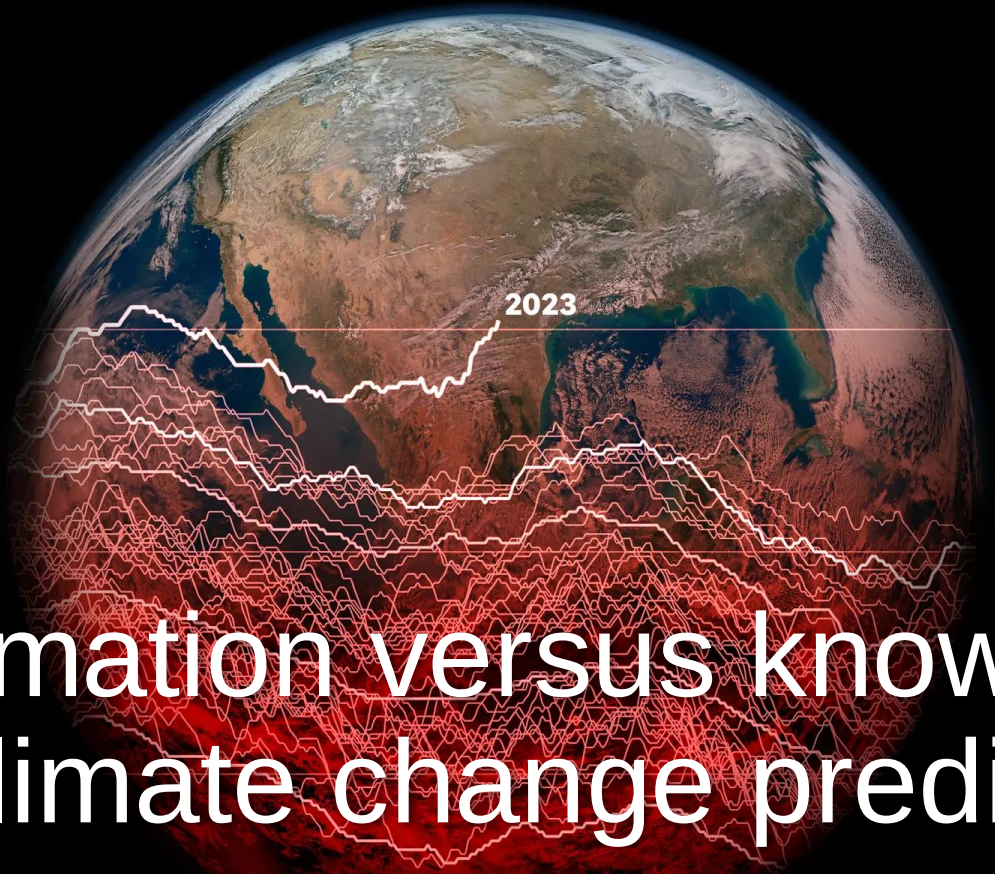


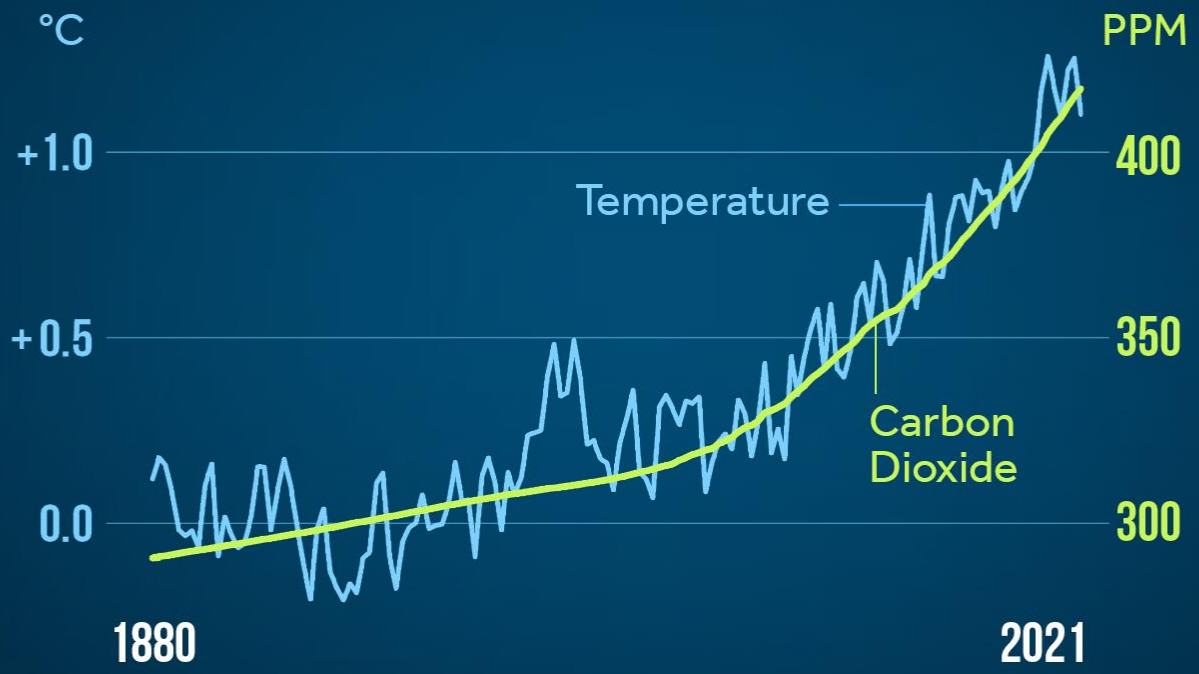
Information versus knowledge in climate change prediction

Tiffany A. Shaw

The University of Chicago

USA TODAY/NASA

TEMPERATURE & CARBON DIOXIDE

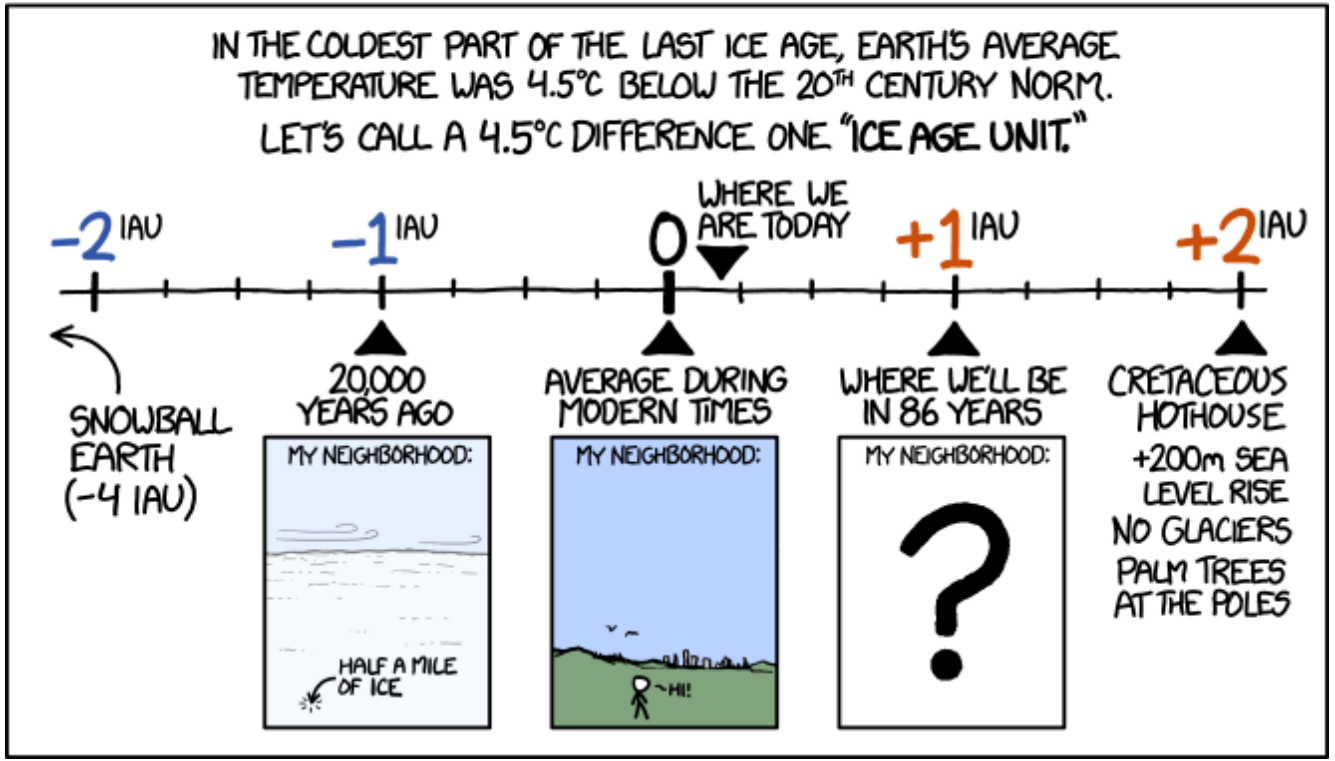


Global temperature anomalies averaged and adjusted to early industrial baseline (1881-1910)
Source: NASA GISS, NOAA NCEI, ESRL

CLIMATE CENTRAL

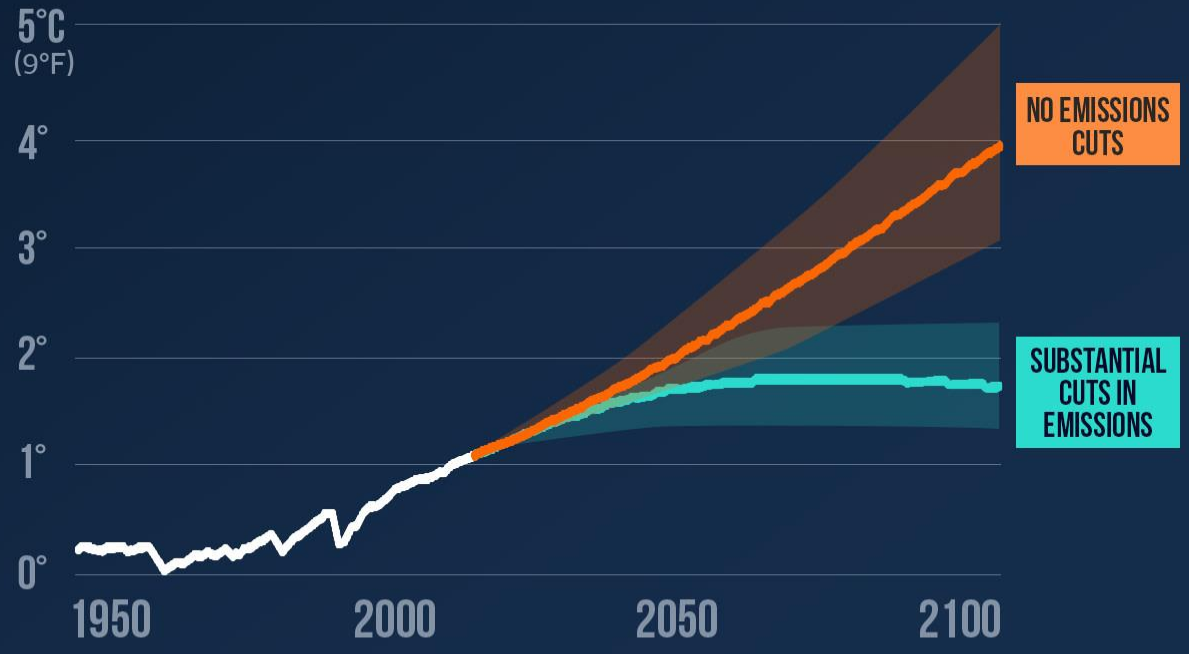
WITHOUT PROMPT, AGGRESSIVE LIMITS ON CO_2 EMISSIONS, THE EARTH WILL LIKELY WARM BY AN AVERAGE OF 4°-5°C BY THE CENTURY'S END.

HOW BIG A CHANGE IS THAT?



FUTURE TEMPERATURES

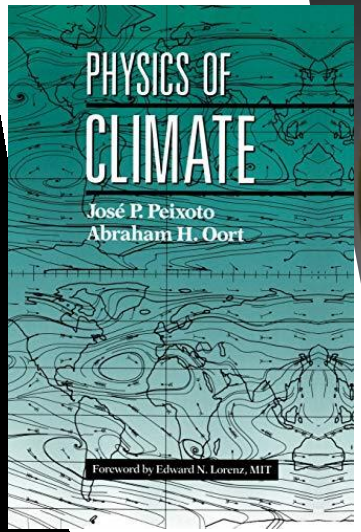
WARMING DEPENDS ON CHOICES TODAY



Global surface temperature (°C) anomaly relative to 1850-1900
High warming scenario: SSP3-7, Low warming scenario from SSP1-2.6.
Source: IPCC AR6 WG1

CLIMATE CENTRAL

Information of the future comes from knowledge of climate physics



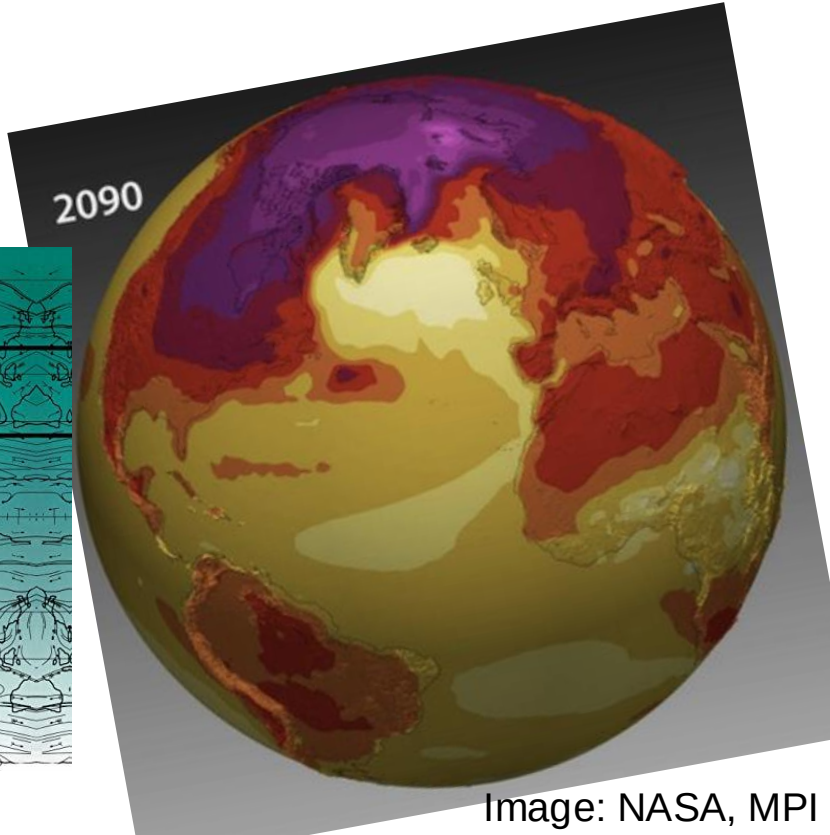
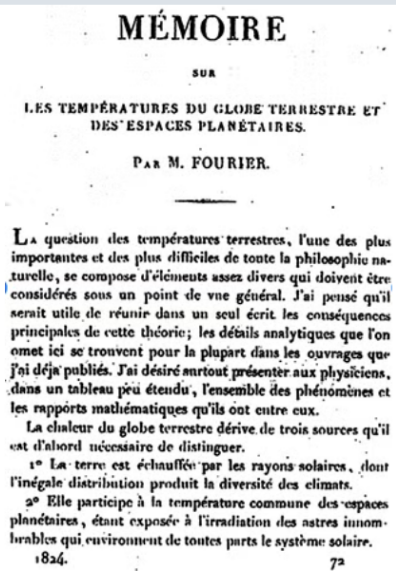


Image: NASA, MPI



MÉMOIRE

SUR

LES TEMPÉRATURES DU GLOBE TERRESTRE ET DES ESPACES PLANÉTAIRES.

PAR M. FOURIER.

LA question des températures terrestres, l'une des plus importantes et des plus difficiles de toute la philosophie naturelle, se compose d'éléments assez divers qui doivent être considérés sous un point de vue général. J'ai pensé qu'il serait utile de réunir dans un seul écrit les conséquences principales de cette théorie; les détails analytiques que l'on omet ici se trouvent pour la plupart dans les ouvrages que j'ai déjà publiés. J'ai désiré surtout présenter aux physiciens, dans un tableau peu étendu, l'ensemble des phénomènes et les rapports mathématiques qu'ils ont entre eux.

La chaleur du globe terrestre dérive de trois sources qu'il est d'abord nécessaire de distinguer.

1° La terre est échauffée par les rayons solaires, dont l'inégale distribution produit la diversité des climats.

2° Elle participe à la température commune des espaces planétaires, étant exposée à l'irradiation des astres innombrables qui environnent de toutes parts le système solaire.

1824. 72

ScienceBlogs

Fourier's 1827 article about the temperature of the Earth

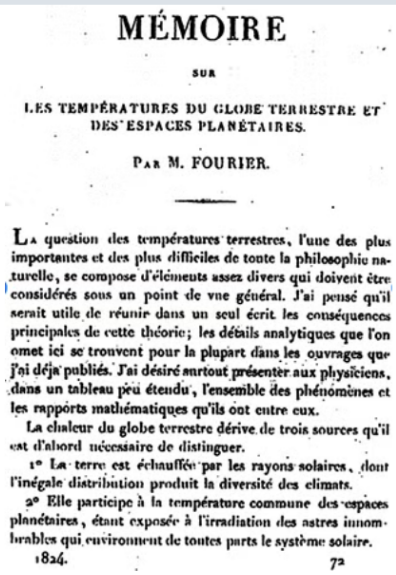
1824

DESCRIBING EARTH'S ATMOSPHERE AS A GREENHOUSE

Jean-Baptiste-Joseph Fourier, a mathematician working for Napoleon, was the first to describe how Earth's atmosphere retains warmth on what would otherwise be a very cold planet.. To help explain the concept, he compared the atmosphere to the glass walls of a

1824

DESCRIBING EARTH'S ATMOSPHERE AS A GREENHOUSE



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1824. 72

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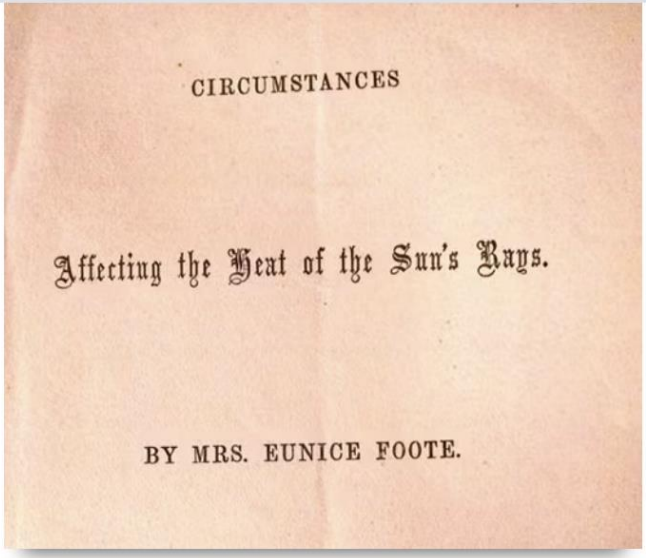


CIRCUMSTANCES

Affecting the Heat of the Sun's Rays.

BY MRS. EUNICE FOOTE.

UCSB

Cover of physicist Eunice Foote's paper about the greenhouse effect presented at the AAAS meeting in 1856

1856

DISCOVERING GASES THAT TRAP HEAT

Eunice Foote, American scientist, discovered that carbon dioxide and water vapor cause air to warm in sunlight. In 1856, she presented her findings at the meeting of the American Association for the Advancement of Science (AAAS).

"A paper was read before the late meeting of the Scientific Association, by Prof. Henry for Mrs. Eunice Foot, detailing her

UCAR

Aino Nyman/Wikipedia

Factory smoke, 1901

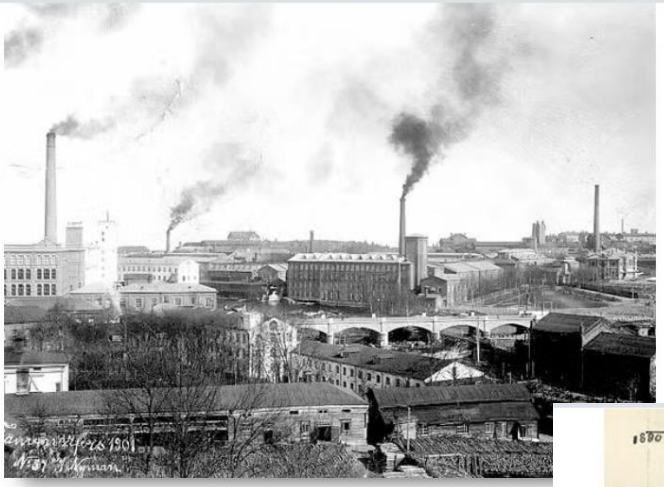
1896

CONNECTING COAL, CARBON DIOXIDE, AND CLIMATE

Swedish chemist Svante Arrhenius recognized that burning coal could increase carbon dioxide and warm the climate. He estimated how much carbon dioxide the ocean could absorb. In an 1896 lecture, Arrhenius noted that it was not yet possible to calculate how fast

1896

CONNECTING COAL, CARBON DIOXIDE, AND CLIMATE



Aino Nyman

Factory smoke, 1901

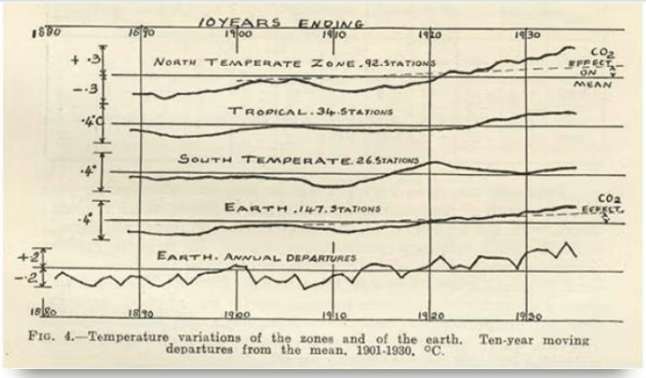


FIG. 4.—Temperature variations of the zones and of the earth. Ten-year moving departures from the mean, 1901-1930. °C.

Figure 4 from Callendar's 1938 paper, The Artificial Production of Carbon Dioxide and its Influence on Temperature

1938

INCREASING CARBON DIOXIDE AND INCREASING TEMPERATURES

British coal engineer George Callendar compiled all carbon dioxide measurements made over the previous 100 years and found that the amount of CO_2 was increasing. He also found that temperatures were rising. His conclusion was that this was a good thing, that the

THE NOBEL PRIZE IN PHYSICS 2021

Illustrations: Niklas Elmehed

Syukuro Manabe

Klaus Hasselmann

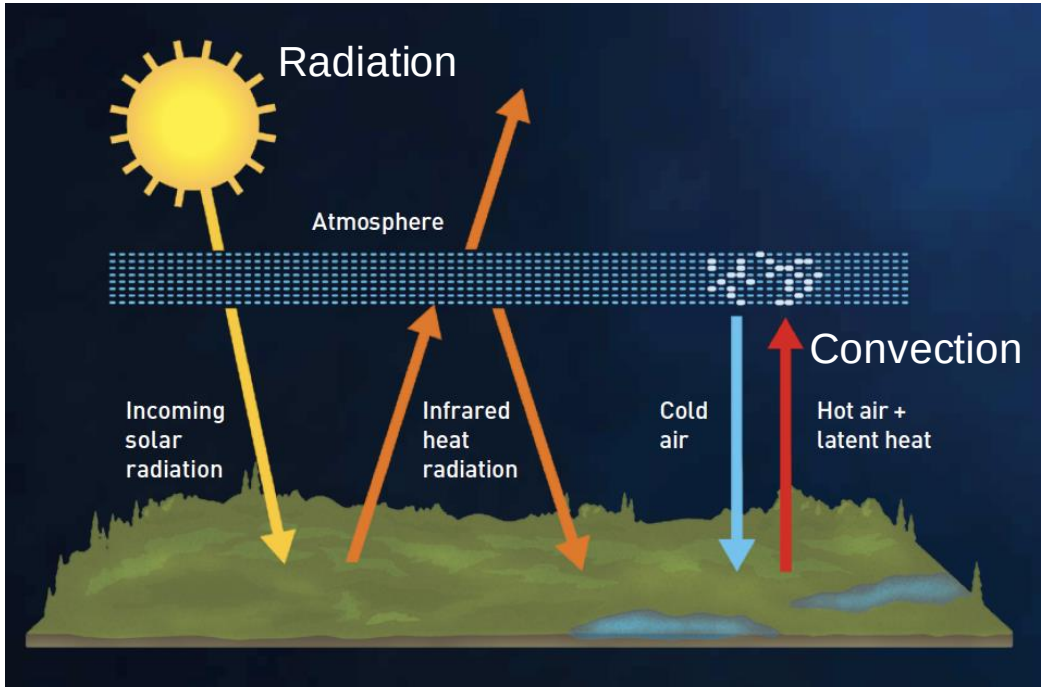
Giorgio Parisi

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

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

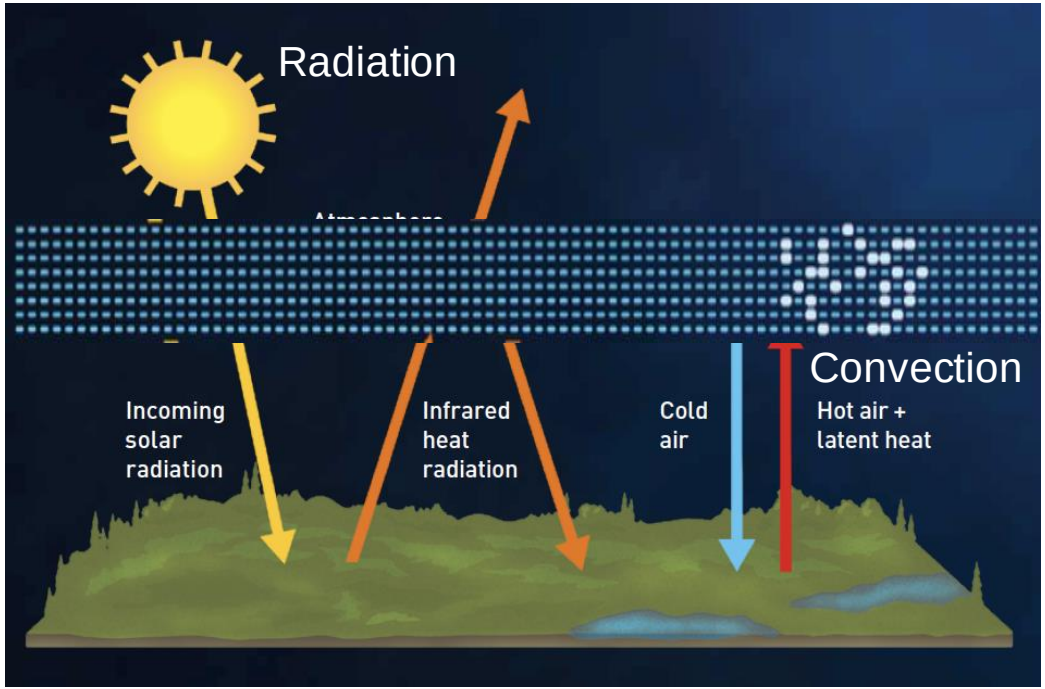
THE ROYAL SWEDISH ACADEMY OF SCIENCES

Manabe's climate predictions relied on applying physical laws to large-scales



Nobel committee

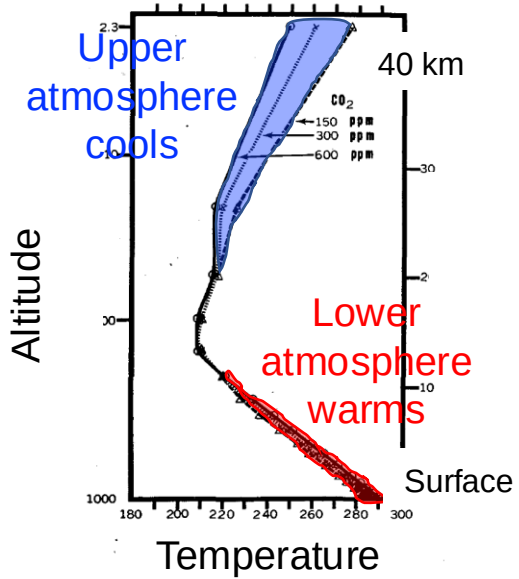
Manabe's climate predictions relied on applying physical laws to large-scales



Nobel committee

Increased CO2 leads to global-mean cooling above, warming below

Response to doubling CO2



Manabe & Weatherald (1967)

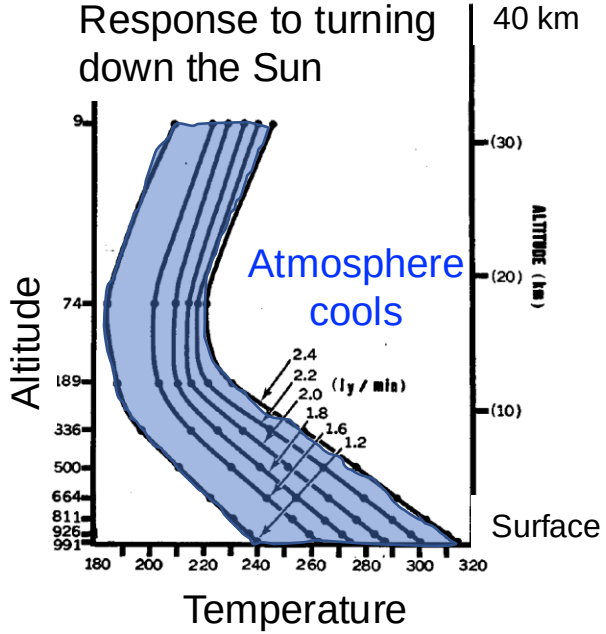
Physical Complexity

Surface warming sensitive to assumptions about moisture and clouds

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

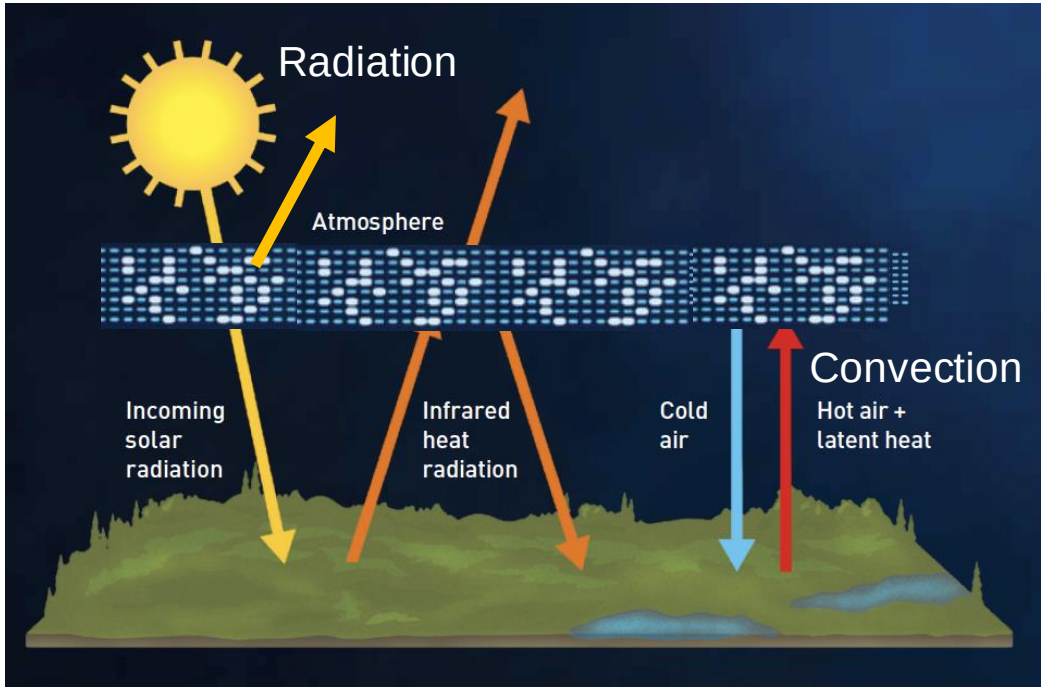
Manabe & Weatherald (1967)

Turning down the sun leads to global-mean cooling at all altitudes



Physical Complexity

Manabe's climate predictions also provide insight into intervention

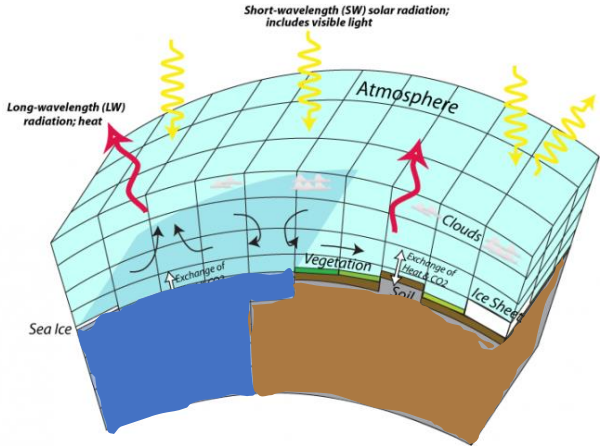


Stratospheric aerosol would reflect sunlight

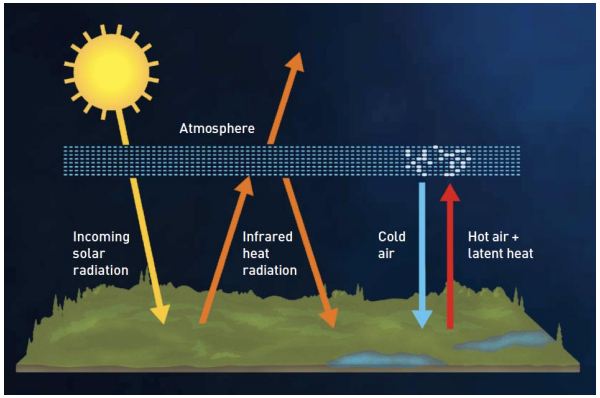
Nobel committee

Climate predictions rely on the application of physical laws to large-scales

Latitude-altitude



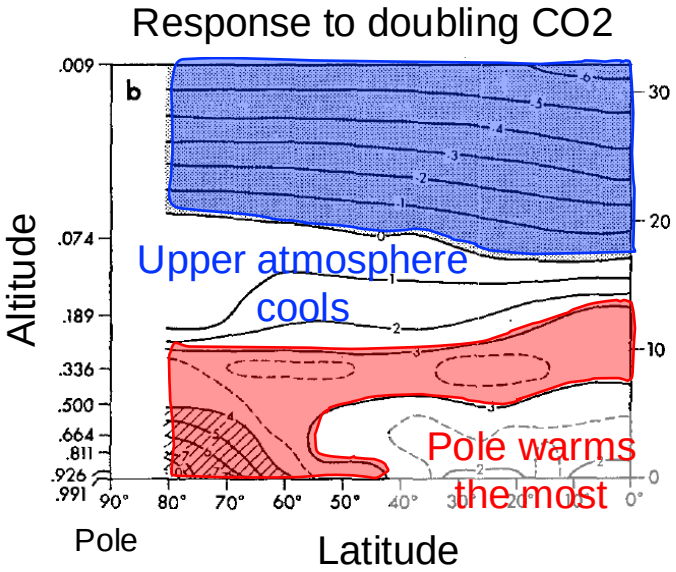
Global-mean (altitude)



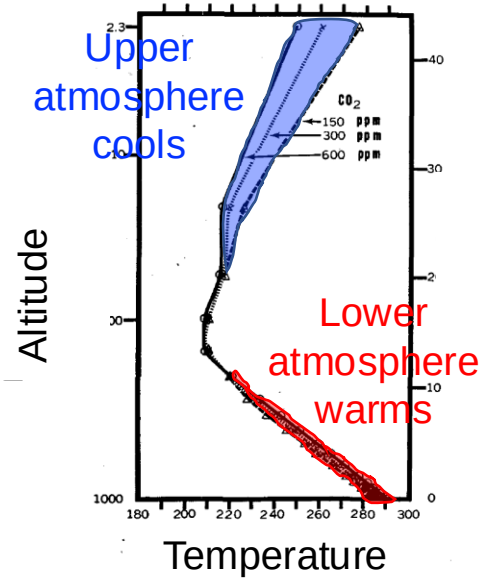
Physical Complexity

Climate predictions rely on the application of physical laws to large-scales

Response to doubling CO2



Manabe & Weatherald (1975)

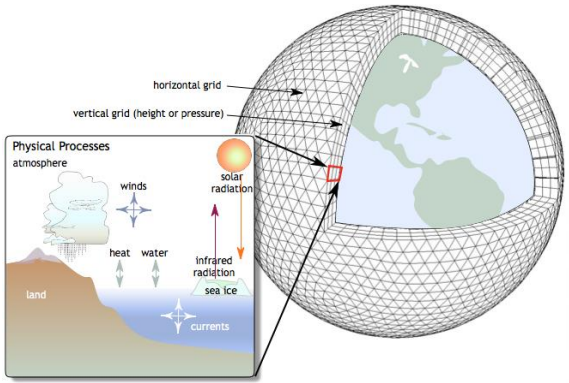


Manabe & Weatherald (1967)

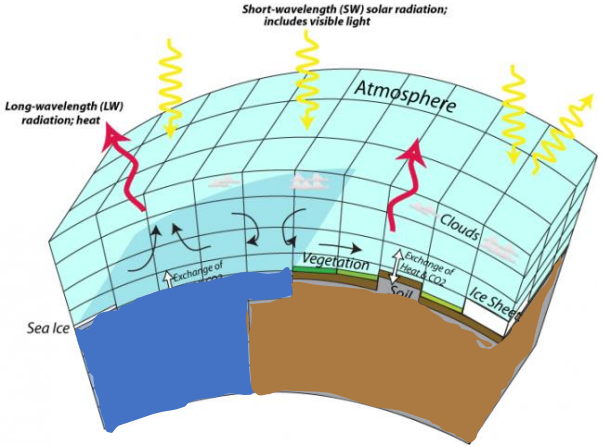
Physical Complexity

Climate predictions rely on the application of physical laws to large-scales

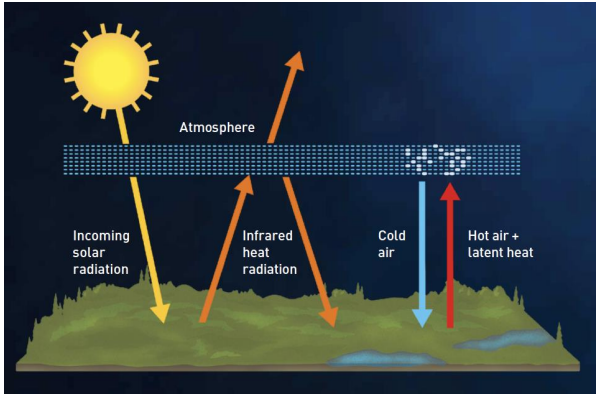
Latitude-longitude-altitude



Latitude-altitude

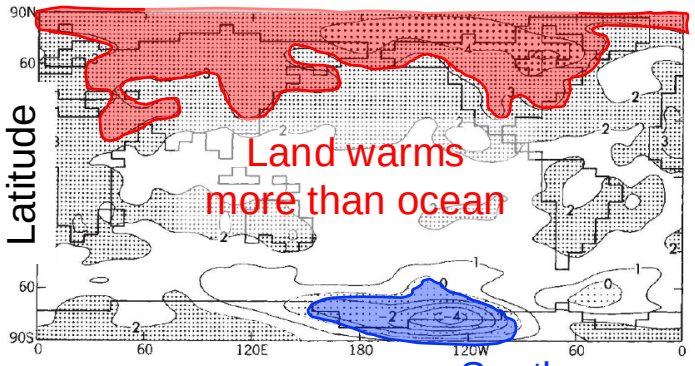


Global-mean (altitude)



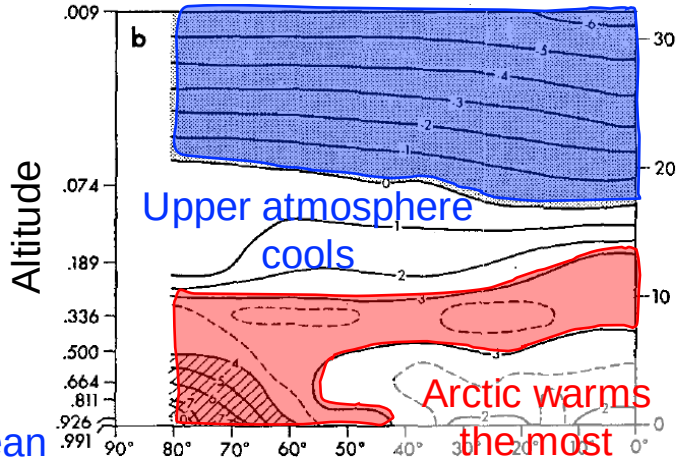
Physical Complexity

Climate predictions rely on the application of physical laws to large-scales



Stouffer, Manabe & Weatherald (1989)

Response to doubling CO2



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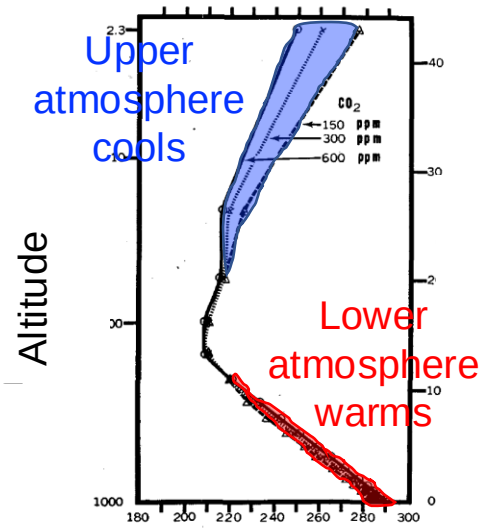
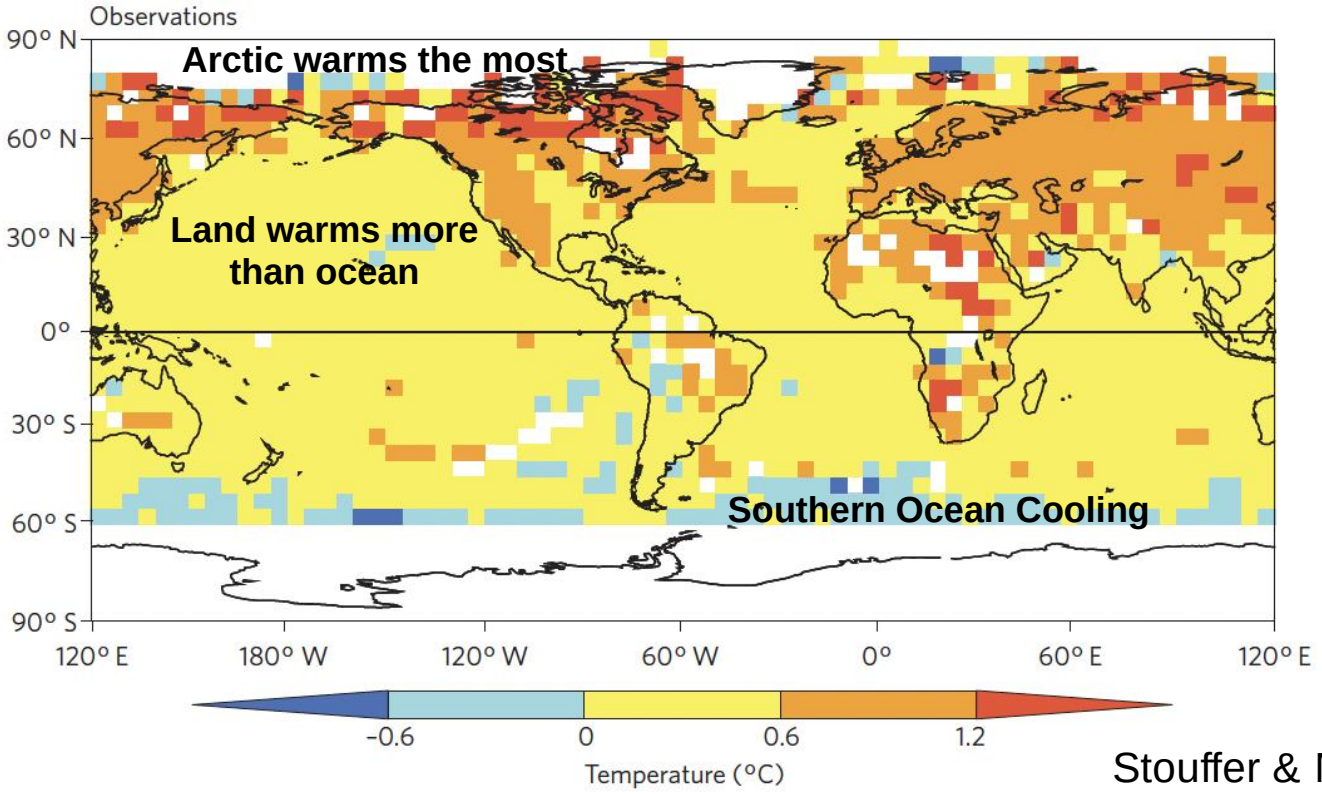


Manabe & Weatherald (1967)

Physical Complexity

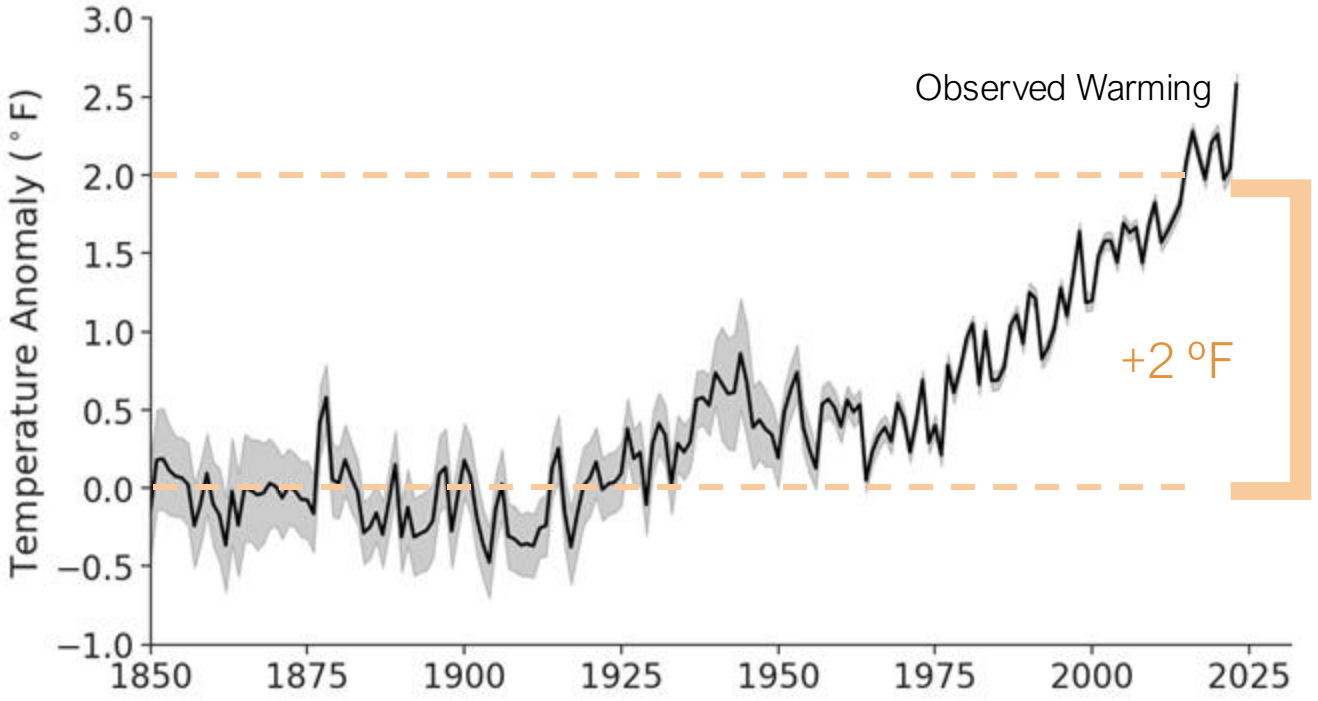
Predicted signals have emerged across many regions and seasons



Stouffer & Manabe (2017)

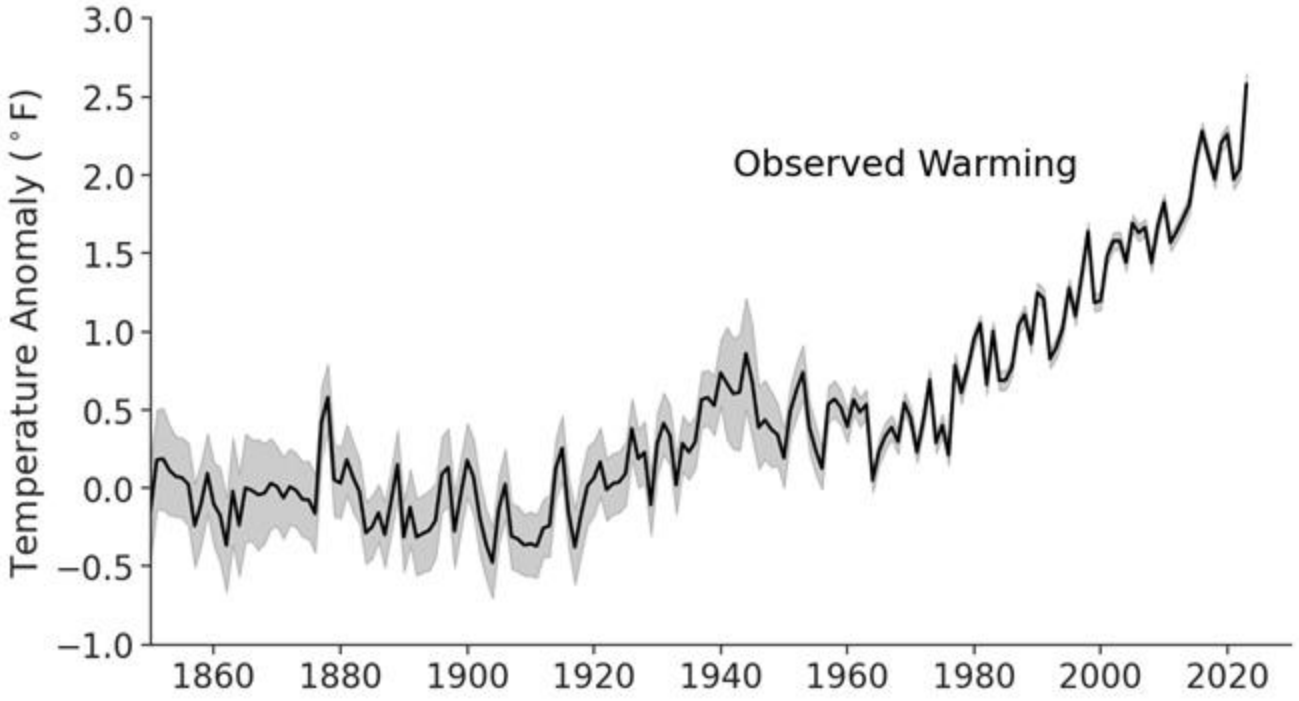
60 years later many modeling centers around the world make climate predictions

Observed global warming is around 2F



Source: HADCRUT5 (Met Office).

Climate predictions show observed warming does not occur without human emissions



Source: Modeled natural changes from FAQ 3.1, Figure 1 in IPCC, 2021: Chapter 3. The Physical Science Basis. Observed warmingis HADCRUT5.

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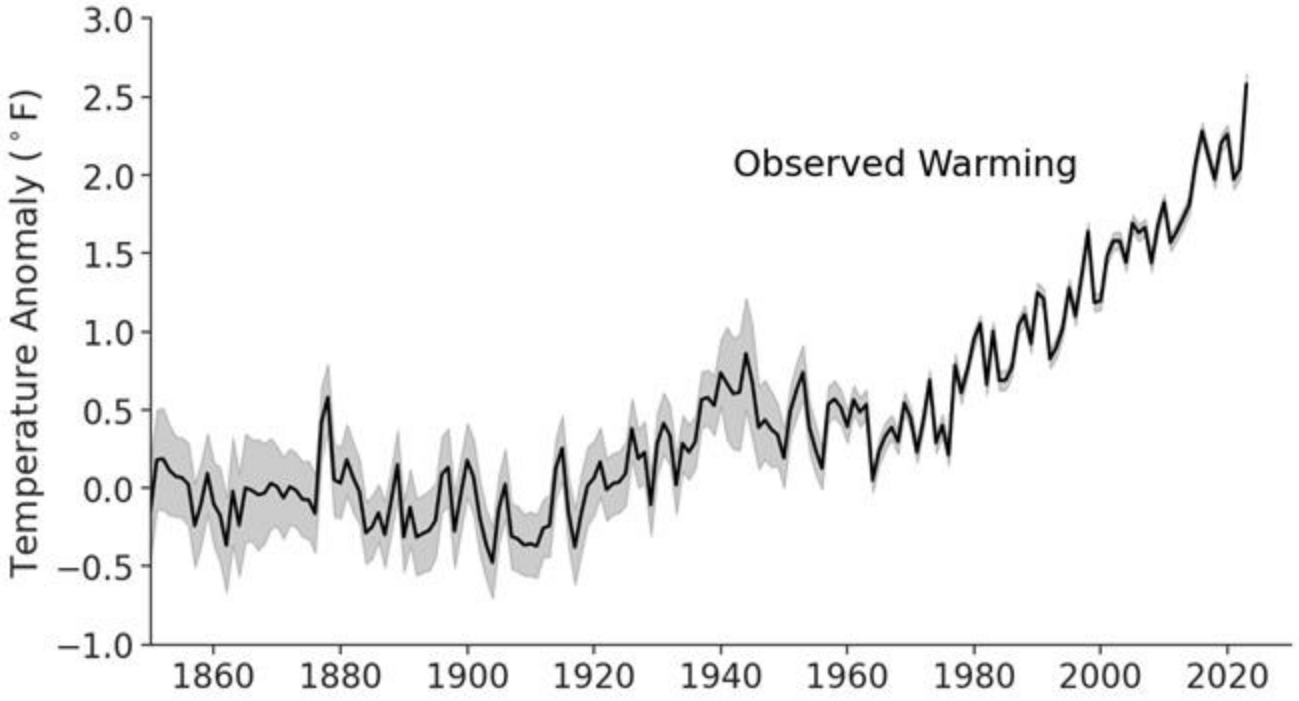
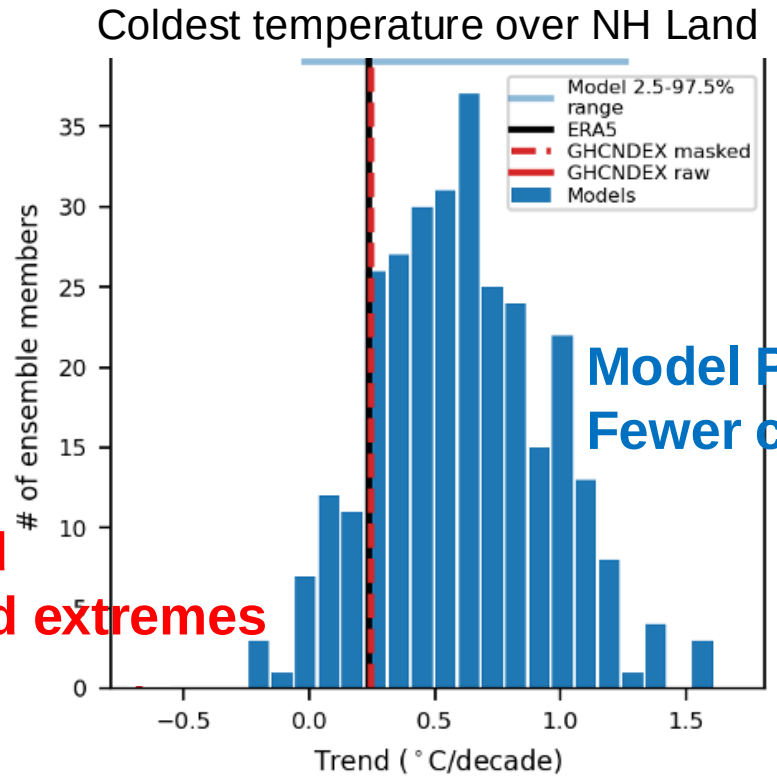


Source: Modeled human + natural changes from FAQ 3.1, Figure 1 in IPCC, 2021: Chapter 3. The Physical Science Basis. Observations are HADCRUT5.

As Earth warms more and more regional predictions are being compared to real world changes


Cold waves
have become
less cold.

Climate predictions with human influence capture increase of coldest land temperature

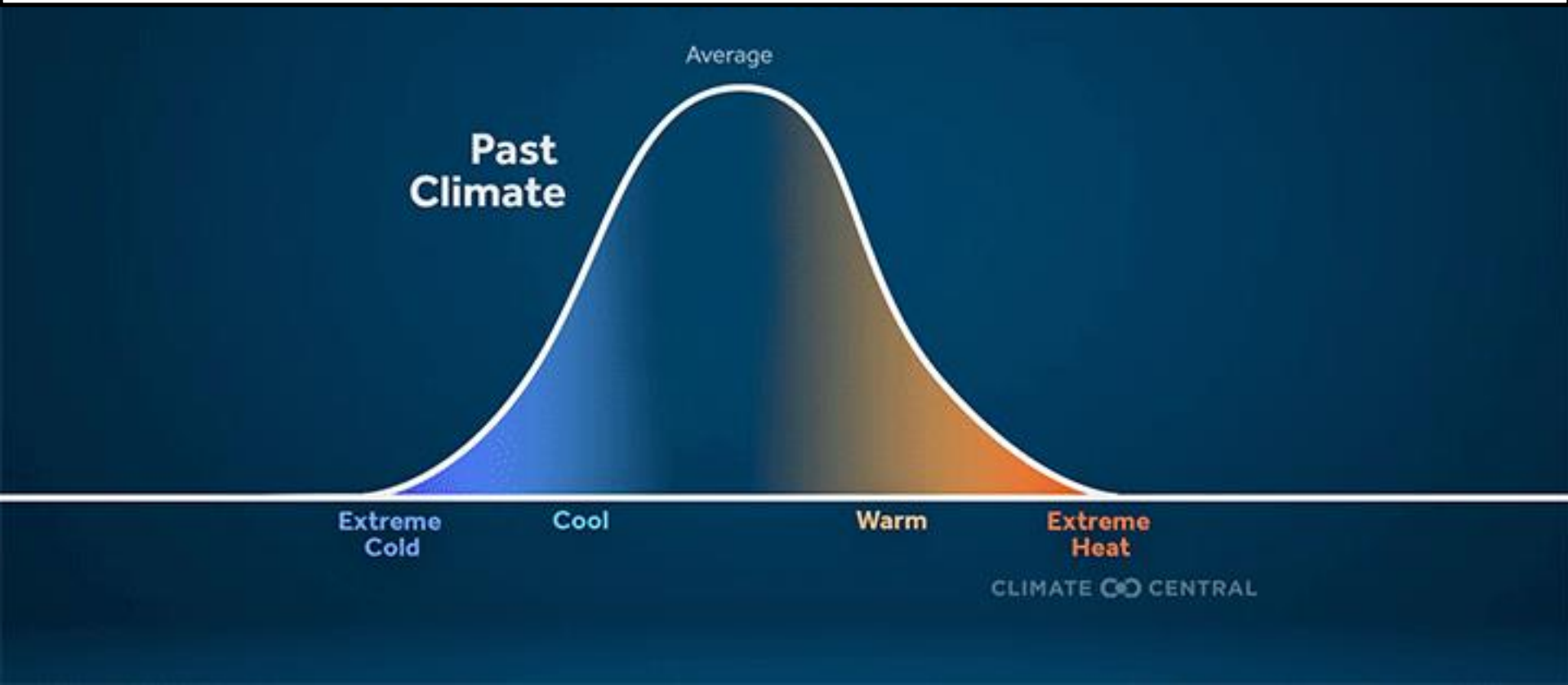


Model Predictions
Fewer cold extremes

Real world
Fewer cold extremes

Blackport et al. (2024)

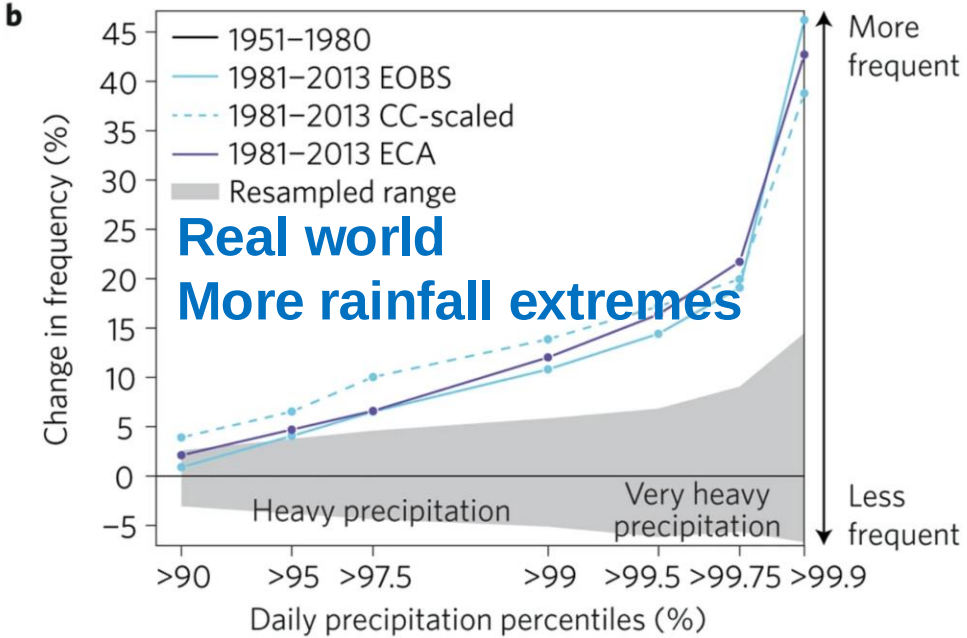
Temperature extremes increase following an increase of the average



Extreme rainfall has *increased.*

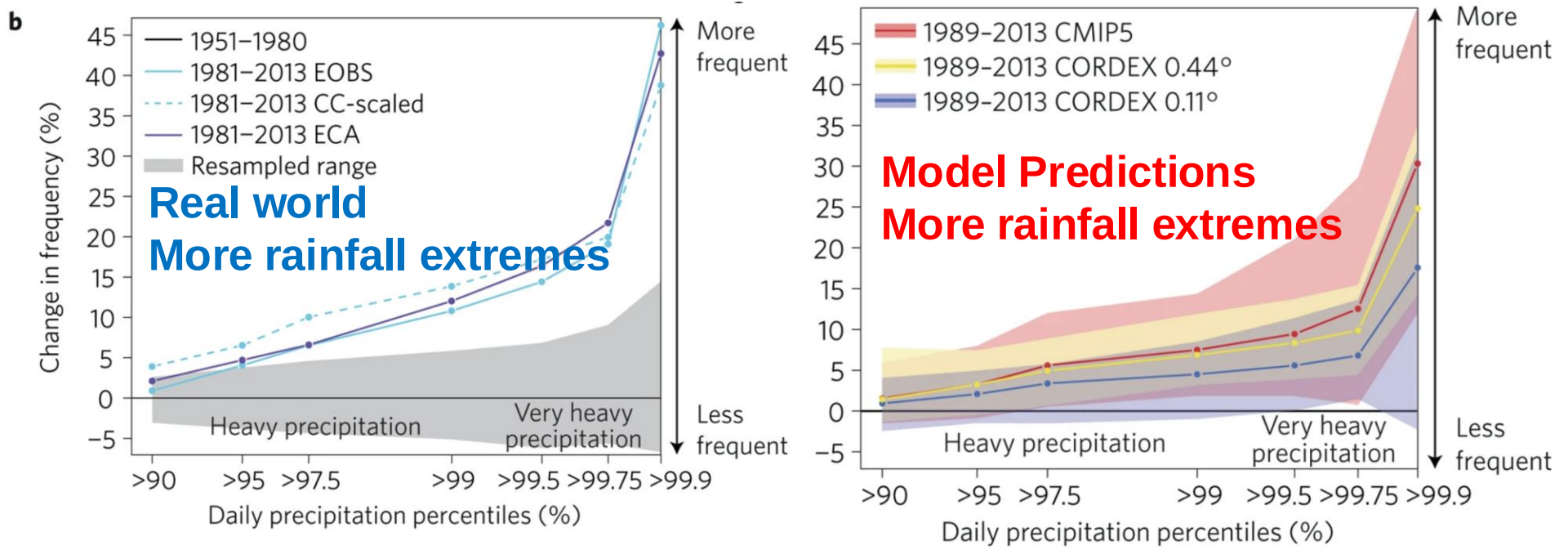
Photo by Kristopher Radder/Brattleboro Reformer via AP

Climate predictions capture increase of European rainfall extremes



Fischer & Knutti (2016)

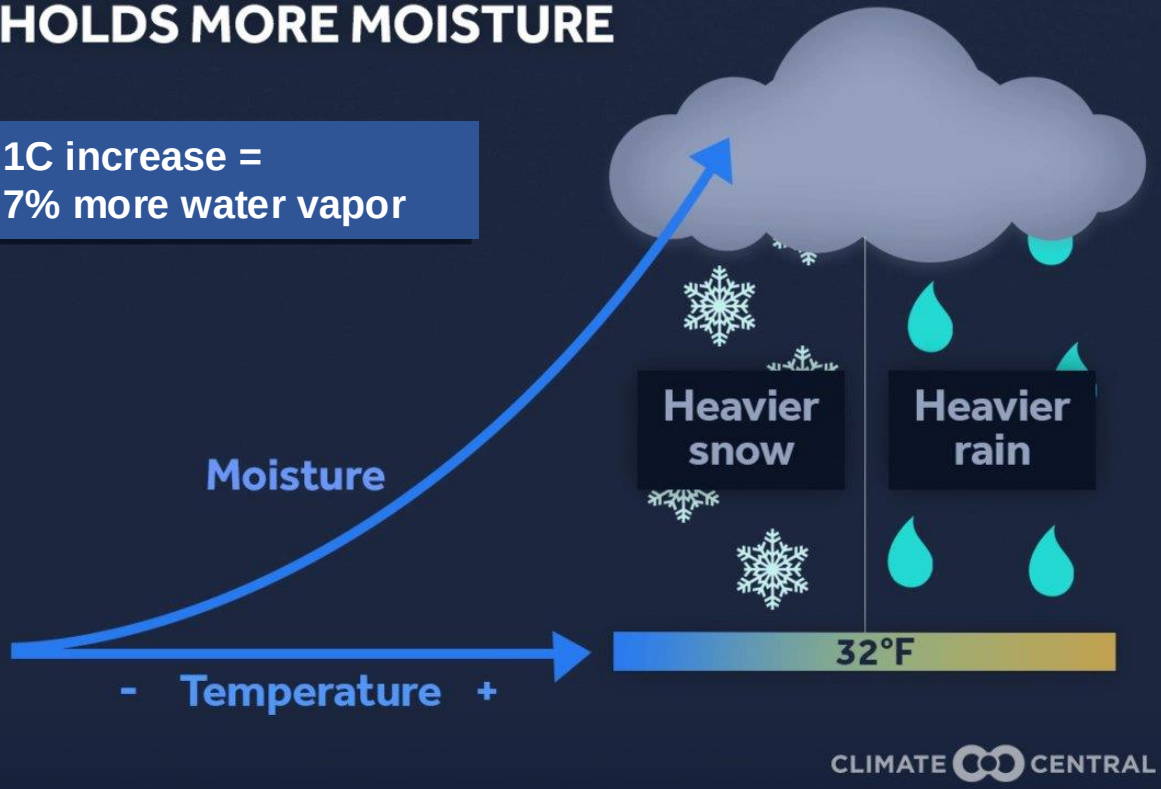
Climate predictions capture increase of European rainfall extremes



Fischer & Knutti (2016)

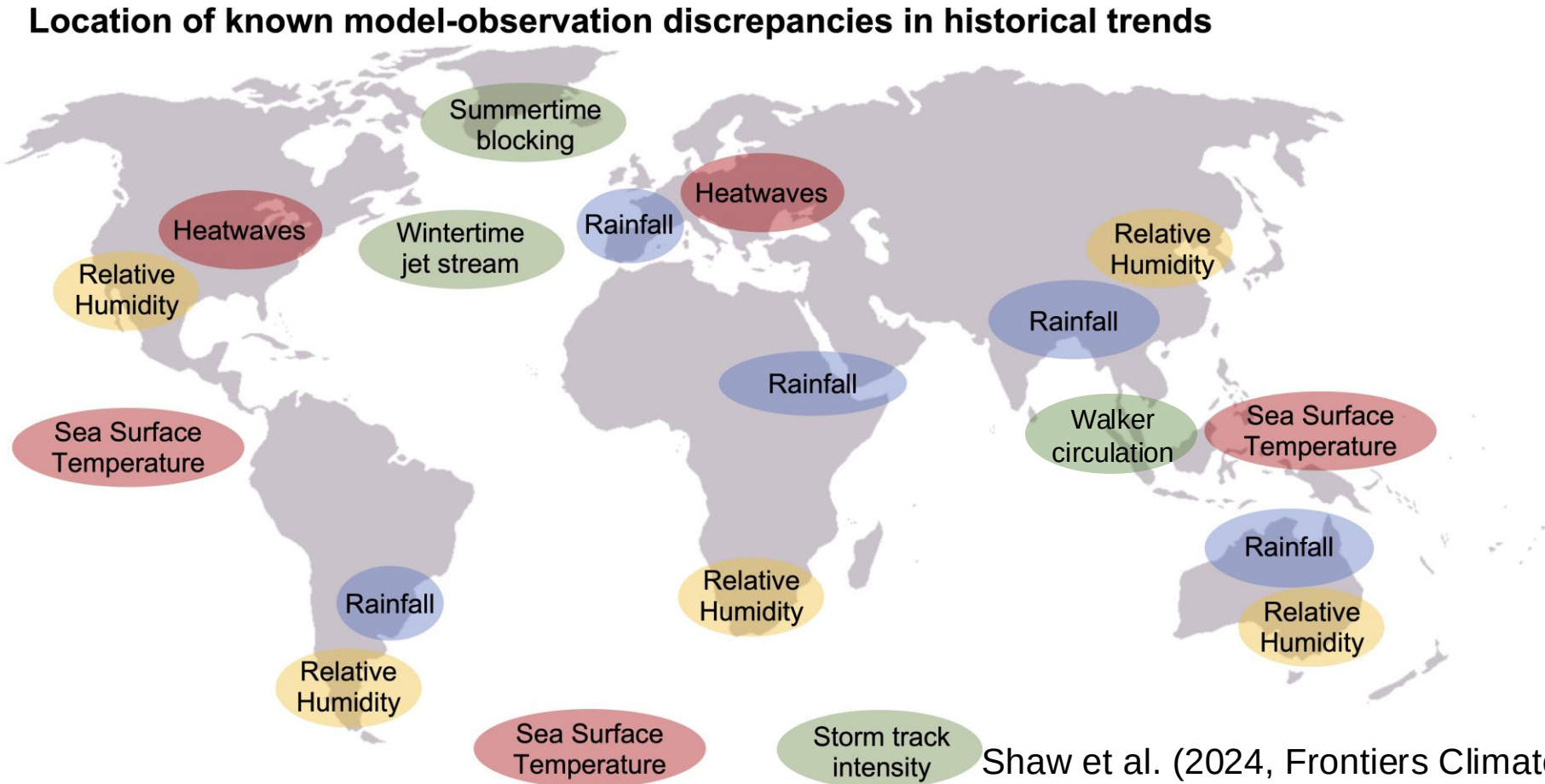
WARMER AIR
HOLDS MORE MOISTURE

1C increase =
7% more water vapor



CLIMATE CENTRAL

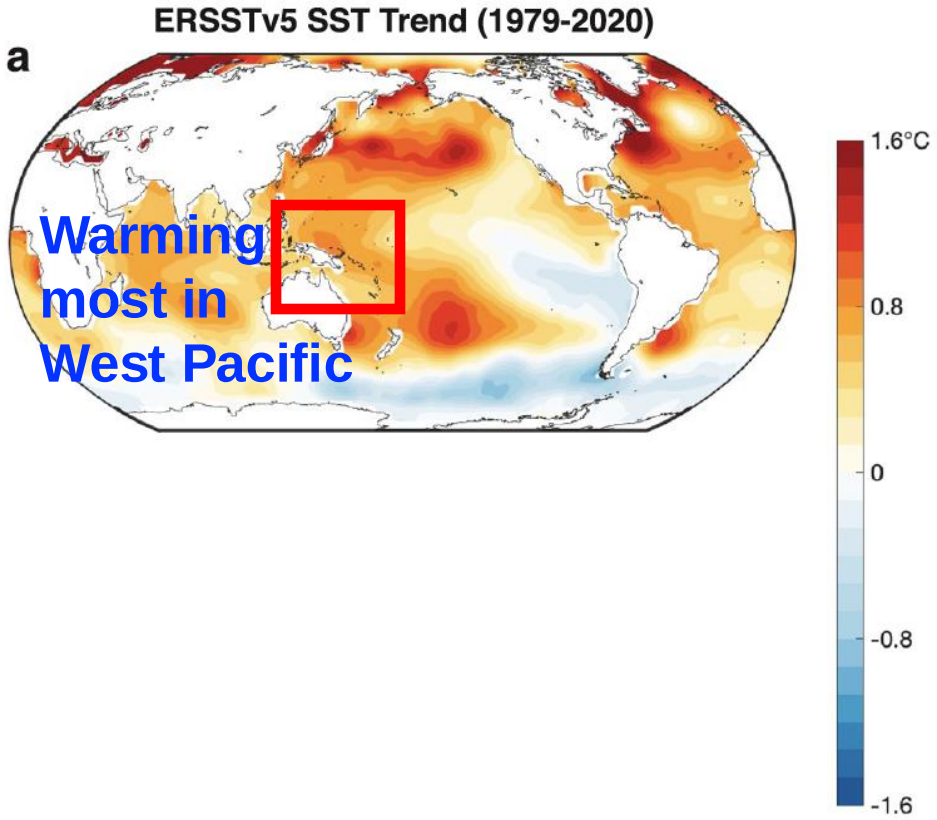
Regional discrepancies have also emerged



Shaw et al. (2024, Frontiers Climate)

Sea surface temperature discrepancy

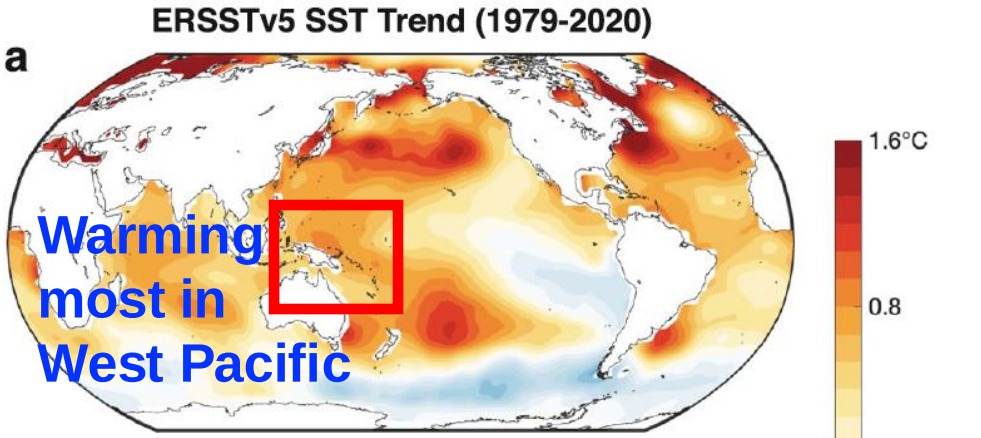
Real world



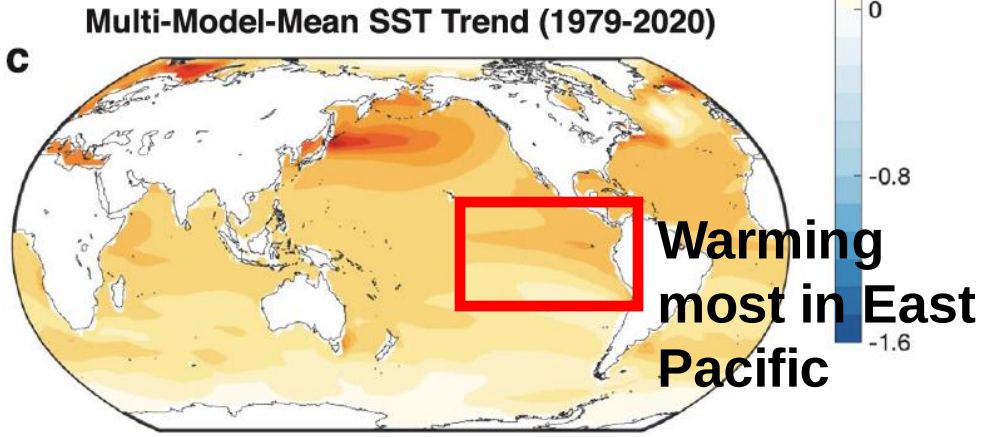
Wills et al (2022, GRL)

Sea surface temperature discrepancy

Real world

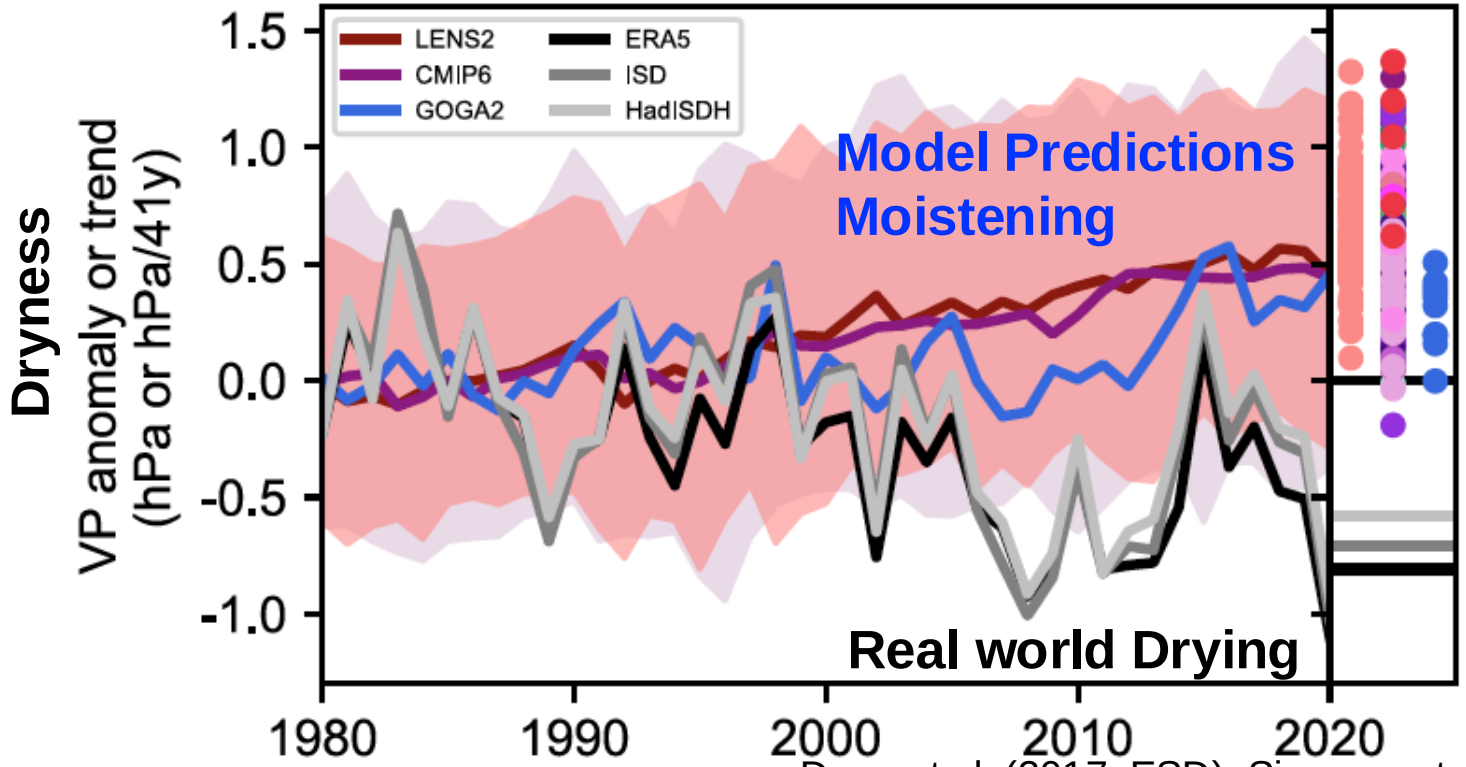


Model Predictions



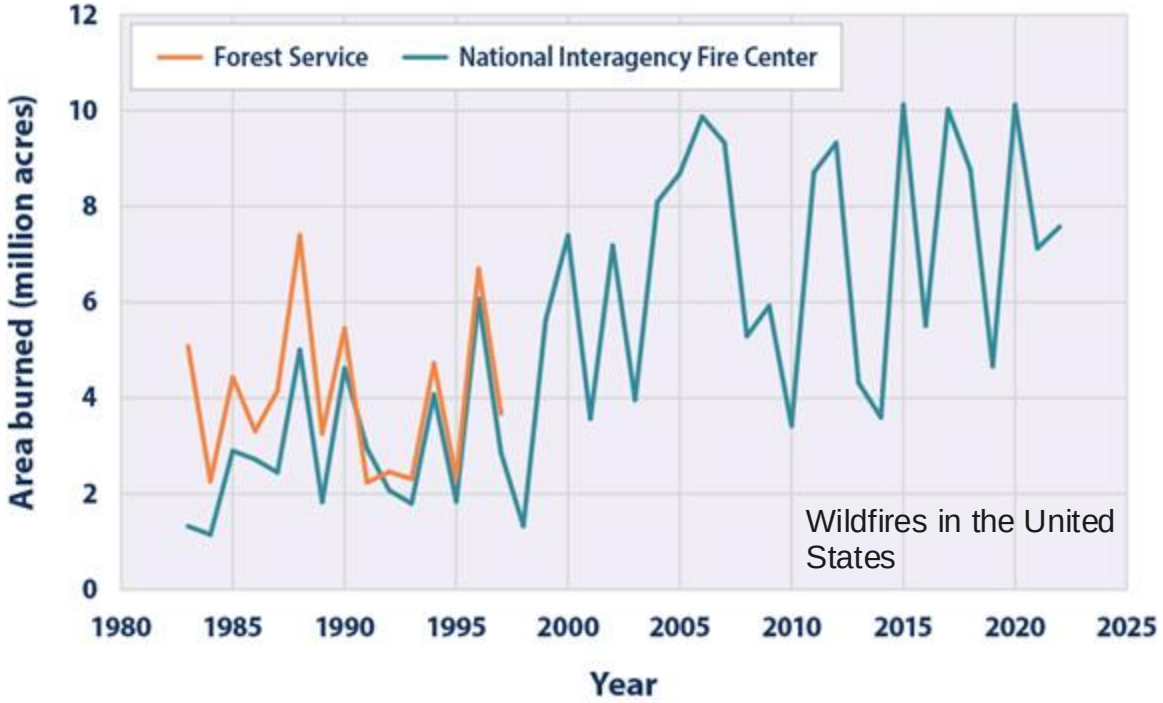
Wills et al (2022, GRL)

Discrepancy in drying trends over US Southwest



Dunn et al. (2017, ESD), Simpson et al (2024, PNAS)

Wildfires in US are trending up, but climate change connection remains uncertain



“In recent decades, wildfires in the western United States have become larger, hotter, and more destructive and deadly due to a suite of factors, including climate change.” -US Fifth National Climate Assessment

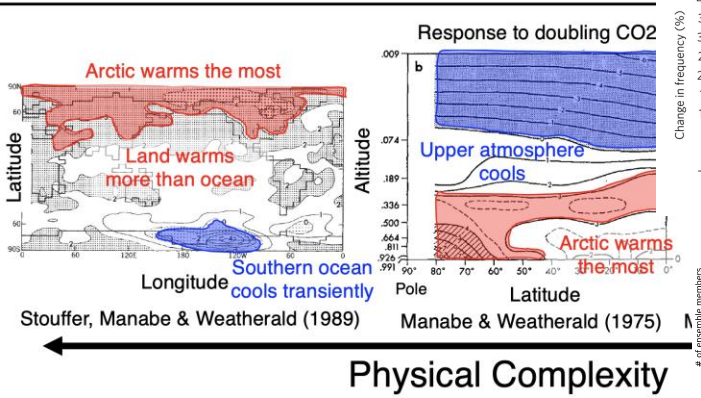
Landscape of regional climate information

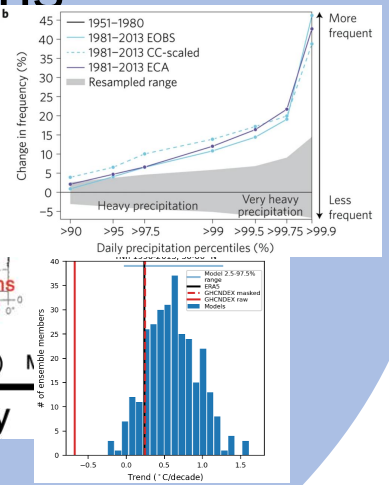
Knowledge

Tied to a chain of reasoning

Multiple lines of evidence

Successful predictions





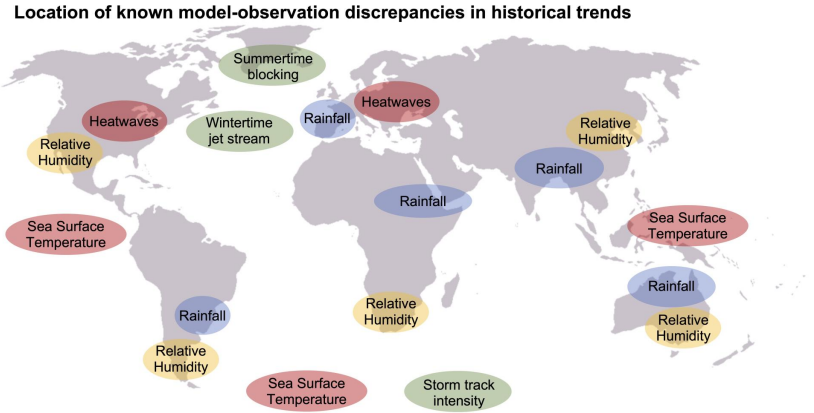
Physical Complexity

Knowledge gap

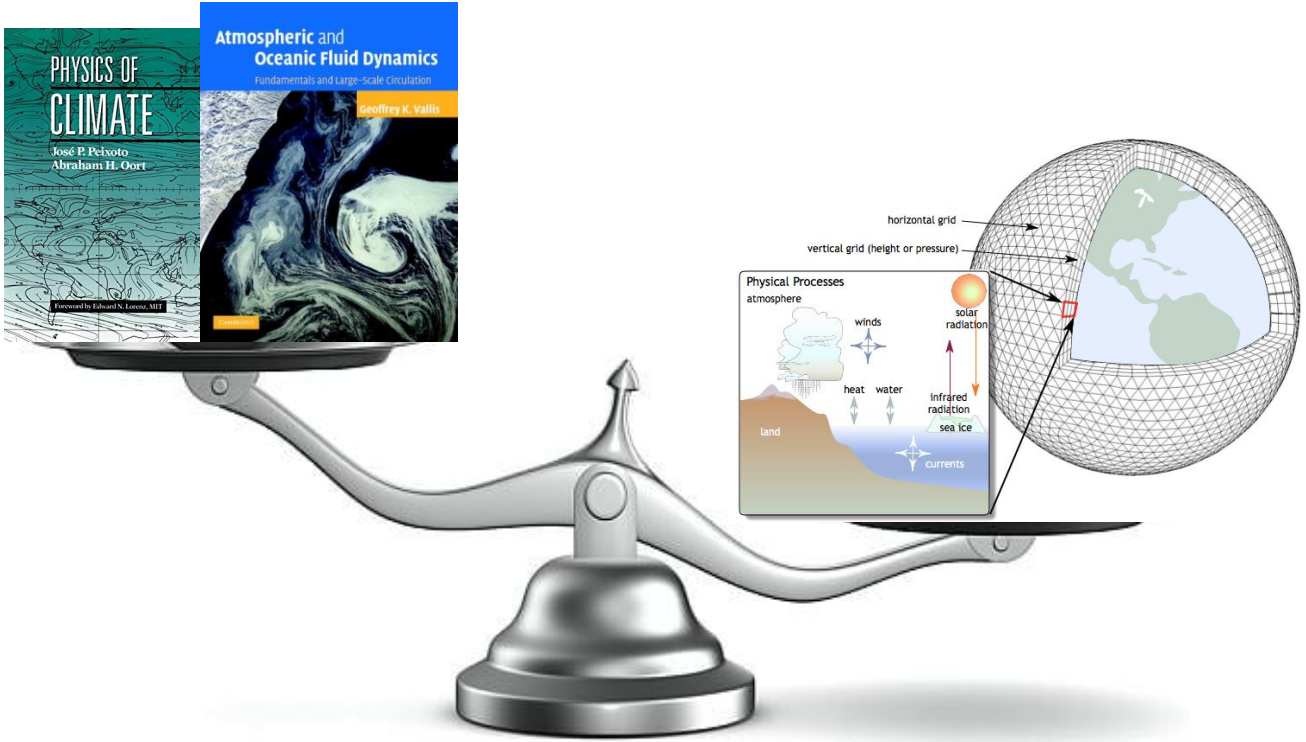
Discrepancies

Failed predictions?

Risk assessment

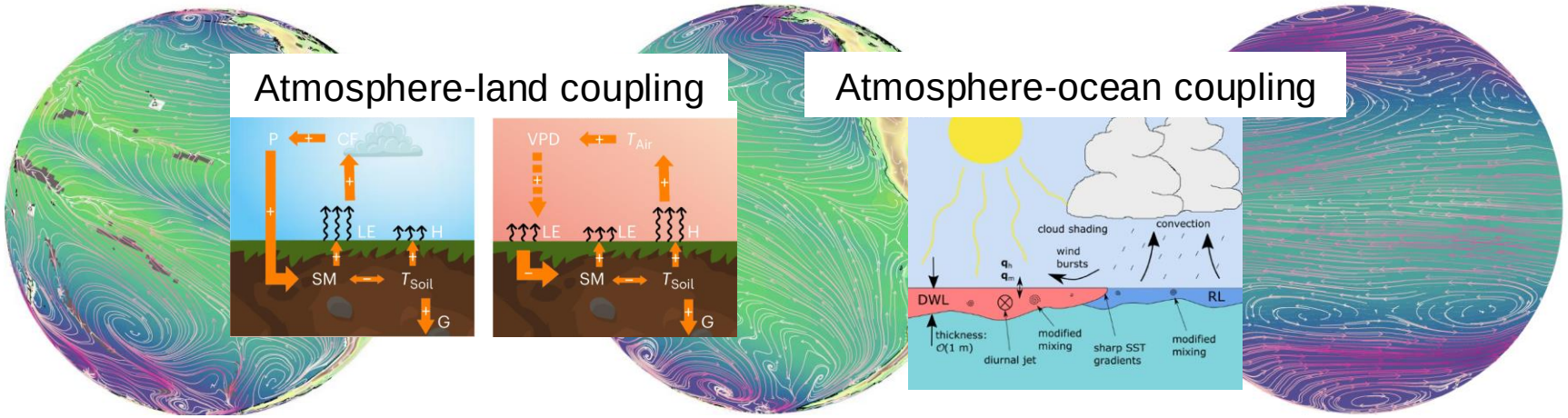


Need to bridge the gap between information and knowledge for regional climate prediction



Held (2005), Emanuel (2020)

We need to fill knowledge gaps related to coupling between climate system components



Atmosphere, ocean, land, ice

Atmosphere, land, ice, prescribed SST

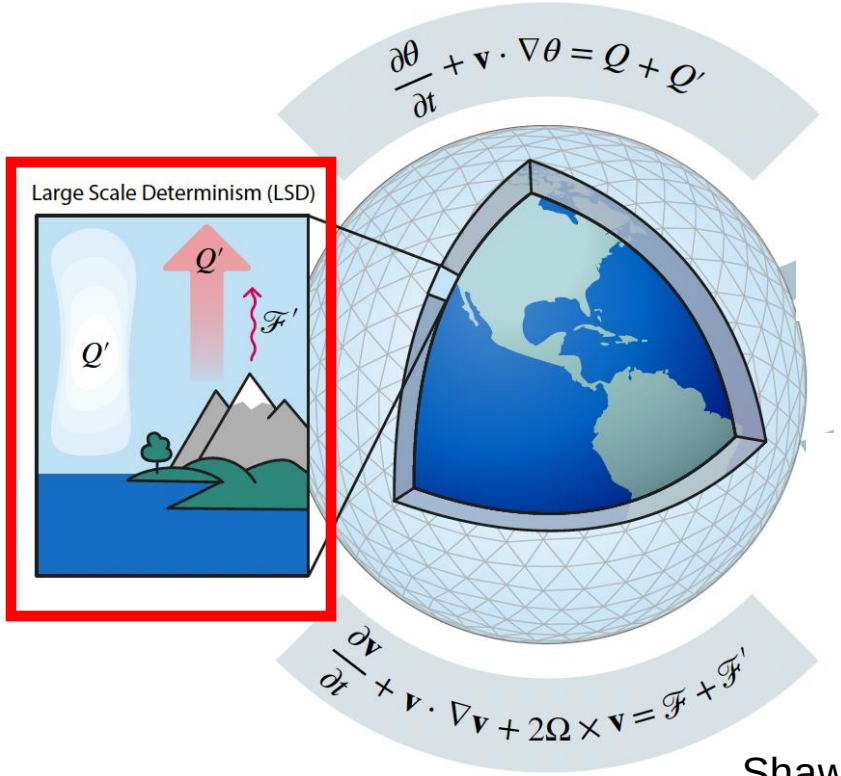
Aquaplanet, prescribed SST

Physical Complexity

Shaw et al. (2016, Nat. Geosc.), Jeevanjee et al. (2017), Maher et al. (2019)

We need to fill knowledge gaps related to the coupling between large and small scales

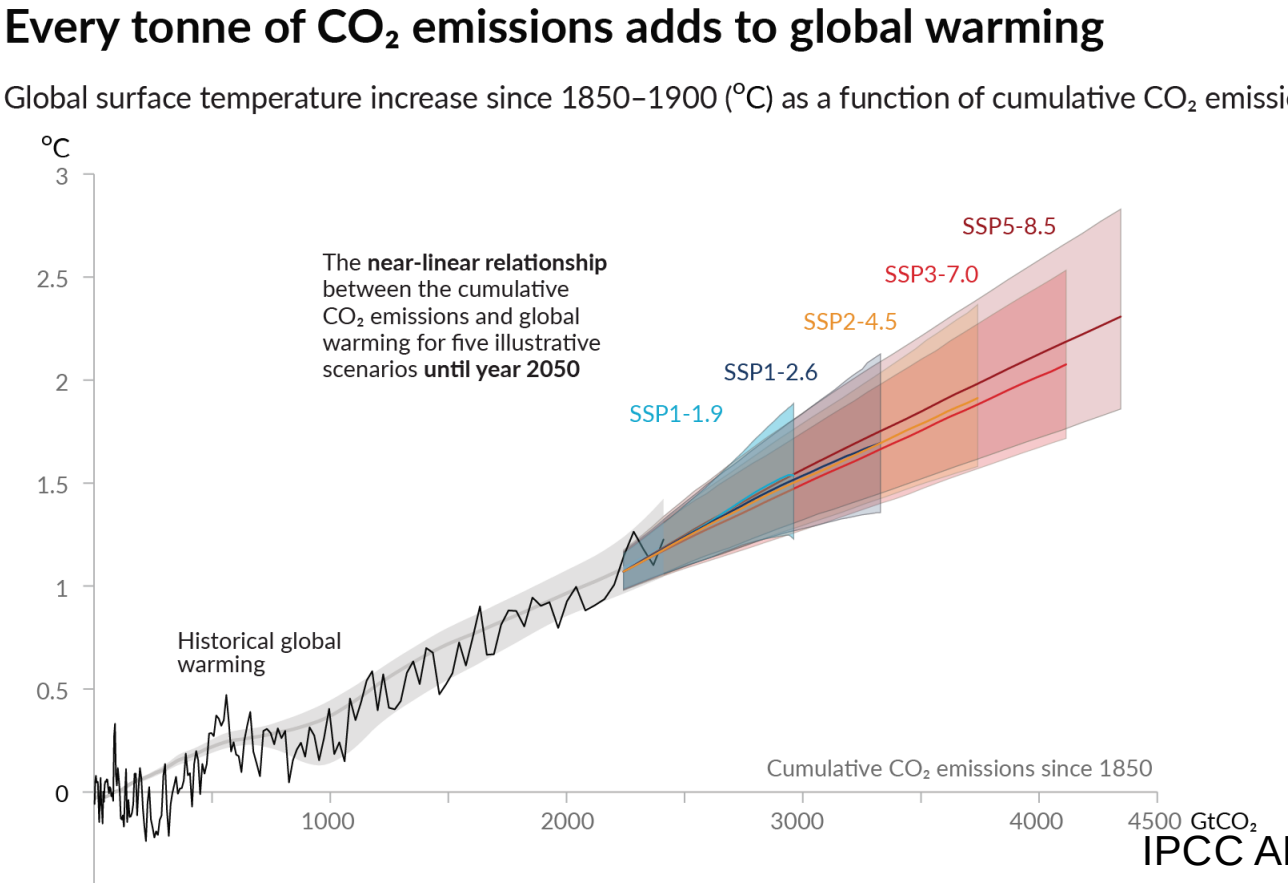
Assume large-scales determine small-scales



Application of physical laws to large-scales

Shaw & Stevens (2025, to appear)

Knowledge gaps do not justify inaction



IPCC AR6 WG1 Fig. SPM10