Earth-2: Accelerating efforts to make AI digital twins of the Earth.

Mike Pritchard, Director of Climate Simulation Research, NVIDIA &
Associate Professor of Earth System Science, University of California, Irvine

Realistic climate simulation is a computational grand challenge

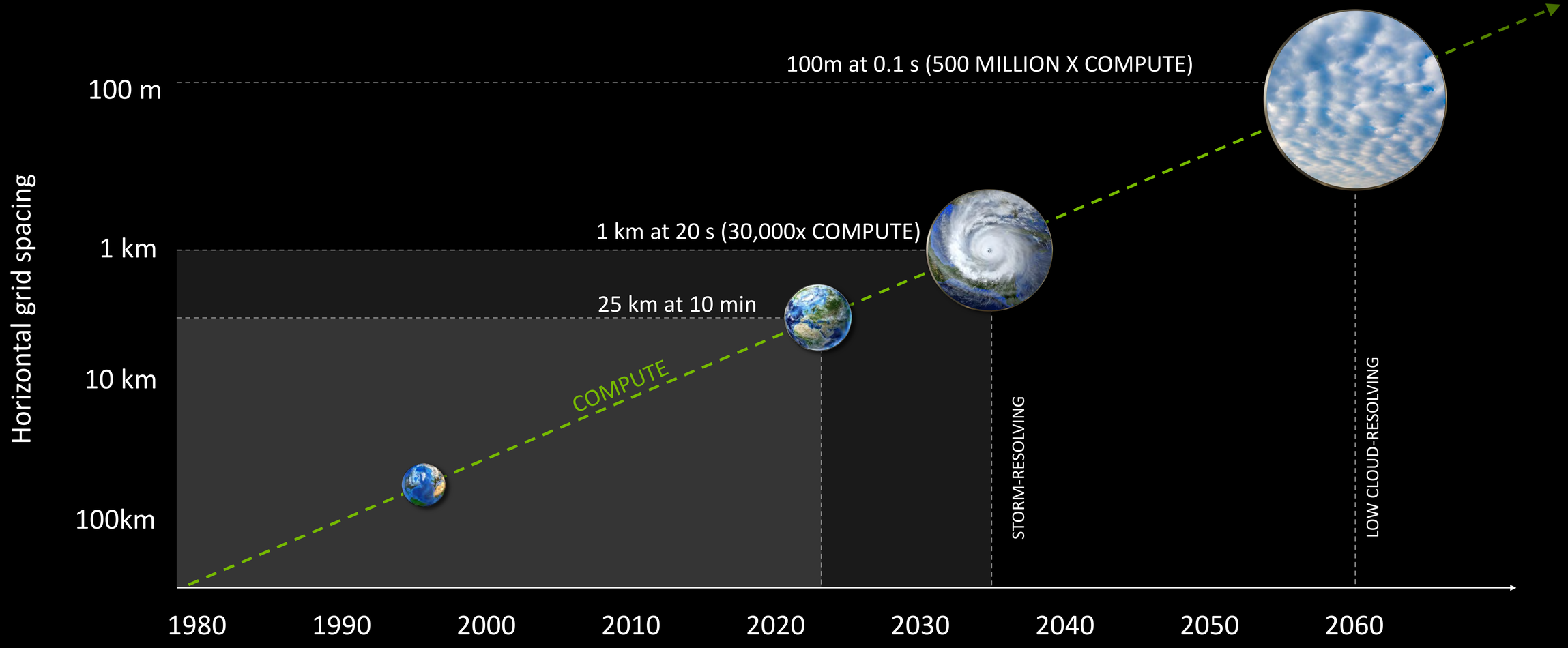


Figure adapted from: Schneider, T., Teixeira, J., Bretherton, C. *et al.* "*Climate goals and computing the future of clouds*". *Nature Climate Change* **7,** 3–5 (2017)

Building supercomputers for next-generation cloud-resolving climate models

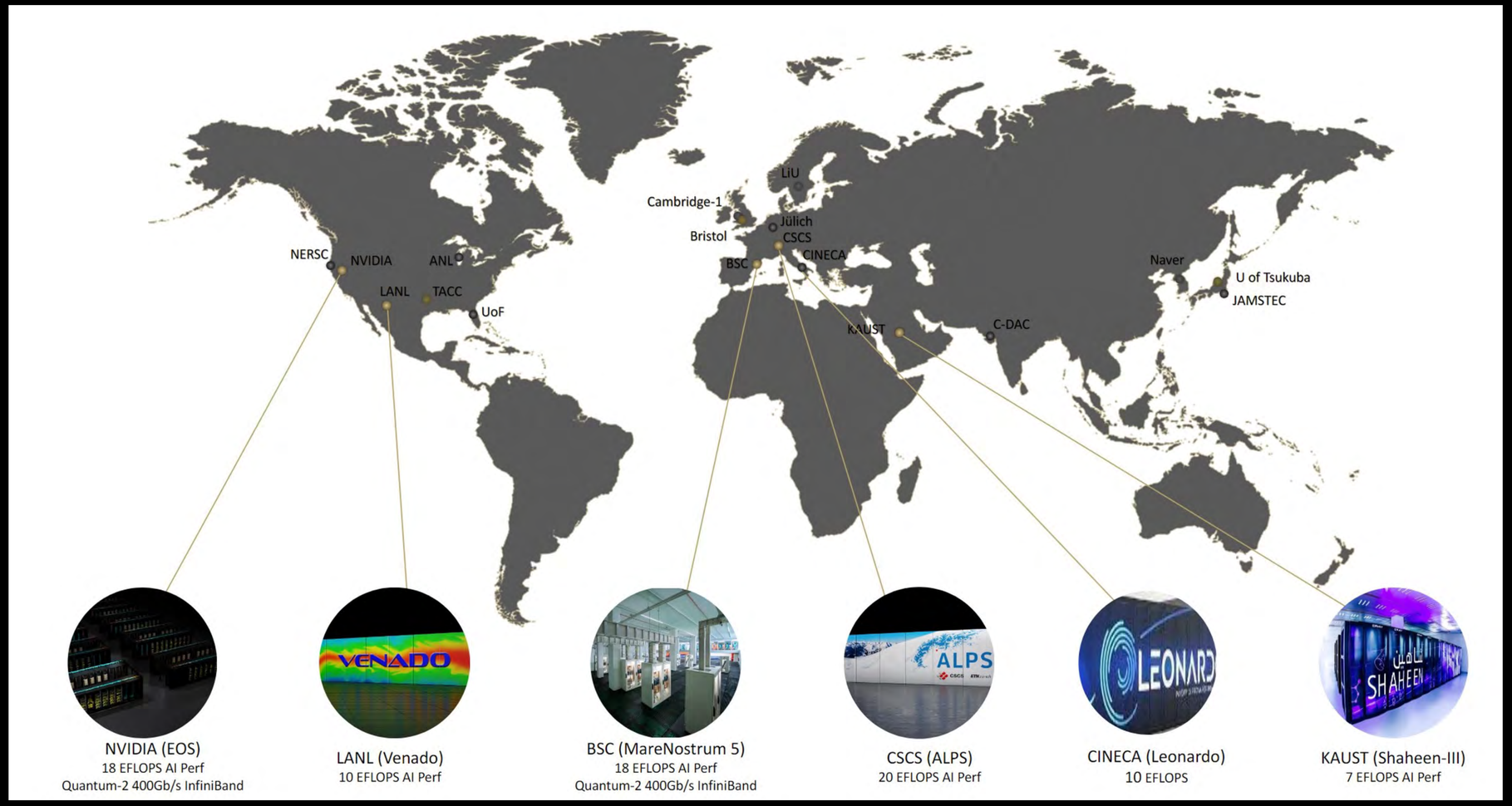
ALPS at the Swiss National Supercomputing Center: AI machine in 2023.

CSCS
Centro Svizzero di Calcolo Scientifico
Swiss National Supercomputing Centre

Hewlett Packard Enterprise

NVIDIA

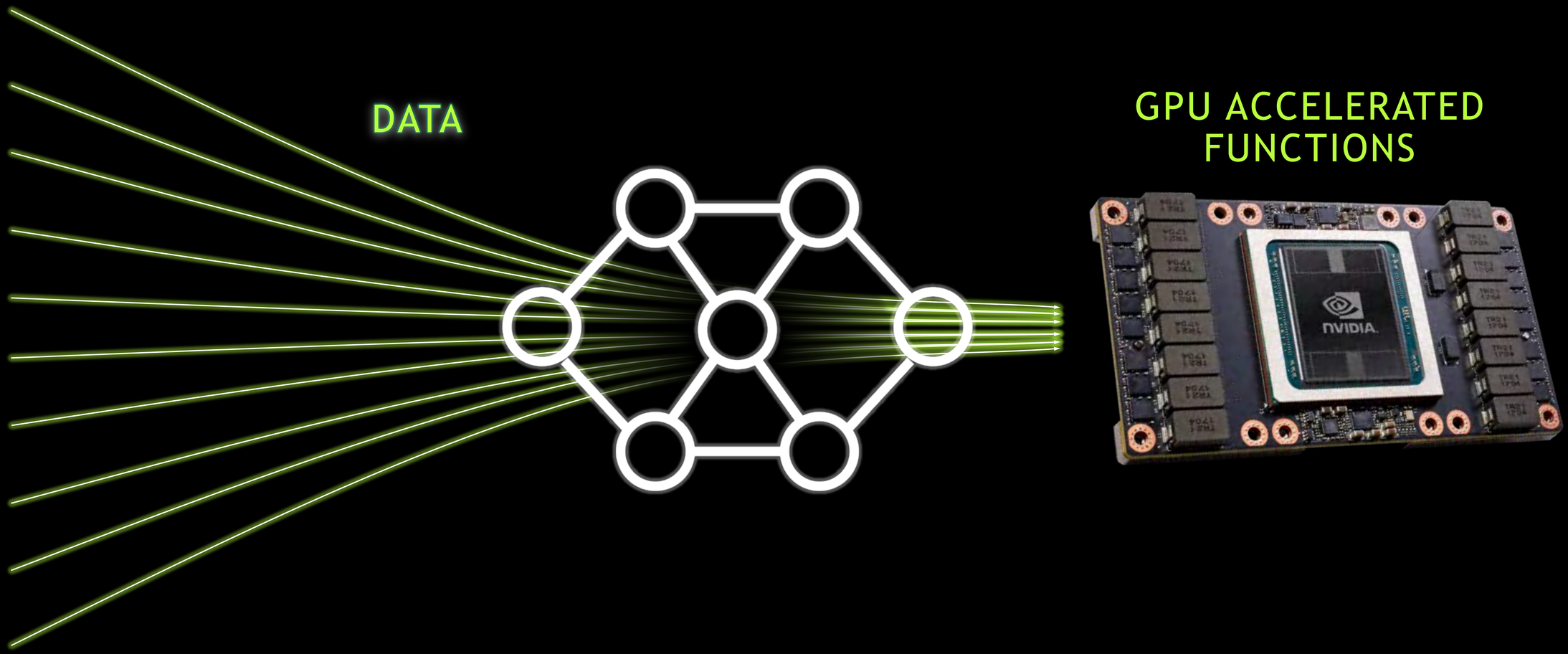
Exascale AI machines for Earth System Science



Worldwide technical collaborations with atmospheric modeling groups

	Model	Organizations	Funding Source
Global:			
	E3SM, MMF, HOMEXX, SCREAM	US DOE: ORNL, SNL	E3SM, ECP
	MPAS-A	NCAR, UWyo, IBM	WACA II
	FV3 Dycore	NOAA, AI2	SENA, AI2
	NUMA/NEPTUNE	US Naval Res Lab, NPS	ONR
	IFS	ECMWF	ESCAPE, US DOE
	GungHo/LFRic	MetOffice, STFC	PSyclone
	ICON	DWD, MPI-M, CSCS, MCH	PASC ENIAC
	GEOS-5	NASA GMAO	NASA
	CLIMA/NUMA	CLiMA (NASA JPL, MIT, NPS)	Private, US NSF
Regional:			
	AROME	Meteo France	MF/CNRS
	COSMO	MCH, CSCS, DWD	PASC GridTools
	AceCAST-WRF	TempoQuest	Venture backed

Enabling the world's AI factories with GPU acceleration



Will AI leapfrog Moore's Law to attain high-res climate prediction?

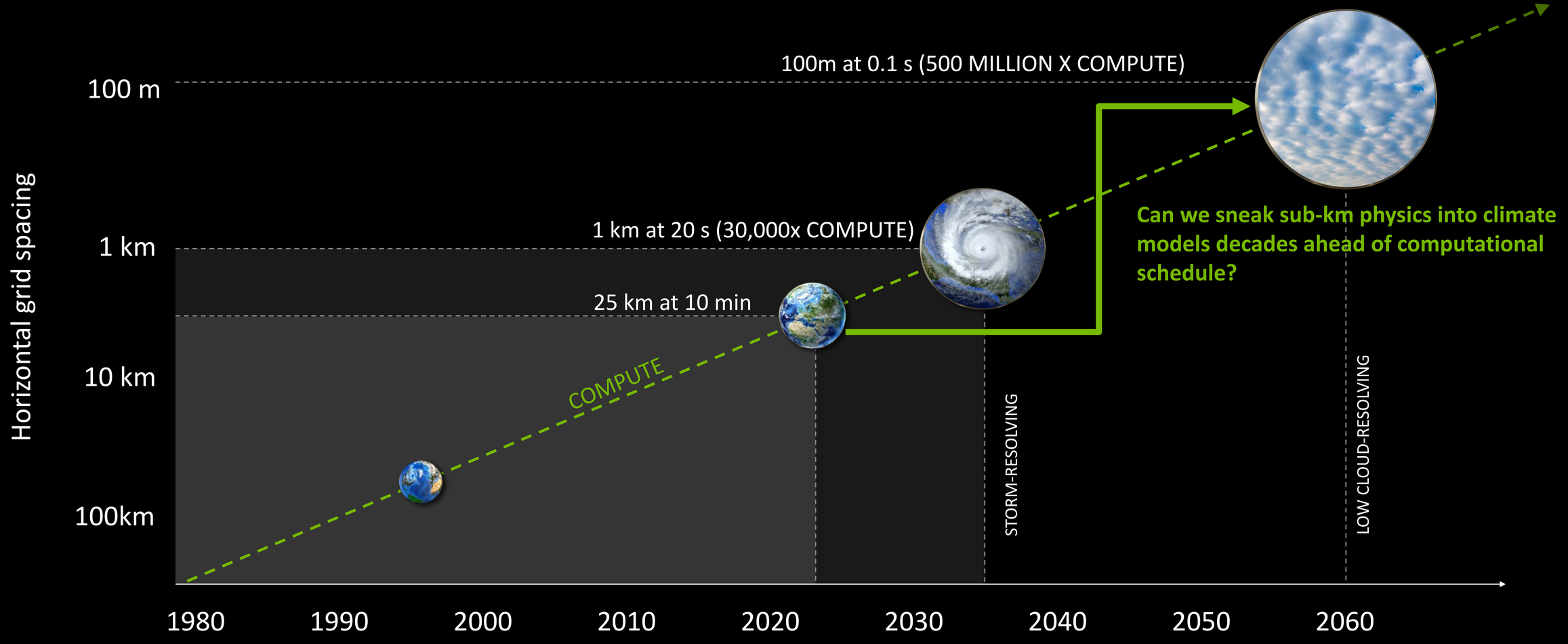


Figure adapted from: Schneider, T., Teixeira, J., Bretherton, C. *et al.* "*Climate goals and computing the future of clouds*". *Nature Climate Change* **7**, 3–5 (2017)

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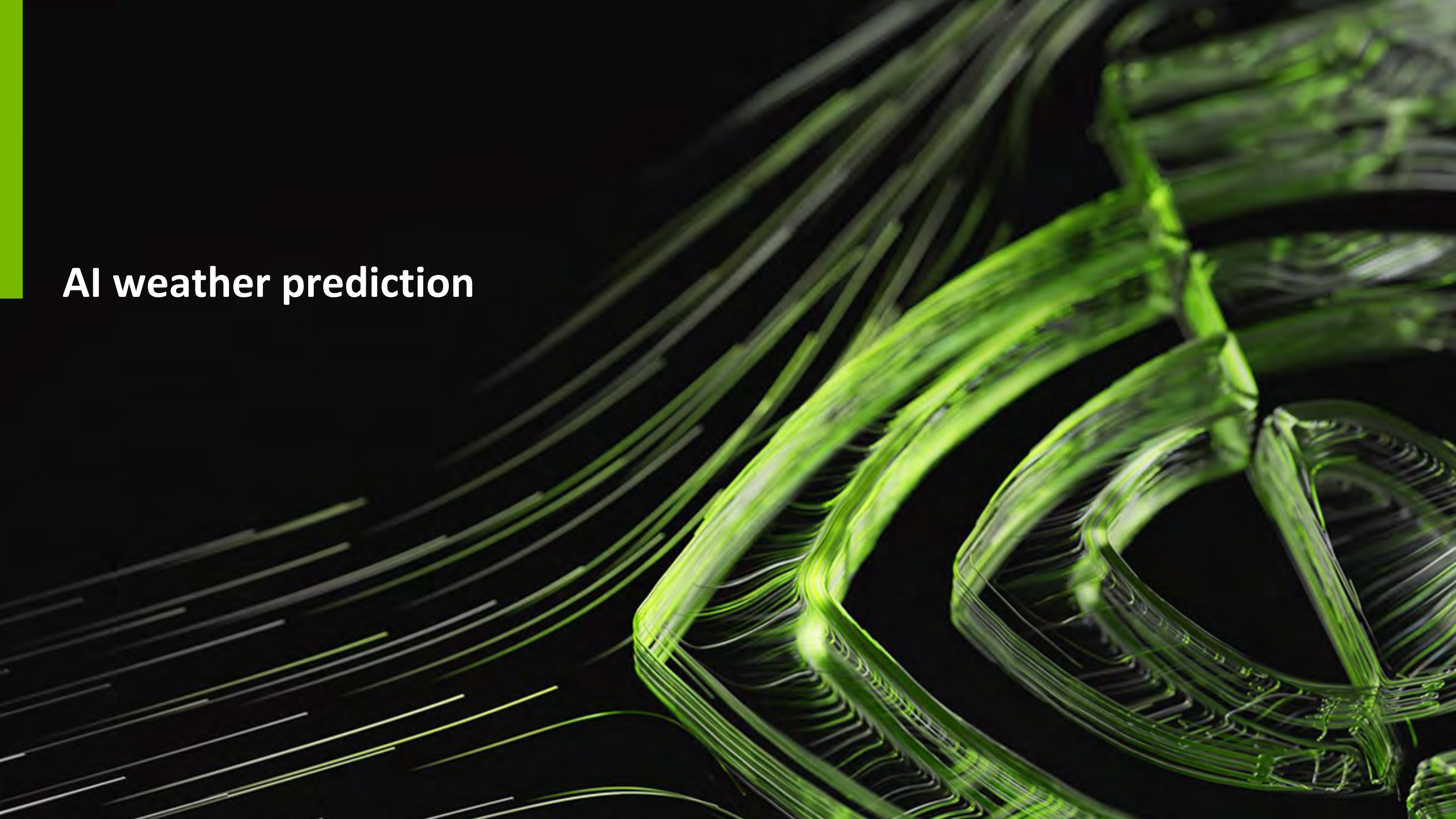
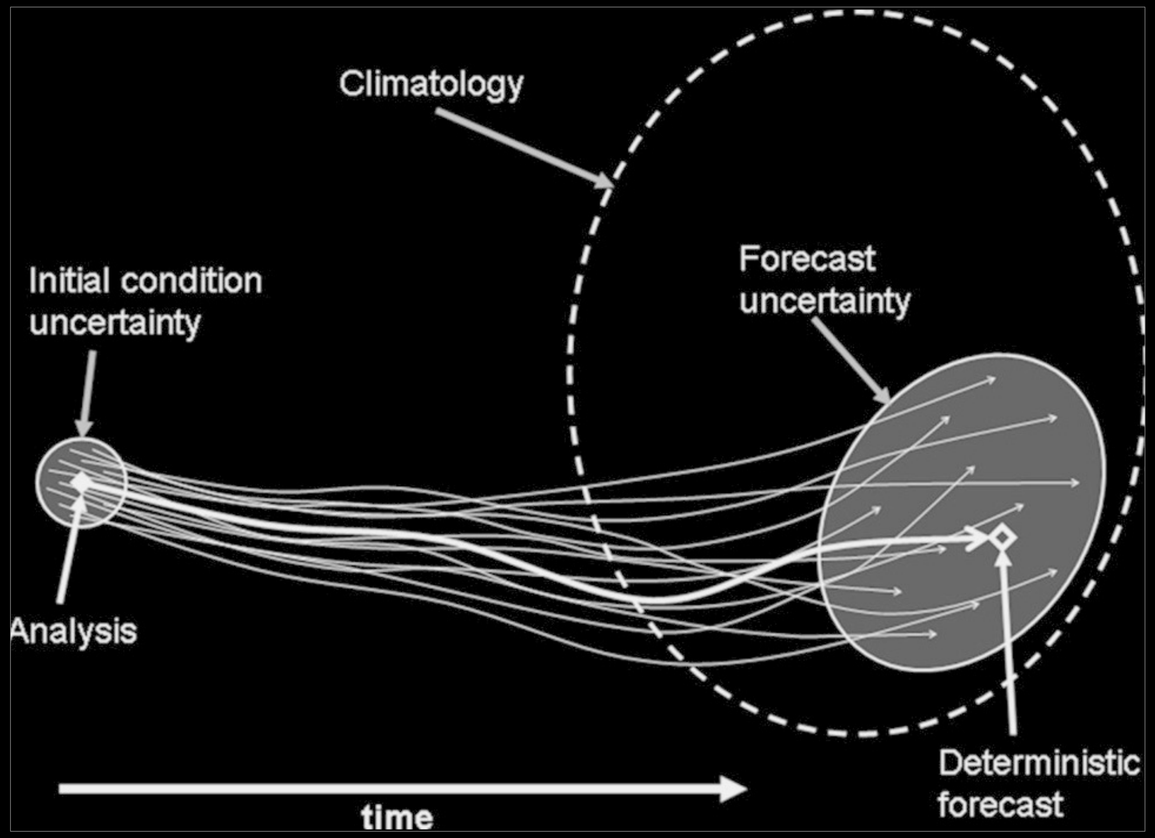
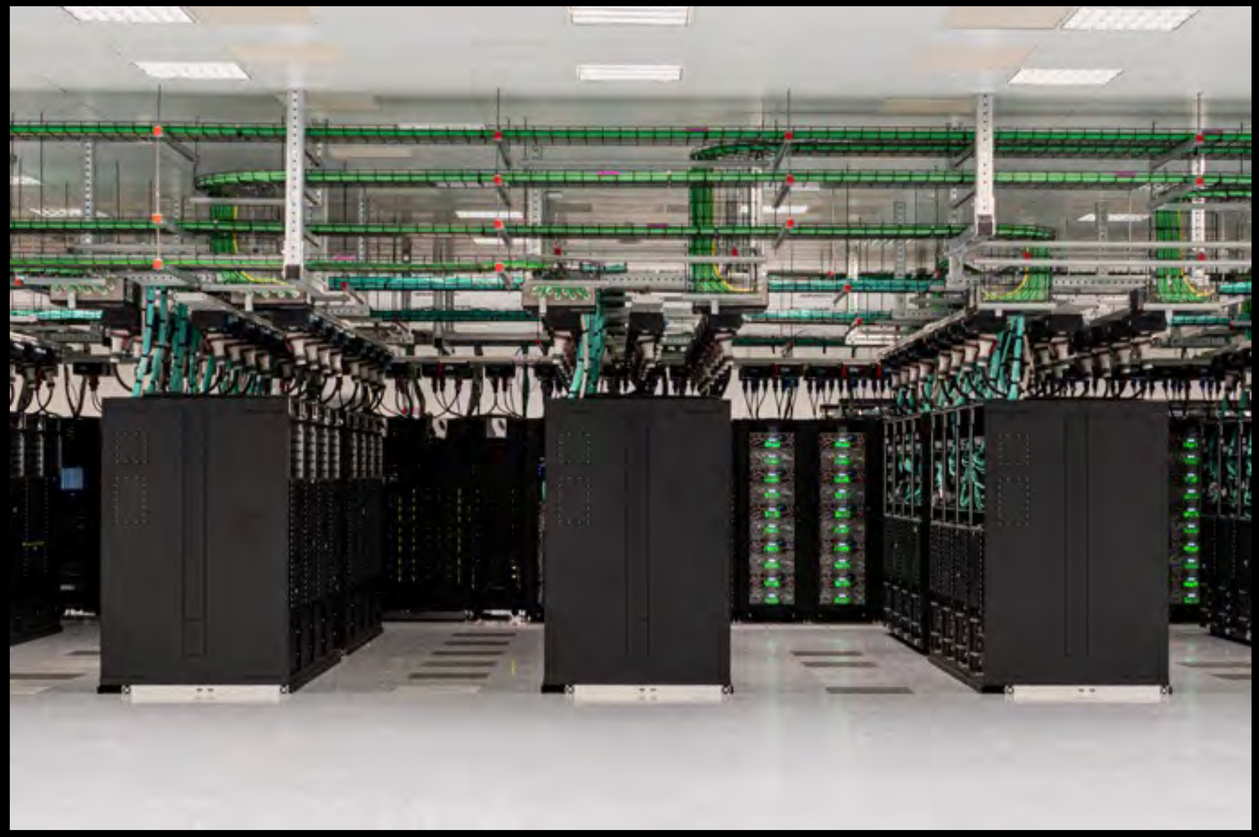
AI weather prediction



Context: Classical Deterministic Numerical Weather Prediction (NWP)

Solving F = ma for incompressible fluid on rotating sphere + lots of tricks

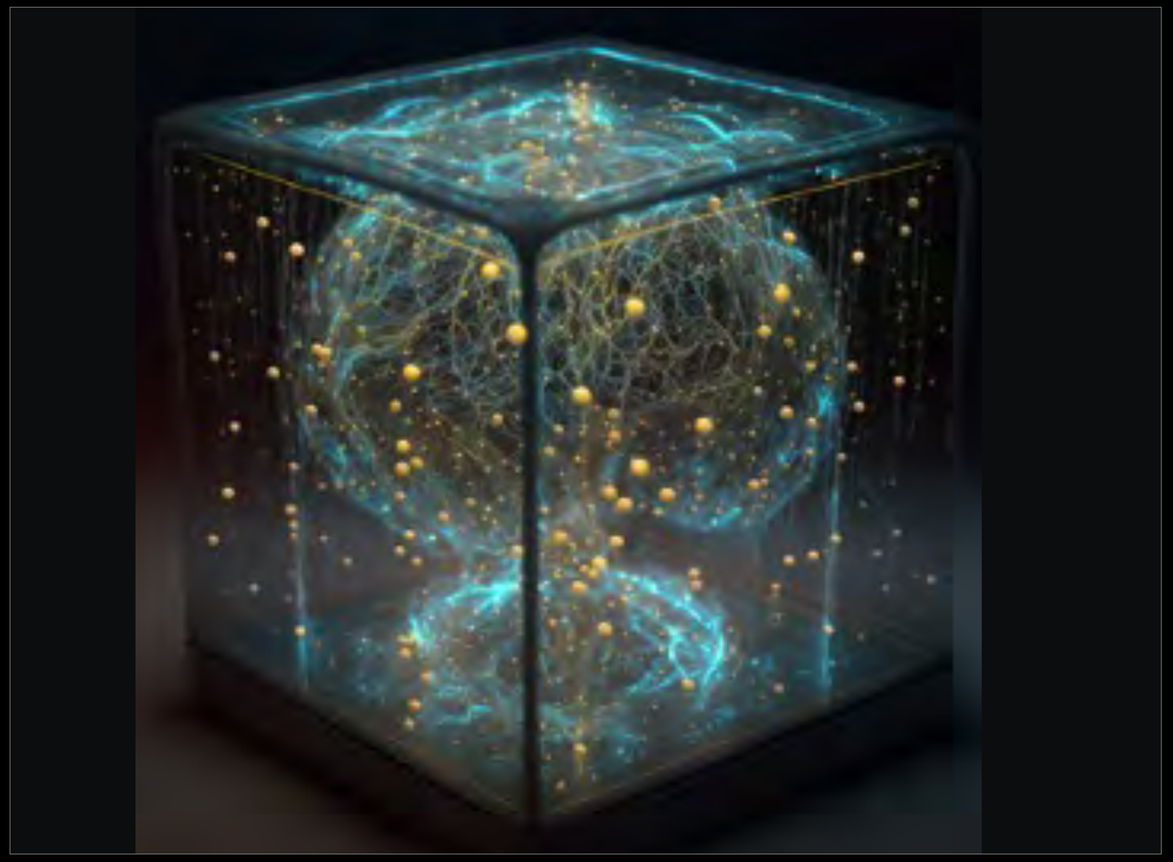




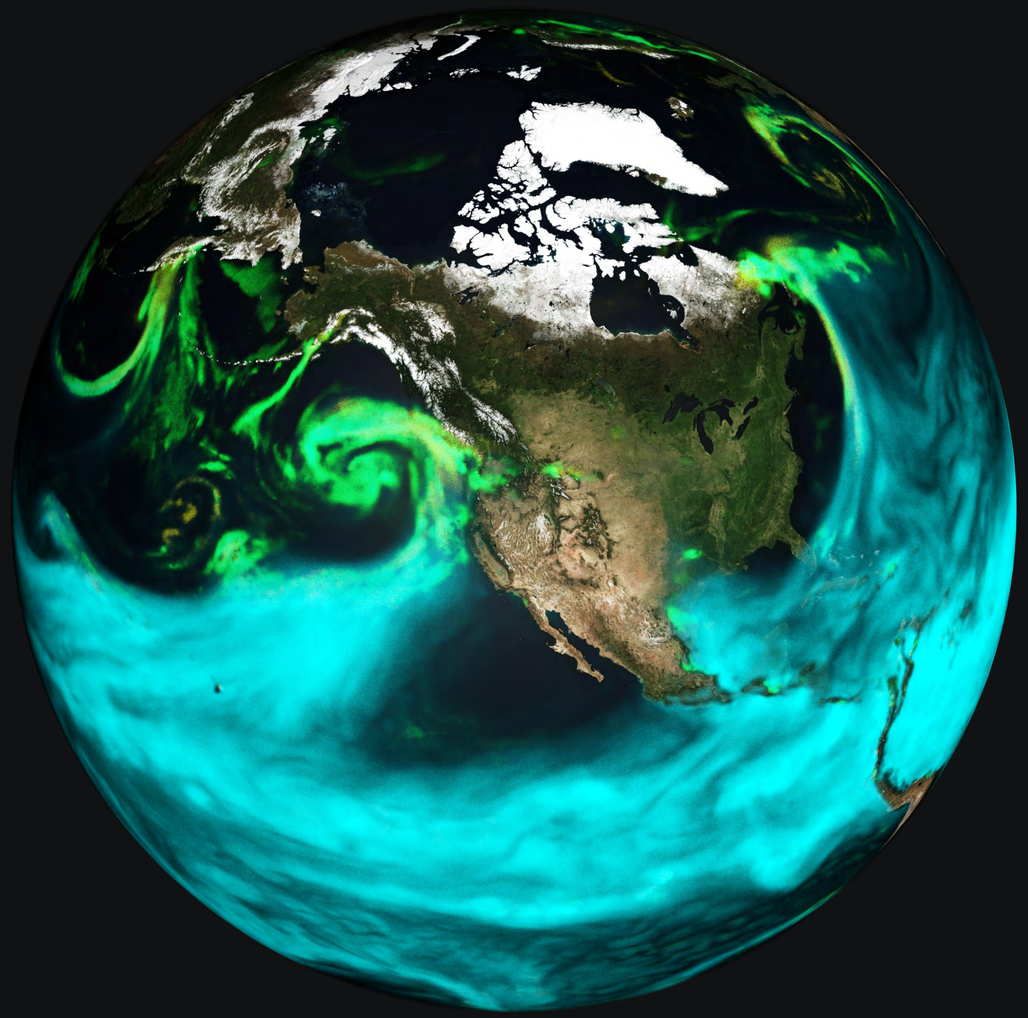
HPC-intensive: European Center for Medium Range Weather Forecasting

AI weather prediction, what's different?

Training transformers to predict the next 6-hour's temperatures, winds, surface pressure with data.



- Like training ML to make 1080p video
- But with > RGB channels (temperatures, winds, pressures…)
- # training samples = length of satellite record (~ 15k days)
- Can be stood up by small teams within tech companies.
- Is producing skill gains rapidly.



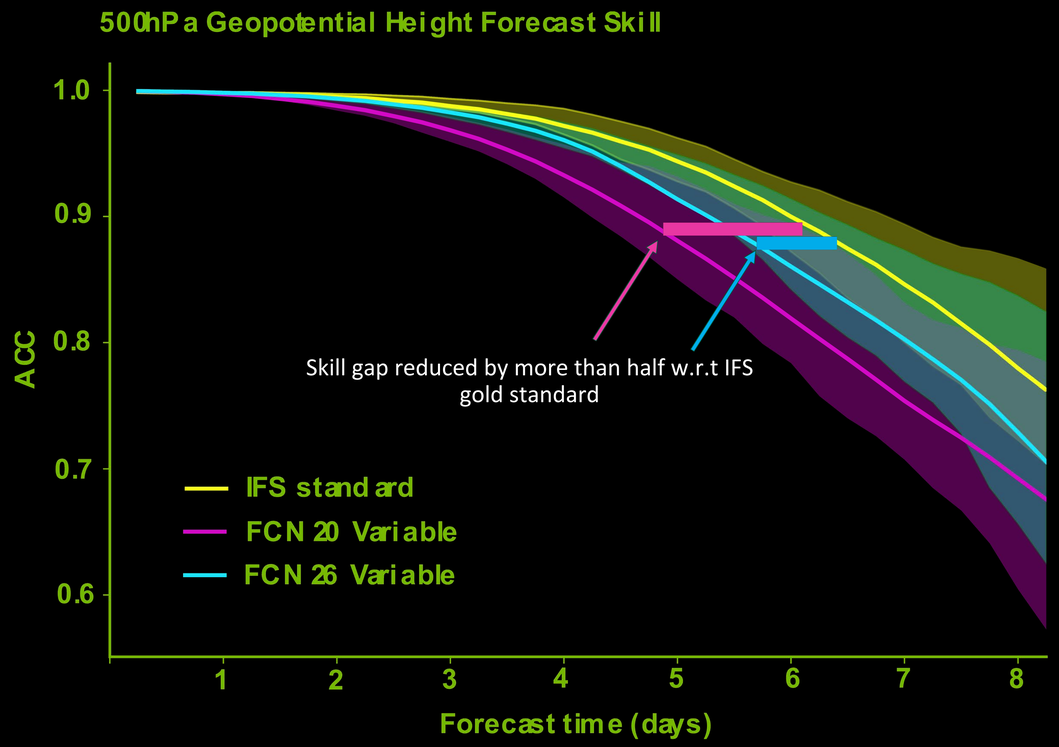
AI Weather Simulation with NVIDIA's FourCastNet

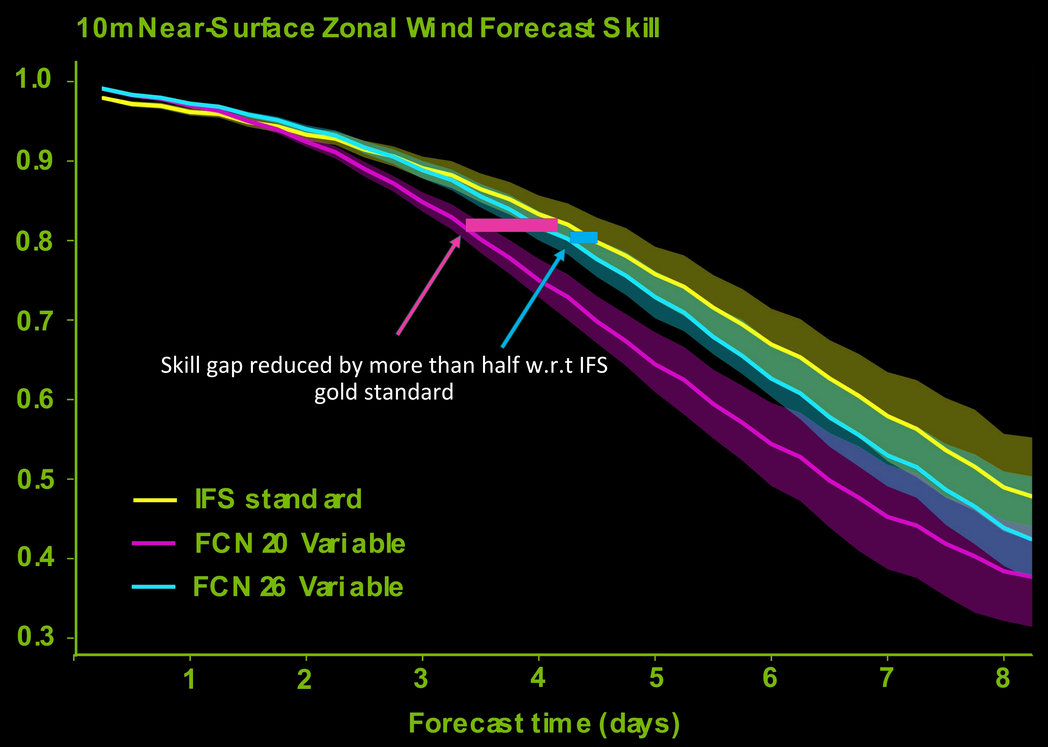
Fully data-driven weather prediction.

• Scope	Global, Medium Range
• Model Type	Full-Model AI Surrogate
• Architecture	AFNO (Adaptive Fourier Neural Op.)
• Resolution:	25km
• Training Data:	ERA5 Reanalysis
• Initial Condition	GFS / UFS
• Inference Time	0.25 sec (2-week forecast)
• Speedup vs NWP	$O(10^4\text{-}10^5)$
• Power Savings	$O(10^4)$

Impressive skill gains in just a few months.

Despite a relatively small team of engineers.



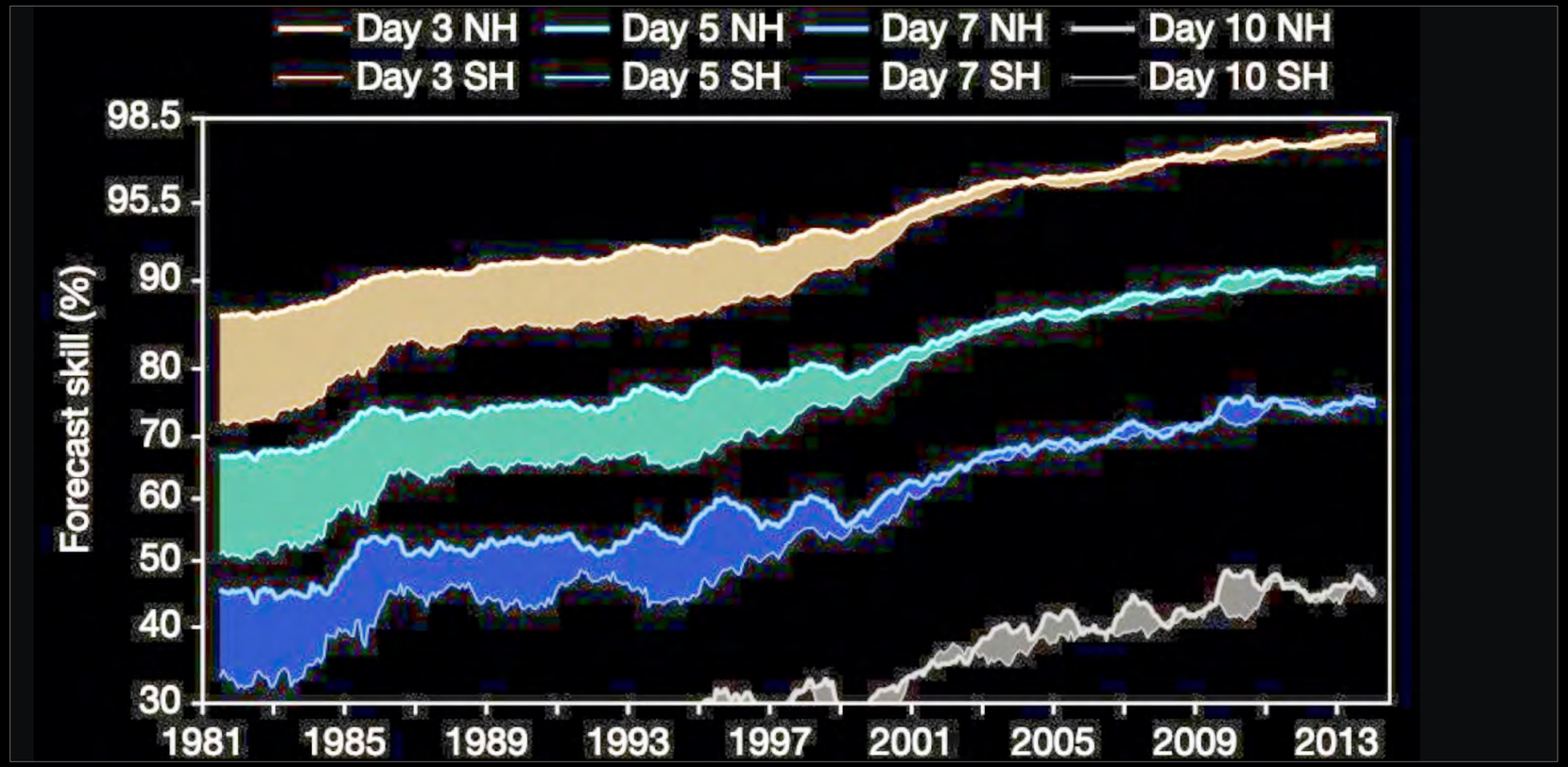


Acronym Alert:
ACC: Anomaly Correlation Coefficient (metric of weather skill)
IFS: The Integrated Forecast System, a gold standard weather model
FCN: FourCastNet, our digital twin of weather.

NVIDIA

Contrast: The slower quiet revolution in classical weather forecasting

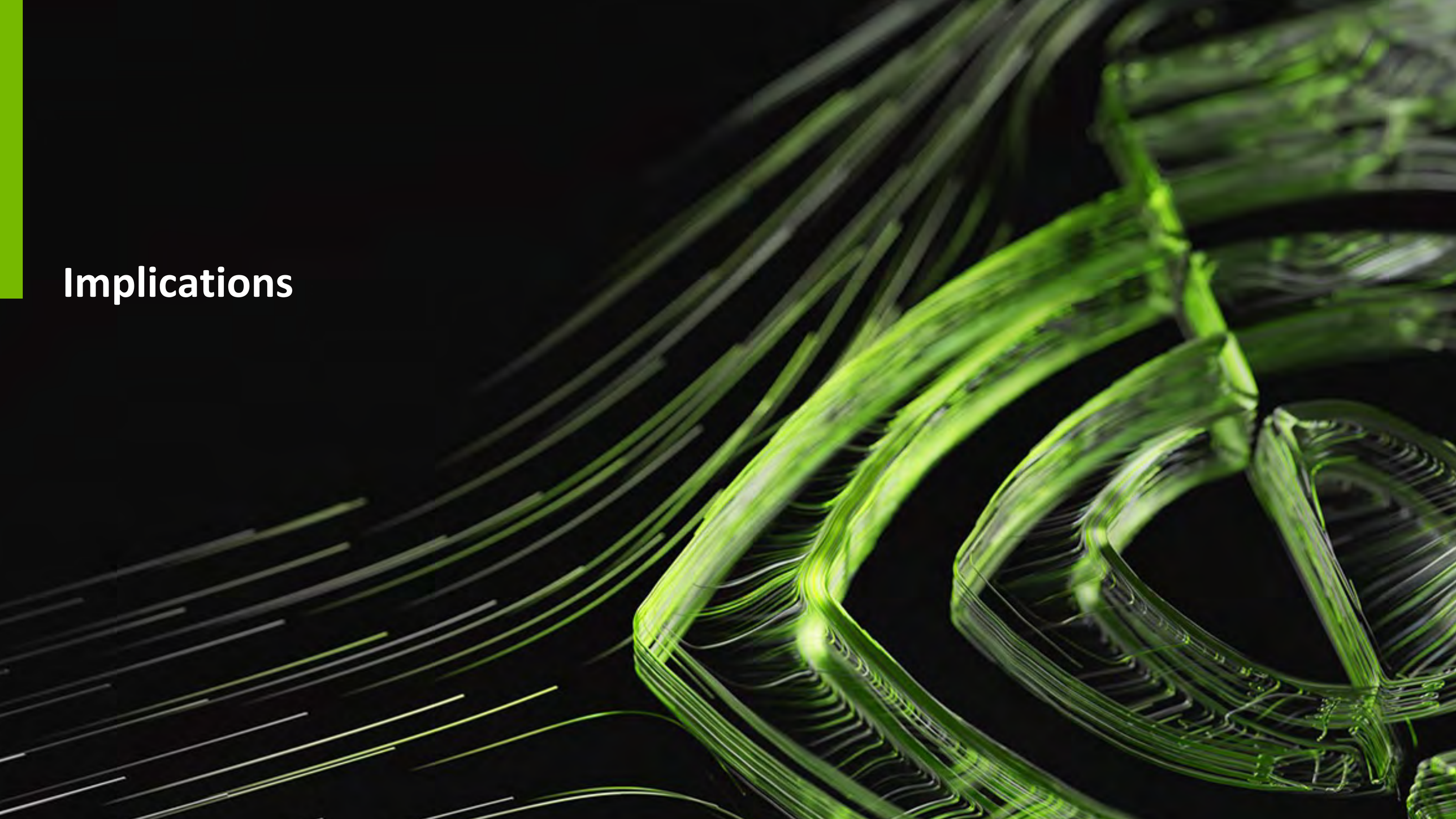
Data assimilation and other advances have slowly revolutionized the quality & accuracy over decades



Bauer et al., *Nature*, 2015

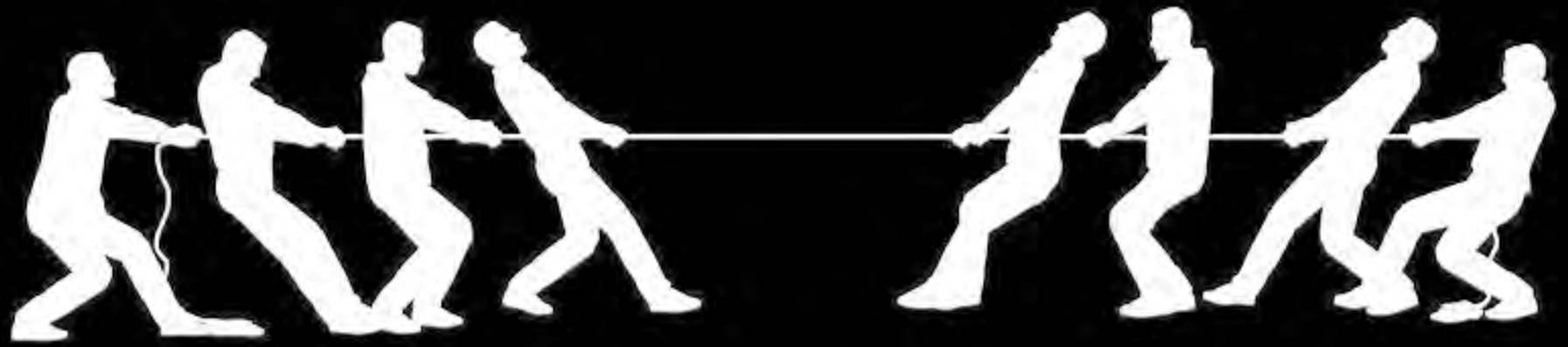
Caveat: These advances are the foundation for assimilated state estimates that ML approaches rely on.

Implications



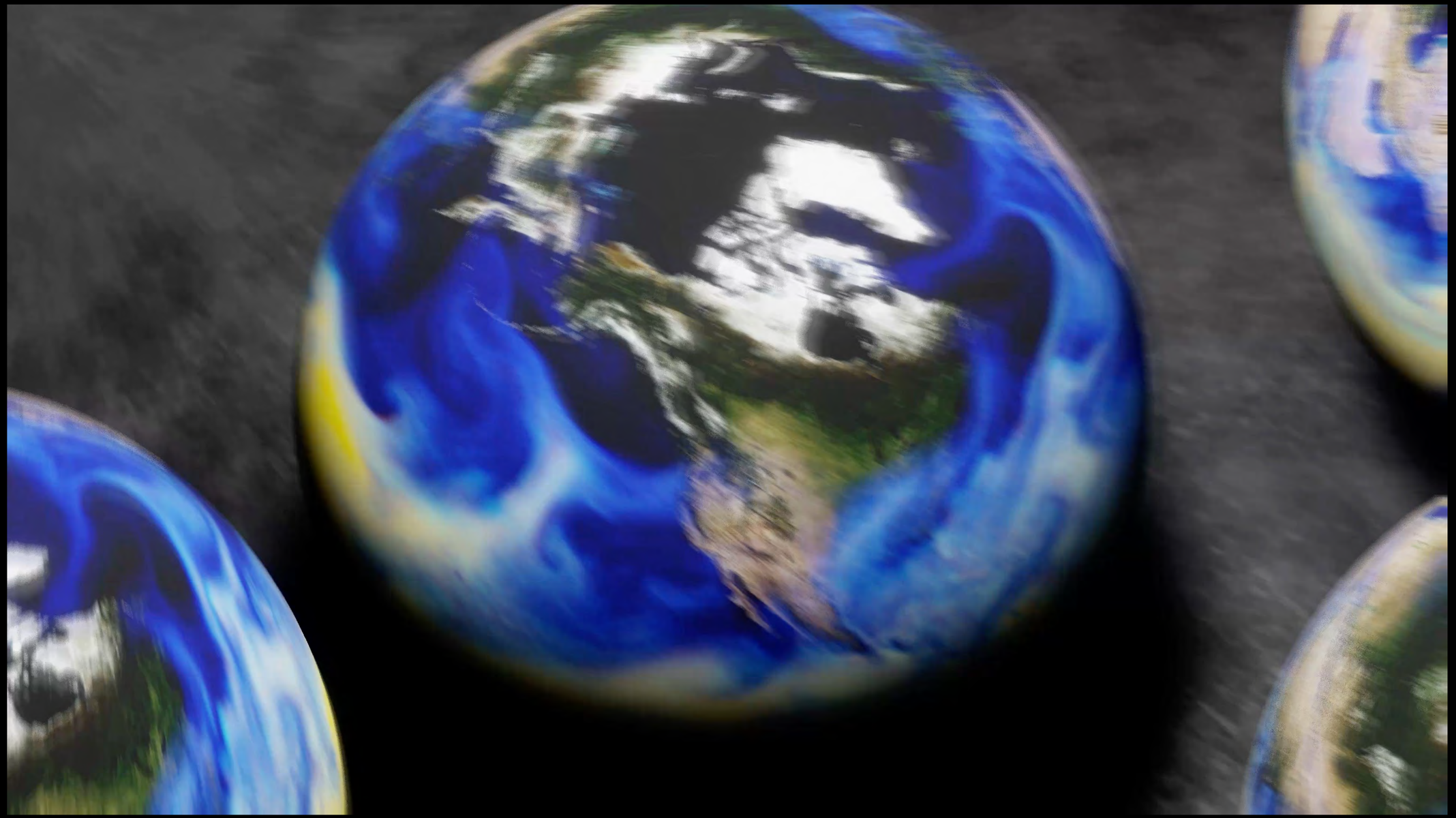
Throughout history, ensemble size of weather forecasts has been limited.

Under computational constraint, trades off against horizontal resolution



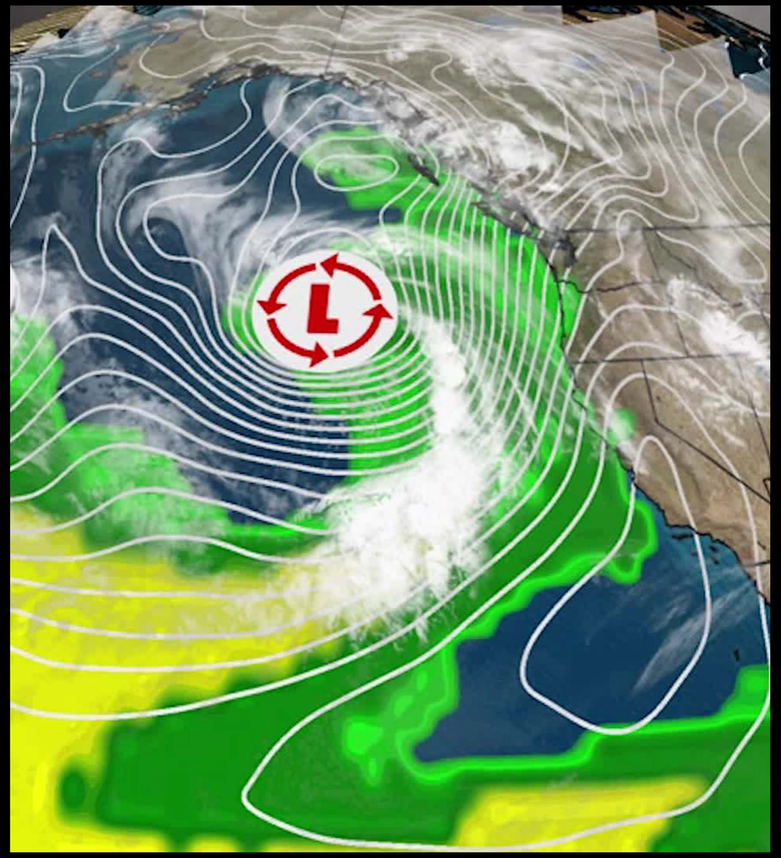
Speed of AI weather prediction changes everything

10,000-member ensembles in minutes, 45,000x less compute, 12,000x less energy.



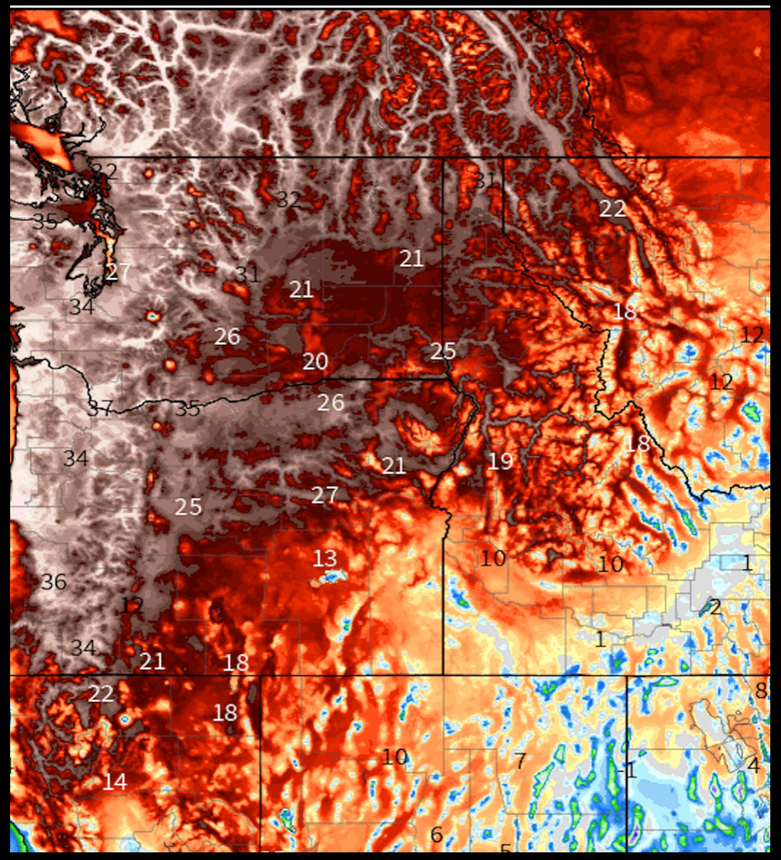
Massive ensembles from AI can sample Low Likelihood High Impact Extremes

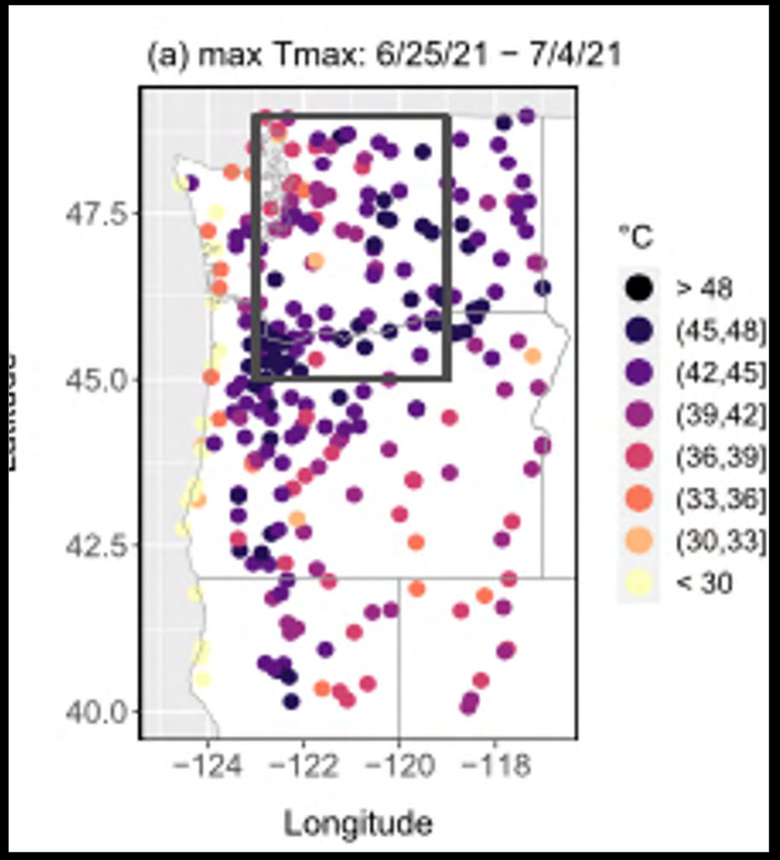
Multiple atmospheric rivers (Ars) landing in California Dec-Jan 2023

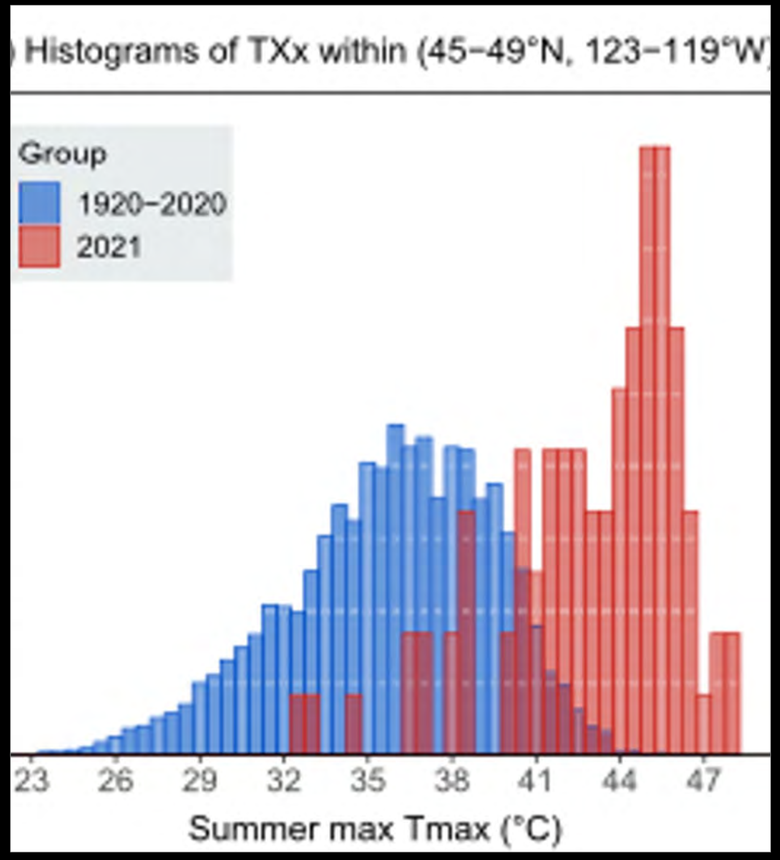


Low Likelihood High Impact Extremes

The 2021 Pacific Northwest Heat Wave





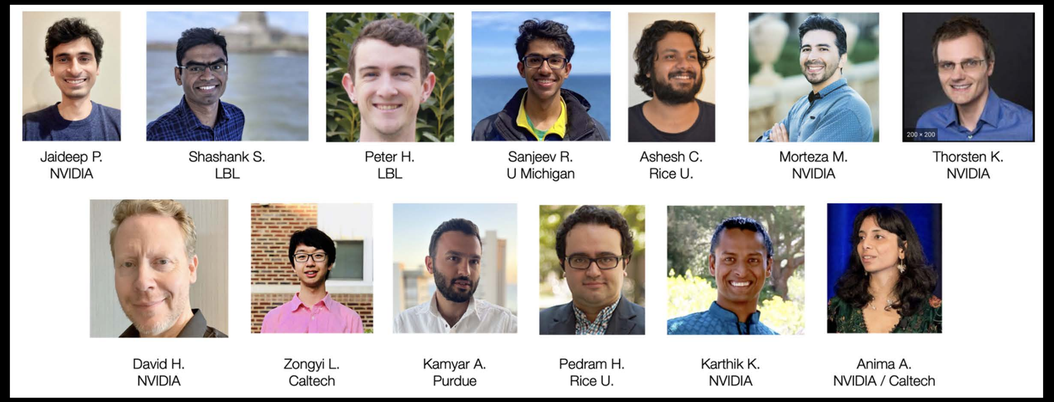


Collaborating with climate scientists on Huge Ensembles of 10^N members

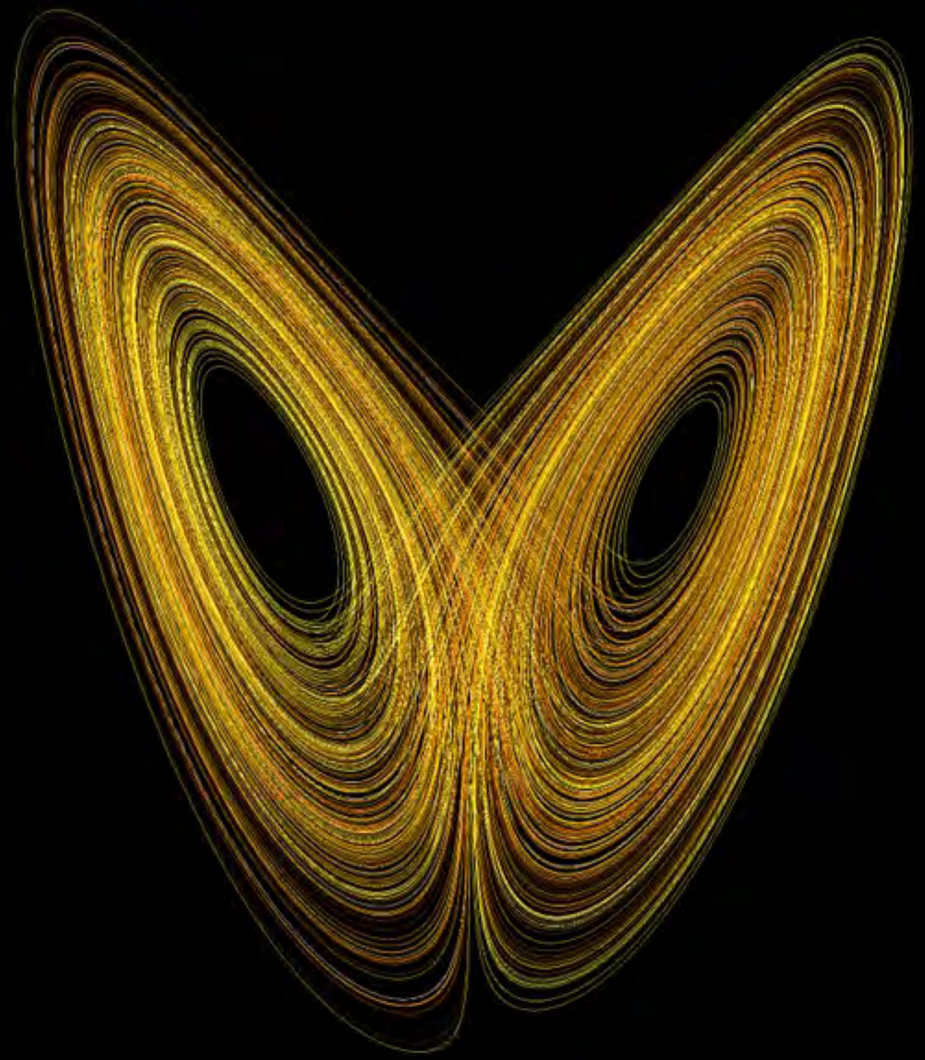
Generating statistics on simulated LLHIs that could have occurred historically, to understand their drivers.

Bill Collins & CASCADE collaborators

- Characterizing the properties of LLHIs requires many realizations of them.
- The only way to produce a sufficient number is via simulation.
- Given their low frequency, only way to conduct these simulations is with an emulation of numerical weather prediction codes that runs orders of magnitudes faster
- FourCastNet is a “killer app” for this type of science.

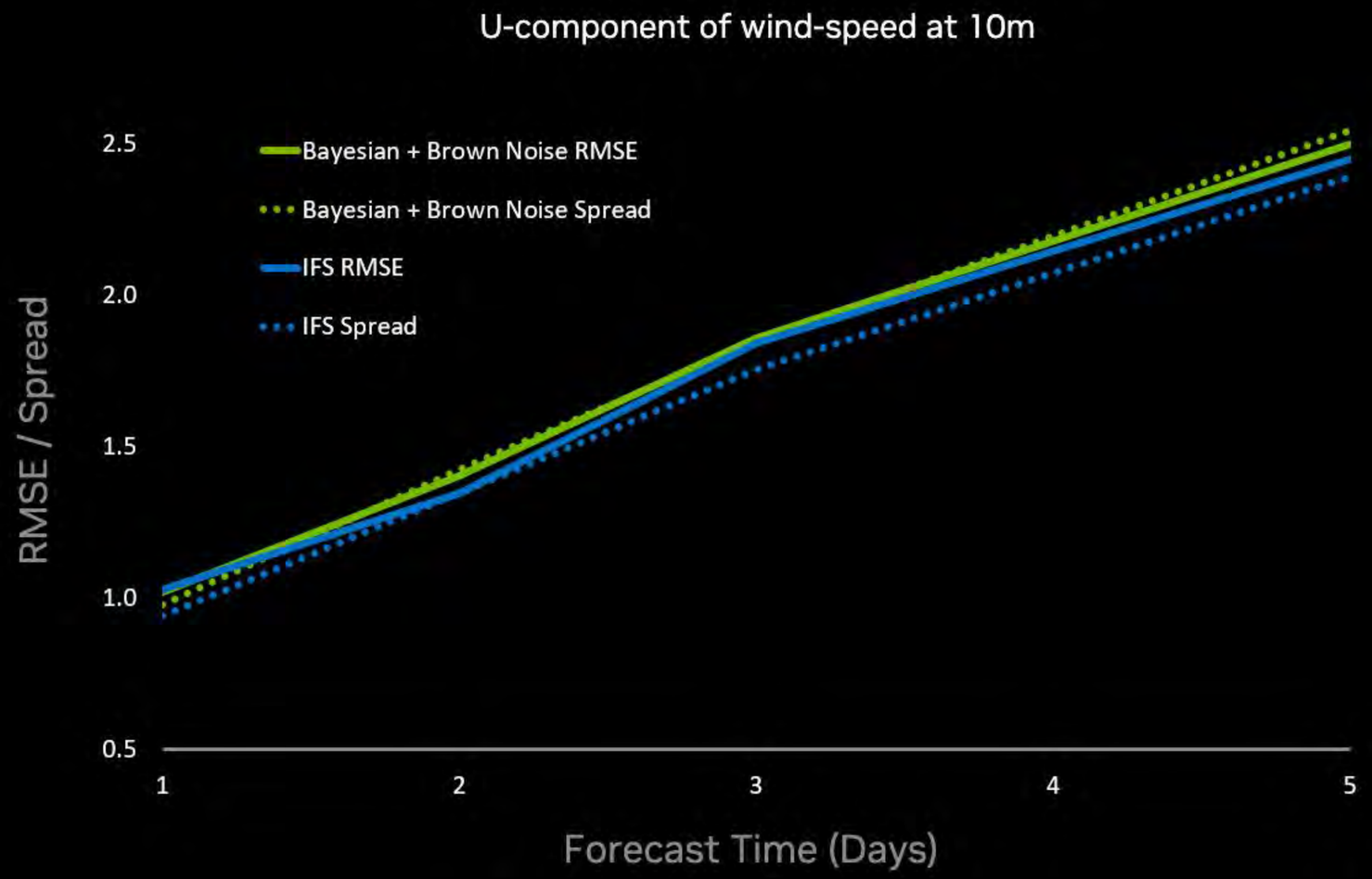


To have value, ensemble forecasts need well calibrated spread



We are working to achieve well-calibrated ensembles with FourCastNet

FCN’s ensembles calibrated using initial condition uncertainty and model uncertainty (Bayesian SWA-G).



Credit: Andre Graubner, Kamyar Azizzadenesheli, Anima Anandkumar

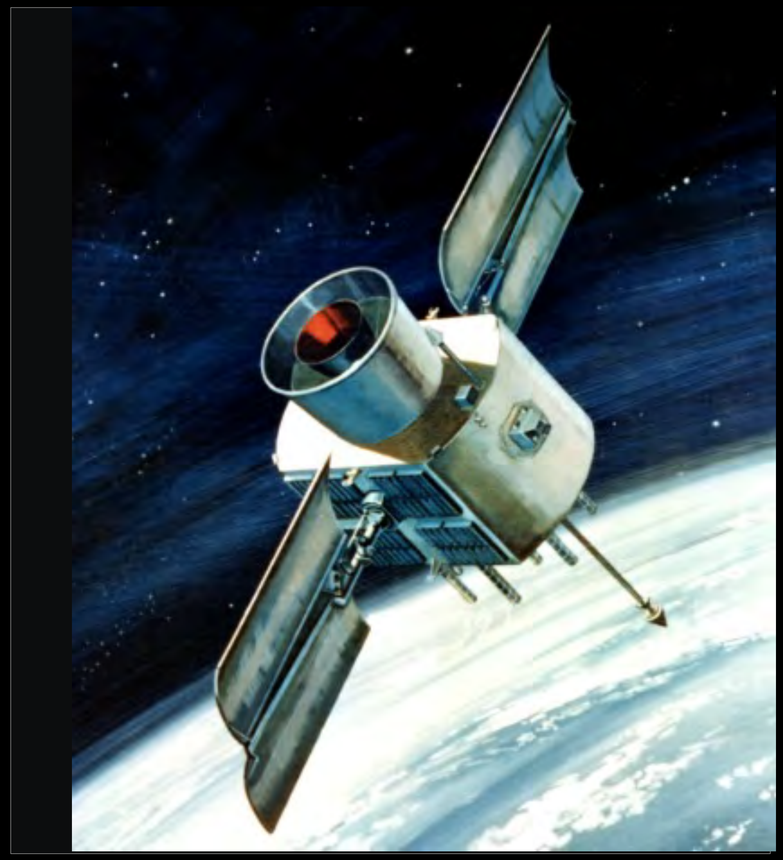
NeurIPS workshop paper: https://www.climatechange.ai/papers/neurips2022/87

Beyond weather: Climate interactivity.

Paradigm-shifting moments in our appreciation of the planet

Hot air ballons

Airplanes



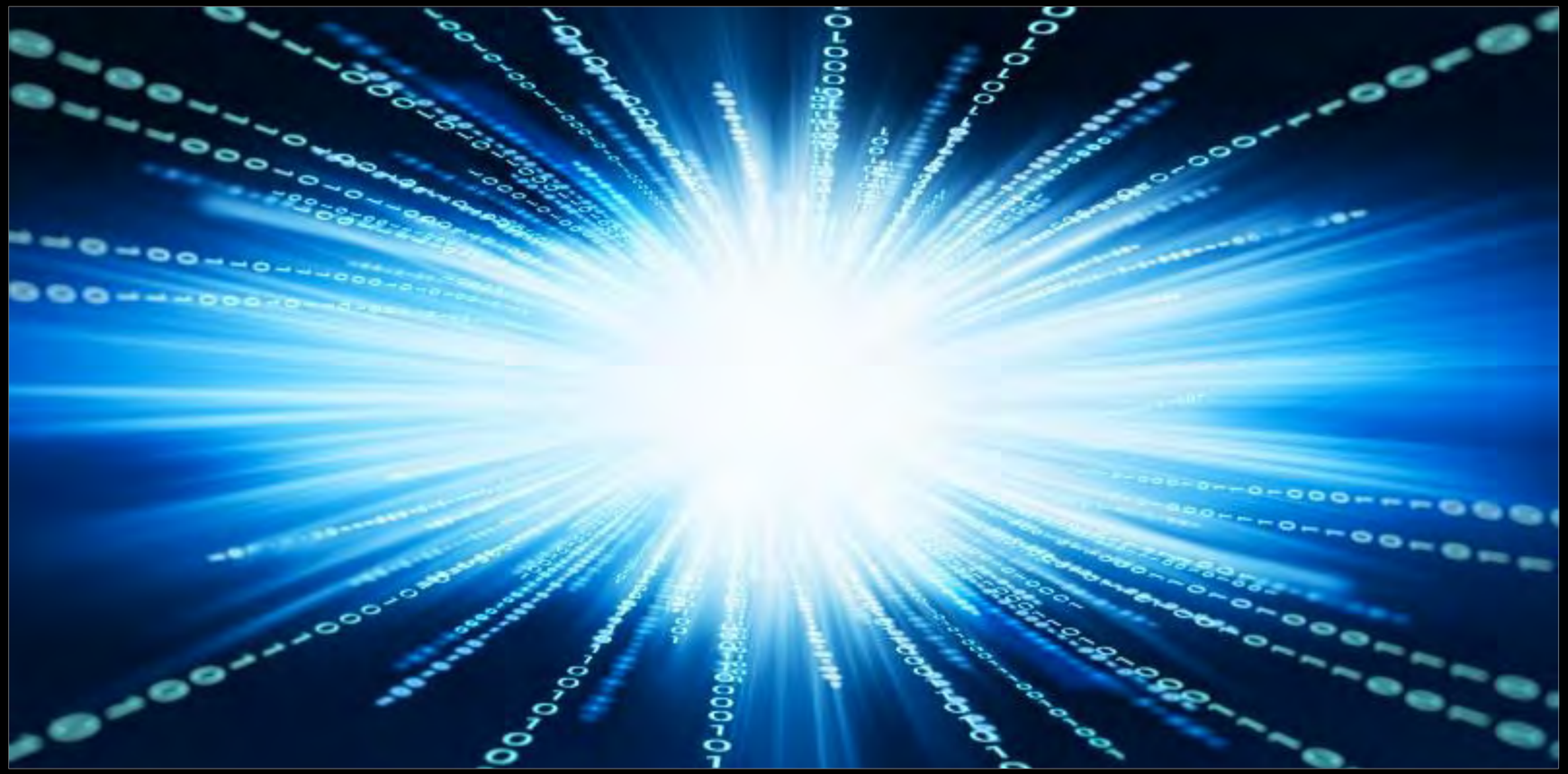
Satellites

The satellite era spurred creative new science & technology

Curious humans flipping through banks of unfamiliar imagery

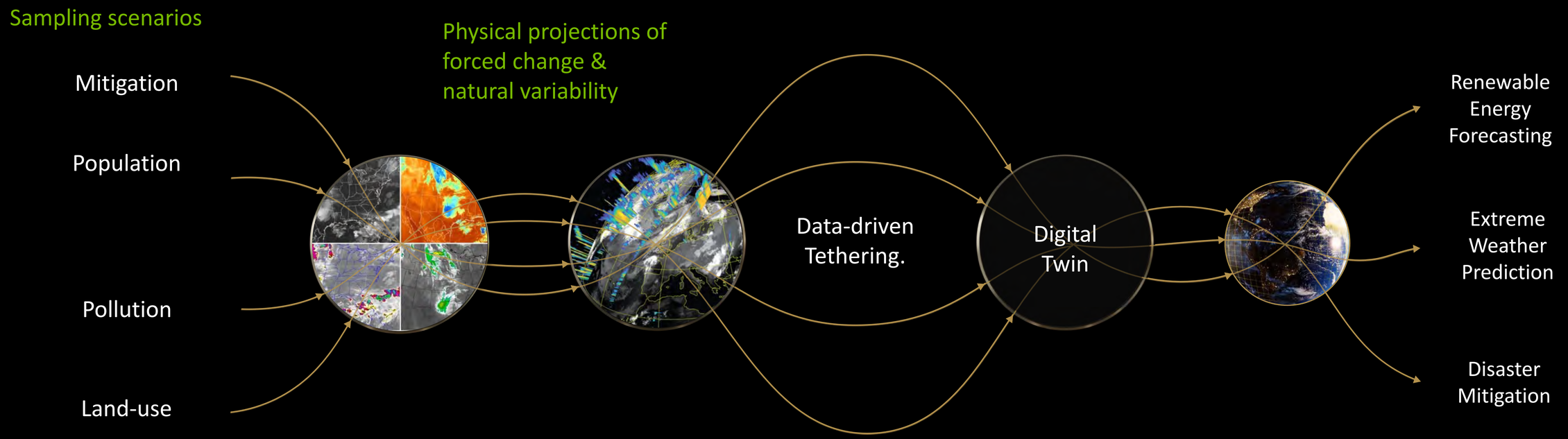
Problem: Nobody knows how to flip through banks of climate predictions

Petabytes of data hiding in archives impenetrable to non-experts.



Training AI Digital Twins on libraries of Future Climate Predictions can help.

Using the world's current data library of 100-km resolution intergovernmental climate predictions.



MONITORING | MULTI-MODAL DATA FUSION | CALIBRATION

PHYSICS-ML MODEL TRAINING & INFERENCE

INTERACTIVITY | VISUALIZATION | ANALYSES

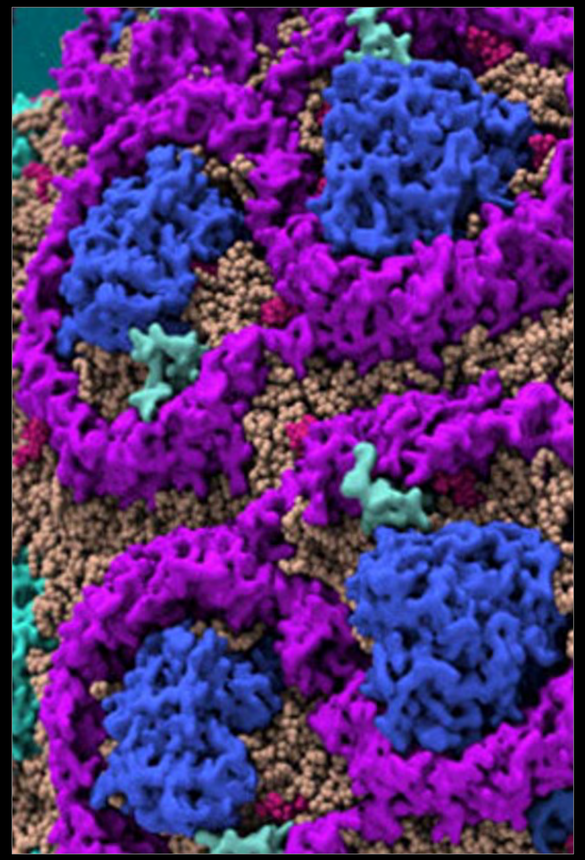
RAPIDS | CuNumeric

DALI | Modulus | CUDA-X AI | TRITON | TensorRT

Omniverse

NVIDIA

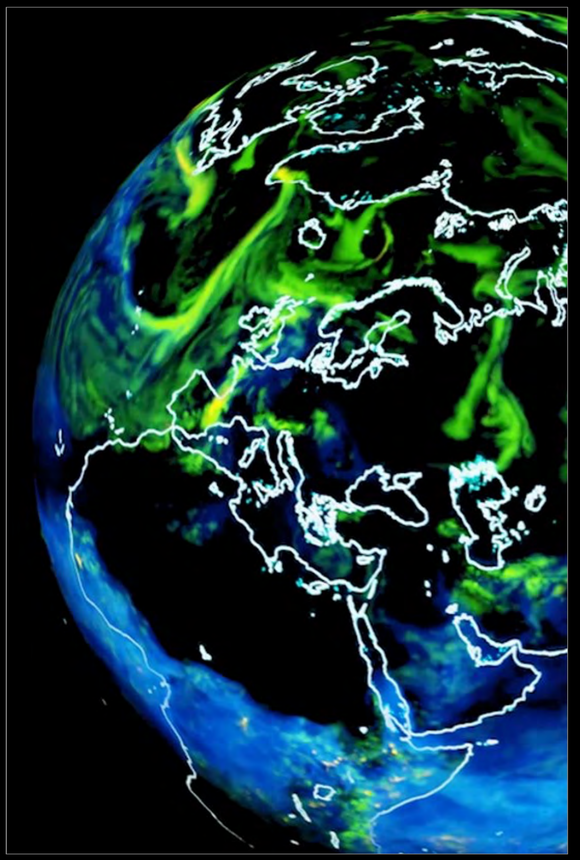
AI digital twins can be built at every scale



MOLECULAR

INDUSTRIAL

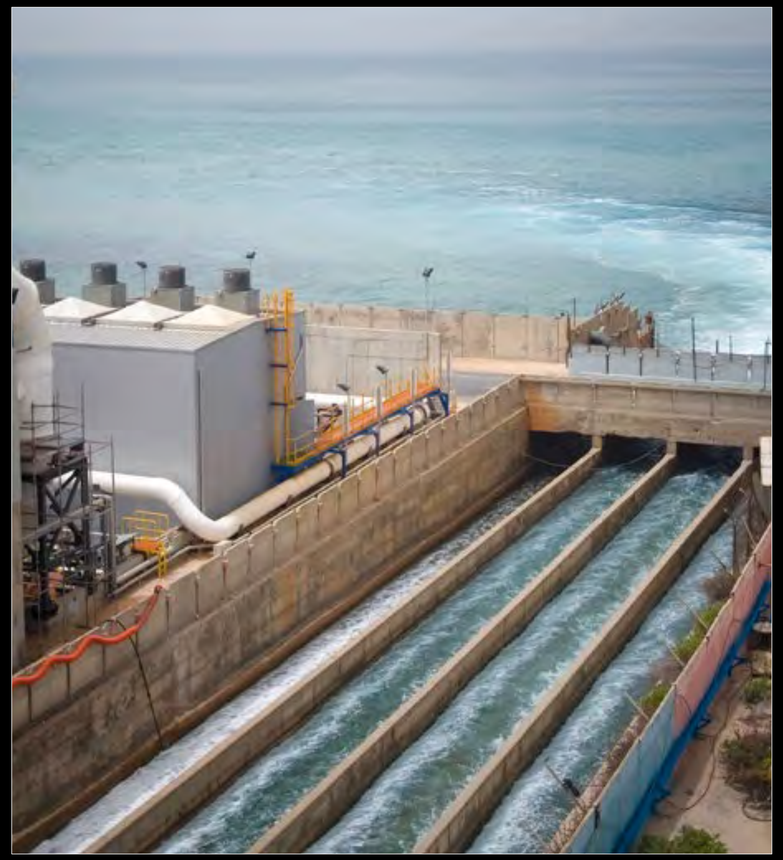
CITY



PLANETARY

Vision: Digital twins to explore potential interventions and solutions.

Renewable Energy



Water Desalinization

Green Cities

Earth-2: Can NVIDIA help the world build a Digital Twin Of The Earth?

Including software, hardware, data and observations needed to make it happen

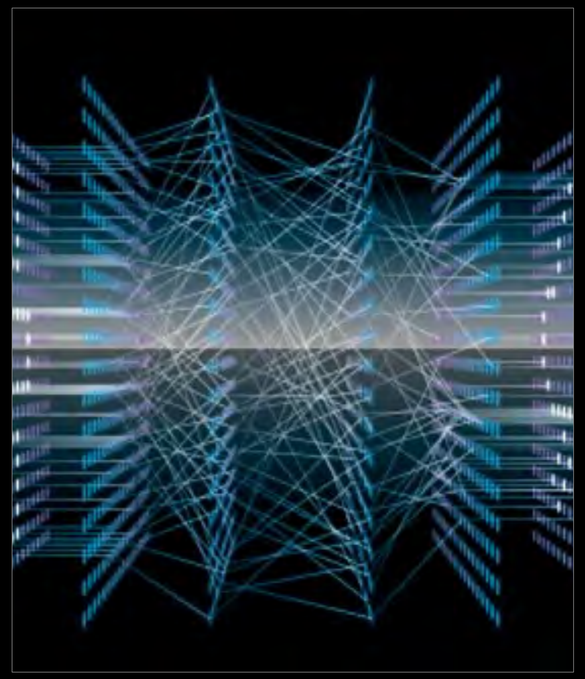
Earth

Twin Earth

- Ultra-fast AI surrogate-models
- Ultra-high resolution
- Continuous-learning
- Omniverse for interactivity
- Plug-and-play applications
- Open global collaboration

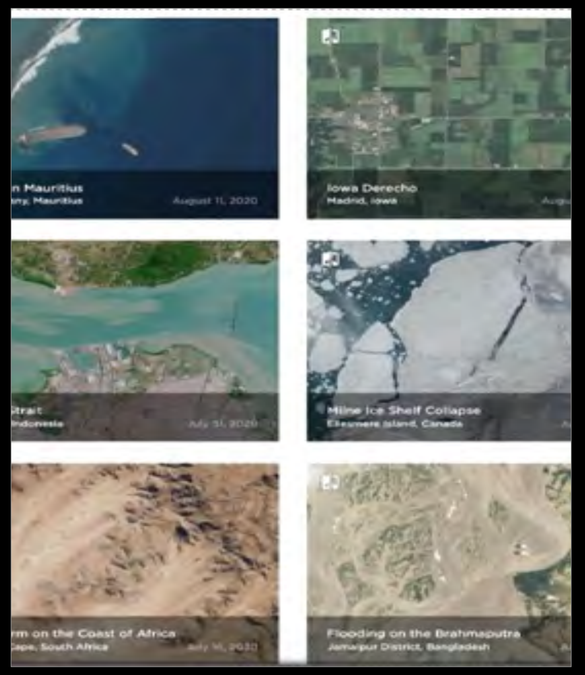
The World is Already Working Hard on these Problems

Example: Project Destination Earth envisions what Earth-System Modeling could be.



Data-driven Models

Storm-Resolving Models



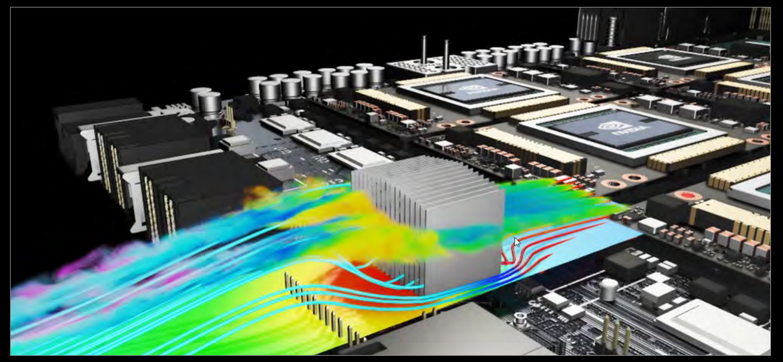
Unified Observations

Exascale Compute

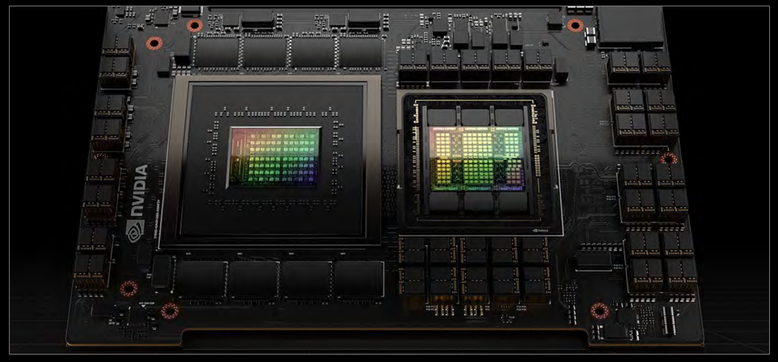
NVIDIA has tools for building digital twins that are fast, powerful & intuitive

OMNIVERSE
USER EXPERIENCE

NUCLEUS
INTEROPERABILITY



MODULUS
PHYSICS -NFORMED

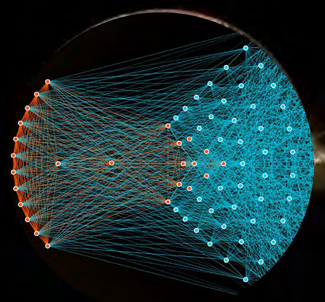


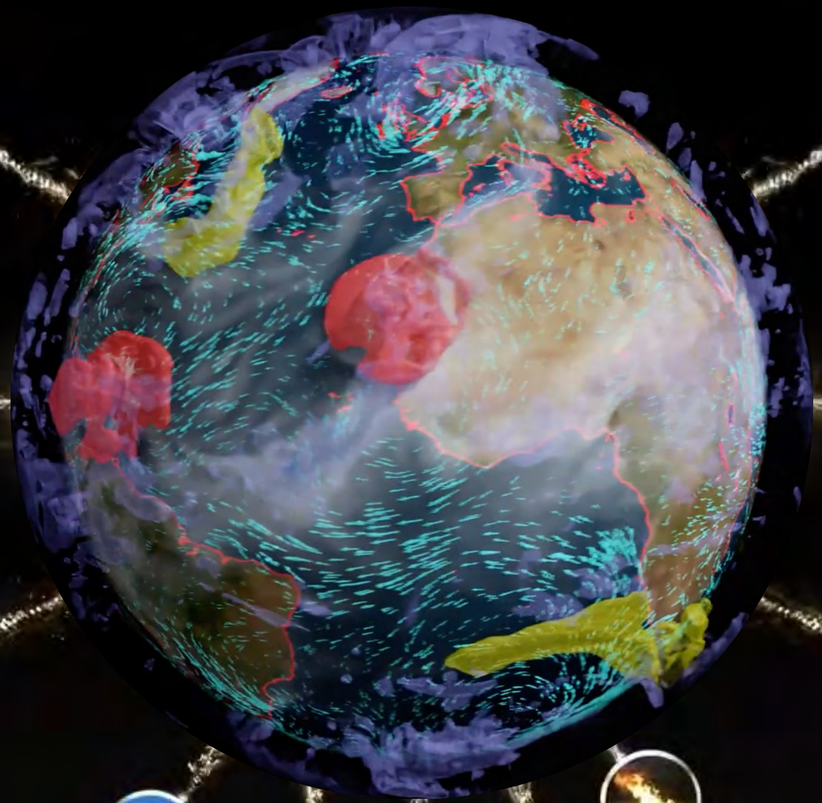
GRACE - HOPPER SUPERCHIP
ACCELERATED COMPUITING

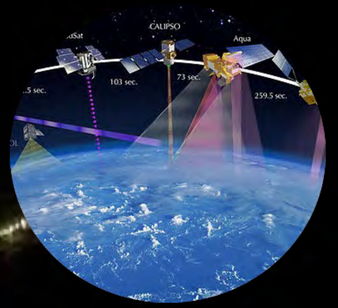
OVX - SUPERPOD
LARGE AI MODELS

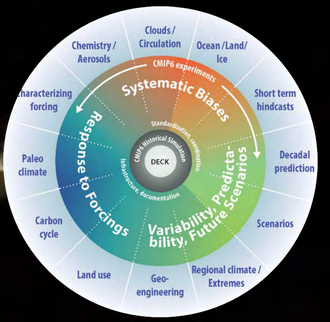
Example: Omniverse to link AI digital twins & data together

Nucleus: A shared space where models, data, tools, services, and applications synchronize









USD

Path Tracing

AI

MDL

Physics

NVIDIA.

Earth-2 is meant to complement others' efforts in industry & government.

Our visualization, hardware, engineering & full-stack AI expertise have unique value.

Thanks