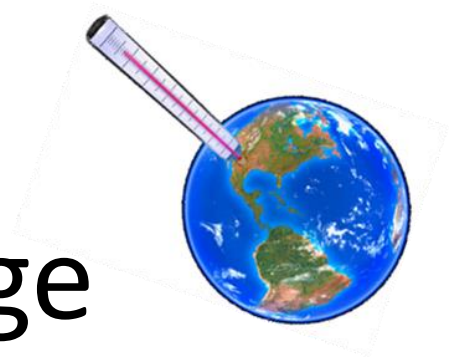
OSHER LIFELONG LEARNING INSTITUTE

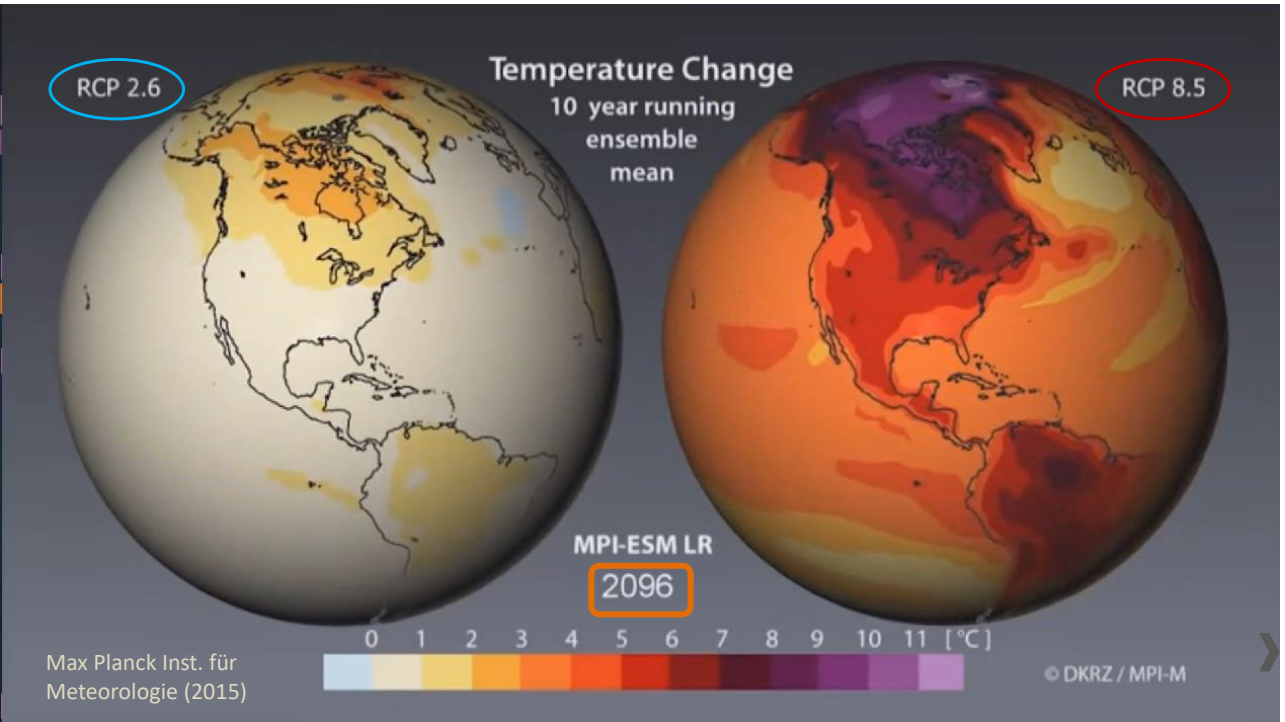


Demystifying Climate Change

Session 7

Impacts and Future Projections for Global Warming

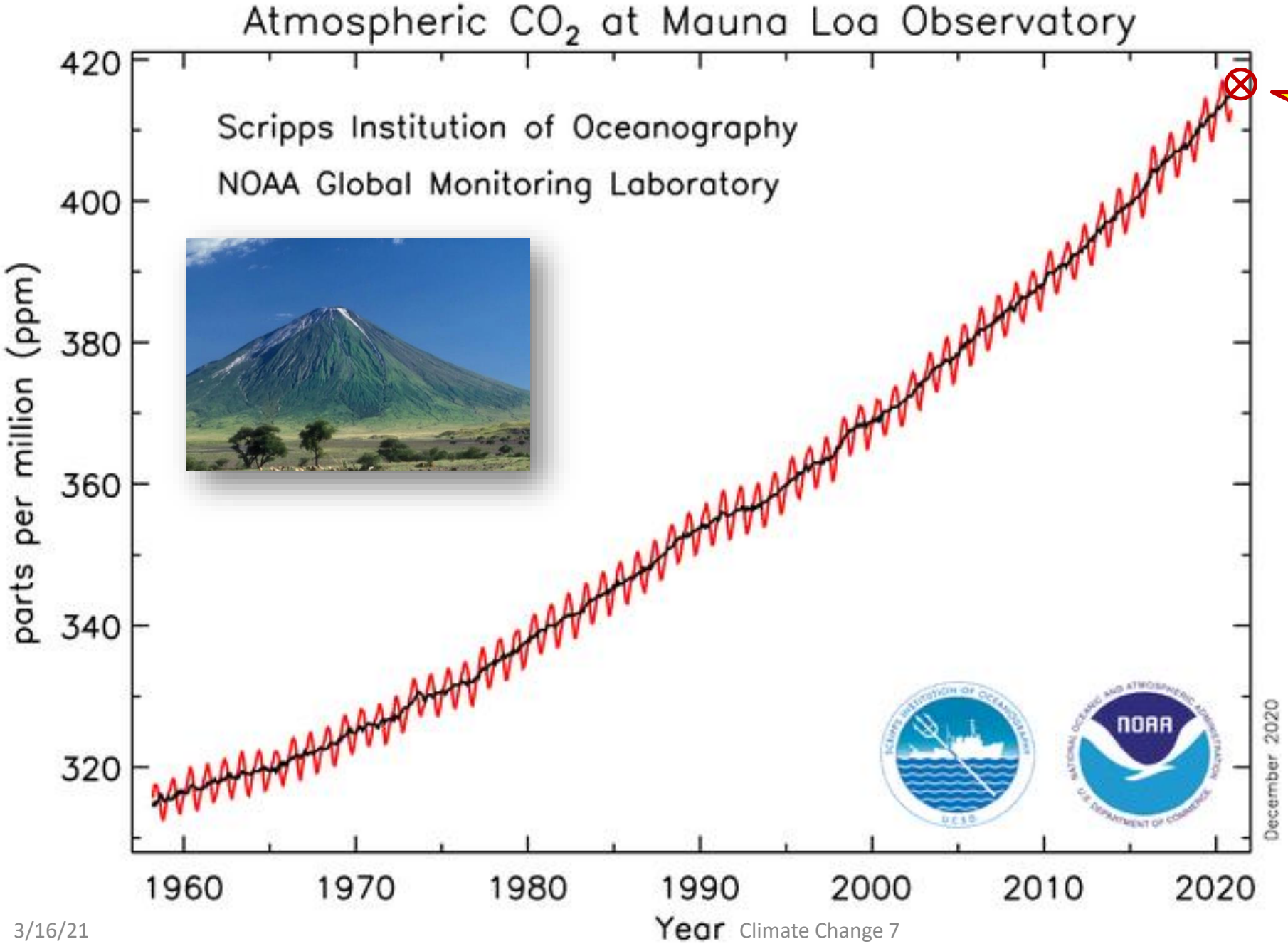
… and Uncertainties



Max Planck Inst. für Meteorologie (2015)

OLLI at Illinois
Spring 2021

D. H. Tracy
DavidHTracy@gmail.com



417.8 ppm
Mar 15, 2021

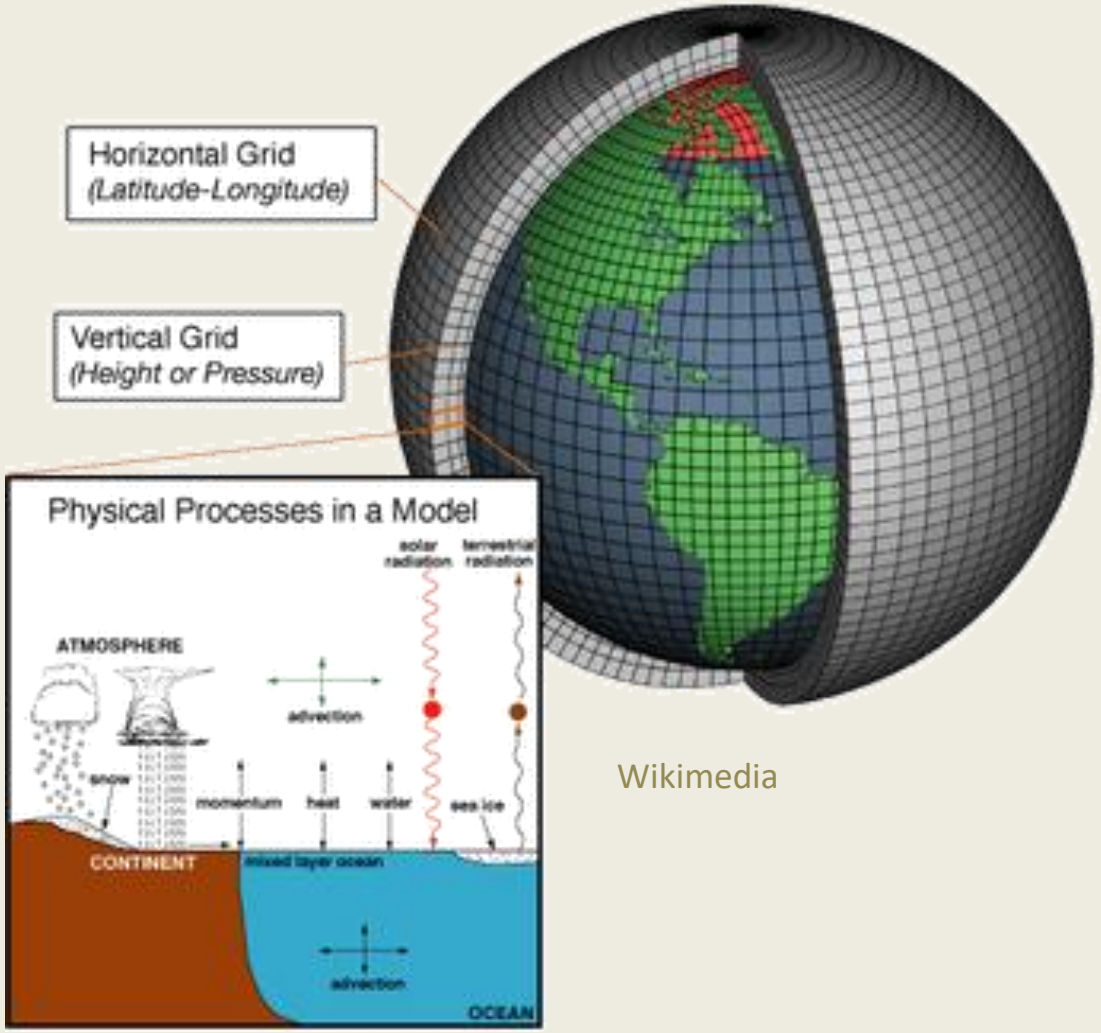
Course Outline

1. Building Blocks: Some important concepts
2. Our Goldilocks Earth: a Radiative Balancing Act
3. The Role of the Atmosphere: Greenhouse Gases & Clouds
4. Global Circulation and Dynamics of the Earth System:
   Oceans, Atmosphere, Biosphere, Cryosphere, People, Lithosphere
5. Natural Variability of the Climate, short and long term. Ice Ages
6. Carbon Dioxide and other Greenhouse Gases:
   Where do they come from, where do they go, how are they regulated?
7. **Impacts and Future Projections for Global Warming -- Uncertainties**
8. Amelioration Strategies. The Climate Debate. Policy Options.

Plan for Today

- How are Predictions made?
- The role of **Chaos** in Prediction
- How well have they worked? Skill
- Progress on refining Predictions Climate Sensitivity
- Current Understanding of the Prognosis
- Global and Regional Impacts
- Tipping Points

Projecting Future Impacts: Global Circulation Models



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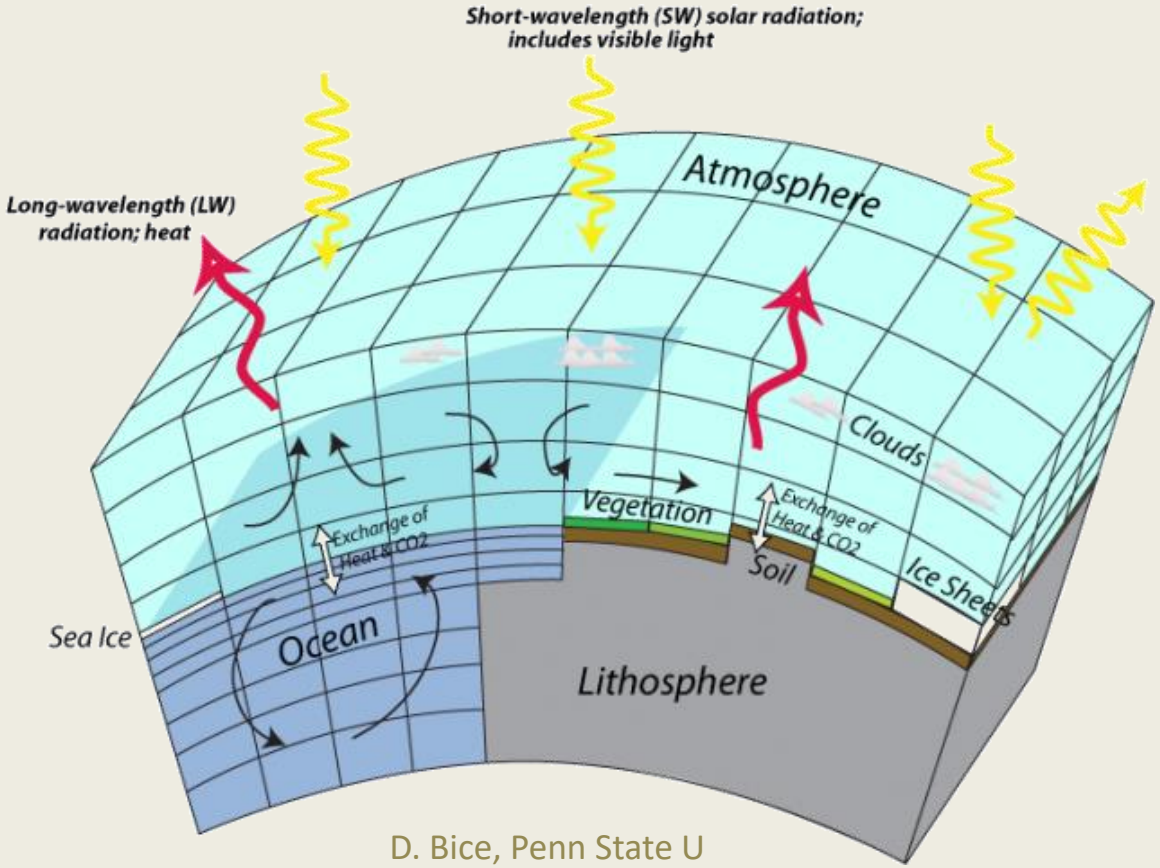
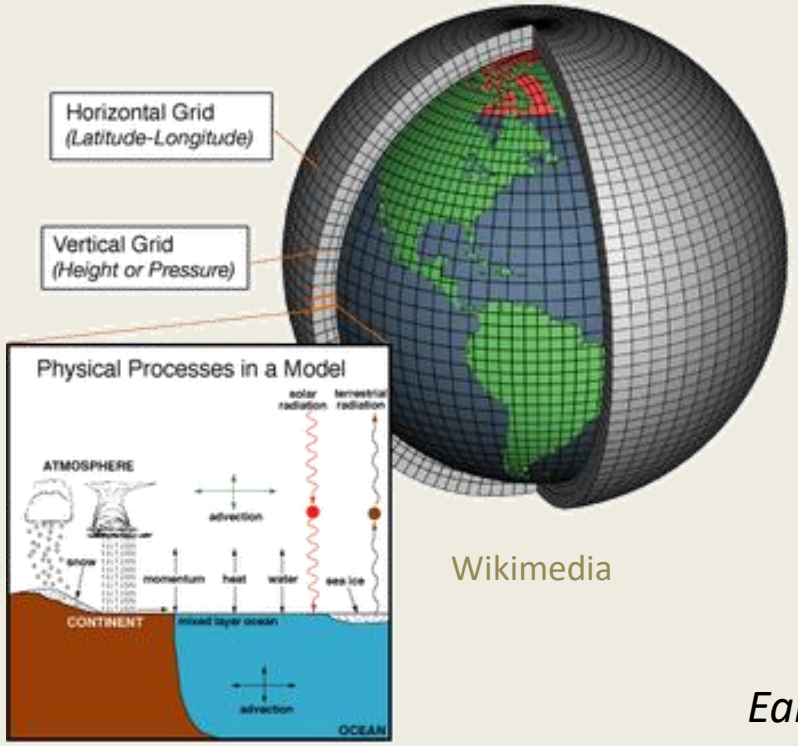


D. Bice, Penn State U

Projecting Future Impacts: Global Circulation Models (GCM)

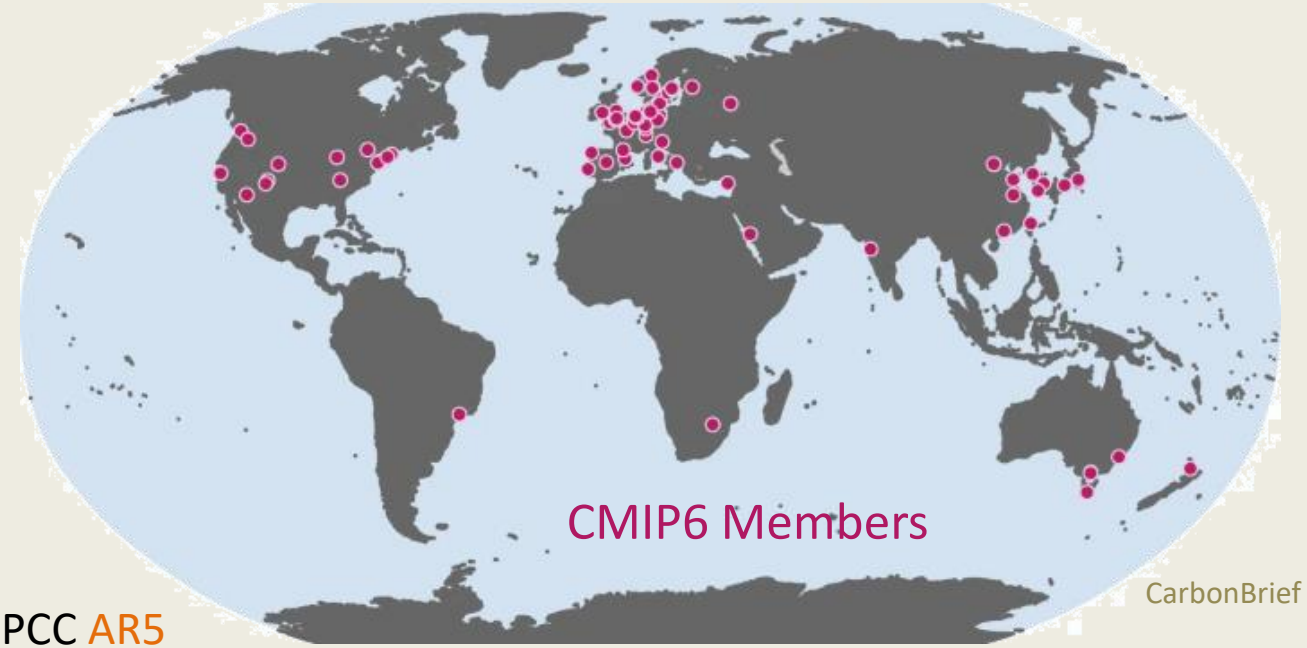


Wikimedia

Many Groups around the world build and test GCMs

Most belong to the **CMIP6** Project

CMIP = **C**limate **M**odel **I**ntercomparison **P**roject



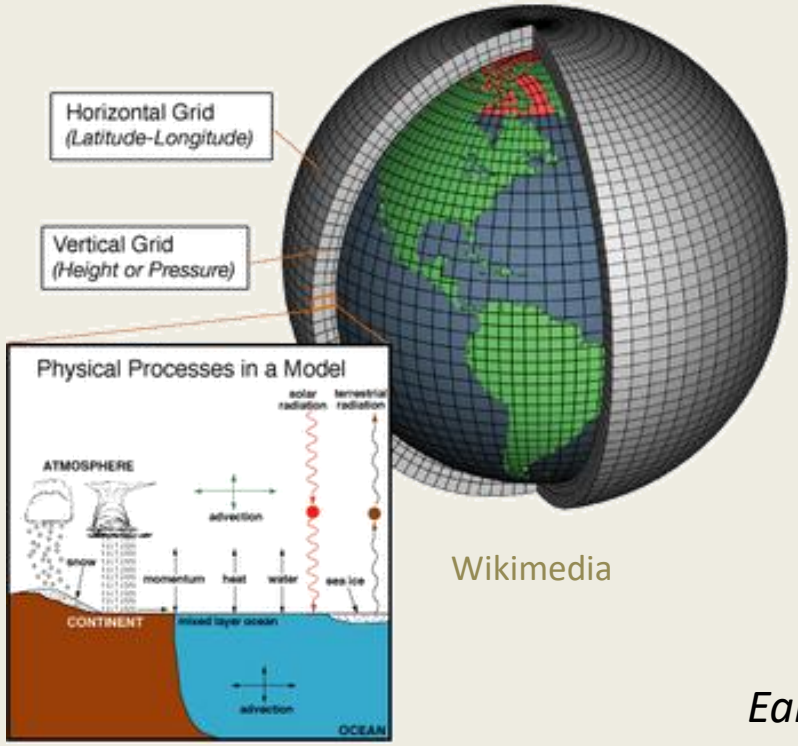
CarbonBrief

Earlier:

CMIP5 → IPCC AR5

CMIP6 → AR6 (due in April 2021)

Projecting Future Impacts: Global Circulation Models (GCM)



Wikimedia

Many Groups around the world build and test GCMs

Most belong to the **CMIP6** Project

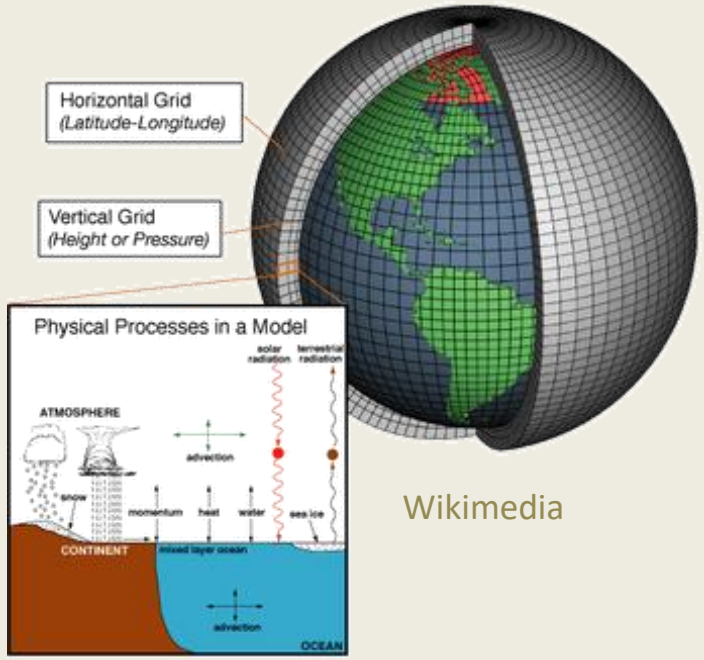
CMIP = **C**limate **M**odel **I**ntercomparison **P**roject

Heavy Hitters Include:

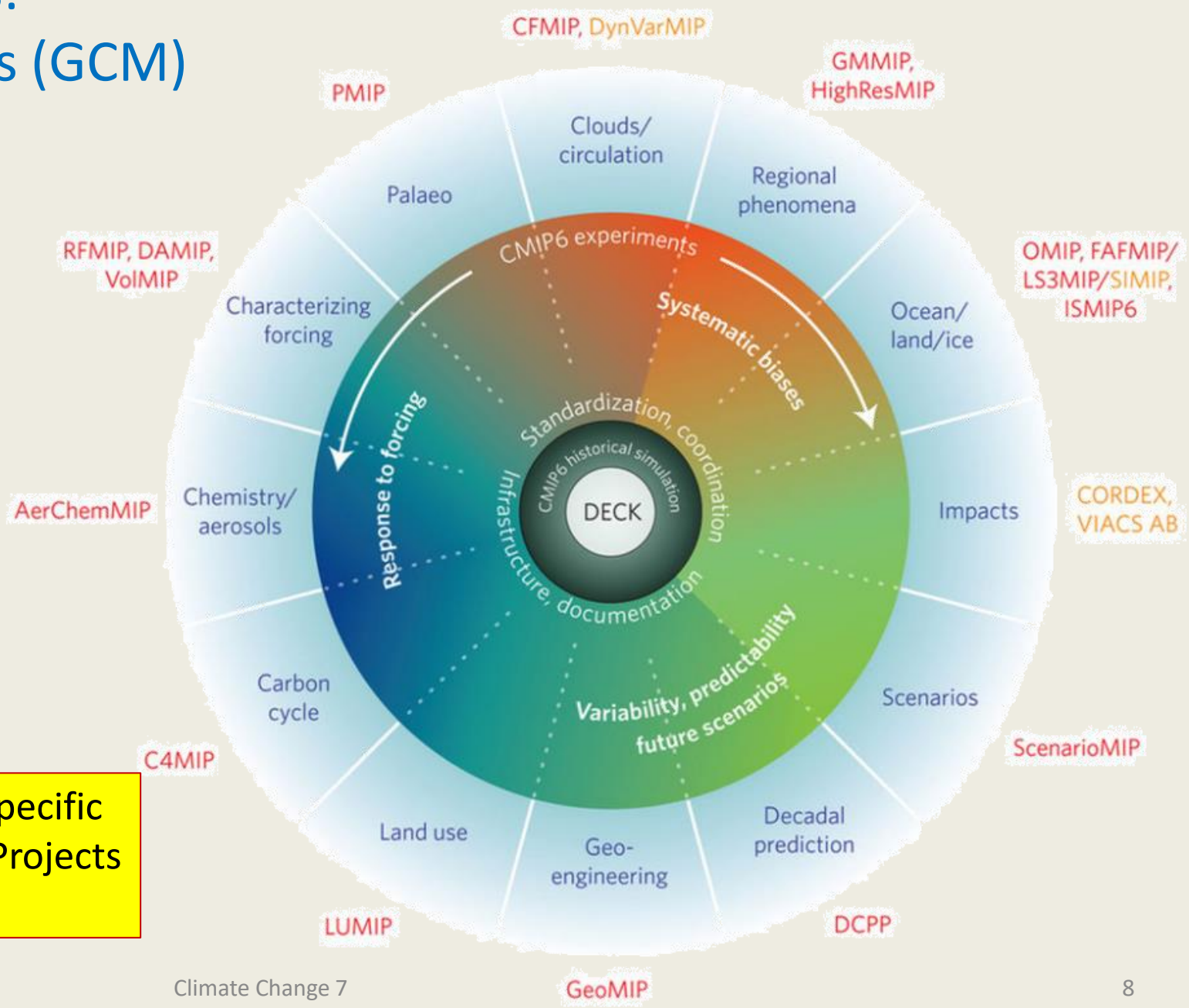
EC-Earth	European consortium
UKESM	UK Meterological Office + others
HADCM	Hadley Centre (UK)
GFDL	Geophysical Fluid Dynamics Lab (Princeton)
CMCC	Centro Euro-Mediterrano sui Cambiamenti Climatici
MIROC	Tokyo University +
GISS	Goddard Institute of Space Science (NASA)

Earlier:
CMIP5 →

Projecting Future Impacts: Global Circulation Models (GCM)

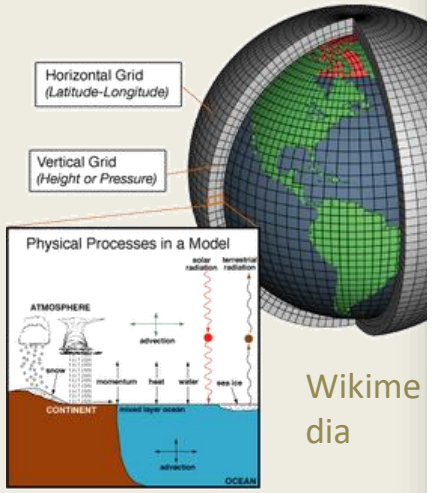


Wikimedia



CMIP6 Contains many specific Model Intercomparison Projects and Experiments

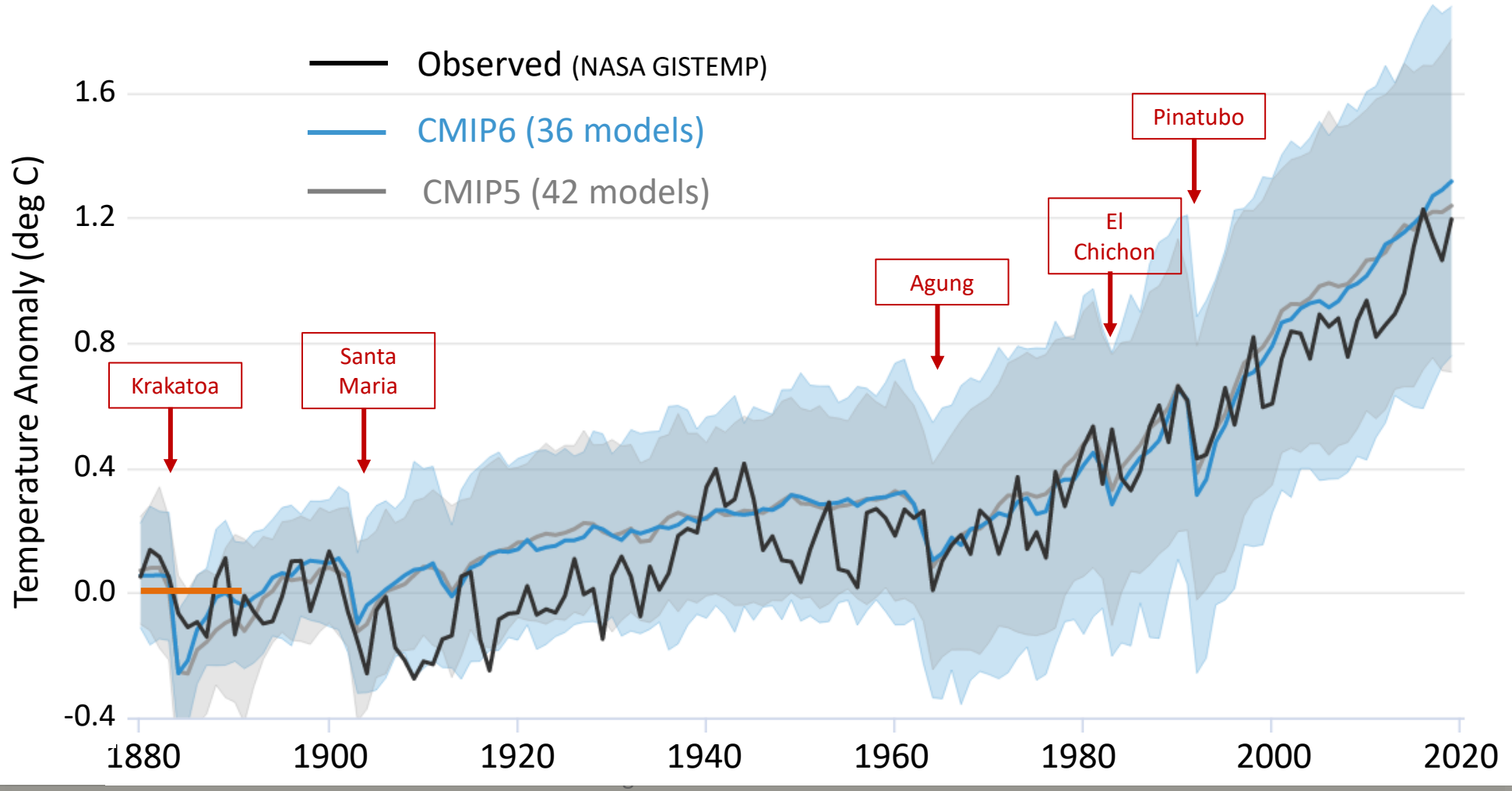
Projecting Future Impacts: Global Circulation Models (GCM)



Wikimedia

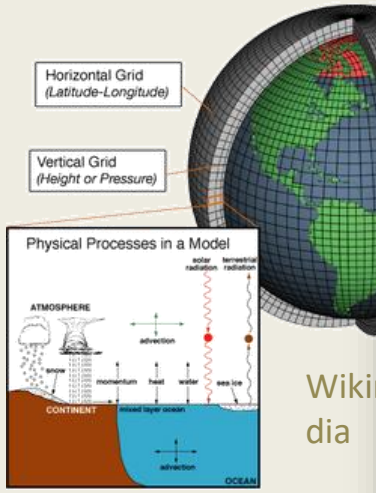
All members were required to do these historical runs

Intercomparison Test Example: Historical Global Temperatures from 1880



Projecting Future Impacts: Global Circulation Models

Global Mean Surface Temp



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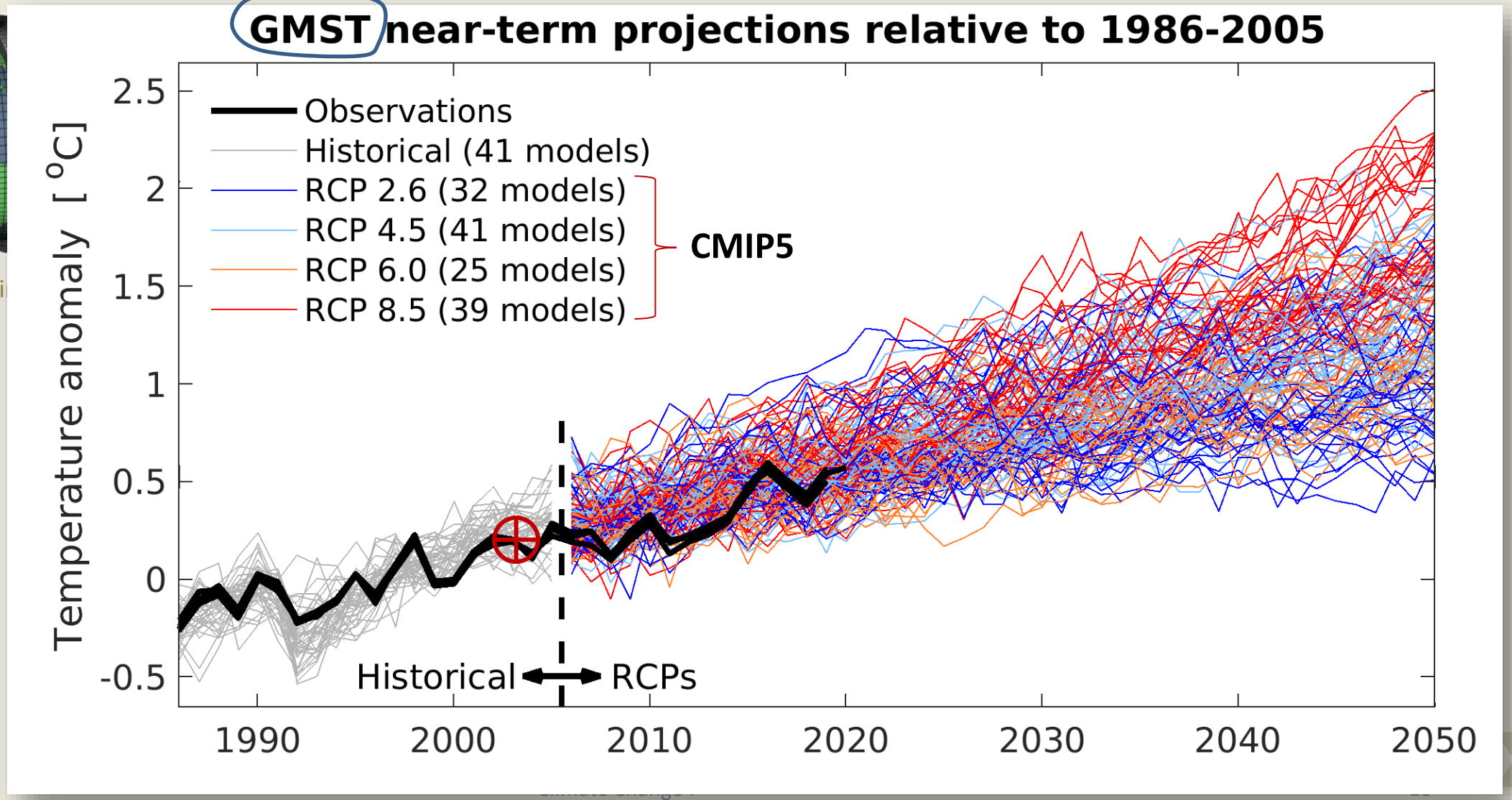
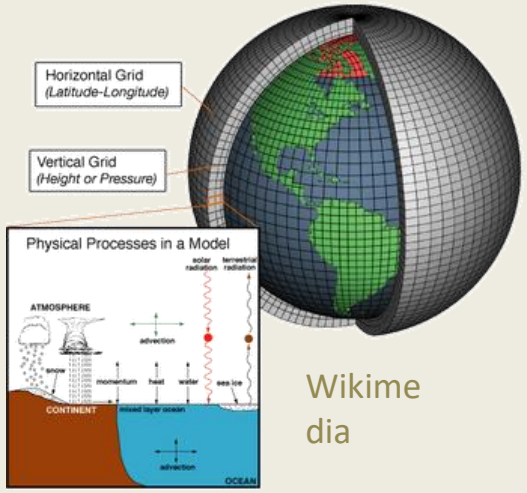


Projecting Future Impacts: Global Circulation Models



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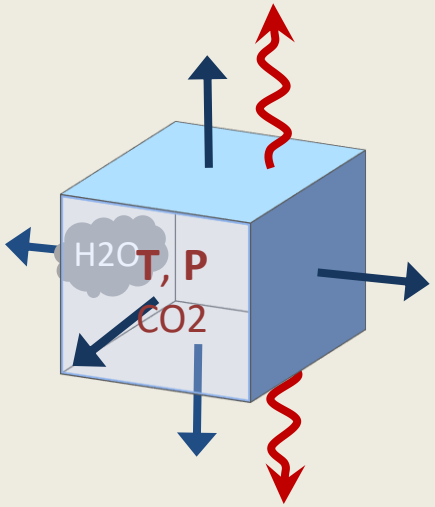
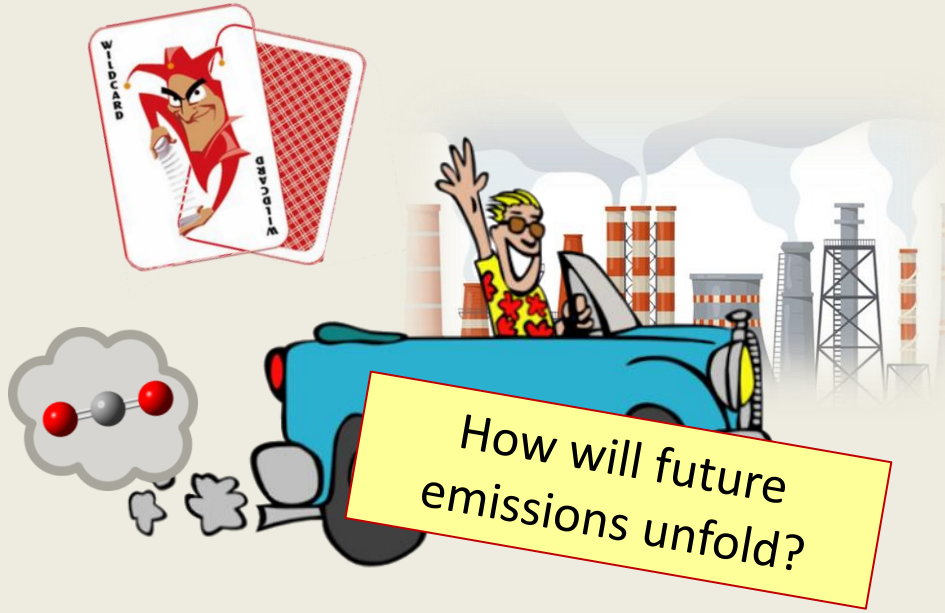
Two Requirements for a GCM Projection:

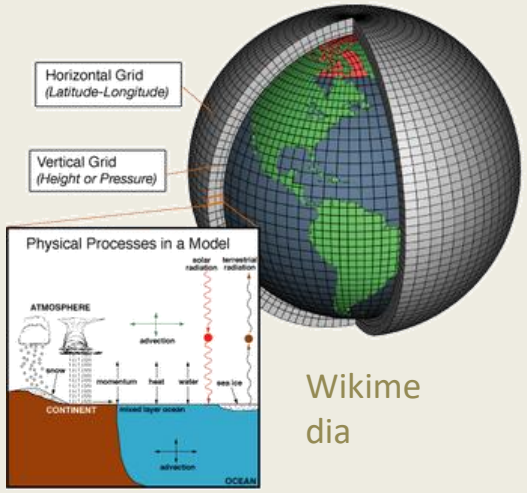


"The Physics"



"Human Behavior"

Projecting Future Impacts: Global Circulation Models



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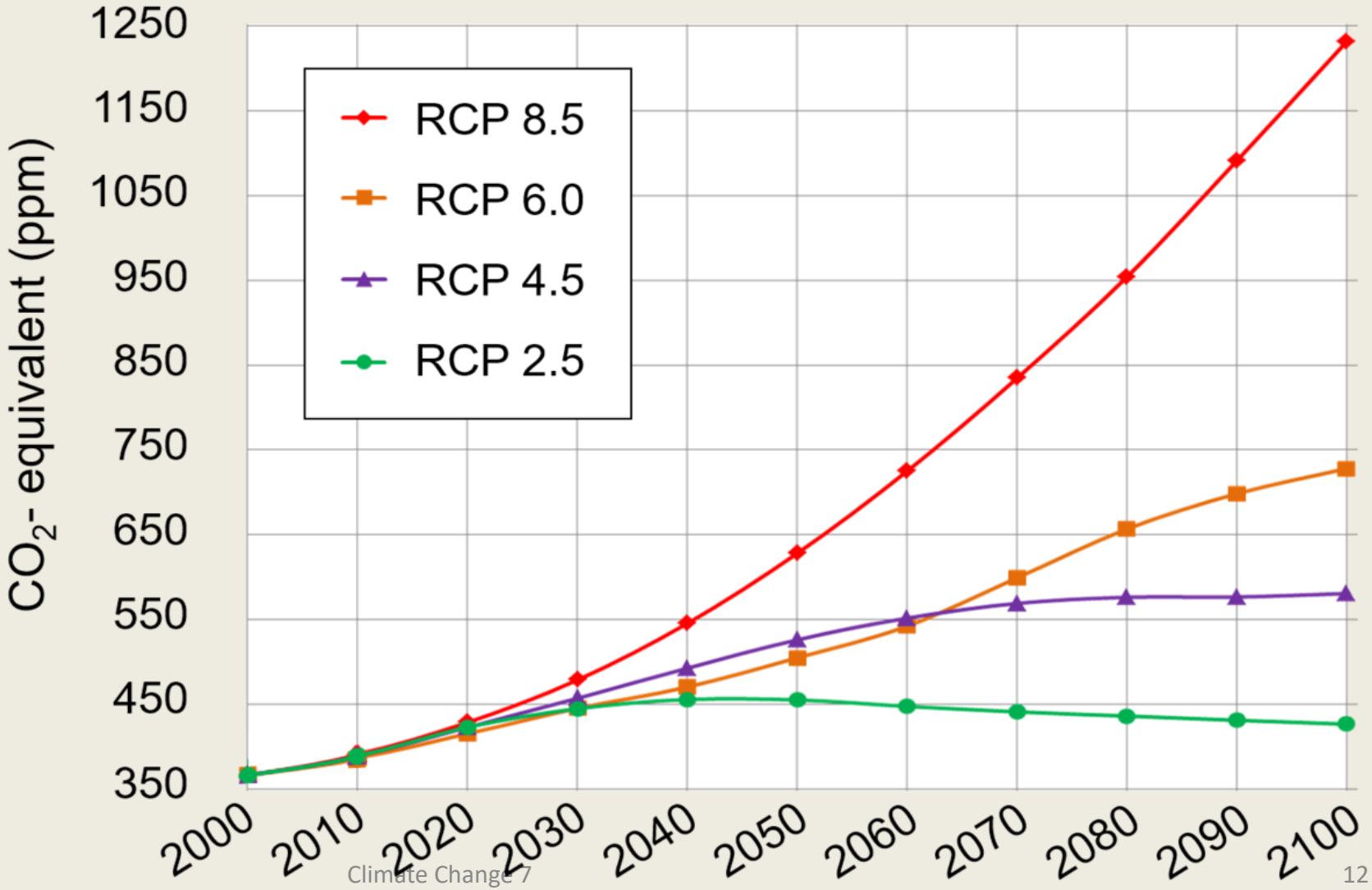
"Human Behavior"

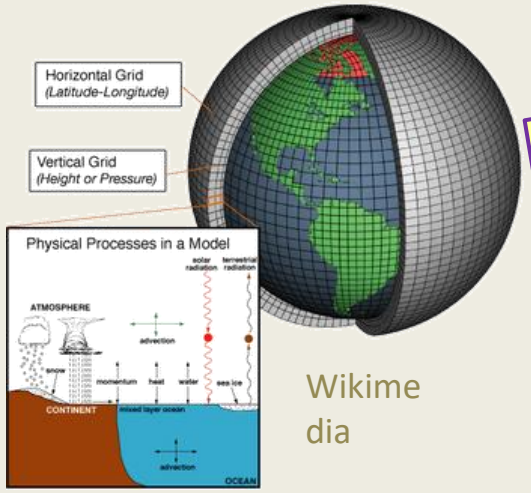
Human Factors handled with RCP's in IPCC **AR5**

- Representative **C**oncentration **P**athways



Projecting Future Impacts: Global Circulation Models

Human Factors handled with RCP's in IPCC **AR5**
- **R**epresentative **C**oncentration **P**athways

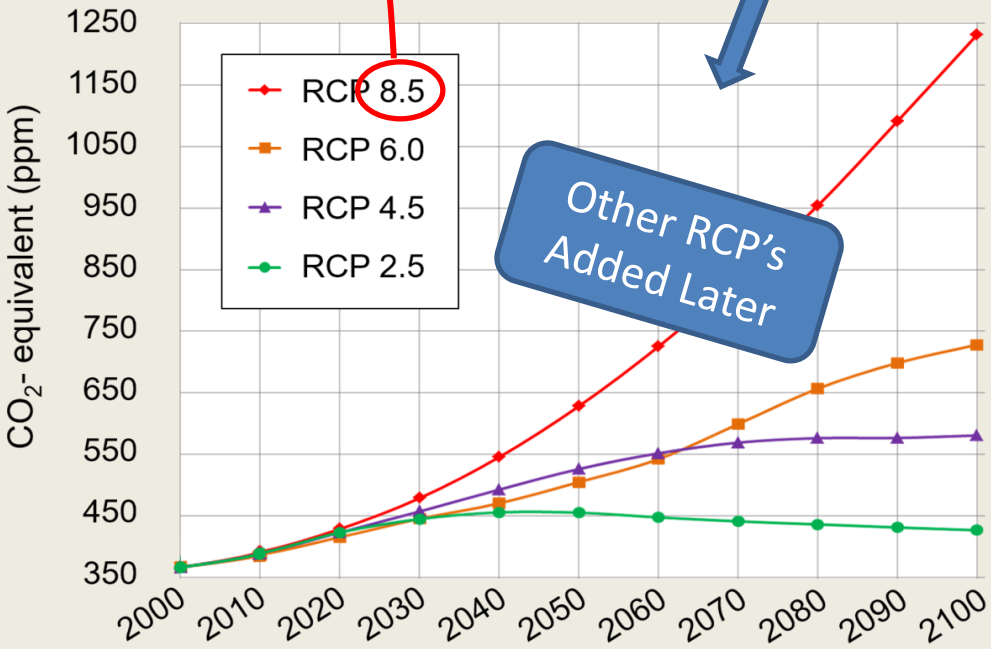


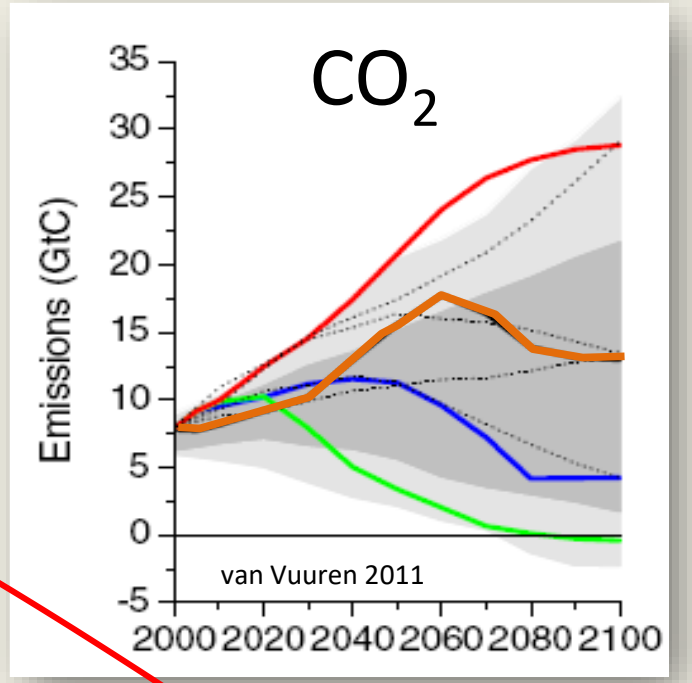
Wikime dia

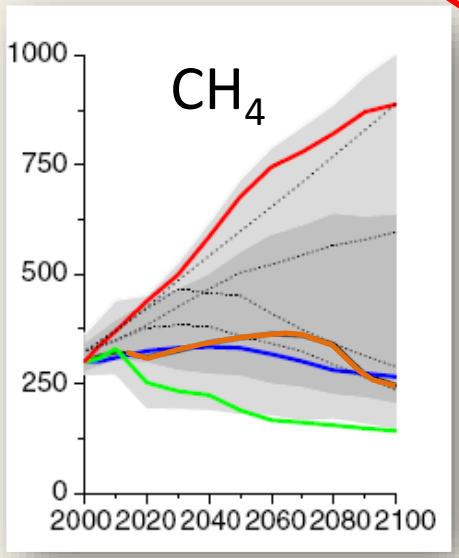
"Human Behavior"

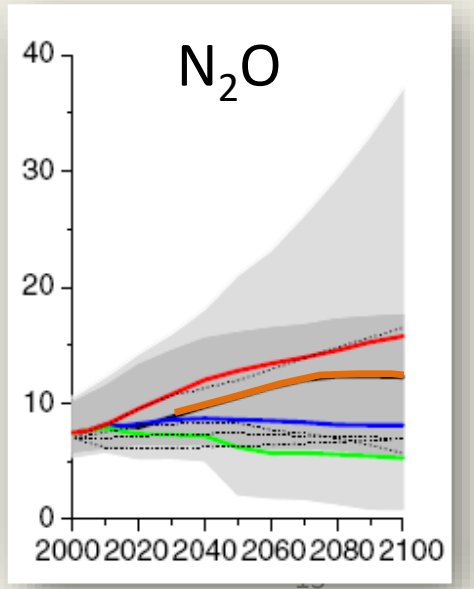
Watts/m^2 of Radiative Forcing in 2100

Human Emissions that would give these Concentrations



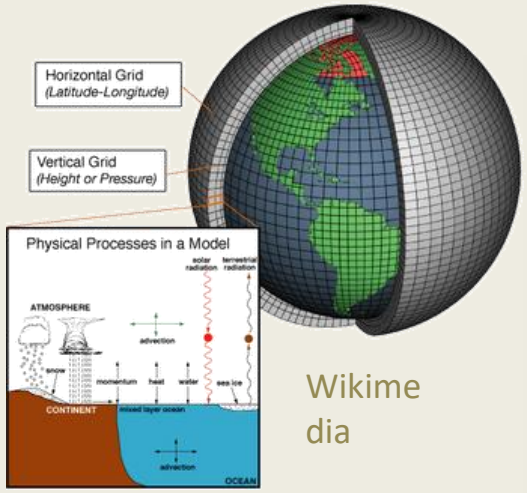






Projecting Future Impacts: Global Circulation Models

RCP's to be *replaced* by SSP's in IPCC **AR6**
-- **S**hared **S**ocioeconomic **P**athways



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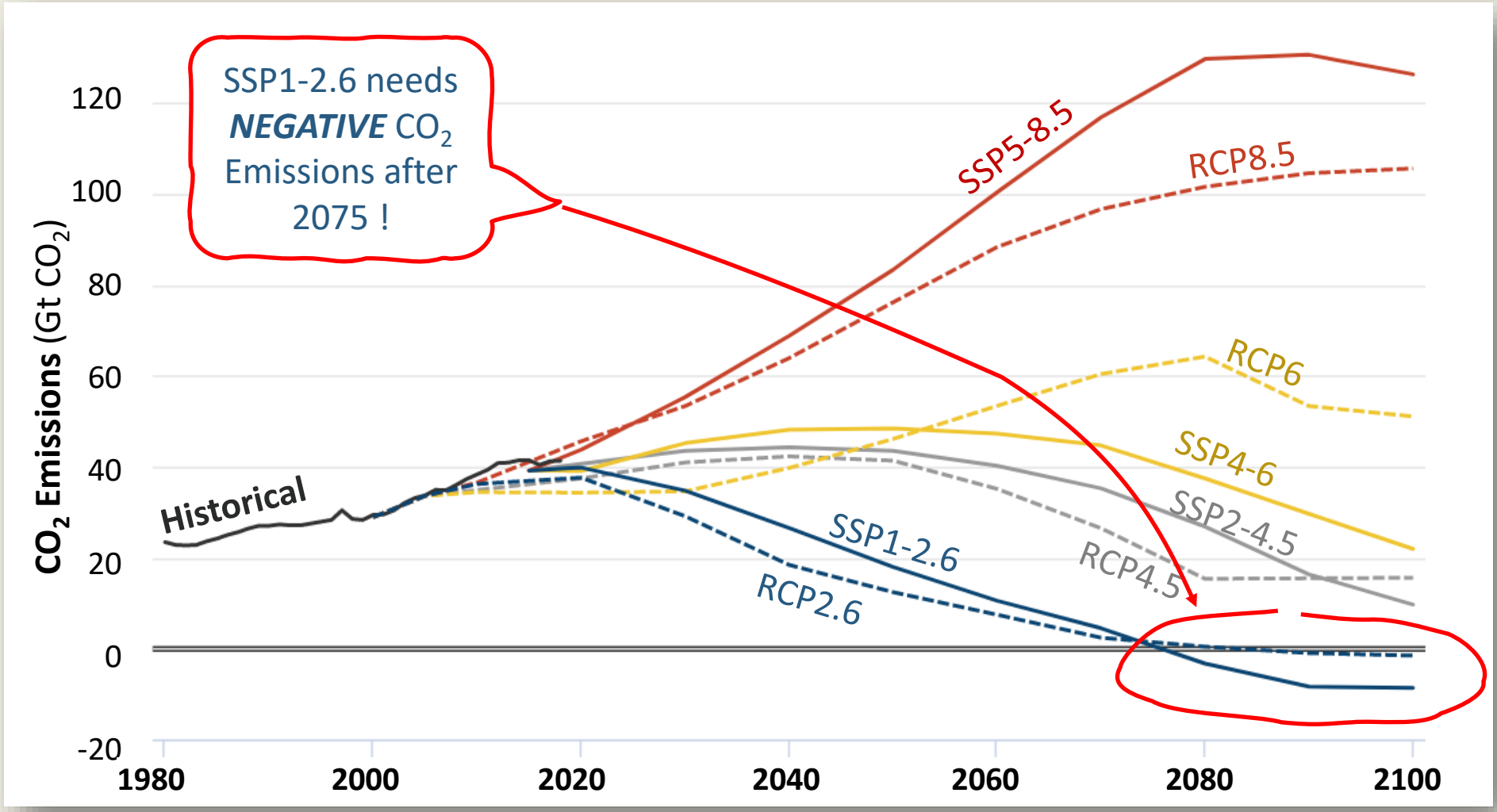
"Human Behavior"



CarbonBrief.org

Projecting Future Impacts: Global Circulation Models

RCP's to be *replaced* by SSP's in IPCC **AR6**
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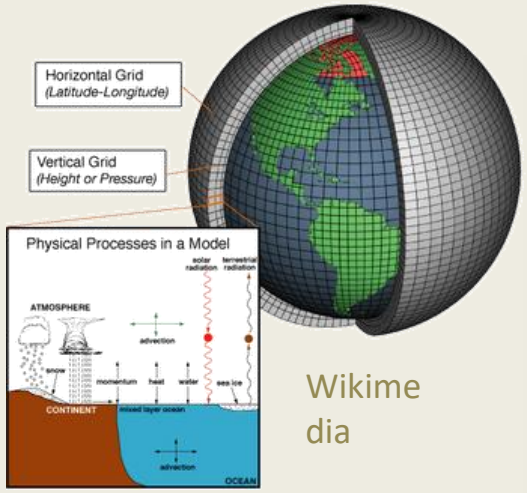
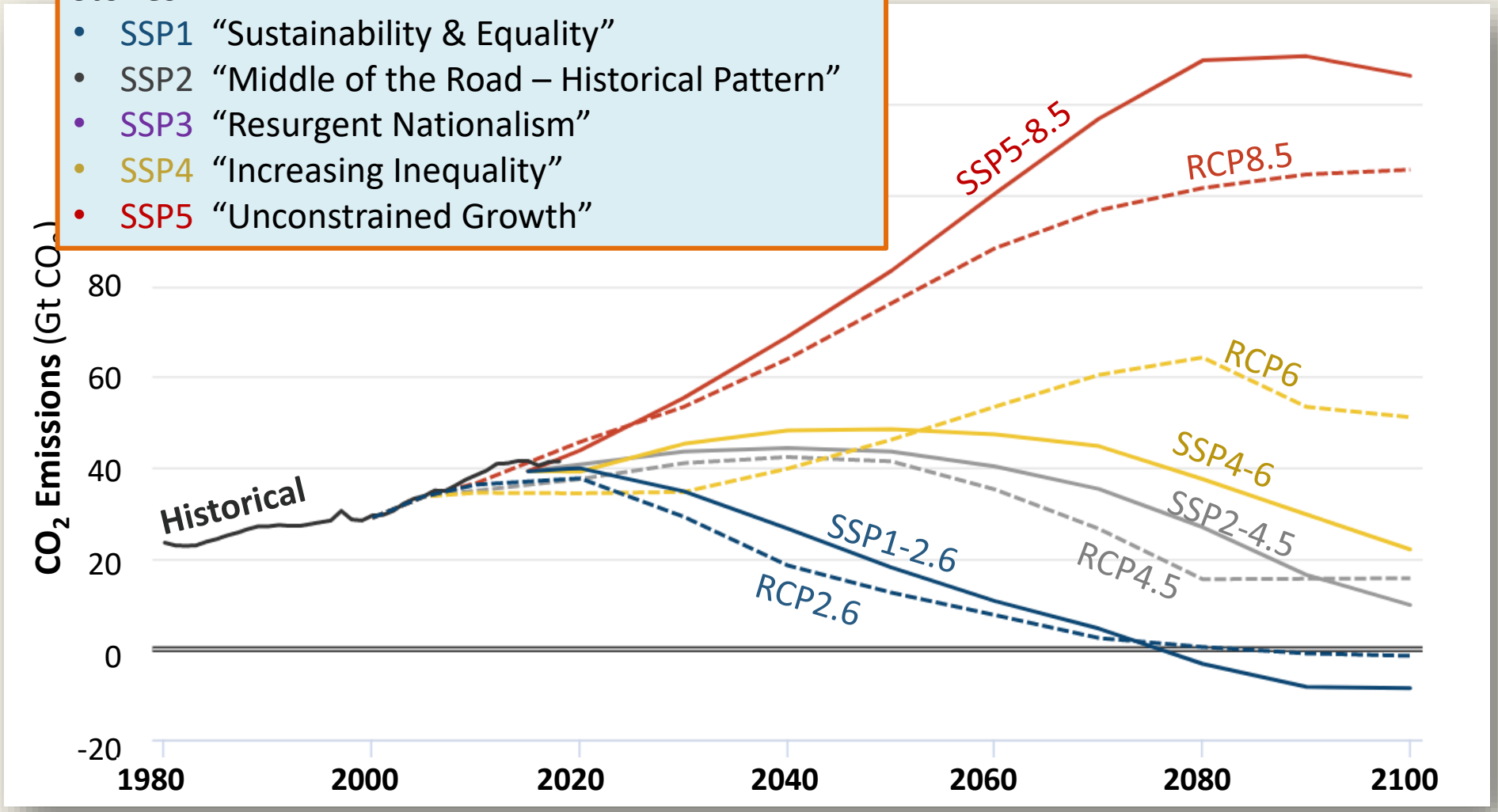


Wikimedia

"Human Behavior"

Stories:

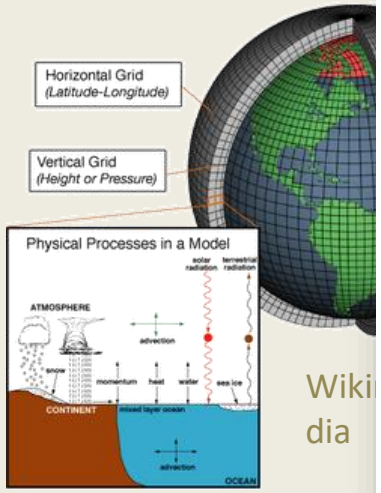
- SSP1 "Sustainability & Equality"
- SSP2 "Middle of the Road – Historical Pattern"
- SSP3 "Resurgent Nationalism"
- SSP4 "Increasing Inequality"
- SSP5 "Unconstrained Growth"



CarbonBrief.org

Projecting Future Impacts: Global Circulation Models

Global Mean Surface Temp



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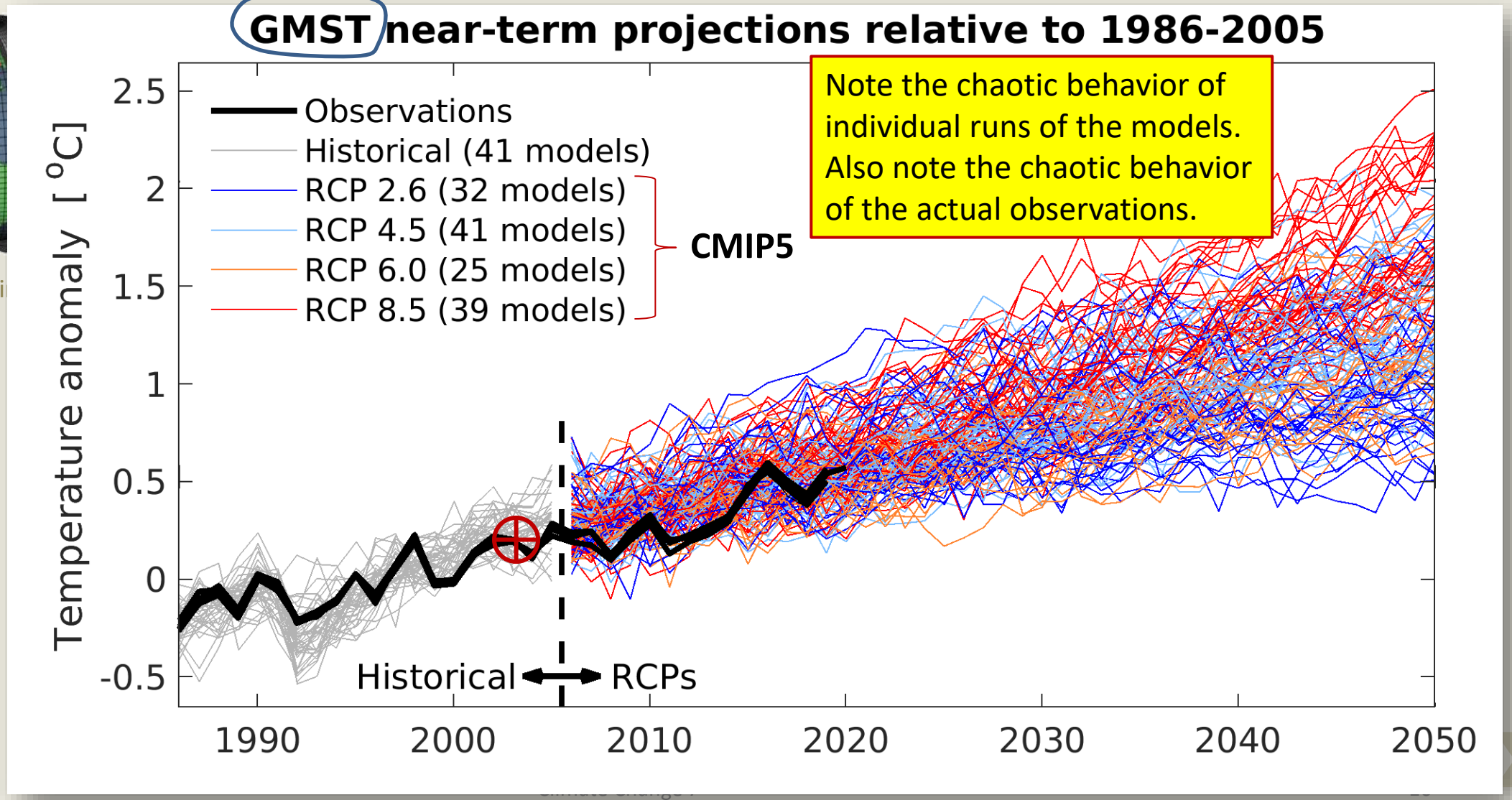
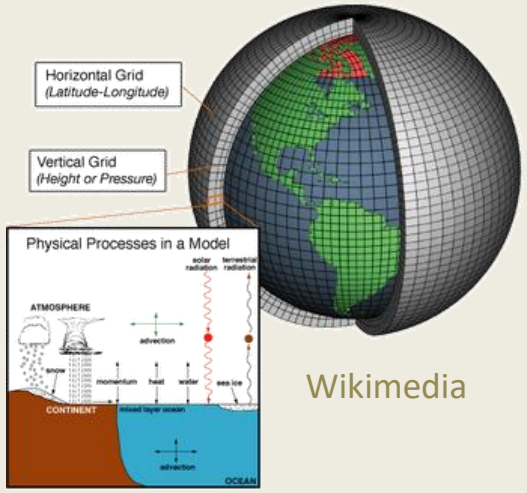


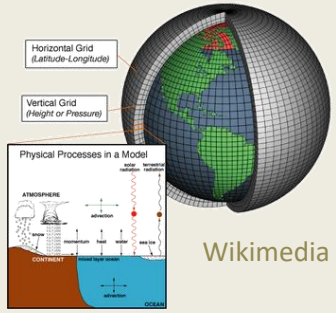
Projecting Future Impacts: Global Circulation Models



Wikimedia

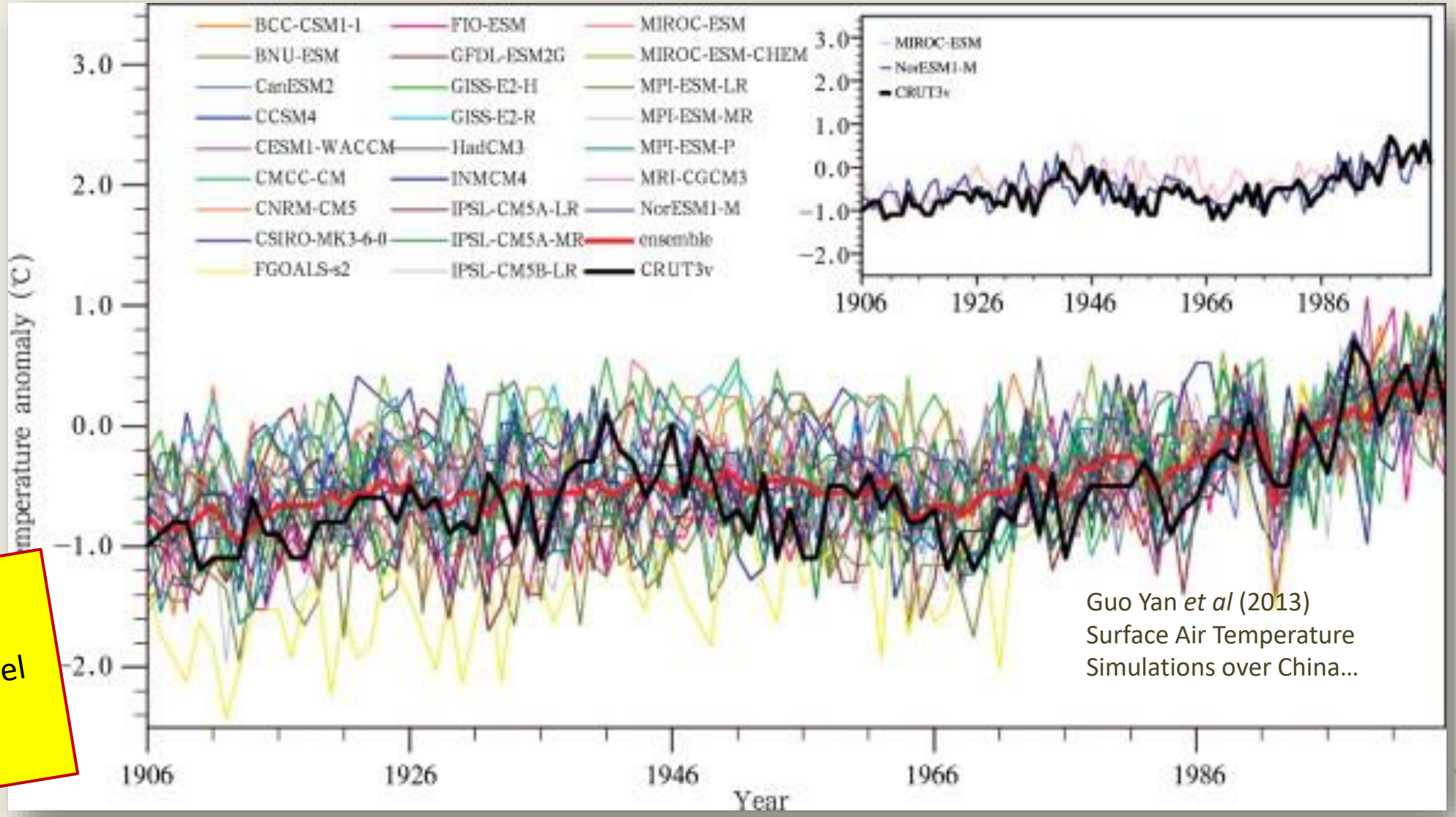
Remember Chaos in non-linear systems from Session 1?

Global Circulation Models are Chaotic -- Just like the Earth itself!



Wikimedia

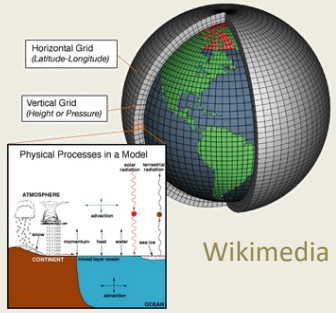
Temperatures in China 1906-2006: 26 GCM Models *versus* Actual



Guo Yan *et al* (2013) Surface Air Temperature Simulations over China…

This is an example illustrating the chaotic nature of individual model runs, this time only for China region.

Global Circulation Models are Chaotic -- Just like the Earth itself!

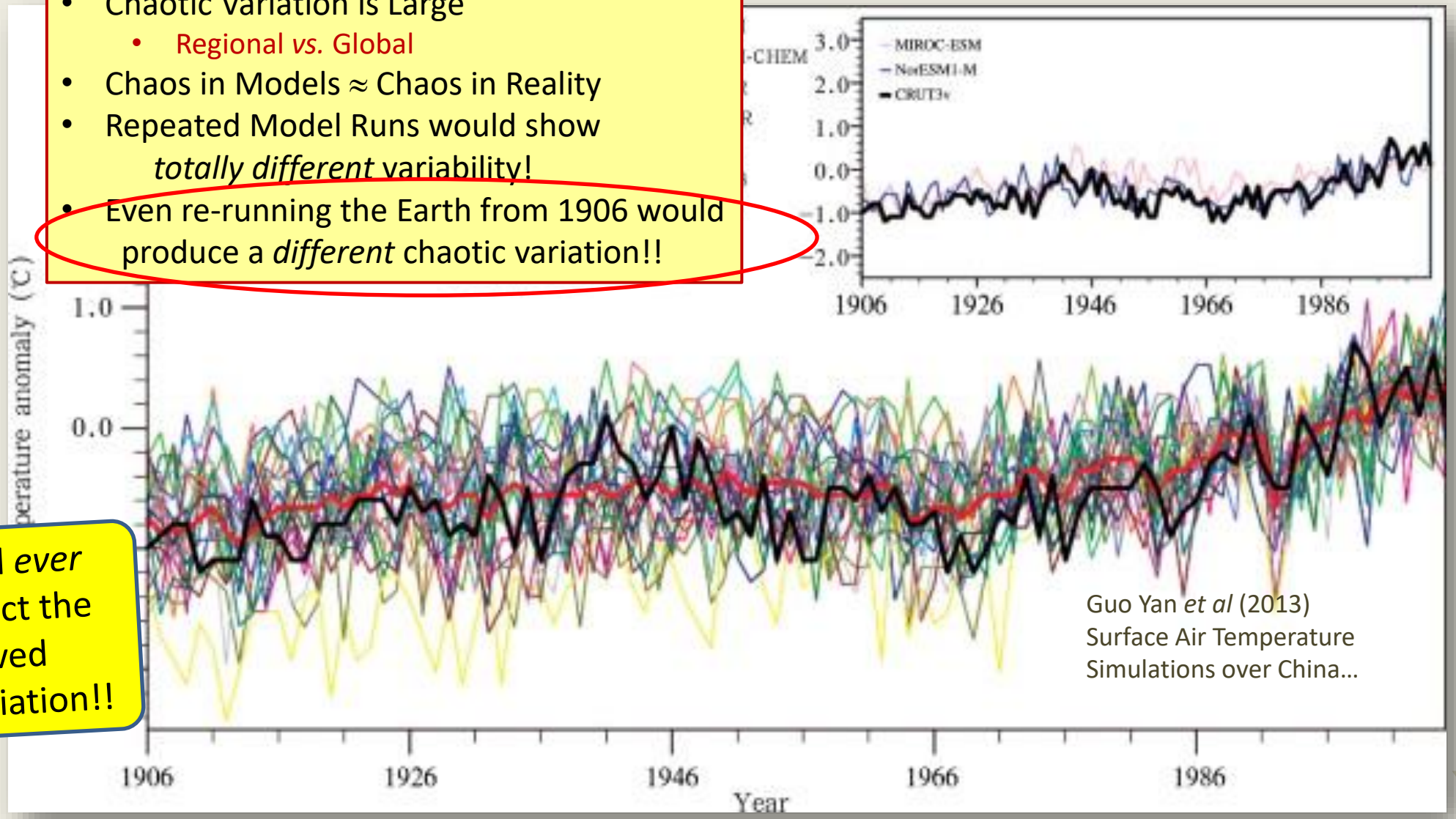


Wikimedia

- Chaotic Variation is Large
  - Regional *vs.* Global
- Chaos in Models ≈ Chaos in Reality
- Repeated Model Runs would show *totally different* variability!
- Even re-running the Earth from 1906 would produce a *different* chaotic variation!!

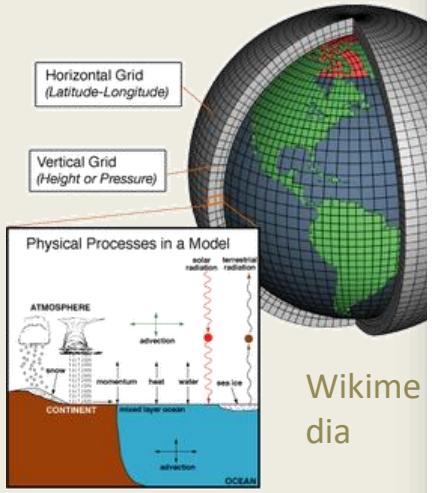
Temperatures in China 1906-2006:
26 GCM Models
versus
Actual

No Model could *ever* accurately predict the actual observed Temperature Variation!!



Guo Yan *et al* (2013)
Surface Air Temperature
Simulations over China…

Projecting Future Impacts: Global Circulation Models (GCM)



Wikimedia

Intercomparison Test Example: Historical Global Temperatures from 1880

Observed (NASA GISTEMP)

CMIP6 (36 models)

CMIP5 (42 models)

If we could rewind the Earth to 1880 and play it again, what would we get?

Krakatoa

Santa Maria

Agung

El Chichon

Pinatubo

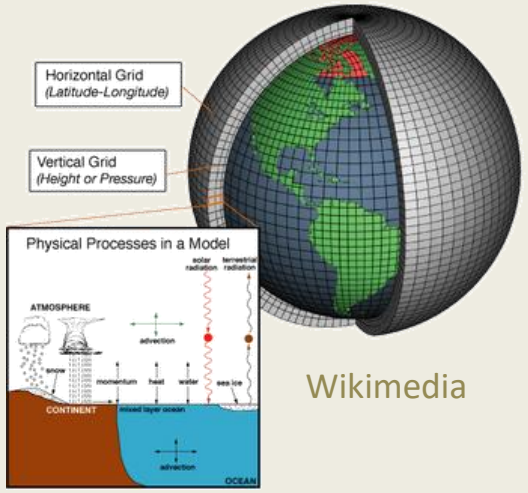
Answer: Same general trend, but entirely different in detail!

Temperature Anomaly (deg C)

1.6
1.2
0.8
0.4
0.0
-0.4

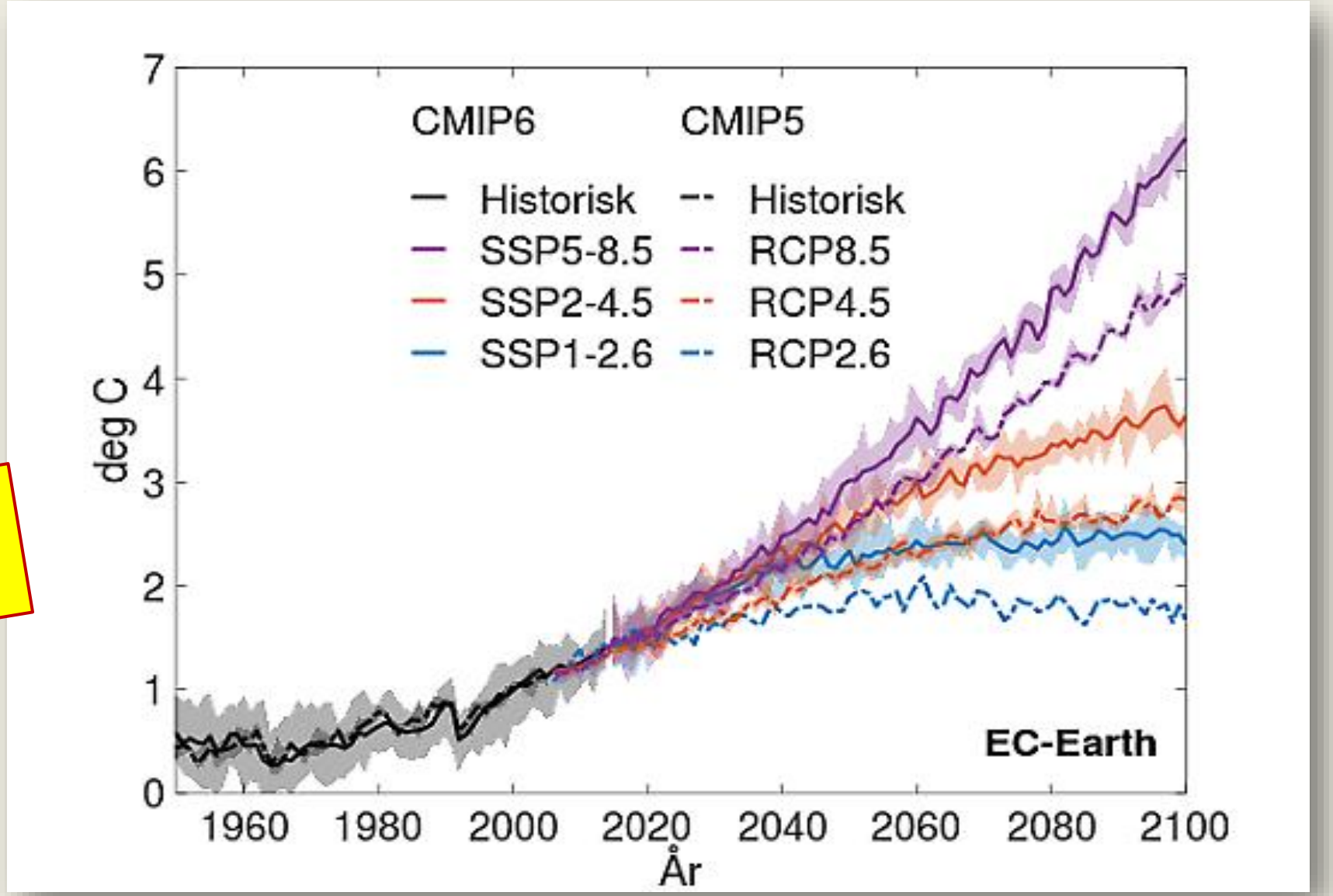
1880 1900 1920 1940 1960 1980 2000 2020

Projecting Future Impacts: Global Circulation Models



Wikimedia

Global average temperature rise for one CMIP6 model under different Scenarios.

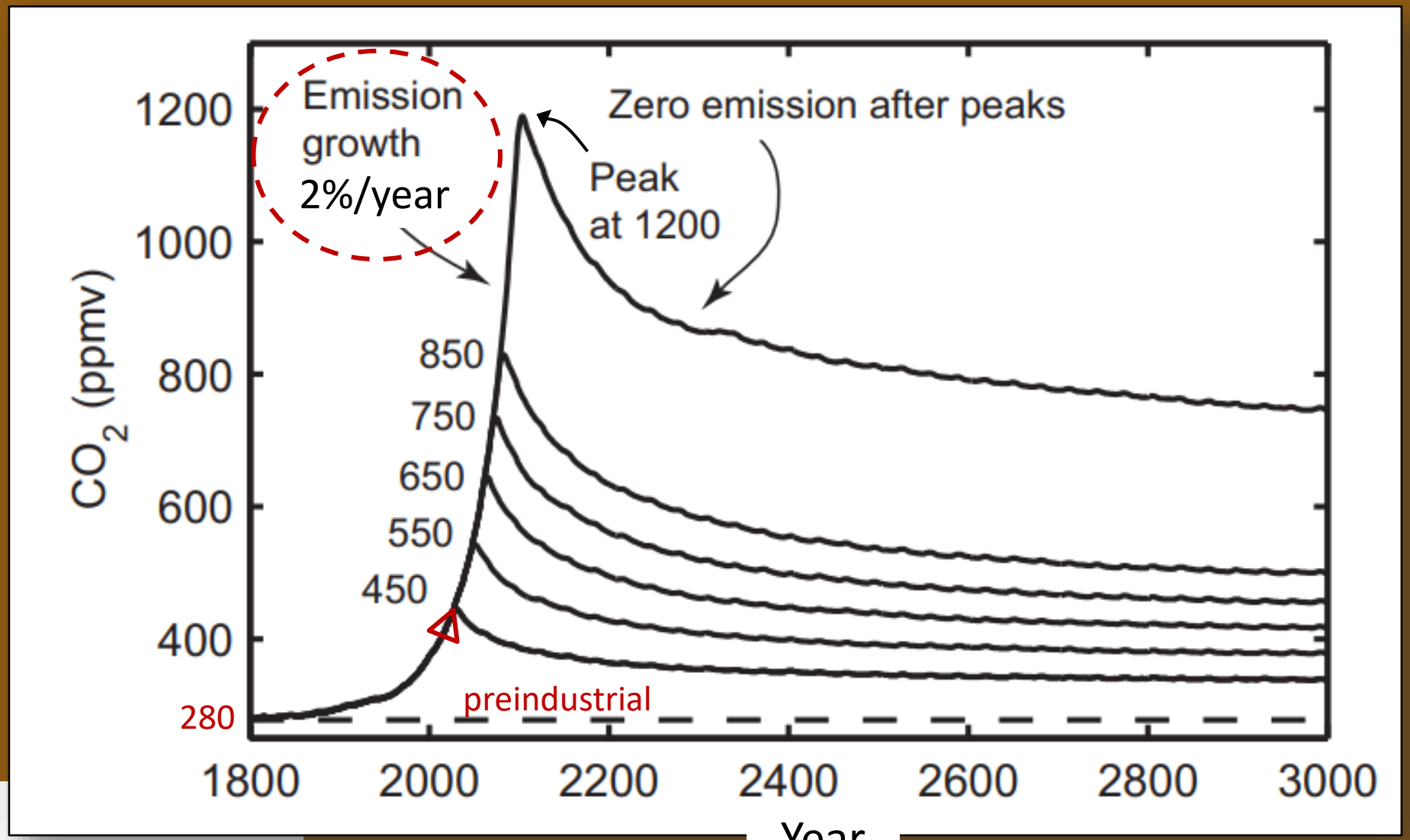


SMHI Rossby Centre (Sweden)

Baked In?

Could we cool it off again?

Future CO_2 Pathways if we Stop Emitting at Various Concentrations

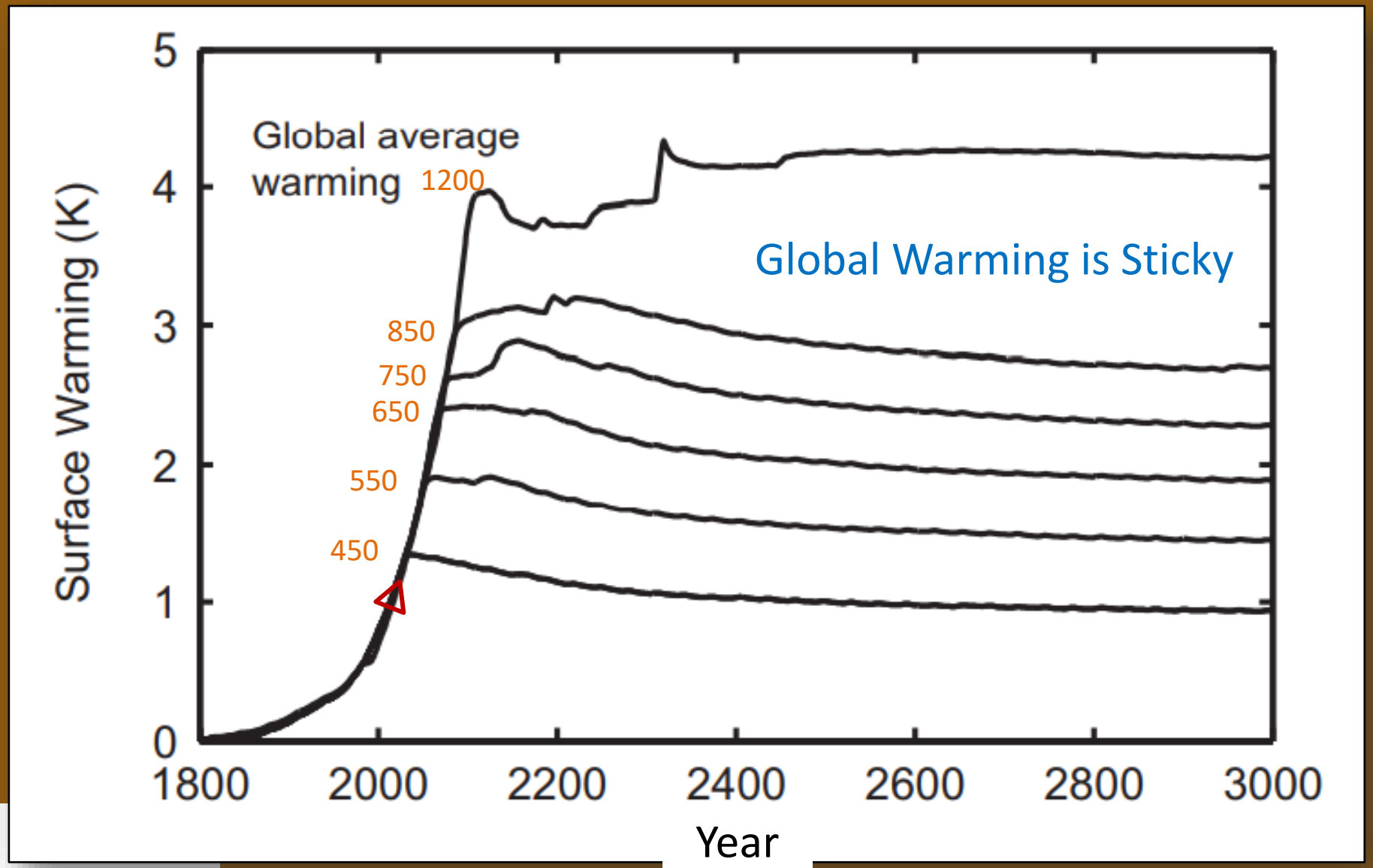


PNAS 2009

Irreversible climate change due to carbon dioxide emissions

Susan Solomon[a,1], Gian-Kasper Plattner[b], Reto Knutti[c], and Pierre Friedlingstein[d]

Future Temperature Pathways if we Stop Emitting CO_2 at these Points



The good news?

We have probably staved off the next Ice Age for a few thousand years…

PNAS 2009

Irreversible climate change due to carbon dioxide emissions

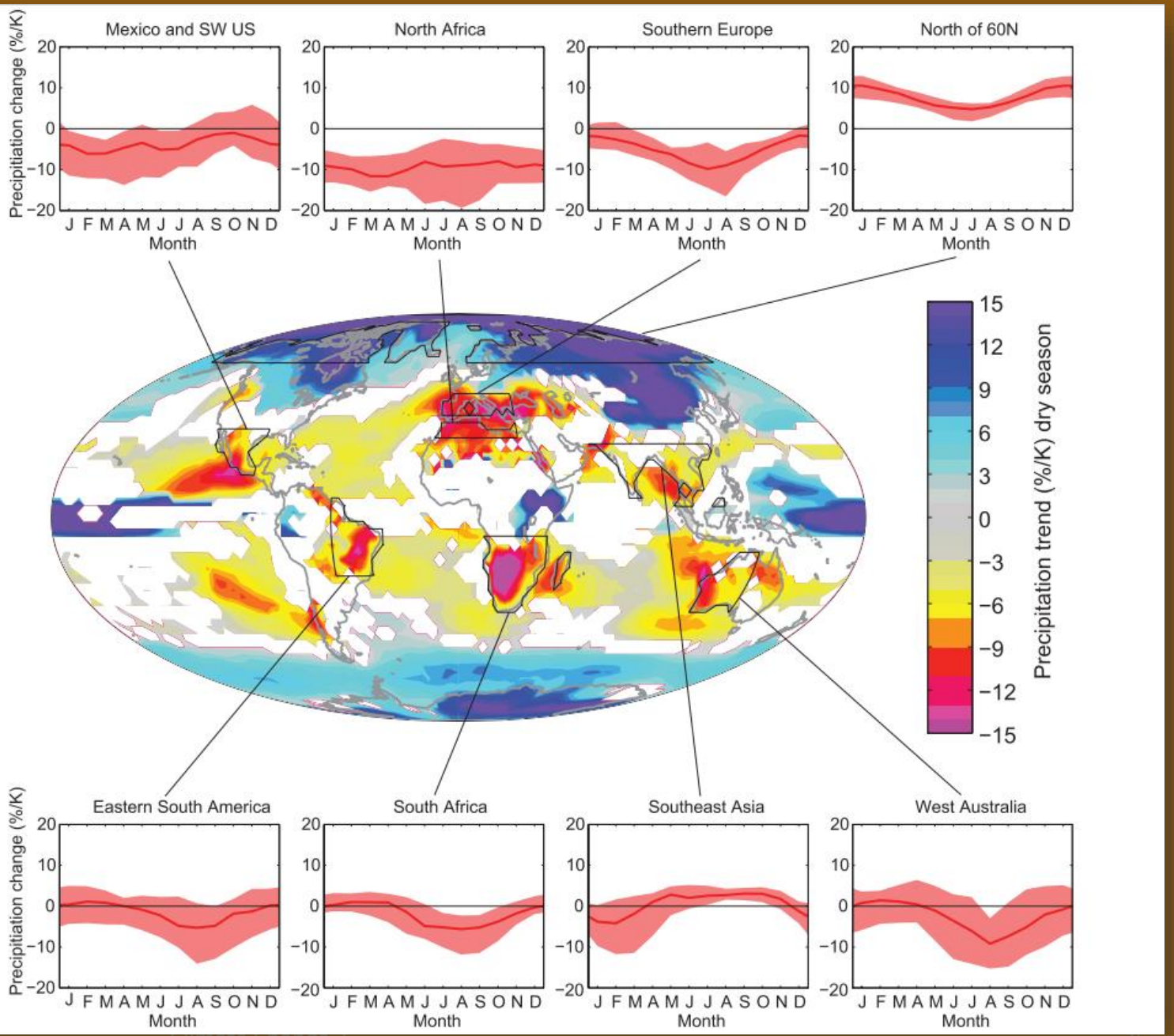
Susan Solomon[a,1], Gian-Kasper Plattner[b], Reto Knutti[c], and Pierre Friedlingstein[d]

Precipitation Trends

The mixed news?

Equatorial and High Latitudes will get Wetter…

Mid-Latitudes will get Dryer



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Precipitation Trends

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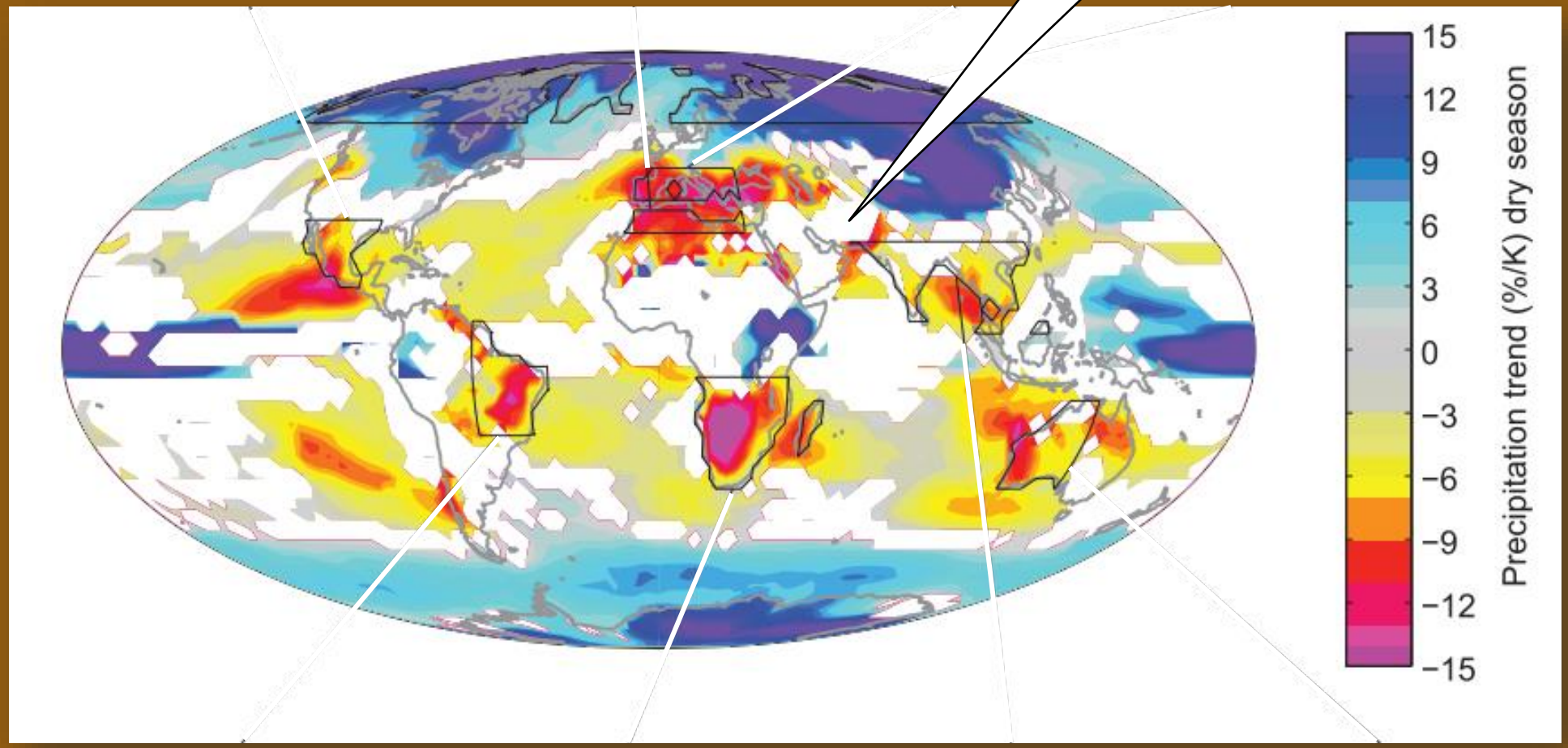
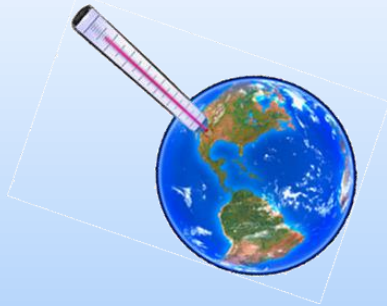


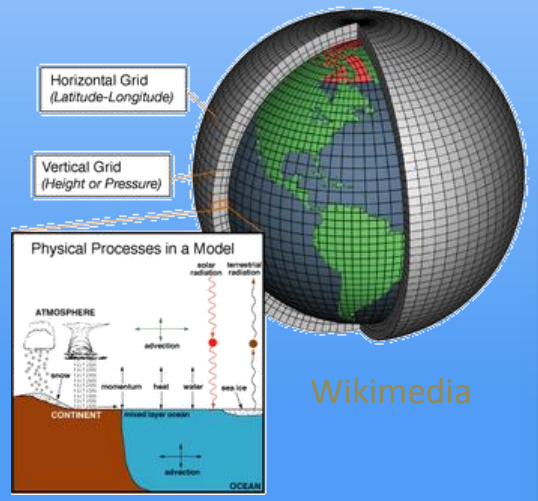
PNAS 2009

Irreversible climate change due to carbon dioxide emissions

Susan Solomon[a,1], Gian-Kasper Plattner[b], Reto Knutti[c], and Pierre Friedlingstein[d]

Questions about Climate Prediction, RCP's , Chaos or Baked-In Warming?





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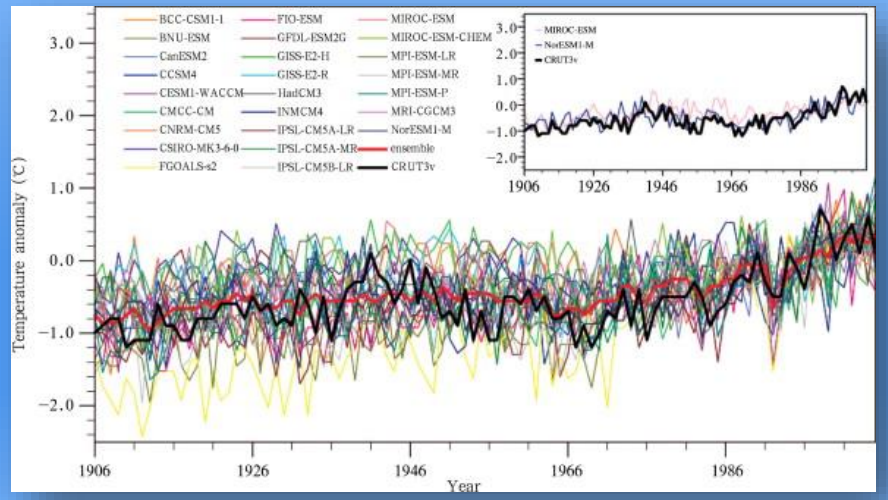
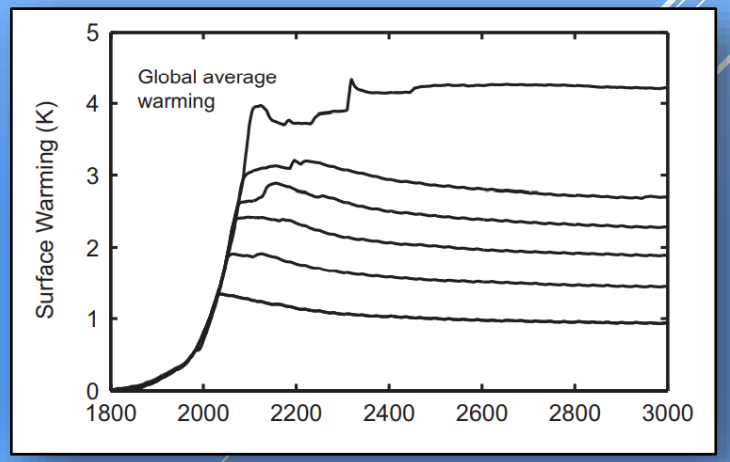


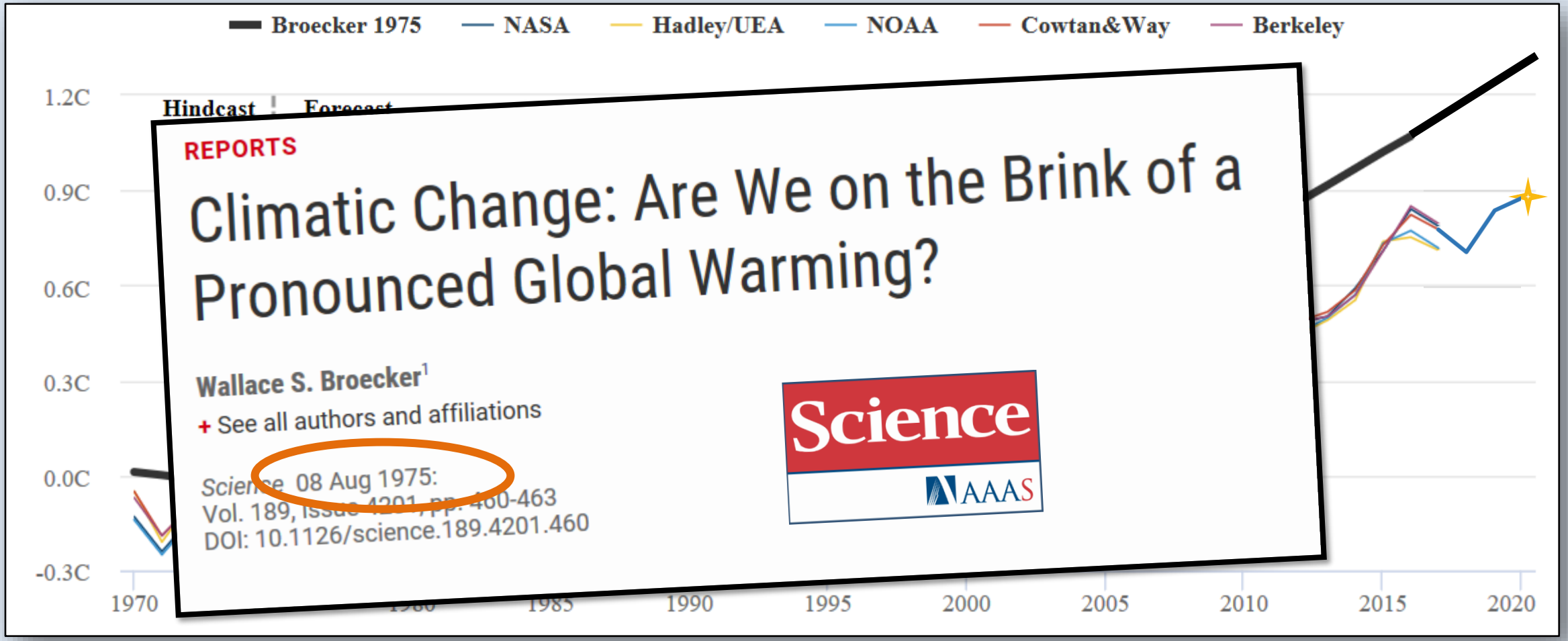


Climate Predictions:

How well did they do so far?

Climate Predictions:

How Well Did They Do?

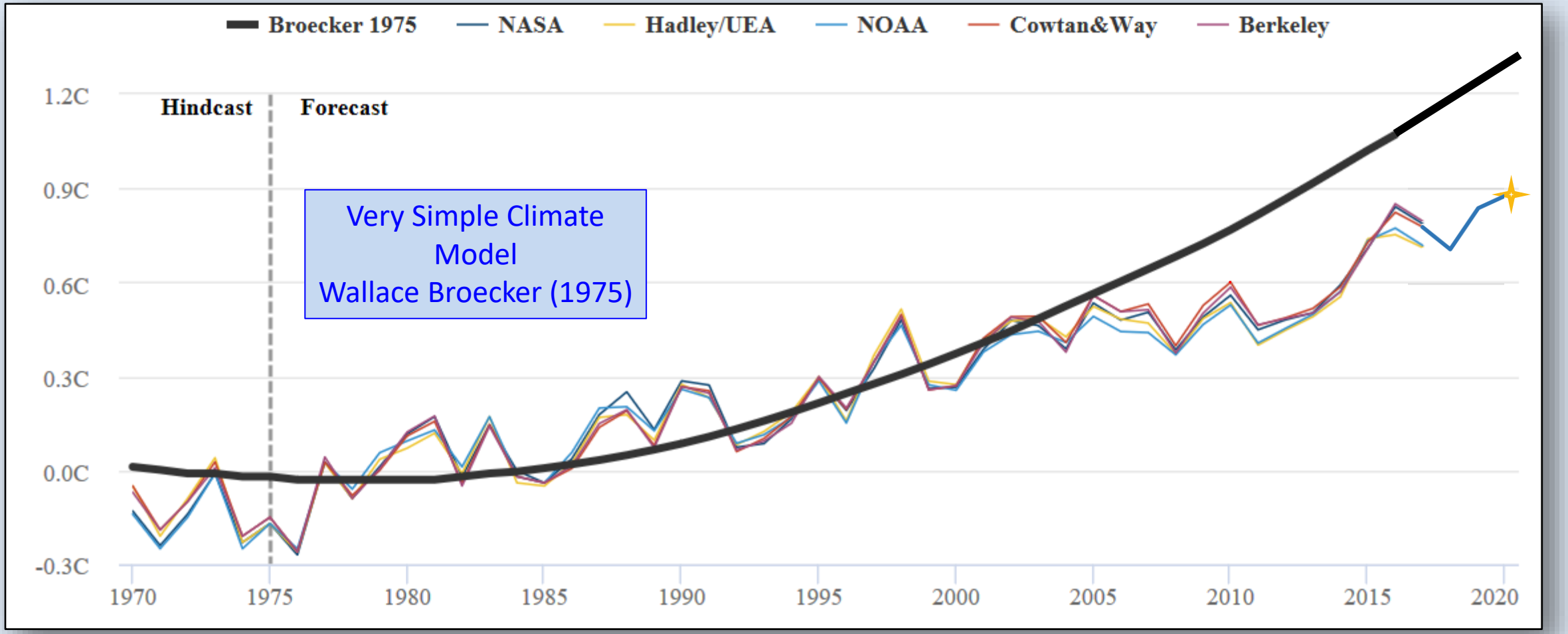


Baseline Period

Data assembled by Z. Hausfather, CarbonBrief.org

Climate Predictions:

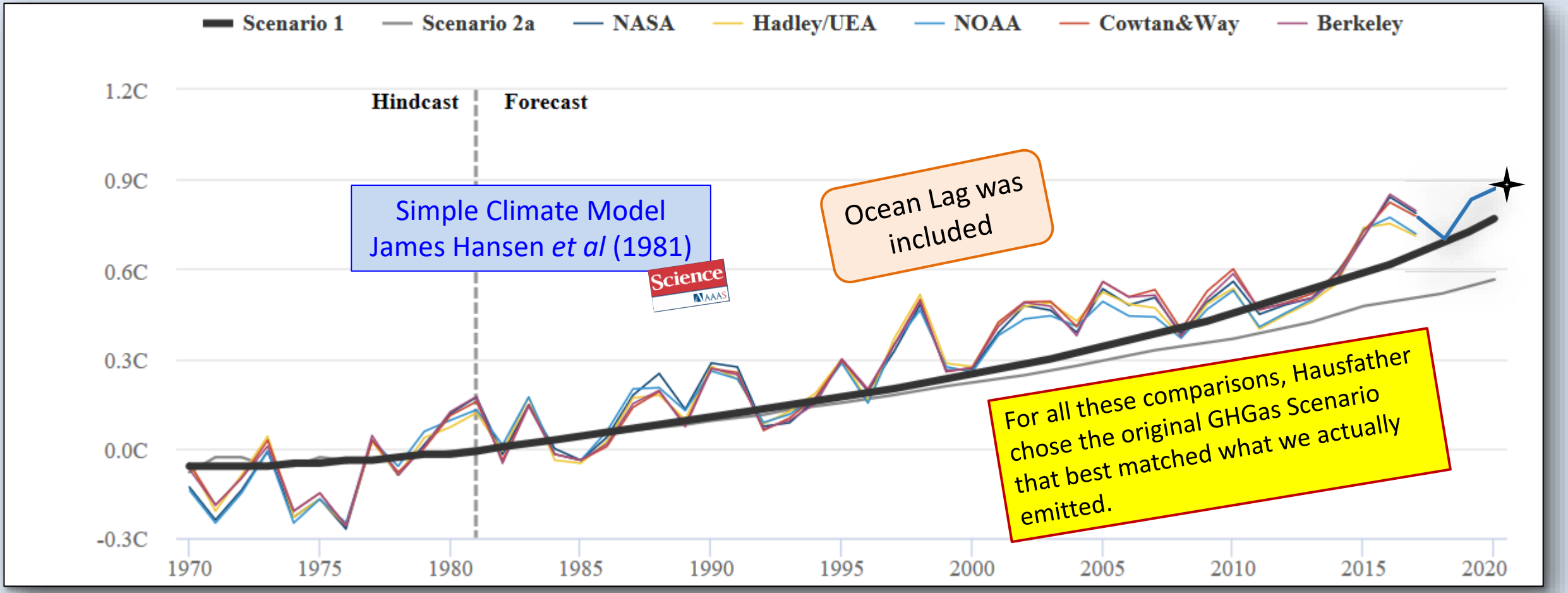
How Well Did They Do?



Data assembled by Z. Hausfather, CarbonBrief.org

Climate Predictions:

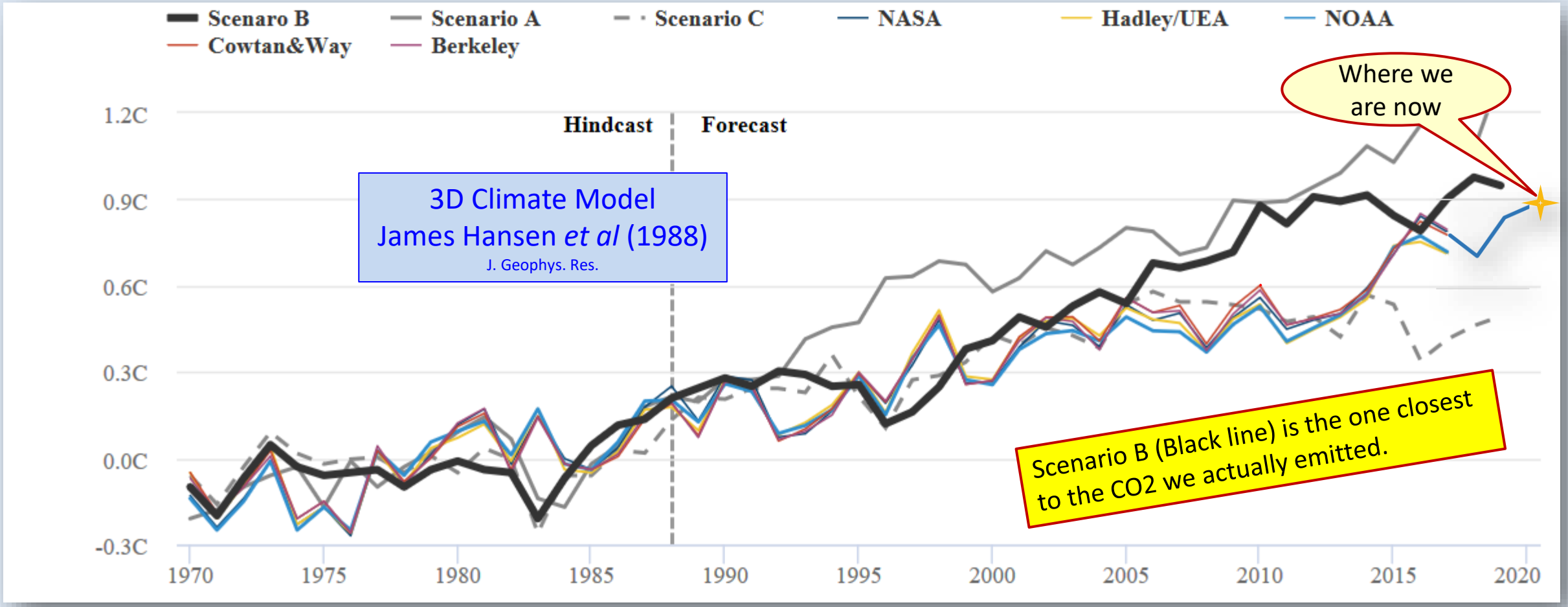
How Well Did They Do?



Data assembled by Z. Hausfather, CarbonBrief.org

Climate Predictions:

How Well Did They Do?

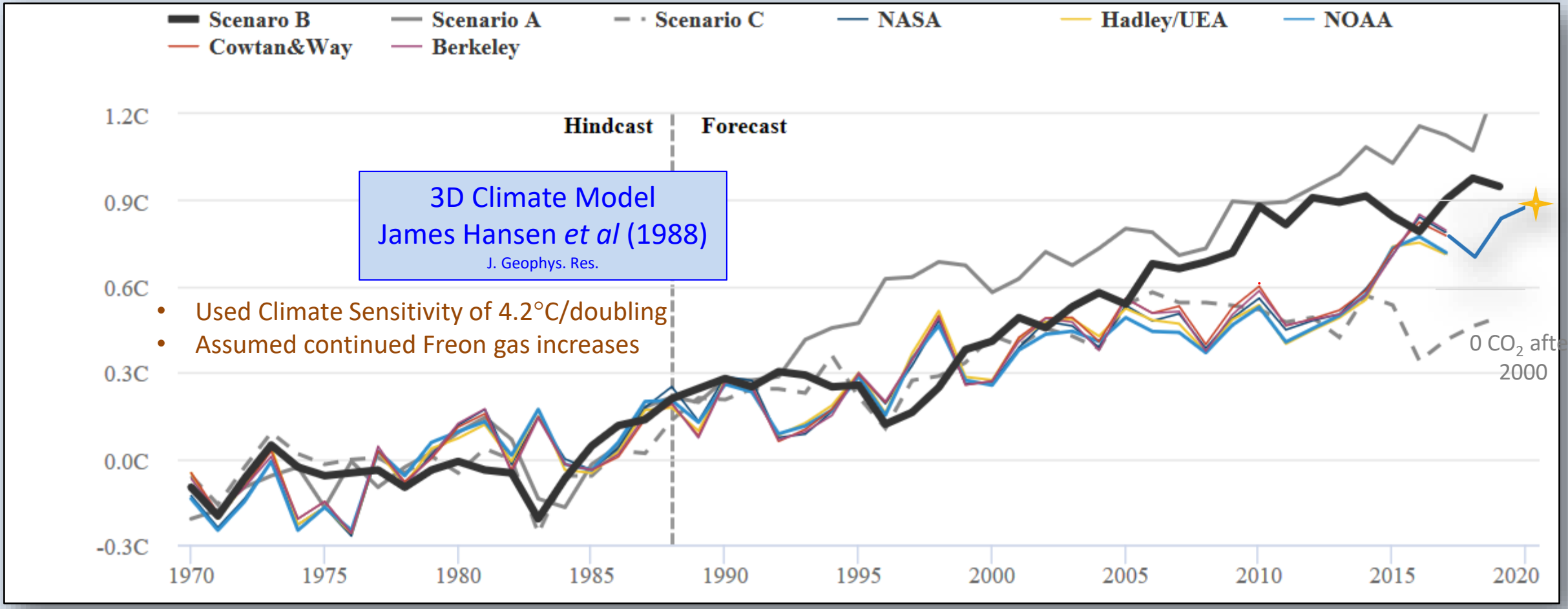


Baseline Period

Data assembled by Z. Hausfather, CarbonBrief.org

Climate Predictions:

How Well Did They Do?



3D Climate Model
James Hansen *et al* (1988)
J. Geophys. Res.

- Used Climate Sensitivity of 4.2°C/doubling
- Assumed continued Freon gas increases

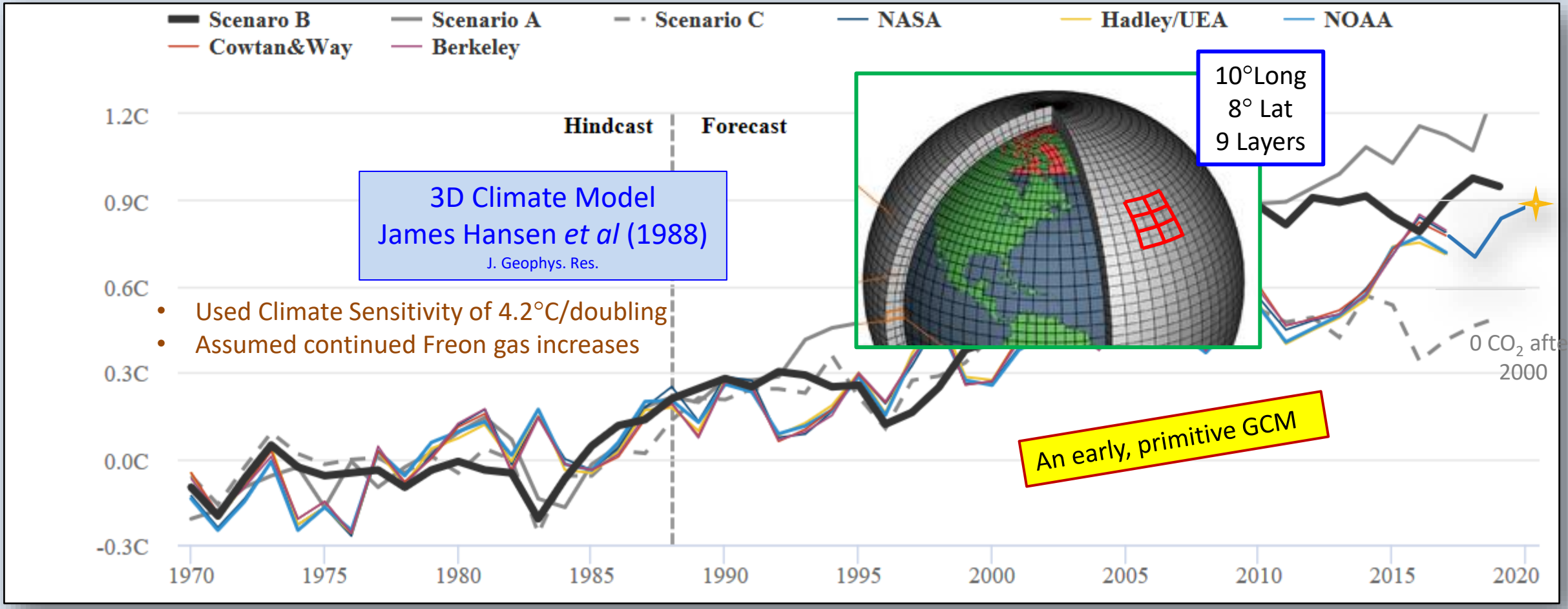
0 CO_2 after 2000

Baseline Period

Data assembled by Z. Hausfather, CarbonBrief.org

Climate Predictions:

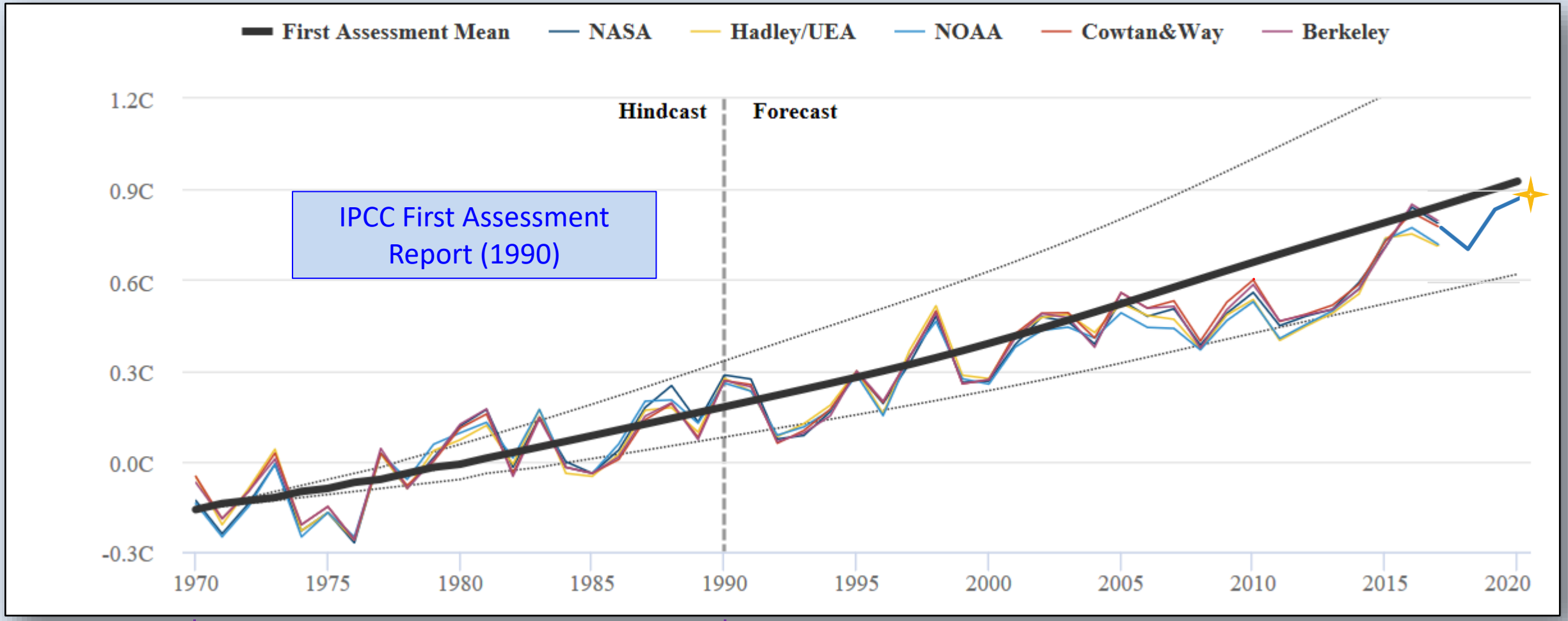
How Well Did They Do?



Data assembled by Z. Hausfather, CarbonBrief.org

Climate Predictions:

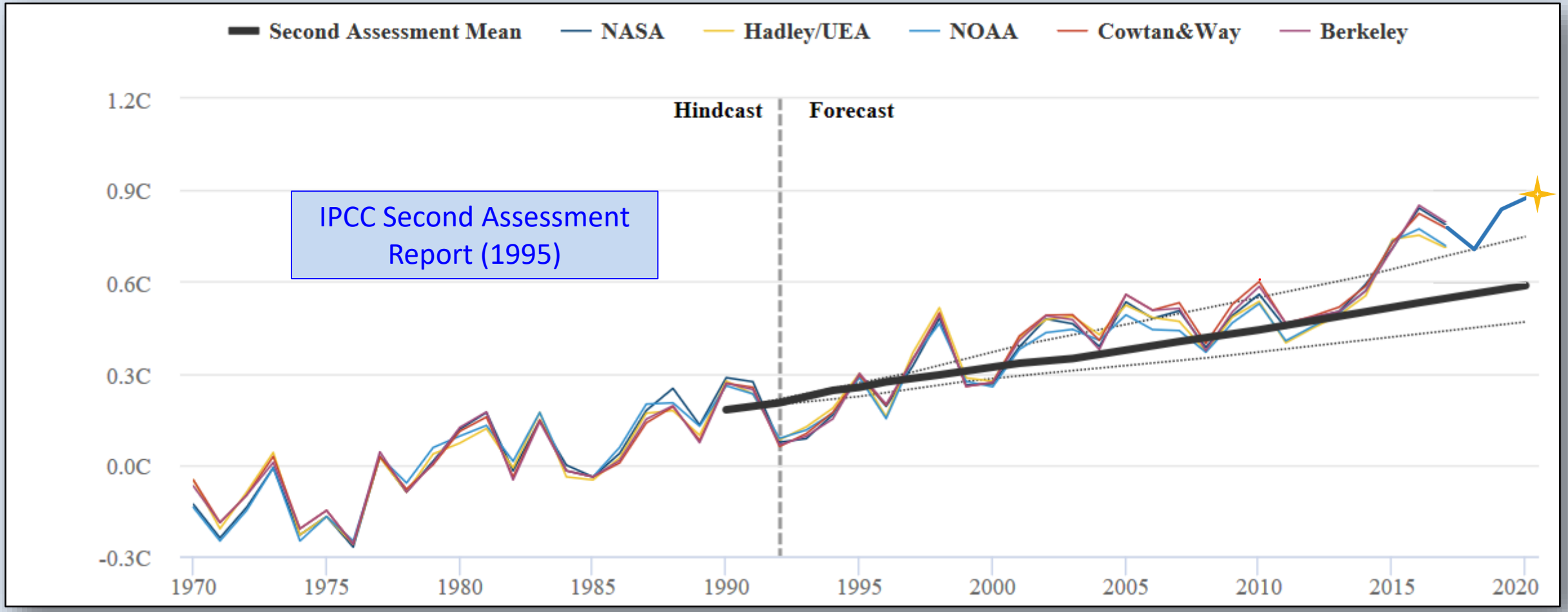
How Well Did They Do?



Data assembled by Z. Hausfather, CarbonBrief.org

Climate Predictions:

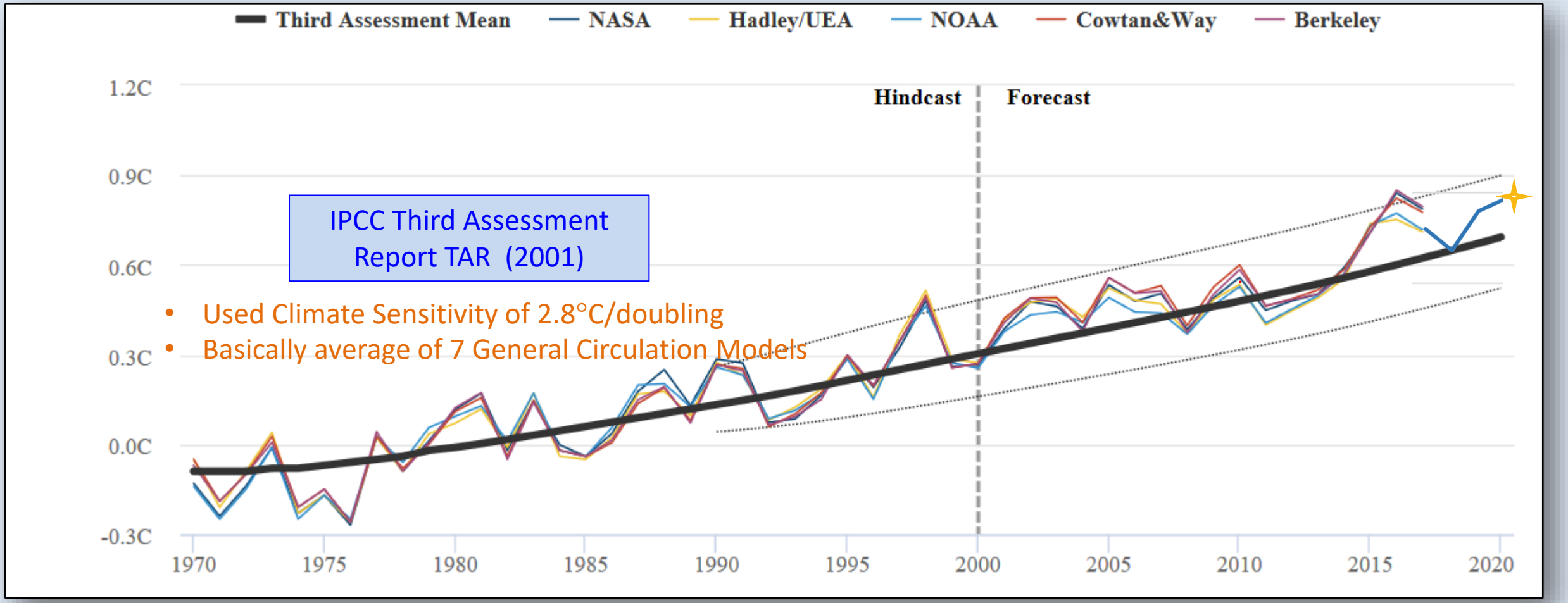
How Well Did They Do?



Data assembled by Z. Hausfather, CarbonBrief.org

Climate Predictions:

How Well Did They Do?



IPCC Third Assessment Report TAR (2001)

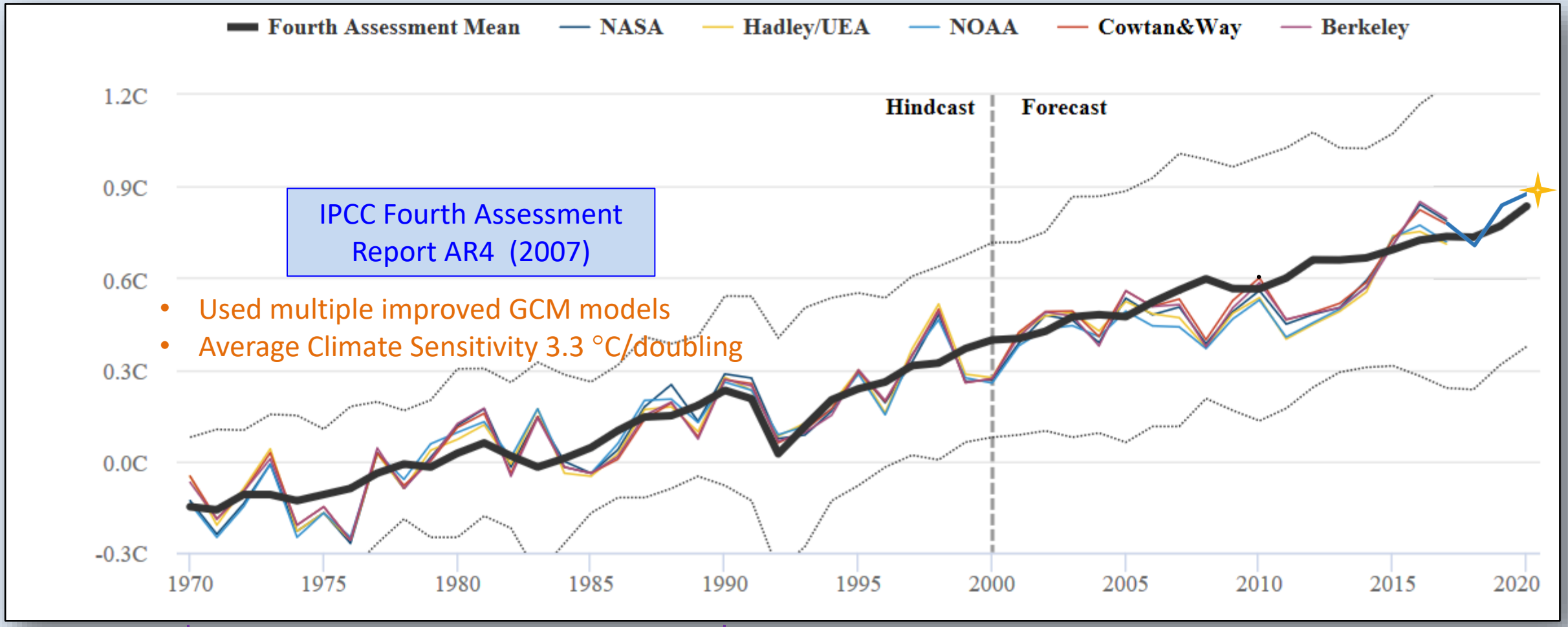
- Used Climate Sensitivity of 2.8°C/doubling
- Basically average of 7 General Circulation Models

Baseline Period

Data assembled by Z. Hausfather, CarbonBrief.org

Climate Predictions:

How Well Did They Do?



IPCC Fourth Assessment Report AR4 (2007)

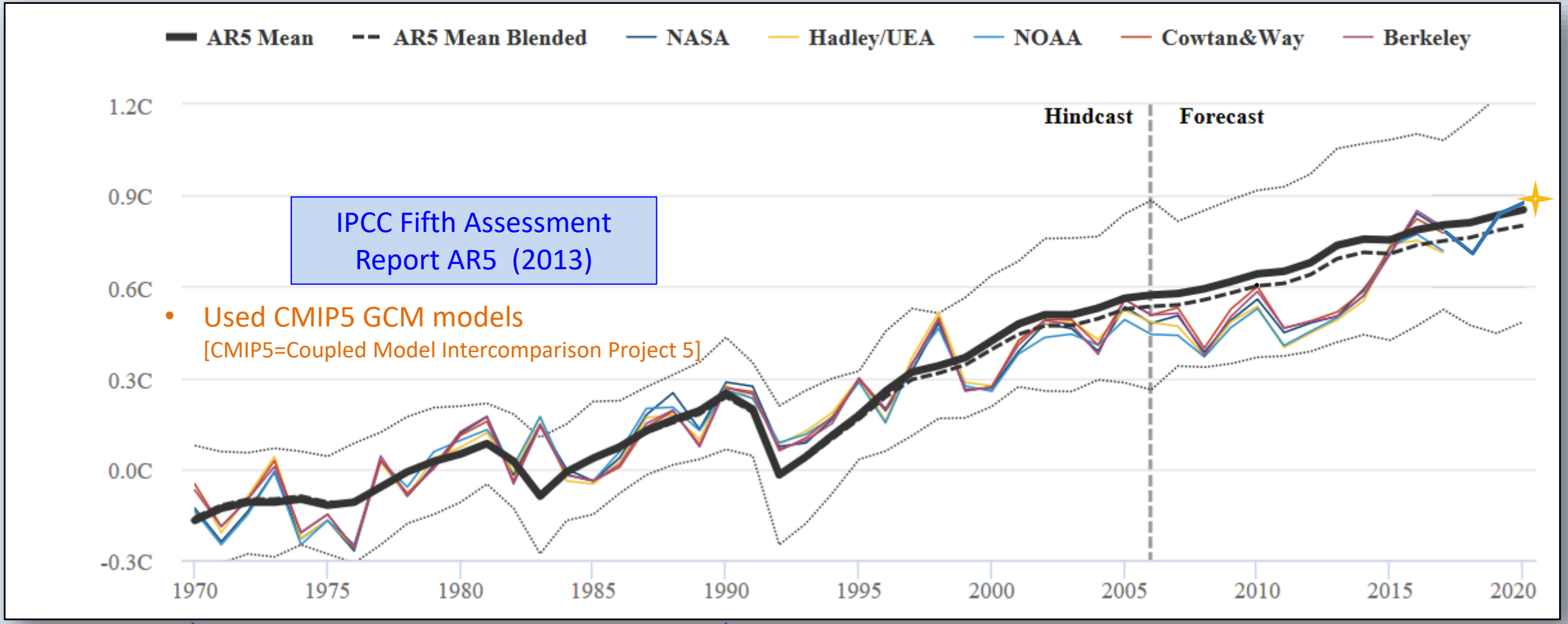
- Used multiple improved GCM models
- Average Climate Sensitivity 3.3 °C/doubling

Baseline Period

Data assembled by Z. Hausfather, CarbonBrief.org

Climate Predictions:

How Well Did They Do?



IPCC Fifth Assessment Report AR5 (2013)

- Used CMIP5 GCM models
  [CMIP5=Coupled Model Intercomparison Project 5]

Baseline Period

Data assembled by Z. Hausfather, CarbonBrief.org

WCRP World Climate Research Programme

AGU ADVANCING EARTH AND SPACE SCIENCE

DEC 2020
92 PAGES

Reviews of Geophysics

REVIEW ARTICLE
10.1029/2019RG000678

Key Points:

- We assess evidence relevant to Earth's climate sensitivity *S*: feedback process understanding and the historical and paleoclimate records
- All three lines of evidence are difficult to reconcile with $S < 2$ K, while paleo evidence provides the strongest case against $S > 4.5$ K
- A Bayesian calculation finds a 66% range of 2.6–3.9 K, which remains within the bounds 2.3–4.5 K under plausible robustness tests

An Assessment of Earth's Climate Sensitivity Using Multiple Lines of Evidence

S. C. Sherwood[1], M. J. Webb[2], J. D. Annan[3], K. C. Armour[4], P. M. Forster[5], J. C. Hargreaves[3], G. Hegerl[6], S. A. Klein[7], K. D. Marvel[8,9], E. J. Rohling[10,11], M. Watanabe[12], T. Andrews[2], P. Braconnot[13], C. S. Bretherton[4], G. L. Foster[11], Z. Hausfather[14], A. S. von der Heydt[15], R. Knutti[16], T. Mauritsen[17], J. R. Norris[18], C. Proistosescu[19], M. Rugenstein[20], G. A. Schmidt[9], K. B. Tokarska[6,16], and M. D. Zelinka[7]

[1]Climate Change Research Centre and ARC Centre of Excellence for Climate Extremes, University of New South Wales Sydney, Sydney, New South Wales, Australia, [2]Met Off... Research Ltd, Settle, UK, [4]University o... niversity of Leeds, Leeds, UK, [6]Scho... lifornia, Berkeley, USA, [8]Departm... USA, [9]NASA Goddard Institute for Sp... an National University, Canberra, AC... rsity of Southampton, Southampt... okyo, Japan, [13]Laboratoire des Science... aris-Saclay, Gif sur Yvette, France, [14]... ic Research, and Centre for Complex S... Institute for Atmospheric and Climate Science, Zuric... Department of Meteorology, Stockholm University, Stockholm, Sweden, [18]Scripps Institution of Oceanography, La Jolla, CA, USA, [19]Department of Atmospheric Sciences and Department of Geology, University of Illinois at Urbana-Champaign, Urbana, IL, USA, [20]Max Planck Institute for Meteorology, Hamburg, Germany

Cristian Proistosescu

UIUC Department of Atmospheric Sciences

Climate Modeler

Correspondence to:
S. Sherwood,
s.sherwood@unsw.edu.au

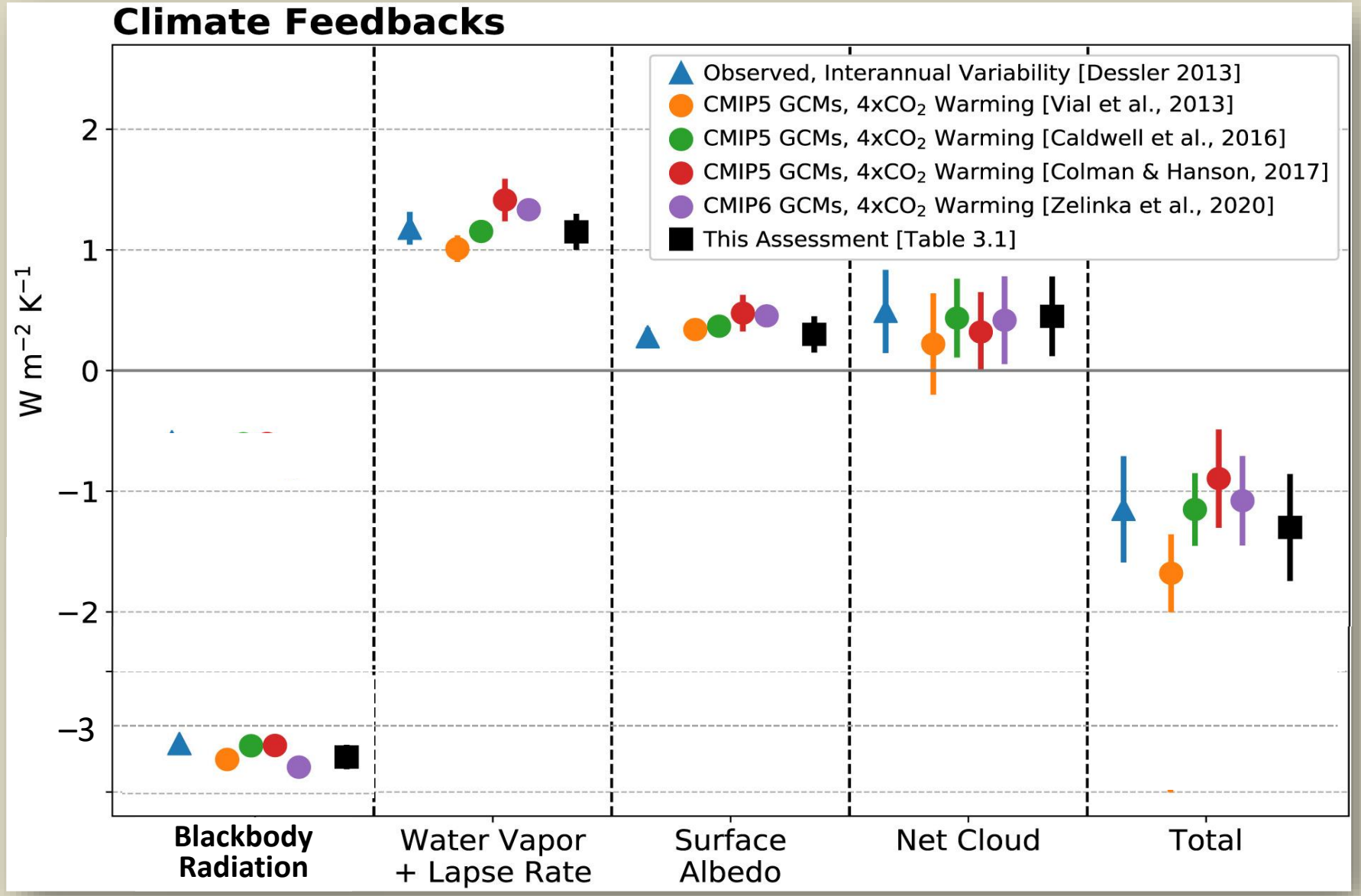
Citation:
Sherwood, S. C., Webb, M. J., Annan, J. D., Armour, K. C., Forster, P. M., Hargreaves, J. C., et al. (2020). An assessment of Earth's climate sensitivity

Basis of WCRP* Climate Sensitivity Estimates

- Analysis of Feedback Processes
  - Water Vapor Feedback
  - Surface Albedo Feedback
  - **Net Cloud Feedback** now thought to be net heating
  - *& others*
- Historical Records: Compatibility with models
- Paleoclimate Records: Compatibility with models
- Use of Bayesian Statistical Methods

* World Climate Research Programme
Sherwood *et al* (2020)

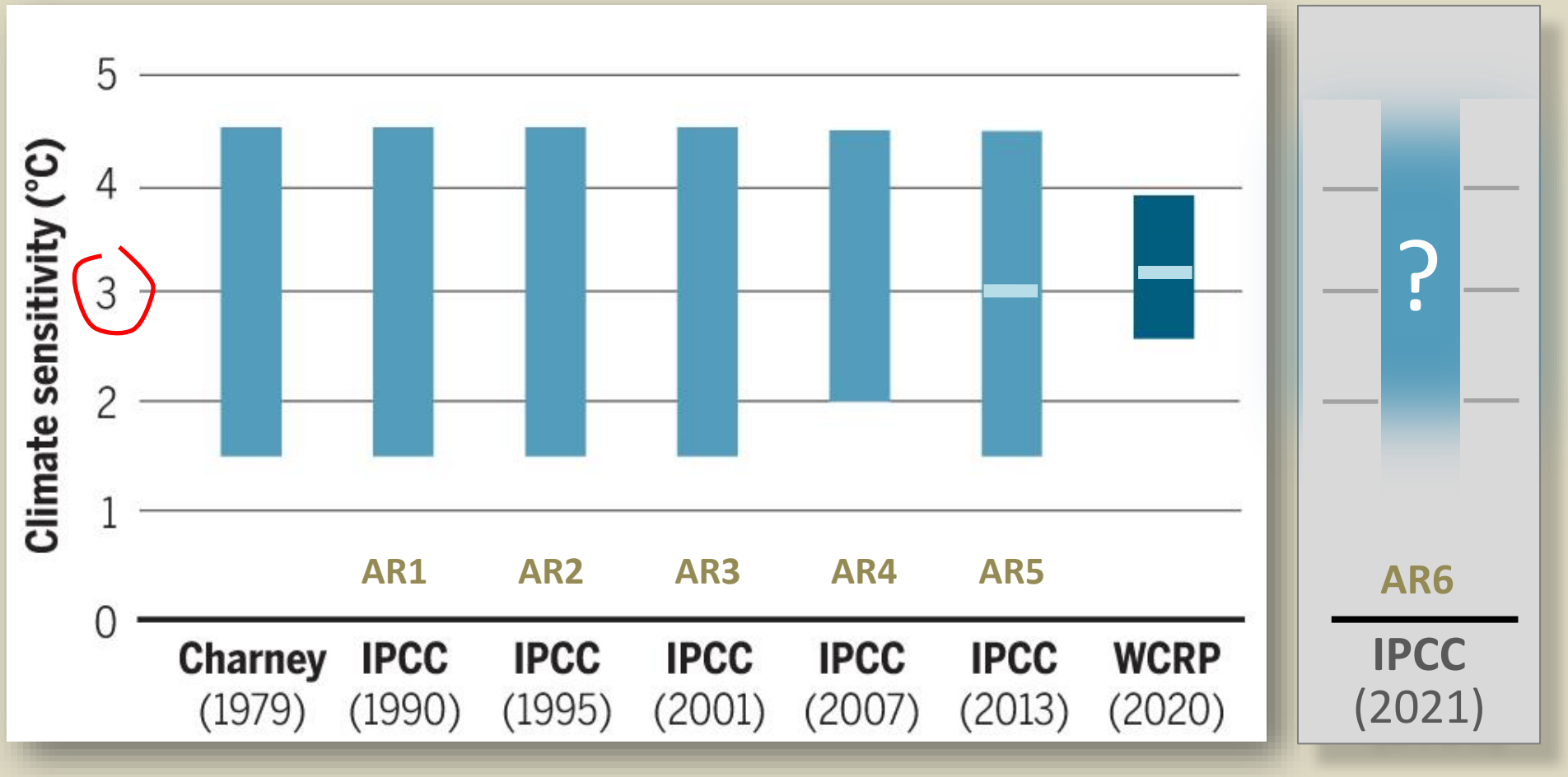
WCRP Climate Sensitivity Estimates



Sherwood *et al* (2020)

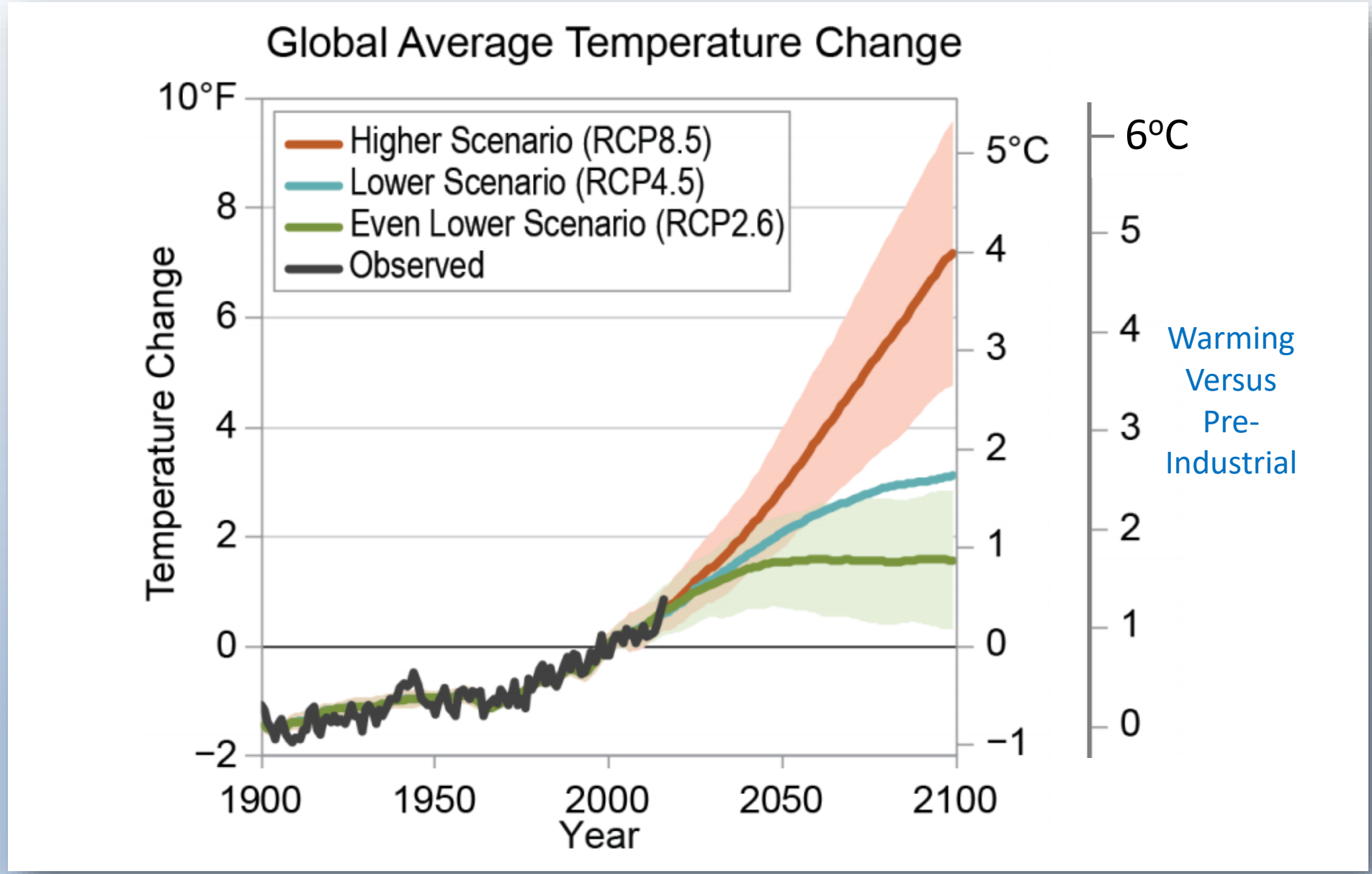
Climate Sensitivity Estimates over Time

Range of "Likely" Temperature Rises for a CO_2 Doubling



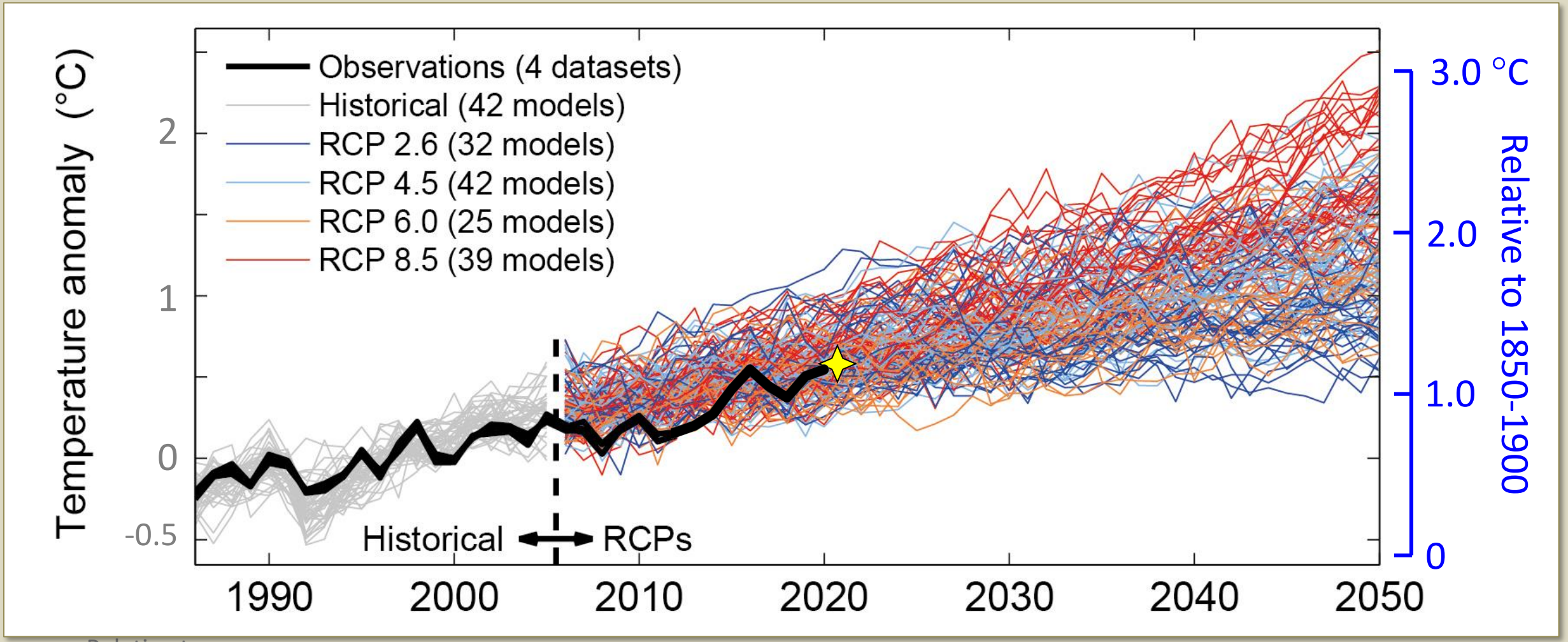
Sherwood *et al* (2020)

Current and Recent Predictions



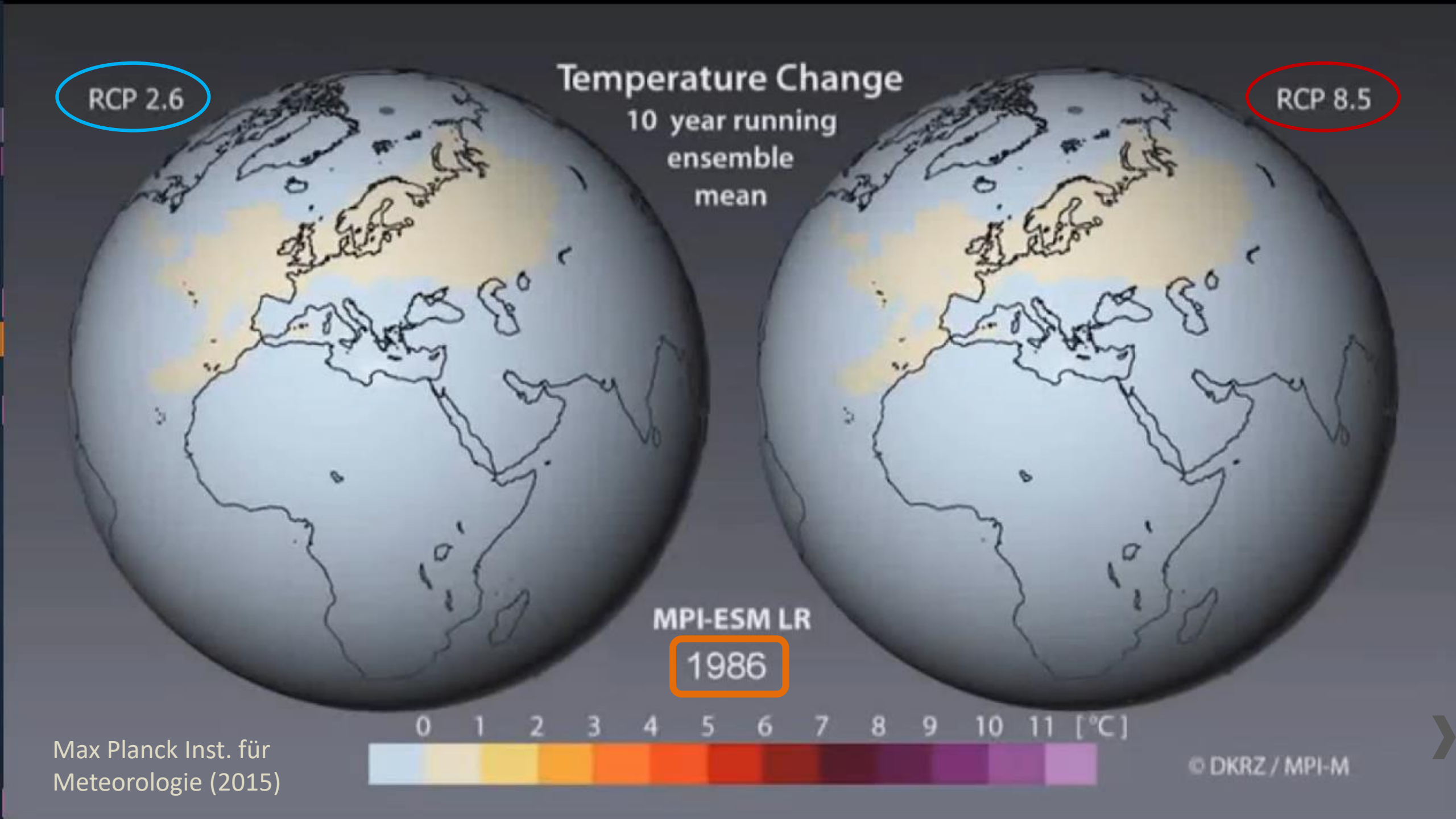
National Climate Assessment 4 (2018) Fig. A5.10

AR5 Projections from ~2007

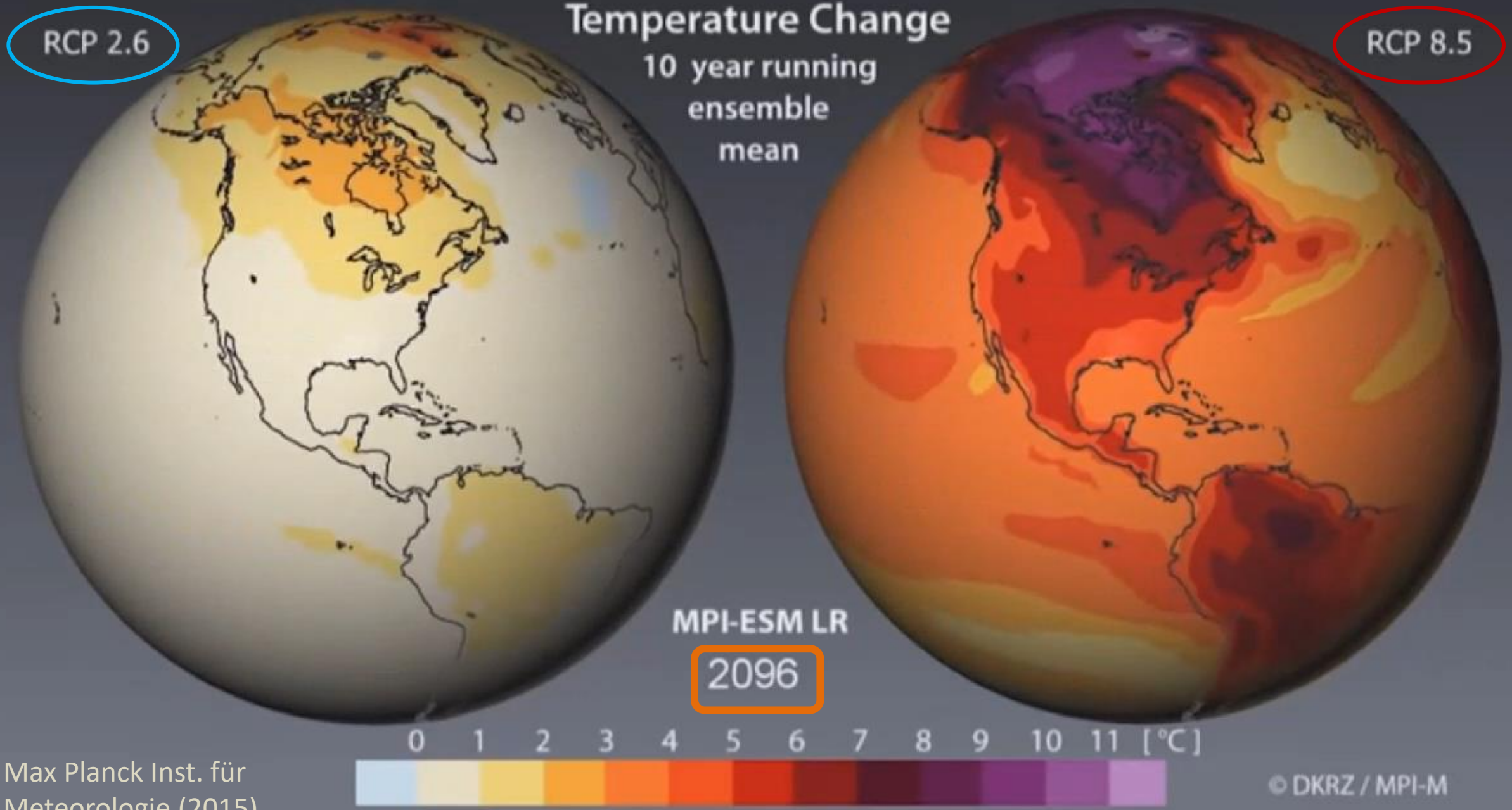


Relative to 1986-2005

IPCC AR5 11.25



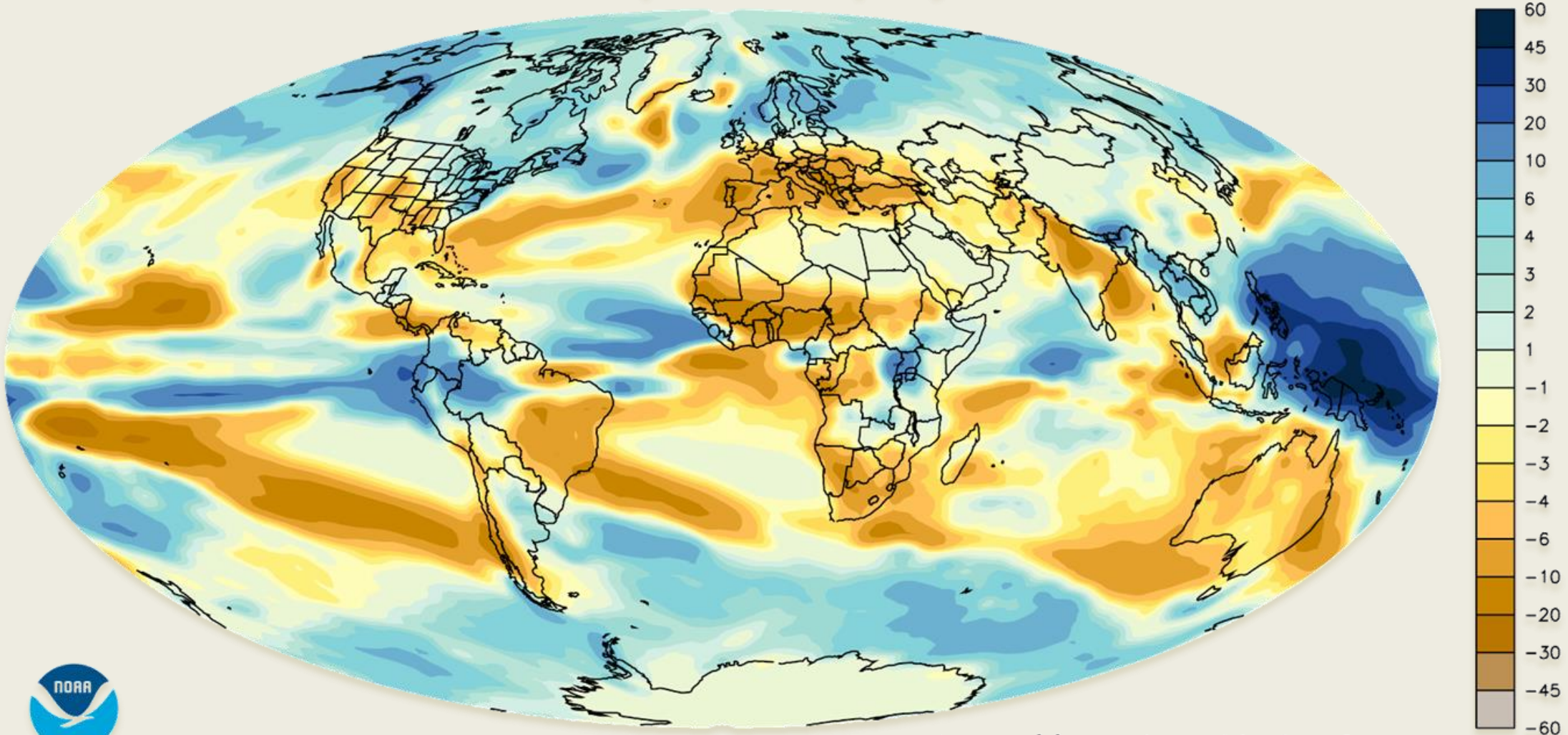
Max Planck Inst. für Meteorologie (2015)



Max Planck Inst. für Meteorologie (2015)

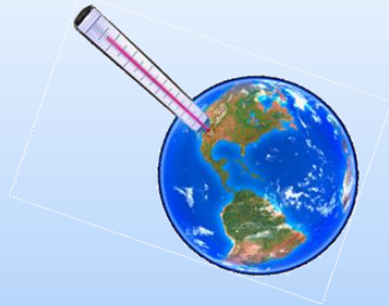
CHANGE IN PRECIPITATION BY END OF 21st CENTURY

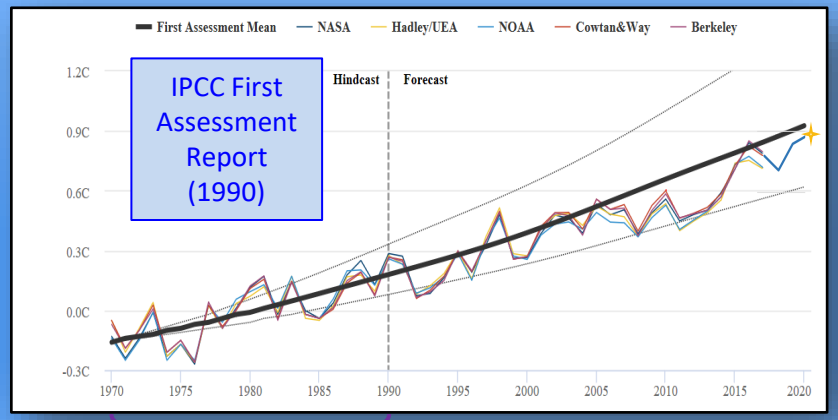
inches of liquid water per year

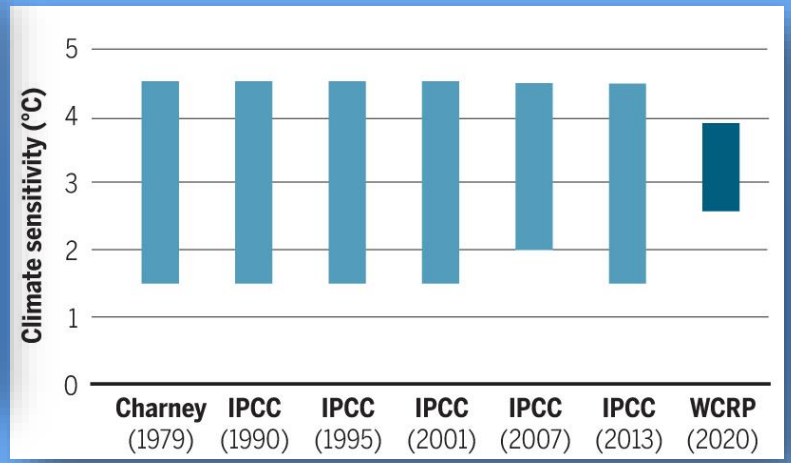


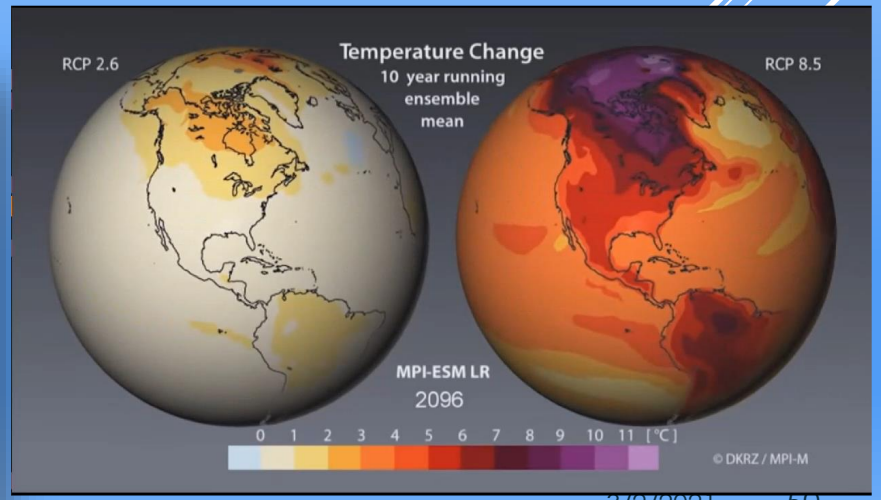
as projected by NOAA/GFDL CM2.1

Questions about Prediction Skill, Climate Sensitivity, Global Trends





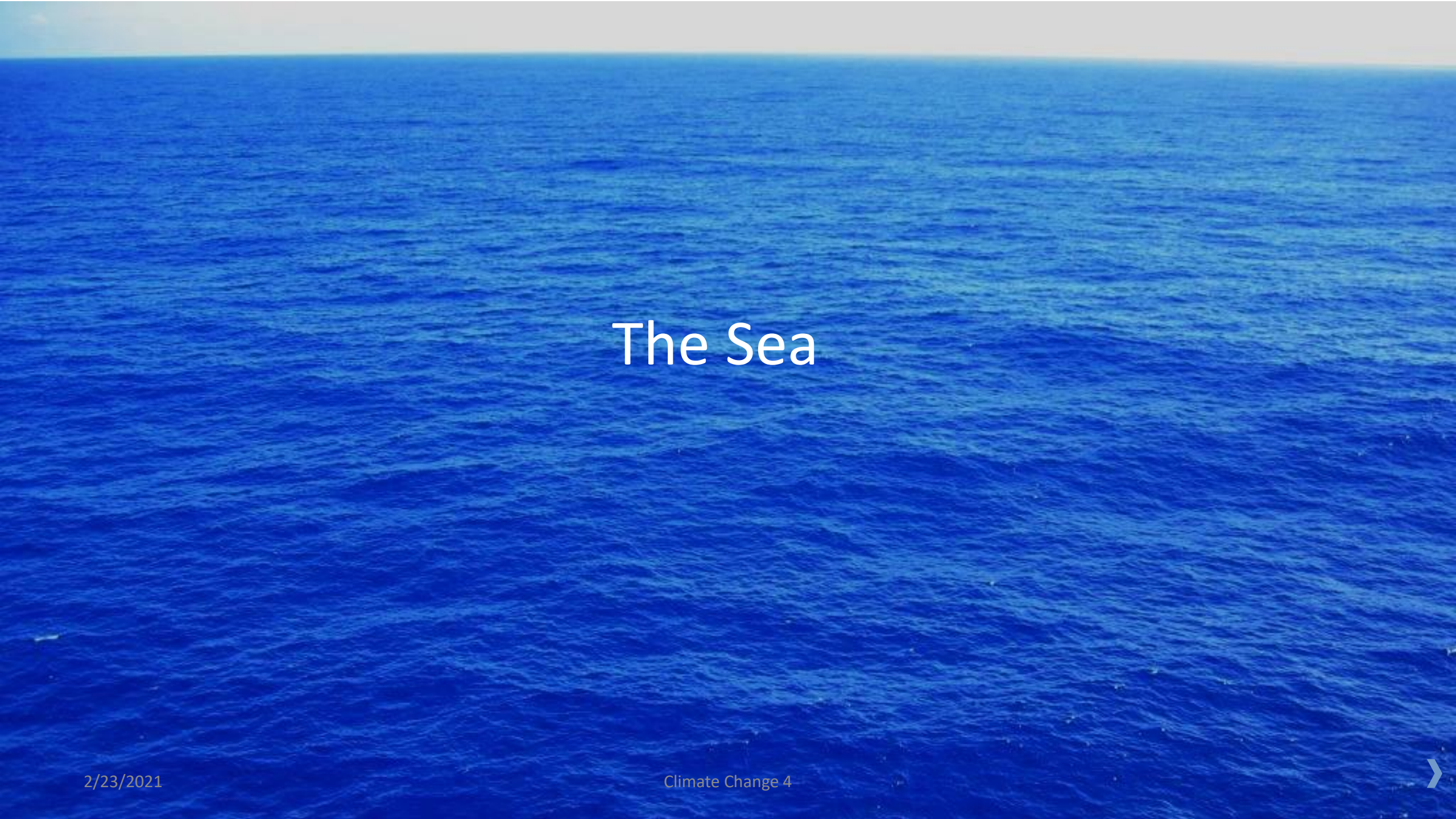


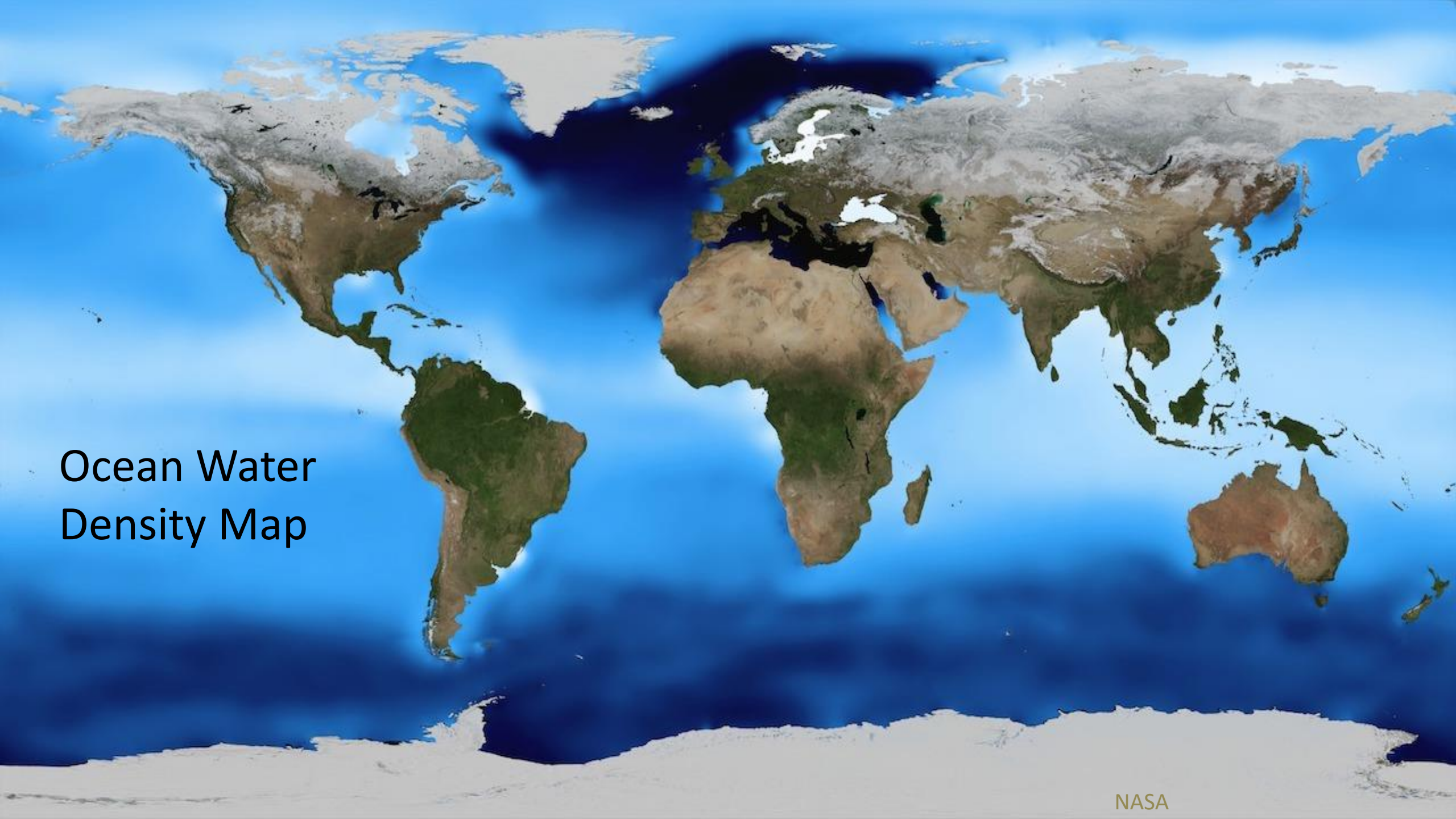


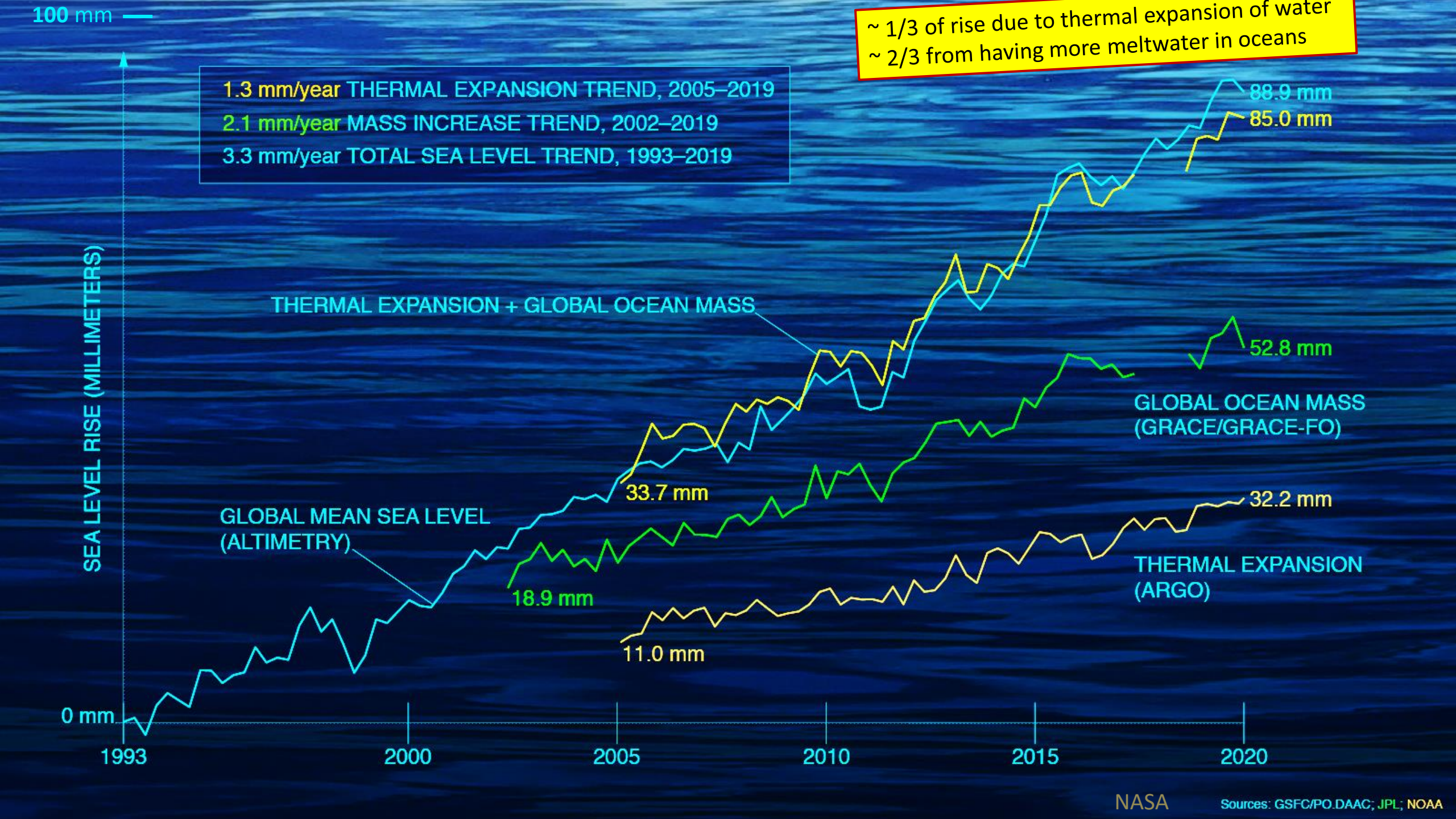
Baseline

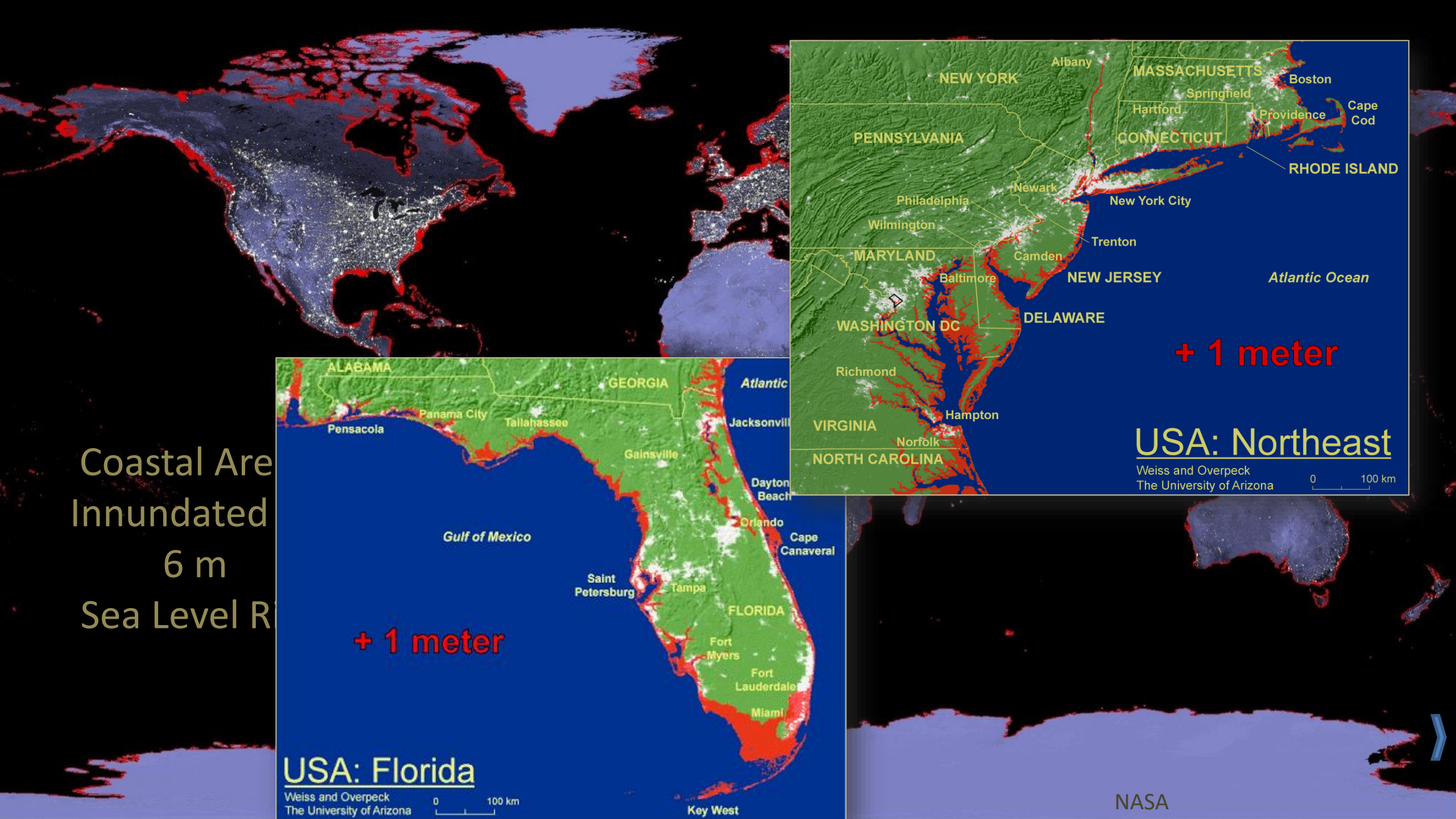
Climate Impacts Expected in This Century and Beyond

- Sea
  - Sea Level Increases
  - Acidification
  - Warming
  - Circulation changes
- Cryosphere melting
- Land
  - Heat and Drought
  - Precipitation/Floods
  - Extreme Weather Events
  - Food Production
  - Biome
- People
  - Migration
  - Health
  - Food Security
  - Economic


The Sea

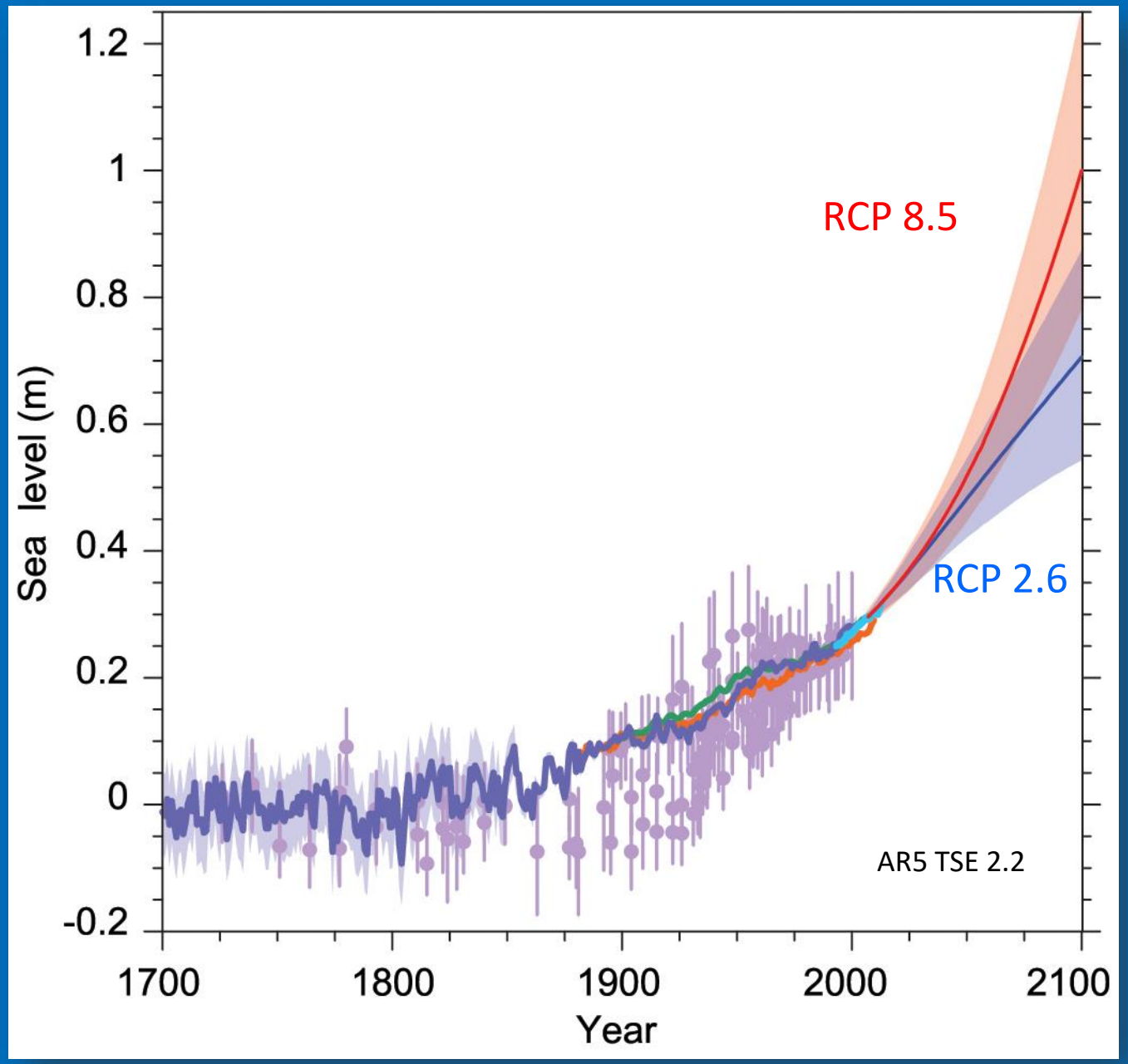

Ocean Water
Density Map
NASA


~ 1/3 of rise due to thermal expansion of water
~ 2/3 from having more meltwater in oceans
100 mm
1.3 mm/year THERMAL EXPANSION TREND, 2005–2019
2.1 mm/year MASS INCREASE TREND, 2002–2019
3.3 mm/year TOTAL SEA LEVEL TREND, 1993–2019
SEA LEVEL RISE (MILLIMETERS)
THERMAL EXPANSION + GLOBAL OCEAN MASS
88.9 mm
85.0 mm
52.8 mm
GLOBAL OCEAN MASS
(GRACE/GRACE-FO)
33.7 mm
GLOBAL MEAN SEA LEVEL
(ALTIMETRY)
32.2 mm
THERMAL EXPANSION
(ARGO)
18.9 mm
11.0 mm
0 mm
1993
2000
2005
2010
2015
2020
NASA
Sources: GSFC/PO.DAAC; JPL; NOAA


Coastal Are
Innundated
6 m
Sea Level R
NEW YORK
Albany
MASSACHUSETTS
Boston
Springfield
Hartford
Providence
Cape Cod
PENNSYLVANIA
CONNECTICUT
RHODE ISLAND
Philadelphia
Newark
New York City
Wilmington
Trenton
MARYLAND
Camden
Baltimore
NEW JERSEY
Atlantic Ocean
WASHINGTON DC
DELAWARE
+ 1 meter
Richmond
Hampton
VIRGINIA
Norfolk
NORTH CAROLINA
USA: Northeast
Weiss and Overpeck
The University of Arizona
0
100 km
ALABAMA
GEORGIA
Atlantic
Panama City
Tallahassee
Pensacola
Jacksonvill
Gainsville
Dayton Beach
Orlando
Gulf of Mexico
Cape Canaveral
Saint Petersburg
Tampa
FLORIDA
+ 1 meter
Fort Myers
Fort Lauderdale
Miami
USA: Florida
Weiss and Overpeck
The University of Arizona
0
100 km
Key West
NASA

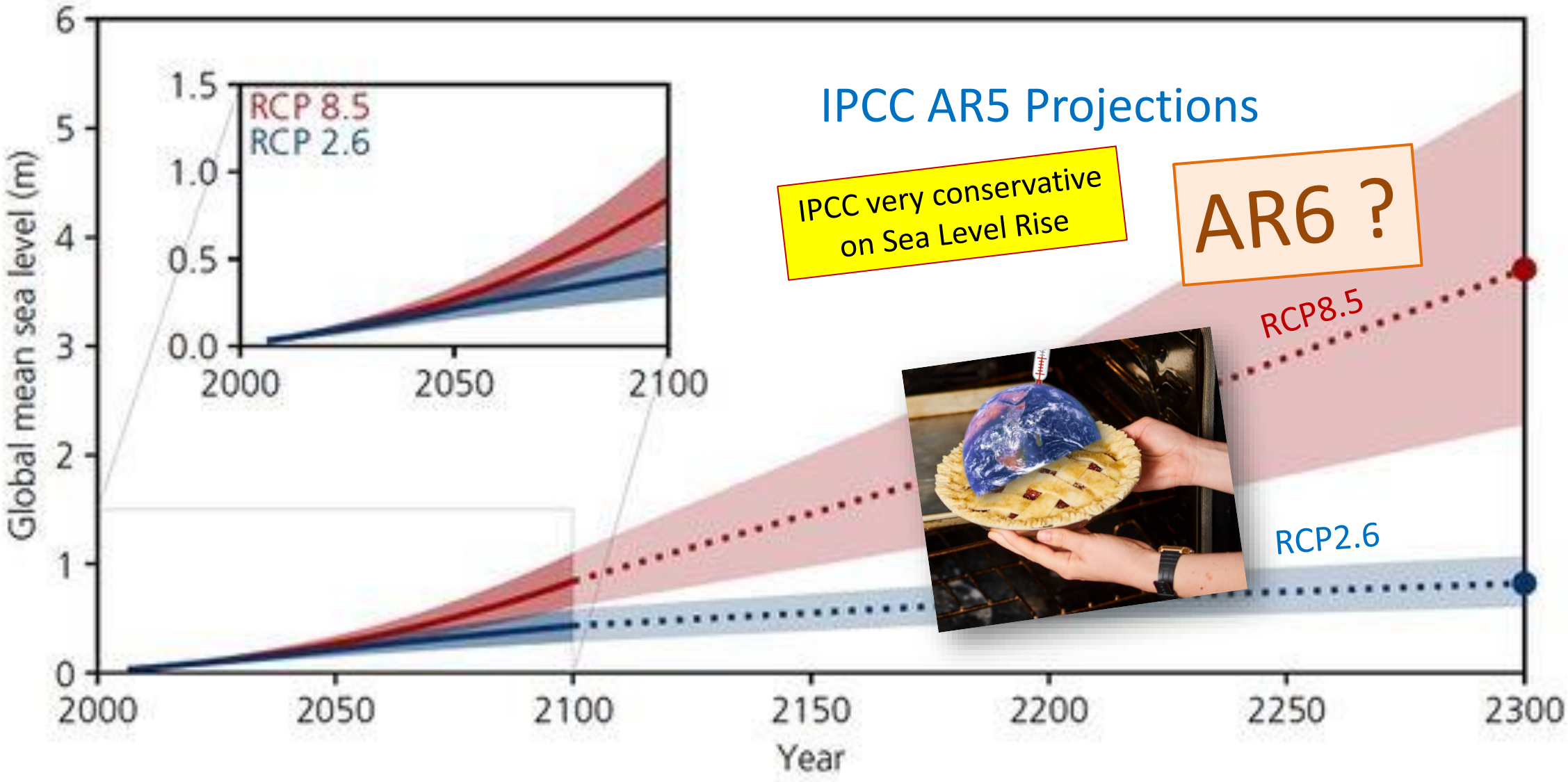
Business Insider

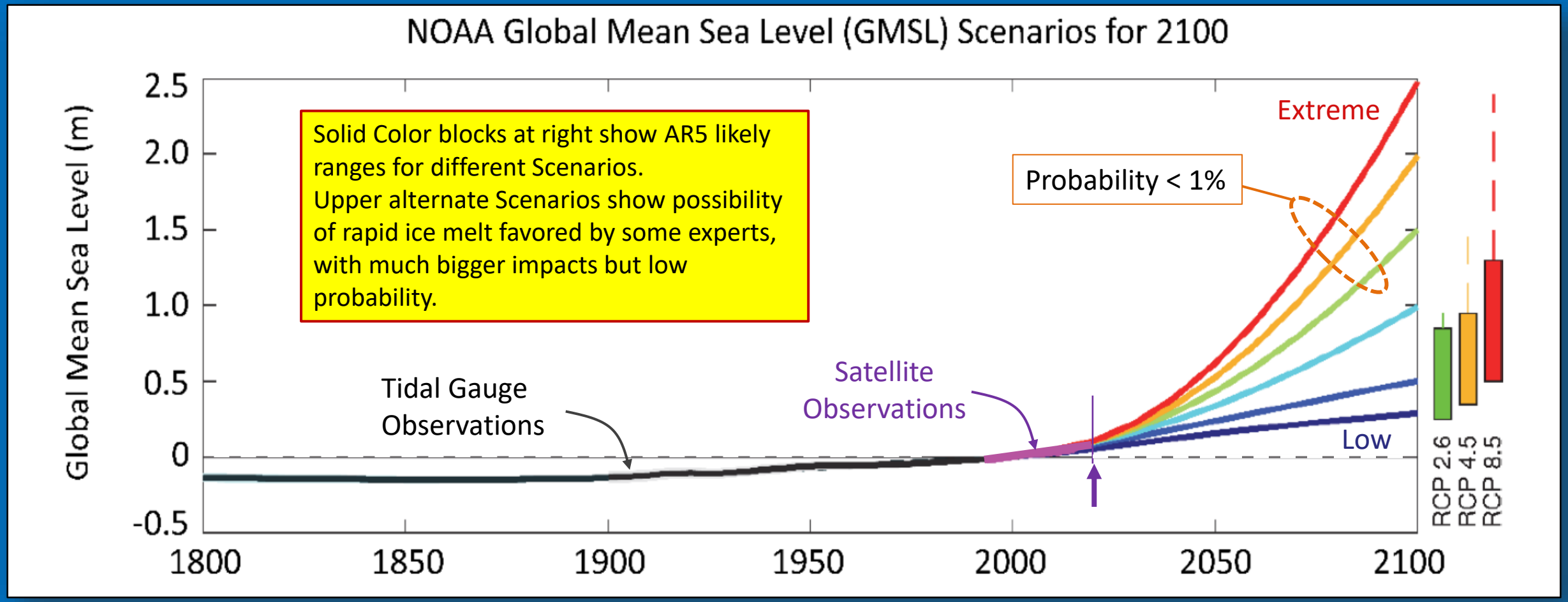
Business Insider


1.2
1
0.8
0.6
0.4
0.2
0
-0.2
Sea level (m)
1700
1800
1900
2000
2100
Year
RCP 8.5
RCP 2.6
AR5 TSE 2.2

RCP 2.6

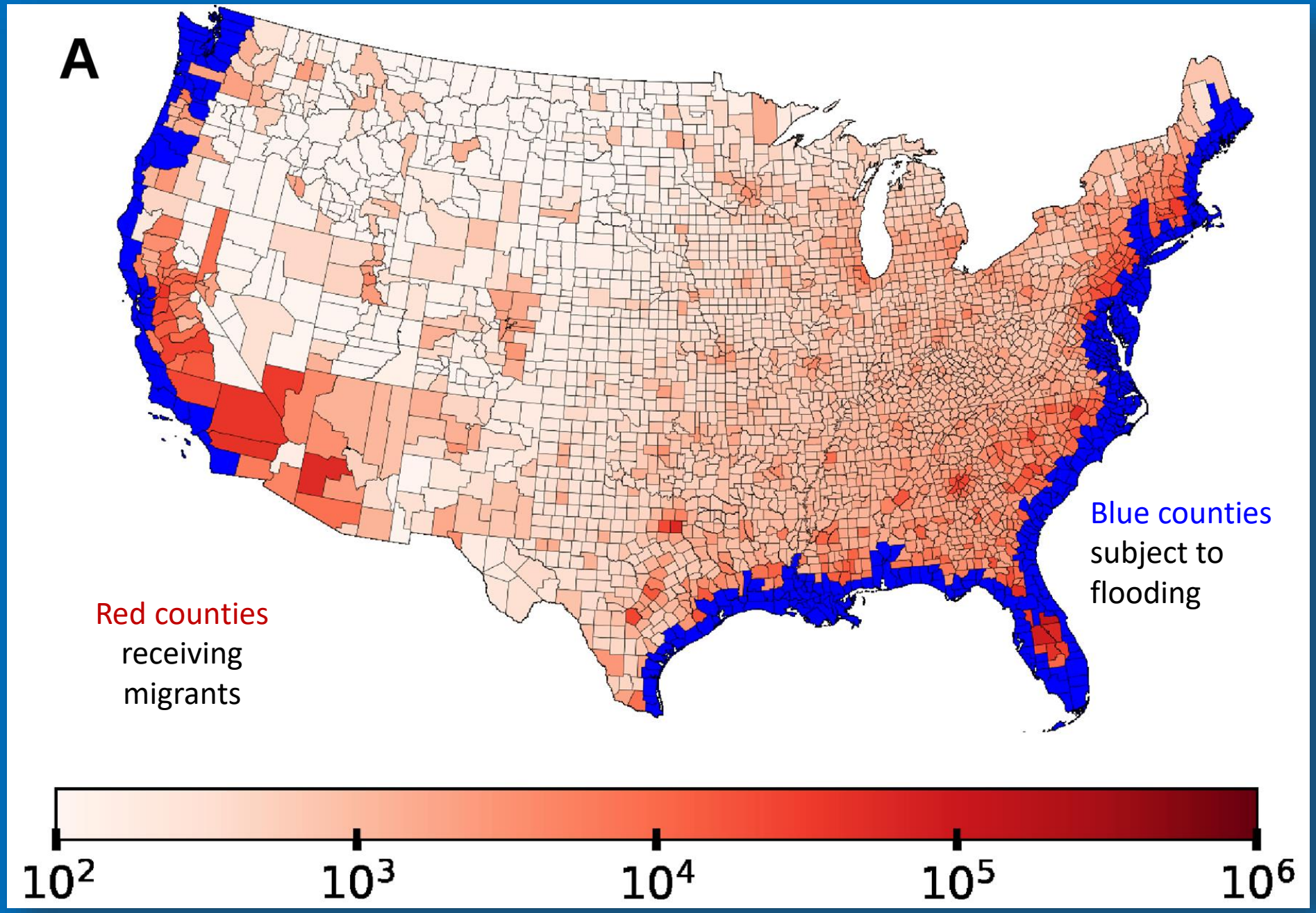
IPCC AR5 Projections





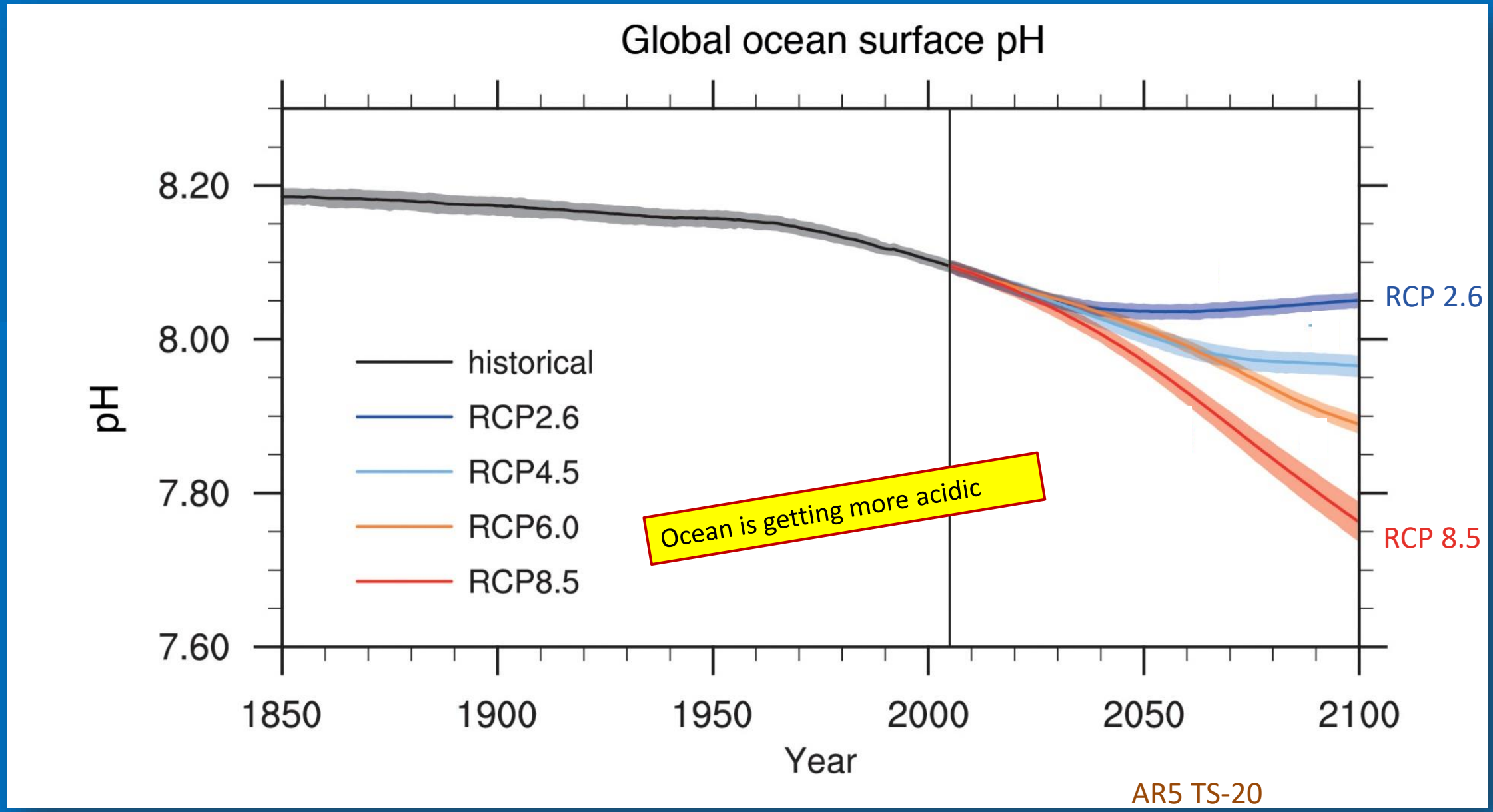
Adapted from Sweet et al, NOAA Technical Report "Global and Regional Sea Level Rise Scenarios for the United States" (2017)

Modeling Migration under Sea Level Rise of 1.8m by 2100



Robinson et al, PLOS|One (2020)

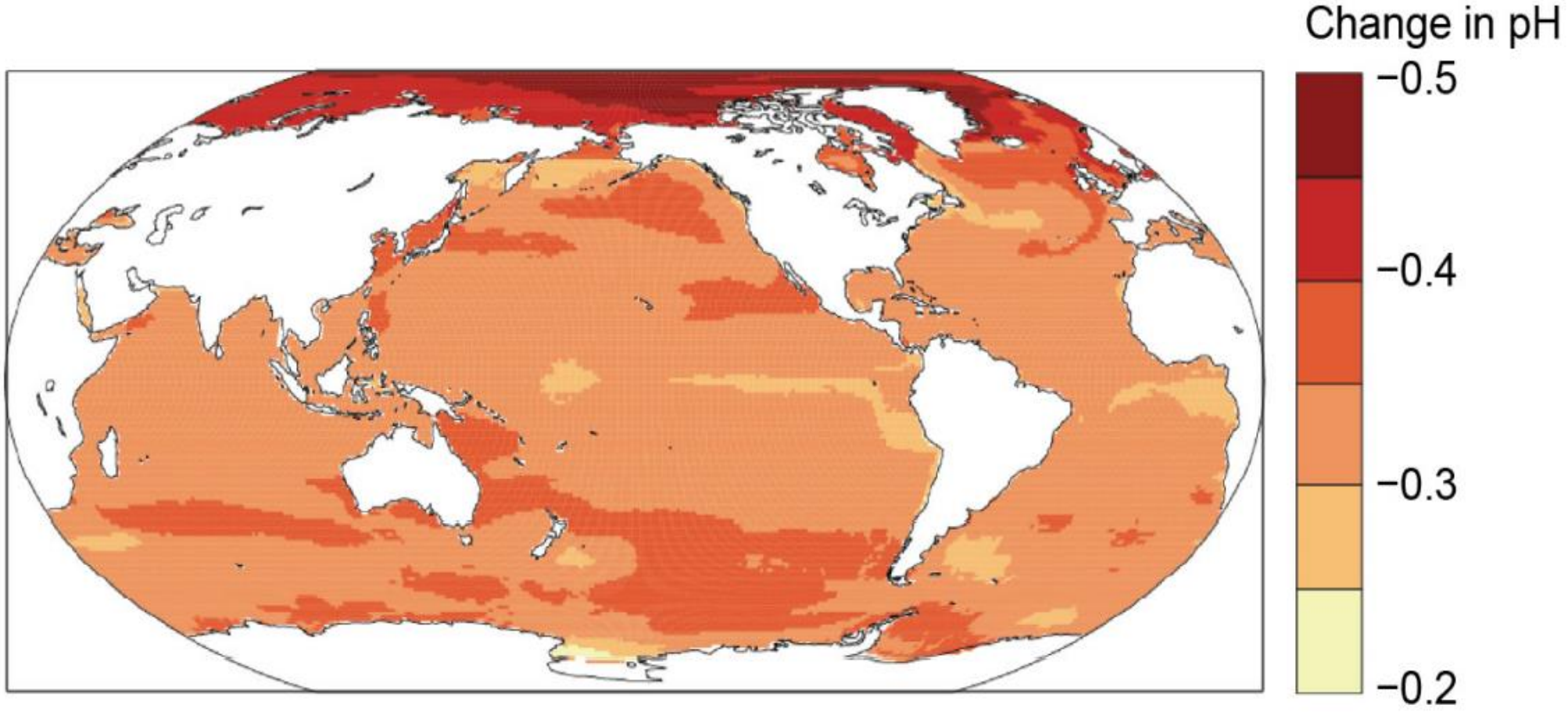
"Modeling Migration Patterns in the USA under Sea Level Rise"


Global ocean surface pH
8.20
8.00
7.80
7.60
pH
1850
1900
1950
2000
2050
2100
Year
historical
RCP2.6
RCP4.5
RCP6.0
RCP8.5
Ocean is getting more acidic
RCP 2.6
RCP 8.5

AR5 TS-20

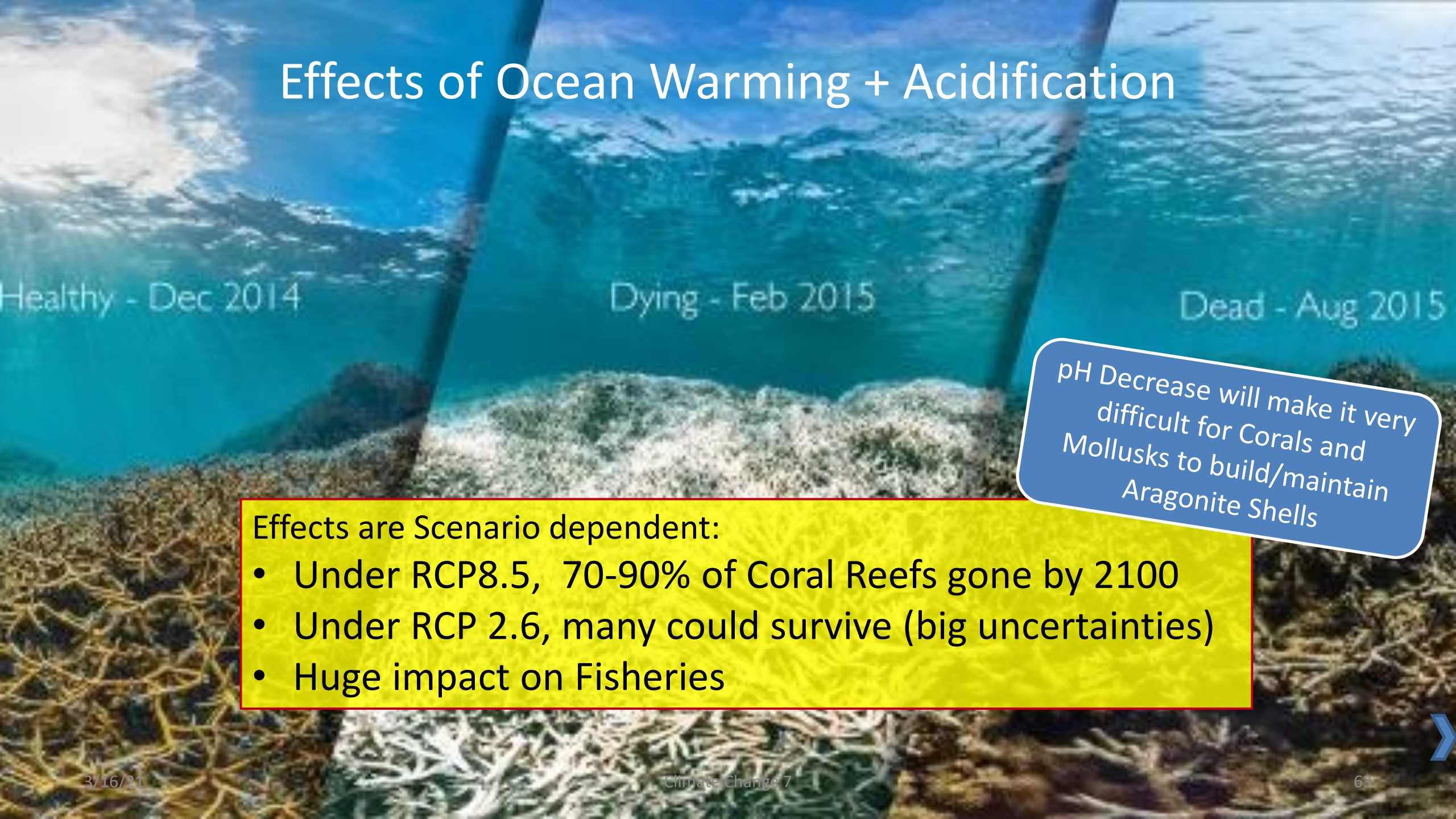
Projected Change in Surface Ocean Acidity

RCP 8.5
[2090-2099
vs
1990-1999]



National Climate Assessment 4 (2018) Fig. A5.30

Effects of Ocean Warming + Acidification

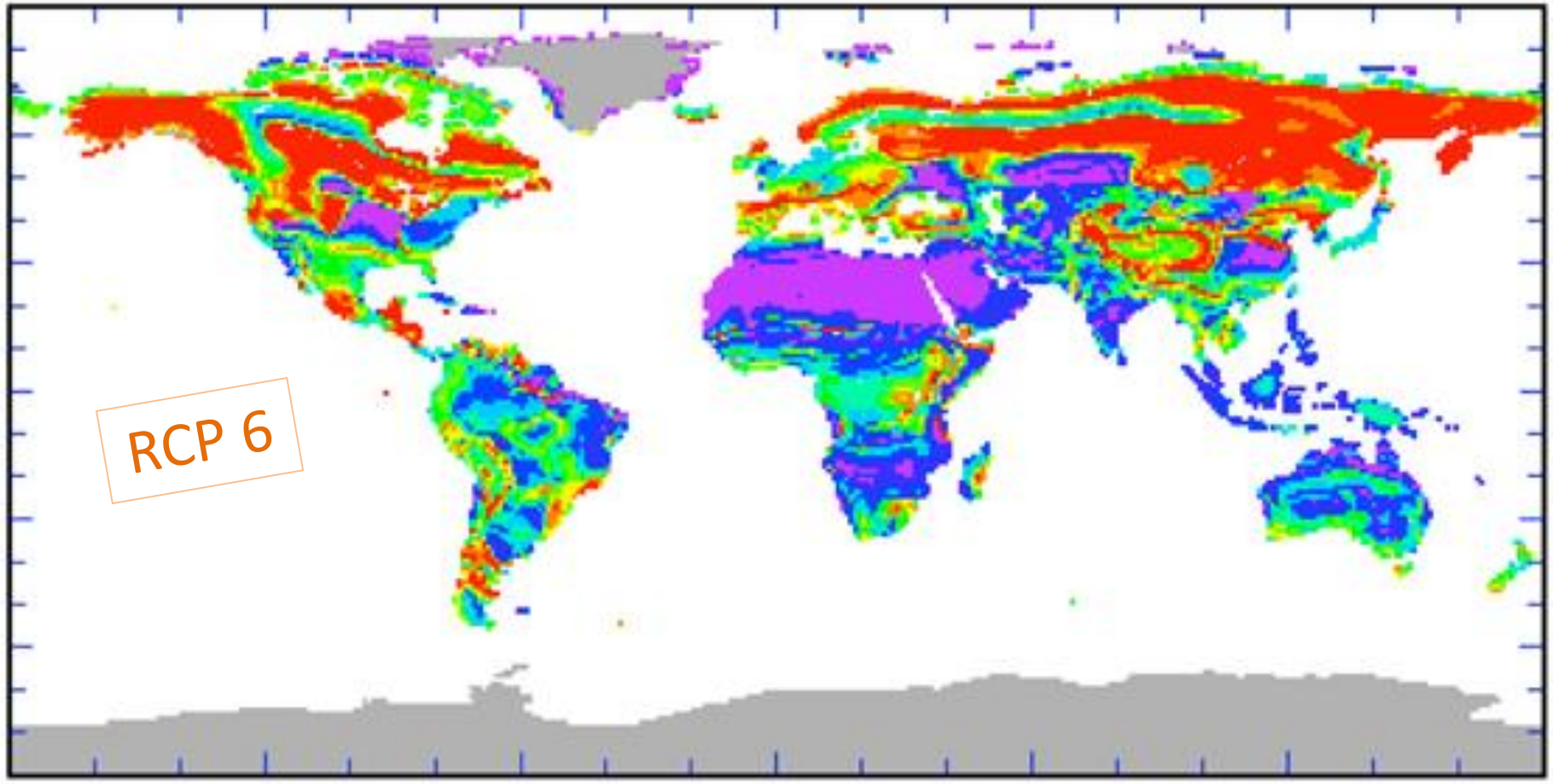


pH Decrease will make it very difficult for Corals and Mollusks to build/maintain Aragonite Shells

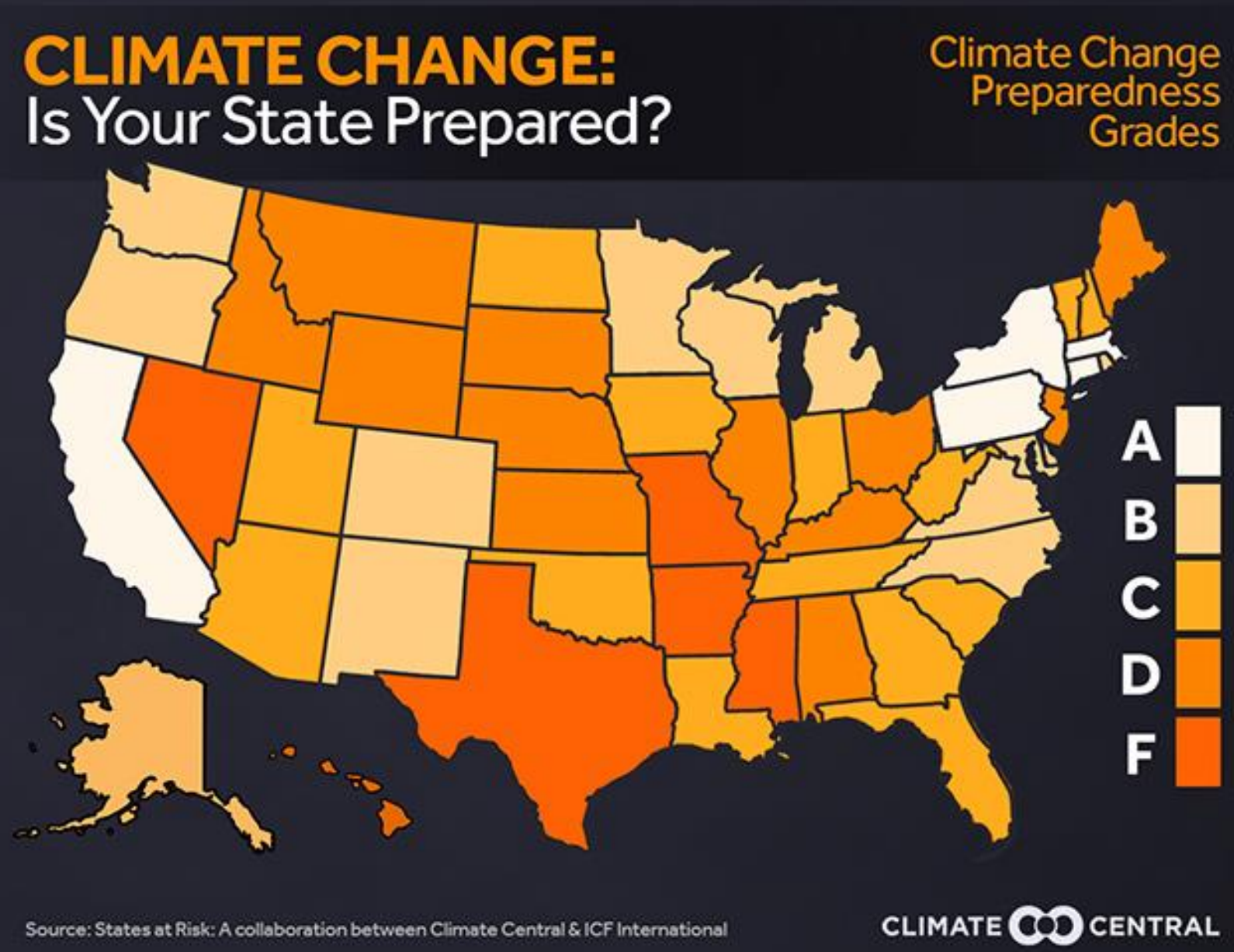
Effects are Scenario dependent:

- Under RCP8.5, 70-90% of Coral Reefs gone by 2100
- Under RCP 2.6, many could survive (big uncertainties)
- Huge impact on Fisheries

Percentage of Plant Species Changing by 2100



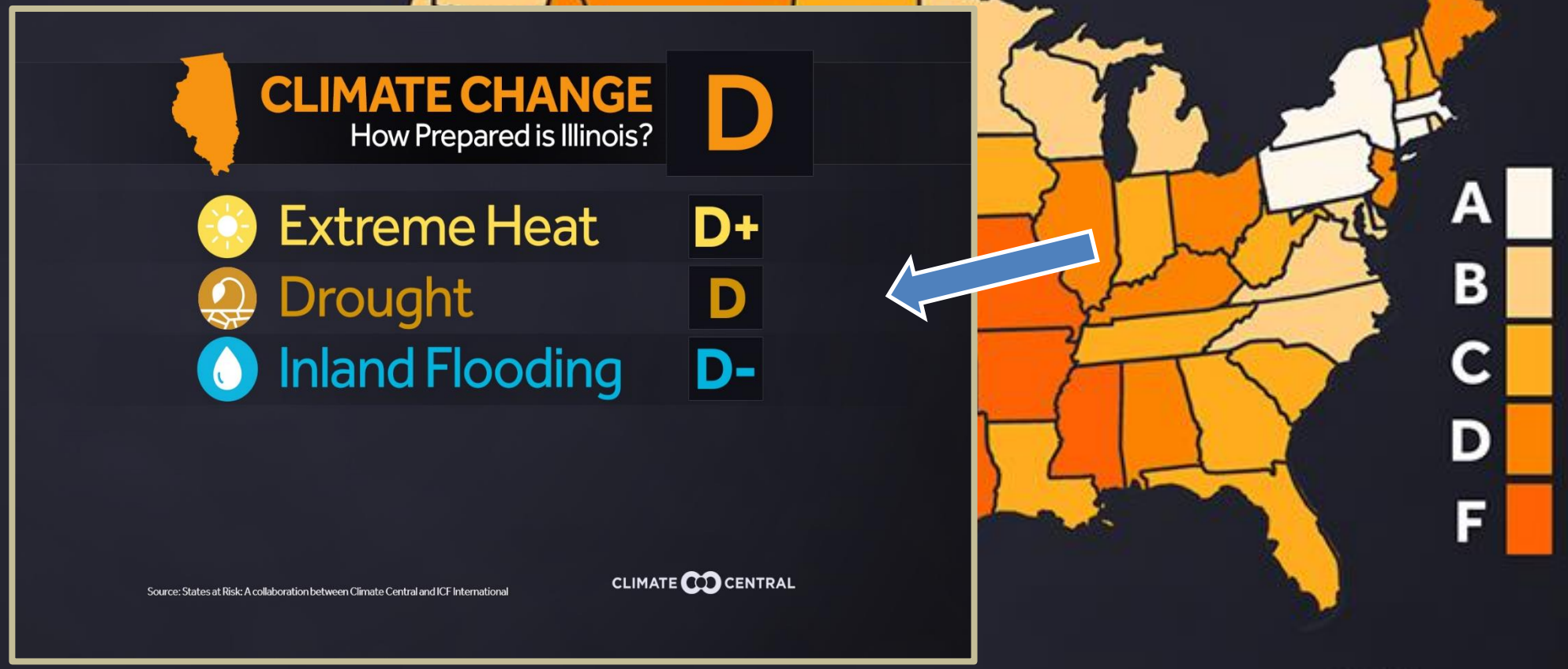
Bergengren (2011)
NASA/JPL/Caltech


CLIMATE CHANGE:
Is Your State Prepared?
Climate Change Preparedness Grades
A
B
C
D
F
Source: States at Risk: A collaboration between Climate Central & ICF International
CLIMATE CENTRAL

(2015)

CLIMATE CHANGE:
Is Your State Prepared?

Climate Change Preparedness Grades



Source: States at Risk: A collaboration between Climate Central & ICF International

CLIMATE CENTRAL

(2015)

The Great Climate Migration Has Begun

New York Times Magazine 7/23/2020

https://www.nytimes.com/interactive/2020/07/23/magazine/climate-migration.html

The Great Climate Migration Has Begun

New York Times Magazine 7/23/2020

PNAS

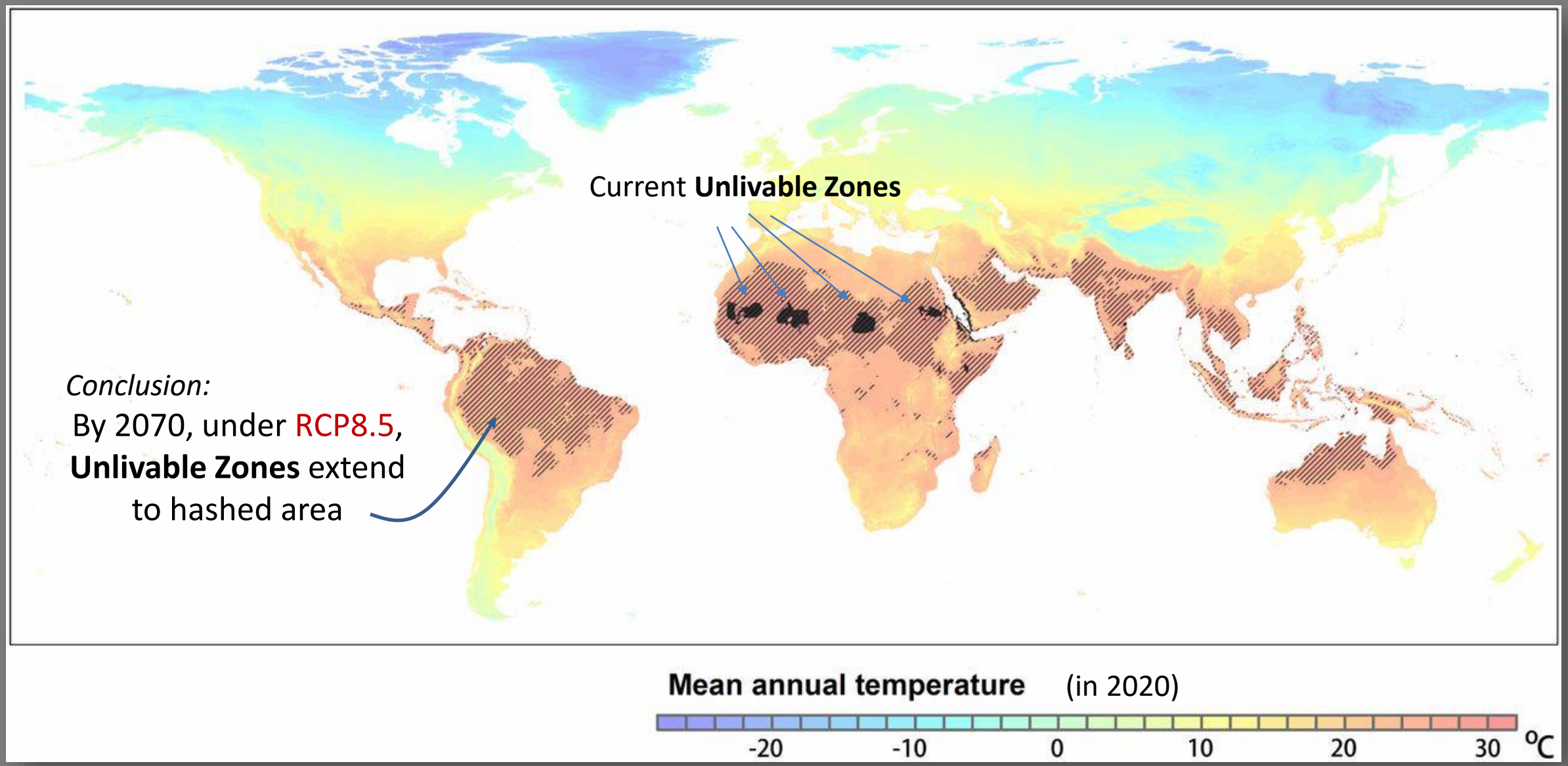
April 2020

Future of the human climate niche

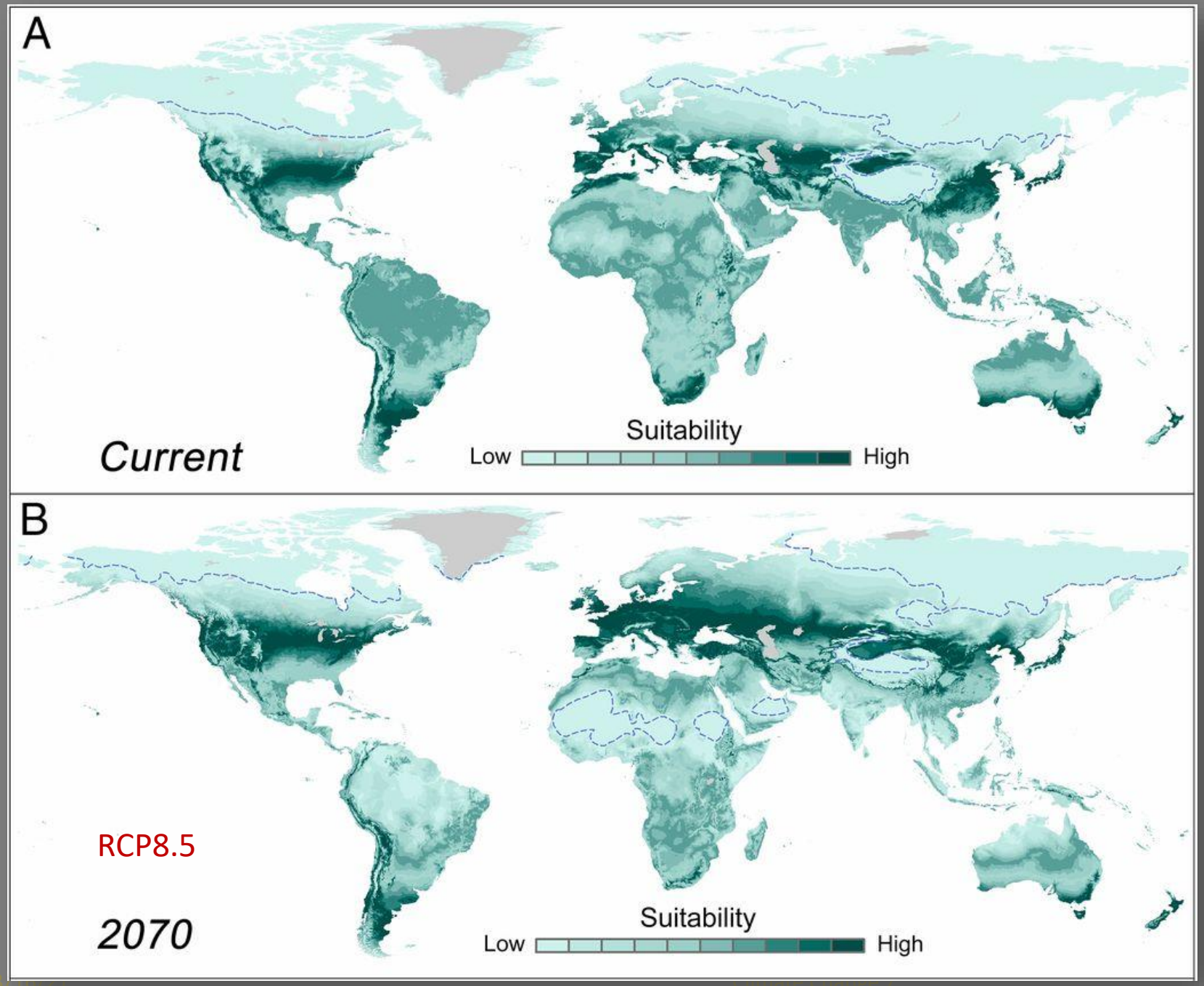
Chi Xu (徐驰)[a,1], Timothy A. Kohler[b,c,d,e], Timothy M. Lenton[f], Jens-Christian Svenning[g], and Marten Scheffer[c,h,i,1]

[a]School of Life Sciences, Nanjing University, Nanjing 210023, China; [b]Department of Anthropology, Washington State University, Pullman, WA 99164; [c]Santa Fe Institute, Santa Fe, NM 87501; [d]Crow Canyon Archaeological Center, Cortez, CO 81321; [e]Research Institute for Humanity and Nature, Kyoto 603-8047, Japan; [f]Global Systems Institute, University of Exeter, Exeter, EX4 4QE, United Kingdom; [g]Center for Biodiversity Dynamics in a Changing World, Department of Bioscience, Aarhus University, DK-8000 Aarhus C, Denmark; [h]Wageningen University, NL-6700 AA, Wageningen, The Netherlands; and [i]SARAS (South American Institute for Resilience and Sustainability Studies), 10302 Bella Vista, Maldonado, Uruguay

"All species have an environmental niche, and despite technological advances, humans are unlikely to be an exception. Here, we demonstrate that for millennia, human populations have resided in the same narrow part of the climatic envelope available on the globe, characterized by a major mode around ~11 °C to 15 °C mean annual temperature (MAT)."



Xu *et al*, Future of the Human Climate Niche, Fig 3

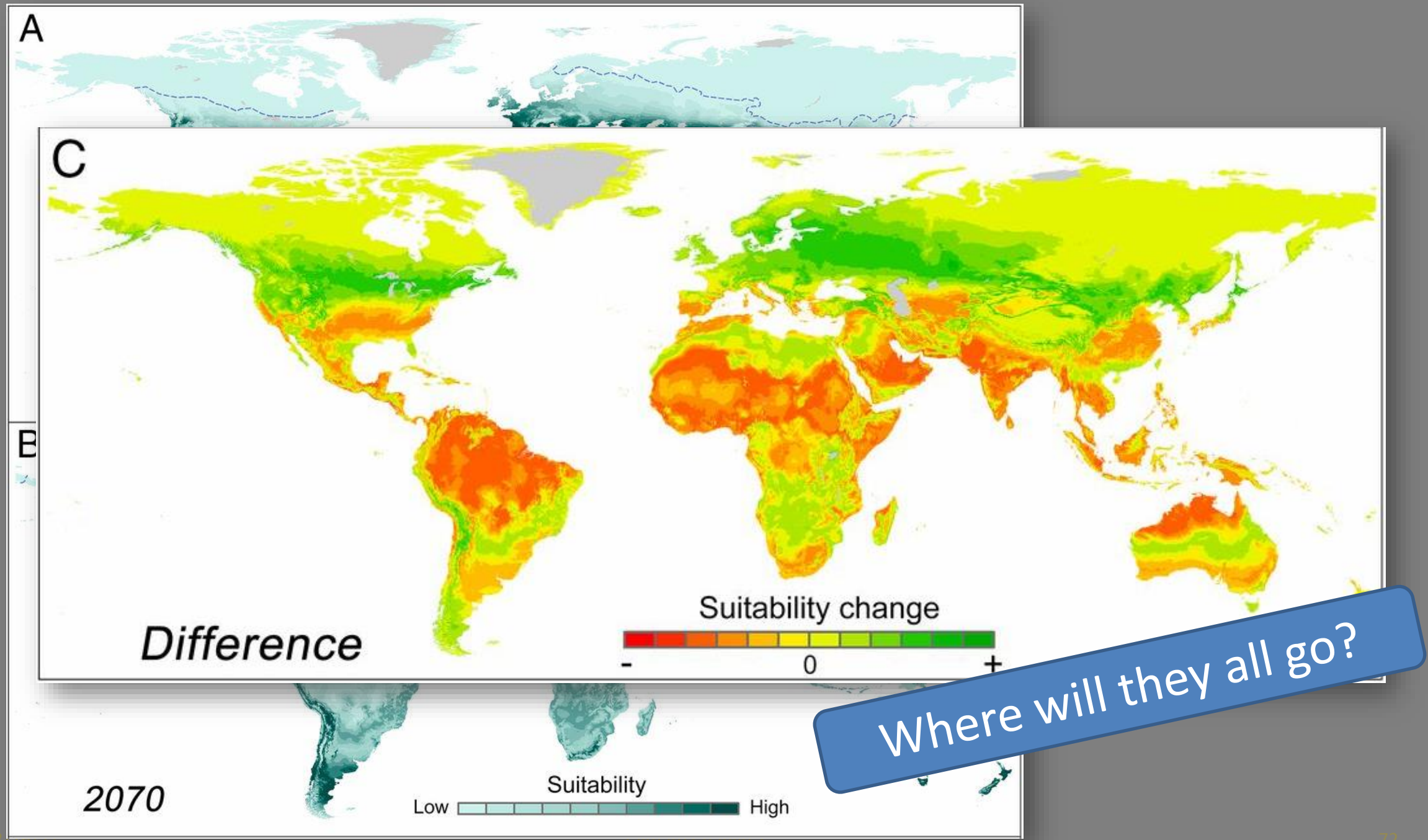


2020

Suitable Zones move toward poles

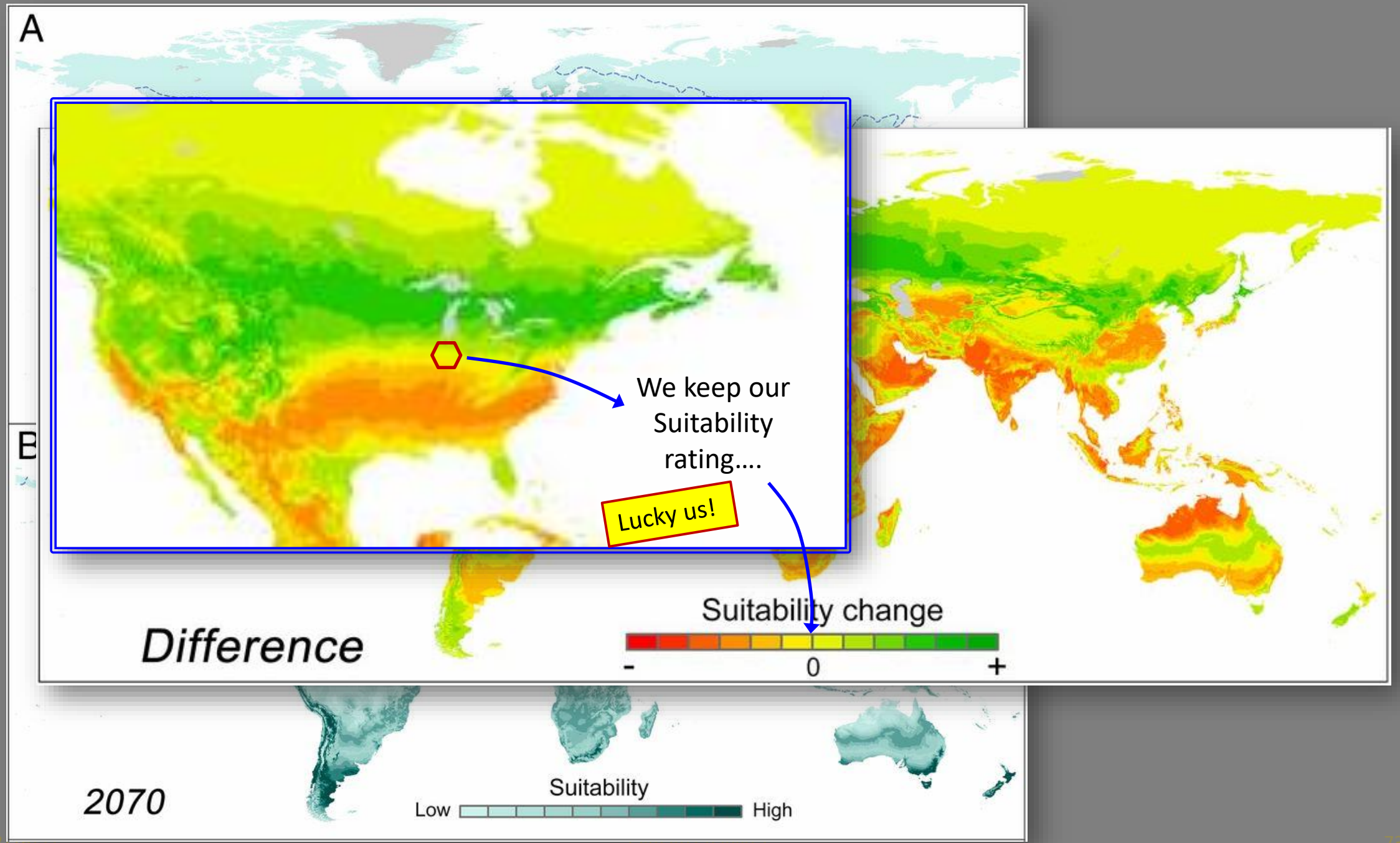
2070

Xu *et al*, Future of the Human Climate Niche, Fig 4



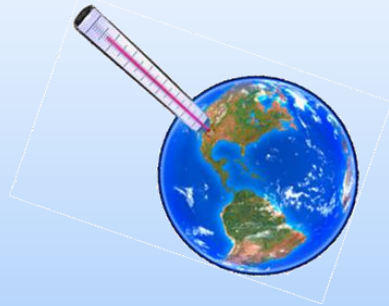
Where will they all go?

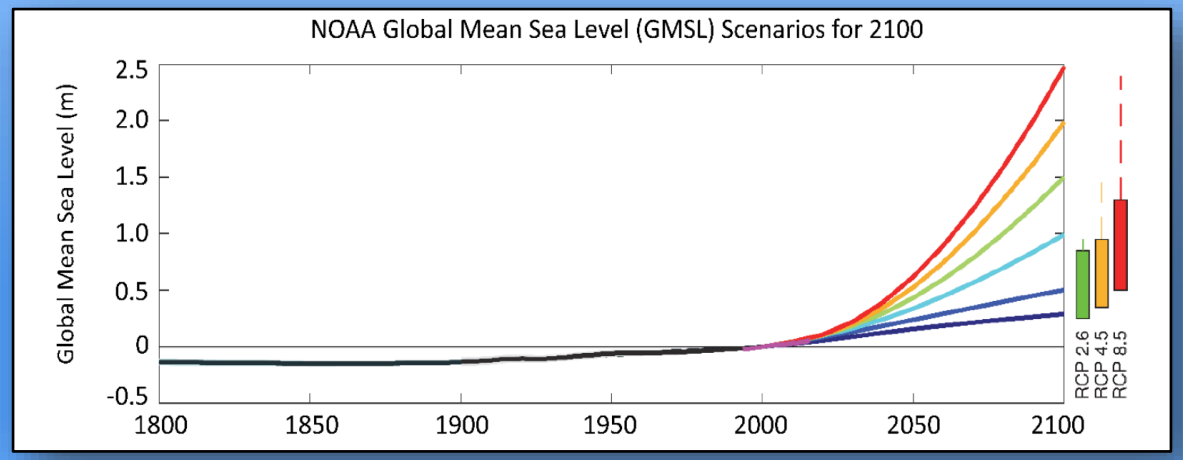
Xu *et al*, Future of the Human Climate Niche, Fig 4

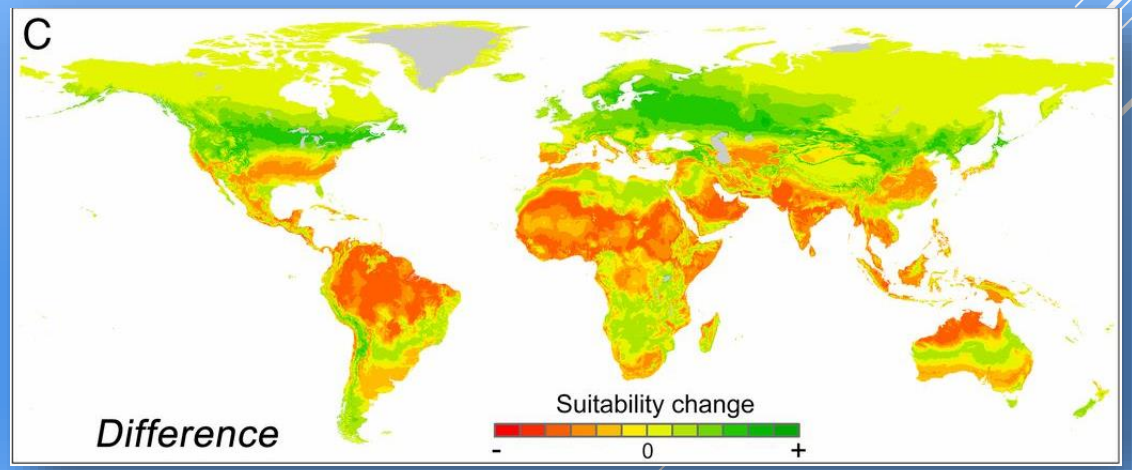


Xu *et al*, Future of the Human Climate Niche, Fig 4

Questions about Global Projections: Sea Level, Migration etc.



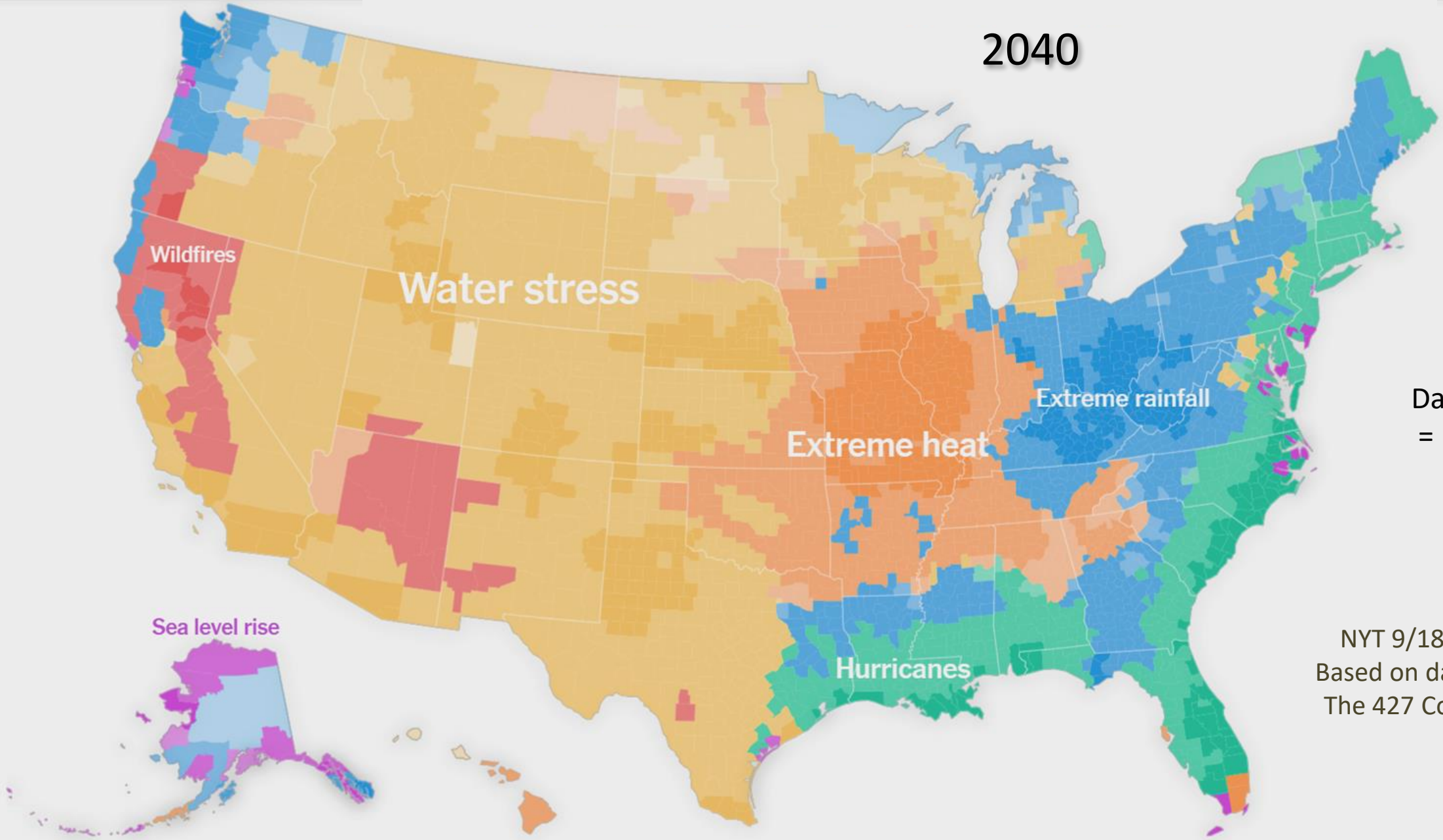




Domestic Impacts

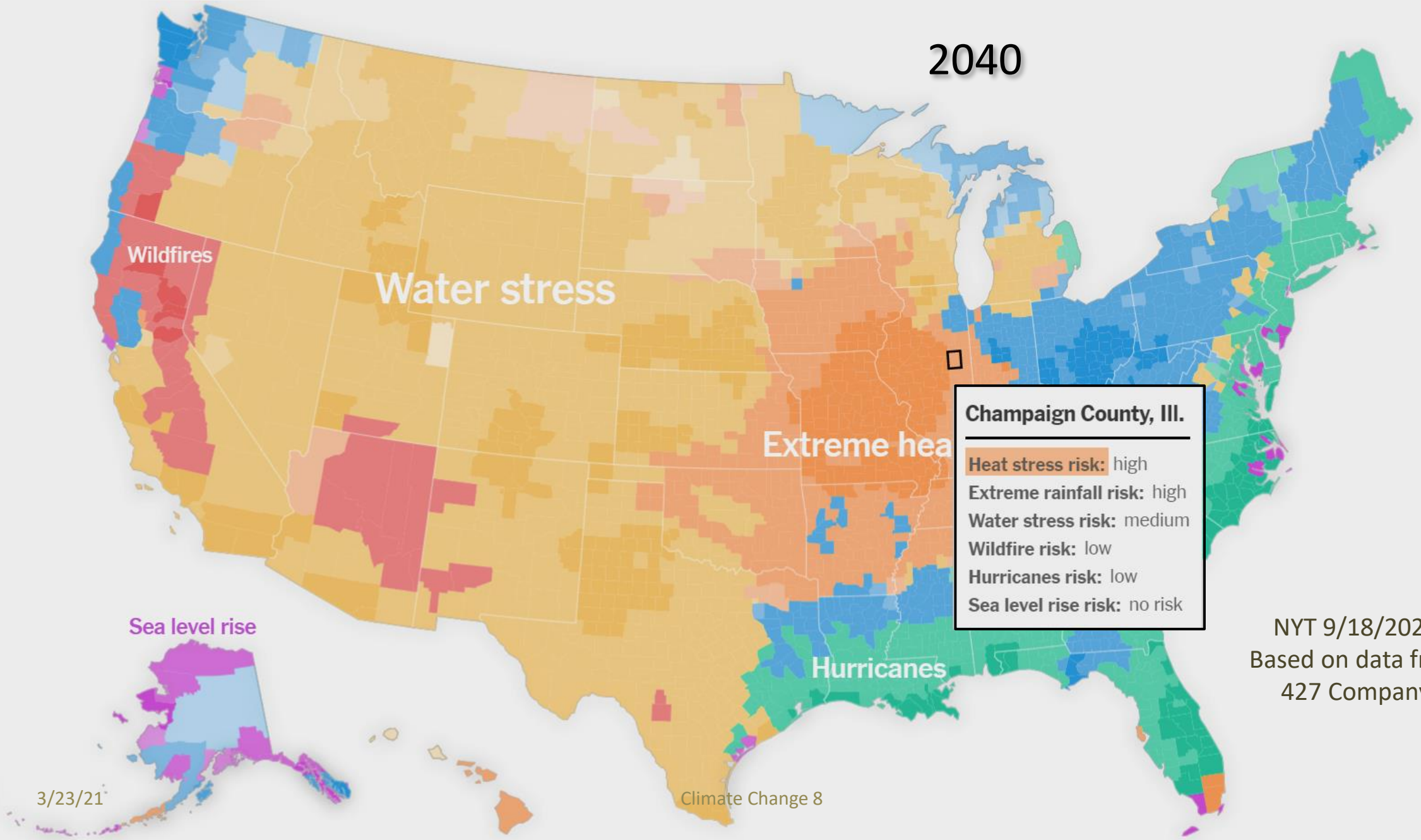
The New York Times

OPINION | Every Place Has Its Own Climate Risk. What Is It Where You Live?

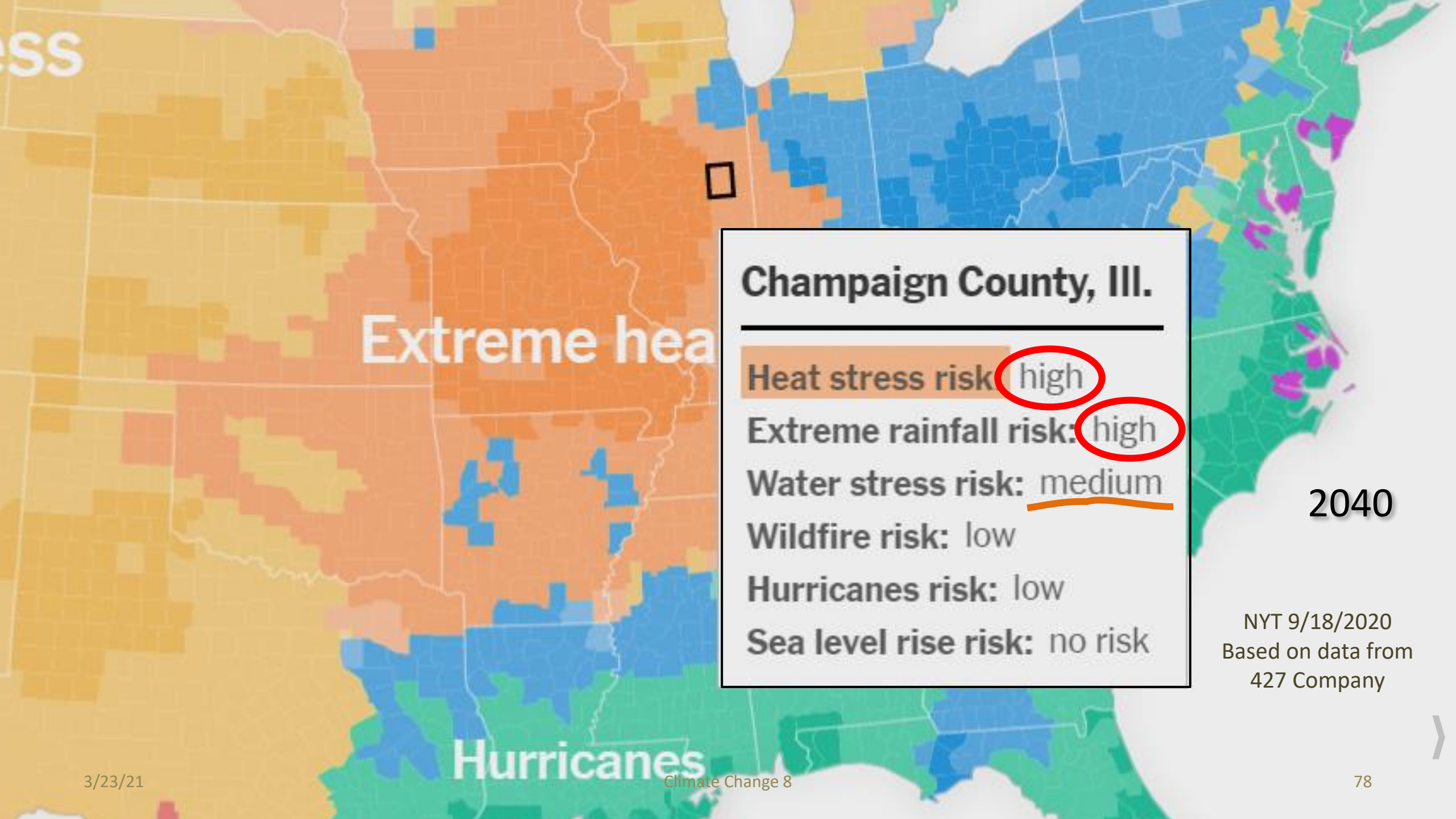


Darker Colors
= Higher Risk

NYT 9/18/2020
Based on data from
The 427 Company

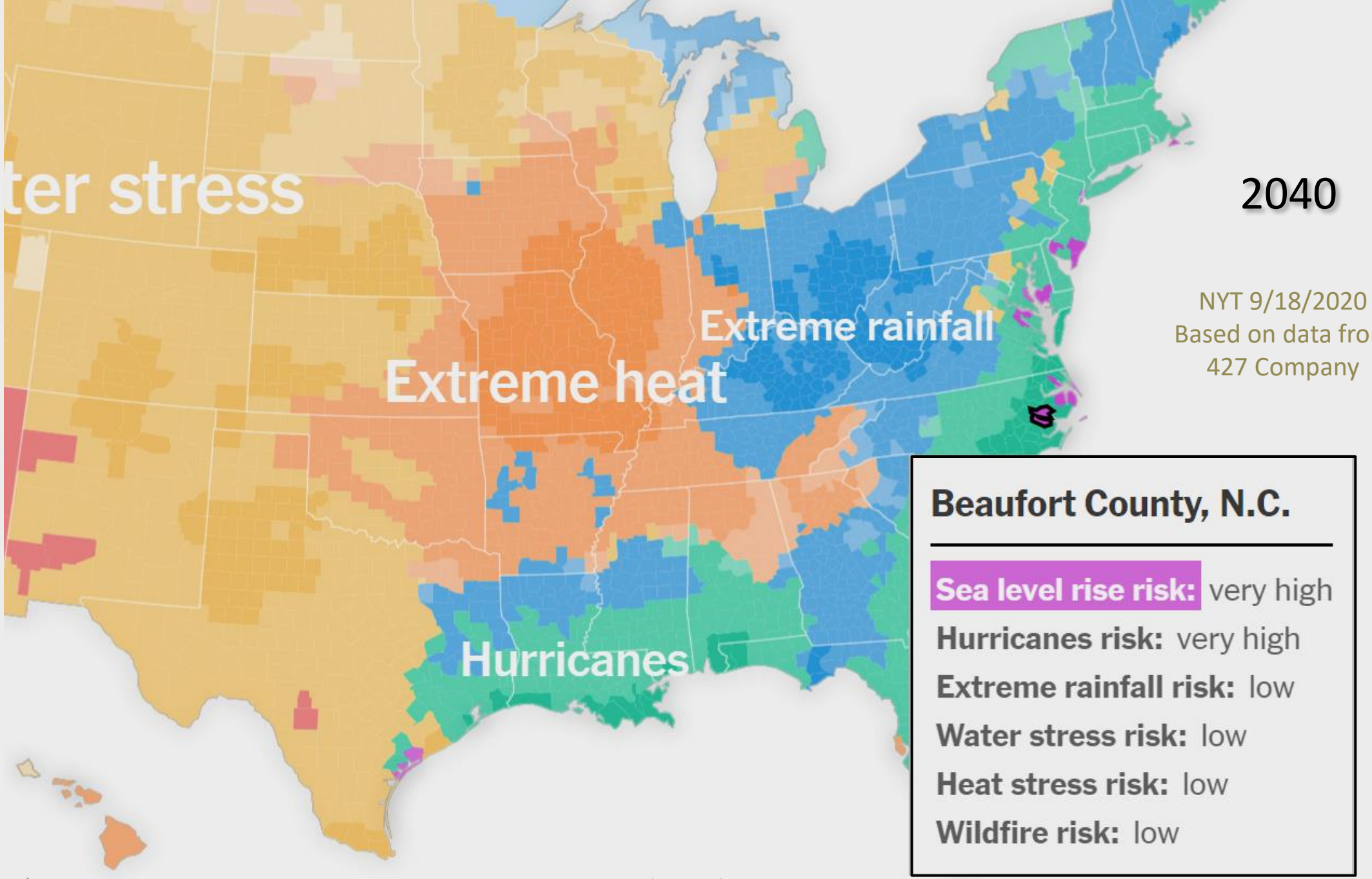


NYT 9/18/2020
Based on data from
427 Company



2040

NYT 9/18/2020
Based on data from
427 Company

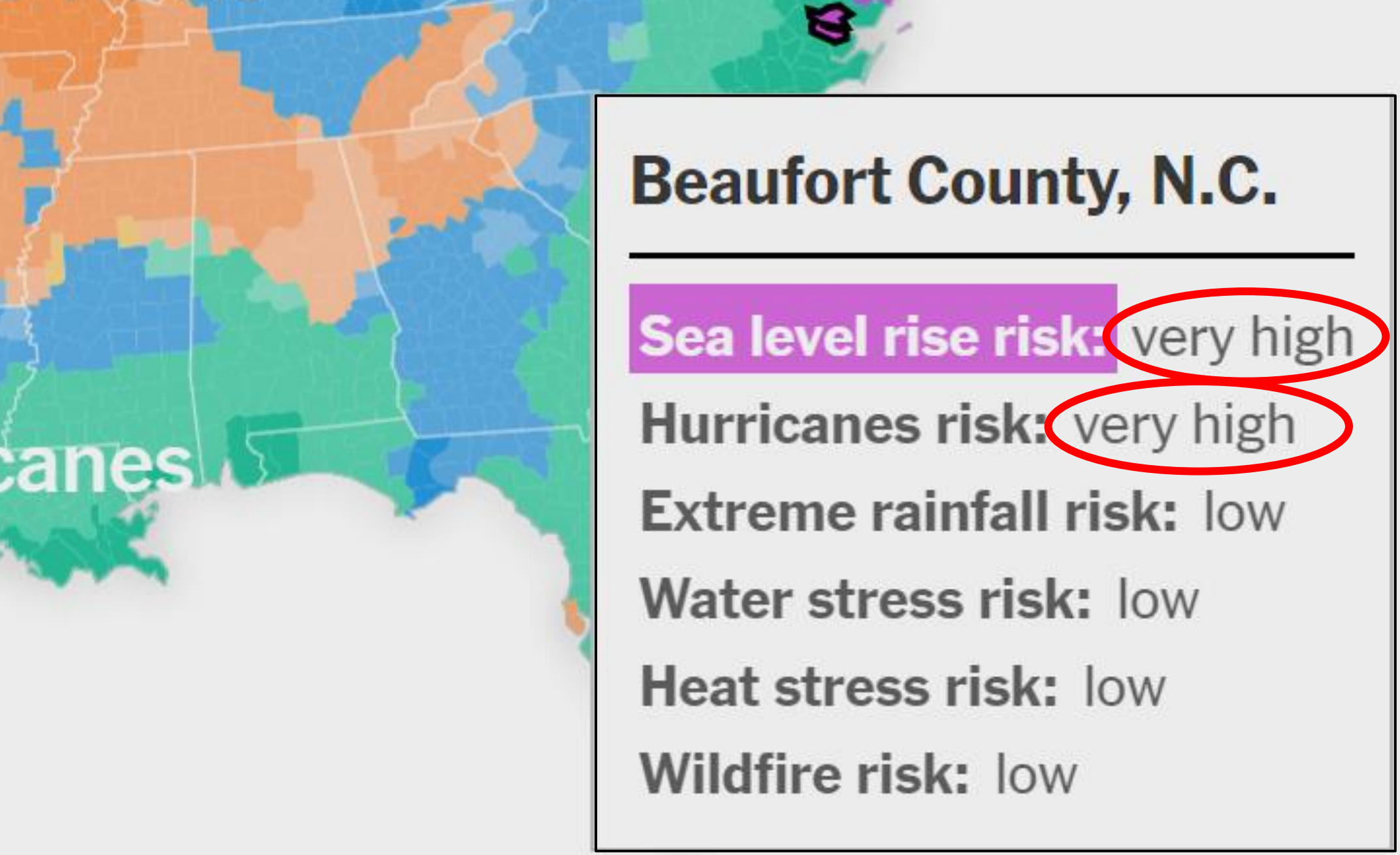


2040

NYT 9/18/2020
Based on data from
427 Company

Beaufort County, N.C.

Sea level rise risk: very high
Hurricanes risk: very high
Extreme rainfall risk: low
Water stress risk: low
Heat stress risk: low
Wildfire risk: low



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NYT 9/18/2020
Based on data from
427 Company

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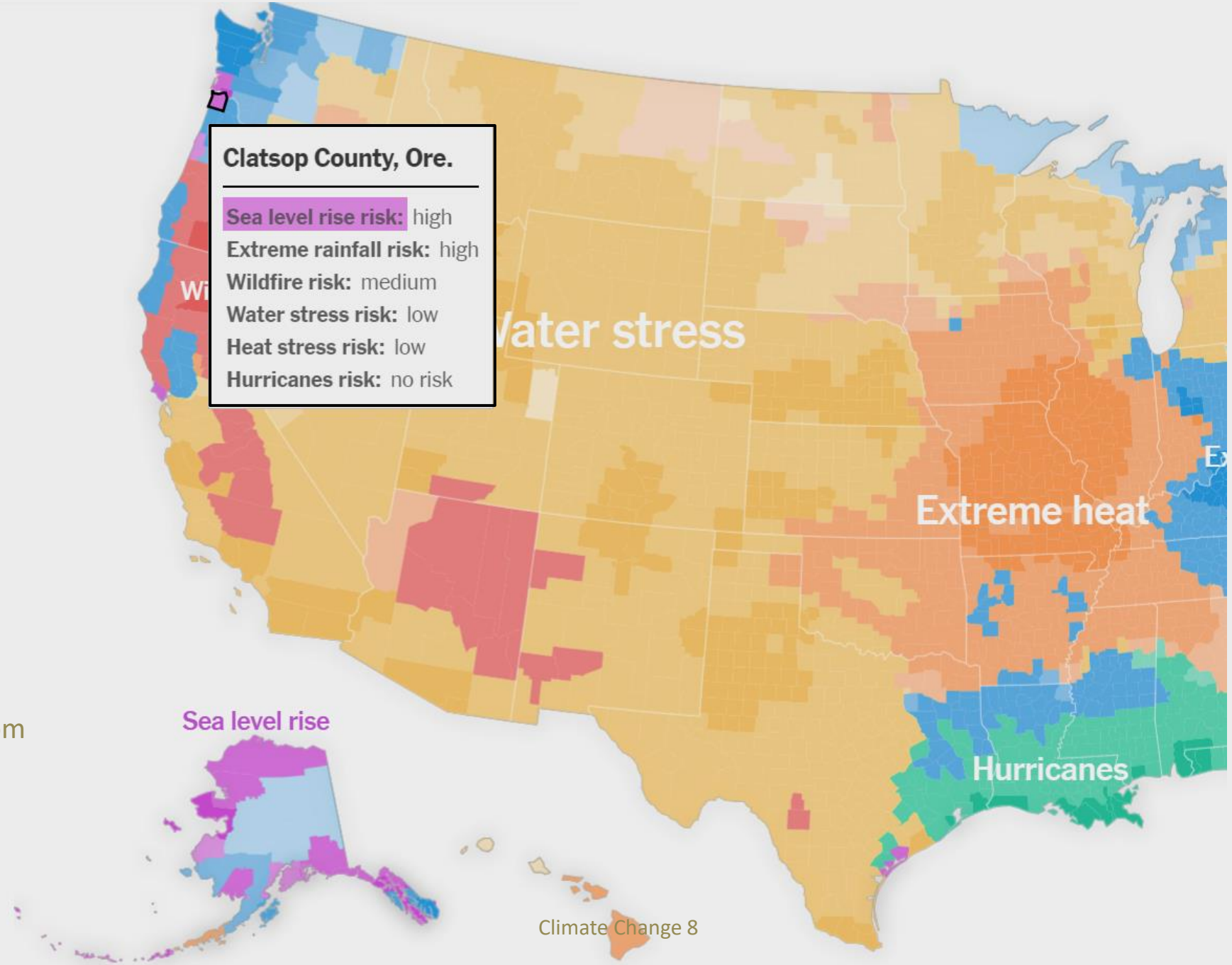

NYT 9/18/2020
Based on data from
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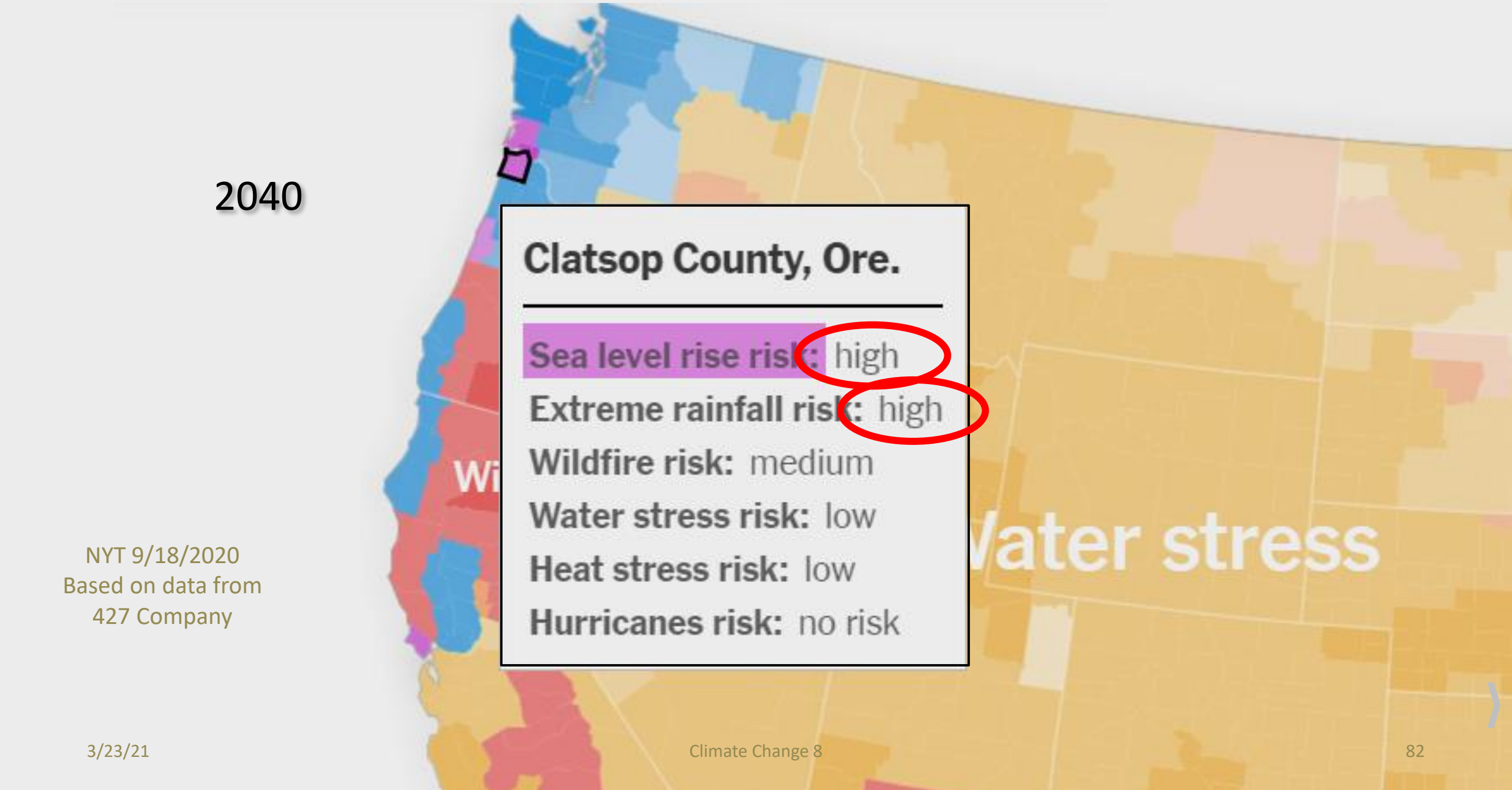

NYT 9/18/2020
Based on data from
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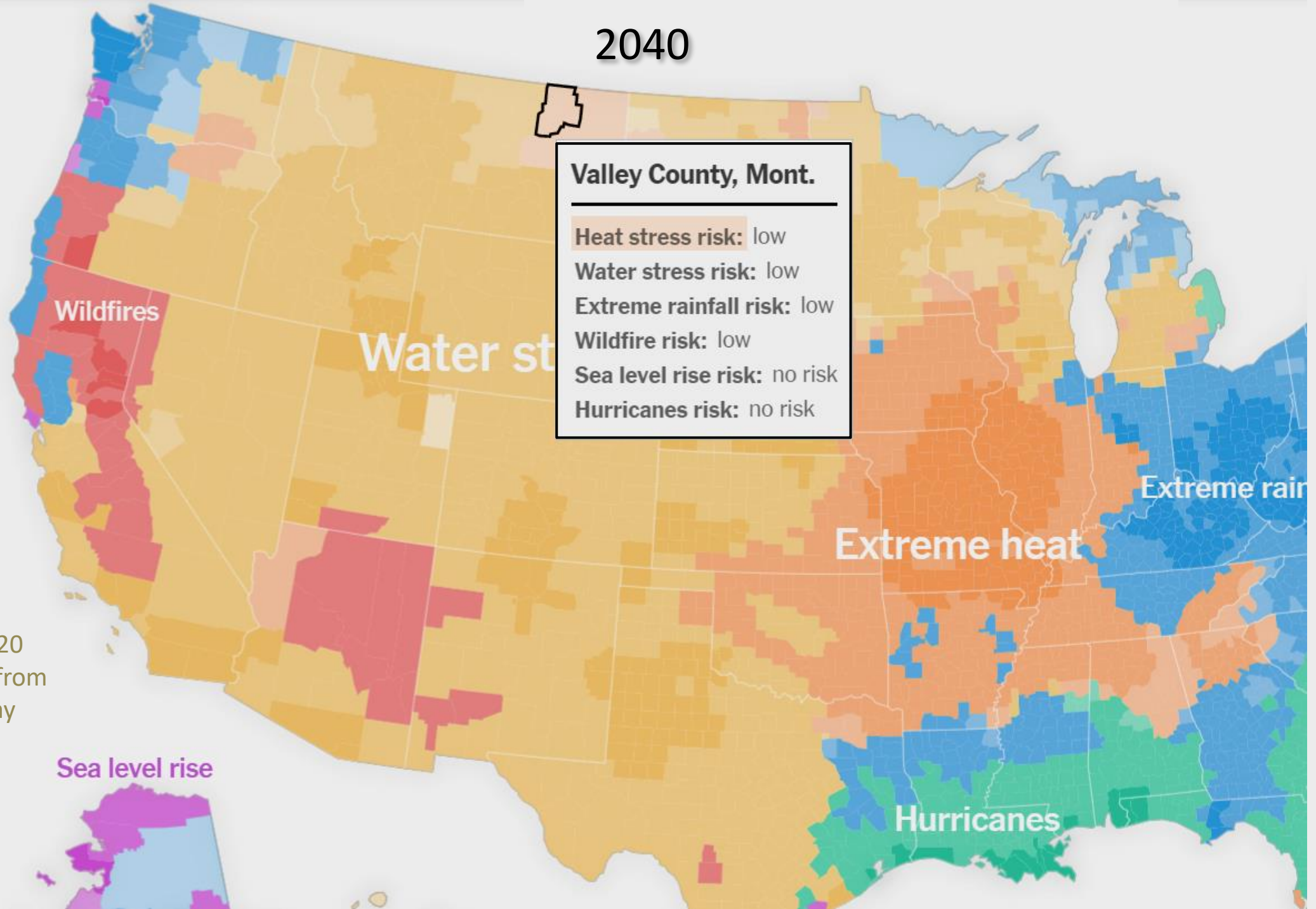

NYT 9/18/2020
Based on data from
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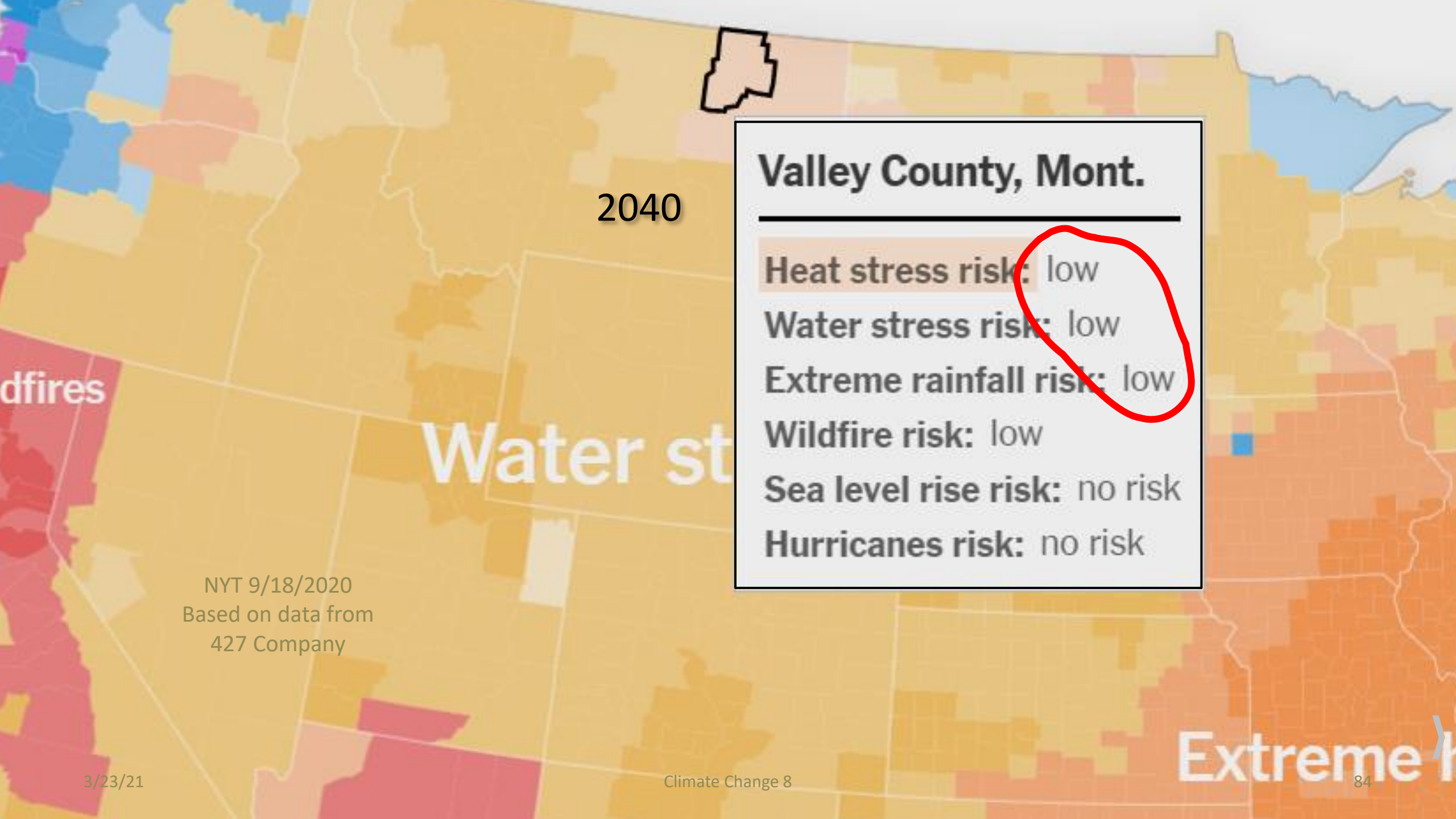
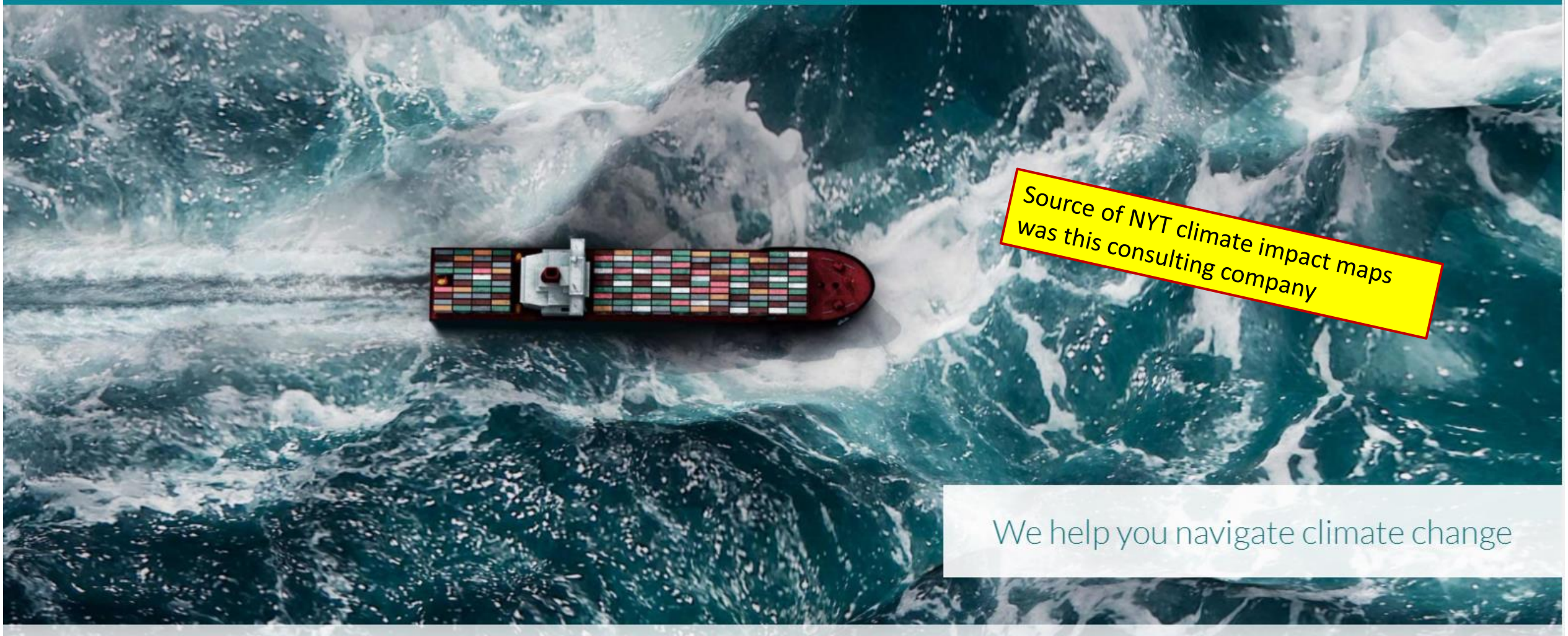
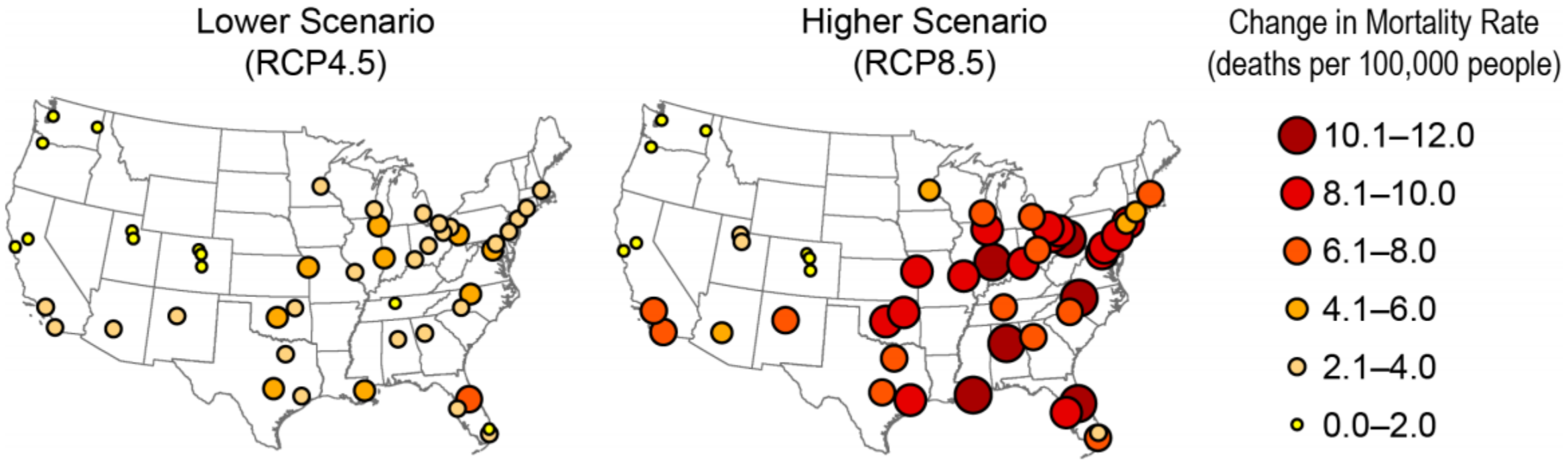


NYT 9/18/2020
Based on data from
427 Company



Four Twenty Seven blends economic modeling with climate science to help you reduce risks, identify new opportunities, and build resilience in the face of climate change.

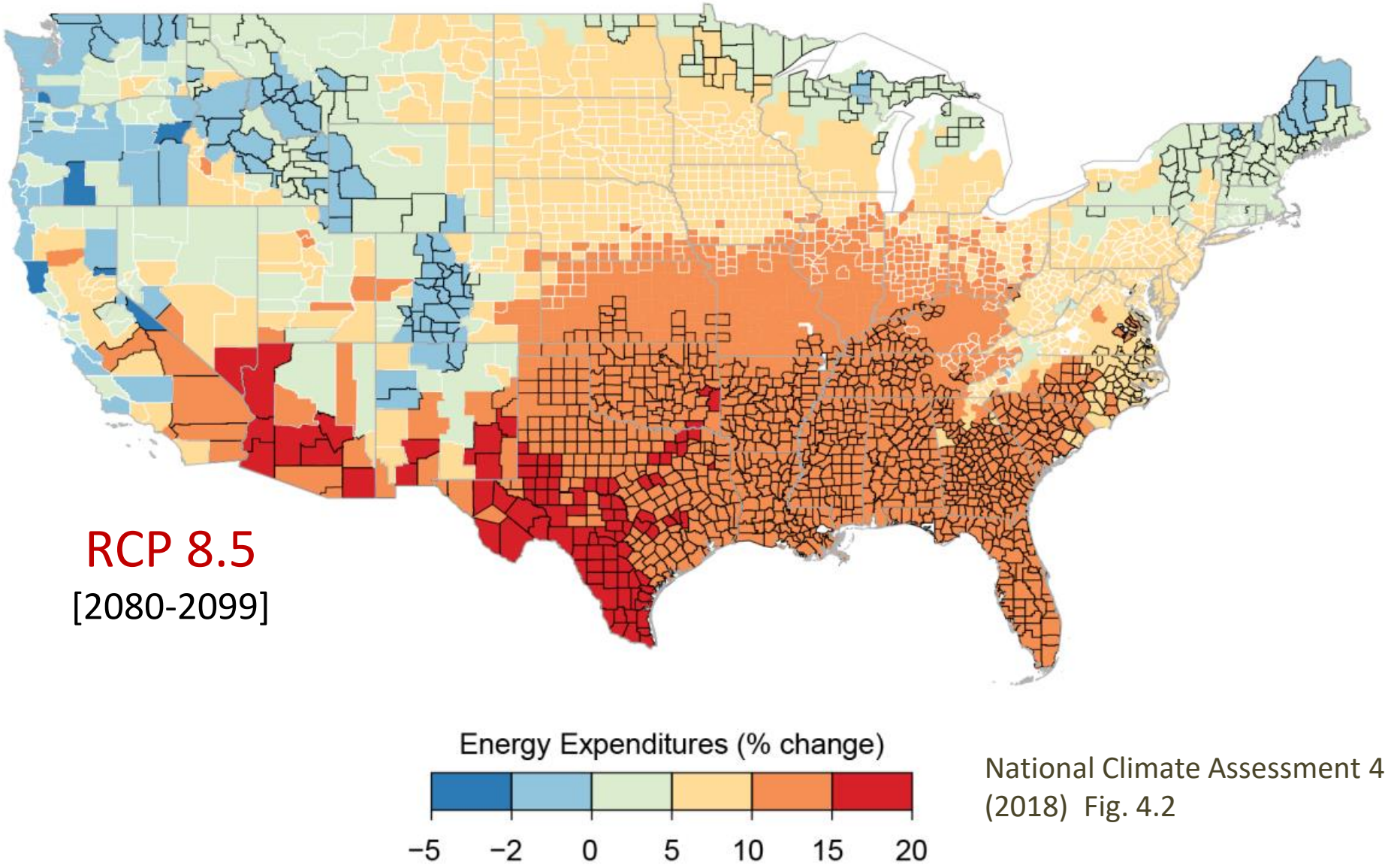
Projected Change in Annual Extreme Temperature Mortality



Excess Mortality for 49 Cities due to Heat and Cold [2080-2099]

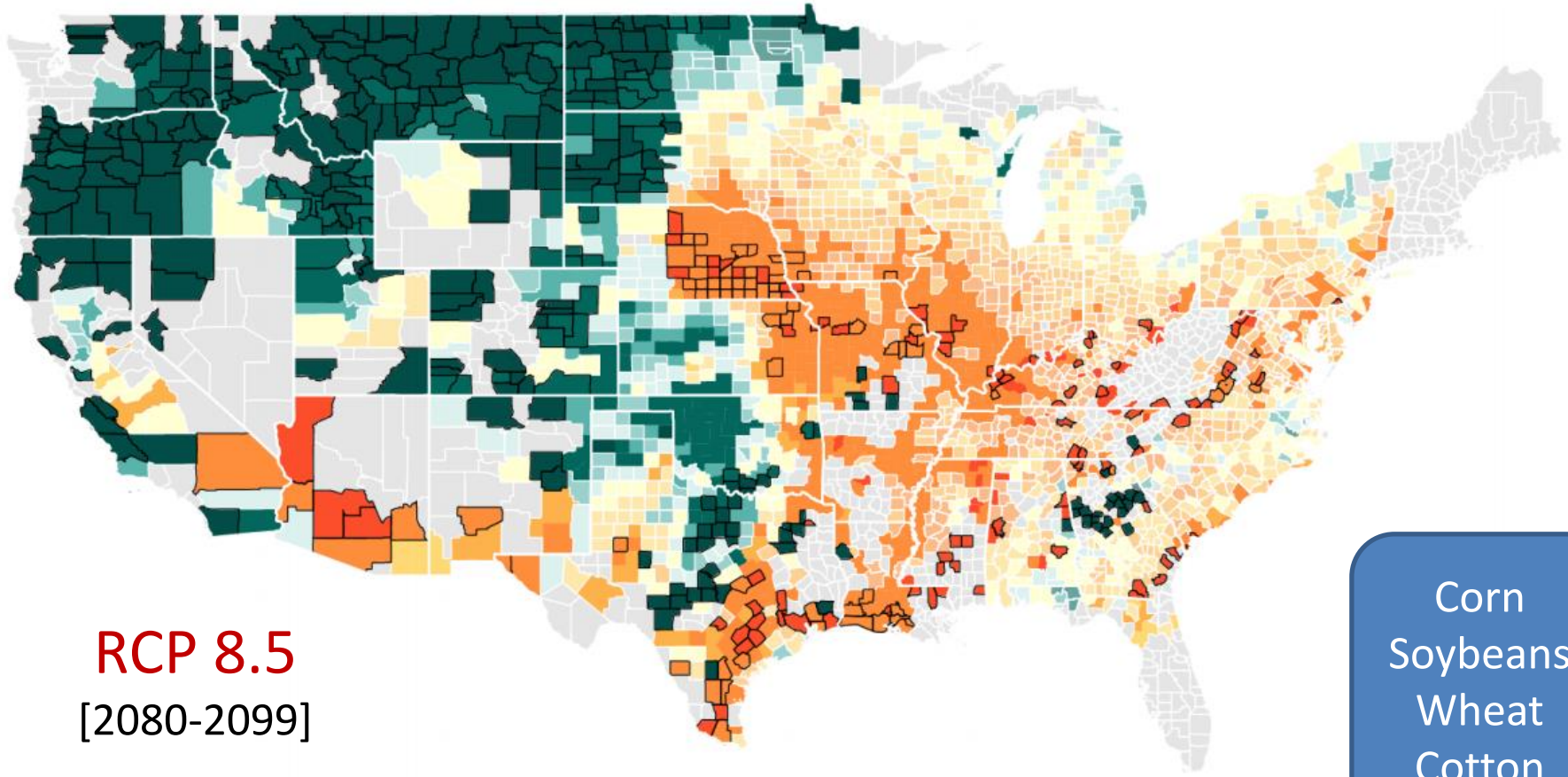
National Climate Assessment 4 (2018) Fig. 14.4

Projected Changes in Energy Expenditures



National Climate Assessment 4 (2018) Fig. 4.2

Agricultural Productivity



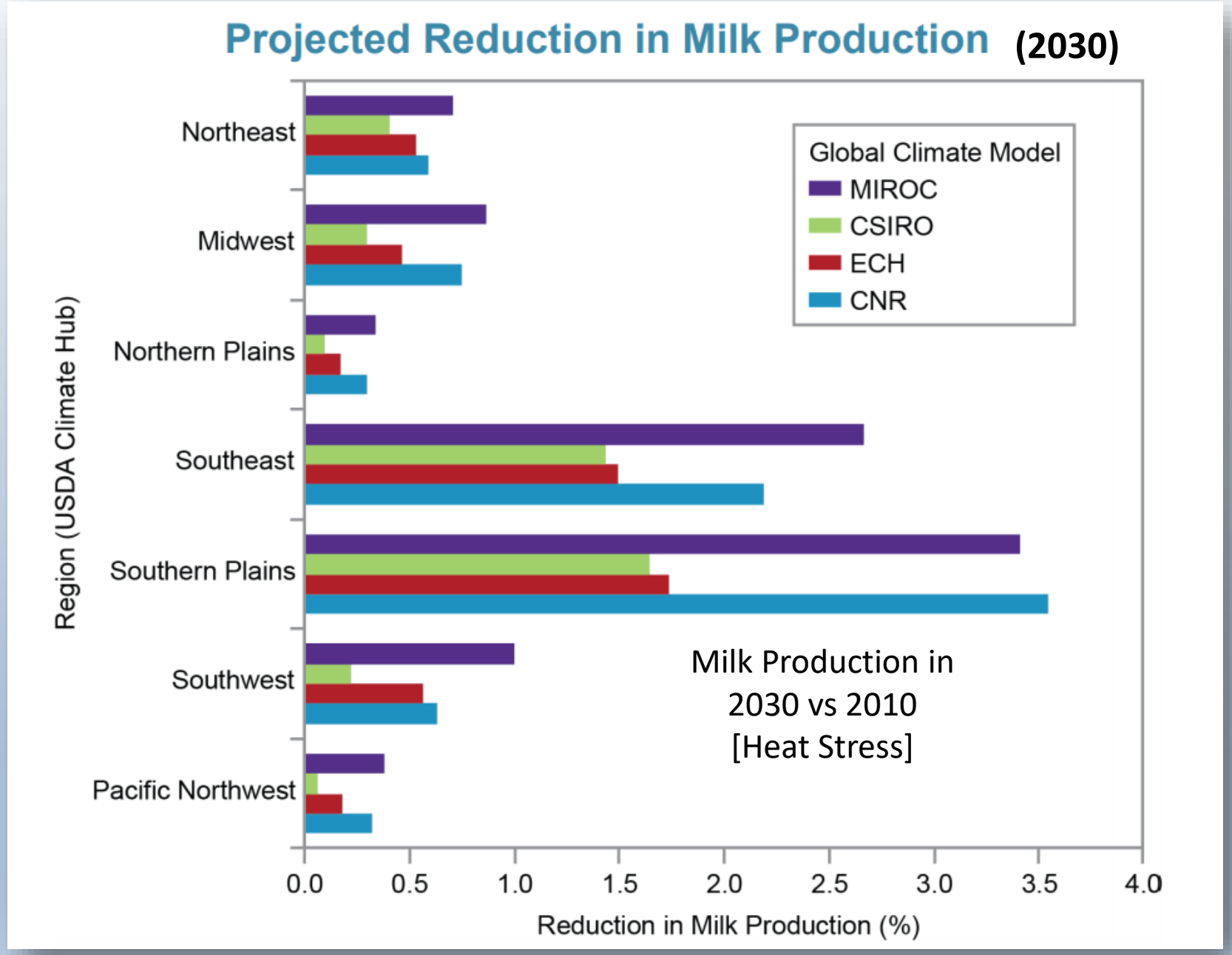
RCP 8.5
[2080-2099]

Agricultural Yields (% change)

−90 −50 −30 −20 −10 0 10 20 30 45

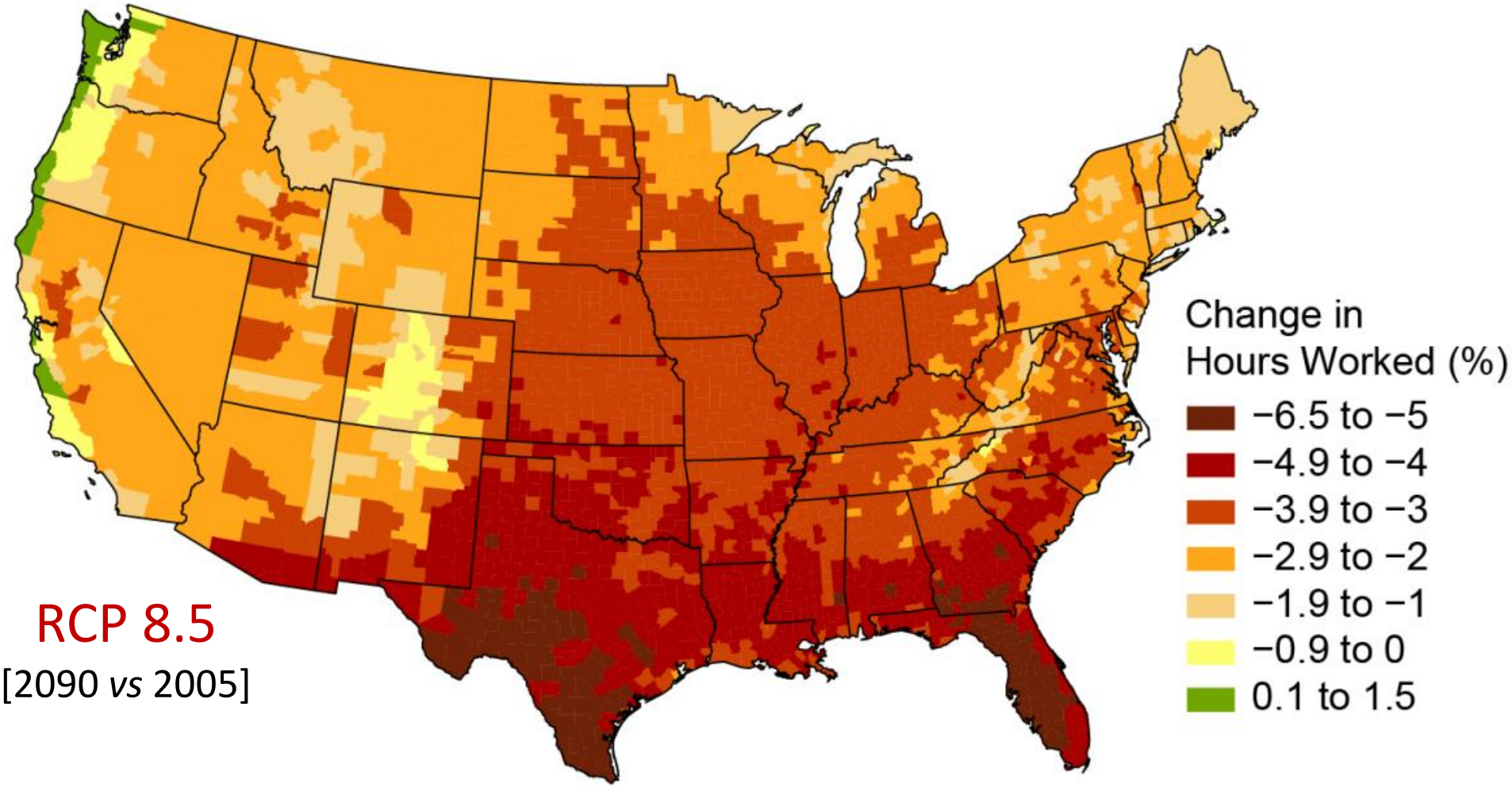
Corn
Soybeans
Wheat
Cotton

National Climate Assessment 4 (2018) Fig. 7.6



National Climate Assessment 4 (2018) Fig. 10.5

Projected Changes in Hours Worked



RCP 8.5

[2090 *vs* 2005]

National Climate Assessment 4 (2018) Fig. 19.21

Climate Change Outpaces Plants' Ability to Shift Habitat Range

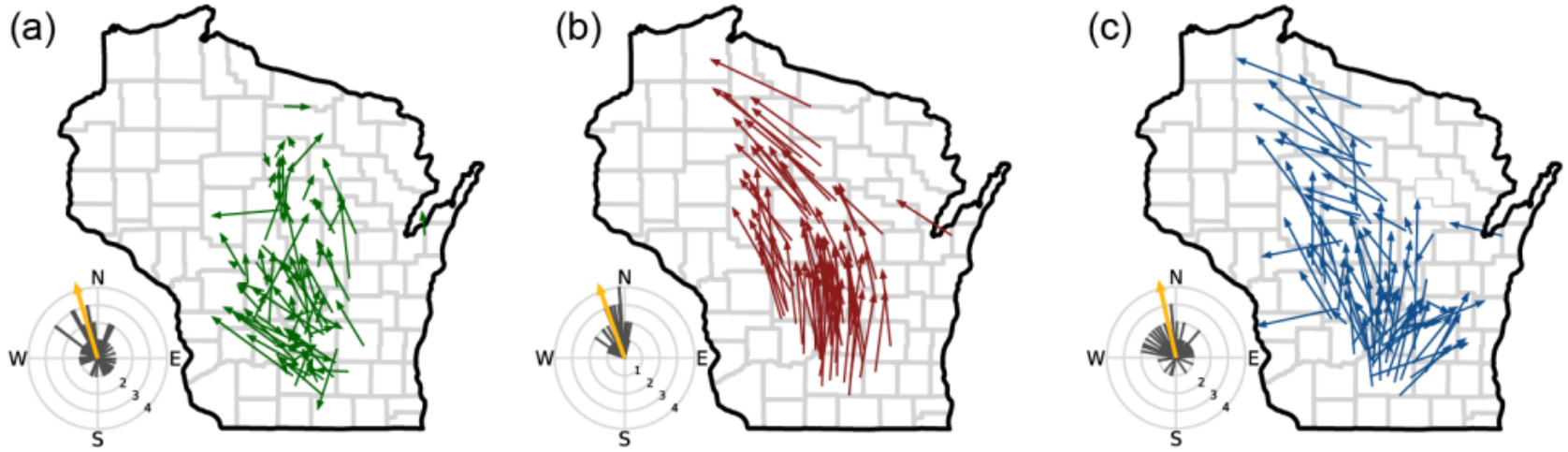
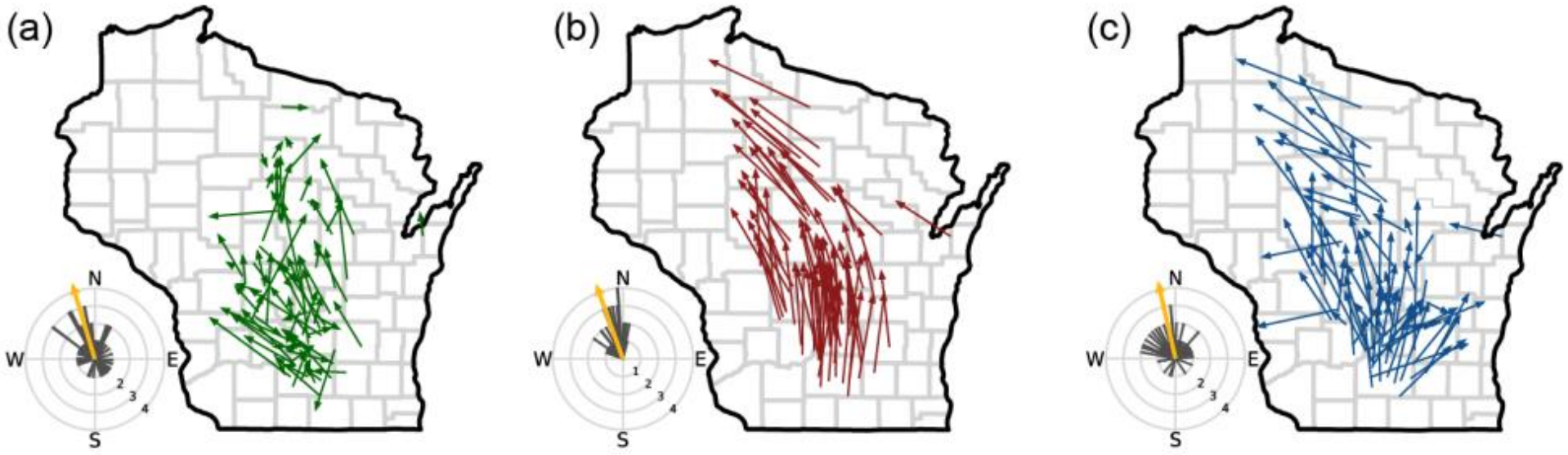


Figure 21.5: While midwestern species, such as understory plants in Wisconsin, are showing changes in range, they may not be shifting quickly enough to keep up with changes in climate. The panels here represent 78 plant species, showing (a) observed changes in the center of plant species abundances (centroids) from the 1950s to 2000s, (b) the direction and magnitude of changes in climate factors associated with those species, and (c) the lag, or difference, between where the species centroid is now located and where the change in climate factors suggests it should be located in order to keep pace with a changing climate. Source: adapted from Ash et al. 2017.[141] ©John Wiley & Sons, Ltd.

National Climate Assessment 4 (2018) Fig. 21.5

Climate Change Outpaces Plants' Ability to Shift Habitat Range



How 78 Plant Species ***Actually*** Moved…

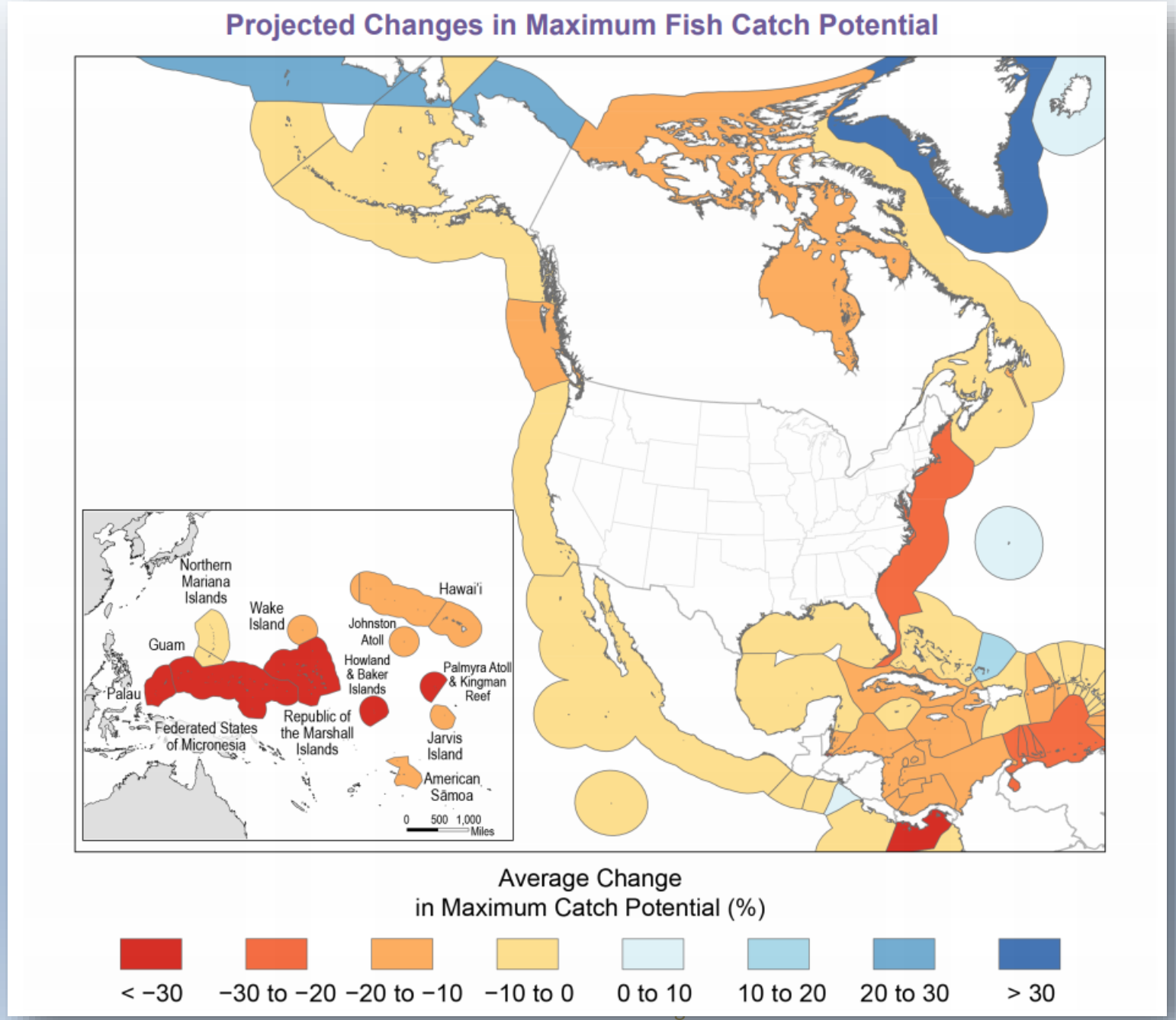
How They ***Should*** Have Moved…

The Lag: How much ***More*** They Should Have Moved…

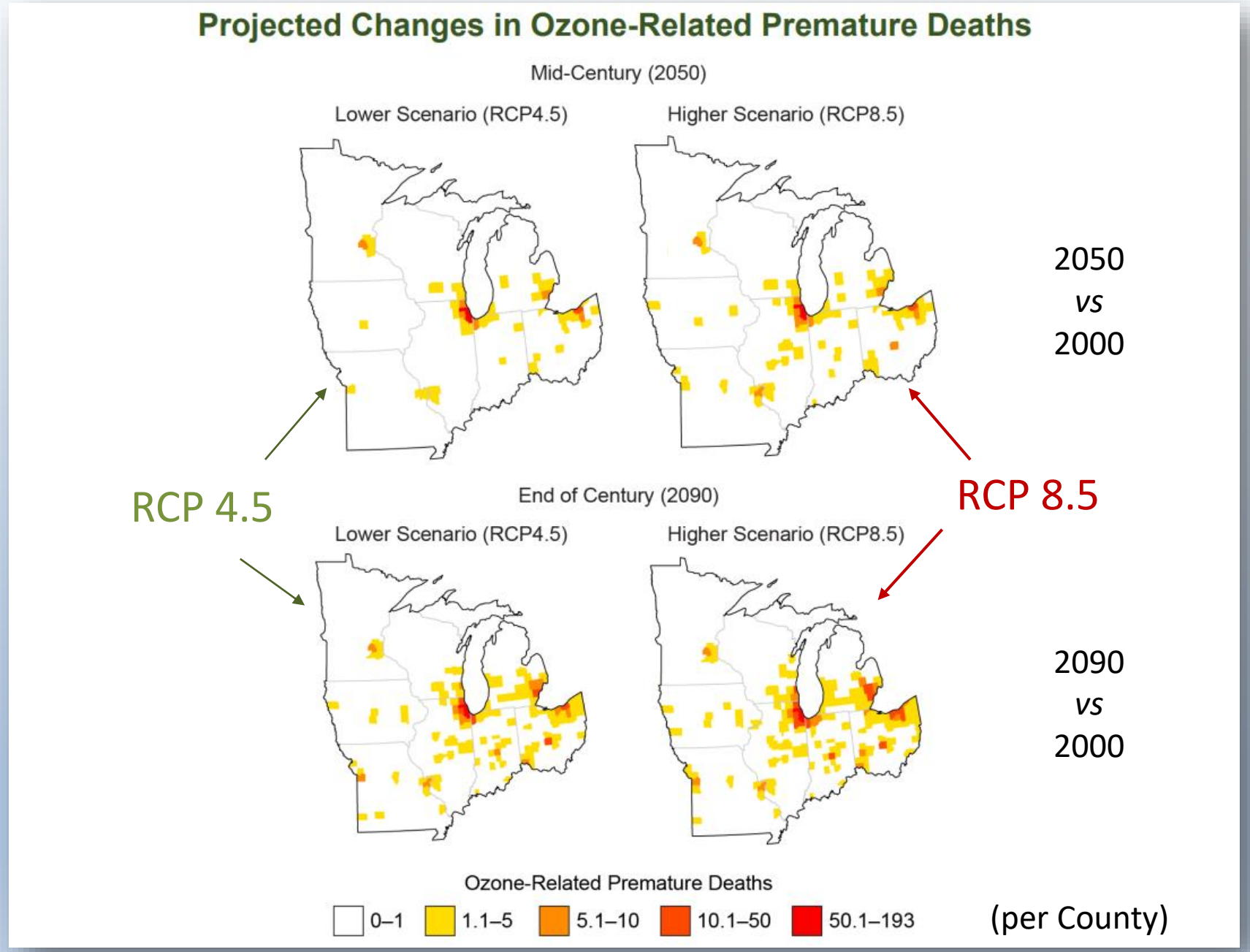
1950's to 2000's

National Climate Assessment 4 (2018) Fig. 21.5

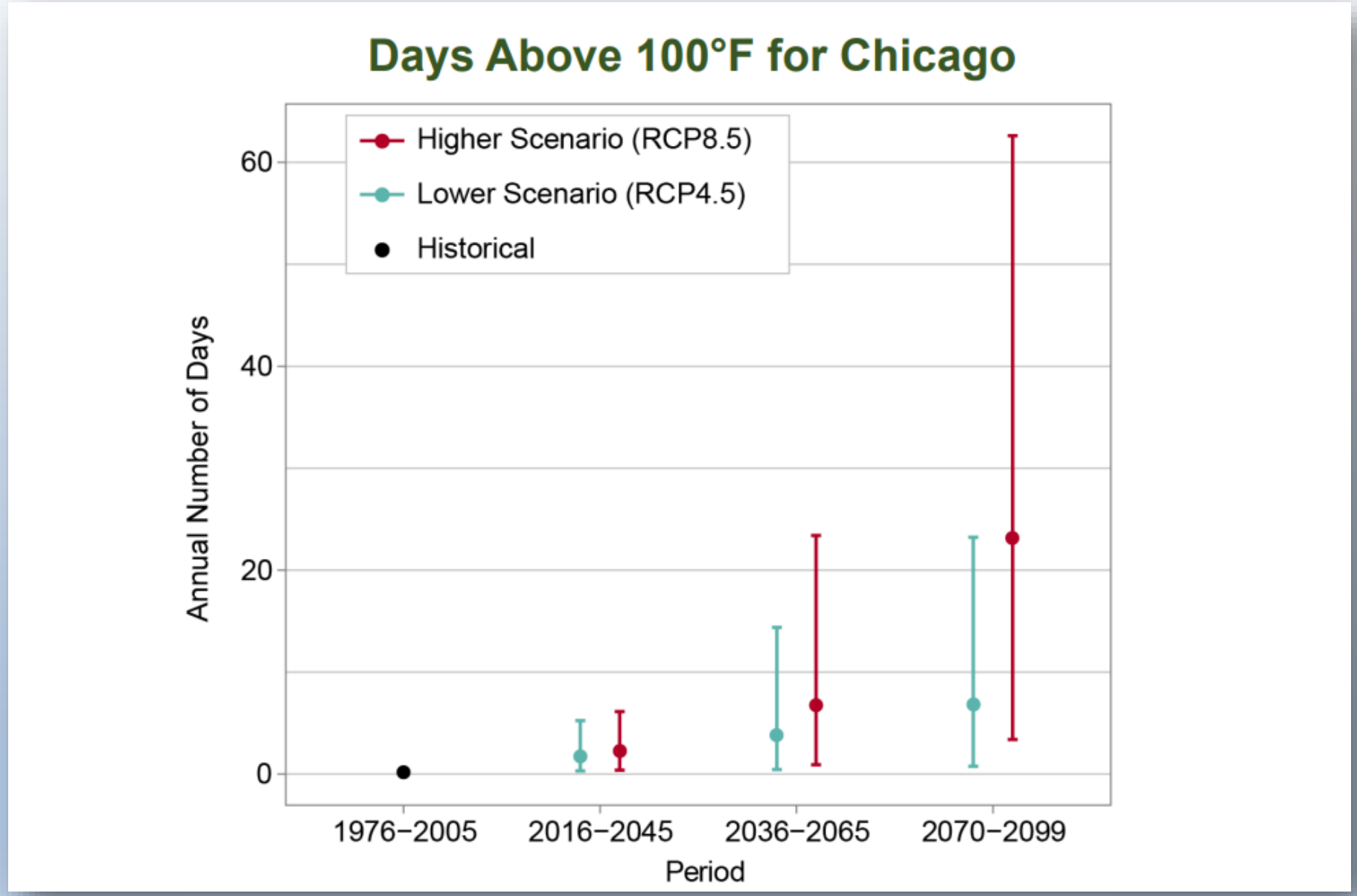
RCP 8.5
[2050 *vs* 2000]



National Climate Assessment 4 (2018) Fig. A5.29



National Climate Assessment 4 (2018) Fig. 21.9



National Climate Assessment 4 (2018) Fig. 21.10

CLIMATE TIPPING POINTS

The point of no return?

ClimateTippingPoints.info

The New York Times

PLAY THE CROSSWORD Account

International edition 3/2/2021
US Edition 3/13/2021

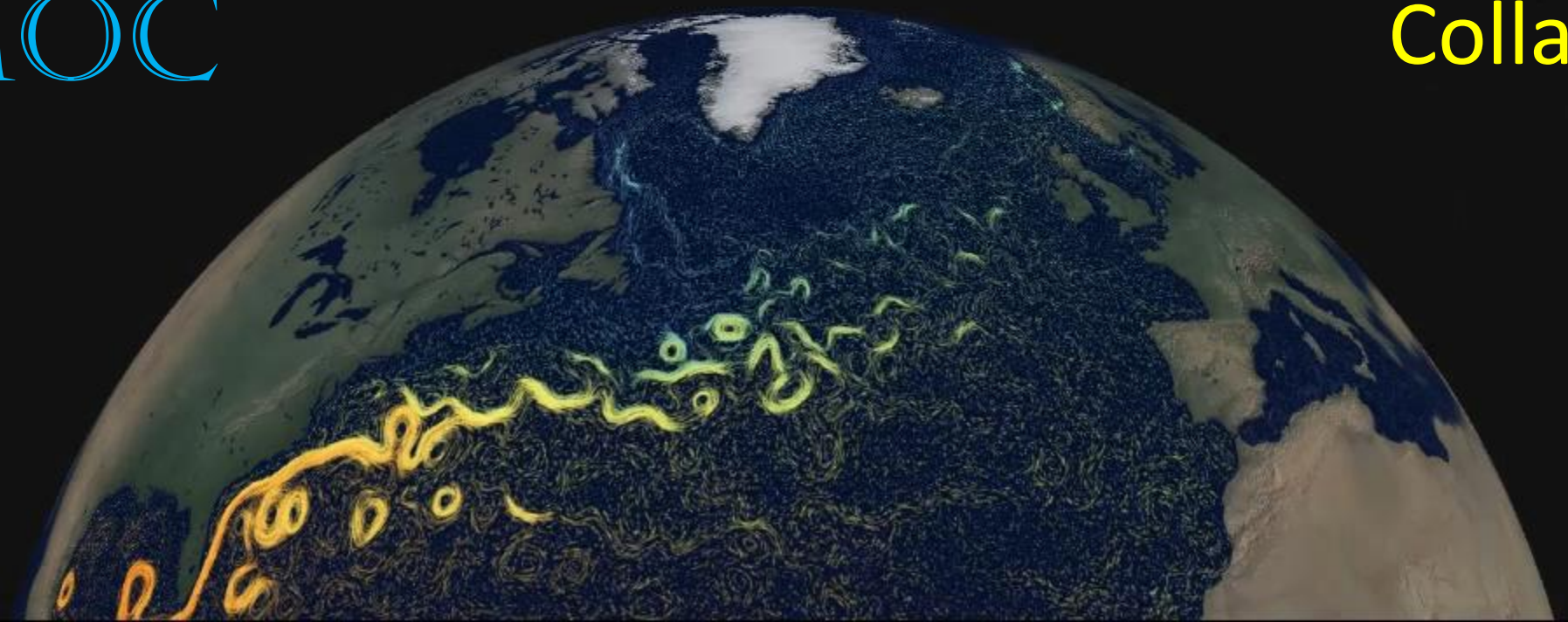
In the Atlantic Ocean, Subtle Shifts Hint at Dramatic Dangers

The warming atmosphere is causing an arm of the powerful Gulf Stream to weaken, some scientists fear.

By MOISES VELASQUEZ-MANOFF and JEREMY WHITE

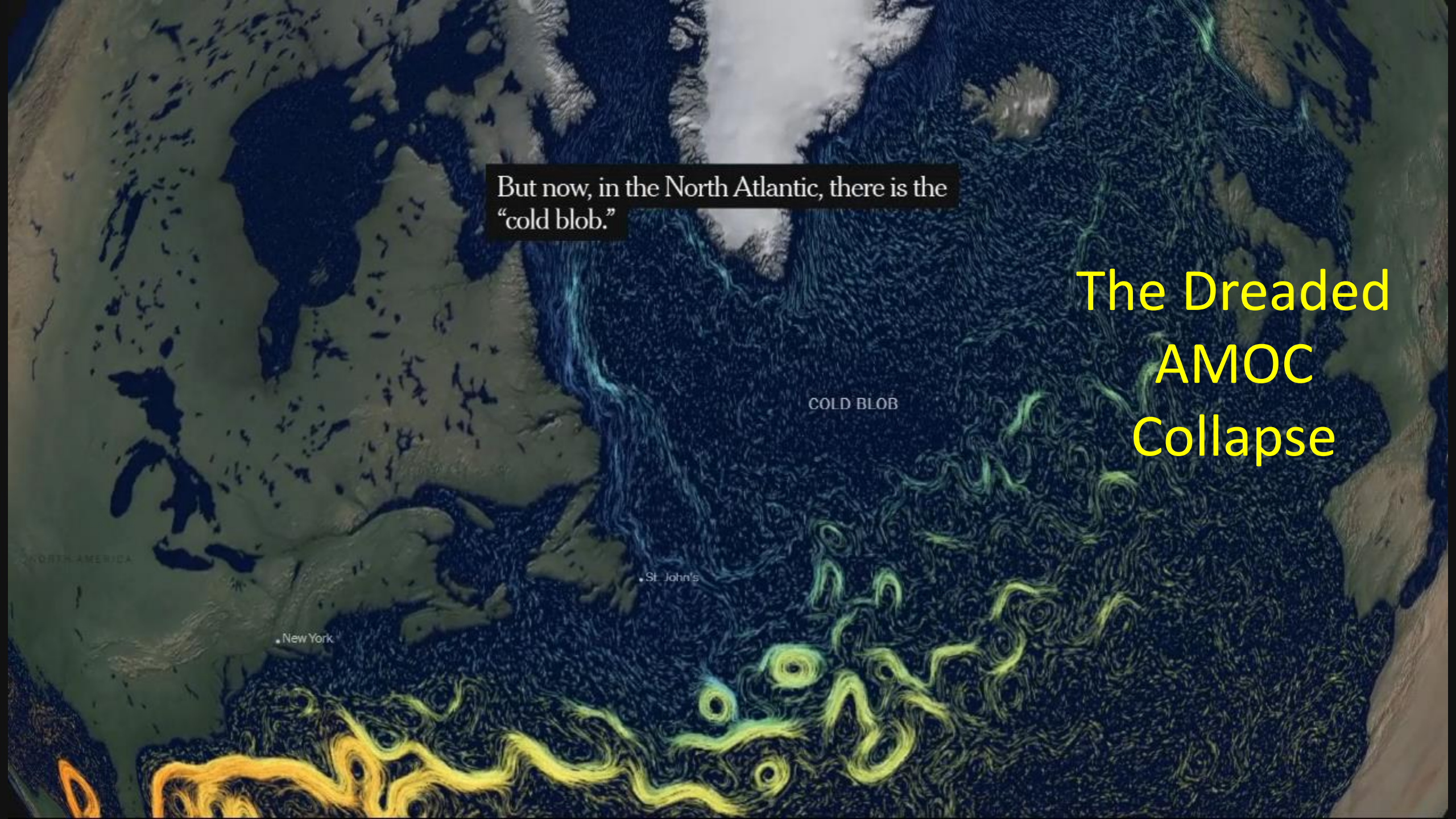
THE AMOC

The Dreaded AMOC Collapse

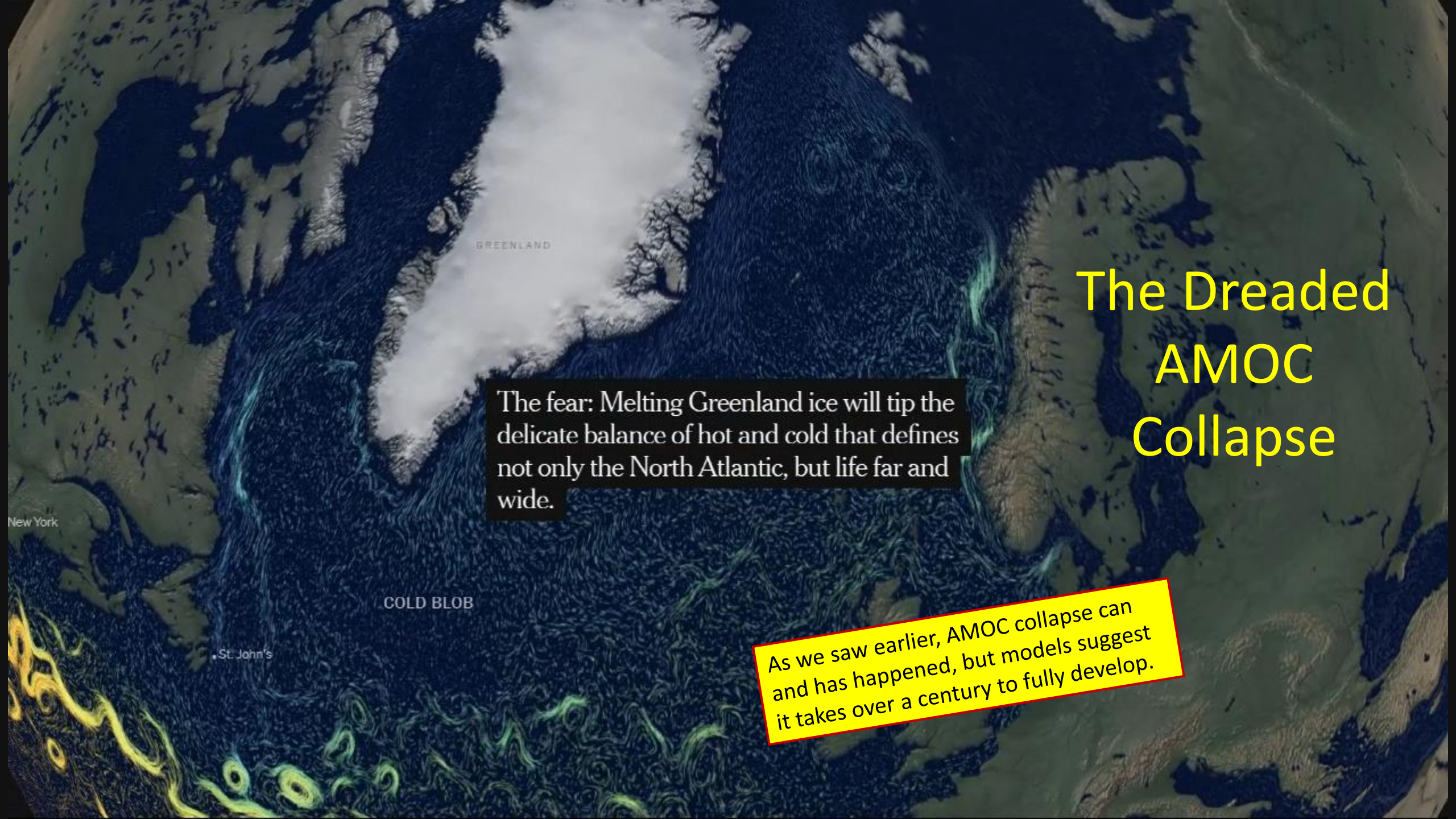



The Dreaded
AMOC
Collapse
Currents swing west from Africa, ultimately influencing weather patterns from Caracas to Miami to Europe.

The Dreaded AMOC Collapse



The Dreaded AMOC Collapse



The Dreaded AMOC Collapse

As we saw earlier, AMOC collapse can and has happened, but models suggest it takes over a century to fully develop.

The New York Times

PLAY THE CROSSWORD Account

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In the Atlantic Ocean, Subtle Shifts Hint at Dramatic Dangers

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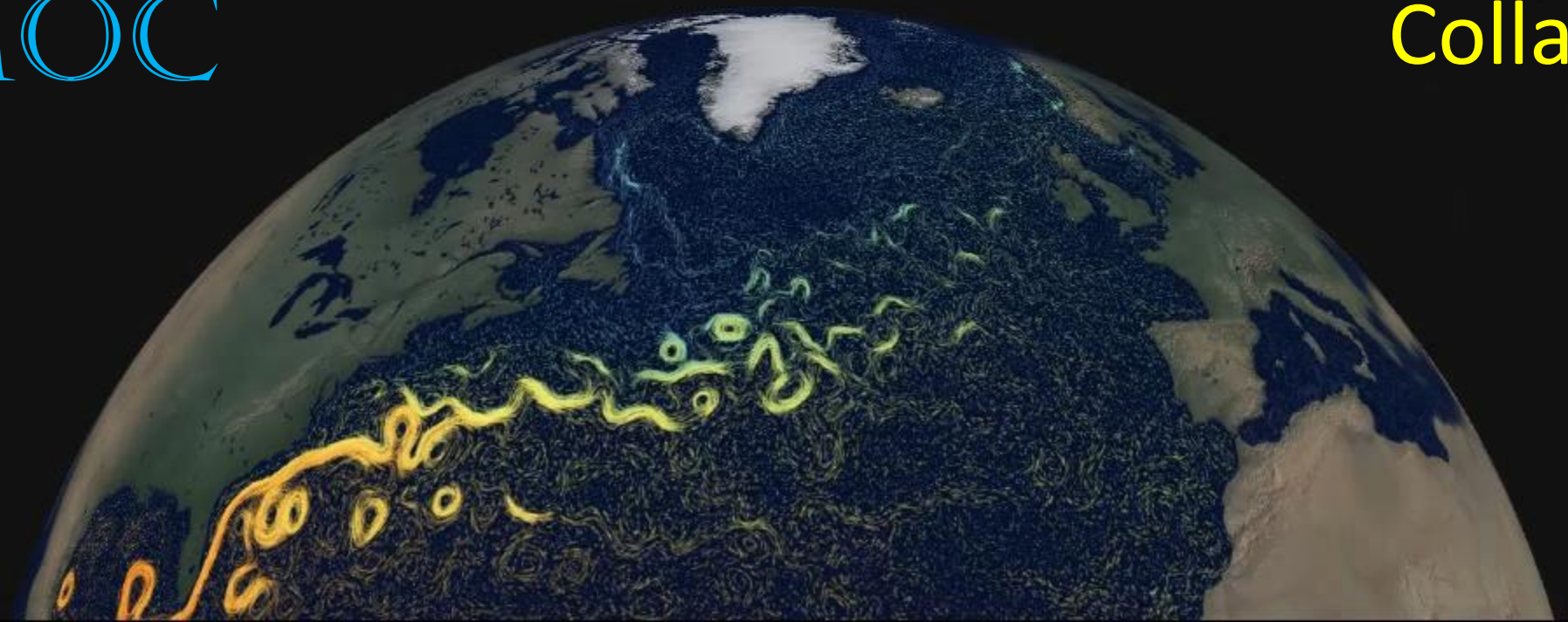


The “Hothouse Earth” Paper

Proceedings of the National Academy of Science

PERSPECTIVE

Trajectories of the Earth System in the Anthropocene

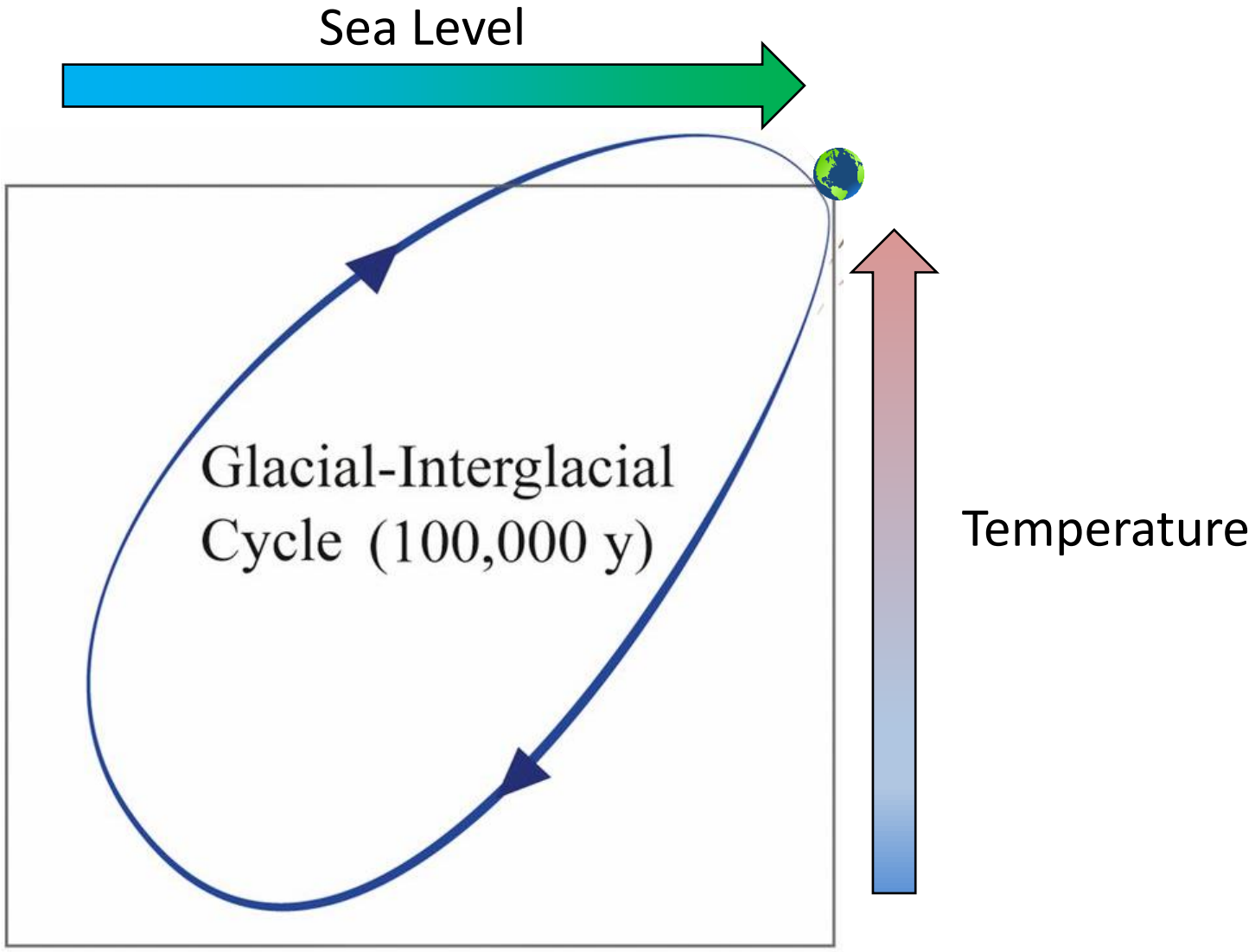
Undefined: 1945 onwards?

Will Steffen[a,b,1], Johan Rockström[a], Katherine Richardson[c], Timothy M. Lenton[d], Carl Folke[a,e], Diana Liverman[f], Colin P. Summerhayes[g], Anthony D. Barnosky[h], Sarah E. Cornell[a], Michel Crucifix[i,j], Jonathan F. Donges[a,k], Ingo Fetzer[a], Steven J. Lade[a,b], Marten Scheffer[l], Ricarda Winkelmann[k,m], and Hans Joachim Schellnhuber[a,k,m,1]

Edited by William C. Clark, Harvard University, Cambridge, MA, and approved July 6, 2018 (received for review June 19, 2018)

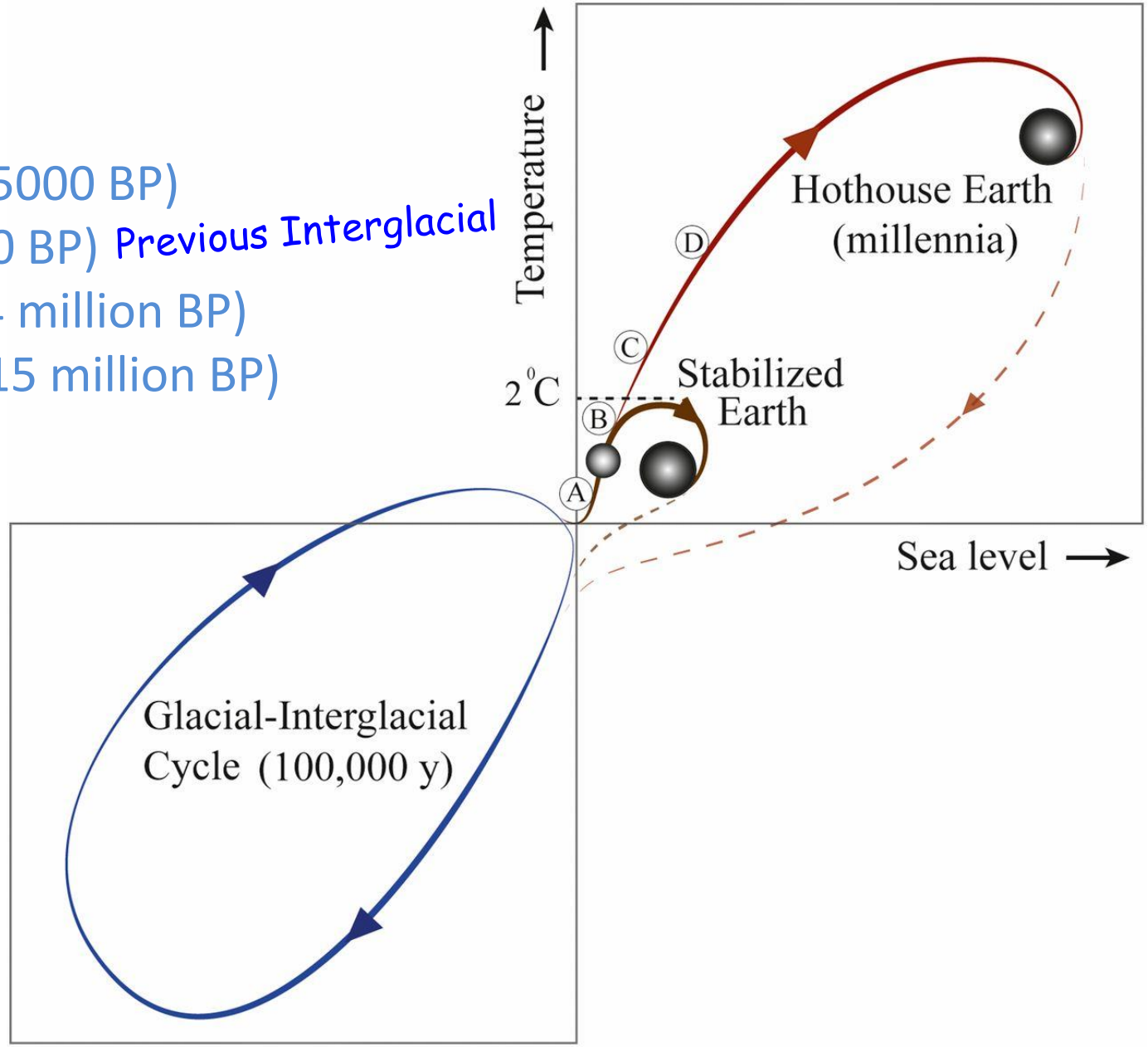
We explore the risk that self-reinforcing feedbacks could push the Earth System toward a planetary threshold that, if crossed, could prevent stabilization of the climate at intermediate temperature rises and cause continued warming on a “Hothouse Earth” pathway even as human emissions are reduced….

"Hothouse Earth" Paper



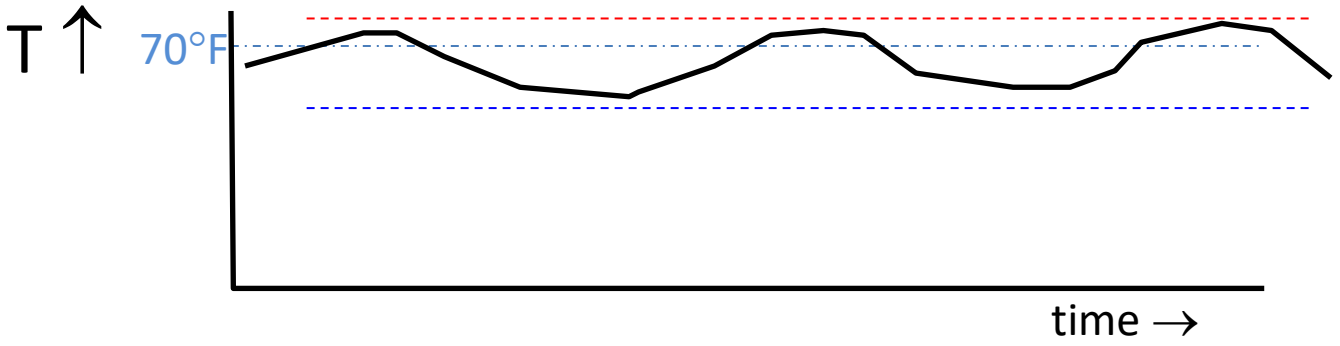
"Hothouse Earth" Paper

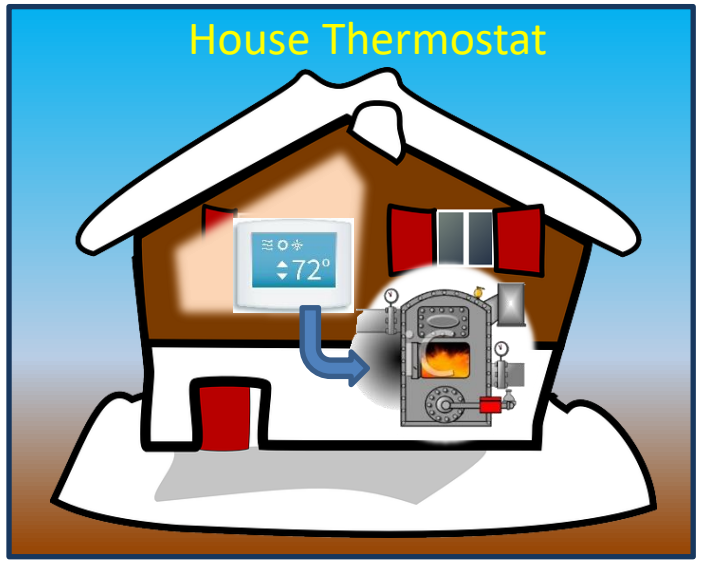
A. Mid-Holocene (~5000 BP)
B. Eemian (~120,000 BP) Previous Interglacial
C. Mid-Pliocene (~ 4 million BP)
D. Mid-Miocene (~ 15 million BP)

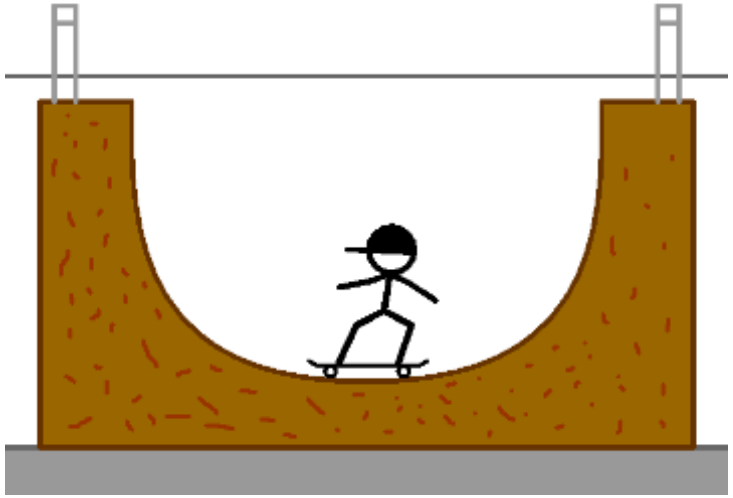


"Hothouse Earth" Paper

"Limit Cycles"







"Hothouse Earth" Paper

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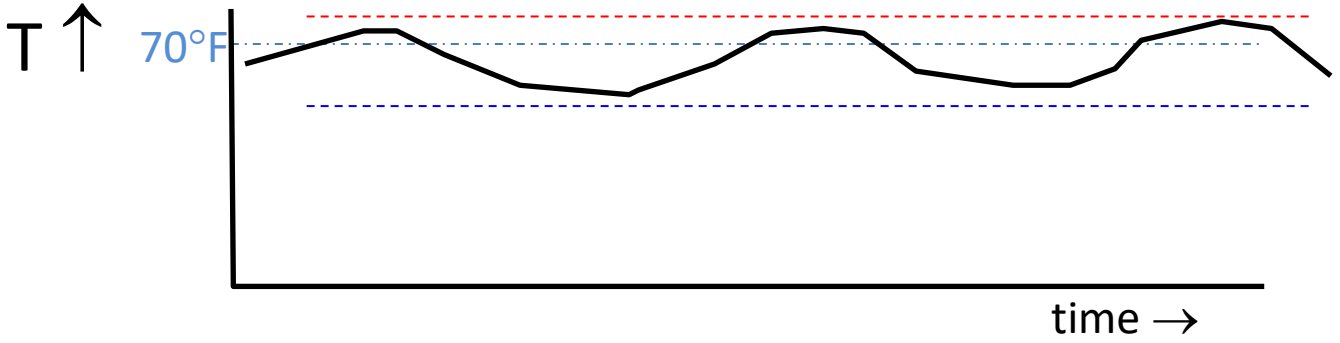

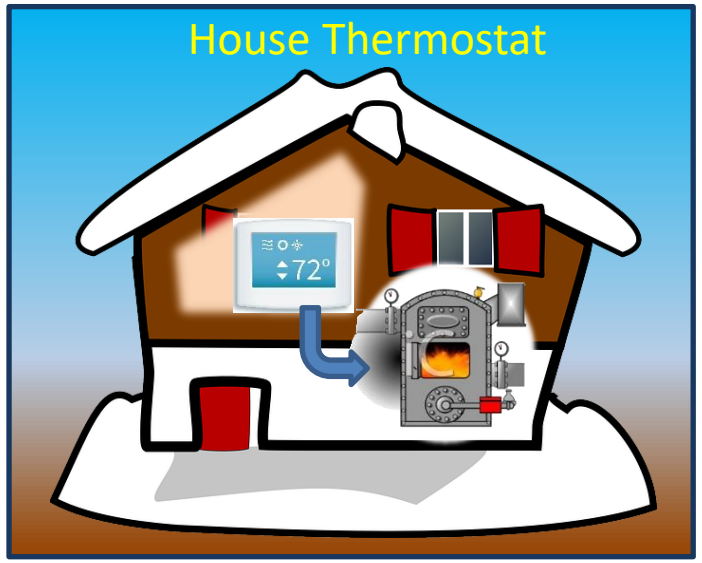

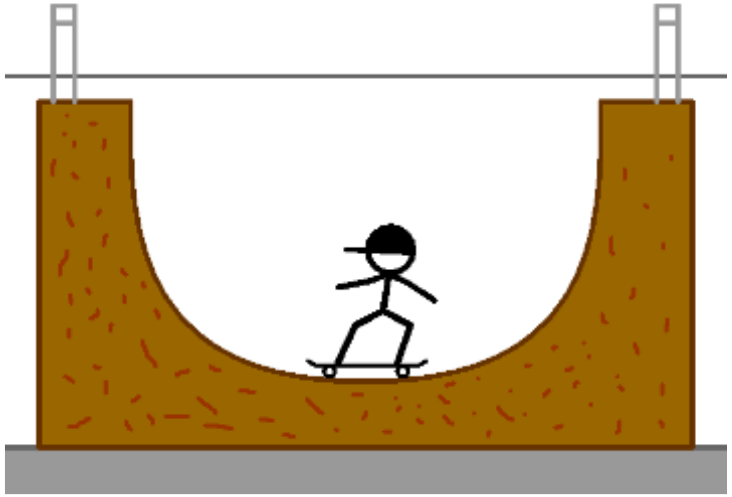

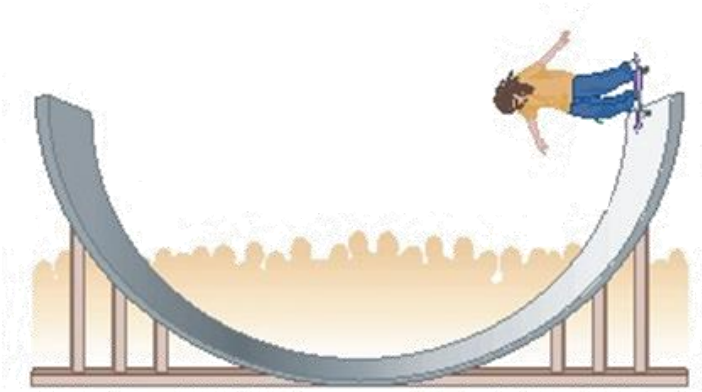

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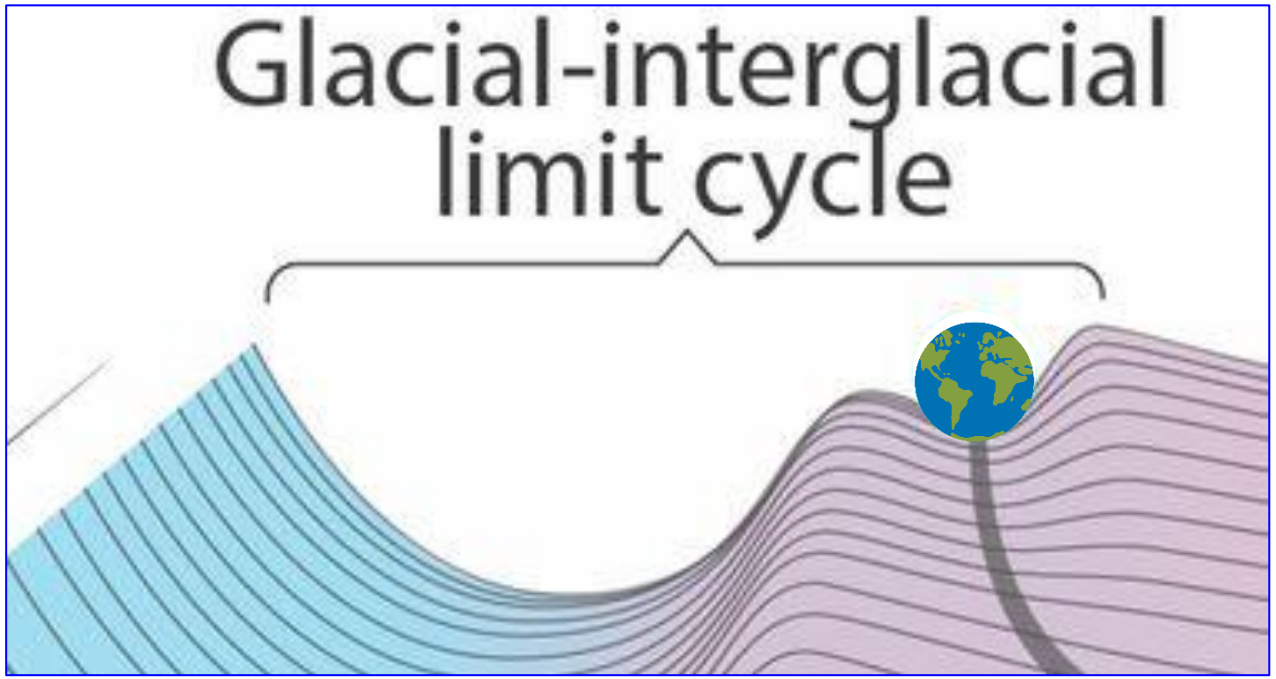

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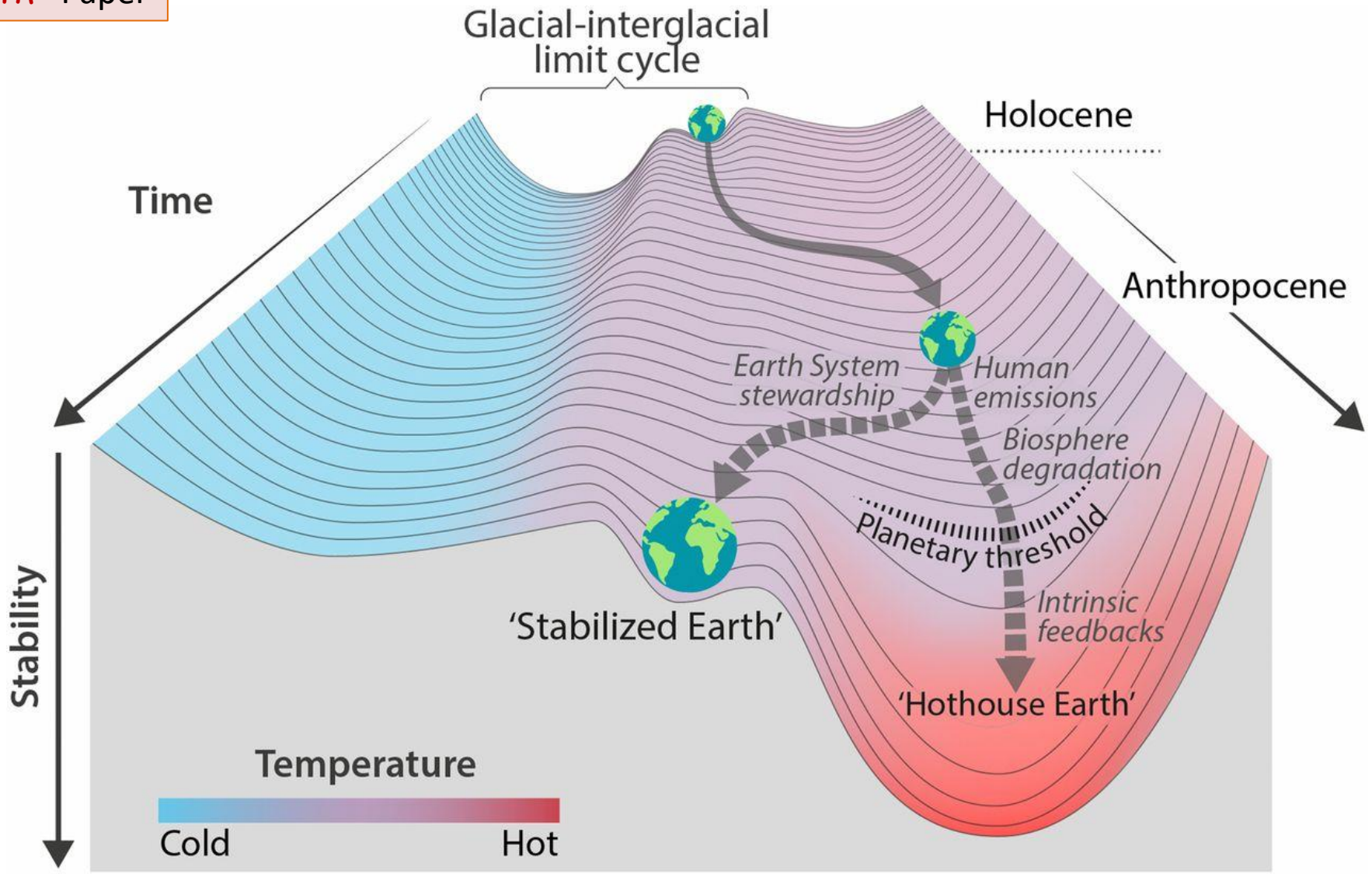

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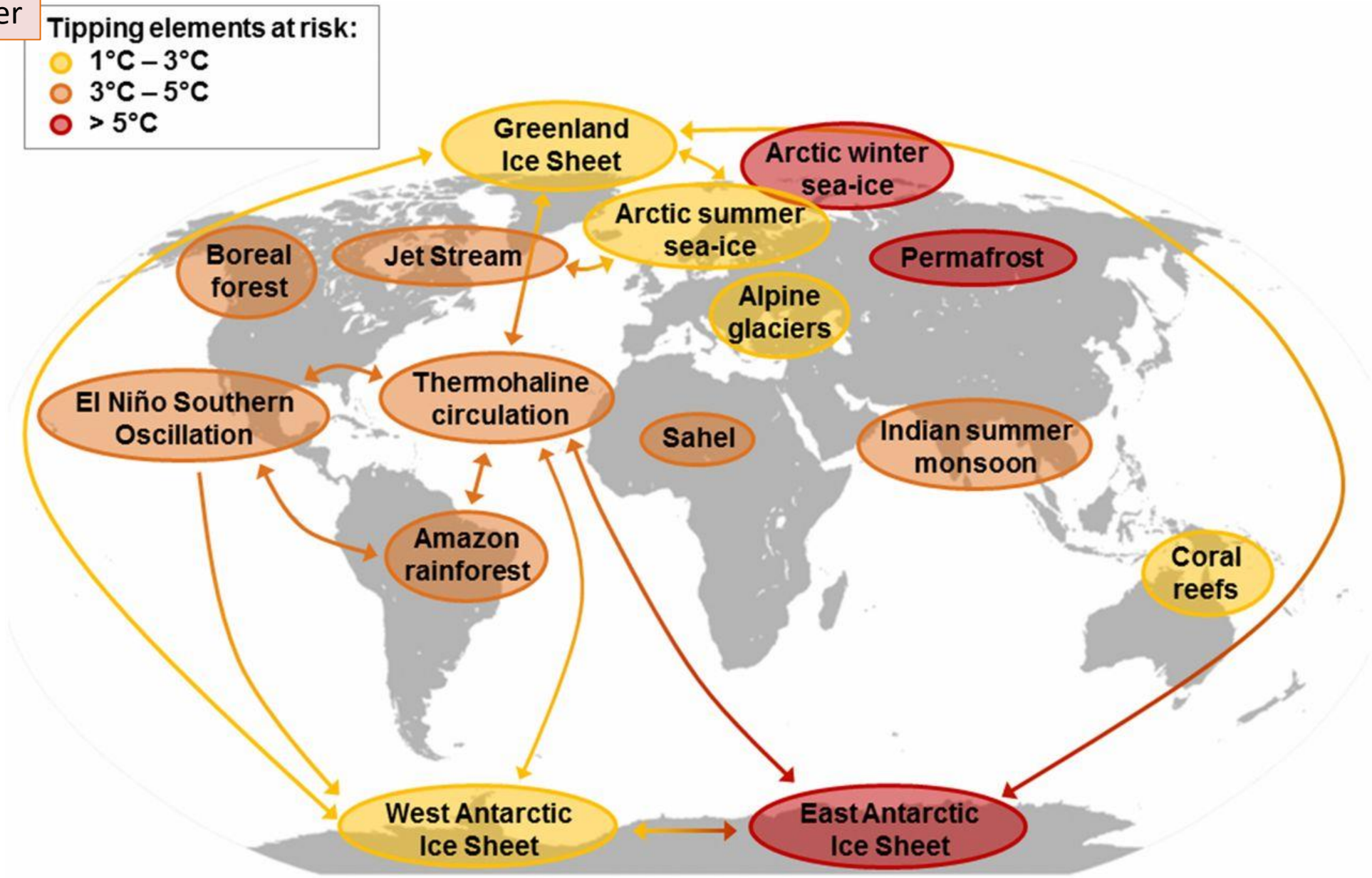
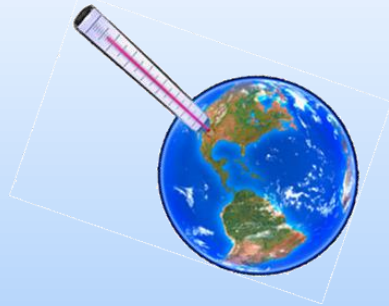
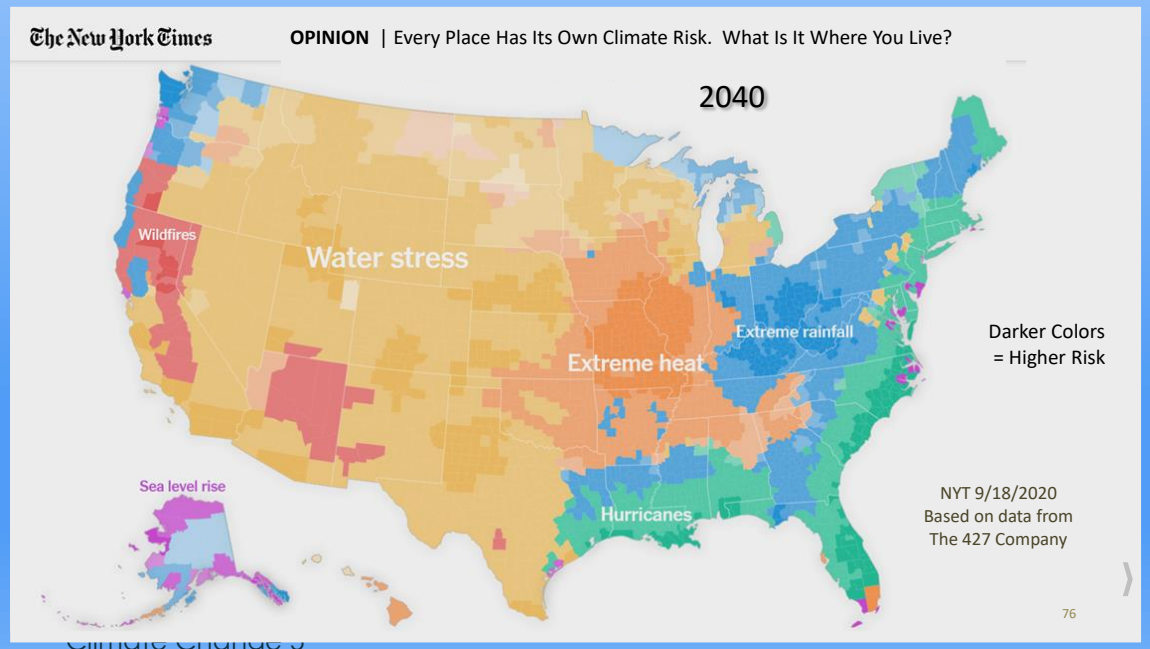
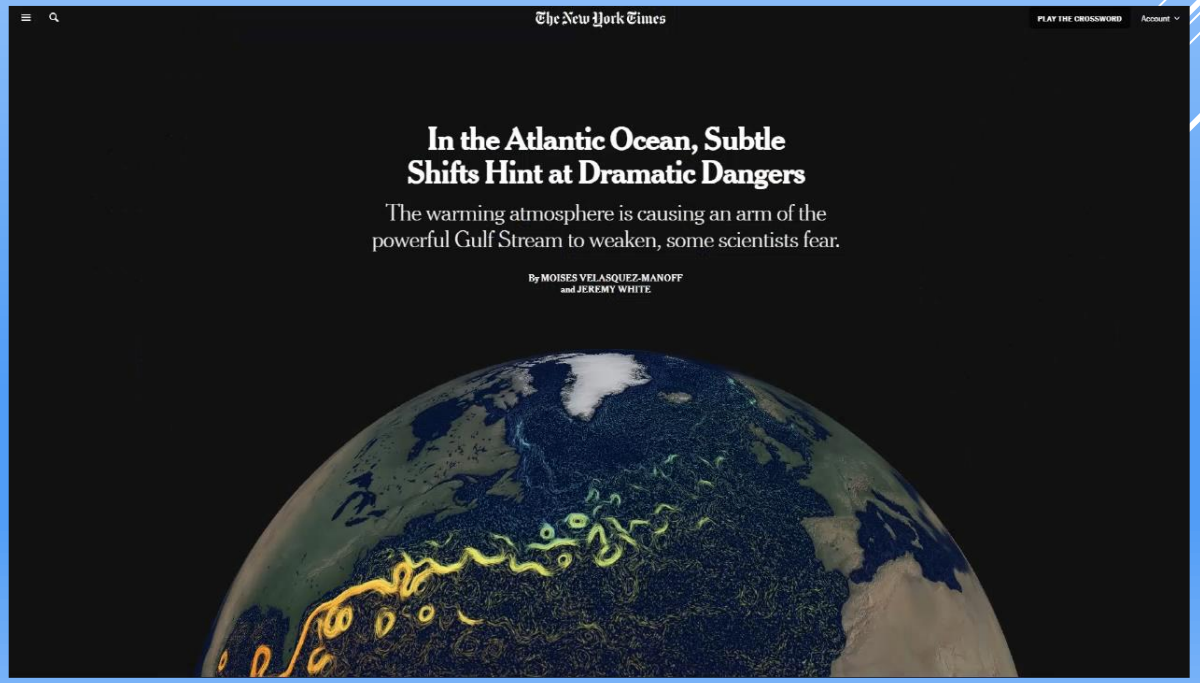


Weakening of biological Carbon takeup (land & sea)

Questions about Regional Projections: Tipping Points, etc.







Course Outline

1. Building Blocks: Some important concepts
2. Our Goldilocks Earth: a Radiative Balancing Act
3. The Role of the Atmosphere: Greenhouse Gases & Clouds
4. Global Circulation and Dynamics of the Earth System:
   Oceans, Atmosphere, Biosphere, Cryosphere, People, Lithosphere
5. Natural Variability of the Climate, short and long term. Ice Ages
6. Carbon Dioxide and other Greenhouse Gases:
   Where do they come from, where do they go, how are they regulated?
7. **Impacts and Future Projections for Global Warming -- Uncertainties**
8. Amelioration Strategies. The Climate Debate. Policy Options.