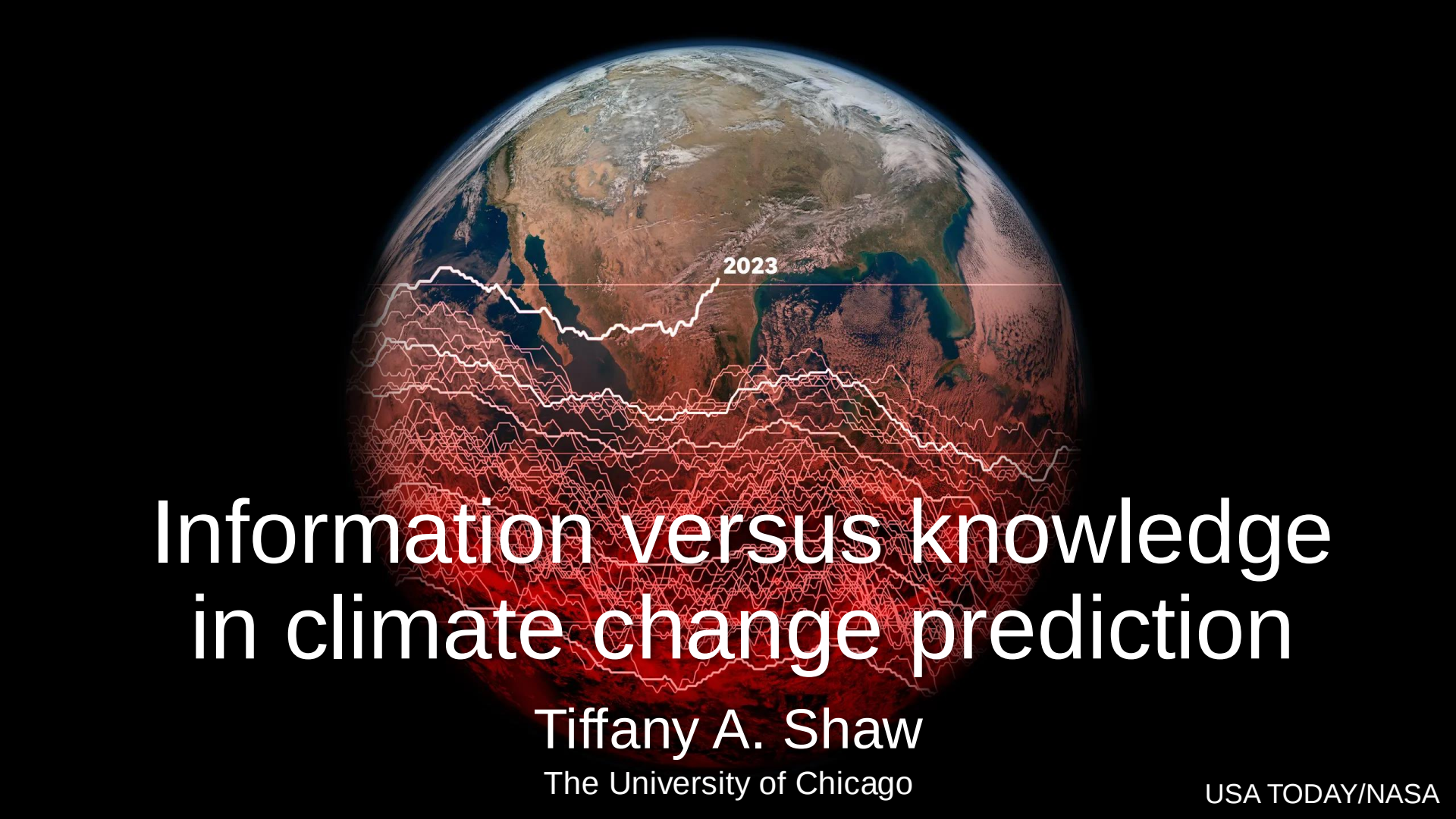


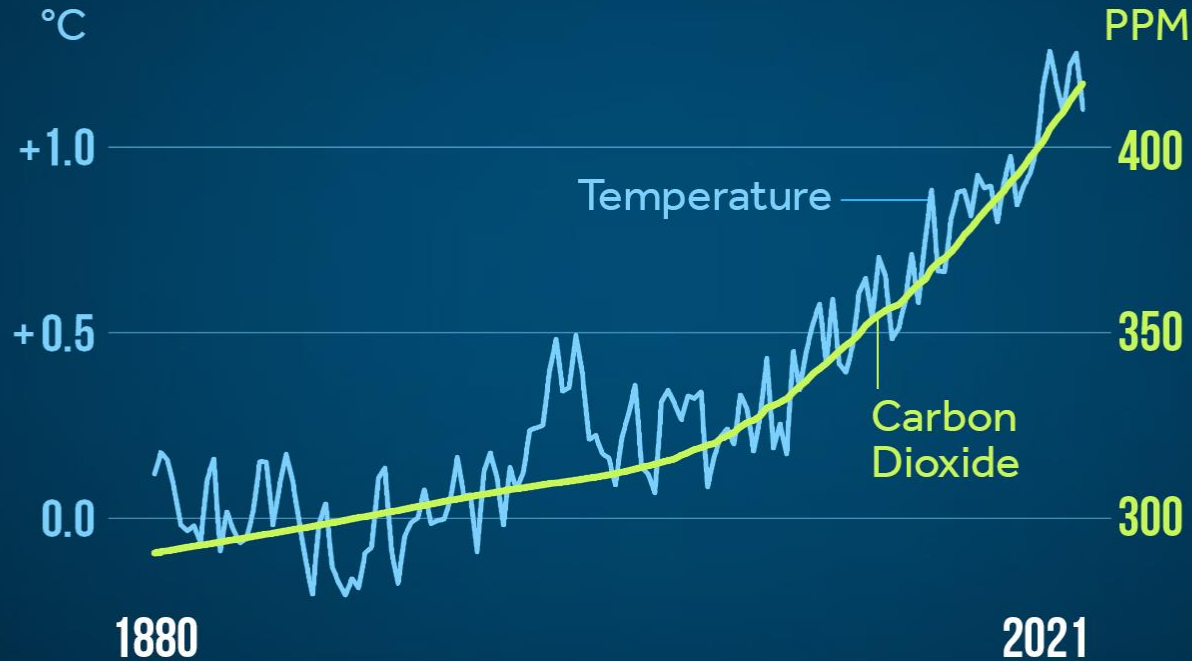


Information versus knowledge in climate change prediction

Tiffany A. Shaw
The University of Chicago

USA TODAY/NASA

TEMPERATURE & CARBON DIOXIDE



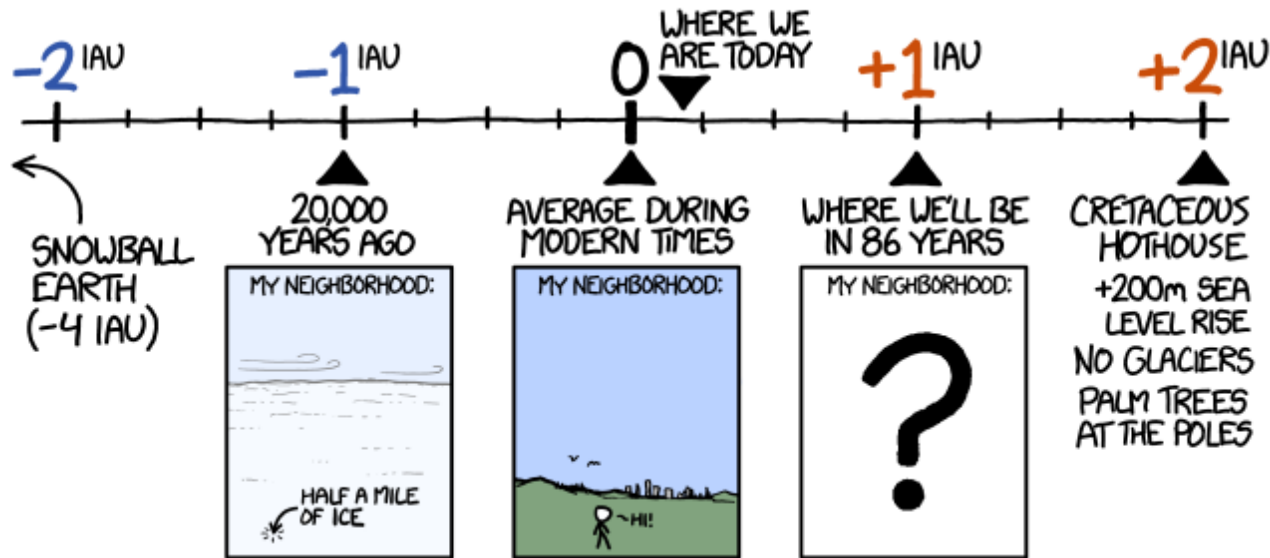
Global temperature anomalies averaged and adjusted to early industrial baseline (1881-1910)
Source: NASA GISS, NOAA NCEI, ESRL

CLIMATE  CENTRAL

WITHOUT PROMPT, AGGRESSIVE LIMITS ON CO₂ EMISSIONS, THE EARTH WILL LIKELY WARM BY AN AVERAGE OF 4°-5°C BY THE CENTURY'S END.

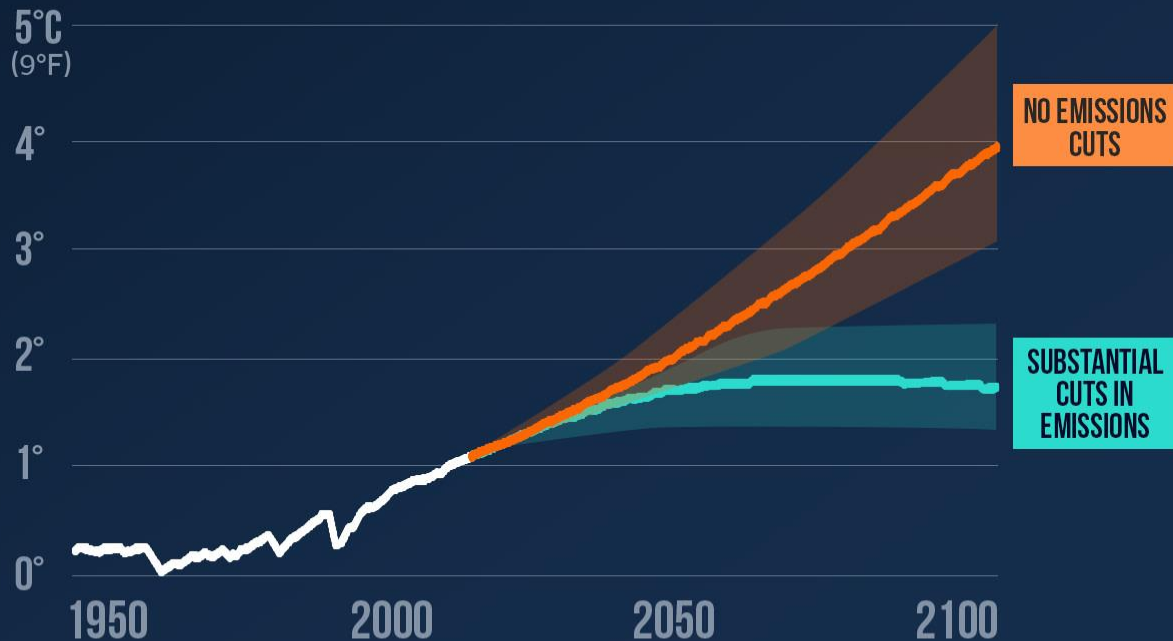
HOW BIG A CHANGE IS THAT?

IN THE COLDEST PART OF THE LAST ICE AGE, EARTH'S AVERAGE TEMPERATURE WAS 4.5°C BELOW THE 20TH CENTURY NORM.
LET'S CALL A 4.5°C DIFFERENCE ONE "ICE AGE UNIT."



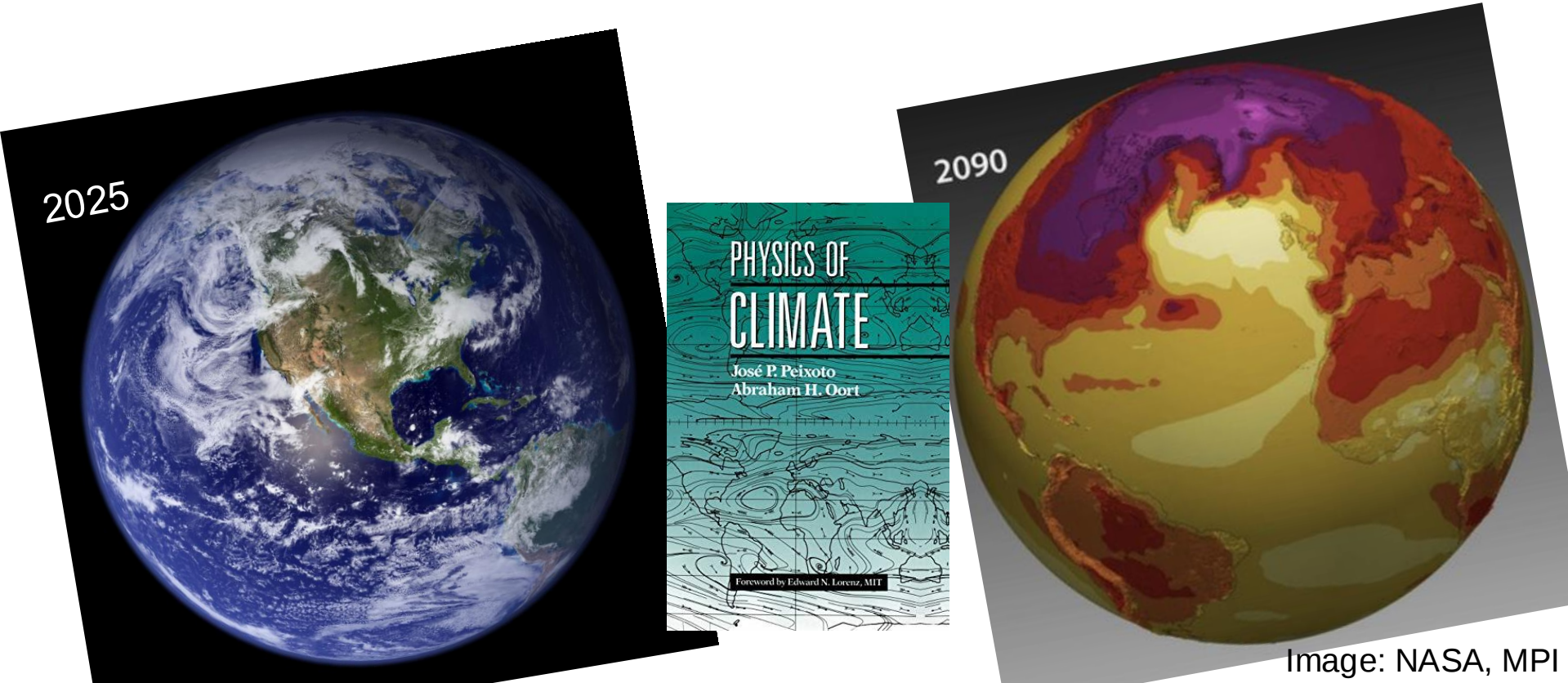
FUTURE TEMPERATURES

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

Information of the future comes from knowledge of climate physics



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

2^o 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.

73

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

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.

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1824.

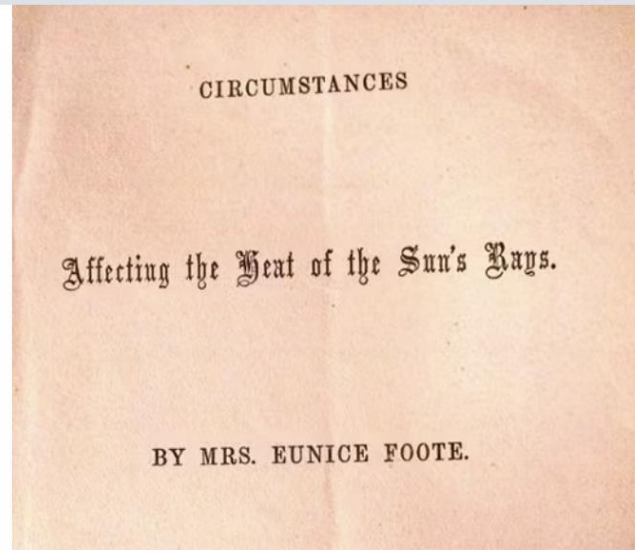
73

ScienceBlogs

Fourier's 1827 article about the temperature of the Earth

1824

DESCRIBING EARTH'S ATMOSPHERE AS A GREENHOUSE



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

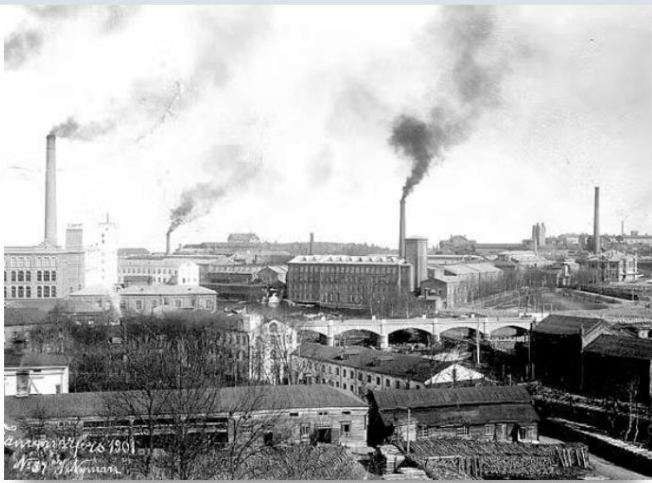
1856

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 Foote, detailing her

UCAR



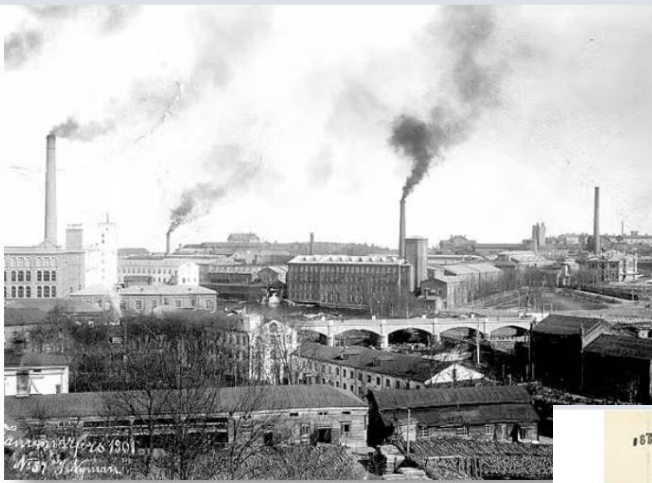
Aino Nyman/Wikipedia

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



Aino Nyman

Factory smoke, 1901

1896

CONNECTING COAL, CARBON DIOXIDE, AND CLIMATE

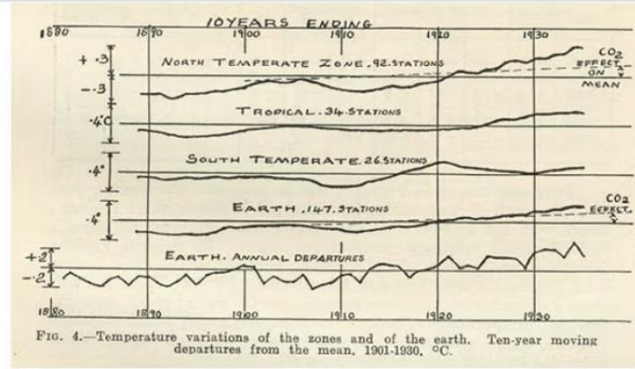


Figure 4 from Callendar's 1938 paper, The Artificial Production of Carbon Dioxide and its Influence on Temperature

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 CO₂ 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

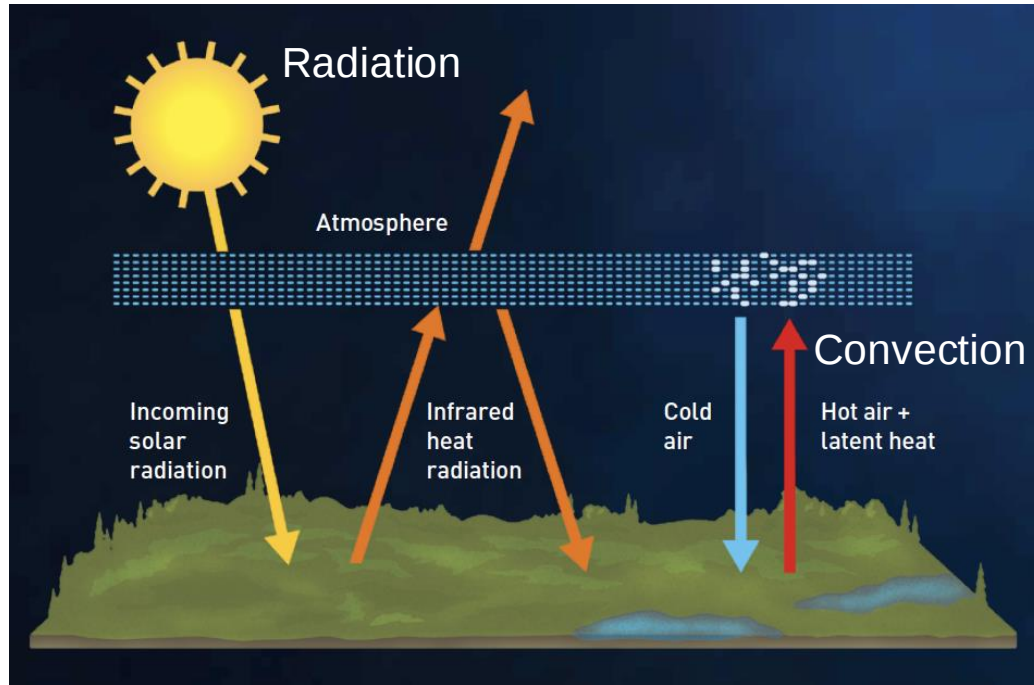
Giorgio
Parisi

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

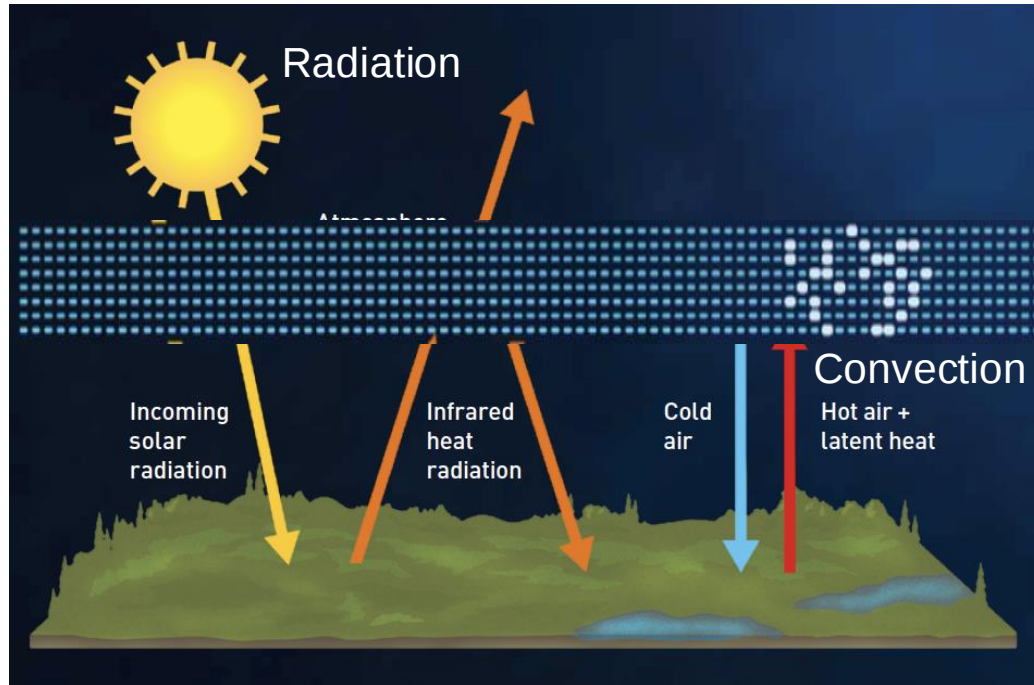
"for the discovery of the
interplay of disorder and
fluctuations in physical
systems from atomic
to planetary scales"

THE ROYAL SWEDISH ACADEMY OF SCIENCES

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

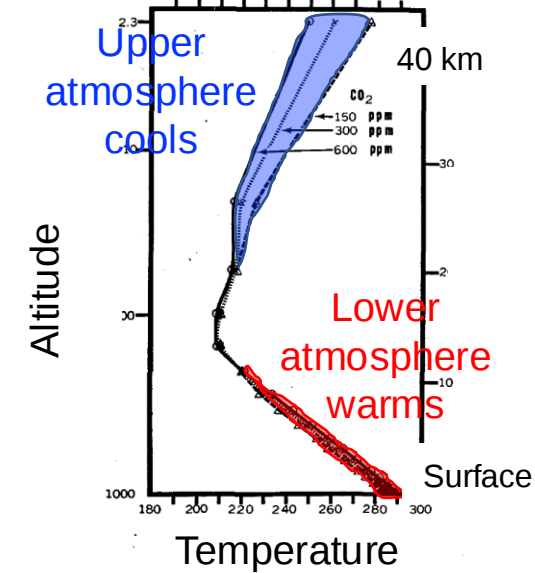


Manabe's climate predictions relied on applying physical laws to large-scales



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

Response to doubling CO₂



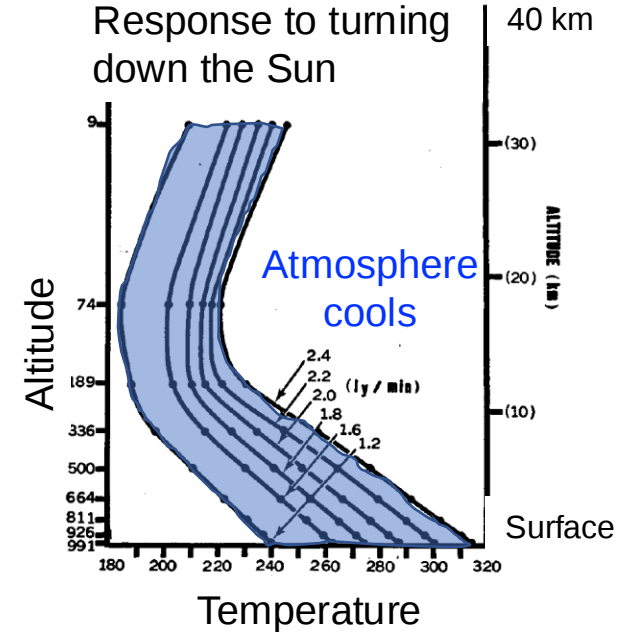
Manabe & Weathervald (1967)

Physical Complexity

Surface warming sensitive to assumptions about moisture and clouds

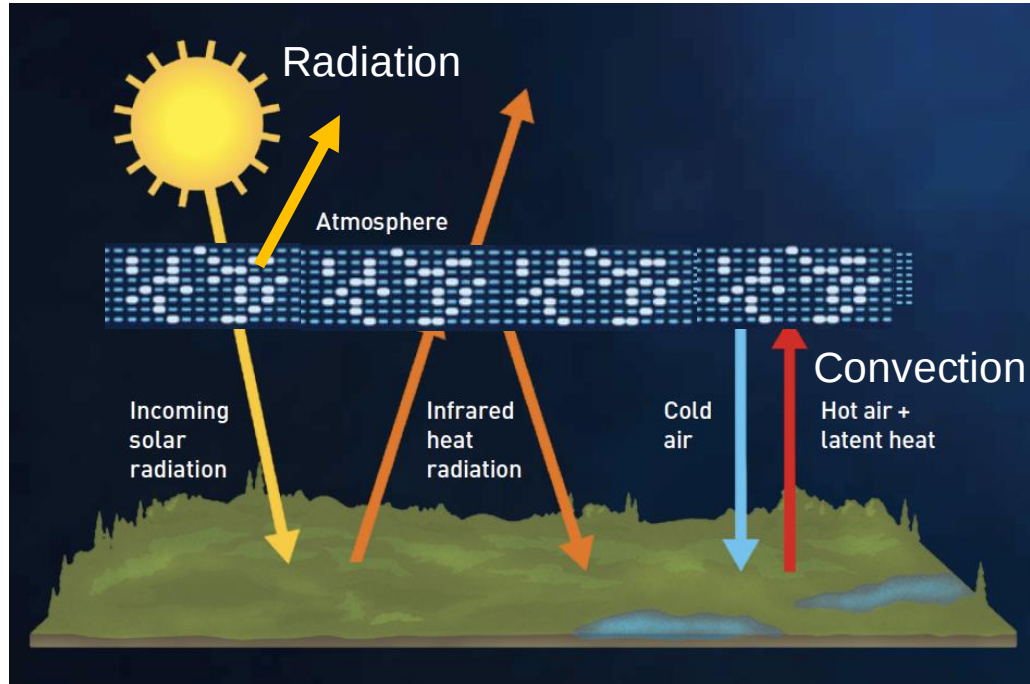
Change of CO ₂ content (ppm)	Fixed relative humidity	
	Average cloudiness	Clear
300 → 600	+2.36	2.92

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



Physical Complexity

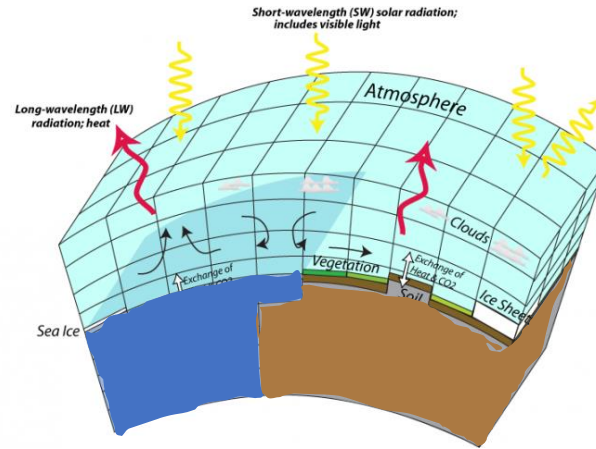
Manabe's climate predictions also provide insight into intervention



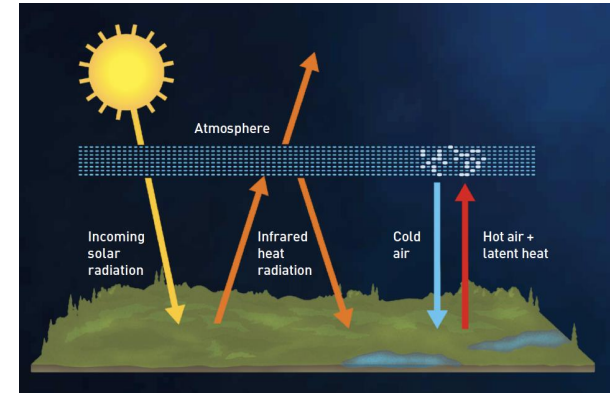
Stratospheric aerosol would reflect sunlight

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

Latitude-altitude



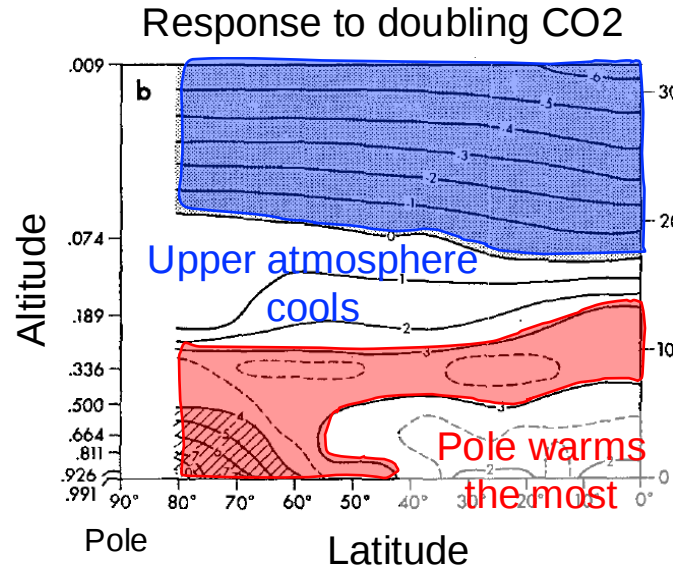
Global-mean (altitude)



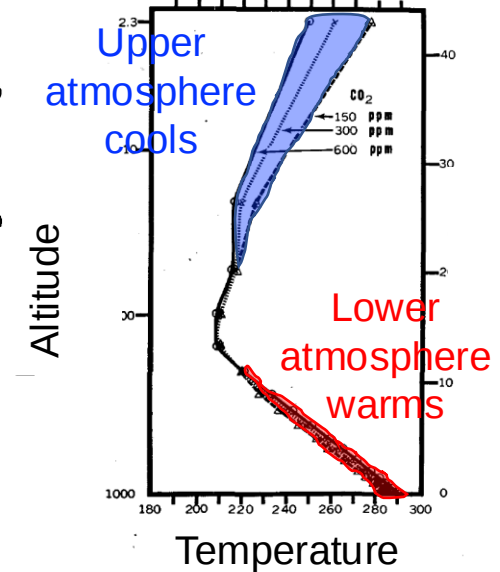
Physical Complexity

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

Response to doubling CO₂



Manabe & Weatherald (1975)

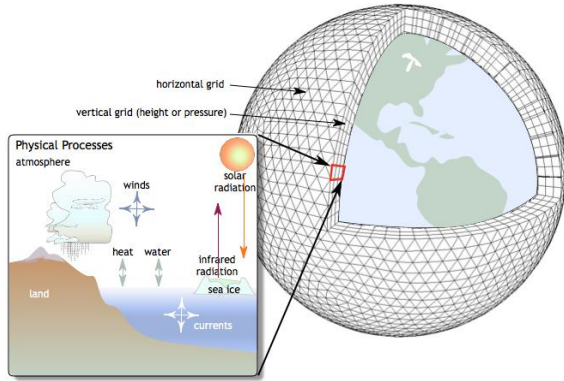


Manabe & Weatherald (1967)

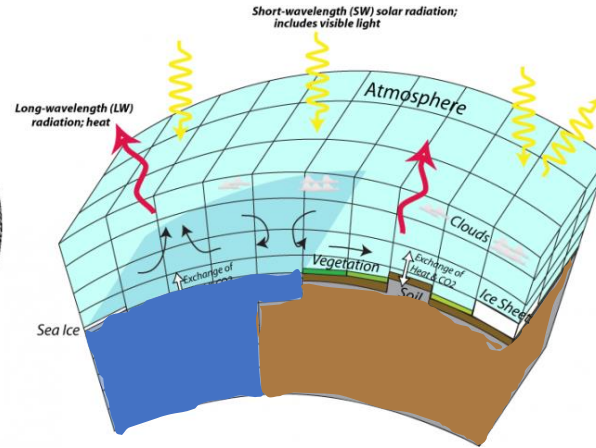
Physical Complexity

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

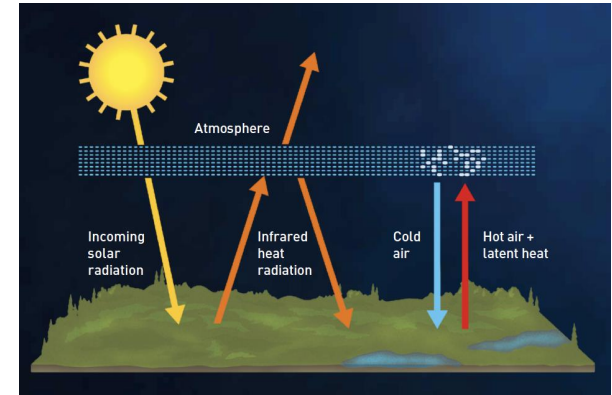
Latitude-longitude-altitude



Latitude-altitude



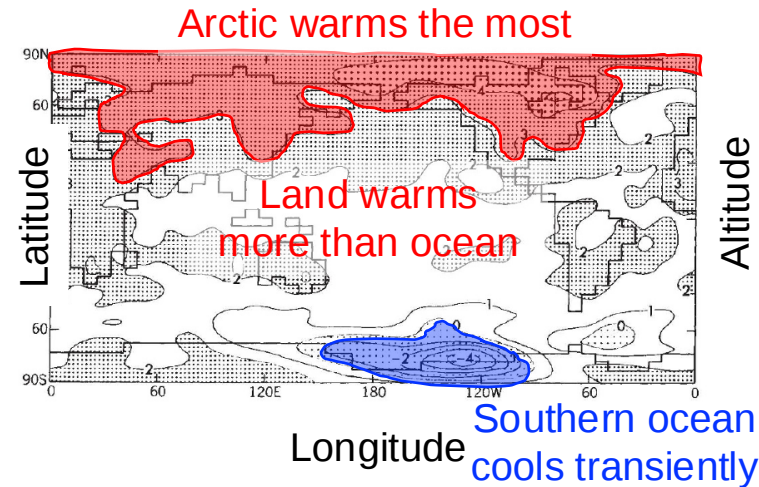
Global-mean (altitude)



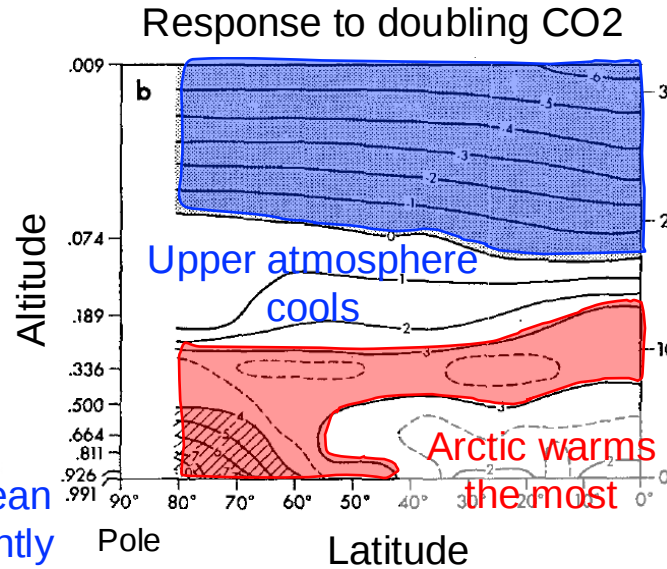
Physical Complexity

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

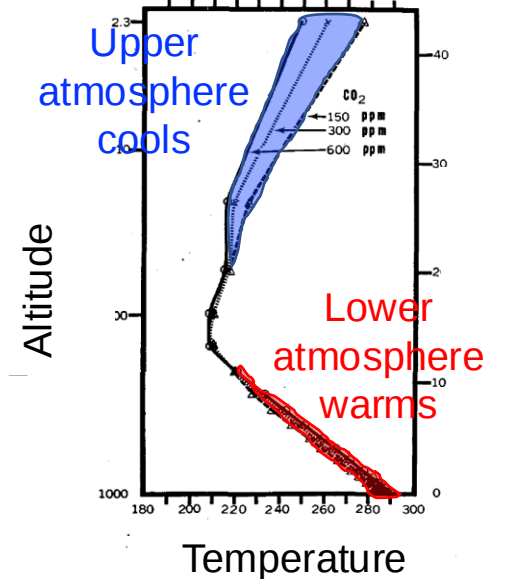
Response to doubling CO₂



Stouffer, Manabe & Weatherald (1989)



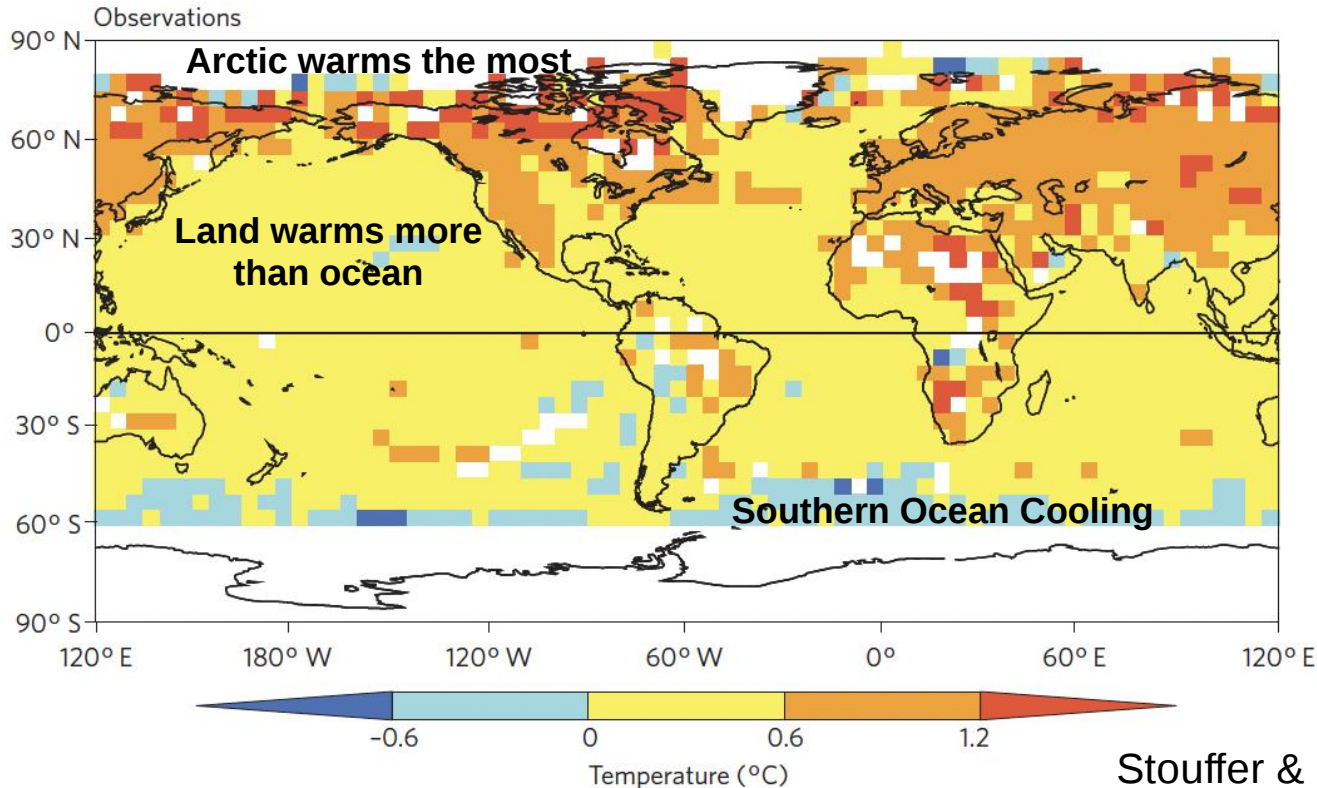
Manabe & Weatherald (1975)



Manabe & Weatherald (1967)

Physical Complexity

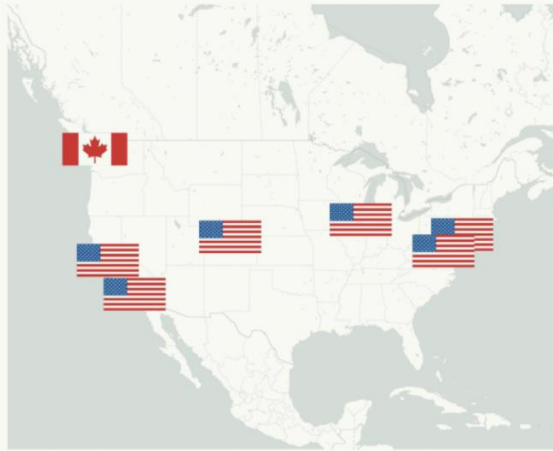
Predicted signals have emerged across many regions and seasons



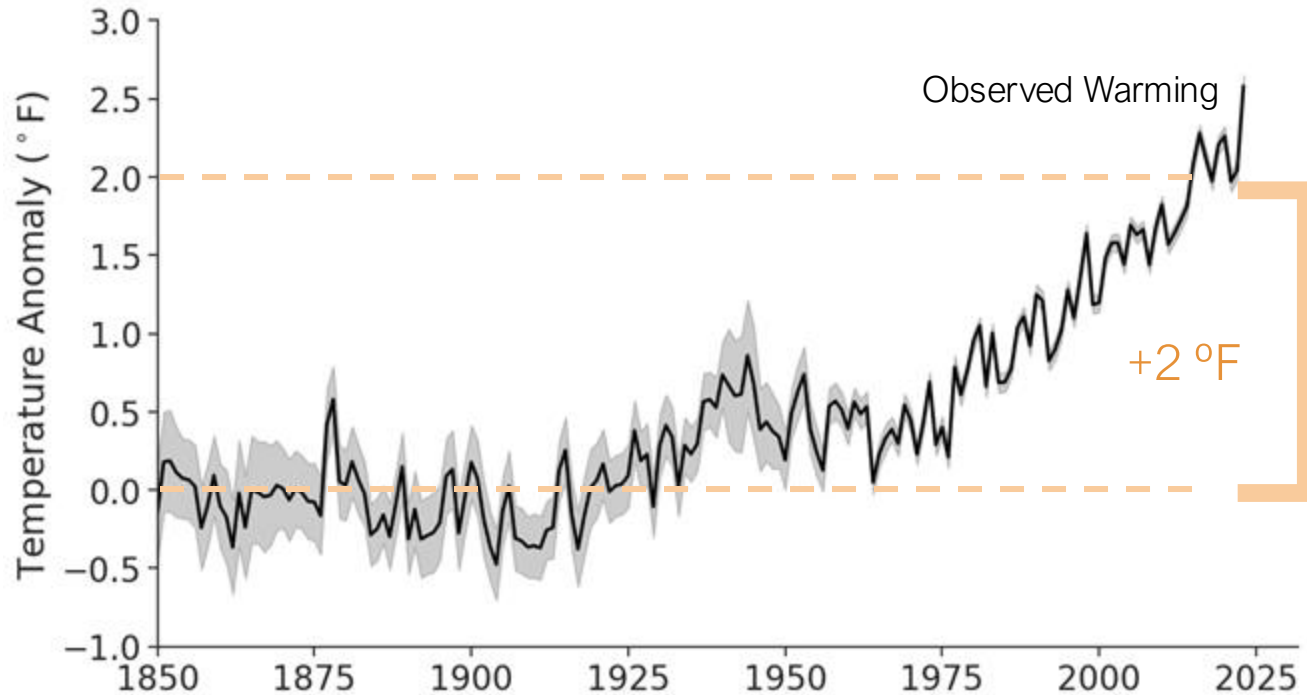
Stouffer & Manabe (2017)

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

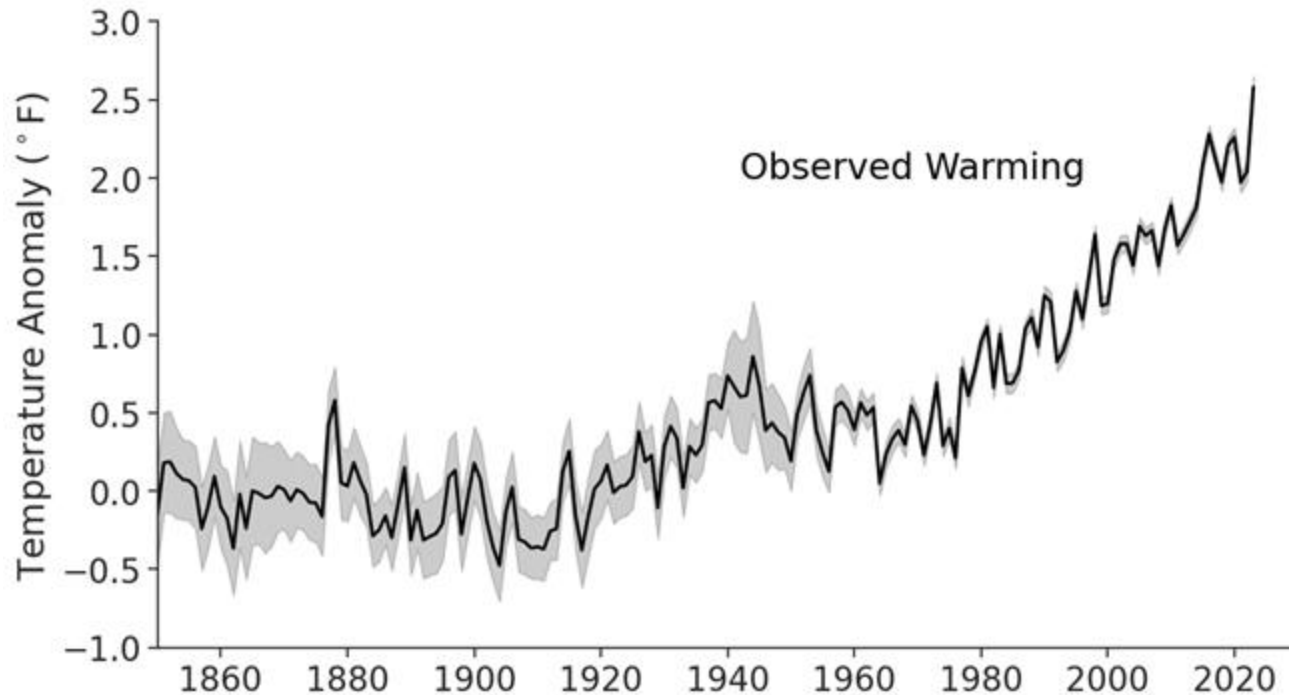
CMIP5 Modeling Centers



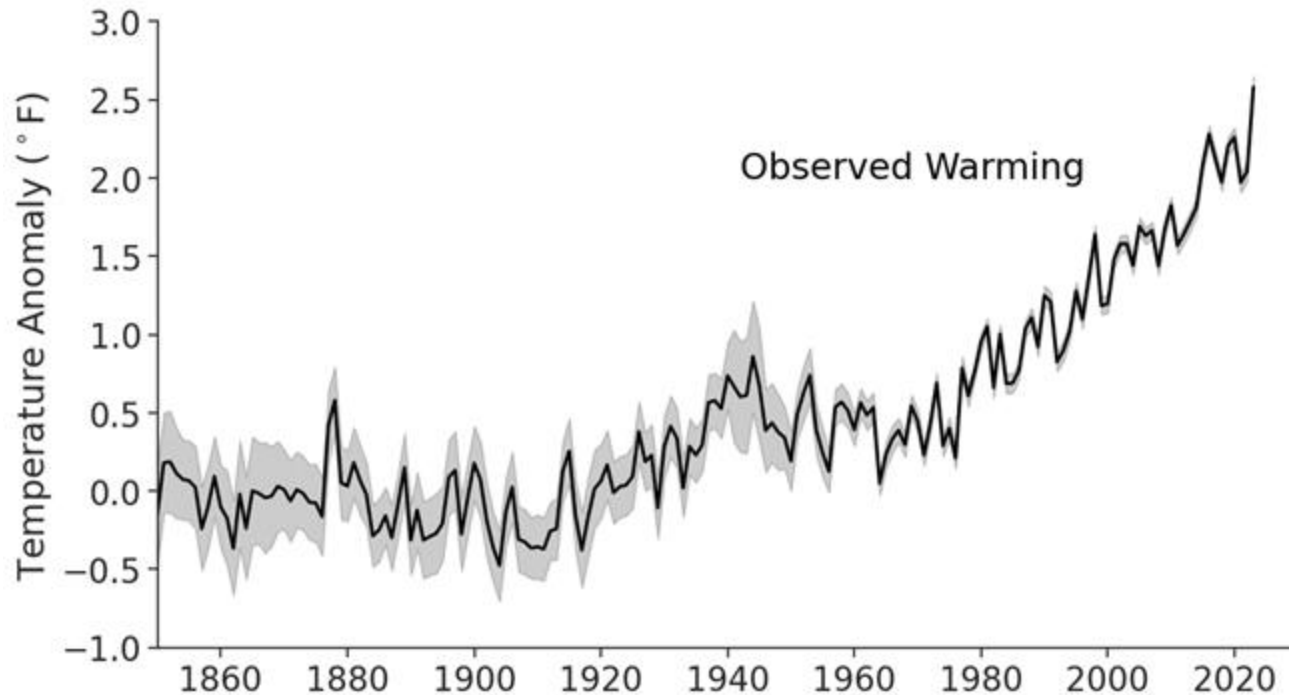
Observed global warming is around 2F



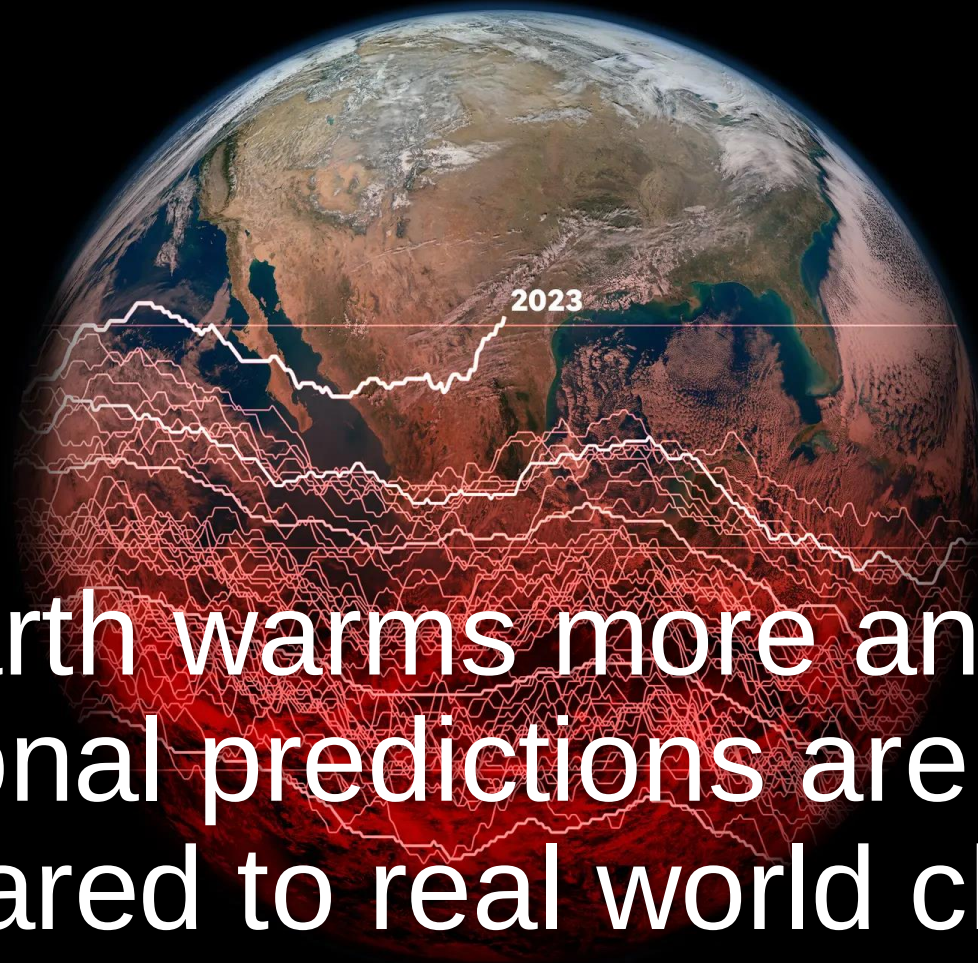
Climate predictions show observed warming does not occur without human emissions



Climate predictions show observed warming does not occur without human emissions



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

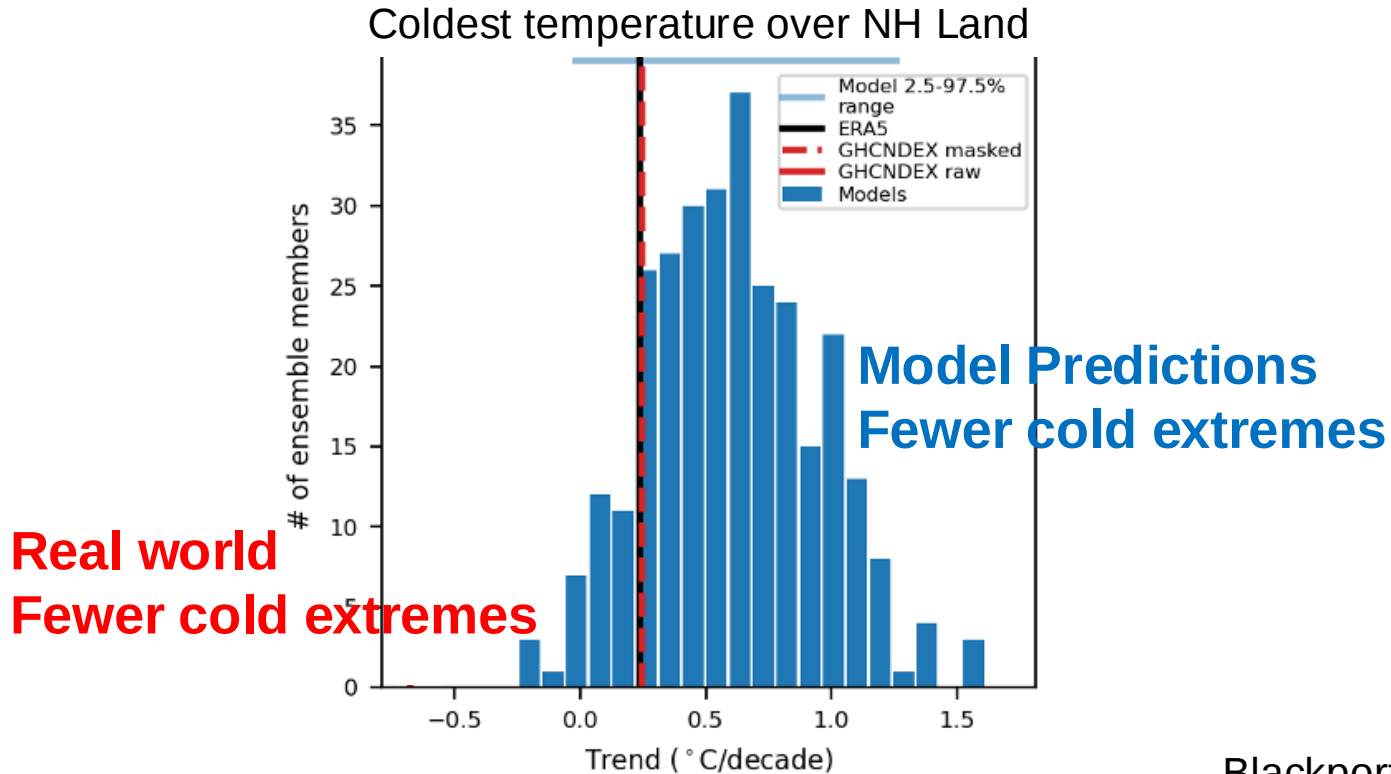


As Earth warms more and more
regional predictions are being
compared to real world changes

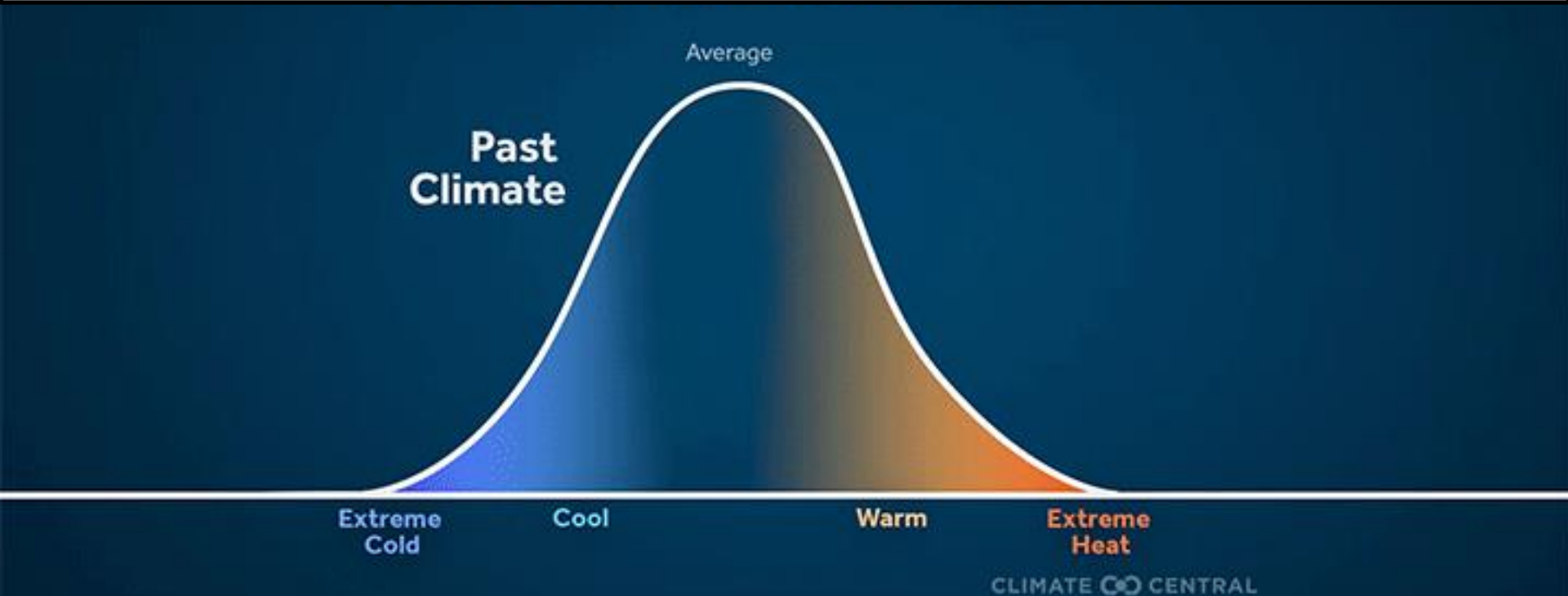
Cold waves
have become
less cold.



Climate predictions with human influence capture increase of coldest land temperature



Temperature extremes increase following an increase of the average

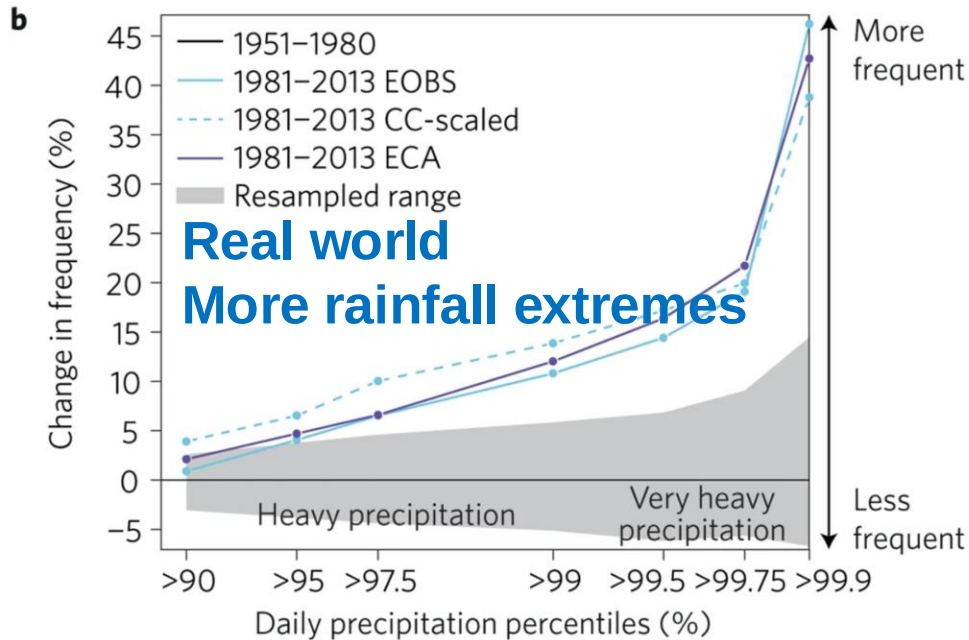


Extreme
rainfall has
increased.

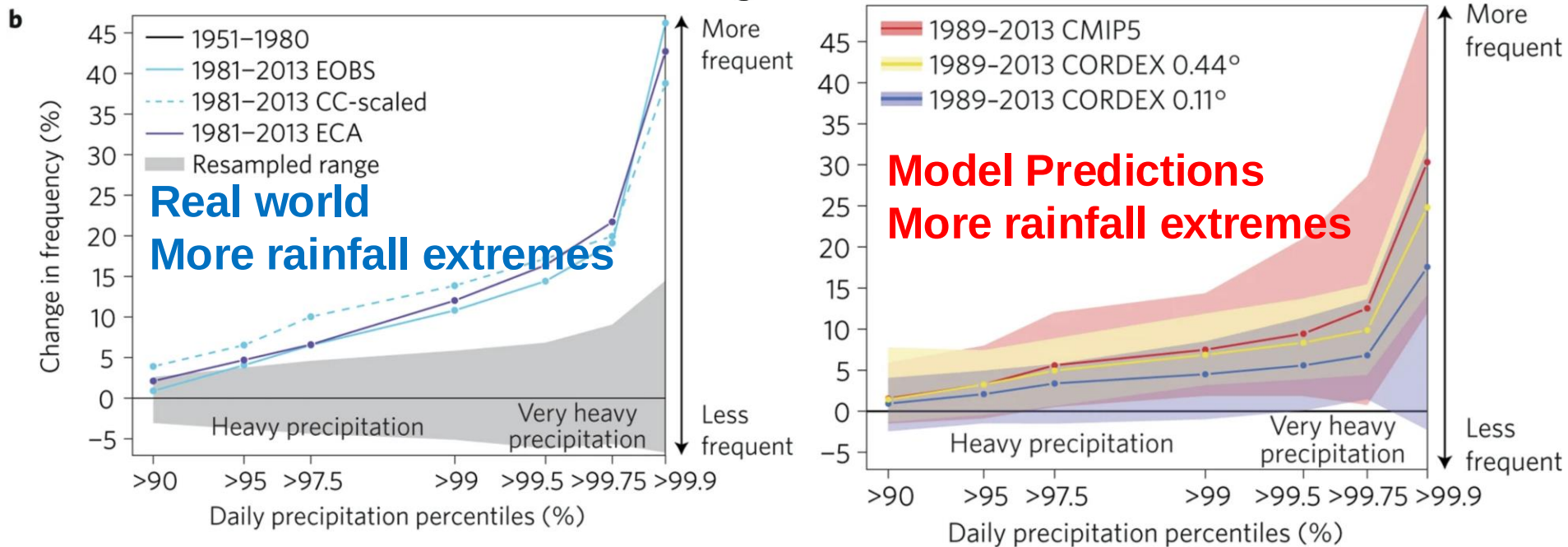


Photo by Kristopher Radder/Brattleboro Reformer via AP

Climate predictions capture increase of European rainfall extremes

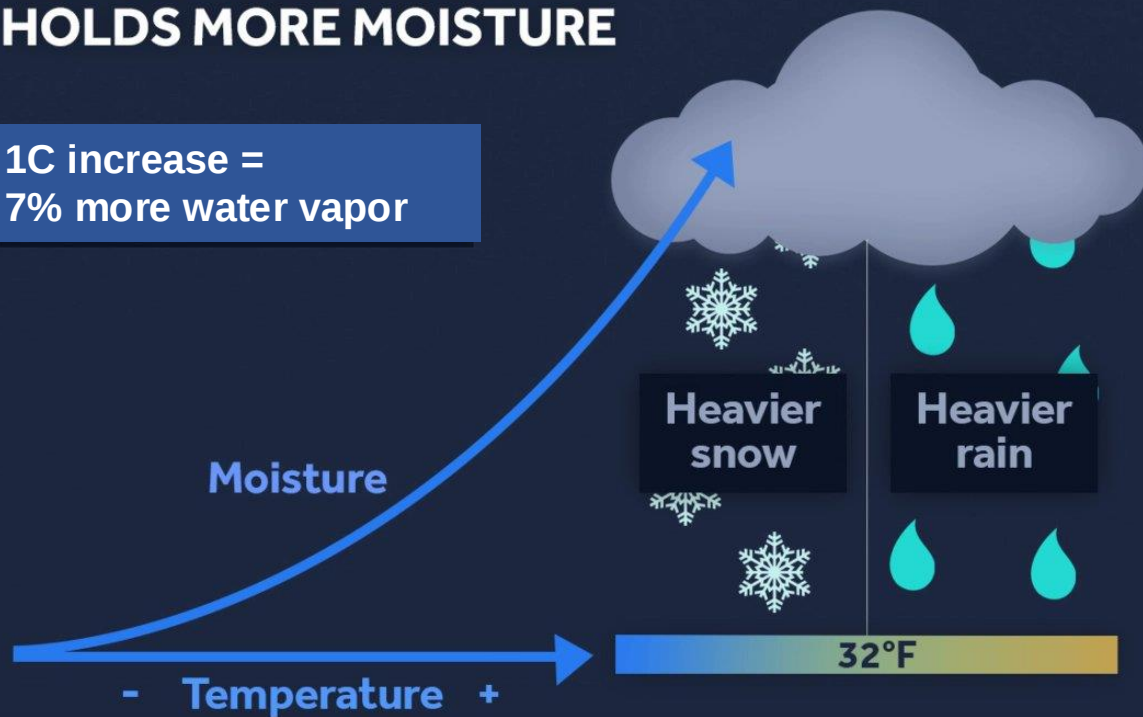


Climate predictions capture increase of European rainfall extremes



WARMER AIR HOLDS MORE MOISTURE

1C increase =
7% more water vapor

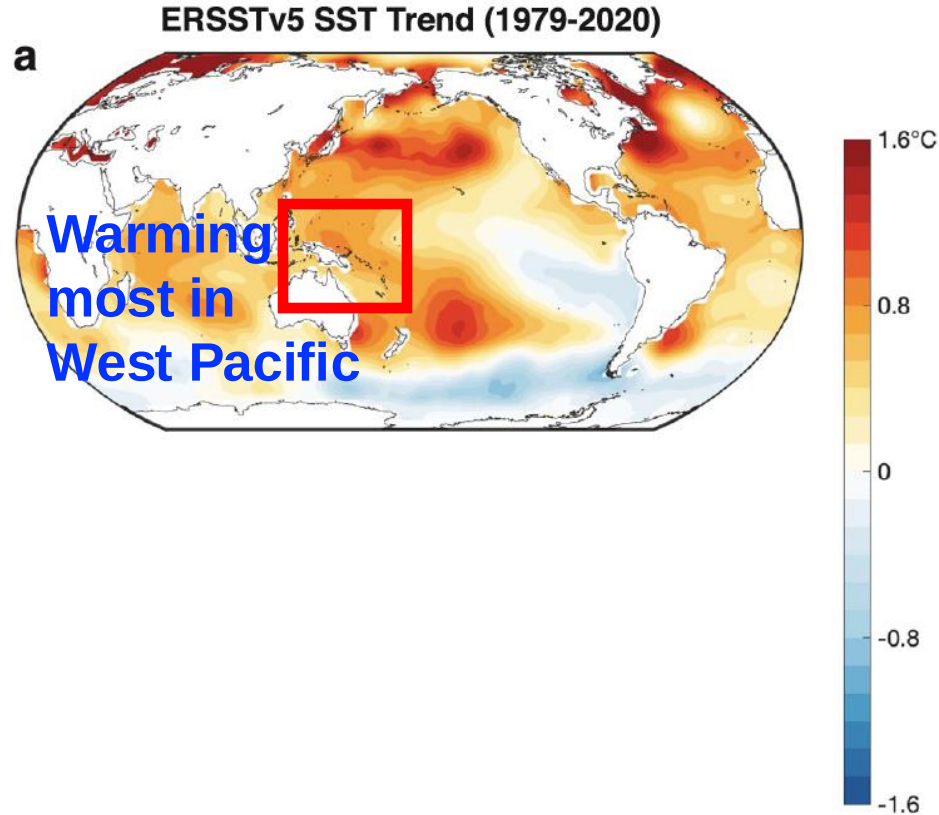


Regional discrepancies have also emerged

Location of known model-observation discrepancies in historical trends



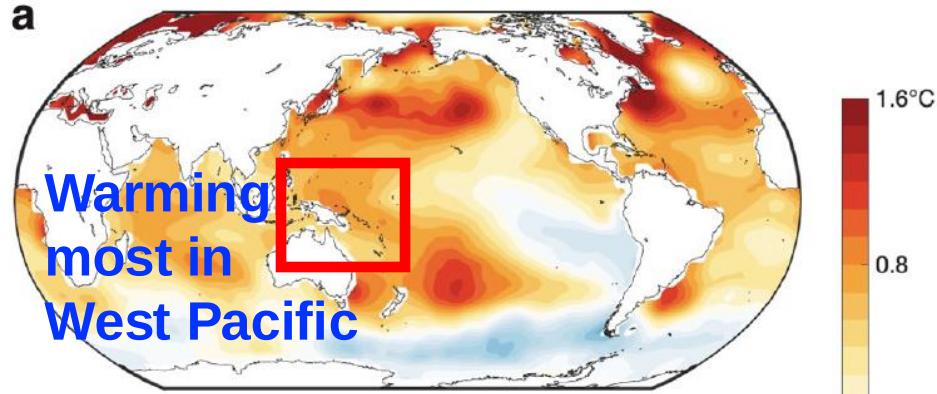
Sea surface temperature discrepancy



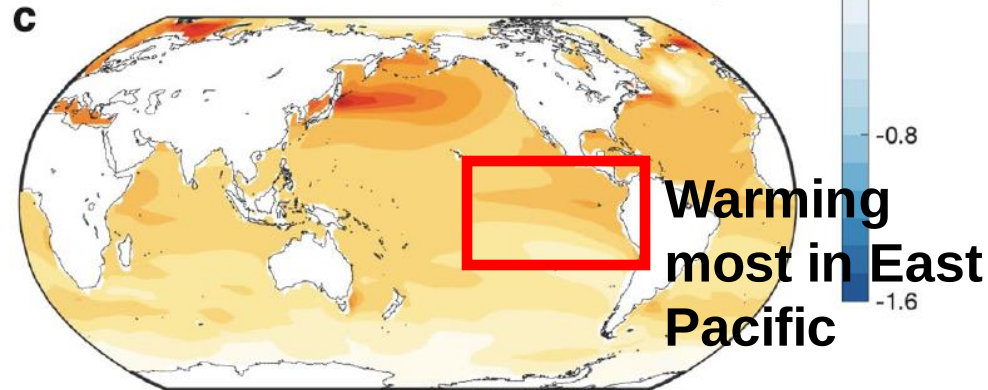
Real world

Sea surface temperature discrepancy

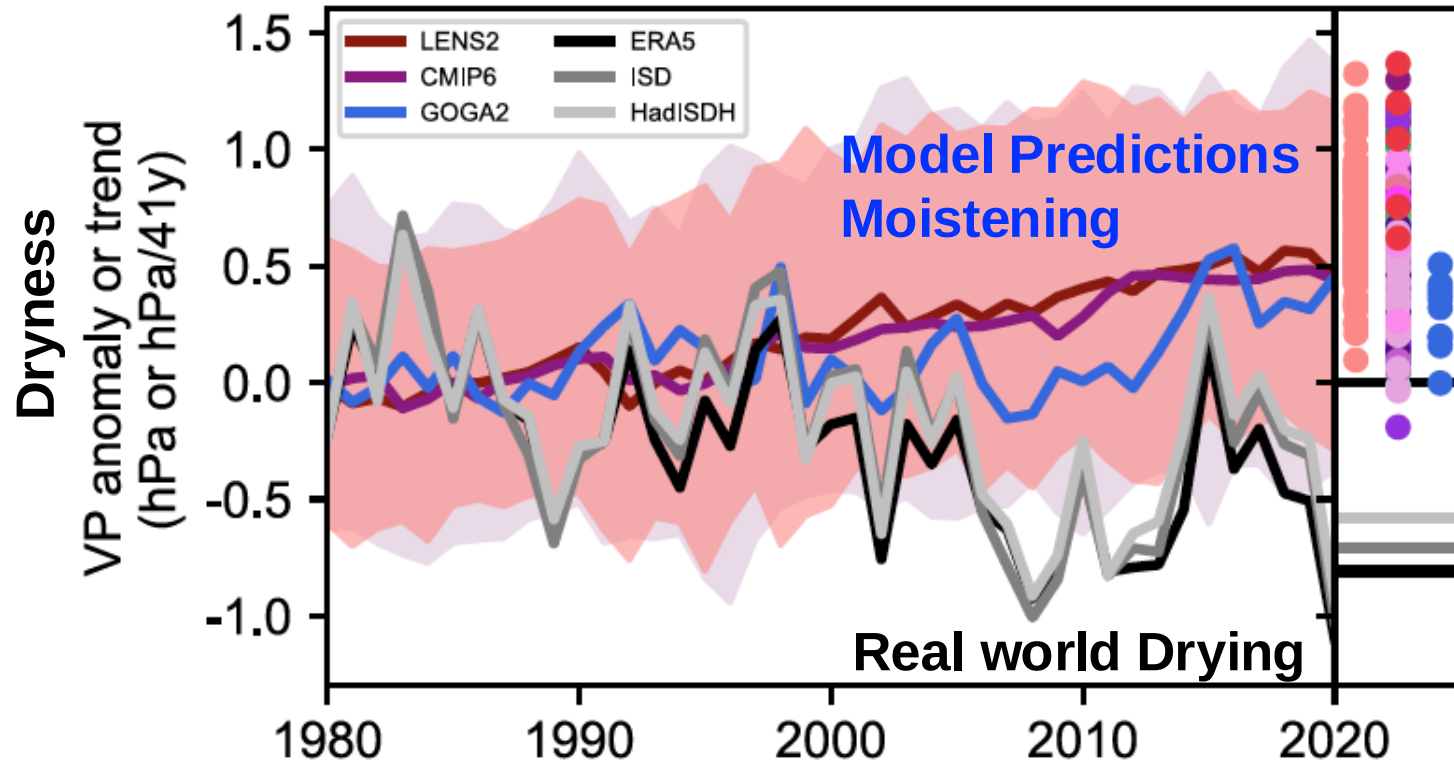
ERSSTv5 SST Trend (1979-2020)



Multi-Model-Mean SST Trend (1979-2020)

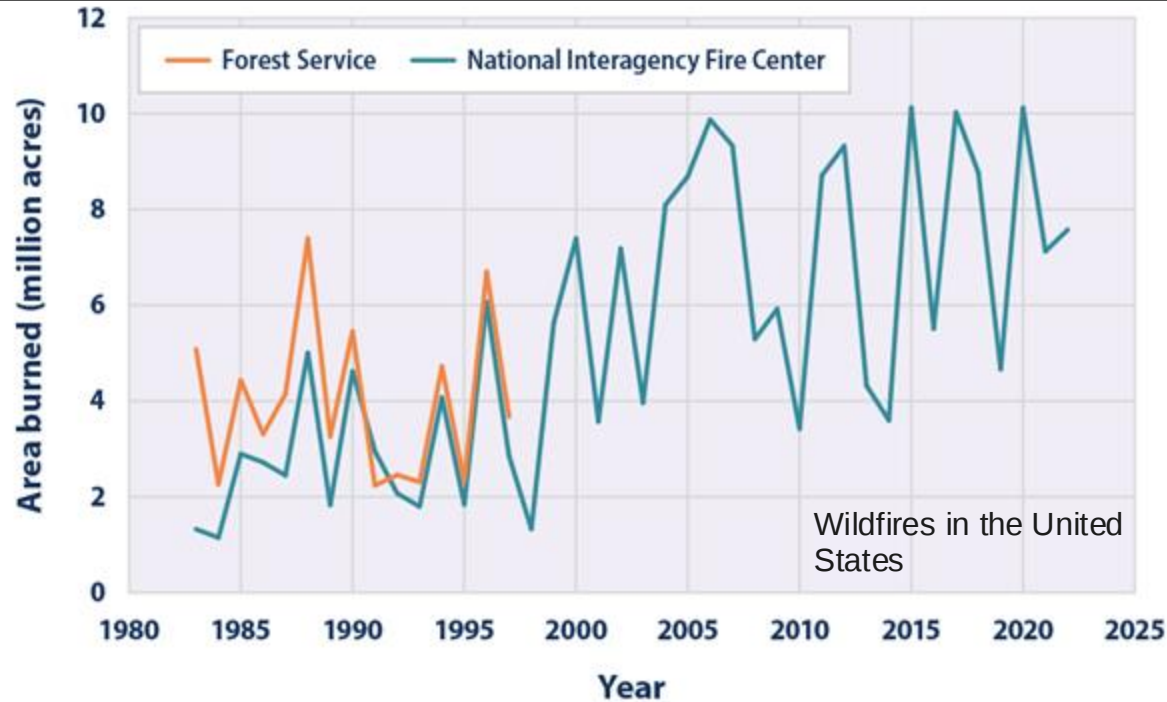


Discrepancy in drying trends over US Southwest



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

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

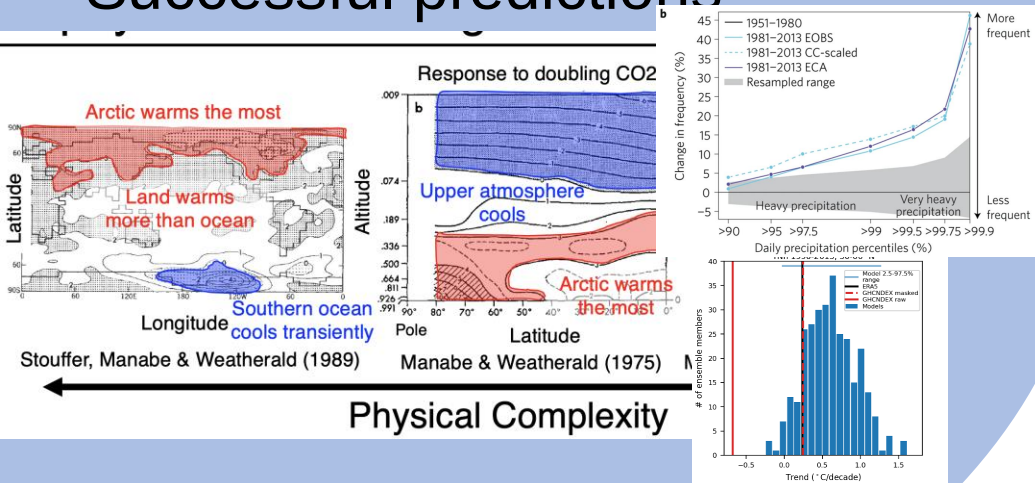


“In recent decades, wildfires in the western United States have become larger, hotter, and more destructive and deadly due to a suite of factors, including climate change.” -US Fifth National Climate Assessment

Landscape of regional climate information

Knowledge

Tied to a chain of reasoning
Multiple lines of evidence
Successful predictions



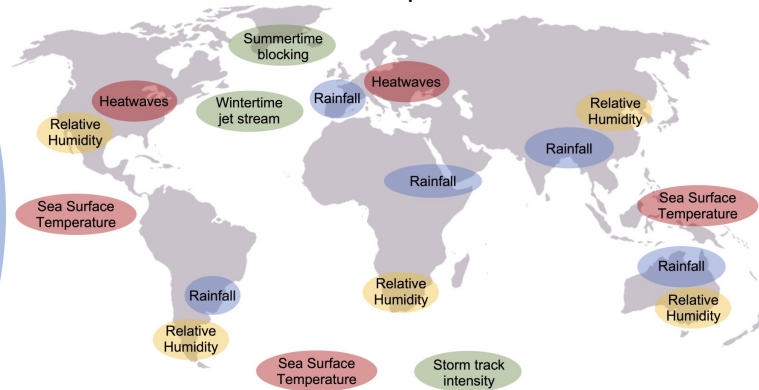
Knowledge gap

Discrepancies

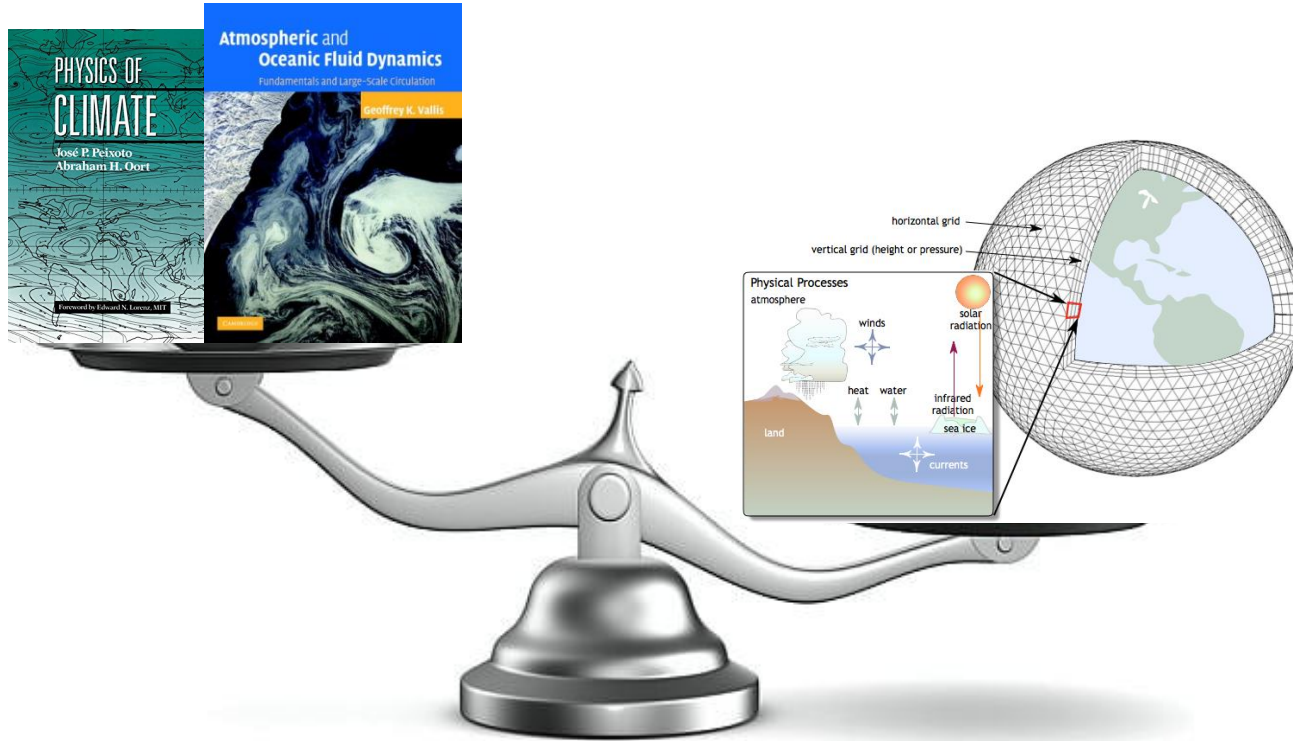
Failed predictions?

Risk assessment

Location of known model-observation discrepancies in historical trends

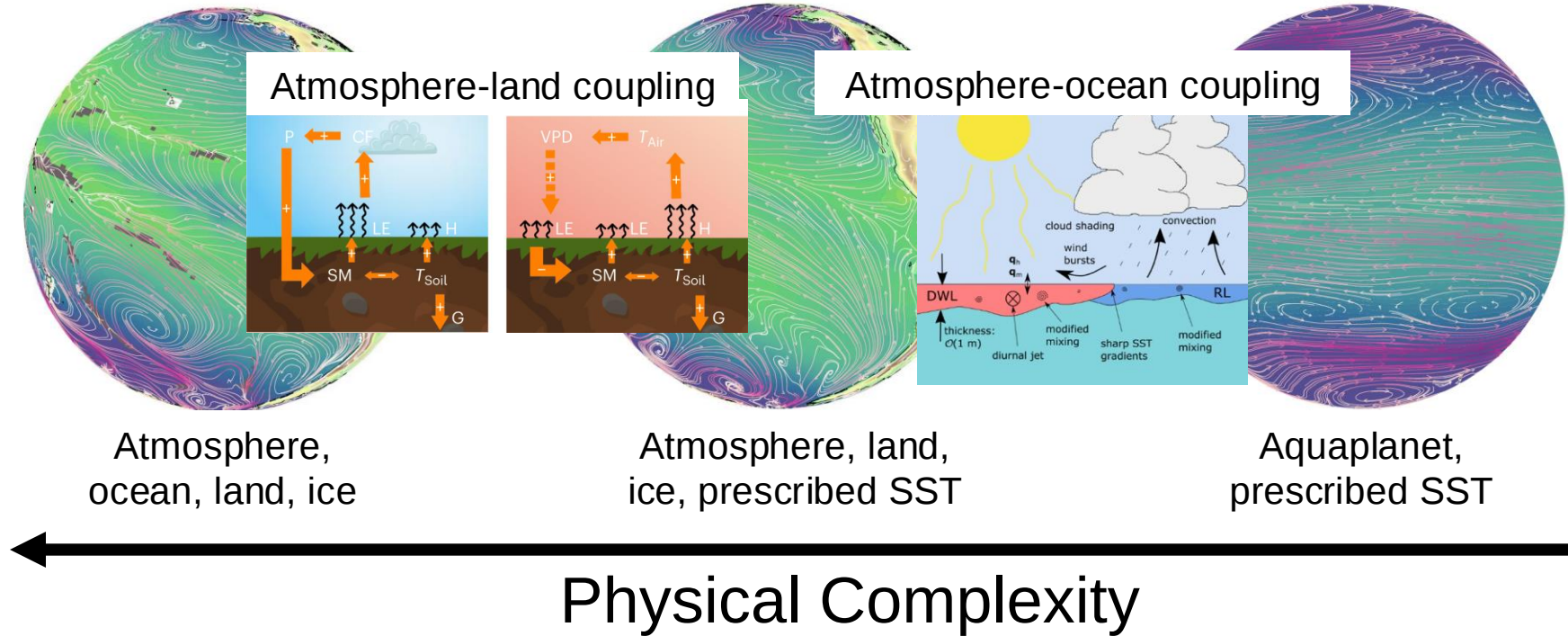


Need to bridge the gap between information and knowledge for regional climate prediction



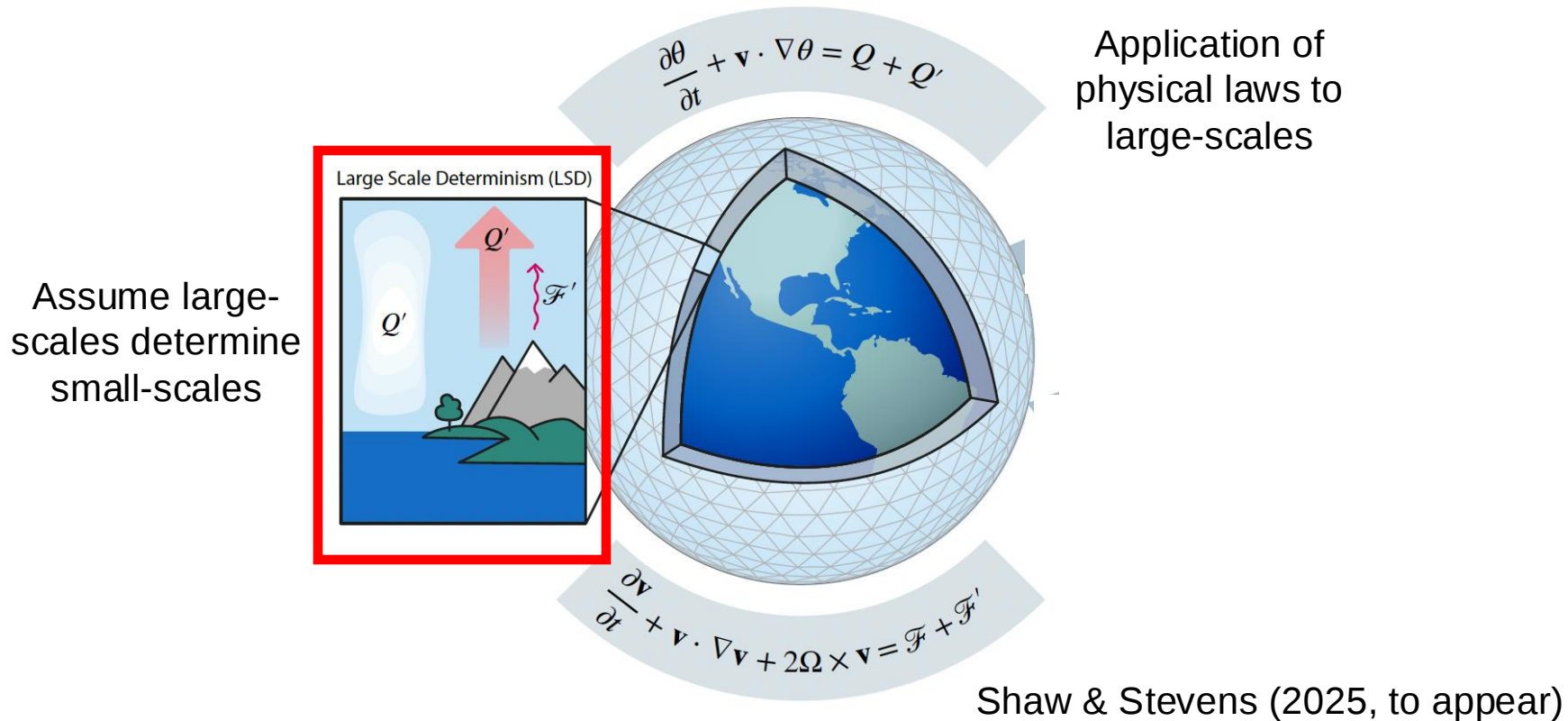
Held (2005), Emanuel (2020)

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



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



Knowledge gaps do not justify inaction

Every tonne of CO₂ emissions adds to global warming

Global surface temperature increase since 1850–1900 (°C) as a function of cumulative CO₂ emissions (GtCO₂)

