Reminders

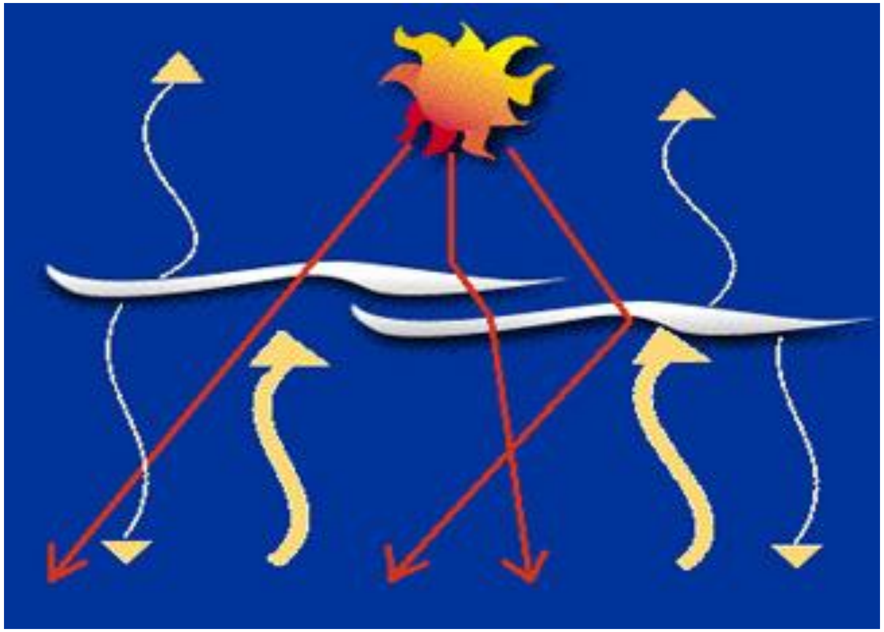
- **Final Exam next week**
- **Via Canvas, Wednesday June 12, 2:30pm – 5pm**
- **Contact me and/or Claire ASAP if you have a valid conflict (graduation, academic event, etc)**

Cloud Forcings and Feedbacks

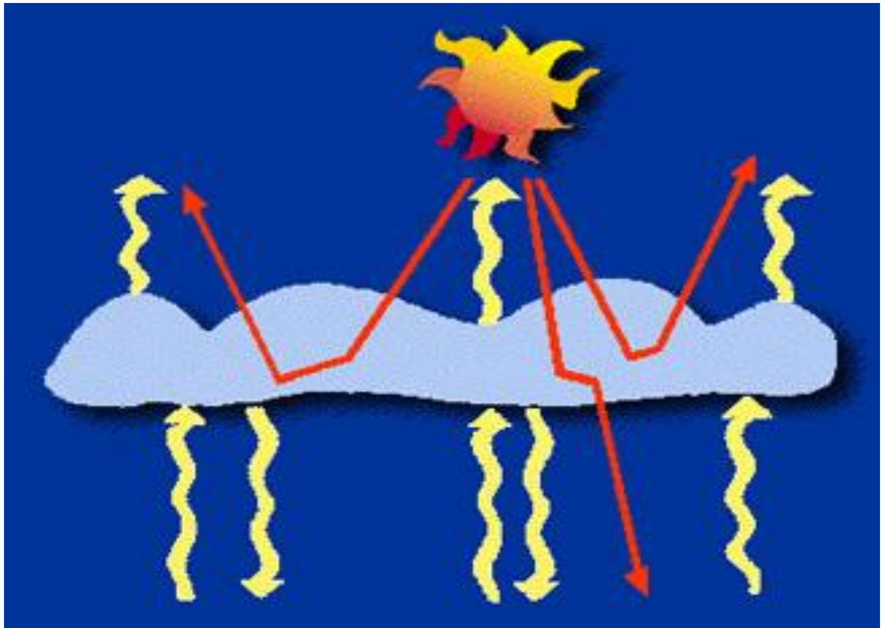
High altitude thin ice clouds
→ Cirrus

Low altitude thick clouds
→ Stratus

Clouds and Climate—a complex problem

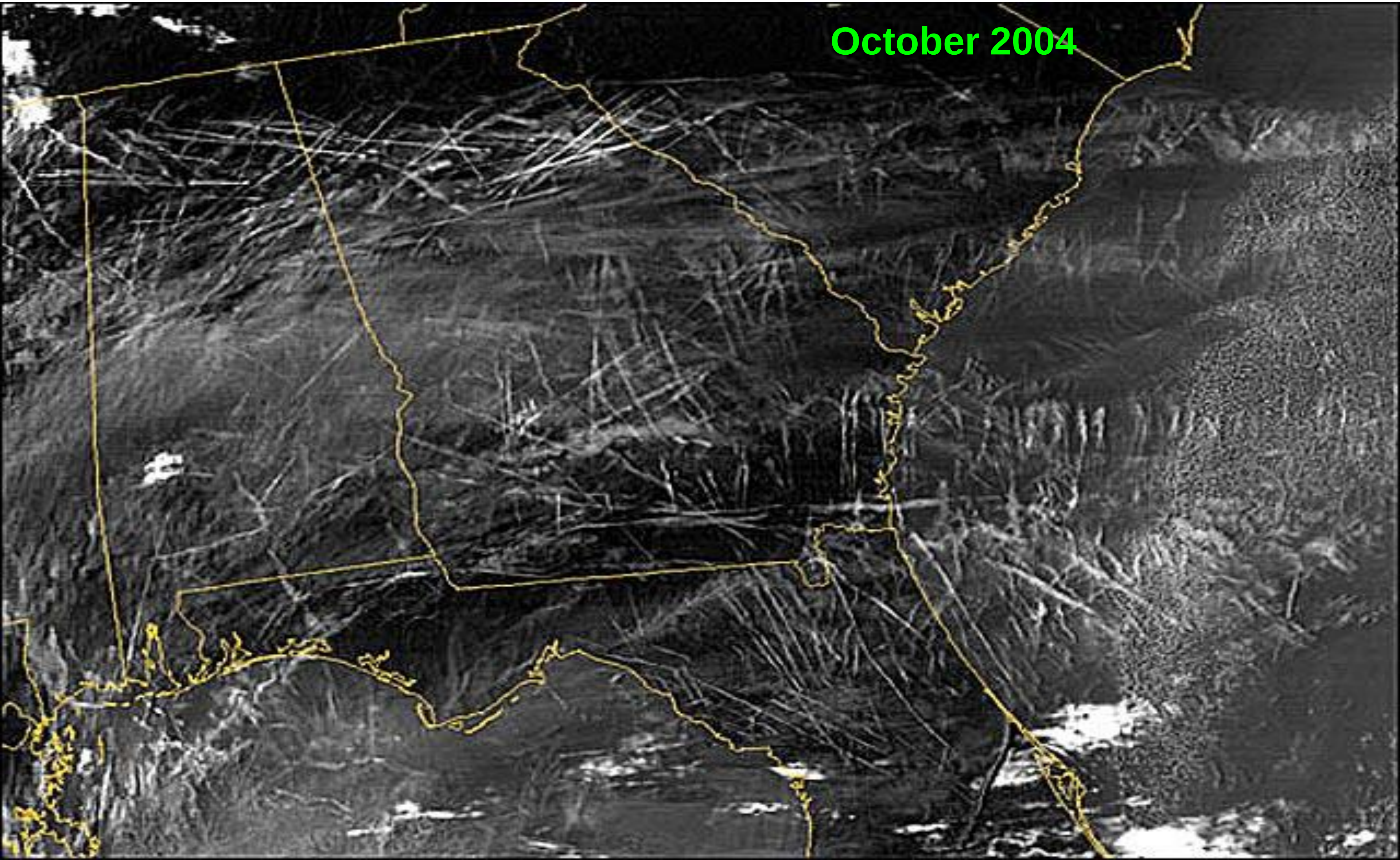


Cirrus: Not so reflective, but absorb IR and emit at cold T



Low Clouds: Reflective, do absorb IR but emit like warm surface.

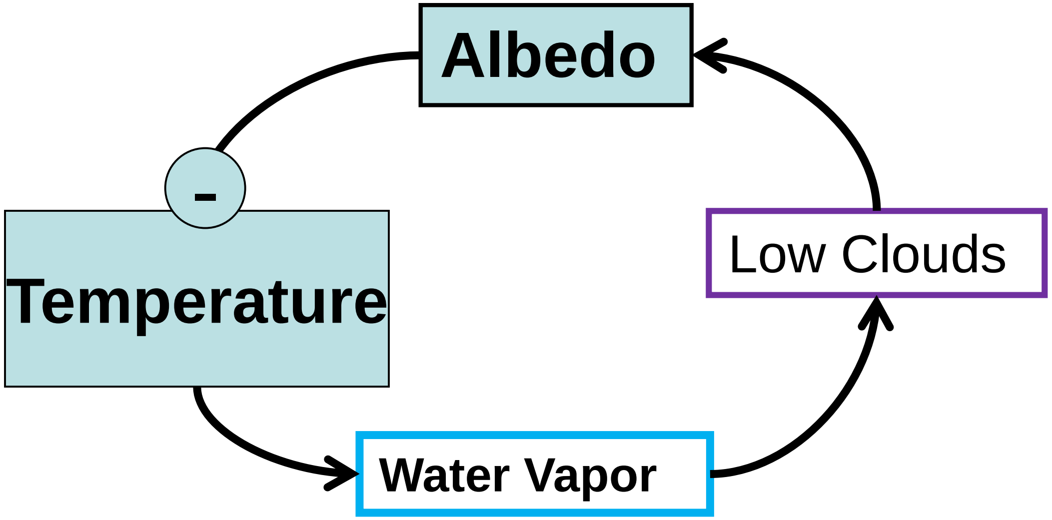
Aviation Contrails—Positive Forcing



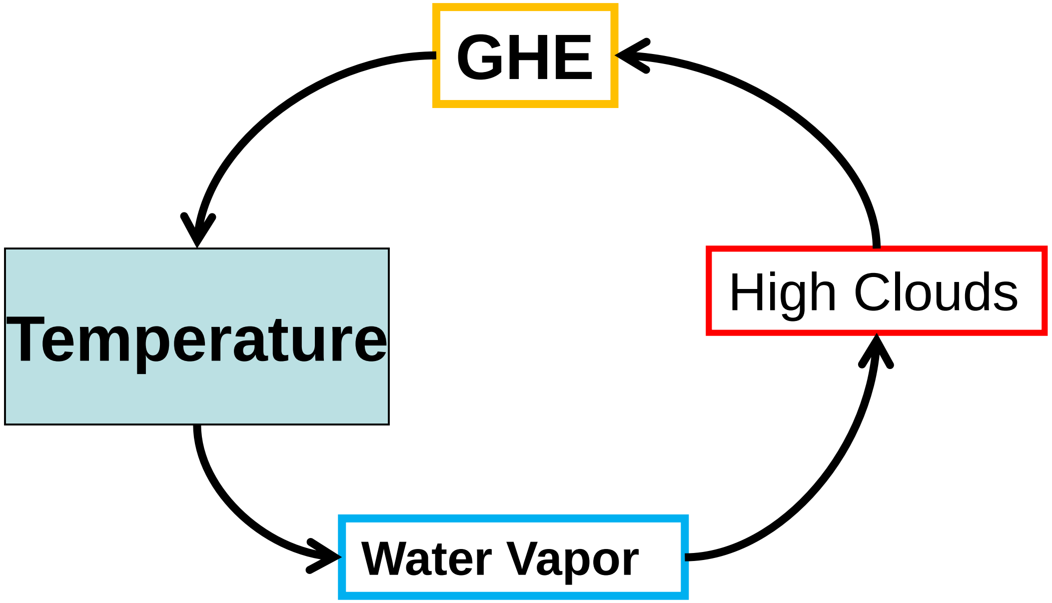
Clouds and Cloud Feedbacks (two examples)

Uncertain!

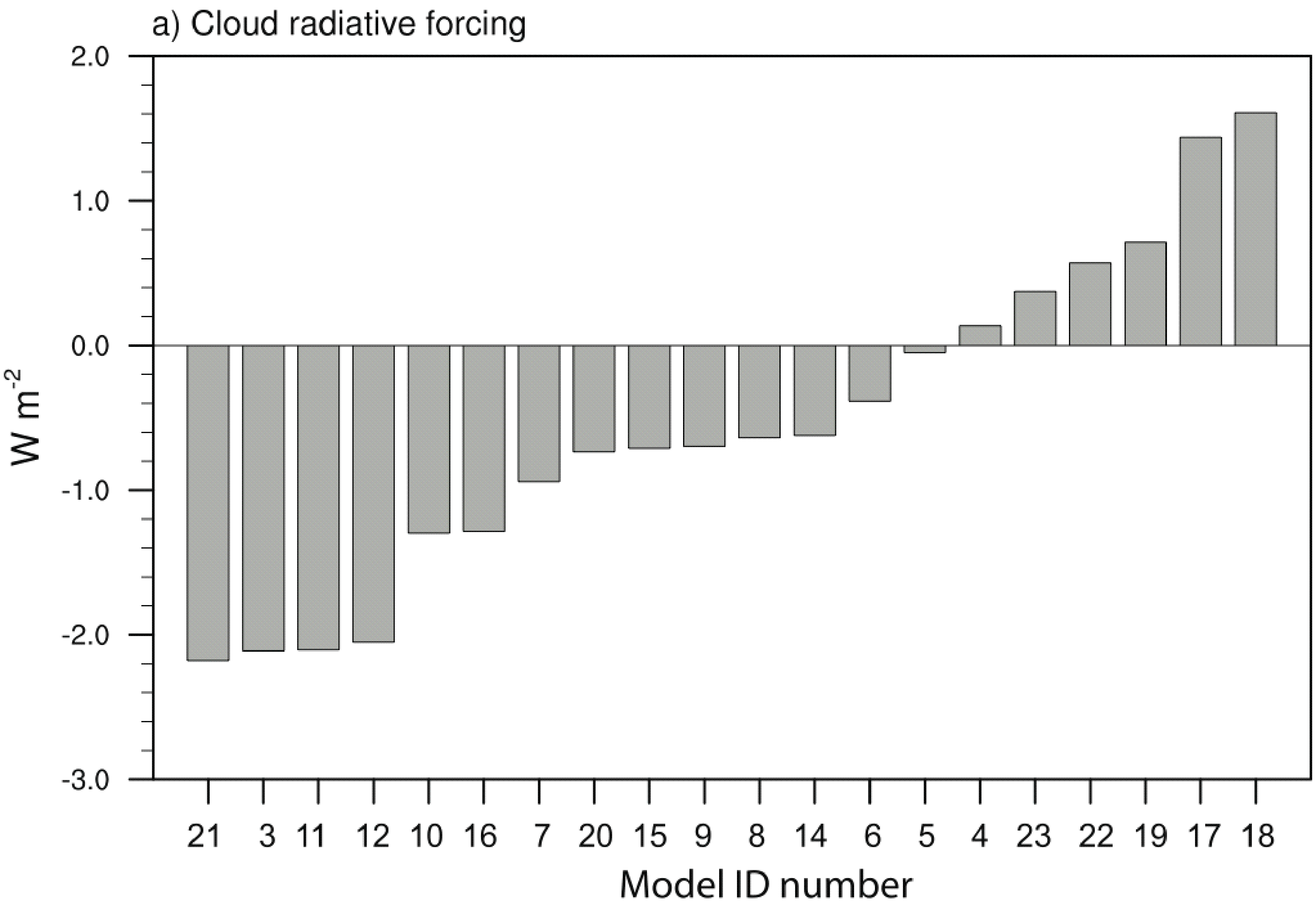
Overall Negative



Overall Positive



Cloud Forcing Predictions by Different Models



IPCC 2007

Impact #3: Cryosphere Melting

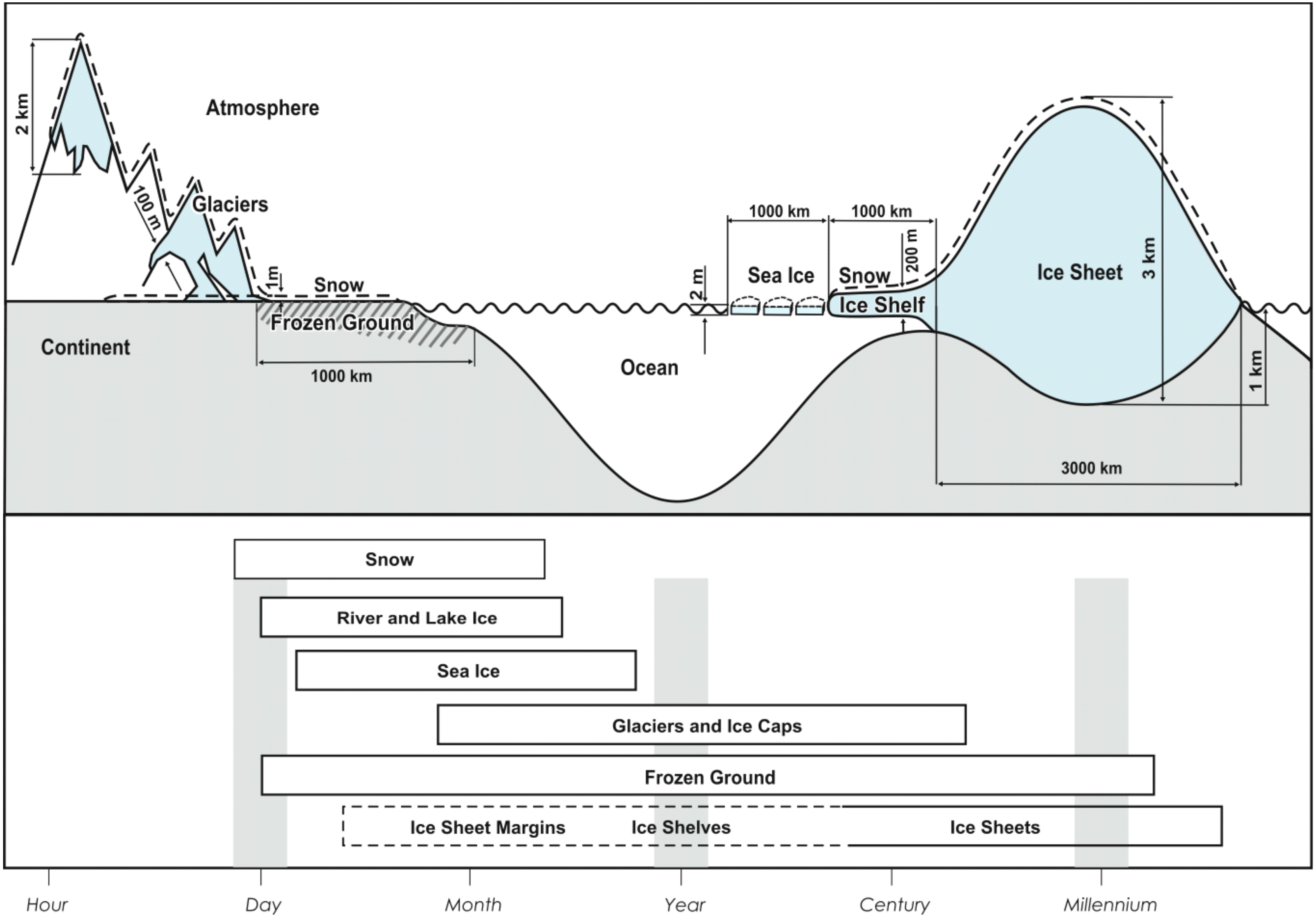
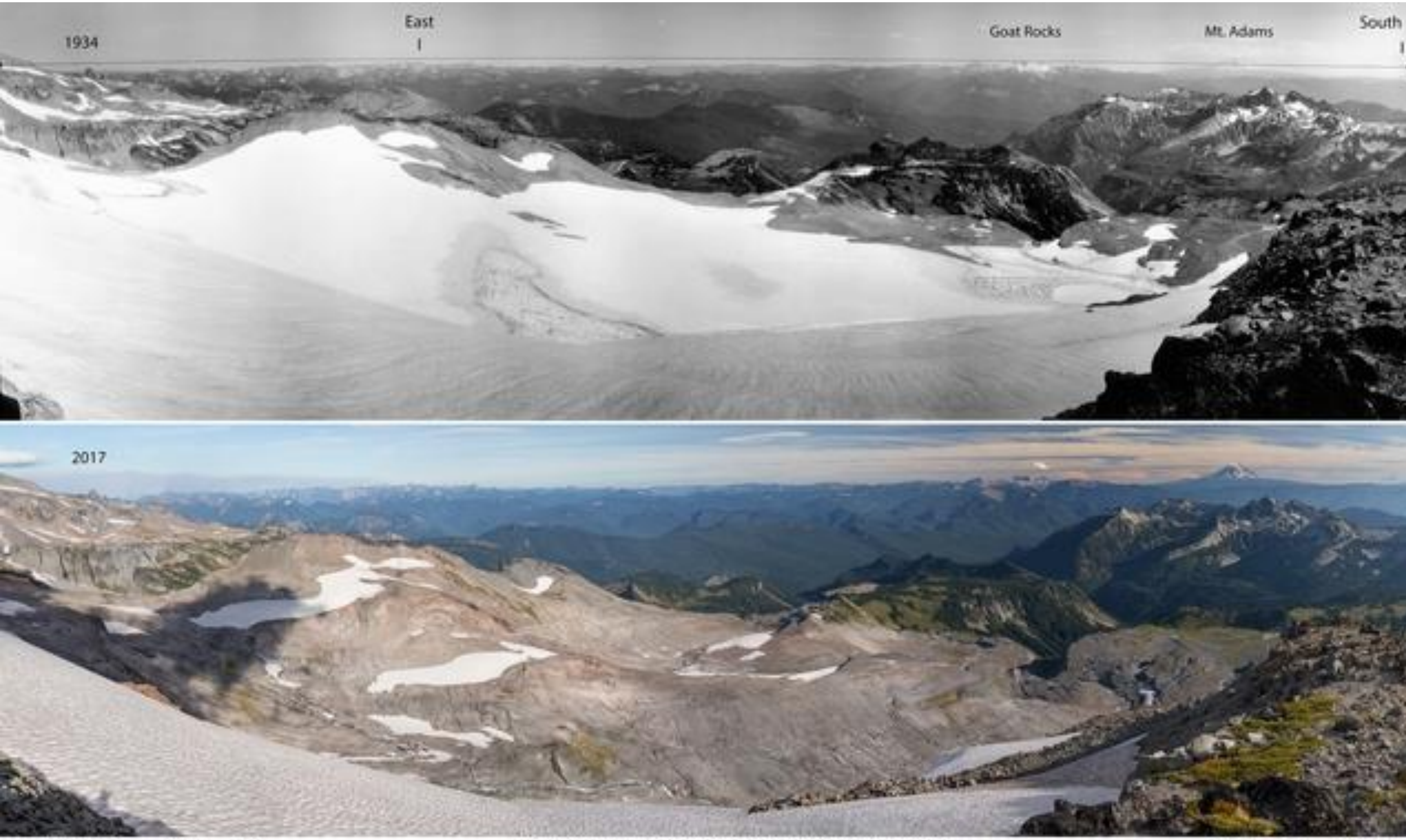


Figure 4.1

Ice Stability and Climate

Mt. Rainier Glaciers



08/08/1934 George B. Clisby, USFS
National Archives and Records Admin.

Historic Photo Comparison from Sugarloaf Rock on Mt. Rainier
Note: Winter 1933-1934 was a low-snowfall year- 316 inches compared to 703 inches in 2016-2017

09/12/2017 John F Marshall
for The Nature Conservancy

Paradise Valley and Stevens

Mt. Rainier Glaciers

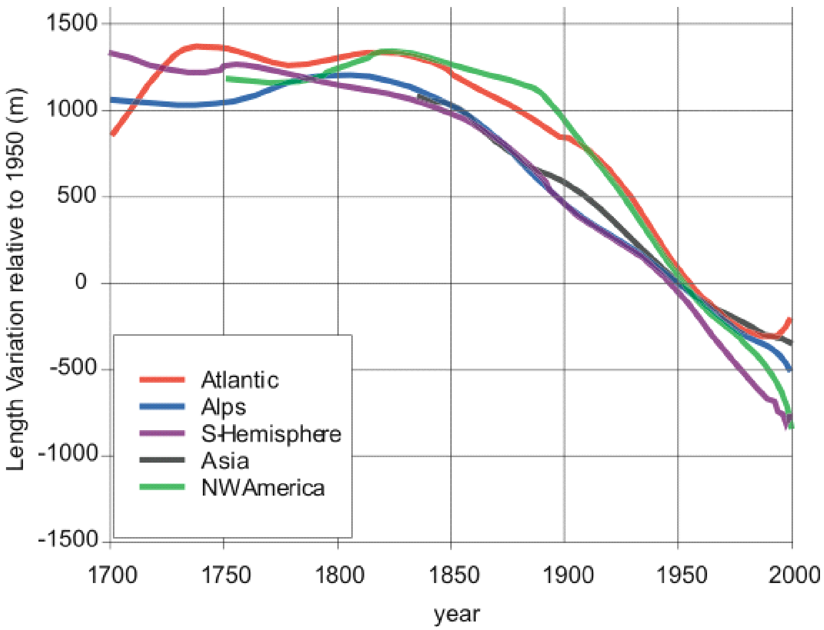
Nisqually

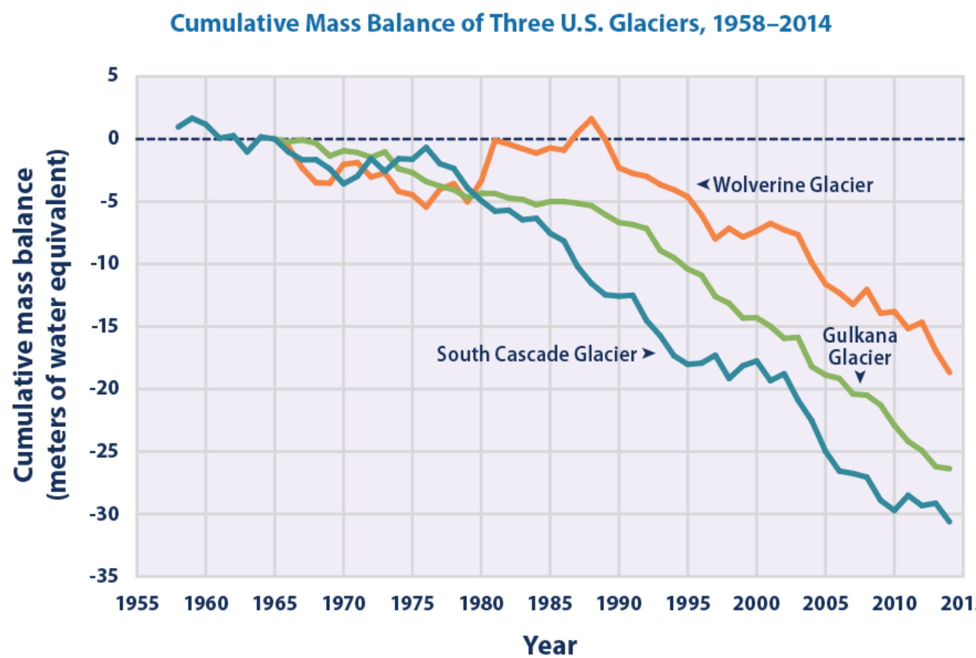
Tropical Glaciers

Qori Kalis

Andes (Peru)

Glacier Lengths



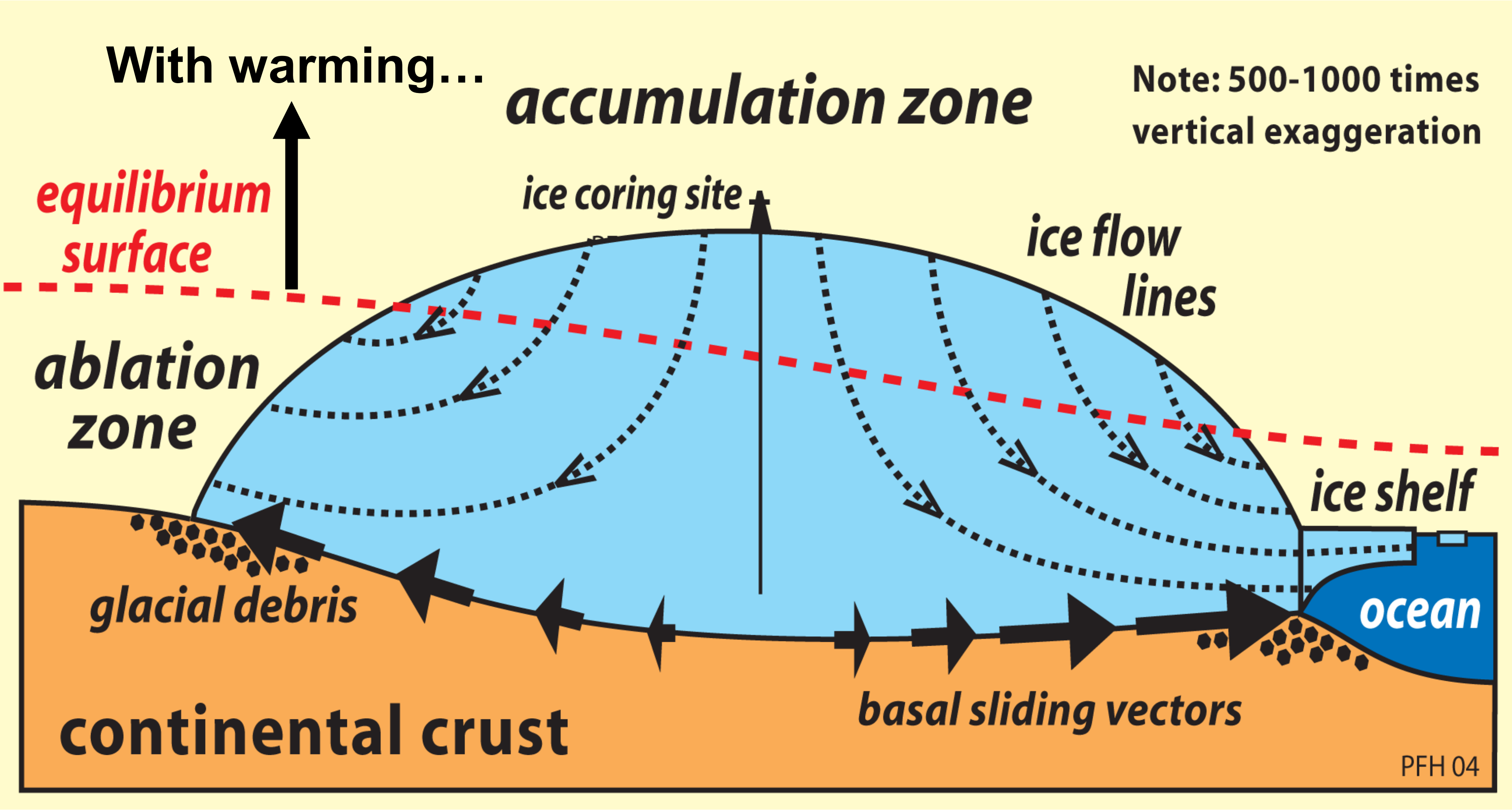


Data sources:
- O'Neel, S., E. Hood, A. Arendt, and L. Sass. 2014. Assessing streamflow sensitivity to variations in glacier mass balance. Climatic Change 123(2):329–341.
- USGS (U.S. Geological Survey). 2015. Water resources of Alaska—glacier and snow program, benchmark glaciers. http://ak.water.usgs.gov/glaciology.

For more information, visit U.S. EPA's "Climate Change Indicators in the United States" at www.epa.gov/climate-indicators.

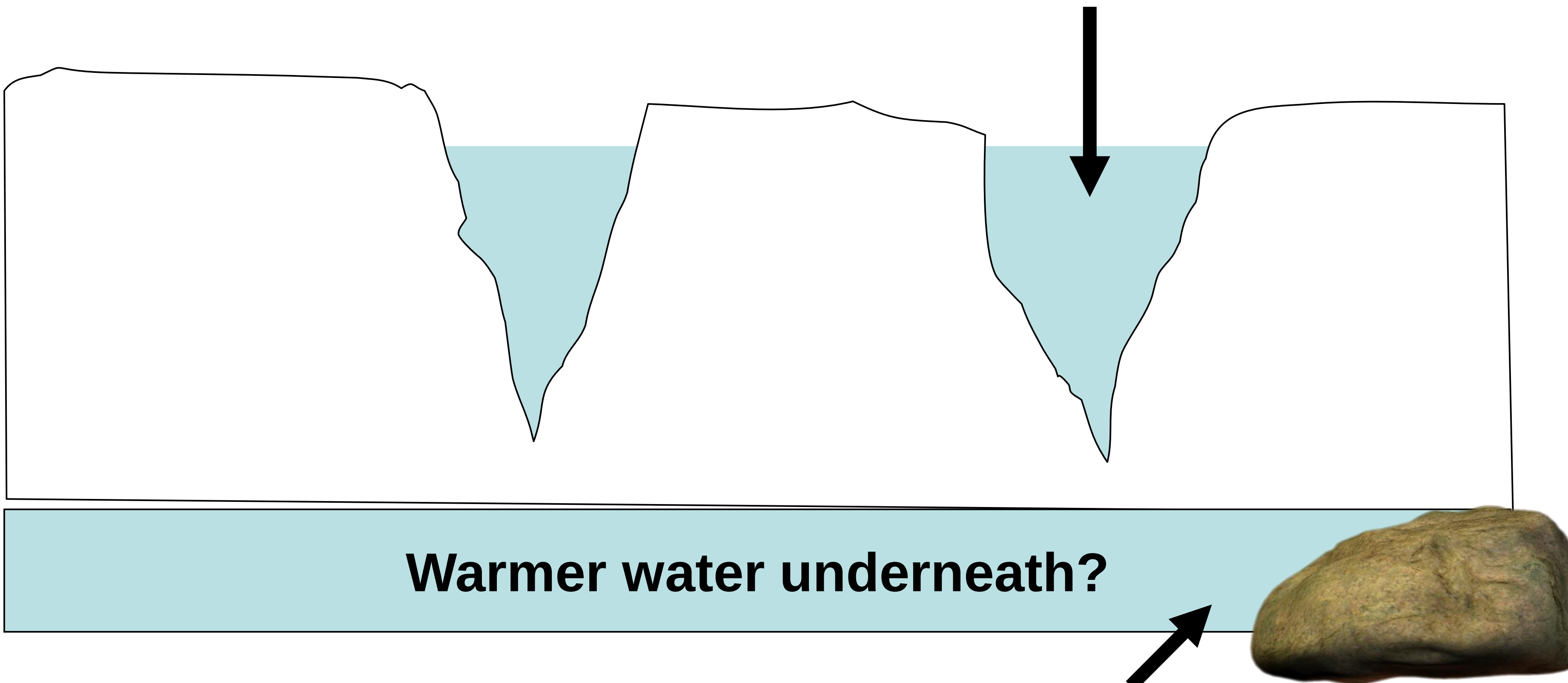
Ice Stability and Climate

Ice Sheet Dynamics

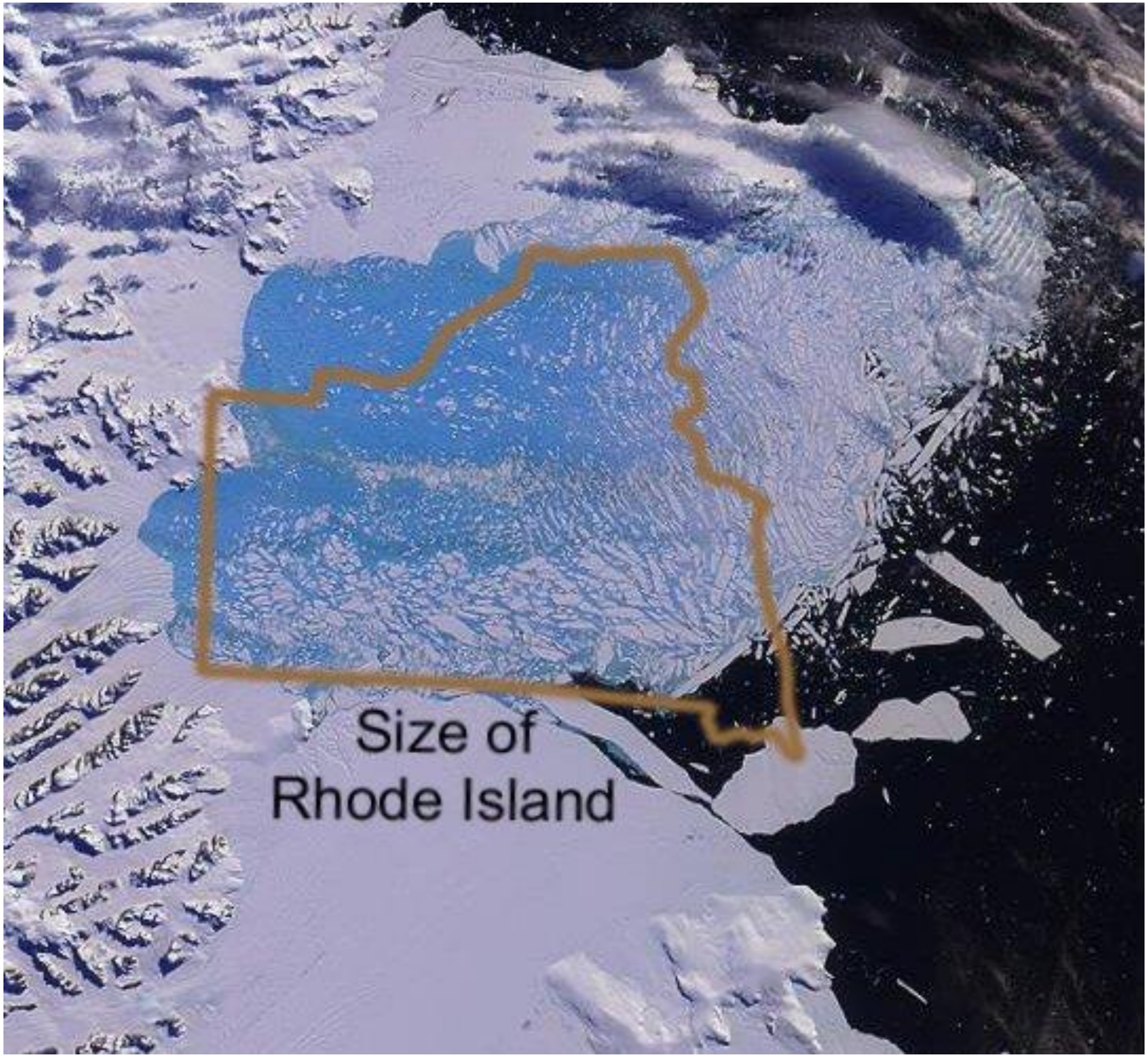


Ice Sheet/Shelf Instabilities?

Potential for positive feedbacks and "tipping points"



Larsen Ice Shelf Collapse



Impact #3: Cryosphere Melting

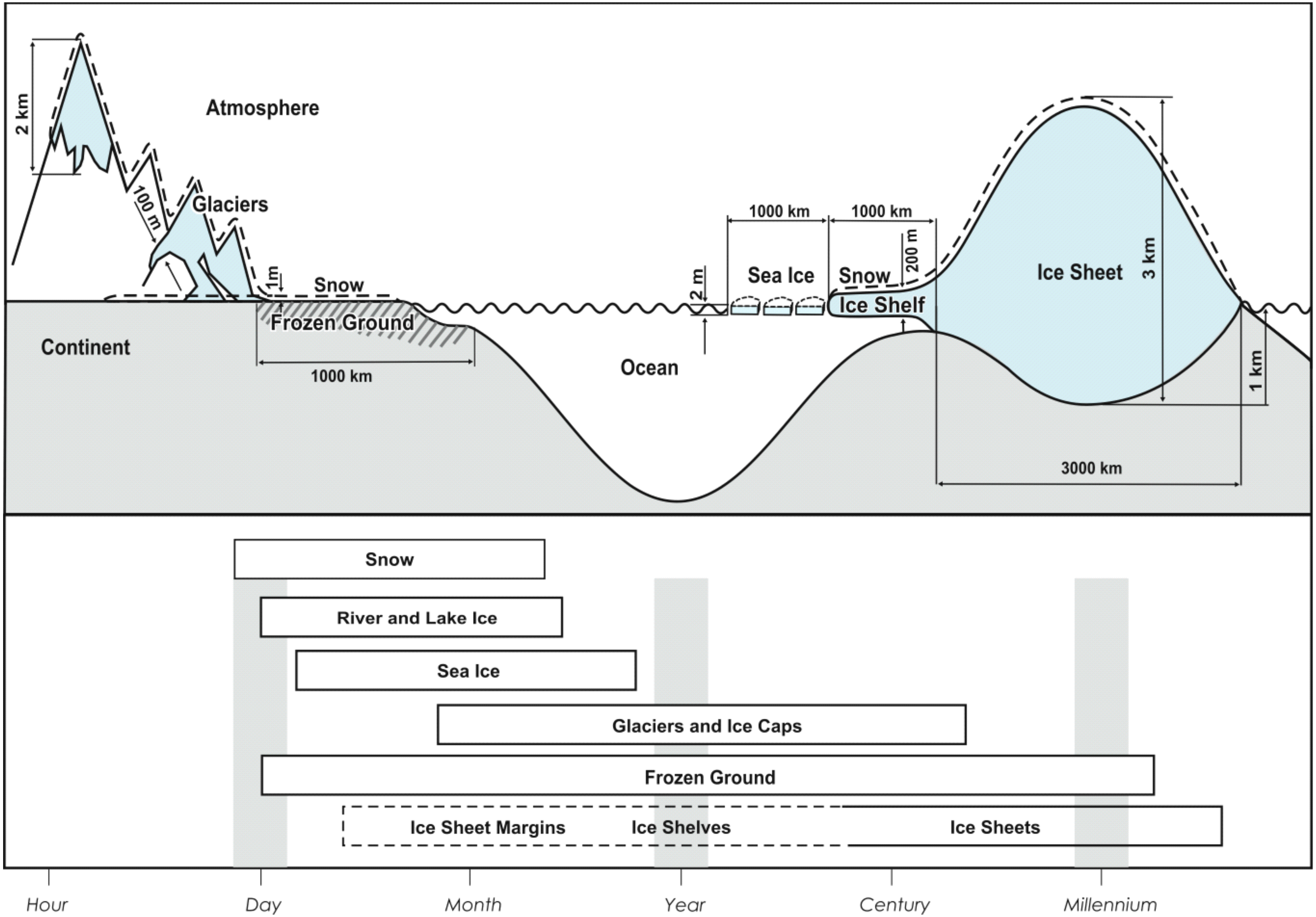
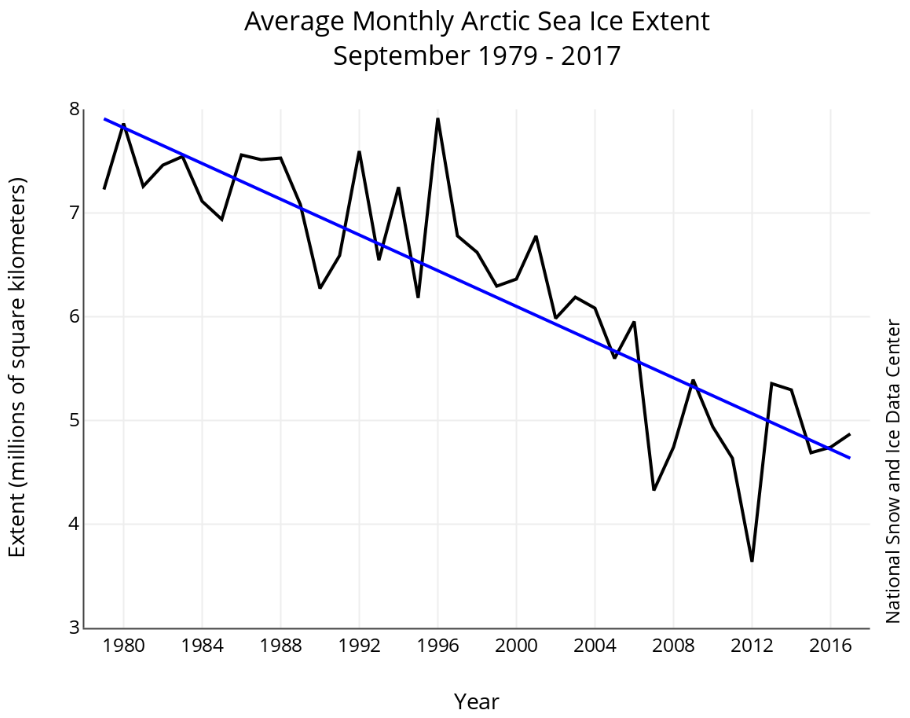
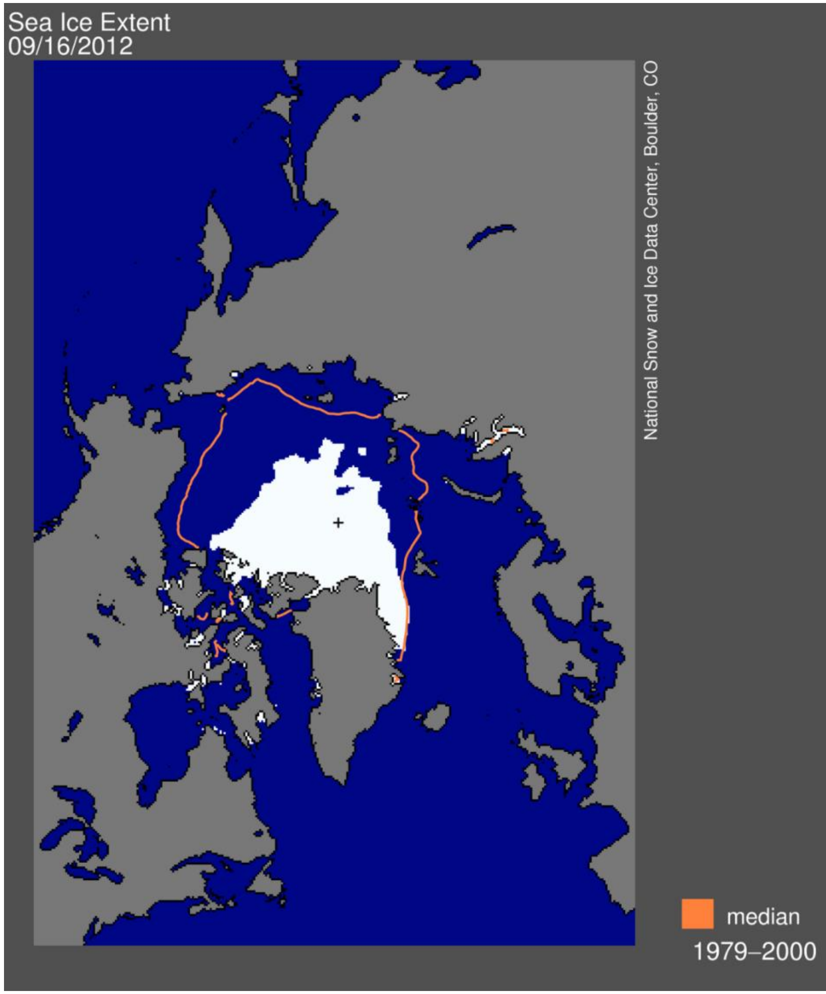


Figure 4.1

Sea Ice Melting

- **Record minimum sea ice extents**
- **Sea ice younger**
- **Young ice is thinner**





Sea-Ice Dependent Ecosystems

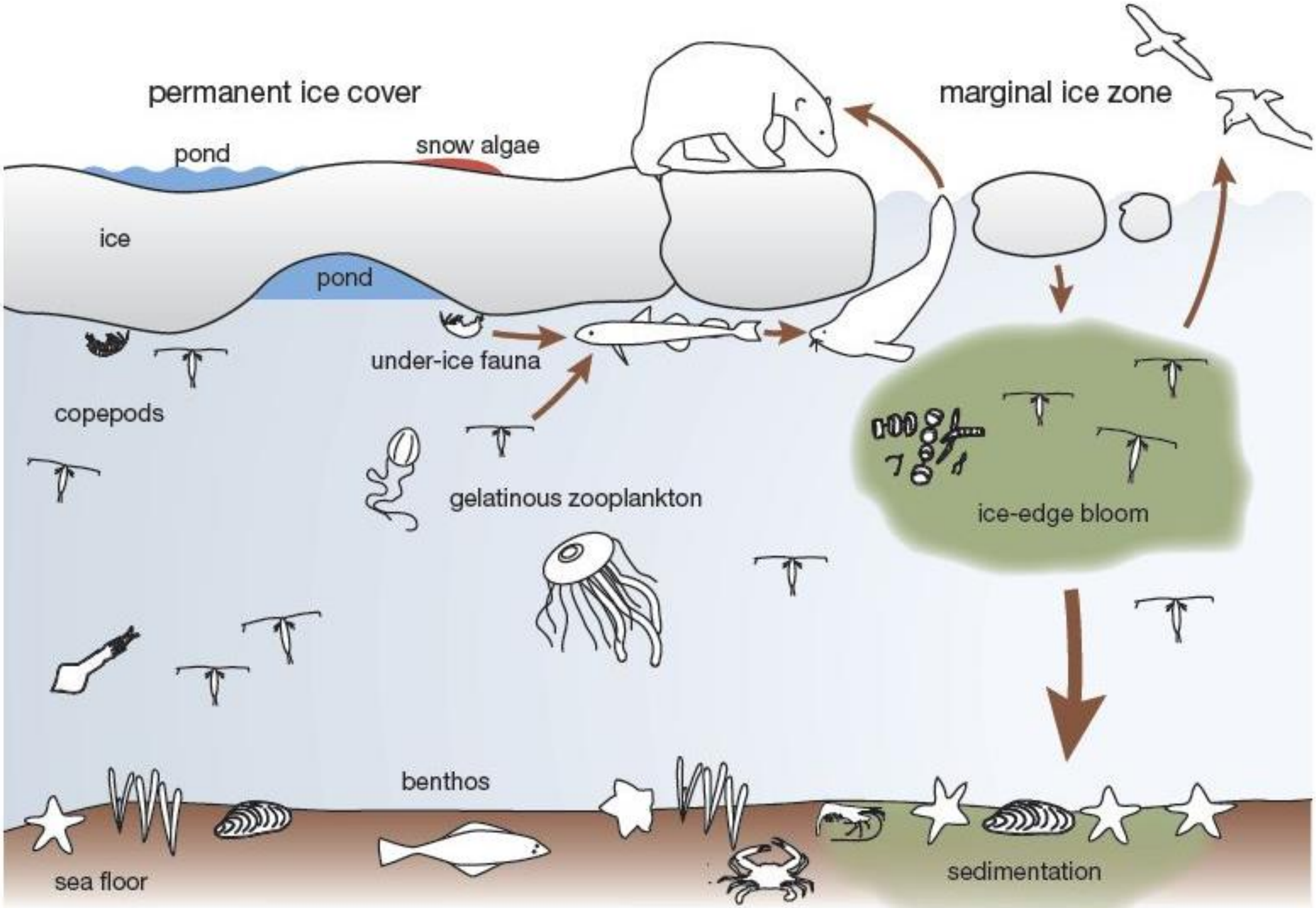
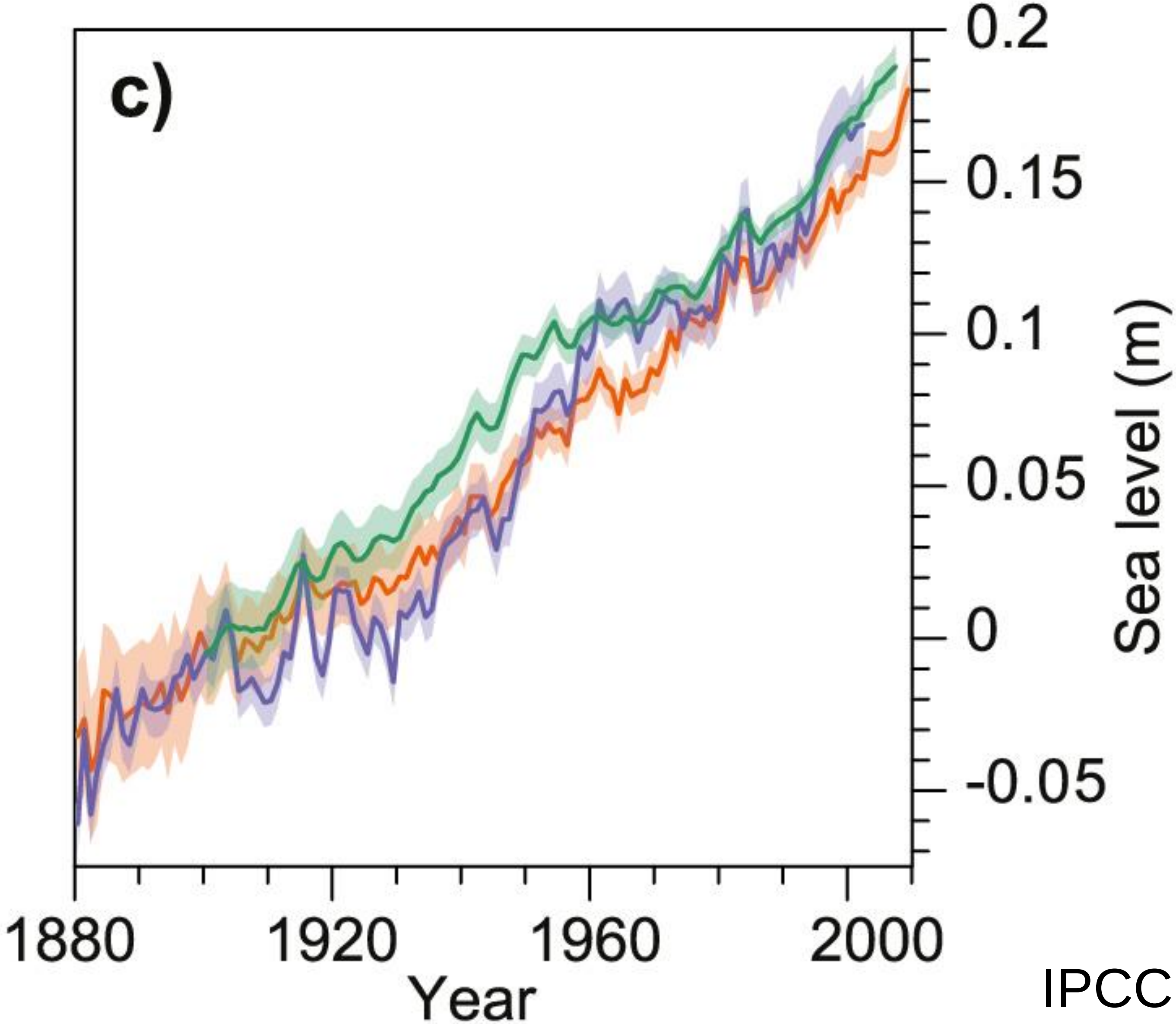


Figure 10.1: Schematic representation of the Arctic marine ecosystem and its interactions [1].

Impact #4: Sea Level

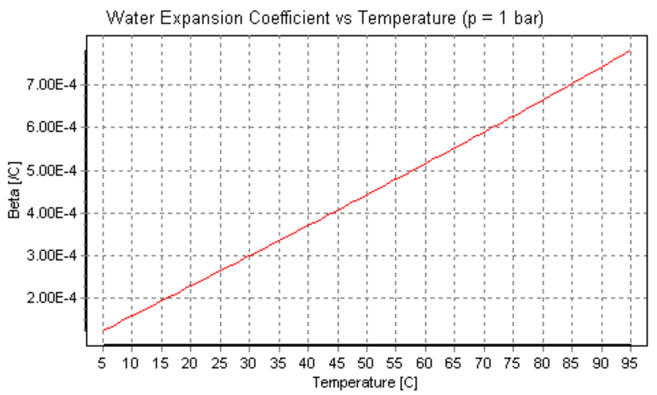
~ 20 cm = 8" ~ 0.5 ft

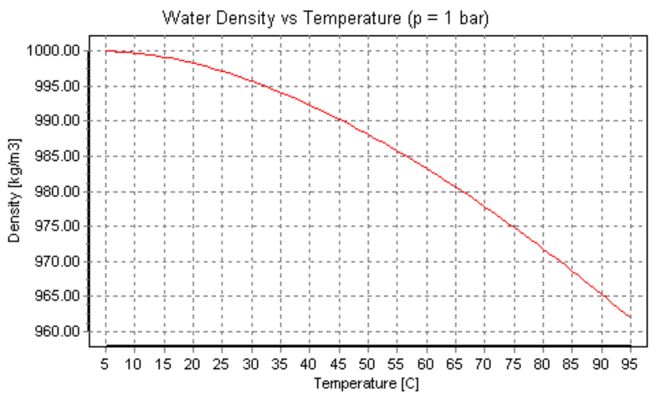


IPCC 2014

Two Contributions to Sea Level Rise

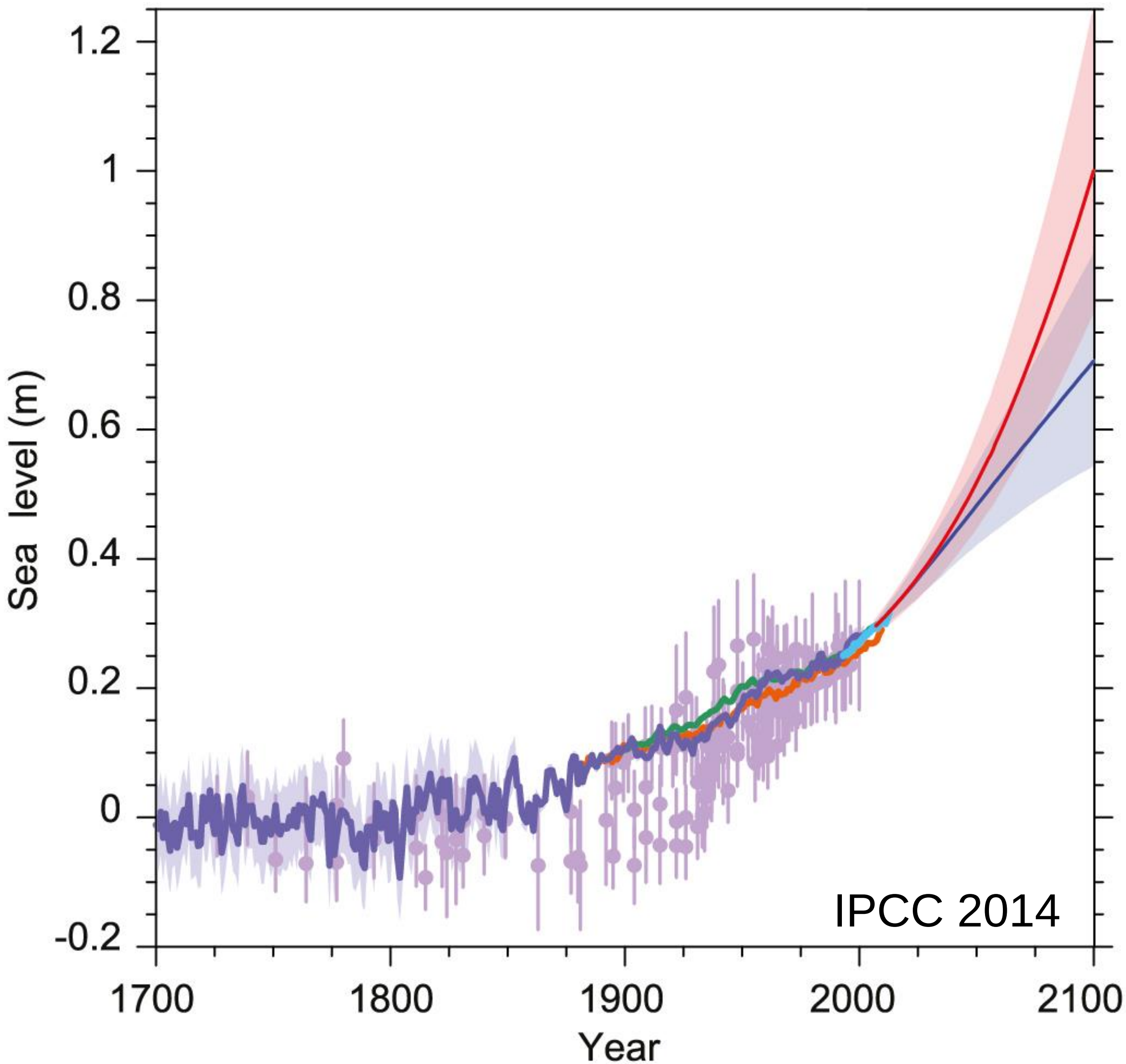
- **Liq. Water expands as it warms**



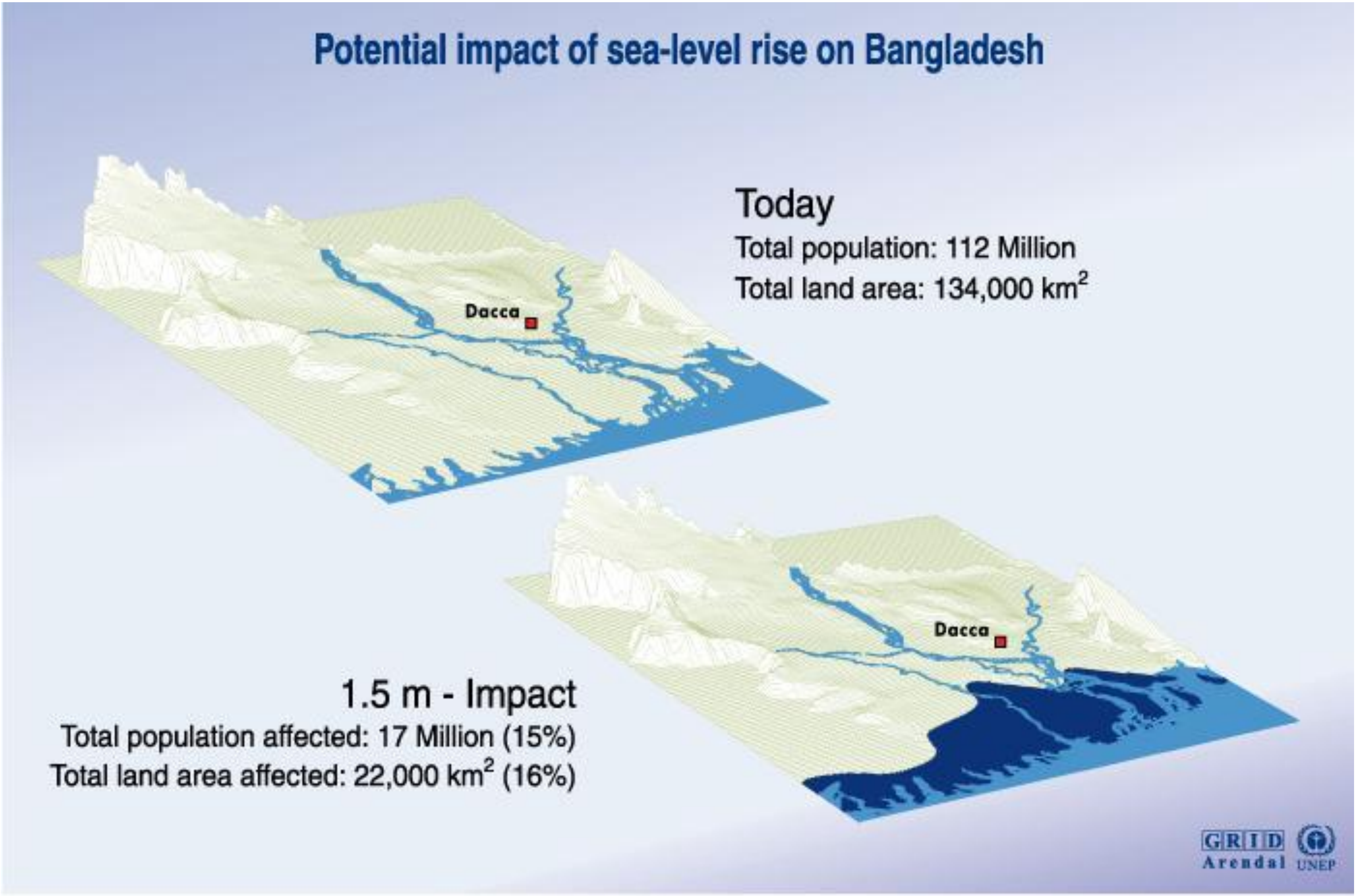


- **Land-based glacier / ice sheet melting**

Sea Level Projections

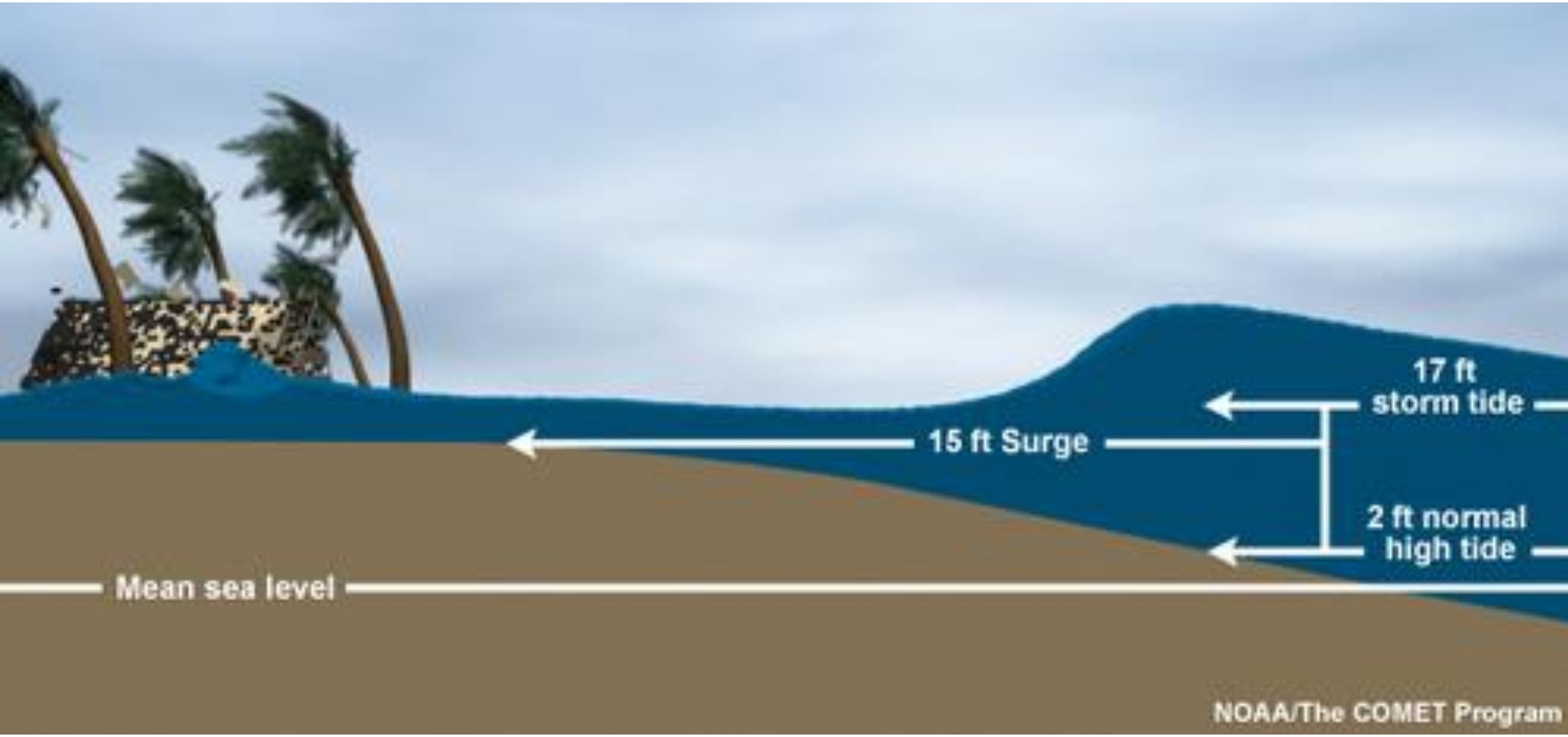


Bangladesh Under ~1.3 m Sea Level Rise



Source : UNEP/GRID Geneva; University of Dacca; JRO Munich; The World Bank; World Resources Institute, Washington D.C.

Sea level isn't static: storm surges



Hurricane Sandy Surge Damage

Storm Surge Vulnerability

- From 1990-2008, population density increased 32% in Gulf coastal counties, 17% in Atlantic coastal counties, and 16% in Hawaii (U.S. Census 2010)

- Much of densely populated US Atlantic and Gulf Coast coastlines lie < 3 m above mean sea level

- Over half US economic productivity is within coastal zones

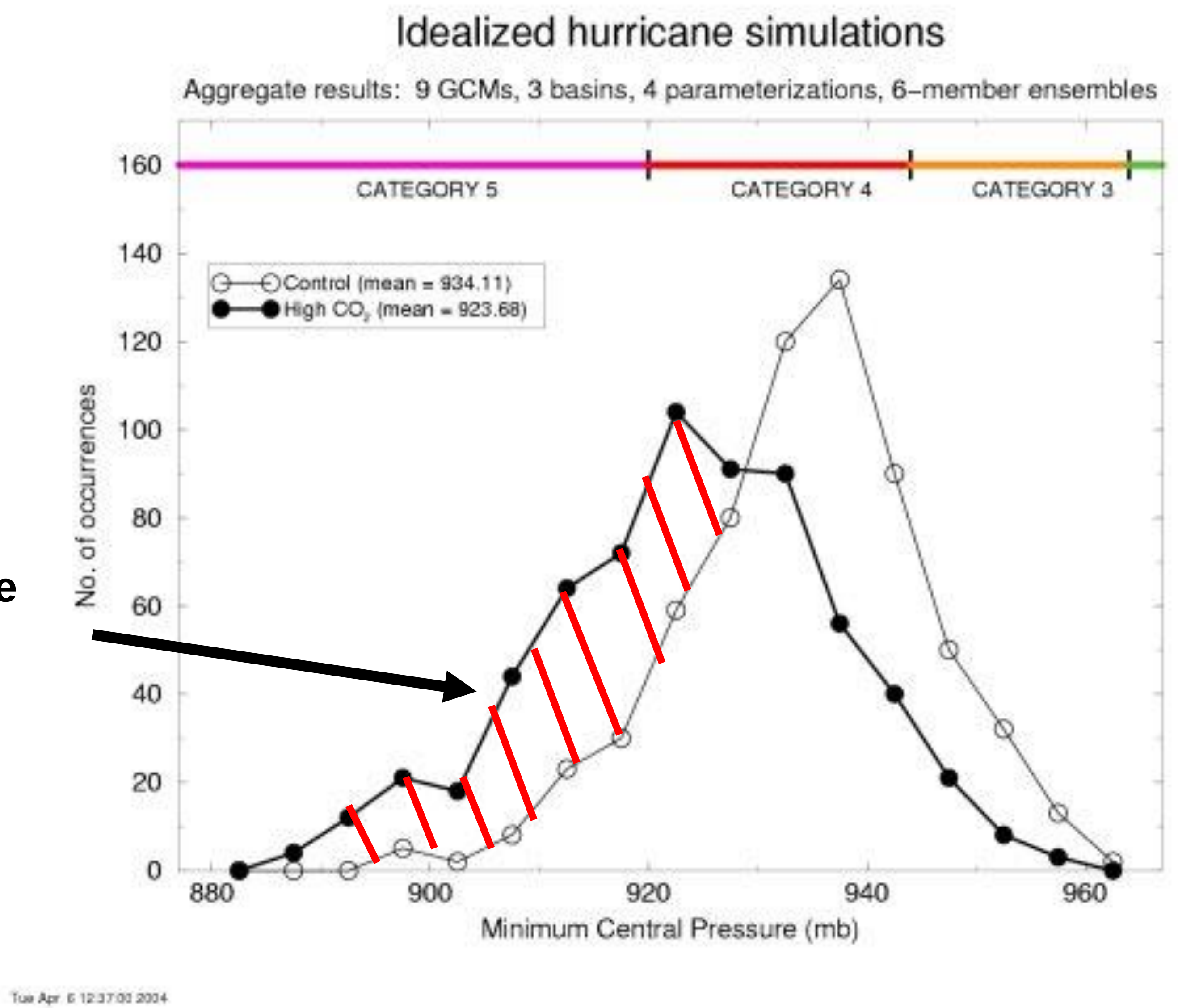
Storm Surge Vulnerability

- **72% of ports, 27% of major roads, and 9% of rail lines within the Gulf Coast region at or below 1.5 m elevation**

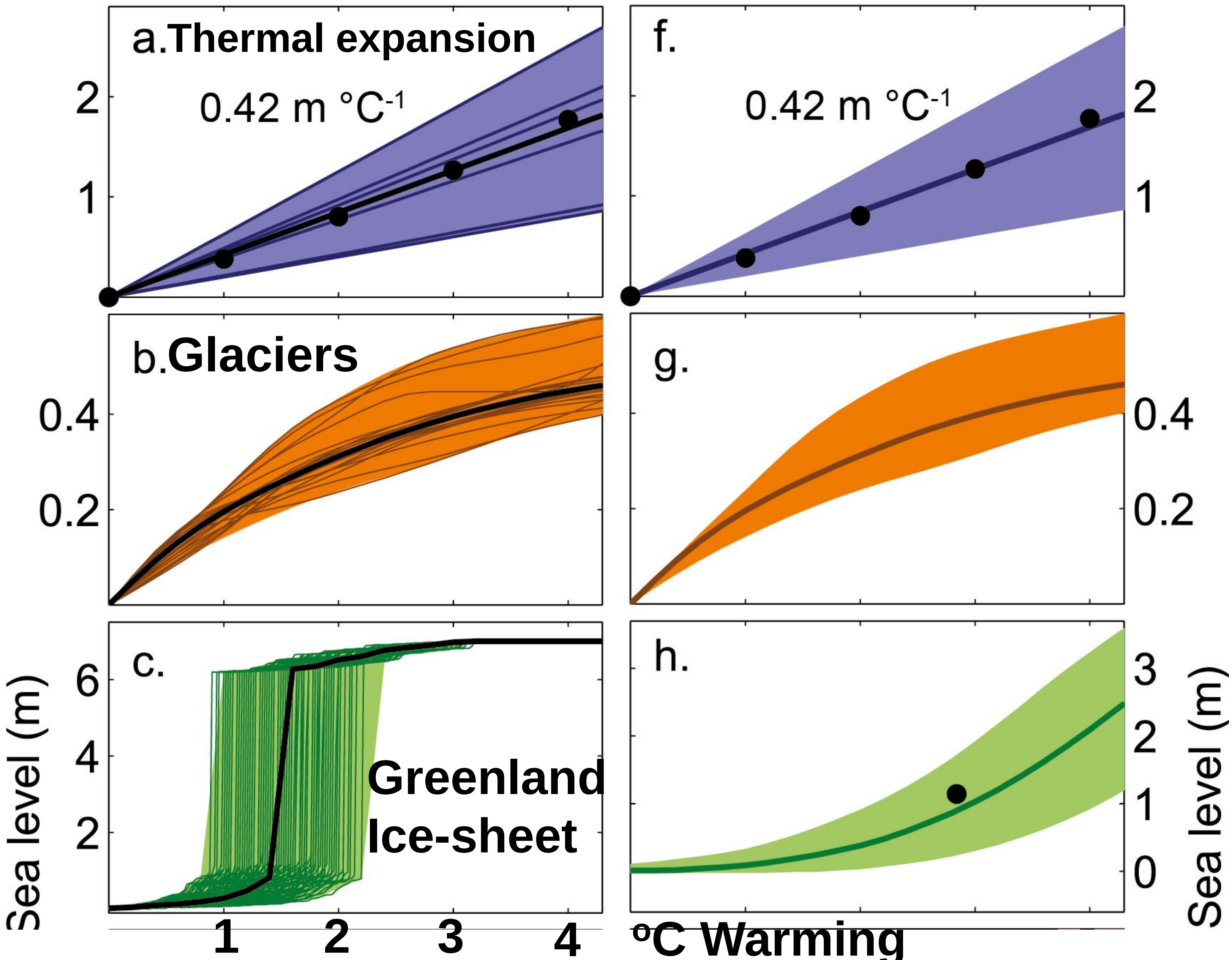
- **In the Gulf Coast (US) a storm surge of 8 m could inundate 67% of interstates, 57% of arterials, almost half of rail miles, 29 airports, and virtually all ports**

Hurricane Intensity Change – Storm Surges…

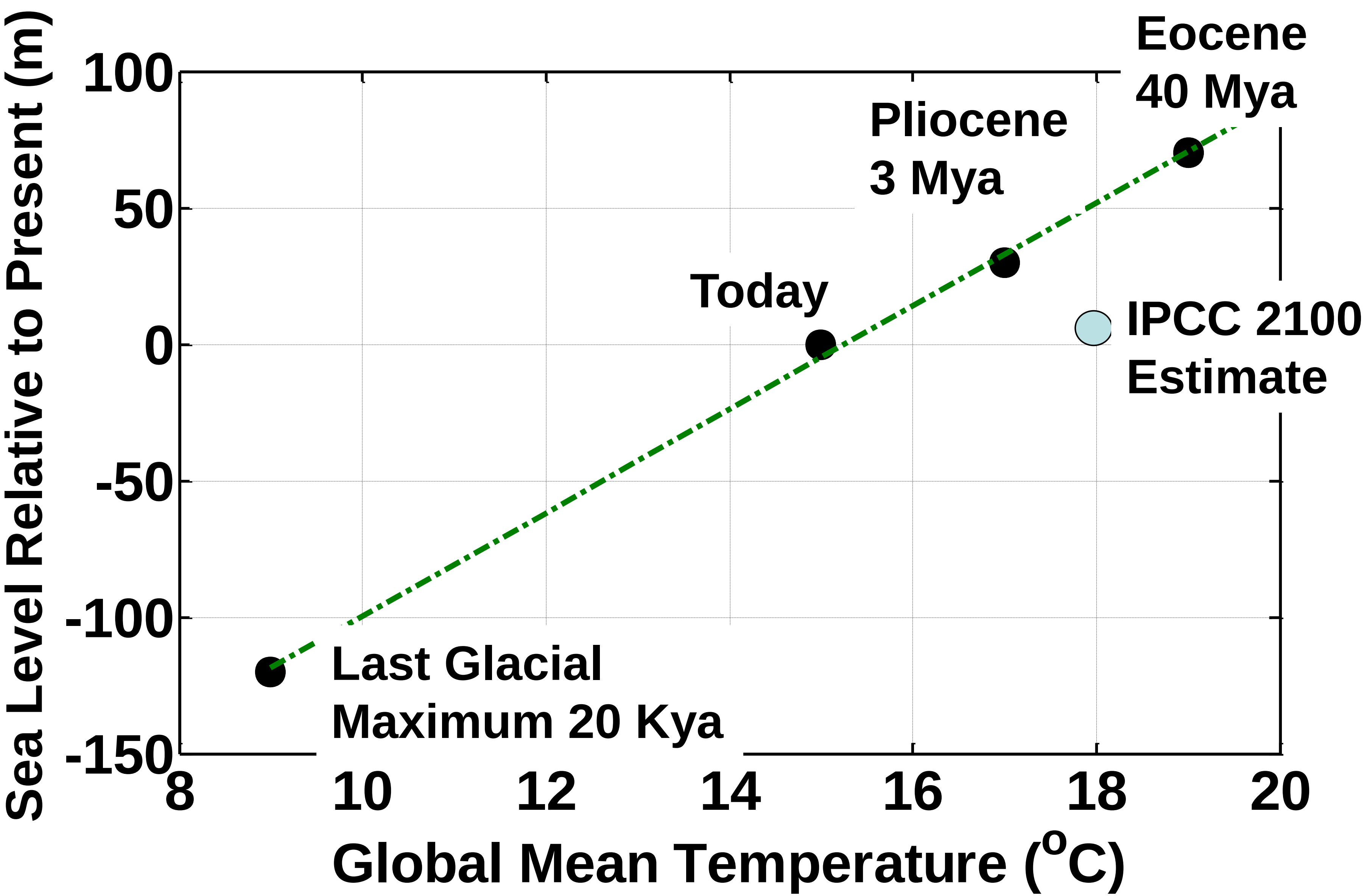
Models predict more intense hurricanes occur more often in higher CO_2 world



Multi-Millenial compared to 2000 yr Sea Level Rise



Sea Level on Geologic Timescales

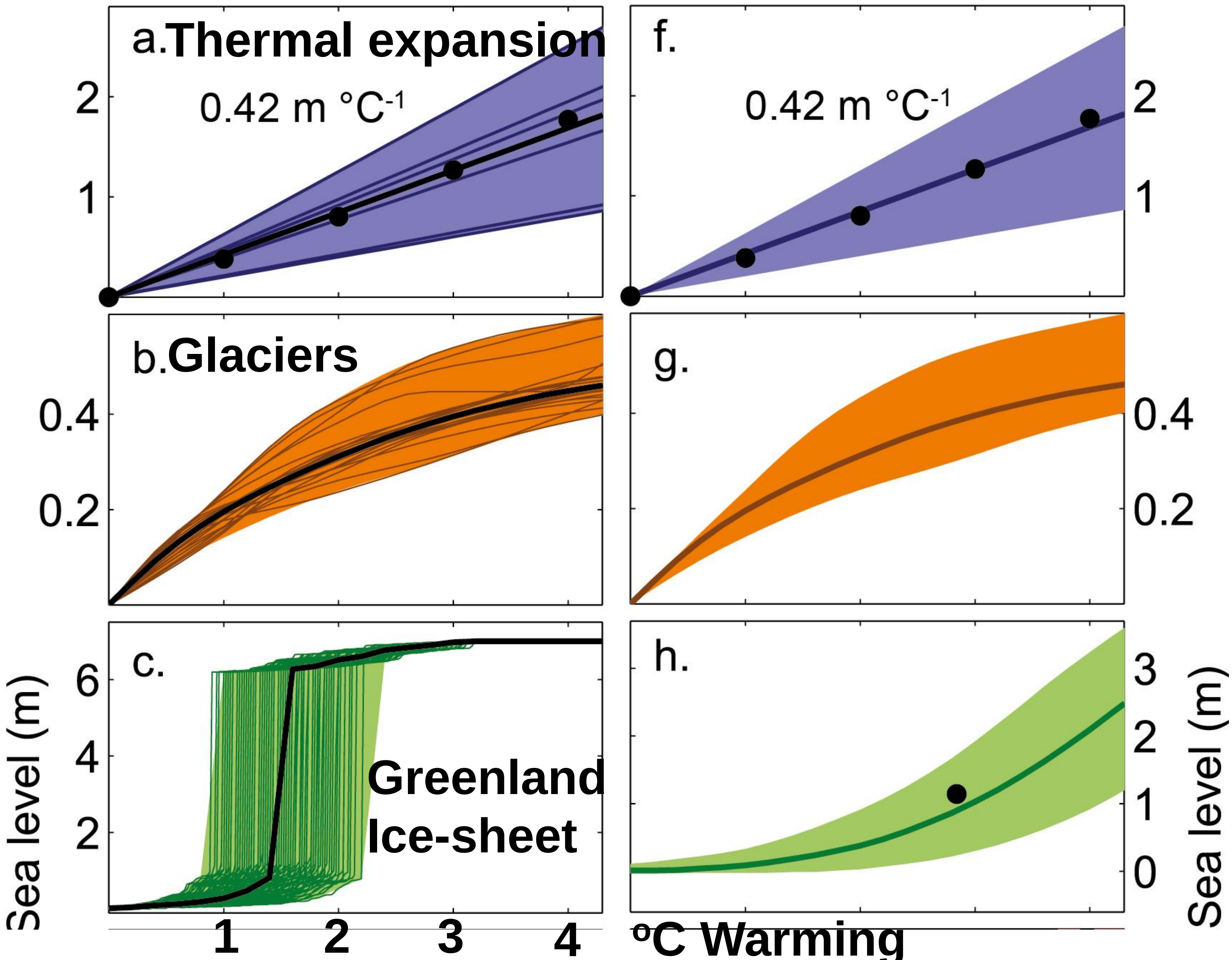


Adapted from Archer, Global Warming

Eastern U.S. 1 m of sea level rise

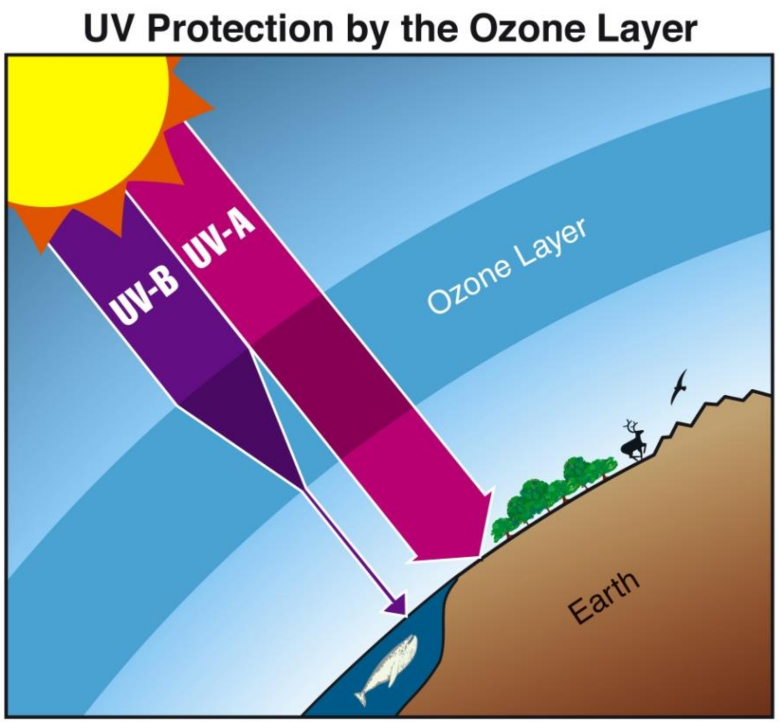
Eastern U.S. 30 m of sea level rise

Multi-Millenial compared to 2000 yr Sea Level Rise



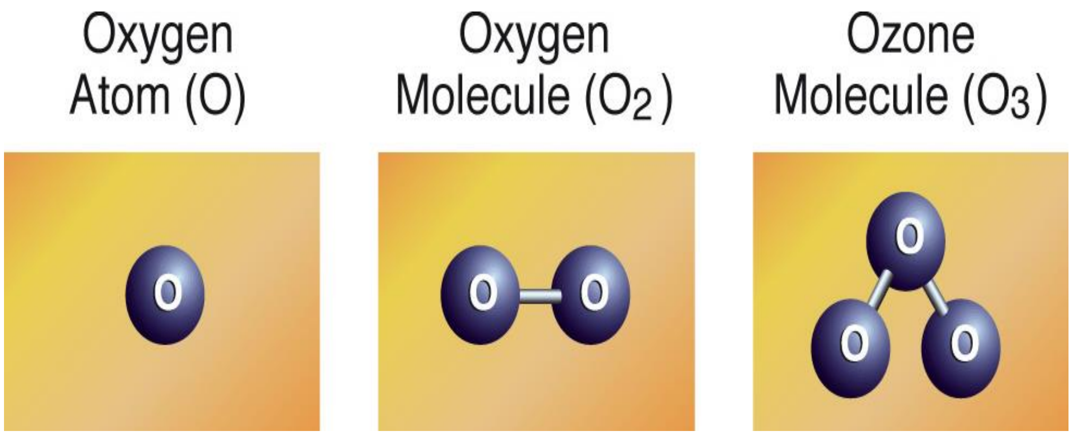
What can be done?

Stratospheric Ozone (O_3) Importance



→prevents exposure of terrestrial and surface water life to harmful UV radiation (causes DNA damage, skin cancer and loss of eyesite)

→ absorption of UV radiation important for atmospheric energy balance circulation, precipitation



Chlorofluorocarbons (CFCs)

Non-toxic, non-flammable, easily compressible gases

Used as refrigerants and as propellants in spray cans

Thought to be ideal…due to safety and durability.

“Aerosol” Spray Cans: NOT SAME AS ATMOSPHERIC AEROSOL PARTICLES

Early Warning Signs – But never predicted ozone hole!

Stratospheric sink for chlorofluoromethanes : chlorine atomc-atalysed destruction of ozone

Mario J. Molina & F. S. Rowland

Department of Chemistry, University of California, Irvine, California 92664

Chlorofluoromethanes are being added to the environment in steadily increasing amounts. These compounds are chemically inert and may remain in the atmosphere for 40–150 years, and concentrations can be expected to reach 10 to 30 times present levels. Photodissociation of the chlorofluoromethanes in the stratosphere produces significant amounts of chlorine atoms, and leads to the destruction of atmospheric ozone.

photolytic dissociation to $CFCl_2$ + Cl and to CF_2Cl + (
respectively,at altitudes of 20–40 km. Each of the reactions crea
two odd-electron species—one Cl atom and one free radic
The dissociated chlorofluoromethanes can be traced to th
ultimate sinks. An extensive catalytic chain reaction leadi
to the net destruction of O_3 and O occurs in the stratosphere

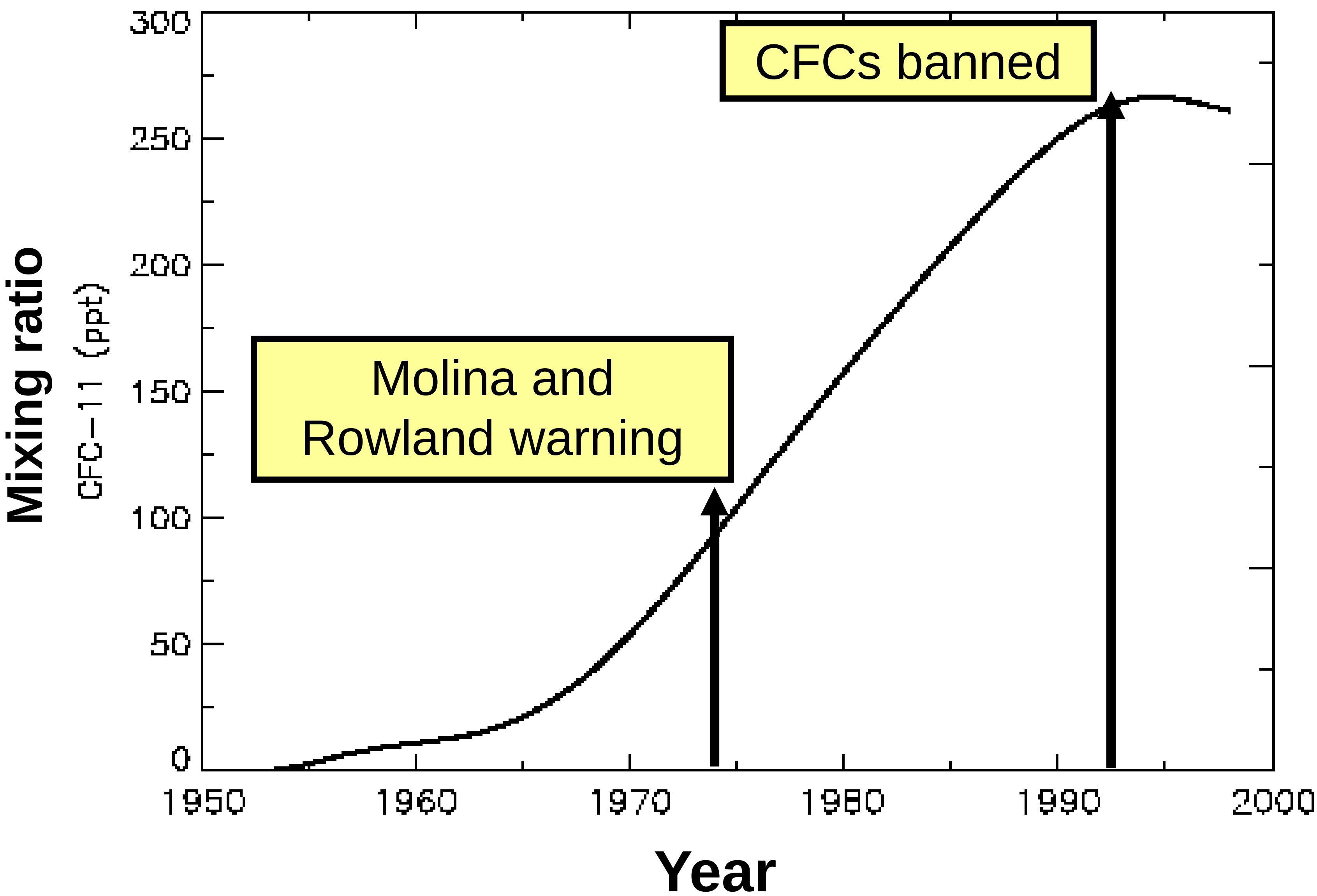
$$Cl + O_3 \rightarrow ClO + O_2$$
$$ClO + O \rightarrow Cl + O_2$$

This has important chemical consequences. Under m
conditions in the Earth's atmospheric ozone layer, (2) is t
slower of the reactions because there is a much lower conc

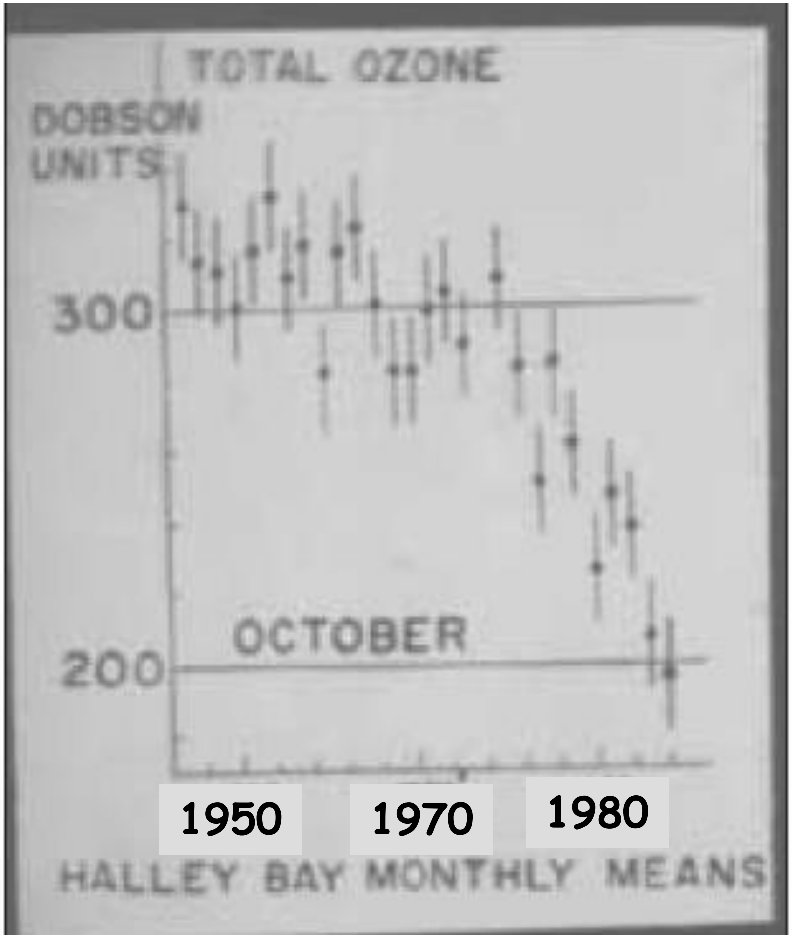
Nature, June 28, 1974

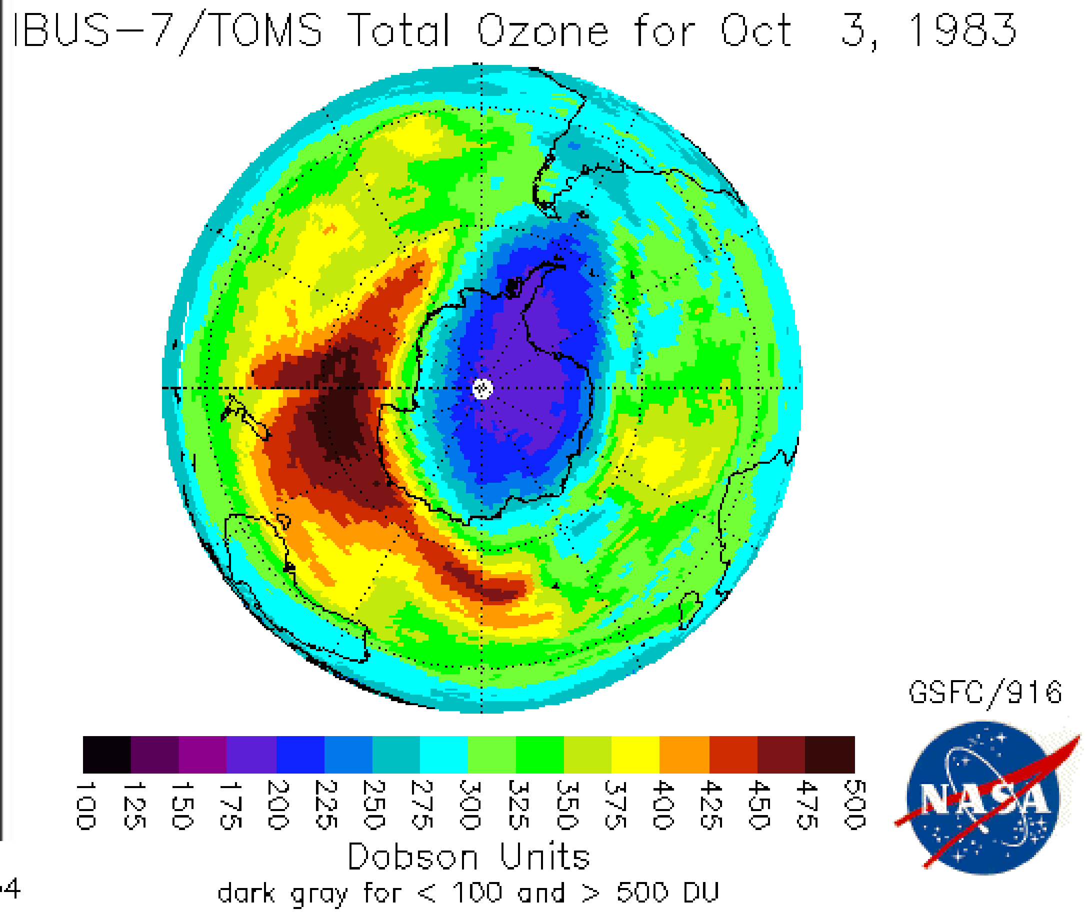
Molina, Rowland, and Crutzen win Nobel Prize in 1994

CFC-11 Atmospheric Abundance



Discovery of Antarctic Ozone Hole





GEN:119/2004

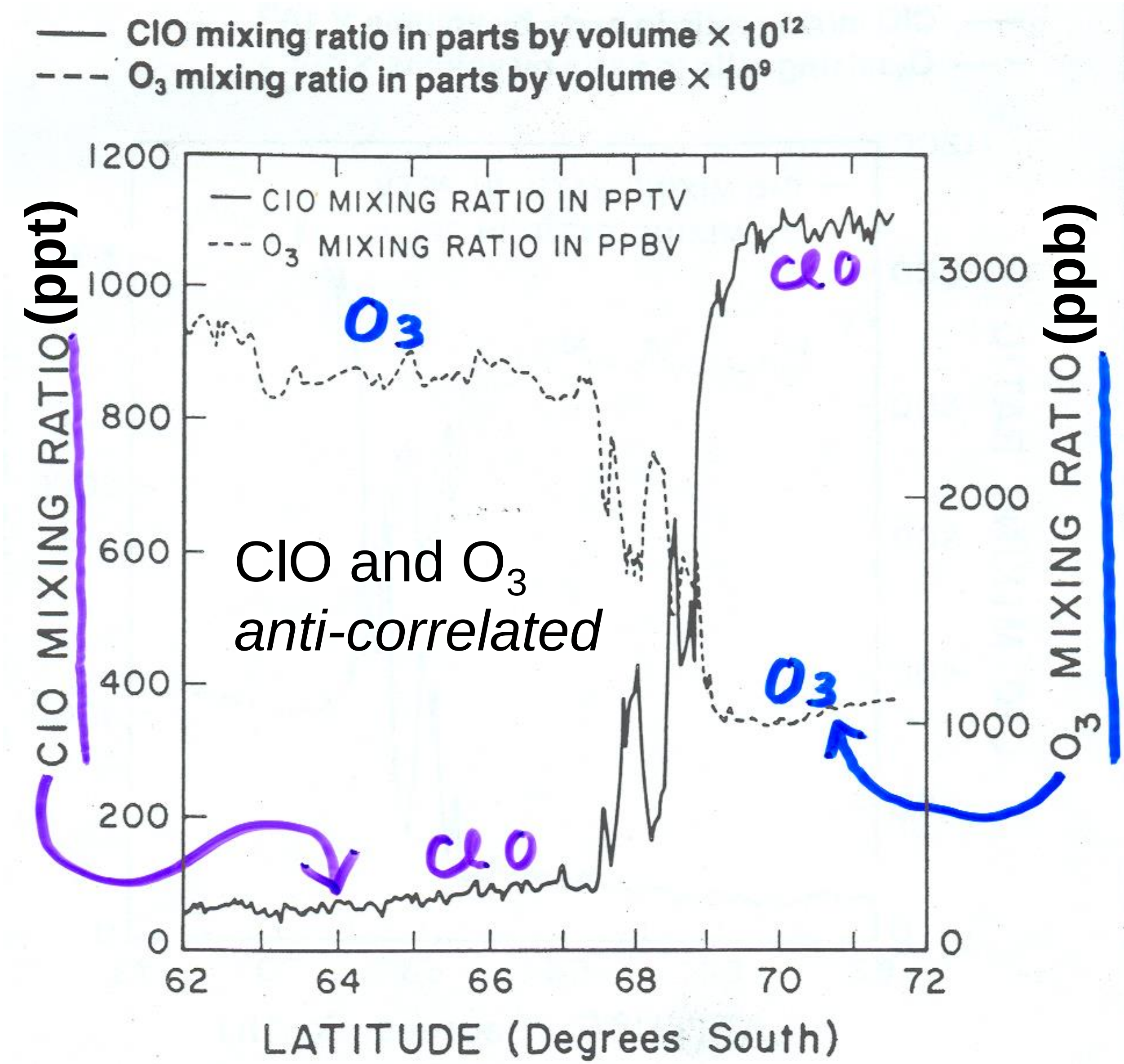
Reality was worse than the predictions!

Antarctic Ozone Hole Theories

Also a real scientific debate

- chemistry versus meteorology
- human versus natural
- solar cycles (again!)

“Human Finger Prints”: Chlorine

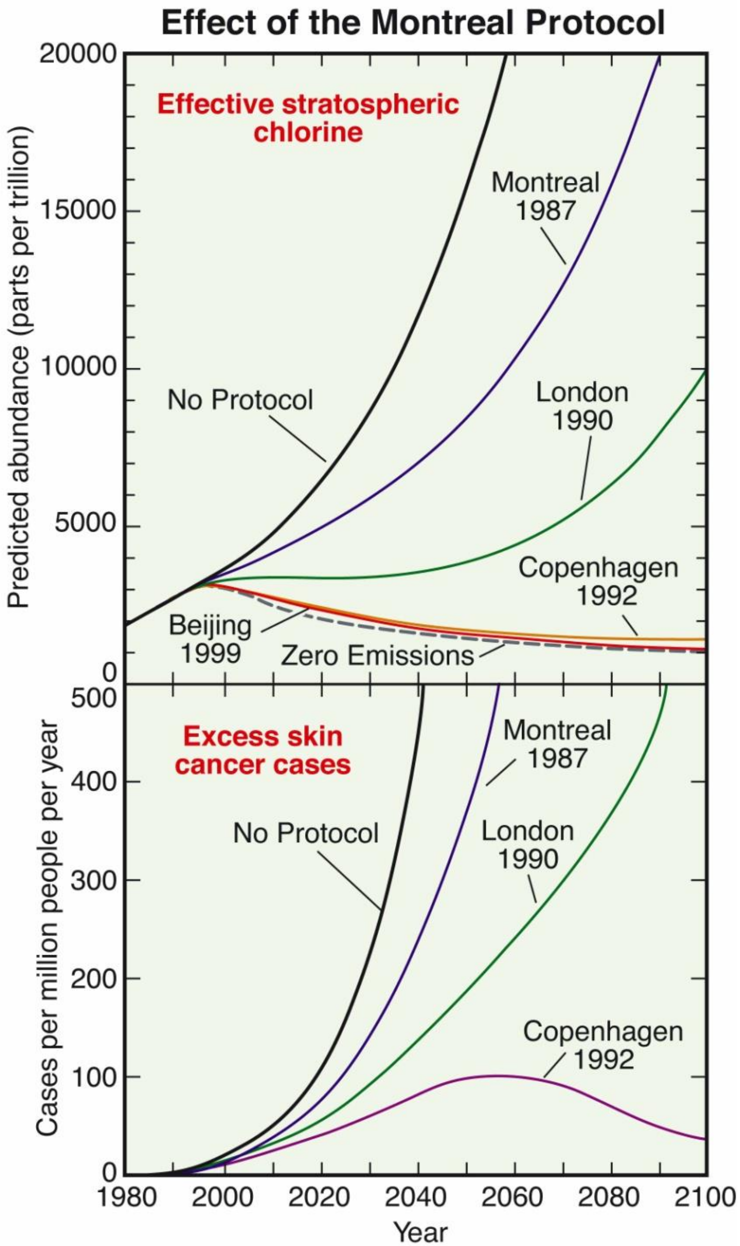


Montreal Protocol (Think “Paris Climate Accord”)

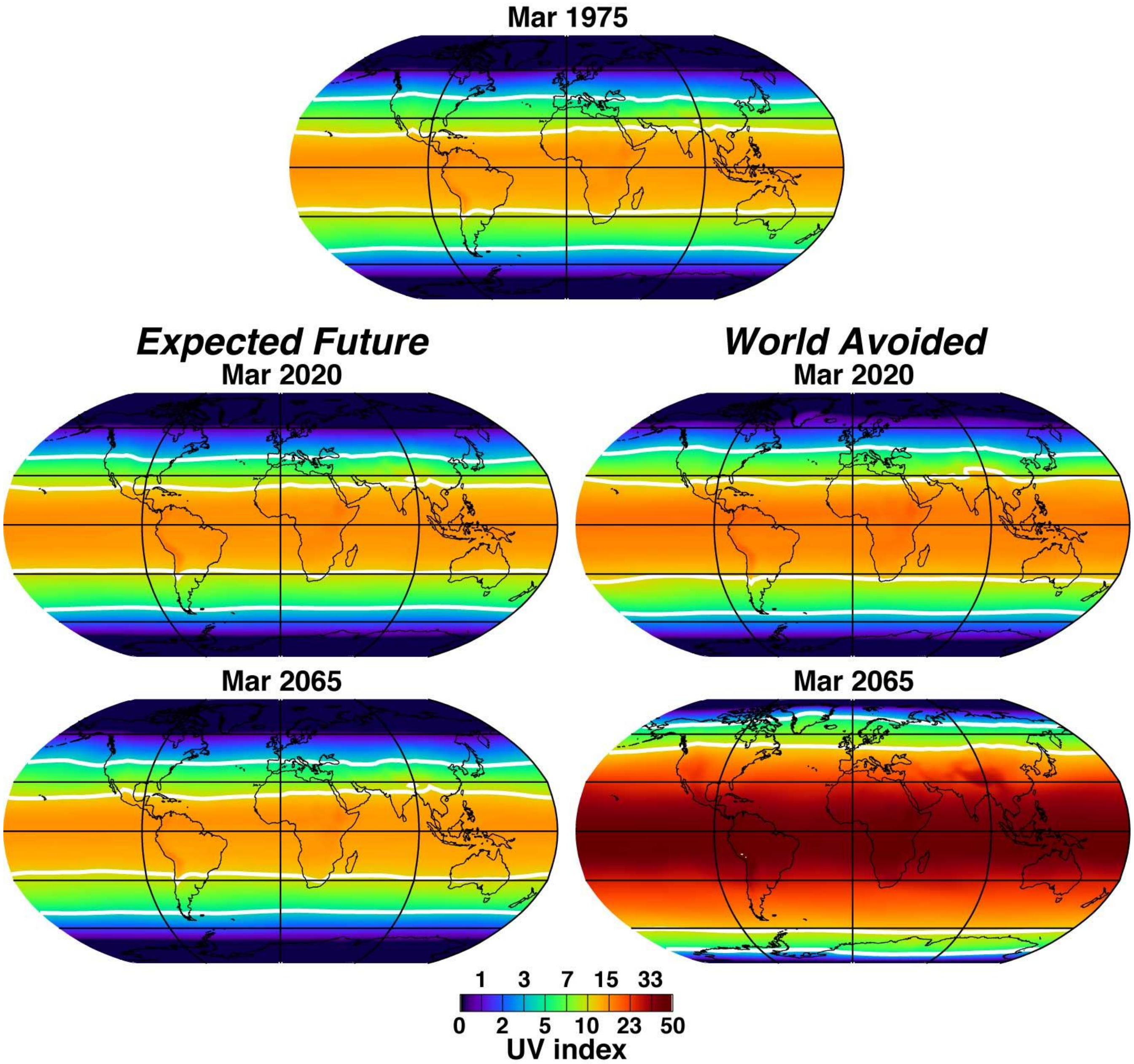
Montreal, 1987: First legally binding international agreement

By 1992: a near complete ban on production and use of CFCs.

Replacements for CFCs, known as HCFCs, fairly easily implemented

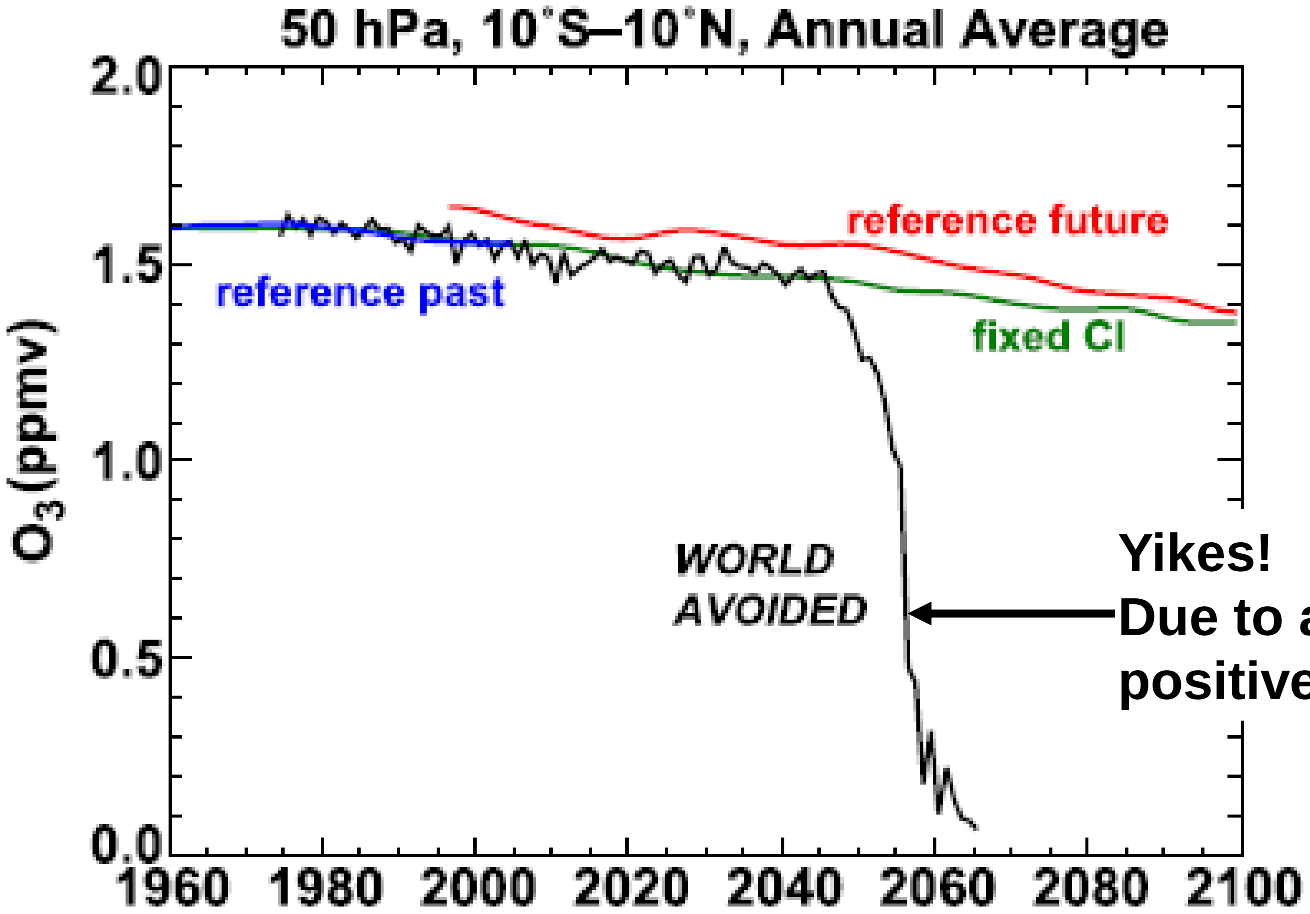


World Avoided: Health (Cancer and Cataracts)



Tipping Point Avoided

Tropical Ozone → **40% of world's population!**

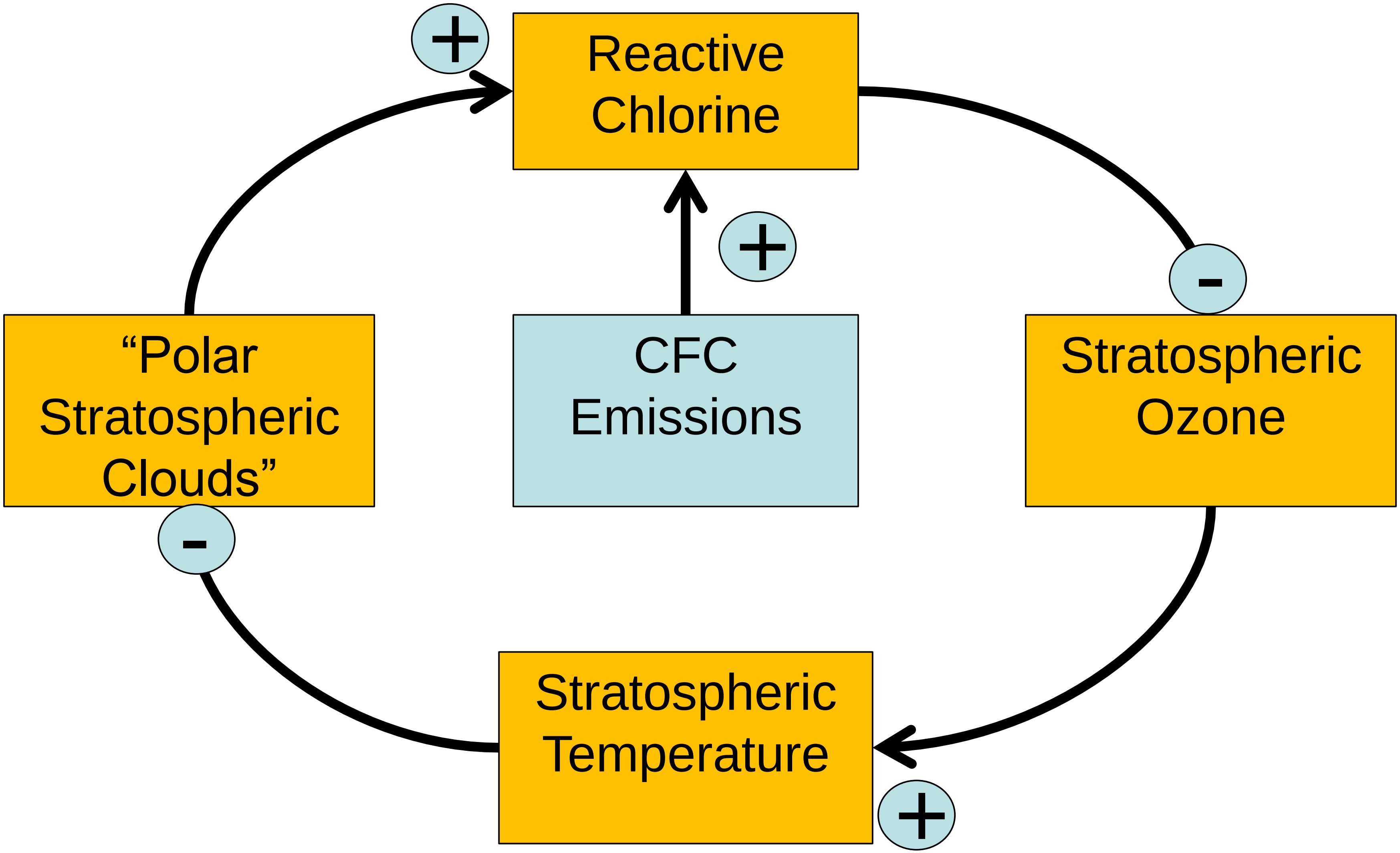


Yikes!
Due to a vicious positive feedback

Year

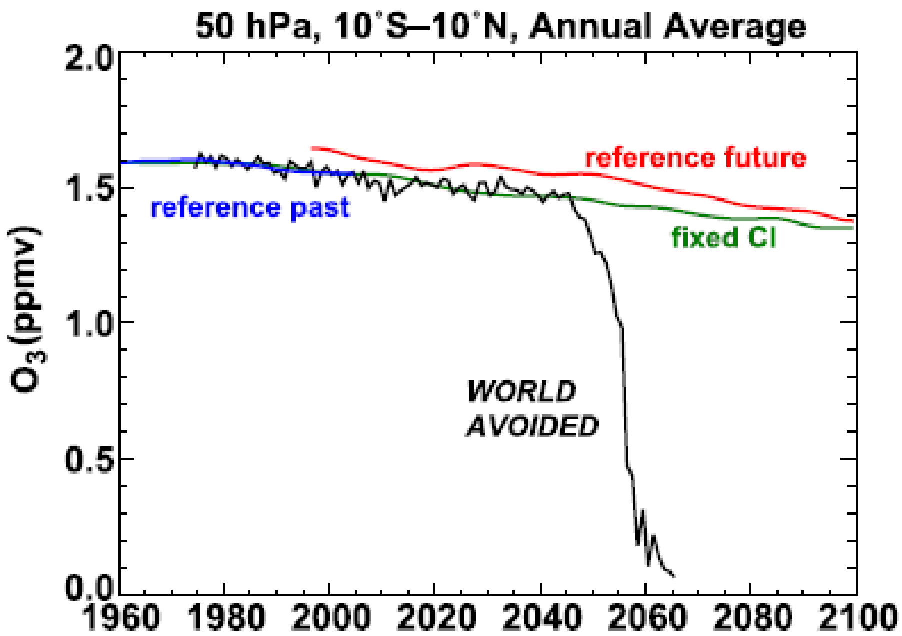
Neuman, et al *Atmos. Chem. Phys.* 2009

A Positive Feedback: CFC-Ozone Depletion-T



Ozone Depletion Problem vs Global Warming

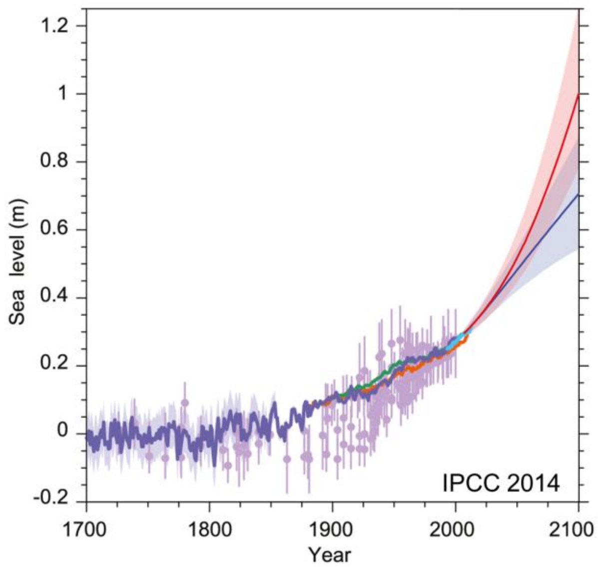
- **Ozone depletion is not a cause of global warming, but it was a global scale environmental problem with major consequences in the distant future**

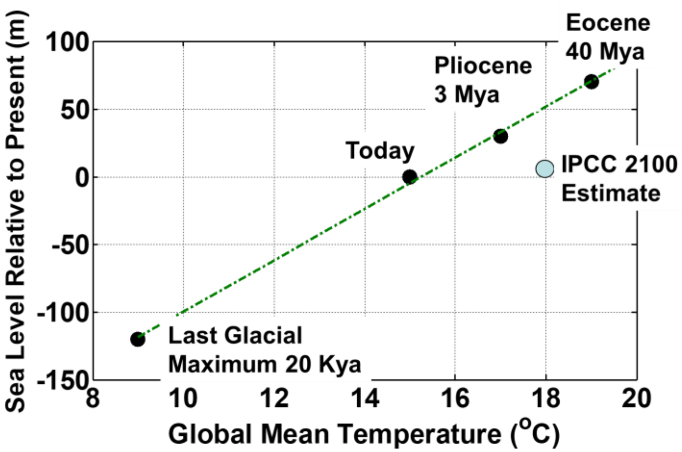


Ozone Depletion Problem vs Global Warming

- **Ozone depletion is not a cause of global warming, but it was a global scale environmental problem with consequences in the distant future**

- **Scope of the ozone depletion problem would have been far worse than expected at time solutions were put into action**
  - **Are global warming predictions *too conservative* (e.g. sea level rise debate)? Or are climate scientists "*crying wolf*?"**





Ozone Depletion Problem vs Global Warming

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- Scope of the ozone depletion problem would have been far worse than expected at time solutions were being sought and put into action
  - Are global warming predictions too conservative? Or are climate scientists “crying wolf?”

- Solution of the ozone depletion problem required (and still requires) international cooperation and changes to consumer/industry practices

Renewed CFC-11 Emissions?

LETTER

Nature 2019

https://doi.org/10.1038/s41586-019-1193-4

Increase in CFC-11 emissions from eastern China based on atmospheric observations

M. Rigby[1,15], S. Park[2,15]*, T. Saito[3,15], L. M. Western[1,15], A. L. Redington[4,15], X. Fang[5,15], S. Henne[6], A. J. Manning[4], R. G. Prinn[5], G. S. Dutton[7,8], P. J. Fraser[9], A. L. Ganesan[10], B. D. Hall[7], C. M. Harth[11], J. Kim[11], K.-R. Kim[2], P. B. Krummel[9], T. Lee[2], S. Li[12], Q. Liang[13], M. F. Lunt[14], S. A. Montzka[7], J. Mühle[11], S. O'Doherty[1], M.-K. Park[12], S. Reimann[6], P. K. Salameh[11], P. Simmonds[1], R. L. Tunnicliffe[1], R. F. Weiss[11], Y. Yokouchi[3] & D. Young[1]

The recovery of the stratospheric ozone layer relies on the continued decline in the atmospheric concentrations of ozone-depleting gases such as chlorofluorocarbons[1]. The atmospheric concentration of trichlorofluoromethane (CFC-11), the second-most abundant chlorofluorocarbon, has declined substantially since the mid-1990s[2]. A recently reported slowdown in the decline of the atmospheric concentration of CFC-11 after 2012, however, suggests that global emissions have increased[3,4]. A concurrent increase in CFC-11 emissions from eastern Asia contributes to the global emission increase, but the location and magnitude of this regional source are unknown[3]. Here, using high-frequency atmospheric observations from Gosan, South Korea, and Hateruma, Japan, together with global monitoring data and atmospheric chemical transport model simulations, we investigate regional CFC-11 emissions from eastern Asia. We show that emissions from eastern mainland China are 7.0 ± 3.0 (±1 standard deviation) gigagrams per year higher in 2014–2017 than in 2008–2012, and that the increase in emissions arises primarily around the northeastern provinces of Shandong and Hebei. This increase accounts for a substantial fraction (at least 40 to 60 per cent) of the global rise in CFC-11 emissions. We find no evidence for a significant increase in CFC-11 emissions from any other eastern Asian countries or other regions of the world where there are available data for the detection of regional emissions. The attribution of any remaining fraction of the global CFC-11 emission rise to other regions is limited by the sparsity of long-term measurements of sufficient frequency near potentially emissive regions. Several considerations suggest that the increase in CFC-11 emissions from eastern mainland China is likely to be the result of new production and use, which is inconsistent with the Montreal Protocol agreement to phase out global chlorofluorocarbon production by 2010.

have contributed to the slow-down, an increase in northern hemispheric emissions is required, starting after 2012, to explain most of these observed changes[3].

High-frequency atmospheric CFC-11 mole fraction data from the AGAGE network[4] and Japanese National Institute for Environmental Studies (NIES)[5] show signals that are consistent with a continuing decline in CFC-11 emissions from Europe, North America and Australia in recent years, but a rise from eastern Asia since 2012 (Fig. 1; Extended Data Fig. 1). In these datasets, enhancements above the hemispheric background mole fractions are observed when plumes from nearby sources impinge on the measurement stations. For the AGAGE stations in Europe, the west coast of North America, Australia and more remote locations, the magnitudes of above-baseline events are relatively small and have declined throughout the study period (2008–2017, inclusive), indicating that emissions near these sites have dropped. A decline in emissions from the continental United States has also been inferred over the 2008 to 2014 period with independent NOAA data[6]. By contrast, observations at Hateruma, Japan (see Extended Data Fig. 2 for location), show persistent above-baseline events throughout 2008–2017, which have not declined substantially or may have increased, and data from Gosan, South Korea, show a strong increase in the magnitude of these events after 2012 (Fig. 1). We focus our analysis on eastern Asia because the existing measurement networks only show an increase in the magnitude of above-baseline events in this region. A qualitative emissions increase from somewhere in this region was also indicated in NOAA data from Hawaii[3].

To quantify emissions from eastern Asian countries, atmospheric observation-based 'inverse' or 'top-down' estimates were carried out with CFC-11 measurements from Gosan and Hateruma observations using two atmospheric chemical transport models and four statistical methods (see Methods). Previous top-down studies in this region

Ozone Depletion Problem vs Global Warming

- **Ozone depletion is not a cause of global warming, but it was a global scale environmental problem with consequences in the distant future**

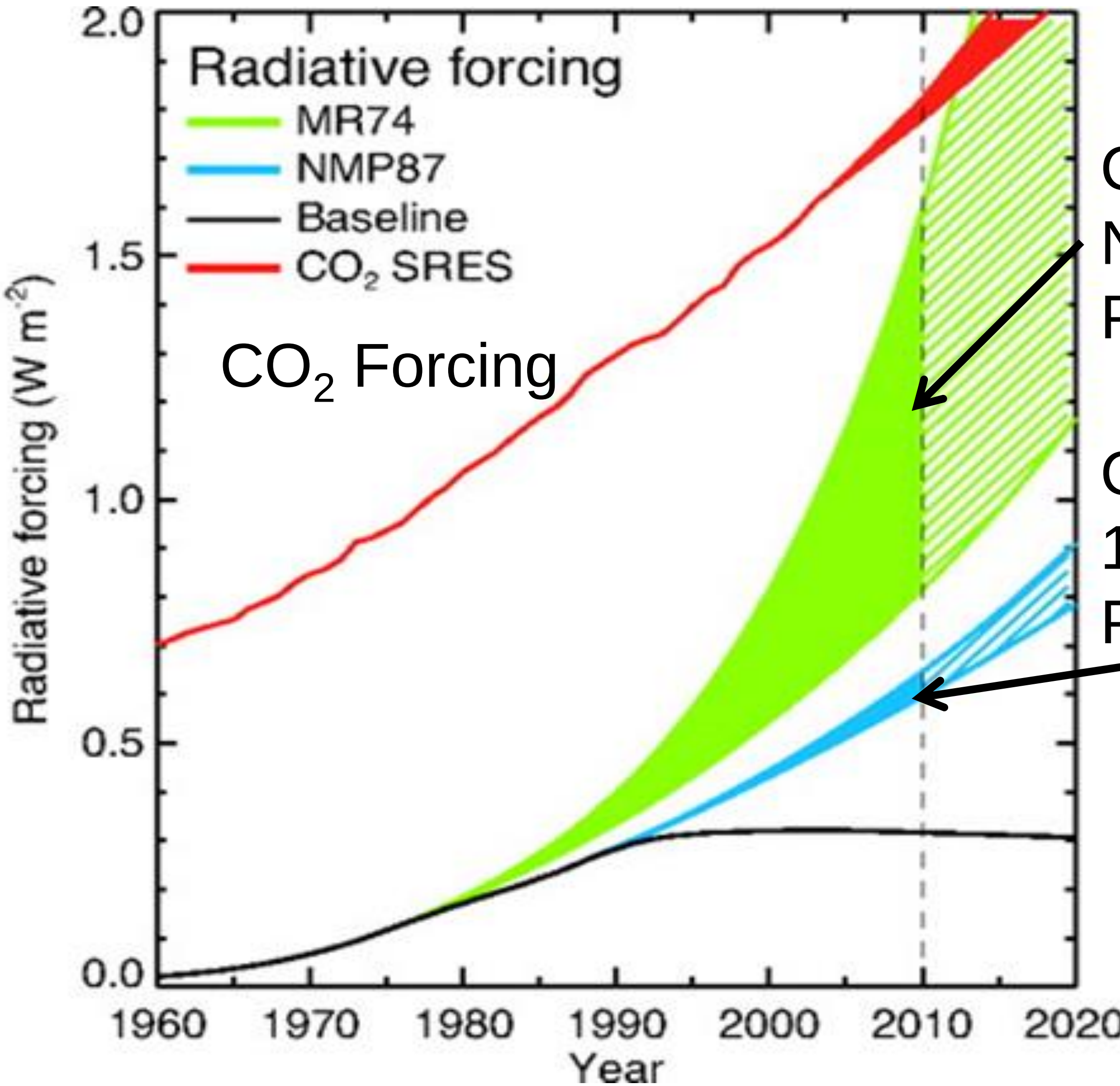
- **Scope of the ozone depletion problem would have been far worse than expected at time solutions were being sought and put into action**
  - **Are global warming predictions too conservative? Or are climate scientists “crying wolf?”**

- **Solution of the ozone depletion problem required (and still requires) international cooperation and changes to consumer/industry practices**

- **Solving the ozone depletion problem was the largest and most successful global warming mitigation policy to date – by banning CFCs which are potent GHGs**

An Ozone Depletion – Global Warming Connection

CFCs are potent Greenhouse Gases!

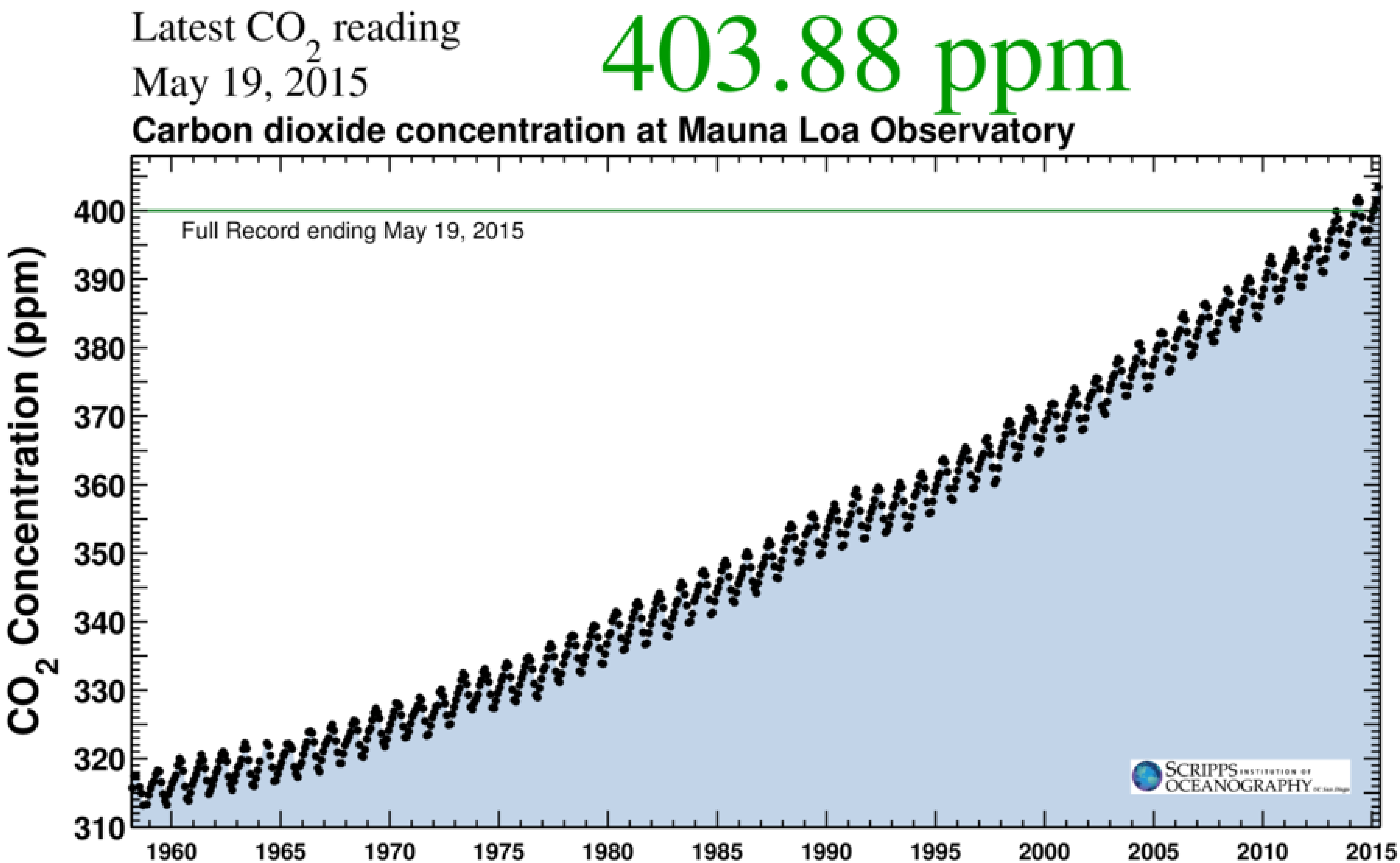


CO_2 Forcing

CFC Forcing No Montreal Protocol

CFC Forcing 1st Montreal Protocol

Anthropogenic GHG Forcing



A Global Problem Requires a Global Solution

UNFCCC COP21 Paris Climate Agreement

Article 2

1. This Agreement, in enhancing the implementation of the Convention, including its objective, aims to strengthen the global response to the threat of climate change, in the context of sustainable development and efforts to eradicate poverty, including by:

(a) Holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels, recognizing that this would significantly reduce the risks and impacts of climate change;

(b) Increasing the ability to adapt to the adverse impacts of climate change and foster climate resilience and low greenhouse gas emissions development, in a manner that does not threaten food production; and

(c) Making finance flows consistent with a pathway towards low greenhouse gas emissions and climate-resilient development.

2. This Agreement will be implemented to reflect equity and the principle of common but differentiated responsibilities and respective capabilities, in the light of different national circumstances.

Stabilizing CO2 emissions at present day rates will allow us to prevent further warming

When poll is active, respond at **PollEv.com/thornton211** Text **THORNTON211** to **22333** once t

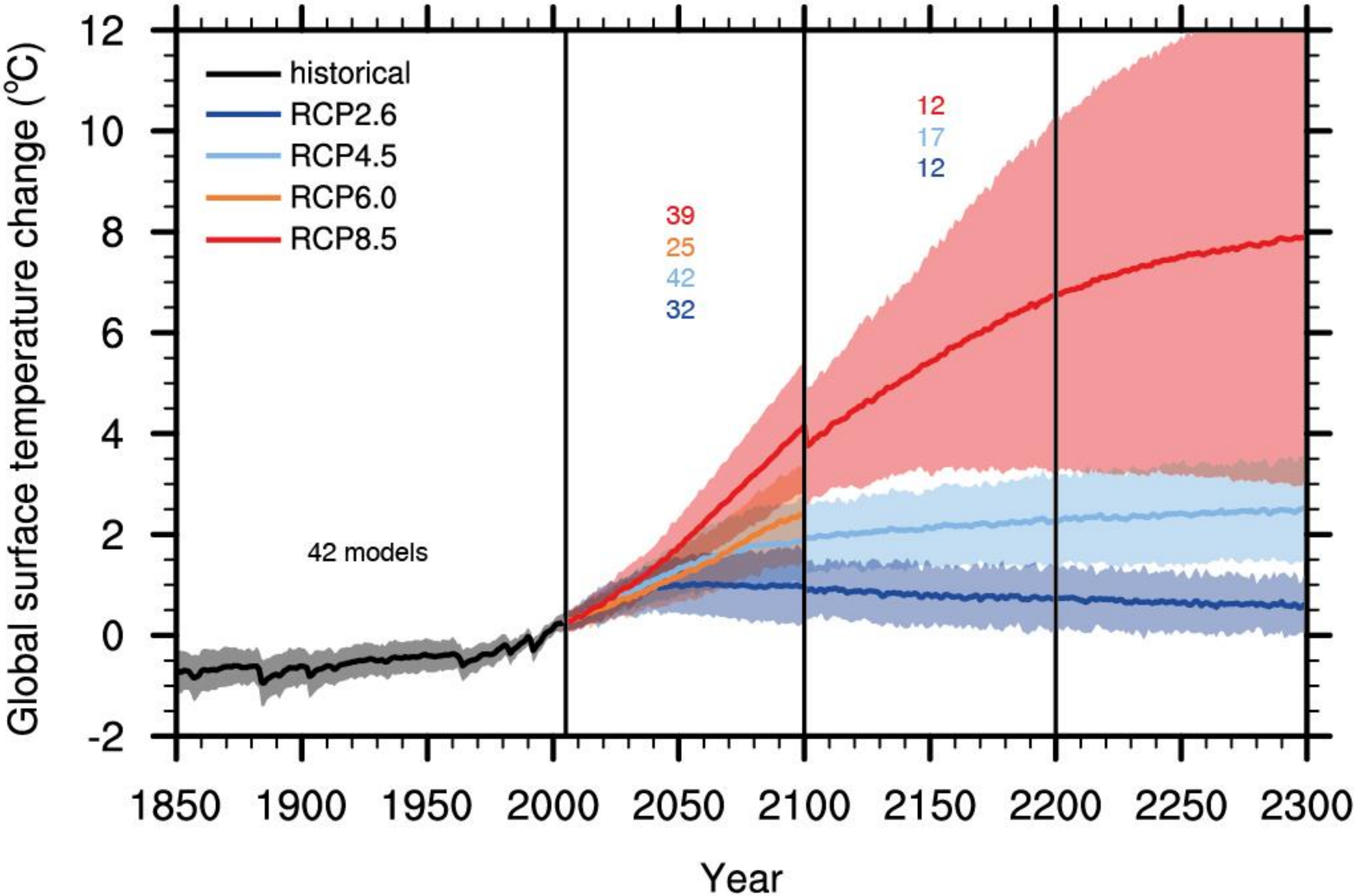
True

False

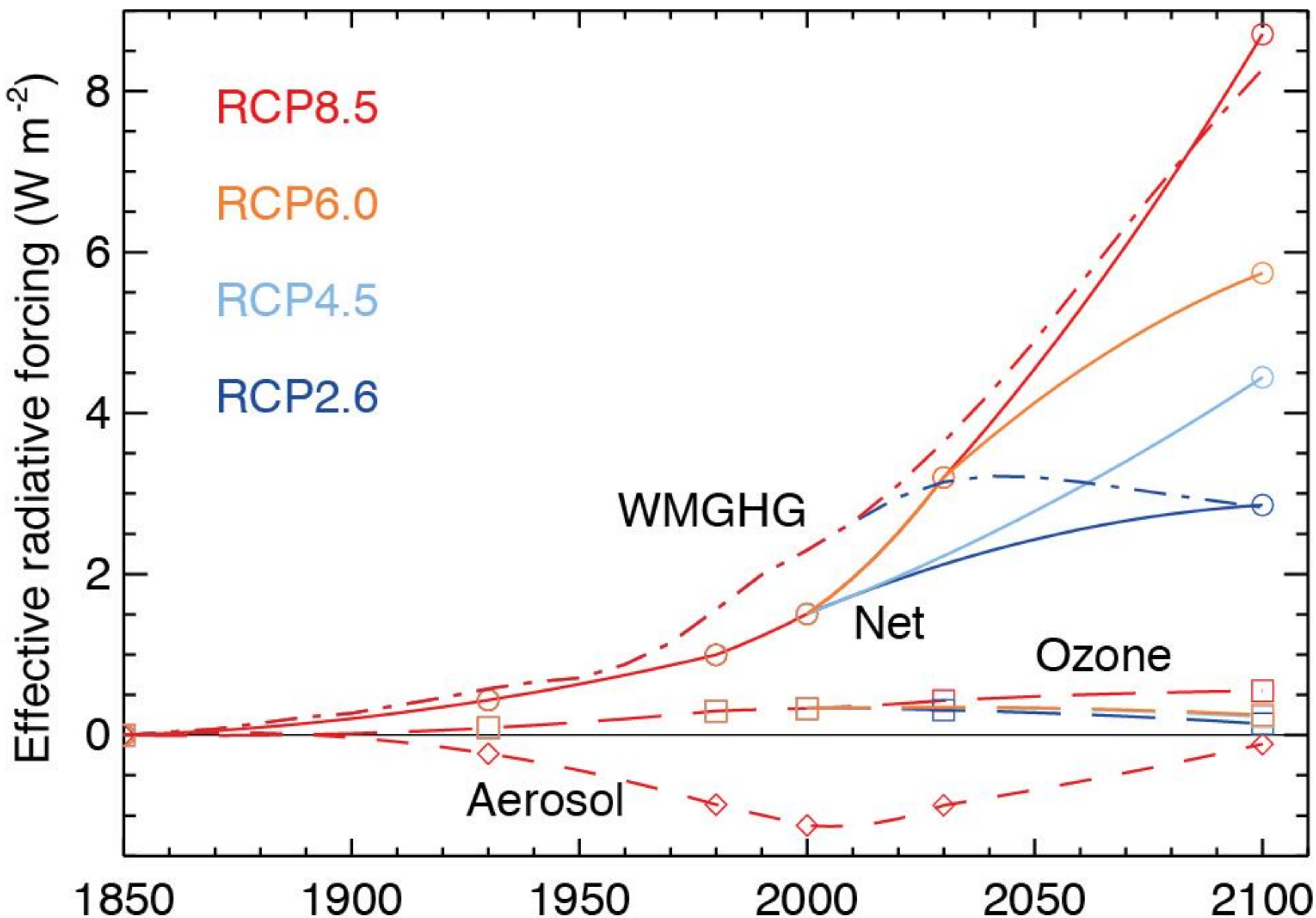
Visual settings
Activate
Show results
Show correct
Lock
Clear results
Fullscreen
Next
Previous

Total Results: 0

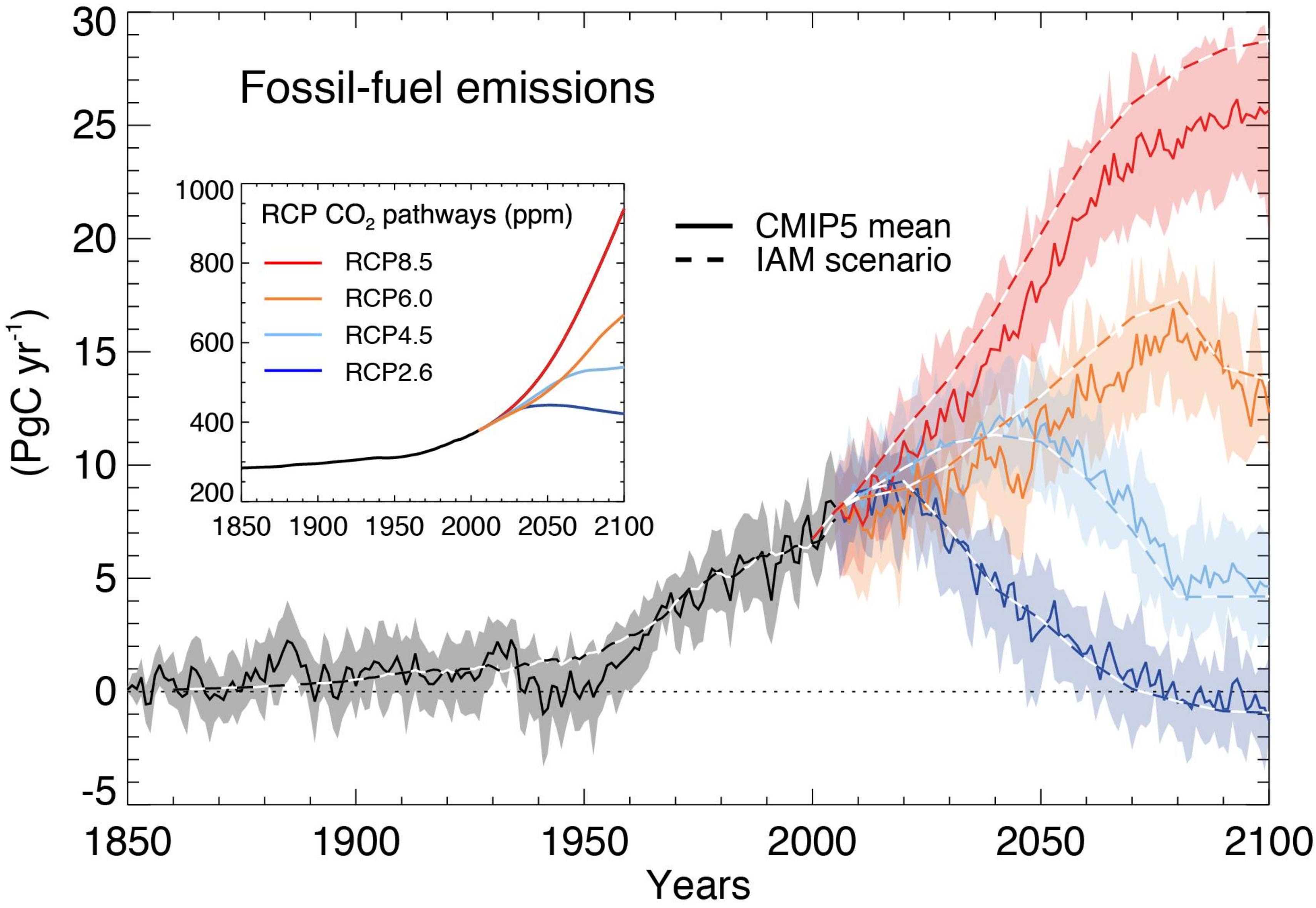
Impact #1: Surface T Increases



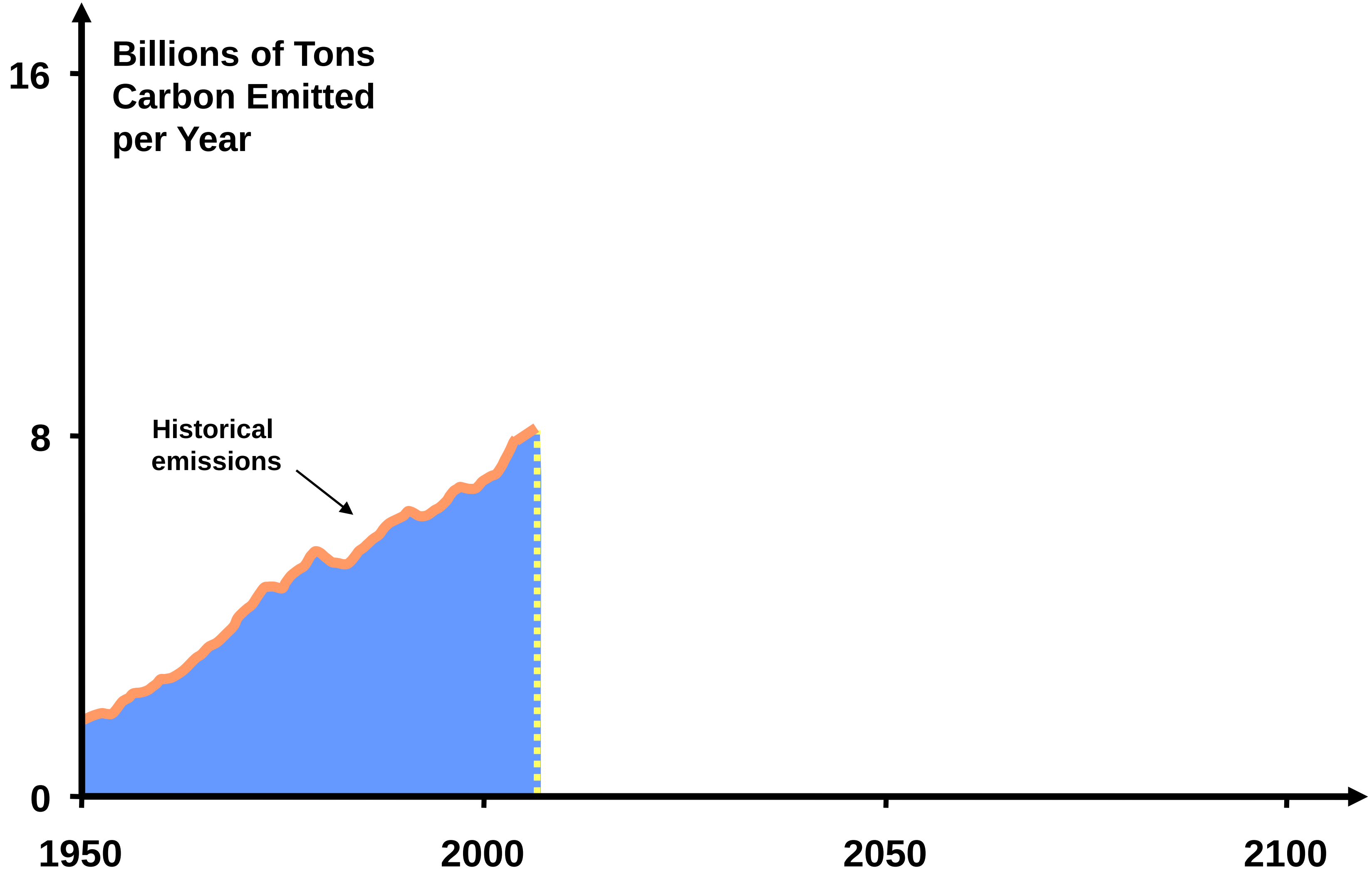
Future: Representative Concentration Pathways



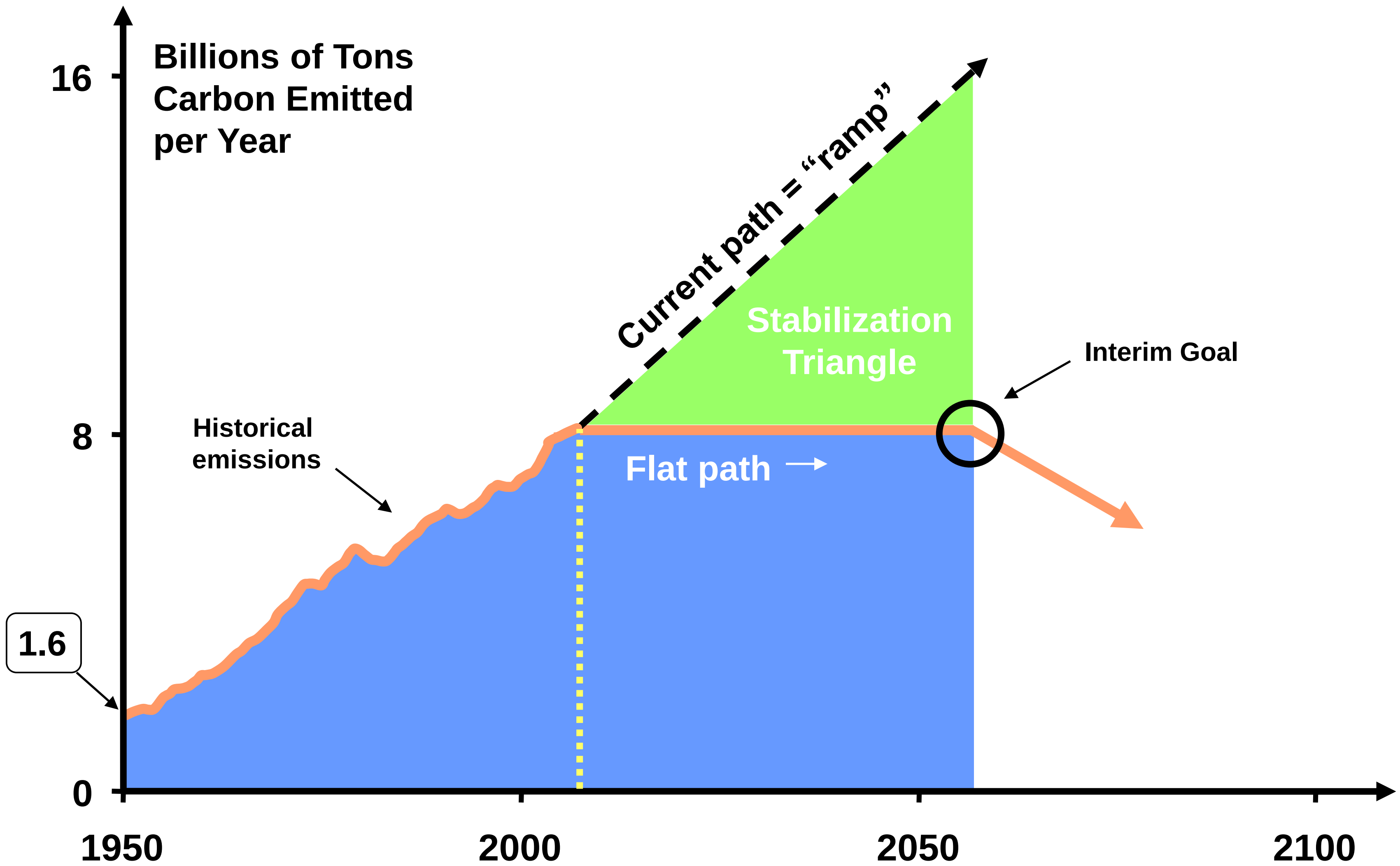
Projections of Future Emissions



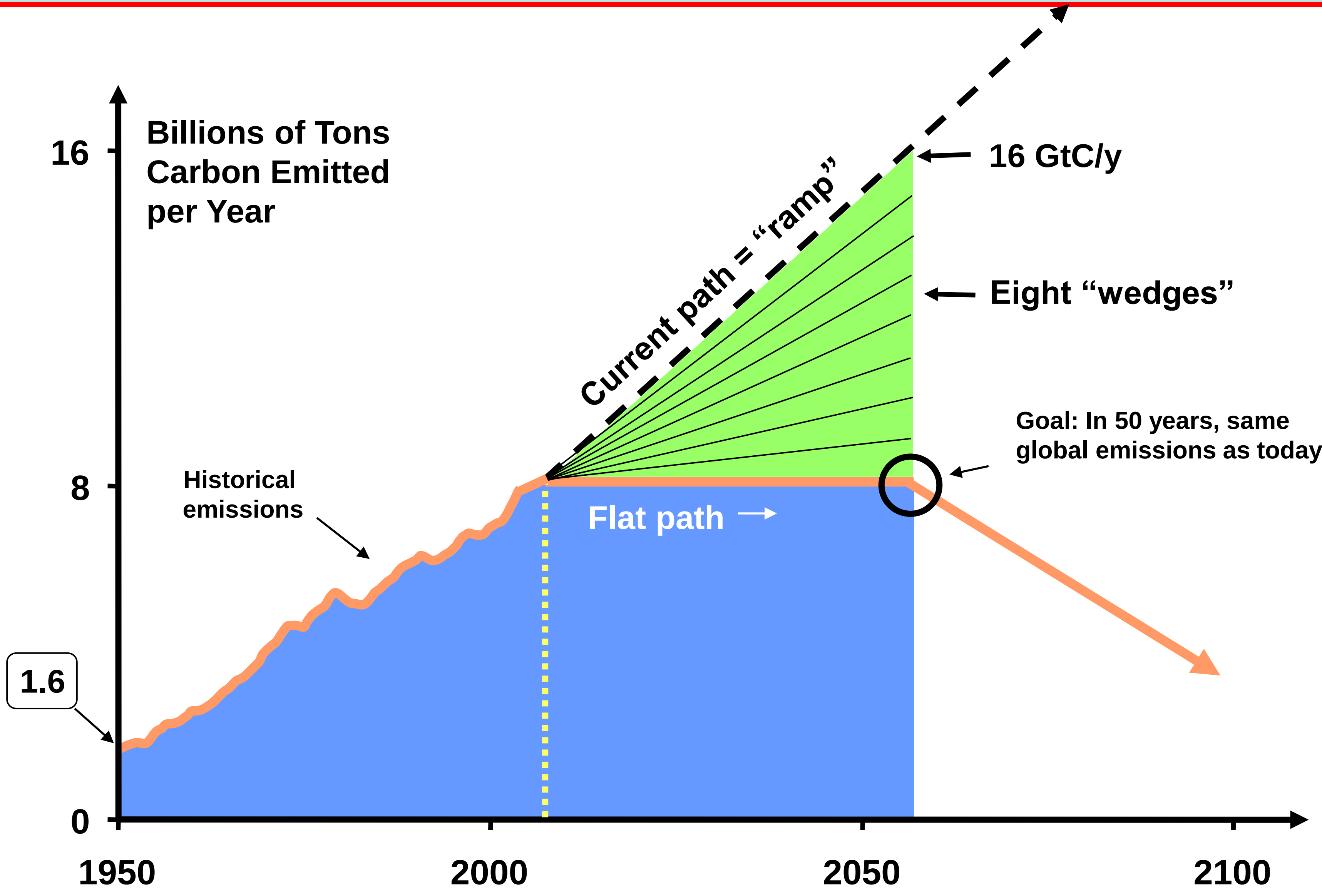
Historical Emissions



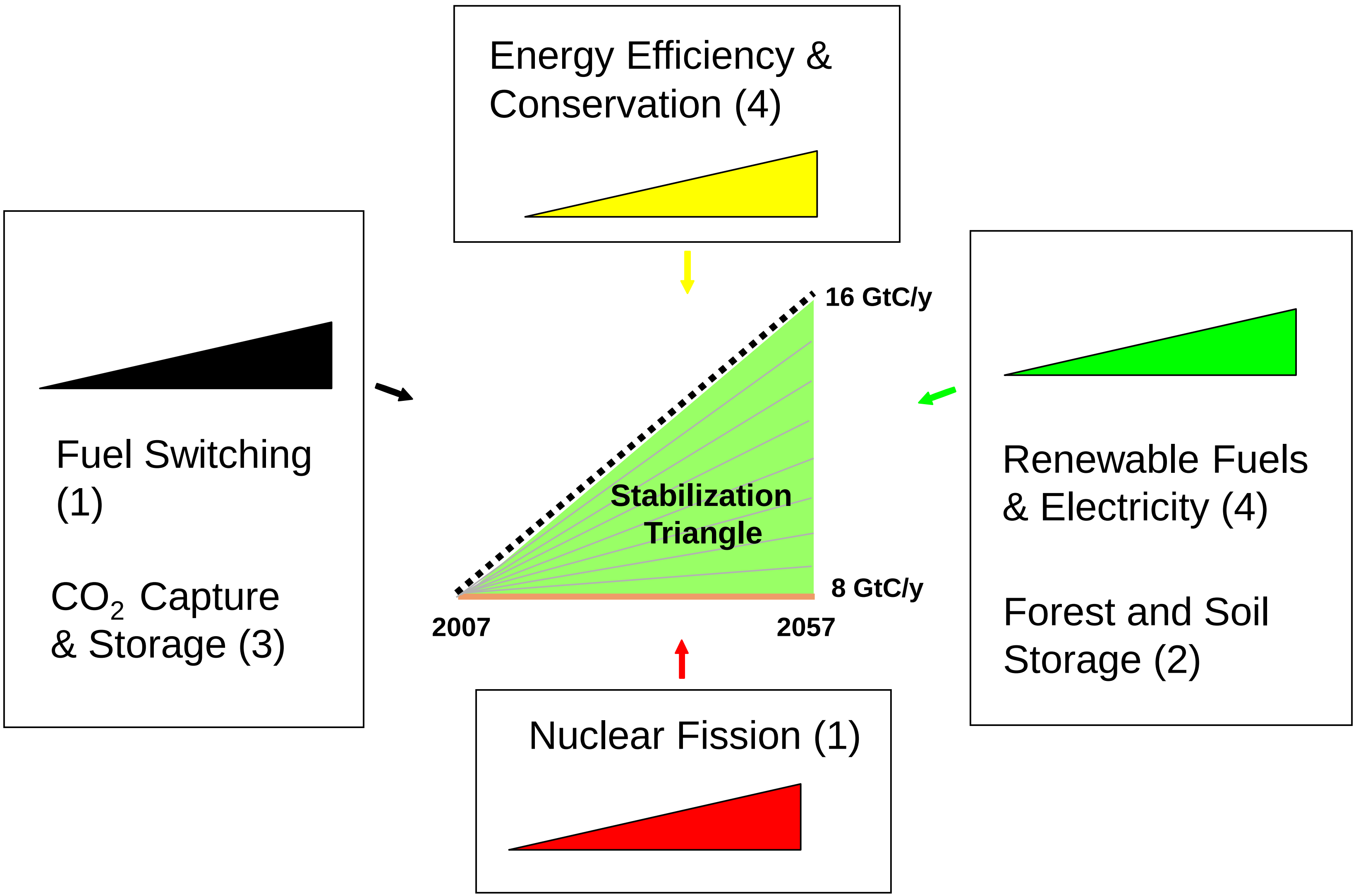
The Stabilization Triangle



Stabilization Wedges



15 Wedge Strategies in 4 Categories



See Carbon Mitigation Initiative

Towards limiting the positive radiative forcing caused by anthropogenic emissions of CO_2, do you think

When poll is active, respond at **PollEv.com/thornton211** Text **THORNTON211** to **22333** once t

- governments should enact taxes on fossil fuel carbon use (pay at the pump)
- governments should enact taxes on fossil fuel emissions
- governments should subsidize carbon-free energy systems (wind, solar, hydro, nuclear) but not tax fossil carbon use or emissions
- governments should do all of the above

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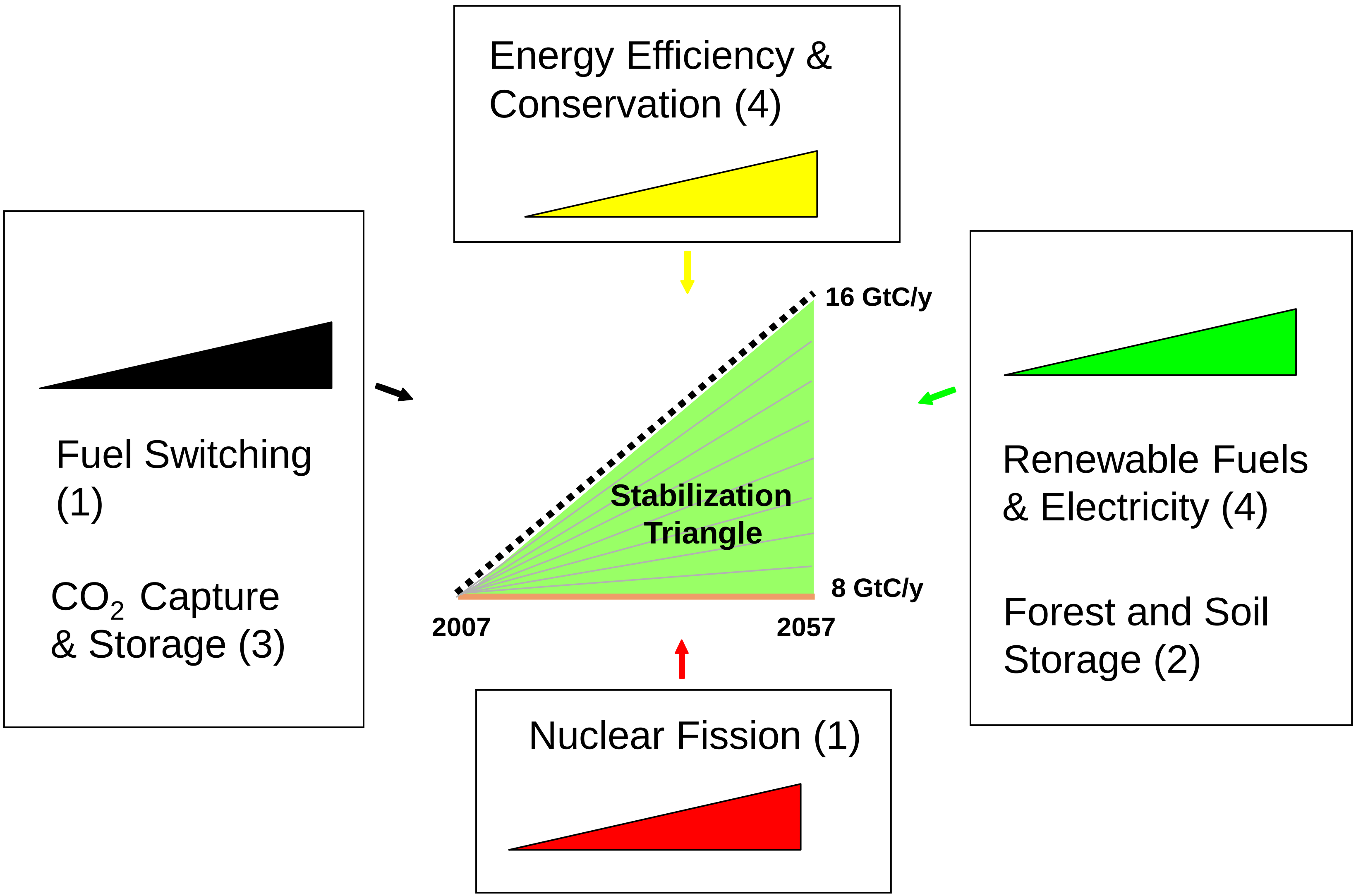
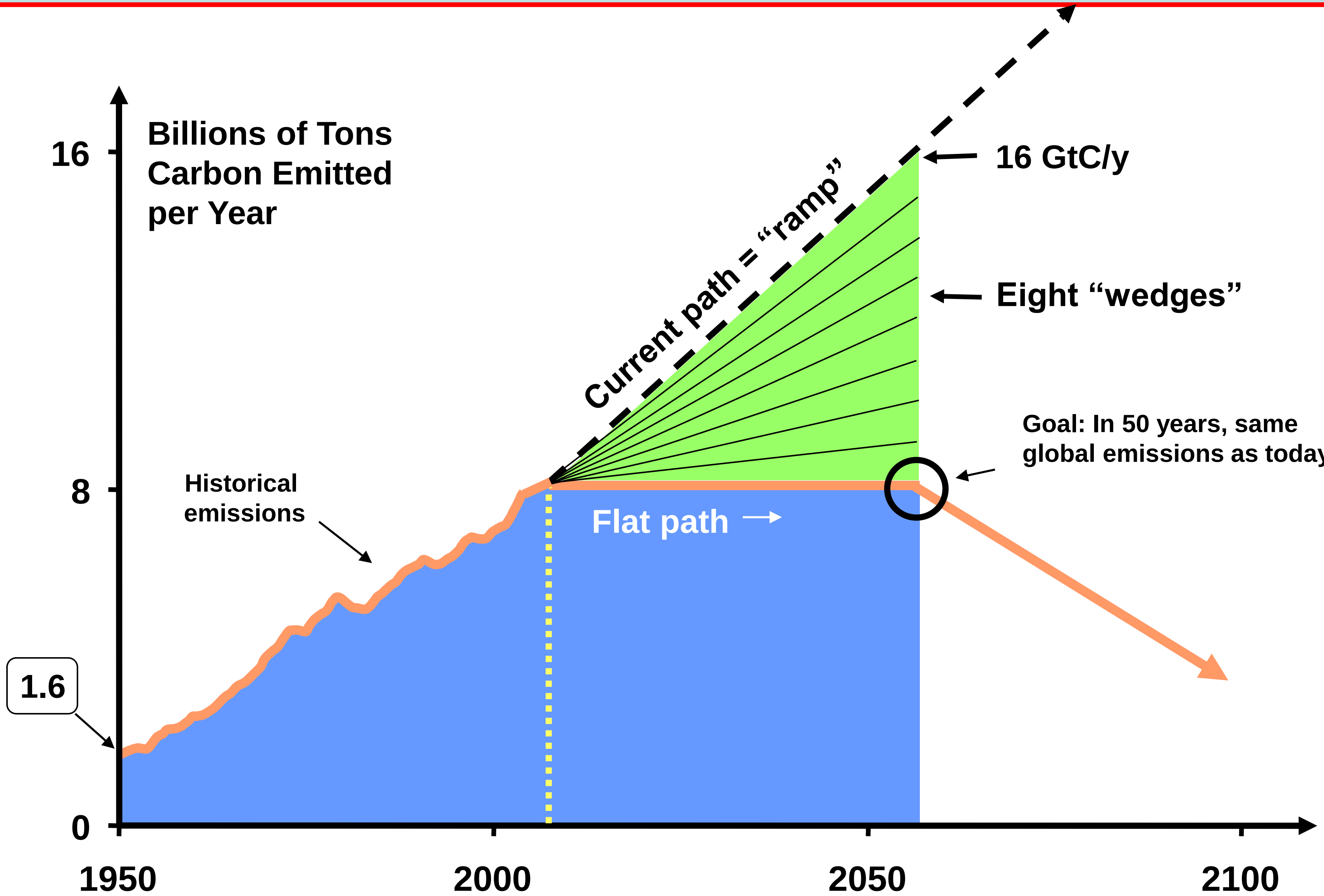
15 Wedge Strategies in 4 Categories

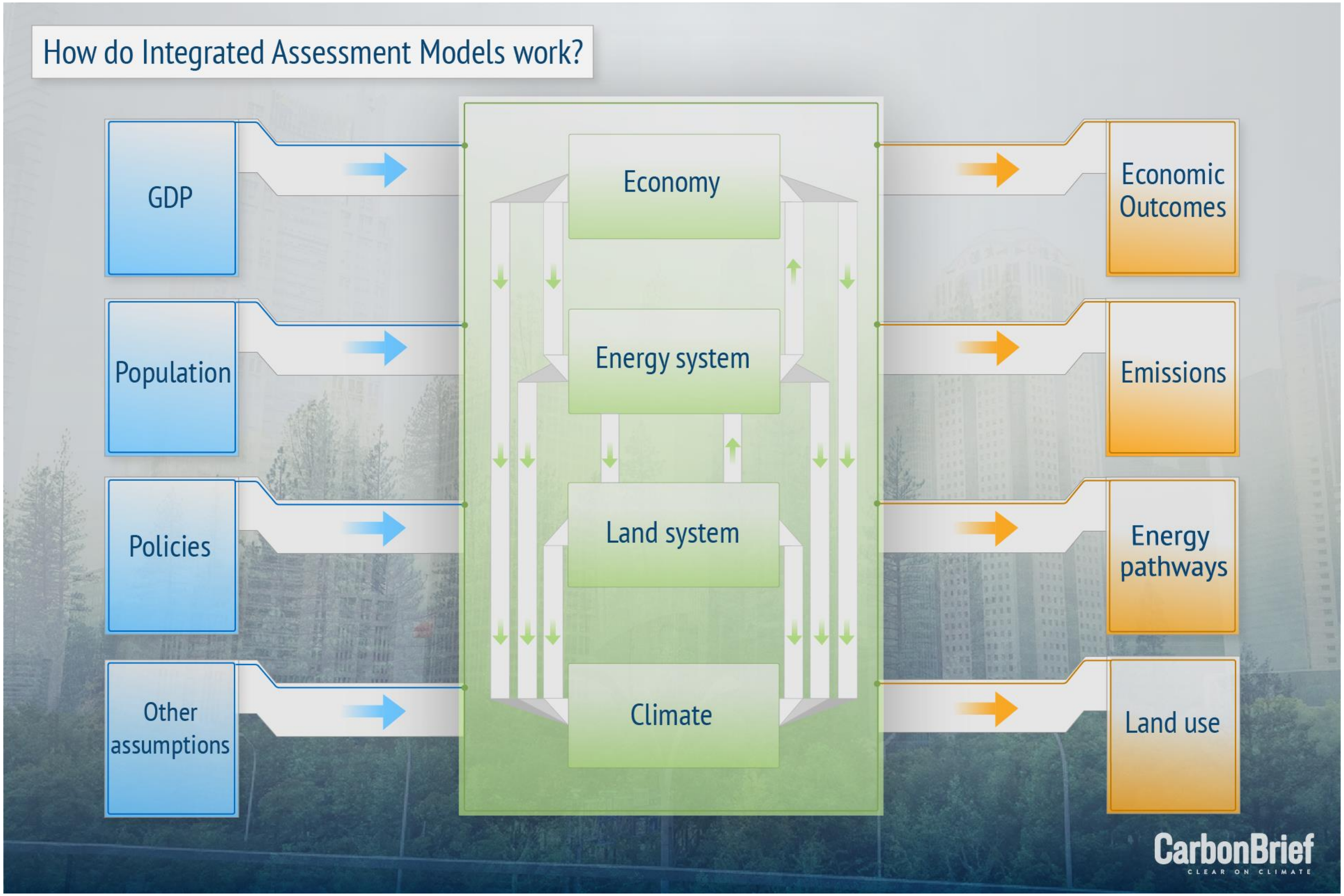


See [Carbon Mitigation Initiative]

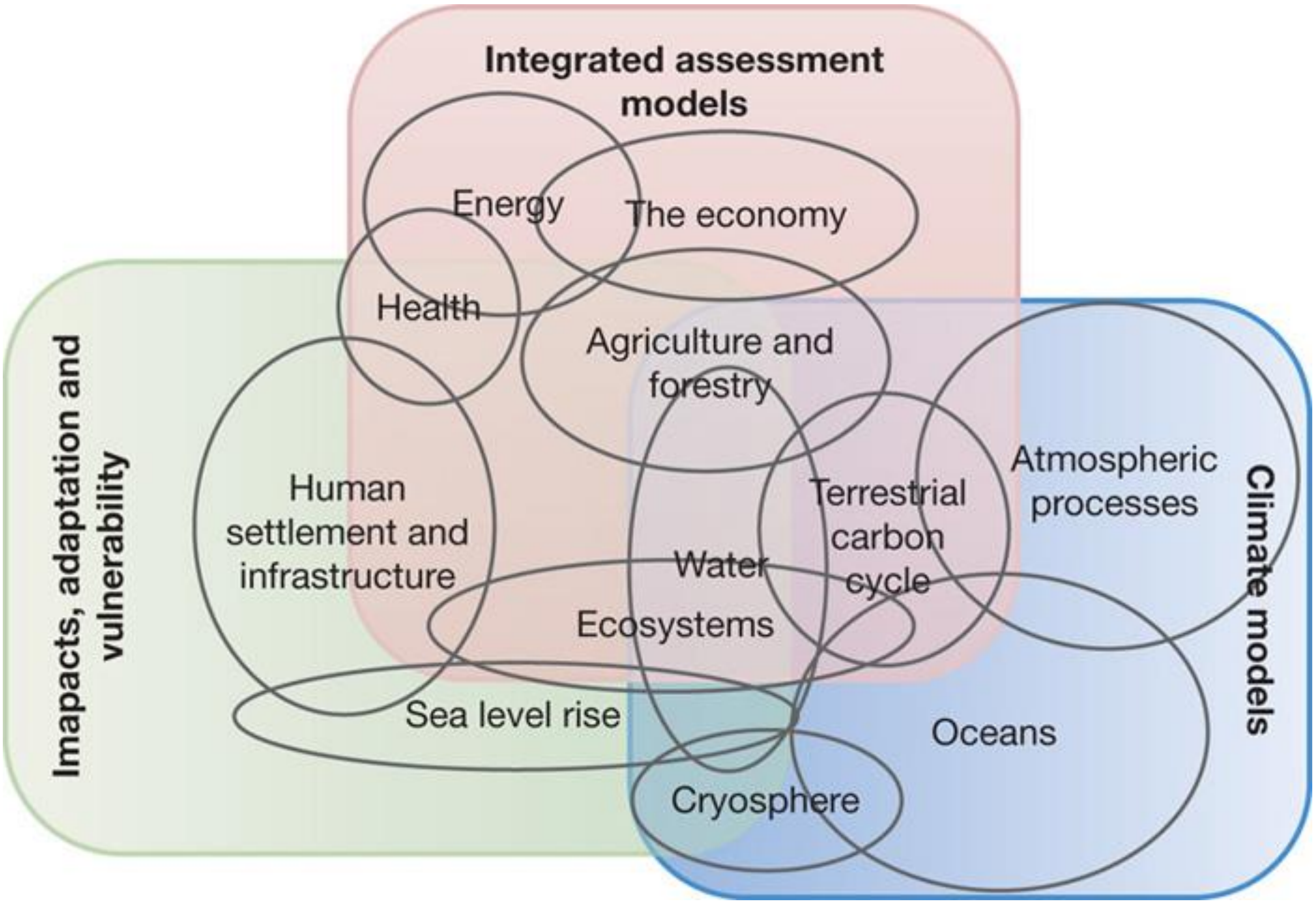
Stabilization Wedges



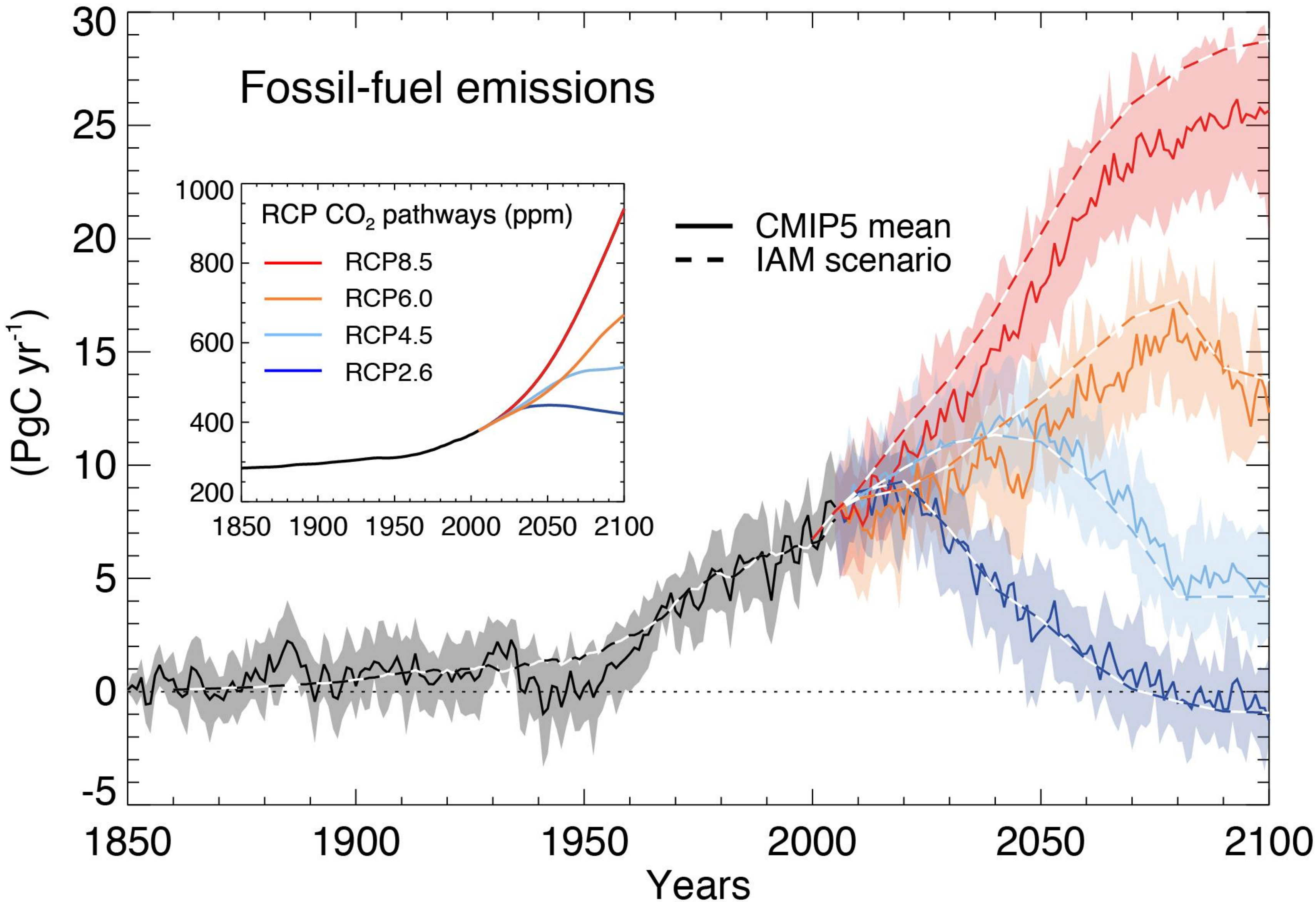
Integrated Assessment Models



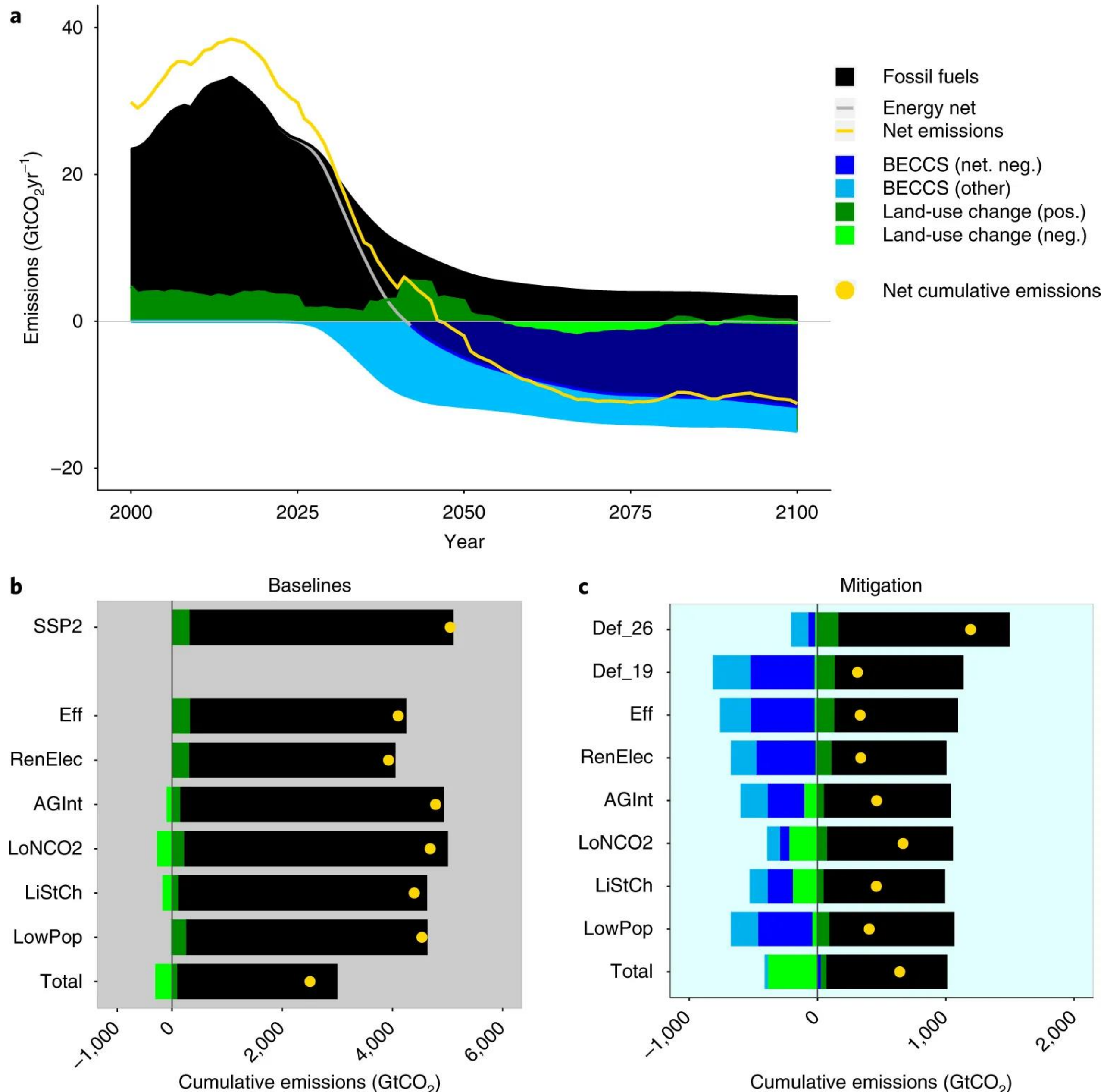
Climate Change, Policy, Impact Modeling



Projections of Future Emissions



Paris Agreement Requires Negative Emissions!



Negative Emissions Are Part of Emission Scenarios

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PERSPECTIVE | CLIMATE CHANGE

The trouble with negative emissions

Kevin Anderson[1,2], **Glen Peters**[3]
+ See all authors and affiliations

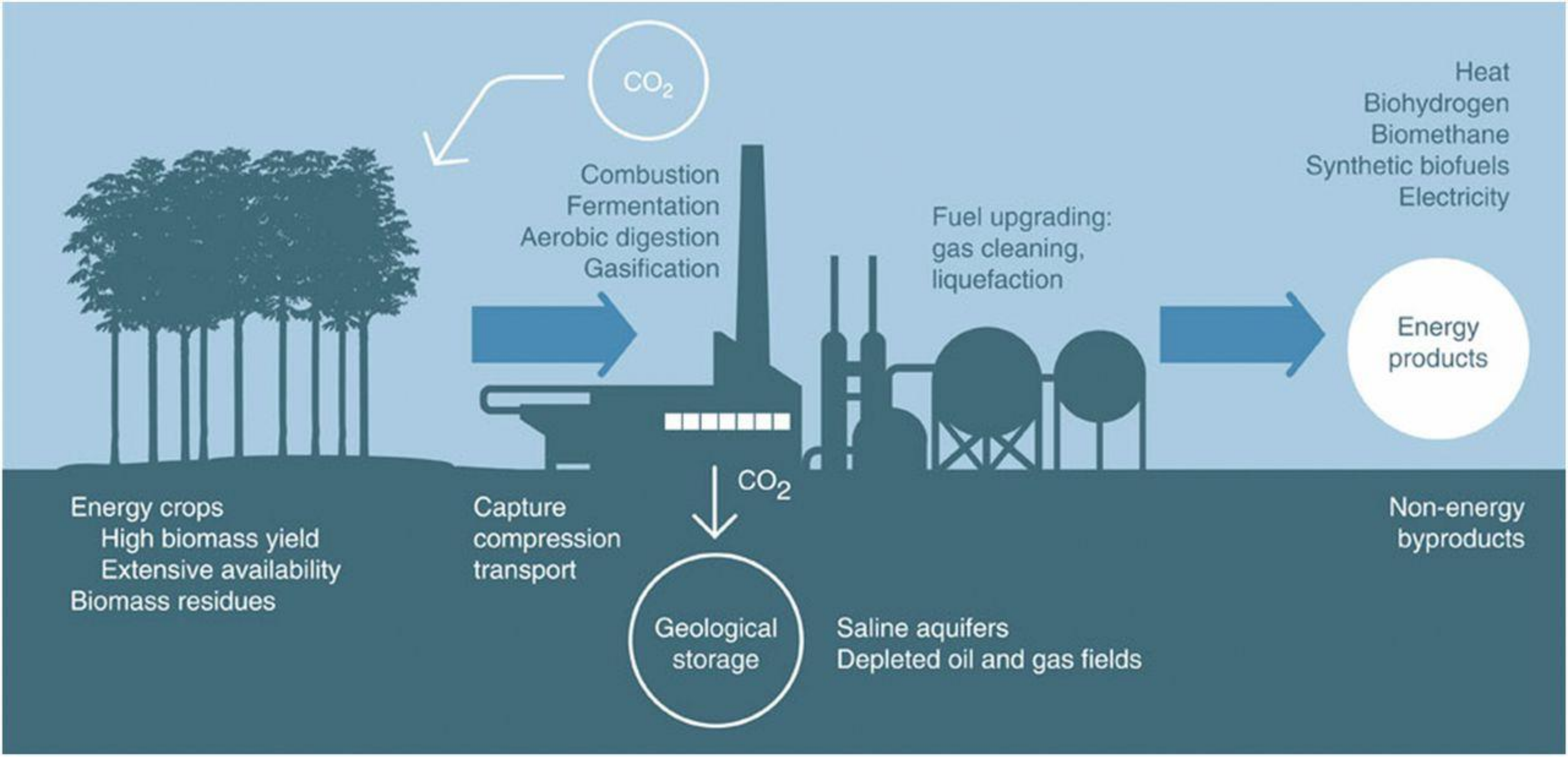
Science 14 Oct 2016:
Vol. 354, Issue 6309, pp. 182-183
DOI: 10.1126/science.aah4567

Article | Figures & Data | Info & Metrics | eLetters | PDF

In December 2015, member states of the United Nations Framework Convention on Climate Change (UNFCCC) adopted the Paris Agreement, which aims to hold the increase in the global average temperature to below 2°C and to pursue efforts to limit the temperature increase to 1.5°C. The Paris Agreement requires that anthropogenic greenhouse gas emission sources and sinks are balanced by the second half of this century. Because some nonzero sources are unavoidable, this leads to the abstract concept of "negative emissions," the removal of carbon dioxide (CO_2) from the atmosphere through technical means. The Integrated Assessment Models (IAMs) informing policy-makers assume the large-scale use of negative-emission technologies. If we rely on these and they are not deployed or are unsuccessful at removing CO_2 from the atmosphere at the levels assumed, society will be locked into a high-temperature pathway.

Some Negative Emission Strategies

Bio-Energy Carbon Capture and Storage (BECCS)



Bioenergy Requires Land and Productivity

REVIEW ARTICLE
PUBLISHED ONLINE: 7 DECEMBER 2015 | DOI: 10.1038/NCLIMATE2870

nature climate change

Biophysical and economic limits to negative CO_2 emissions

Pete Smith[1*], Steven J. Davis[2], Felix Creutzig[3,4], Sabine Fuss[3], Jan Minx[3,5,6], Benoit Gabrielle[7,8], Etsushi Kato[9], Robert B. Jackson[10], Annette Cowie[11], Elmar Kriegler[5], Detlef P. van Vuuren[12,13], Joeri Rogelj[14,15], Philippe Ciais[16], Jennifer Milne[17], Josep G. Canadell[18], David McCollum[15], Glen Peters[19], Robbie Andrew[19], Volker Krey[15], Gyami Shrestha[20], Pierre Friedlingstein[21], Thomas Gasser[16,22], Arnulf Grübler[15], Wolfgang K. Heidug[23], Matthias Jonas[15], Chris D. Jones[24], Florian Kraxner[15], Emma Littleton[25], Jason Lowe[24], José Roberto Moreira[26], Nebojsa Nakicenovic[15], Michael Obersteiner[15], Anand Patwardhan[27], Mathis Rogner[15], Ed Rubin[28], Ayyoob Sharifi[29], Asbjørn Torvanger[19], Yoshiki Yamagata[30], Jae Edmonds[31] and Cho Yongsung[32]

To have a >50% chance of limiting warming below 2 °C, most recent scenarios from integrated assessment models (IAMs) require large-scale deployment of negative emissions technologies (NETs). These are technologies that result in the net removal of greenhouse gases from the atmosphere. We quantify potential global impacts of the different NETs on various factors (such as land, greenhouse gas emissions, water, albedo, nutrients and energy) to determine the biophysical limits to, and economic costs of, their widespread application. Resource implications vary between technologies and need to be satisfactorily addressed if NETs are to have a significant role in achieving climate goals.

Despite two decades of effort to curb emissions of CO_2 and other greenhouse gases (GHGs), emissions grew faster during the 2000s than in the 1990s[1], and by 2010 had reached ~50 Gt CO_2 equivalent (CO_2eq) yr^{-1} (refs 2,3). The continuing rise in emissions is a growing challenge for meeting the international goal of limiting warming to less than 2 °C relative to the pre-indus-

options, to be able to decide which pathways are most desirable for dealing with climate change.

There are distinct classes of NETs, such as: (1) bioenergy with carbon capture and storage (BECCS)[11,12]; (2) direct air capture of CO_2 from ambient air by engineered chemical reactions (DAC)[13,14]; (3) enhanced weathering of minerals (EW)[15], where natural weath-

Bioenergy – Land Use – Food Are Connected

Bioenergy

Food Security

Land-Use

Supplement other pathways

nature climate change

ARTICLES

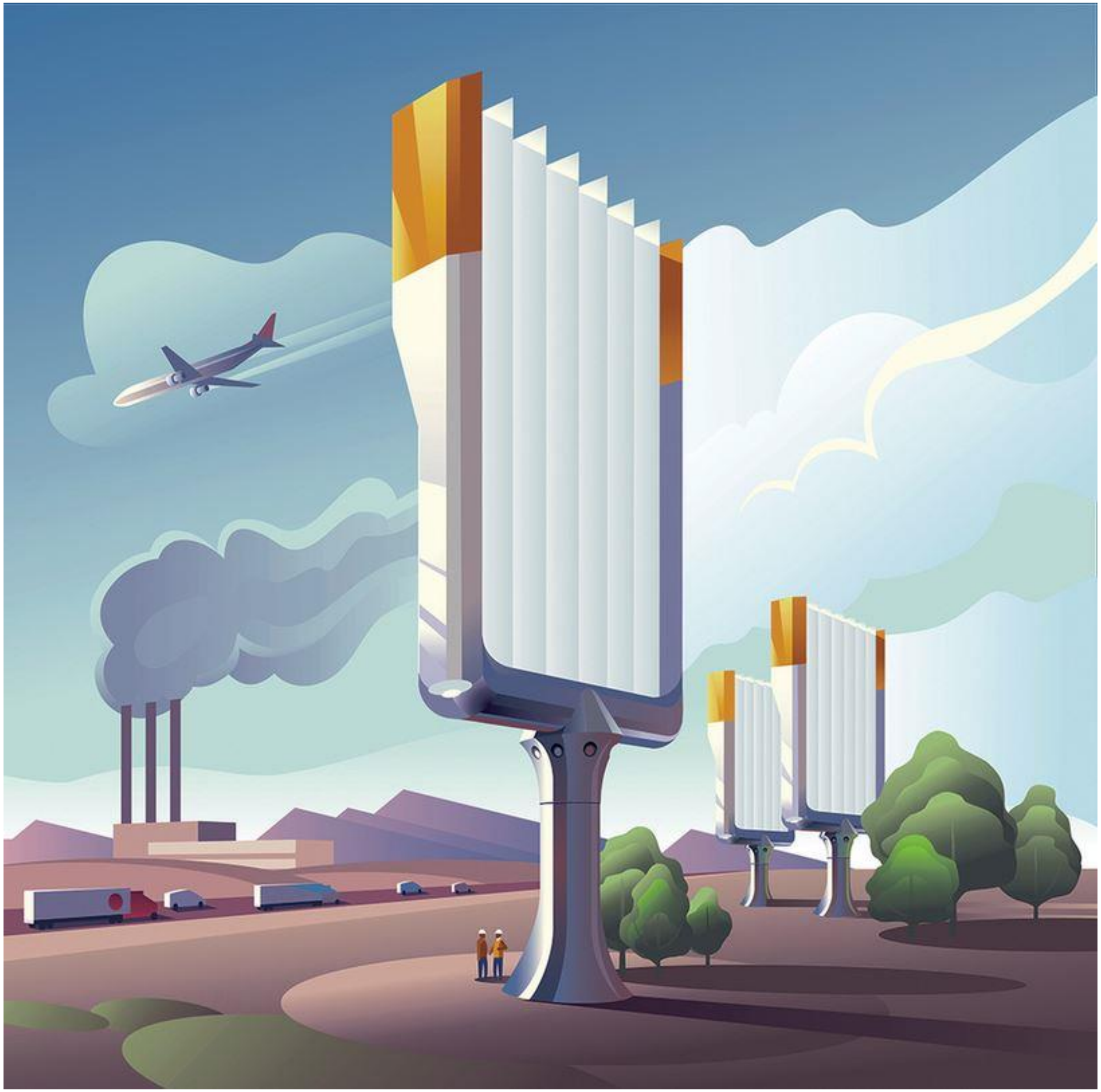
https://doi.org/10.1038/s41558-018-0119-8

Alternative pathways to the 1.5 °C target reduce the need for negative emission technologies

Detlef P. van Vuuren[1,2*], Elke Stehfest[1], David E. H. J. Gernaat[1,2], Maarten van den Berg[1], David L. Bijl[2], Harmen Sytze de Boer[1,2], Vassilis Daioglou[1,2], Jonathan C. Doelman[1], Oreane Y. Edelenbosch[1,2], Mathijs Harmsen[1,2], Andries F. Hof[1,2] and Mariësse A. E. van Sluisveld[1,2]

Mitigation scenarios that achieve the ambitious targets included in the Paris Agreement typically rely on greenhouse gas emission reductions combined with net carbon dioxide removal (CDR) from the atmosphere, mostly accomplished through large-scale application of bioenergy with carbon capture and storage, and afforestation. However, CDR strategies face several difficulties such as reliance on underground CO_2 storage and competition for land with food production and biodiversity protection. The question arises whether alternative deep mitigation pathways exist. Here, using an integrated assessment model, we explore the impact of alternative pathways that include lifestyle change, additional reduction of non-CO_2 greenhouse gases and more rapid electrification of energy demand based on renewable energy. Although these alternatives also face specific difficulties, they are found to significantly reduce the need for CDR, but not fully eliminate it. The alternatives offer a means to diversify transition pathways to meet the Paris Agreement targets, while simultaneously benefiting other sustainability goals.

Negative Emissions Strategy: Carbon Dioxide Removal (CDR)



Alternative to the Wedges Approach: Geo-engineering?

Solar Radiation Management
--increase albedo to offset GHG warming

Carbon Dioxide Removal (CDR)
--actively scrub CO_2 from the atmosphere

Geo-engineering: Particles in Stratosphere

GEOPHYSICAL RESEARCH LETTERS, VOL. 35, L02809, doi:10.1029/2007GL032179, 2008

Click Here for Full Article

Exploring the geoengineering of climate using stratospheric sulfate aerosols: The role of particle size

Philip J. Rasch,[1] Paul J. Crutzen,[2,3] and Danielle B. Coleman[1]

Received 1 October 2007; revised 26 November 2007; accepted 19 December 2007; published 26 January 2008.

[1] Aerosols produced in the lower stratosphere can brighten the planet and counteract some of the effects of global warming. We explore scenarios in which the amount of precursors and the size of the aerosol are varied to assess their interactions with the climate system. Stratosphere-troposphere exchange processes change in response to greenhouse gas forcing and respond to geoengineering by aerosols. Nonlinear feedbacks influence the amount of aerosol required to counteract the warming. More aerosol

impacts. The first response of society to this evidence ought to be to reduce greenhouse gas emissions, but a second step might be to explore strategies to mitigate some of the planetary warming. Two recent papers [*Crutzen*, 2006; *Wigley*, 2006] explored a geoengineering idea going back to *Budyko* [1974], who speculated that a deliberate production of stratospheric aerosols might increase the planetary albedo, and cool the planet, ameliorating some (but not all) of the effects of increasing CO_2 concentrations.

Estimates: Need 1 – 5 Tg S/yr to negate doubled CO_2

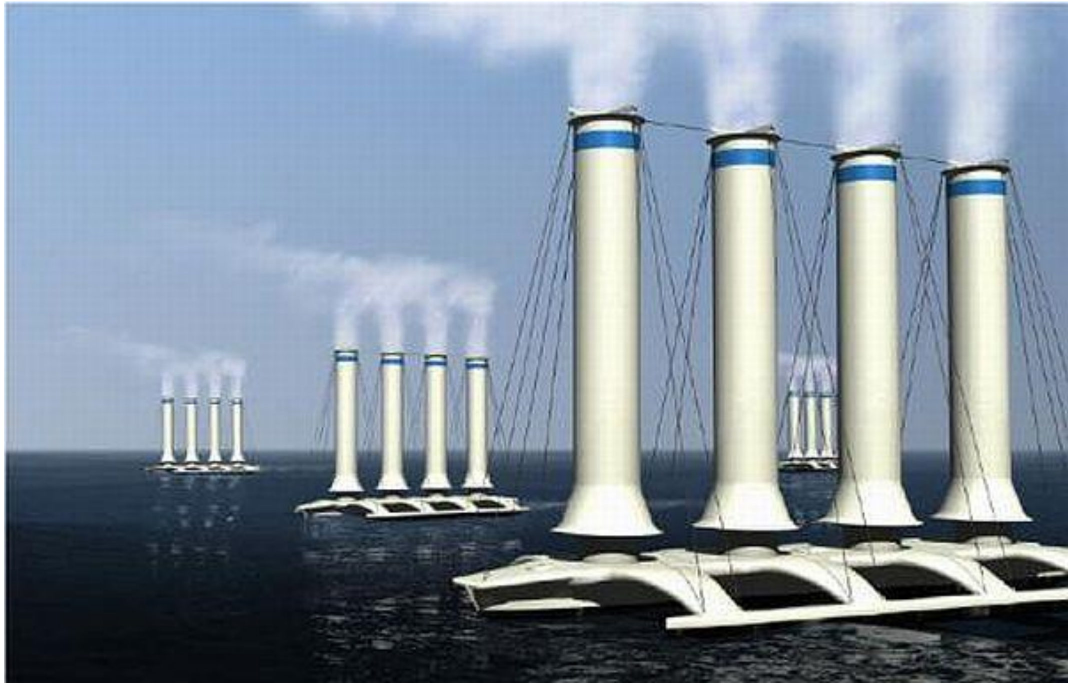
Geo-engineering: Particles in Stratosphere

~20 Tg S in stratosphere

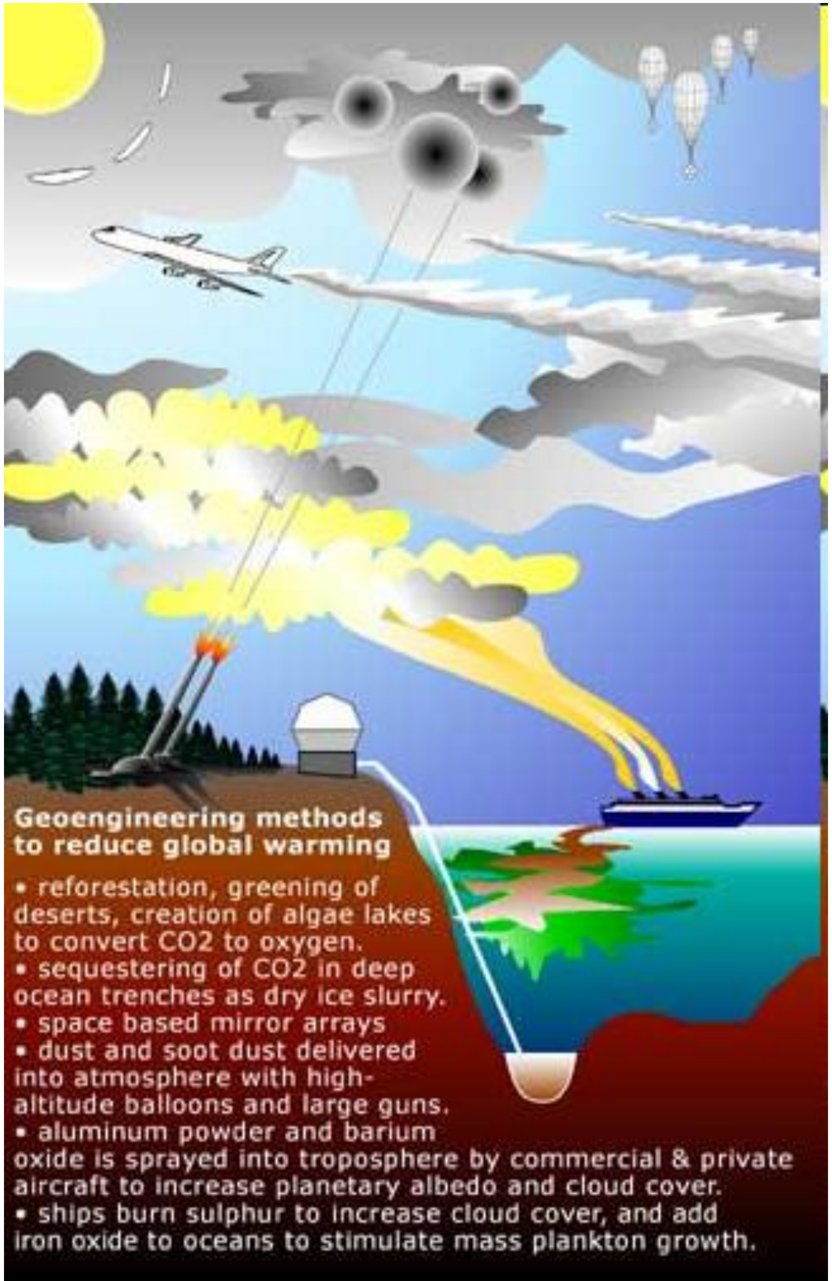
Need Mt. Pinatubo every 2-4 years…

Marine Cloud Brightening

- **https://twitter.com/i/status/1121455609465974786**



Various Geo-engineering Schemes



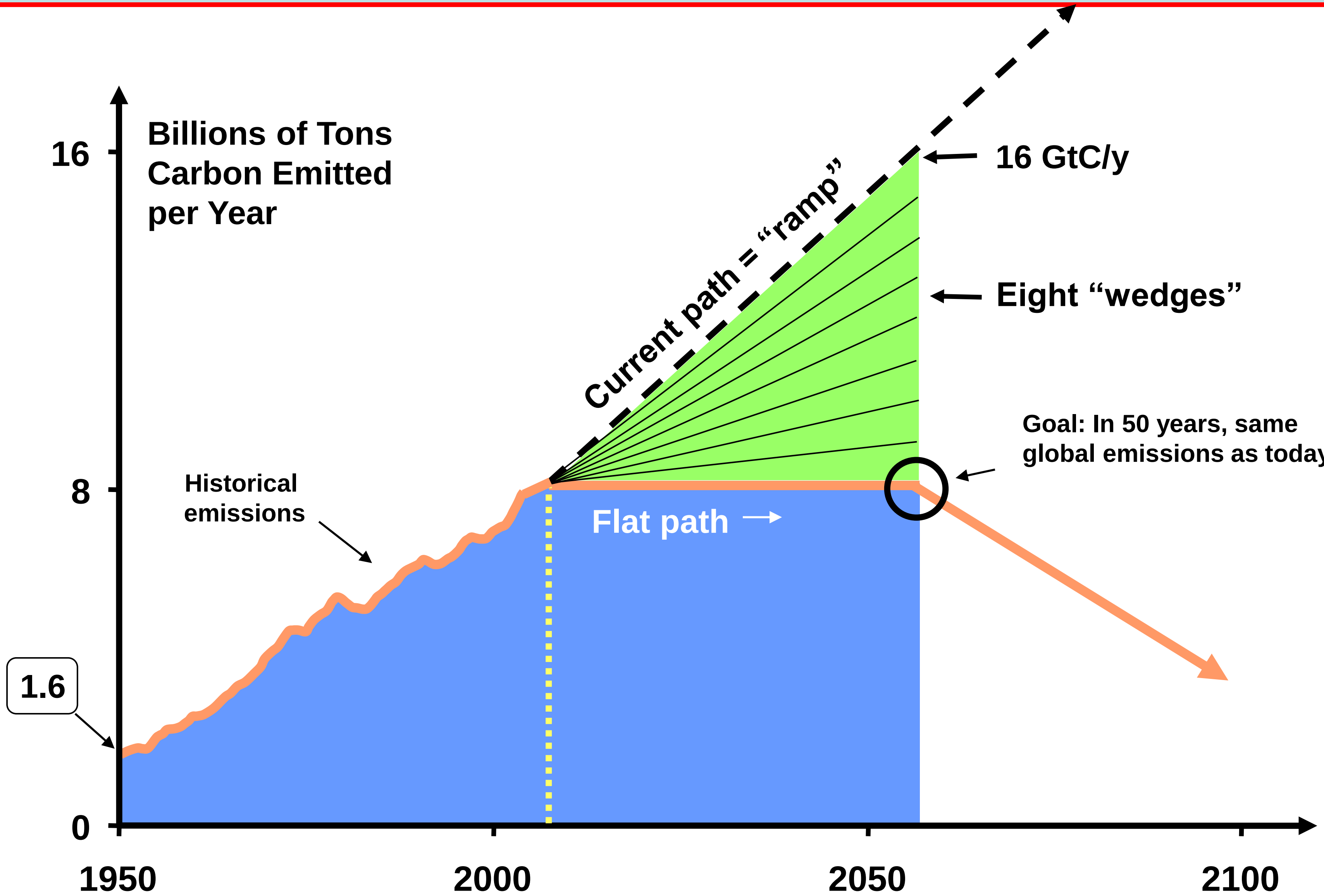
What laws and treaties exist or are needed?

Who will control the desired climate?

What happens if there is an interruption in the scheme (CO_2 still increasing)?

Global average T is not the only problem associated with increasing CO_2, what about those?

Stabilization Wedges



International Agreements are Voluntary

While free-riding is pervasive, it is particularly difficult to overcome for global public goods. Global public goods differ from national market failures because no mechanisms—either market or governmental—can deal with them effectively. Arrangements to secure an international climate treaty are hampered by the Westphalian dilemma. The 1648 Treaty of Westphalia established the central principles of modern international law. First, nations are sovereign and have the fundamental right of political self-determination; second, states are legally equal; and third, states are free to manage their internal affairs without the intervention of other states. The current Westphalian system requires that countries consent to joining international agreements, and all agreements are therefore essentially voluntary (Treaty of Vienna 1969, article 34).

Climate Club Example

The theory of clubs is a little-known but important corner of the social sciences. (For an early analysis, see Buchanan 1965, while for a fine survey, see Sandler and Tschirhart 1980.) The major conditions for a successful club include the following: (i) that there is a public-good-type resource that can be shared (whether the benefits from a military alliance or the enjoyment of a golf course); (ii) that the cooperative arrangement, including the dues, is beneficial for each of the members; (iii) that non-members can be excluded or penalized at relatively low cost to members; and (iv) that the membership is stable in the sense that no one wants to leave. For the current international-trade system, the advantages are the access to other countries' markets with low trade barriers. For military alliances, the benefits are peace and survival. In all cases, countries must contribute dues—these being low trade barriers for trade or burden sharing in defense treaties. If we look at successful international clubs, we might see the seeds of an effective international system to deal with climate change.

"Club" of countries agree to emissions reductions

Countries not agreeing (and not meeting targets) are penalized via tariffs on imports

An Economic Approach

American Economic Review 2015, 105(4): 1339–1370
http://dx.doi.org/10.1257/aer.15000001

Climate Clubs: Overcoming Free-riding in International Climate Policy†

By William Nordhaus*

Notwithstanding great progress in scientific and economic understanding of climate change, it has proven difficult to forge international agreements because of free-riding, as seen in the defunct Kyoto Protocol. This study examines the club as a model for international climate policy. Based on economic theory and empirical modeling, it finds that without sanctions against non-participants there are no stable coalitions other than those with minimal abatement. By contrast, a regime with small trade penalties on non-participants, a Climate Club, can induce a large stable coalition with high levels of abatement. (*JEL* Q54, Q58, K32, K33)

Climate Clubs

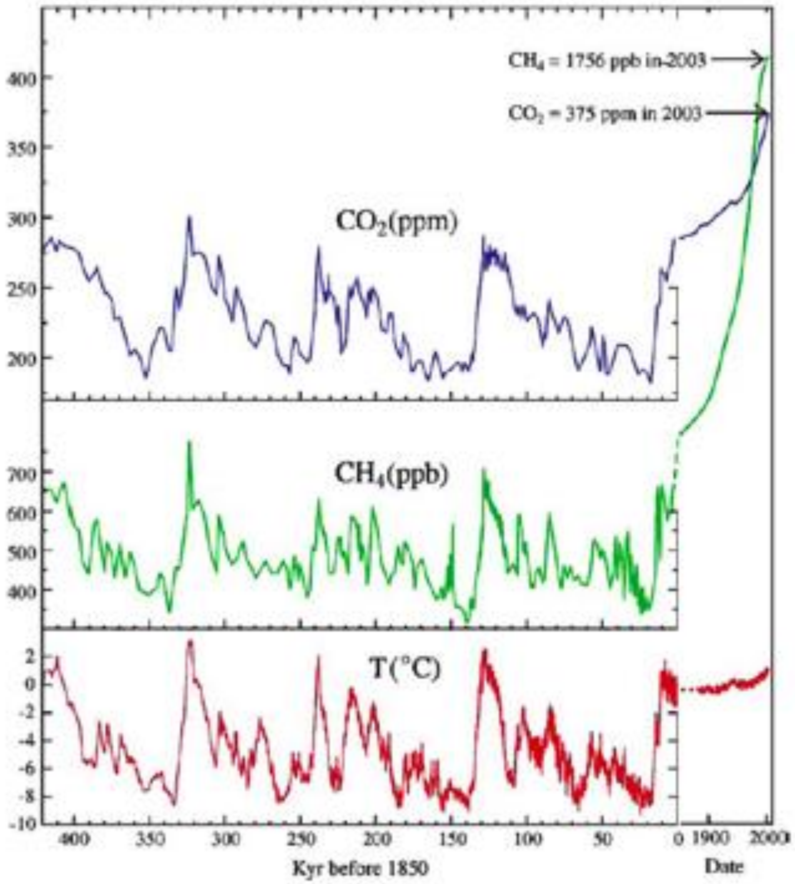
[New York Times: Climate Deal Needs a Big Stick, Eduardo Porter](#)

June 2, 2015

According to calculations by William Nordhaus, an expert on the economics of climate change at Yale, the United States, on net, would gain $8 billion a year by benefiting from everybody else's efforts to slow down the Earth's warming without having to exert any effort itself.

But if the other advanced nations had a stick — a tariff of 4 percent on the imports from countries not in the "climate club" — the cost-benefit calculation for the United States would flip. Not participating in the club would cost Americans $44 billion a year.

Course Goals

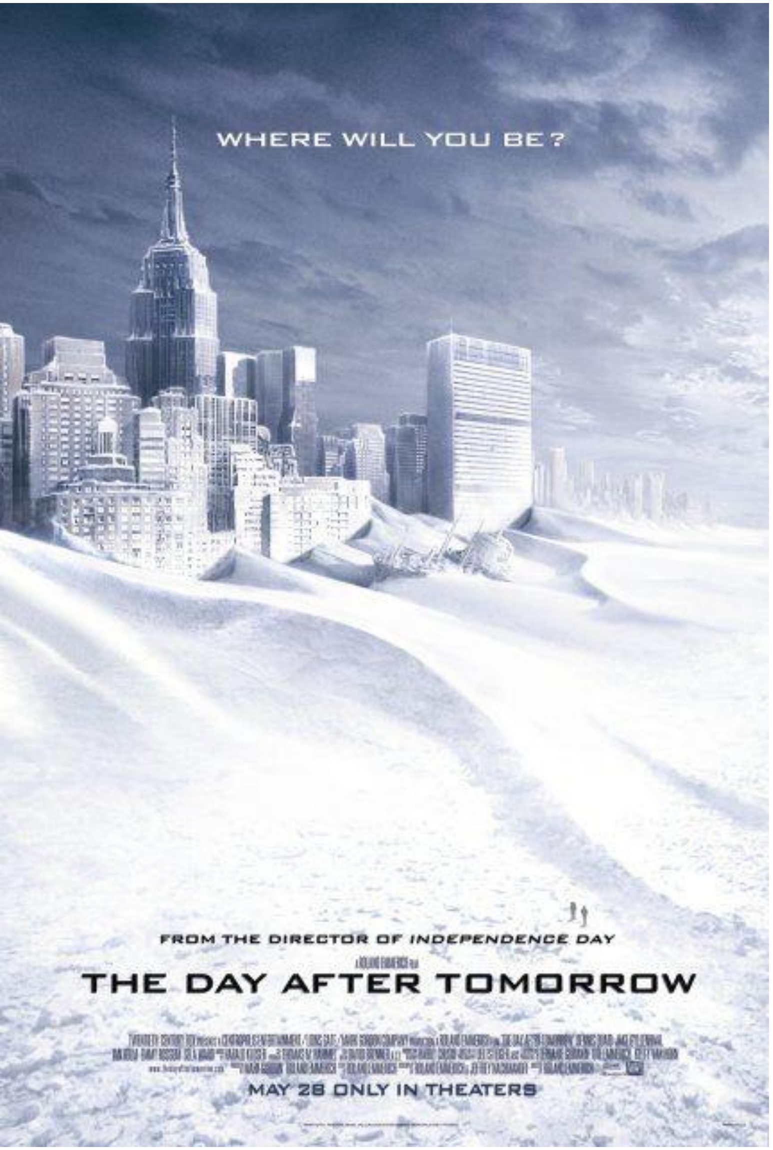


1. Introduce you to climate science and the scientific method

2. Give you tools to understand and <u>critically evaluate</u> modern environmental problems

https://uw.iasystem.org/survey/190740

It isn’t rocket science



1. **Increasing greenhouse gases is a positive radiative forcing.**

2. **Temperature should increase (1880’s physics): natural positive feedbacks amplify warming**

3. **Impacts of increased temperature: ice melts, sea water expands, soil moisture evaporates faster, more water vapor means heavier rains**

Some opinions (not necessarily endorsed by me)

http://thedailyshow.cc.com/videos/8q3nmm/burn-noticed

https://www.youtube.com/watch?v=3E0a_60PMR8

https://www.youtube.com/watch?v=YDL4Bs3NbB0