Challenges of Climate Change
Introductory Lecture, Part 1

David Mond

Warwick, October 5 2018

- Science: the greenhouse effect
- Evaluating evidence
- Uncertainty
- Developing a response
- Justice
- Reaching agreement

Understanding and responding to climate change requires the collaboration of many disciplines

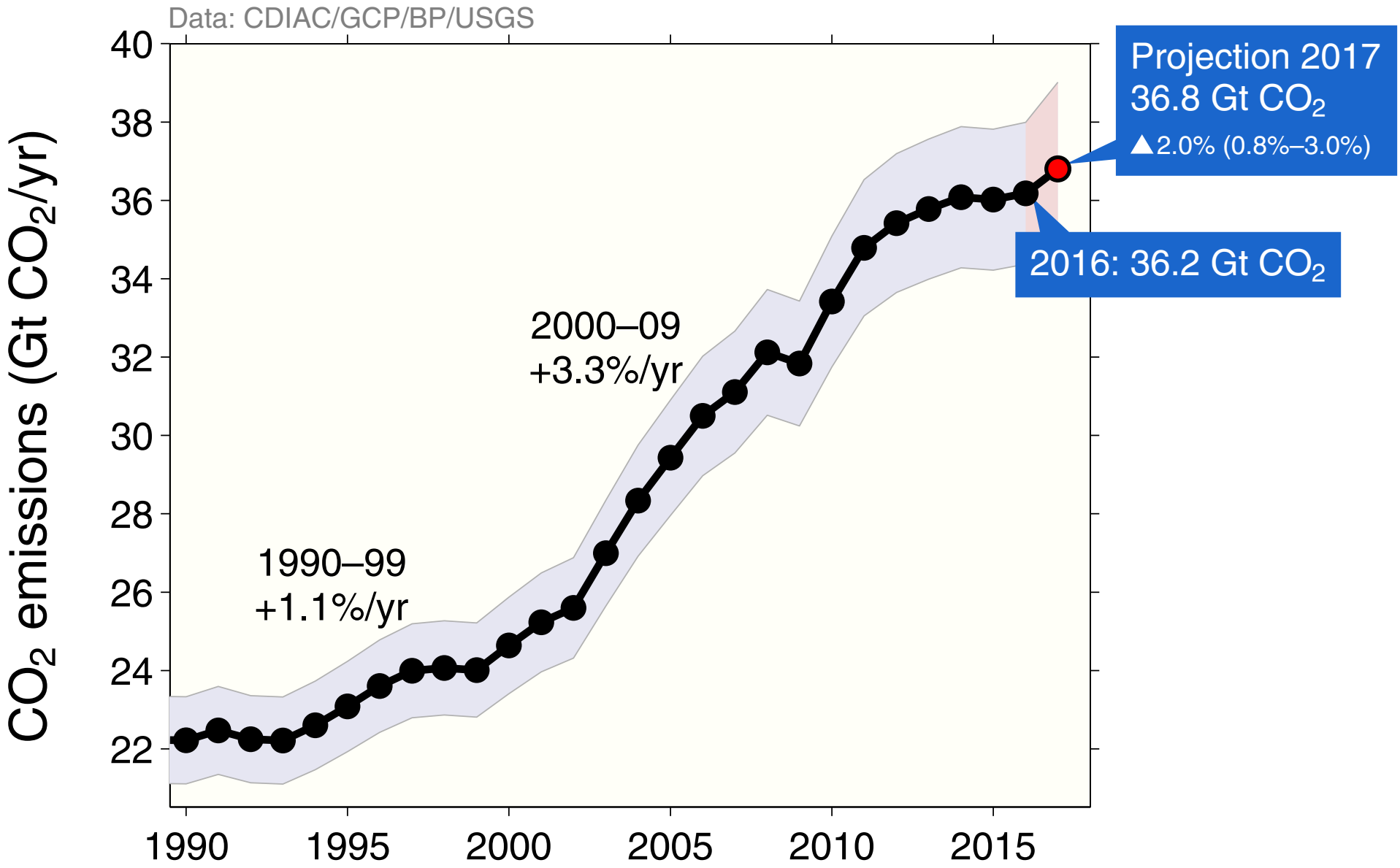
Greenhouse Effect – Theory

The problem begins with the increase, in the atmosphere, of gases which transmit the high frequency electromagnetic radiation that constitutes sunlight, but absorb the low frequency (infrared) radiation emitted by the earth.

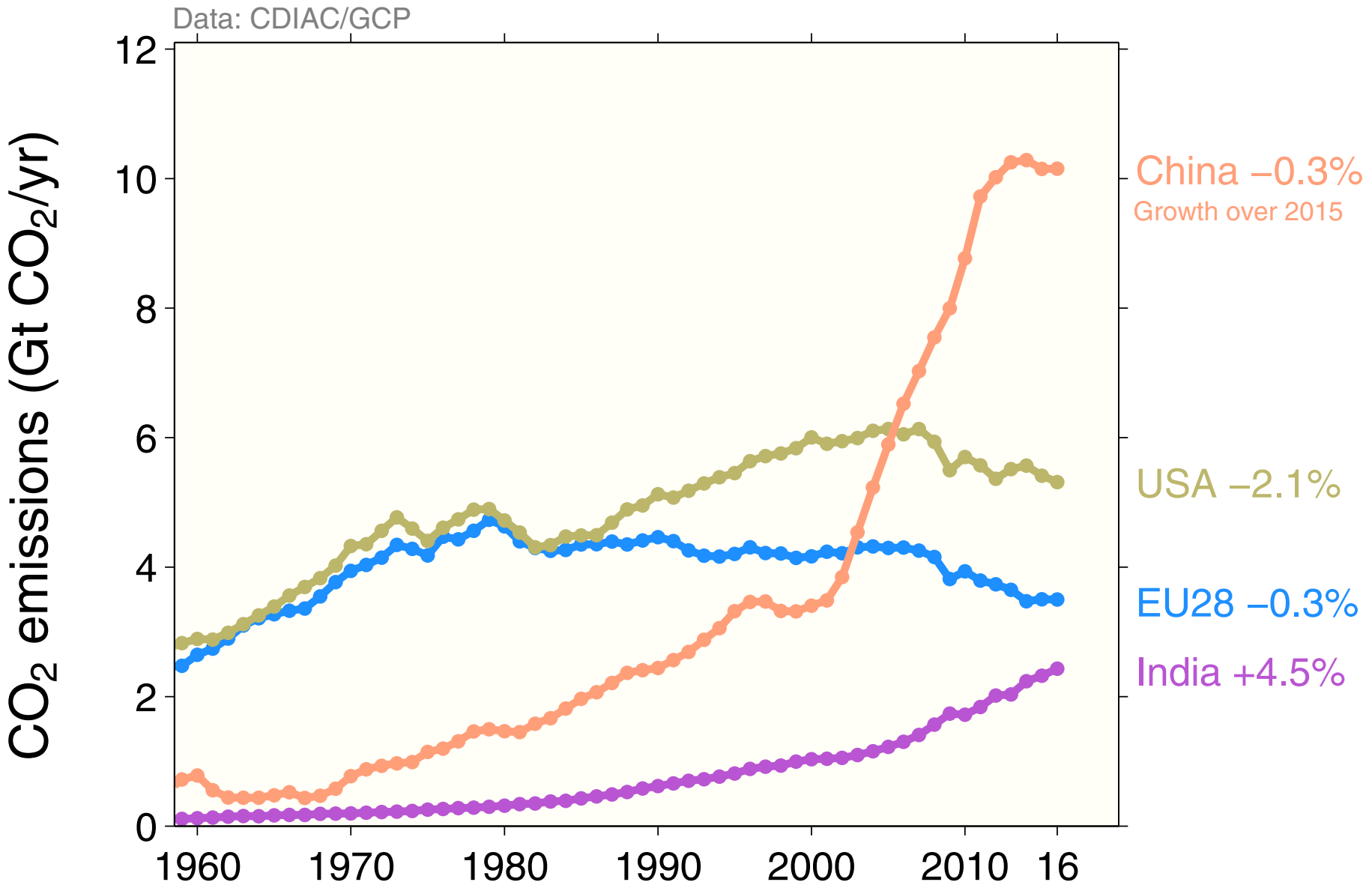
This prevents the earth from radiating back into space some of the energy it receives from the sun. The presence of the right level makes our kind of life possible: too little implies too cold, too much implies too hot.

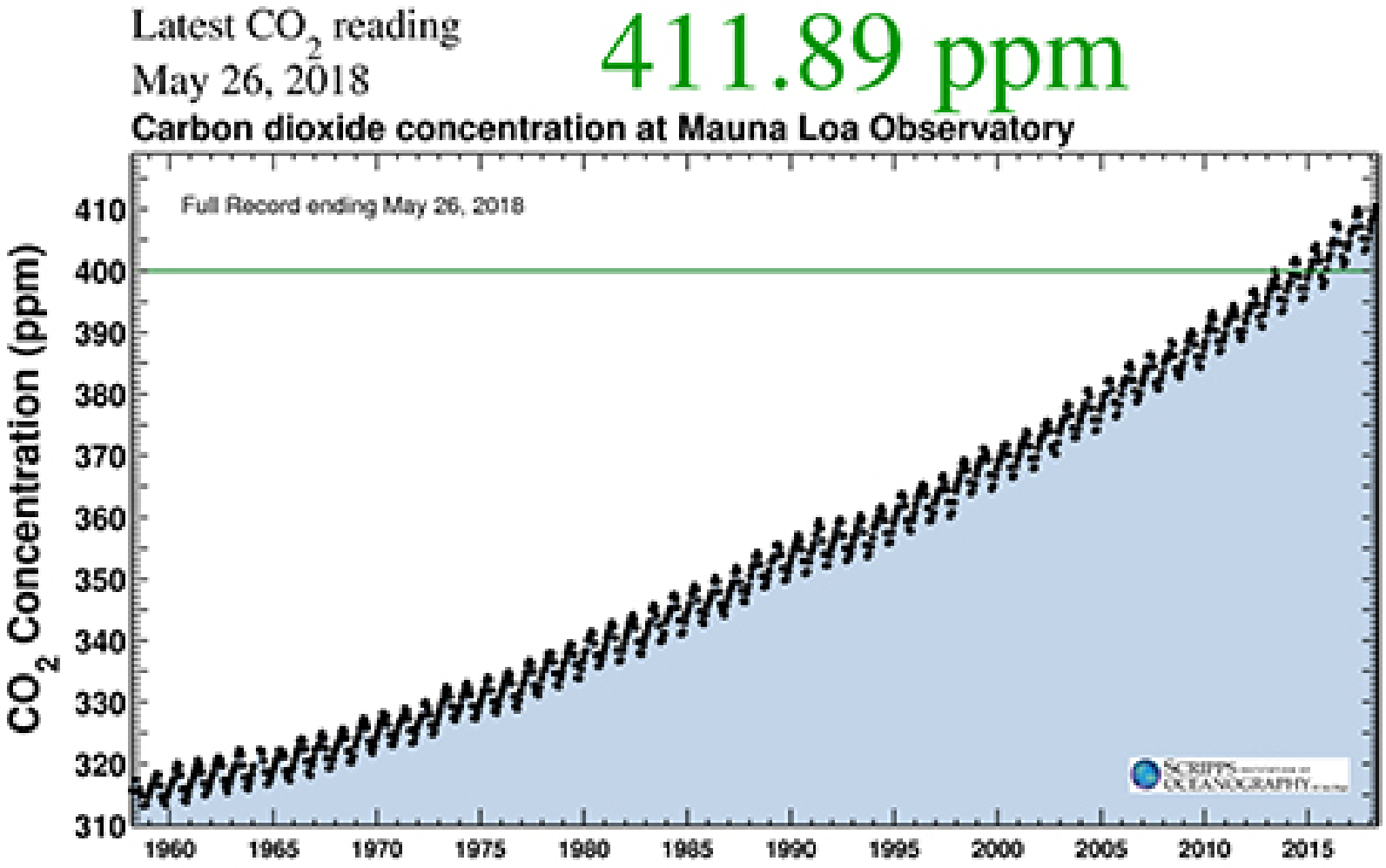
These gases are, in order of importance, water vapour, carbon dioxide and methane, plus some others. We have no control over the quantity of water vapour in the atmosphere. But burning fossil fuels, and keeping large herds of cattle, releases large quantities of CO2 and methane into the atmosphere. We *can* influence that.

CO2 Emissions 1990-2017



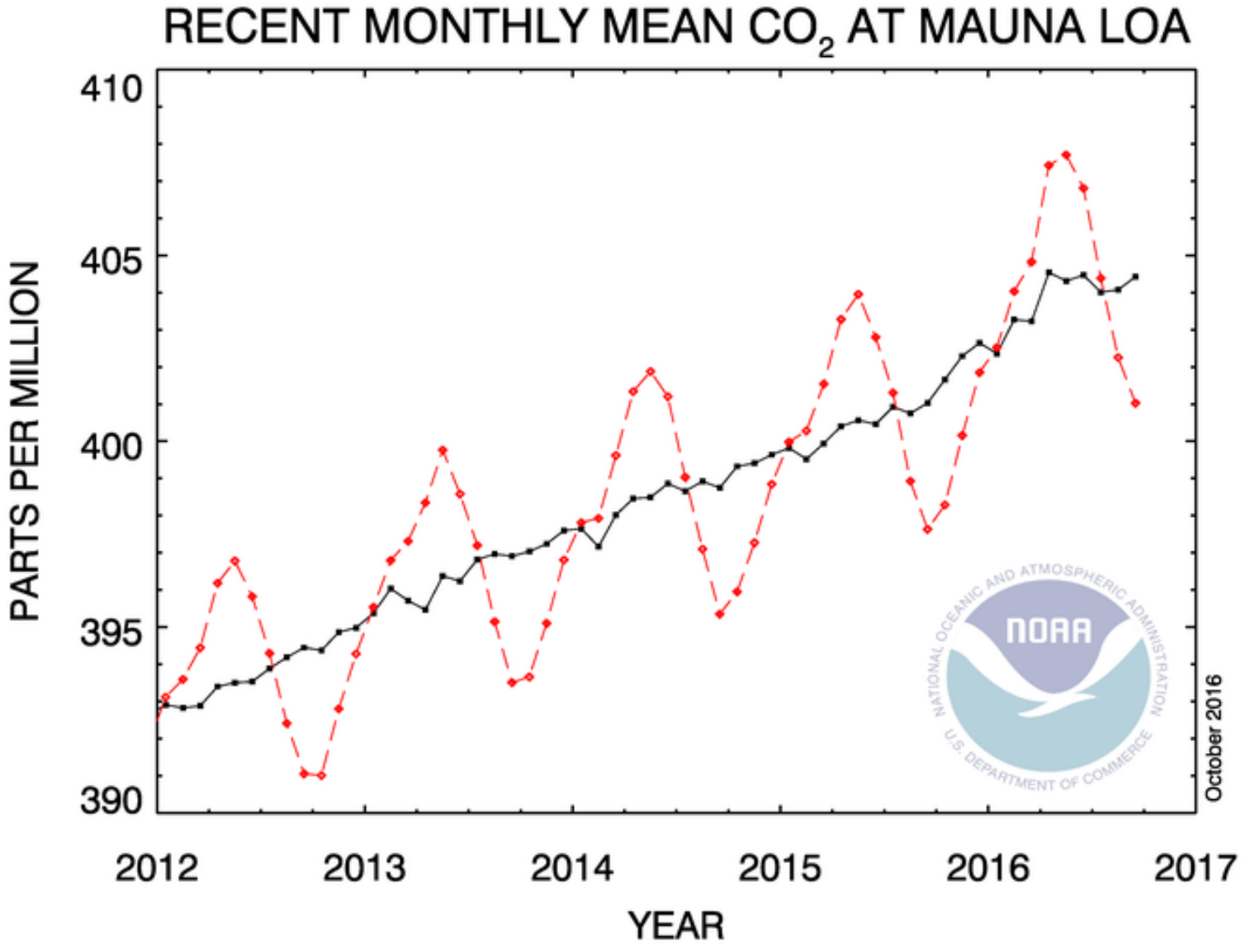
CO2 Emissions 1960-2016



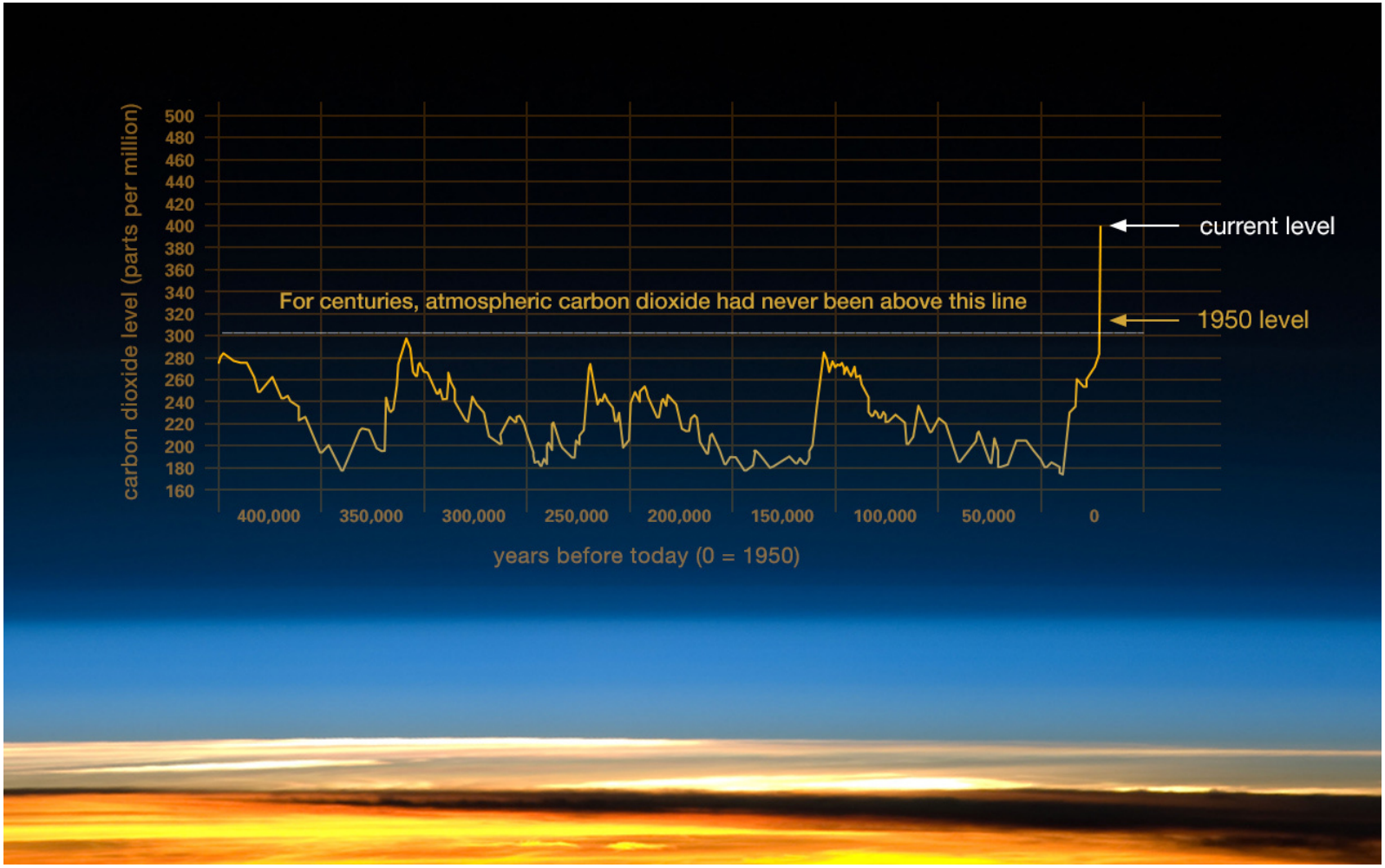


Keeling curve

Source: Scripps Institution of Oceanography, University of California San Diego


RECENT MONTHLY MEAN CO_2 AT MAUNA LOA
PARTS PER MILLION
410
405
400
395
390
2012
2013
2014
2015
2016
2017
YEAR
October 2016
NOAA
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
U.S. DEPARTMENT OF COMMERCE

CO2 levels over the last 400,000 years



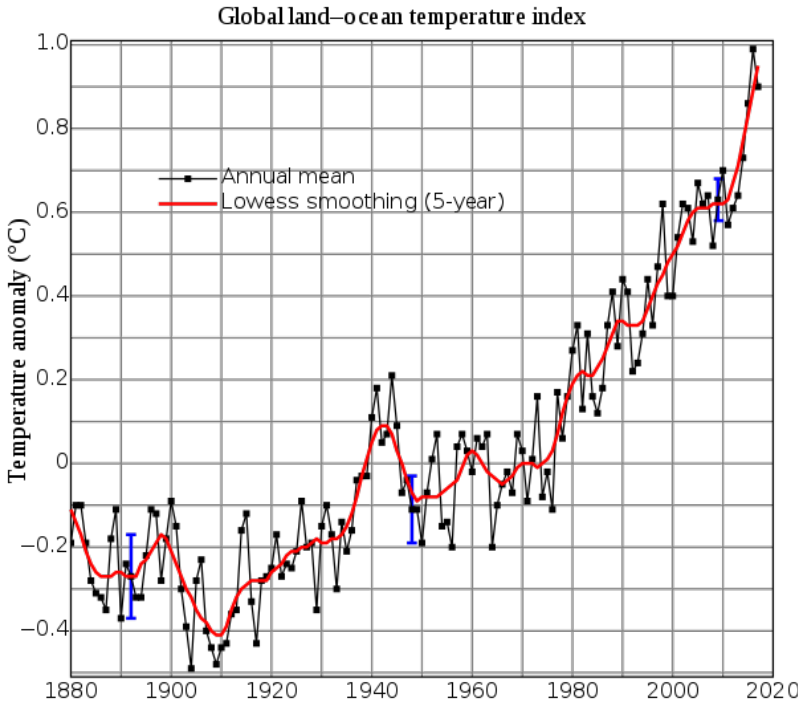
Source: NASA

Greenhouse Effect – Information. Who to trust?

- Intergovernmental Panel on Climate Change, IPCC, formed by UN in 1988, produces periodic Assessment Reports every five to seven years, summarising existing research. The first was in 1990, the fifth in 2014. Special report on $1.5^{\circ}\mathrm{C}$ to be released on 8-10-2018.

  IPCC reports are subject to political pressure e.g. by Saudi delegation; pilloried in the popular press for occasional overestimates; regarded as too cautious by many experts.
- United Nations Environment Program *Emissions Gap Report*, (most recent released 2017)
- NASA and other US Government Agencies display a lot of information online.
- UK Government Committee on Climate Change
- Climate Action Tracker
- Scientists publishing in peer reviewed journals
- Some media organisations (e.g. *Guardian* newspaper) have *Environment* section/website
- Global Warming Policy Foundation (for contrarian view)

Greenhouse Effect – Evidence?



Top 10 warmest years (NOAA)
(1880–2017)

Rank	Year	Anomaly °C	Anomaly °F
1	2016	0.94	1.69
2	2015	0.90	1.62
3	2017	0.84	1.51
4	2014	0.74	1.33
5	2010	0.70	1.26
6	2013	0.66	1.19
7	2005	0.65	1.17
8	2009	0.64	1.15
9	1998	0.63	1.13
10	2012	0.62	1.12

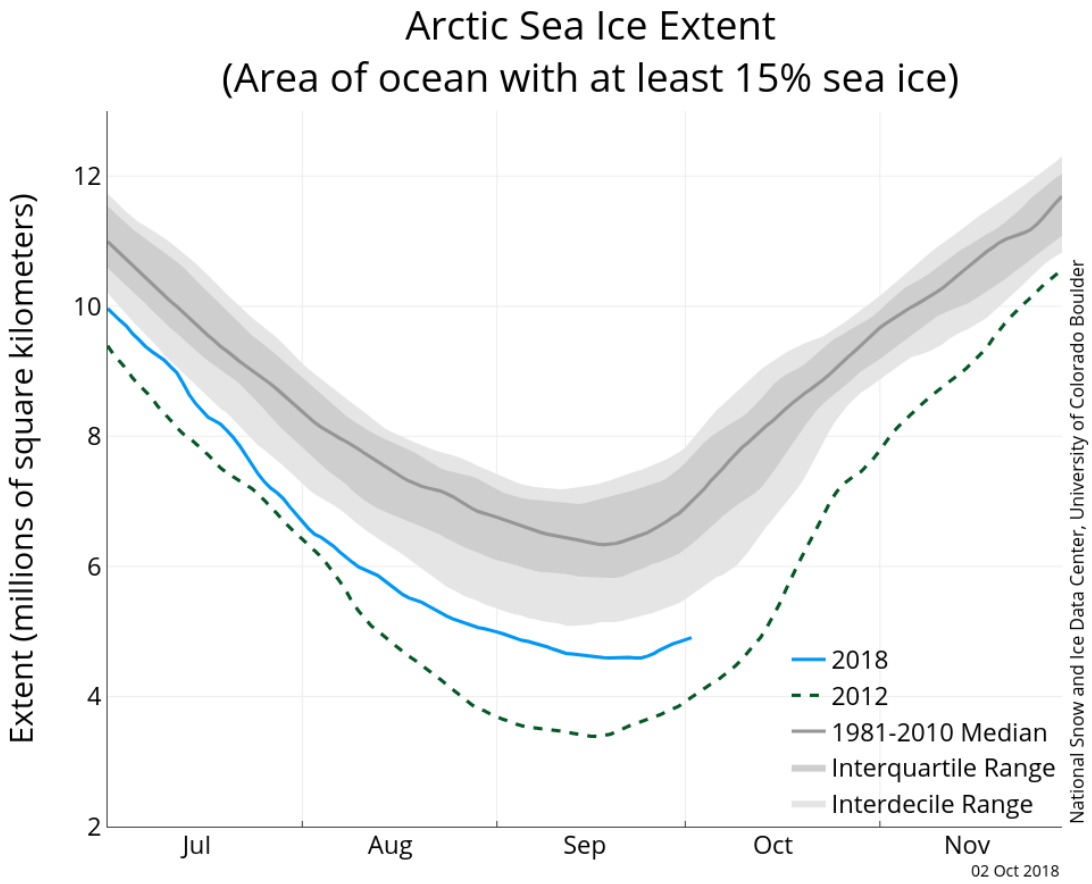
Source: NASA

Fourteen of the fifteen hottest years in recorded history have occurred since 2000. (UN World Meteorological Organisation, 2015)

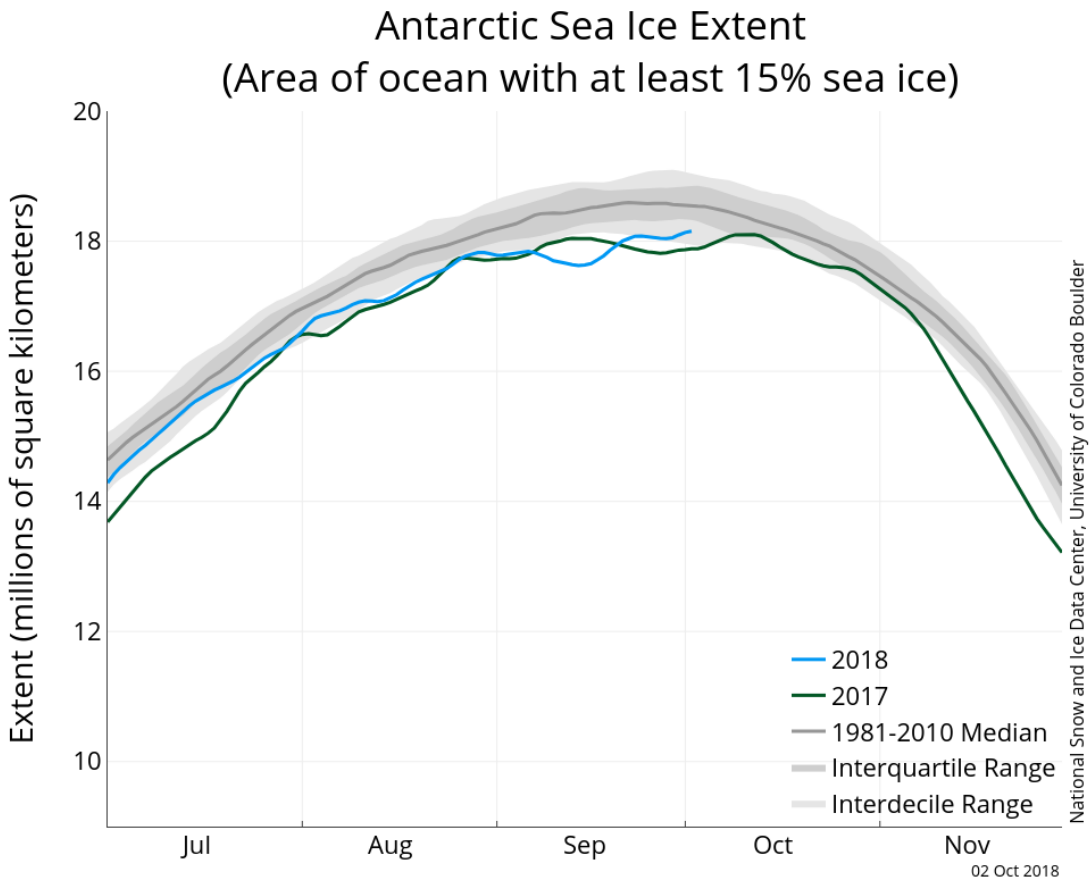
The period from 1983 to 2012 was likely the warmest 30-year period of the last 1400 years in the Northern Hemisphere (Fifth IPCC report, 2014)

For comparison: 20,000 years ago, during the last ice age, global average temperature was approximately $6^{\circ}\mathrm{C}$ colder than today.

Greenhouse Effect – Evidence?



Greenhouse Effect – Evidence?



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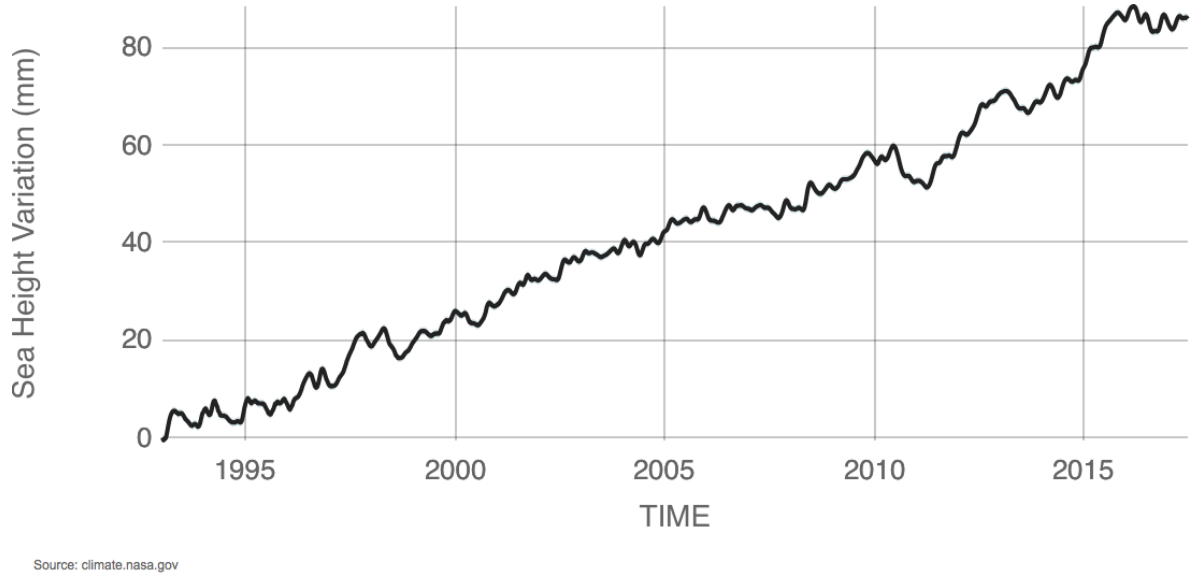

The two major causes of global sea level rise are thermal expansion caused by warming of the ocean (since water expands as it warms) and increased melting of land-based ice, such as glaciers and ice sheets. The oceans are absorbing more than 90 percent of the increased atmospheric heat associated with emissions from human activity.

Higher sea levels mean that deadly and destructive storm surges push farther inland than they once did, which also means more frequent nuisance flooding. Disruptive and expensive, nuisance flooding is estimated to be from 300 percent to 900 percent more frequent within U.S. coastal communities than it was just 50 years ago.

Source: US Dept of Commerce National Oceanic and Atmospheric Administration

Greenhouse Effect – Evidence?

1	Katrina	$62.2bn	2005
2	Sandy	$29.5bn	2012
3	Ike	$18.5bn	2008
4	Andrew	$17bn	1992
5	Ivan	$13.8bn	2004
6	Wilma	$12.5bn	2005
7	Rita	$12.1bn	2005
8	Charley	$8bn	2004
9	Irene	$6bn	2011
10	Frances	$5.5bn	2004

The 10 costliest hurricanes to strike the United States before 2017, as measured by insured losses (Source: Munich Re, Geo Risks Research, in *Vox*, Sep 18, 2017)

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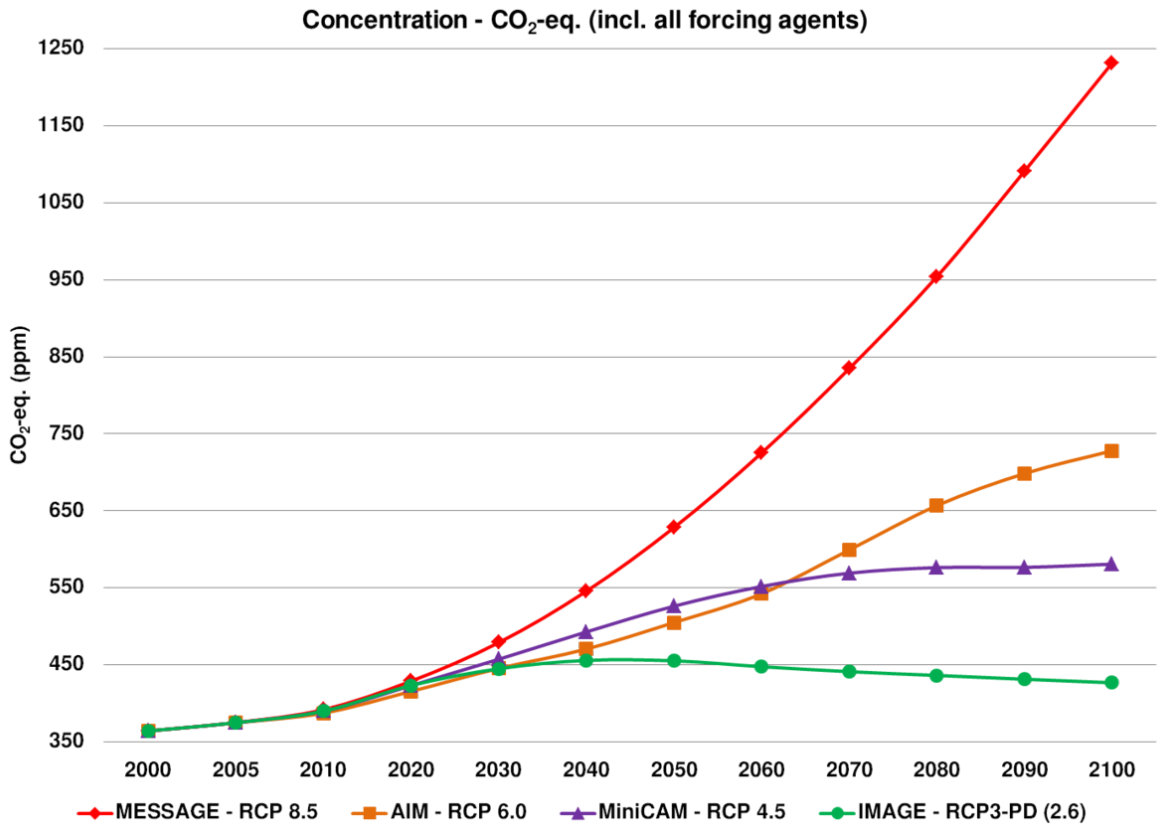
The 10 costliest hurricanes to strike the United States before 2017, as measured by insured losses (Source: Munich Re, Geo Risks Research, in *Vox*, Sep 18, 2017)

Harvey	$150bn	2017
Irma	$75bn	2017
Maria	$40-85bn	2017
Total	$265-305bn	2017
US GDP= $18.57tn.	285bn / 18.5tn $\simeq$ 1.5% of GDP	

Sources: Lloyds underwriter Hiscox for Harvey & Irma (*Independent*, October 2nd 2017; catastrophe modelling firm AIR Worldwide for María, http://www.air-worldwide.com/Press-Releases/AIR-Worldwide-Estimates-Industry-Insured-Losses-for-Hurricane-Maria-in-the-Caribbean/, 25-9-2017.

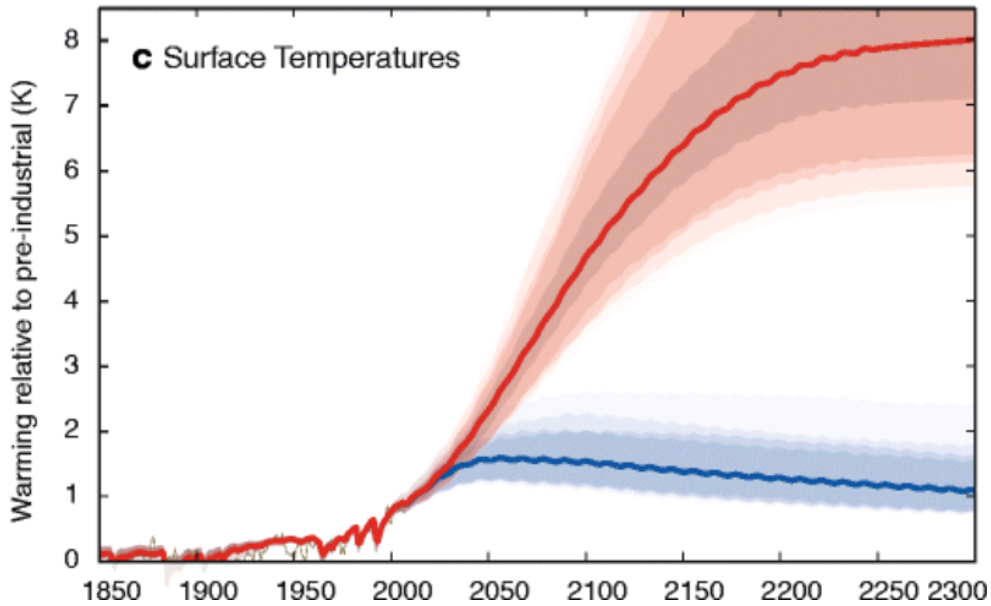
Greenhouse Effect – Predictions

RCP= Representative Concentration Pathway (in 5th IPCC Report). The four RCPs are labelled by the possible range of radiative forcing values in the year 2100 relative to pre-industrial values (+2.6, +4.5, +6.0, and +8.5 W/m2, respectively).



Source: Wikipedia article "Representative Concentration Pathways"

Greenhouse Effect – Predictions



Source: Meinhausen et al, The RCP greenhouse gas concentrations and their extensions from 1765 to 2300, Climatic Change, November 2011, 109:213 (Open access)

Greenhouse Effect – Predictions

IPCC AR5 global mean sea level increase projections (metres)

	2046-2065	2081-2100
Scenario	Mean/Likely range	Mean/Likely range
RCP2.6	0.24 / 0.17 to 0.32	0.40 / 0.26 to 0.55
RCP4.5	0.26 / 0.19 to 0.33	0.47 / 0.32 to 0.63
RCP6.0	0.25 / 0.18 to 0.32	0.48 / 0.33 to 0.63
RCP8.5	0.30 / 0.22 to 0.38	0.63 / 0.45 to 0.82

Greenhouse Effect – Predictions

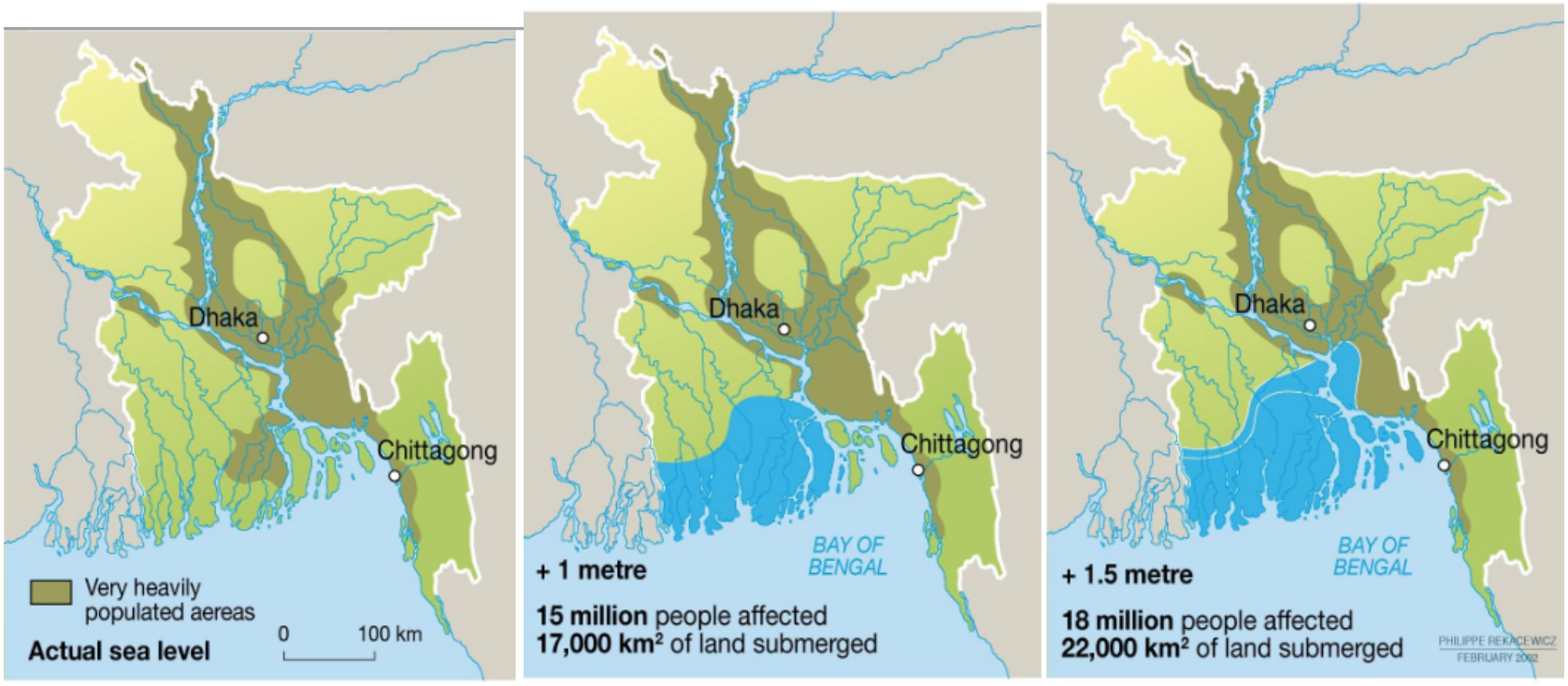
IPCC AR5 global mean sea level increase projections (metres) 90 experts

	2046-2065	2081-2100	2100
Scenario	Mean/Likely range	Mean/Likely range	
RCP2.6	0.24 / 0.17 to 0.32	0.40 / 0.26 to 0.55	0.4 to 0.6
RCP4.5	0.26 / 0.19 to 0.33	0.47 / 0.32 to 0.63	
RCP6.0	0.25 / 0.18 to 0.32	0.48 / 0.33 to 0.63	
RCP8.5	0.30 / 0.22 to 0.38	0.63 / 0.45 to 0.82	0.7 to 1.2

IPCC estimates have been criticised as too conservative. A 2013 paper in Quaternary Sciences Review surveyed 90 experts in 18 countries, and found higher average estimates.

B.Horton et al, Expert Assessment of Sea Level Rise by 2100 and 2300, Quaternary Science Reviews 84 (2014), 1-6

Greenhouse Effect – Predictions: Bangladesh



Where will they go?

Source Vital Water Graphics 2 Cartographer: Phillipe Rekacewicz, February 2008
http://www.grida.no/resources/5648

Greenhouse Effect – Predictions: USA

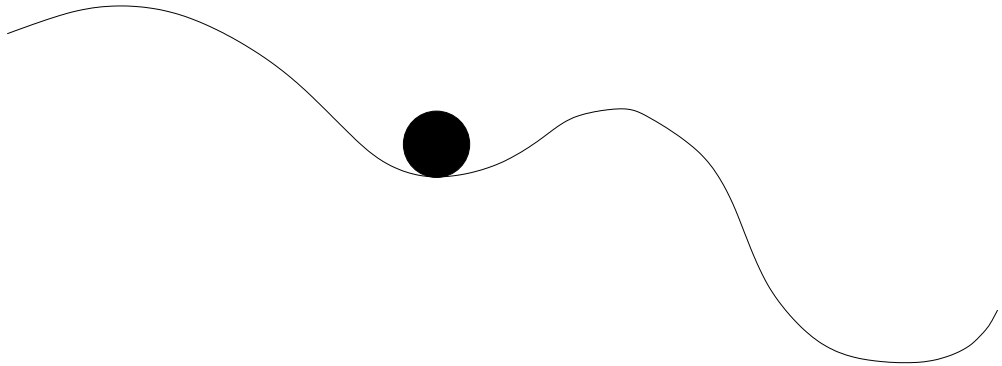
By the end of the century, chronic flooding will be occurring from Maine to Texas and along parts of the West Coast. It will affect as many as 670 coastal communities, including Cambridge, Massachusetts; Oakland, California; Miami and St. Petersburg, Florida; and four of the five boroughs of New York City. The magnitude of the coming calamity is so great, the ripple effects will reach far into the interior.

Source: National Geographic Magazine, July 12, 2017

Melting of all the world's icecaps would raise sea-level by 70 metres. (Homework: draw the new coastline of the UK.) But this is far in the future. How far, we do not know. Probably thousands of years – but beware non-linear effects and feedbacks.

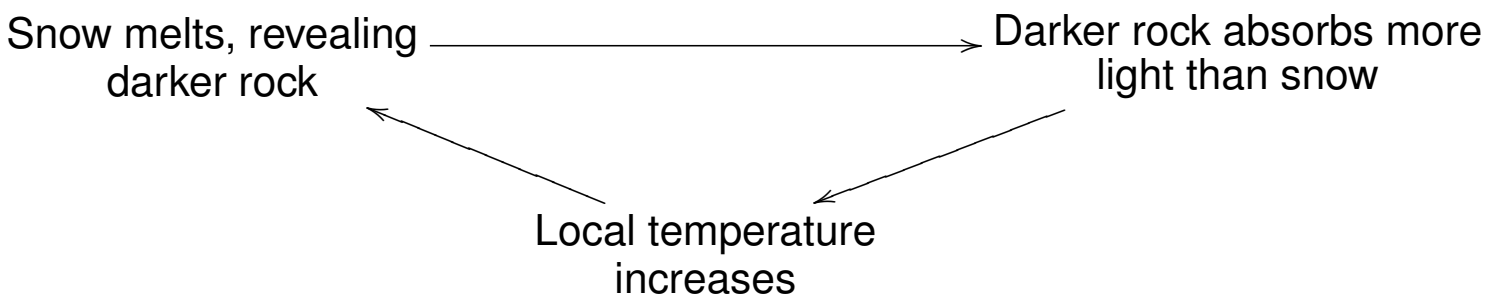
Non-linear phenomena and tipping points

Non-linear: response not proportional to stimulus.

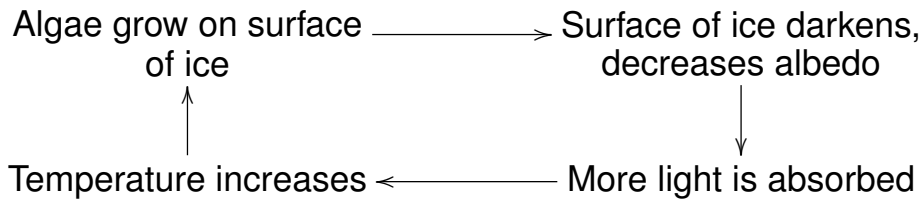


World's best metaphor? See: evolutionary landscape, fitness landscape, energy landscape, ...

Can occur due to feedback mechanisms. Well known example:



Unexpected feedback recently detected on Greenland ice-cap:



Source: *Nature*, July 15th, 2016

We may not know enough to make accurate predictions!

How much temperature rise would be safe?

For reasons more political than scientific, a rise of $2^{\circ}\mathrm{C}$ has become regarded as the upper limit of what is "safe", and an acceptable aim for climate treaties. This is what Paris treaty aimed for, though with the additional hope that the temperature rise would be limited to $1.5^{\circ}\mathrm{C}$ if possible. Recently $1.5^{\circ}\mathrm{C}$ has become more prominent, probably due to the realisation that $2^{\circ}\mathrm{C}$ would lead to the disappearance of several small island nations under the sea.

Would limiting temperature change to 2 °C prevent dangerous climate change?

Not at all clear. Significant tipping points, leading to major changes in climate – e.g. disruption of the North Atlantic thermo-haline circulation (NATHC) – are more likely to occur with greater temperature changes, but might occur even with this "safe" temperature rise. (Average temperatures in Kamchatka, Siberia, at same latitude as Scotland, are 12°C colder. Disruption of NATHC would lead to similar degree of *warming* in the Caribbean.)

A 2015 paper in Proc Nat Acad Sci USA finds that many of the IPCC climate models predict significant tipping points occur before a 2°C rise: (Sybren Drijfhout et al *Catalogue of abrupt shifts in IPCC climate models*)

Example: Unexpected growth of algae on warming Greenland ice surface.

Possibility: Release of methane clathrates from warming tundra and sea-beds.
(http://worldoceanreview.com/en/wor-1/ocean-chemistry/climate-change-and-methane-hydrates/)

2. But let's stick with 2°C . . . How to achieve it?

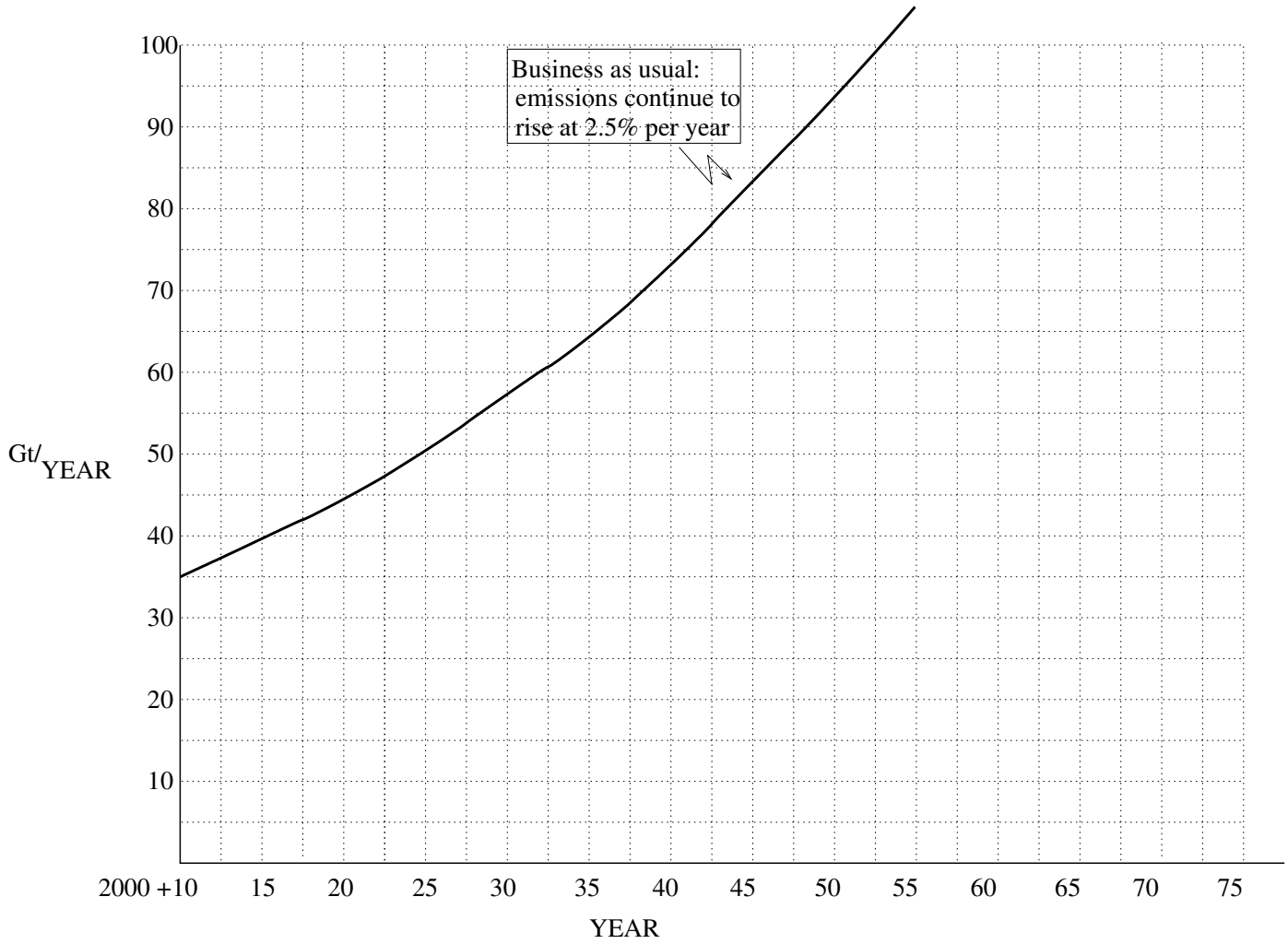
Simple answer (with much uncertainty): limit atmospheric CO2 to about 3 670 gigatonnes (Gt).
Since the industrial revolution, the world has emitted around 1,900 Gt CO2 and so has used up a large part of this budget. Other anthropogenic greenhouse gases have an impact on global warming and reduce the total available budget to about 2 900 Gt CO2.
This leaves less than about 1 000 Gt CO2 to emit in the future.(Source: United Nations Environment Programme *Fifth Emissions Gap Report*, 2014)

How can these emissions best be spread out over time; at what point should net emissions fall to zero? Can they fall to zero?

We can make a crude calculation ourselves:

How to limit the temperature rise to 2°C ?

To limit atmospheric CO2 to about 3 670 Gt, what emissions can we allow?



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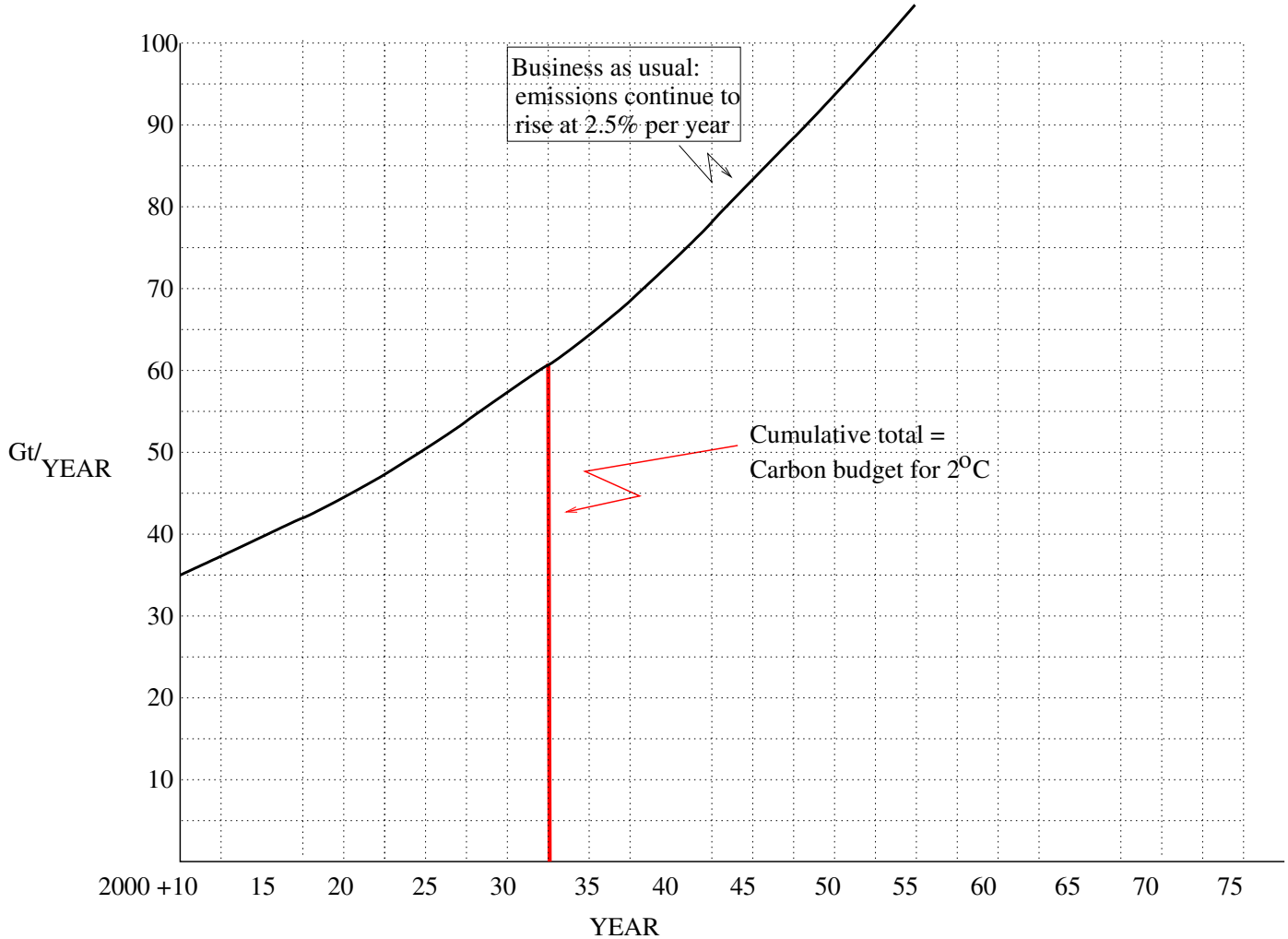

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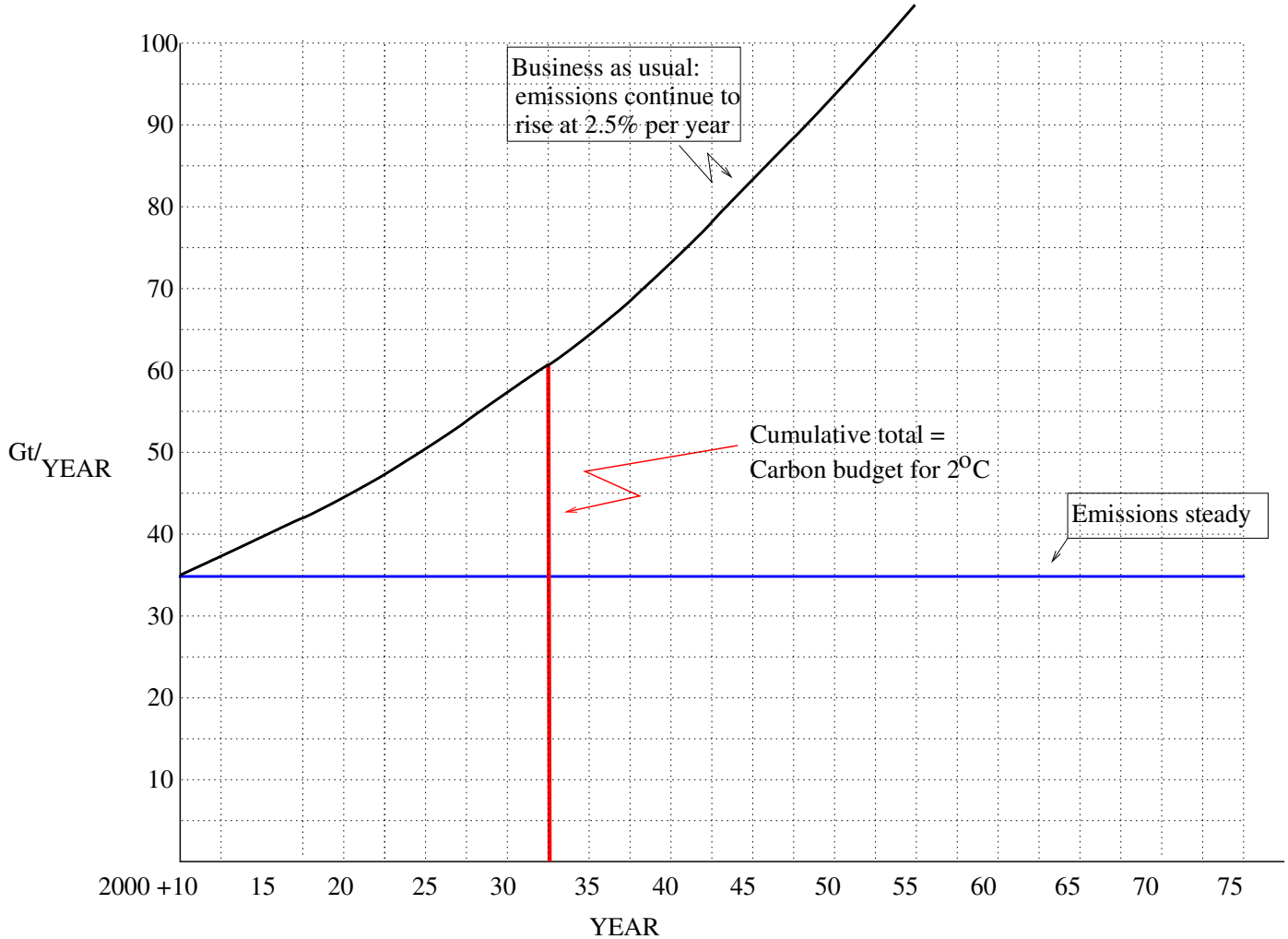

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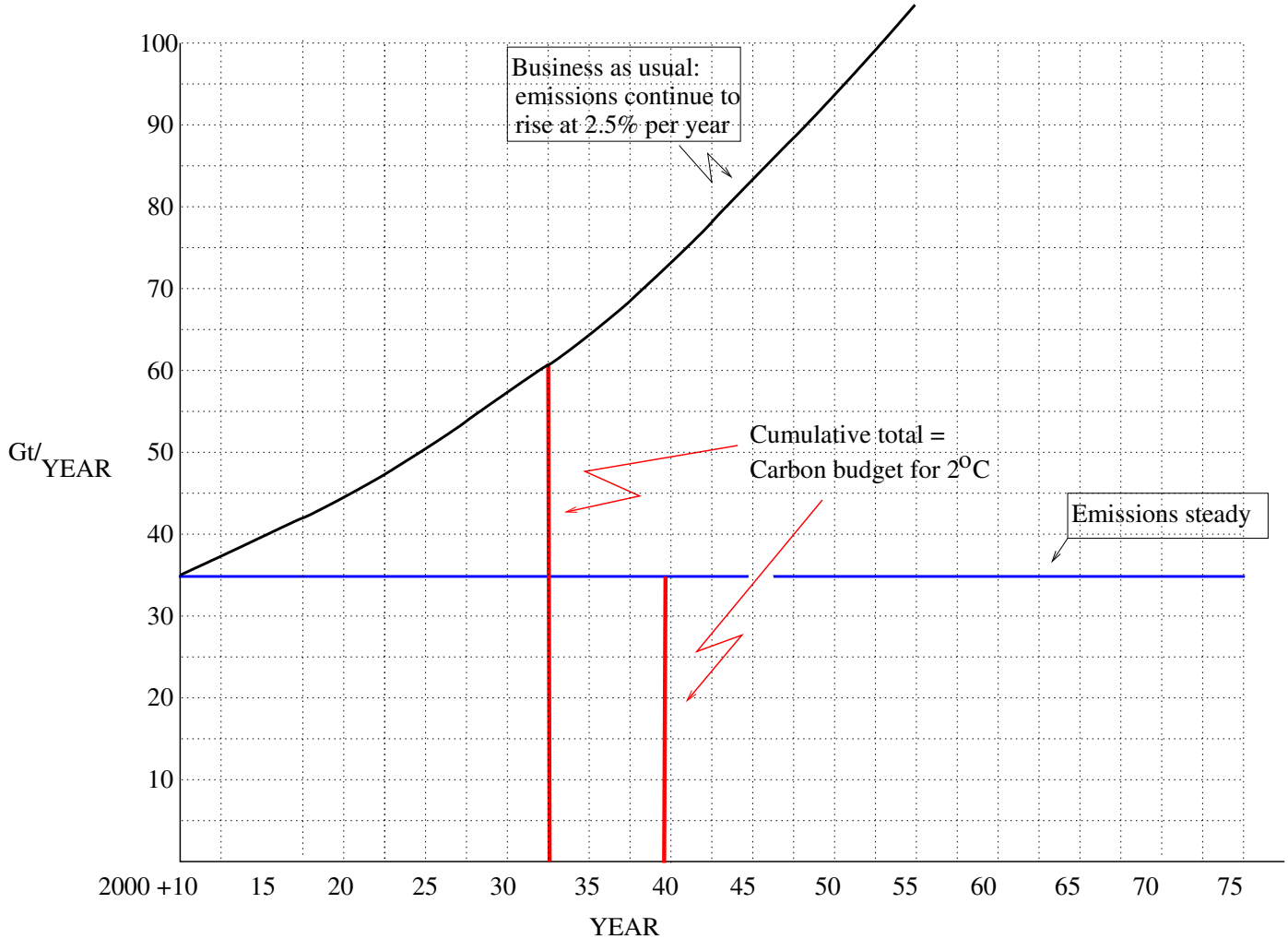

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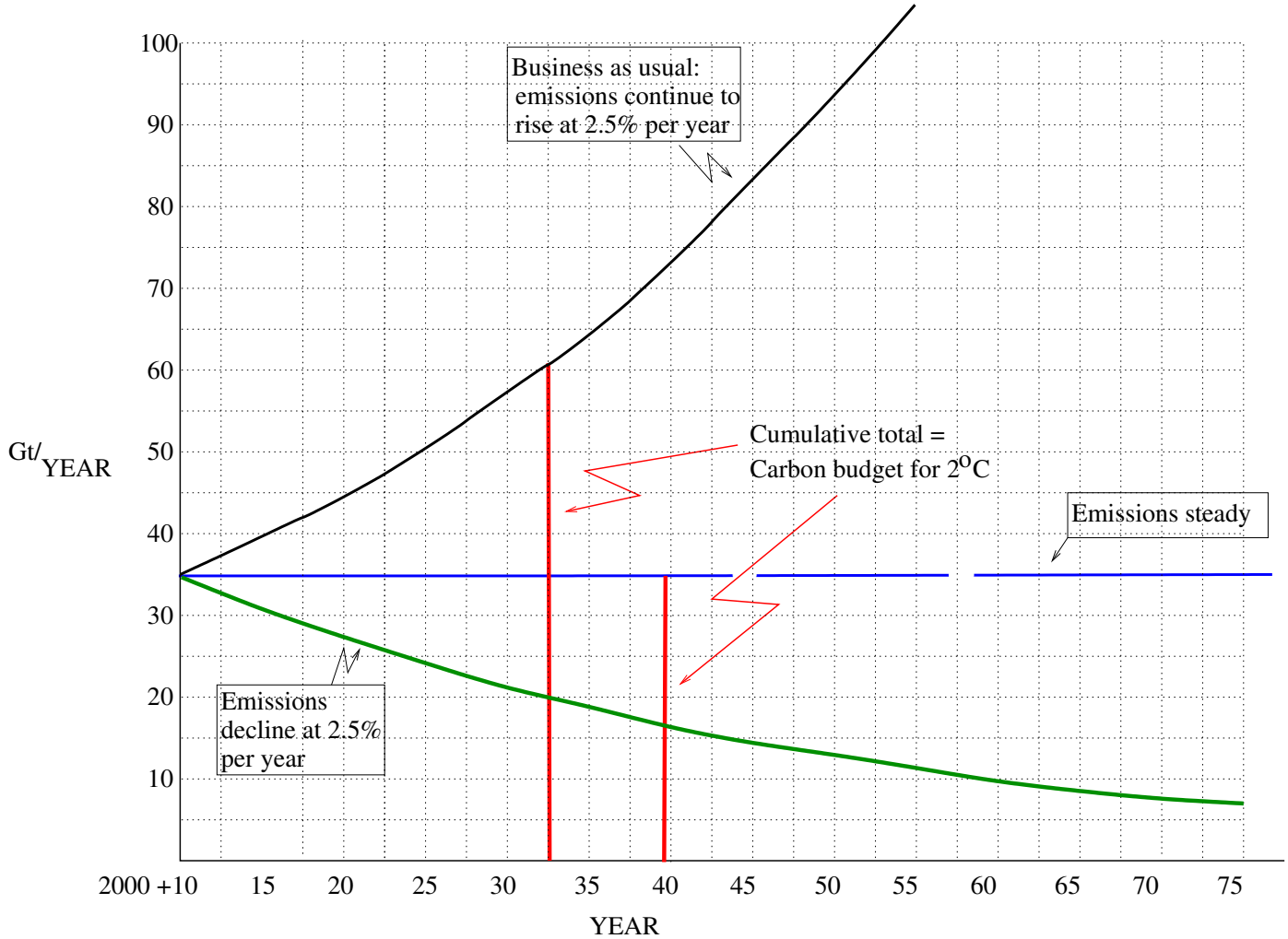

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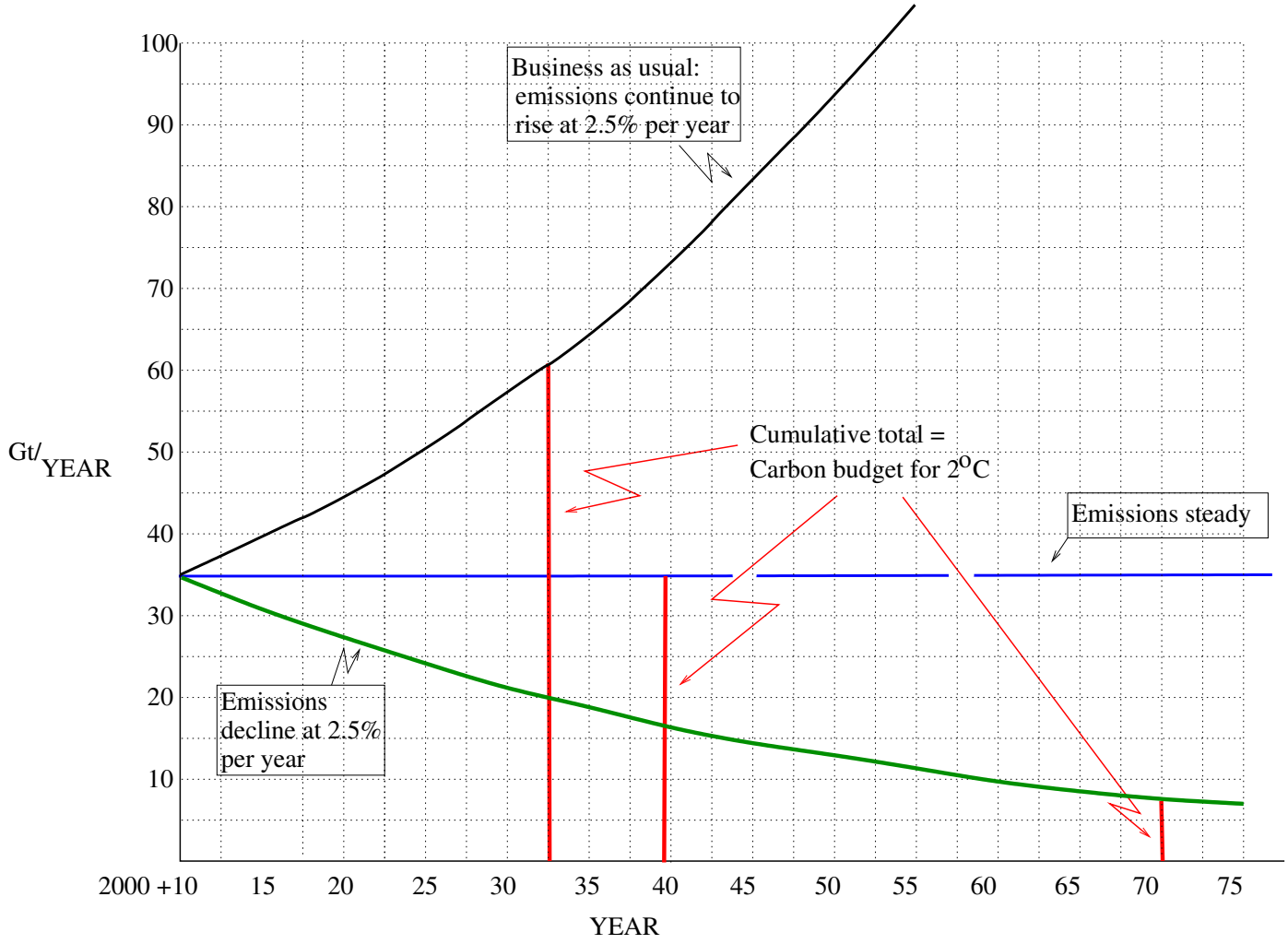
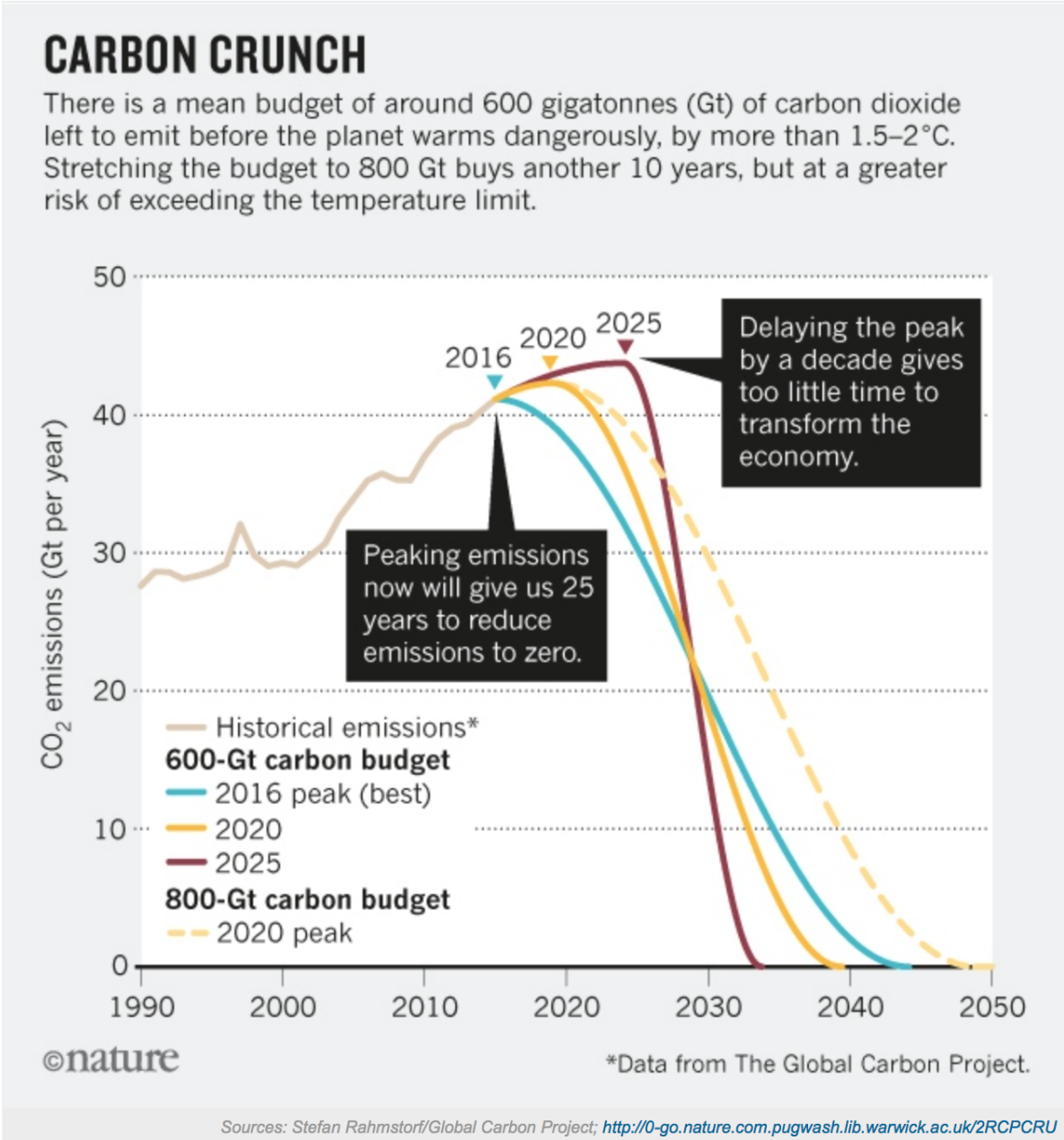


A more urgent calculation from the Potsdam Institute for Climate Research



What if we overshoot?

Can we extract carbon from the atmosphere? Some means to do this already exist, e.g. forests.

Tropical forests, the heaviest, contain 170-250 tonnes of carbon per hectare. So an overshoot of 100 Gt of CO2 ($=$ 27Gt C), one tenth of the remaining carbon budget for $2^{\circ}\mathrm{C}$, would require between 10^8 and 1.5×10^8 hectares of tropical forest, $=$1 to 1.5 million square km of tropical forest, fully grown. Roughly twice as much boreal forest would be required. The area of the Amazon rainforest is 5.5 million sq km.

But population increase is driving in the opposite direction: forests are being cut rather than planted. A recent study published in *Science* finds that tropical forests are now a carbon source rather than a sink, due to deforestation and depletion.

High-tech fixes?

Carbon capture and storage/sequestration, CCS, can in principle remove up to 90% of the CO2 during combustion, but is expensive. Several trials took place in the UK. The most advanced, the White Rose project based at the Drax power station in Yorkshire, was closed in April 2016. In 2016, MIT closed its CCS programme.

BECCS (Bioenergy with CCS – burn biomass instead of fossil fuels) – can be carbon *negative*. There are 15 pilot projects worldwide. The scale is challenging: to remove 10 gigatons of carbon without destroying existing forest would require creating forest the size of India. IPCC estimates in 2014 suggested a cost of between \$60 and \$250 per ton of carbon removed. Most IPCC scenarios that limit warming to $2^{\circ}\mathrm{C}$ rely on BECCS

But BECCS and CCS can never compete on cost alone with unfiltered fuels, so large scale implementation inmpossible without regulation, subsidy or a carbon tax.

Purely technological techniques for capturing existing CO2 are being researched. The *Virgin Earth Challenge* offers a prize of \$25 million for a technology tried and proven over 10 years, beginning in 2011. Its website lists 11 finalists.

It is possible that no fix will enable us to continue burning fossil fuels, or will rapidly reduce CO2 if it exceeds the budget for $2^{\circ}\mathrm{C}$. To stay within the budget for $2^{\circ}\mathrm{C}$, carbon emissions need to shrink to zero some time between 2050 and 2060.

How to achieve this?

The United Nations Framework Convention on Climate Change, UNFCCC

is an international environmental treaty adopted on May 9, 1992. Since 1995 it has run an annual "conference of the parties" (COP) with the aim of achieving agreement on emissions limitations.

Its 48'th session, to prepare a special report "Global Warming of $1.5^{\circ}\mathrm{C}$ " ends today (see press release on IPCC website and via our *Climate Change in the News* page).

In 1997 COP3, in Kyoto, approved the Kyoto Protocol, under which developed nations agreed to reduce their emissions by an average of 5% while leaving developing nations free to continue to emit as before. The United States and Canada signed but later withdrew, and the overall results were mixed.

Despite nearly 30 years of the UNFCCC's efforts, CO2 emissions, and temperatures, continue to rise.

Not just rocket science ...

Why so little success?

- Is it politics?
- Is it big business?
- Is it the dishonest press, in the hands of the fossil fuel lobby?
- Is it our electoral system, incapable of dealing with a threat that takes longer than one electoral cycle to materialise?
- Is it the division of the world into separate competing nations?
- Is it capitalism?
- Is it the timescale of climate change, whose future victims are out of sight and beyond the range of our concern?

> *In terms of getting people to care about global warming enough to demand a government response or to take personal action, you couldn't design a problem that's a worse fit for our psychology*

Andrew Leiserowitz, director of the Yale Project on Climate Change Communication

Paris 2015: COP21- a new approach

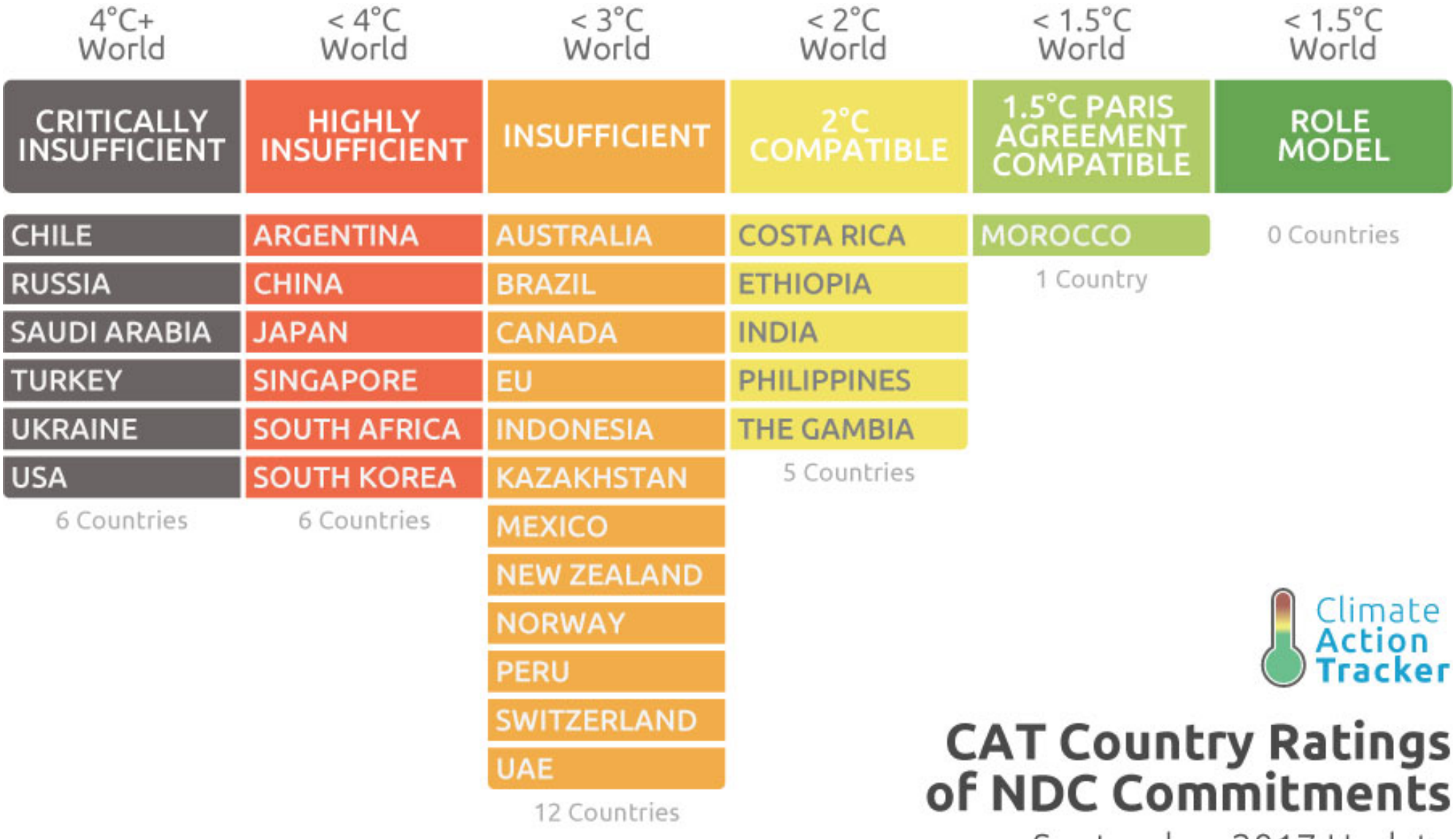
Until COP21, the emphasis had always been on getting a binding agreement. The problem was that no-one was willing to be bound. Developing nations insisted on their right to emit as much carbon as the developed nations as they strove to reach the rich world's levels of prosperity. Developed nations insisted that unless the developing nations agreed to limit their emissions, to do so themselves would unfairly burden their economies.

The strategy at Paris was different. Each nation was invited to submit an Intended Nationally Determined Contribution – a pledge to reduce its carbon emissions by whatever amount it independently chose. The pledges were made and the agreement signed in December 2015. The pledges would be activated if and when a sufficient number of the participants (55, accounting for at least 55% of global emissions) ratified the agreement. This was achieved in October 2016. The INDCs became NDCs.

Preparation for COP21 was led by Christiana Figueres, of Costa Rica – see her TED talk.

Are the pledges sufficient? The website Carbon Action Tracker has assessed 30 NDCs and rated each one:

CAT ratings


4°C+ World
< 4°C World
< 3°C World
< 2°C World
< 1.5°C World
< 1.5°C World
CRITICALLY INSUFFICIENT
HIGHLY INSUFFICIENT
INSUFFICIENT
2°C COMPATIBLE
1.5°C PARIS AGREEMENT COMPATIBLE
ROLE MODEL
CHILE
RUSSIA
SAUDI ARABIA
TURKEY
UKRAINE
USA
6 Countries
ARGENTINA
CHINA
JAPAN
SINGAPORE
SOUTH AFRICA
SOUTH KOREA
6 Countries
AUSTRALIA
BRAZIL
CANADA
EU
INDONESIA
KAZAKHSTAN
MEXICO
NEW ZEALAND
NORWAY
PERU
SWITZERLAND
UAE
12 Countries
COSTA RICA
ETHIOPIA
INDIA
PHILIPPINES
THE GAMBIA
5 Countries
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1 Country
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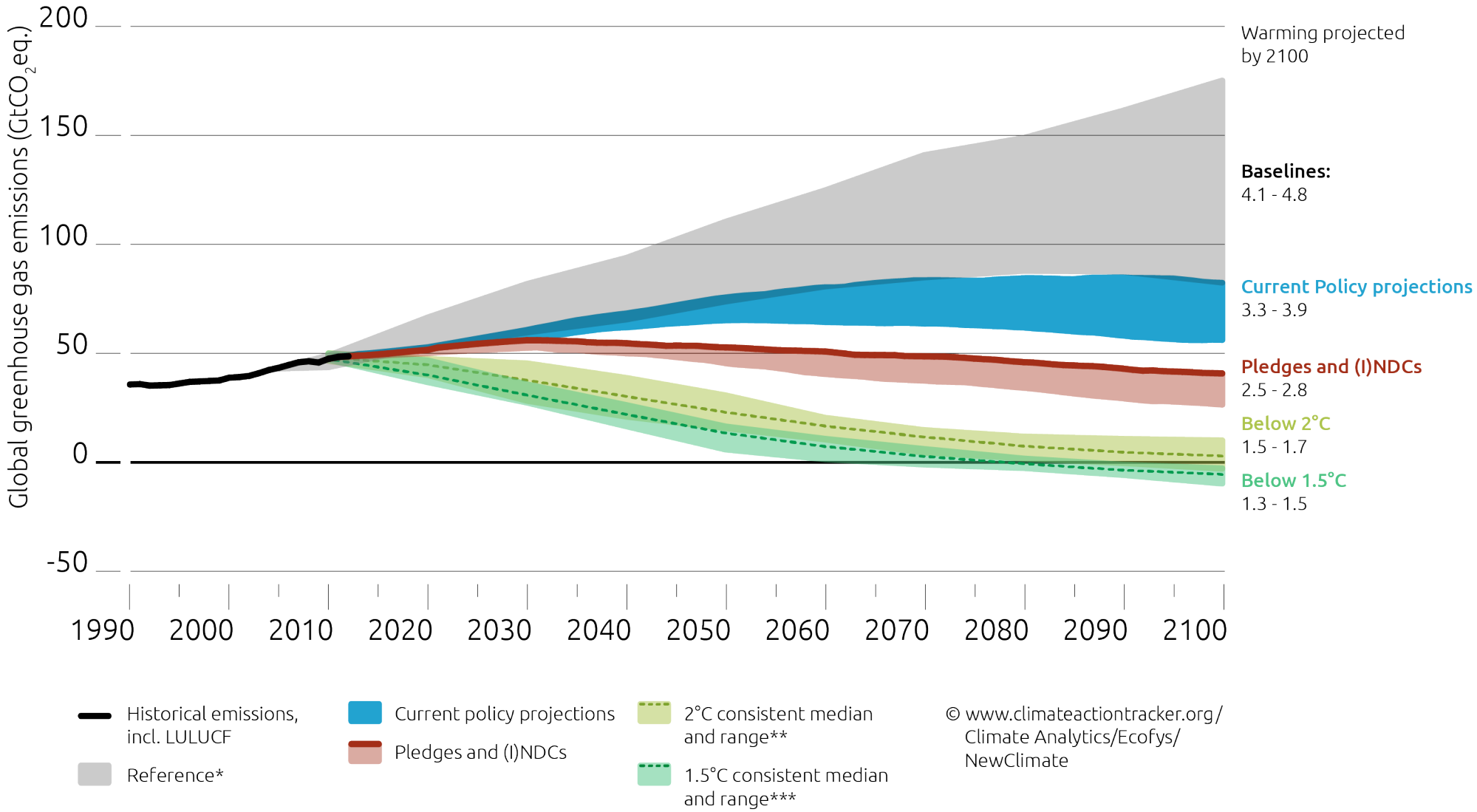
Climate Action Tracker
CAT Country Ratings of NDC Commitments
September 2017 Update

CAT predictions



* 5%-95% percentile of AR5 WGIII scenarios in concentration category 7, containing 64% of the baseline scenarios assessed by the IPCC

** Greater than 66% chance of staying within 2°C in 2100. Median and 10th to 90th percentile range. Pathway range excludes delayed action scenarios and any that deviate more than 5% from historic emissions in 2010.

*** Greater than or equal to 50% chance of staying below 1.5°C in 2100. Median and 10th to 90th percentile range. Pathway range excludes delayed action scenarios and any that deviate more than 5% from historic emissions in 2010.

Will it work? Two comments on the Paris Agreement

- James Hansen, the father of climate change research:

  It's a fraud really, a fake. It's just bullshit for them to say: "We'll have a 2C warming target and then try to do a little better every five years." It's just worthless words. There is no action, just promises. As long as fossil fuels appear to be the cheapest fuels out there, they will be continued to be burned.

- John Kerry, then US Secretary of State

  Look, I have great respect for Jim Hansen [. . .] I understand the criticisms of the agreement because it doesn't have a mandatory scheme and it doesn't have a compliance enforcement mechanism. That's true.
  What we're doing is sending the marketplace an extraordinary signal – that those 186 countries are really committed – and that helps the private sector to move capital into that, knowing there's a future that is committed to this sustainable path.
  The result will be a very clear signal to the marketplace of the world that people are moving into low carbon, no carbon, alternative renewable energy. And I think it's going to create millions of jobs, enormous new investment in R& D, and that R& D is going to produce the solutions, not government.

Sources: Oliver Milman, "James Hansen, Father of Climate Change Awareness, Calls Paris 'A Fraud', *Guardian*, 12-12-2015, and "John Kerry rejects leading climate scientist's claim Paris talks were 'fraud'", *Guardian* 13-12-2015