National Institute for Standards and Technology
Boulder, CO
11 June 2014

Contributing to the Climate Change Building: A scientist-to-scientist perspective

by

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Outline

- Introduction
- IPCC report
- Montreal Protocol
- Black Carbon
- New ideas
- Summary

Search 'fahey nist colloquium'

EARTH SYSTEM RESEARCH LABORATORY
Serving Society through Science

CIRES
COOPERATIVE INSTITUTE FOR RESEARCH IN ENVIRONMENTAL SCIENCES

Why am I here today?

Photo: NASA

Importance

Looking after Earth is a rather difficult and important thing.

Joe Farman (1930-2013)

Urgency

We're the first generation to feel the impact of climate change and the last generation that can do something about it.

Gov. Jay Inslee of Washington State

Duty

Science has the first word on everything, but the last word on nothing.

Victor Hugo

The Climate Change Building: *Our Grand Challenge*

http://www.diplomacy.edu

This drawing illustrates Diplo's approach to training and research on climate change.

IPCC:
The Wisdom of Crowds

World Meteorological Organization
United Nations Environment Programme

- Working Group I Co-Chairs:
  Thomas Stocker* (Switzerland)
  Dahe Qin (China)

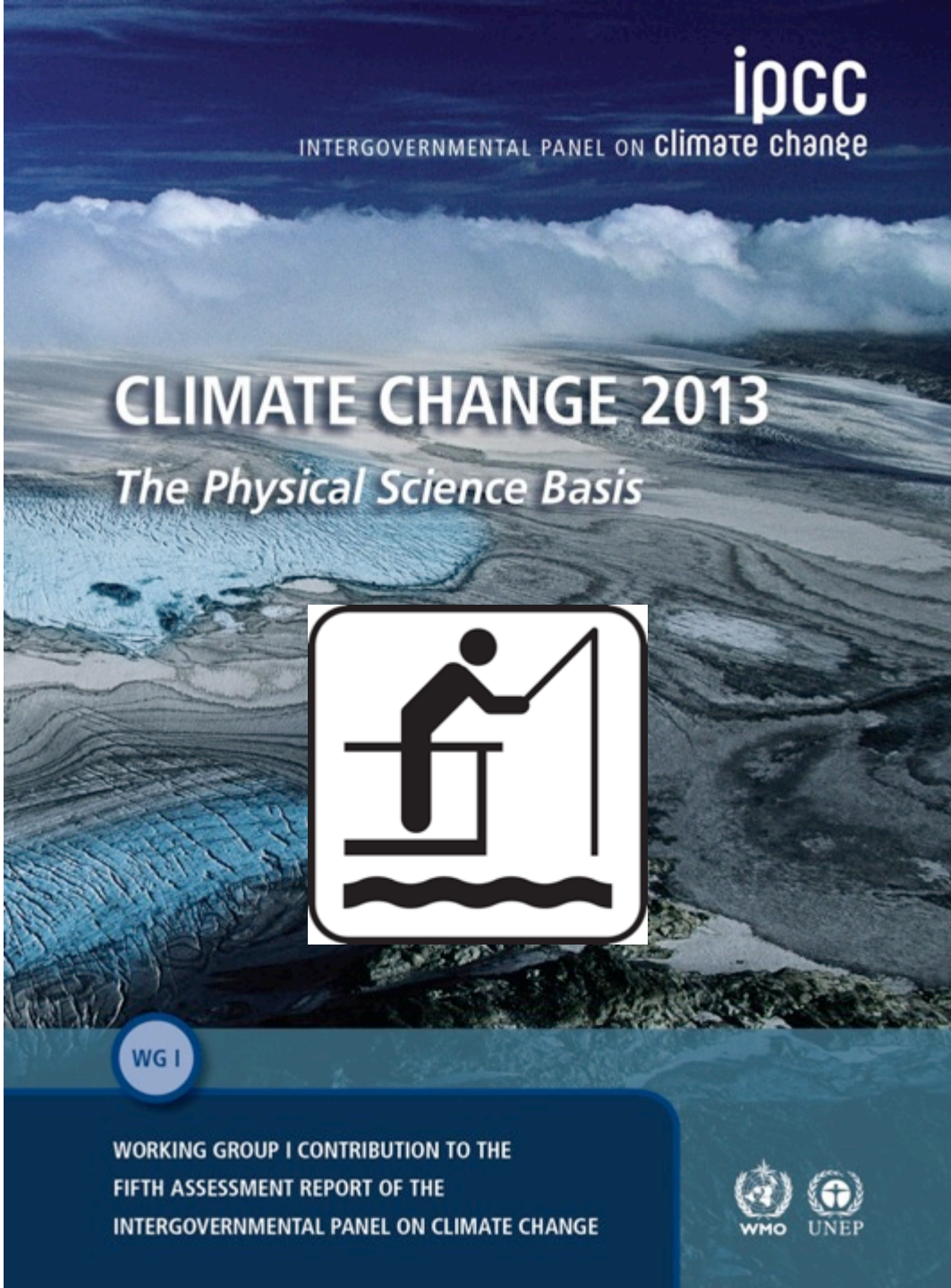
Structure:

- Summary for Policymakers (29 pgs)
- Technical Summary (82 pgs)
- 14 chapters (1.1 million words)
- 259 authors selected in 2010
- >54,000 review comments by >1000 experts and govt reviewers
- Policy neutral; policy relevant

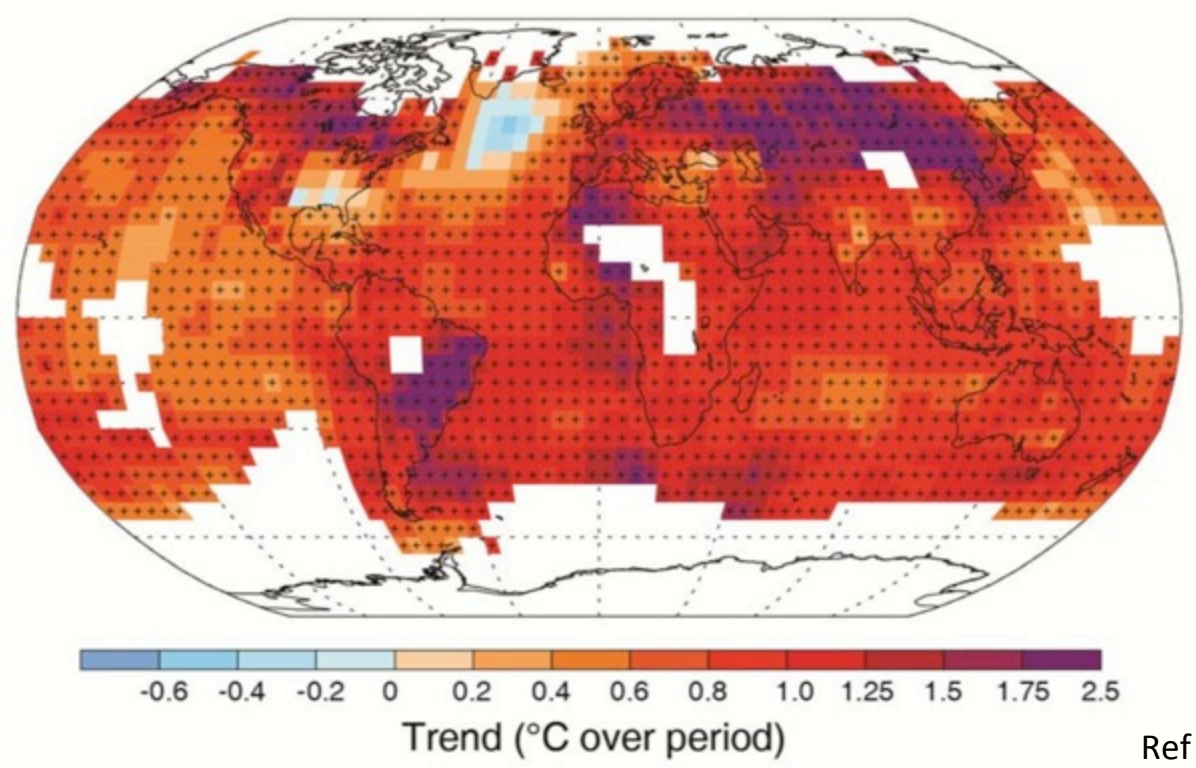
➢ Intellectually stunning, physically beautiful, content-accessible document

* Acknowledge helpful guidance with IPCC results.

www.climatechange2013.org



Observed change in surface temperature 1901 - 2012

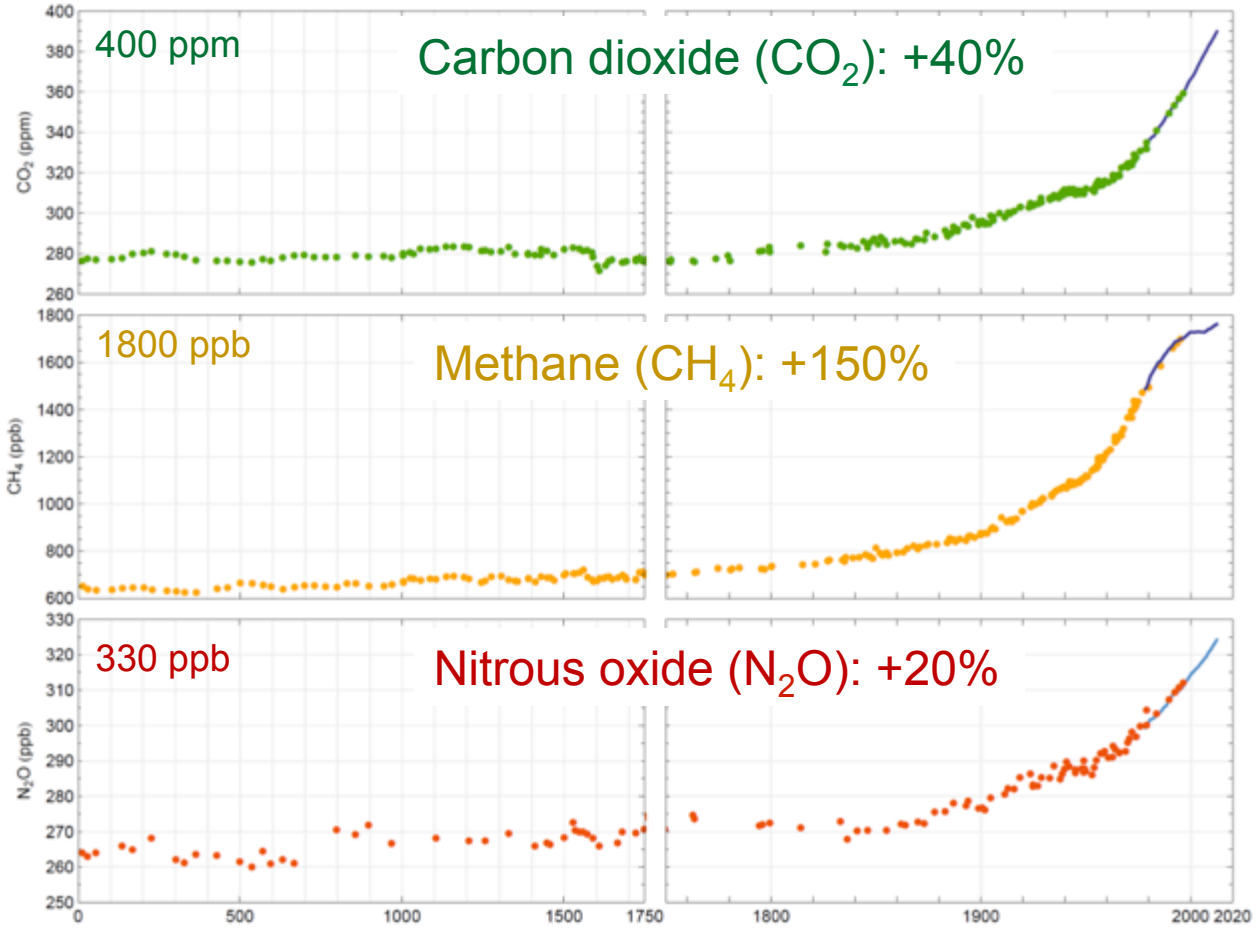


IPCC 2013, Fig. SPM.1b

Ref = 1961-1990 mean

Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, sea level has risen, and the concentrations of greenhouse gases have increased.

Changes in greenhouse gas concentrations

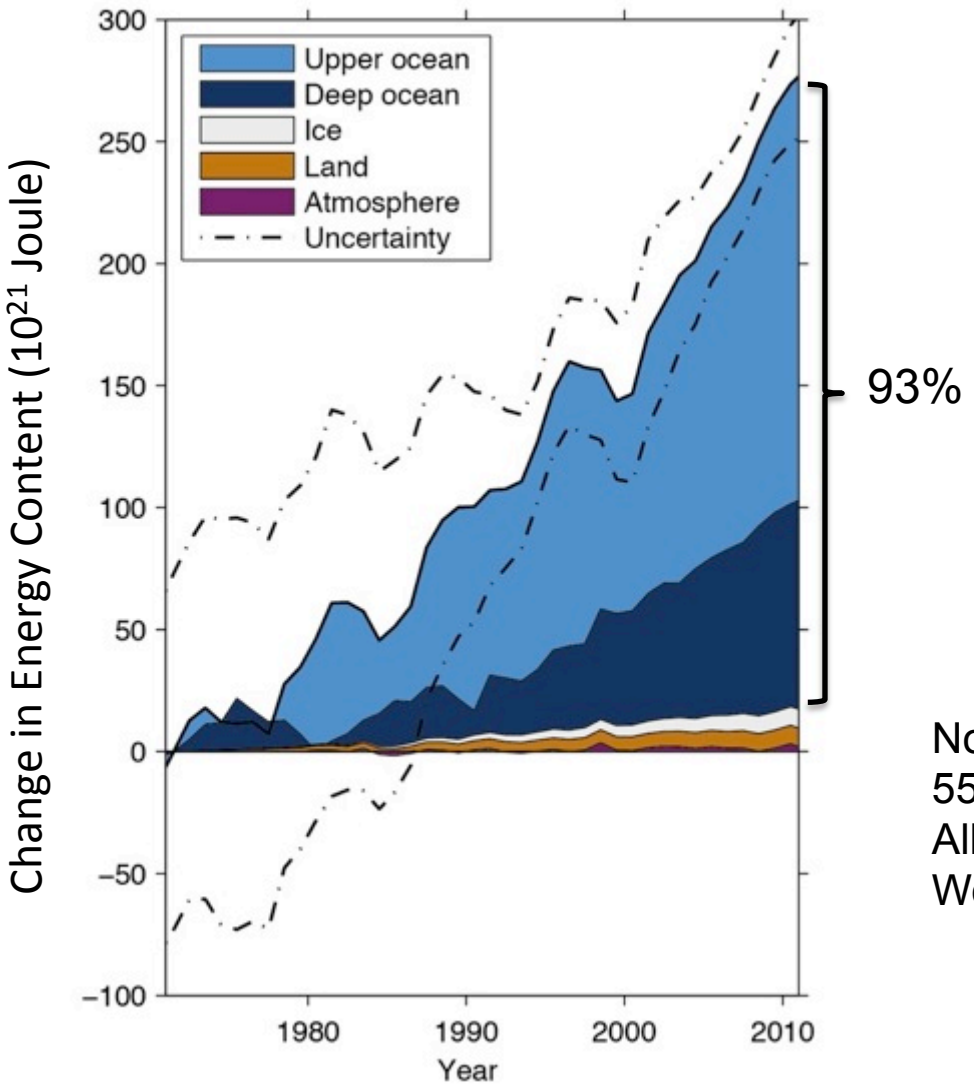


IPCC 2013, Fig. 6.11

	Global warming potentials	Radiative forcing in 2011
CO_2	1	1.82 Wm^{-2}
CH_4	28	0.48
N_2O	265	0.17

Concentrations of CO_2, CH_4 and N_2O have all increased since 1750 due to human activity. All are greenhouse gases which trap heat in the atmosphere.

Energy uptake in the climate system since 1970



IPCC 2013, Box 3.1, Fig. 1

Total energy increase
= 275 x 10^{21}J
= 76 x 10^{6} TWhr

Ocean increase is 93%
= 199 TW (39 yrs)
= 0.55 Wm^{-2}

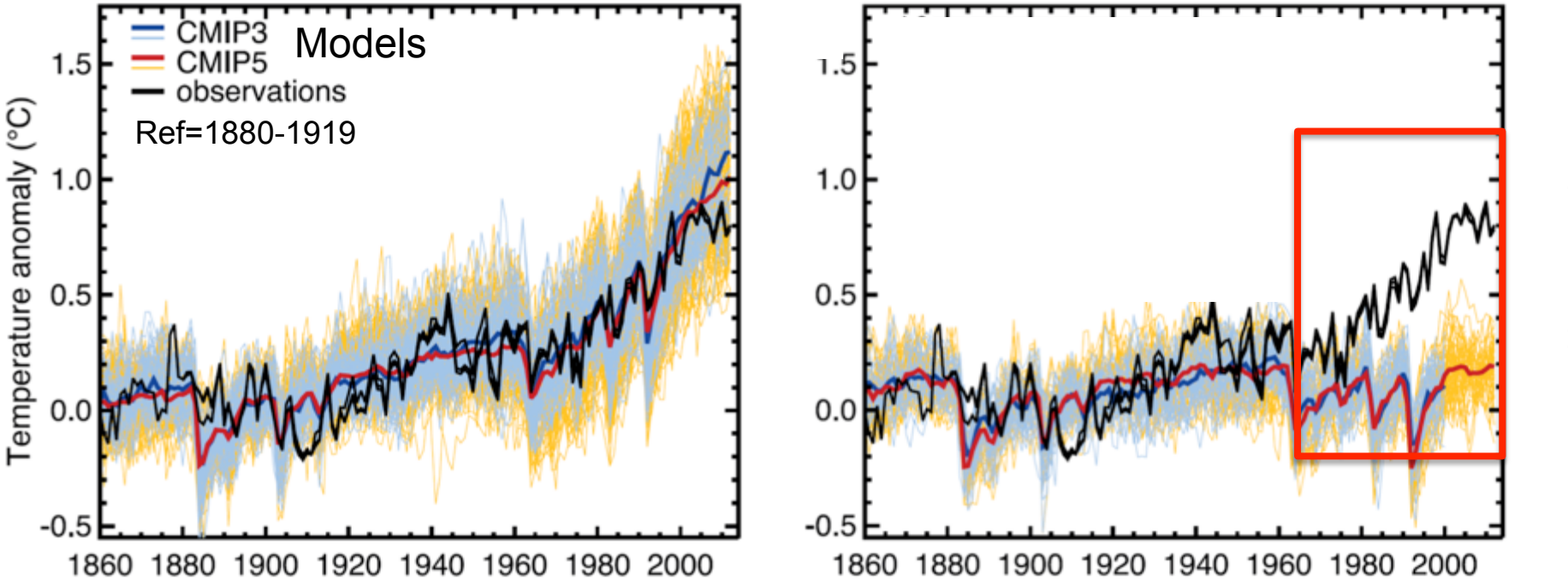
Note:
55 x 10^{21}J boils the Great Lakes.
All the coal ever burned = 15 x 10^{21}J.
World ocean volume = 1.37 x 10^{21} liters.

It is *virtually certain* that the upper ocean has warmed from 1971 to 2010….

Understanding from global climate models

(Atmosphere-Ocean General Circulation Models + Earth System Models)

- with CO_2 changes
- no CO_2 changes



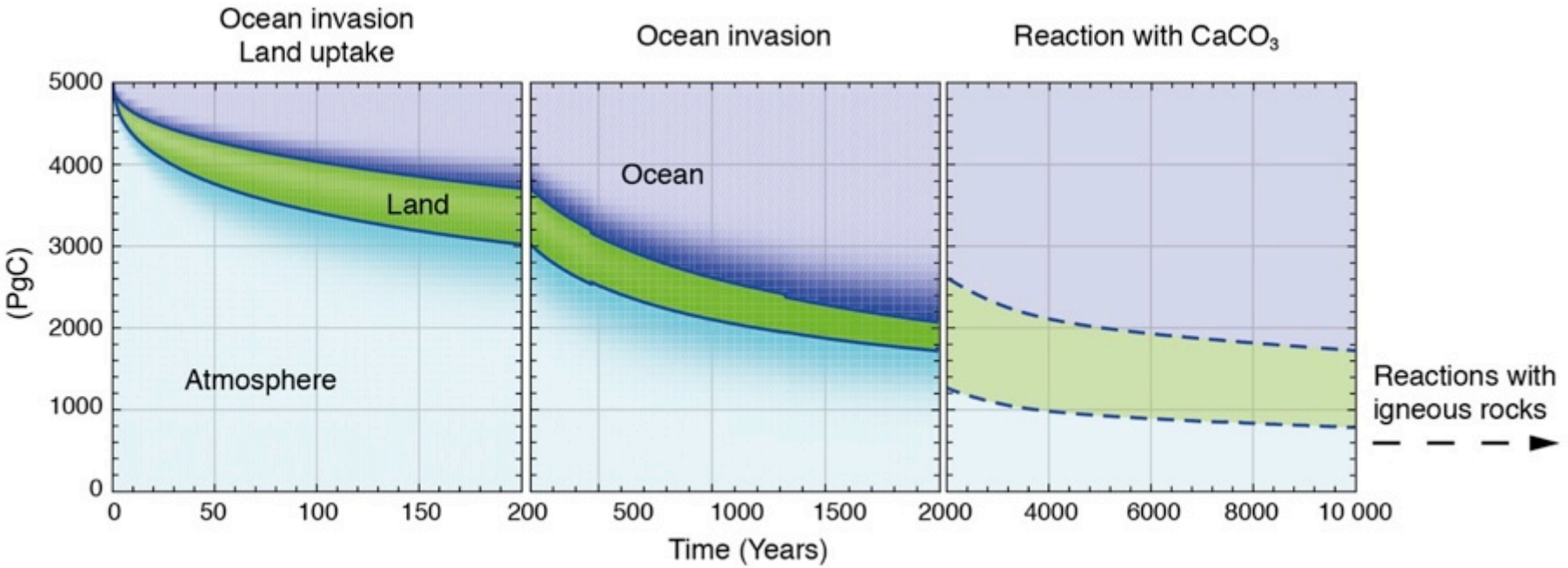
IPCC 2013, Fig. TS.9

Ref = 1880-1919 mean

It is extremely likely that human influence has been the dominant cause of the observed warming since the mid-20th century.

Carbon dioxide: the *forever gas*

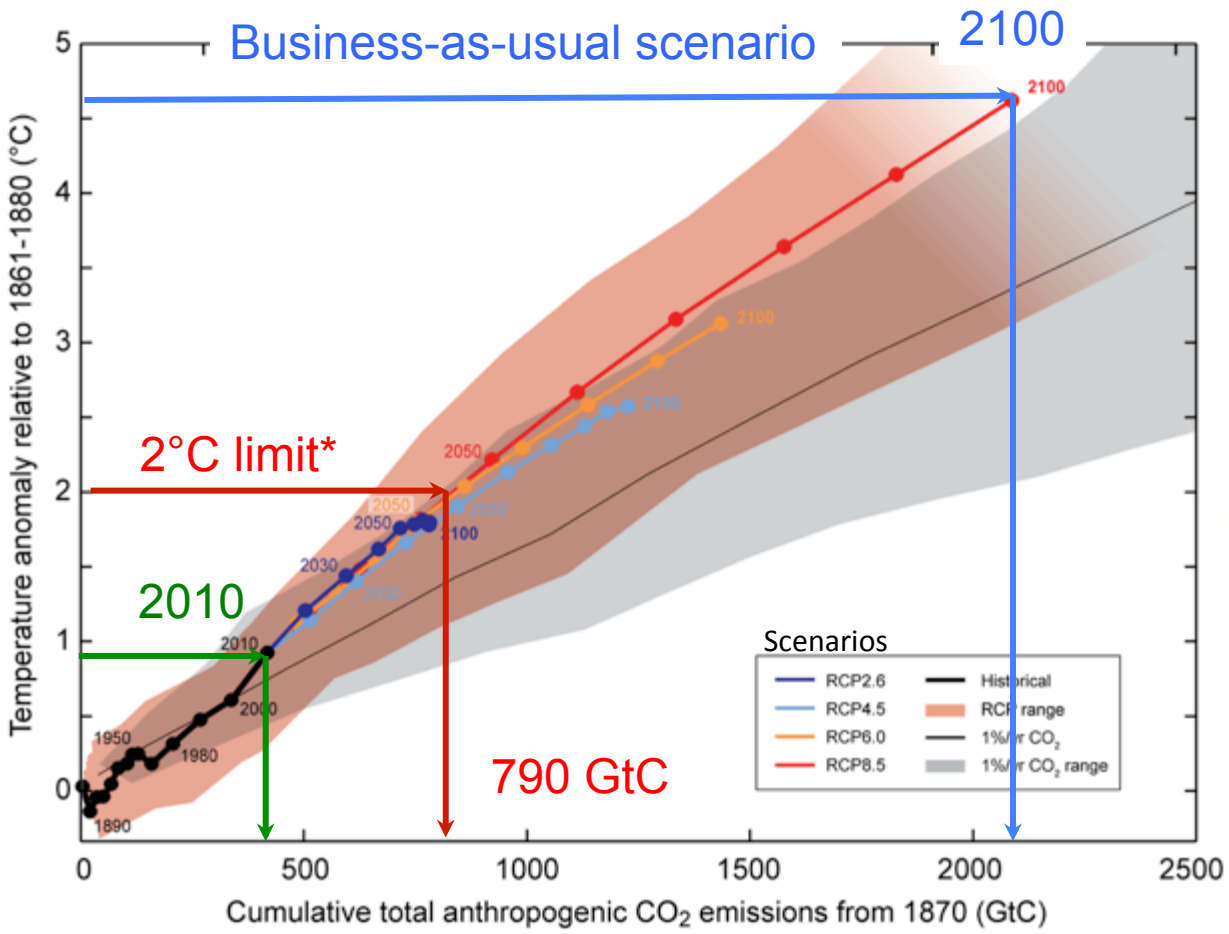
CO_2 atmospheric amounts following a pulse injection of 5000 PgC



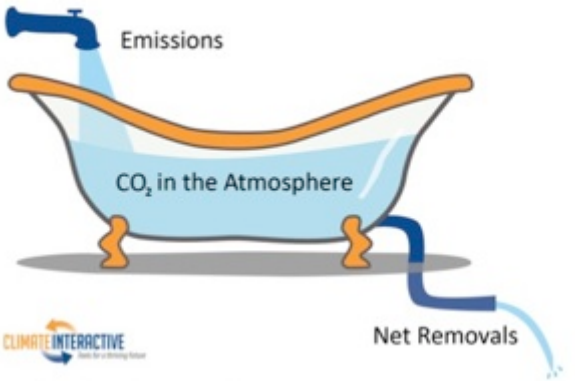
IPCC 2013, Fig. Fig. FAQ6.2-2

- 20 - 40% of added CO_2 from fossil fuel combustion remains in the atmosphere > 10,000 yrs

The linear response of temperature to cumulative CO_2 emissions



IPCC 2013, Fig. SPM.10



The bathtub analogy: For a given temperature increase, the volume is fixed.

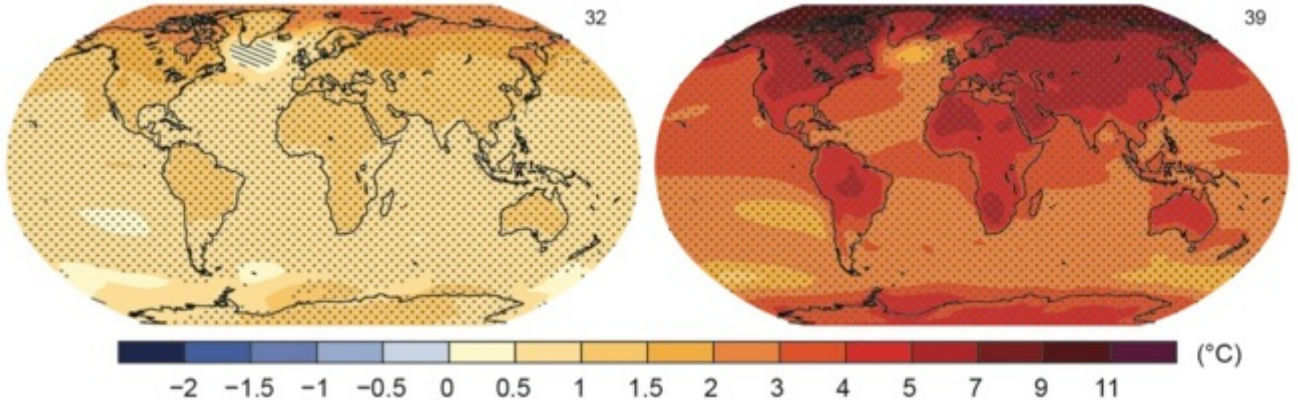
*For *dangerous interference* with the climate system

Limiting climate change to 2°C will require substantial and sustained reductions of greenhouse gas emissions, approaching zero in 2100.

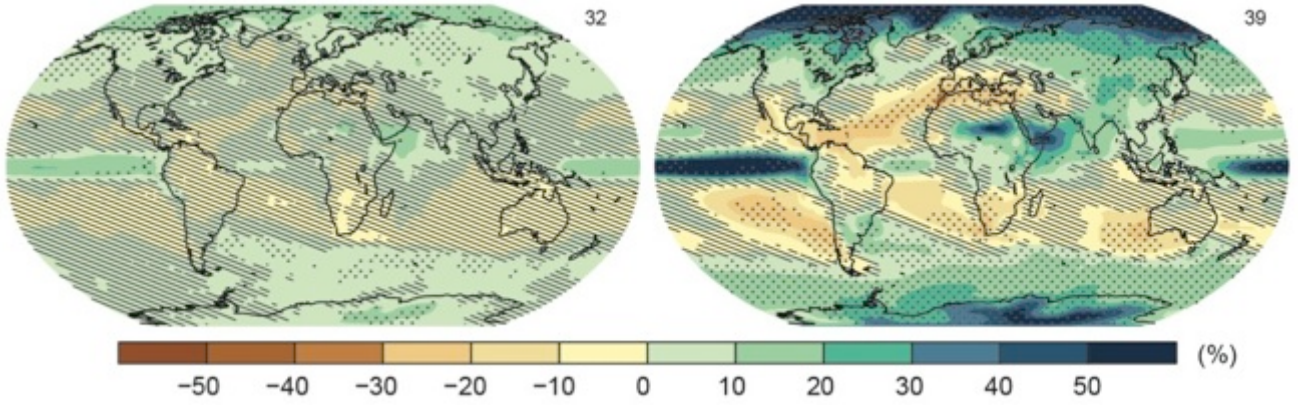
The world can still choose its climate future

2°C world **4.5°C world**

Change in average surface temperature (1986-2005 to 2081-2100)

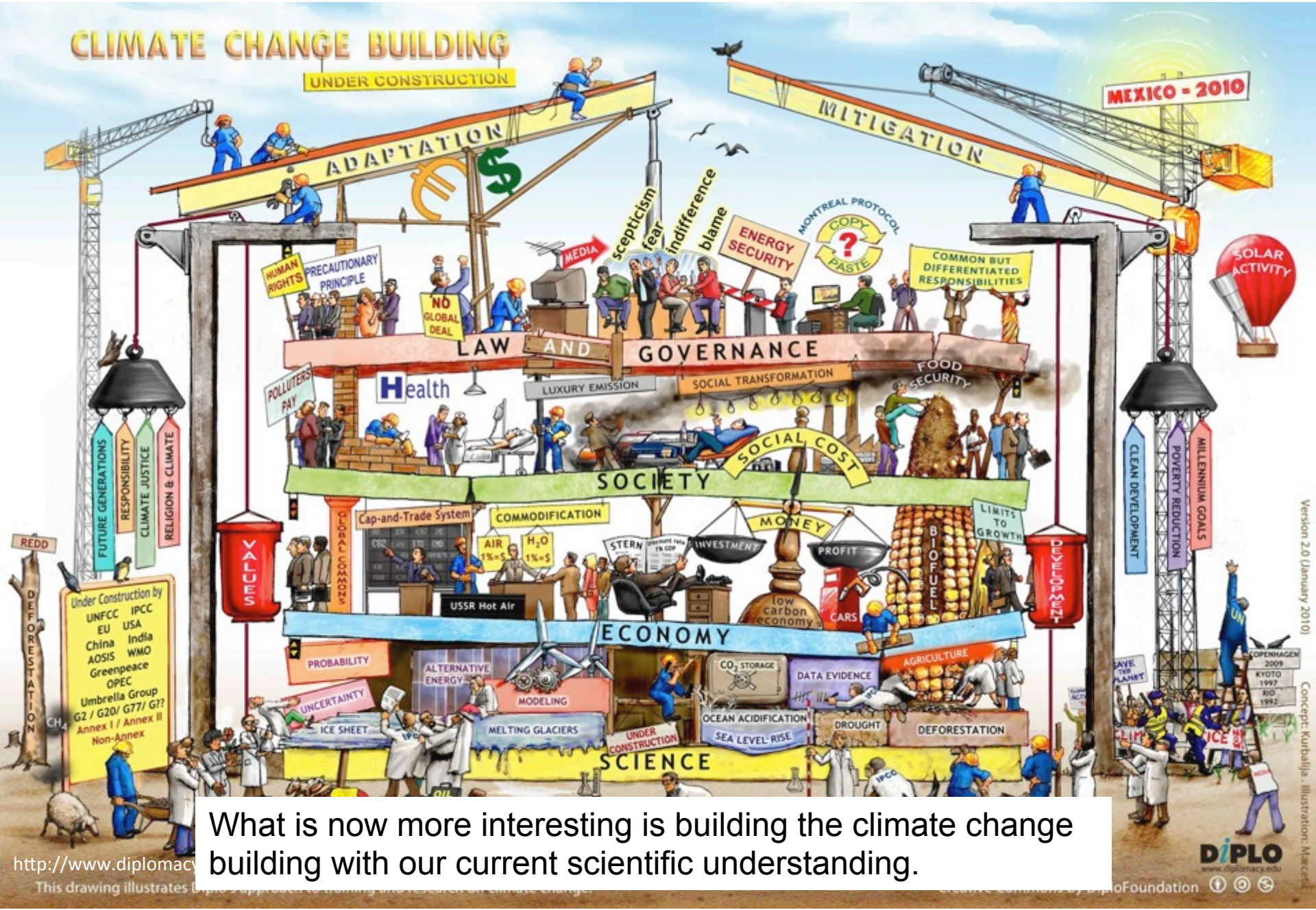


Change in average precipitation (1986-2005 to 2081-2100)



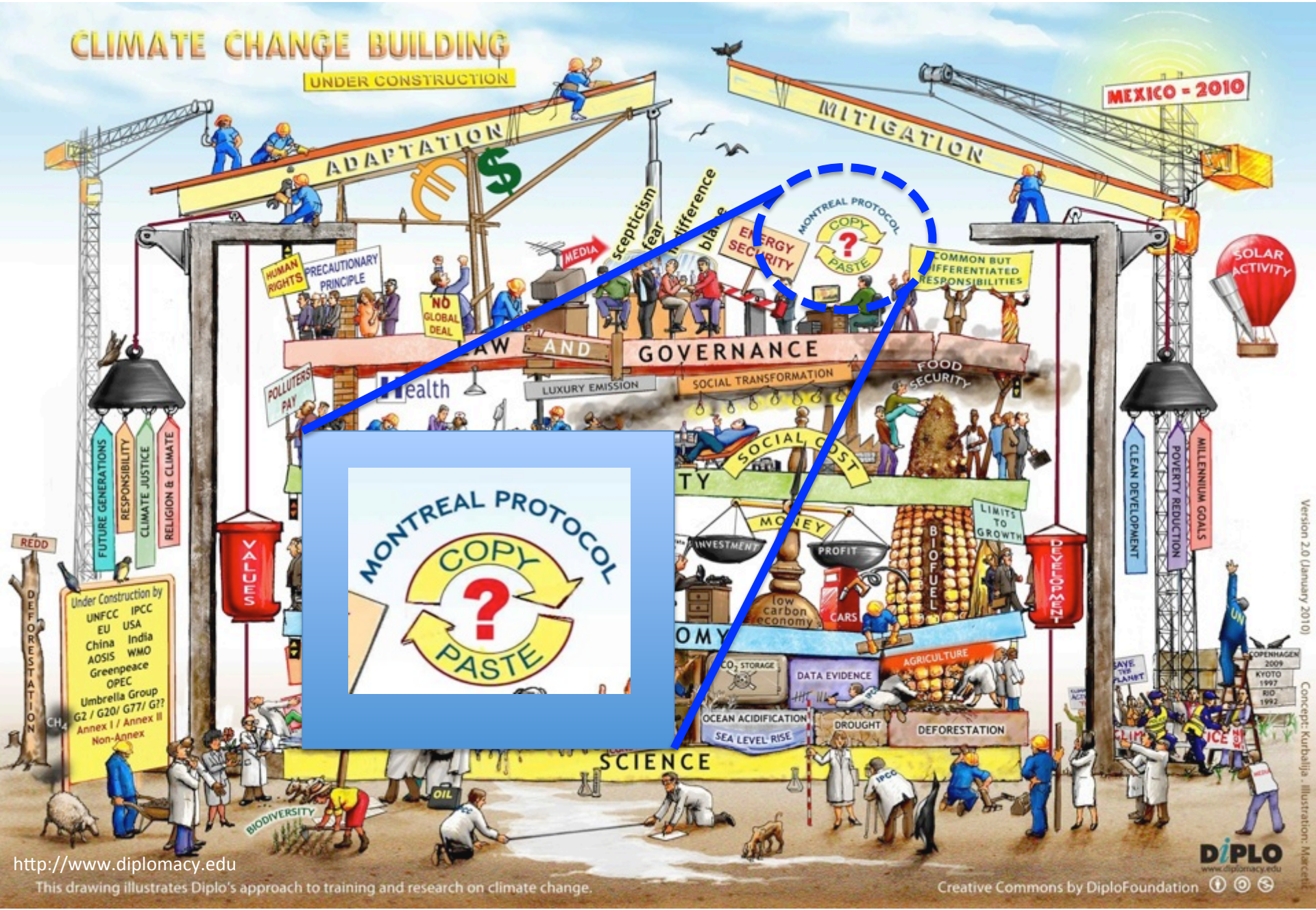
IPCC 2013, Fig. SPM.8

The Climate Change Building: *Our Grand Challenge*



What is now more interesting is building the climate change building with our current scientific understanding.

The Climate Change Building: *Our Grand Challenge*



MONTREAL PROTOCOL
COPY
?
PASTE

http://www.diplomacy.edu

This drawing illustrates Diplo's approach to training and research on climate change.

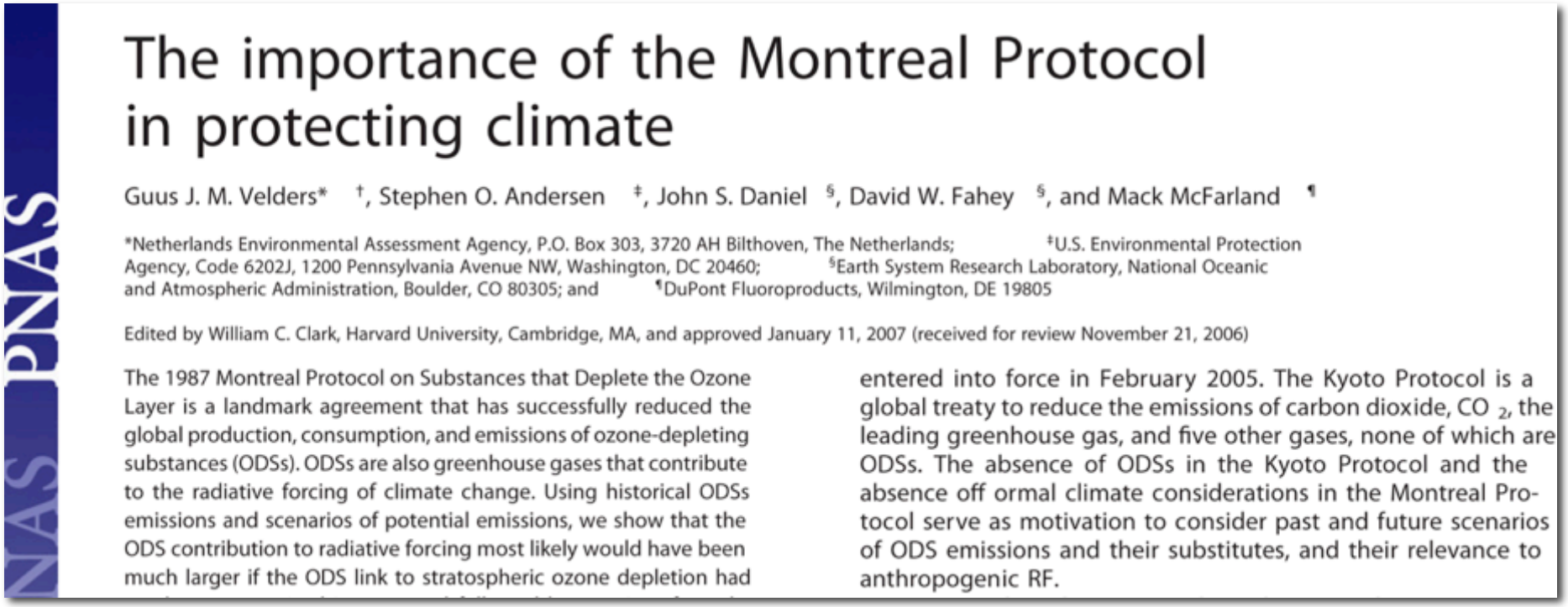
Q: What is the first, global (195 nations), legally binding, fully funded action specifically to protect Earth's climate?

A: The 2007 Amendment to the Montreal Protocol to accelerate the phaseout of hydrochlorofluorocarbons (HCFCs) in developing nations by 10 years (from 2040 to 2030).

- The 1987 Montreal Protocol on Substances that Deplete the Ozone Layer is the world's most successful environmental treaty.
- It has imposed legally binding controls on the global consumption and production of synthetic gases known as ozone-depleting substances (ODSs)
  - chlorofluorocarbons (CFCs) and halons
  - hydrochloroflurocarbons (HCFCs)
- ODSs are also greenhouse gases, *i.e.* they trap heat in the atmosphere. ODSs are 1000s of times more effective greenhouse gases than CO_2.
- Therefore, the Montreal Protocol has had a dual benefit: the protection of the ozone layer and the protection of climate.

How did this happen?

The Paper



PNAS

The importance of the Montreal Protocol in protecting climate

Guus J. M. Velders* †, Stephen O. Andersen ‡, John S. Daniel §, David W. Fahey §, and Mack McFarland ¶

*Netherlands Environmental Assessment Agency, P.O. Box 303, 3720 AH Bilthoven, The Netherlands; ‡U.S. Environmental Protection Agency, Code 6202J, 1200 Pennsylvania Avenue NW, Washington, DC 20460; §Earth System Research Laboratory, National Oceanic and Atmospheric Administration, Boulder, CO 80305; and ¶DuPont Fluoroproducts, Wilmington, DE 19805

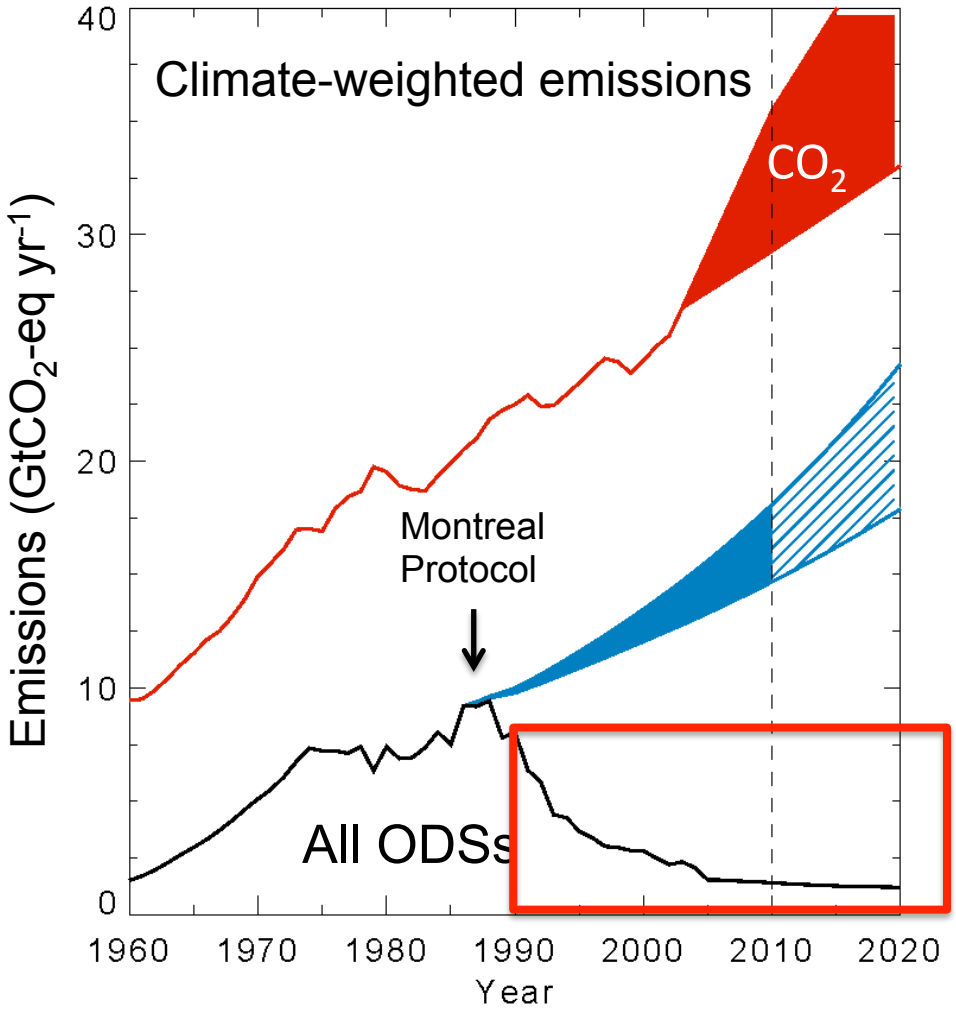
Edited by William C. Clark, Harvard University, Cambridge, MA, and approved January 11, 2007 (received for review November 21, 2006)

The 1987 Montreal Protocol on Substances that Deplete the Ozone Layer is a landmark agreement that has successfully reduced the global production, consumption, and emissions of ozone-depleting substances (ODSs). ODSs are also greenhouse gases that contribute to the radiative forcing of climate change. Using historical ODSs emissions and scenarios of potential emissions, we show that the ODS contribution to radiative forcing most likely would have been much larger if the ODS link to stratospheric ozone depletion had entered into force in February 2005. The Kyoto Protocol is a global treaty to reduce the emissions of carbon dioxide, CO_2, the leading greenhouse gas, and five other gases, none of which are ODSs. The absence of ODSs in the Kyoto Protocol and the absence off ormal climate considerations in the Montreal Protocol serve as motivation to consider past and future scenarios of ODS emissions and their substitutes, and their relevance to anthropogenic RF.

Velders *et al*., *Proc. Nat. Acad*. *Sci*., March 2007.

Our simple message: Using historical ODSs emissions and scenarios of potential emissions, we showed that the ODS contribution to climate change most likely would have been much larger without the Montreal Protocol.

Montreal Protocol protection of climate



CO_2 emissions

World avoided (2-3%/yr)
by the Montreal Protocol

Climate protection:
~11 $GtCO_2$-eq/yr in 2010

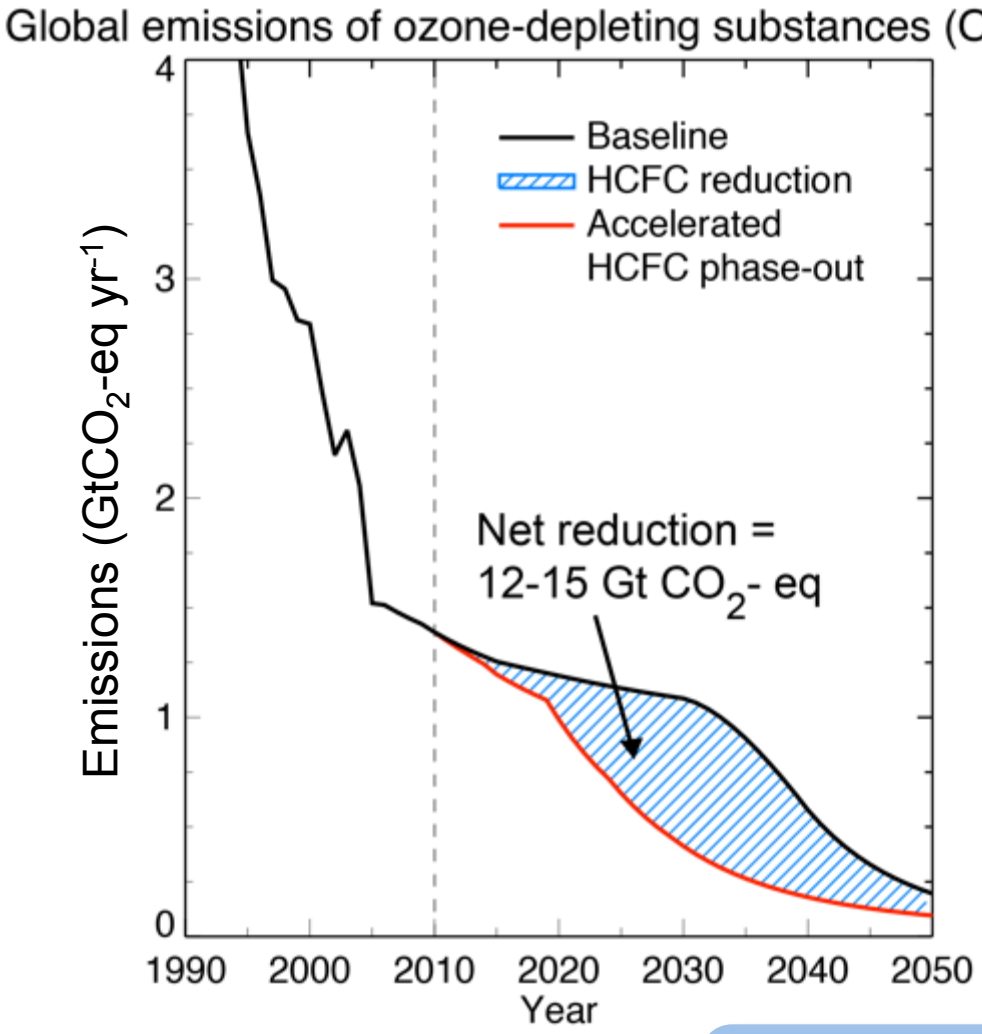
(US automobile fleet consumption
= 100 billion gallons of gasoline/yr
= ~ 1 $GtCO_2$-eq/yr)

1 $GtCO_2$ =
1 billion metric tons CO_2

This simple message was adopted by environmental lawyers and other advocates who proposed further actions by Montreal Protocol nations based on this quantitative evaluation.

Velders *et al.*, *PNAS* (2007)

The accelerated HCFC phaseout adopted by the Montreal Protocol in September 2007

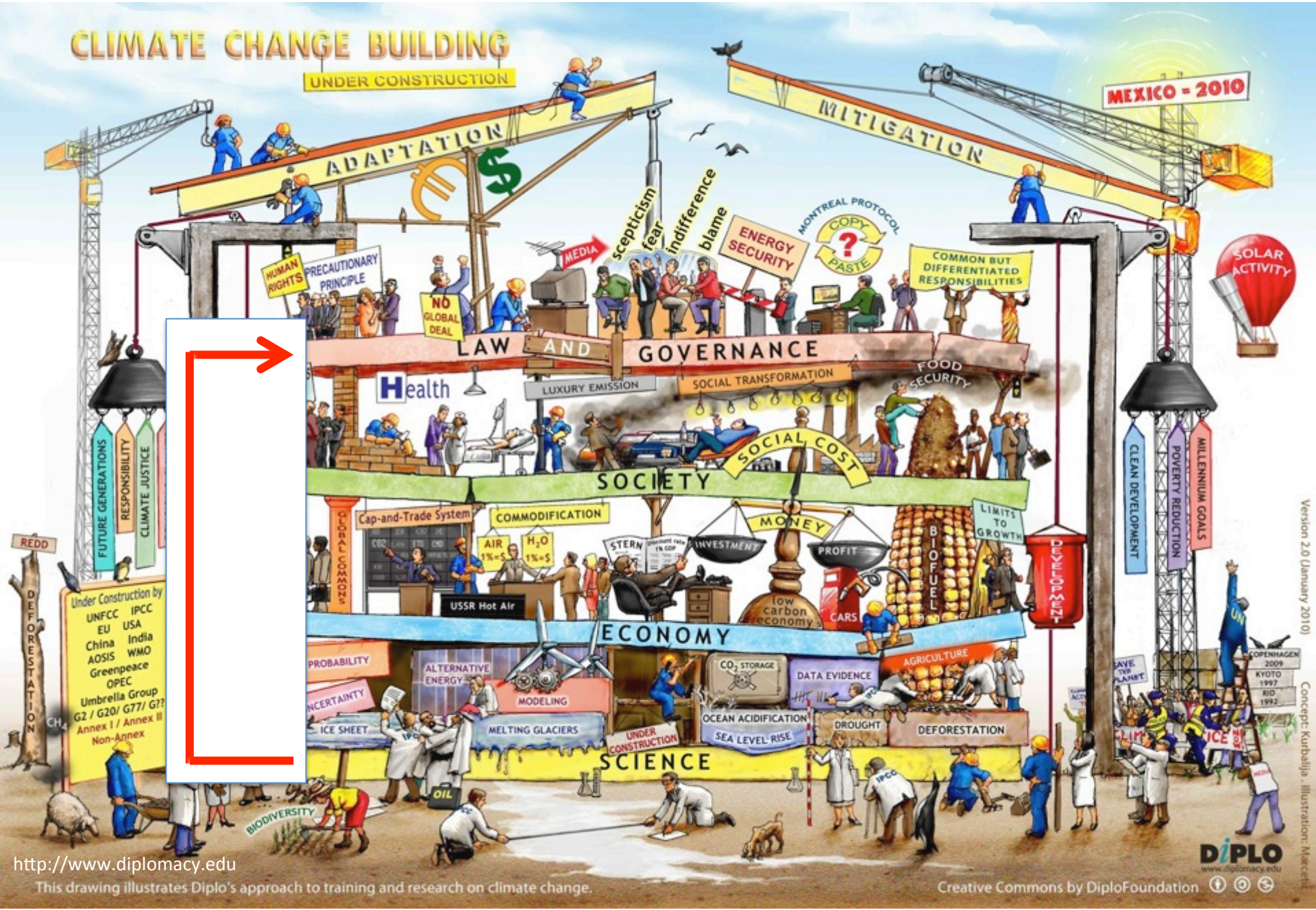


- Advanced phaseout by 10 years for developing nations.
- Reduction = 12-15 years of US automobile CO_2 emissions
- Implemented by earlier use of hydrofluorocarbon (HFC) gases.
- Ultimately, climate benefit will depend on choice of HFCs.

Bottom line: A scientific perspective communicated to decision makers (Law and Governance floor) changed the world.

Velders *et al., PNAS*, 2007

The Climate Change Building: *Our Grand Challenge*



http://www.diplomacy.edu

This drawing illustrates Diplo's approach to training and research on climate change.

Atmospheric black carbon (BC) aerosol

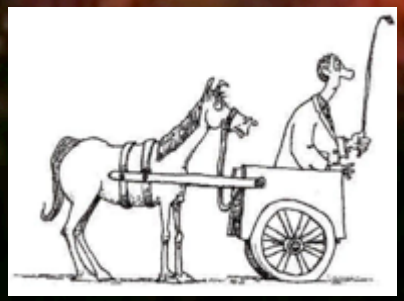
- BC is the ubiquitous product of incomplete fossil fuel and biofuel combustion.
- BC is considered the leading climate forcing agent after CO_2 and CH_4 but highly undersampled in the atmosphere.
- Breathing BC damages human health, e.g., biofuel use in 100s of millions cook stoves.
- Policy makers want to use global BC reductions to slow climate change.

iStockPhoto.com

V. Ramanathan

UNEP Climate and Clean Air Coalition to Reduce Short-Lived Climate Pollutants

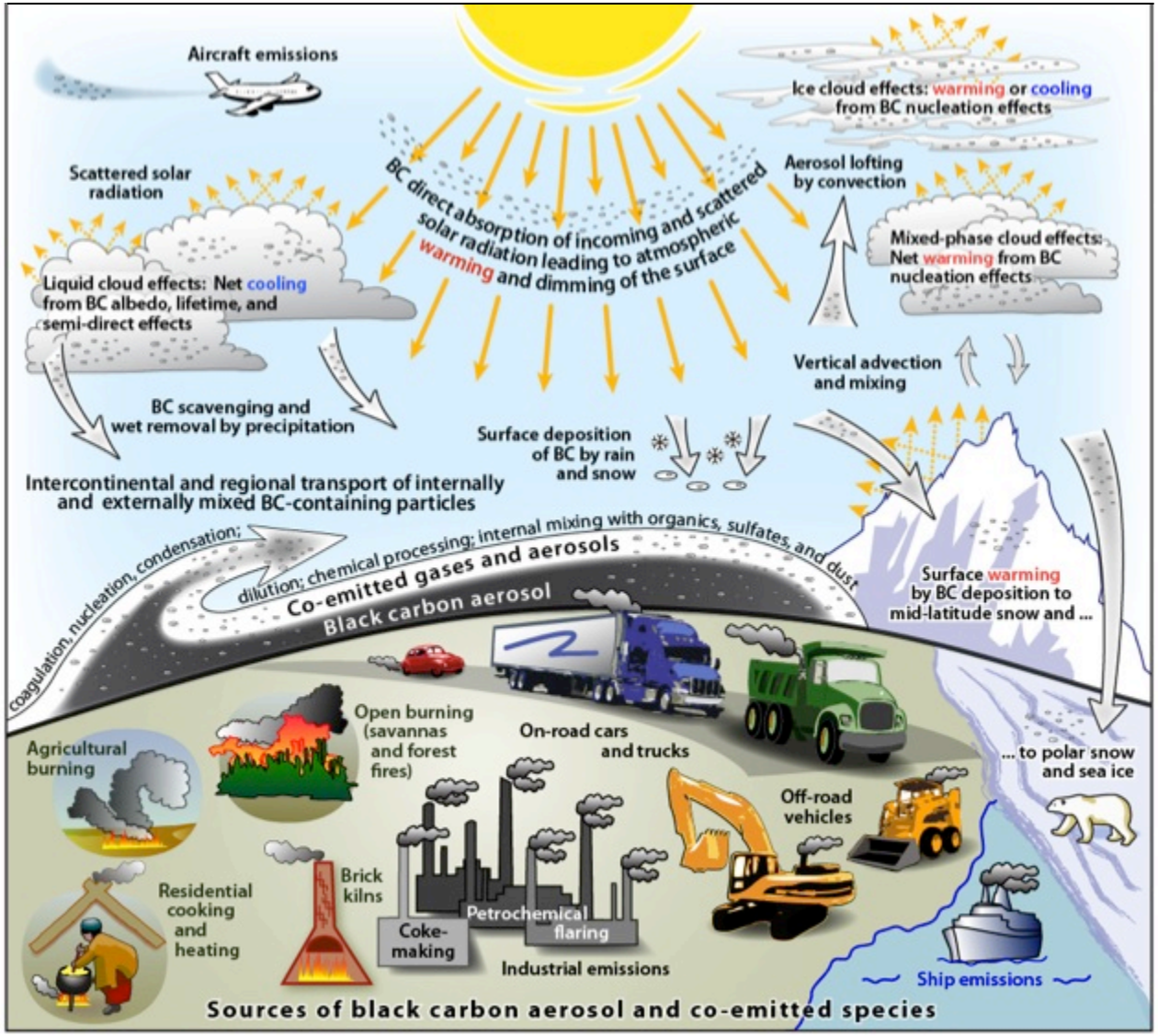
- Growing concern about the lack of adequate scientific foundation for black carbon's role in climate forcing from regulators, policy makers, non-governmental organizations (NGOs), advocates, ….



Science Policy

http://www.metronetiq.com

Black carbon processes in the climate system



- Black carbon aerosol has a complex role in the climate system.

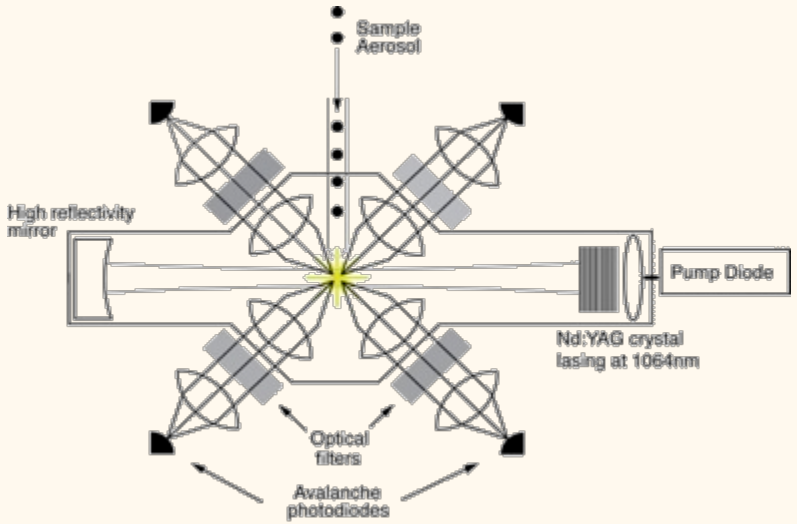
Bond *et al., J Geophys. Res.*, 2013

I. Build custom sampling instrumentation for black carbon aerosol

- The Single-particle soot photometer (SP2) detects refractory black-carbon mass component of individual particles

- Uses 1μm laser light to heat BC mass to incandescence (4000K)

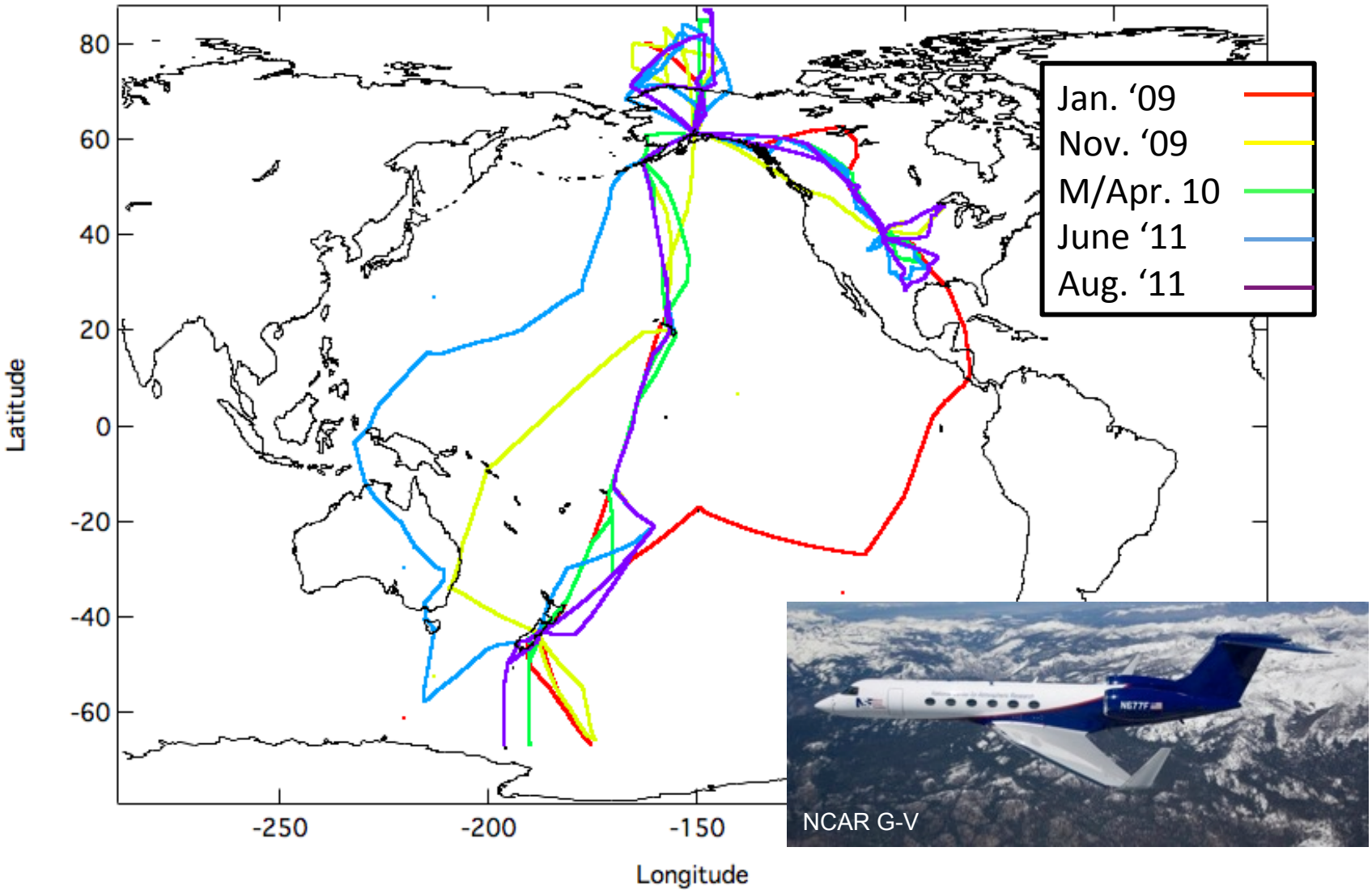
- Continuous sampling provides atmospheric mass loadings of BC and other parameters



Schwarz *et al.*, *JGR*, 2006

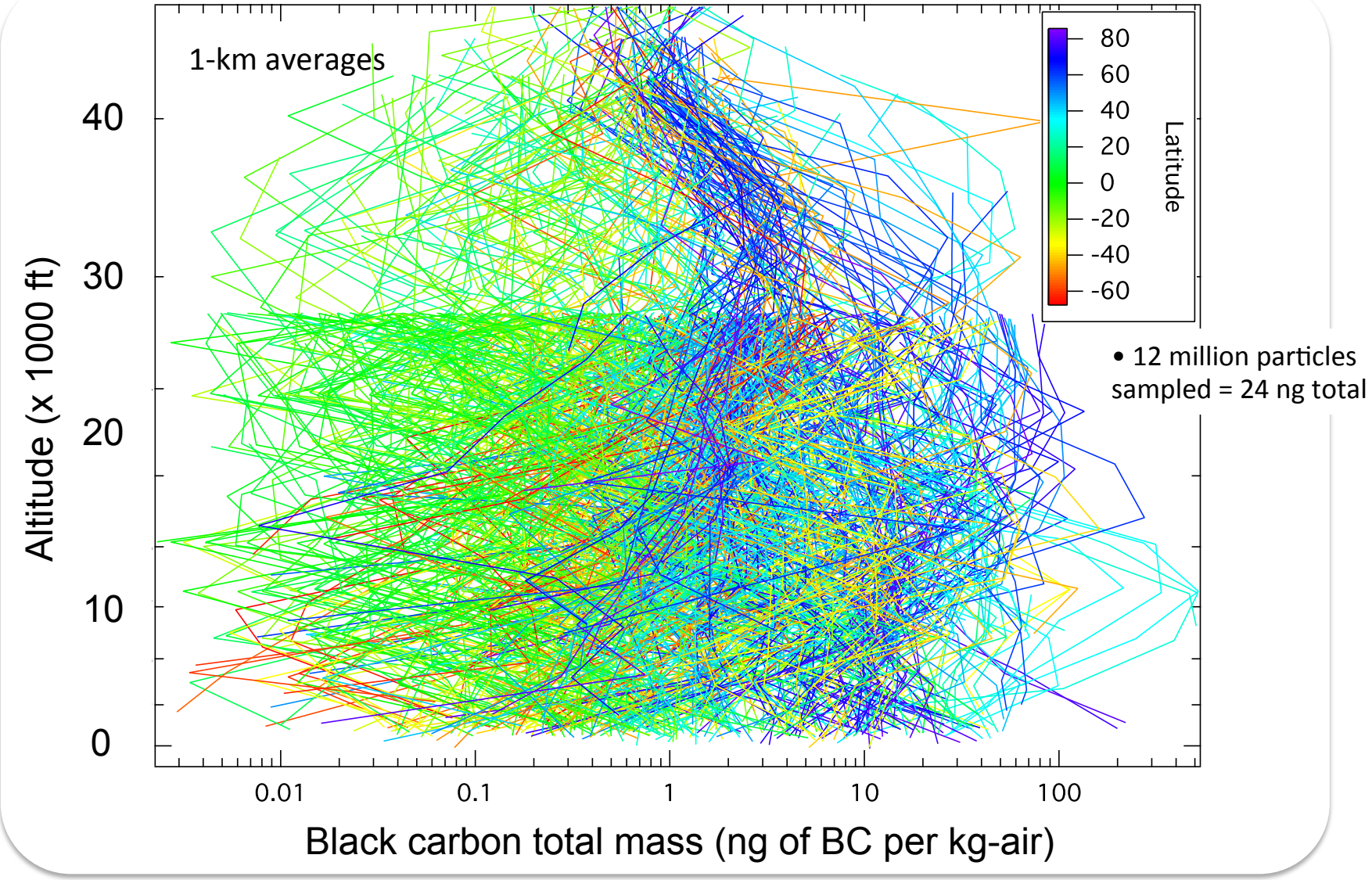
II. Sample black carbon in the background atmosphere

Continuous vertical profiling (85°N – 65°S) over 250K km in all seasons



- Unprecedented information about atmospheric black carbon

III. Analyze the black carbon data and compare to global models



➢ Global aerosol models systematically over estimate black carbon in the remote atmosphere

Schwarz *et al.*, 2013

IV. Conduct the first comprehensive black carbon assessment

Bounding the role of black carbon in the climate system: A scientific assessment

T. C. Bond,[1] S. J. Doherty,[2] D. W. Fahey,[3] P. M. Forster,[4] T. Berntsen,[5] B. J. DeAngelo,[6] M. G. Flanner,[7] S. Ghan,[8] B. Kärcher,[9] D. Koch,[10] S. Kinne,[11] Y. Kondo,[12] P. K. Quinn,[13] M. C. Sarofim,[6] M. G. Schultz,[14] M. Schulz,[15] C. Venkataraman,[16] H. Zhang,[17] S. Zhang,[18] N. Bellouin,[19] S. K. Guttikunda,[20] P. K. Hopke,[21] M. Z. Jacobson,[22] J. W. Kaiser,[23] Z. Klimont,[24] U. Lohmann,[25] J. P. Schwarz,[3] D. Shindell,[26] T. Storelvmo,[27] S. G. Warren,[28] and C. S. Zender[29]

Received 26 March 2012; revised 6 December 2012; accepted 4 January 2013; published 6 June 2013.

[1] Black carbon aerosol plays a unique and important role in Earth's climate system. Black carbon is a type of carbonaceous material with a unique combination of physical properties. This assessment provides an evaluation of black-carbon climate forcing that is comprehensive in its inclusion of all known and relevant processes and that is quantitative in providing best estimates and uncertainties of the main forcing terms: direct solar

JOURNAL OF GEOPHYSICAL RESEARCH: ATMOSPHERES, VOL. 118, 5380–5552, doi:10.1002/jgrd.50171, 2013

- 31 authors from 9 countries and 4 yrs of effort

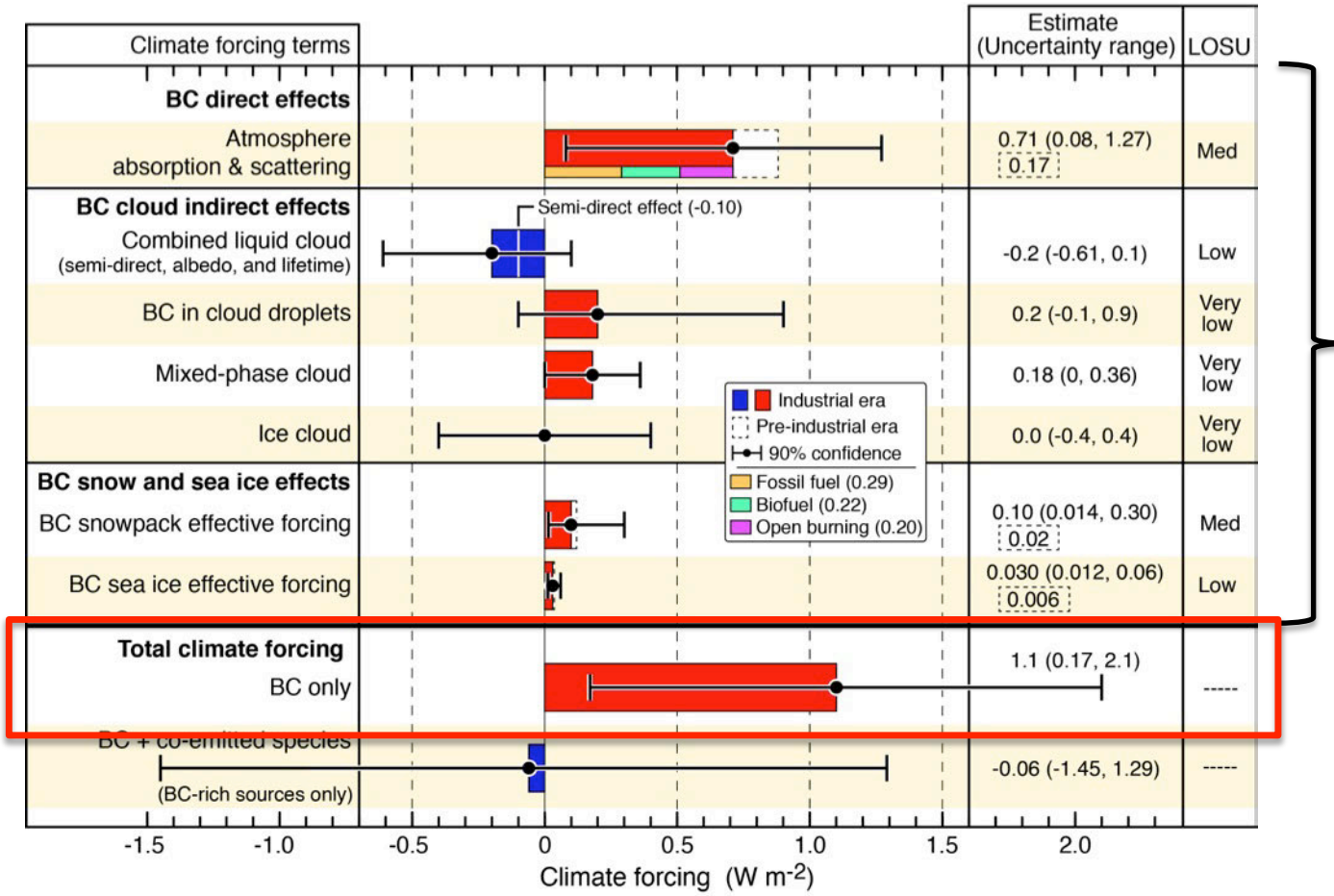
Guiding Principles:

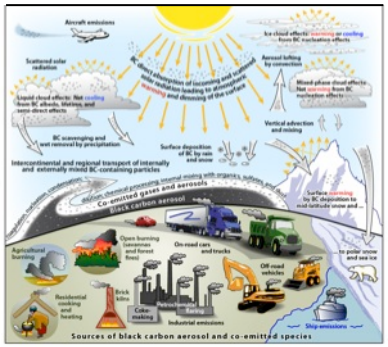
Comprehensive

Quantitative

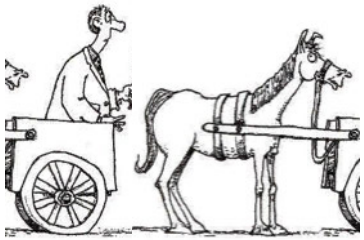
Policy neutral

Global climate forcing of black carbon emissions (2005)





- Black carbon is the 2nd most important climate forcing agent from human activities (high uncertainty).
- These results appear extensively in the IPCC assessment of black carbon radiative effects.



Policy Science

Improved

Bond *et al.*, JGR, 2013

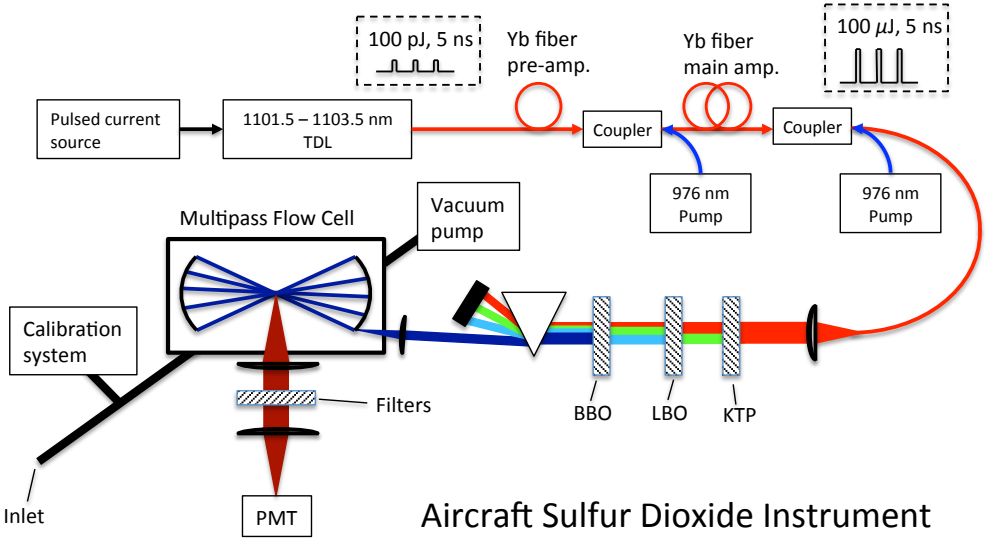
NOAA – NIST collaboration on new measurement techniques

Andrew Rollins and Troy Thornberry, ESRL Chemical Sciences Division

Esther Baumann and Fabrizio Giorgetta
Fiber Sources and Applications Group,
Quantum Electronics and Photonics Division

Goal: Understanding of the sulfur budget in the lower stratosphere using next generation detectors

Objective: Develop fiber laser amplifiers for generation of tunable UV (~220 nm) for SO_2 fluorescence measurements

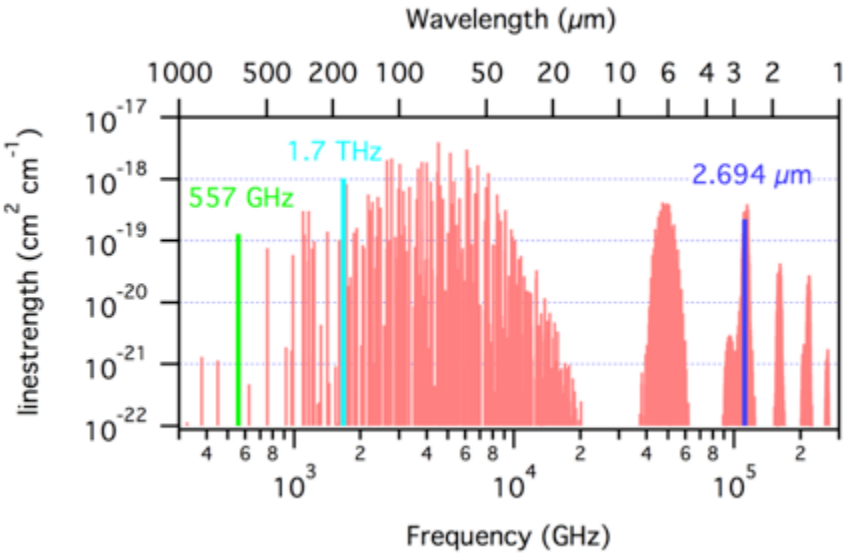


Aircraft Sulfur Dioxide Instrument

Erich Grossman and Richard Chamberlin
Terahertz Imaging and Sources Group,
Quantum Electronics and Photonics Division

Goal: Understanding of the microphysics of water vapor removal in the upper troposphere and lower stratosphere

Objective: Development of a compact terahertz source for improved measurement of low water vapor mixing ratios in the atmosphere



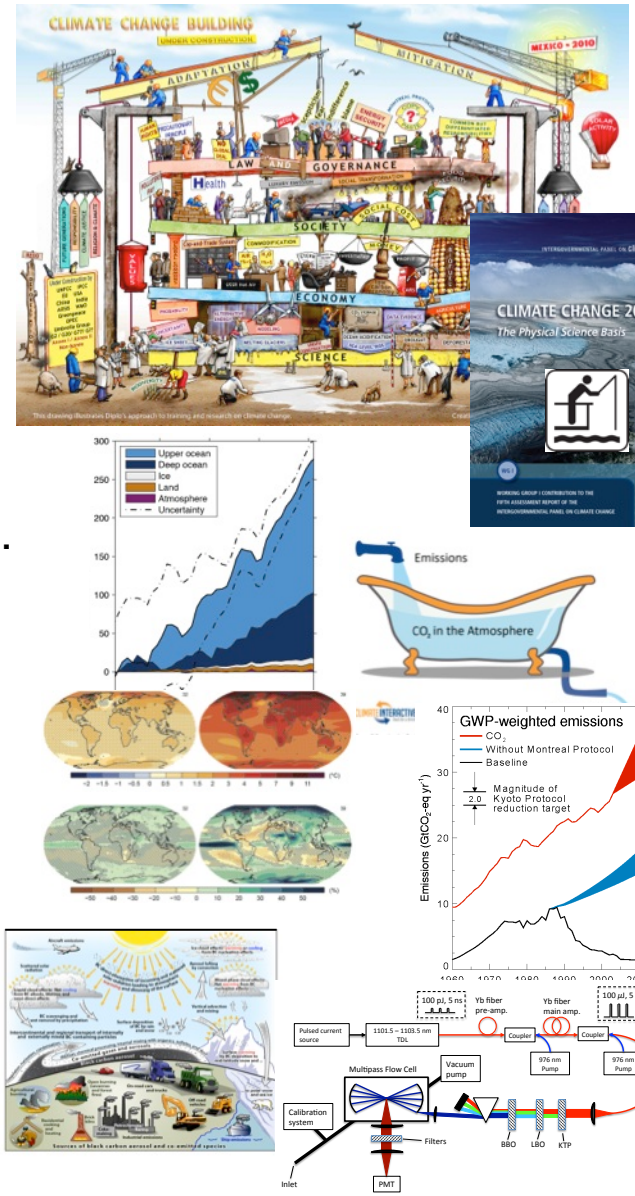
Summary messages

- The climate change building is our grand challenge.
- IPCC represents the Wisdom of Crowds.
- Human influence on the climate system is clear.
- Energy uptake = 275 x 10^{21} Joules and increasing.
- CO_2 is the forever gas.
- Limiting climate change requires reduced emissions.
- The world can still choose its climate future.

- The Montreal Protocol has taken unprecedented and unequaled global action to protect climate.
- Assessment of black carbon aerosol shows it is the 2nd most important climate forcing agent.

- *Thank you* NIST for helping us out in our new experimental adventures.

- I hope you find your way to contribute to the climate change building.
- "Science has the first word on everything, but the last word on nothing."



Links

IPCC AR5 Working Group I, The Science of Climate Change

www.climatechange2013.org

For WGI chapter pdfs and graphics see:

http://www.climatechange2013.org/report/full-report/

https://www.ipcc.ch/report/ar5/wg1/

For 20 Questions and Answers about the Ozone Layer see:

http://www.esrl.noaa.gov/csd/assessments/ozone/2010/twentyquestions/

Backup slides

Headline Statements from the Summary for Policymakers (1 of 5)

• Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, sea level has risen, and the concentrations of greenhouse gases have increased.

• Each of the last three decades has been successively warmer at the Earth's surface than any preceding decade since 1850. In the Northern Hemisphere, 1983–2012 was likely the warmest 30-year period of the last 1400 years. SPM.1

• Ocean warming dominates the increase in energy stored in the climate system, accounting for more than 90% of the energy accumulated between 1971 and 2010 (high confidence). It is virtually certain that the upper ocean (0–700 m) warmed from 1971 to 2010, and it likely warmed between the 1870s and 1971.

• Over the last two decades, the Greenland and Antarctic ice sheets have been losing mass, glaciers have continued to shrink almost worldwide, and Arctic sea ice and Northern Hemisphere spring snow cover have continued to decrease in extent (high confidence). SPM.3

IPCC, AR5

Headline Statements from the Summary for Policymakers (2 of 5)

• The rate of sea level rise since the mid-19th century has been larger than the mean rate during the previous two millennia (high confidence). Over the period 1901–2010, global mean sea level rose by 0.19 [0.17 to 0.21] m.

• The atmospheric concentrations of carbon dioxide (CO2), methane, and nitrous oxide have increased to levels unprecedented in at least the last 800,000 years. CO2 concentrations have increased by 40% since pre-industrial times, primarily from fossil fuel emissions and secondarily from net land use change emissions. The ocean has absorbed about 30% of the emitted anthropogenic carbon dioxide, causing ocean acidification.

• Total radiative forcing is positive, and has led to an uptake of energy by the climate system. The largest contribution to total radiative forcing is caused by the increase in the atmospheric concentration of CO2 since 1750. SPM.5

• Human influence on the climate system is clear. This is evident from the increasing greenhouse gas concentrations in the atmosphere, positive radiative forcing, observed warming, and understanding of the climate system.

IPCC, AR5

Headline Statements from the Summary for Policymakers (3 of 5)

• Climate models have improved since the AR4. Models reproduce observed continental-scale surface temperature patterns and trends over many decades, including the more rapid warming since the mid-20th century and the cooling immediately following large volcanic eruptions (very high confidence).

• Observational and model studies of temperature change, climate feedbacks and changes in the Earth's energy budget together
provide confidence in the magnitude of global warming in response to past and future forcing.

• Human influence has been detected in warming of the atmosphere and the ocean, in changes in the global water cycle, in reductions in snow and ice, in global mean sea level rise, and in changes in some climate extremes. This evidence for human influence has grown since AR4. It is extremely likely that human influence has been the dominant cause of the observed warming since the mid-20th century. SPM.6

• Continued emissions of greenhouse gases will cause further warming and changes in all components of the climate system. Limiting climate change will require substantial and sustained reductions of greenhouse gas emissions.

IPCC, AR5

Headline Statements from the Summary for Policymakers (4 of 5)

• Global surface temperature change for the end of the 21st century is likely to exceed 1.5°C relative to 1850 to 1900 for all RCP scenarios except RCP2.6. It is likely to exceed 2°C for RCP6.0 and RCP8.5, and more likely than not to exceed 2°C for RCP4.5. Warming will continue beyond 2100 under all RCP scenarios except RCP2.6. Warming will continue to exhibit interannual-to-decadal variability and will not be regionally uniform.

• Changes in the global water cycle in response to the warming over the 21st century will not be uniform. The contrast in precipitation between wet and dry regions and between wet and dry seasons will increase, although there may be regional exceptions.

• The global ocean will continue to warm during the 21st century. Heat will penetrate from the surface to the deep ocean and affect ocean circulation.

• It is very likely that the Arctic sea ice cover will continue to shrink and thin and that Northern Hemisphere spring snow cover will decrease during the 21st century as global mean surface temperature rises. Global glacier volume will further decrease.

• Global mean sea level will continue to rise during the 21st century. Under all RCP scenarios the rate of sea level rise will very likely exceed that observed during 1971–2010 due to increased ocean warming and increased loss of mass from glaciers and ice sheets.

IPCC, AR5