

What business does industry have in weather?

Peter Battaglia
Google DeepMind (GDM)

2023 NOAA AI4NWP workshop - Boulder, Colorado
November 28, 2023

About our team

Me (Peter Battaglia)

PhD/postdoc in computational cognitive psychology. Worked on generative models and physical reasoning

Joined GDM 9 years ago

Relevant research areas:
ML for simulation
Graph neural networks

Co-lead GDM Weather efforts
Co-lead GDM Sustainability Program

Backgrounds of some key team members



Matthew Willson

Background in math/stats. GDM Research Engineer for 7 years



Alvaro Sanchez

Background in quantum optics. GDM Research Engineer for 6 years



Remi Lam

Background in aerospace engineering and climate. GDM Research Scientist for 5 years

About Google DeepMind (GDM)



GDM is an R&D unit within Google.

Our mission: *"Build AI responsibly to benefit humanity"*

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GDM is an R&D unit within Google.

Our mission: *"Build AI responsibly to benefit humanity"*

Historically, GDM conducted more open-ended research,
but now the path from **R** → **D** → **Product** is shorter and straighter

Why?

1. ML tools have matured, and scaled to real-world challenges
2. Application areas have become easier to interface with
 - a. Bigger, better curated data
 - b. Standardized metrics for evaluating performance
3. More ML experts with domain expertise, and vice versa

R&D: Why the path from **R** → **D** → **Product** is shorter and straighter

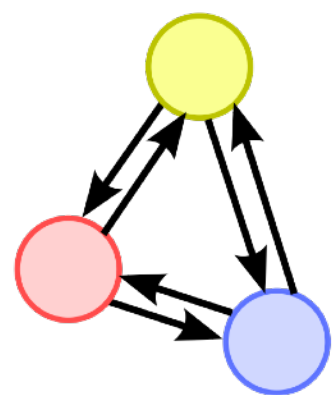
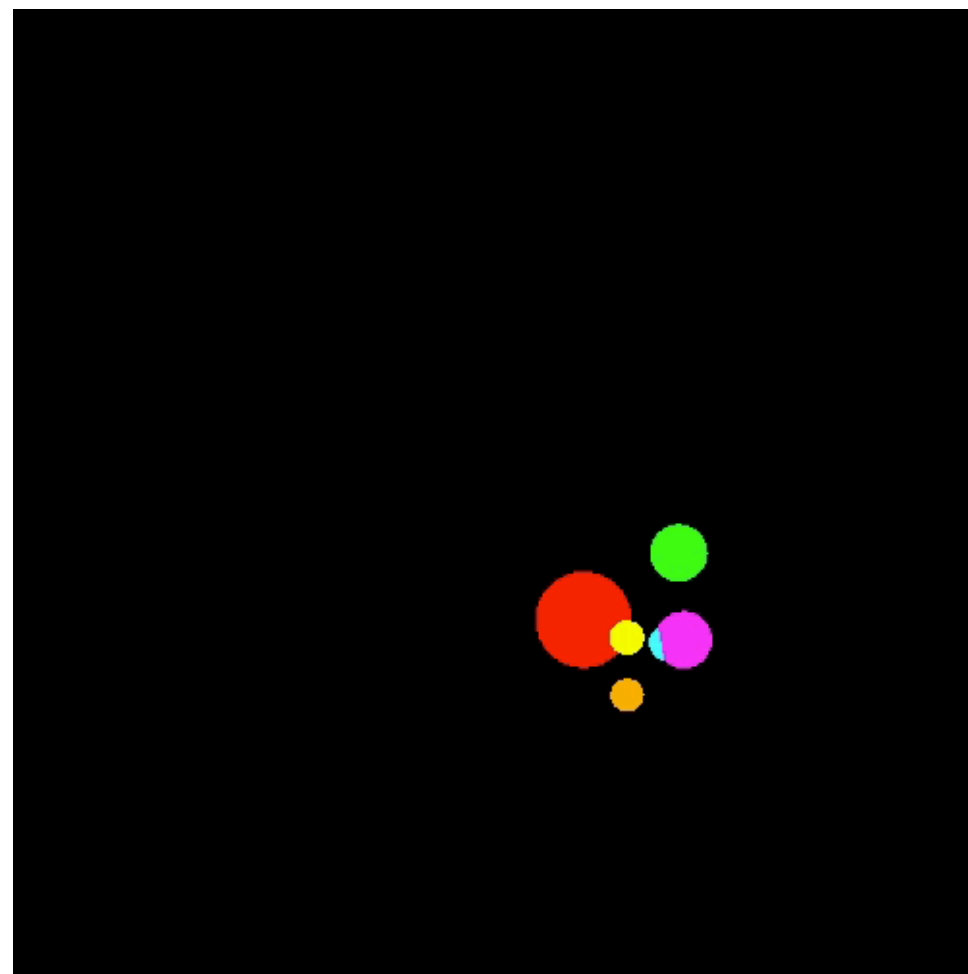
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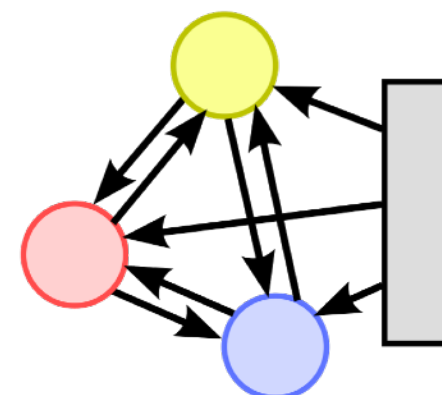
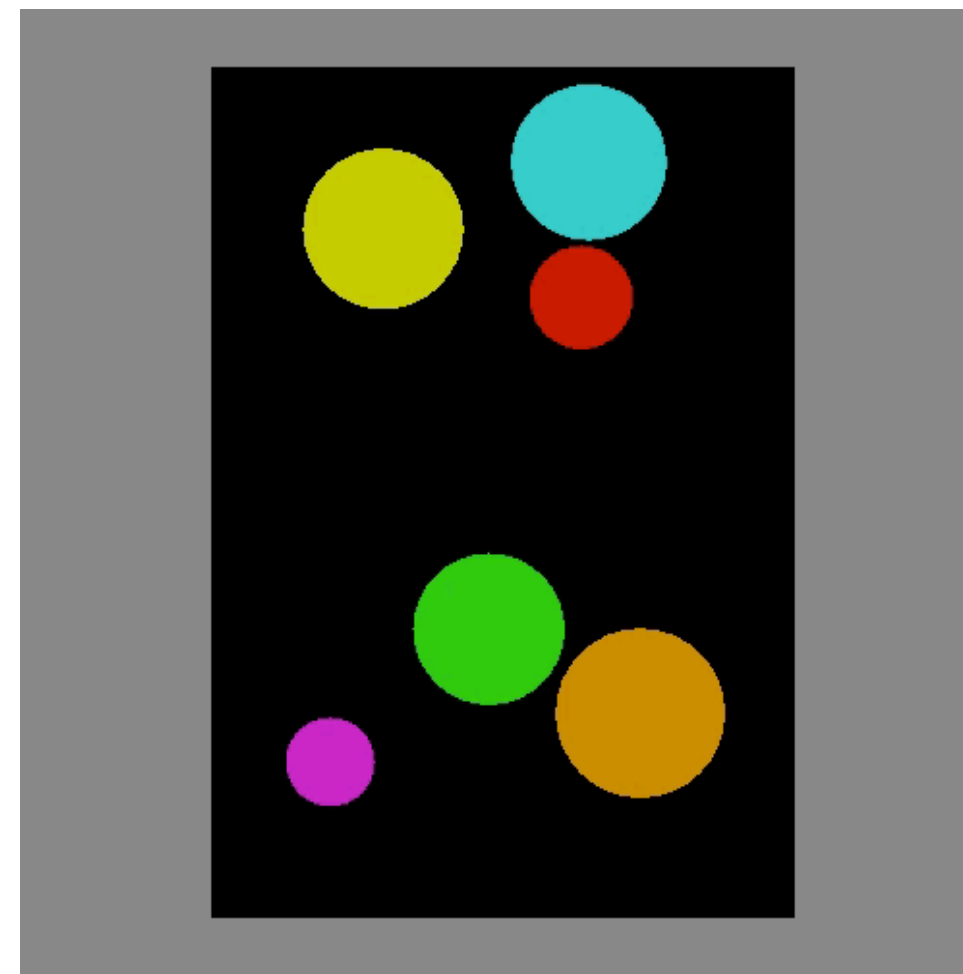
Example of some of our early work that preceded GraphCast and weather modeling

N-body: 3-9 nodes



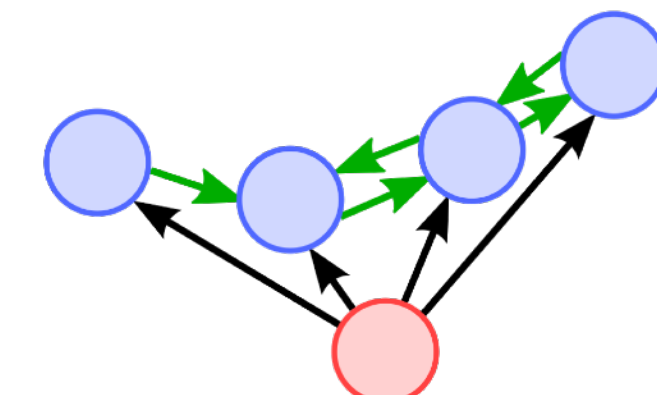
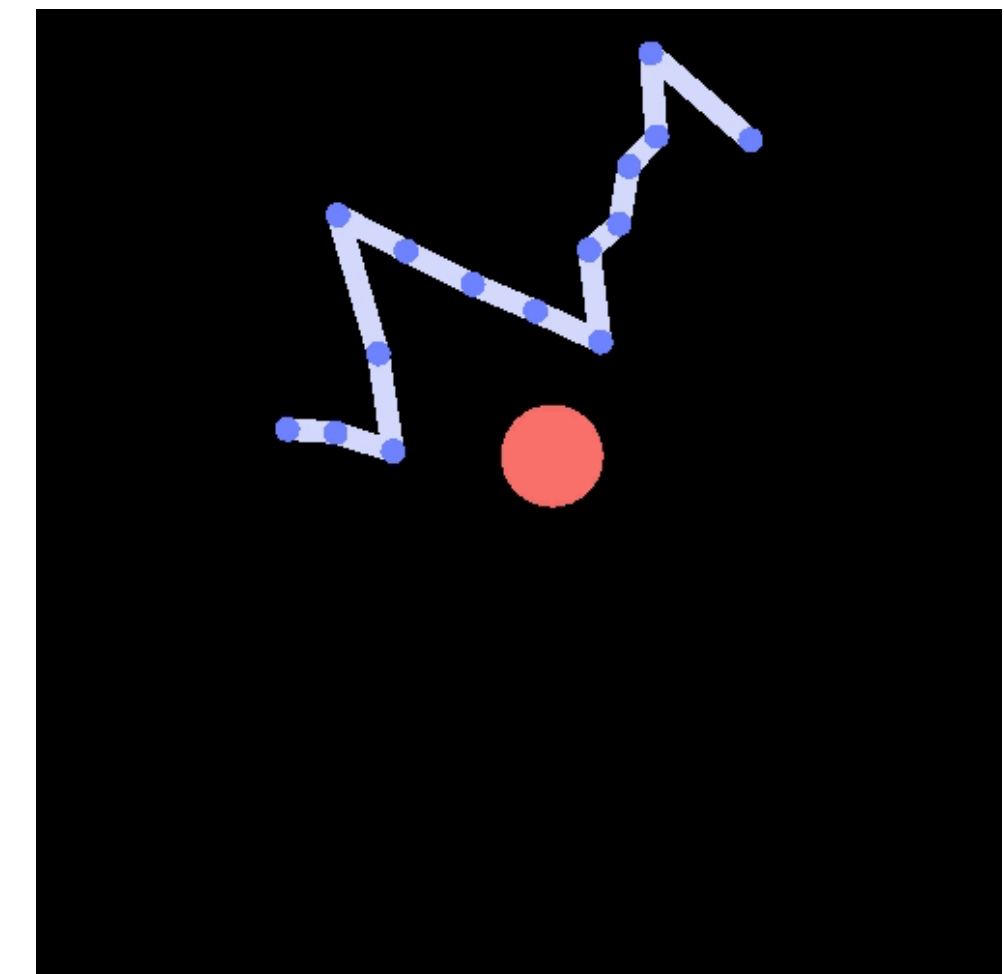
Nodes: bodies
Edges: gravitational forces

Rigids: 7-13 nodes



Nodes: balls
Edges: rigid collisions between objects

String: 6-31 nodes

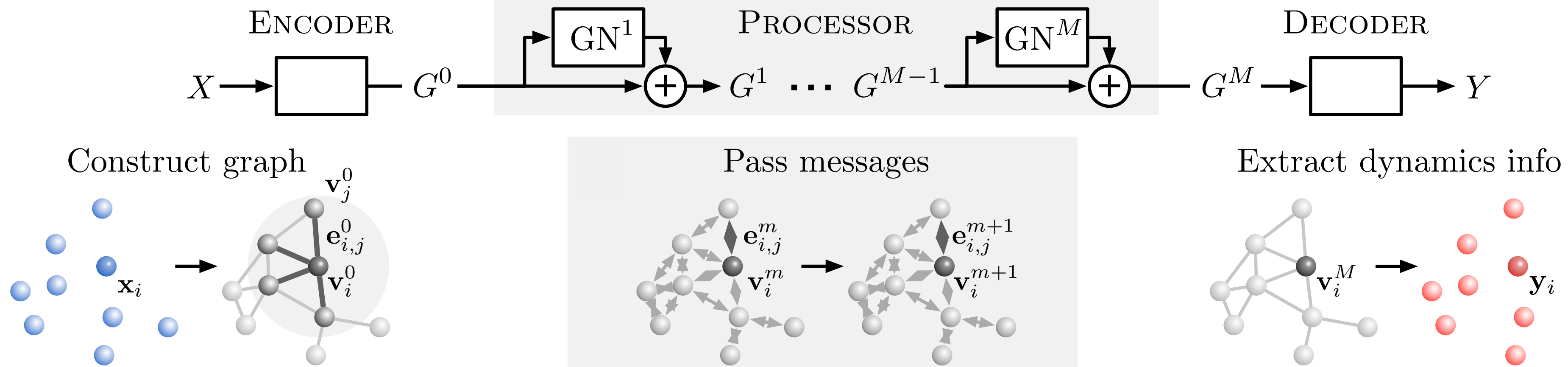
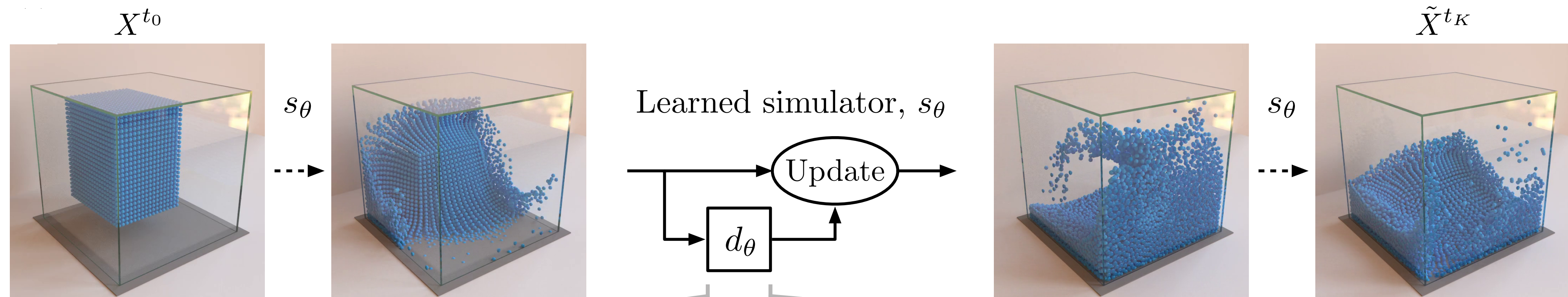


Nodes: masses
Edges: springs and rigid collisions

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As has happened across ML, we built more sophisticated methods and tested them on more complex systems

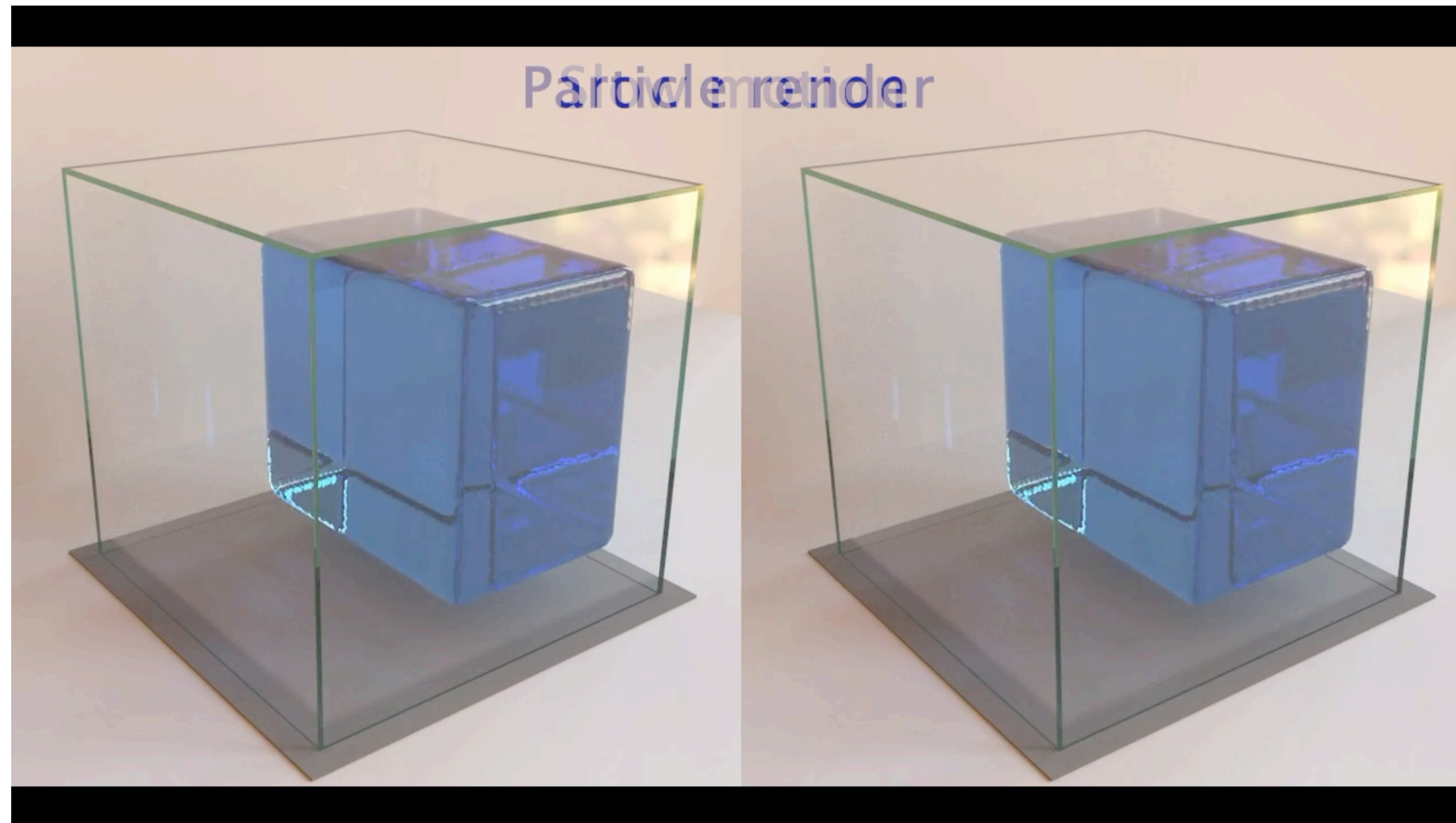


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Water, sand, goop: ~10k nodes

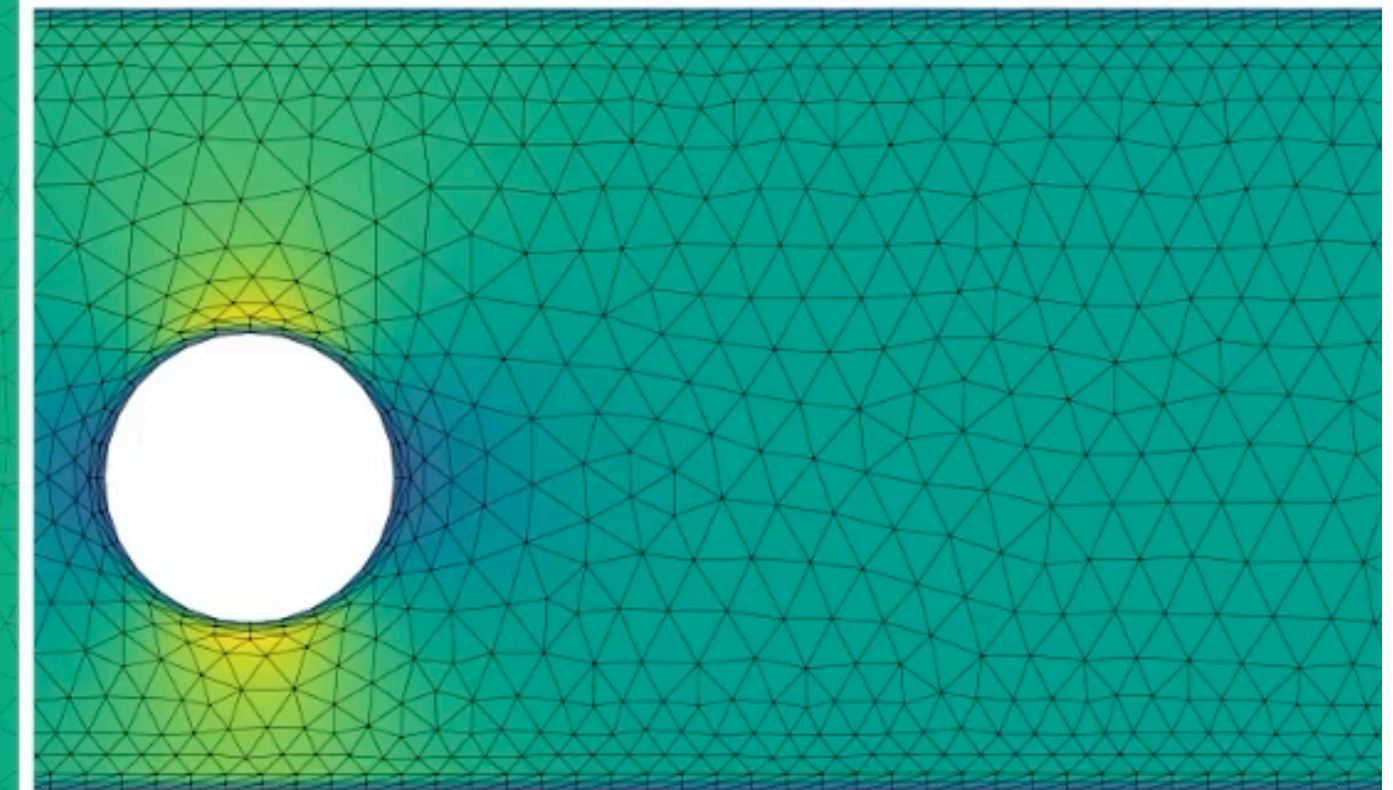
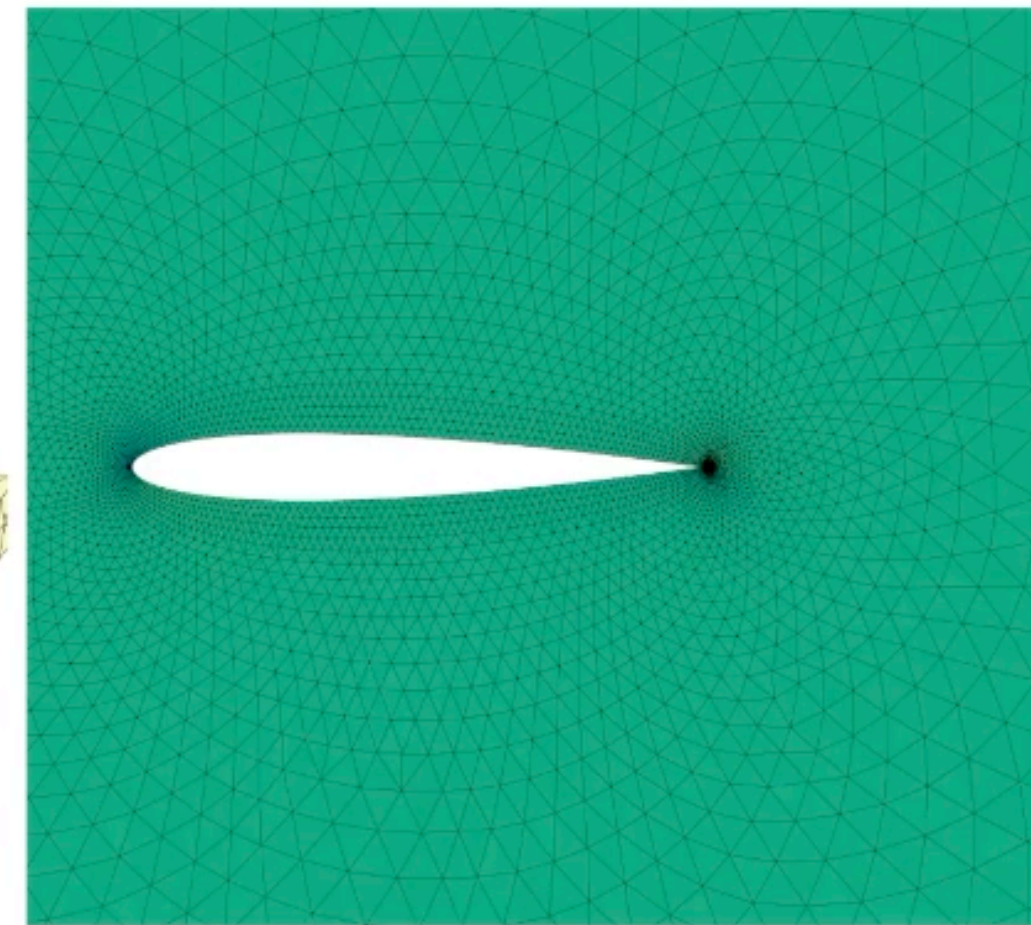
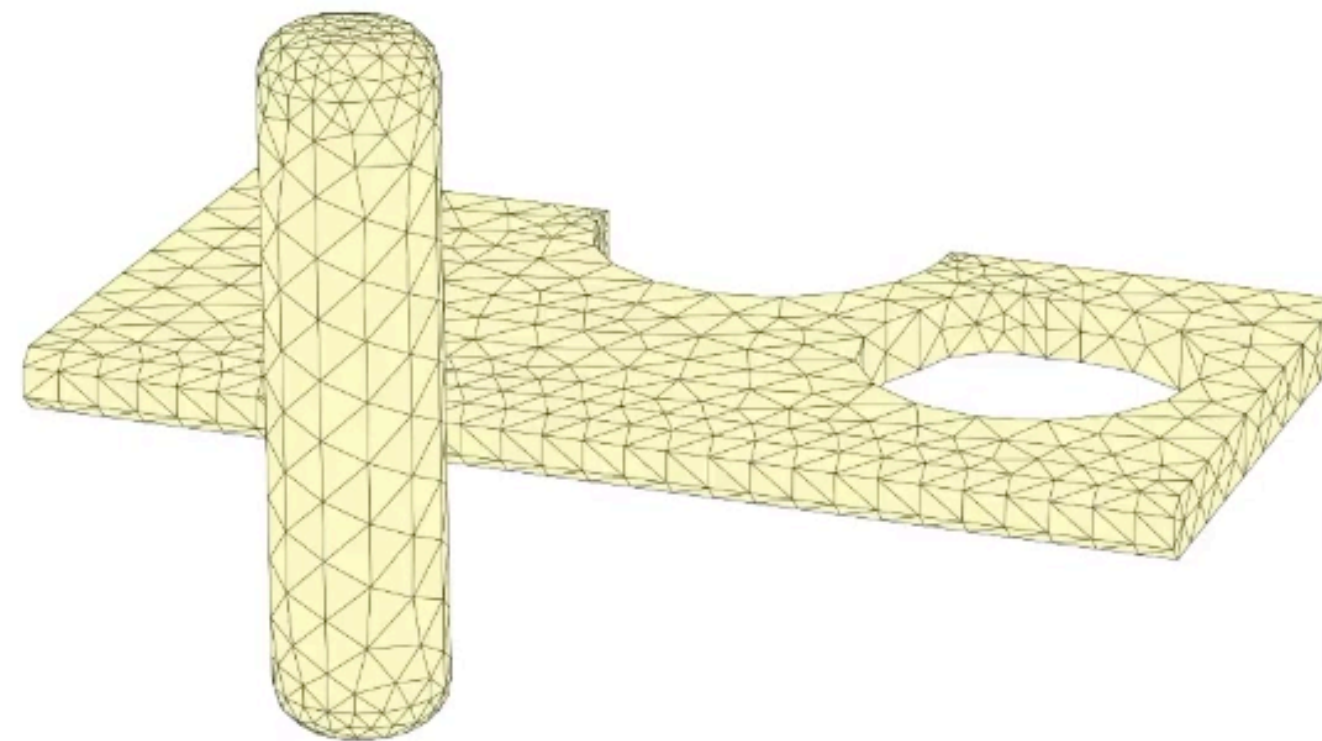


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Cloth, deformable solids, fluids: ~10k nodes

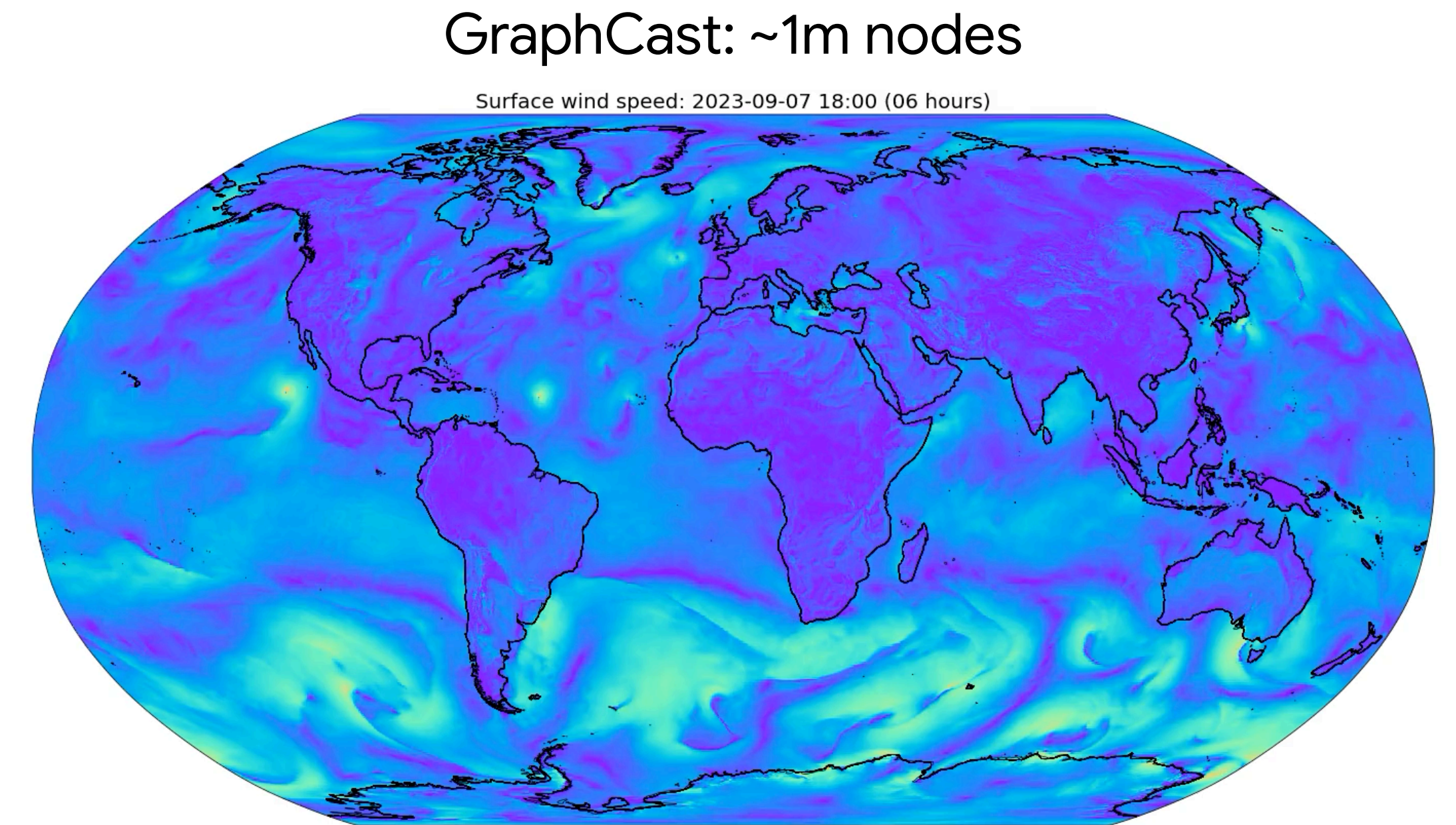
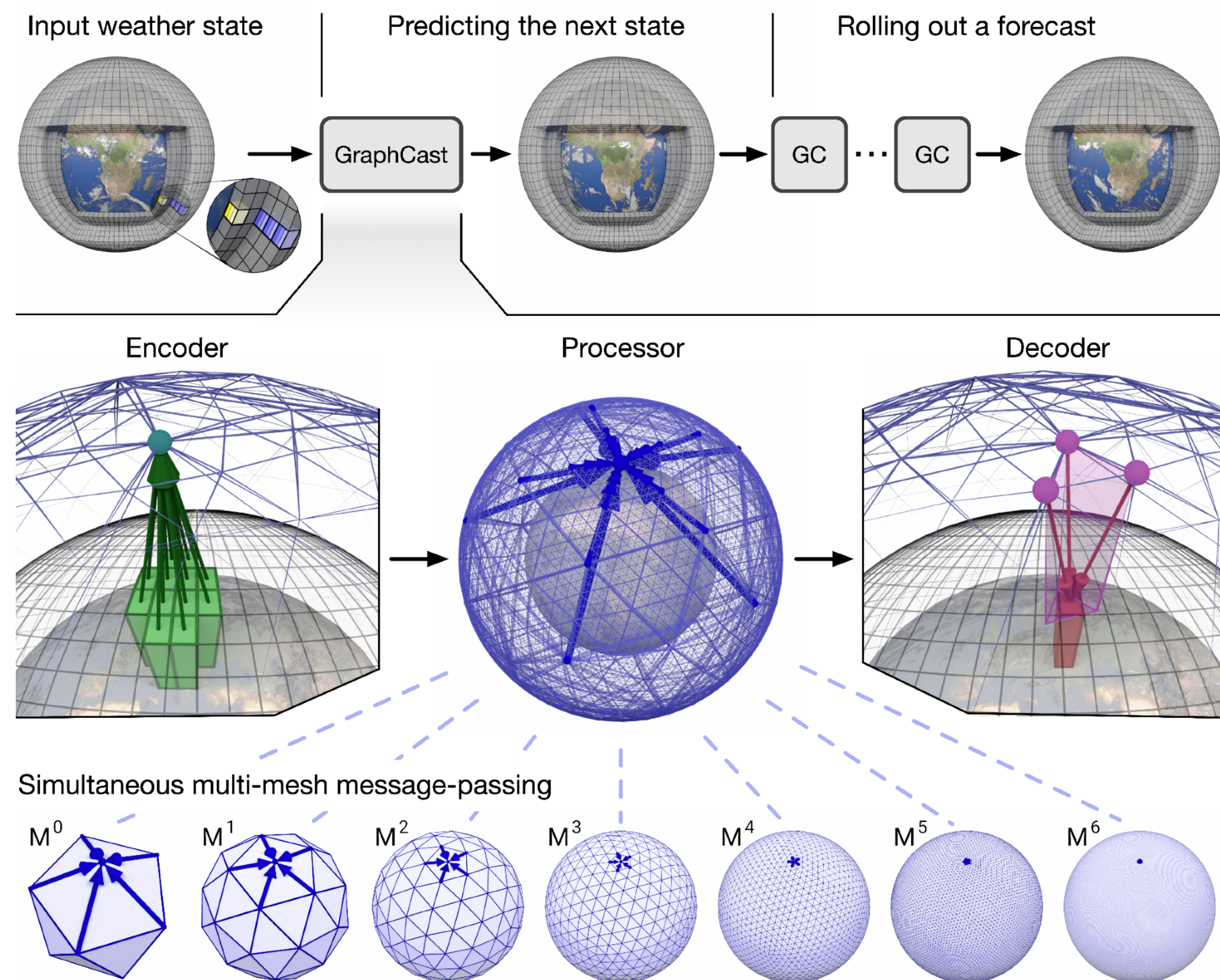


(This "MeshGraphNets" model was also part of the technical foundation of [Keisler et al. 2022](#))

R&D: Why the path from **R** \rightarrow **D** \rightarrow **Product** is shorter and straighter

1. ML tools have matured, and scaled to real-world challenges

Eventually we and others reached very mature systems that could scale to global weather modeling



Lam et al., 2023, Science

Also shout-outs to our Google/GDM colleagues:

- [MetNet](#): Sønderby/Espeholt/Andrychowicz et al 2020/22/23
- [DeepMind Nowcasting](#): Ravuri et al 2021
- [Neural GCM](#): Kochkov et al 2023

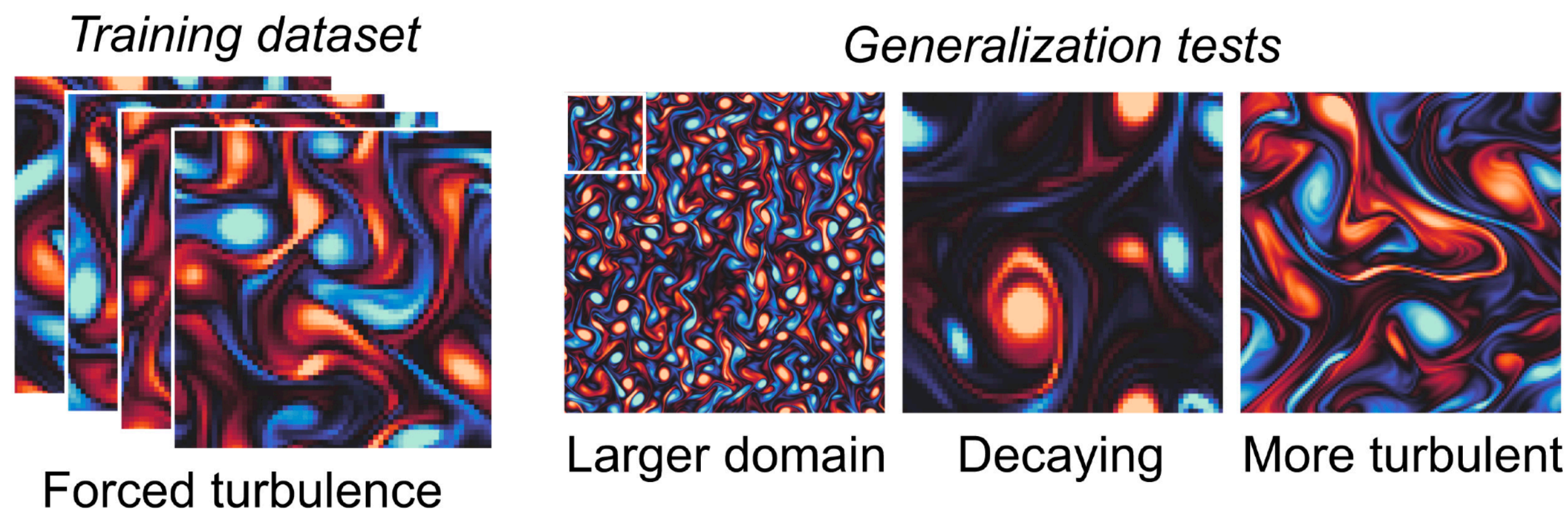
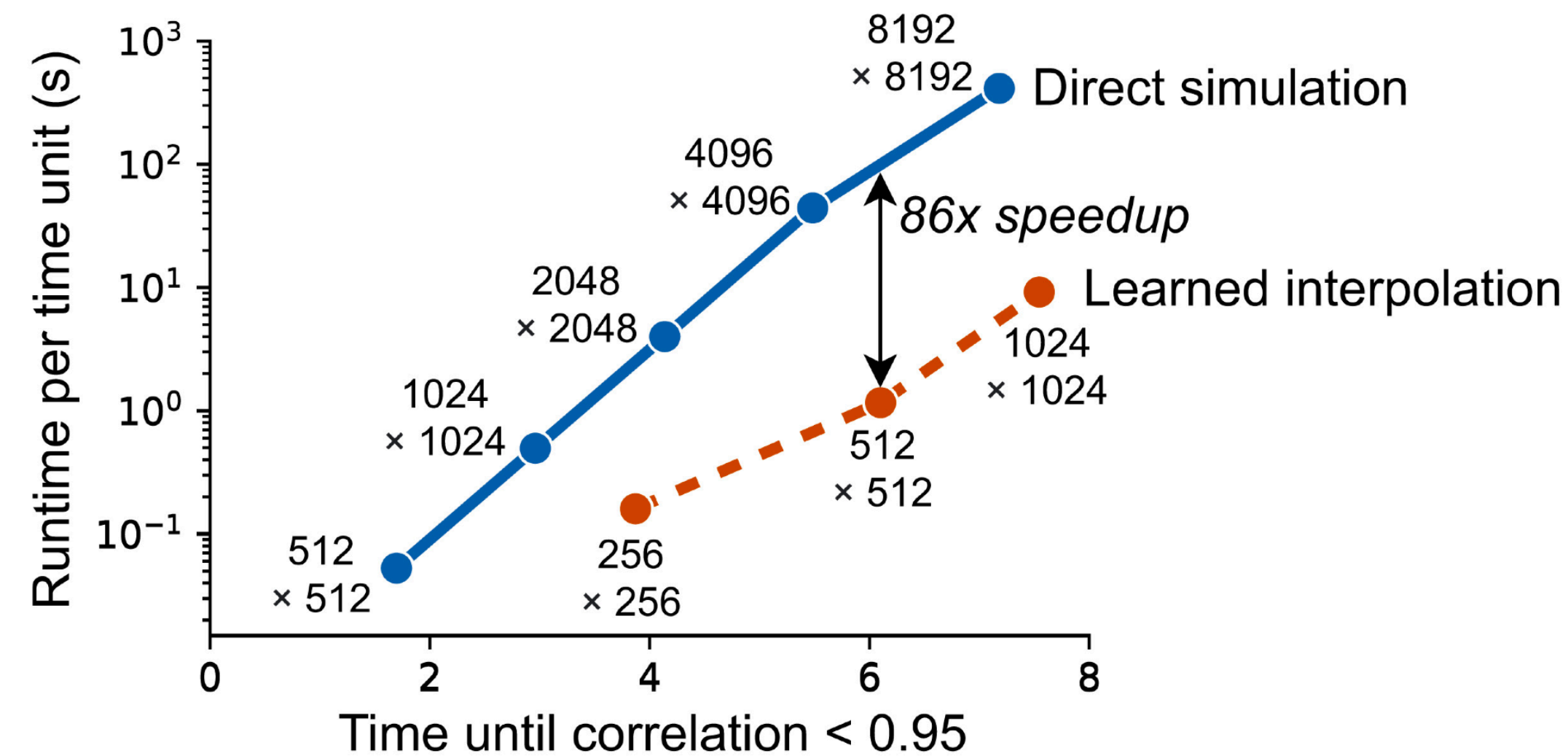
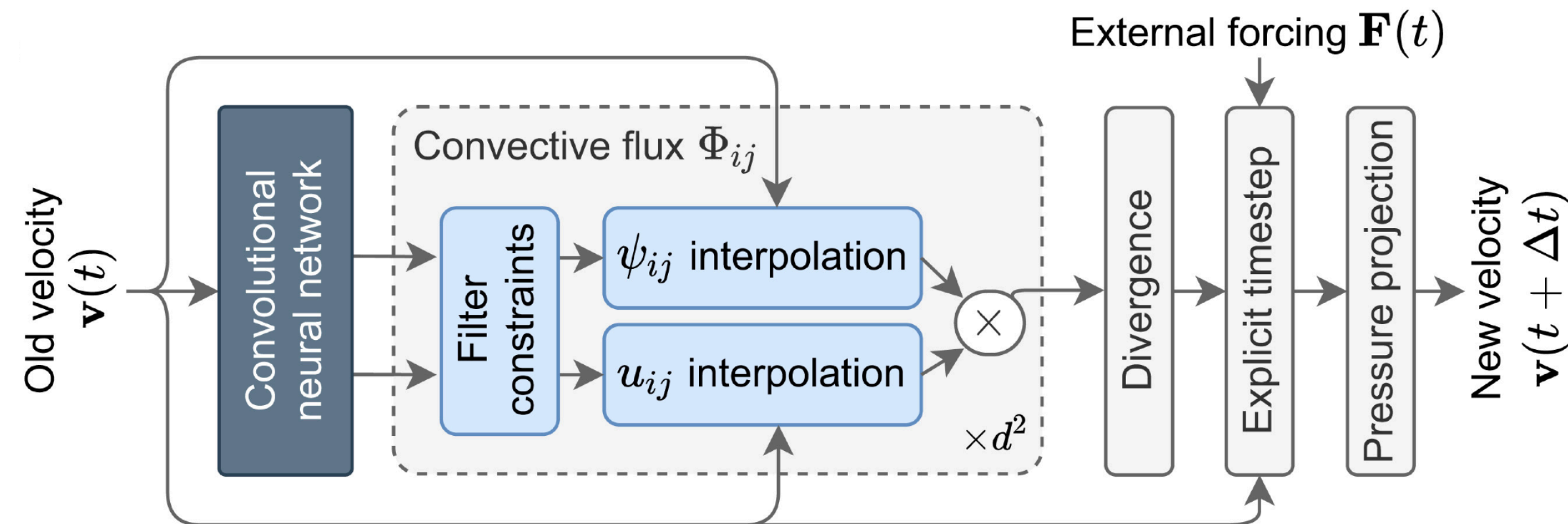
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1. ML tools have matured, and scaled to real-world challenges

A similar story unfolded for Stephan Hoyer's team: 2021 PNAS paper on ML-augmented numerical solvers



Stephan Hoyer



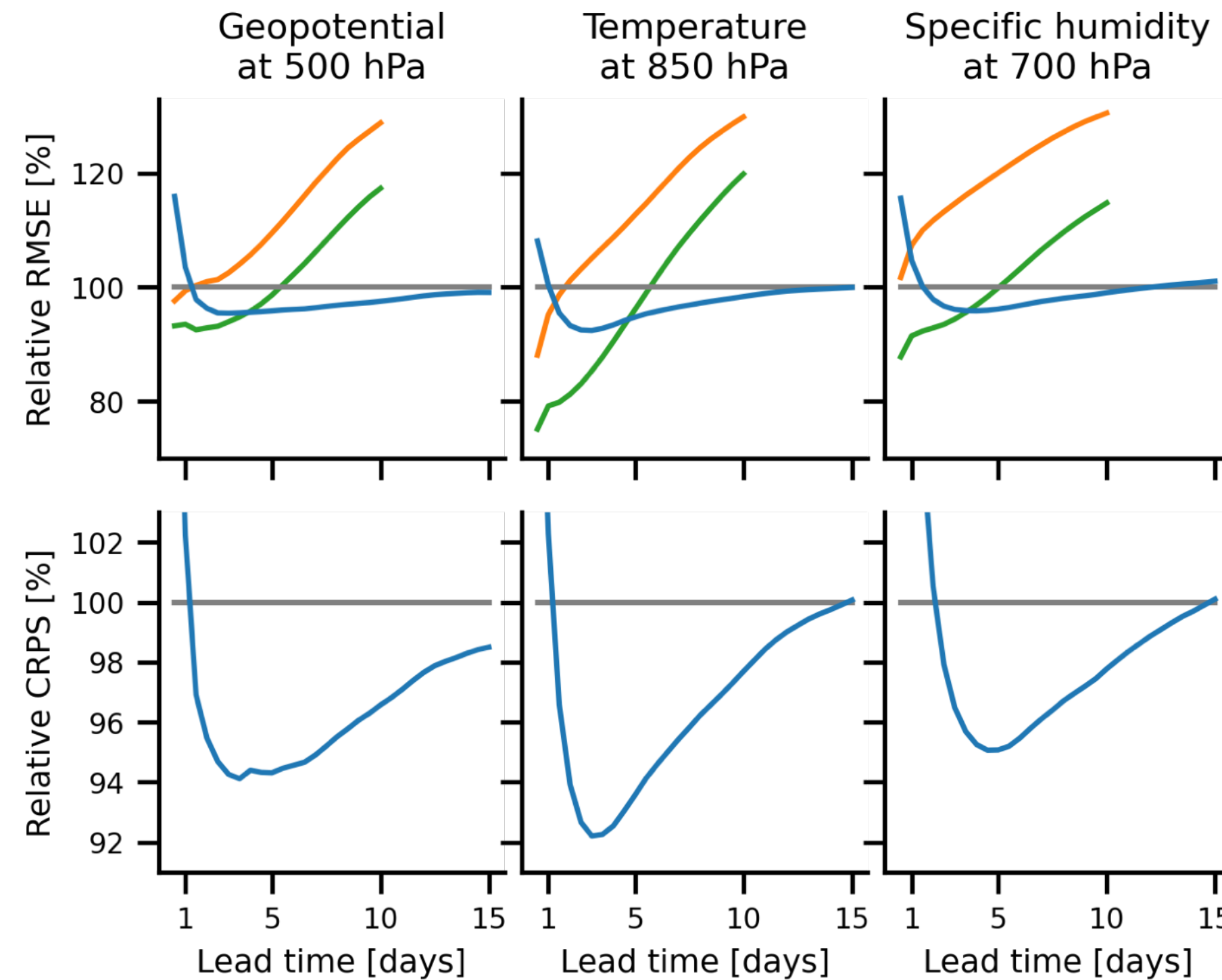
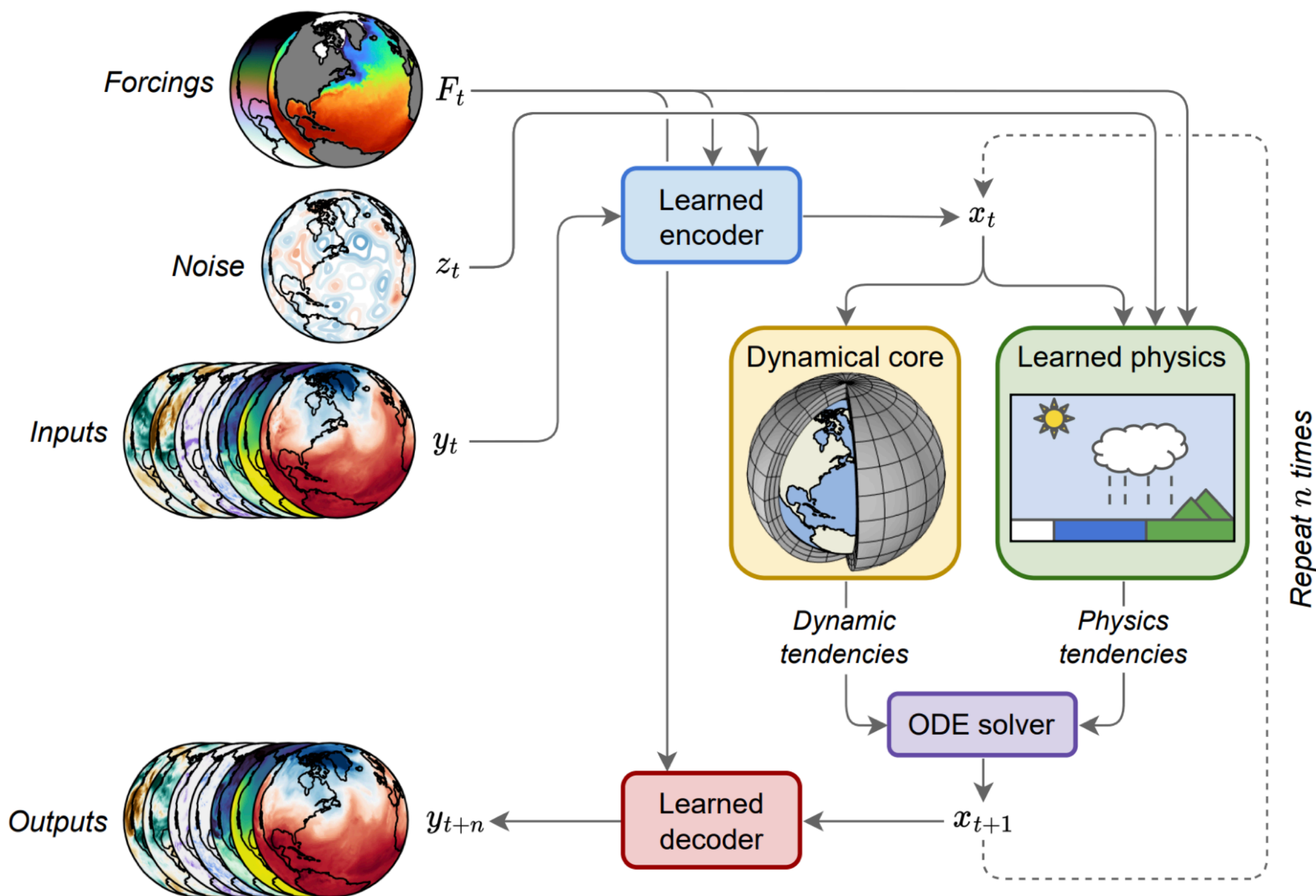
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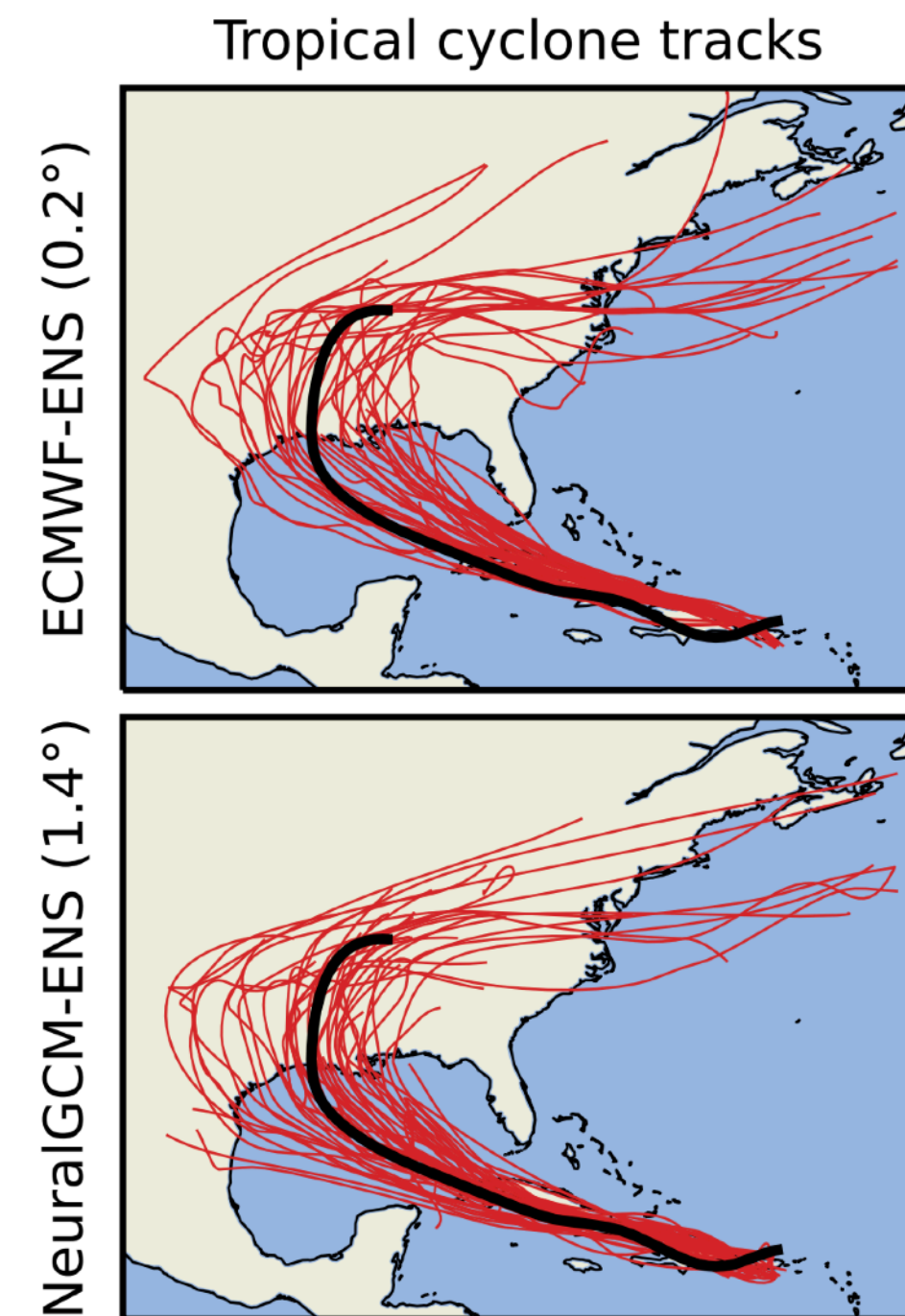
A similar story unfolded for Stephan Hoyer's team: 2023 pre-print on very competitive / SotA weather



Stephan Hoyer



— ECMWF-HRES
— GraphCast
— ECMWF-ENS
— NeuralGCM-ENS



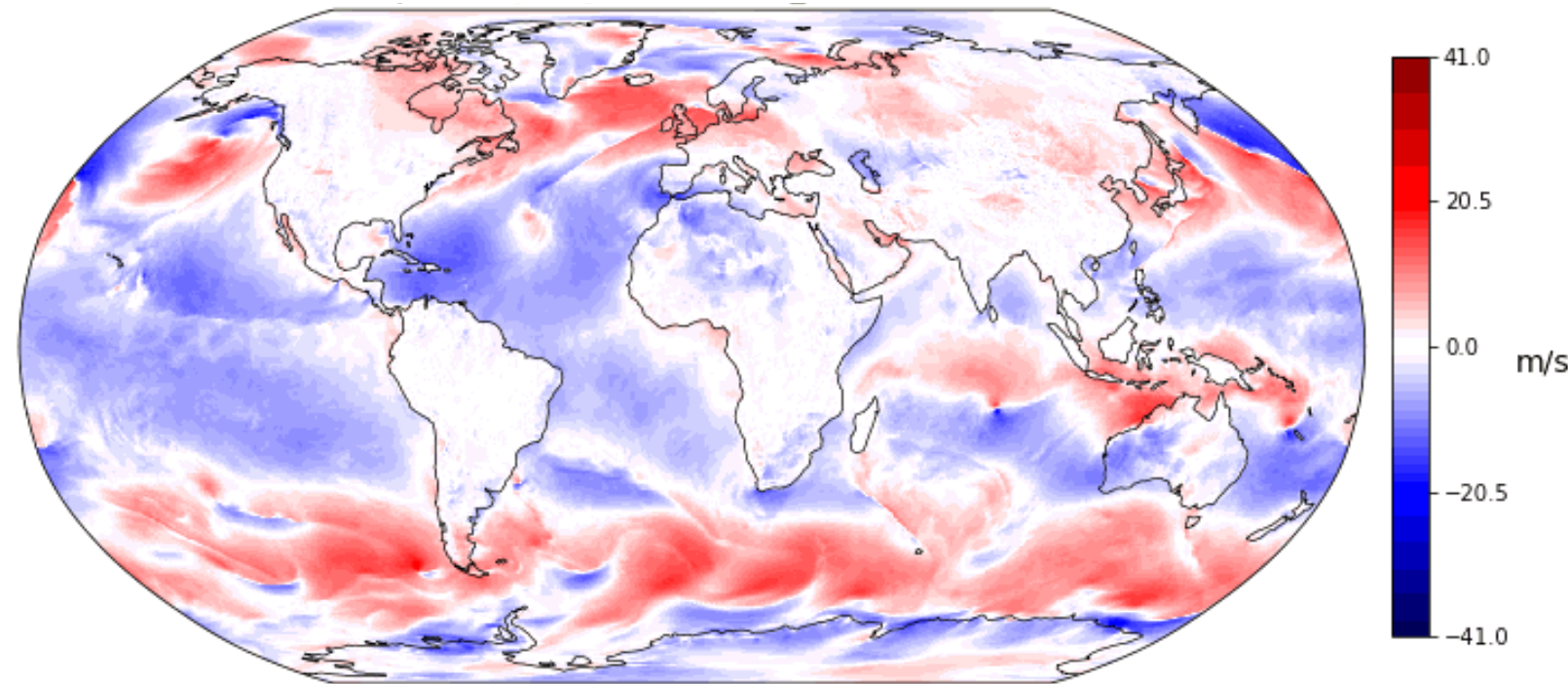
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2. Application areas have become easier to interface with

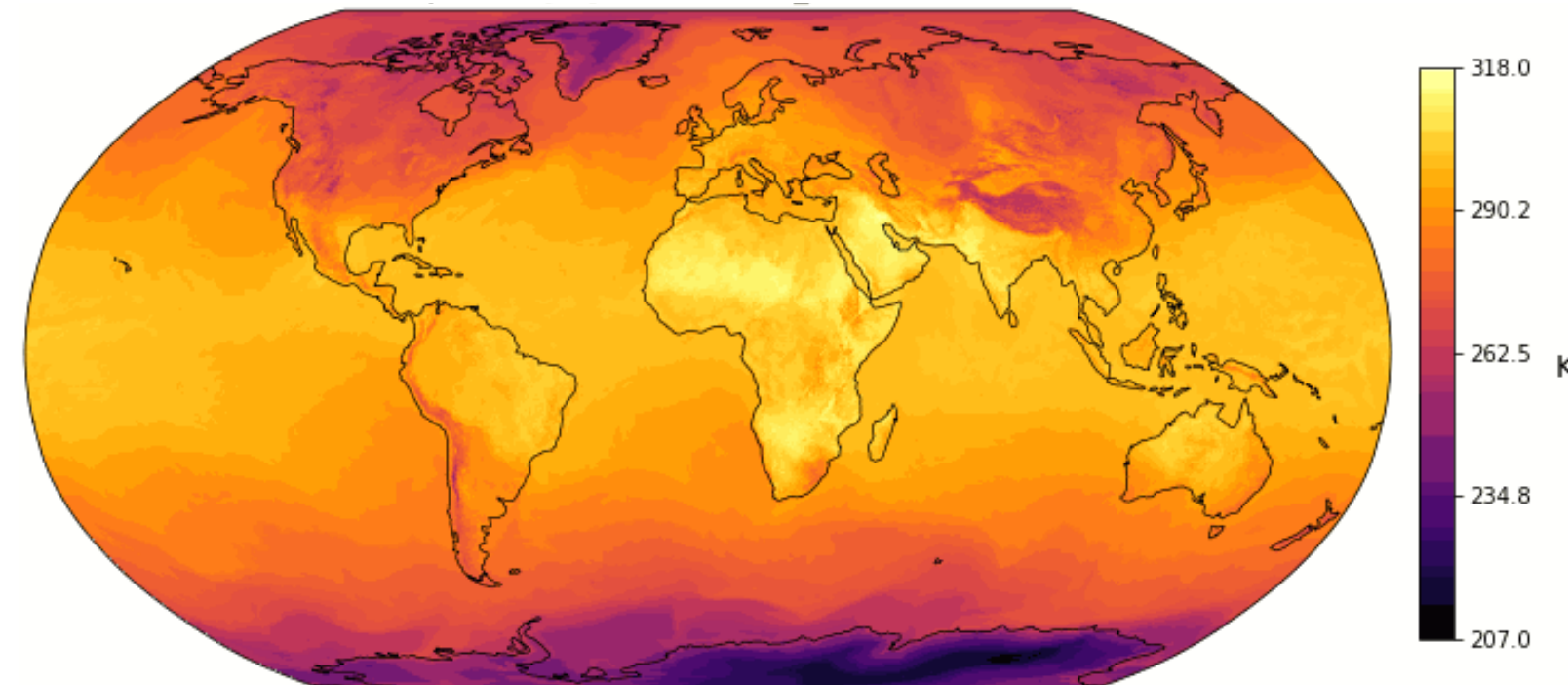
a. Bigger, better curated data

Datasets like ERA5, which represent decades of Earth's weather at 1* hour steps and 0.25° resolution, are invaluable for ML

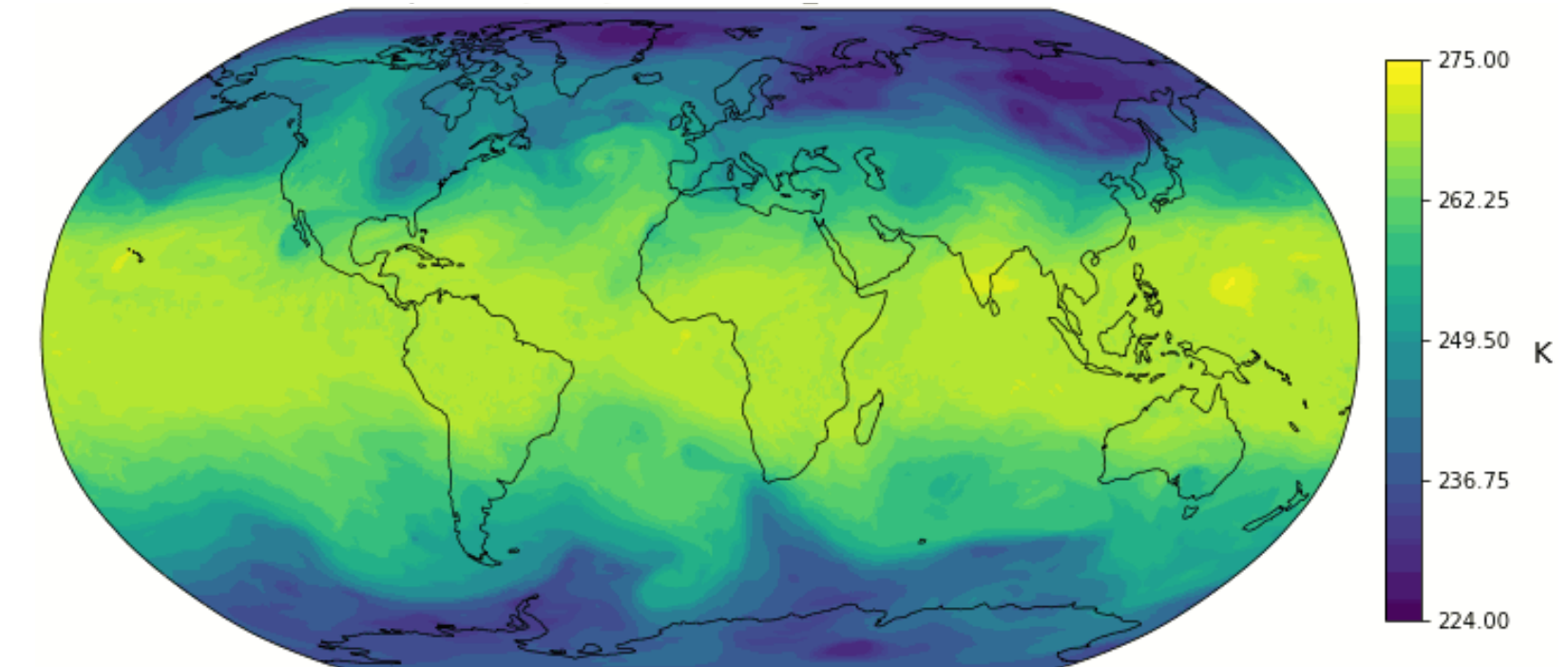
Surface E-W wind



Surface temperature



Temperature @ 500 hPa



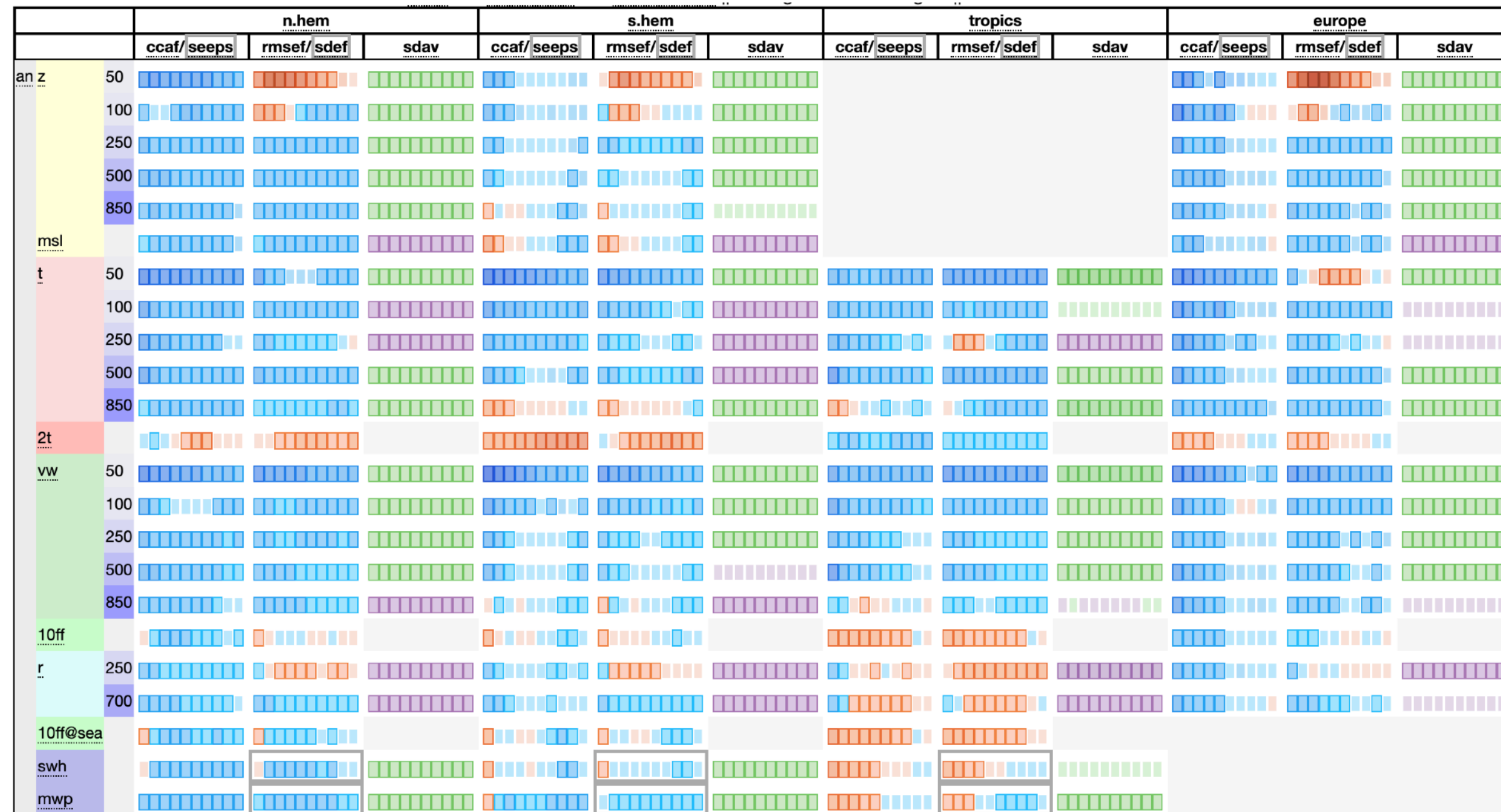
Echoing Sergey's points in his talk:

Data is the lifeblood of ML. More data. Higher quality data. This is the primary source of knowledge in ML algorithms, especially those with less inductive biases.

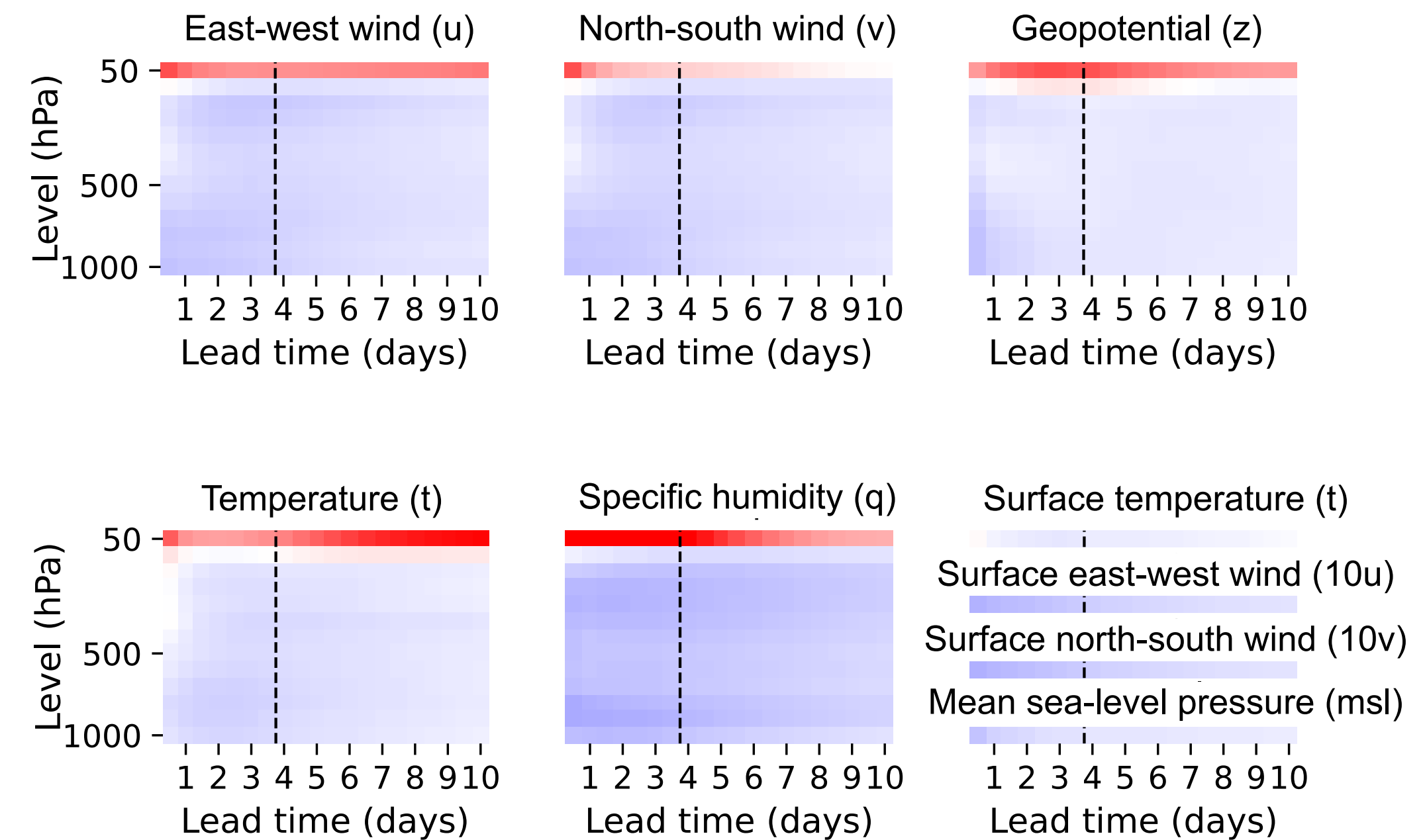
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- 2. Application areas have become easier to interface with
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ECMWF Scorecard: HRES 48r1 vs 47r3



Our Scorecard: GraphCast vs HRES

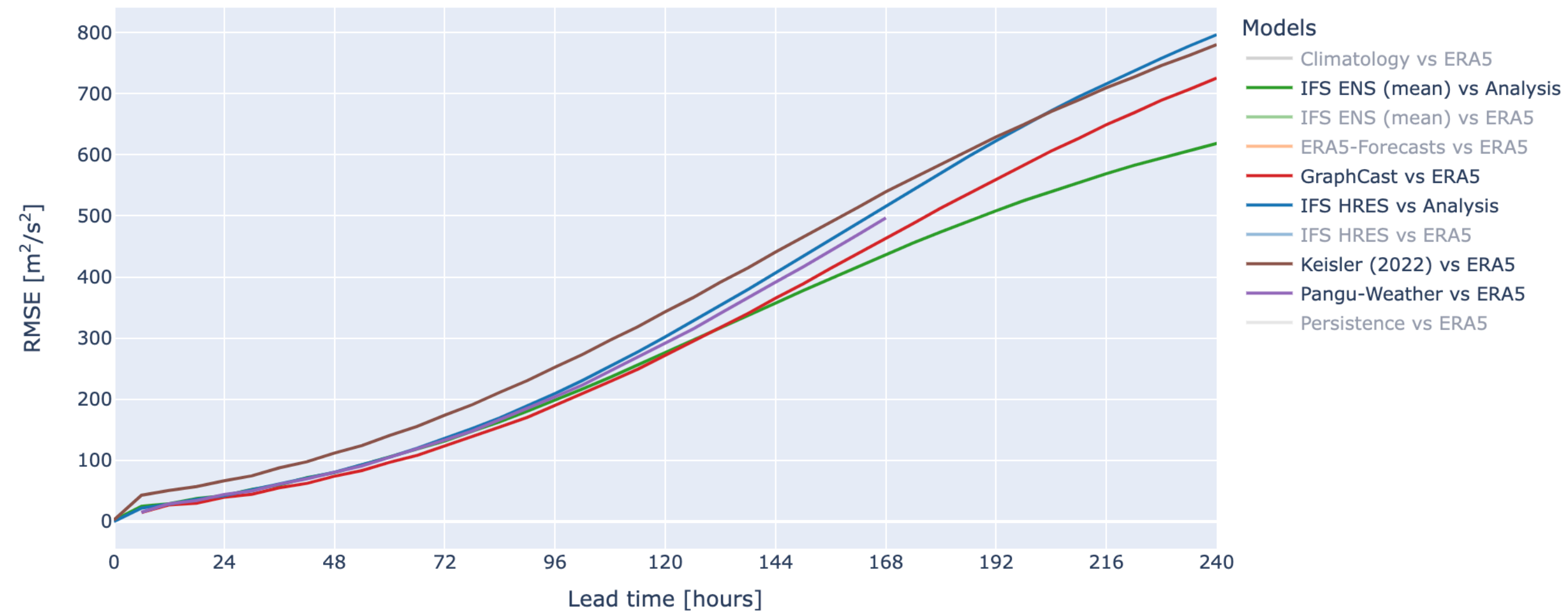


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 - Standardized metrics for evaluating performance

[WeatherBench 2](#) by Rasp, Hoyer, et al 2023

Variable: Geopotential
Metric: RMSE
Level: 500
Region: Global
Year: 2020
Resolution: 240x121
Mode: Absolute scores Compare to model
Model to compare to: IFS HRES vs Analysis
Appearance: Toggle line patterns



R&D: Why the path from **R** → **D** → **Product** is shorter and straighter

3. More ML experts with domain expertise, and vice versa



Many ML experts bring along their background expertise in other technical domains. Similarly, people in many technical areas are developing strong ML expertise.



This provides a critical bridge between the most technically sophisticated corners of ML and scientific communities.



Through these interactions, powerful ML tools can be applied successfully to very challenge scientific domains.

What business does industry have in weather?

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(speaking about Google, at least)

Google has made commitments to [sustainability](#)

[100%, 24/7 renewable energy by 2030](#)



[White paper](#)

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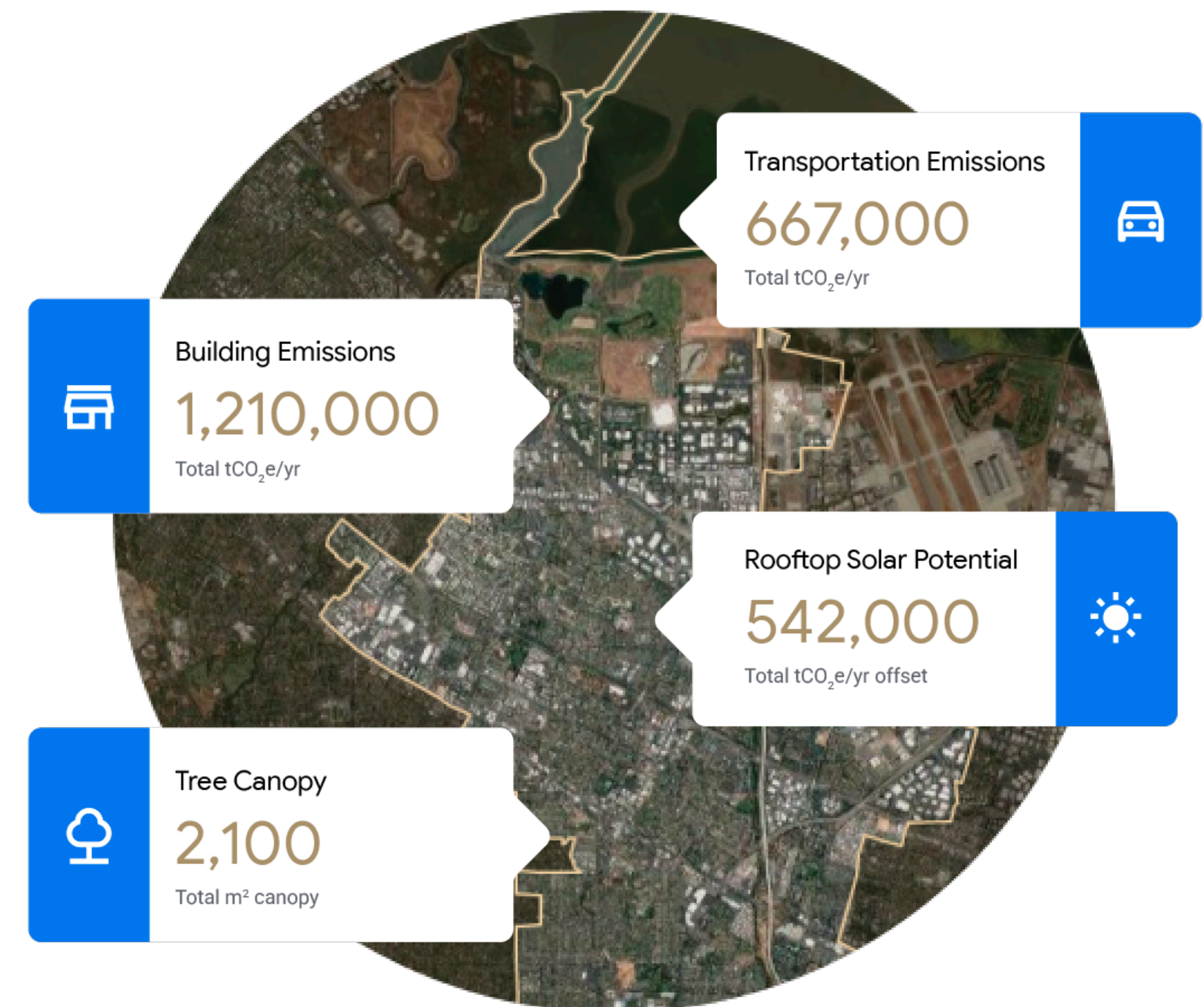
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[White paper](#)

[1 gigaton/year CO2e reduction in cities](#)

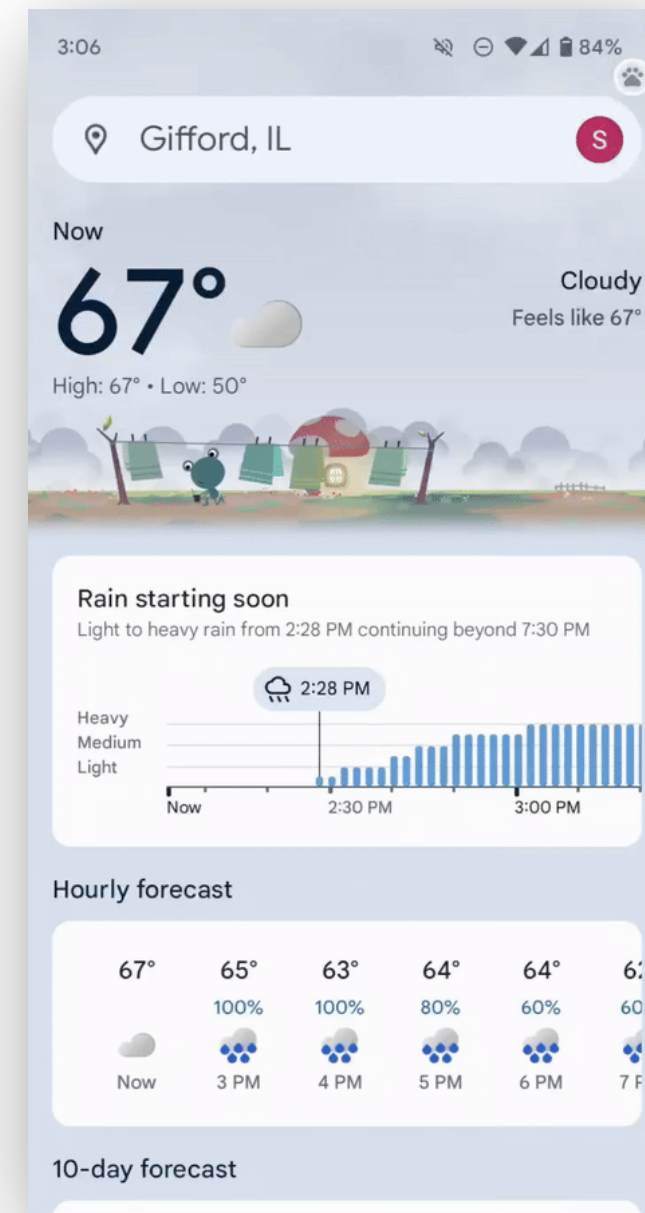
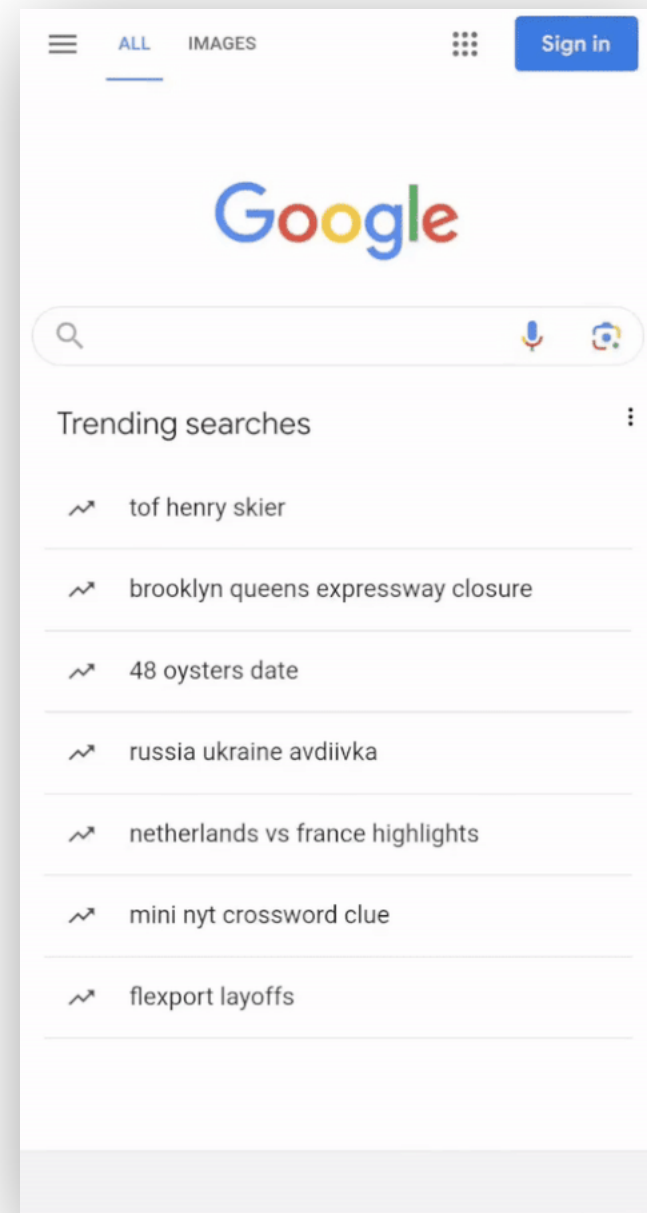


[Environmental Insights Explorer](#)

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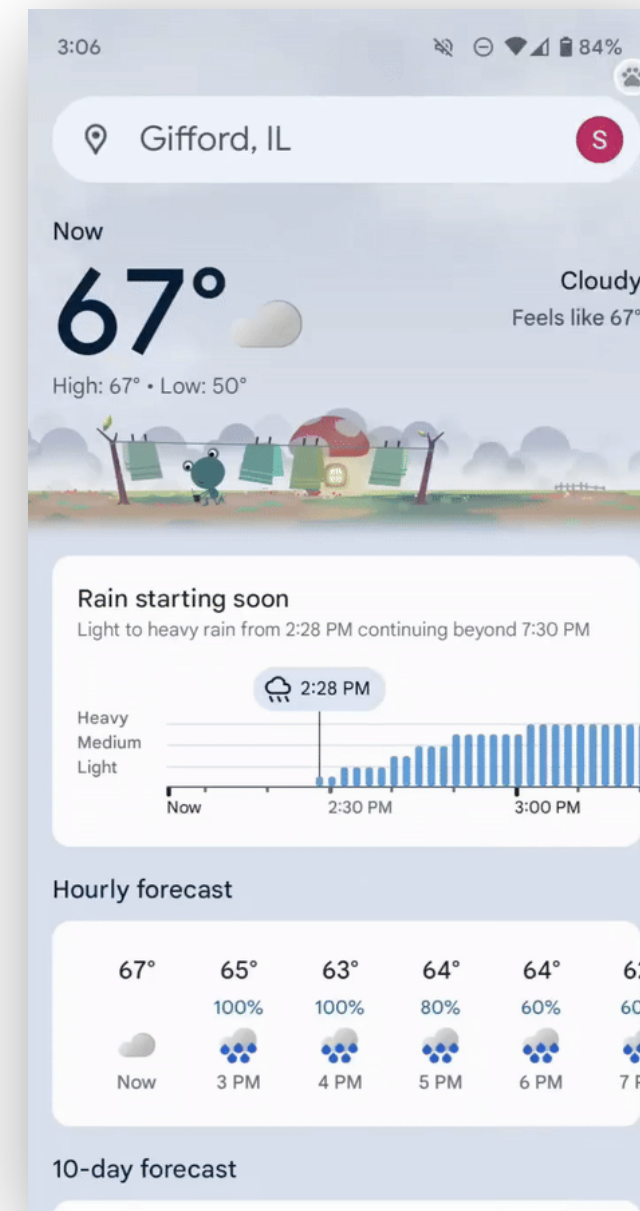
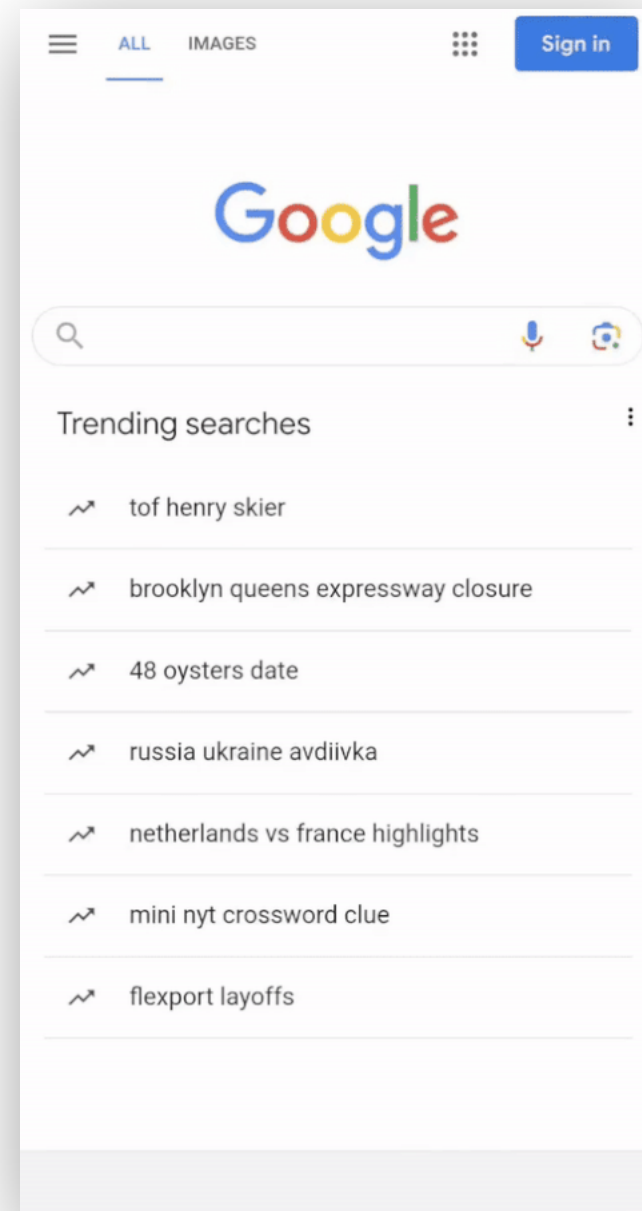
[Google Search: 24 h precipitation](#)



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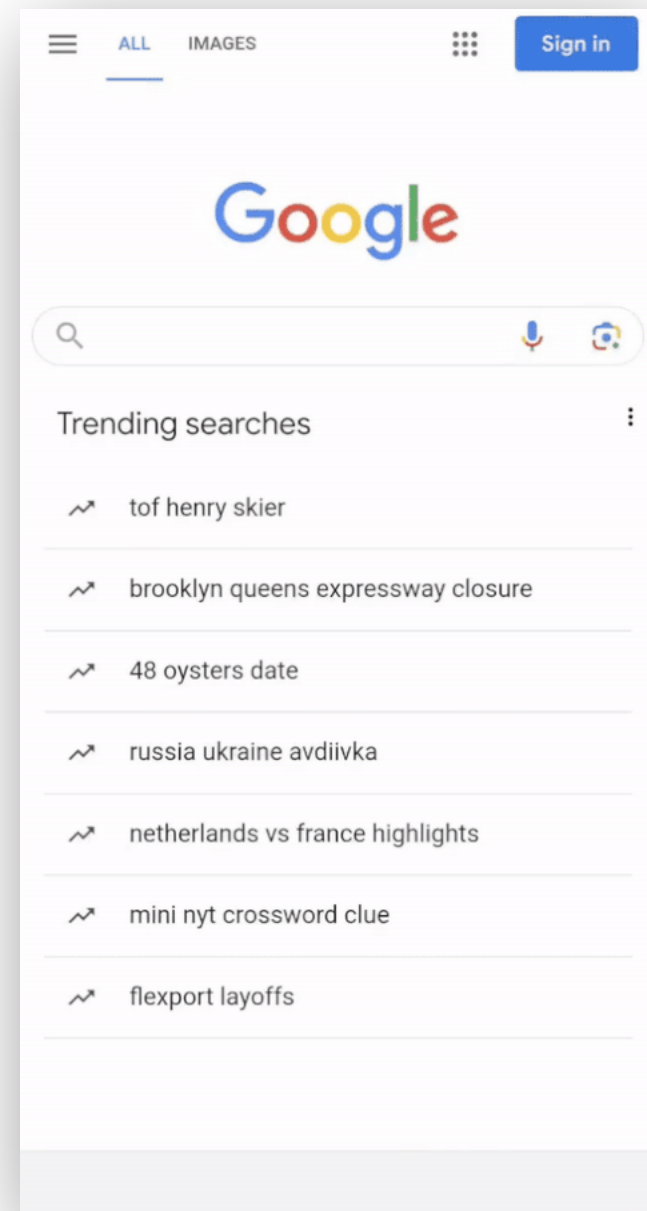
[Flood forecasting](#)



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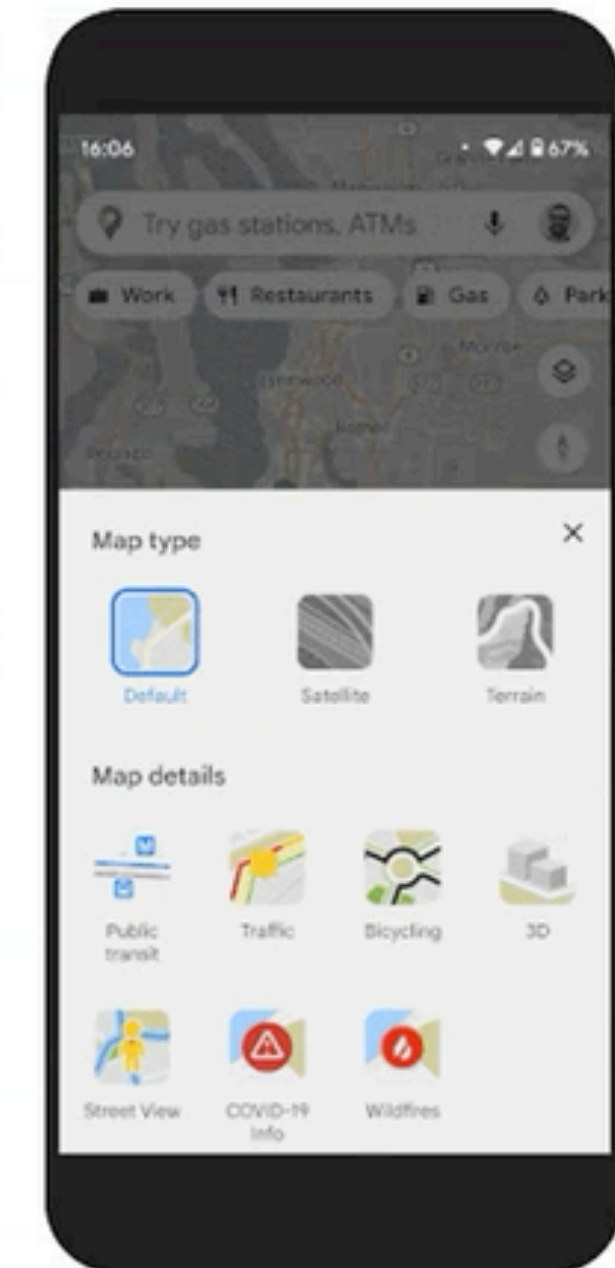
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Flood forecasting



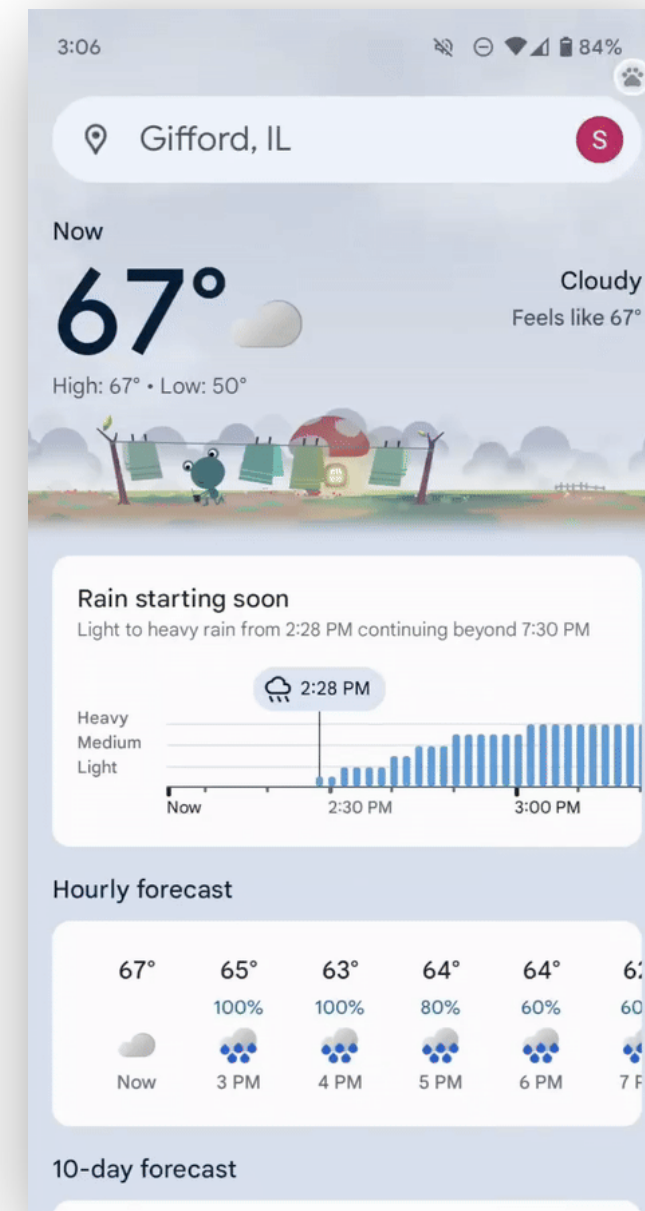
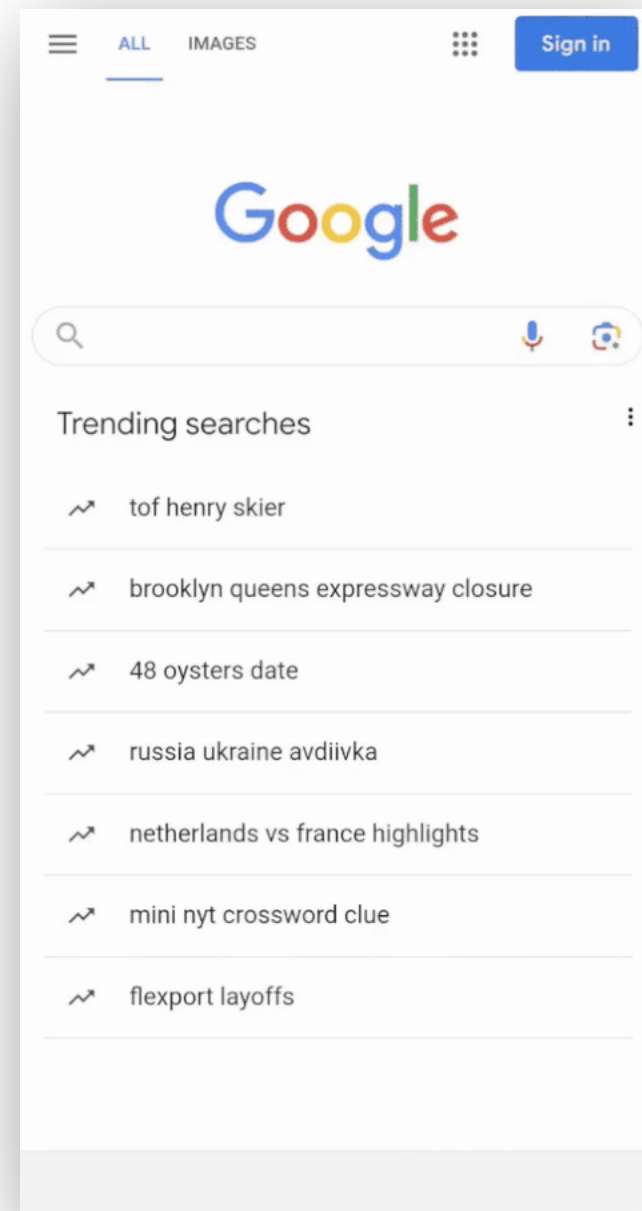
Wildfires



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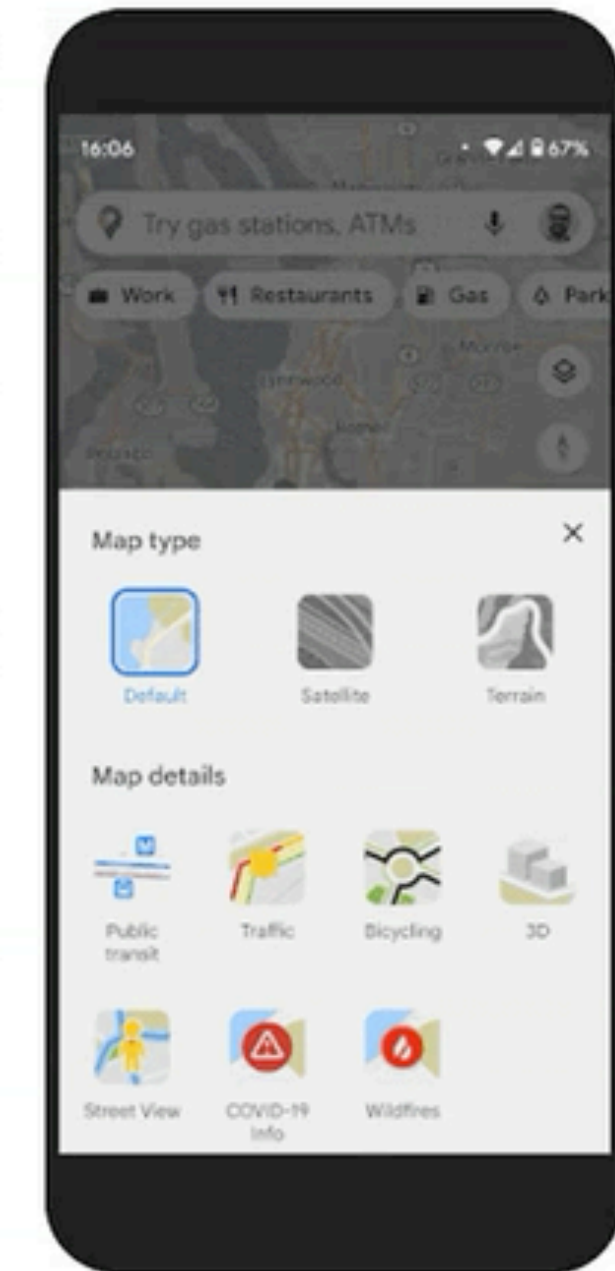
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Flood forecasting



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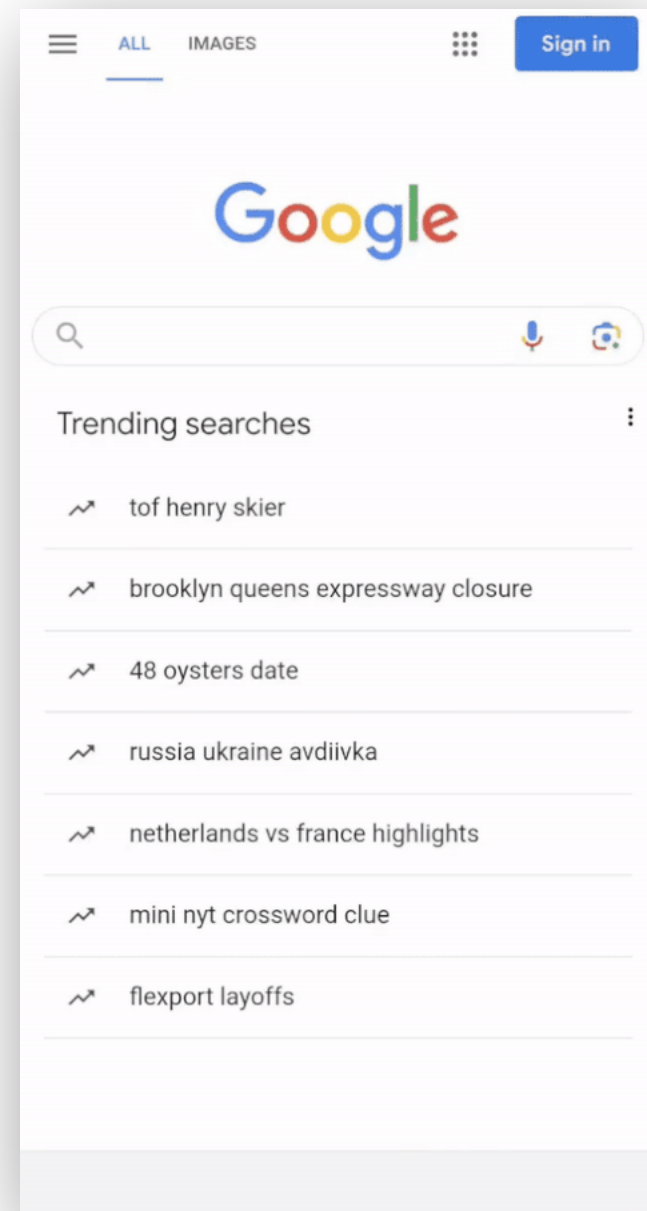
Extreme heat



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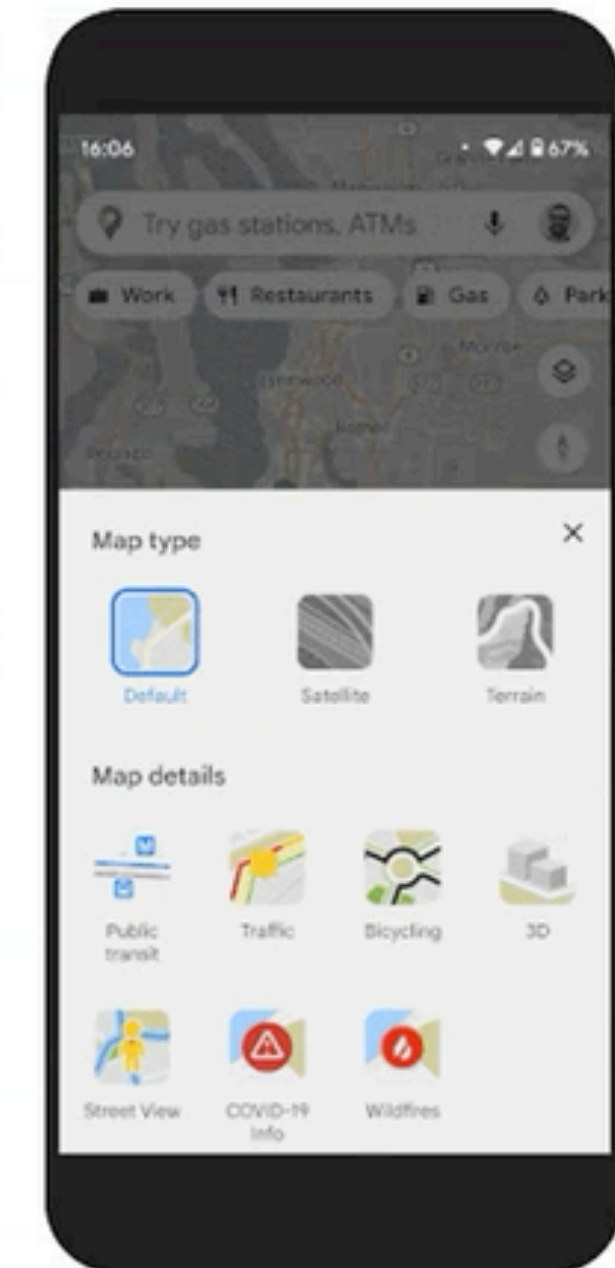
Google Search: 24 h precipitation



Flood forecasting



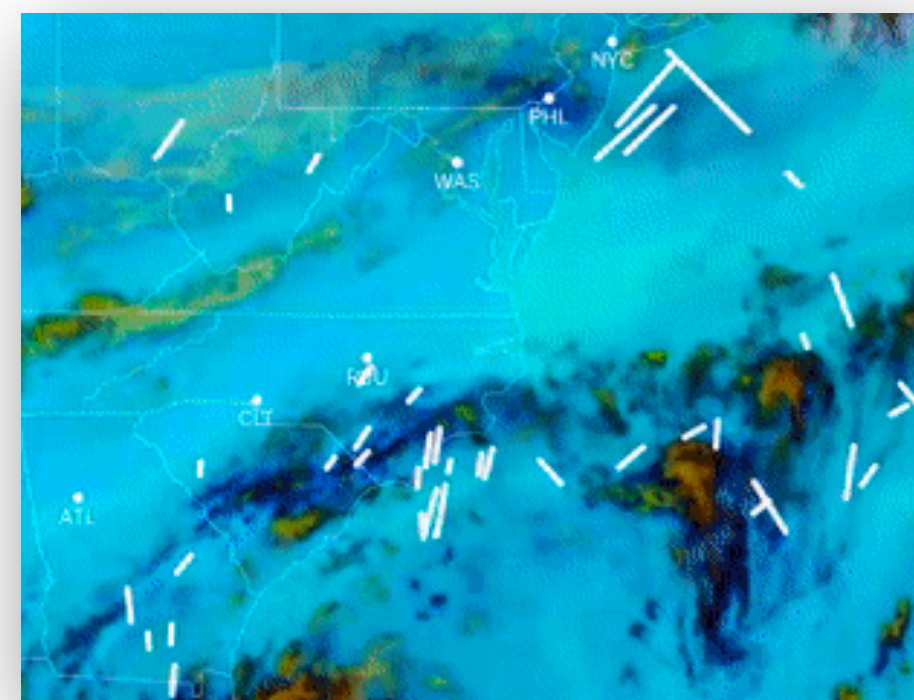
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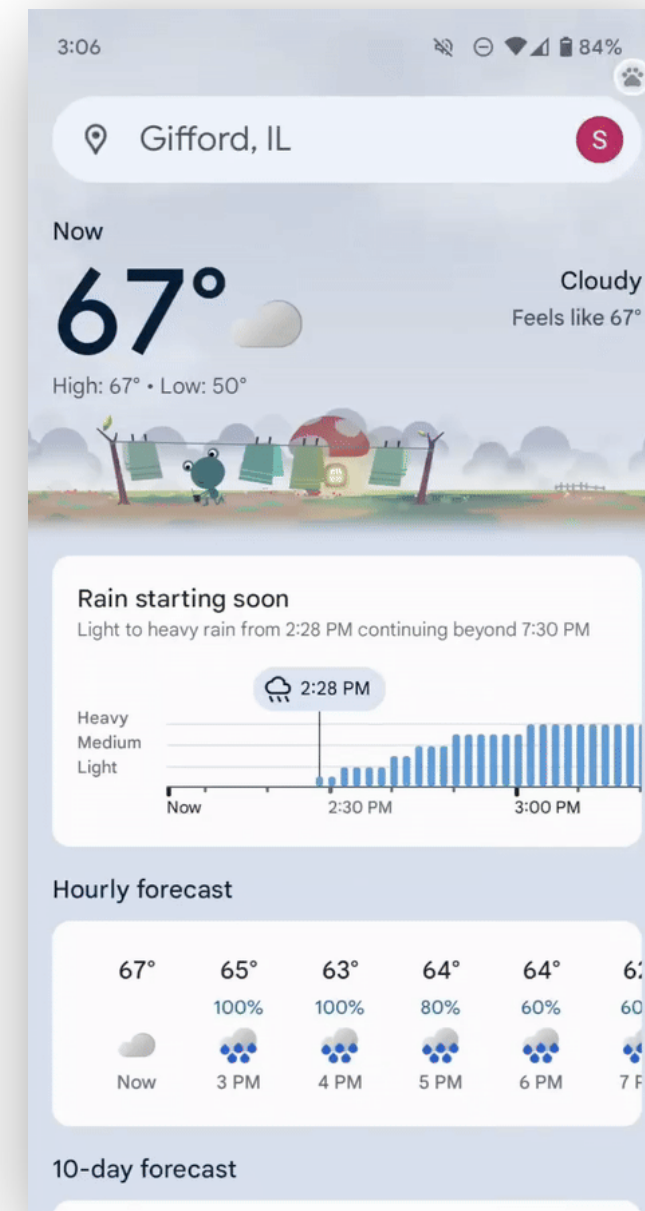
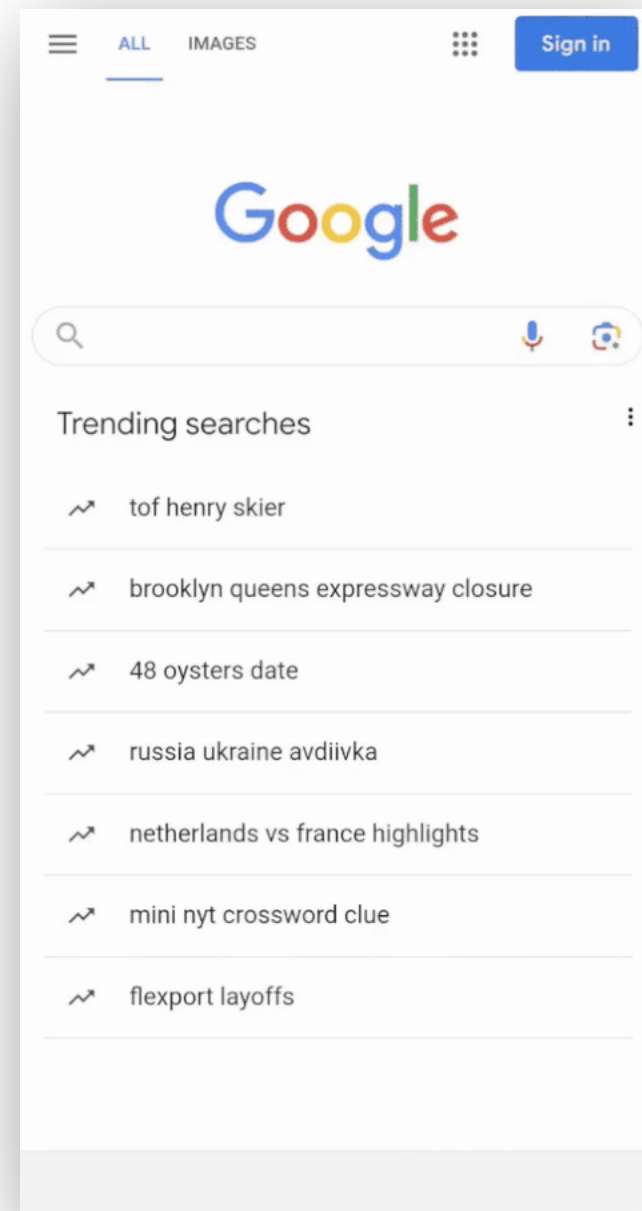
Contrails



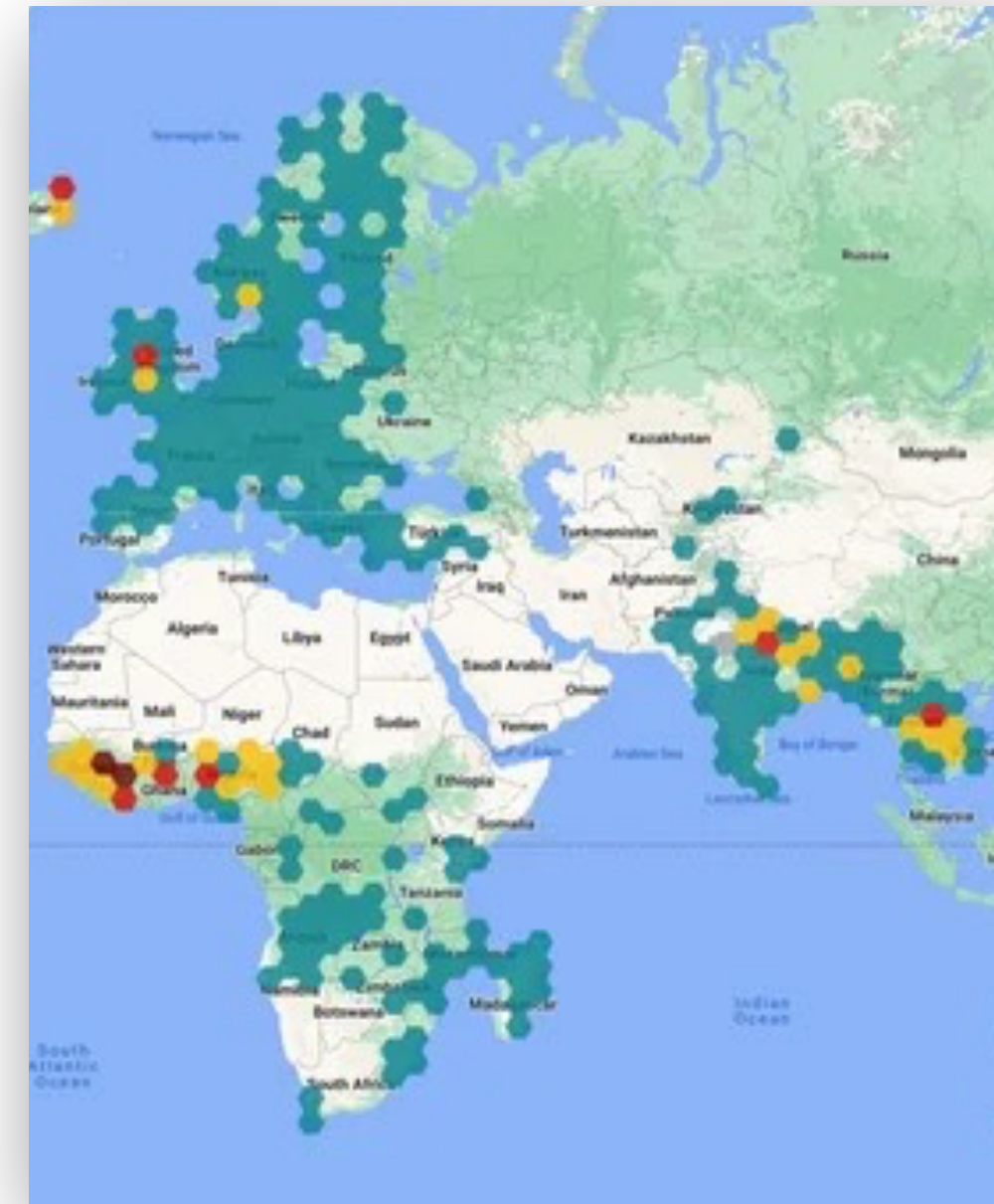
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Flood forecasting



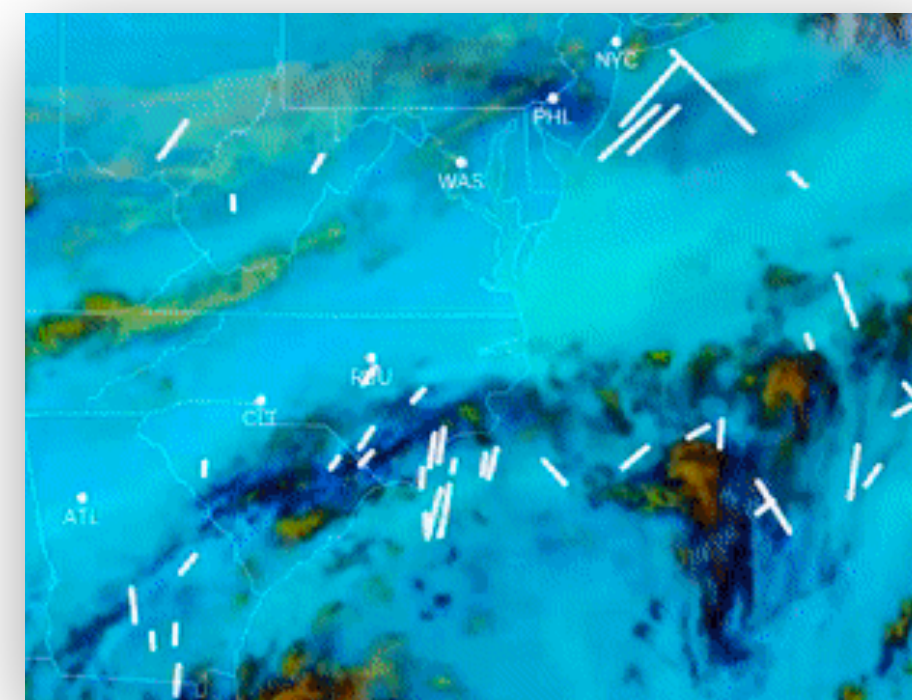
Wildfires



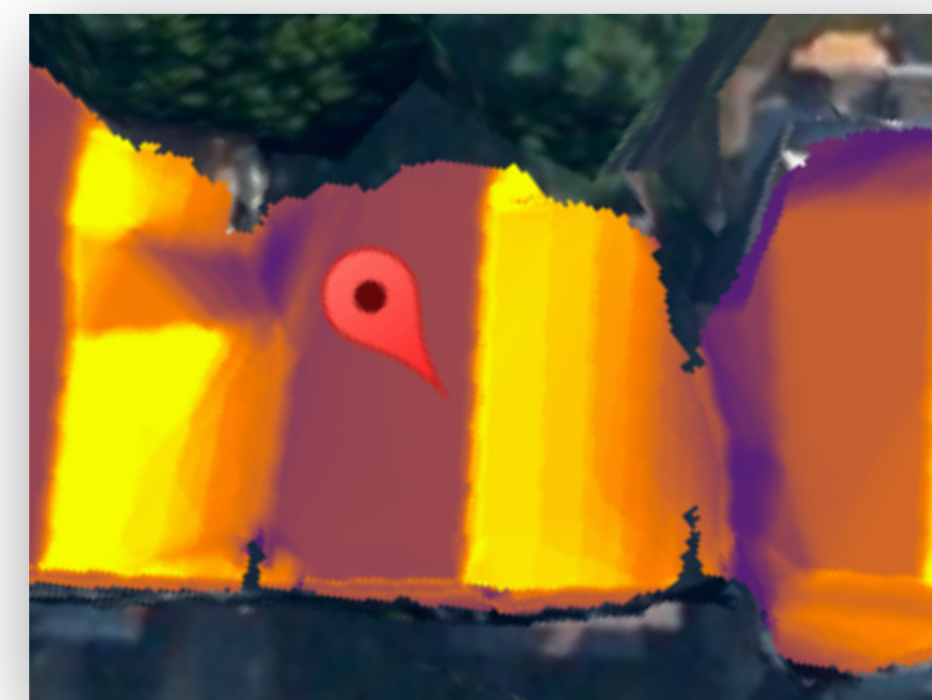
Extreme heat



Contrails



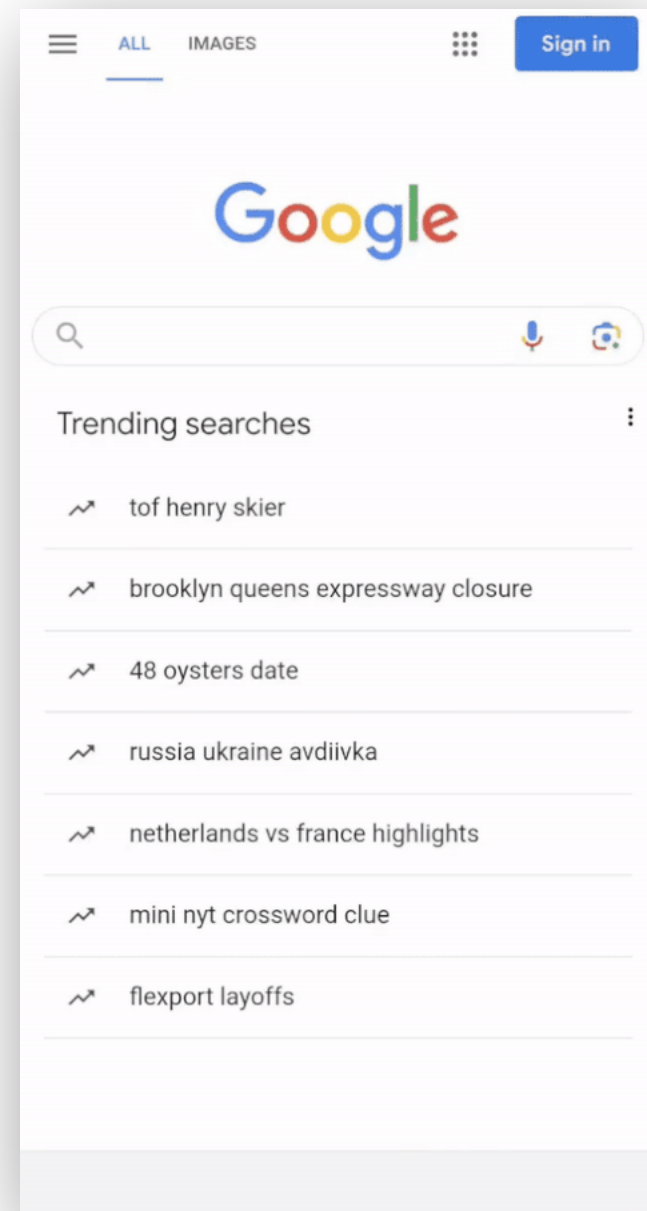
Sunroof



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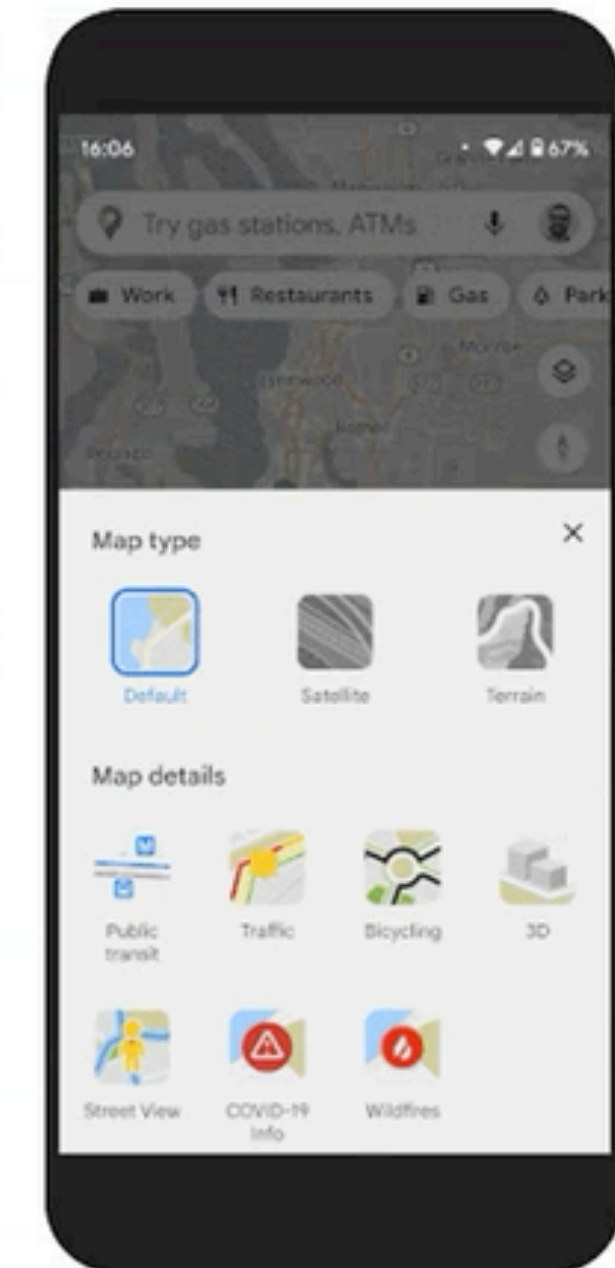
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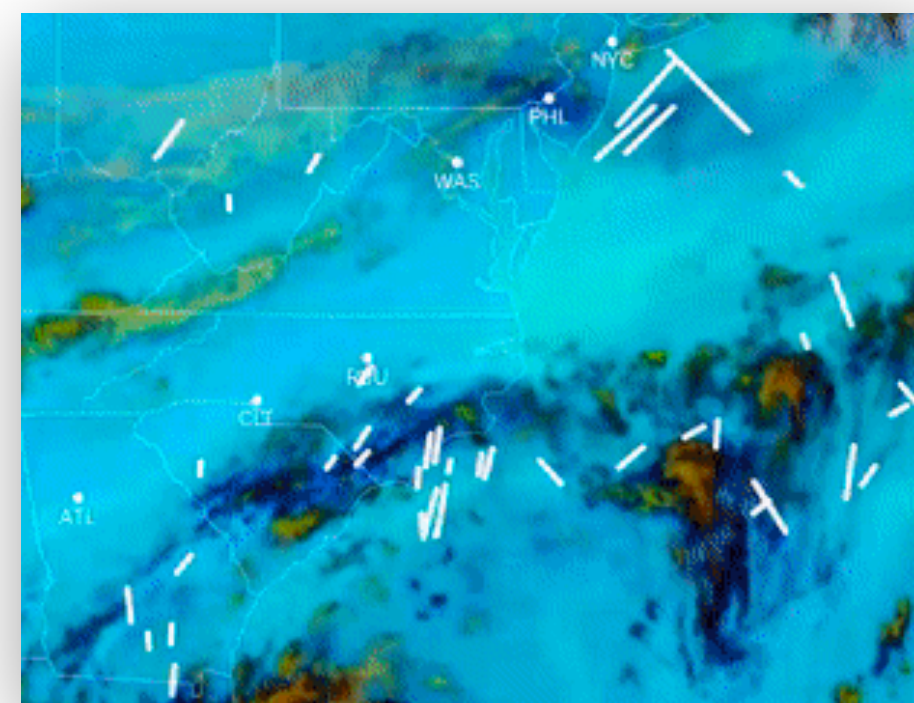
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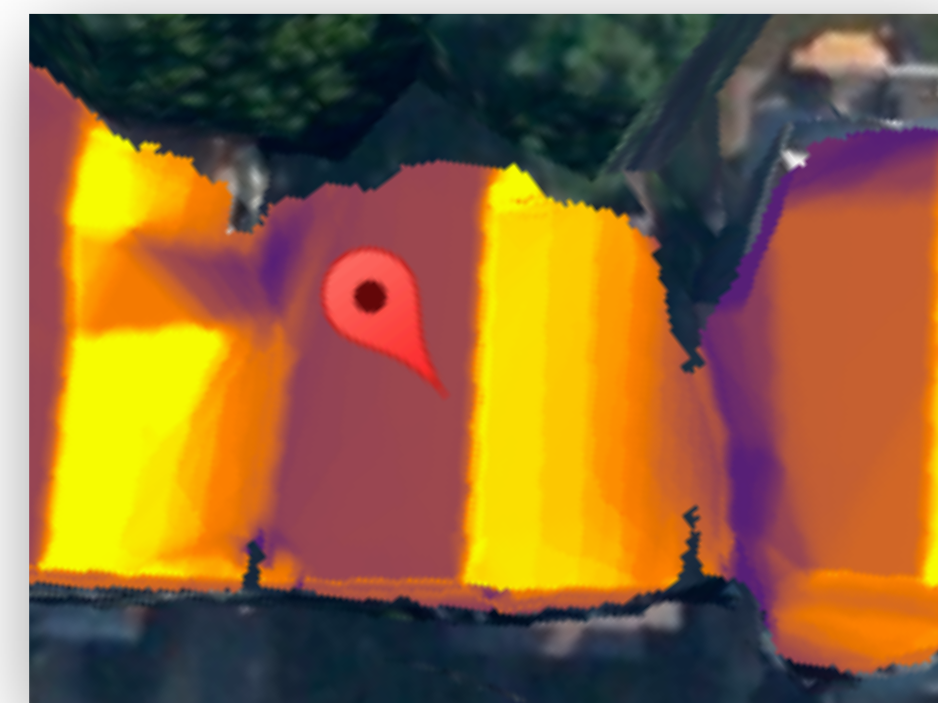
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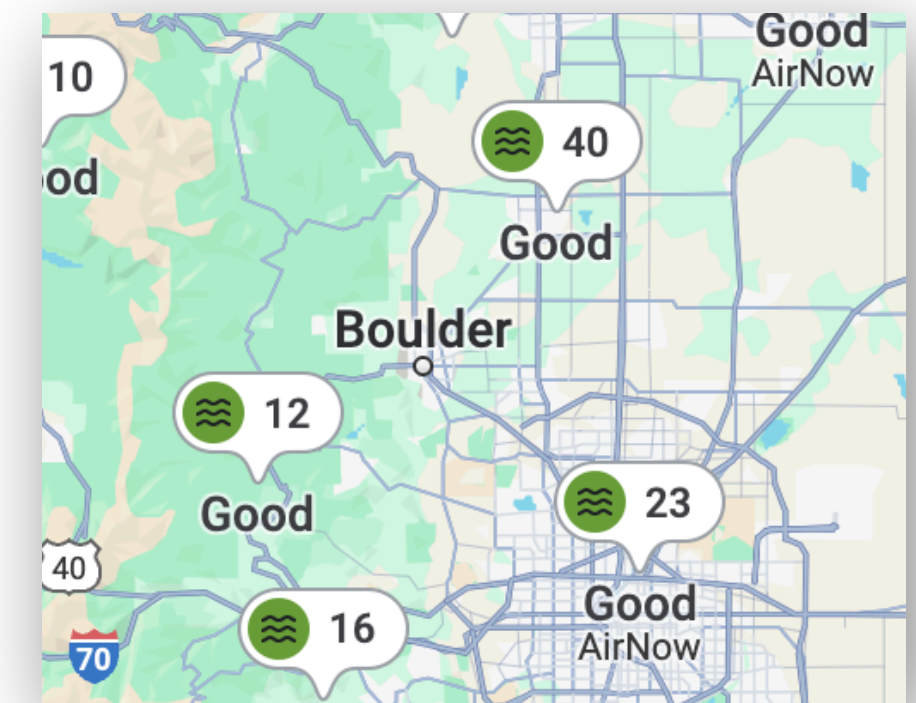
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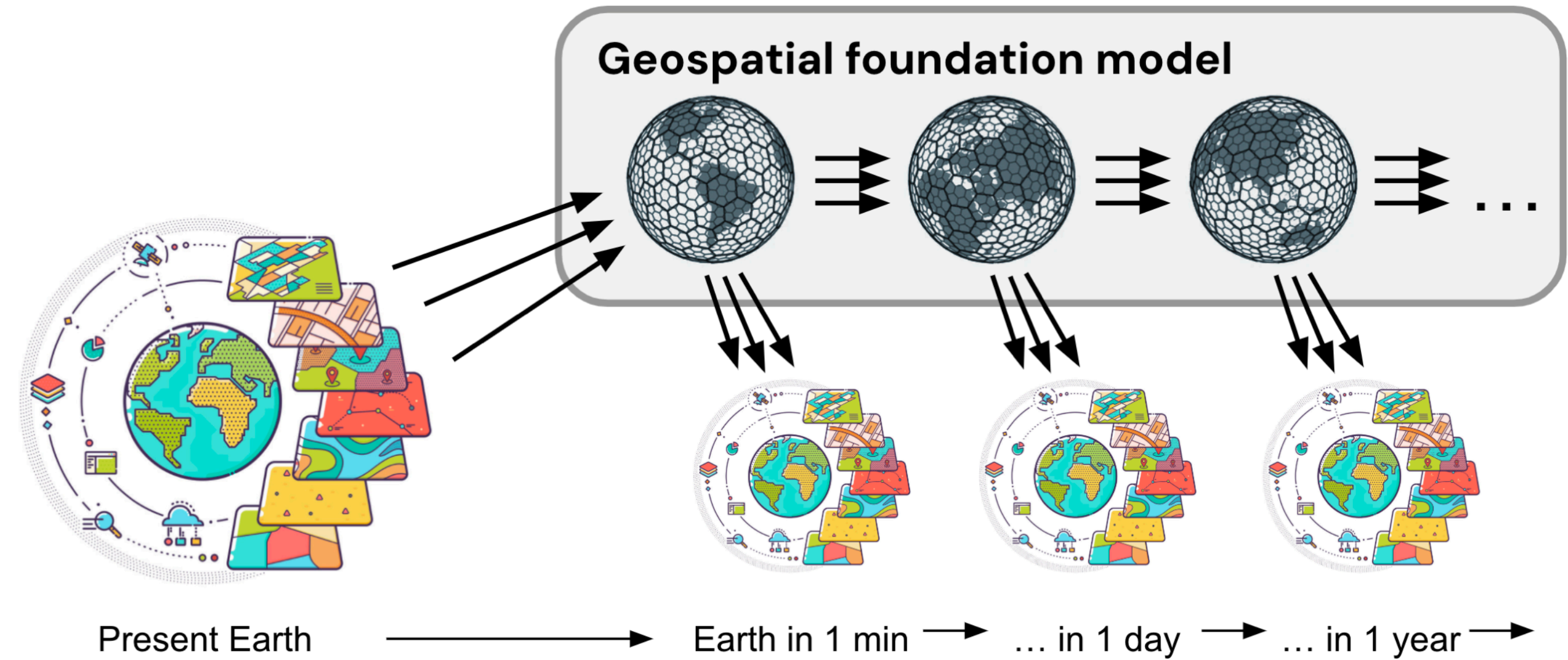
Air quality / BreezoMeter



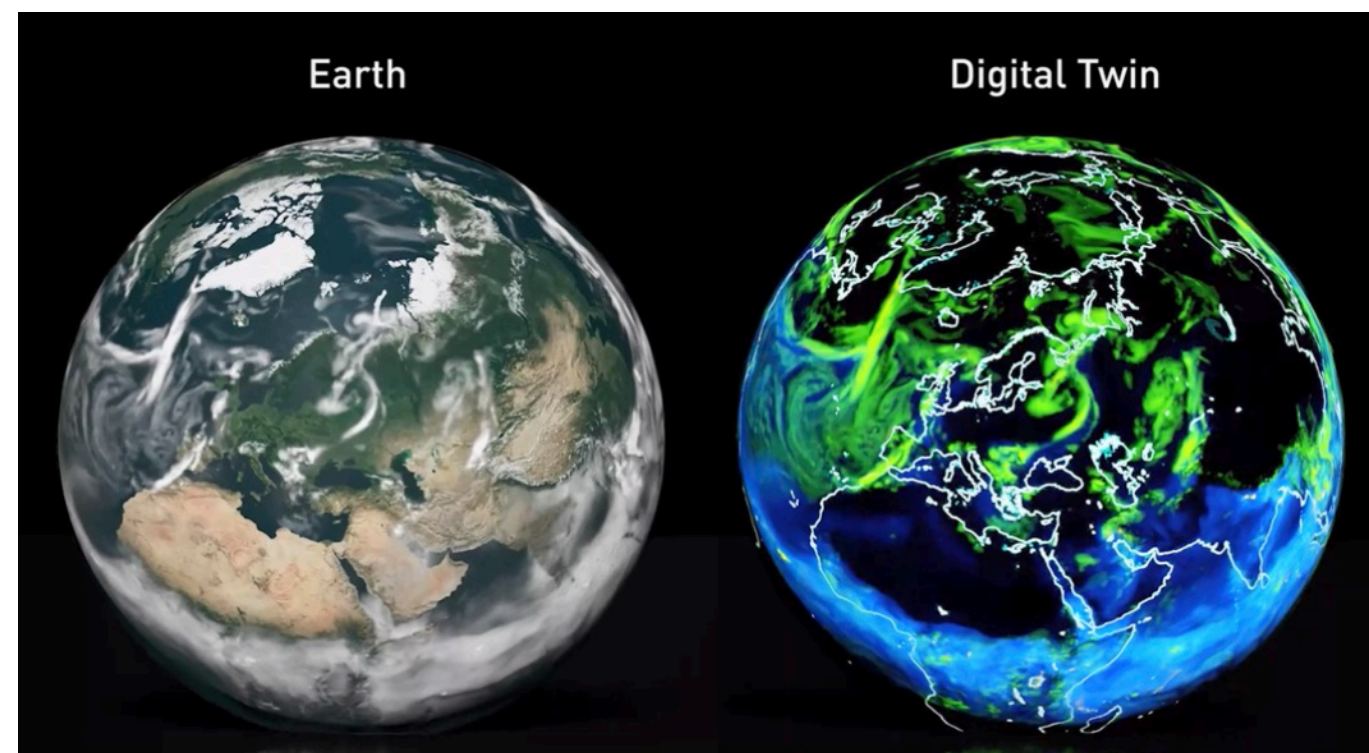
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Towards geospatial foundation models

- General idea: jointly model many diverse geospatial data sources
- Potential to capitalize on the strong coupling between the atmosphere, ocean, land, ice, ecology, human habitation and activity



NVIDIA's [Earth 2](#)



Microsoft's [ClimaX](#)



IBM / NASA's [geospatial foundation model](#)



How can industry partner with the weather community?

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Our aims

- Develop more accurate, efficient weather models -- we've only scratched the surface
- Support downstream use cases
- Advance our sustainability objectives
- Innovate methods for ML-based simulation

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We're very interested in building stronger relationships

- Potential technical areas to partner on:
 - Domain expertise
 - Datasets
 - Verification / benchmarks
- How to collaborate:
 - We have a partnerships team, and have lots of ways to proceed
 - I've covered our interests, but what does the weather community want, and want from us?

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Let's discuss!