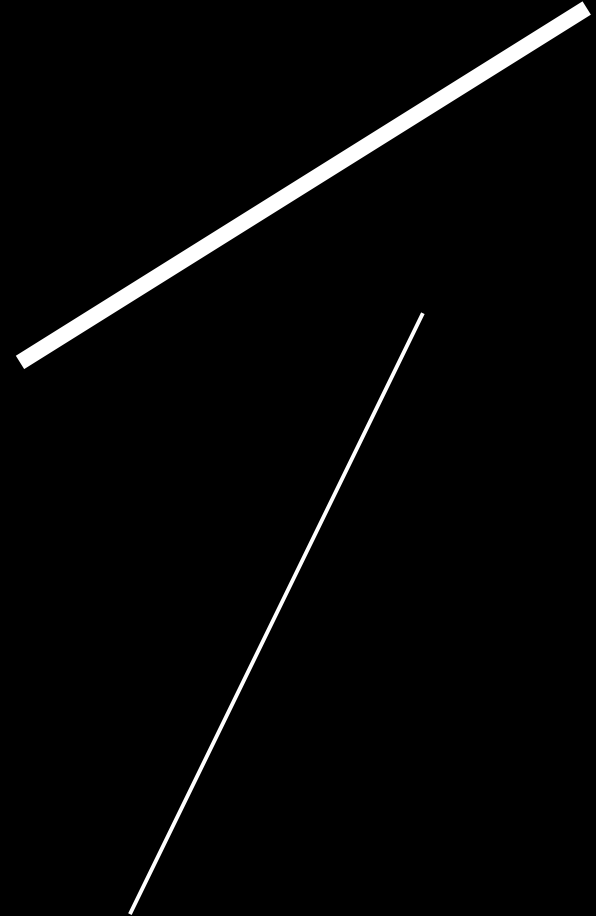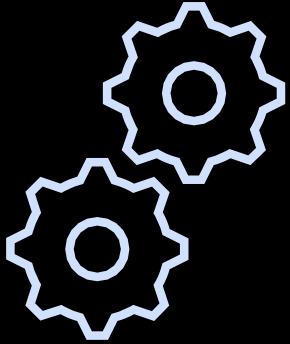# AI for Climate, Environment and beyond

Hendrik F. Hamann
IBM Research
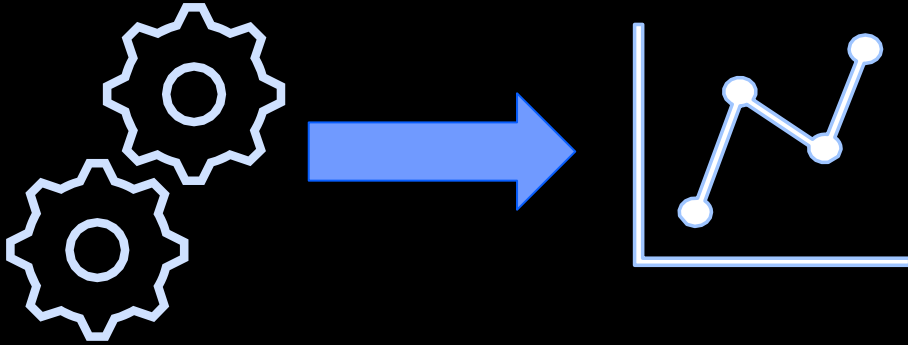
Ever improving, lower-cost computation, storage and networks

Computation &
storage & networks

- 50% better performance/year
  at less cost

Ever improving, lower-cost computation, storage and networks generate massive data
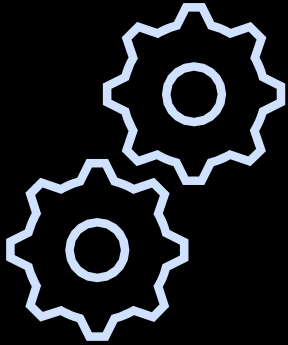

Computation &
storage & networks

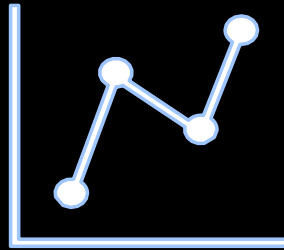- 50% better performance/year at less cost

Massive
Data

- 90% of all data created in the last two years

Ever improving, lower-cost computation, storage and networks generate massive data fueling the ML/AI (r)evolution

Computation &
storage & networks

Massive
Data

Machine Learning
& Artificial Intelligence

- 50% better performance/year at less cost

- 90% of all data created in the last two years

- Already 98% of enterprises already using AI

Digitization and the use of ML/AI is progressing rapidly

Media   Business   Social   Physical   ....
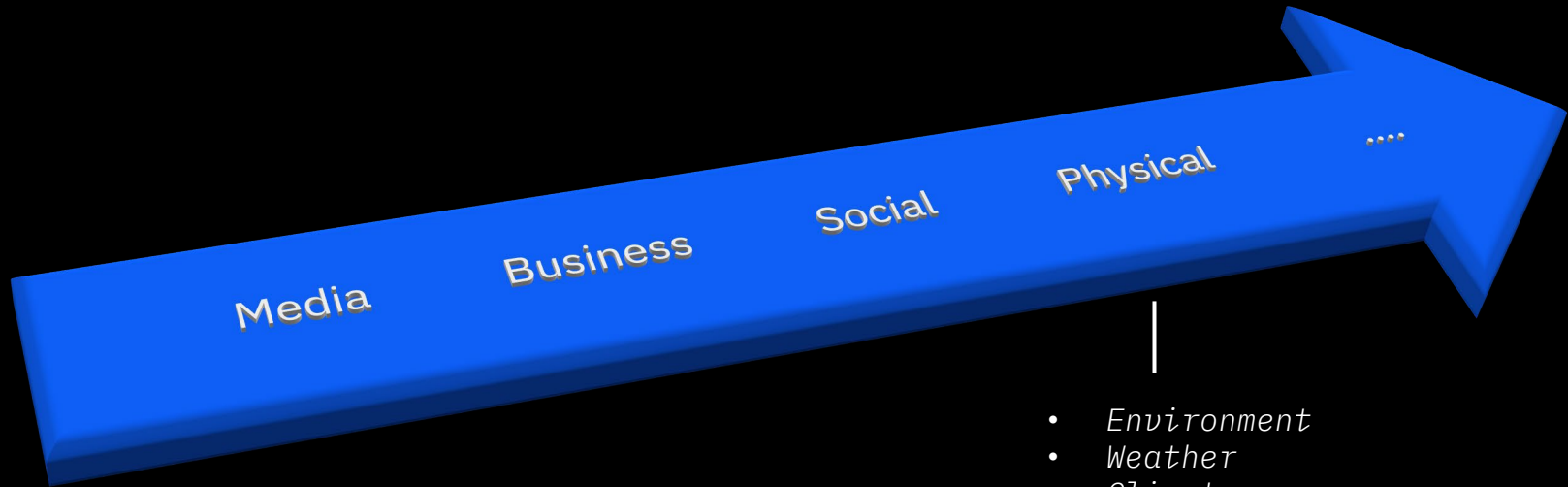
- *Environment*
- *Weather*
- *Climate*
- *Materials*
- *Chemistry*
- *….*

Foundation Models have rapidly emerged

| 80s | Big data | 80s to ~2010 | Massive data + Compute | 2010 -2017+ | Self-supervision at scale + Massive data + Compute |

Expert Systems
Hand-crafted symbolic representations

Machine Learning
Task-specific hand-crafted feature representations

Deep Learning
Task-specific learnt feature representations

Foundation Models
Generalizable & adaptable learnt representations

The AI Foundation Model approach includes three steps
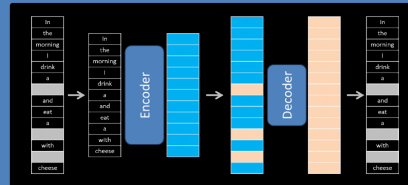
3. Inference and operationalize

2. Fine-tuning using specific labels/data
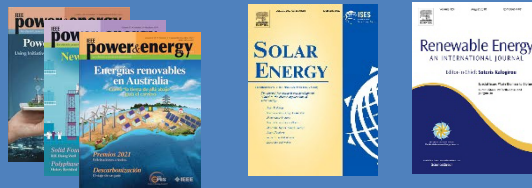
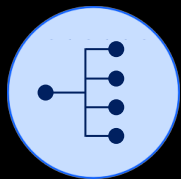## 1. Pre-training using self-supervision with attention networks

In the morning, I drink a cup of ████ and eat a ████ with crème cheese.

In the morning, I drink a cup of **coffee** and eat a **bagel** with crème cheese.

AI Foundation Models provide a clear pathway to scale AI

One base model + Less label + Better or similar accuracy + Faster development =

Economy of scale

Bommasani et al. (2021). On the Opportunities and Risks of Foundation Models.

Text-centric Foundation Models have taken the world by storm...Can we repeat the successes in other domains?

	Text
Data availability	Available
Data type	Sequence
Data variety	Limited numbers of words
Context	Relative complete
Architectures	Transformers

Text-centric Foundation Models have taken the world by storm...Can we repeat the successes in other domains?

	Text	Climate, environmental and biological data
Data availability	Available	TBD
Data type	Sequence	Multi-modal, multi-dimensional
Data variety	Limited numbers of words	TBD
Context	Relative complete	TBD
Architectures	Transformers	TBD: Transformers, Graphs, Operators

A closer look at geospatial data…
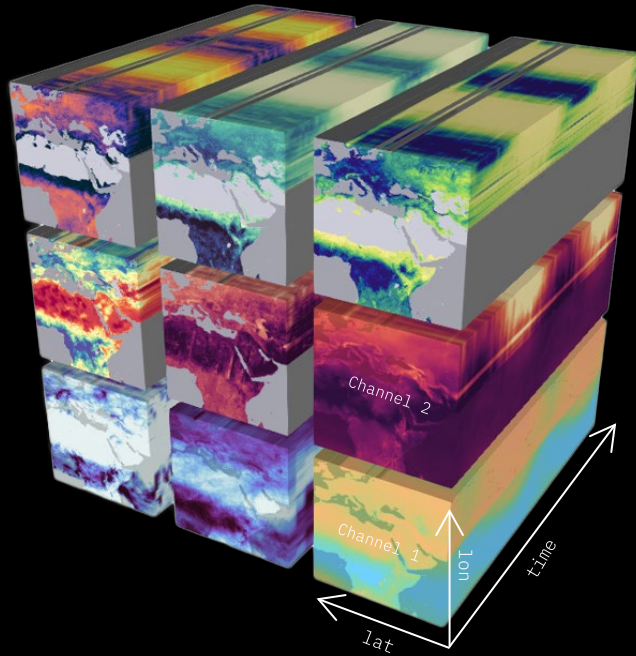
Geospatial data is a unique modality where "almost" unlimited spatial, temporal, and channel relations exist.

AI Foundation Models are well suited to discover new relations between space, time and channels.

Technical challenges include training complexity and balance between local and global attention

Developing Foundation Models based on earth observation and weather/climate data
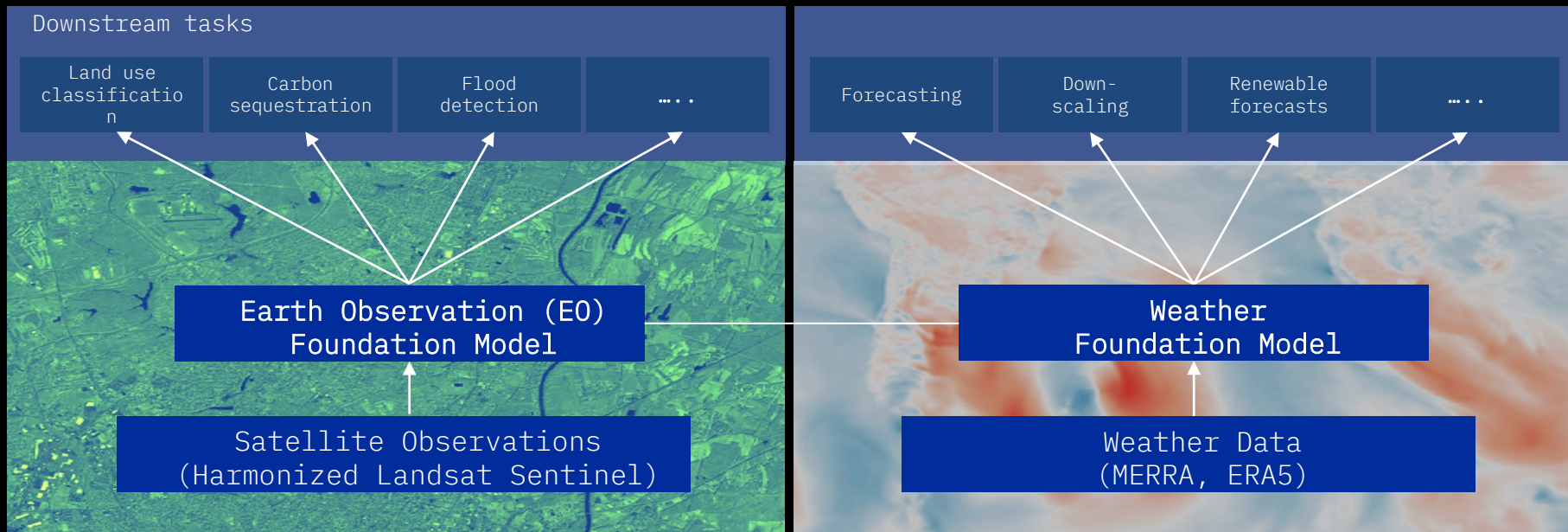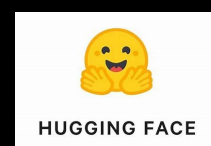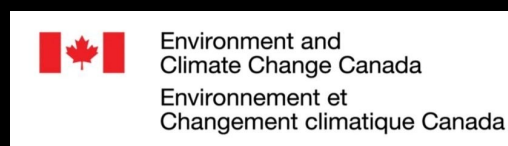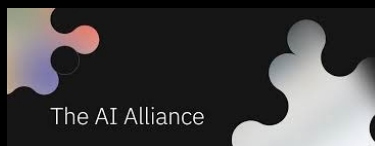
Self-supervised learning to pre-train geospatial Foundational Models

Training Signal

Masked Input

Encoder
(Large)

Decoder

Reconstructed Output

Foundation
Model

To be finetuned
decoder head

t-1

t

t

t+1
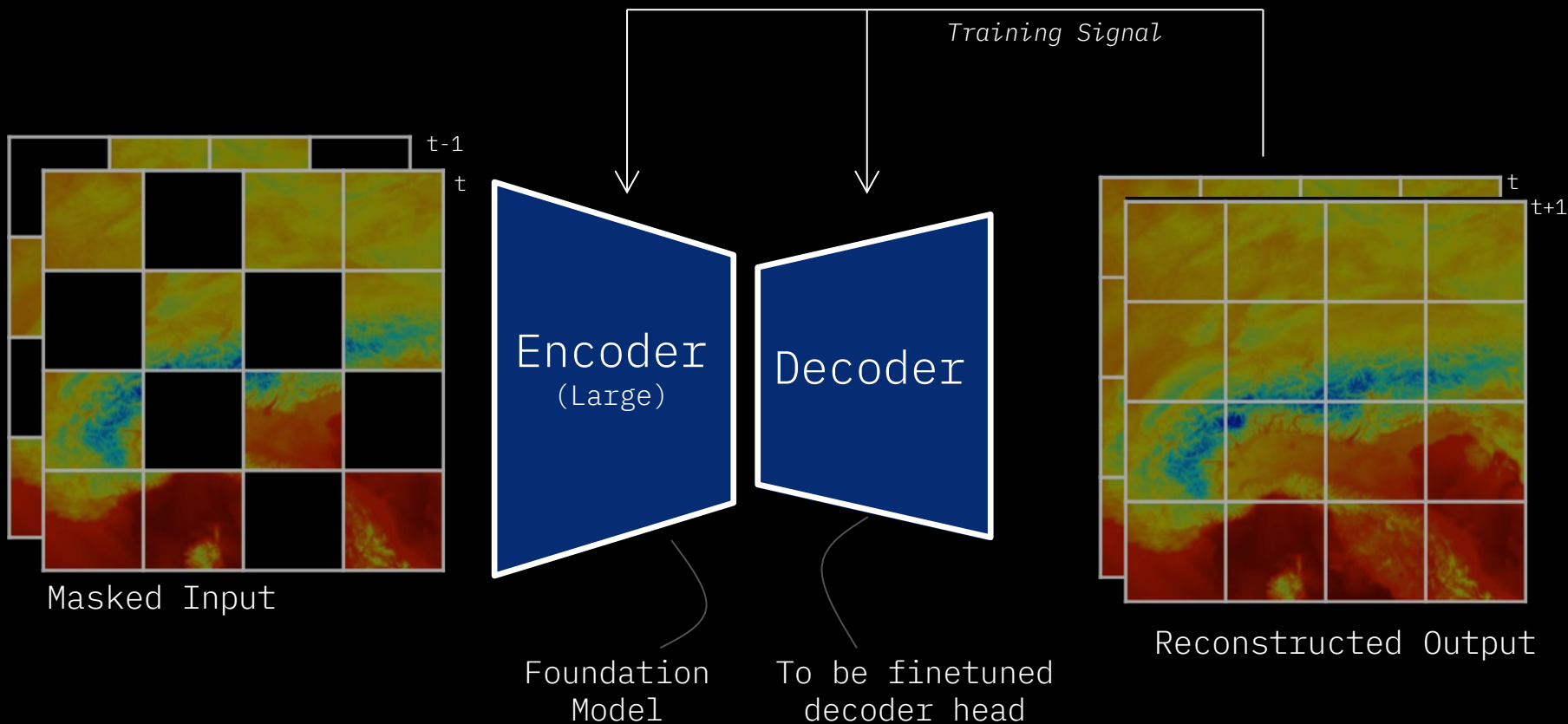
Pre-training of an earth observation FM
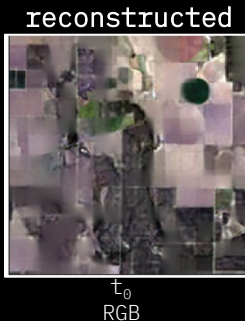
Work in progress
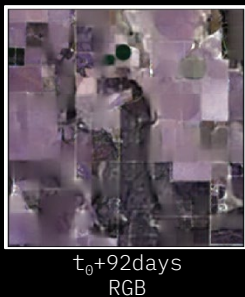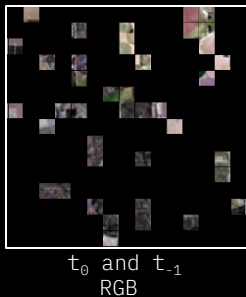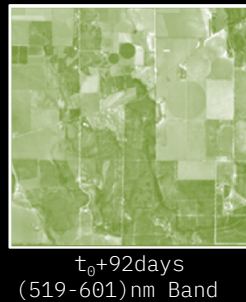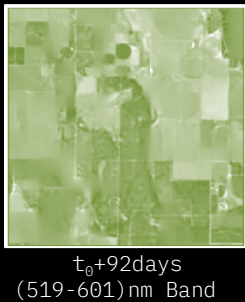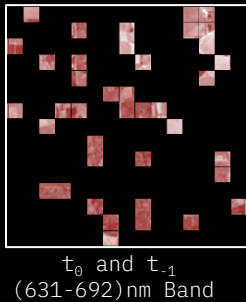
Pre-training of a weather FM
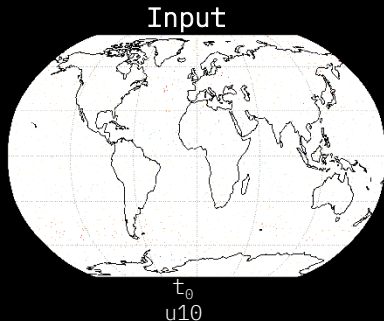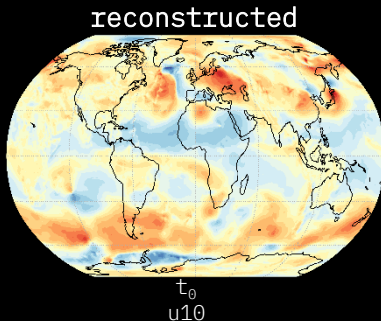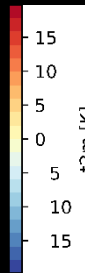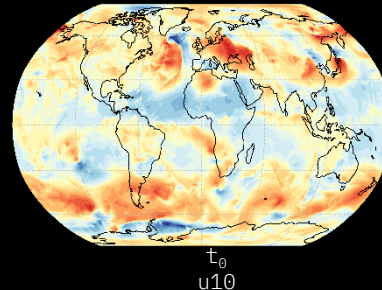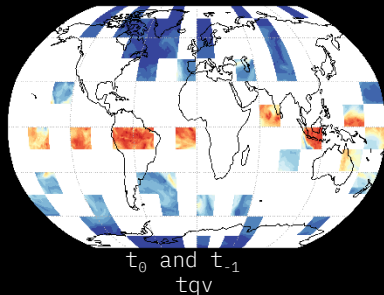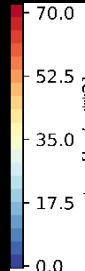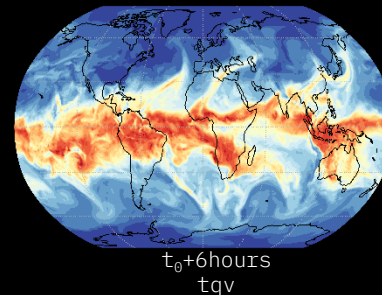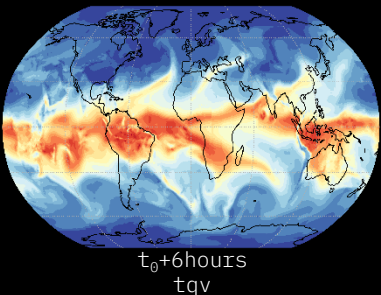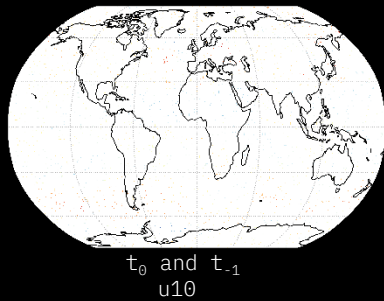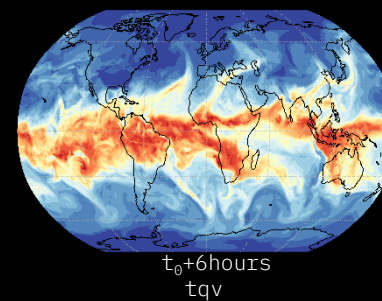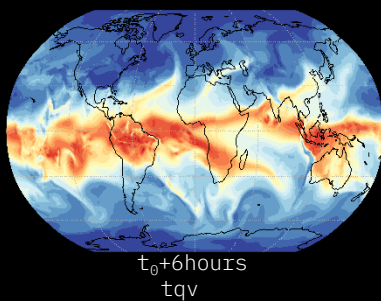
Work in progress

Zero-shot reconstruction applications are plentiful

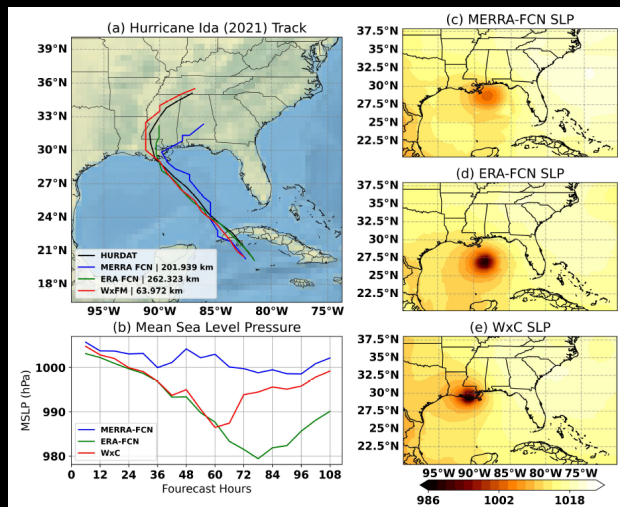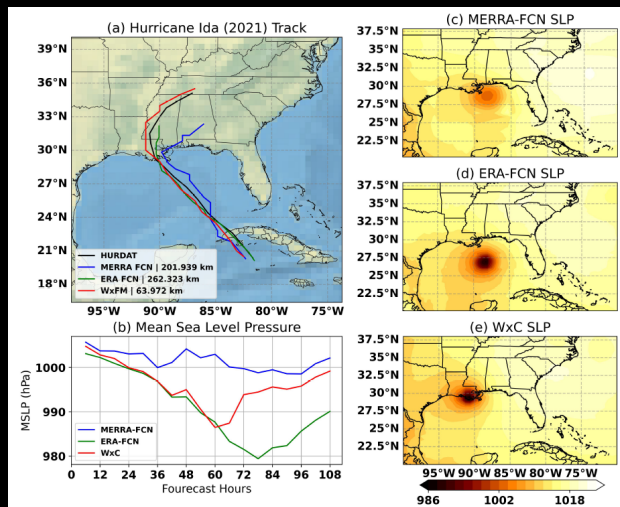**①** *Weather FM*

- Forecasting
- Assimilation
- Nowcasting
- ...

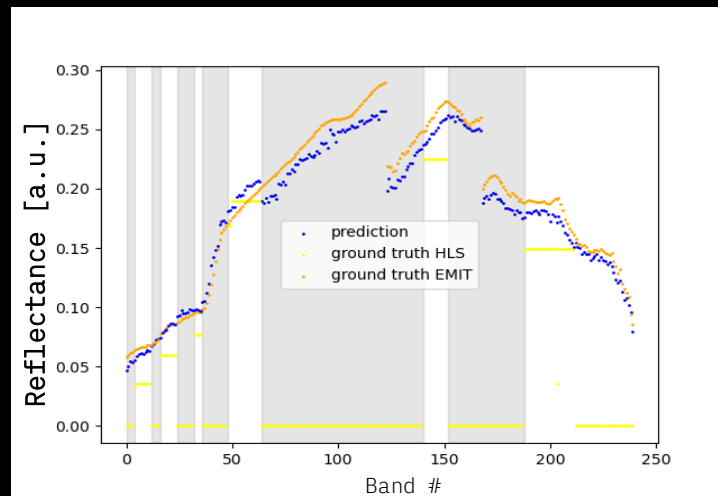# Zero-shot reconstruction applications are plentiful

① *Weather FM*

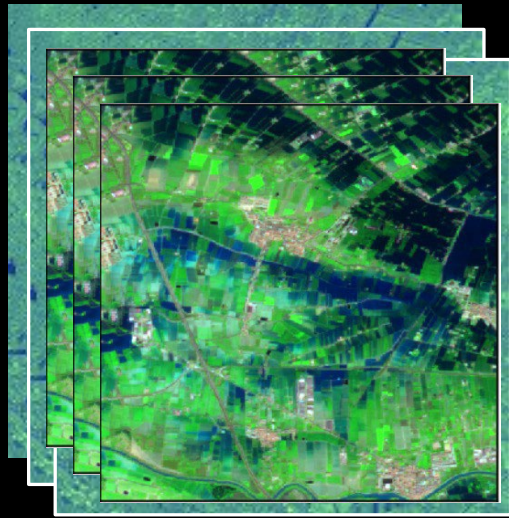- Forecasting
- Assimilation
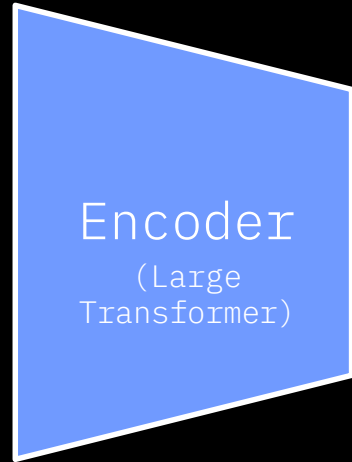- Nowcasting
- ...

② *Earth Observation FM*

- Cloud removal
- Assimilation
- Harmonization
- ...

Fine-tuning examples with an EO FM

Flood detection

Floods

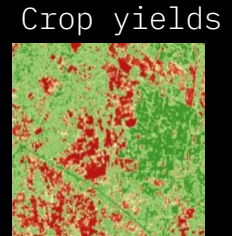Semantic Segmentation

Additional satellite data & labels

Encoder
(Large Transformer)

HLS Satellite foundation model

Nature-based carbon sequestration

Biomass

Classi-fication
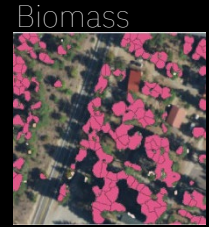
Yield forecasting

Crop yields

Regression
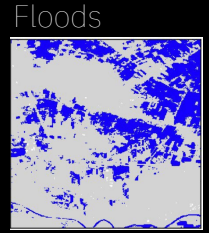
Example fine-tuned models

Fine-tuning examples with a weather FM
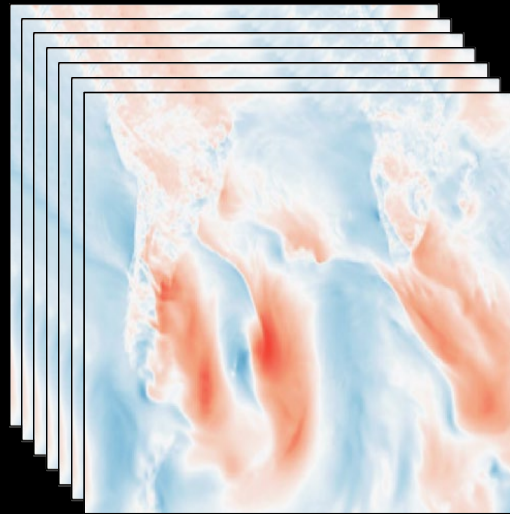
Additional weather data & labels
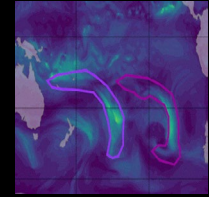
Encoder (Large Transformer)
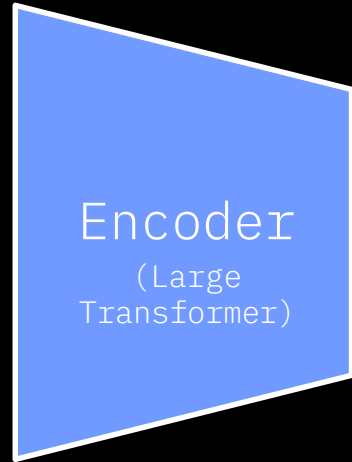
MERRA/ERA5 foundation model

Extreme weather

Semantic Segmentation

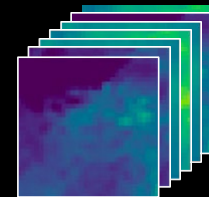Atmospheric Rivers

Tornado identification

Classi-fication

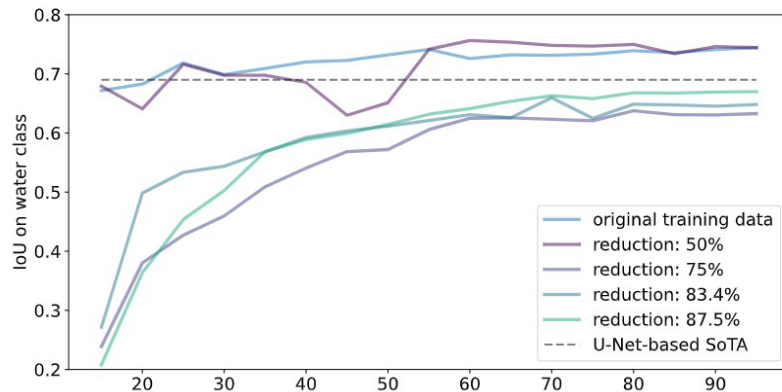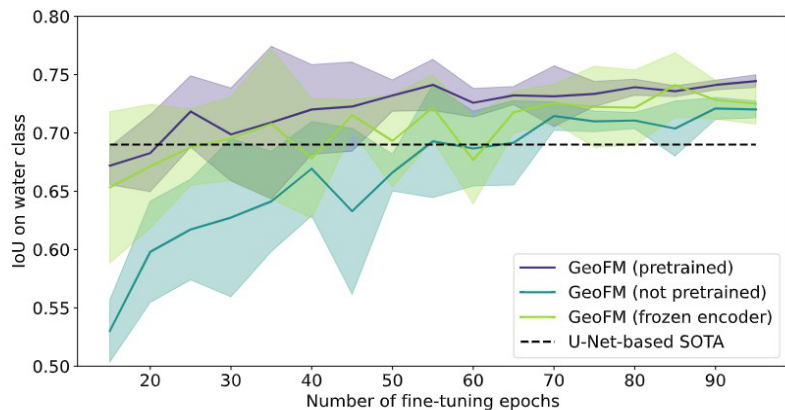Tornado strengths

Down scaling

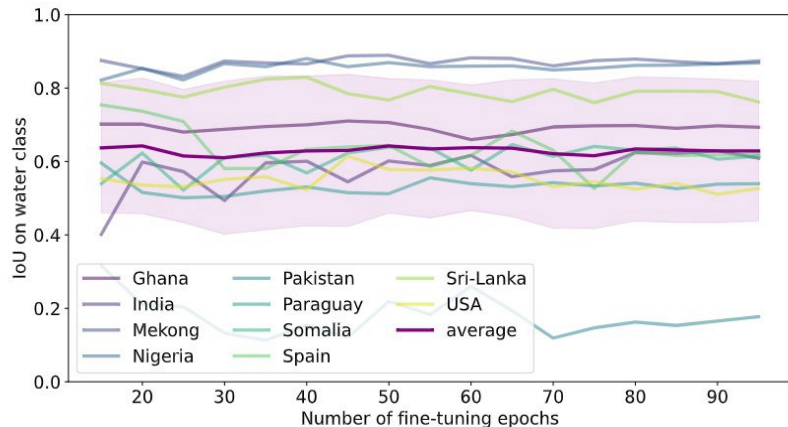Regression
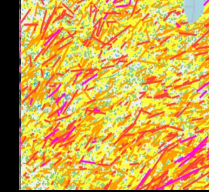
Forecasts

Example fine-tuned models

Fine-tuning results for flood detection

Finetuned FM outperform SOTA by more than 20% (IoU) with significant
- less training epochs (> 2x) and
- less labels (>2x)

FM generalizes well for different regions across the globe

Weather and EO Foundation Models have been open-sourced

IBM and NASA Open Source Largest Geospatial AI Foundation Model on Hugging Face

Effort aims to widen access to NASA earth science data for geospatial intelligence and accelerate climate-related discoveries

Aug 3, 2023
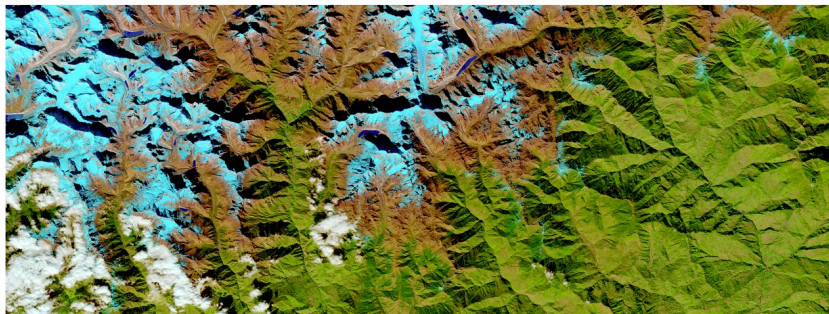
IBM, NASA, Oak Ridge National Lab announce open-source AI model for weather, climate

The model trained on 40 years of data could be used to create more targeted forecasts and predict severe storms, IBM said Monday.

BY MADISON ALDER • SEPTEMBER 23, 2024

Powerful AI representations can be
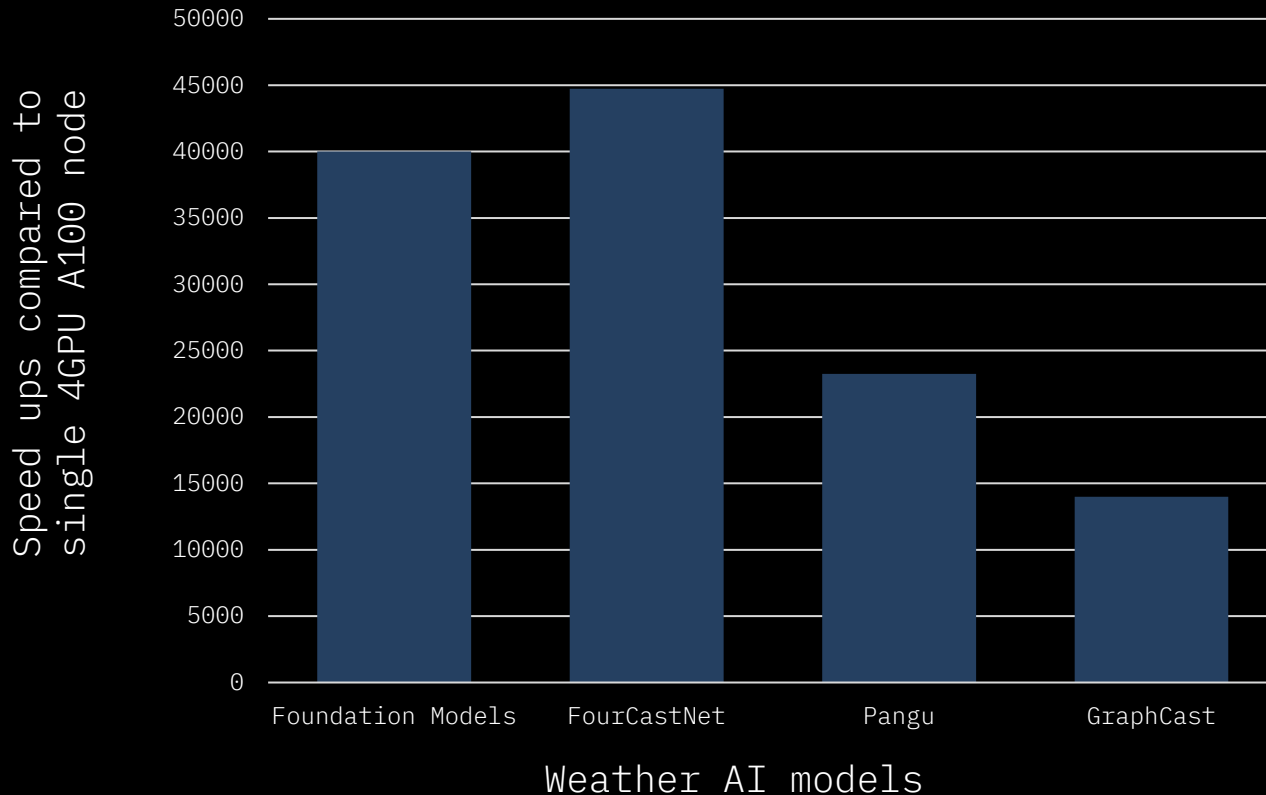created by learning the temporal, spatial
and inter-channel relations of large
weather and earth observation data sets….

But so what?

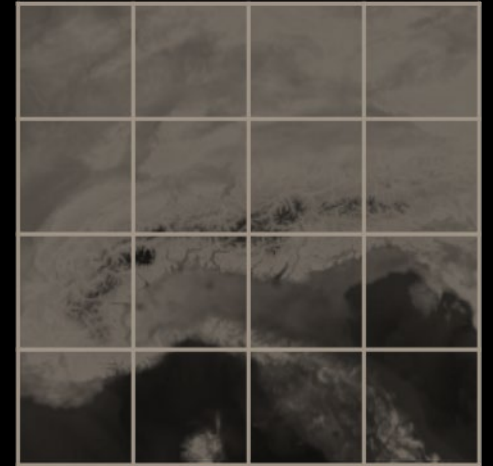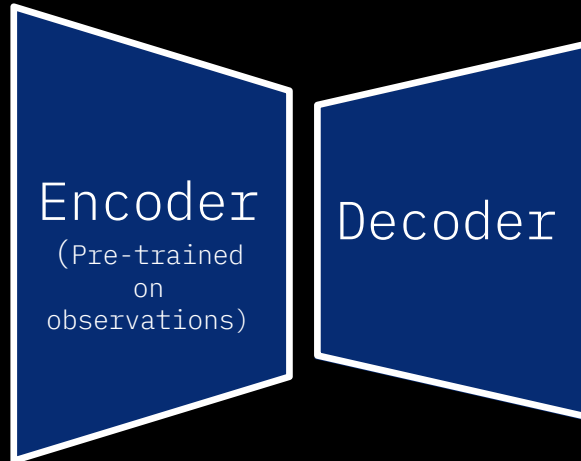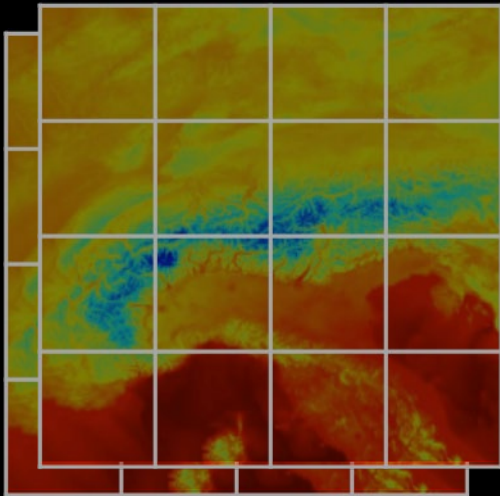# AI acceleration can be significant: Example weather forecasting

Foundation Models for scientific discovery - Digital twins

Example questions:
- How do aerosols affect hail formation?
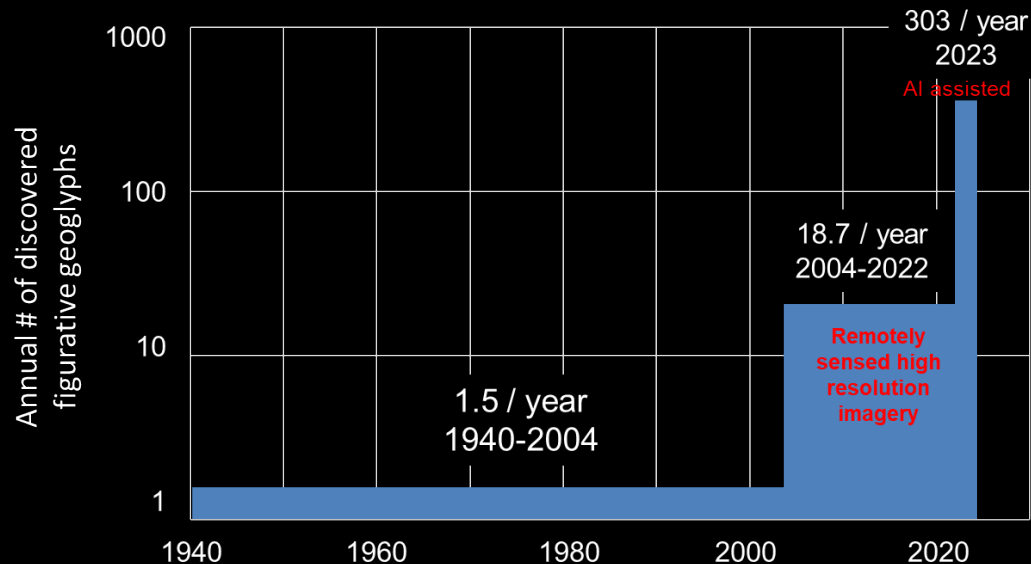- What is the role of supercell thunderstorms in hail formation?

Answers:
- ...
- ...

Encoder
(Pre-trained on observations)

Decoder

Foundation Models for scientific discovery - Automation

20 examples of 303 newly discovered geoglyphs

Sakai, M., Sakurai, A., Lu, S., Olano, J., Albrecht, C. M., Hamann, H. F., & Freitag, M. (2024). AI-accelerated Nazca survey nearly doubles the number of known figurative geoglyphs and sheds light on their purpose. Proceedings of the National Academy of Sciences, 121(40), e2407652121.

Conclusion

- Foundation Models are a paradigm shift in AI…

- (Non-text) centric Foundation Models are the next wave, which require innovations but offer unique and new opportunities for BER

- Observation-to-Observation Foundation Models will become "digital twins" for scientific discovery