The other climate crisis

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USA TODAY/NASA

The assumptions that enabled successful large-scale prediction may no longer be sufficient for decision-relevant regional risk

USA TODAY/NASA

THE NOBEL PRIZE IN PHYSICS 2021

Illustrations: Niklas Elmehed

Syukuro Manabe

"for the physical modelling of Earth's climate, quantifying variability and reliably predicting global warming"

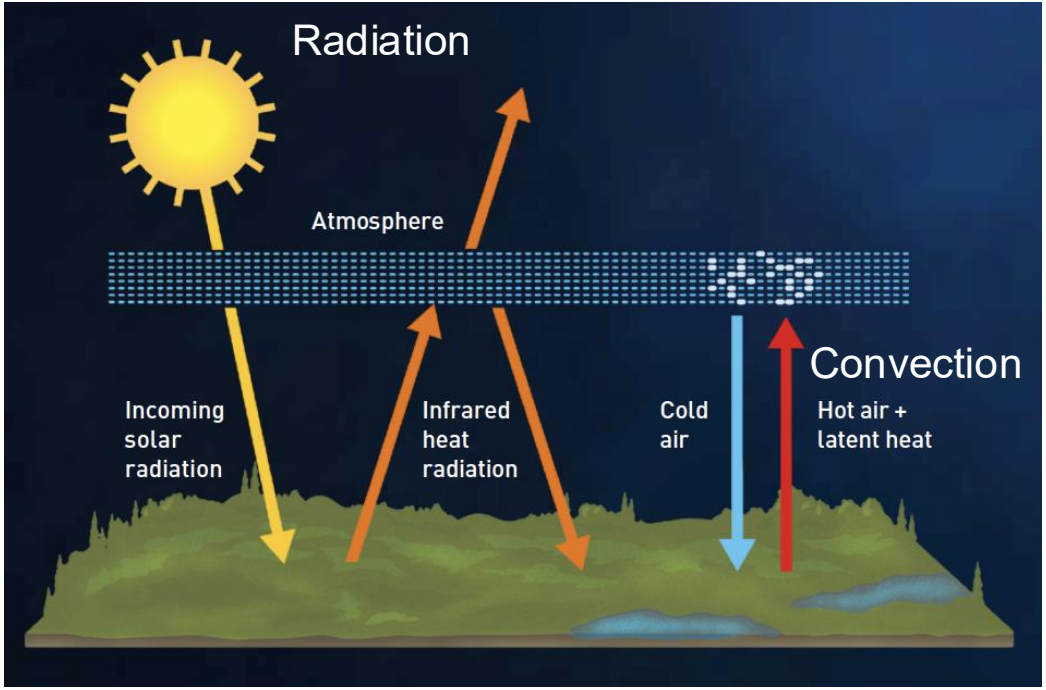
Klaus Hasselmann

Giorgio Parisi

"for the discovery of the interplay of disorder and fluctuations in physical systems from atomic to planetary scales"

THE ROYAL SWEDISH ACADEMY OF SCIENCES

Standard approach assumes large scales constrain small scales

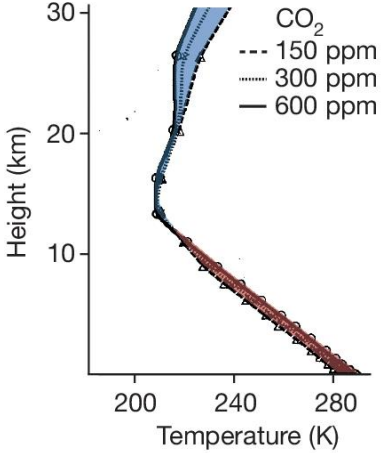


Don’t need to know small scale details (clouds, quantum mechanics etc)

Nobel committee

Standard approach has made many successful predictions planetary-scale predictions

Atmospheric energy balance



Increasing CO2 concentration leads to tropospheric warming, stratospheric cooling

Manabe & Wetherald (1967)

Physical Complexity

Prediction was sensitive to assumptions about moisture and clouds (structural uncertainty)

Change of CO_2 content (ppm)	Fixed relative humidity	
	Average cloudiness	Clear
300 → 600	+2.36	2.92

Manabe & Wetherald (1967)

Standard approach has made many successful predictions planetary-scale predictions

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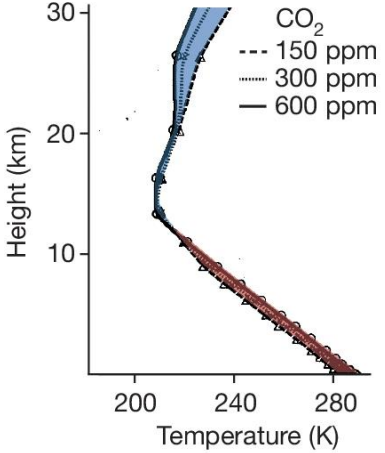
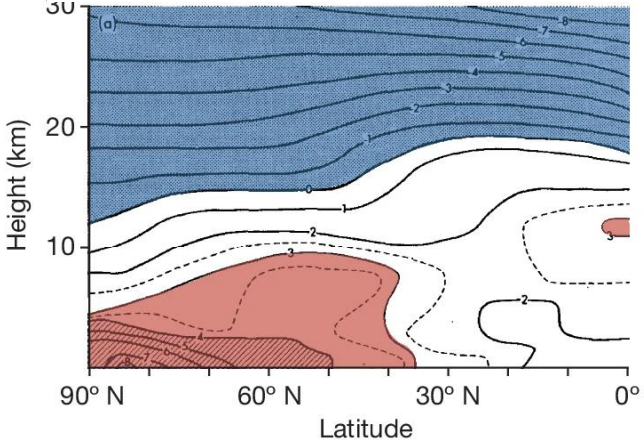


Manabe & Wetherald (1967)

Atmospheric energy (1st law) and momentum (2nd law) balance



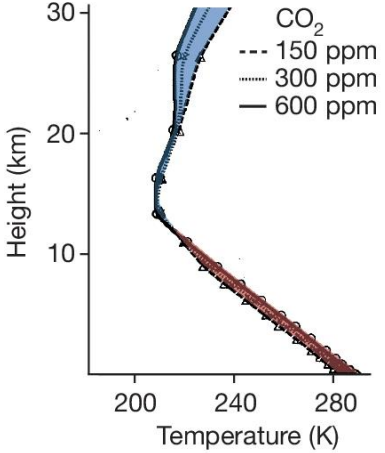
Manabe & Wetherald (1980)

Increasing CO2 concentration leads to Arctic amplified warming

Physical Complexity

Standard approach has made many successful predictions planetary-scale predictions

Atmospheric energy balance



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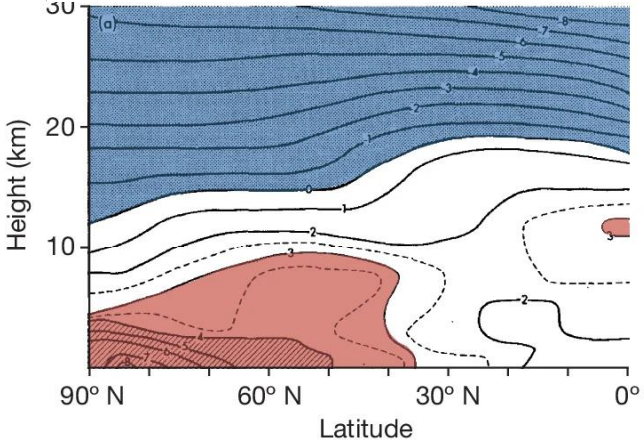
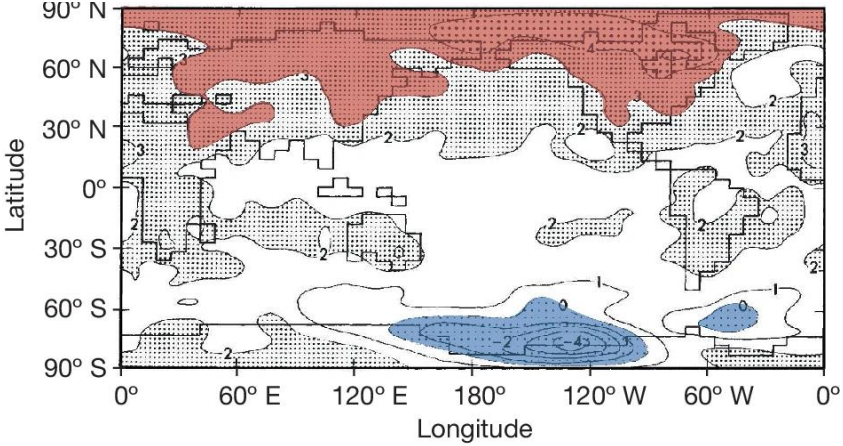


Manabe & Wetherald (1980)

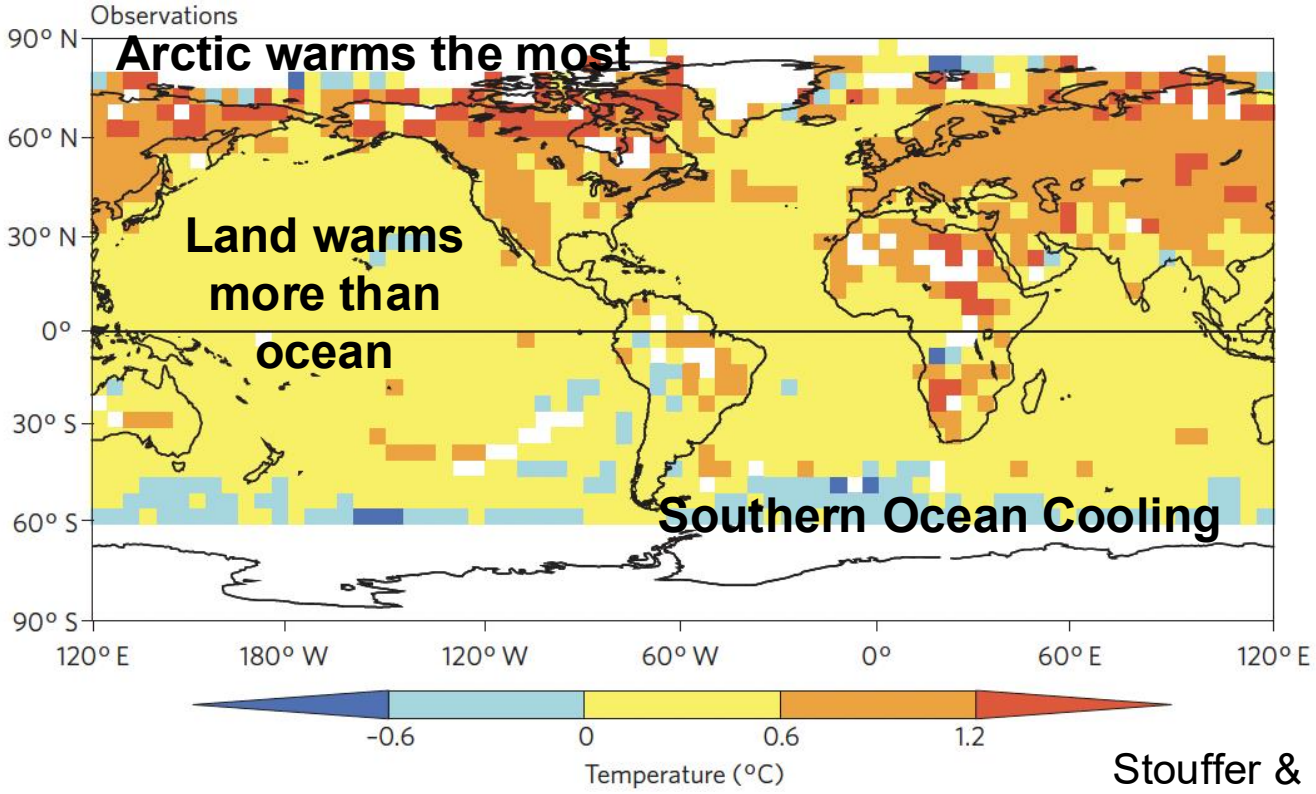
Atmosphere & Ocean energy and momentum balance



Stouffer et al. (1989)

Physical Complexity

These signals were predicted decades before they were observed



Stouffer & Manabe (2017)

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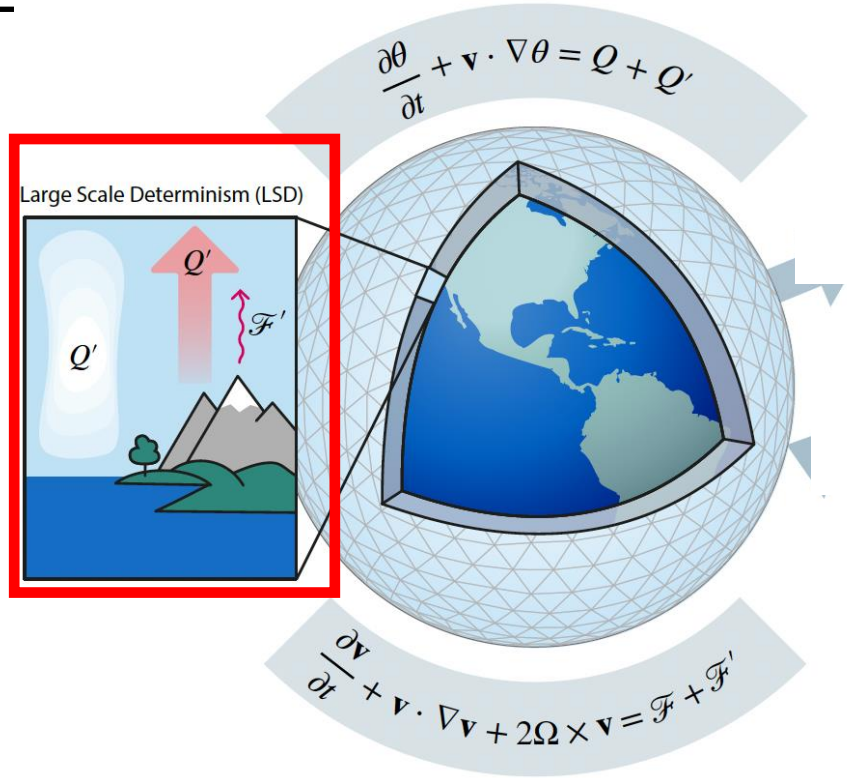
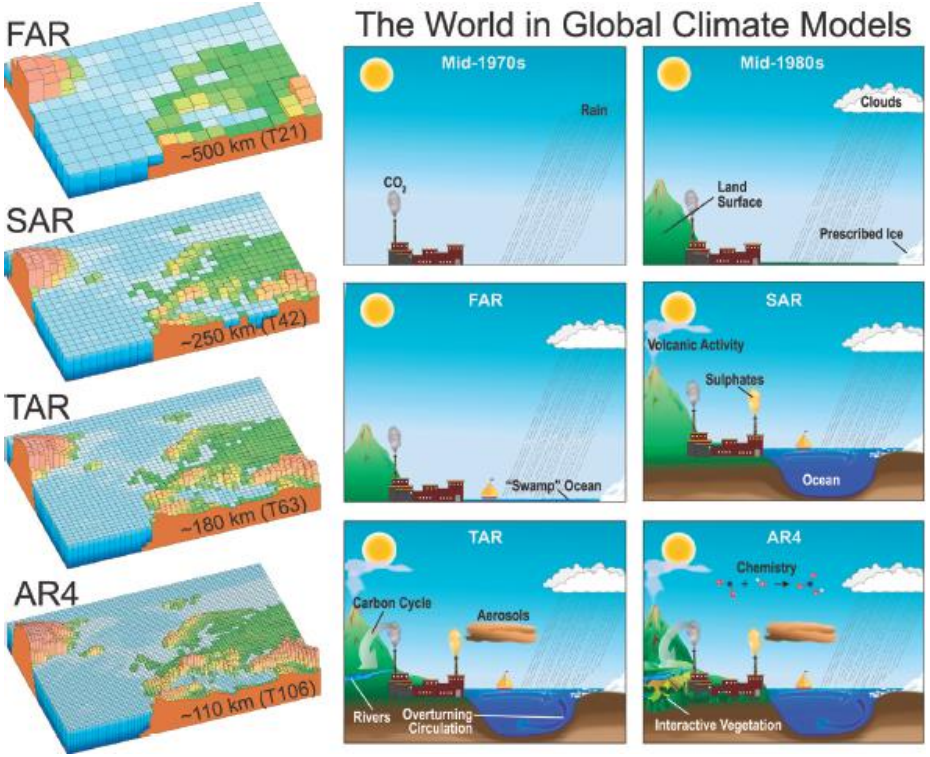
THE ROYAL SWEDISH ACADEMY OF SCIENCES

Remarkable success created confidence that progressively finer scale prediction would follow naturally form increasing resolution and compute



Shaw & Stevens (2025, Nature)

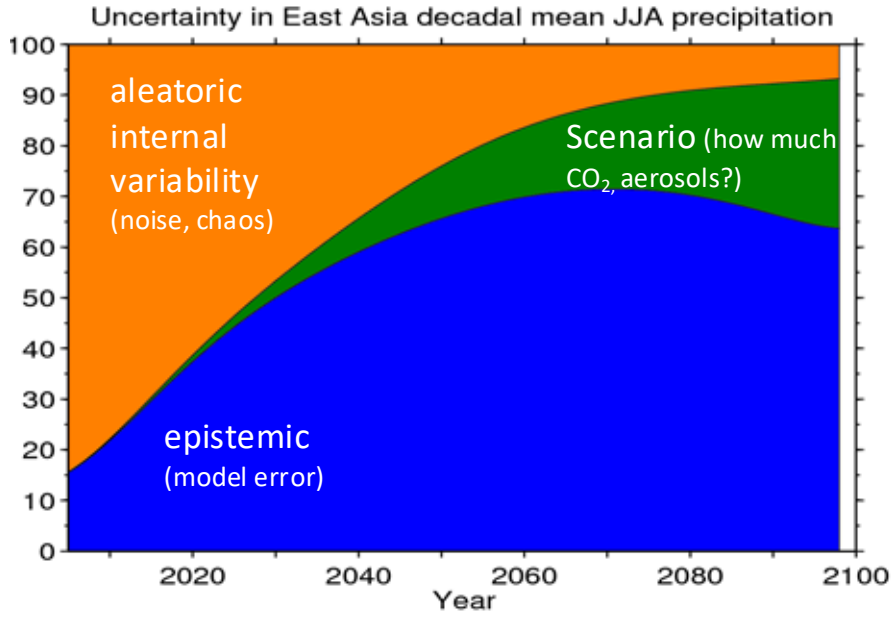
60 years later…"We've gotten better at doing pretty much the same thing" D. Randall



National Academy of Sciences

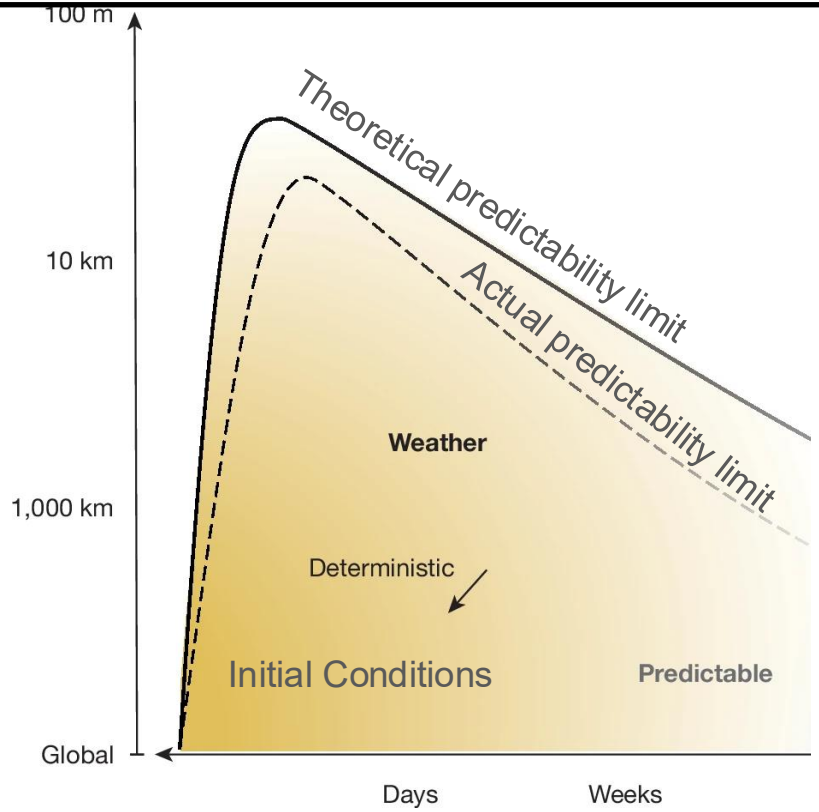
CMIP paradigm built on running standard approach models with emission scenarios

Uncertainty of regional predictions quantified but never calibrated with observations



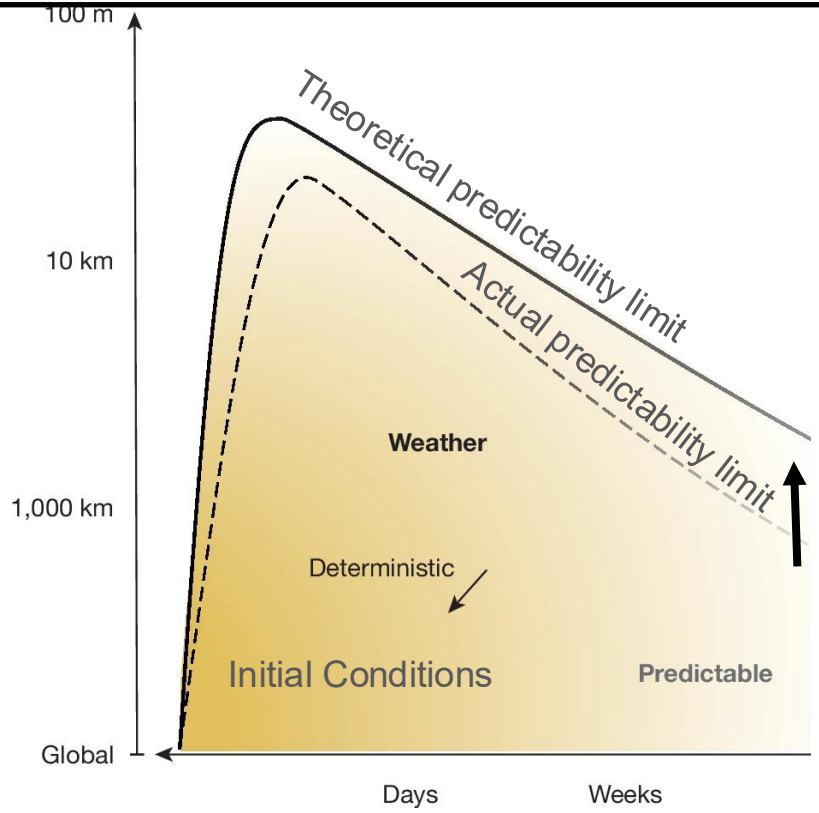
Hawkins & Sutton (2009, BAMS)

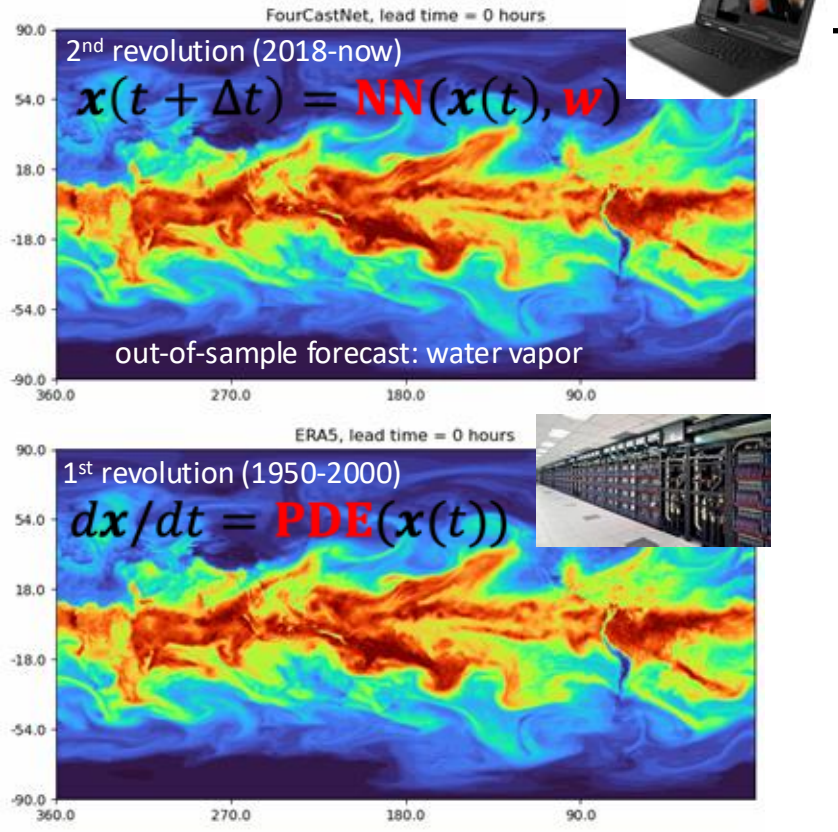
Successful weather predictions from days to weeks



Shaw & Stevens (2025, Nature)

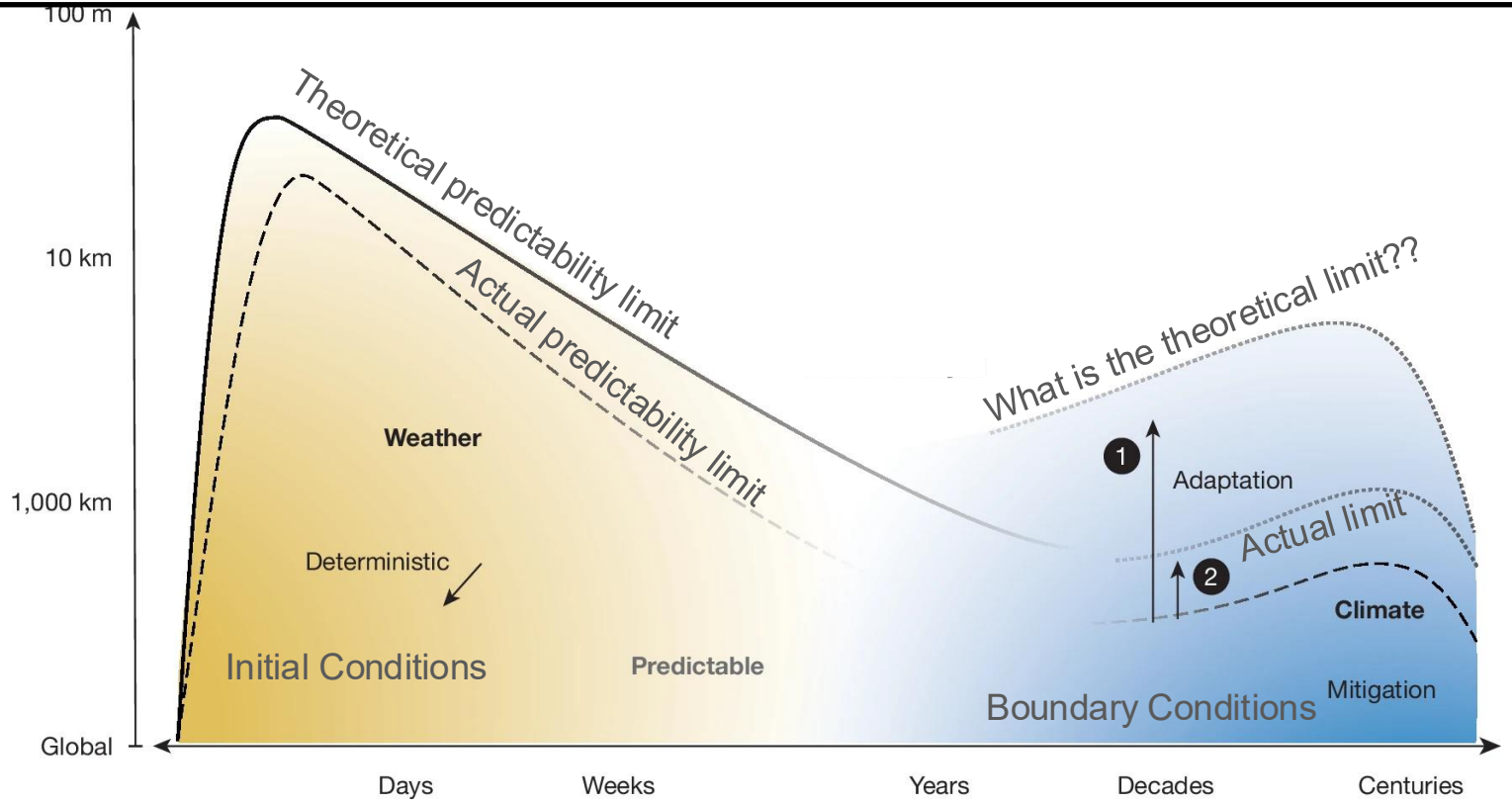
AI emulators have led to 2nd revolution in weather forecasting



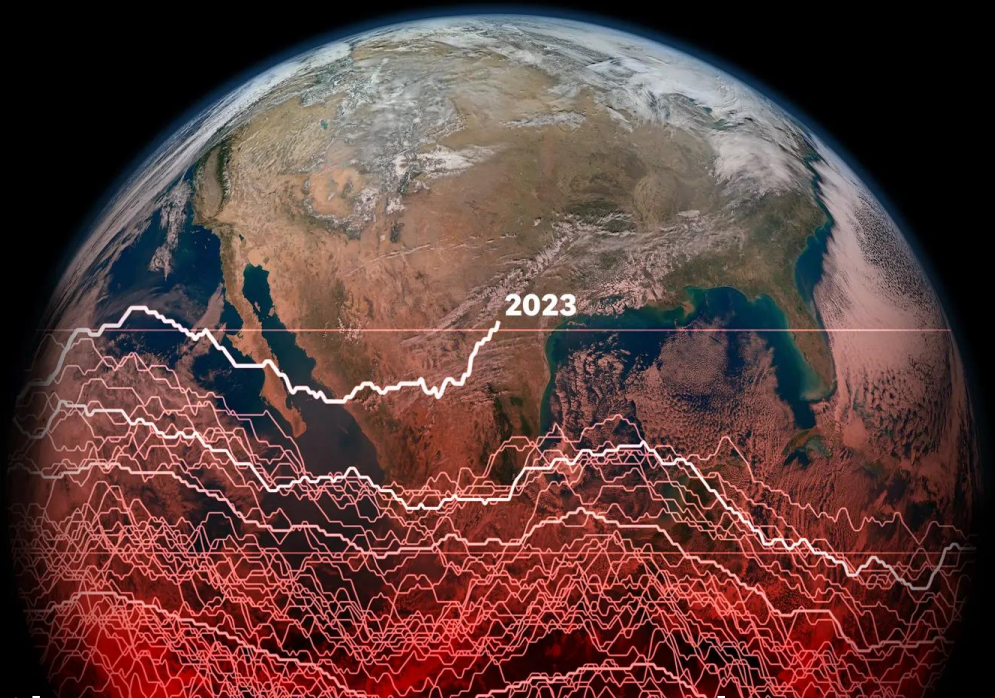


Shaw & Stevens (2025, Nature)

Successful climate predictions are bounded at planetary-scales but regional limit is unclear

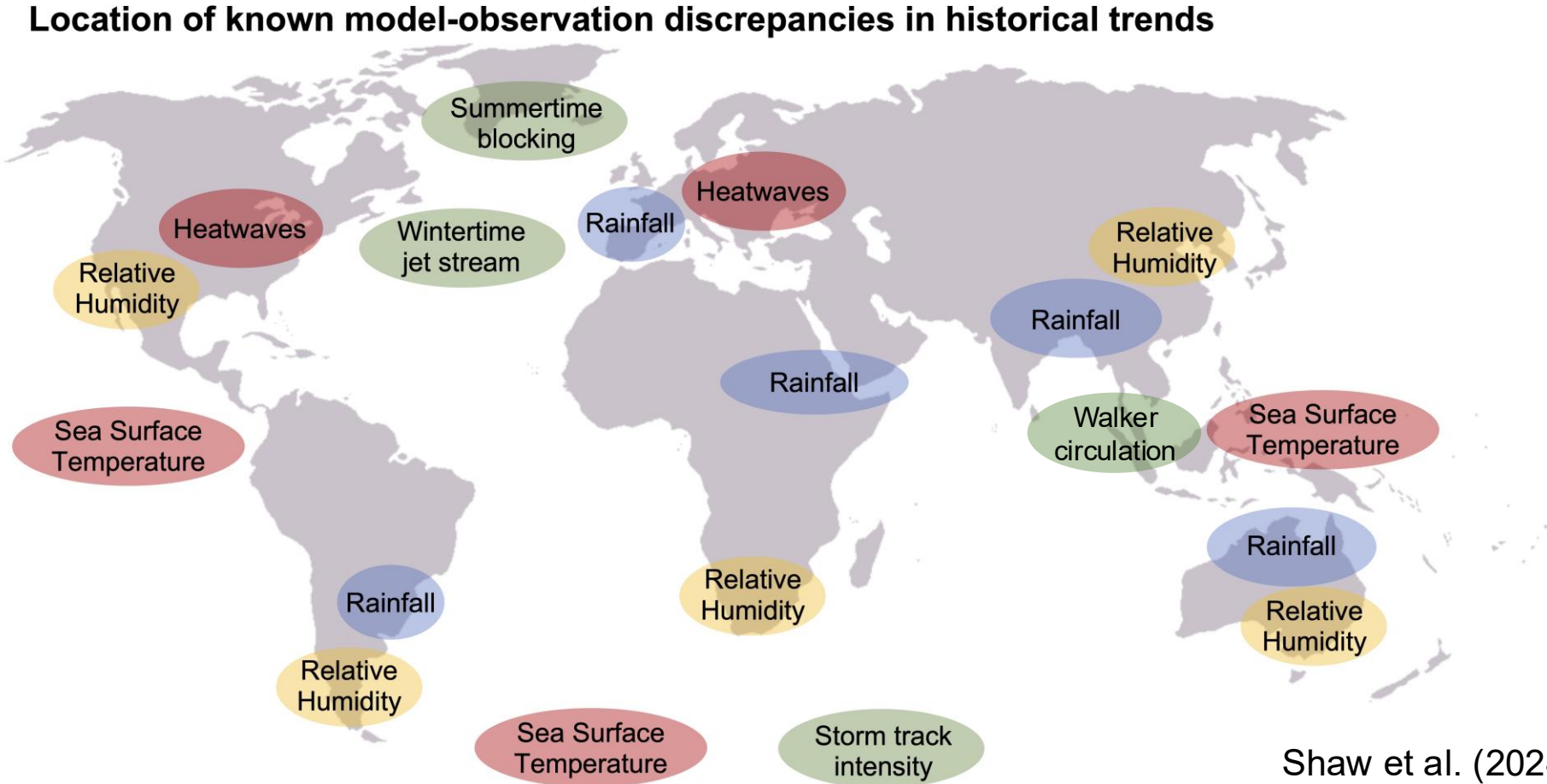


Shaw & Stevens (2025, Nature)



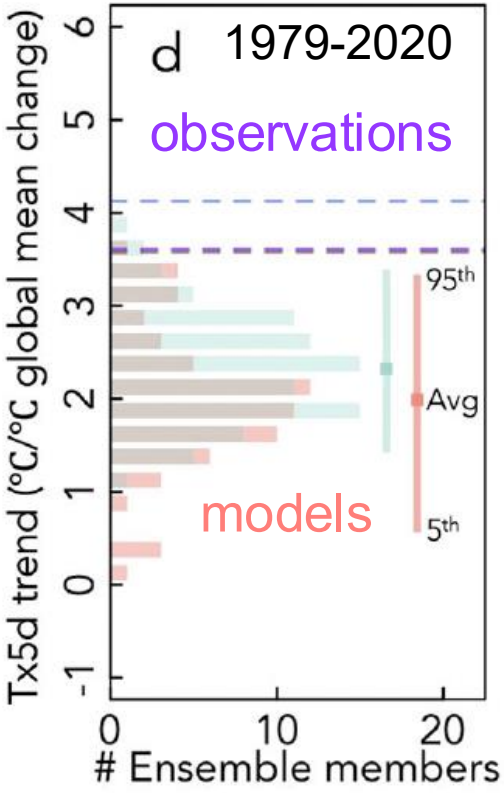
As Earth warms more and more regional signals are emerging and being compared to climate model predictions

Regional discrepancies have emerged



Shaw et al. (2024)

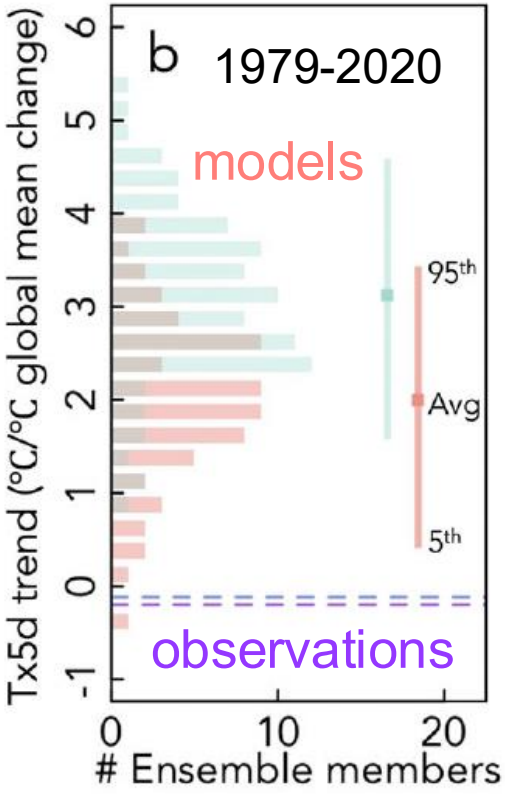
Possible critical model deficiencies are emerging for heat wave trends over Western Europe



Increase of Western European heat waves 3.5-4x the global mean not captured by models

Singh et al. (2023, Comm Earth & Env.)

Climate model predictions don't capture heat wave "hole" in Midwest US



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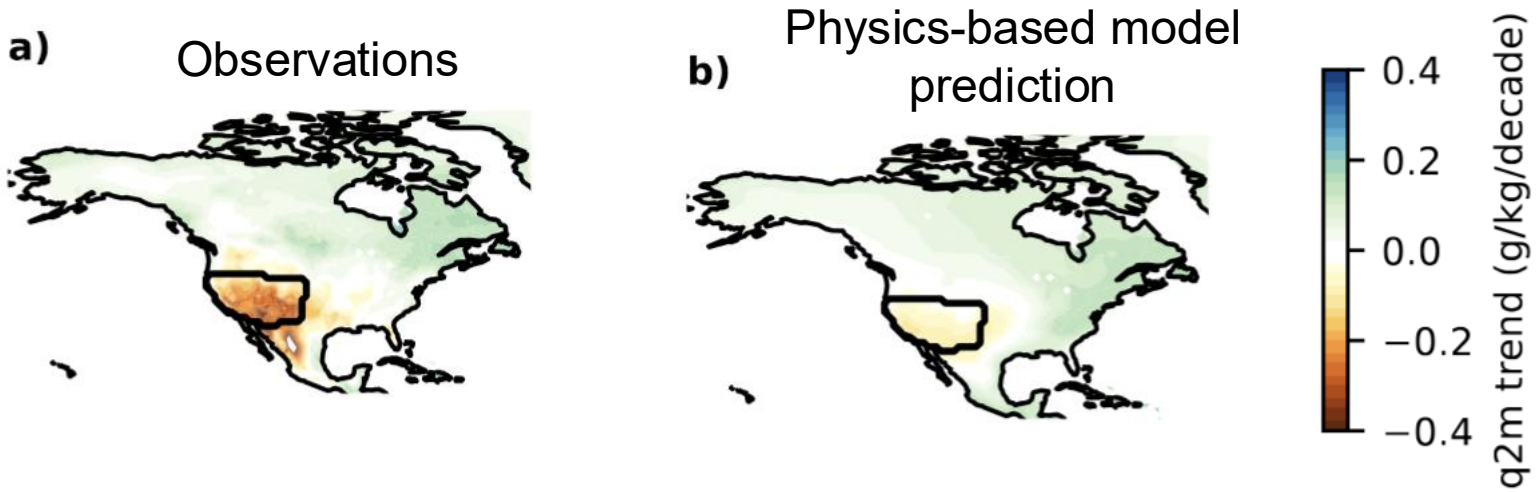
Possible critical model deficiencies are also emerging for drying over arid regions

US Southwest Humidity Trends (1981-2021)



Rucker et al. (2025, GRL)

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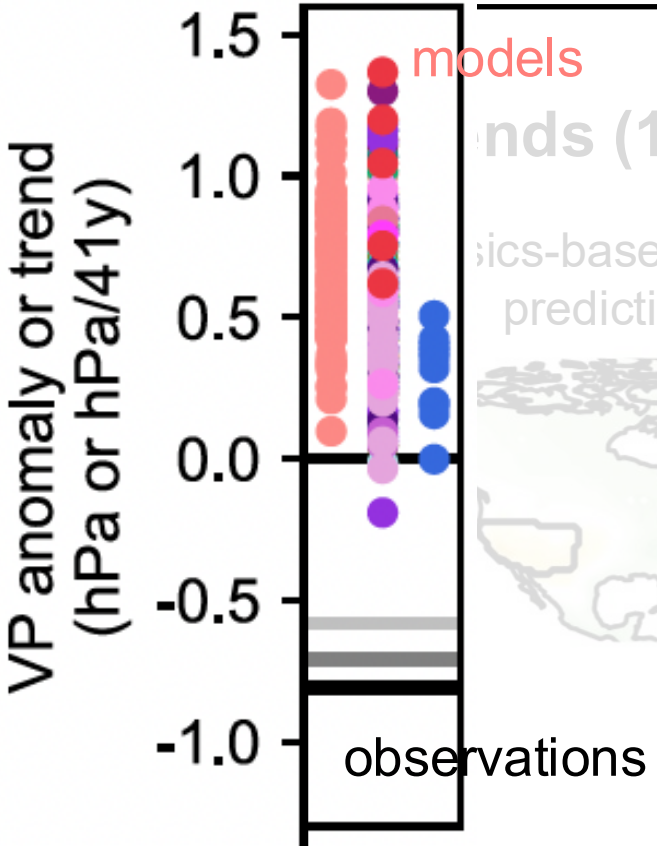
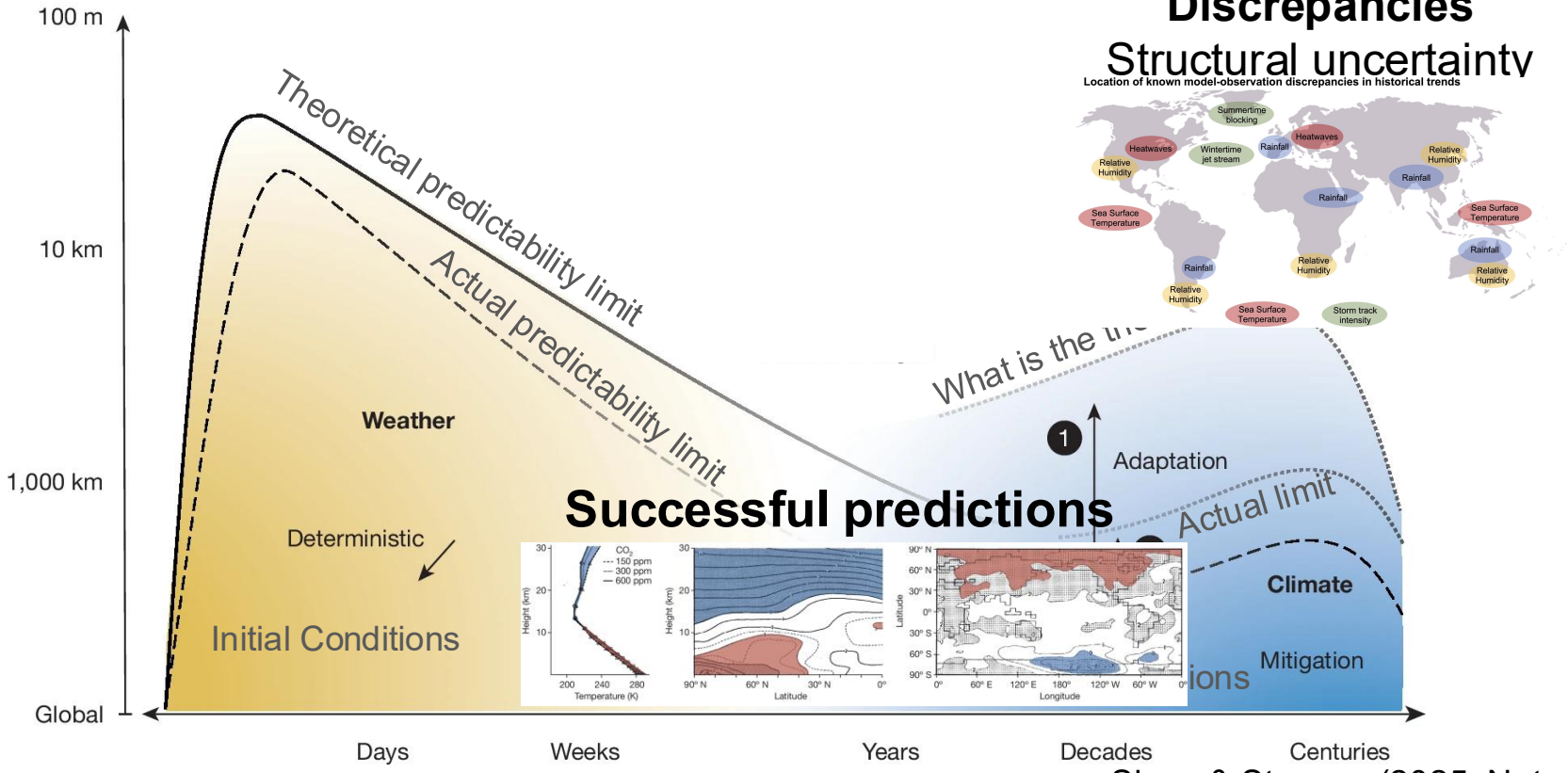


Rucker et al. (2025, GRL)

Anomalies don’t invalidate a paradigm but accumulation changes scientific behavior

Shaw et al. (2024)

Landscape of climate information is evolving

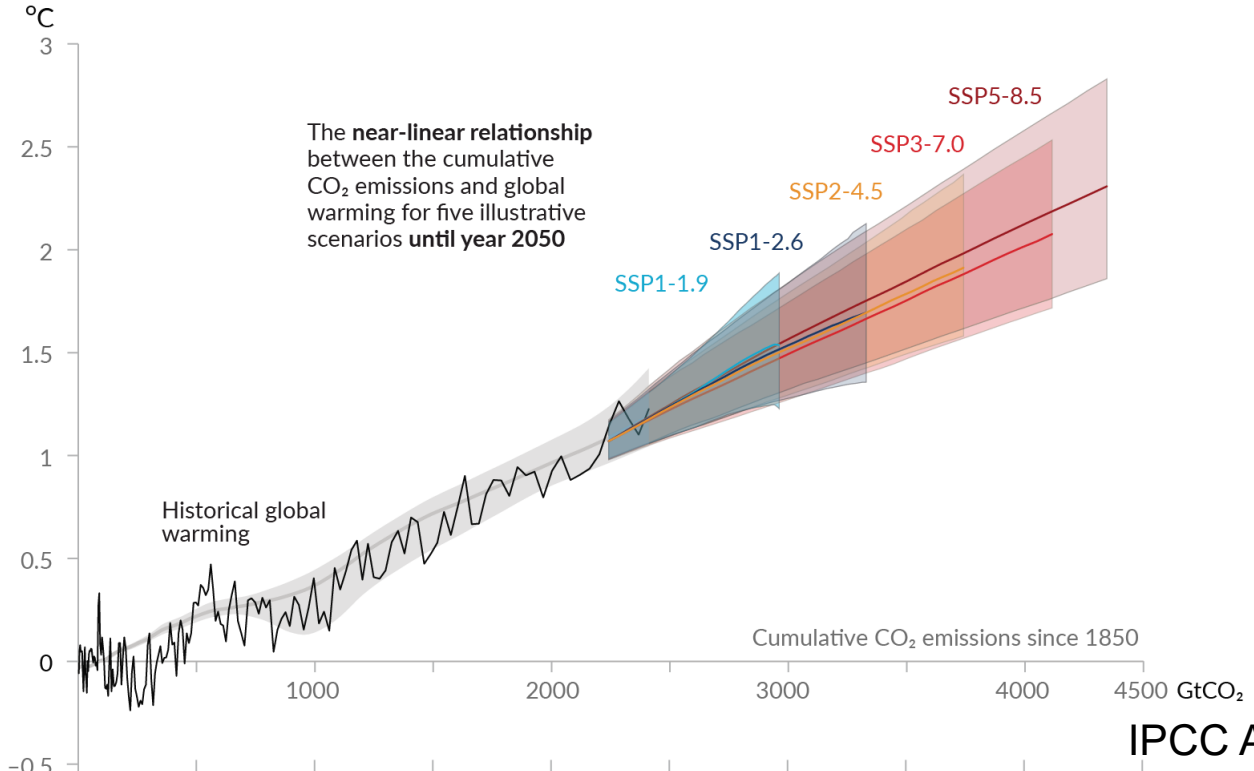


Shaw & Stevens (2025, Nature)

Structural uncertainty does not justify inaction

Every tonne of CO_2 emissions adds to global warming

Global surface temperature increase since 1850–1900 (°C) as a function of cumulative CO_2 emissions ($GtCO_2$)



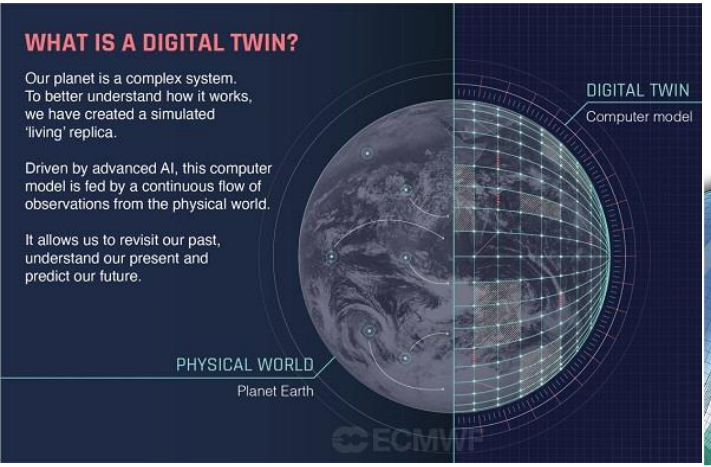
IPCC AR6 WG1 Fig. SPM10

The assumptions that enabled successful large-scale prediction may no longer be sufficient for decision-relevant regional risk

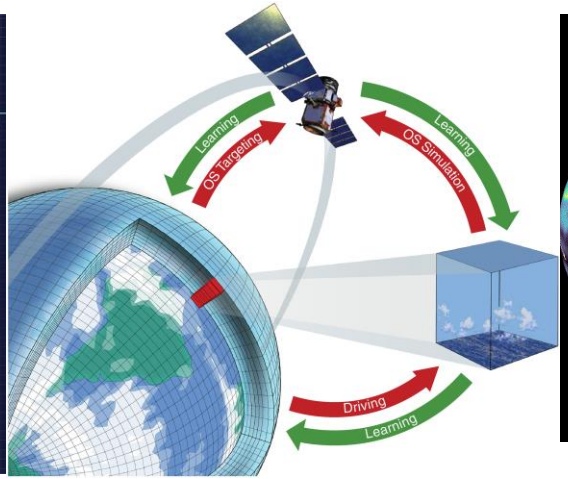
USA TODAY/NASA

New modeling paradigms have emerged that challenge assumptions of the standard approach

Digital twins

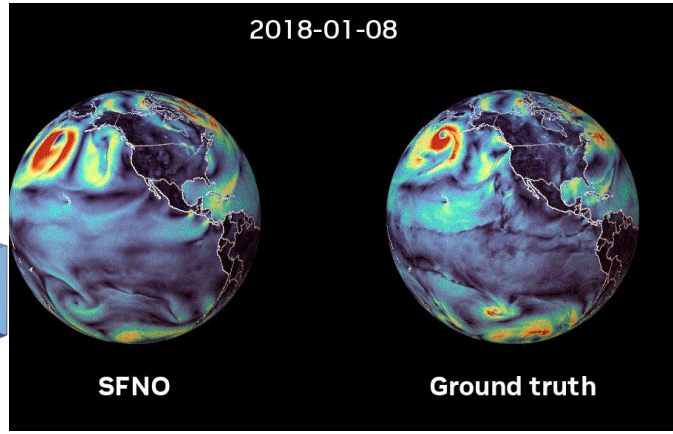


Hybrid



Schneider et al. (2017)

AI emulators

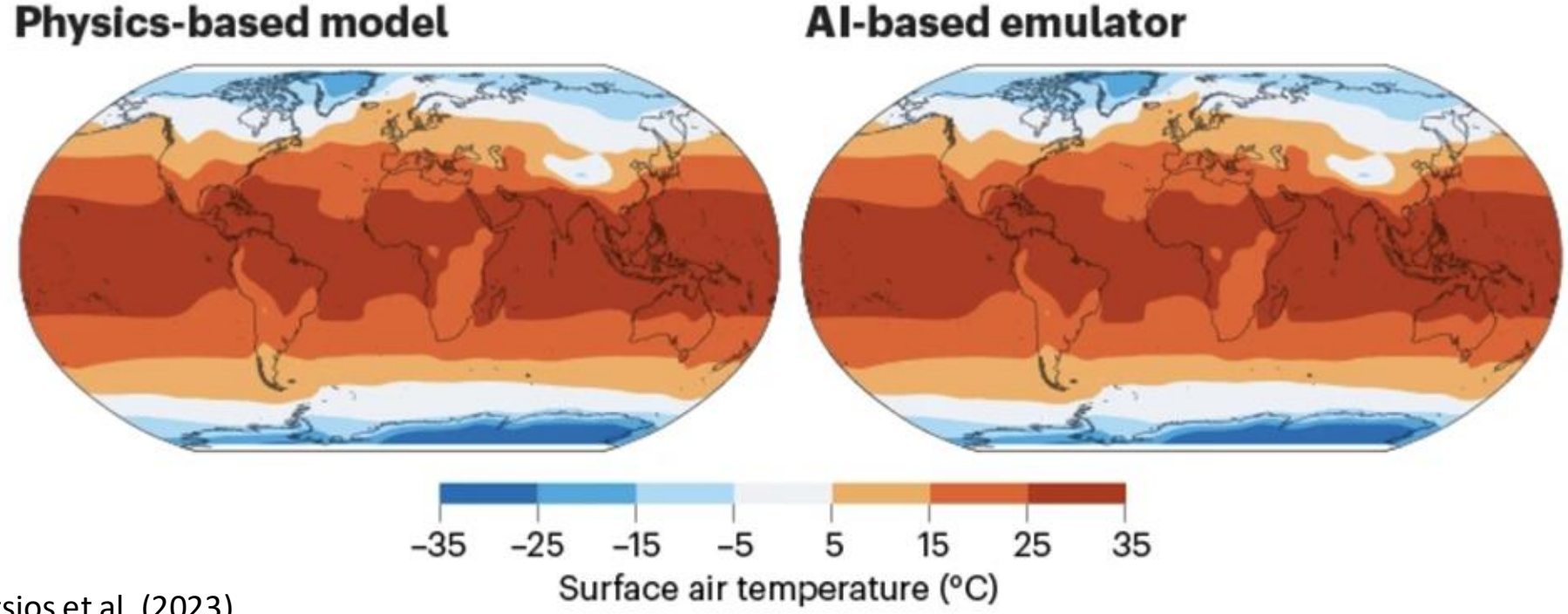


NVDIA

Destination Earth, Max Planck Institute for Meteorology

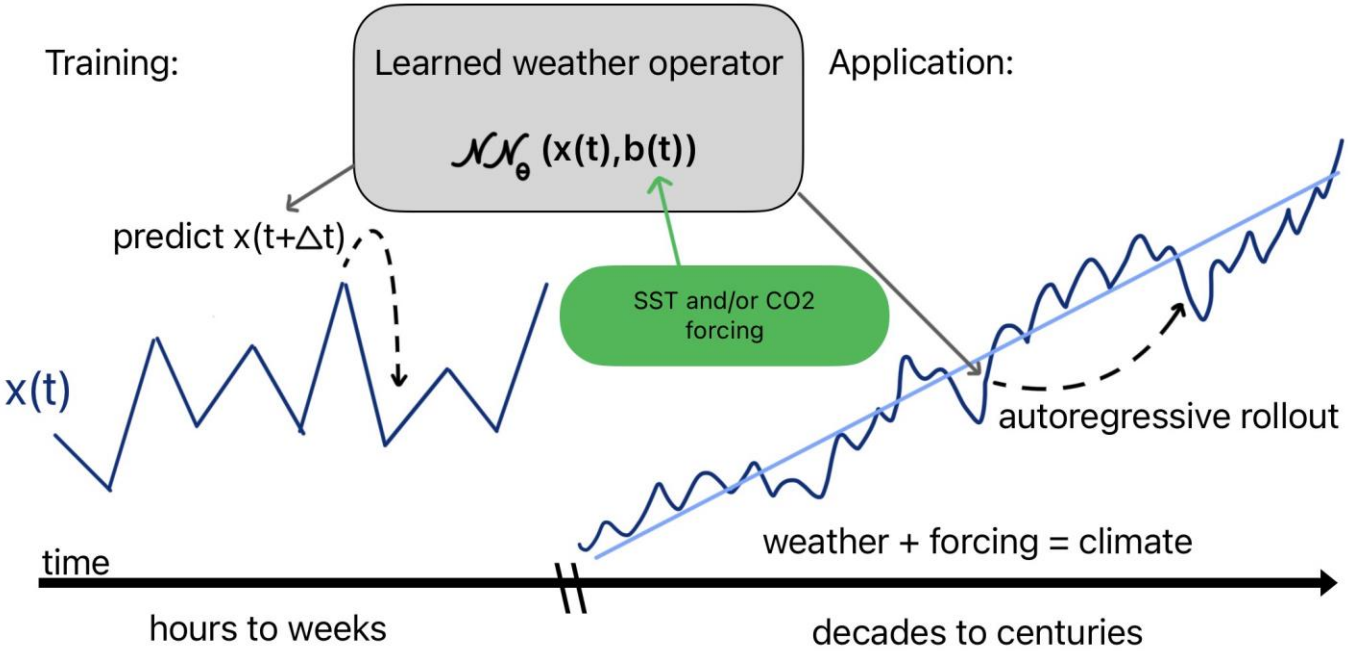
AI CLIMATE MODEL WORKS AT SPEED

In projections of global surface air temperature up to the year 2100, output from the QuickClim climate emulator (right), a machine-learning system, closely matches that of the physics-based climate model it is trained on (left). However, QuickClim generates the output about one million times faster.



Kitsios et al. (2023)

AI emulators trained on the weather task, asked to predict the climate task



LABS & PROGRAMS

AI for Climate

A program of the Institute and Data Science Institute, AI for Climate aims to accelerate and transform climate research with a focus on both scientific advances and societal impacts.

AI emulators are a completely new paradigm that can outperform physics-based models

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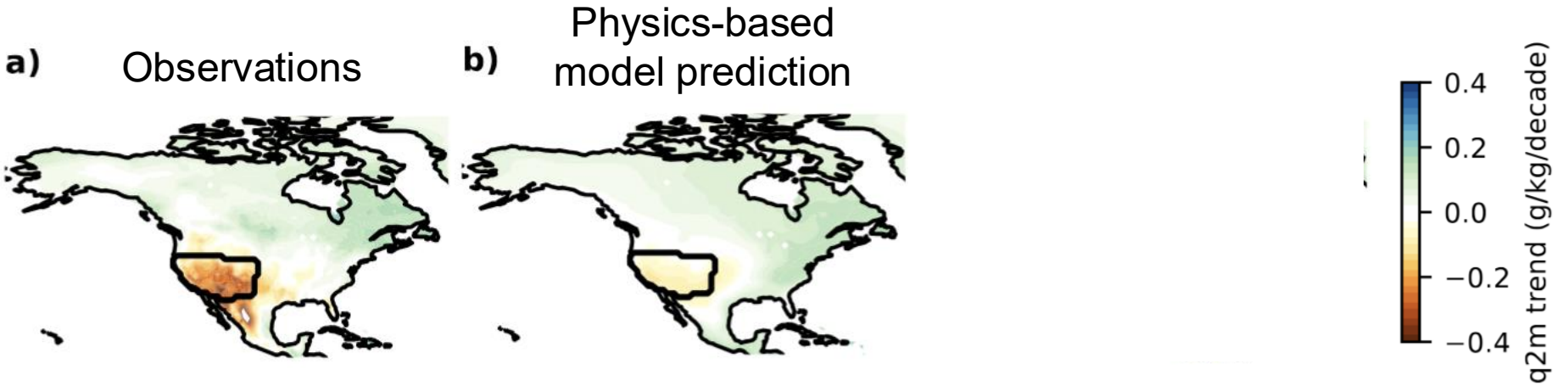

Rucker et al. (2025, GRL)

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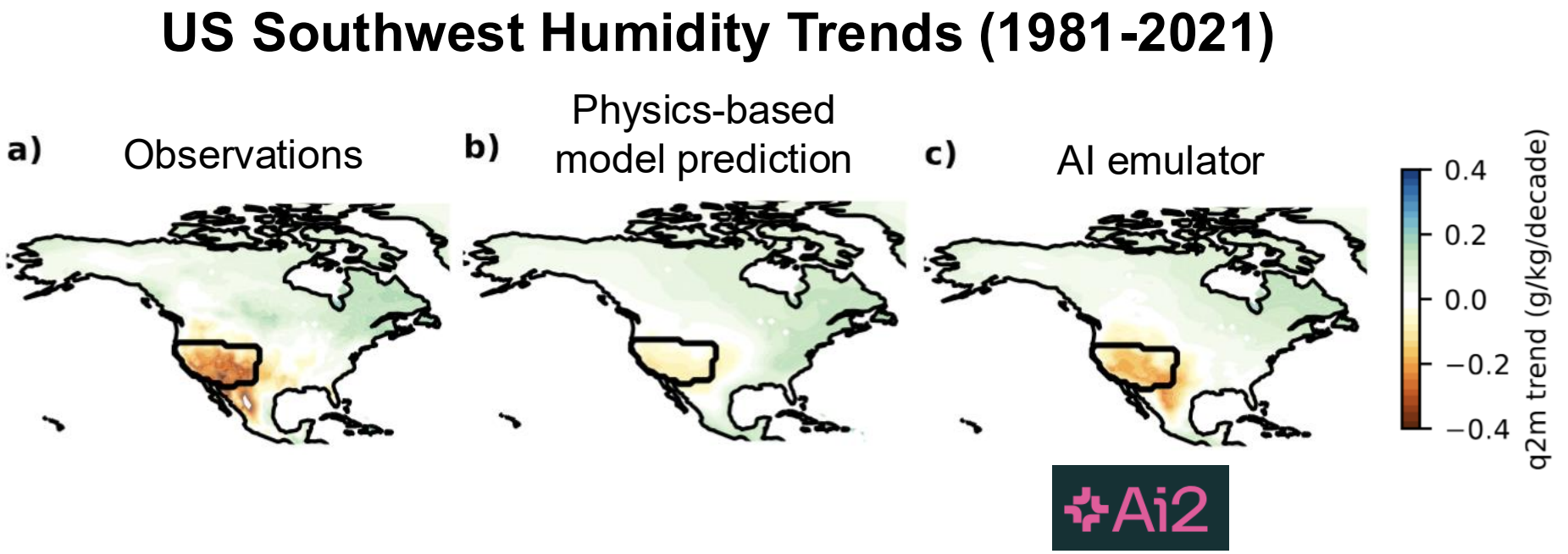

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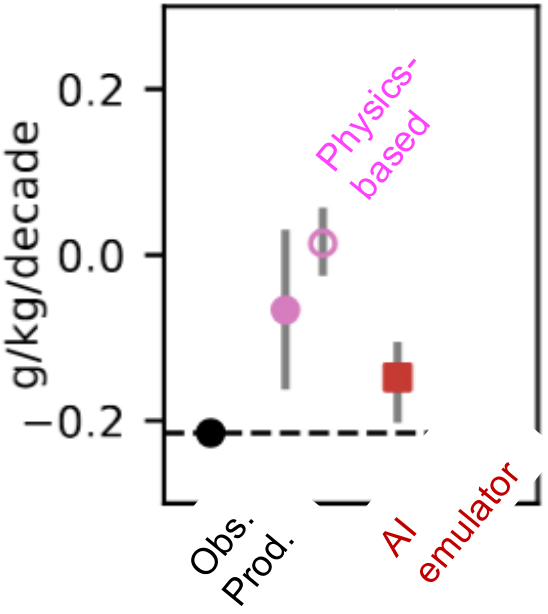
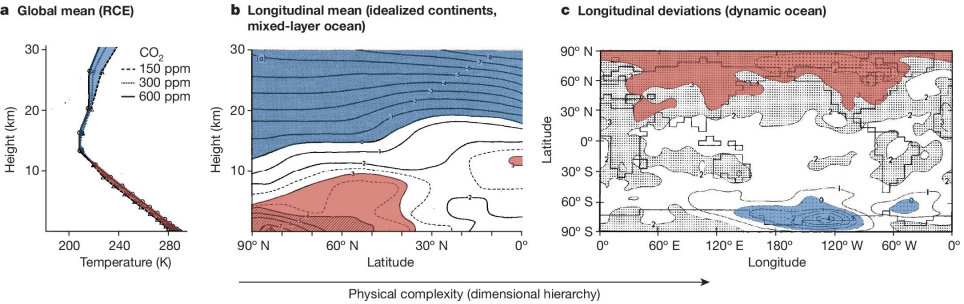


On going work is testing whether AI models get the right answer for the right reason

Rucker et al. (2025, GRL)

Consensus – standard approach



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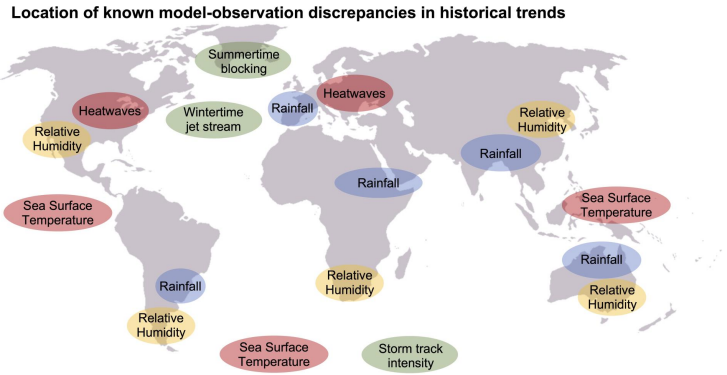
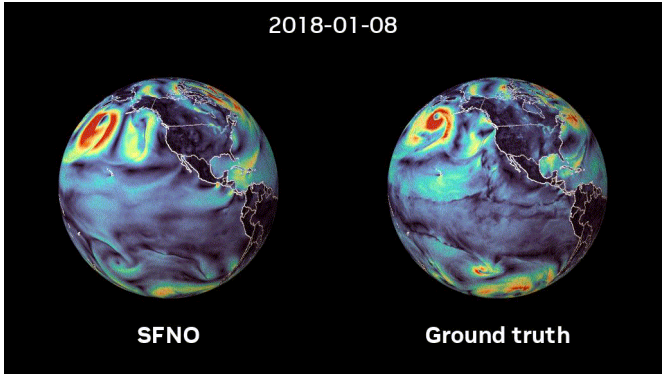
Discrepancies + Disruptions





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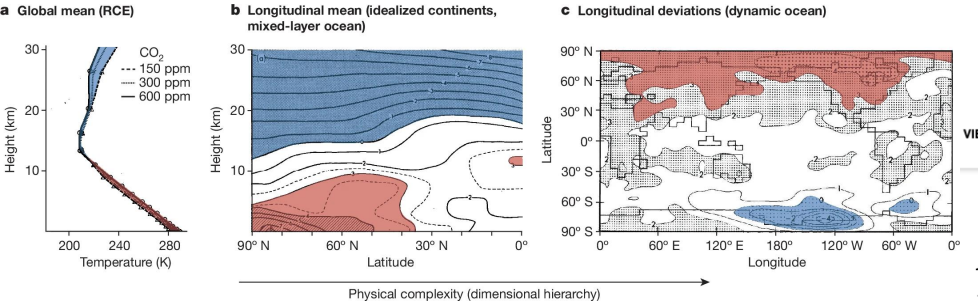

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Challenging the standard cosmological model

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Quanta magazine

A Deepening Crisis Forces Physicists to Rethink Structure of Nature's Laws

By Natalie Wolchover

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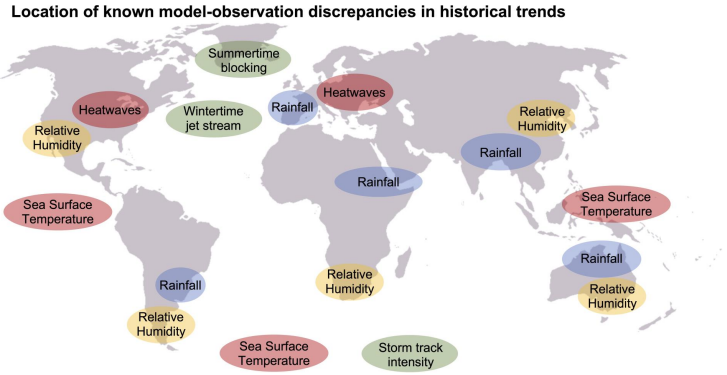
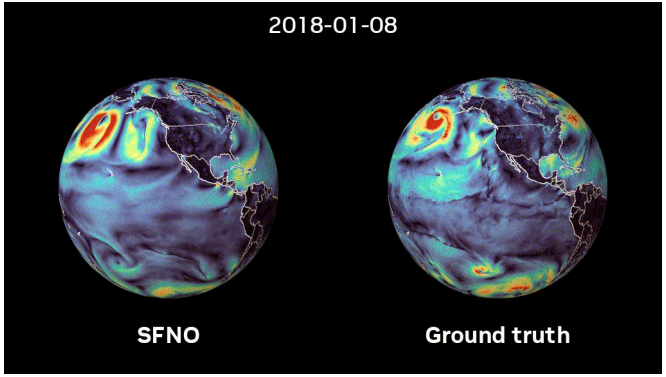
Discrepancies



Disruptions



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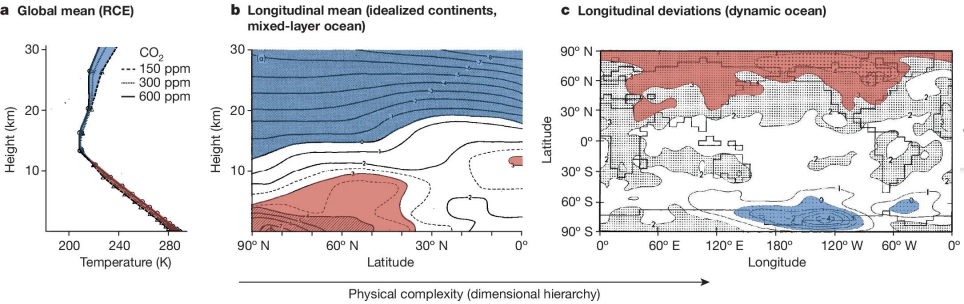
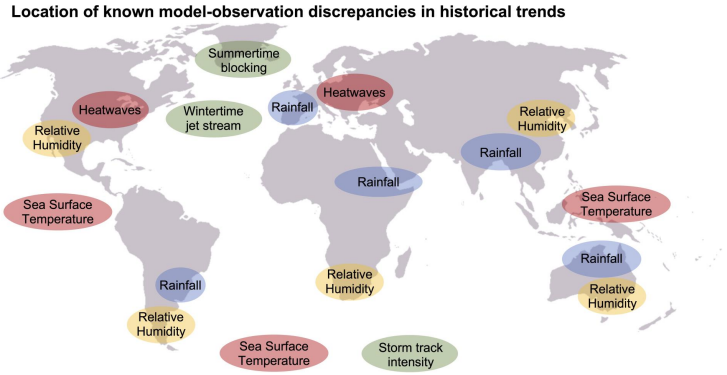


How to make robust decisions as scientific paradigm evolves?

Rethink Structure of Nature's Laws

By Natalie Wolchover

Discrepancies



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