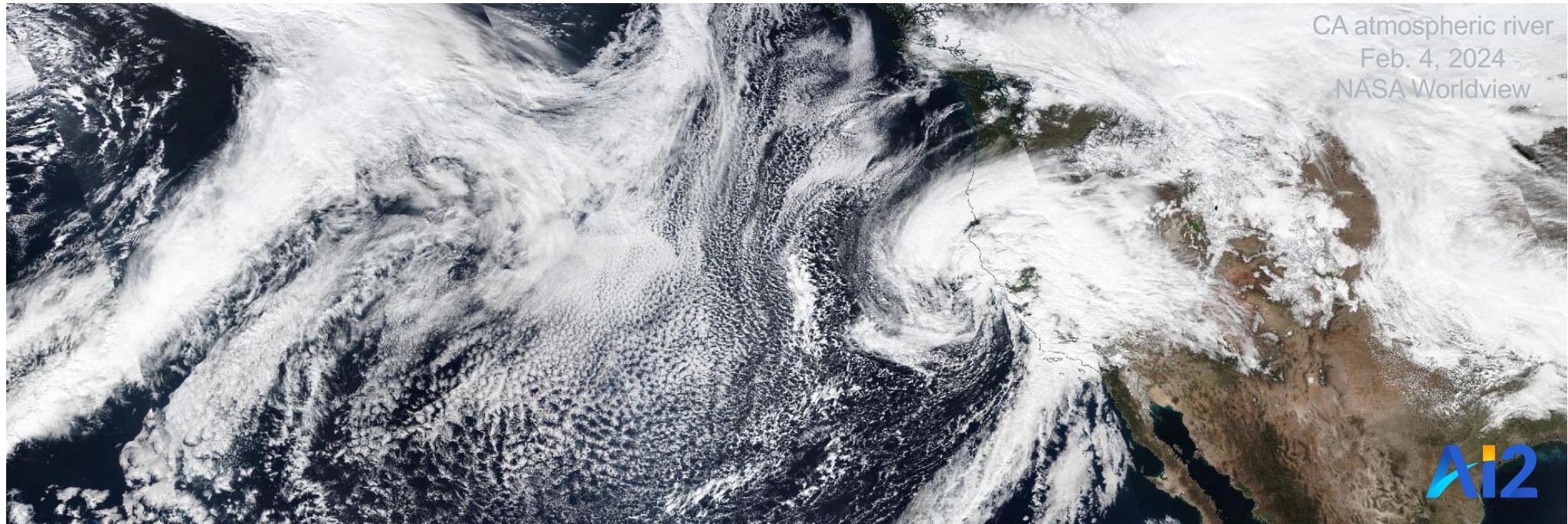


Machine Learning has Taken Weather Forecasting by Storm How About Climate Modeling?

Christopher Bretherton
Senior Director of Climate Modeling
Allen Institute for Artificial Intelligence (AI2), Seattle, USA



AI2 Climate Modeling ML group



Philanthropic project of the Paul G. Allen estate since 2019, at Vulcan and now AI2.

- Goal: Use ML to better foresee regional climate change and precipitation extremes
- Strategy: Fast, efficient, user-friendly ML emulators of expensive SOTA physics-based models to better inform local and regional planning for climate change

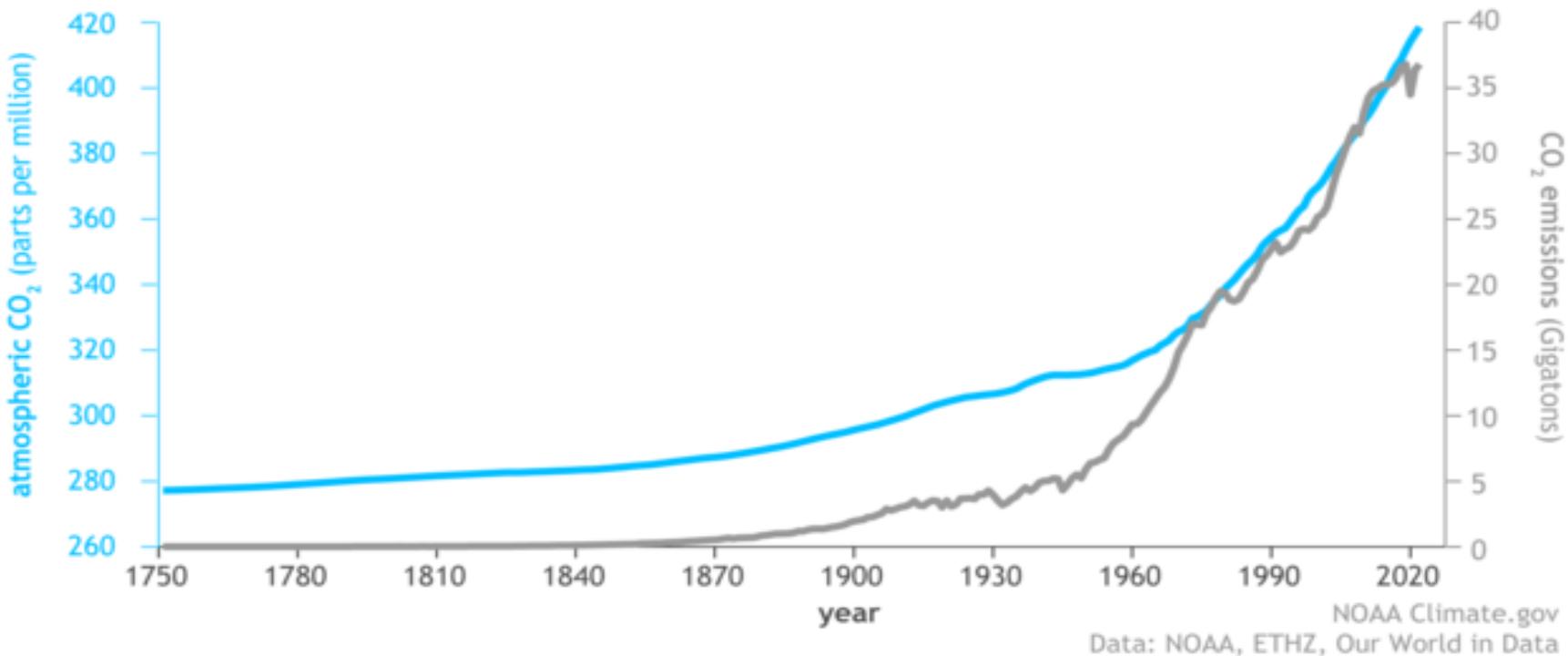
Collaborators:

- NOAA Geophysical Fluid Dynamics Laboratory (Princeton)
- DOE Lawrence Livermore National Laboratory (Livermore CA)
- NVIDIA: Developers of FourCastNet
- Academic partners & summer interns (UW, Columbia, UC schools, etc.)



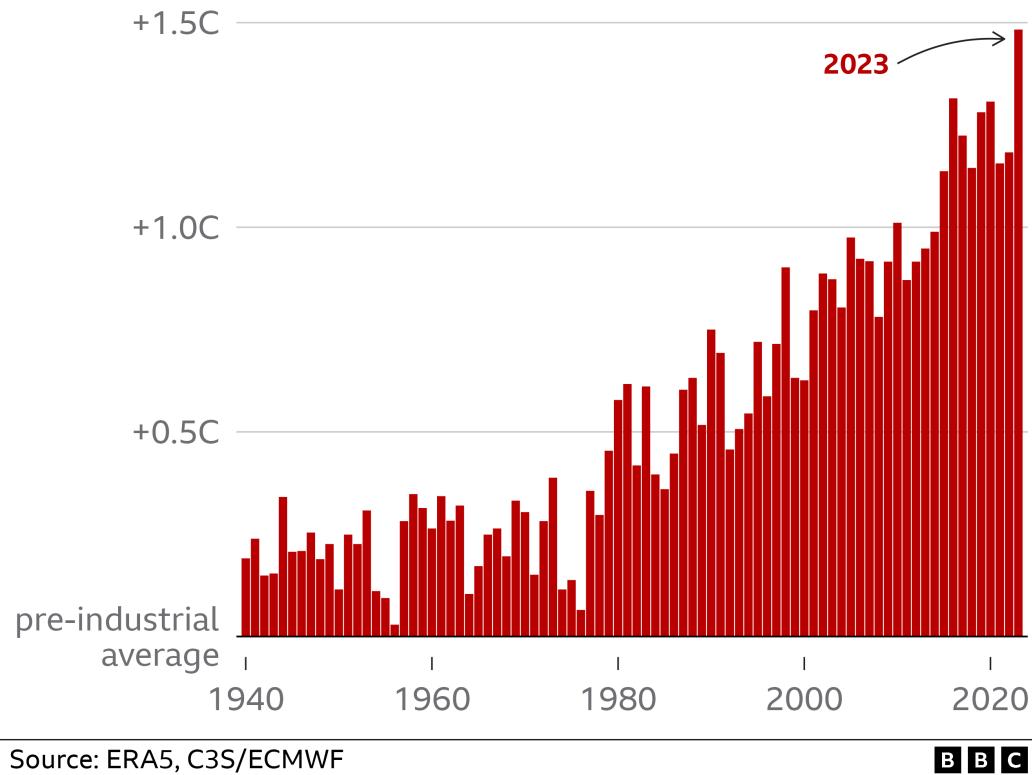
The Anthropocene Era

Global atmospheric carbon dioxide compared to annual emissions (1751-2022)



The Anthropocene Era

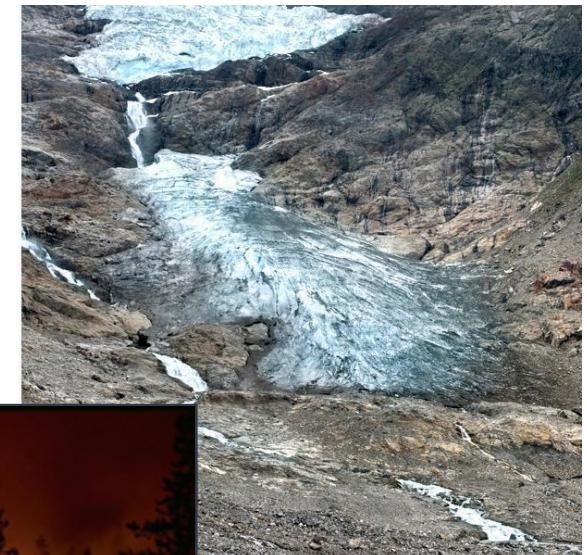
Global average temperature by year, compared with pre-industrial average (1850-1900)



BBC

AI2

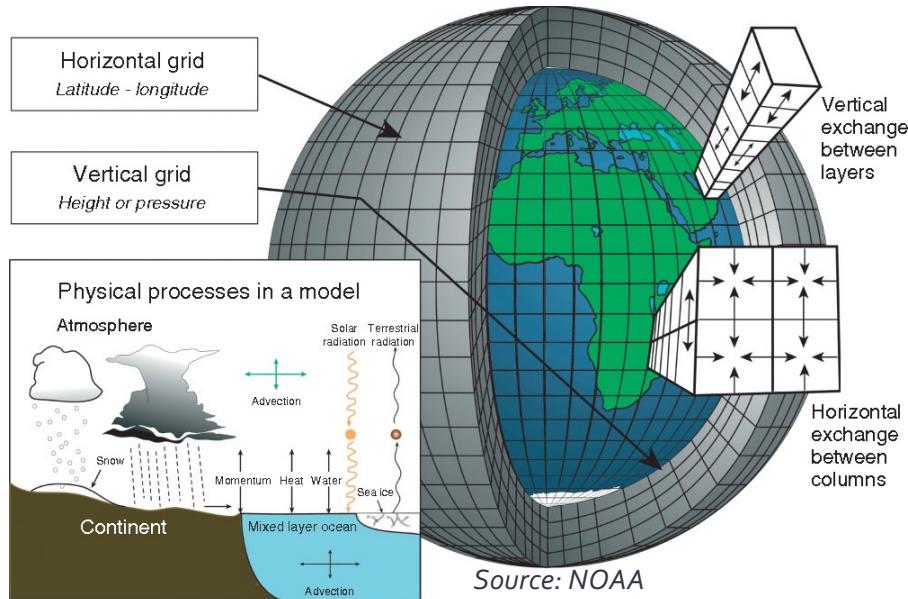
Unprecedented extremes are unfolding



60 years of global climate modeling

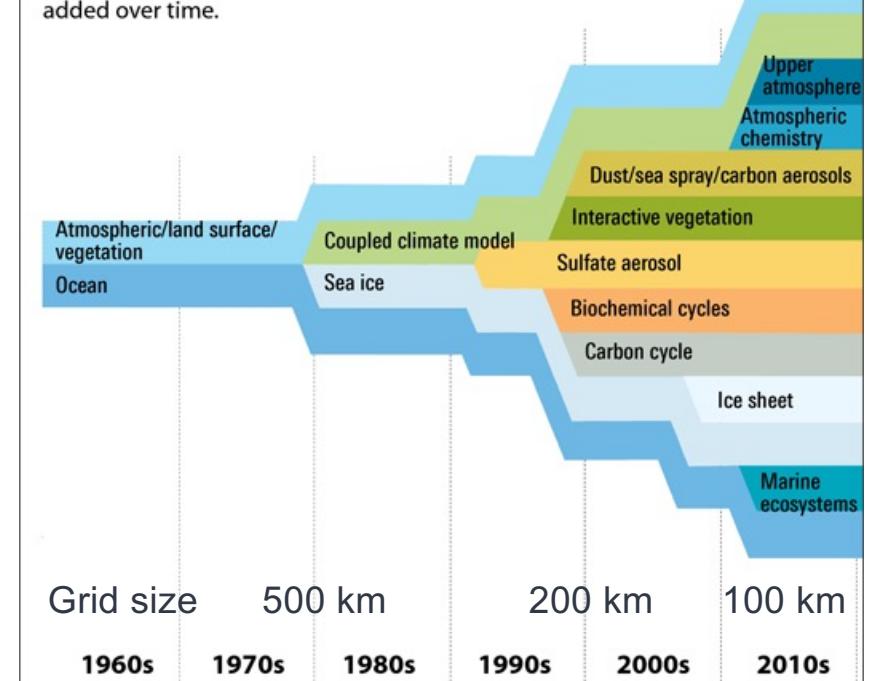


Physics-based climate models



Growth of Climate Modeling

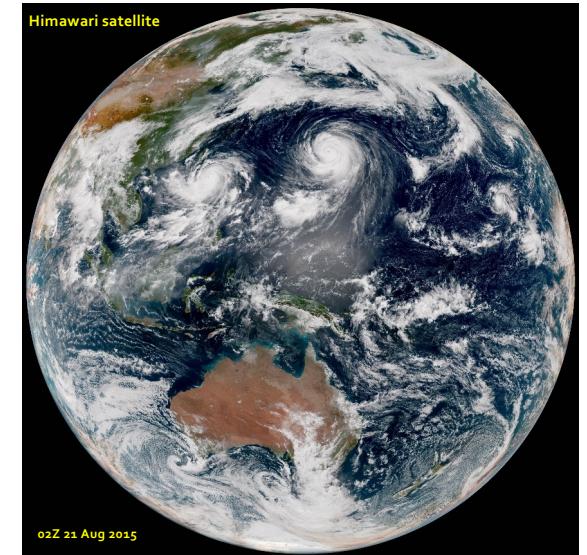
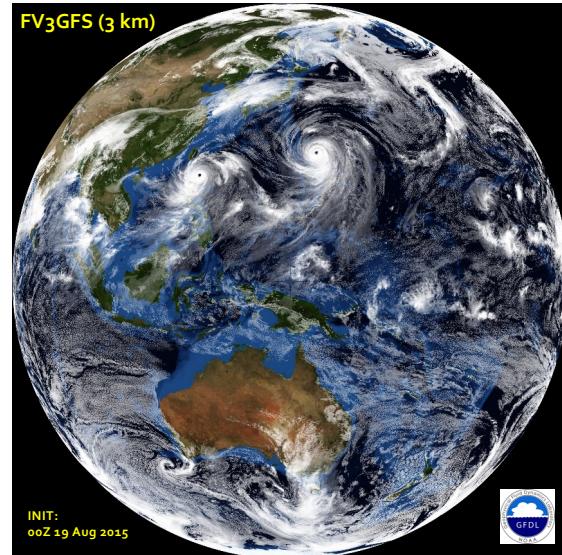
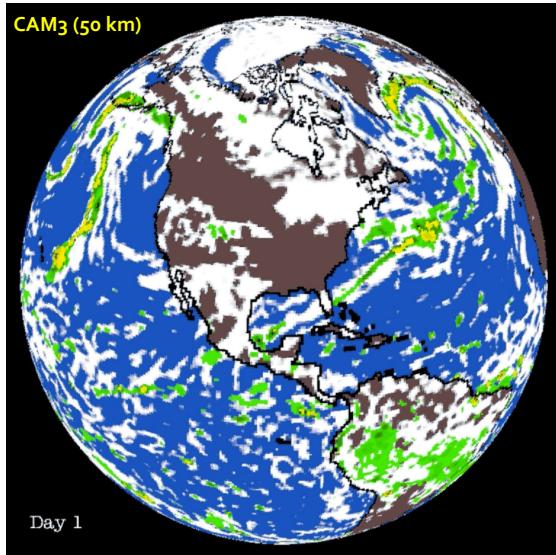
As computing power expanded, climate modeling became more sophisticated and drew in additional influences on global temperature and climate. These are a few of the areas added over time.



SOURCE: University Corporation for Atmospheric Research (UCAR)

InsideClimate News

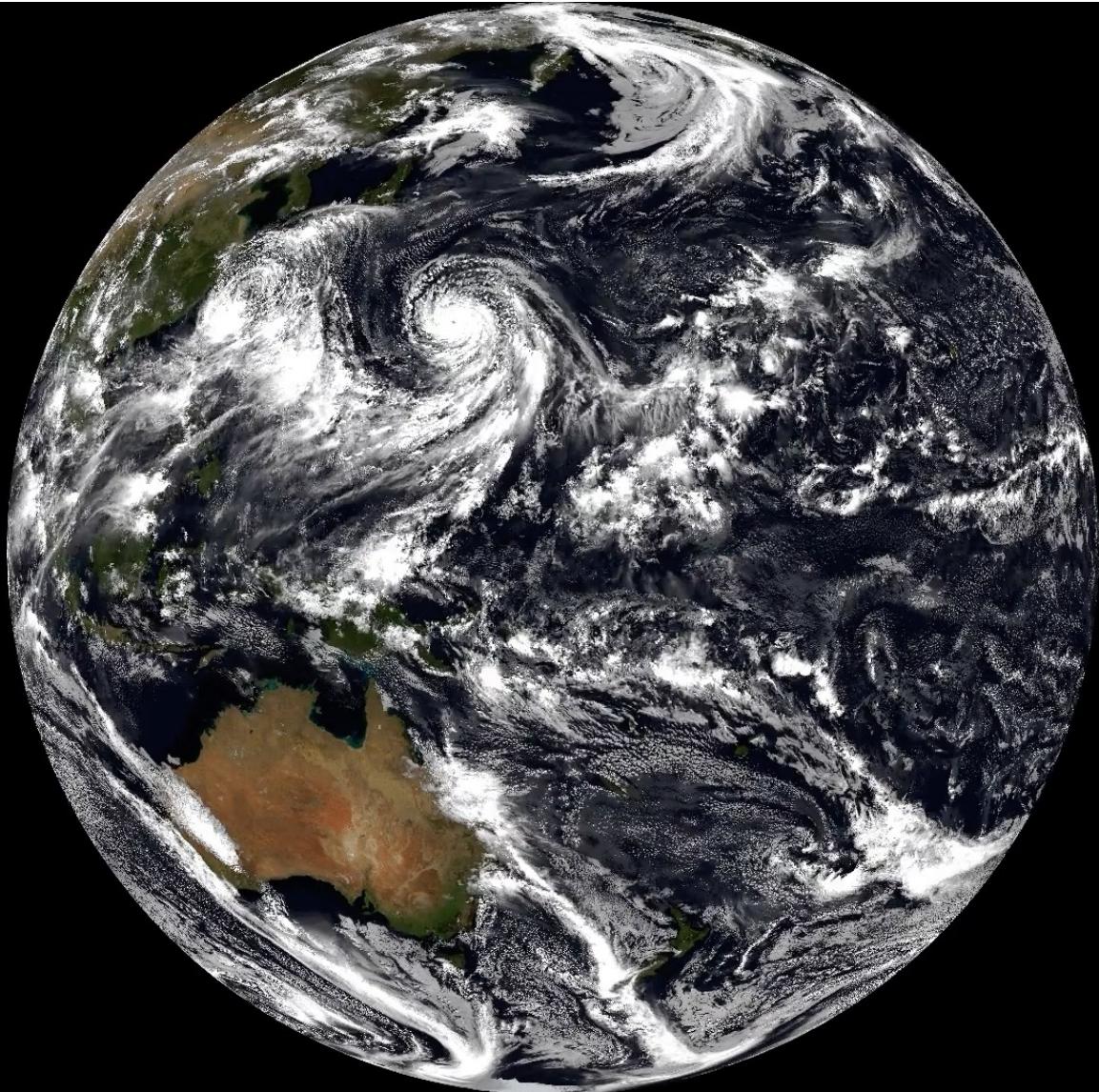
‘Digital twins’



Beautiful but expensive:

- GFDL gets 0.05 simyear/day on 14K cores of their GAEA system
- DOE group won 2023 Gordon Bell Prize for achieving 1 simyear/day for 3 km SCREAM model on Frontier
- Electrical consumption of 1000 MW-hr/simyear ~ same as 300 US residents for one year





2016-08-11 18:00Z
258 Forecast Hours
FV3 3km

Visualization
Xi Chen@FV3 team

The ML revolution in weather forecasting

Challenges and design choices for global weather and climate models based on machine learning

Peter D Improving Data-Driven Global Weather Prediction Using Deep Convolutional Neural Networks on a Cubed Sphere

Receive Jonathan A. V FOURCASTNET: A GLOBAL DATA-DRIVEN HIGH-RESOLUTION WEATHER MODEL USING ADAPTIVE FOURIER NEURAL OPERATORS

Revised ¹Department of Atmospheric Sciences, University of Washington, WA, USA

Corres. Author: Jaideep Iyer, NVIDIA Corporation, Santa Clara, CA, USA

Abstract We propose a new framework for global weather prediction using a deep convolutional neural network (DCNN) trained on a cubed sphere.

Forecasting Global Weather with Graph Neural Networks

Pangu-Weather: A 3D High-Resolution System for Fast and Accurate Global Weather Forecast

Kaifeng E GraphCast: Learning skillful medium-range global weather forecasting

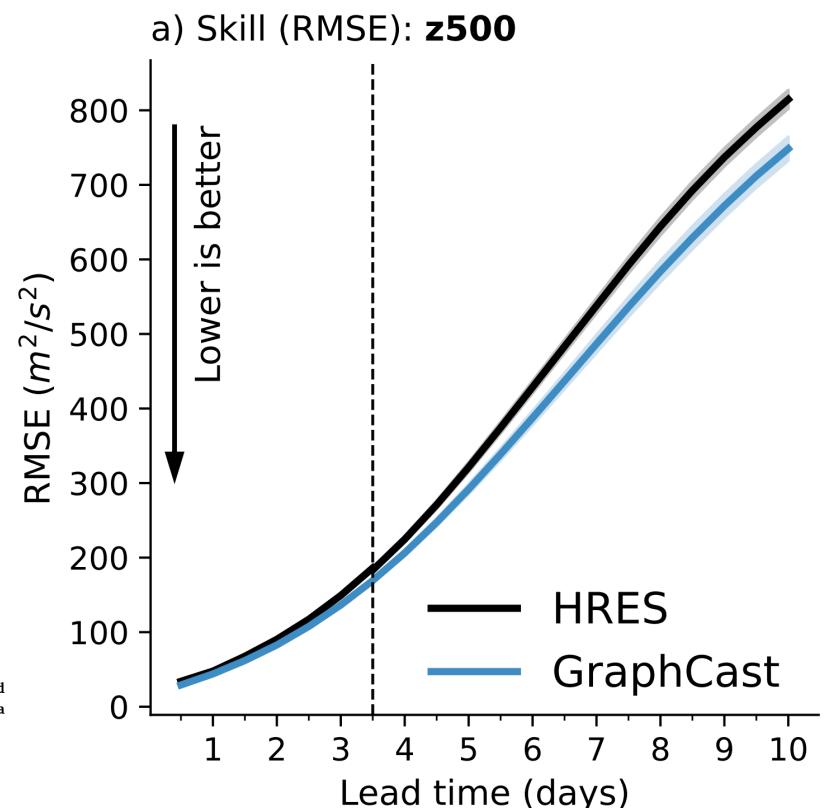
Remi Lam^{*,†}, Alvaro Sanchez-Gonzalez^{*,†}, Ferran Alet¹, Timo Ewalds¹, Andrew El-Kadi², Jacklynn Stott¹, Stephan Hoyer², Peter Battaglia¹

*equal contribution,

Ilan Price^{*,†}, Alvaro Sanchez-Gonzalez^{*,†}, Ferran Alet¹, Timo Ewalds¹, Andrew El-Kadi², Jacklynn Stott¹, Shakir Mohamed¹, Peter Battaglia¹, Remi Lam¹ and Matthew Willson¹

[†]Equal contributions, ¹Google DeepMind, ²Imperial College, London

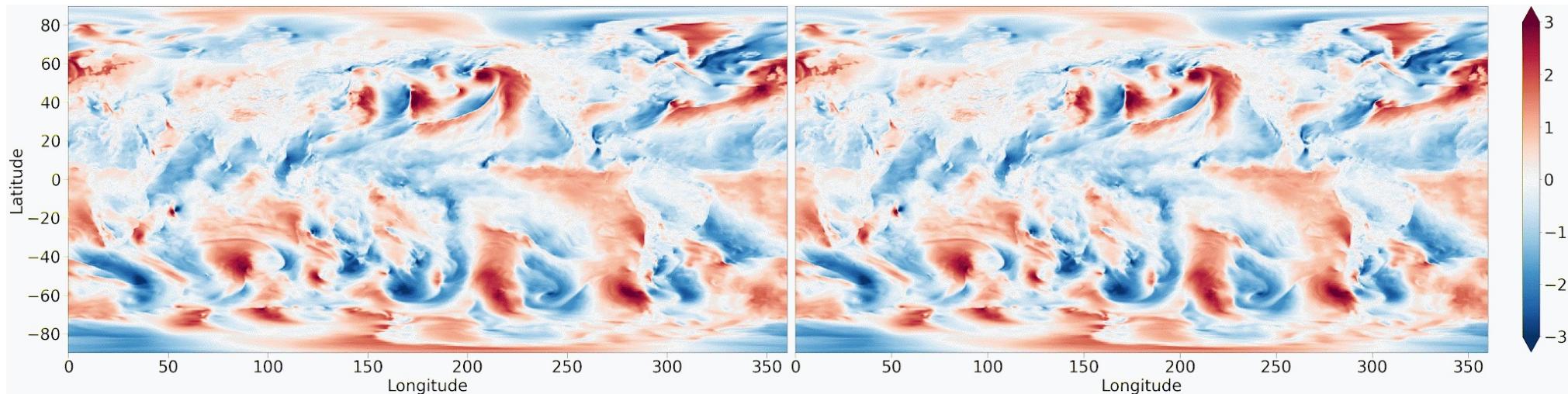
Probabilistic weather forecasting is critical for decision-making in high-impact domains such as flood forecasting, energy system planning or transportation routing, where quantifying the uncertainty of a



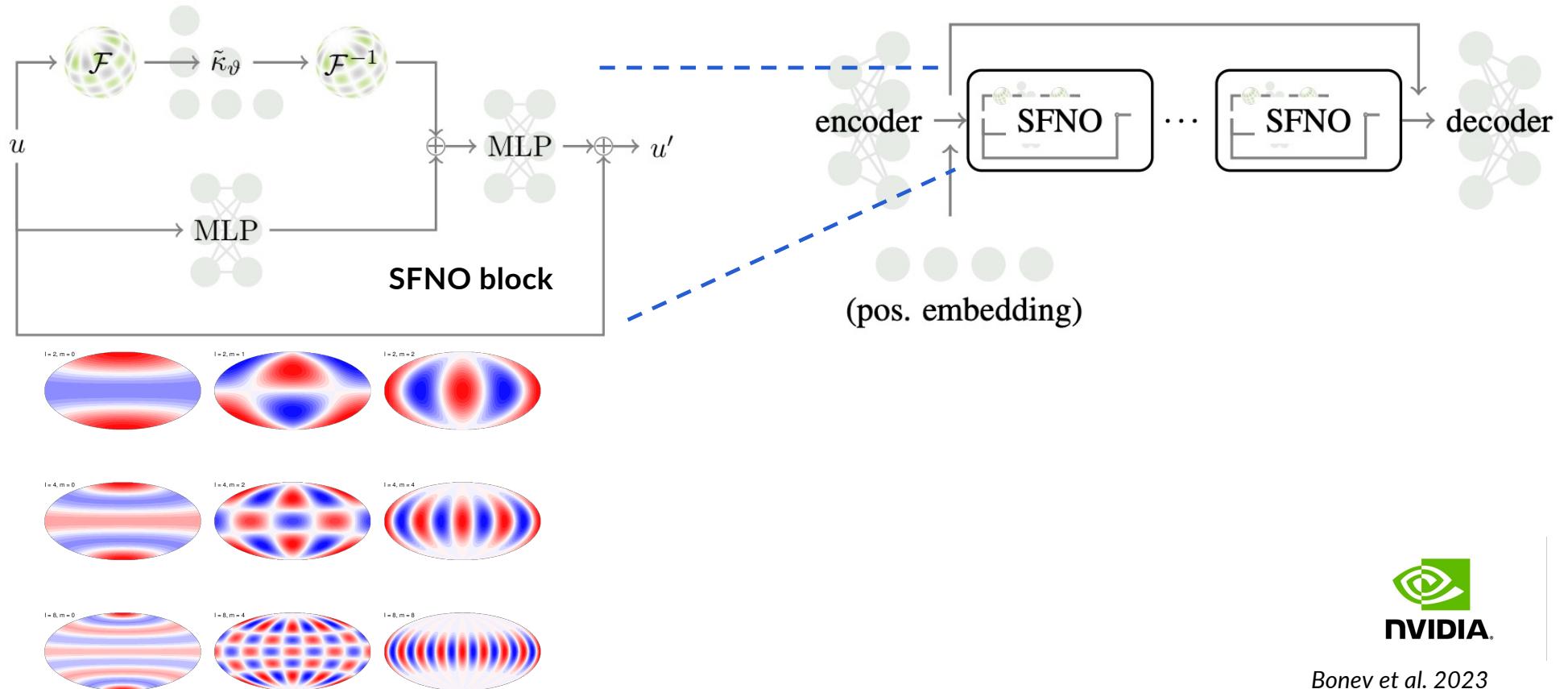
Lam et al. 2022

From weather to climate - it's not so easy!

Three-week forecast of northward wind with earlier version of FourCastNet



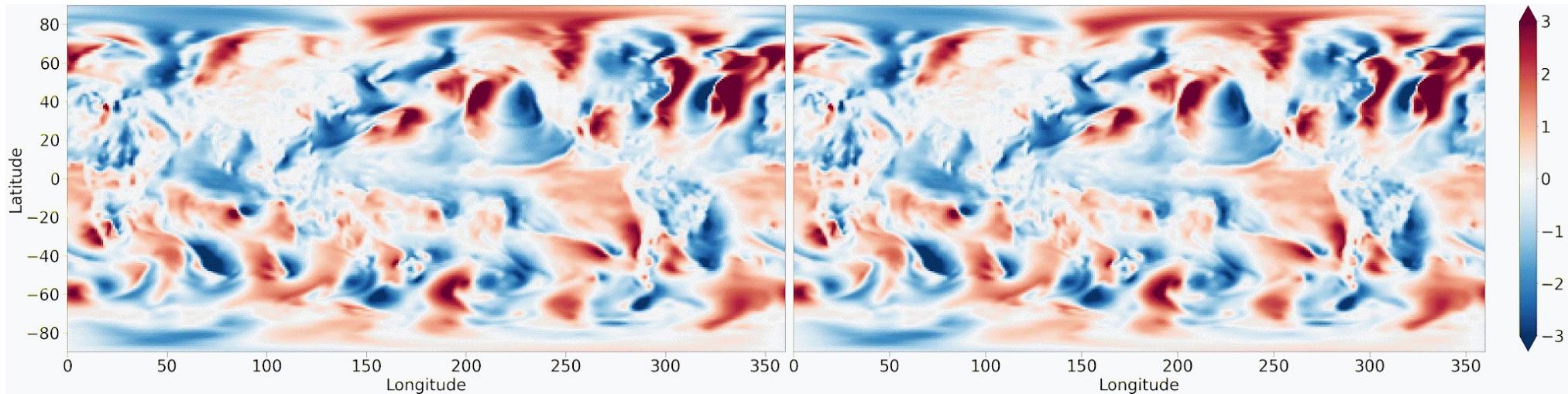
NVIDIA's SFNO architecture



Bonev et al. 2023

AI2 upgrades SFNO for climate modeling

AI2 climate emulator (ACE) trained on 100 yrs of reference NOAA model (100 km grid)
Forced by repeating seasonal cycle of ocean temperature and sunlight



Trains in 2.5 days on 4 A100 GPUs

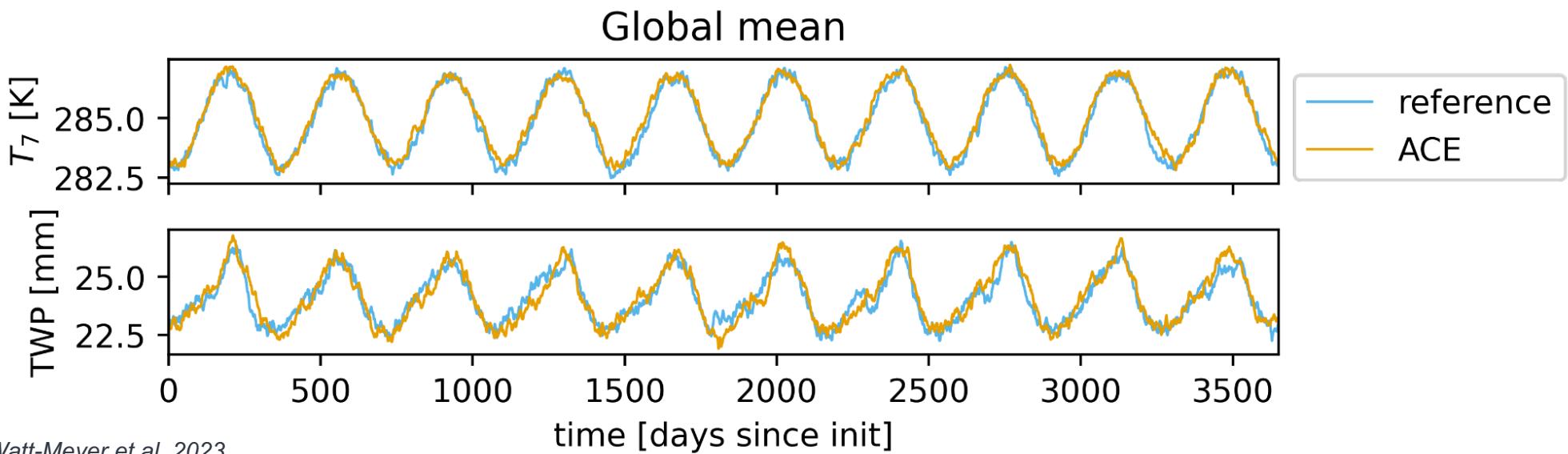
100 yr simulation in 3 hrs on one A100 GPU!

Reference@NOAA: 50x slower, 1000x power on 864 CPU cores



AI2 upgrades SFNO for climate modeling

ACE trained on reference NOAA model is highly accurate for at least 100 yrs

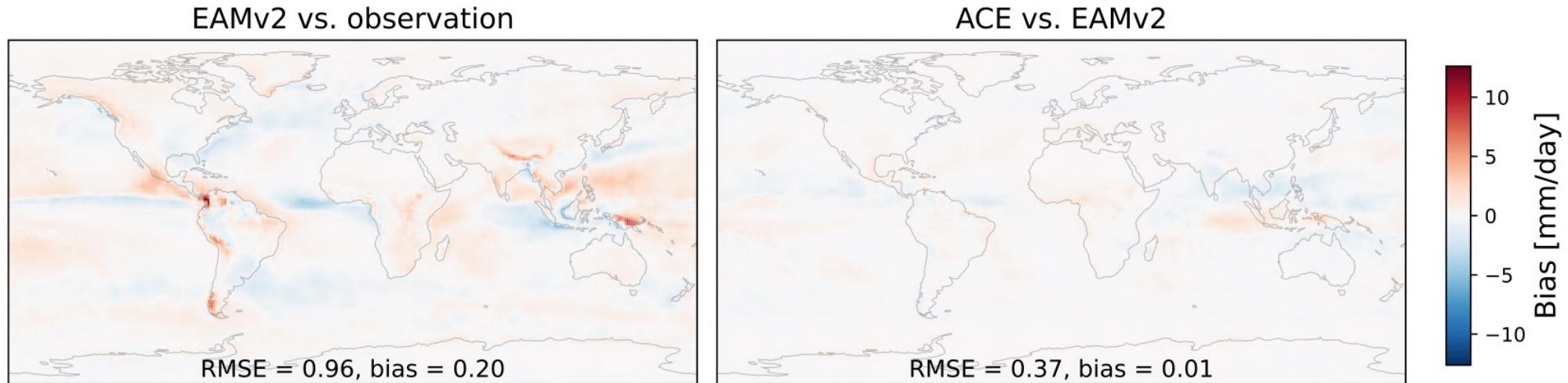


Watt-Meyer et al. 2023



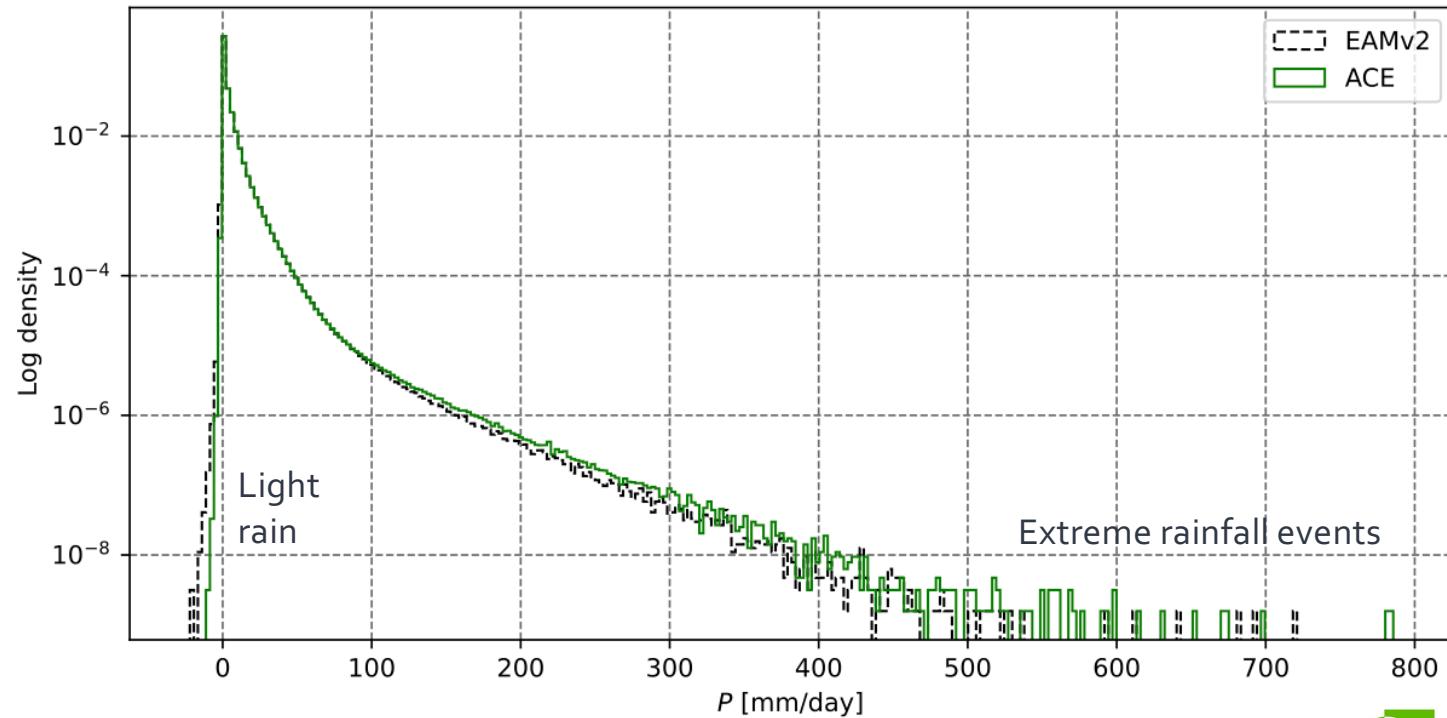
AI2 upgrades SFNO for climate modeling

ACE trained on reference DOE model (100 km grid) is just as skillful



AI2 upgrades SFNO for climate modeling

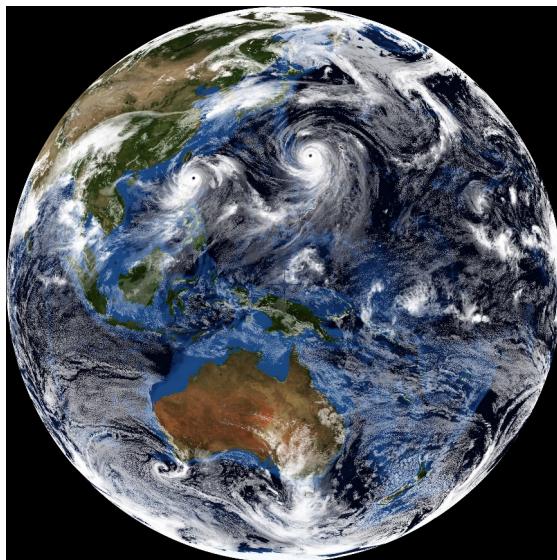
ACE reproduces the extreme rainfall frequency of reference DOE model



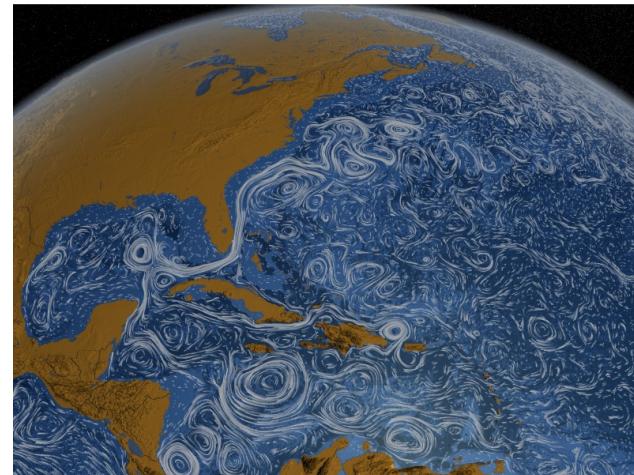
Duncan et al. 2024



The digital twin climate emulator we'll want to have



+



=

Fast coupled emulator
trained for unparalleled
realism across a broad
range of climates at 10^{-4}
the computing cost of
the ultrafine physics-
based models



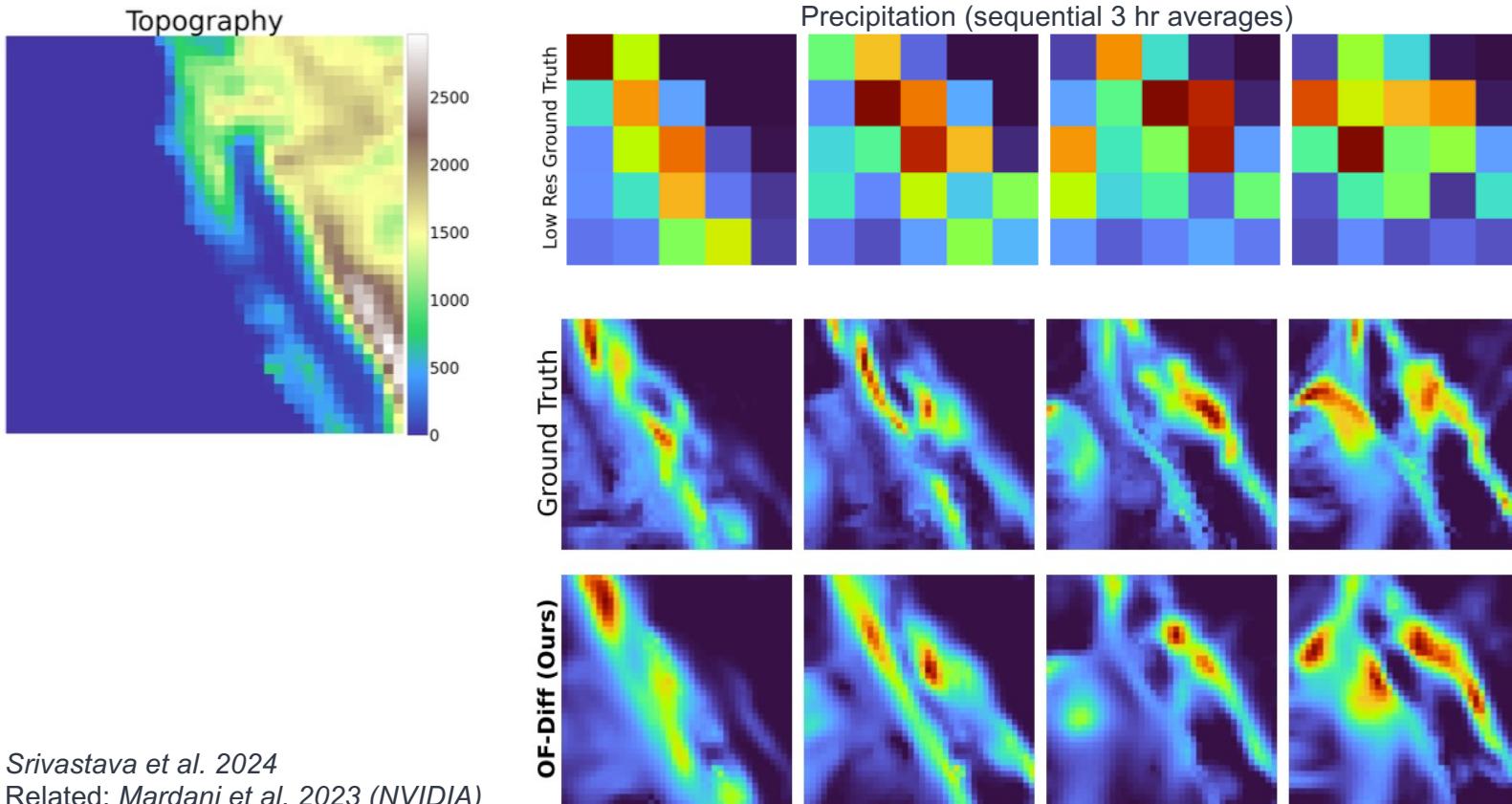
0.25° atmospheric emulator
16 GPUs
1000x faster, 10000x more efficient



0.25° ocean emulator
(almost 'free')

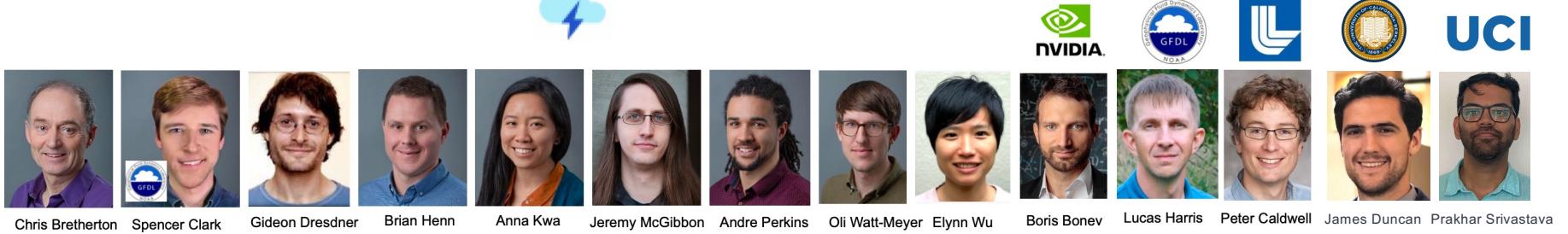


ML downscaling via generative video super-resolution



Srivastava et al. 2024
Related: Mardani et al. 2023 (NVIDIA)

It takes a village...



...and lots of great colleagues:

Mike Pritchard, Karthik Kashinath and Noah Brenowitz at NVIDIA
Stephan Hoyer of Google, and many others.

...plus the generous support of AI2 by the Allen Foundation

Together we will all go further and better...

ML for climate has a bright and exciting future – stay tuned!

