Climate Science and Global Climate Change

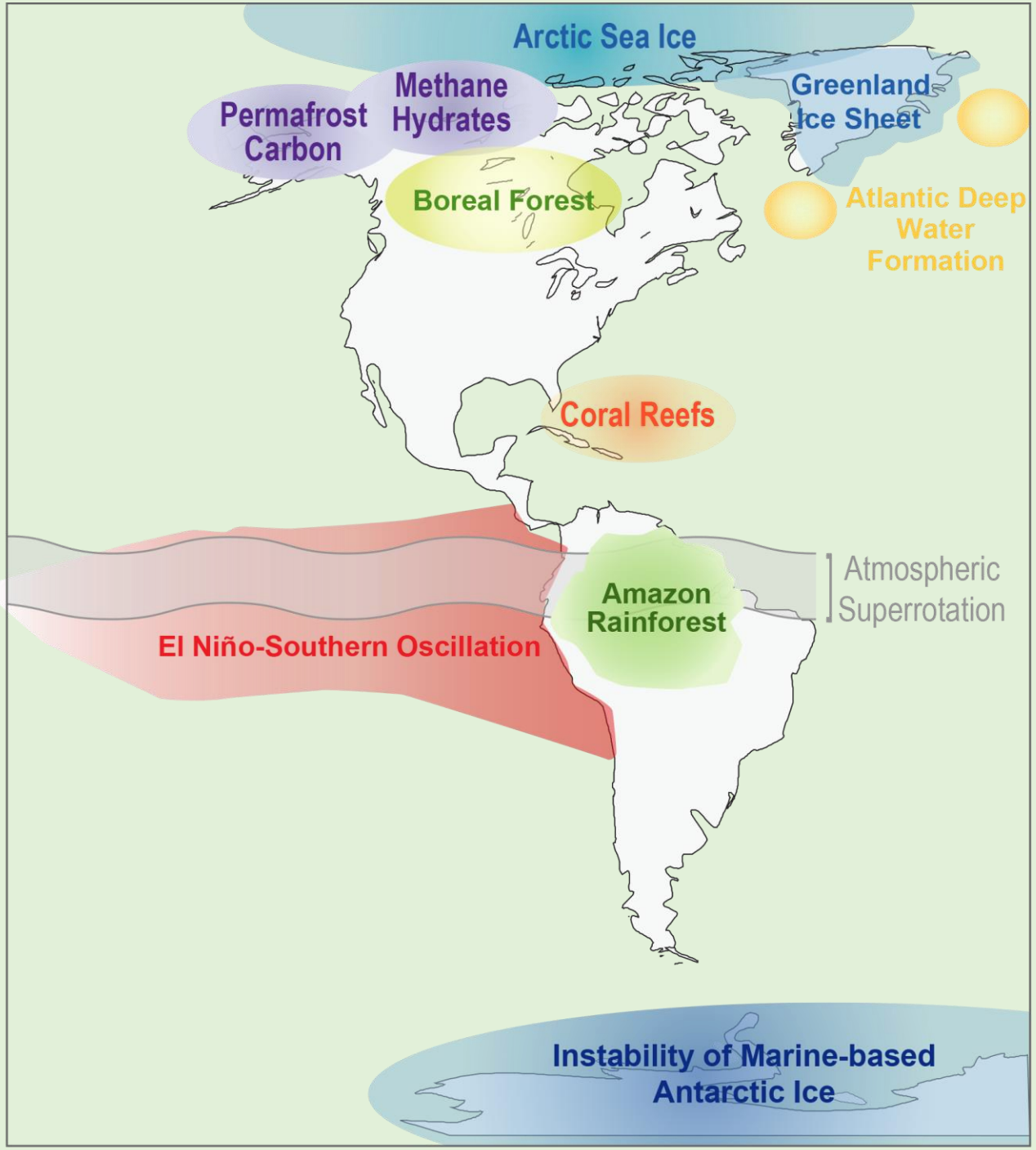
Session 5

- Consequences of global warming
- *IPCC* Goals
- Future temperatures?
- Adaptation and Mitigation
- Challenges and Positive Trends

Spring 2018
Univ. of Arizona OLLI
Lockwood Carlson PhD

Tipping points, non-linear processes, exponential events:

disaster, catastrophe, end-of-the-world, "OMG", the sky is Glowing

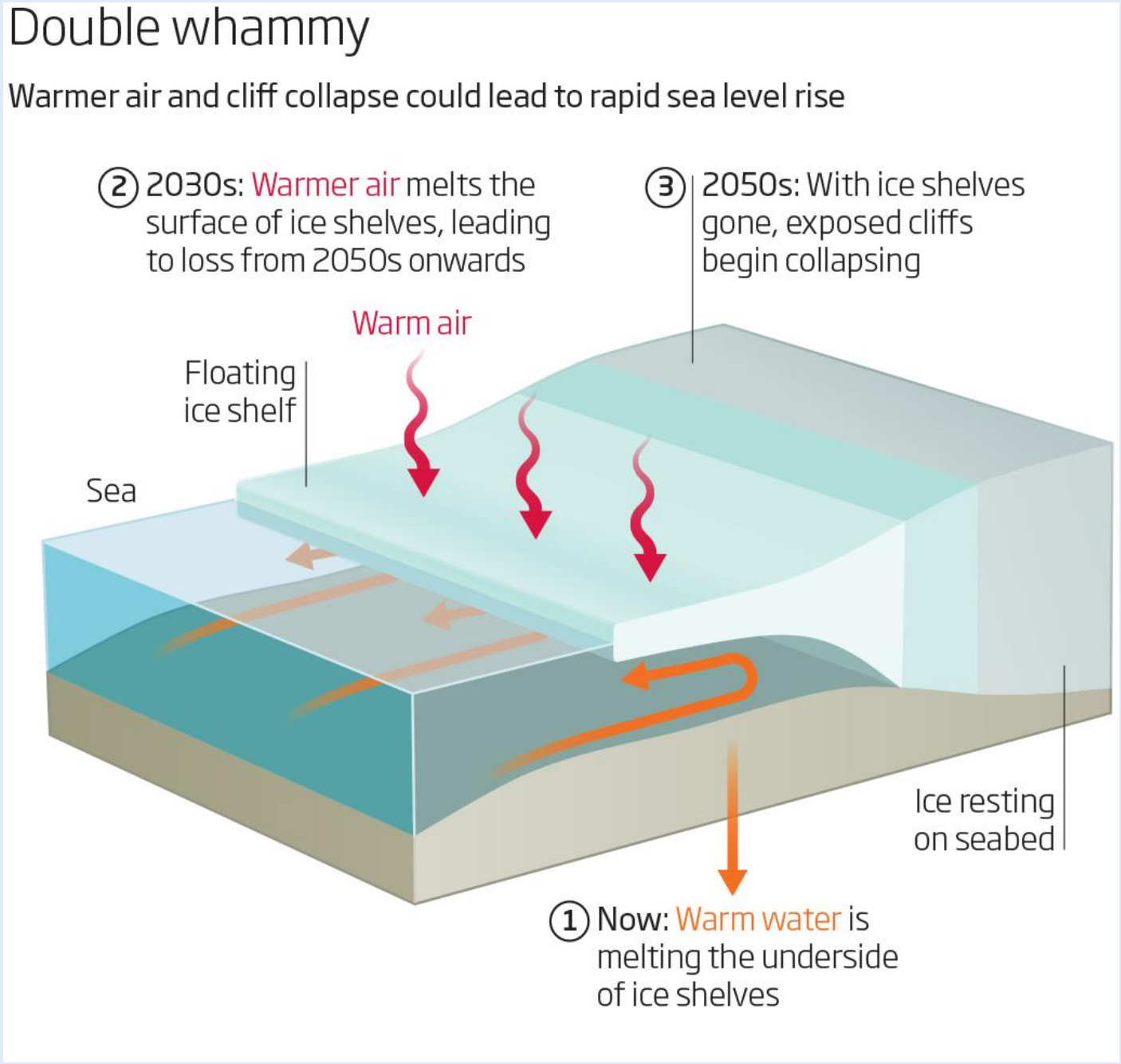


Potential climatic tipping elements affecting the Americas

U.S. Global Change Research Program
https://science2017.globalchange.gov/chapter/15/

Candidate Climatic Tipping Element	State Shift	Main Impact Pathways
Atmosphere–ocean circulation		
Atlantic meridional overturning circulation	Major reduction in strength	Regional temperature and precipitation; global temperature; regional sea level
El Niño–Southern Oscillation	Increase in amplitude	Regional temperature and precipitation
Equatorial atmospheric superrotation	Initiation	Cloud cover; climate sensitivity
Regional North Atlantic Ocean convection	Major reduction in strength	Regional temperature and precipitation
Cryosphere		
Antarctic Ice Sheet	Major decrease in ice volume	Sea level; albedo; freshwater forcing on ocean circulation
Arctic sea ice	Major decrease in summertime and/or perennial area	Regional temperature and precipitation; albedo
Greenland Ice Sheet	Major decrease in ice volume	Sea level; albedo; freshwater forcing on ocean circulation
Carbon cycle		
Methane hydrates	Massive release of carbon	Greenhouse gas emissions
Permafrost carbon	Massive release of carbon	Greenhouse gas emissions
Ecosystem		
Amazon rainforest	Dieback, transition to grasslands	Greenhouse gas emissions; biodiversity
Boreal forest	Dieback, transition to grasslands	Greenhouse gas emissions; albedo; biodiversity
Coral reefs	Die-off	Biodiversity

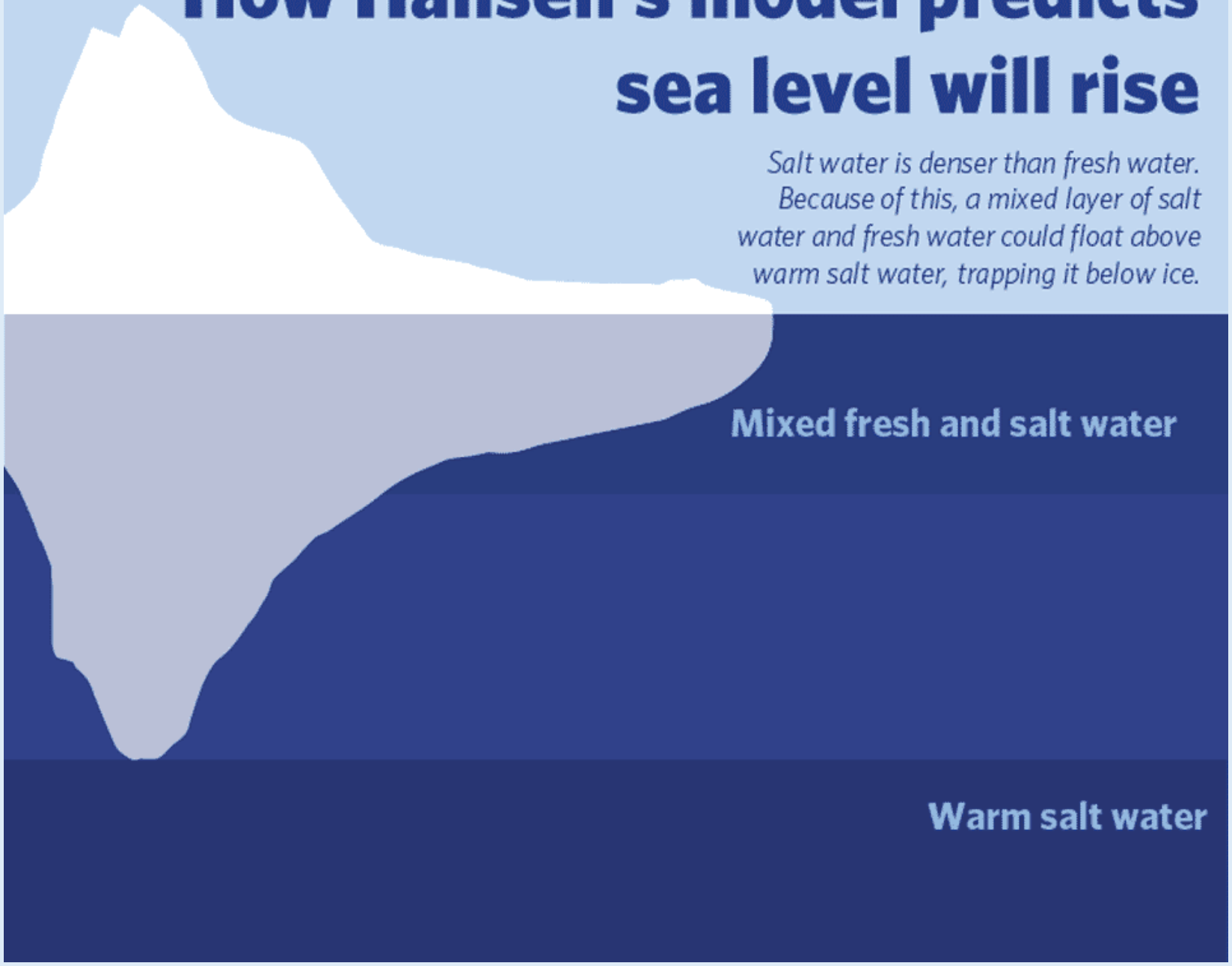
https://science2017.globalchange.gov/chapter/15/



Antarctic Ice Sheets

How Hansen's model predicts sea level will rise

Salt water is denser than fresh water. Because of this, a mixed layer of salt water and fresh water could float above warm salt water, trapping it below ice.



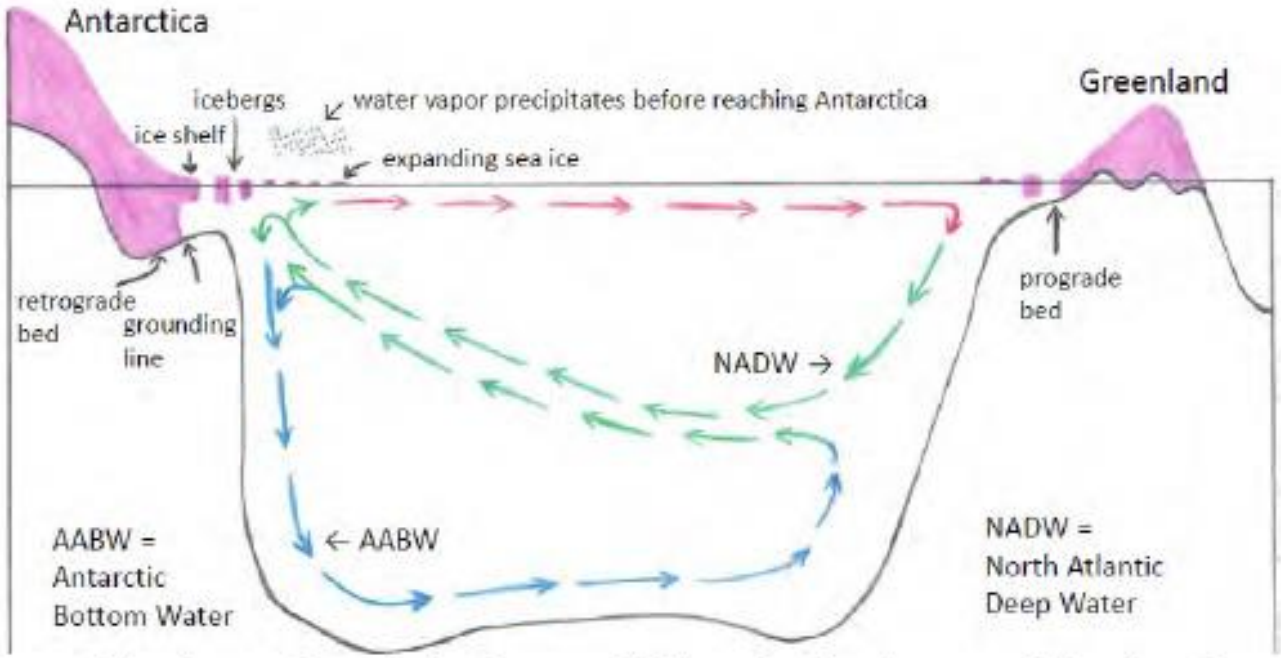
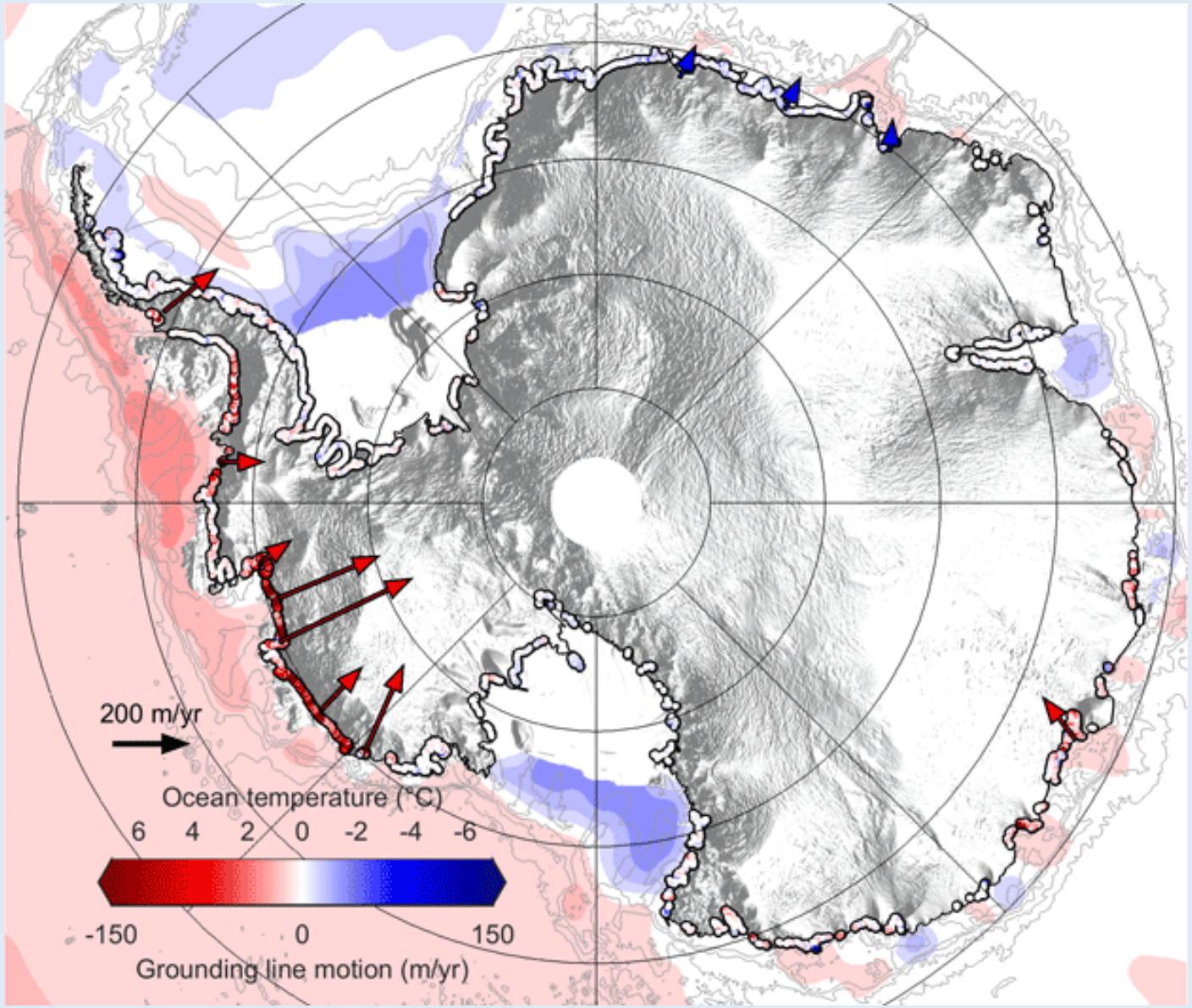


Fig. 18. Schematic of stratification and precipitation amplifying feedbacks. Stratification: increased freshwater flux reduces surface water density, thus reducing AABW formation, trapping NADW heat, and increasing ice shelf melt. Precipitation: increased freshwater flux cools ocean mixed layer, increases sea ice area, causing precipitation to fall before it reaches Antarctica, reducing ice sheet growth and increasing ocean surface freshening. Ice in West Antarctica and the Wilkes Basin, East Antarctica is most vulnerable because of the instability of retrograde beds.

Ice Melt, Sea Level Rise and Superstorms: Evidence from Paleoclimate Data, Climate Modeling, and Modern Observations that 2°C Global Warming is Dangerous, preprint 2016

Net retreat of Antarctic glacier grounding lines

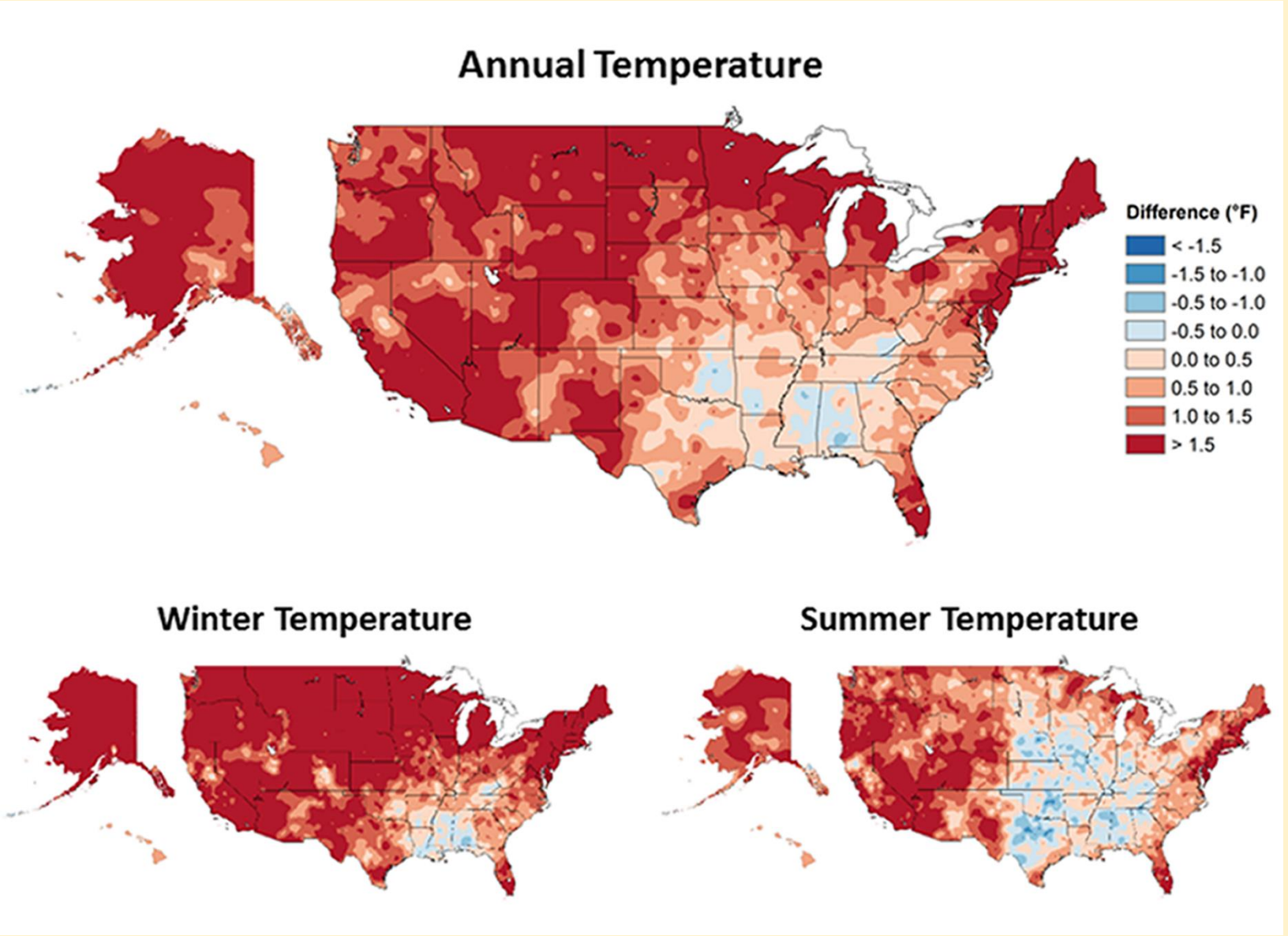


Between 2010 and 2016, 22%, 3% and 10% of surveyed grounding lines in West Antarctica, East Antarctica and at the Antarctic Peninsula retreated at rates faster than 25 m yr^{-1} (the typical pace since the Last Glacial Maximum) and the continent has lost 1,463 km^2 ± 791 km^2 of grounded-ice area.

Nature Geoscience (2018)

02 April 2018

Fig. 1: Rates of grounding-line migration between 2010 and 2016 along the Antarctic grounding line [8] derived from CryoSat-2 and bedrock topography [24] observations.



Observed changes in annual, winter, and summer temperature (°F). Changes are the difference between the average for present-day (1986–2016) and the average for the first half of the last century (1901–1960 for the contiguous United States, 1925–1960 for Alaska and Hawai‘i). Estimates are derived from the nClimDiv dataset. , (Figure source: NOAA/NCEI).

Southwest US Climate Change

Megadrought Risk: Ault et al.,
Sci. Adv. 2016;2: e1600873 5 October 2016

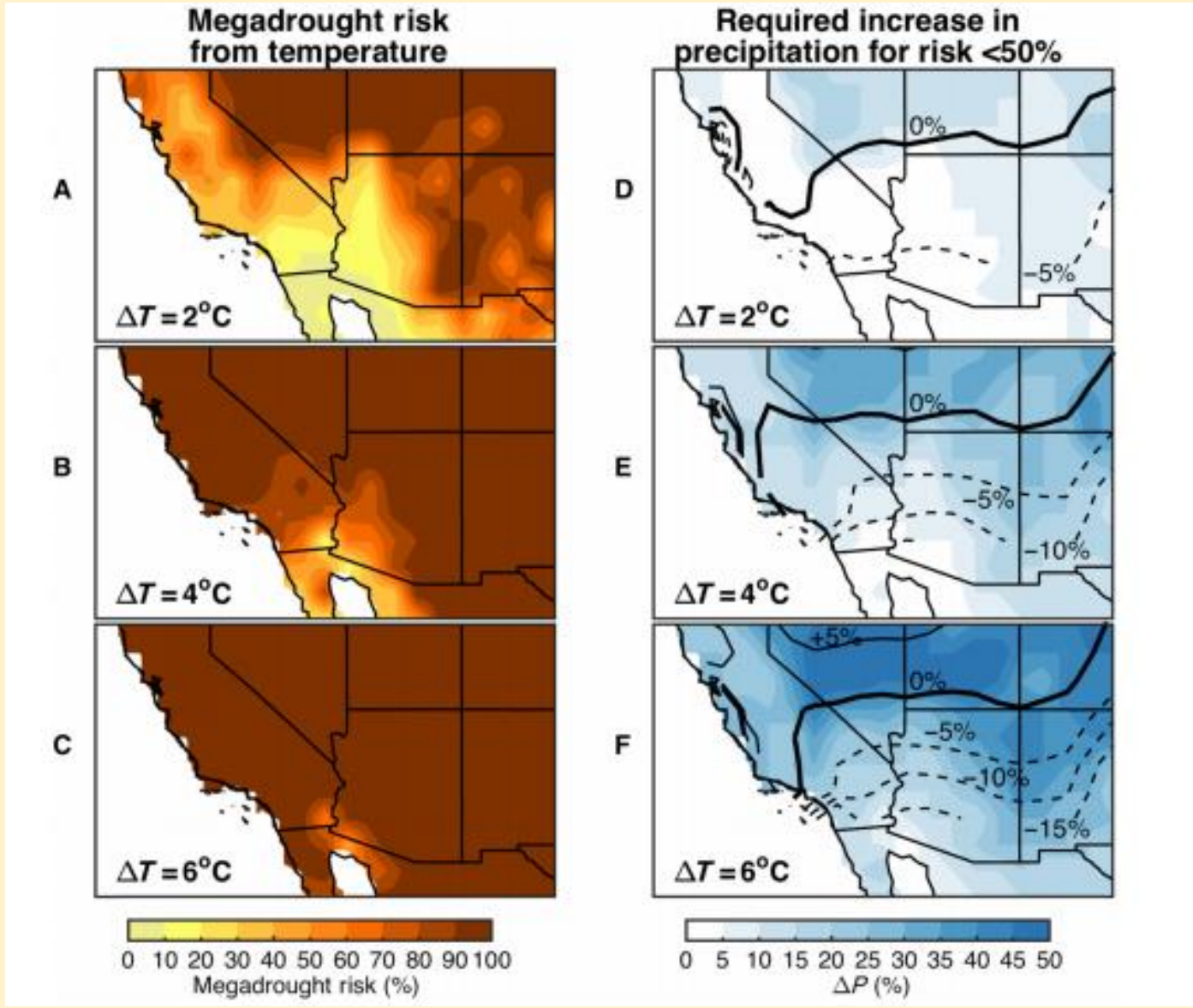
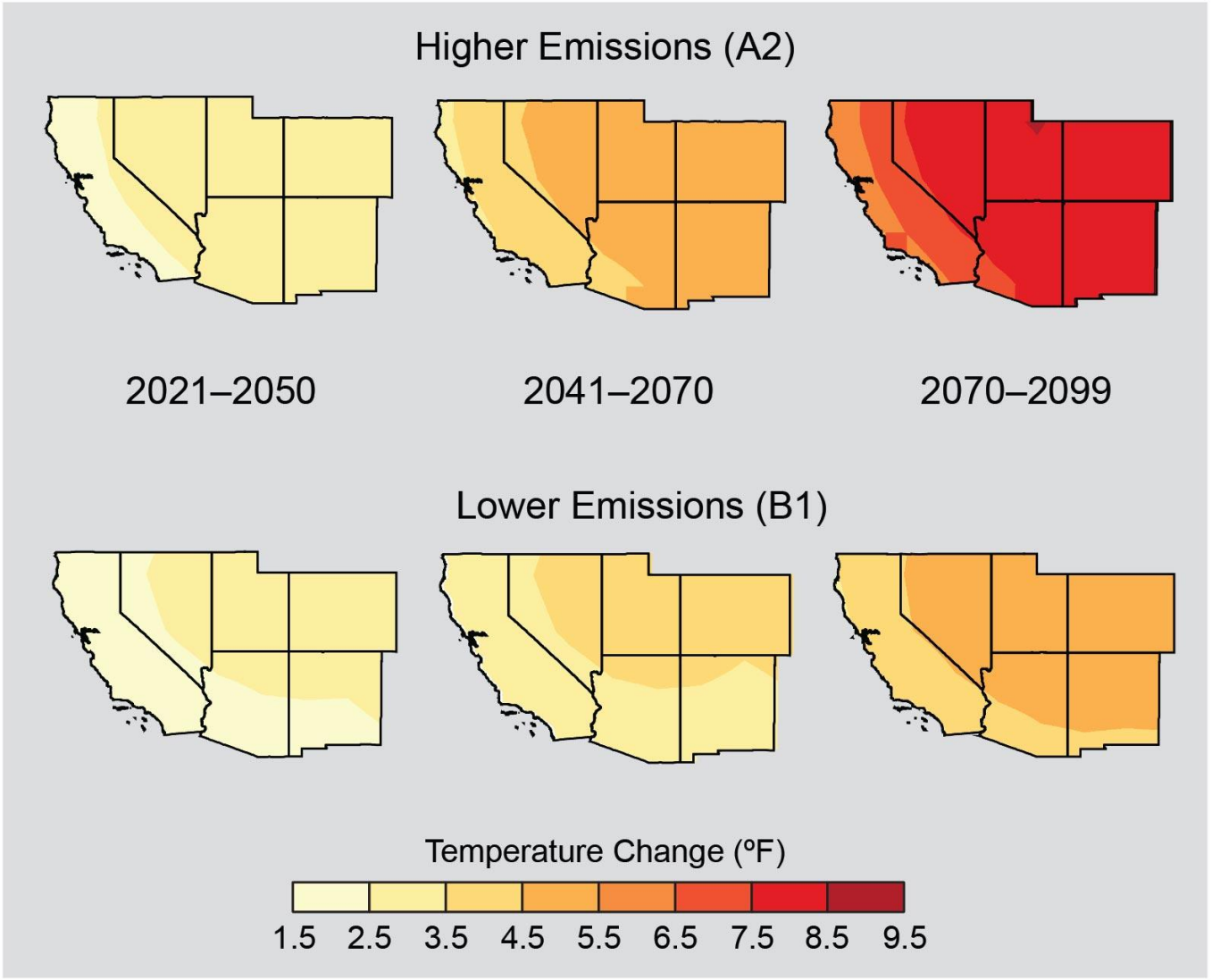
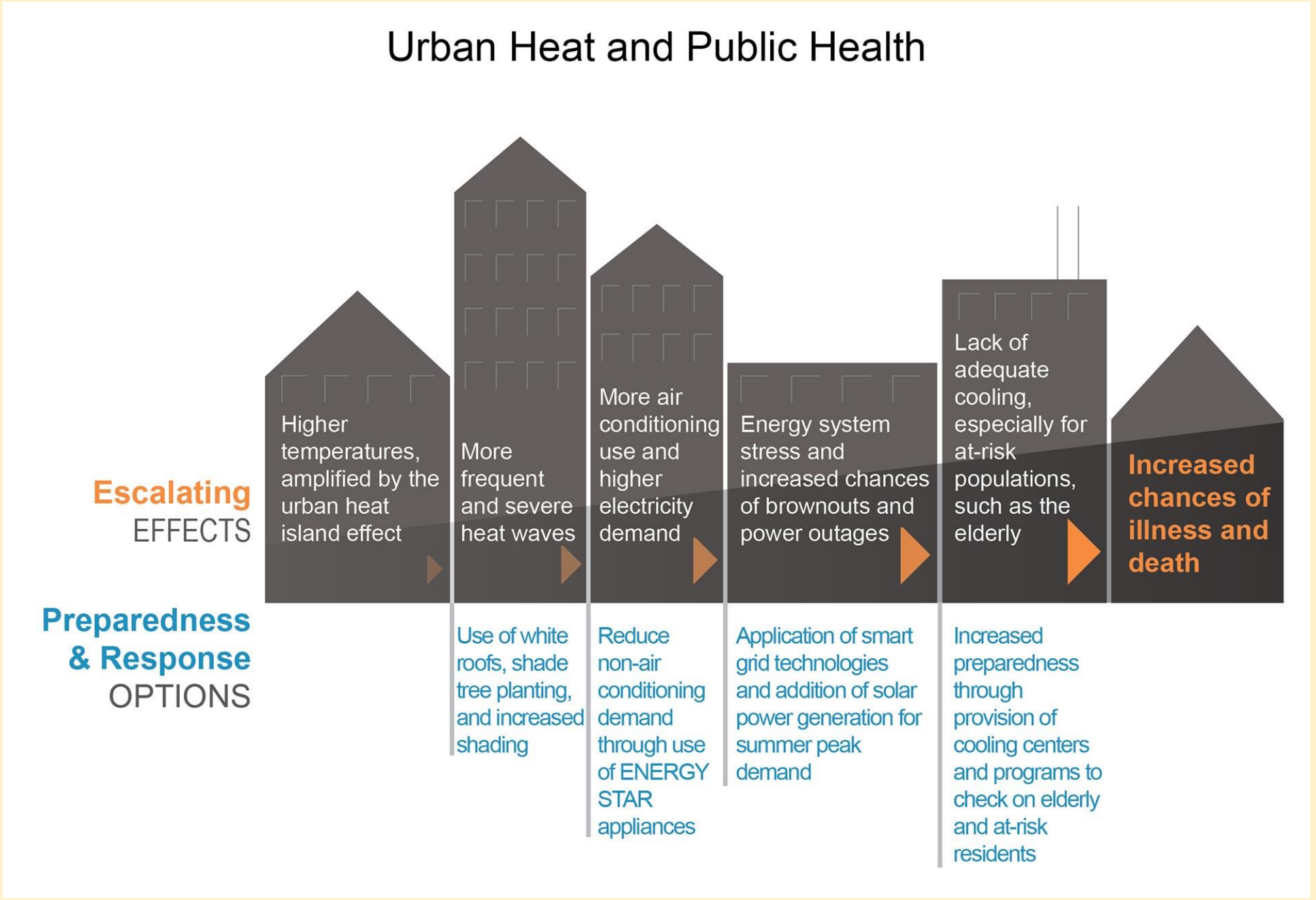


Fig. 4. Maps of megadrought risk for the American Southwest under different levels of warming, and the required increase in precipitation to compensate for that warming. (**A** to **C**) Maps of megadrought risk for the entire American Southwest domain at constant (historical) precipitation climatology ($\Delta P = 0\%$) and various levels of warming. These estimates are based on the Monte Carlo procedure of observational and reanalysis data, not on CMIP5 (see Materials and Methods). (**D** to **F**) Increases in precipitation (blue shading) needed to maintain megadrought risks below 50% for different levels of regional warming. Contours map the projected changes in precipitation derived from the multimodel CMIP5 mean and are shown for reference at each level of temperature change.

Projected Temperature Increases



http://nca2014.globalchange.gov/report/regions/southwest



The projected increase in heat waves in Southwest cities increases the chances that a chain of escalating effects could lead to serious increases in illness and death due to heat stress. The top of the figure provides some of the links in that chain, while the bottom of the figure provides adaptation and improved governance options that can reduce this vulnerability and improve the resilience of urban infrastructure and community residents.

nca2014.globalchange.gov/report/regions/southwest

Future climate projections

Possible scenarios for global GHG emissions up to year 2100

How does the climate depend on atmospheric CO2 concentrations?

Climate impacts:

- Global surface temp.
- Sea surface temp.
- Sea level rise, sea ice extent
- Ocean pH
- Precipitation
- Regional climate change

Some consequences of greenhouse gas emissions:

Climate impacts:

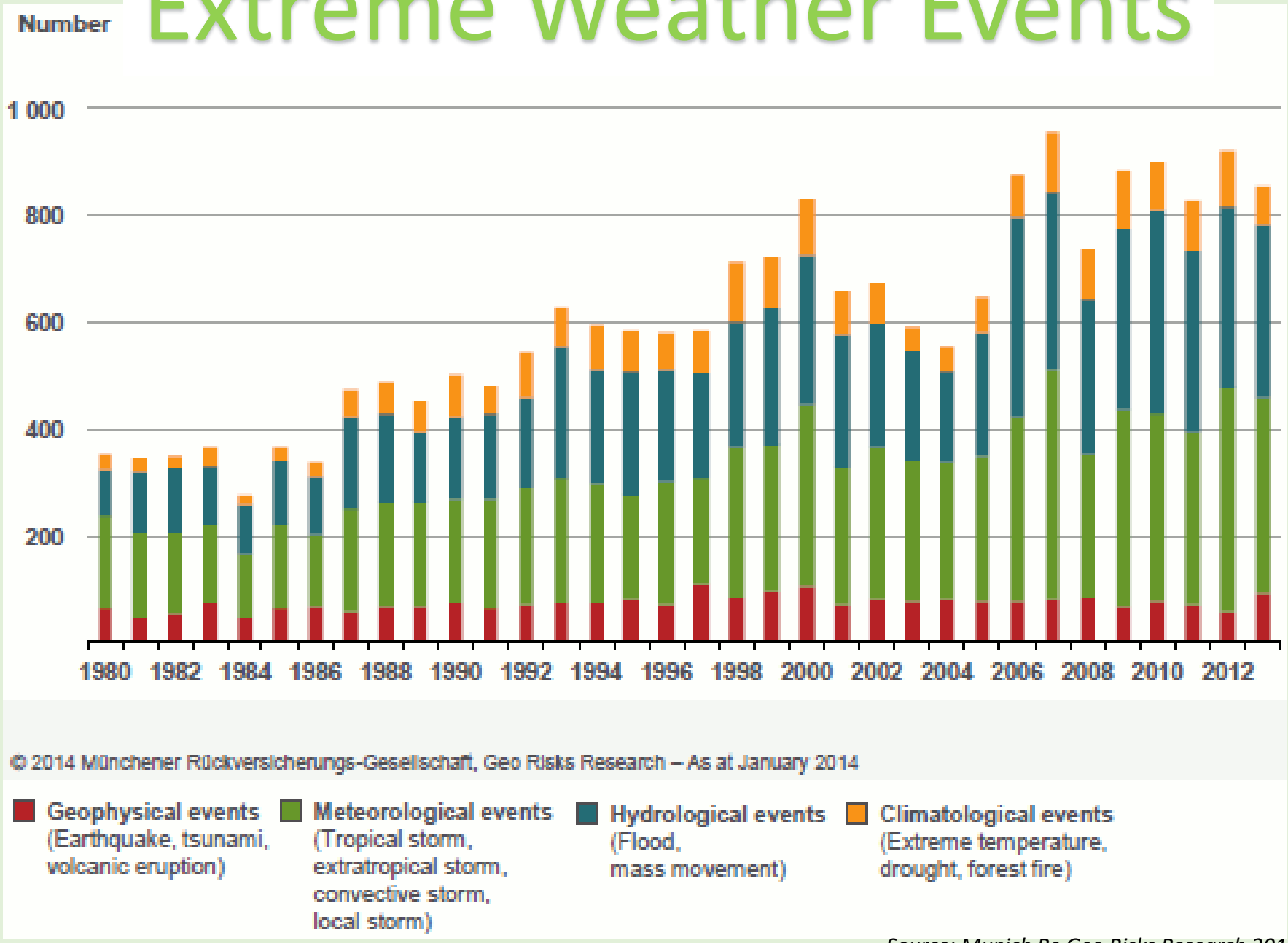
- Global surface temp.
- Sea surface temp.
- Sea level rise, sea ice extent
- Ocean pH
- Precipitation
- Regional climate change

Littoral flooding
Long term droughts
Agricultural disruption
Extreme weather events
Species extinction

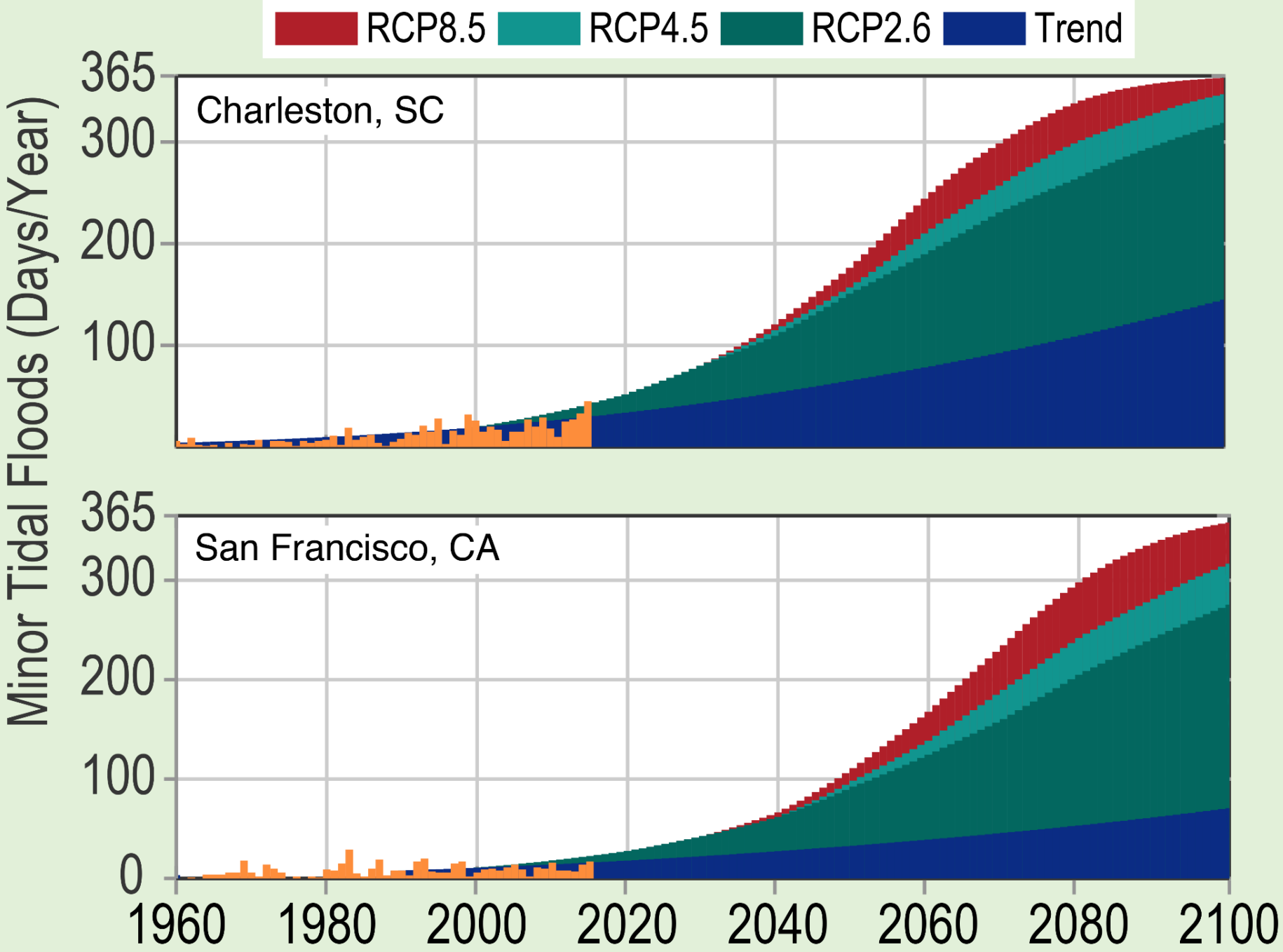
?

Human diseases increase
Clean water shortages
Food scarcity
Major economic disruptions
Population displacements
Wars

Extreme Weather Events



Source: Munich Re Geo Risks Research 2016



U.S. Global Change Research Program Climate Science Special Report 2017

ipcc
INTERGOVERNMENTAL PANEL ON climate change

CLIMATE CHANGE 2014:

IMPACTS, ADAPTATION, AND VULNERABILITY

Most places will continue to get warmer, especially at night and in winter. The temperature change will benefit some regio
tourism wi
health ar
food sup
and extrem
directly ha
and a press

Sea levels will continue to rise for many centuries. The last time the planet was 3°C warmer than now, the sea level was at least 6 meters (20 feet) higher.(2
millions
Shangha
generati
ruinousl
storm su

Weather patterns will keep changing toward an intensified water cycle with stronger floods and droughts. Most regions now subject to droughts will probably get drier
(because
regions w
more fre
intense r
will get m
winter sn
supply sy
happen i

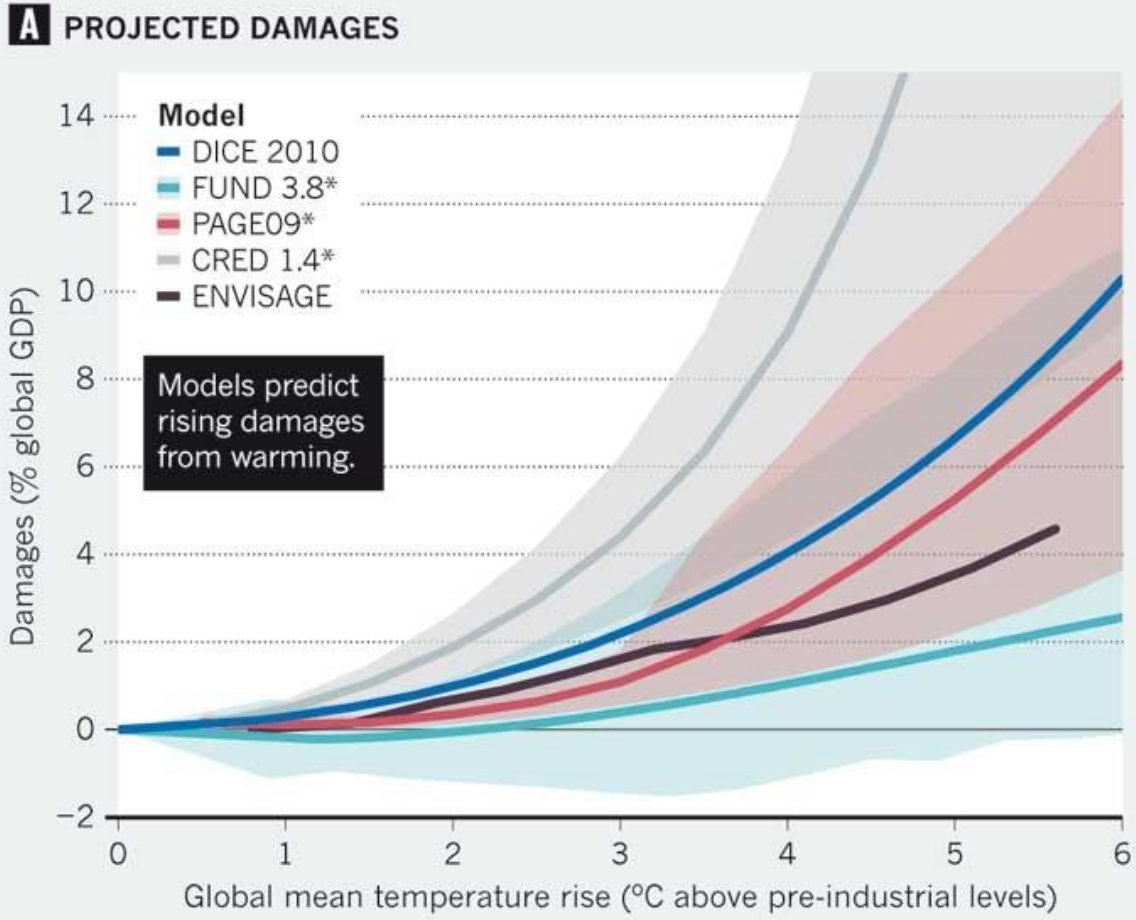
Ecosystems will be stressed, although some managed agricultural and forestry systems might benefit in the first decades of warmin
mountain
that cann
diseases
problems

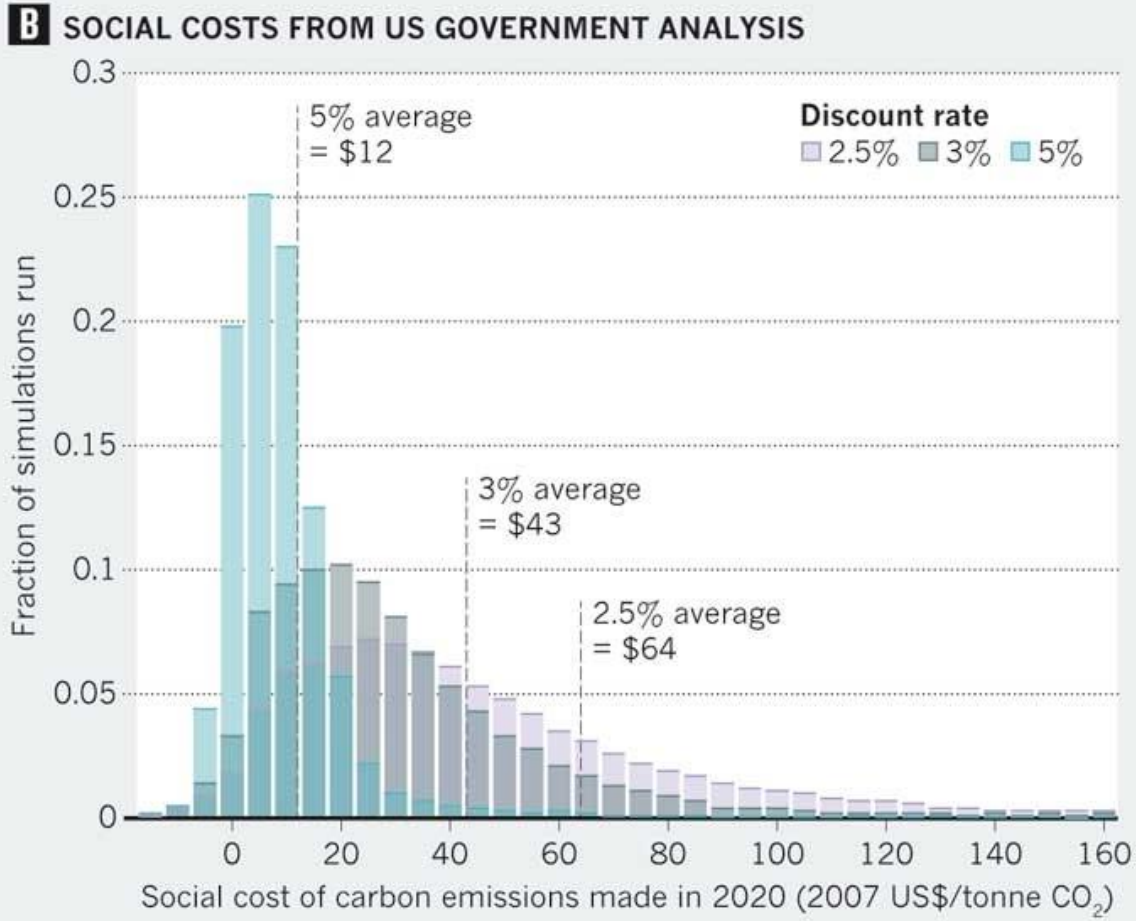
Increased carbon dioxide levels will affect biological systems independent of climate change. Some crops will be fertilized, as will some invasive weeds (the balance of benefit vs. harm is uncertain). The oceans will continue to become markedly more acidic, gravely endangering coral reefs, and probably harming fisheries and other marine life.

Econometric Forecasts

CARBON'S COSTLY LEGACY

Economic models of climate change project that resulting damage worldwide (**A**) will increase with future emissions and may cost several per cent of global gross domestic product (GDP) with the warming expected by 2100. Uncertainties in future socio-economics, emission rates and climate impacts result in a range of estimates of the social cost of carbon, which is also affected by the choice of 'discount rate' used to convert future harms into today's money (**B**).





*Shaded regions indicate 5% and 95% confidence intervals for FUND 3.8 and PAGE09, and a high–low range for CRED 1.4.

10 APRIL 2014 | VOL 508 | NATURE | 173

The Global Commons

The seas and the atmosphere belong to all of humanity.

Paris COP21: the *IPCC* Agreement

PARIS AGREEMENT

Getting to "YES"- Paris COP21 December 2015
Paris Agreement (+ Annex)

197 countries
18 years since first *Kyoto* agreement
Voluntary emissions reductions
Phased in over several years- not specified
Includes periodic 'stock-taking' with full transparency (starts in 2023)
"common but differentiated responsibility" (not 'liability')
    Strong voice for developing countries
    Strong voice for small island nations
Inclusion of *sustainable development* context for actions
Includes need for initial payments to developing countries- $100 Billion

Legally binding parts and 'decisions' (ambitions and goals)
Opened for signature in April 2016

Paris Agreement Status:

- 175 countries (out of 197) have ratified
- Entered ‘force’ November 2016 (ratified by countries accounting for 55% of global CO2 emissions)

http://unfccc.int/paris_agreement/items/9444.php

Country	CO_2 emissions (kt) in 2014[2]	Emission per capita (t) in 2014[3]
World	35,669,000	5.0
China	10,540,000	7.6
United States	5,334,000	16.5
European Union	3,415,000	6.7
India	2,341,000	1.8
Russia	1,766,000	12.4
Japan	1,278,000	10.1
Germany	767,000	9.3
International Shipping	624,000	—
Iran	618,000	7.9
South Korea	610,000	12.3
Canada	565,000	15.9
Brazil	501,000	2.5
Saudi Arabia	494,000	16.8
International Aviation	492,000	—

https://en.wikipedia.org/wiki/List_of_countries_by_carbon_dioxide_emissions

Mitigation: *reducing* emissions

Governments agreed:

• long-term goal global average temperature to **well below 2°C** above pre-industrial levels;

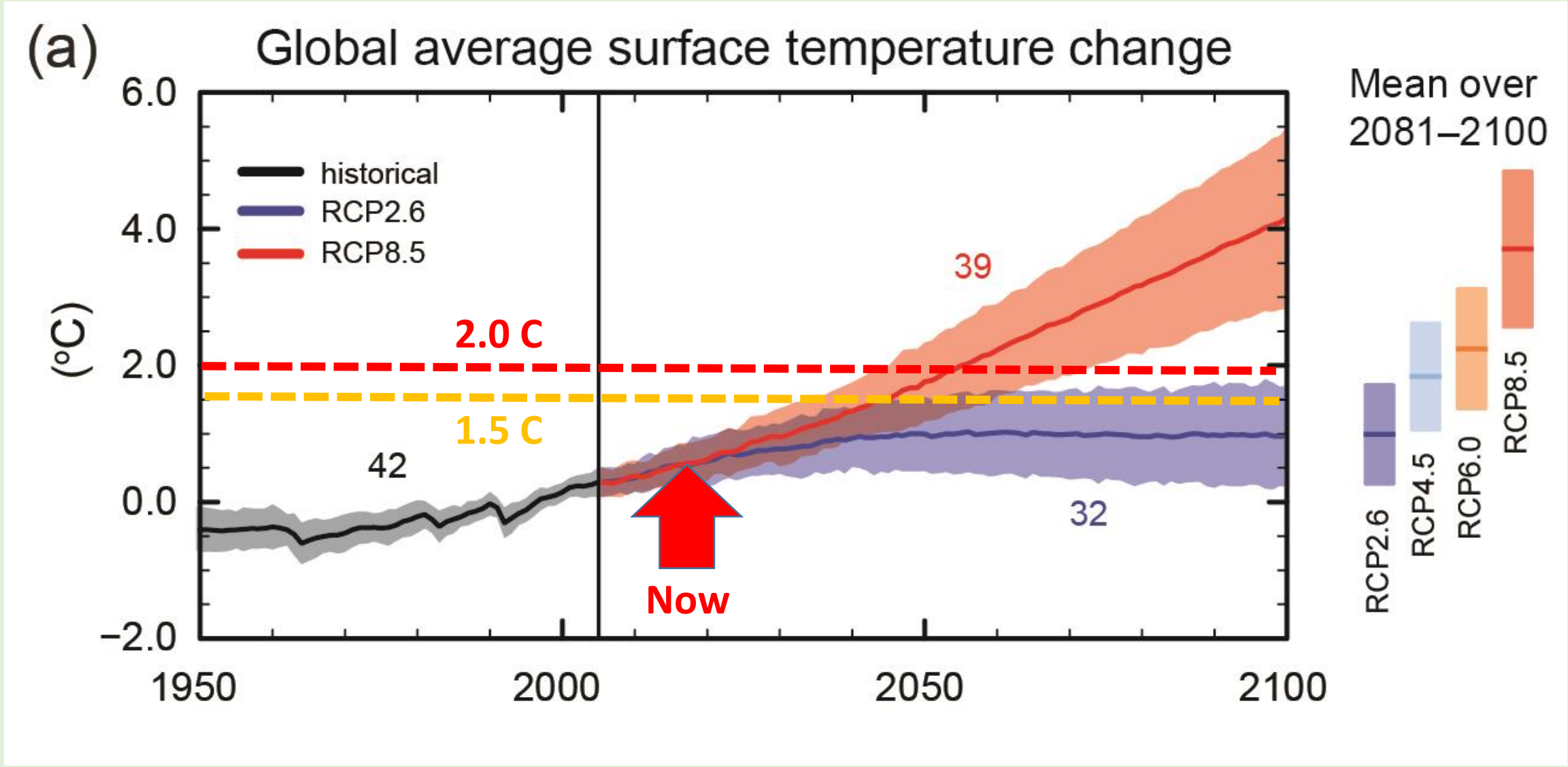
•Aim to limit the increase to **1.5°C**

• **global emissions to peak as soon as possible**, recognizing that this will take longer for developing countries;

• **rapid reductions thereafter**

- **National climate action plans** These are not yet enough to keep global warming below 2°C, but the agreement traces the way to achieving this target.

IPCC Temperature Goals



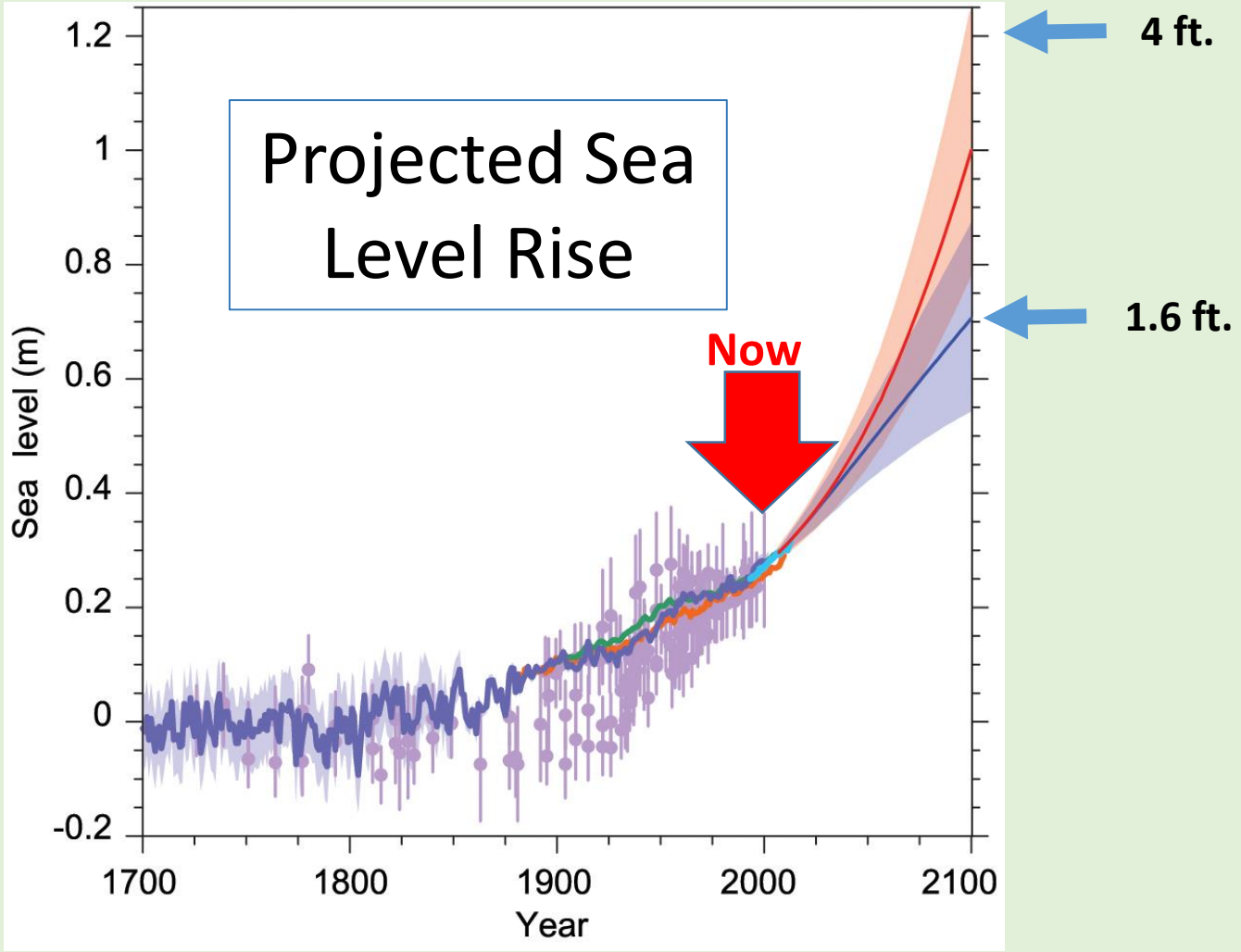


Figure SPM.9 | Projections of global mean sea level rise over the 21st century relative to 1986–2005 from the combination of the CMIP5 ensemble with process-based models, for RCP2.6 and RCP8.5. The assessed likely range is shown as a shaded band. The assessed likely ranges for the mean over the period 2081–2100 for all RCP scenarios are given as coloured vertical bars, with the corresponding median value given as a horizontal line. For further technical details see the Technical Summary Supplementary Material {Table 13.5, Figures 13.10 and 13.11; Figures TS.21 and TS.22}

http://www.ipcc.ch/report/graphics/index.php?t=Assessment%20Reports&r=AR5%20-%20WG1

COP21
December 2015

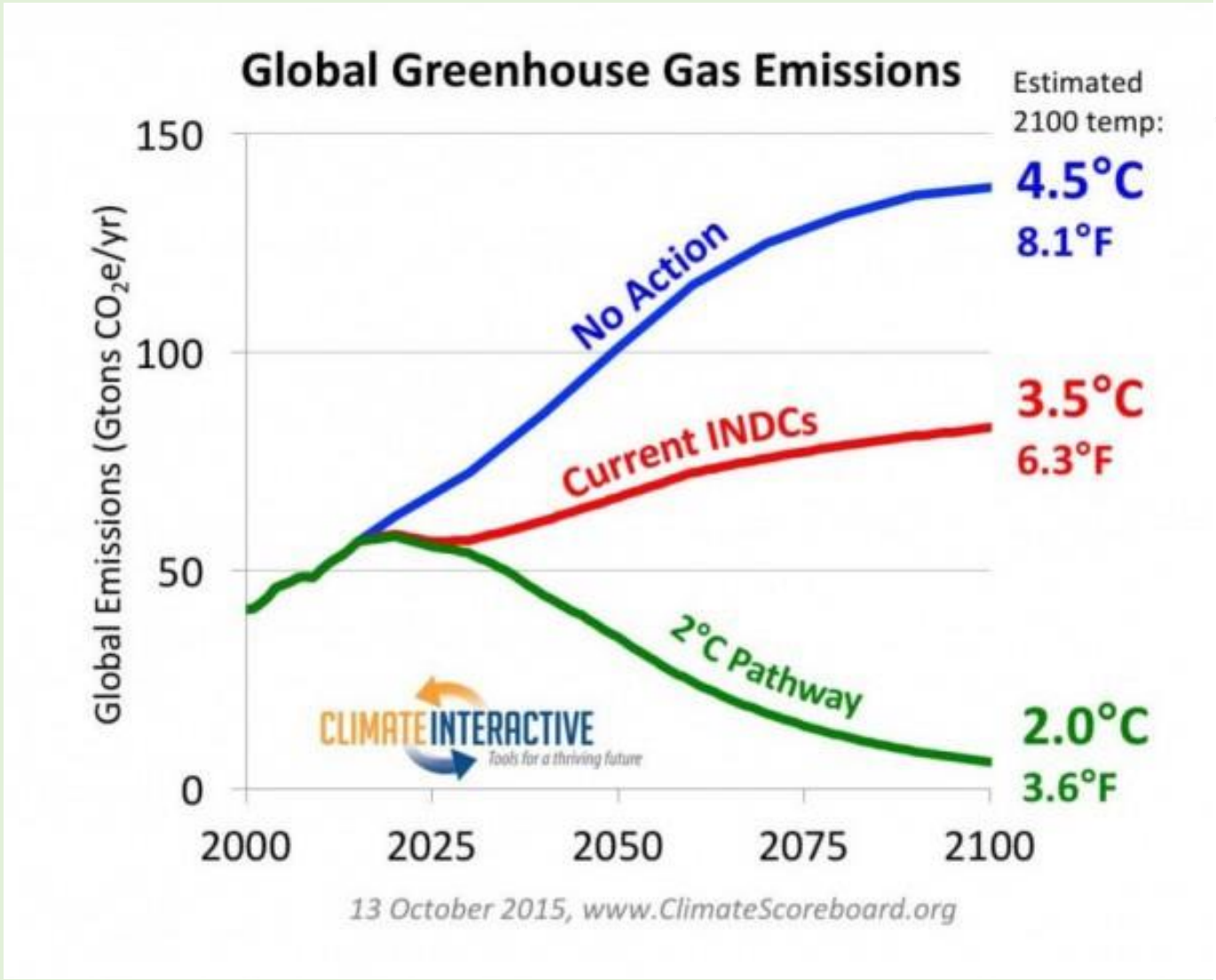
The Paris “Bubble”

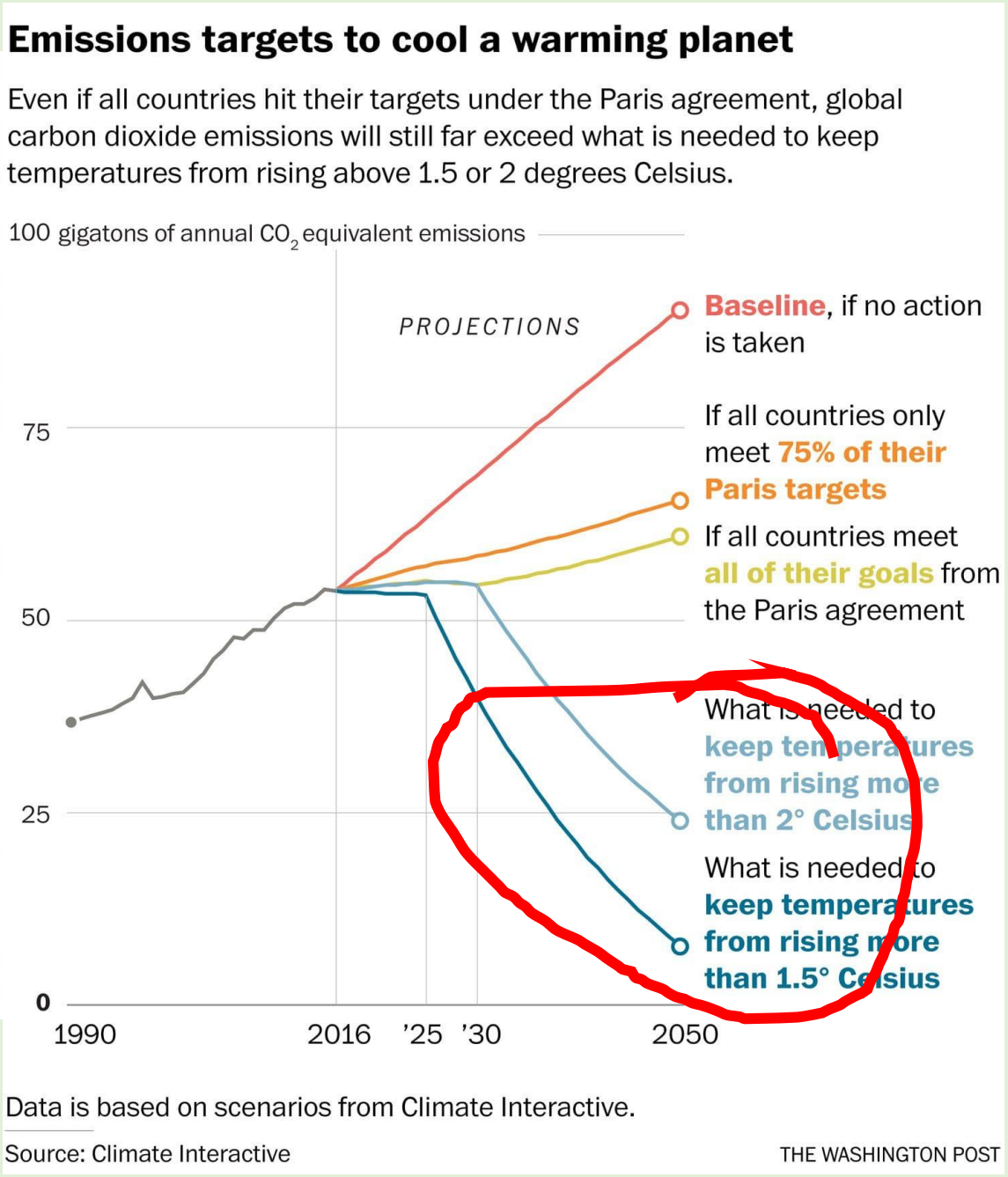
‘Targets’
or ‘Goals’
or Aspirations
(or hopes)?

Scientist/Activist comment on Paris Agreement:

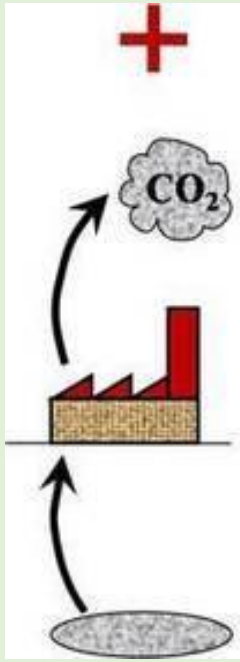
Paris. "Shameless preplanned back-slapping accompanied a Paris climate accord that guaranteed nothing except continued high fossil fuel emissions. Low oil and gas prices afforded a golden opportunity to introduce a rising carbon fee, the only practical way to achieve honest pricing of fossil fuels. However, such a simple honest approach without any giveaways to special interests was dismissed as being too complex to be considered. Instead continued low fossil fuel prices will spur construction of more fossil fuel infrastructure with lock-in of high future emissions."

James Hansen 29 December 2015


Global Greenhouse Gas Emissions
Estimated 2100 temp:
4.5°C
8.1°F
3.5°C
6.3°F
2.0°C
3.6°F
No Action
Current INDCs
2°C Pathway
Global Emissions (Gtons CO_2e/yr)
150
100
50
0
2000
2025
2050
2075
2100
CLIMATE INTERACTIVE
Tools for a thriving future
13 October 2015, www.ClimateScoreboard.org


Emissions targets to cool a warming planet
Even if all countries hit their targets under the Paris agreement, global carbon dioxide emissions will still far exceed what is needed to keep temperatures from rising above 1.5 or 2 degrees Celsius.
100 gigatons of annual CO_2 equivalent emissions
PROJECTIONS
Baseline, if no action is taken
If all countries only meet 75% of their Paris targets
If all countries meet all of their goals from the Paris agreement
What is needed to keep temperatures from rising more than 2° Celsius
What is needed to keep temperatures from rising more than 1.5° Celsius
75
50
25
0
1990
2016
'25
'30
2050
Data is based on scenarios from Climate Interactive.
Source: Climate Interactive
THE WASHINGTON POST

Paris climate goals mean emissions need to drop below zero

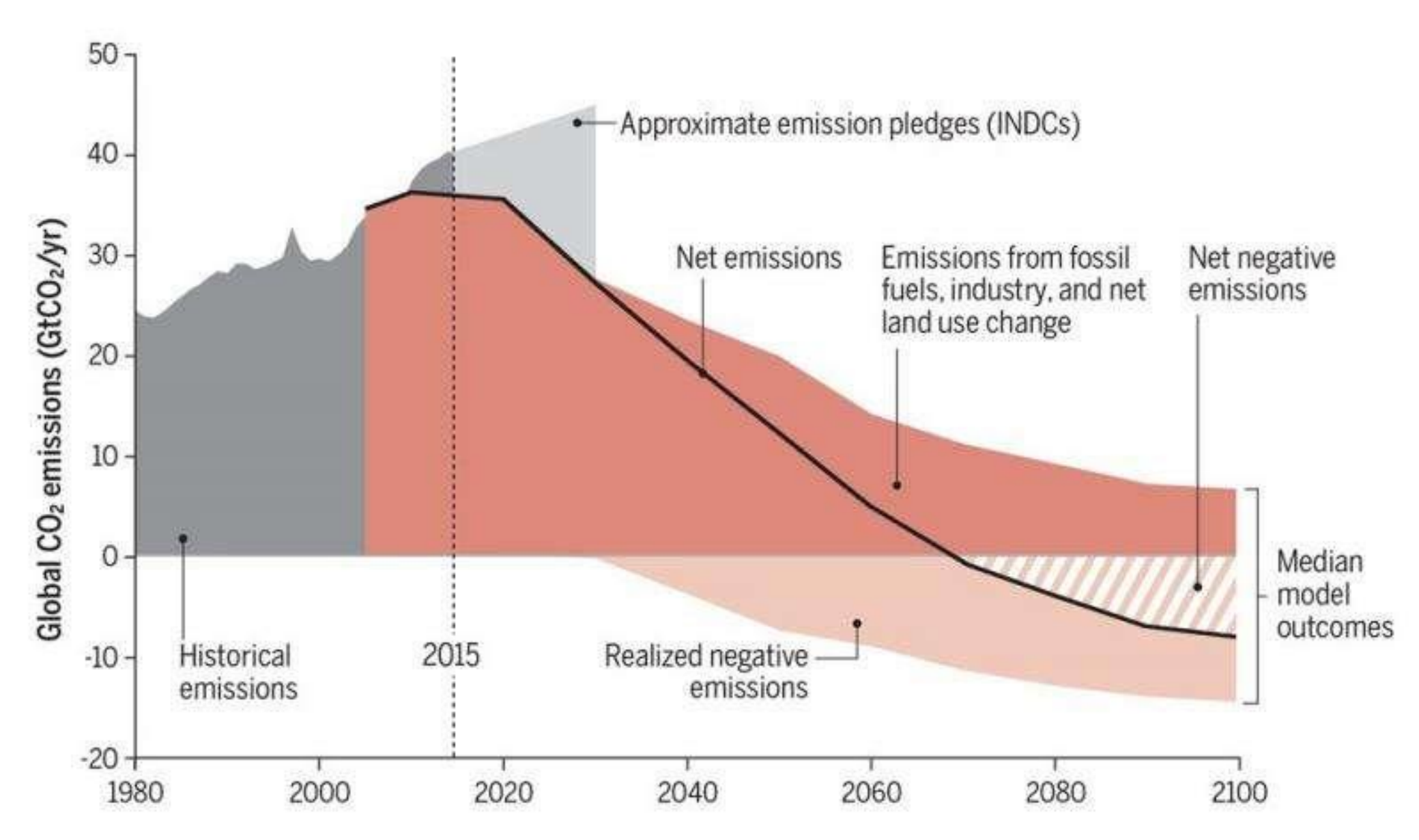


Bioenergy to the rescue?

The trouble with negative emissions

By **Kevin Anderson** *and* **Glen Peters**

14 OCTOBER 2016 VOL 354 ISSUE 6309 page **182** sciencemag.org **SCIENCE**



Goal: keep global warming to 2 C by 2100
"Ambition" to keep below 1.5 C

How to get to the goal?

?

The implicit scenario by the Agreement: deep and rapid decarbonization (coal, oil, gas reductions) and, by 2050, *BECCS* (biomass energy carbon capture and storage) with negative CO2 emissions thereafter.

Science and technology done by
politicians, bureaucrats, and diplomats (!)

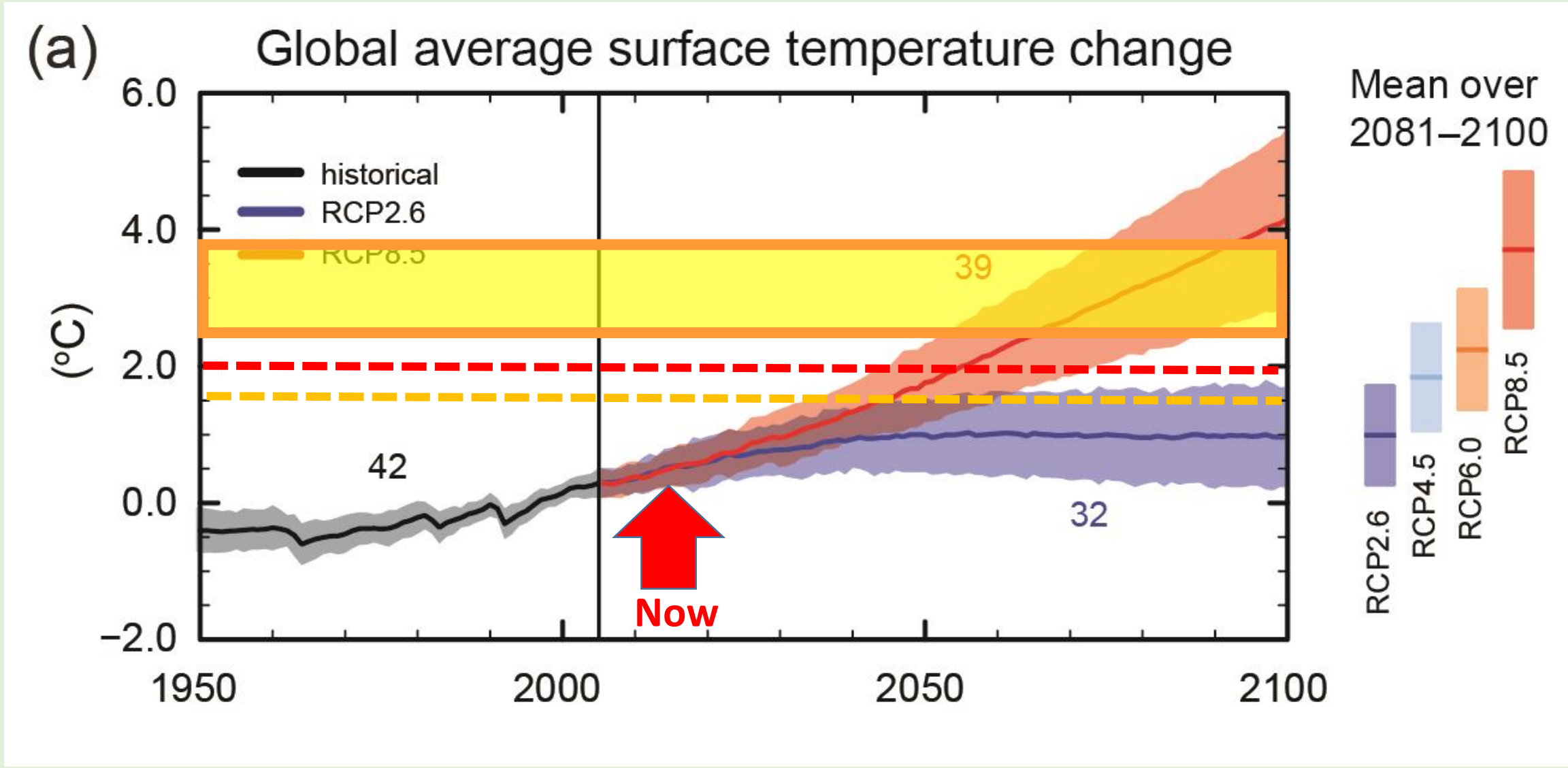
!

Realistic but challenging scenario: "**early** reductions in energy demand with rapid substitution of fossil fuels by zero-carbon alternatives frames a 2 °C agenda that does not rely on negative emissions." (Kevin Anderson)

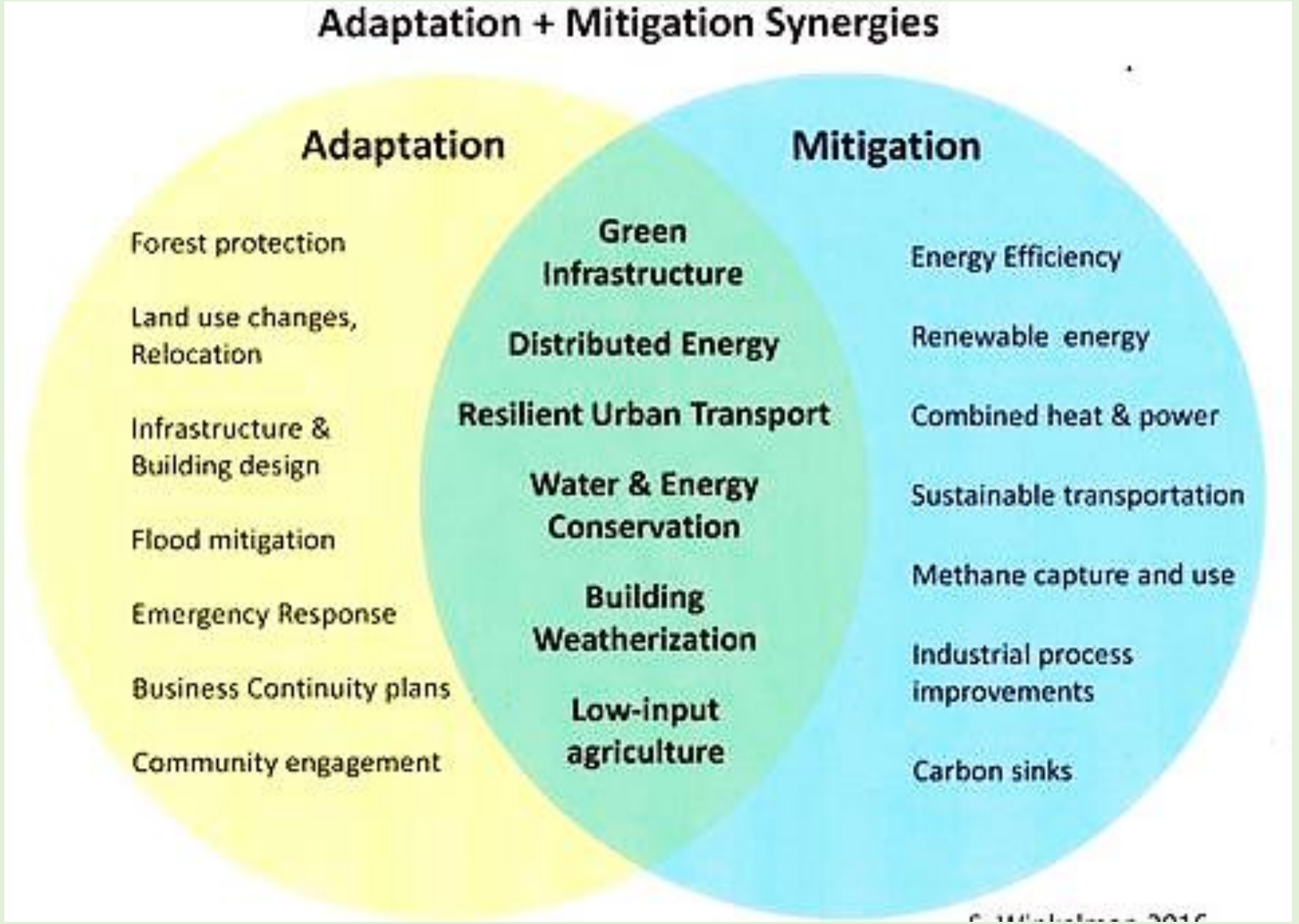
- Canada, Mexico and a coalition of 15 US State Governors signed a Joint Declaration to jointly strengthen climate action. California, Washington, New York, Oregon and Virginia are among the US state signatories. A new North American Climate Leadership Dialogue to address topics such as clean transportation, carbon pricing initiatives and reducing short-lived climate pollutants.

- The EU, China and California announced on 14 November they will step up cooperation on carbon markets.

- A further 25 national and subnational jurisdictions have signed on to the UK and Canada's alliance to phase-out coal in their energy systems.


(a)
Global average surface temperature change
6.0
4.0
2.0
0.0
−2.0
(°C)
historical
RCP2.6
RCP8.5
39
42
32
Now
1950
2000
2050
2100
Mean over
2081–2100
RCP2.6
RCP4.5
RCP6.0
RCP8.5

Adaptation and Mitigation


Adaptation + Mitigation Synergies
Adaptation
Forest protection
Land use changes, Relocation
Infrastructure & Building design
Flood mitigation
Emergency Response
Business Continuity plans
Community engagement
Green Infrastructure
Distributed Energy
Resilient Urban Transport
Water & Energy Conservation
Building Weatherization
Low-input agriculture
Mitigation
Energy Efficiency
Renewable energy
Combined heat & power
Sustainable transportation
Methane capture and use
Industrial process improvements
Carbon sinks

Key climate science uncertainties in future estimates:

- Role of low and high altitude clouds in warming and cooling
- Effects of aerosols on warming or cooling the atmosphere
- Heat dynamics of the oceans and their currents
- Ice shelf feeding sea level rise and weather patterns: Antarctica and Greenland
- "*Climate Sensitivity*": warming induced by a doubling of the CO2 levels

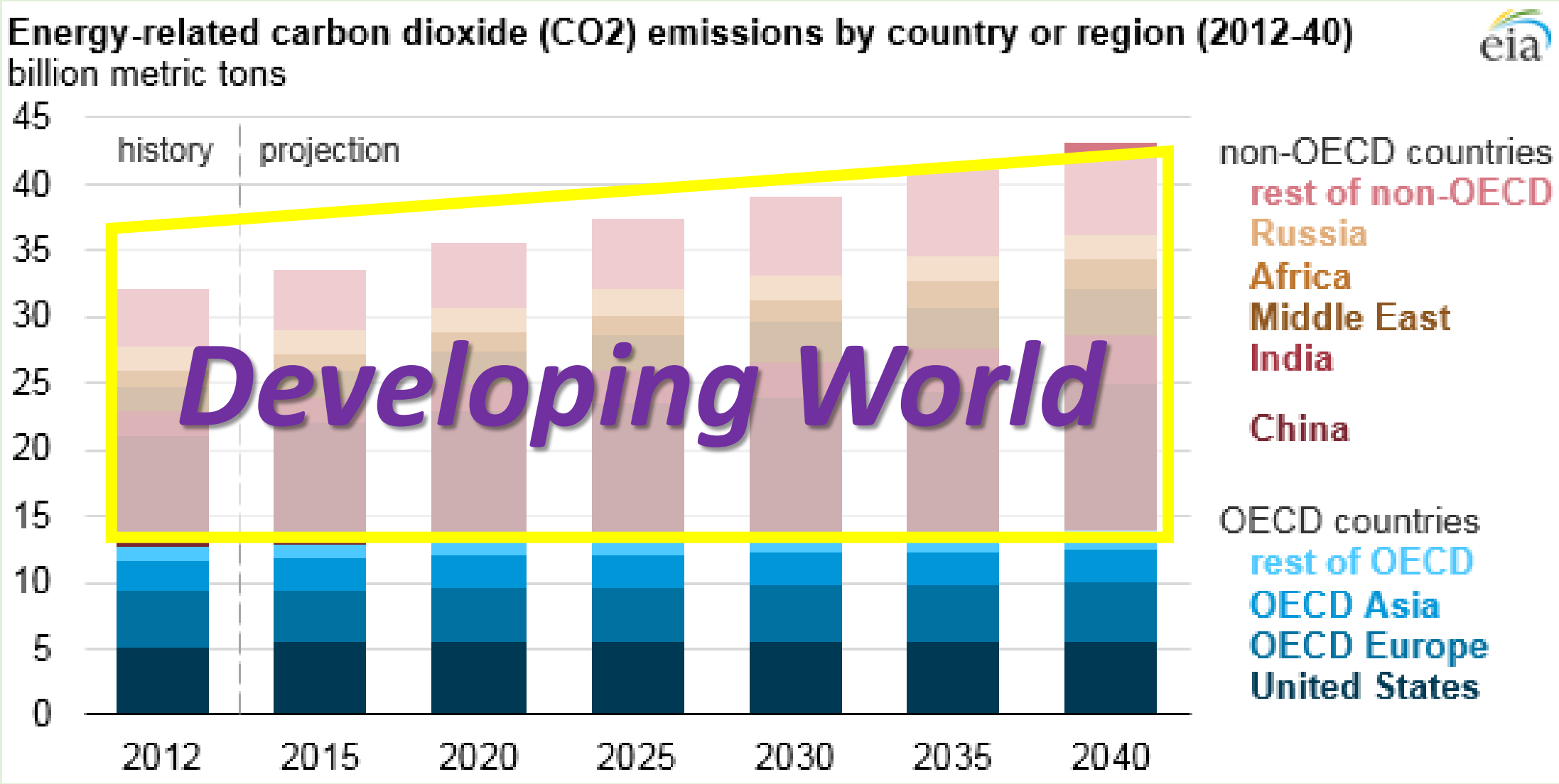
Future Climate

Global CO2 emissions by 2050 +?

Technological innovation in energy and mitigation?

Energy and climate policies of nation states?

Climate science uncertainties



http://www.eia.gov/todayinenergy/detail.php?id=26252

Big Problems with Coal

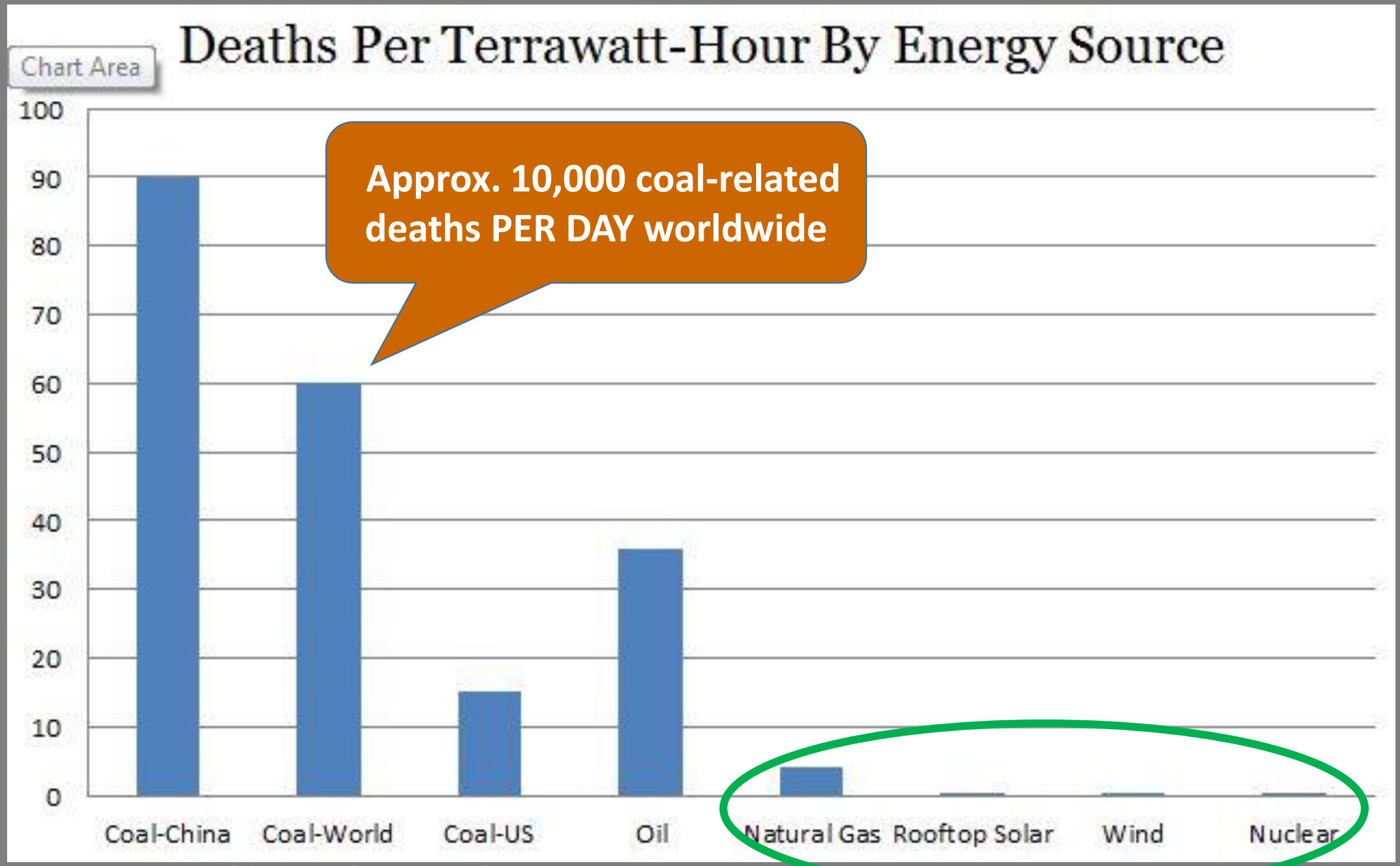
- Air pollution
- Water pollution
- Acid rain
- Particulates
- Environmental destruction

+ Carbon Dioxide emissions

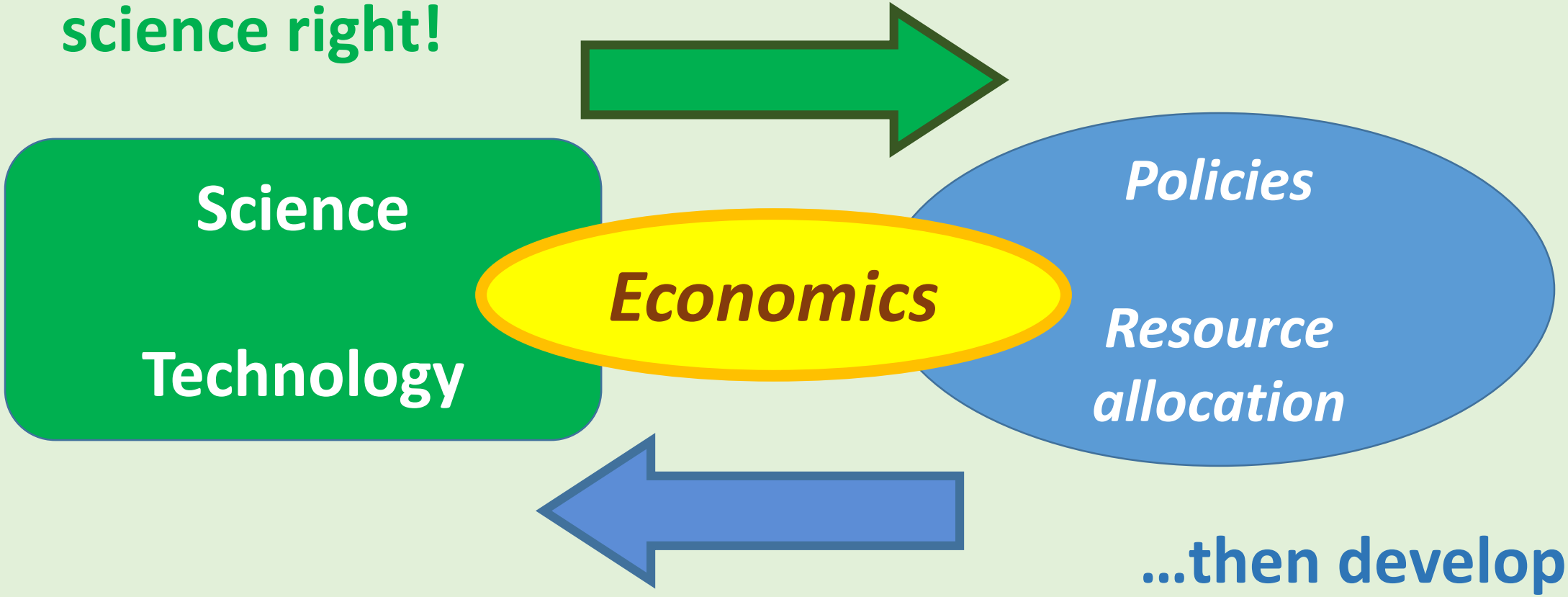
The Canary in The Coal Industry

Since the start of this course 4 weeks ago, we have added 1 gigaton of carbon into our atmosphere.

2,000,000,000,000 pounds.

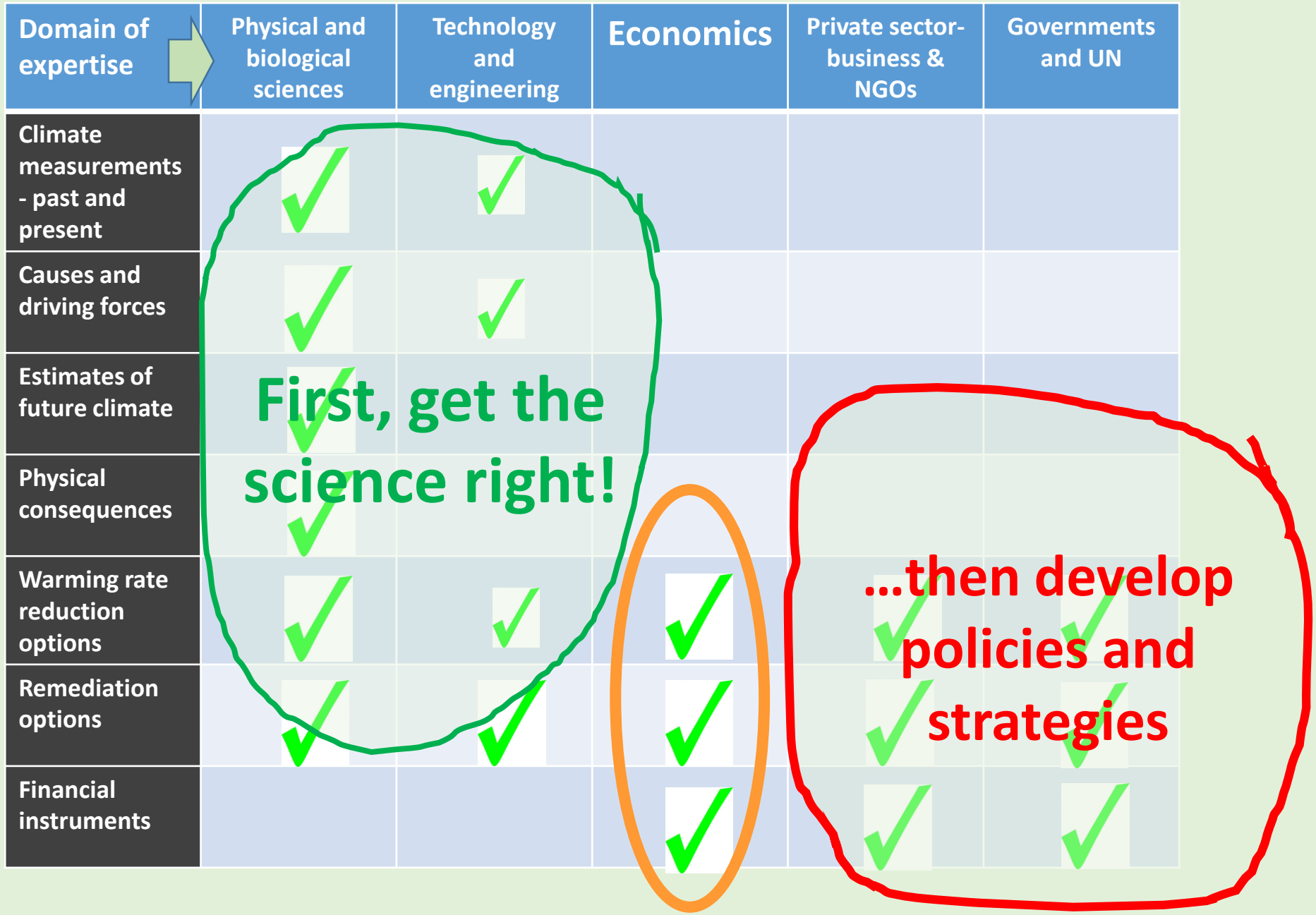

Deaths Per Terrawatt-Hour By Energy Source
Chart Area
100
90
80
70
60
50
40
30
20
10
0
Approx. 10,000 coal-related deaths PER DAY worldwide
Coal-China
Coal-World
Coal-US
Oil
Natural Gas
Rooftop Solar
Wind
Nuclear

First, get the science right!



…then develop strategies and policies

Domain of expertise	Physical and biological sciences	Technology and engineering	Economics	Private sector-business & NGOs	Governments and UN
Climate measurements - past and present	✓	✓			
Causes and driving forces	✓	✓			
Estimates of future climate					
Physical consequences					
Warming rate reduction options					
Remediation options					
Financial instruments					


Domain of expertise
Physical and biological sciences
Technology and engineering
Economics
Private sector-business & NGOs
Governments and UN
Climate measurements - past and present
Causes and driving forces
Estimates of future climate
Physical consequences
Warming rate reduction options
Remediation options
Financial instruments
First, get the science right!
…then develop policies and strategies

What can be done activate ‘the commons’ for action on climate change?

United Nations actions- *IPCC*
Multipartite treaties
Providing compelling technological options
Moral suasion by leading global powers
Financial incentives

The ***pivotal role*** of the United States in mitigation of global warming

US *engagement* with the world through the *IPCC*

US *leadership* including

- **Climate science research- NASA, NOAA, EPA, Universities**
- **Eliminate COAL; backfill with natural gas**
- **Clean technologies- advanced nuclear, solar, and wind**
- **‘Electrification’, especially electric vehicles**
- **Improved energy efficiency**
- **Carbon tax (fee)**

Reasons for Contingent optimism

- Rapid advances in climate science: modeling, understanding of ocean heat and clouds, regional effects, sensors and measurements
- US and EU carbon emissions rates levelling
- Indicators for China reducing emissions growth
- Reduced ‘energy intensity’ globally- increasing efficiency of HVAC , appliances, etc.
- Advanced nuclear reactor developments
- Growth of wind and solar energy sources
- Coal declining in the developed world
- Public awareness and support increasing

The Global Commons

The seas and the atmosphere belong to all of humanity.

The lands belong to sovereign states.

The *CHALLENGE* faces us all:

how can all of us <u>reduce</u> greenhouse gas emissions to mitigate the global consequences of climate change?