BUILDING DIGITAL TWINS OF THE EARTH FOR NVIDIA’S EARTH-2 INITIATIVE

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CLIMATE SCIENCE REQUIRES MILLION-X SPEEDUPS

Computational constraints limit model resolution

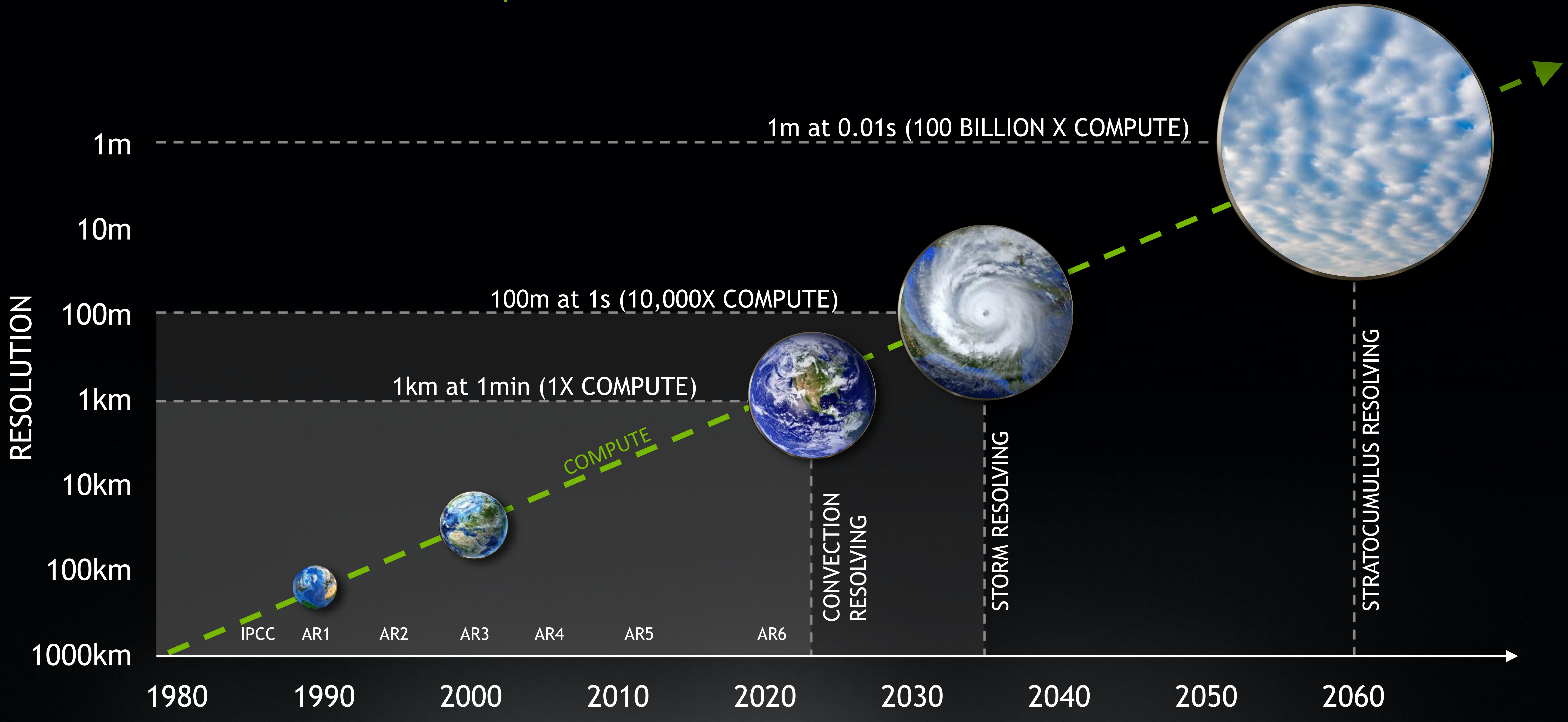
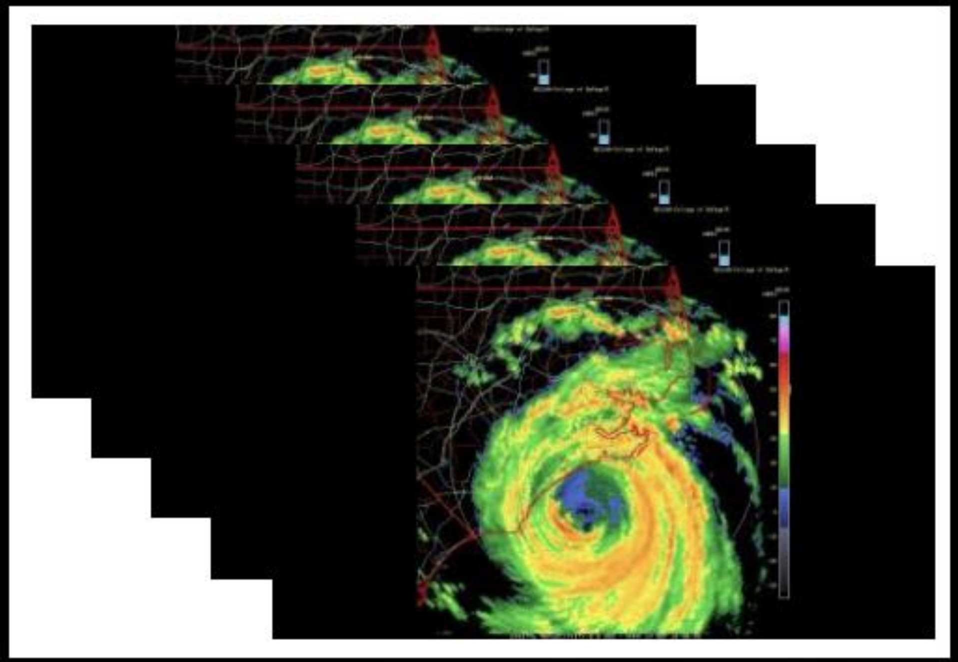


Figure adapted from: Schneider, T., Teixeira, J., Bretherton, C. *et al.* Climate goals and computing the future of clouds. *Nature Climate Change* **7,** 3–5 (2017). https://doi.org/10.1038/nclimate3190

CLIMATE SCIENCE REQUIRES MILLION-X SPEEDUPS

Computational constraints limit the size of ensembles and how many scenarios can be explored

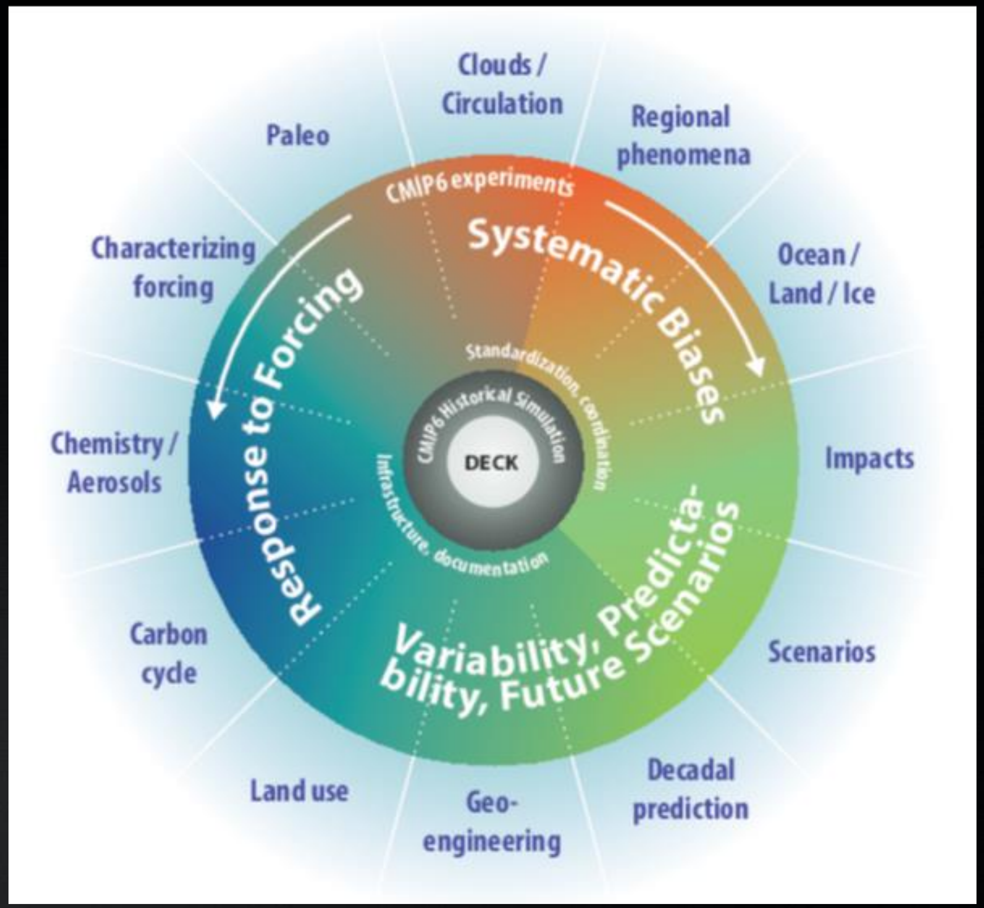
10s —> 1000s OF MEMBERS



ENSEMBLES

SCENARIOS

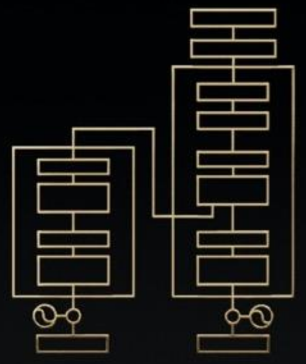
10s —> 1000s OF SCENARIOS



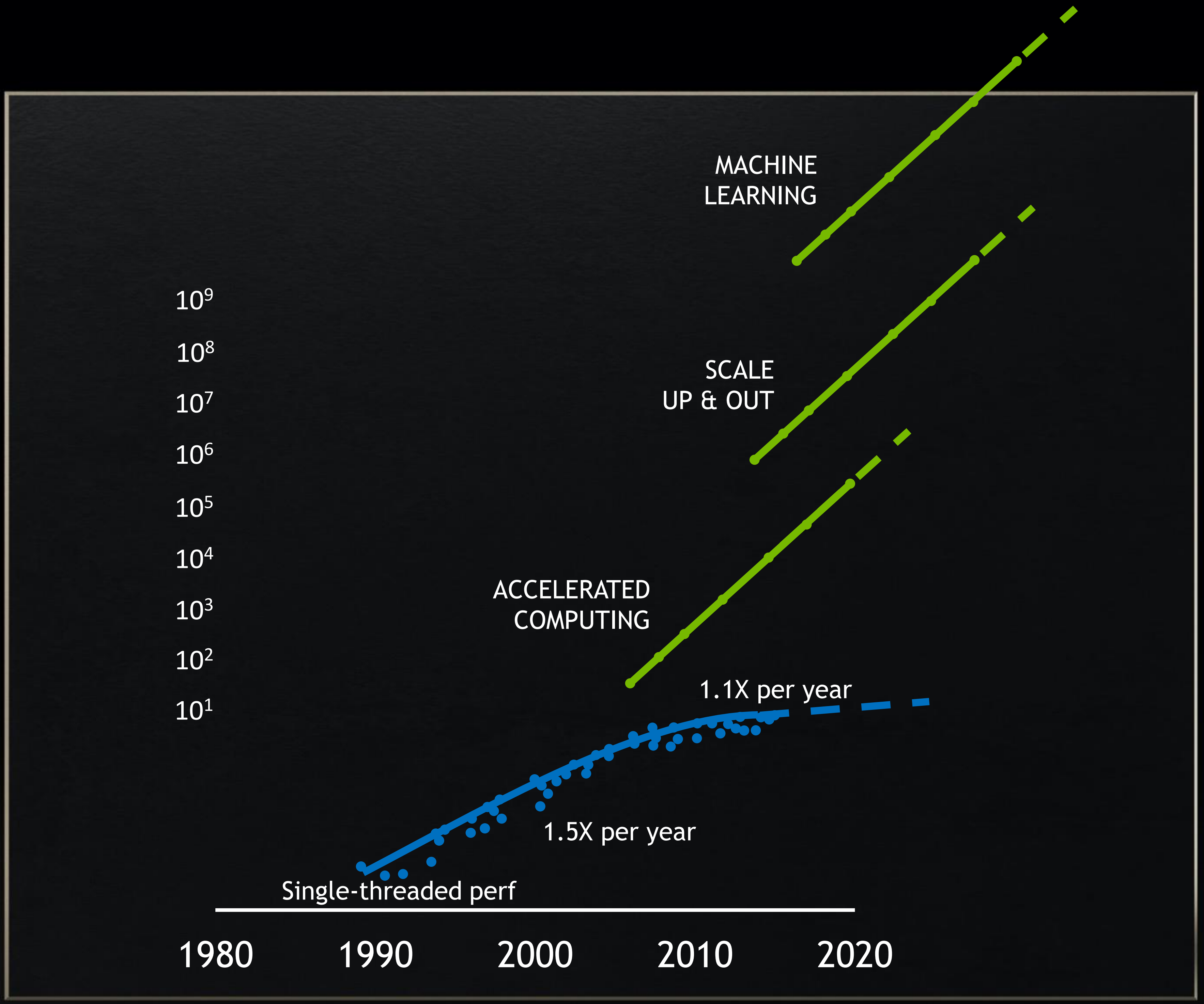
ADVANCES IN COMPUTING AND ML PROMISE MILLION-X SPEEDUPS

Accelerated Computing

AI



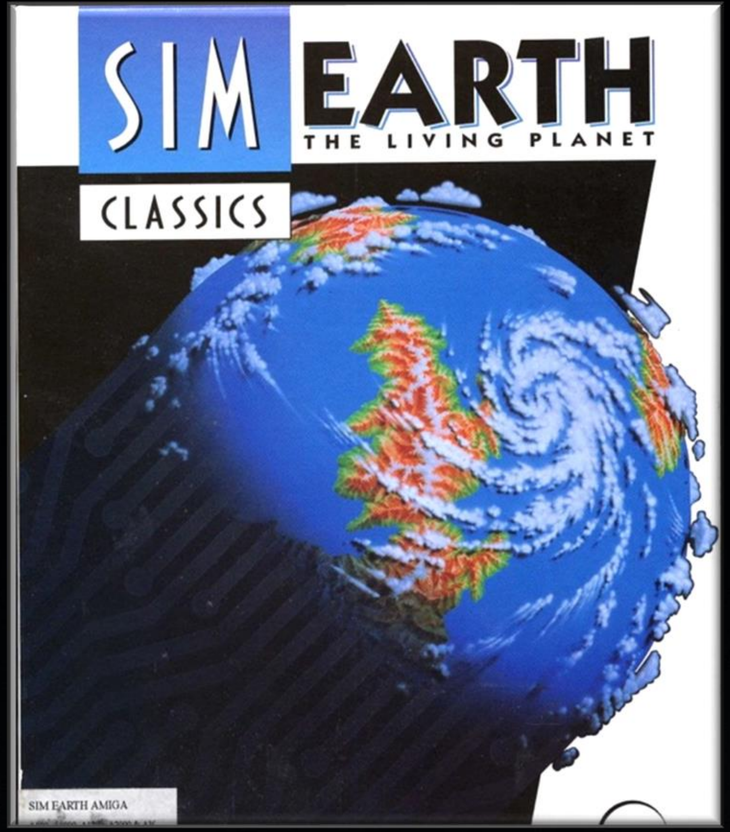
Data Center Scale



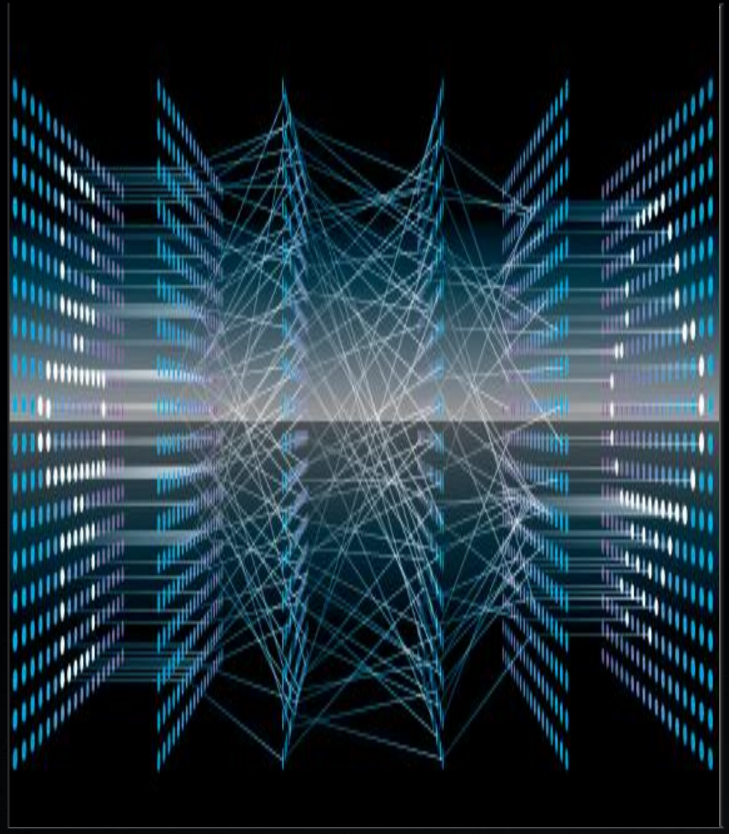
DESTINATION-EARTH: DIGITAL REPLICAS OF EARTH

Project DestinE envisions what Earth-system modeling could be

Intuitive User Interface: What-if Q & A

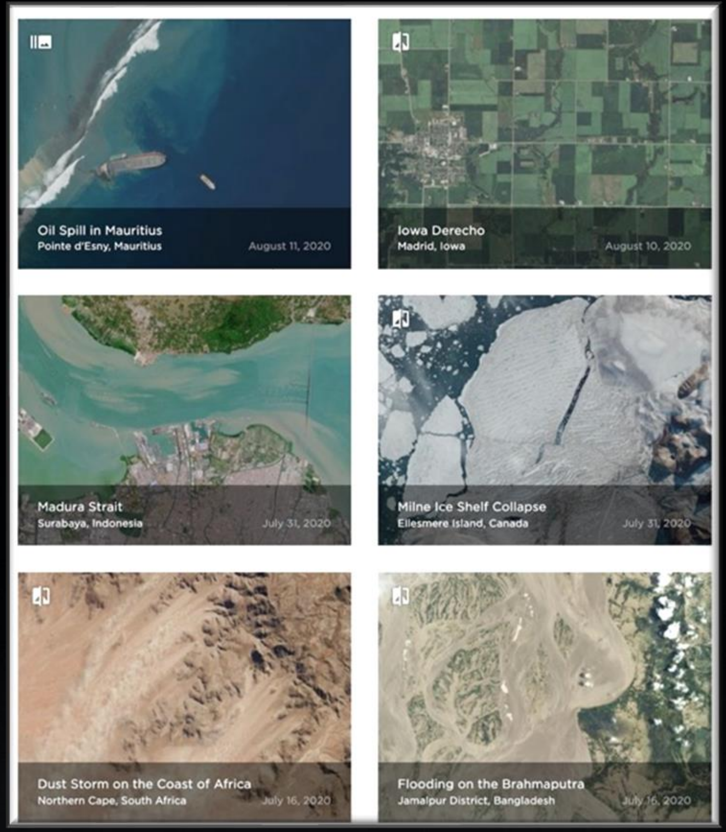


Data-driven Models



Storm-resolving Models

Unified Observations



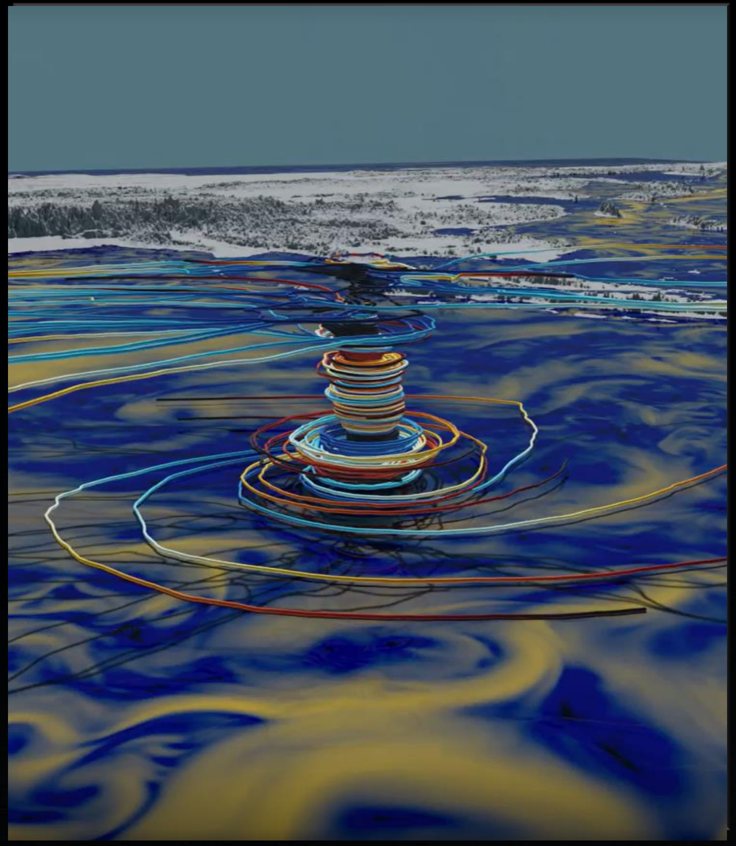
Exascale Compute

https://digital-strategy.ec.europa.eu/en/library/destination-earth

DESTINATION-EARTH: DIGITAL REPLICAS OF EARTH

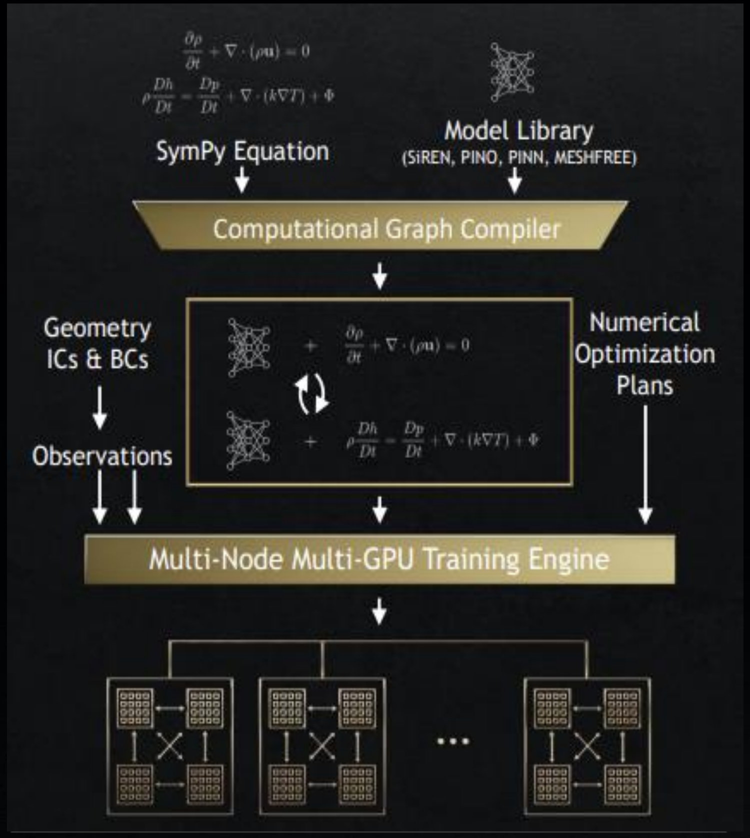
NVIDIA has technologies needed to make this vision a reality

Intuitive User Interface: What-if Q & A



OMNIVERSE

Data-driven Models



PHYSICS-ML / MODULUS

Storm-resolving Models

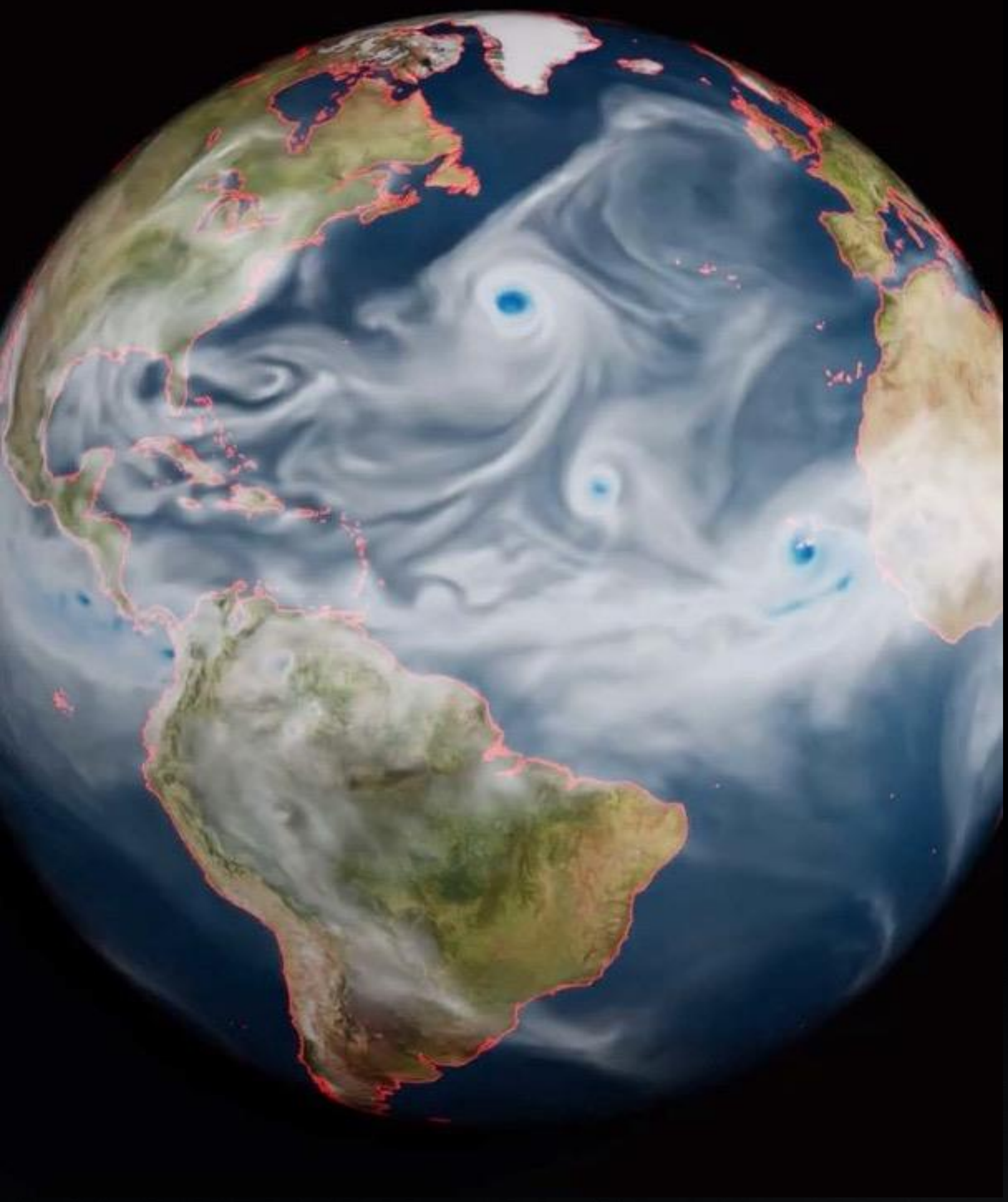
GPU-ACCELERATION

Unified Observations

OMNIVERSE NUCLEUS

Exascale Compute

OVX SUPERPOD

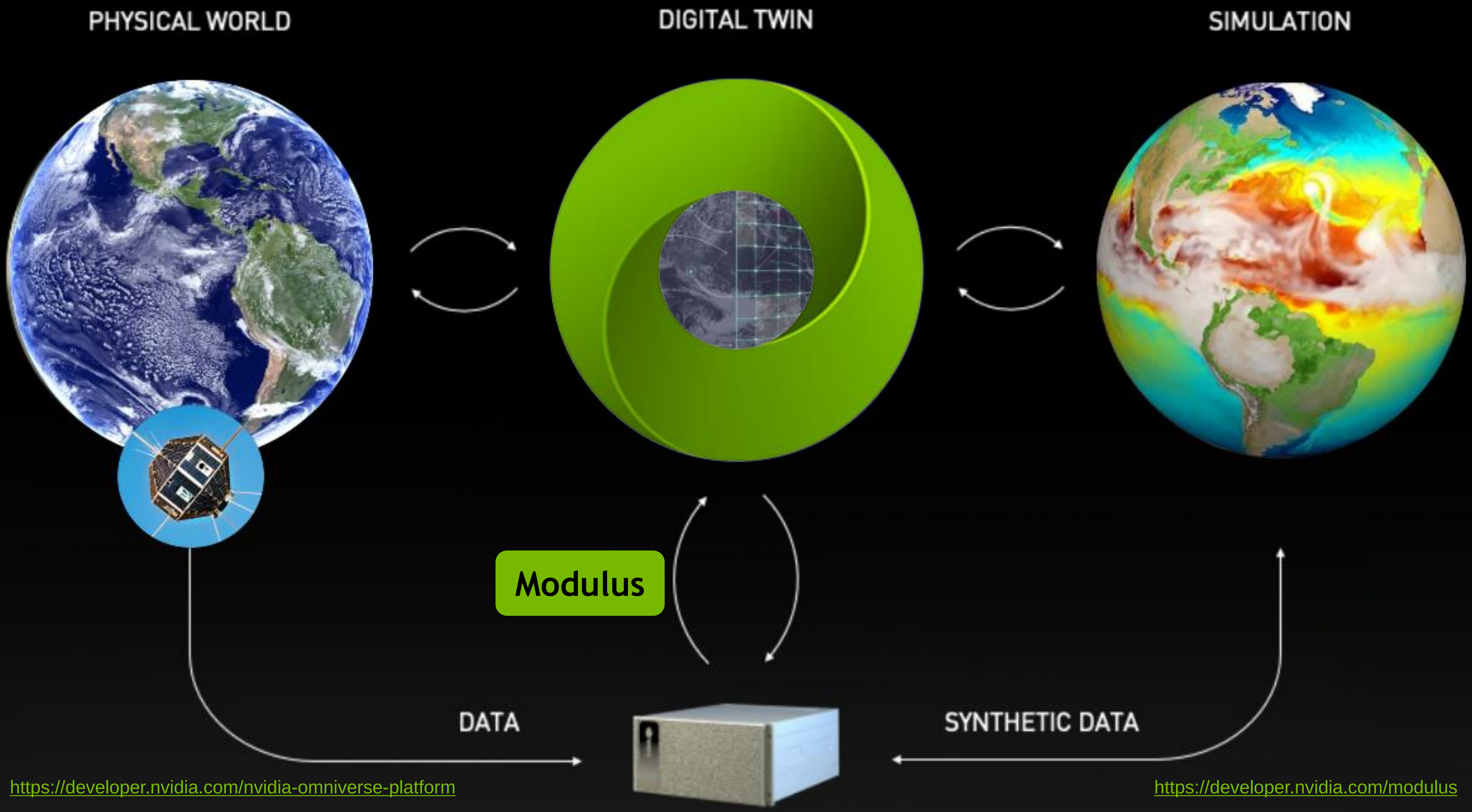


Earth-2

WHY?
INTERACTIVITY AT SCALE: UNFOLD AND EXTRACT INFORMATION

HOW?
DIGITAL TWINS TO MONITOR, PREDICT, MITIGATE, AND ADAPT

https://blogs.nvidia.com/blog/2021/11/12/earth-2-supercomputer/



https://developer.nvidia.com/nvidia-omniverse-platform

https://developer.nvidia.com/modulus

EARTH DIGITAL TWIN
DEEP LEARNING CHALLENGES AND APPROACHES

CHALLENGES

- Extrapolation
- Physical consistency & causality
- Uncertainty quantification & Calibration
- Data fusion & assimilation
- Scale up & out
- …

APPROACHES

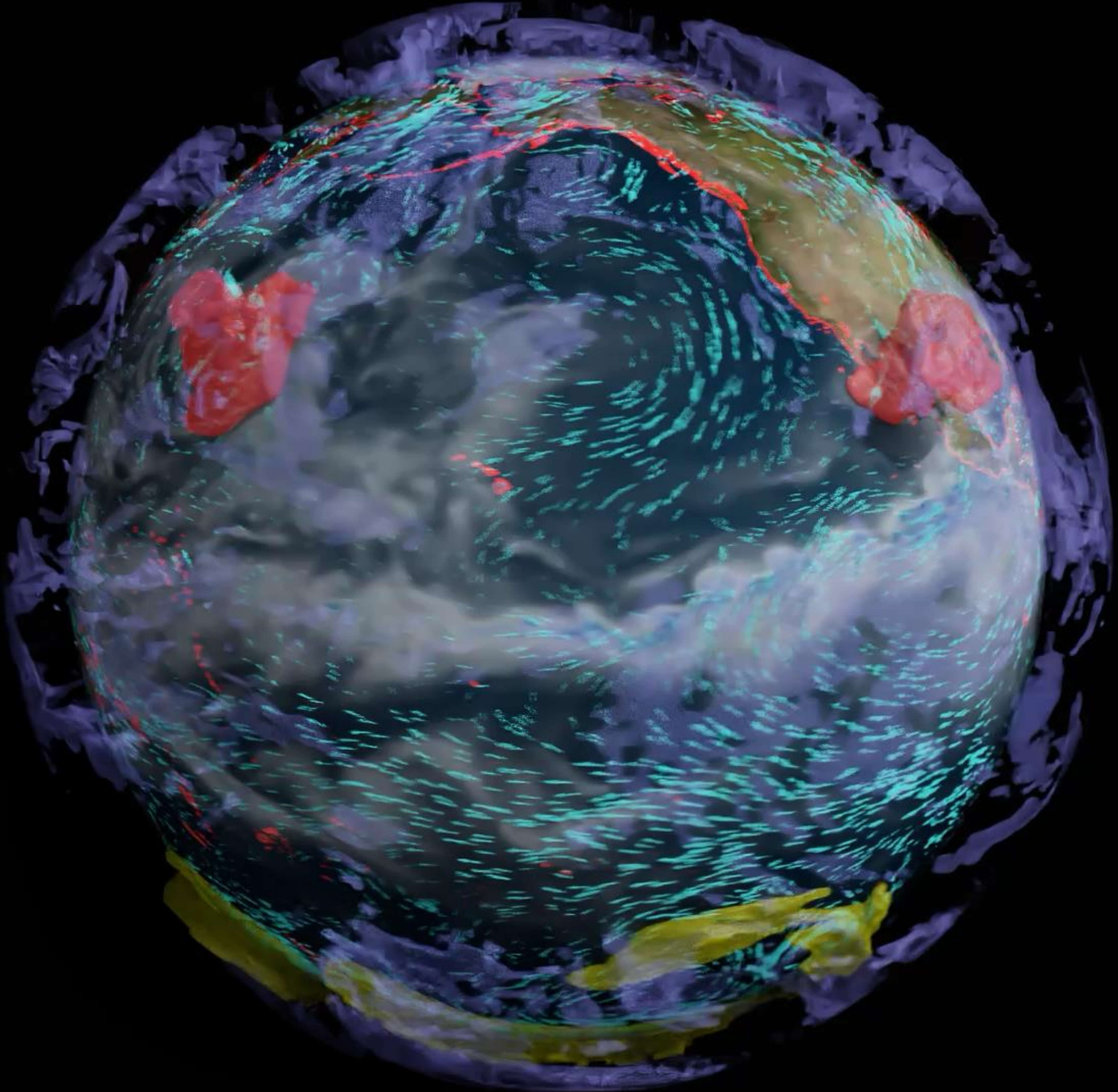
- Emulation
- Super-resolution
- Segmentation
- Online learning
- Reinforcement Learning
- …

YEAR 2100

+3 C Global Temperature

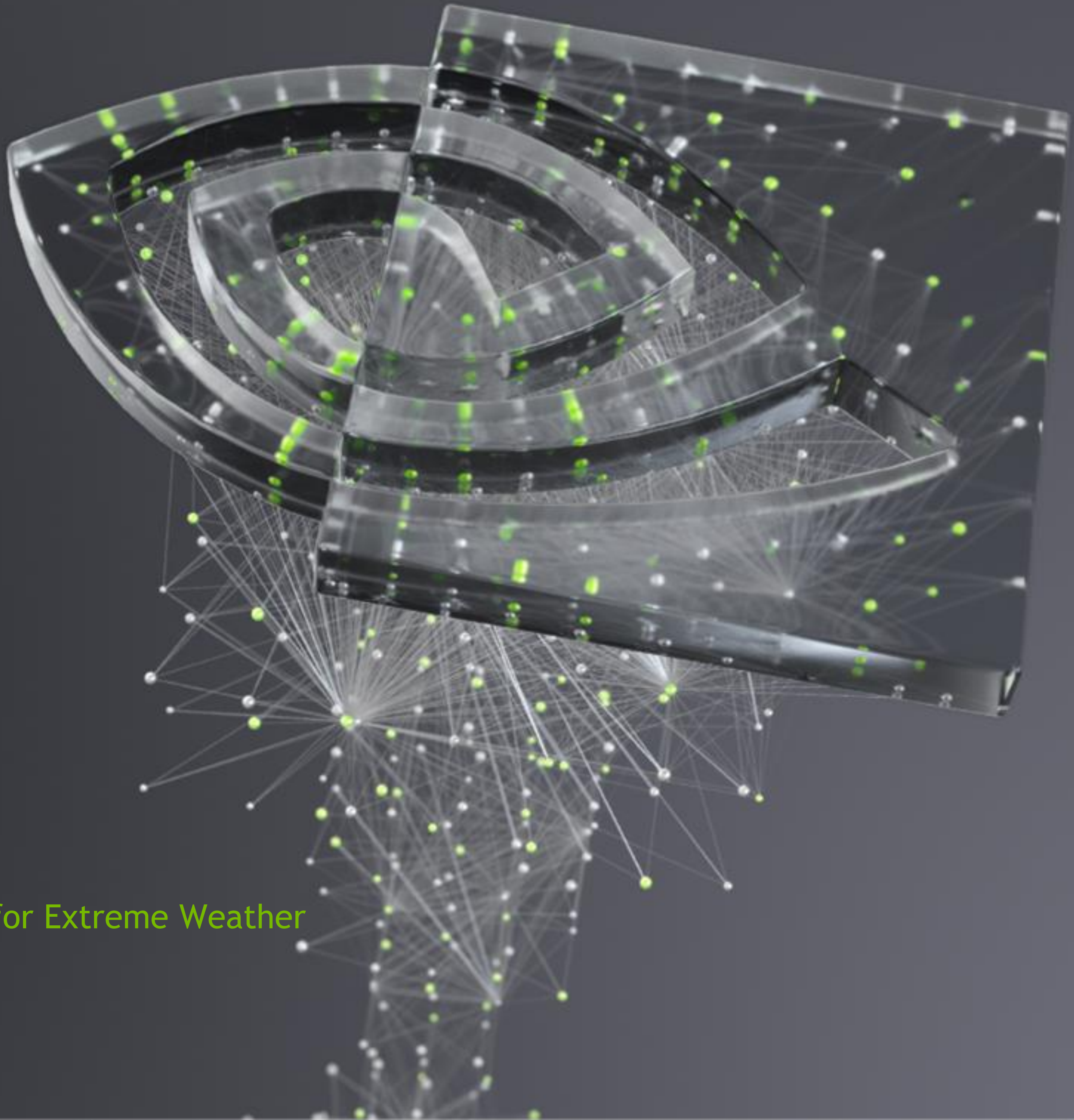
+60% Extreme Tropical Cyclones

+400% Extreme Atmospheric Rivers



2100, SEP 14

- TROPICAL CYCLONES
- ATMOSPHERIC RIVERS
- CLOUDS
- WINDS



NVIDIA

FourCastNet

Global data-driven high-resolution Earth digital twin for Extreme Weather

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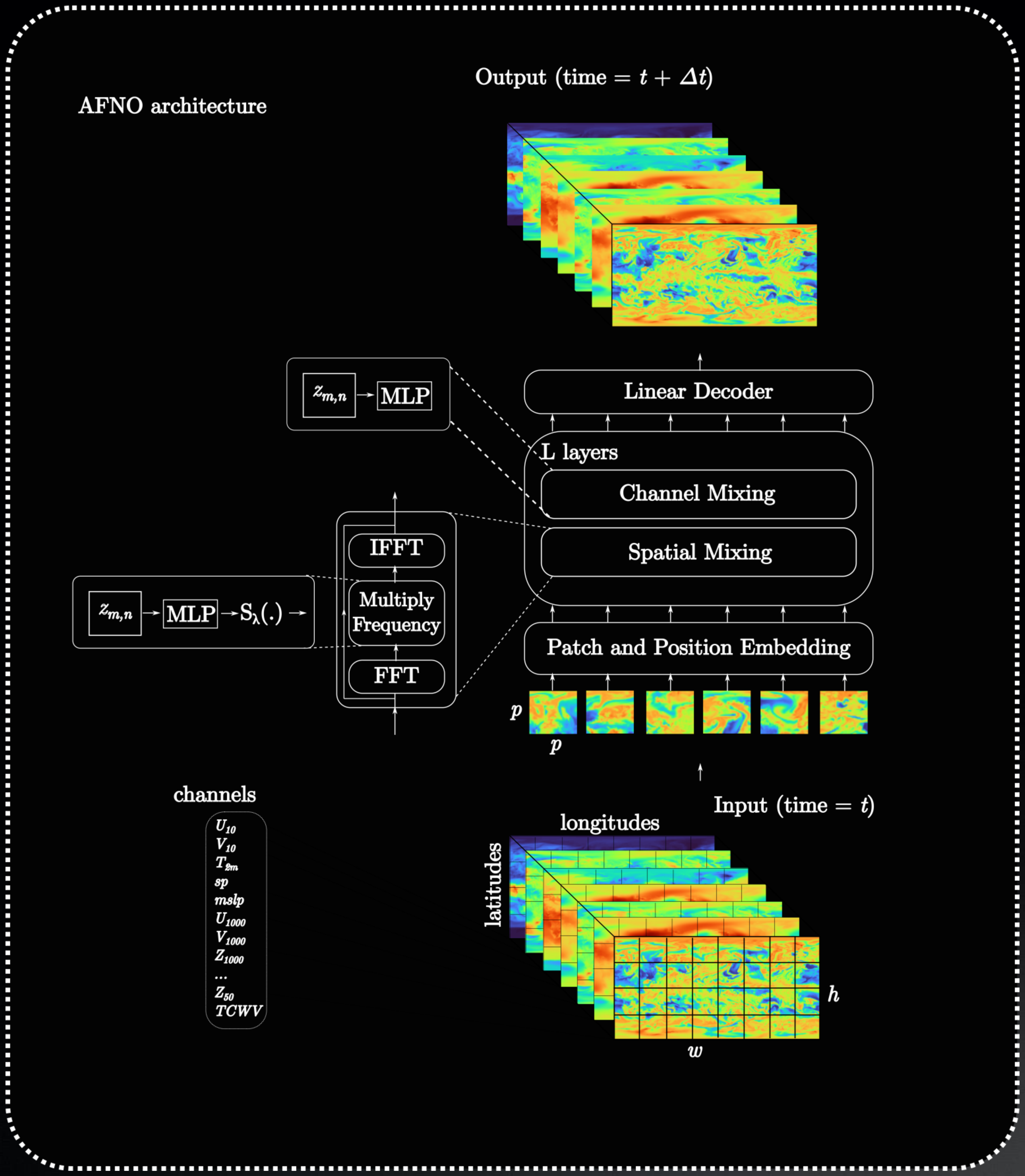
FOURCASTNET (FOURIER FORECASTING NETWORK)



Purely data-driven machine learning surrogate weather model

Trained on ERA5 reanalysis data at the native resolution of 0.25 degrees.

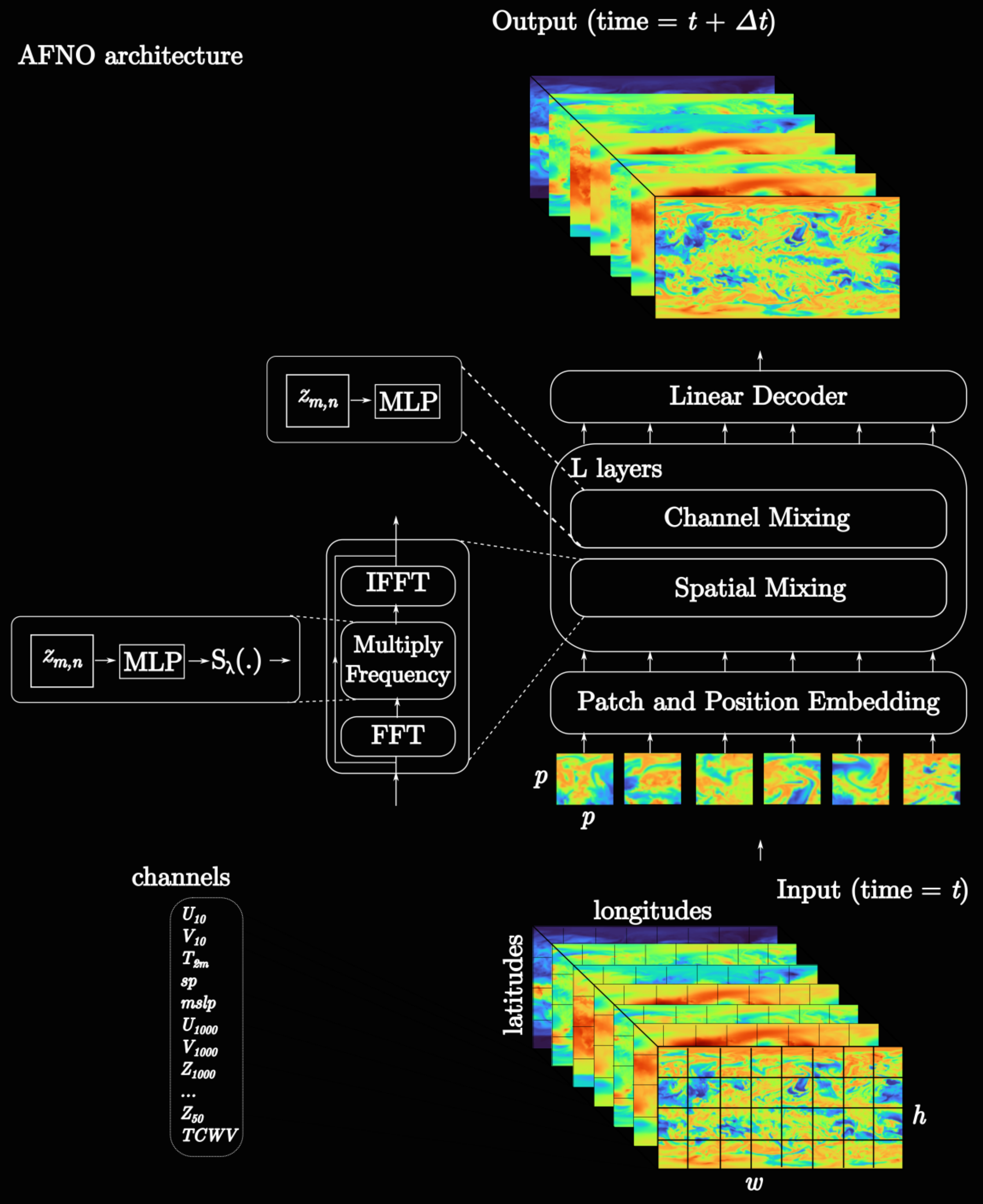
State-of-the-art for Deep Learning based weather surrogate models.

Highest resolution data driven model ever trained.

Guibas et al. (2022), Adaptive Fourier Neural Operators: Efficient Token Mixers for Transformers, ICLR 2022.

Pathak et al. (2022), FourCastNet: A Global Data-driven High-resolution Weather Model using Adaptive Fourier Neural Operators, arXiv:2202.11214

FOURCASTNET (FOURIER FORECASTING NETWORK)



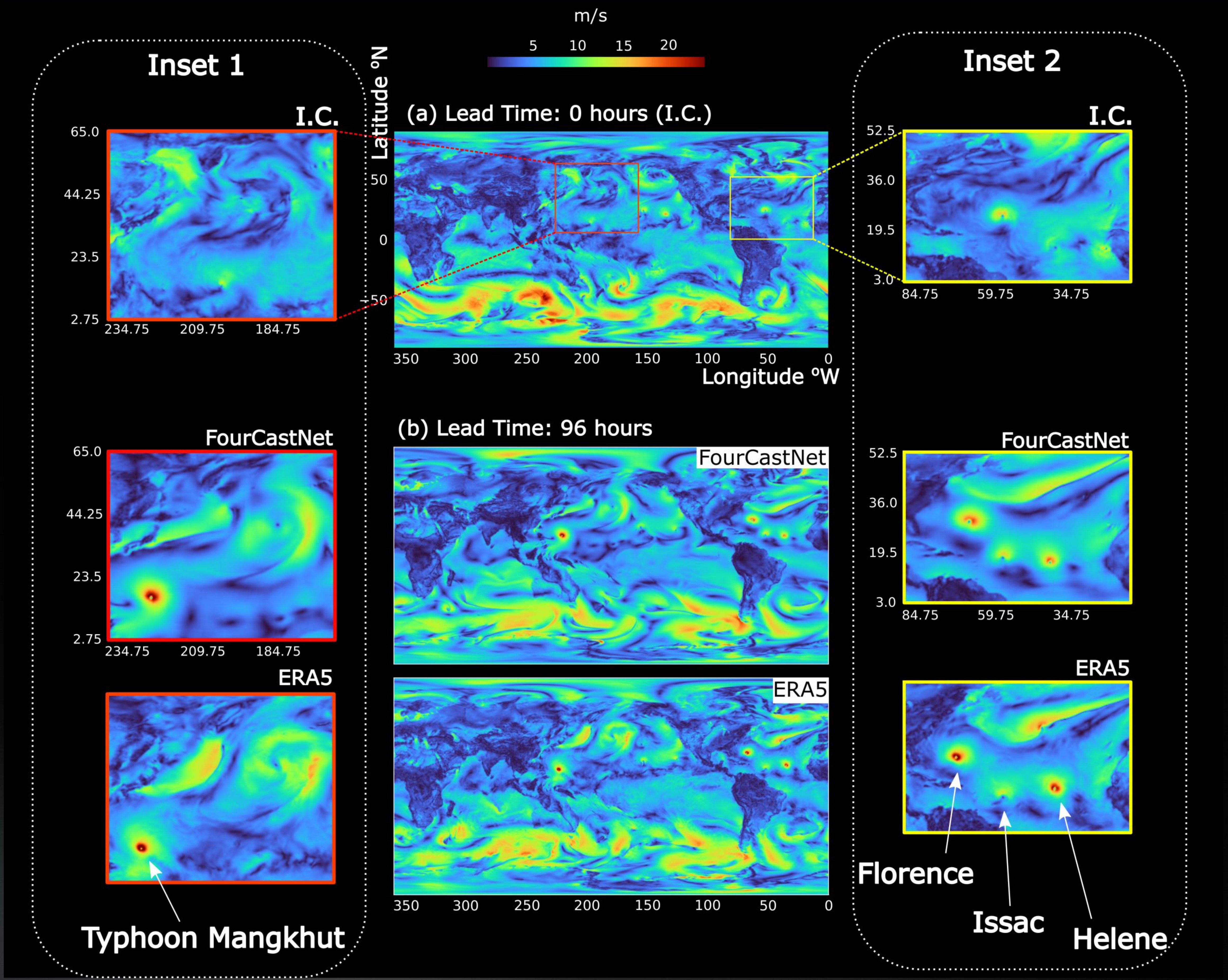
Vertical Level	Variables
Surface	$U_{10}, V_{10}, T_{2m}, sp, mslp$
$1000hPa$	U, V, Z
$850hPa$	T, U, V, Z, RH
$500hPa$	T, U, V, Z, RH
$50hPa$	Z
Integrated	$TCWV$

Currently models 21 atmospheric variables.

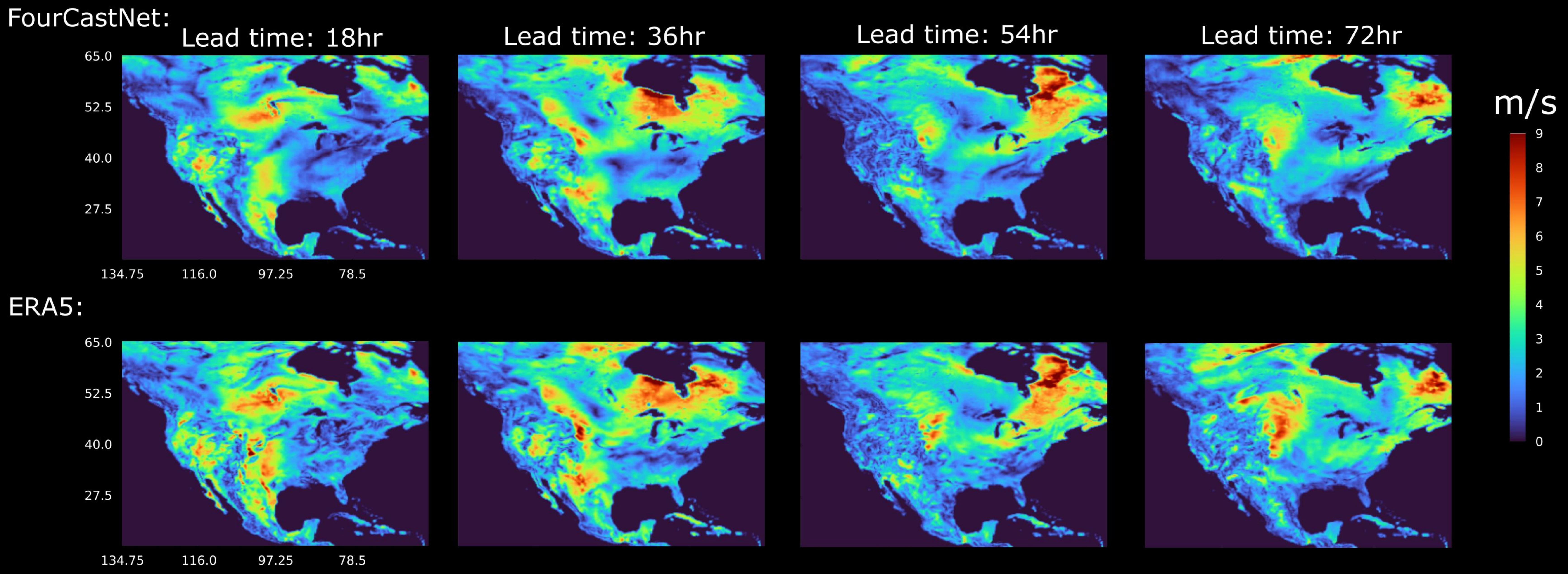
Soon to be extended to a larger set of variables to include radiation processes, vapor transport, more moisture variables, clouds.

Training set: 1979 to 2015
Validation set: 2016, 2017
Held out: 2018 onwards

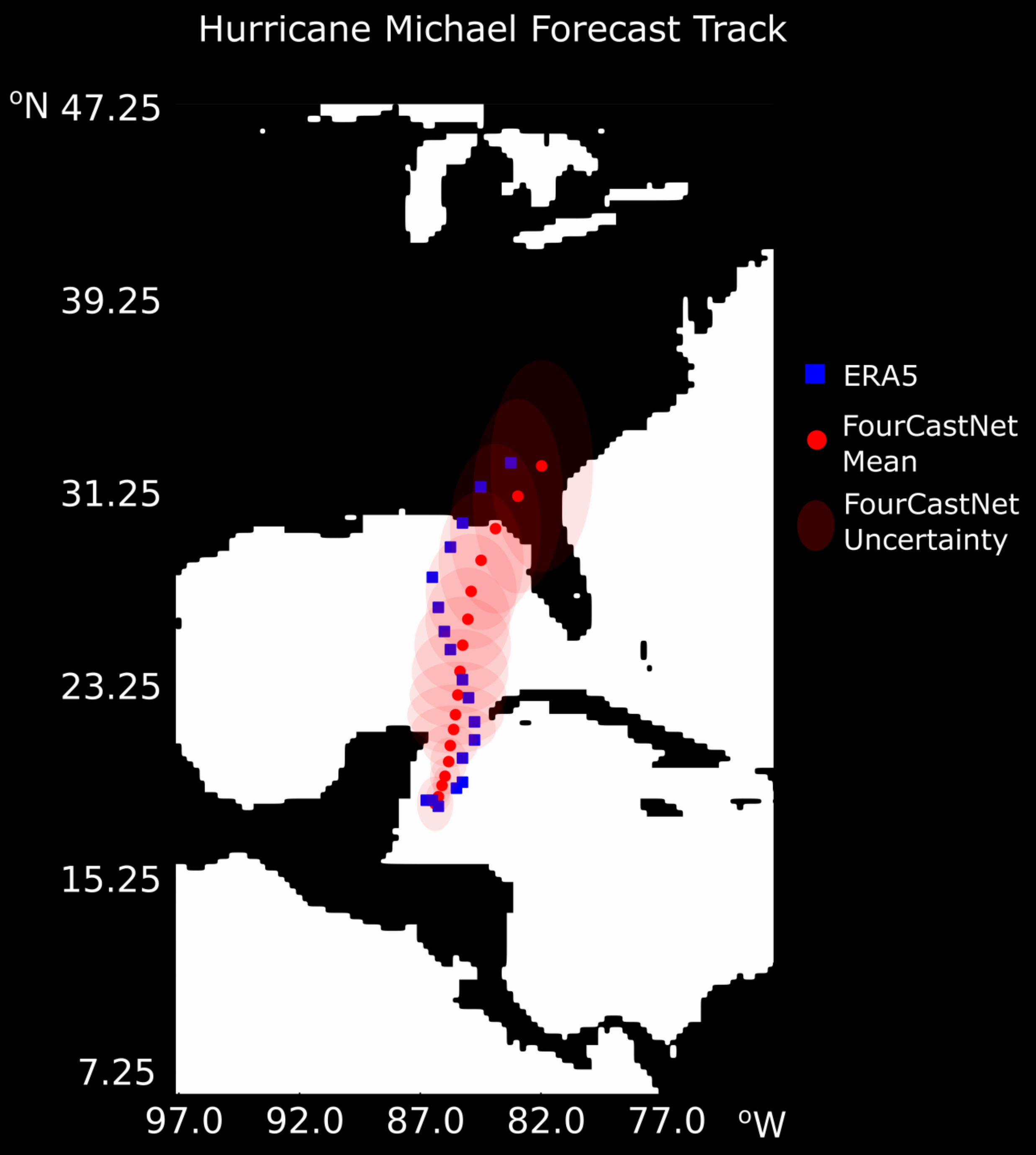
EXCELLENT SKILL ON FORECASTING SURFACE WINDS

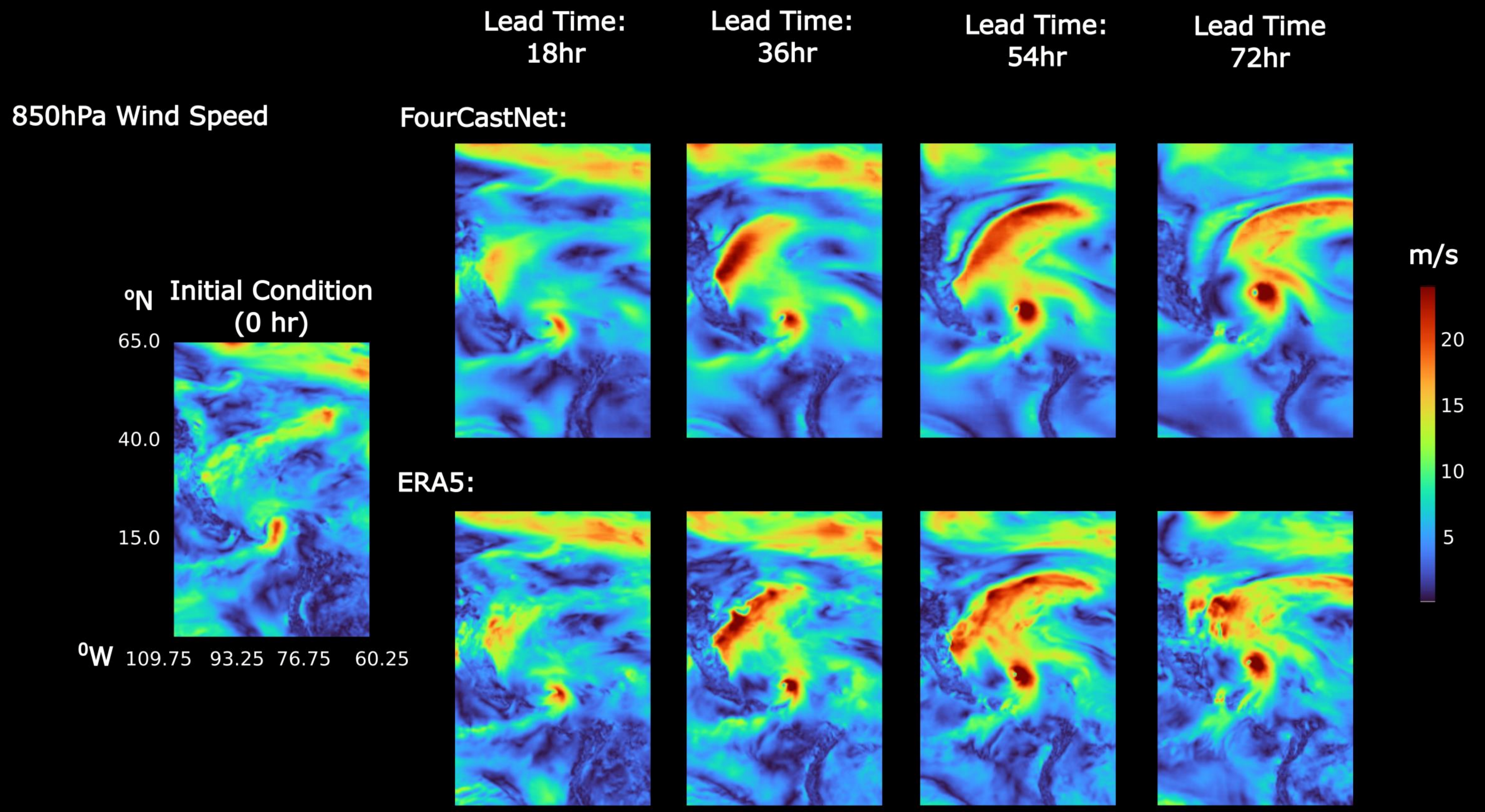


FOURCASTNET PREDICTS NEAR-SURFACE WIND FIELDS OVER LAND ACCURATELY: IMPORTANT IMPLICATIONS FOR WIND ENERGY PLANNING

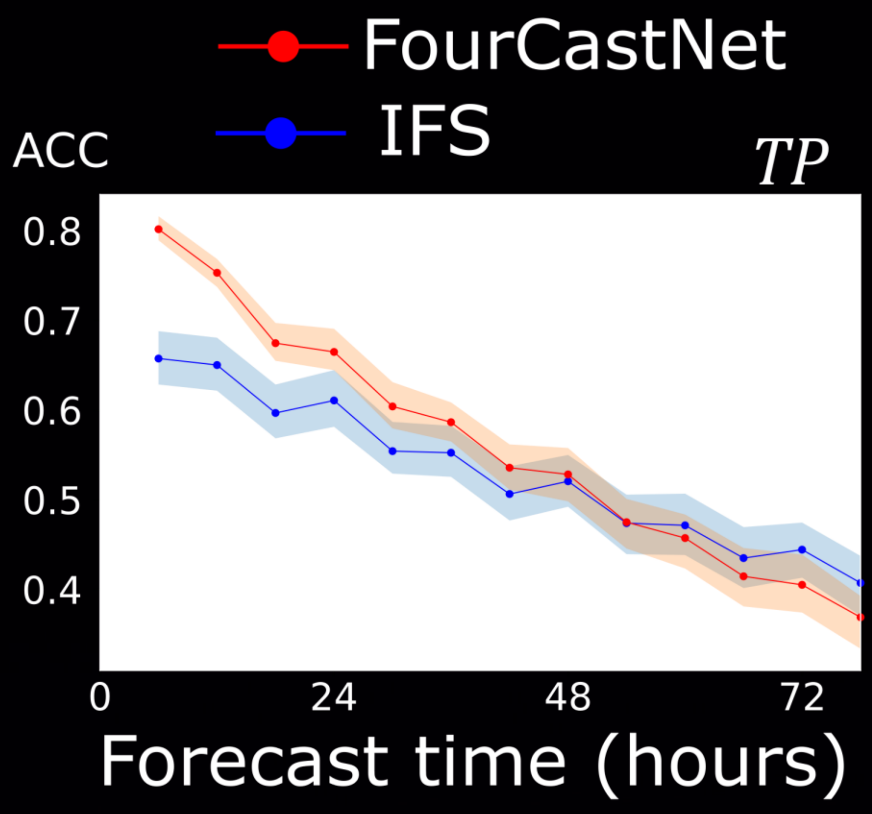


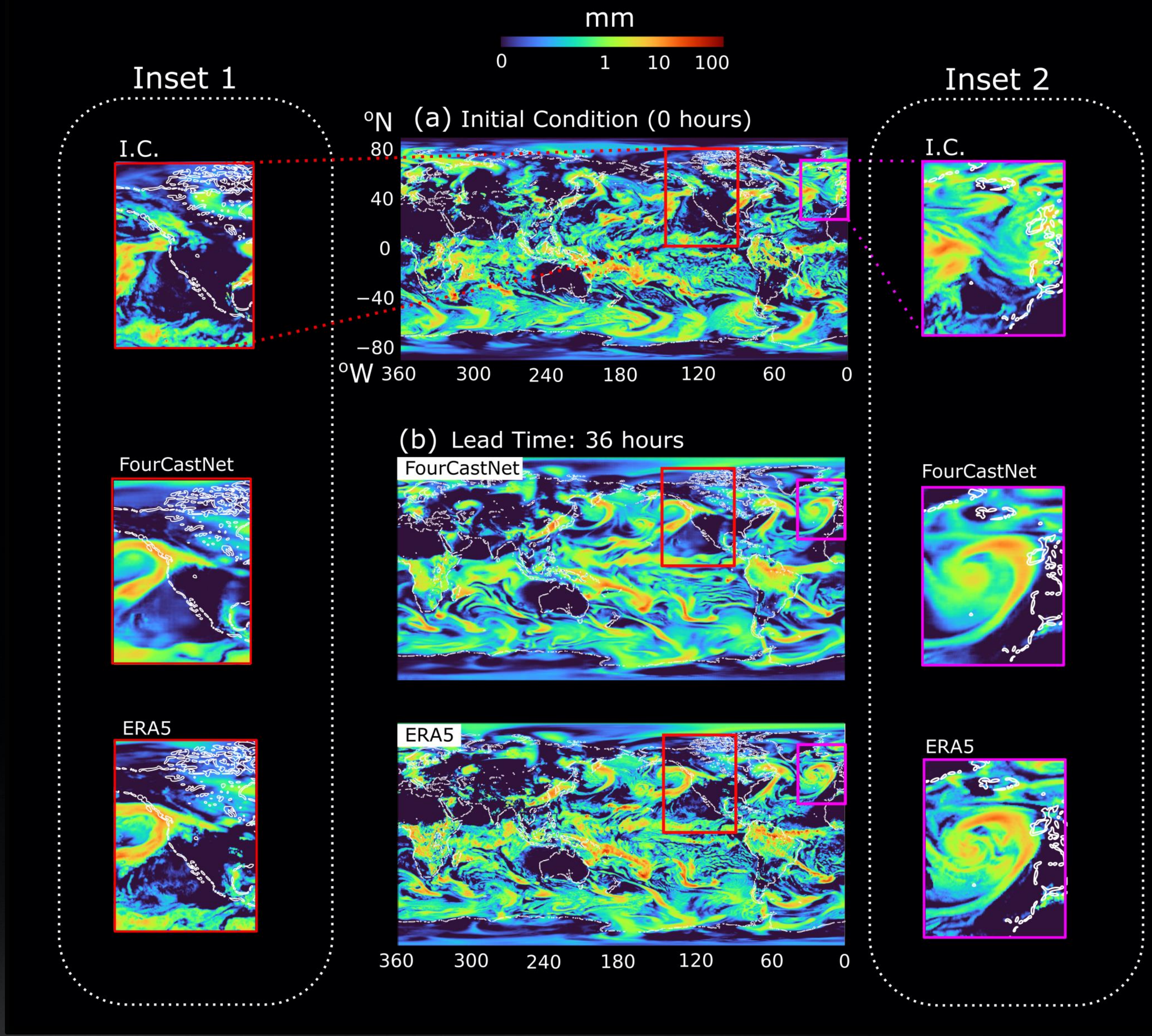
FOURCASTNET PREDICTS HURRICANE PATHS AND INTENSITIES





PRECIPITATION



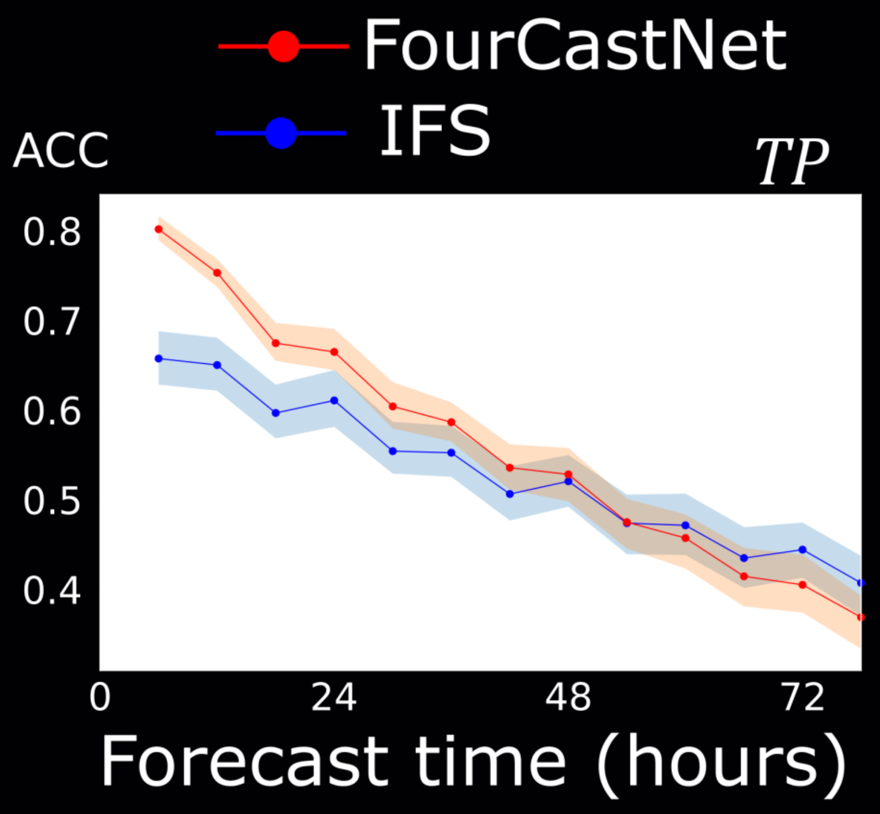


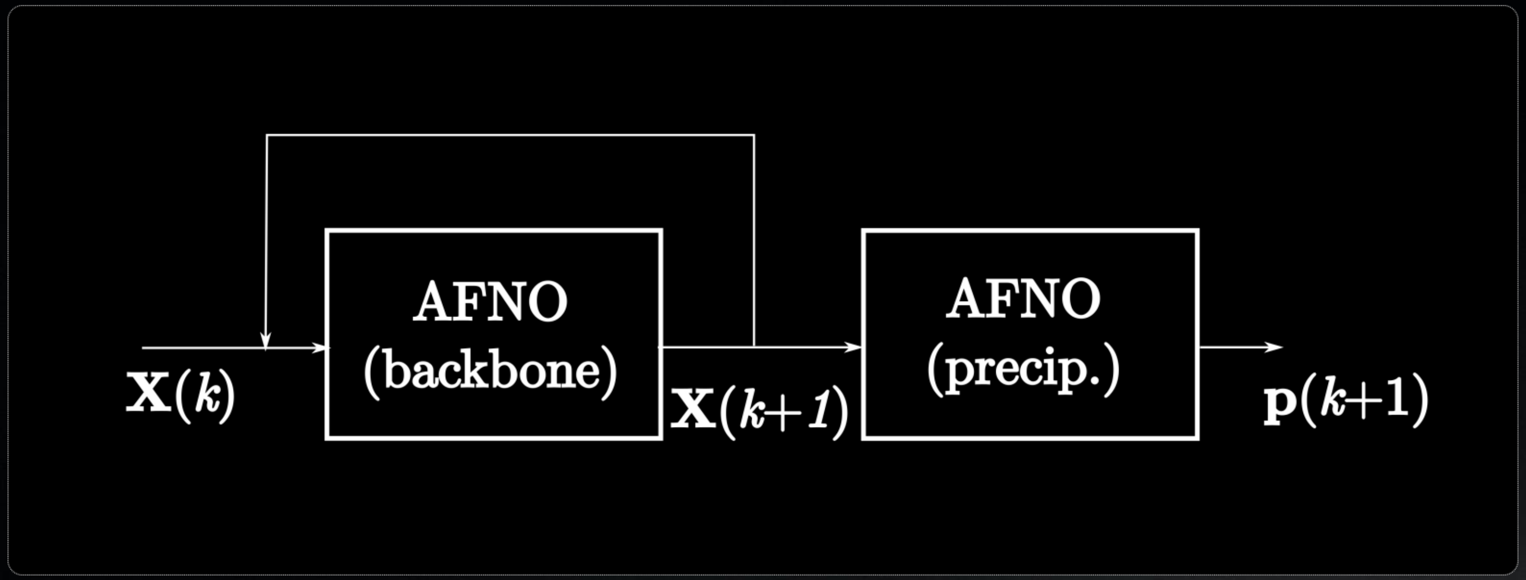
Excellent performance on forecasting precipitation with small scale features captured really well.

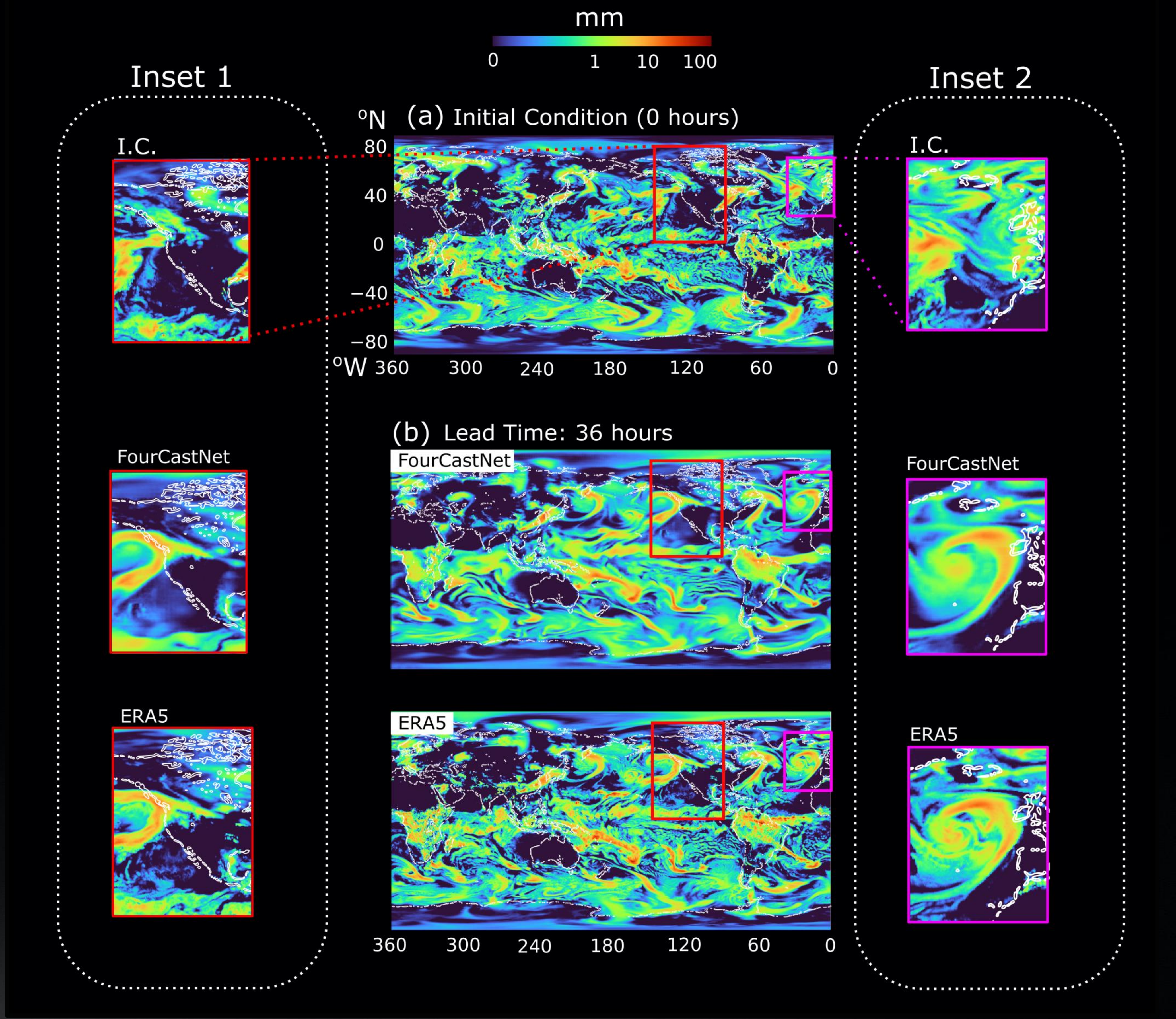
Currently we compare our forecasts to ERA5 rather than observations

Pathak et al. (2022), FourCastNet: A Global Data-driven High-resolution Weather Model using Adaptive Fourier Neural Operators, arXiv:2202.11214

PRECIPITATION

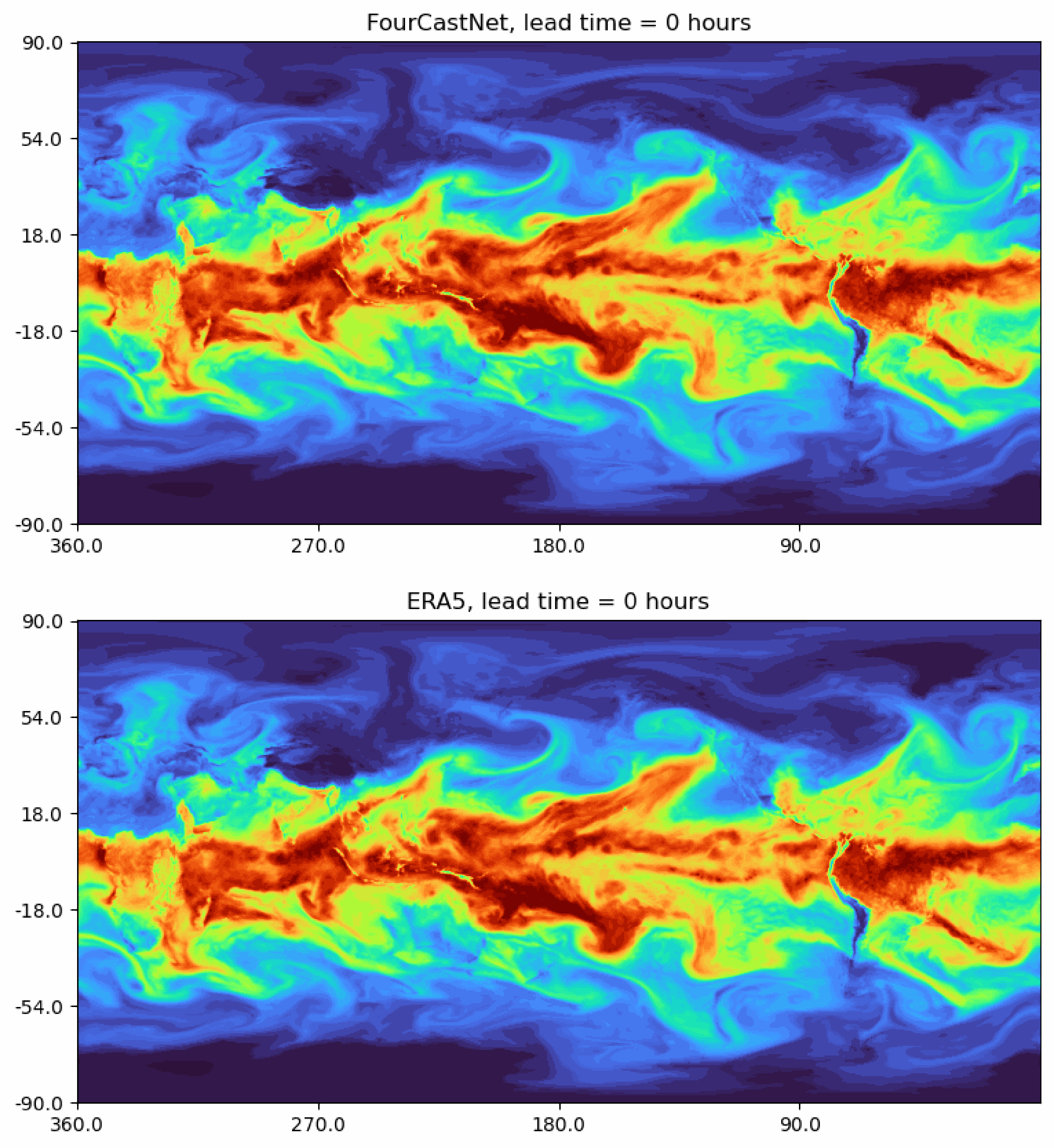


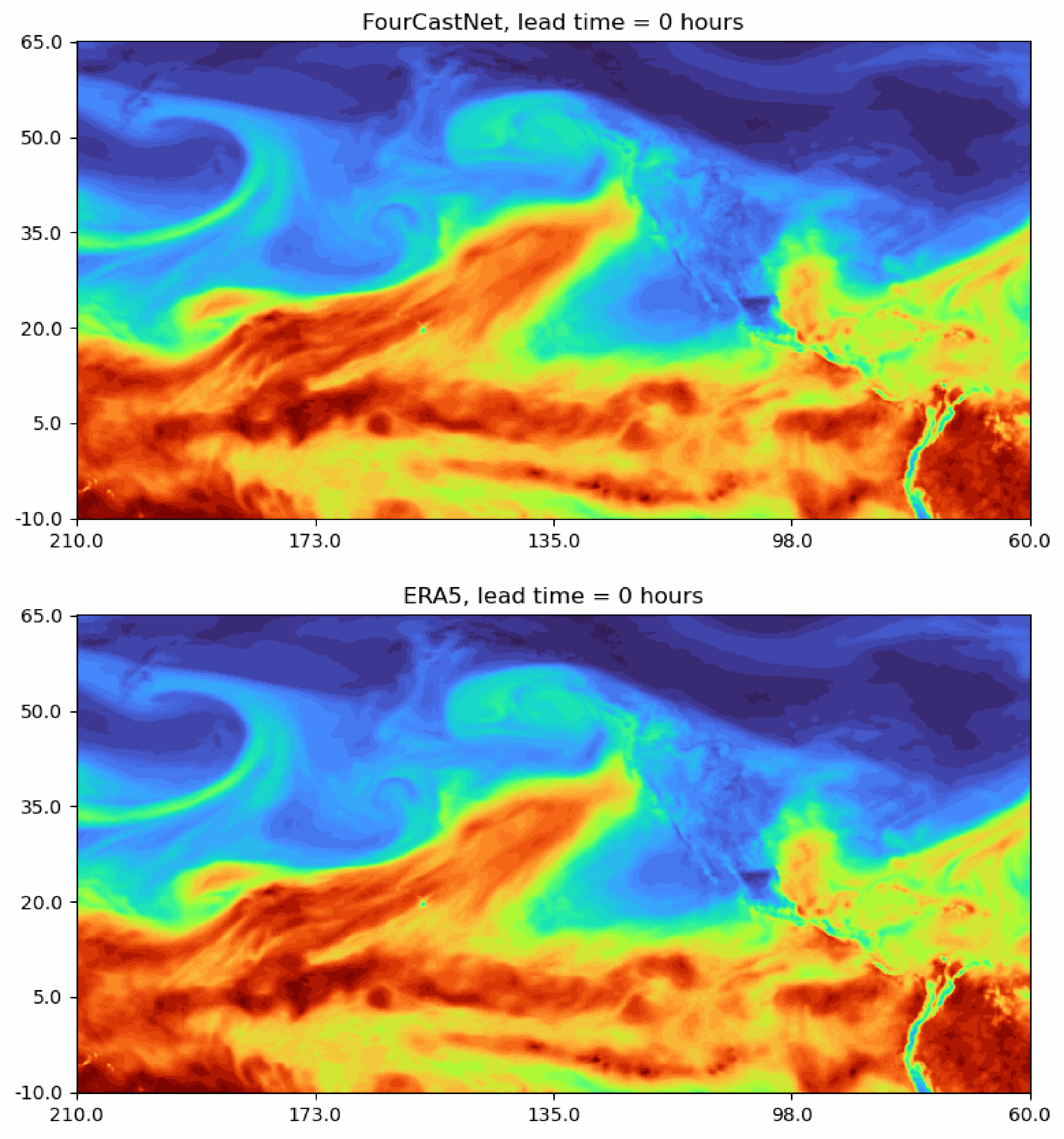




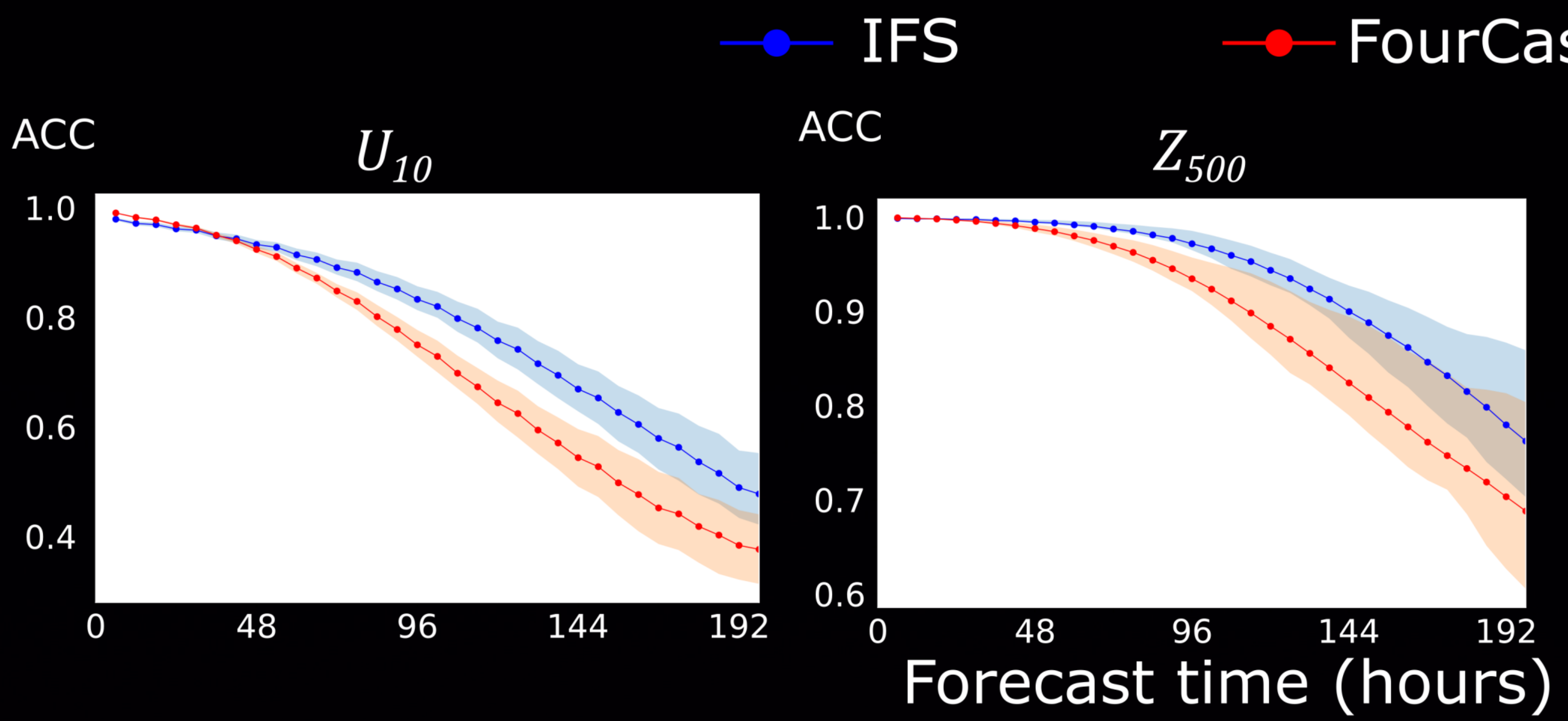
Pathak et al. (2022), FourCastNet: A Global Data-driven High-resolution Weather Model using Adaptive Fourier Neural Operators, arXiv:2202.11214

MOISTURE VARIABLES: WATER VAPOR





SHORT-TERM ACC CLOSE TO IFS

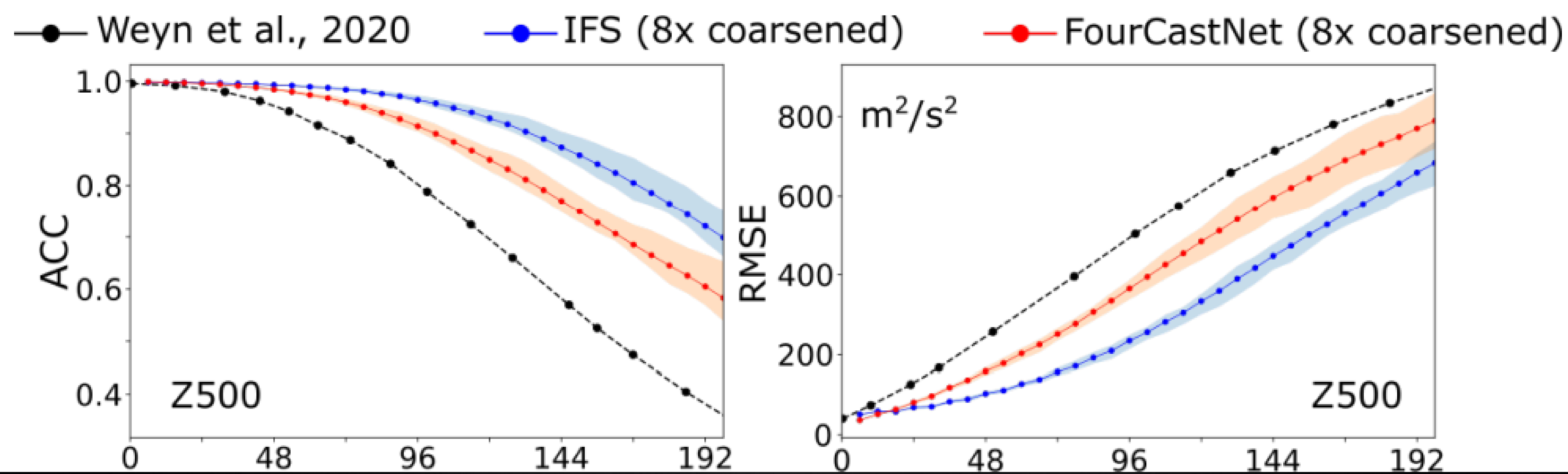


Caveat: Comparisons are made to ERA5 rather than directly to observations.

Pathak et al. (2022), FourCastNet: A Global Data-driven High-resolution Weather Model using Adaptive Fourier Neural Operators, arXiv:2202.11214

COMPARISON AGAINST STATE-OF-ART (DLWP, WEYN ET AL.)

8X higher resolution, significantly higher skill at weather timescales



Note: DLWP can predict reliably at S2S timescales

TODAY

- Unprecedented skill
- 1000-member ensemble in seconds
- 4 to 5 orders-of-magnitude speedup over NWP
- 4 orders-of-magnitude smaller energy footprint

LOOKING AHEAD

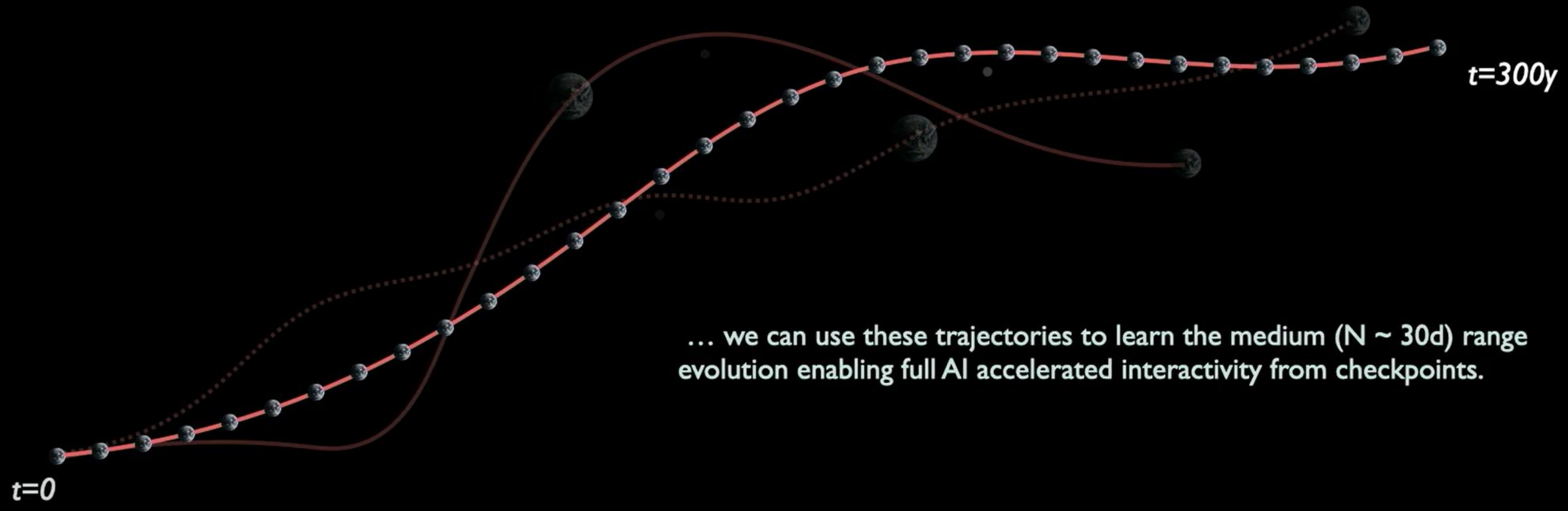
- Physics constraints
- Full state vector
- Generative models for fine-scales
- Uncertainty Calibration
- Observational ground truth / diagnostics

Climate as a trajectory in a Tera-dimensional (10^{12}) trajectory phase space

We can compute these, but can't effectively extract the information content from an XByte trajectory, let alone interact with it.

Source: Bjorn Stevens' keynote on "Digital Twins for Understanding and Adapting to Climate Change" at GTC Spring 2022

If we can compute these trajectories



… we can use these trajectories to learn the medium (N ~ 30d) range evolution enabling full AI accelerated interactivity from checkpoints.

If only as a first step for learning the entire system $N \to \infty$

Source: Bjorn Stevens' keynote on "Digital Twins for Understanding and Adapting to Climate Change" at GTC Spring 2022