

A wide-angle photograph of an Arctic landscape. The foreground is dominated by a vast expanse of broken sea ice, with numerous small, irregular ice floes scattered across a dark blue sea. The ice floes vary in size and shape, some appearing as thin sheets and others as larger, more substantial chunks. In the background, a large, dark, rocky landmass or ice shelf rises from the water, partially covered in snow and ice. The sky is a clear, pale blue, suggesting a bright, sunny day. The overall scene conveys a sense of a remote, cold, and dynamic environment.

# The Fun and Frontiers of AI in Arctic Science

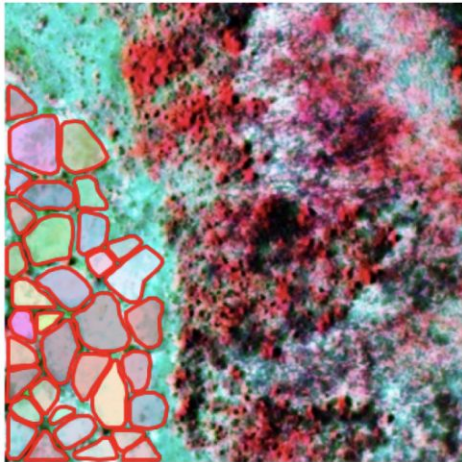
**Wenwen Li** and **Anna Liljedahl**



# AI's two big subfields

## Image analysis/Computer vision

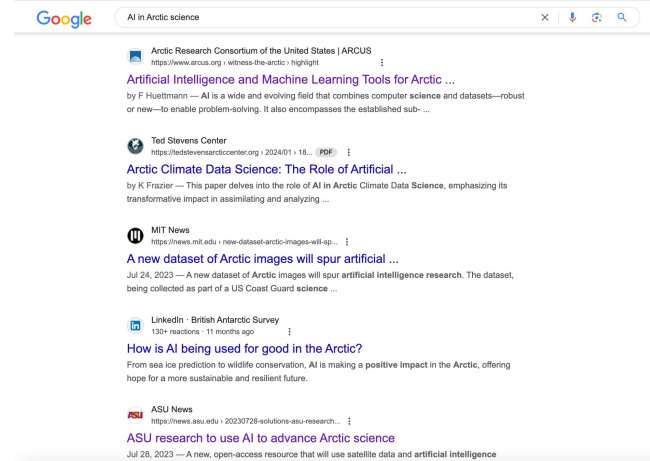
- Image classification
- Object detection and recognition
- Facial recognition
- Medical imaging



Segmenting IWP from Maxar imagery

## Natural language processing

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

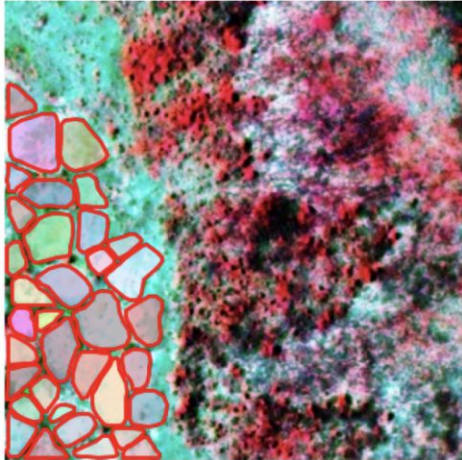


Google search for "AI in Arctic science"

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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, slough, or break. [🔗](#)

### Landslides and erosion

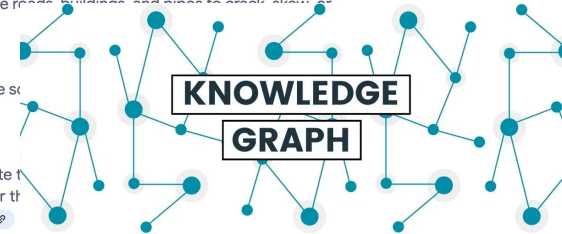
Thawing permafrost can make soil unstable, leading to landslides and erosion, especially along coasts. [🔗](#)

### Changes to ecosystems

Thawing permafrost can create shallow ponds. It can also alter the landscape and impact aquatic wildlife. [🔗](#)

### Release of greenhouse gases

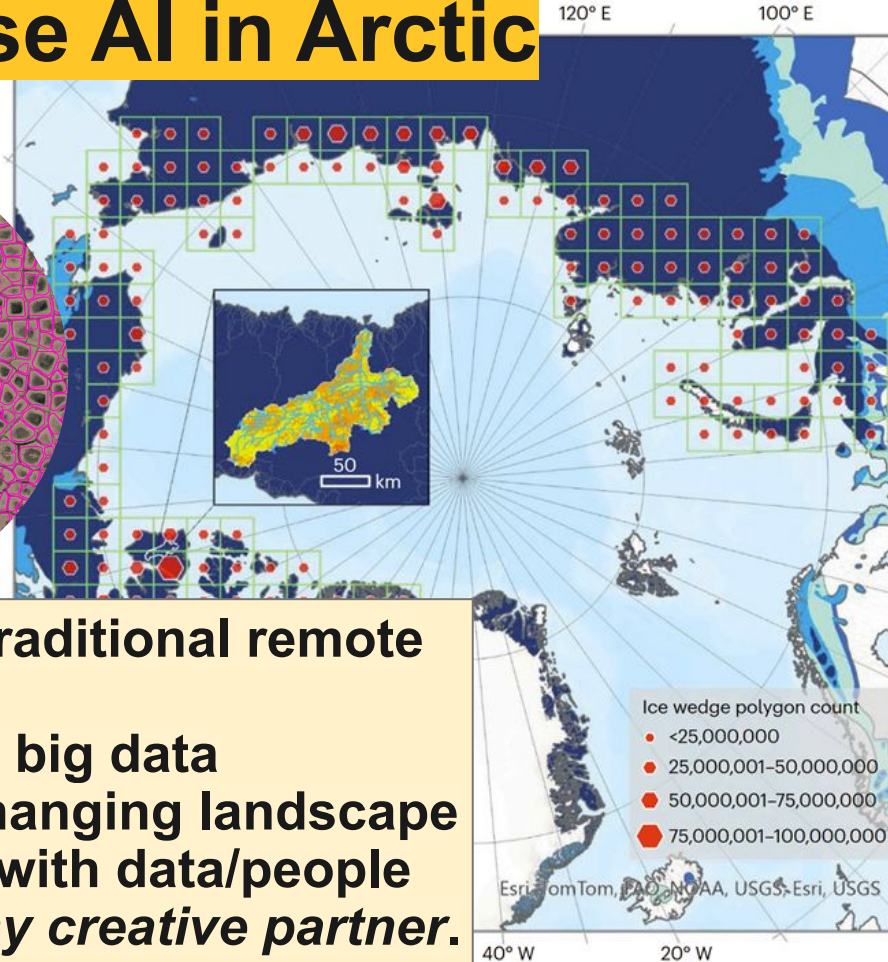
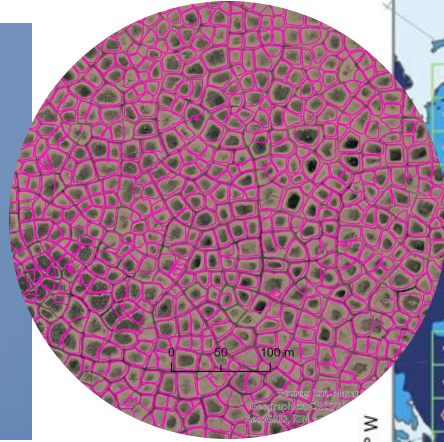
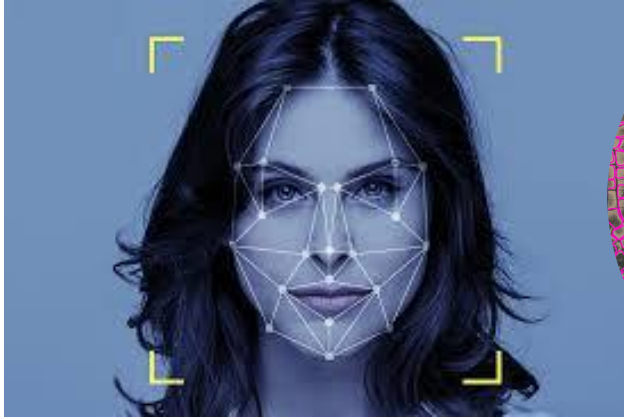
When permafrost thaws, microbes decompose the organic carbon in the soil, releasing carbon dioxide and methane into the atmosphere. These greenhouse gases trap heat in the atmosphere, which can lead to further thawing of permafrost. This creates a feedback cycle called the permafrost carbon feedback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



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.*

# 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

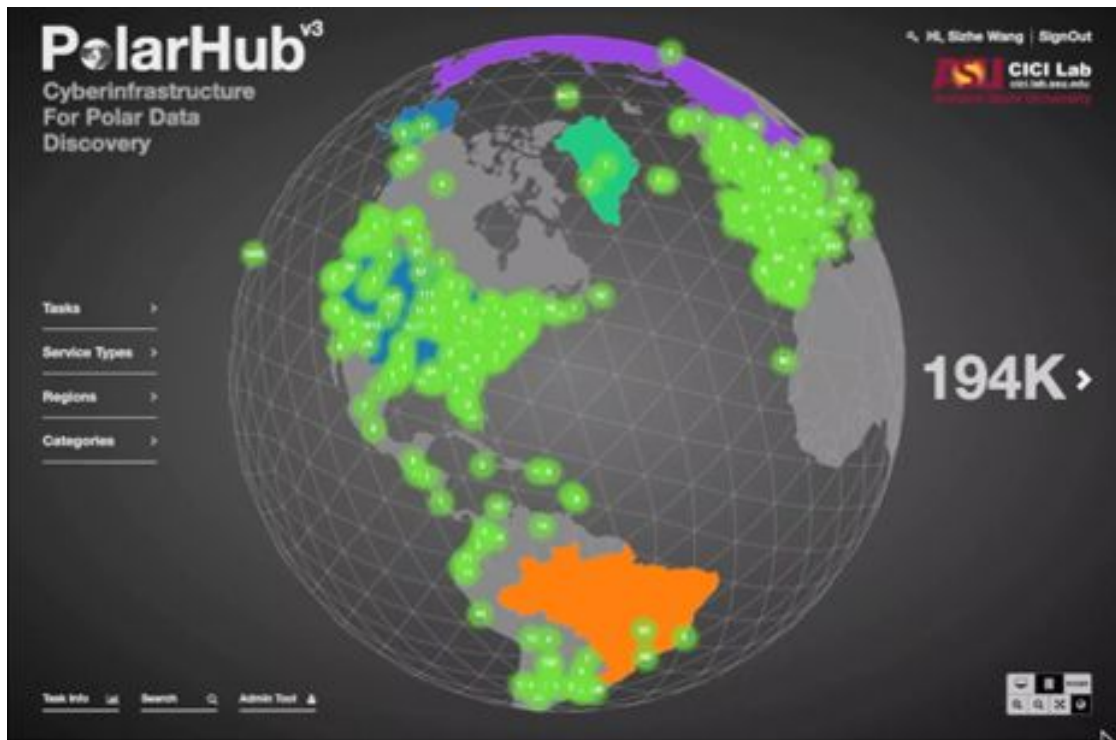
## PolarHub: large-scale web crawler for distributed polar data

### 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

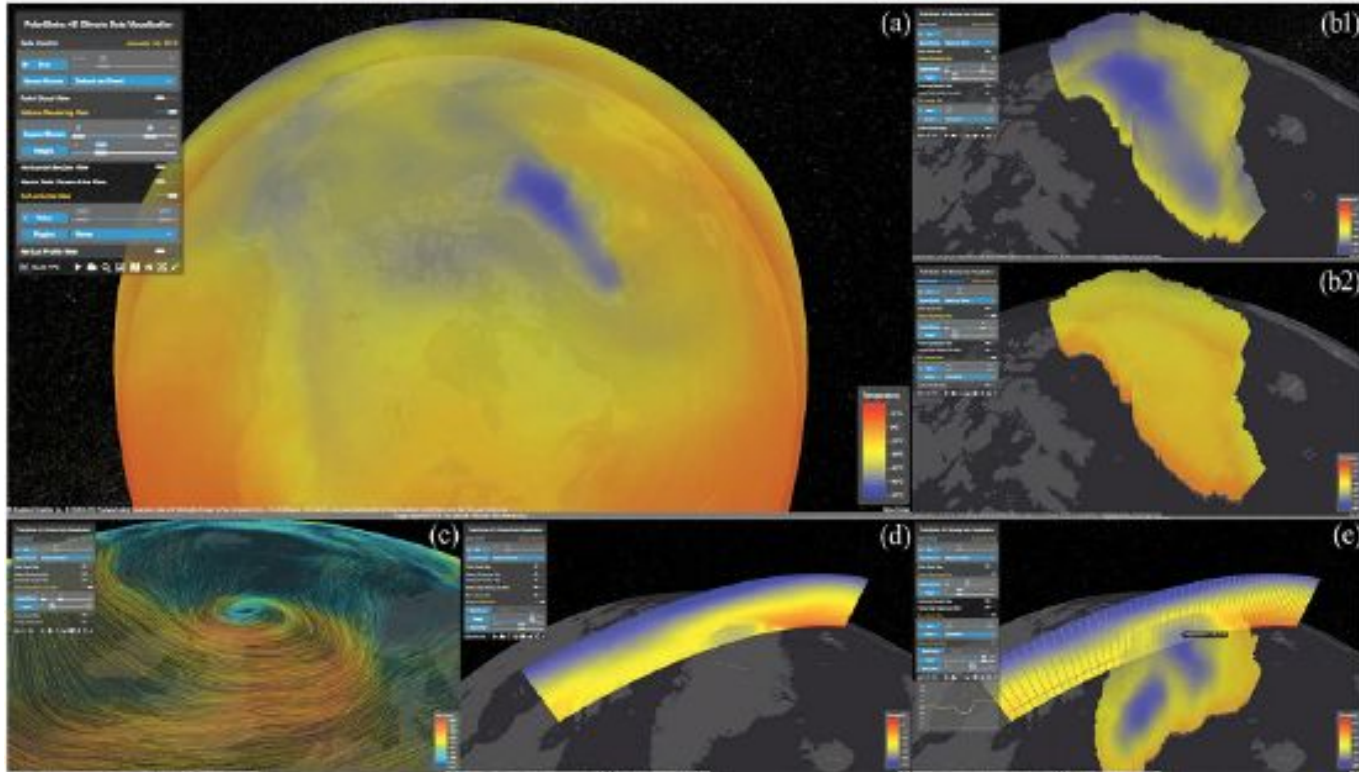


<https://cici.lab.asu.edu/polarhub3>



# Cyberinfrastructure and big data

## PolarGlobe: Real-time climate data visualization



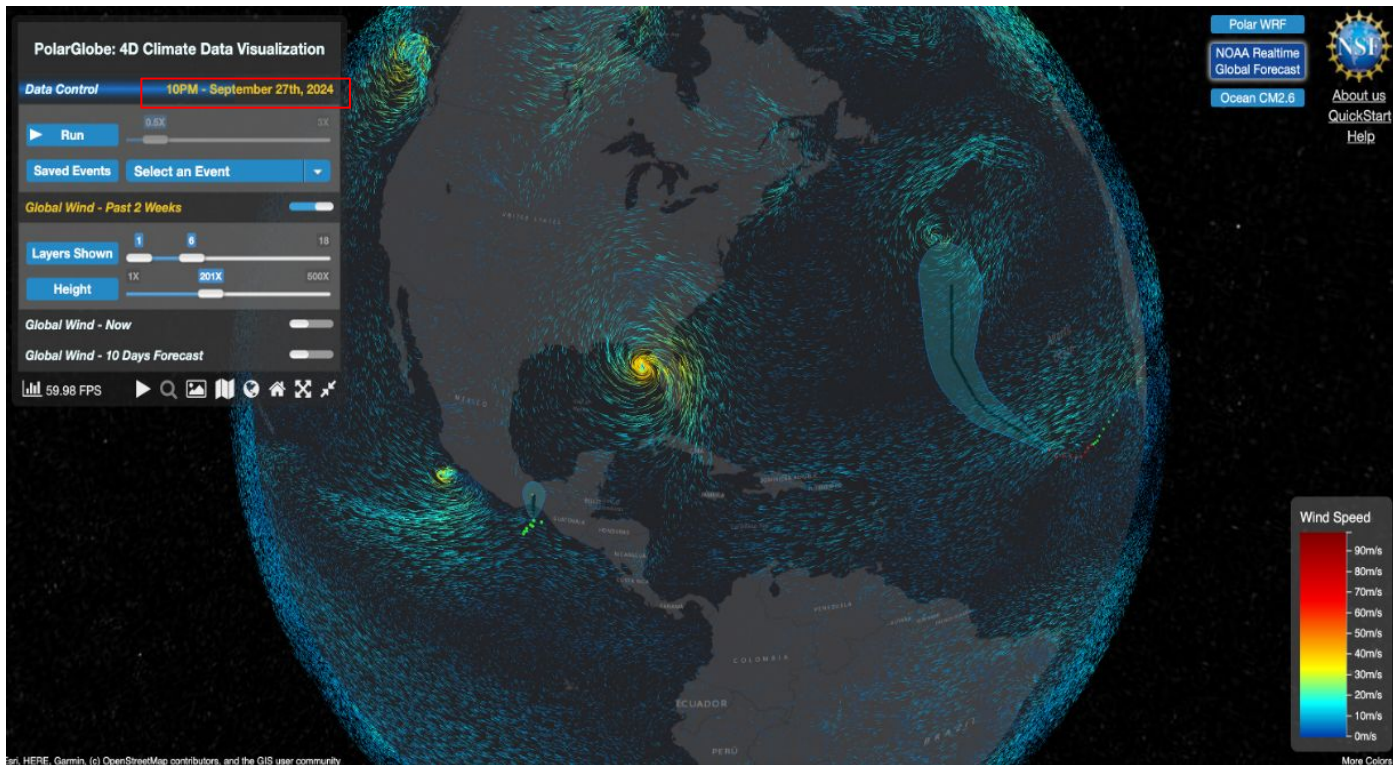
<https://cici.lab.asu.edu/polarglobe>





# Cyberinfrastructure and big data

## PolarGlobe: Real-time climate data visualization

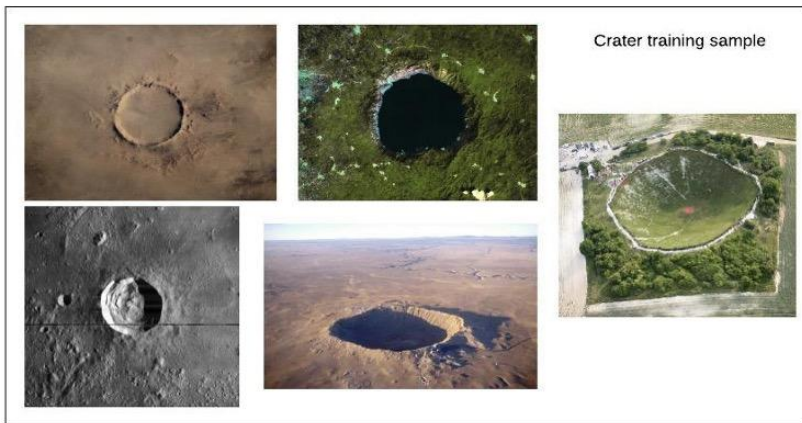


<https://cici.lab.asu.edu/polarglobe>

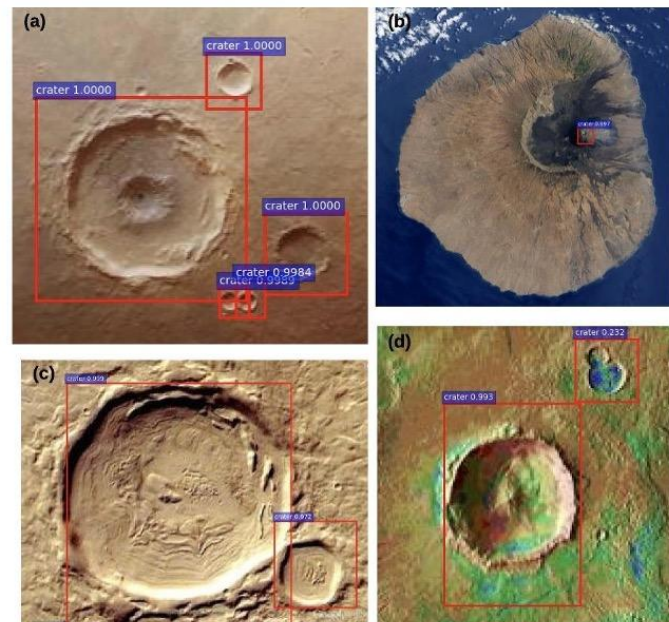
Use of PolarGlobe to track Hurricane Helene, which hit the Florida coast on September 27, 2024

# GeoAI for Intelligent Mapping

## Mapping the Earth's natural features - craters



Li et al. 2017



Crater detection using CNN  
**mAP(crater) = 99%**

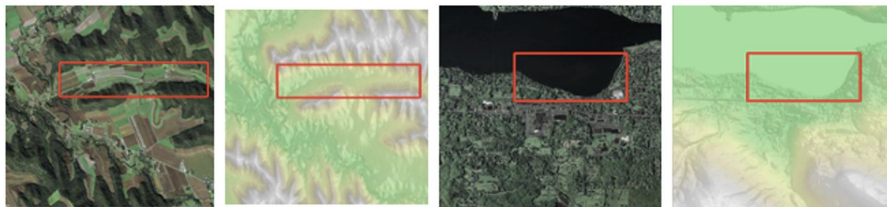
# GeoAI for Intelligent Mapping

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



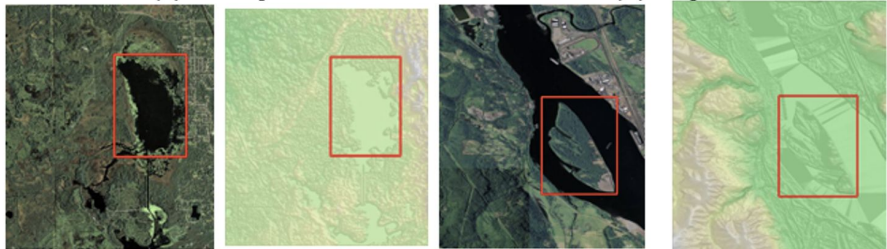
(a) Basin

(b) Ridge



(c) Valley

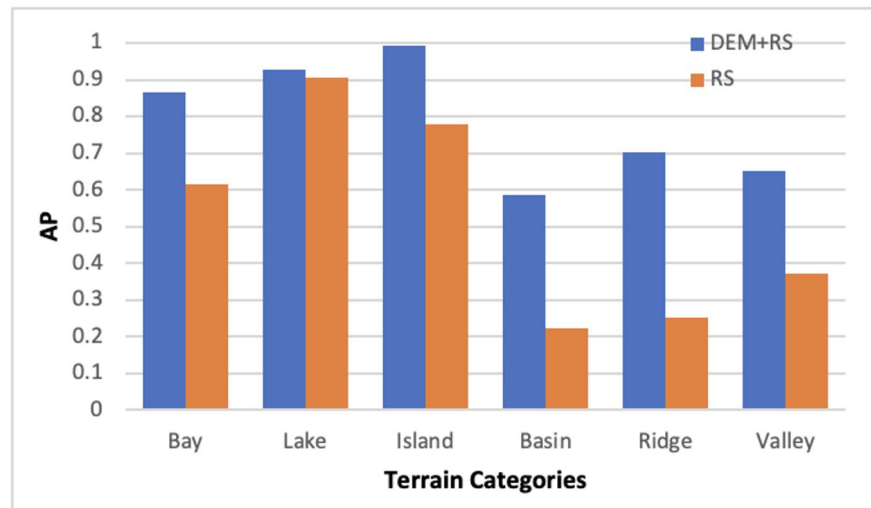
(d) Bay



(e) Lake

(f) Island

## GeoImageNet



AP: Average Precision

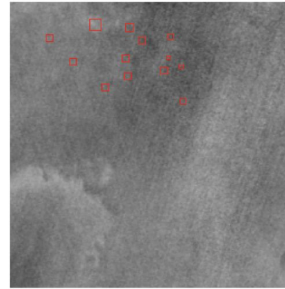
Wang et al. (2021)



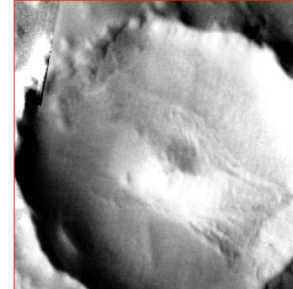
# Mapping Mars craters

Incubator for the NSF Cyber2A project

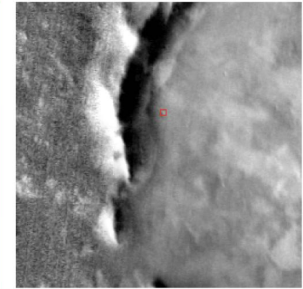
- 102,675 images scenes covering global Martian surface
- THEMIS image at 100m resolution
- 640k craters



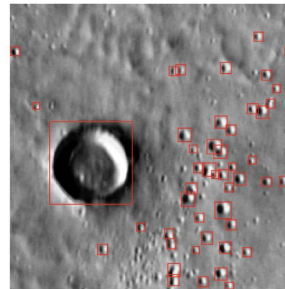
(a) Example of small craters



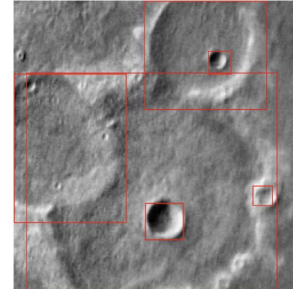
(b) Example of large craters



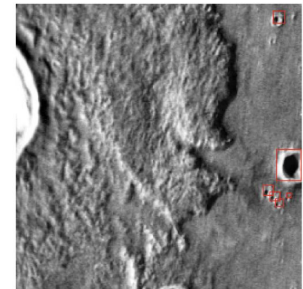
(c) Example of sparsely distributed craters



(d) Example of densely distributed craters



(e) Example of overlapping craters



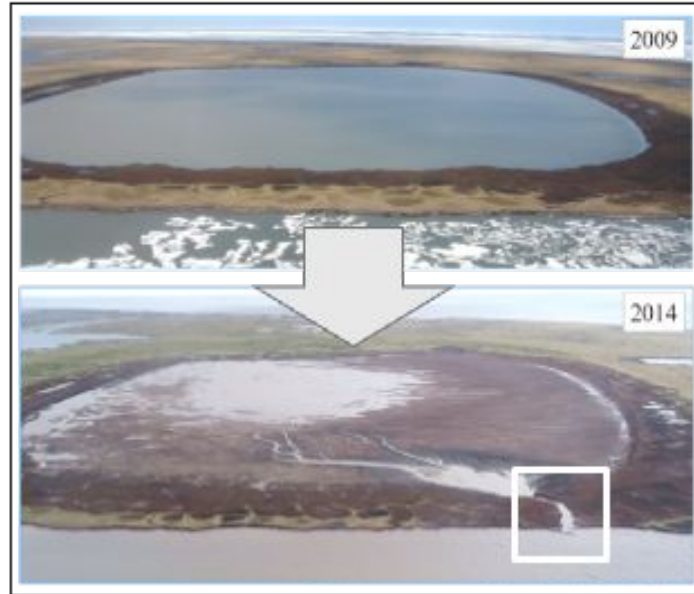
(f) Craters in more complex terrains

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

# Mapping the Arctic Permafrost



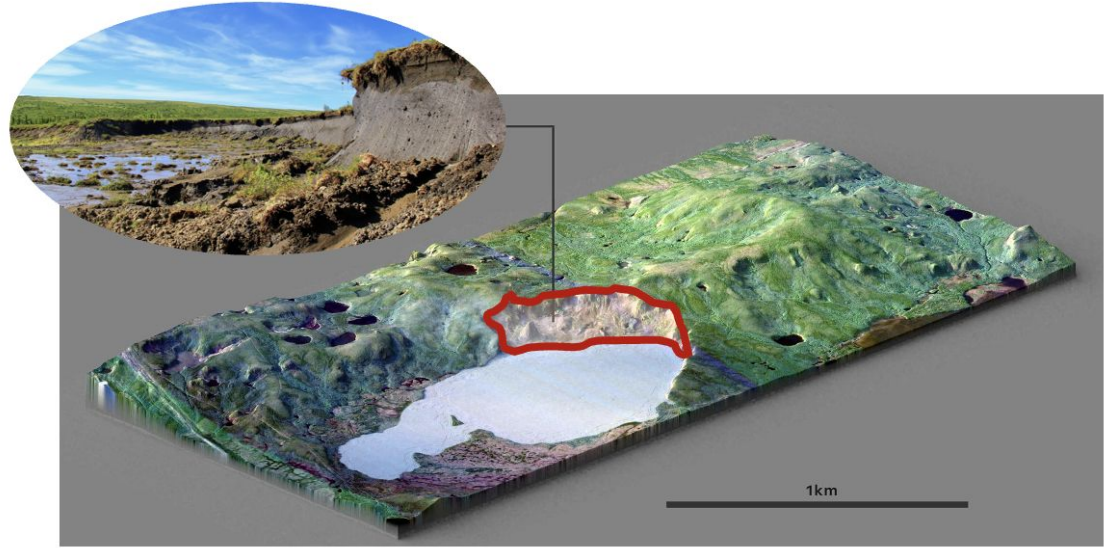
Google.org



# Mapping the Arctic Permafrost



**Ice-Wedge Polygons**



**Retrogressive Thaw Slump (RTS)**

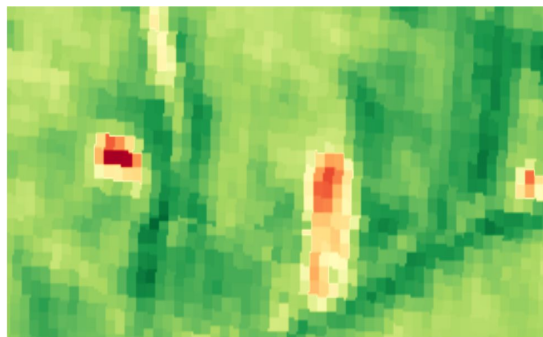


# Mapping Arctic Permafrost Thaw

A multimodal + feature fusion approach

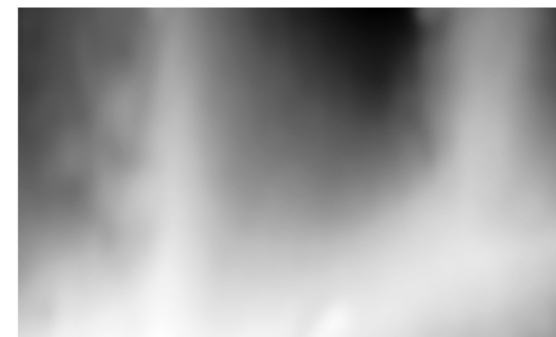


Optical image



NDVI

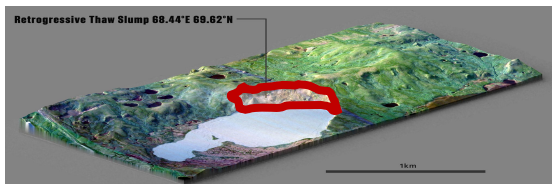
(Normalized Difference  
Vegetation Index)



ArcticDEM

(Digital Elevation  
Model)

The higher the value,  
the greener it is

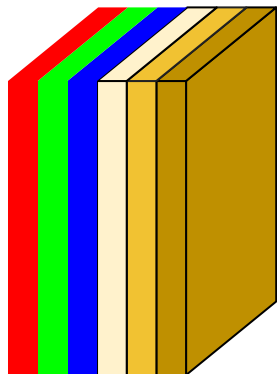


# Mapping Arctic Permafrost Thaw - Methods

## Feature-level data fusion

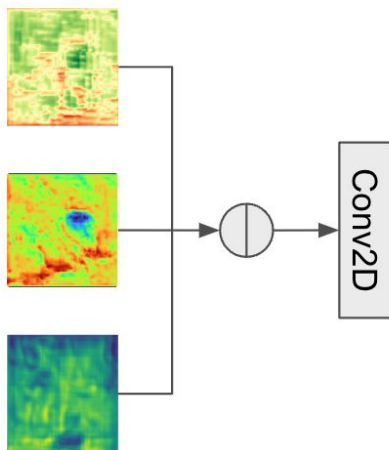
Prior solutions

### Channel expansion



Yang et al. 2023

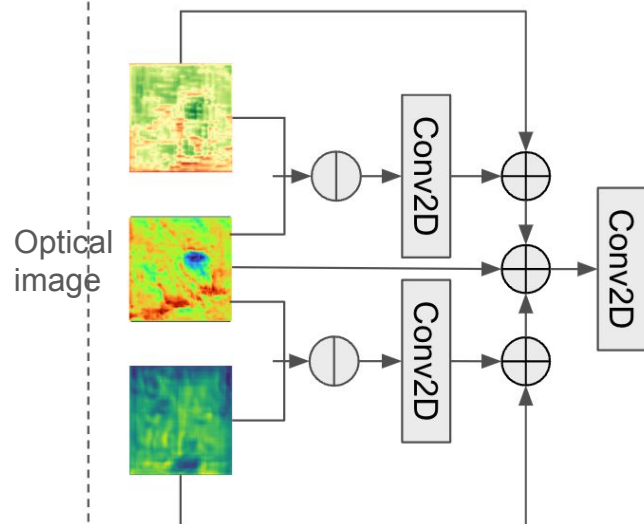
### Convolutional Fusion



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

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

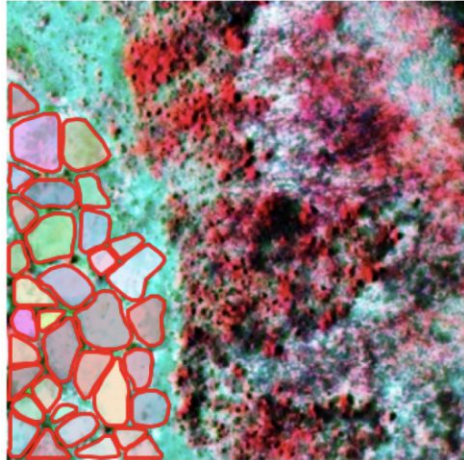
# AI-based medium range weather forecasting

- 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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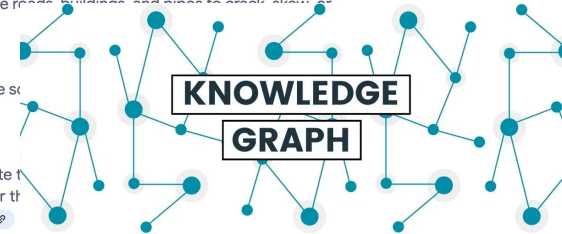
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Text understanding and knowledge representation




# Embracing Large Language Models for Arctic Research


# AI enhanced event search and recommendation

Generative AI for deterministic tasks

**LEO** 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.

search  [Advanced Search](#)

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

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

By Brian Venus, KMTX - Kodiak | October 2, 2023



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

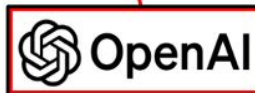
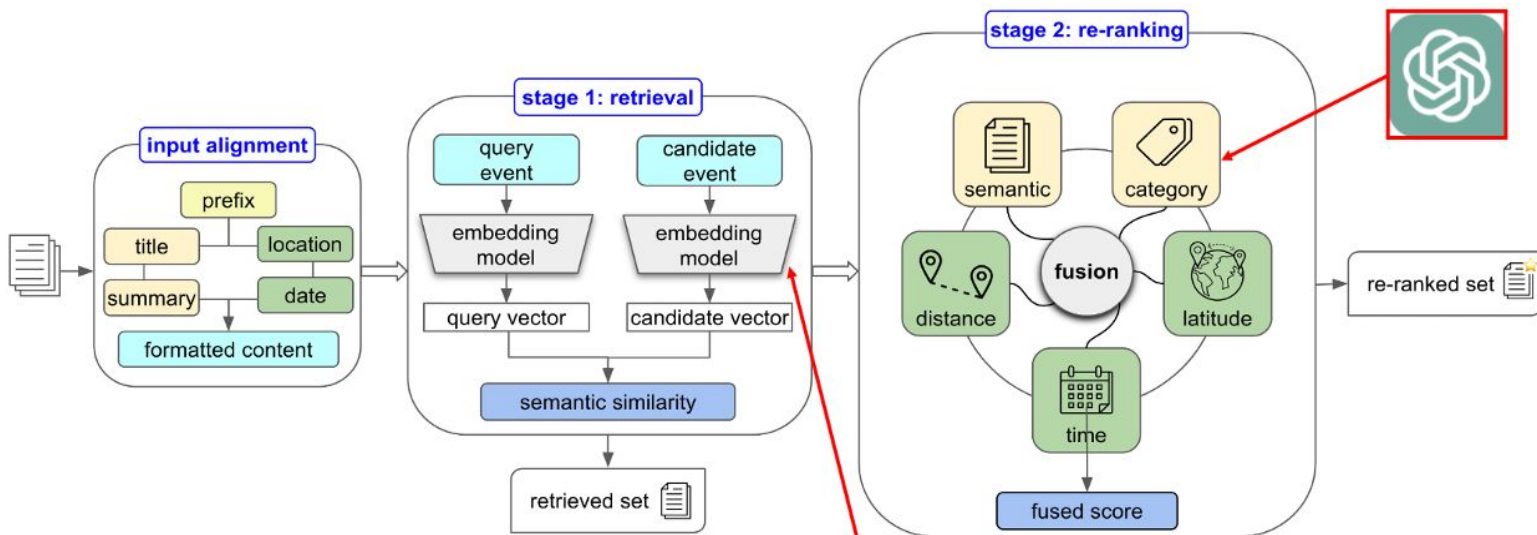
# LEON Event Search & Recommendation

- 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 displays the LEO (Local Event Organizer) interface. At the top, there's a navigation bar with 'LEO' logo, 'Follow', 'My Maps', 'Share', and 'Add Comment' buttons. The main content area shows a news article from Alaska Public Media, dated 2 OCTOBER 2023, titled 'Humpback found dead near Kodiak gets Alaska's first 2023 whale necropsy'. The article includes a location map for Kodiak, Alaska, and a 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.' Below the article, there are options to 'Read On' or 'translated into' the article, and a 'View a screenshot of the article' link. A 'Similar events' section lists five related events, each with a thumbnail image, title, location, date, and source. The events are: 1. 'Sitka team conducts first humpback whale necropsy in 5 years' (MAR 23, 2021, Alaska Public Media); 2. 'Alaska's third dead gray whale of the year reported on Kodiak coast' (MAY 23, 2019, Anchorage Daily News); 3. 'Three dead gray whales wash up on Kodiak Island beaches in one week' (JUL 5, 2018, Alaska Public Media); 4. 'Dead Humpback (Megaptera novaeangliae) Near Birchwood' (OCT 19, 2015, Alaska Public Media); 5. 'Dead Humpback Whale (Megaptera novaeangliae)' (SEP 23, 2015, Alaska Public Media).

# AI-enhanced search and recommendation

- Leveraging large language models (LLM)

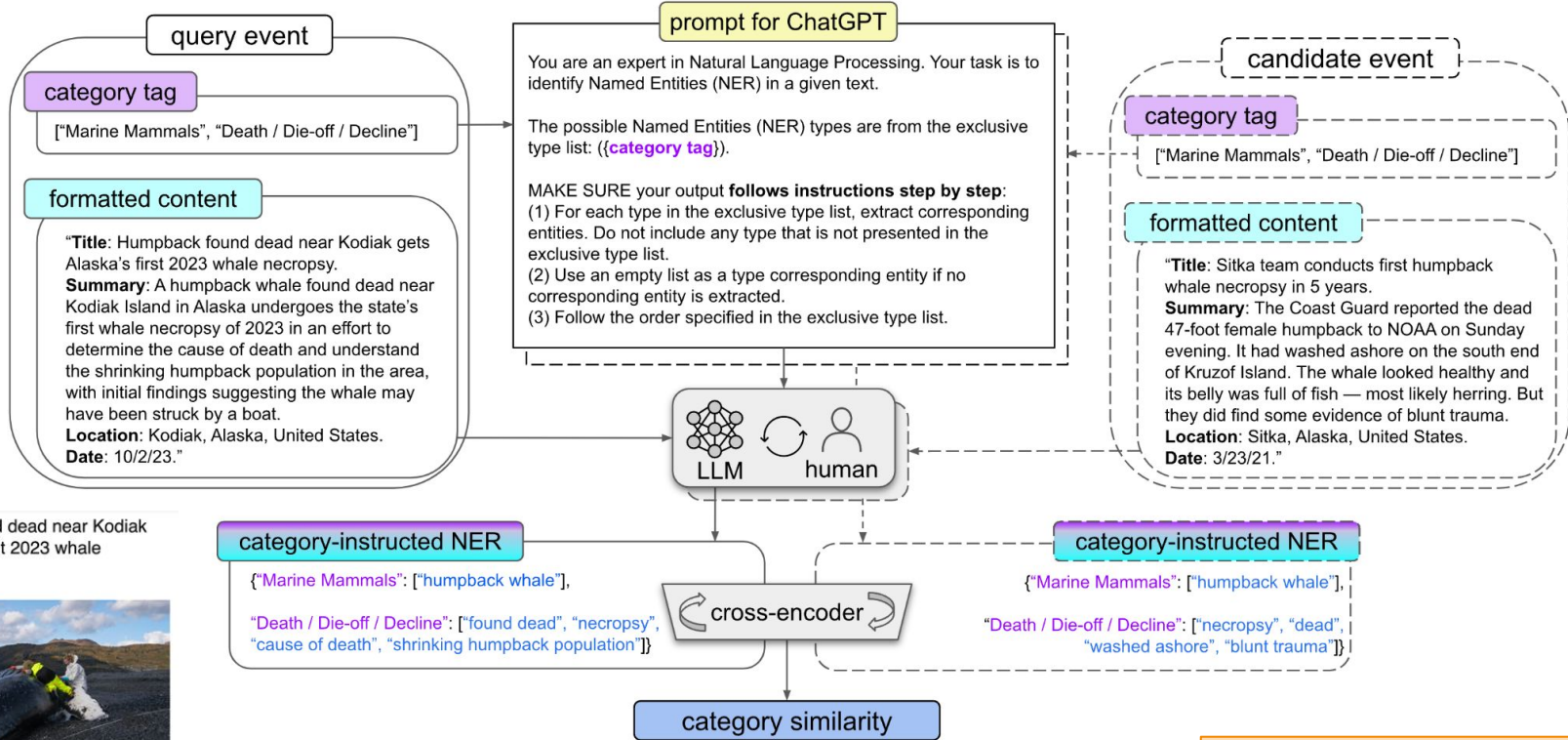


Tian, Li, et al. 2024 (under review)



# AI-enhanced search and recommendation

## LLM-based Named Entity Recognition



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



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

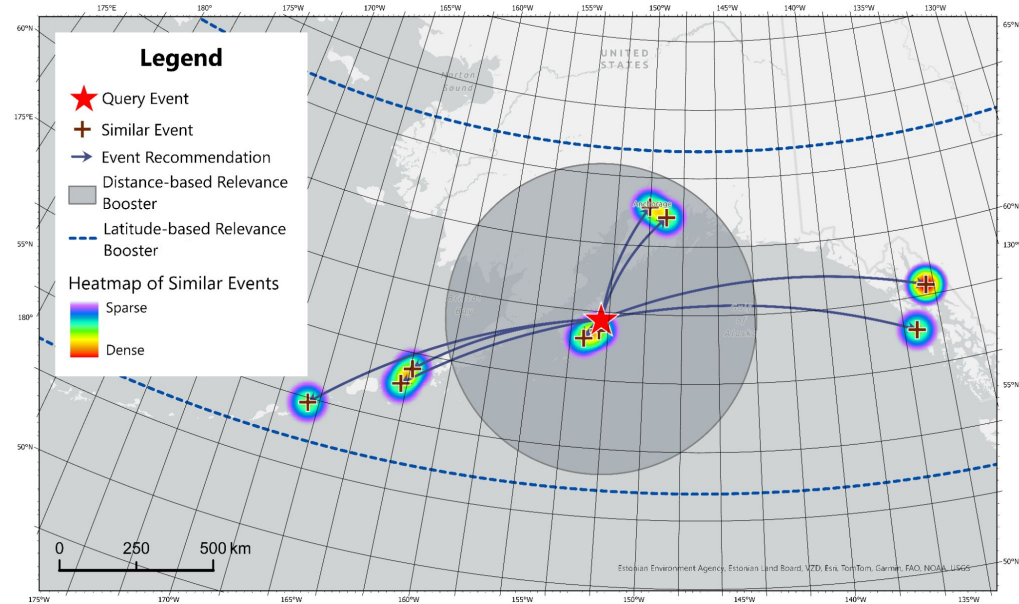
Tian, Li, et al. 2024 (under review)

# 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 (Megaptera novaeangliae)	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 (Megaptera novaeangliae)	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 (Megaptera novaeangliae) 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

-  LAND MAMMALS
-  SAFETY
-  UNUSUAL ANIMAL BEHAVIOR

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

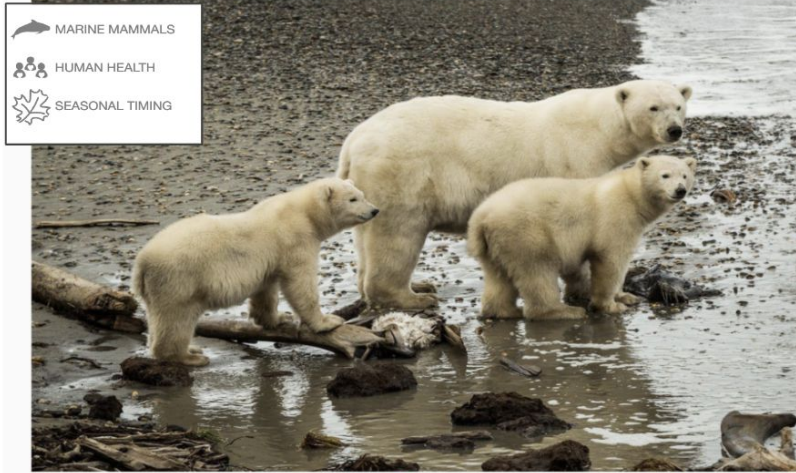
[N 37° 48' 23.04" W 122° 27' 58.656"](#)

[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



MLLM

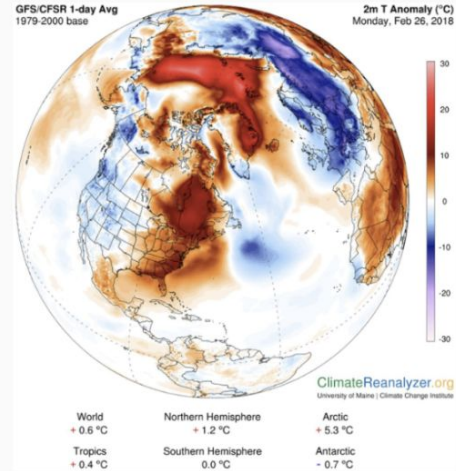
## Cue\_Category

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

## Cue\_Location

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

WEATHER



MLLM

## Cue\_Category

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

## Cue\_Location

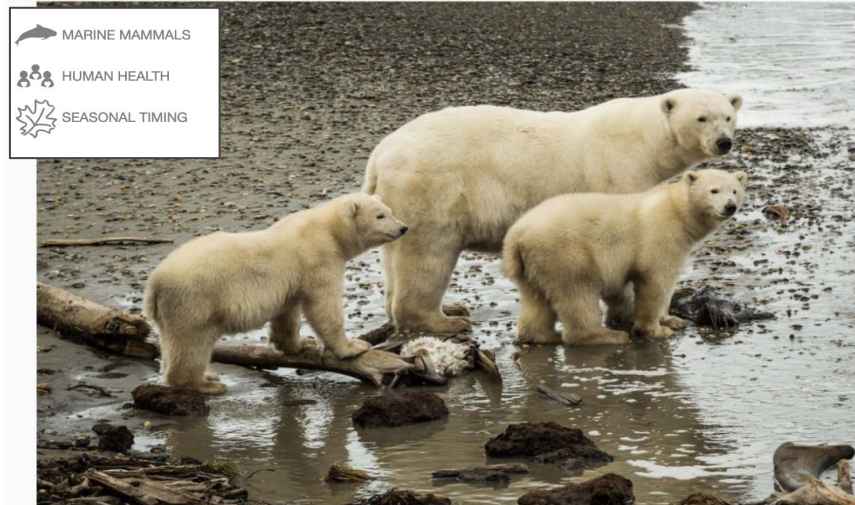
The map prominently displays the **Northern Hemisphere**, with clear indications of temperature anomalies in this region.

## 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



MLLM

### Cue\_Category

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

### Cue\_Location

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



MLLM

### Cue\_Category

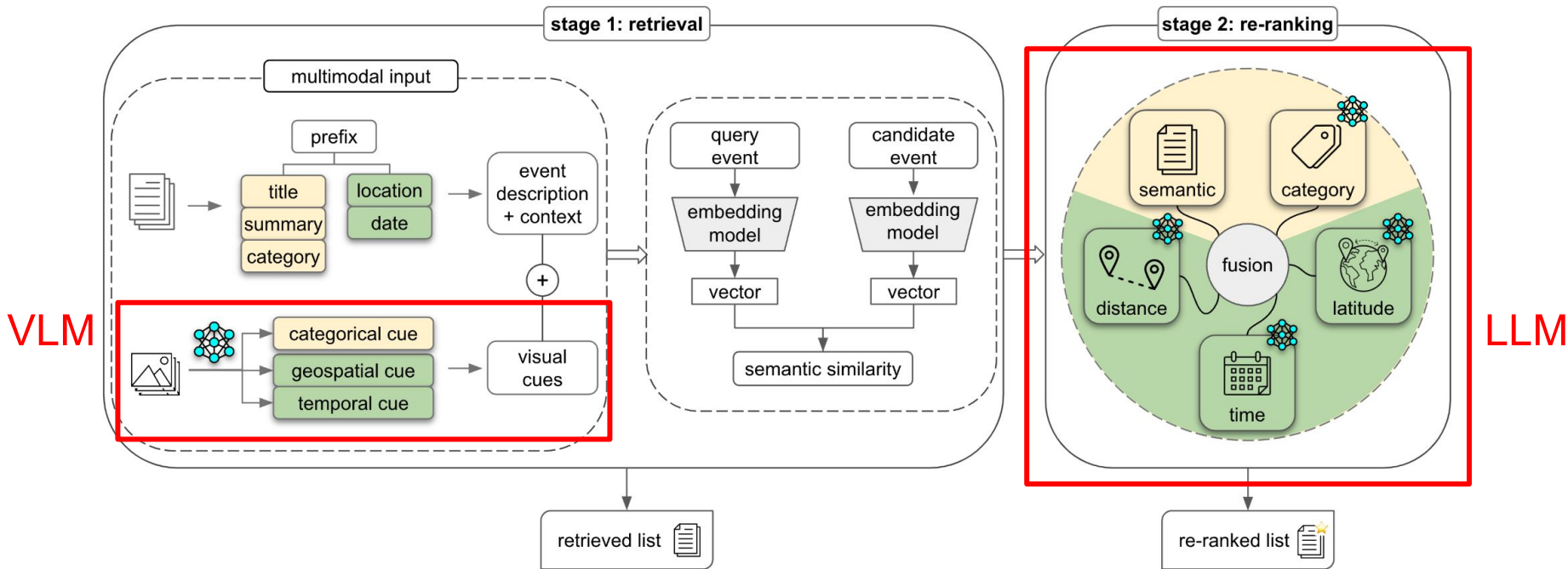
The presence of crosses indicates a **burial site**. The visible ground and ice suggest **changes in permafrost**.

### 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)**

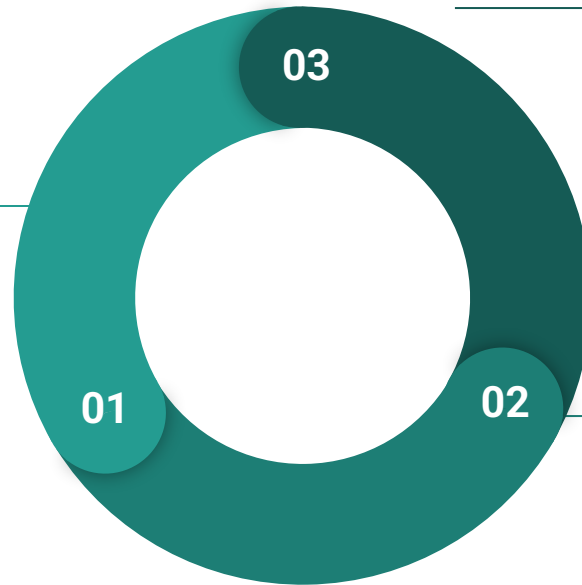
Representation	Retrieval	Re-ranking	nDCG	MRR
unimodal <b>Text-based</b>	Ada-002	-	44.70	52.20
	Ada-002	MiniLM	42.10	49.00
	Ada-002	BGE reranker	36.40	44.40
	Ada-002	Cohere rerank	33.10	38.90
	Ada-002	GPT-3.5 Turbo	32.30	42.50
	Ada-002	RankGPT	41.40	49.00
	Ada-002	GT-R	<b>47.40</b>	<b>55.80</b>
multimodal <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

## Intelligent mapping

Vision models (CNN, Vision transformer, foundation models)



## Vision language models

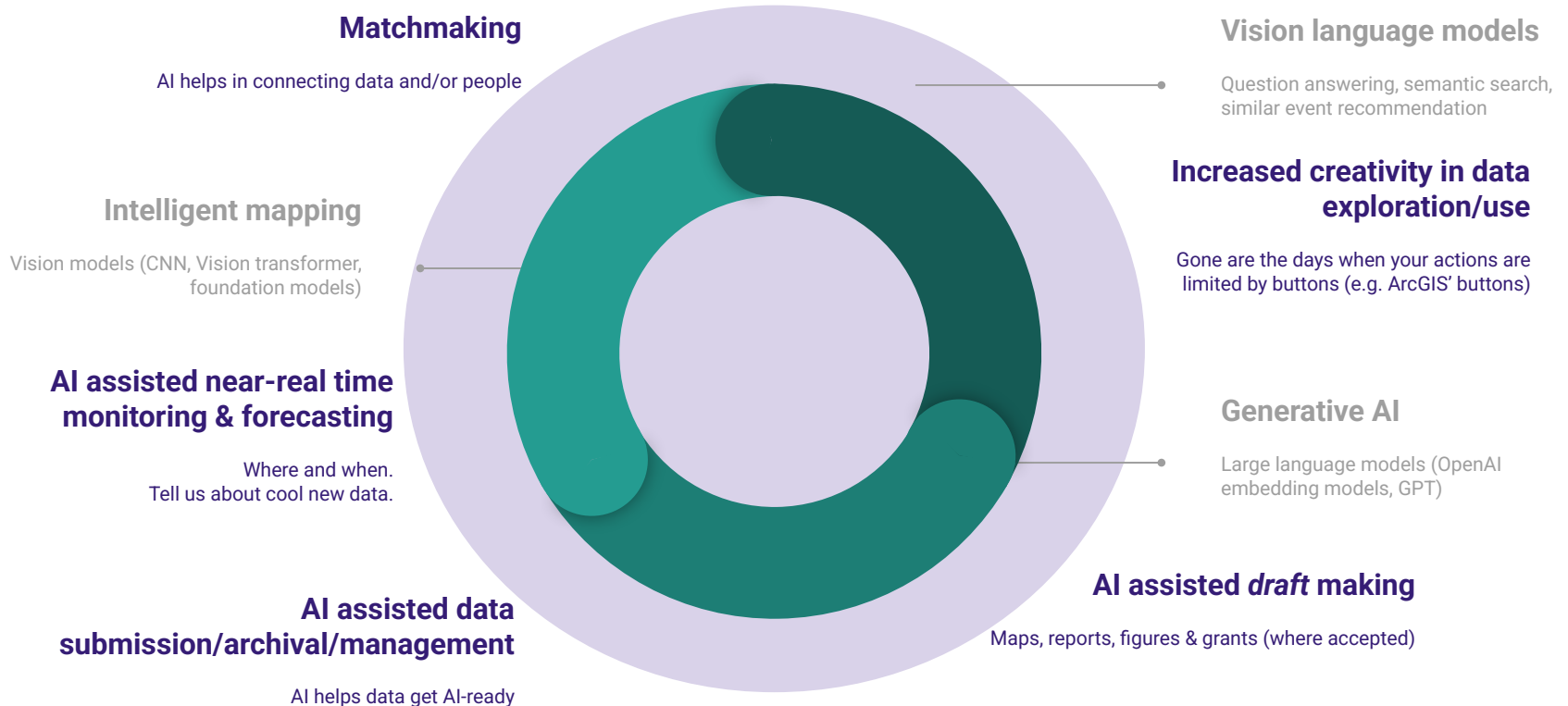
Question answering, semantic search, similar event recommendation

## Generative AI

Large language models (OpenAI embedding models, GPT)

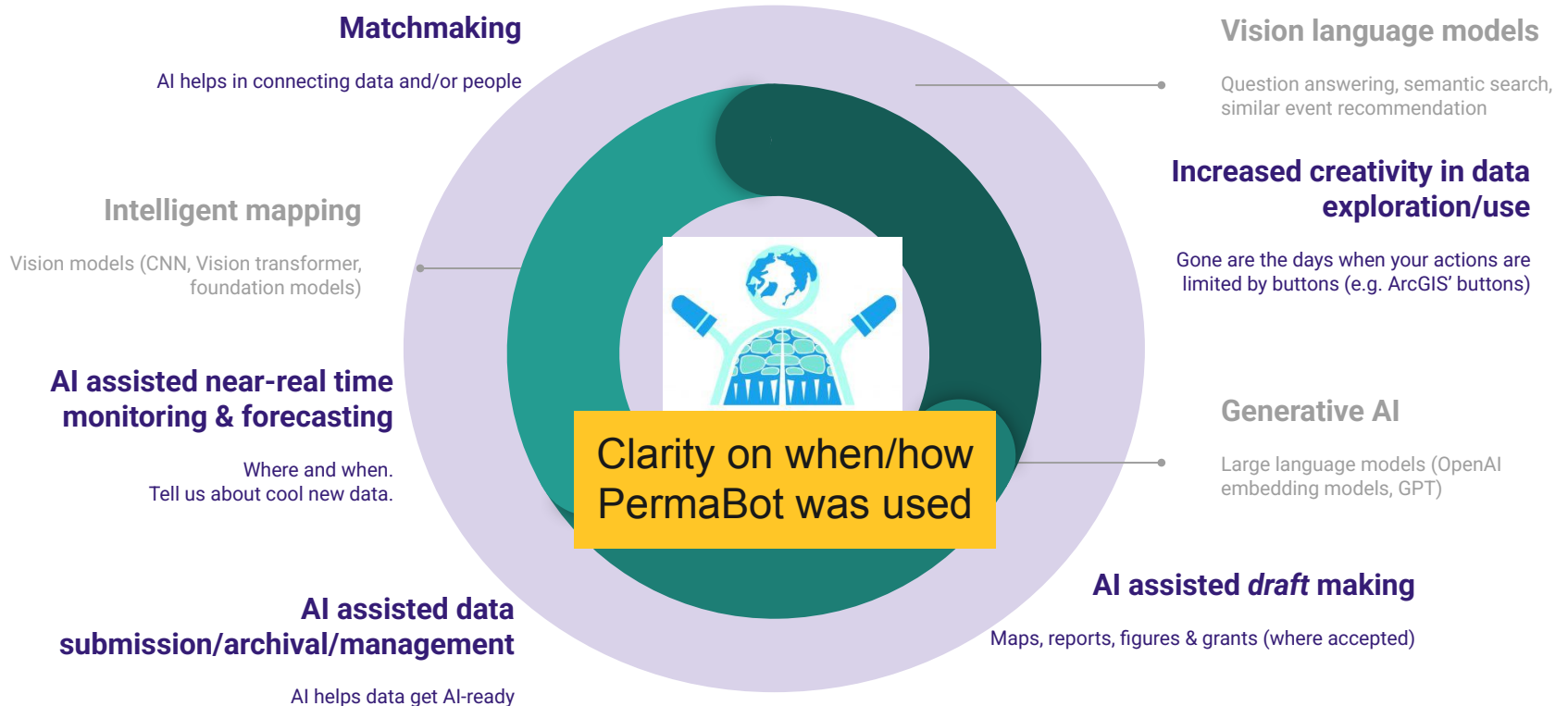
# Big vision and aspiration for PDG

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!

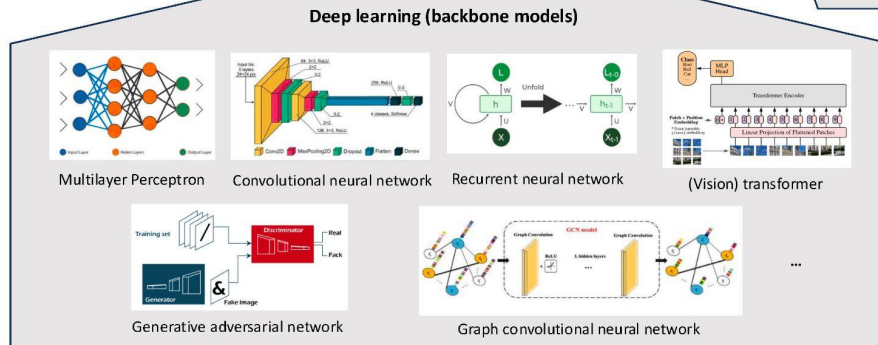
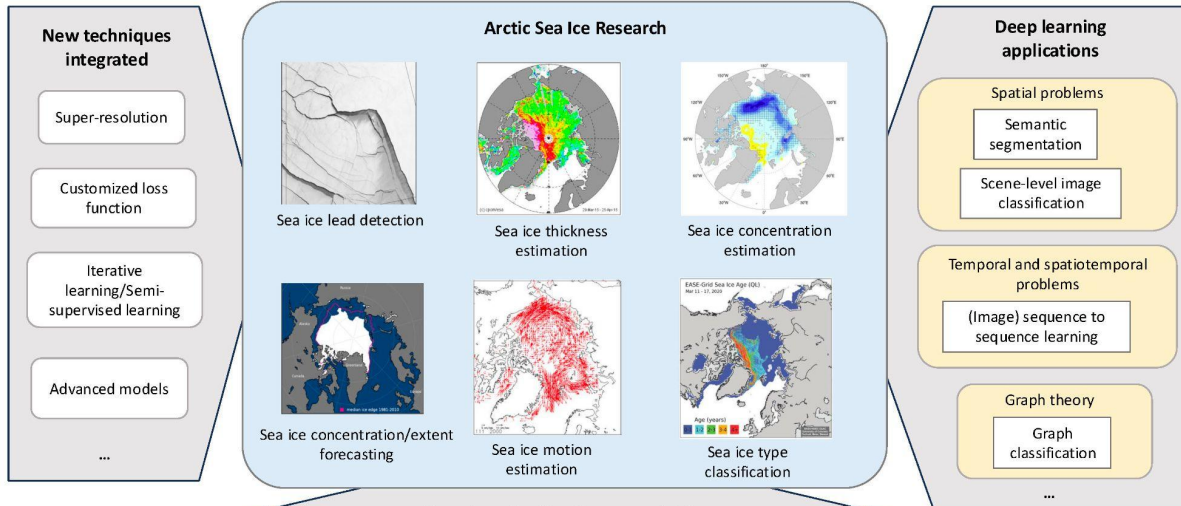


# Moving beyond Permafrost Research



# 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 (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 know 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

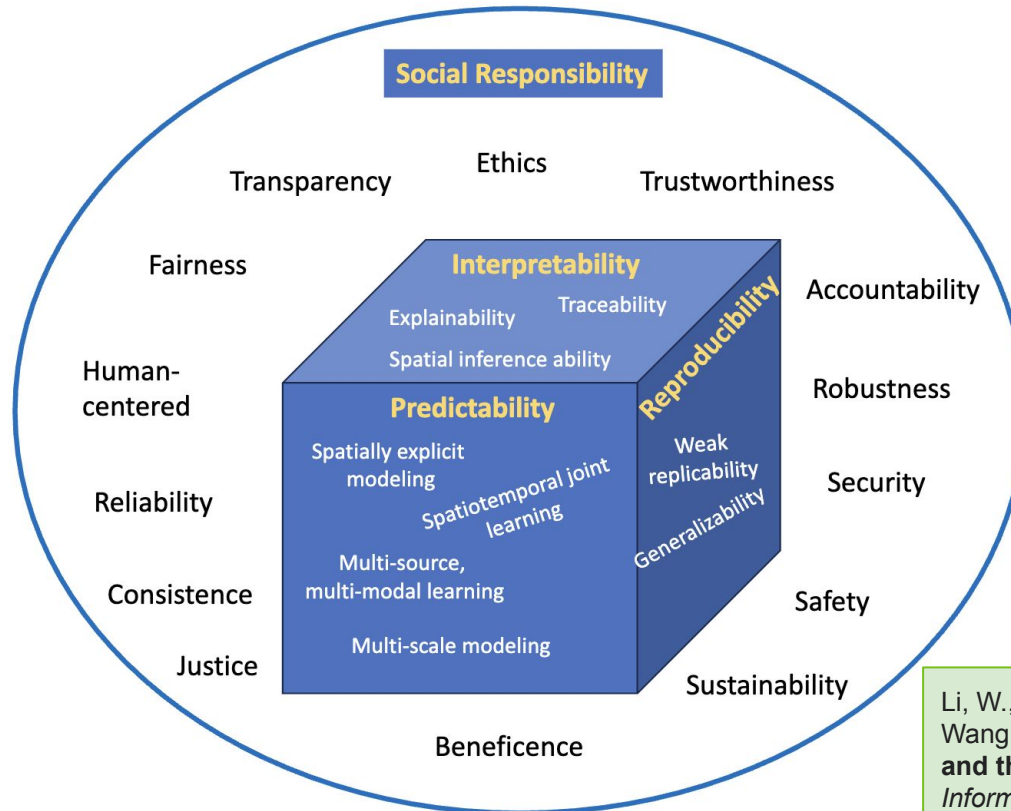
Hooman Shahrokhi\*  
Mehrdad Farajtabar<sup>†</sup>

Apple

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

# Big models, big concerns

## The Science of GeoAI



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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