AI Research
for Climate Change and Environmental Sustainability

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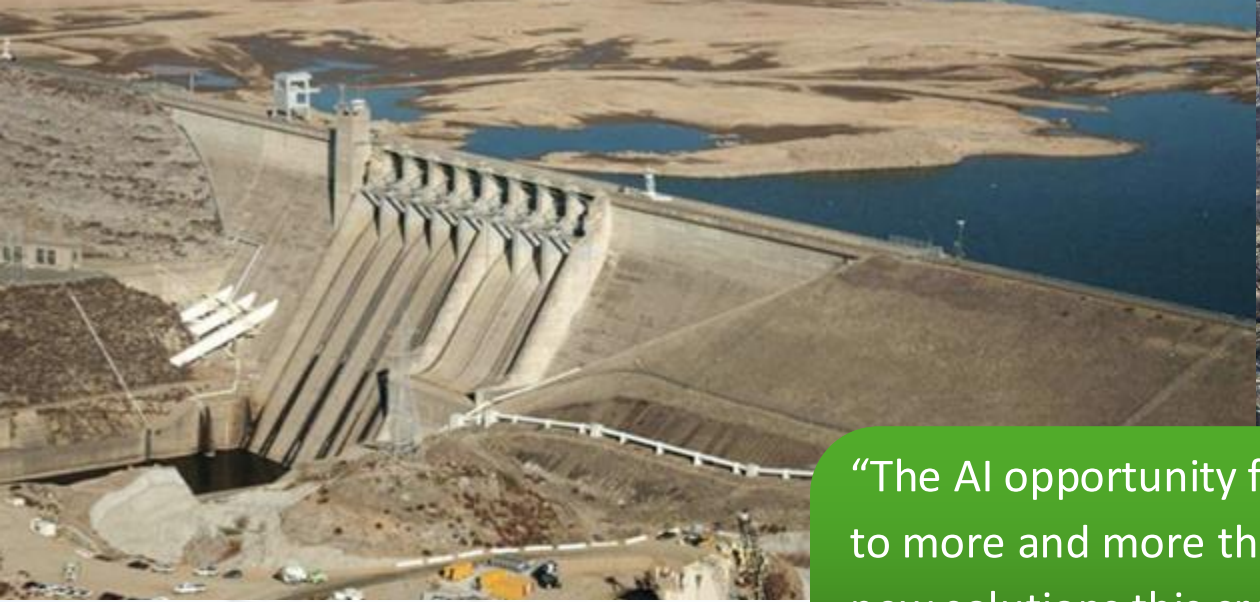
December 2021: Boulder County, Colorado

- Snow drought conditions through fall and winter 2021 created dry land-cover
- 80-100 mph winds, combined with ignition, launched an uncontrollable "fire storm"
- Loss of 2 lives. 1000 homes and 20 businesses were destroyed, and more damaged

January 2018: Montecito, Santa Barbara County

- Thomas Fire destroyed 1063 structures and led to poor air quality
- Intense rainfall as the fire was nearing containment produced a debris flow
- 23 lives and over 130 homes were lost
- Damage to critical transportation and water resource infrastructure



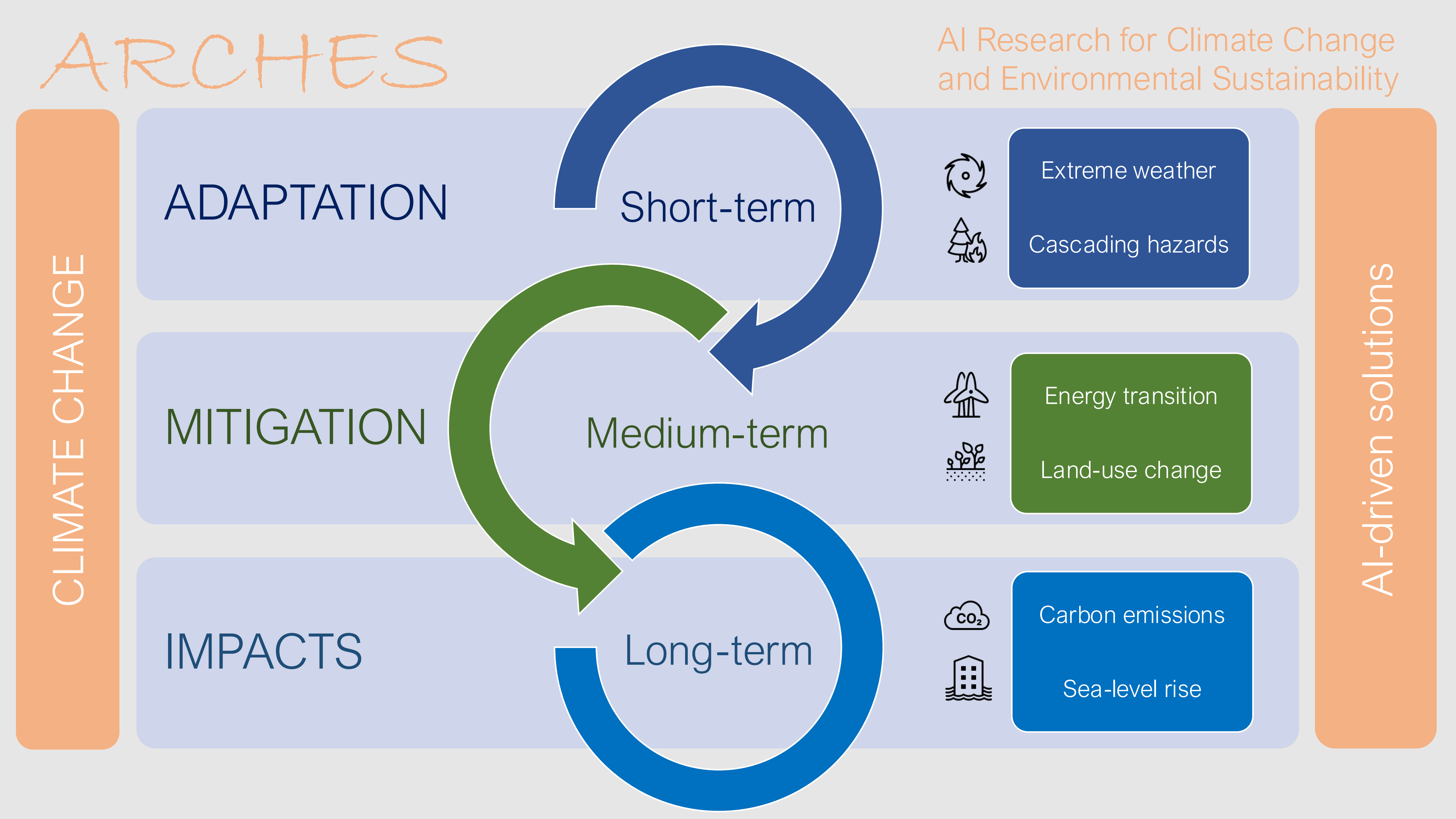

"The AI opportunity for the Earth is significant. Today's AI explosion will see us add AI to more and more things every year.... As we think about the gains, efficiencies and new solutions this creates for nations, business and for everyday life, we must also think about how to maximize the gains for society and our environment at large."

– The World Economic Forum: Harnessing Artificial Intelligence for the Earth. 2018


Climate Informatics: using Machine Learning to address Climate Change

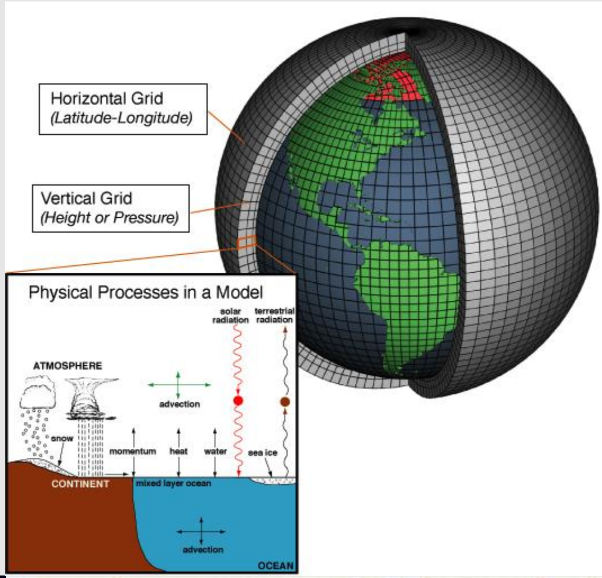
- 2008 Started research on Climate Informatics, with Gavin Schmidt, NASA
- 2010 “Tracking Climate Models” [Monteleoni et al., NASA CIDU, Best Application Paper Award]
- 2011 Launched International Workshop on Climate Informatics, New York Academy of Sciences
- 2012 Climate Informatics Workshop held at NCAR, Boulder, for next 7 years
- 2013 “Climate Informatics” book chapter [M et al., SAM]
- 2014 “Climate Change: Challenges for Machine Learning,” [M & Banerjee, NeurIPS Tutorial]
- 2015 Launched Climate Informatics Hackathon, Paris and Boulder
- **2018 World Economic Forum recognizes Climate Informatics as key priority**
- 2021 Computing Research for the Climate Crisis [Bliss, Bradley @ M, CCC white paper]
- 2022 First batch of articles published in Environmental Data Science, Cambridge University Press
- 2024 13th Conference on Climate Informatics, Turing Institute, London

2025 14th Conference on Climate Informatics, April 28-30th, Rio de Janeiro, Brazil


ARCHES
AI Research for Climate Change
and Environmental Sustainability
CLIMATE CHANGE
ADAPTATION
Short-term
Extreme weather
Cascading hazards
MITIGATION
Medium-term
Energy transition
Land-use change
IMPACTS
Long-term
CO_2
Carbon emissions
Sea-level rise
AI-driven solutions

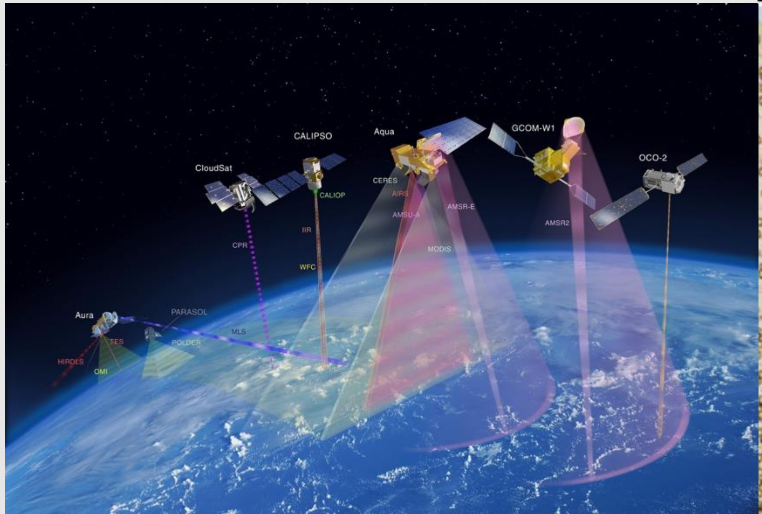
Approach: Exploit all available data

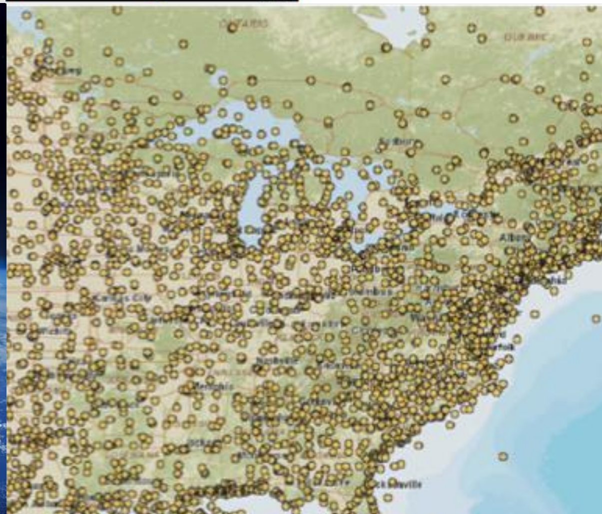
- Simulated data generated by physics-based models
  - Numerical Weather Prediction (NWP) models
  - General Circulation Models (GCM)
  - Regional Climate Models (RCM)



- Reanalysis data
  - Gridded data products from <u>data assimilation</u>: applies physical laws to observations

- Observation data
  - Satellite remote sensing data
  - In-situ data





AI Methods

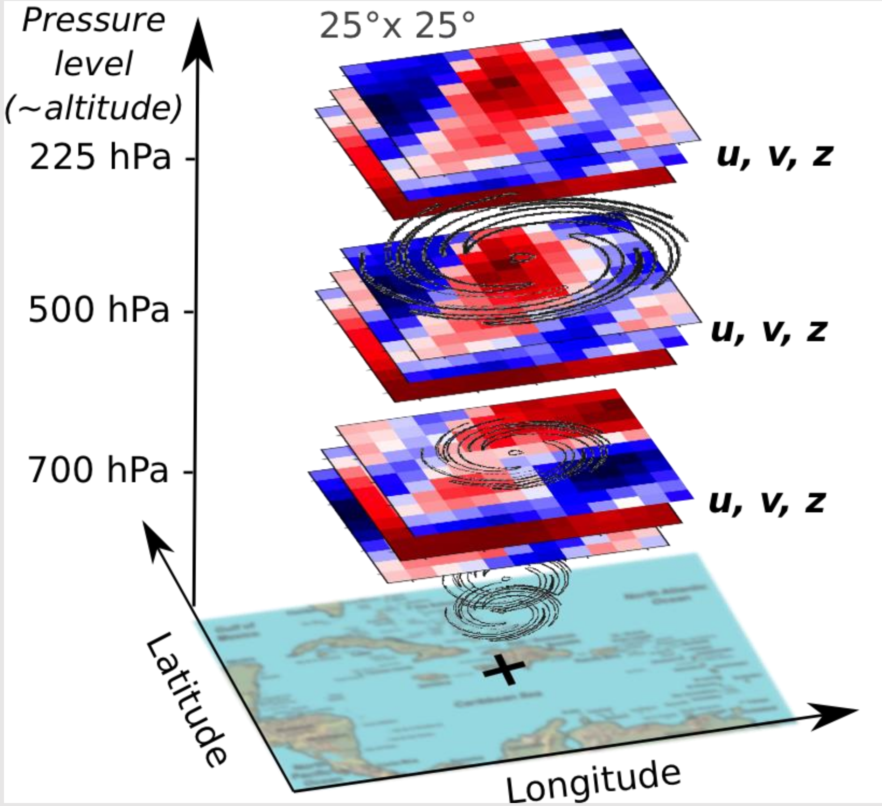
- Semi-supervised, unsupervised, self-supervised learning
  - New methods for downscaling (super-resolution), interpolation of geospatial data
  - New pretext tasks for self-supervised learning, e.g., STINT [Harilal et al., 2024]
  - Regularization via multi-tasking over variables, lead-times

- Generative AI
  - VAE, Normalizing Flows
  - Diffusion and flow-based training
  - Develop new generative downscaling methods, e.g., [Groenke et al., 2020]

- Learning under non-stationarity
  - Learn level of non-stationarity over time and space

ADAPTATION

AI for Extreme Weather and Cascading Hazards



[Giffard-Roisin et al., Frontiers 2020]

Hurricane track prediction

Forecasting Indian Summer Monsoon precipitation extremes

Avalanche detection

Generative AI for weather forecasting

MITIGATION

Reducing carbon emissions

Accelerate green energy transition

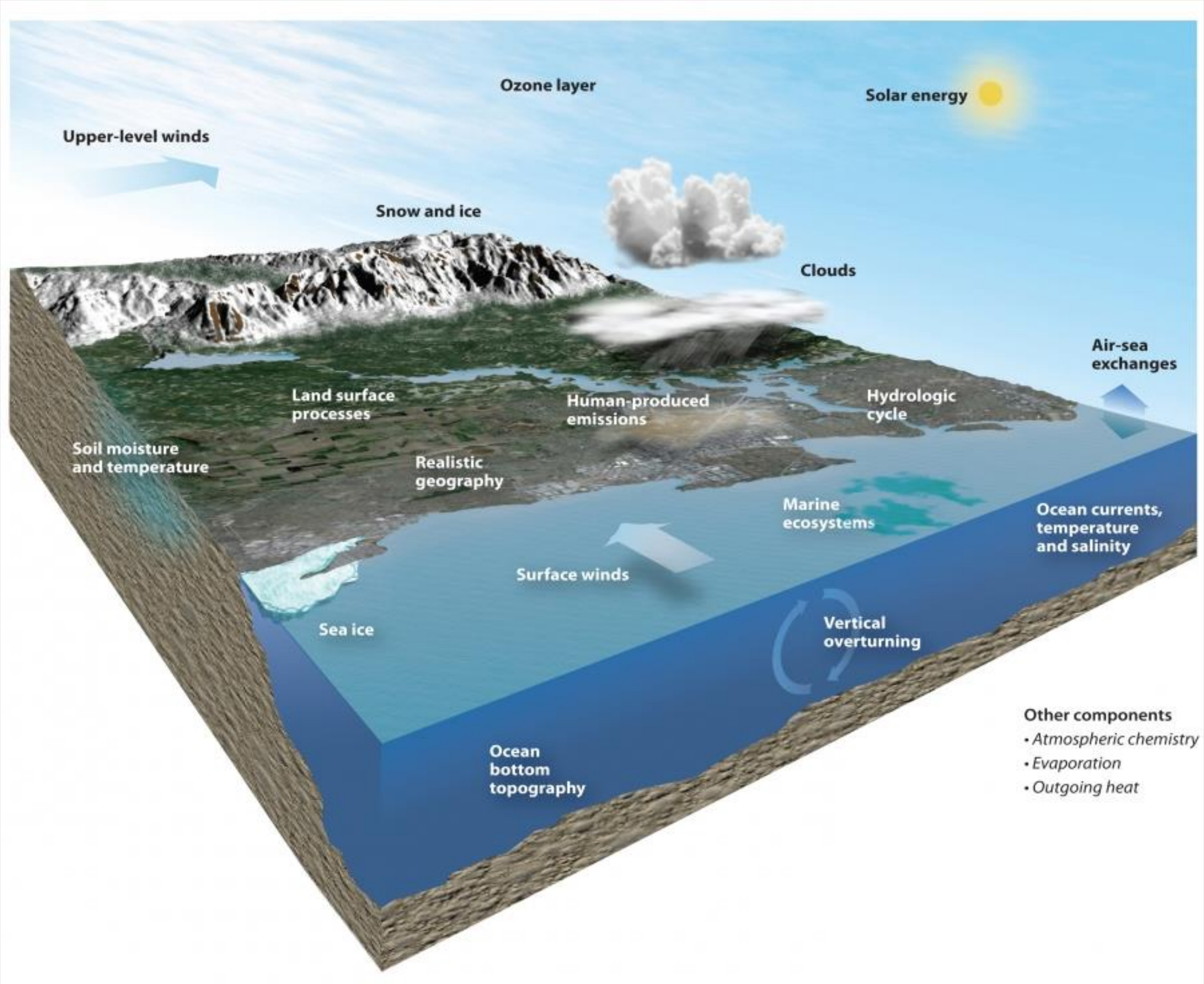
- AI-driven forecasting of solar, wind
- AI to downscale solar and wind data

Reduce compute for weather and climate modeling

- Once trained, AI is significantly faster at prediction than physical models

IMPACTS

AI for Understanding and Predicting Climate Change



UCAR Science Education

Use AI to learn relations between IPCC simulations and observations

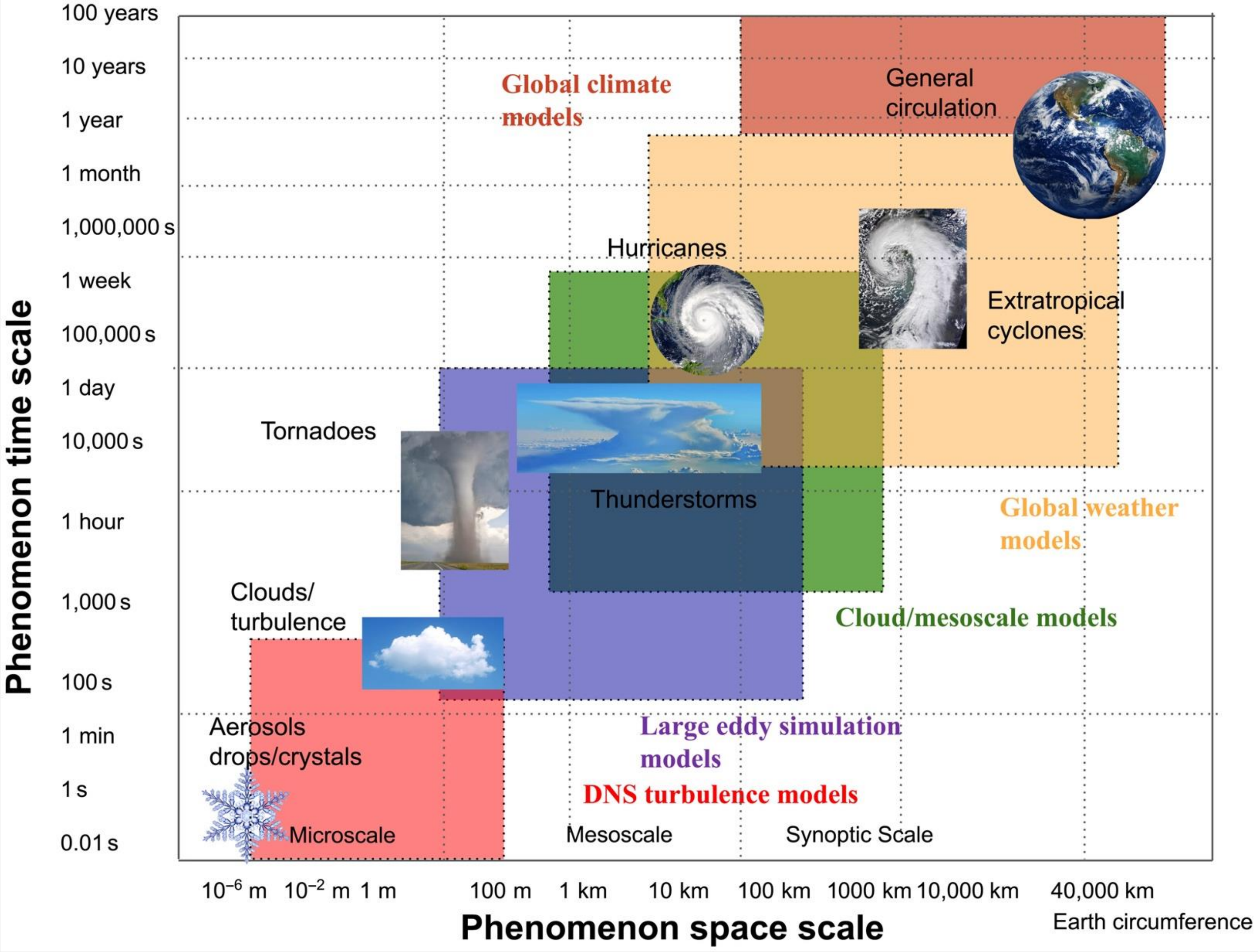
- Robustify climate model ensemble forecasts
- Projecting long-term sea-level rise
- Projecting long-term carbon emissions

AI for downscaling spatiotemporal data

Global climate model simulations are coarser scale (in space and time) than needed for multiple tasks in:

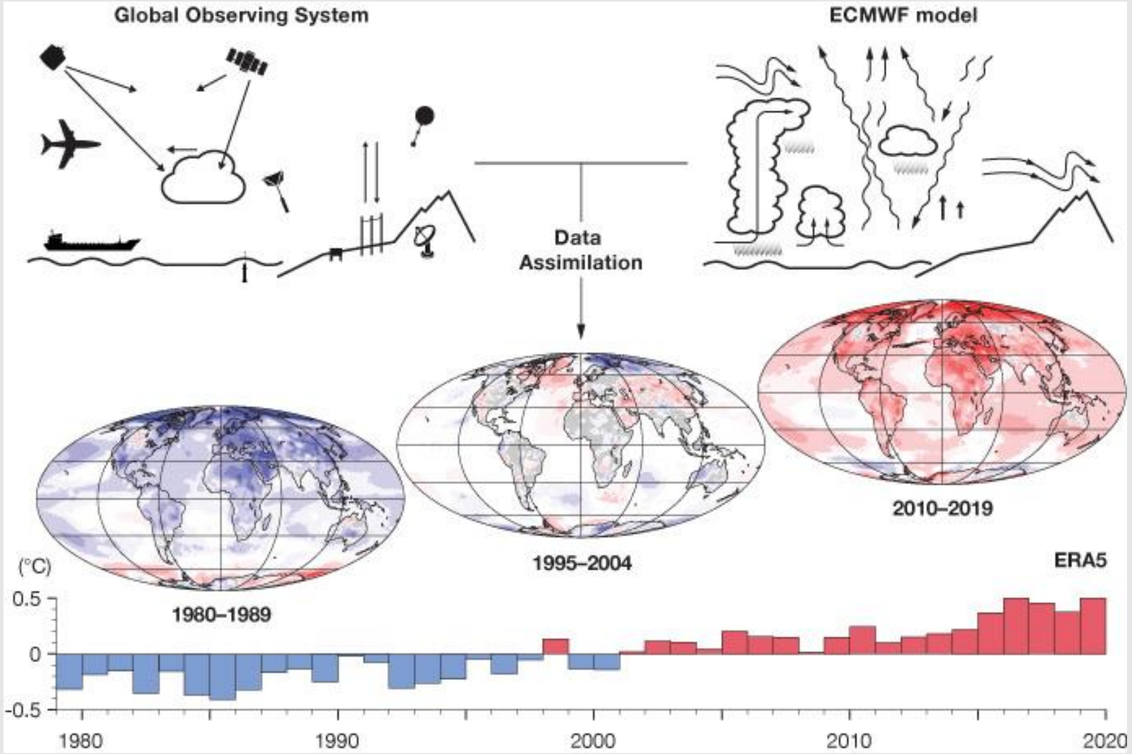
- Climate change adaptation
- Climate change mitigation
- Projecting long-term impacts

Approach: Use ML to downscale climate model data to relevant scales



[Gettelman, et al., Science Advances, 2022]

Revolution in AI for weather forecasting



What is reanalysis data?

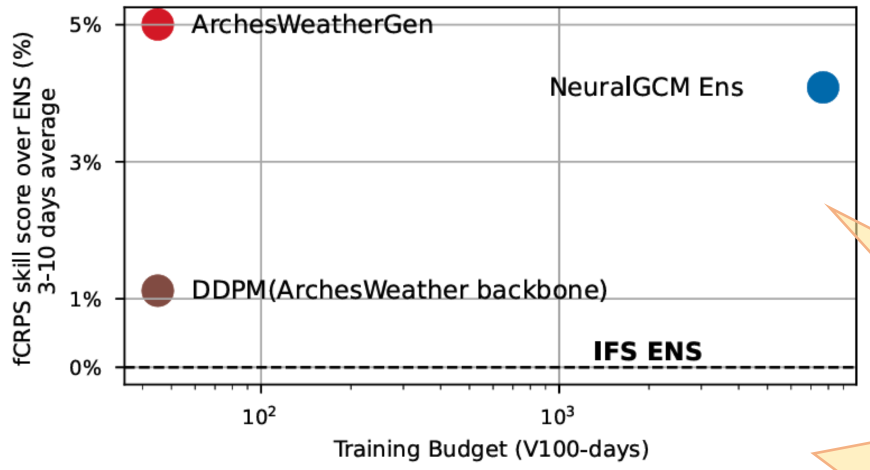
Since 2022, a variety of AI models have shown weather forecasting performance comparable or **BETTER** than numerical weather prediction (NWP).

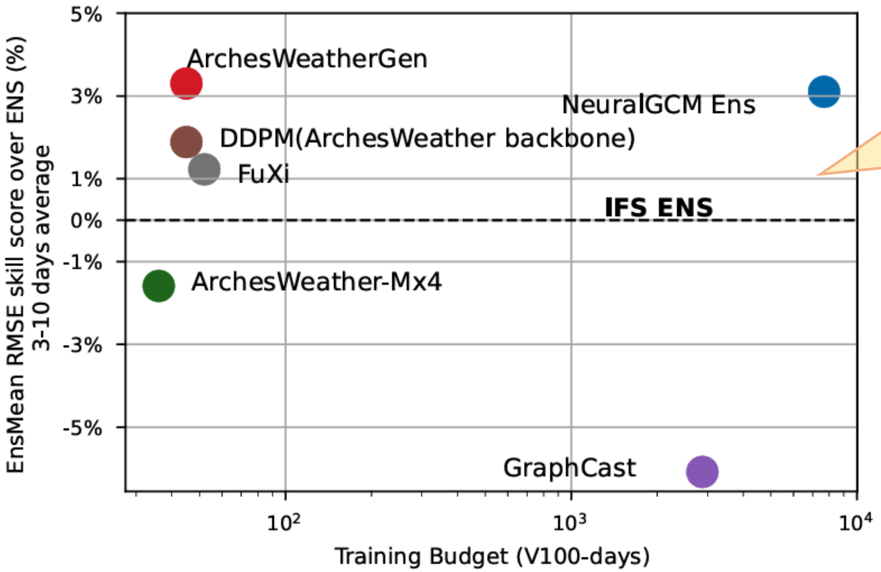
These deep learning (DL) models are trained on reanalysis data (ERA5) to predict the next weather state given the current state

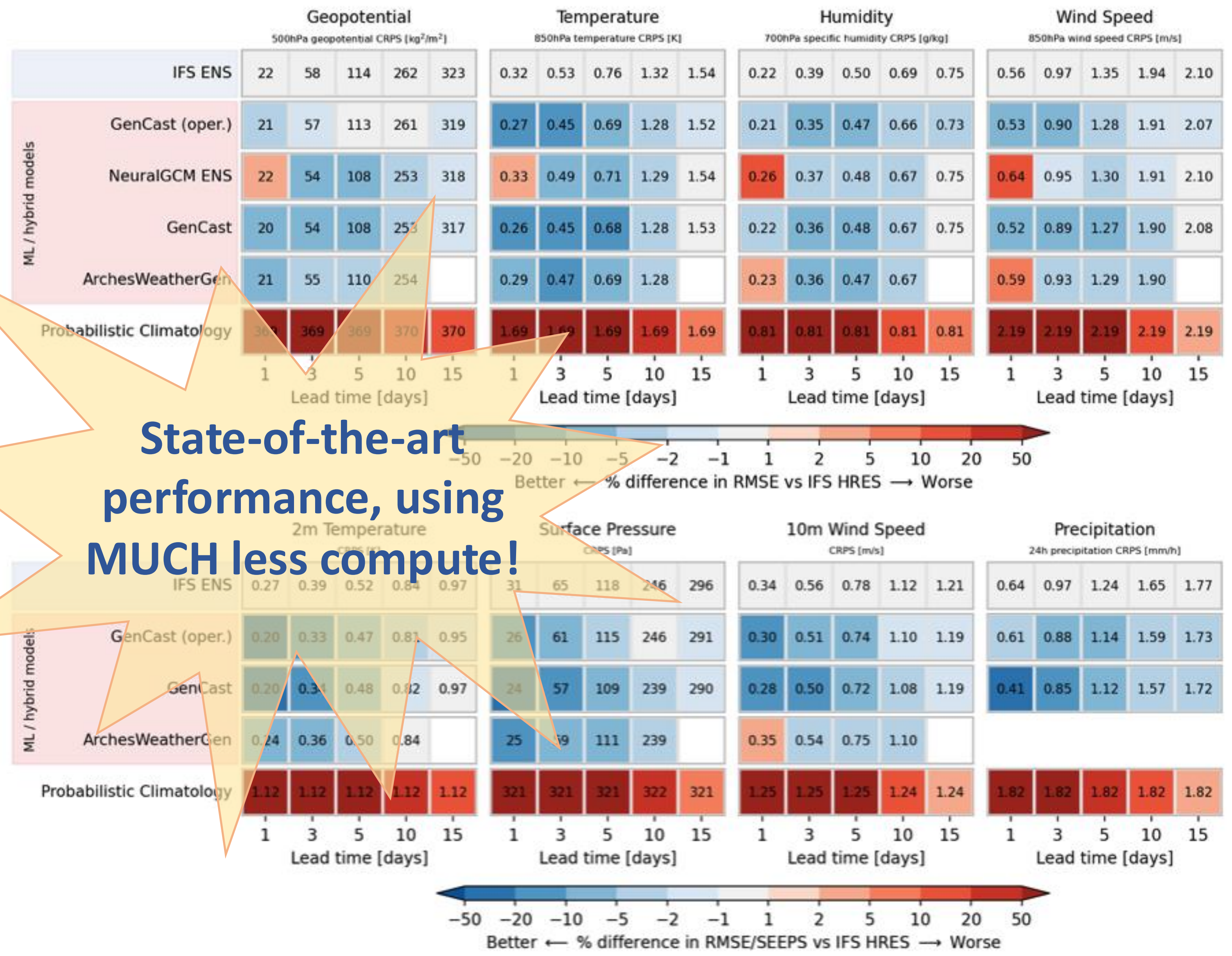
Model predictions are then « rolled-out » to forecast 7-10 days in the future

Image credit: European Center for Medium Range Weather Forecasting (ECMWF) website

ArchesWeatherGen





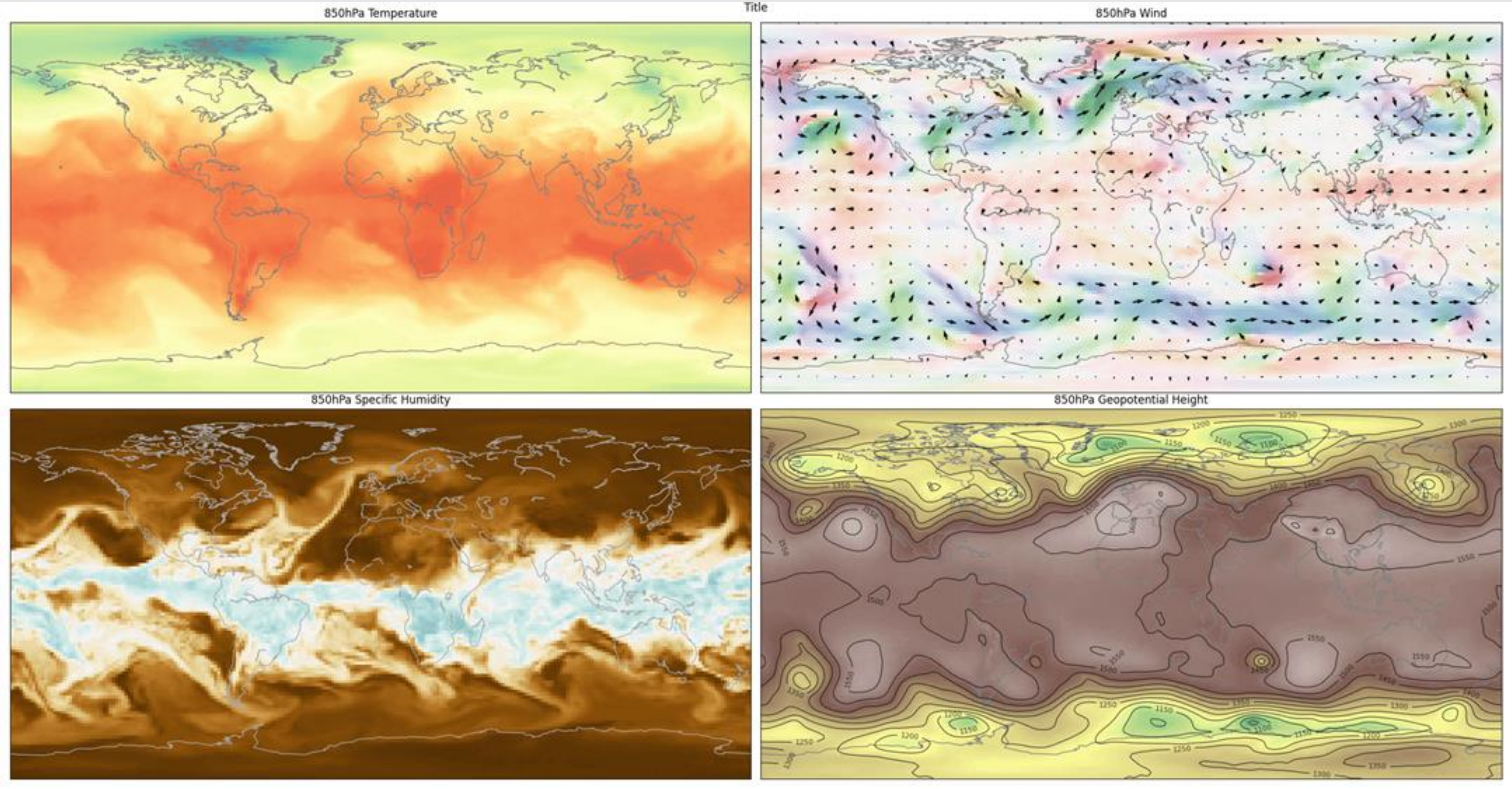


State-of-the-art performance, using MUCH less compute!

[Couairon, Singh, Charantonis, Lessig, Monteleoni, 2024]

Score cards on Google's Weather Bench 2

Generative AI for weather forecasting



[ArchesWeatherGen, Couairon, Singh, Charantonis, Lessig, Monteleoni, 2024]

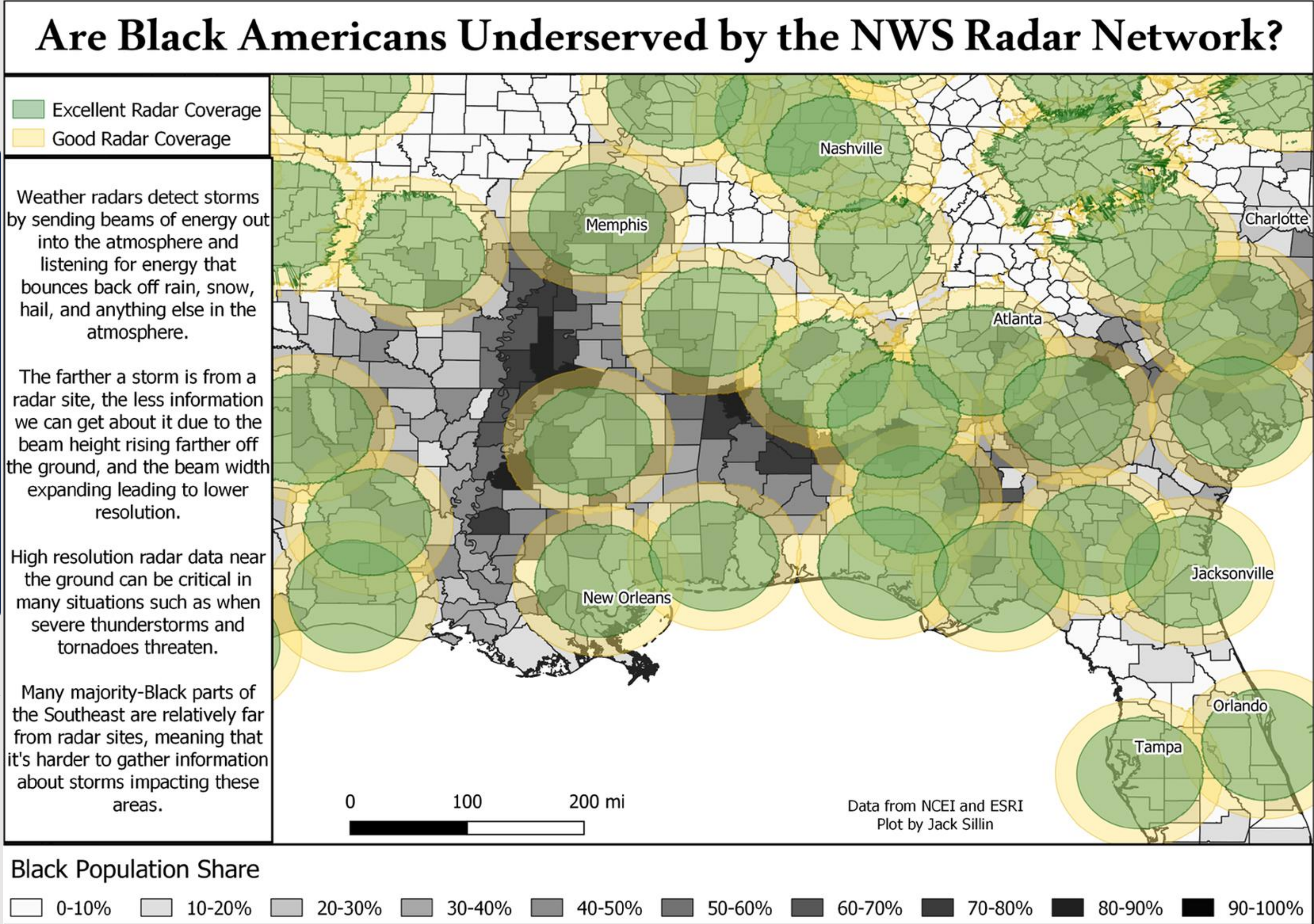
AI for Climate Data Equity

- Train models in high-data regions and apply them in low-data regions
  - Train and validate them in high-data regions
  - Fine-tune them using the limited data in the low-data regions and use them to generate more data.

- Contribution to climate data equity
  - Local scales (e.g. legacy of environmental injustice in USA)
  - Global scales:
    - Global North historically emitted more carbon; Meanwhile there's typically more data there
    - Global South is suffering the most severe effects of the resulting warming

"Many majority-Black parts of the Southeast [USA] are relatively far from radar sites, meaning that it's harder to gather information about storms impacting these areas."

Credit: Jack Sillin, in [McGovern et al., Environmental Data Science, 2022]



Long-term goals

Cascading Hazards

- Goal: move beyond individual weather extremes, to how they couple
- With massive wildfires everywhere, there is extreme urgency!

Climate Justice

- Our research should always help increase climate equity
- Ultimately, we should strive for approaches to help UNDO the legacy of climate IN-justice

Climate and Machine Learning Boulder (CLIMB)

Thank you!

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Cheng Tang, *Amazon*

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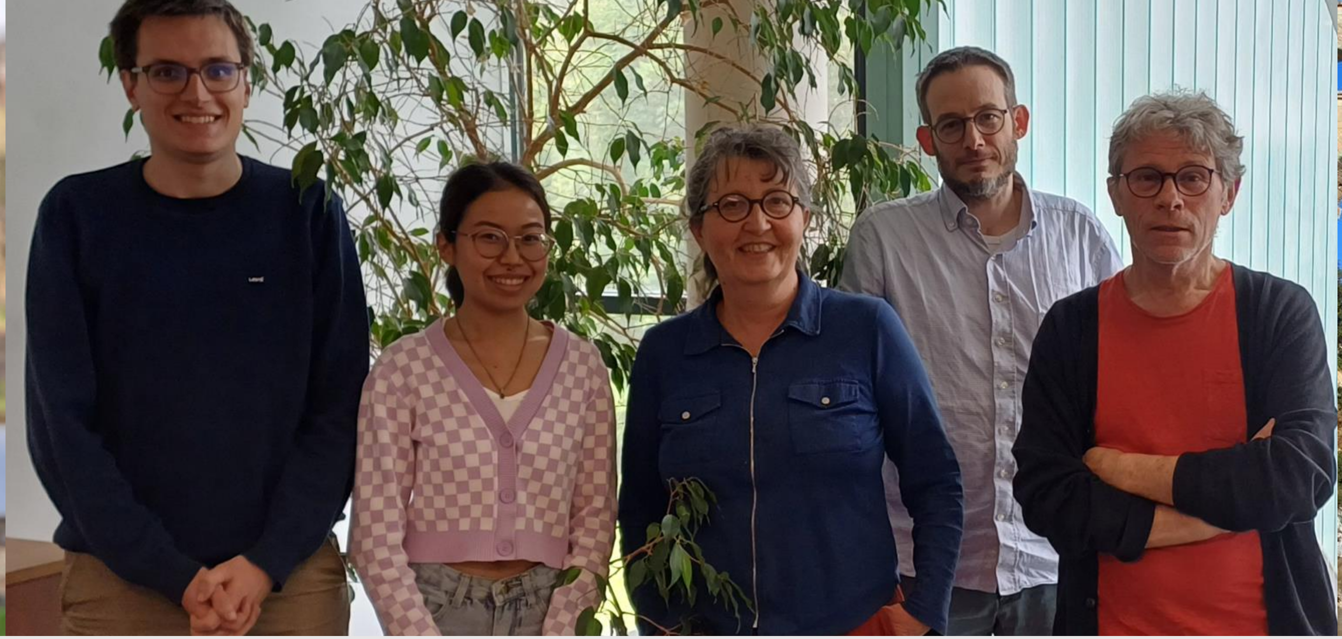


AI Research for Climate Change and Environmental Sustainability (ARCHES)

Environmental Data Science Innovation & Inclusion Lab

A national accelerator linking data, discovery, & decisions

ESIIL

NSF's newest data synthesis center,
hosted by the University of Colorado Boulder & CIRES,
with key partners CyVerse & the University of Oslo

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