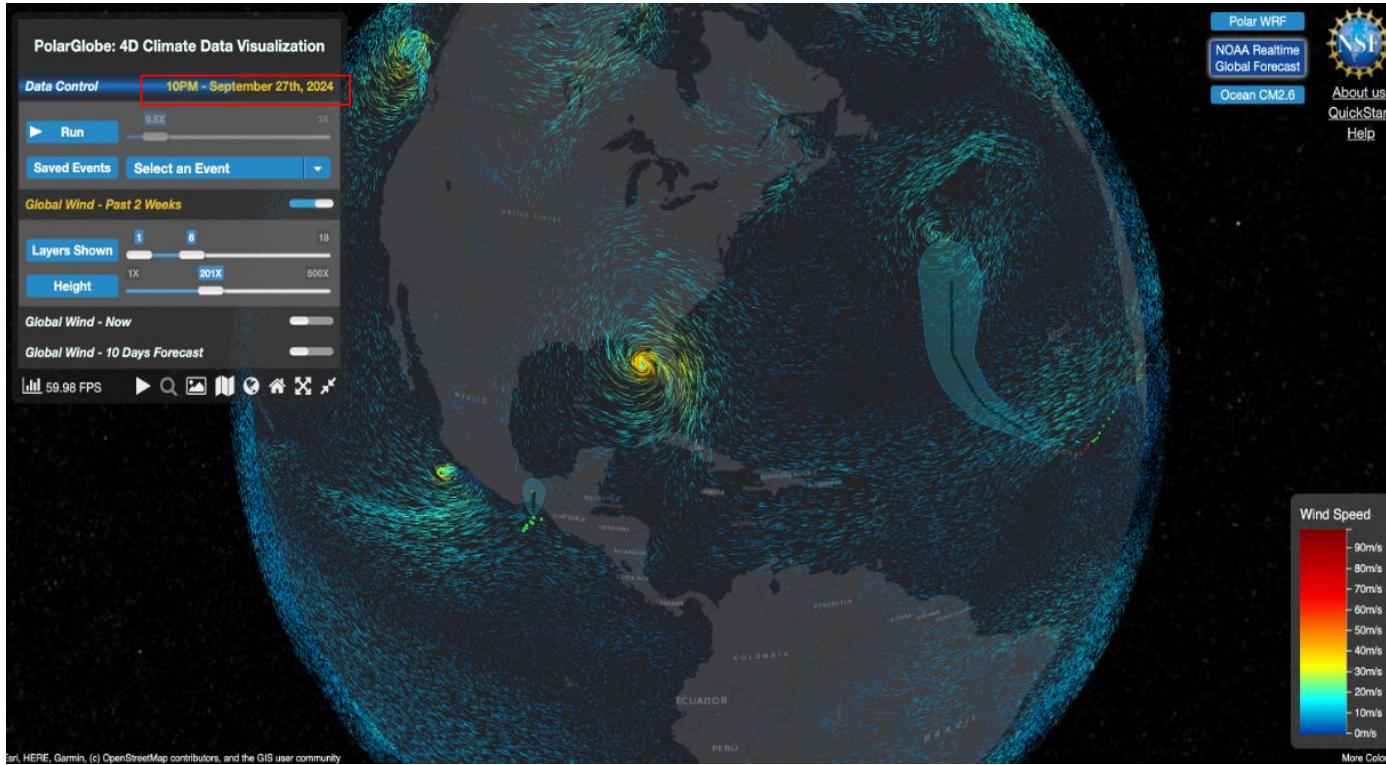
PolarGlobe: Real-time climate data visualization



<https://cici.lab.asu.edu/polarglobe>

# Cyberinfrastructure and big data

## PolarGlobe: Real-time climate data visualization



Use of PolarGlobe to track Hurricane Helene, which hit the Florida coast on September 27, 2024

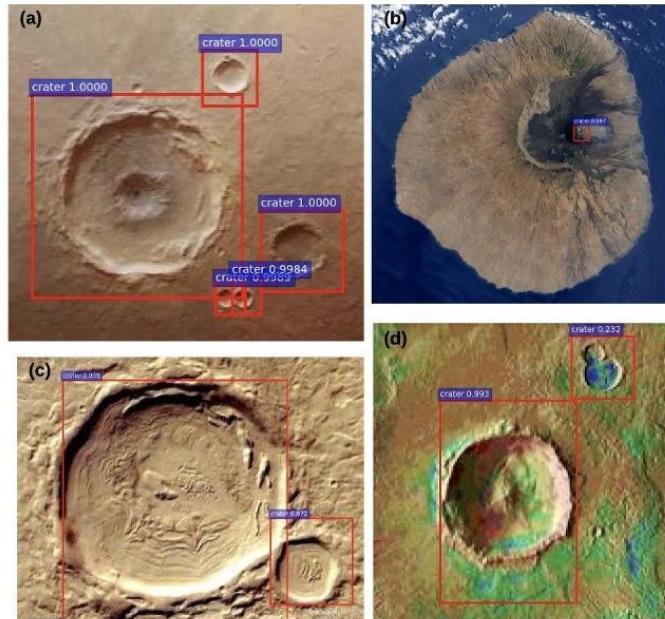
<https://cici.lab.asu.edu/polarglobe>

# GeoAI for Intelligent Mapping

Mapping the Earth's natural features - craters



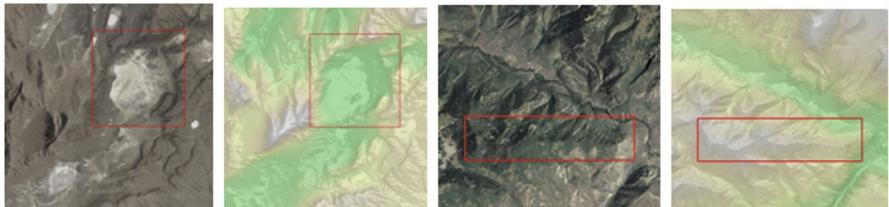
Li et al. 2017



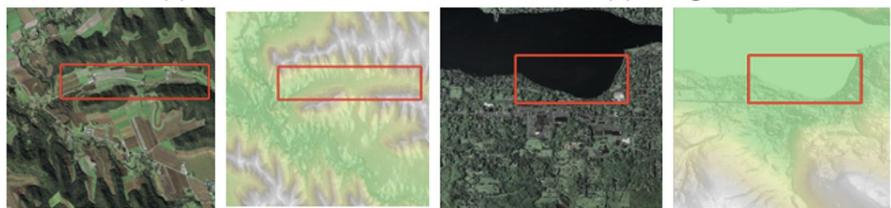
Crater detection using CNN  
 $mAP(\text{crater}) = 99\%$

# GeoAI for Intelligent Mapping

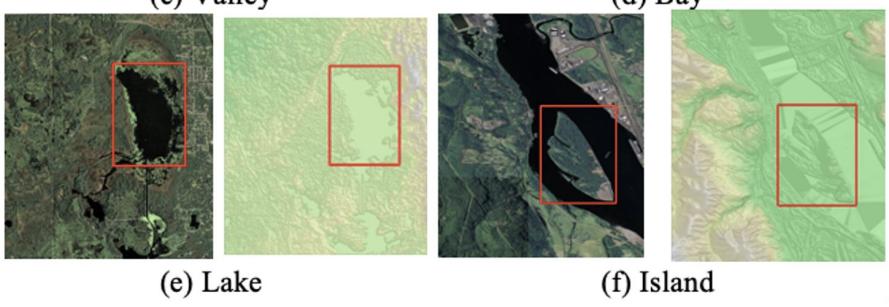
Mapping the Earth's natural features - multi-source, multi-type



(a) Basin



(b) Ridge



(c) Valley



(d) Bay

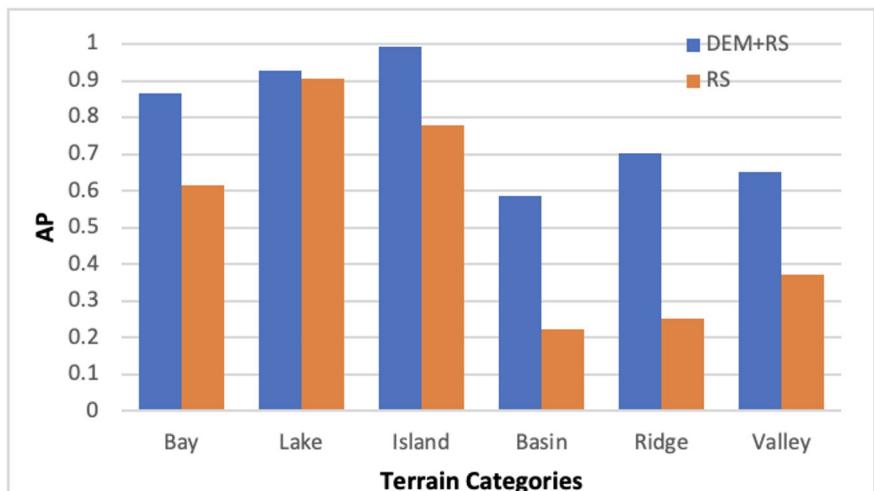


(e) Lake



(f) Island

## GeoImageNet



**AP:** Average Precision

Wang et al. (2021)

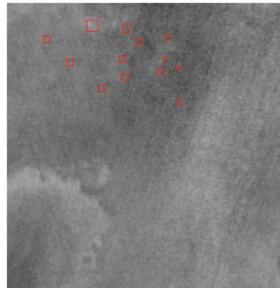
# Mapping Mars craters

Incubator for the NSF Cyber2A project

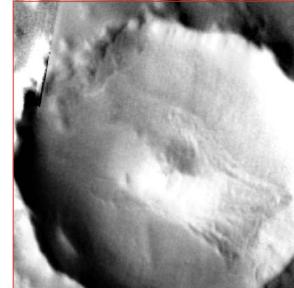
- 102,675 images scenes covering global Martian surface
- THEMIS image at 100m resolution
- 640k craters



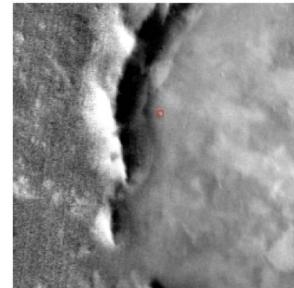
**GeoAI Martian  
Challenge**



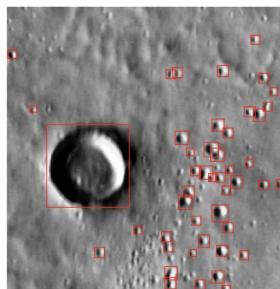
(a) Example of small craters



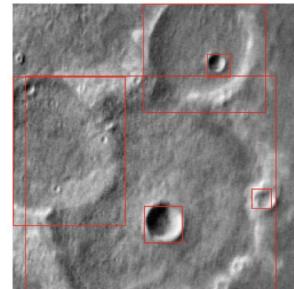
(b) Example of large craters



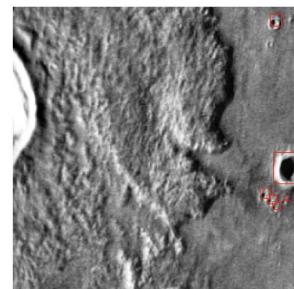
(c) Example of sparsely distributed craters



(d) Example of densely distributed craters



(e) Example of overlapping craters



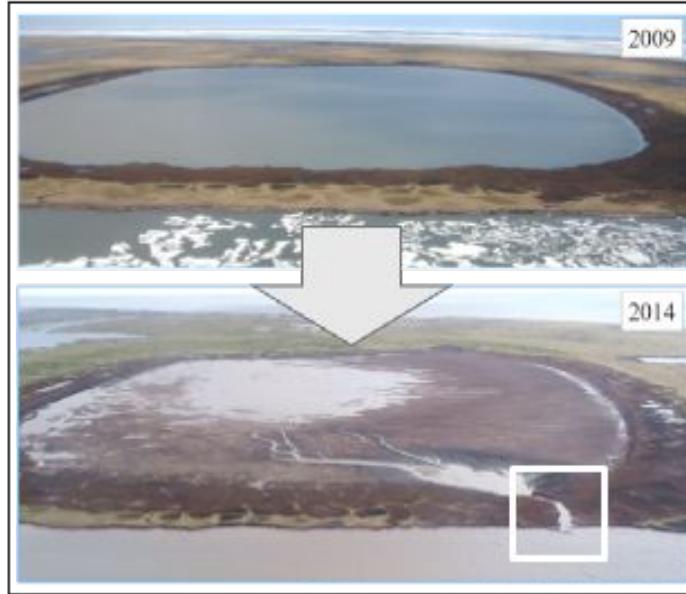
(f) Craters in more complex terrains

<https://cici.lab.asu.edu/martian>



# Mapping the Arctic Permafrost

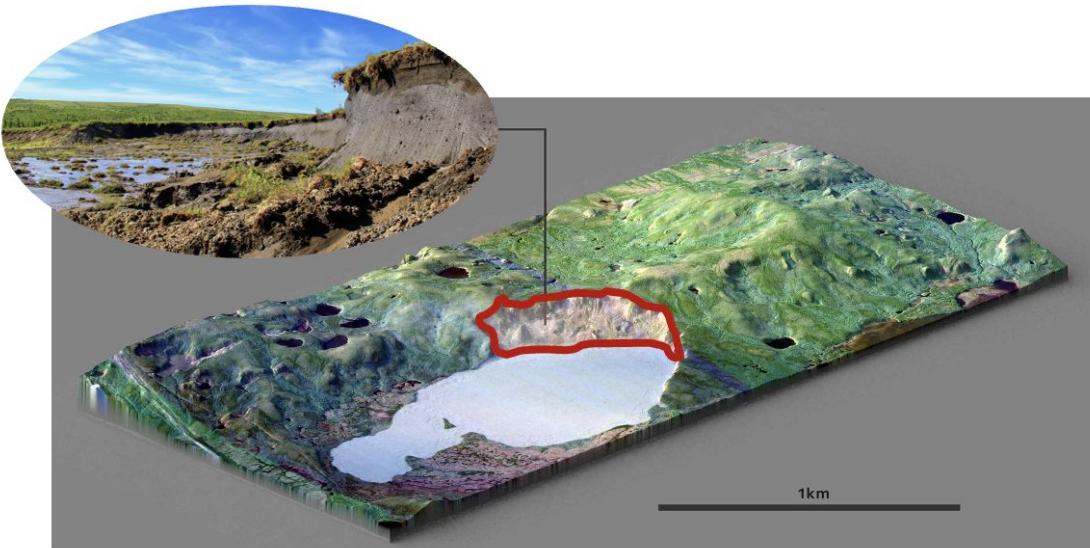
Google.org



# Mapping the Arctic Permafrost



Ice-Wedge Polygons



Retrogressive Thaw Slump (RTS)

# Mapping Arctic Permafrost Thaw

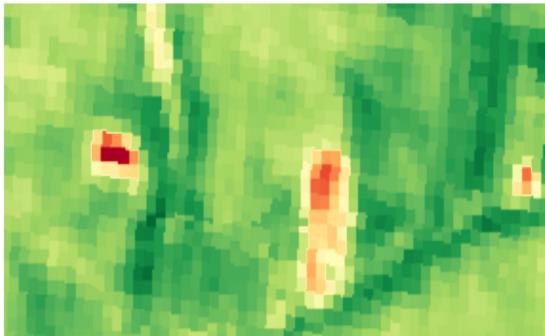
A multimodal + feature fusion approach



Google.org



Optical image



NDVI

(Normalized Difference  
Vegetation Index)



ArcticDEM

(Digital Elevation  
Model)

The higher the value,  
the greener it is

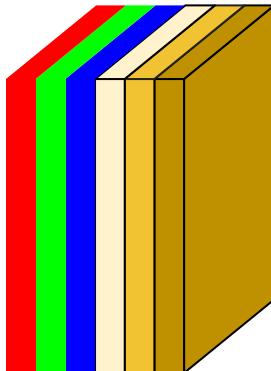


# Mapping Arctic Permafrost Thaw - Methods

## Feature-level data fusion

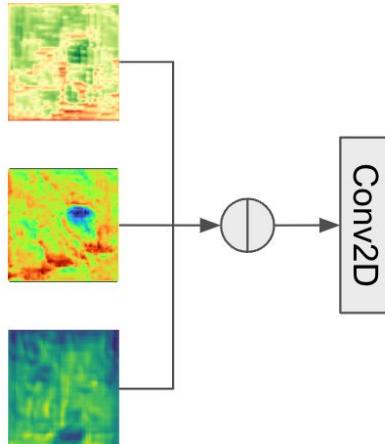
Prior solutions

### Channel expansion



Yang et al. 2023

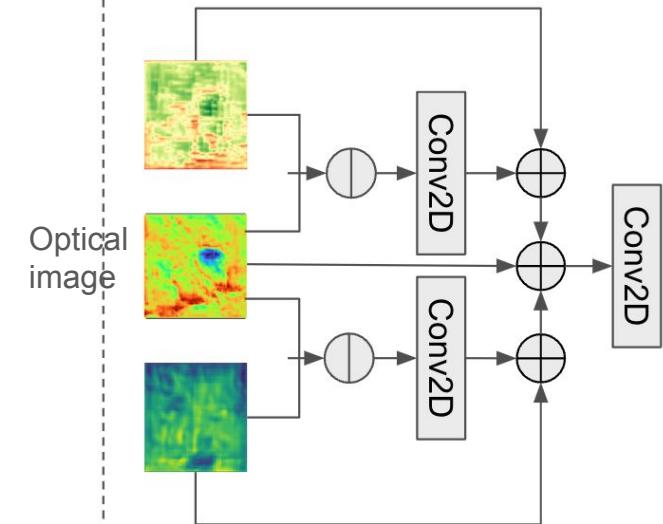
### Convolutional Fusion



Ophoff et al., 2019; Wang and Li, 2021

Our proposed solution

### Residual Connection Fusion



Gu, Li, et al. 2024 (under review)

# Mapping Arctic Permafrost Thaw - Results

## Feature-level data fusion

| Fusion Type   | Fusion Strategy            | Input Modalities              |              |              |                  |
|---------------|----------------------------|-------------------------------|--------------|--------------|------------------|
|               |                            | RGB                           | RGB + NDVI   | RGB + DEM    | RGB + NDVI + DEM |
| Data level    | Channel Expansion          | 39.73                         | 42.74        | 36.59        | 43.01            |
| Feature level | Convolutional Fusion       | (baseline, no fusion applied) | 44.51        | <b>43.66</b> | 44.59            |
| Feature level | Residual Connection Fusion |                               | <b>46.08</b> | 43.39        | <b>45.78</b>     |

### Observations:

- Multi-modality is helpful
- Fusion method is important
- Low quality (vertical accuracy) of DEM lowered the model performance



ArcticDEM

# Forecasting Arctic Permafrost Thaw

- We need to have the trigger data, but existing data are not of desired resolution (1km)
  - Climate
  - Disaster (wildfire)
- Thaw indicator data
  - RTS formation
  - Lake change data (pond formation/lake drainage)

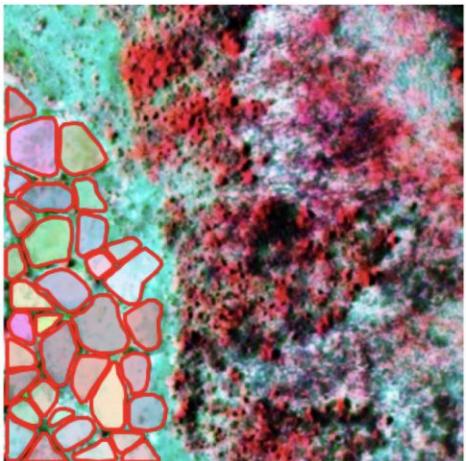
# AI-based medium range weather forecasting

- Significant success in this area
  - **Huawei-Pangu** (Bi et al. 2023 in *Nature*)
    - 3D neural network based on Swin Transformer
    - Training data: 30 years of reanalysis (1979-2017) with 69 factors (e.g., T, U, V, Geopotential, humidity) at 13 pressure levels
    - Higher prediction **accuracy** and 10k times **faster** than the **IFS** (Integrated Forecasting System) model from ECMRW
  - **Google DeepMind- GraphCast** (Lam et al. 2023, *Science*)
    - More lightweight and higher accuracy than than Pangu

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**KNOWLEDGE  
GRAPH**

Text understanding and knowledge representation

# **Embracing Large Language Models for Arctic Research**

# AI enhanced event search and recommendation

Generative AI for deterministic tasks

 Local Environmental Observer (LEO) Network



LEO Network members share unusual environmental events that help us understand our changing world. [Please join us](#) and contribute your observations or news articles.

 [Advanced Search](#)

<https://www.leonetwork.org/>

Humpback found dead near Kodiak gets Alaska's first 2023 whale necropsy

By Brian Vensel, KMXT - Kodiak • October 2, 2023



Biologists conduct a necropsy on a humpback whale that washed ashore near Kodiak on Sept. 25, 2023. (Brian Vensel/KMXT)

# LEON Event Search & Recommendation

- Current method:
  - Full text search (BM25 model)
    - Keyword matching
    - Context matters!
  - Distance & category boosting
  - Manual work:
    - Multiple rounds of keyword-based search and human judgement

The screenshot shows a news article from Alaska Public Media. The article title is "Humpback found dead near Kodiak gets Alaska's first 2023 whale necropsy". It includes a map of Kodiak, Alaska, and details about the location (N 57° 47' 24" W 152° 24' 25.992" and nearby). The article is dated October 2, 2023, and is attributed to Brian Venua, KMXT - Kodiak. The summary notes that a humpback whale found dead near Kodiak Island undergoes the state's first whale necropsy of 2023 to determine the cause of death and understand the shrinking humpback population. Below the main article, there are sections for "Similar events" and "See Also", each listing a related news item from Alaska Public Media.

**Date**: 2 OCTOBER 2023 / [Alaska Public Media](#) / [Brian Venua, KMXT - Kodiak](#) [EVENT](#)

**Title**: Humpback found dead near Kodiak gets Alaska's first 2023 whale necropsy

**Category**: MARINE MAMMALS / DEATH / DIE-OFF / DECLINE

**Location**: Kodiak, Alaska, United States  
N 57° 47' 24" W 152° 24' 25.992"  
Nearby

**Summary**: A humpback whale found dead near Kodiak Island in Alaska undergoes the state's first whale necropsy of 2023 in an effort to determine the cause of death and understand the shrinking humpback population in the area, with initial findings suggesting the whale may have been struck by a boat.

**Read On**: [Alaska Public Media](#) (English) [View a screenshot of the article](#)

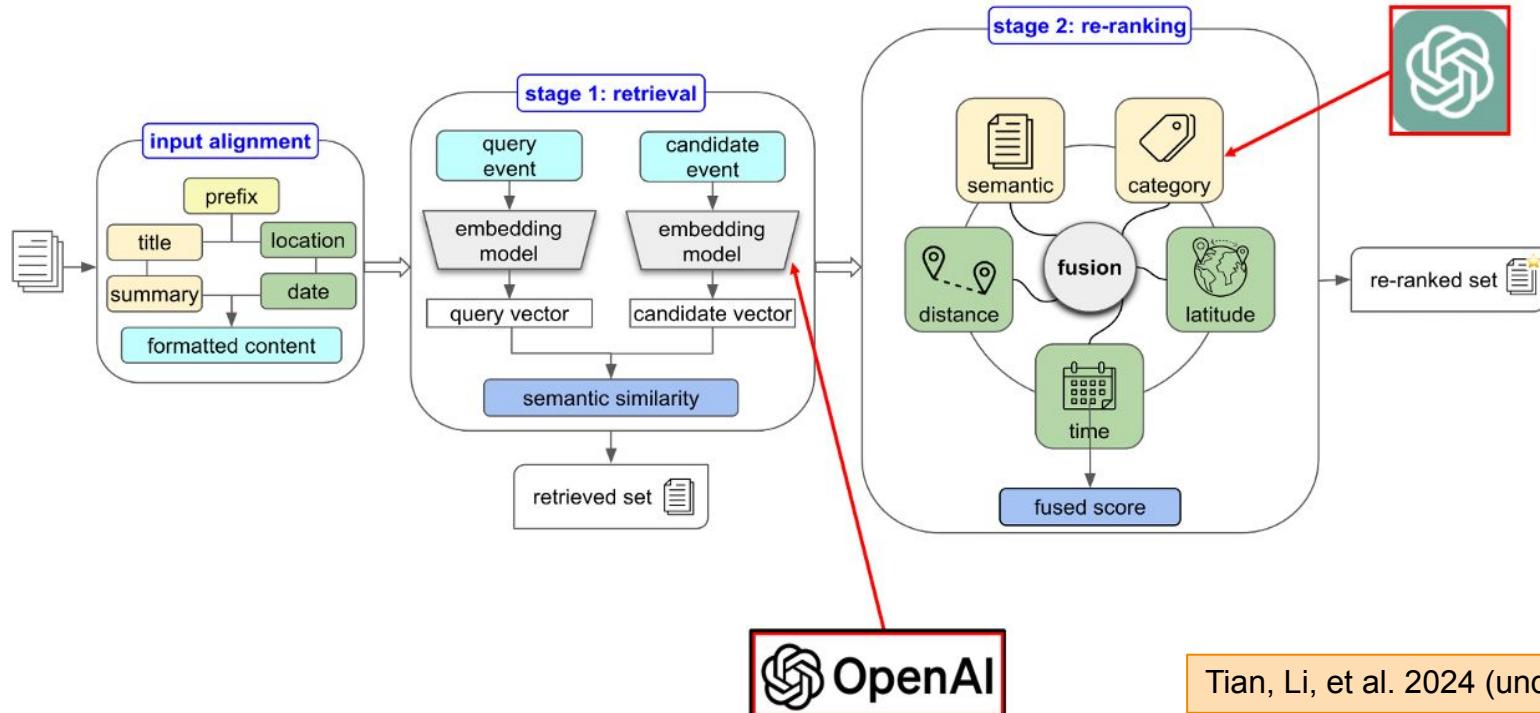
**Similar events**

**See Also**

- Sitka team conducts first humpback whale necropsy in 5 years
- Alaska's third dead gray whale of the year reported on Kodiak coast
- Three dead gray whales wash up on Kodiak Island beaches in one week
- Dead Humpback (*Megaptera novaeangliae*) Near Birchwood
- Dead Humpback Whale (*Megaptera novaeangliae*)

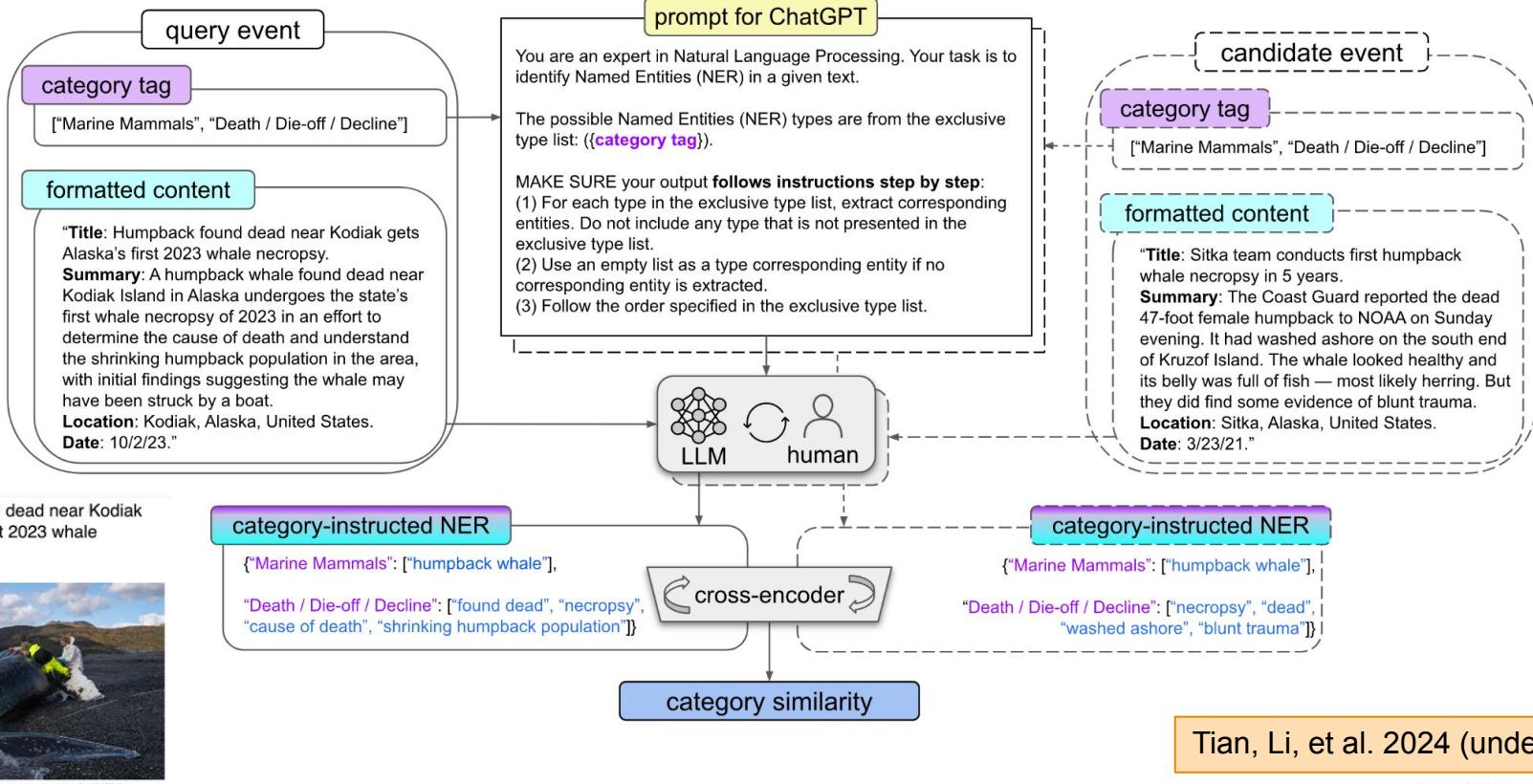
# AI-enhanced search and recommendation

- Leveraging large language models (LLM)



# AI-enhanced search and recommendation

## LLM-based Named Entity Recognition



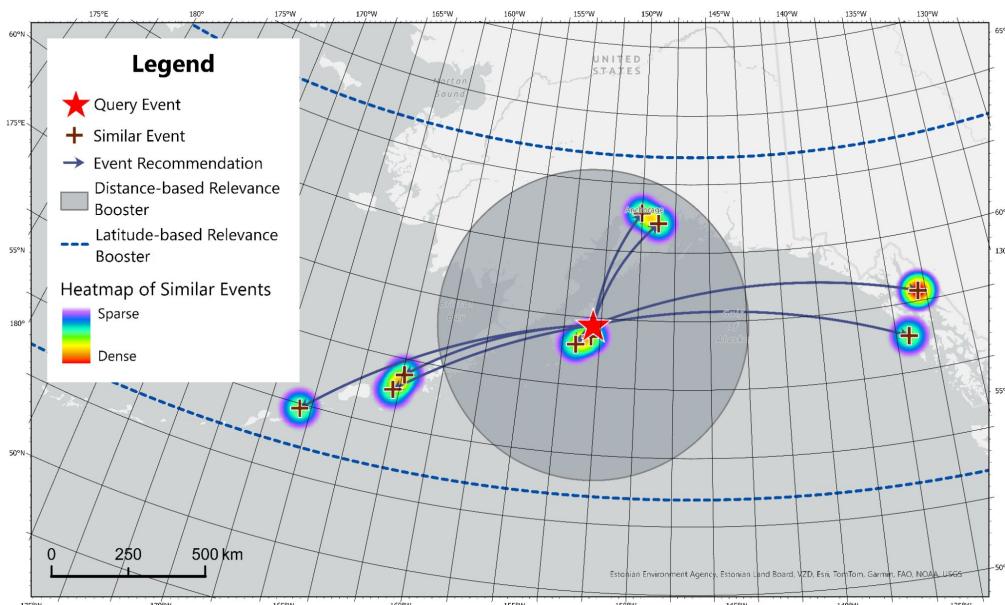
# AI-enhanced search and recommendation

Our results

LEON human subject ranking



|                | Rank | Label | Title  | Location                                     | Date     |
|----------------|------|-------|--|--|----------|
| query event    |      |       | Humpback found dead near Kodiak gets Alaska's first 2023 whale necropsy                                  | Kodiak, Alaska, United States                | 10/02/23 |
| similar events | #1   | hit   | Alaska's third dead gray whale of the year reported on Kodiak coast                                      | Kodiak, Alaska, United States                | 05/23/19 |
|                | #2   |       | Dead Humpback Whale ( <i>Megaptera novaeangliae</i> )  | Old Harbor, Alaska, United States            | 08/23/12 |
|                | #3   | hit   | Sitka team conducts first humpback whale necropsy in 5 years   | Sitka, Alaska, United States                 | 03/23/21 |
|                | #4   |       | The dead whale floating in Cook Inlet has washed ashore at Kincaid Park                                  | Cook Inlet, Anchorage, Alaska, United States | 09/25/17 |
|                | #5   | hit   | Dead Humpback Whale ( <i>Megaptera novaeangliae</i> )  | King Cove, Alaska, United States             | 09/23/15 |
|                | #6   |       | Beluga whale found dead south of Anchorage will help scientists better understand the endangered animals | Girdwood, Alaska, United States              | 05/27/21 |
|                | #7   |       | Dead whales wash up near Unalaska, but pandemic complicates necropsies                                   | Unalaska, Alaska, United States              | 08/27/20 |
|                | #8   |       | Dead humpback whale calf washes up near Juneau, may have been struck by vessel                           | Juneau, Alaska, United States                | 08/28/23 |
|                | #9   |       | Dead Humpback Whale ( <i>Megaptera novaeangliae</i> ) Floating by Moller Point                           | King Cove Alaska                             | 08/18/20 |
|                | #10  |       | Whale's body spotted near Tenakee Inlet  | Juneau, Alaska, United States                | 02/10/22 |



# **Integration of vision and language models**

# Vision language model for LEON search and recommendation

Image as an important cue for theme



Alaska Public Media

29 SEPTEMBER 2020 /  Alaska Public Media EVENT

## Bear in Denali National Park euthanized over safety concerns



Denali National Park, Alaska, United States

📍 N 63° 32' 26.808" W 151° 43' 24.996"

🔍 Nearby

The bear had entered buildings and food caches, according to National Park Service officials.

Read On  [Alaska Public Media](#)

Or translated into

[View a screenshot of the article](#) 



San Francisco Chronicle

 MARINE MAMMALS



3 AUGUST 2021 /  Anchorage Daily News / Ray Levy Uyeda, The Washington Post

BACKGROUND

Climate change is endangering sacred land. For these Native women, it threatens 'everything we are.'



Newell, California, United States

📍 N 41° 36' 39.44" W 121° 33' 13.09"

🔍 Nearby

Wildfires in Western states have razed structures, displaced residents and altered air quality - and fundamentally changed the relationship between Native women and the land they have historically stewarded.

31 MARCH 2021 /  San Francisco Chronicle / Steve Rubenstein EVENT

## A gray whale carcass washed ashore at S.F.'s Crissy Field



San Francisco, California, United States

📍 N 37° 48' 23.04" W 122° 27' 58.656"

🔍 Nearby

A gray whale carcass washed ashore at Crissy Field on Wednesday morning.

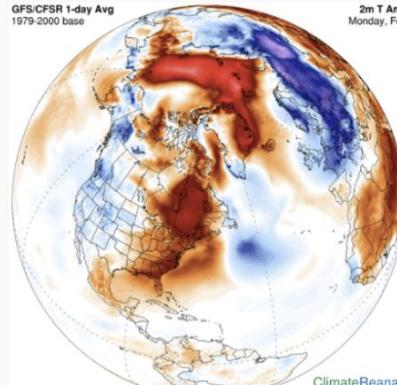
Veterinarians and biologists from the center and from the California Academy of Sciences plan to perform a necropsy in coming days on the island to determine the cause of death.

# Extracting visual cues with GPT-4o



GFS/CFSR 1-day Avg  
1979-2000 base

2m T Anomaly (°C)  
Monday, Feb 26, 2018



ClimateReanalyzer.org  
University of Maine | Climate Change Institute

World  
+0.6 °C  
Tropics  
+0.4 °C  
Northern Hemisphere  
+1.2 °C  
Southern Hemisphere  
0.0 °C  
Arctic  
+5.3 °C  
Antarctic  
-0.7 °C



## Cue\_Category

The image features polar bears, which are **marine mammals**.

## Cue\_Location

Polar bears are native to the **Arctic** region.



## Cue\_Category

The image shows a temperature anomaly map, which is directly related to **weather** patterns.

## Cue\_Location

The map prominently displays the **Northern Hemisphere**, with clear indications of temperature anomalies in this region.

## Cue\_Time

The date on the image is February 26, 2018, which falls in the **winter** season in the Northern Hemisphere.

# Extracting visual cues with ChatGPT

## Location + category



### Cue\_Category

The image features polar bears, which are **marine mammals**.

### Cue\_Location

Polar bears are native to the **Arctic** region.



### Cue\_Category

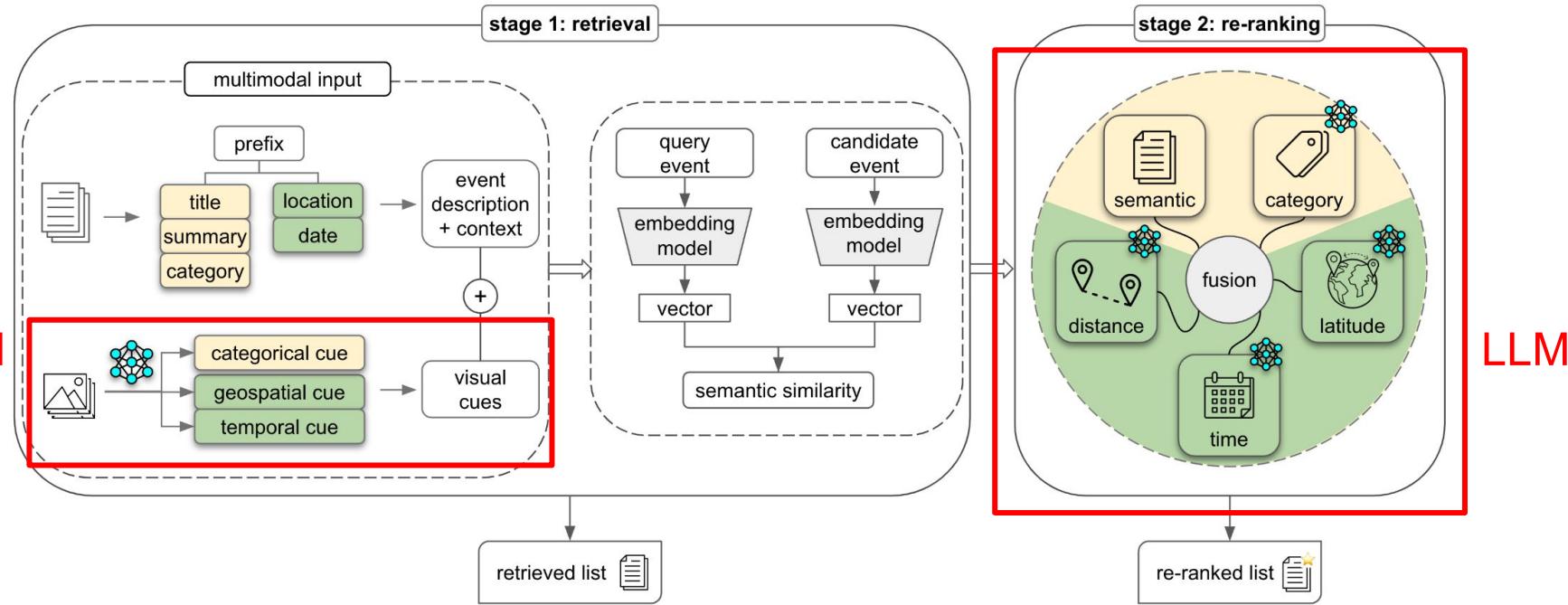
The presence of crosses indicates a **burial site**. The visible ground and ice suggest **changes in permafrost**.

### Cue\_Location

The landscape, including the frozen ground and sparse vegetation, is characteristic of the **Arctic** region.

# A new VLM-enhanced search strategy

- VLM: Vision language model



# A new VLM-enhanced search strategy

## ● Results

Ranking performance metrics

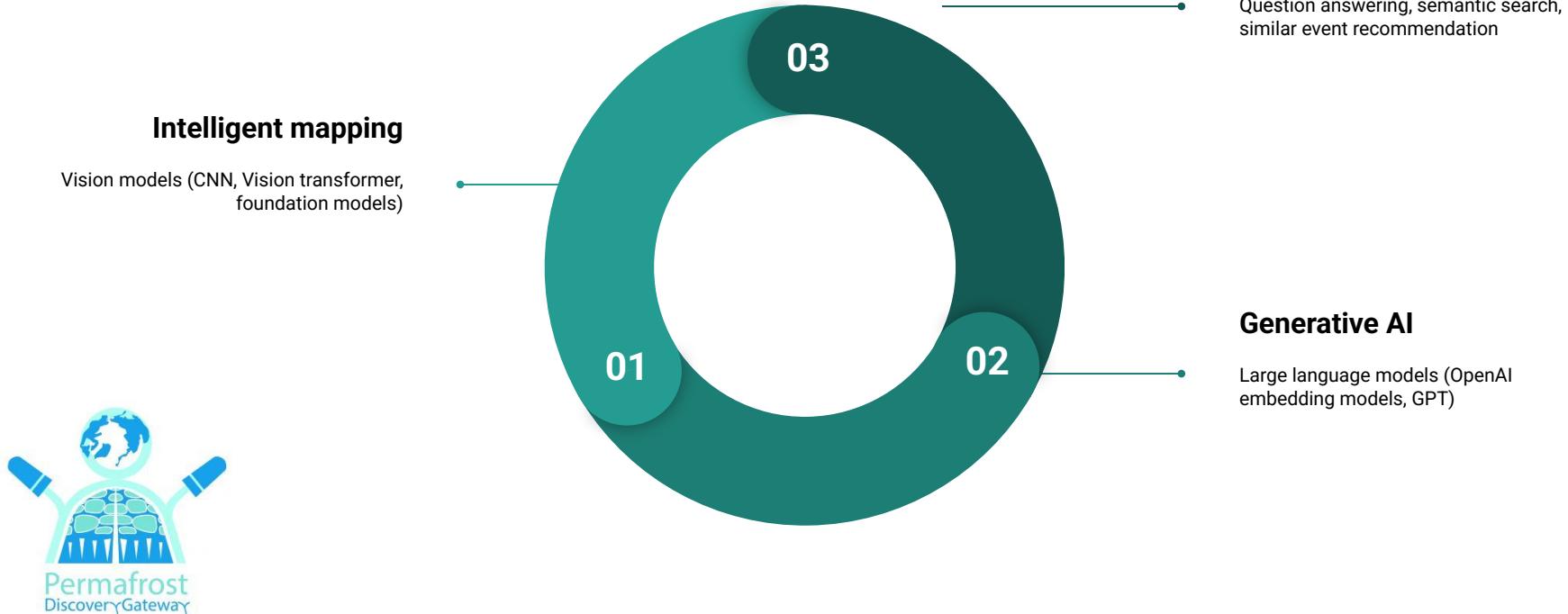
**nDCG**: normalized discounted cumulative gain

**MRR**: Mean Reciprocal Rank

**Table 2: Comparison of Re-ranking Performance on Unimodal Representation and Multimodal Representation(metric@10)**

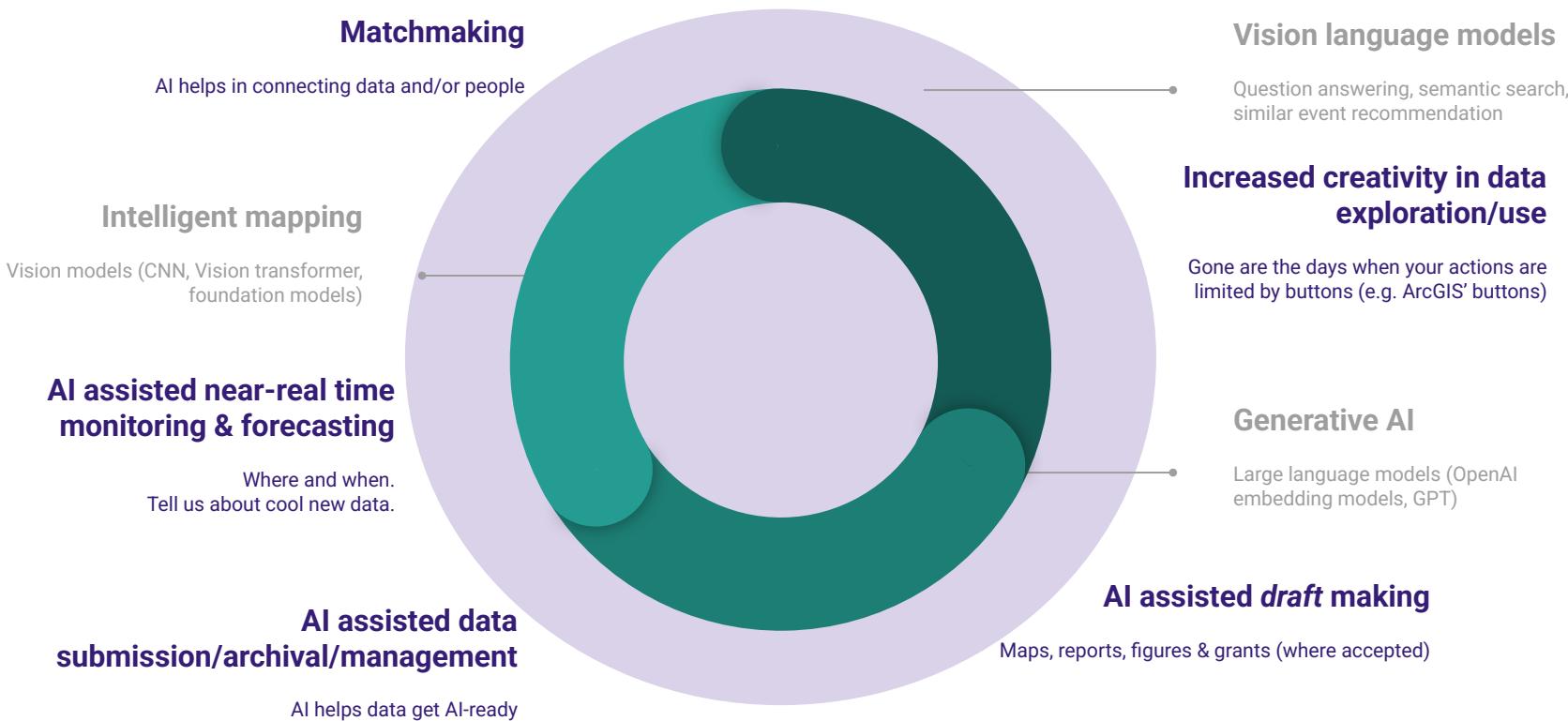
| Representation                        | Retrieval    | Re-ranking    | nDCG         | MRR          |
|---------------------------------------|--------------|---------------|--------------|--------------|
| unimodal<br><br><b>Text-based</b>     | Ada-002      | -             | 44.70        | 52.20        |
|                                       | Ada-002      | MiniLM        | 42.10        | 49.00        |
|                                       | Ada-002      | BGE reranker  | 36.40        | 44.40        |
|                                       | Ada-002      | Cohere rerank | 33.10        | 38.90        |
|                                       | Ada-002      | GPT-3.5 Turbo | 32.30        | 42.50        |
|                                       | Ada-002      | RankGPT       | 41.40        | 49.00        |
|                                       | Ada-002      | GT-R          | <b>47.40</b> | <b>55.80</b> |
| multimodal<br><br><b>Text + image</b> | emb.-3-large | -             | 50.48        | 57.28        |
|                                       | emb.-3-large | GT-R          | 50.80        | 57.07        |
|                                       | emb.-3-large | ASTRA (ours)  | <b>51.22</b> | <b>57.60</b> |

# A quick summary of our research under Permafrost Discovery Gateway



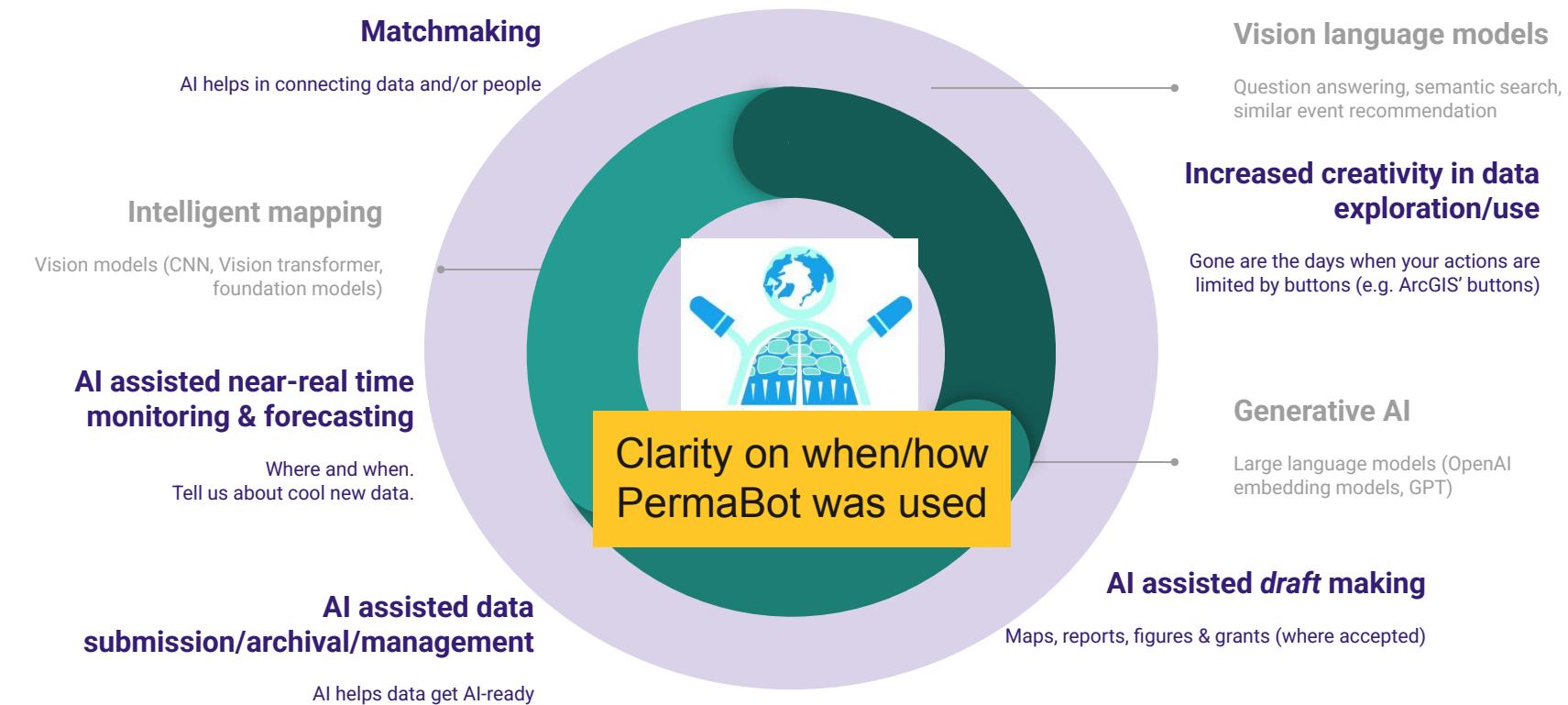
# Big vision and aspiration for PDG

AI tools → More time for our creativity and (real-world) action!



# Big vision and aspiration for PDG

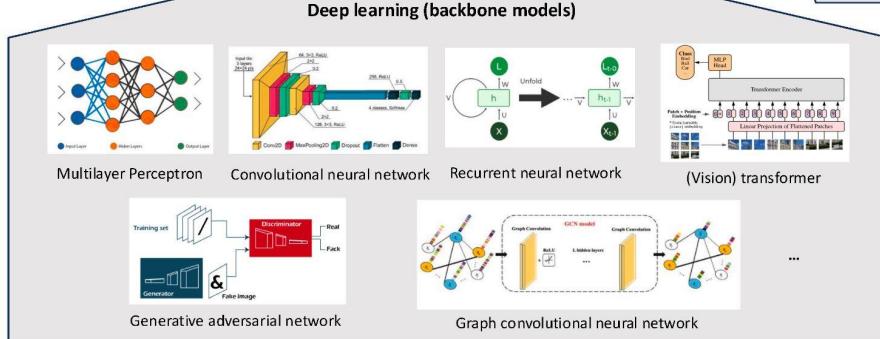
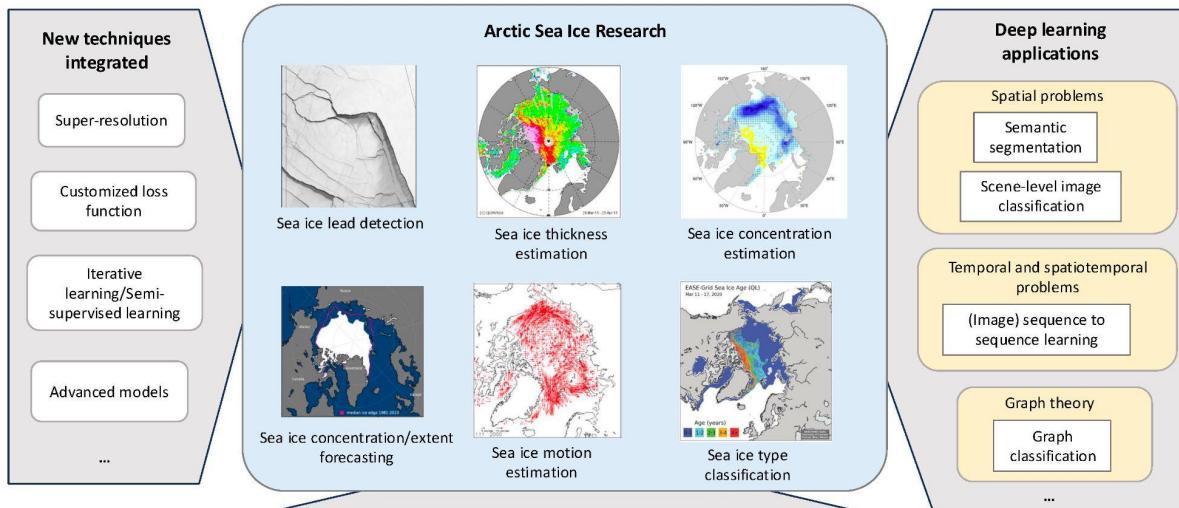
AI tools → More time for our creativity and (real-world) action!



# **Moving beyond Permafrost Research**

# AI for Sea Ice Remote Sensing

What is happening in the sea ice world?



Li, W., Hsu, C. Y., & Tedesco, M. (2024). **Advancing Arctic Sea Ice Remote Sensing with AI and Deep Learning: Opportunities and Challenges.** *Remote Sensing*, 16(20), 3764.

# AI for Sea Ice Remote Sensing

**Table 4.** Deep learning solution techniques for sea ice concentration forecasting.

| Sea Ice Application               | Deep Learning Problem Formulated | Deep Learning Techniques (Models)           | Output   | References       |
|-----------------------------------|----------------------------------|---|--|------------------|
| Sea ice concentration forecasting | Time-series forecasting          | Semantic segmentation (U-Net, SICNet)       | Classify each pixel into a SIC type, with multi-channel output and each channel represents the SIC classification for a future timestamp (e.g., month) | [66,68,74]       |
|                                   |                                  | RNN (LSTM, attention-based LSTM, gated RNN) | Predict sea ice concentration in future timestamps through sequence-to-sequence learning. The forecast could be for one or multiple timestamps         | [75,76,77,78]    |
|                                   |                                  | CNN+RNN<br>(ConvLSTM, multi-task ConvLSTM)  |  | [69,71,72,79,80] |

# AI for Sea Ice Remote Sensing

## Future research directions

- Enhanced multimodal deep learning capabilities
- Better ability to quantify uncertainty
- Deeper integration with physics-based models
- Better leveraging AI foundation models
- Open benchmark datasets and open models
  - AI4Arctic (for sea ice charting)
  - SealceWeather (from cruise)
- ...

# Big models, big concerns

- Transformer does not how to reason, they are only advanced pattern matching tools

## GSM-Symbolic: Understanding the Limitations of Mathematical Reasoning in Large Language Models

Iman Mirzadeh<sup>†</sup>  
Oncel Tuzel

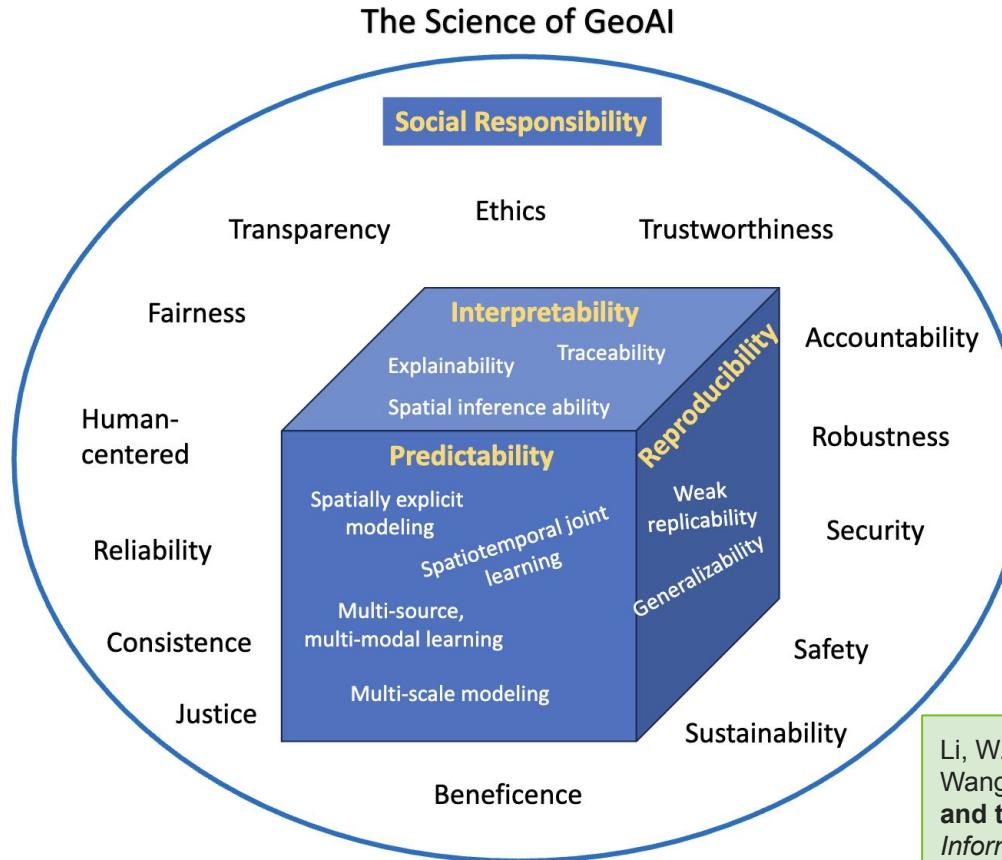
Keivan Alizadeh  
Samy Bengio

Hooman Shahrokhi\*  
Mehrdad Farajtabar<sup>†</sup>

Apple

<https://arxiv.org/abs/2410.05229>

# Big models, big concerns



Li, W., Arundel, S., Gao, S., Goodchild, M., Hu, Y., Wang, S., & Zipf, A. (2024). **GeoAI for Science and the Science of GeoAI**. *Journal of Spatial Information Science*, (29), 1-17.

# Thank you!

Follow the PDG news here: <https://arcticdata.io/catalog/portals/permafrost>

Follow Cyber2A events here: <https://cyber2a.github.io/>

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