IPCC RCP scenarios –
Implications for averting catastrophic Earth system changes

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Intergovernmental Panel on Climate Change

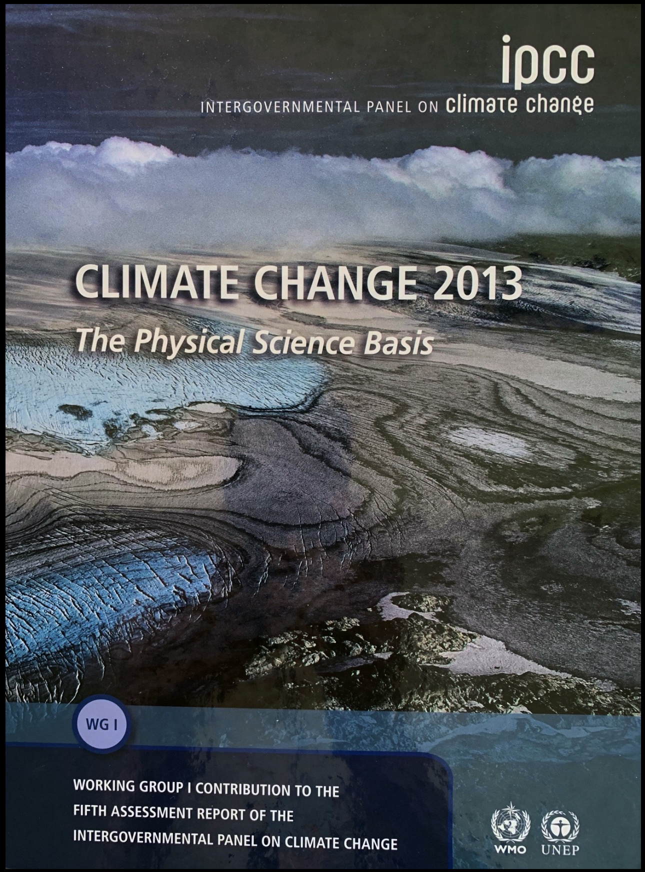
IPCC is the United Nations body for assessing the science related to climate change.

- Divided into three working groups (WG):
  - WG I – The Physical Science Basis of Climate Change
  - WG II – Climate Change Impacts, Adaptation & Vulnerability
  - WG III – Mitigation of Climate Change

- Produced five assessment reports (AR) since 1990

Representative Concentration Pathway (RCP) is a greenhouse gas concentration trajectory adopted in AR5.

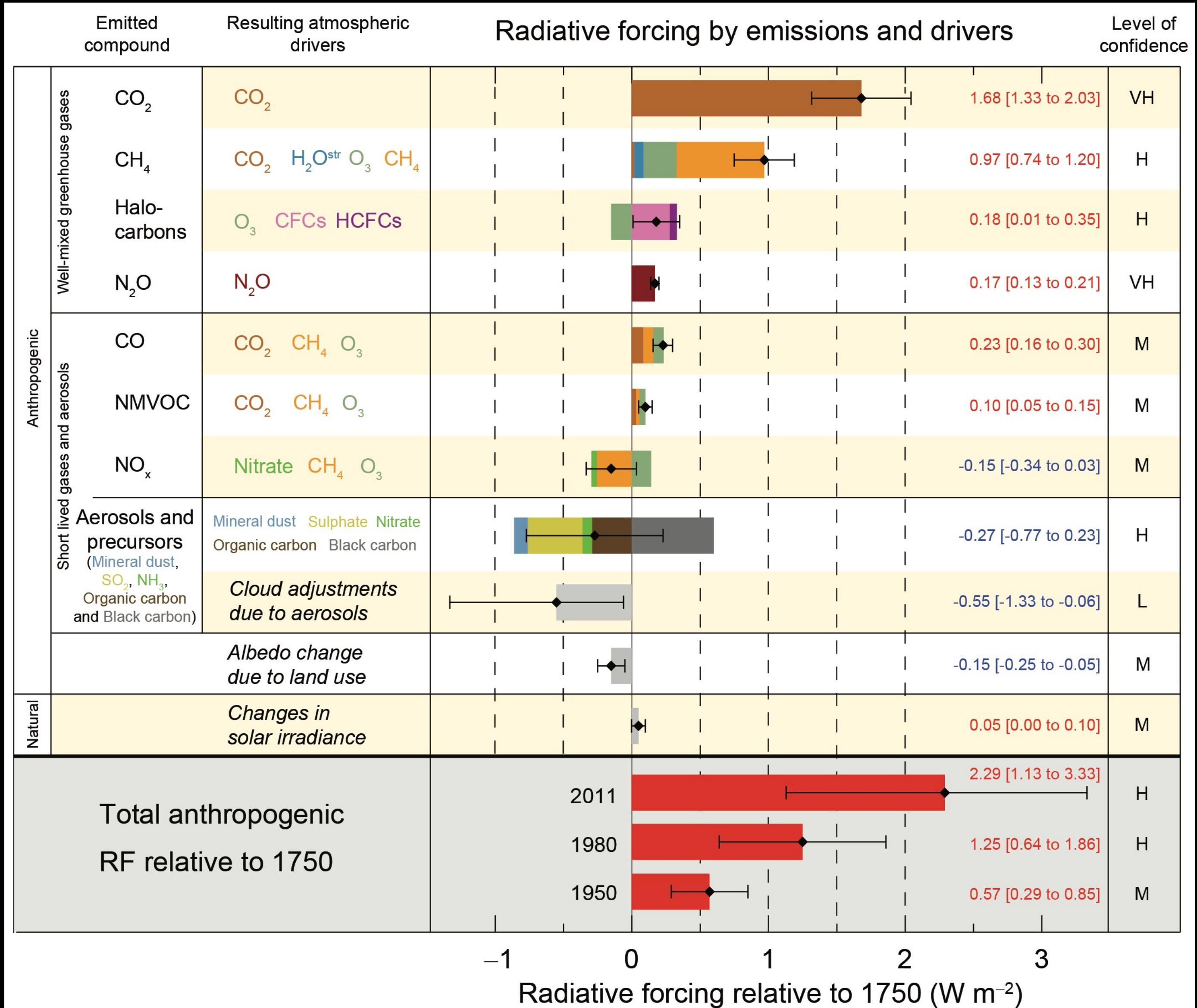
- Named after a range of possible radiative forcing values (W/m^2) in the year 2100 (relative to 1750)
  - 2.6
  - 4.5
  - 6.0
  - 8.5



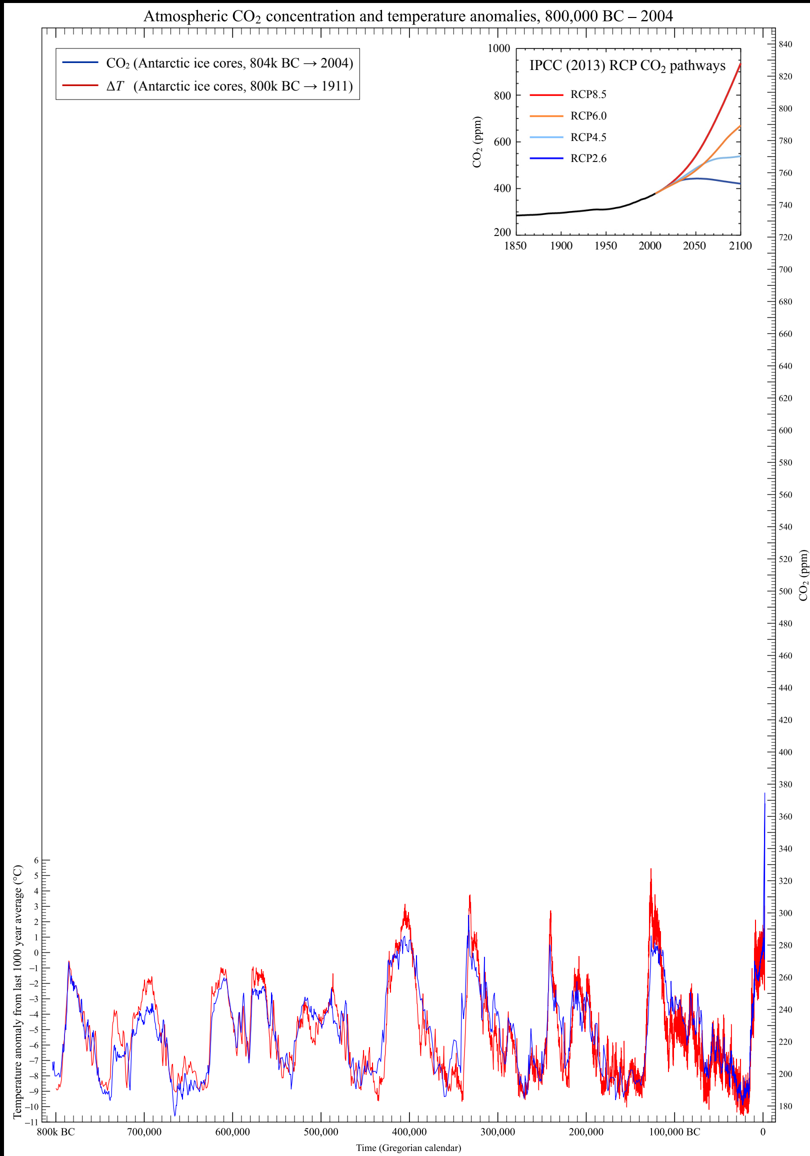
Radiative forcing [W/m²]: the change in the net, downward minus upward, radiative flux due to a change in an external driver of climate change, *e.g.*

– CO_2 concentration change
– solar output

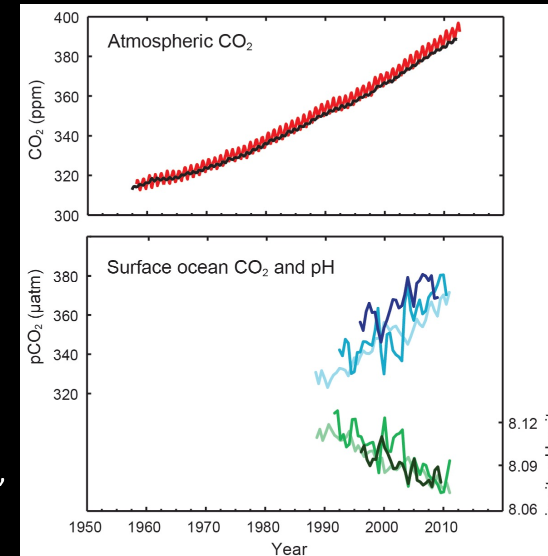
Total human RF is +2.3 W/m²
=> uptake of energy by the climate system
=> warming until energy balance is restored



(IPCC, 2013)

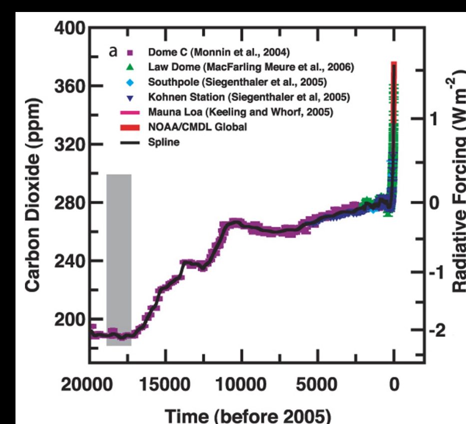


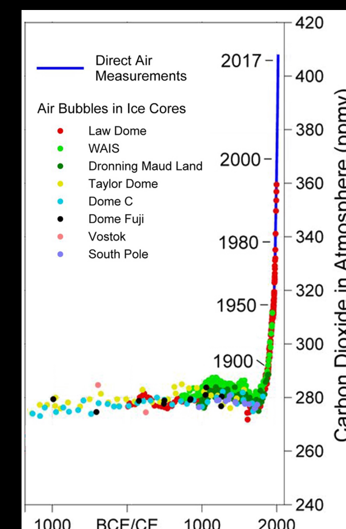
(Bereiter *et al.*, 2015, Jouzel *et al.*, 2007, IPCC, 2013)



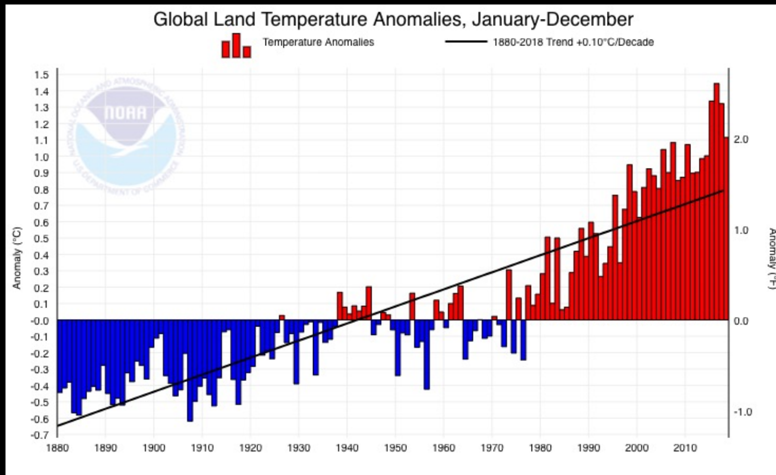
The ocean has absorbed ~30% of human CO_2 emissions, causing observed ocean acidification

(IPCC, 2013)

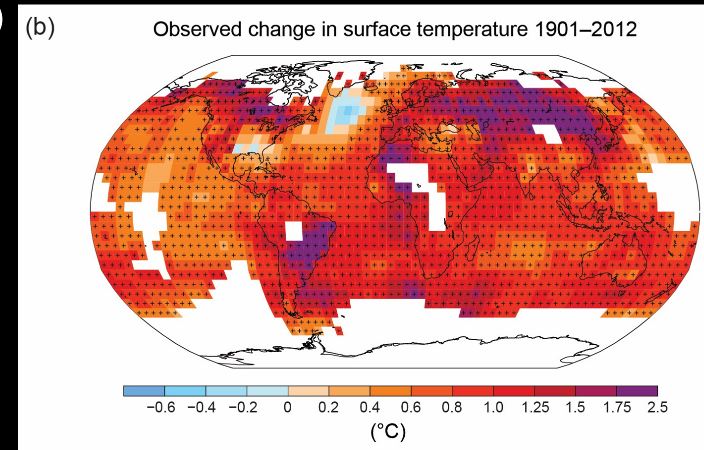




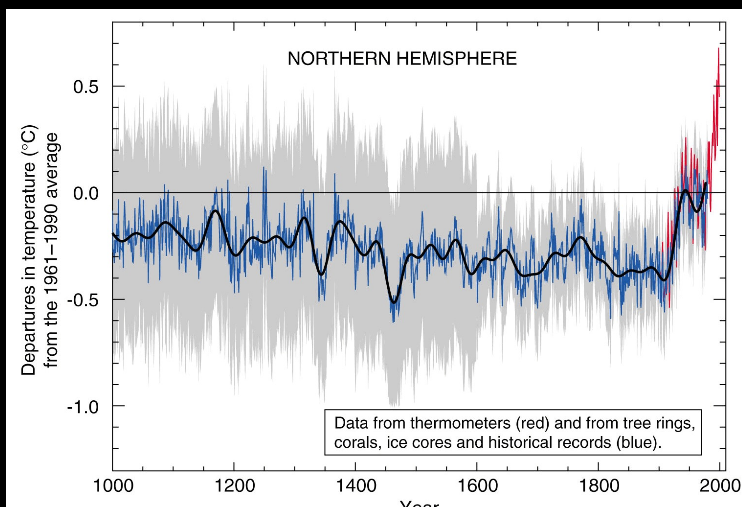
Surface temperature change



(IPCC, 2013)



Globally and annually averaged warming due to human activity since 1750 is approaching 1.5 °C

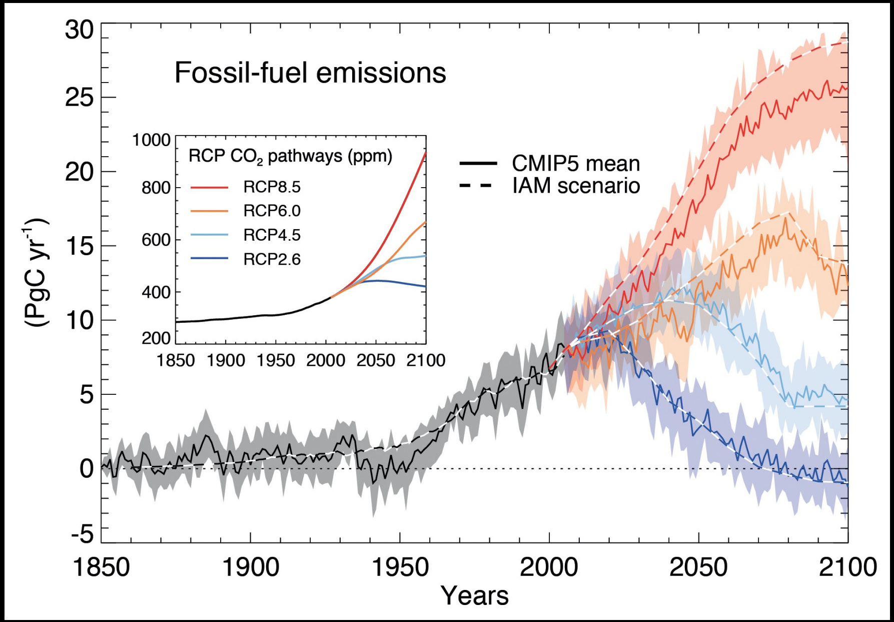


Δ 10°C = 18°F

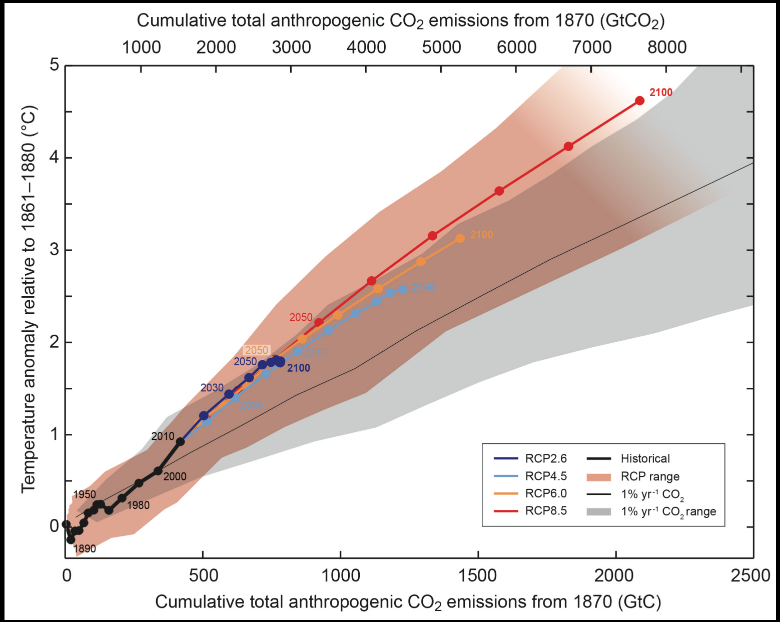
(Mann and Bradley, 1999)

Muir Glacier, AK (NASA)

RCP scenarios

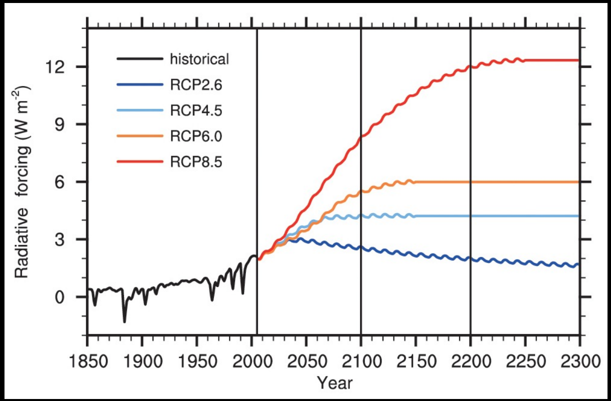


(IPCC, 2013)



2018 emissions: 37.1 $GtCO_2$ (Global Carbon, 2018)

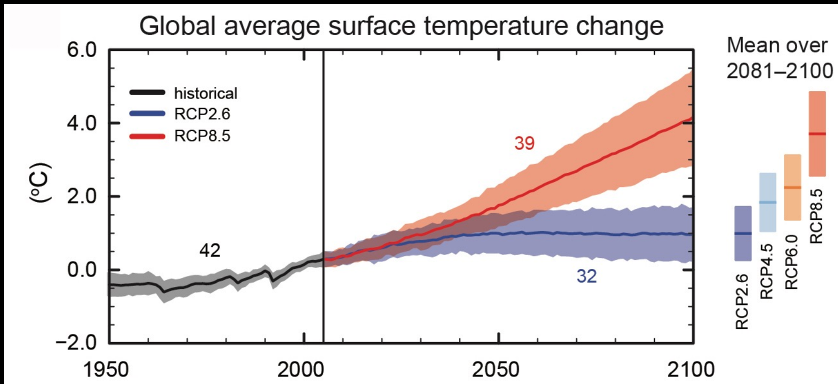
Humanity is currently exceeding RCP 8.5



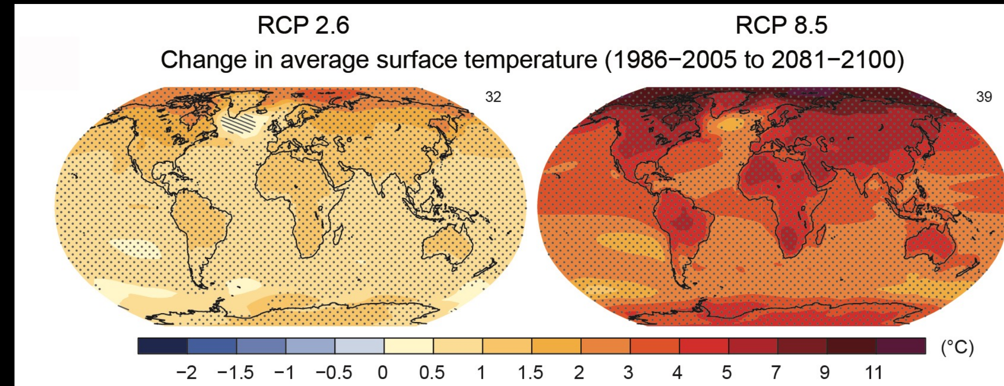
(IPCC, 2013)

1 ppm ≈ 2.1 GtC = 7.8 $GtCO_2$
1 PgC = 1 GtC = 3.7 $GtCO_2$

Surface temperature change projections



(IPCC, 2013)



(IPCC, 2013)

“At present, the Paris Agreement (COP 21) voluntary emission reduction commitments, if implemented, would result in planetary warming of 3.4°C by 2100 without taking into account ‘long-term’ carbon- cycle feedbacks.”

“With a higher climate sensitivity figure of 4.5°C, for example, which would account for such feedbacks, the Paris path would result in around 5°C of warming, according to a MIT study.” (Spratt 2018)

Δ 10°C = 18°F

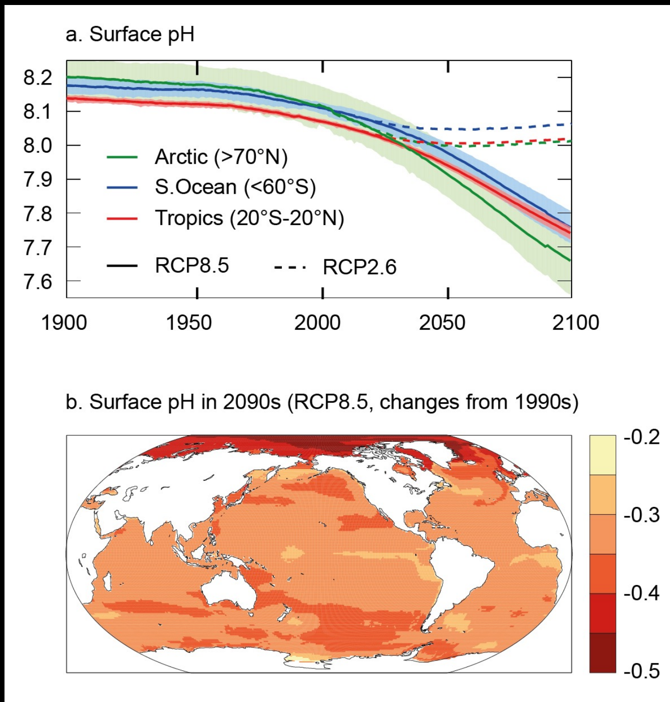
Δ 4°C (globally & annually averaged)
=> 6–8°C in China
8–10°C in Central Europe
10–12°C in New York

4°C => “Incompatible with an organized global community, is likely to be beyond ‘adaptation’, is devastating to the majority of ecosystems, and has a high probability of not being stable”.
– Prof. Kevin Anderson

“The limits for adaptation for natural systems would largely be exceeded throughout the world” (Warren, 2011)

“A 4°C warming by 2100 would subject 47% of the land area and almost 74% of the world population to deadly heat, which could pose existential risks to humans and mammals alike unless massive adaptation measures are implemented.”
(Xu & Ramanathan, 2017)

Ocean acidification



(IPCC, 2013)

In the past 200 years, ocean water has become ~30% more acidic.

"Evidence suggests that the current rate of ocean acidification is the fastest in the last 66 million years and possibly even the last 300 million years" (USGCRP, 2017)

Pteropod shell dissolved over 45 days in seawater with pH projected for 2100: IS92a path, ~ between RCP 6.0 & 8.5. (Orr *et al.,* 2005)

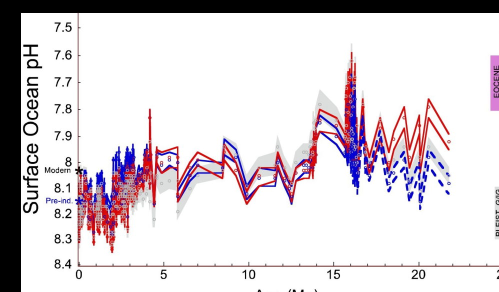
'Severe levels' of Pteropod shell dissolution in the Southern Ocean were first reported in 2012 (Bednaršek *et al.*, 2012)

The decrease in surface ocean pH is projected to be:

- ~0.065 (RCP 2.6) => 15 to 17% ↑ in acidity
- ~0.31 (RCP 8.5) => 100 to 109% ↑ in acidity

"Some of the presumed acidification events in Earth's history have been linked to selective extinction events suggestive of how guilds of species may respond to the current acidification event." (USGCRP, 2017)

RCP 8.5 could result in the lowest pH levels (~7.8) observed in the last 14 million years (Sosdian *et al.*, 2018)



(Sosdian *et al.*, 2018)

Mitigation strategies for avoiding dangerous to catastrophic climate changes

Risk categories
- >1.5 °C: dangerous
- >3.0 °C: catastrophic
- >5.0 °C: unknown, implying beyond catastrophic, including existential threats.

Probability categories
- LPHI: low-probability (5%) high-impact warming
- Central warming: ~50% probability

Case: unchecked emissions 2050
- Central warming in dangerous category
- LPHI warming in catastrophic category

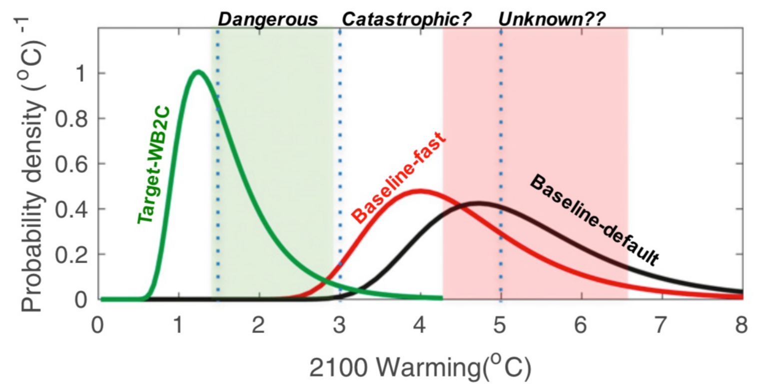


Fig. 2. Probability density function of projected warming in 2100 for the baseline-default, baseline-fast, and Target-WB2C (CN2030 + SLCP2020 + CES1t) scenarios. The green and red color shading shows the 50–95% range of the projection for the Target-WB2C and baseline-fast scenarios due to uncertainty in climate sensitivity. The vertical dotted lines indicate the range of the three risk categories as defined in this study.

(Xu and Ramanathan, 2017)

Table 1. Scenarios of CO_2 and SLCPs considered in the study

Scenario acronyms	Decarbonization pathway toward carbon neutrality starting at?	SLCPs mitigation starting at?	CES included?
Baseline-default (RCP8.5)	No (*SI Appendix*, Fig. S1*B*)	No	No
Baseline-fast (RCP6.0-like)	No (*SI Appendix*, Fig. S1*A*)	No	No
Target-2C (CN2030 + SLCP2020)	2030 (*SI Appendix*, Fig. S2*A*)	2020 (*SI Appendix*, Fig. S4)	No
Target-1.5C (CN2020 + SLCP2020)	2020 (*SI Appendix*, Fig. S2*B*)	2020 (*SI Appendix*, Fig. S4)	No
Target-WB2C (CN2030 + SLCP2020 + CES1t)	2030 (*SI Appendix*, Fig. S2*A*)	2020 (*SI Appendix*, Fig. S4)	Yes (*SI Appendix*, Fig. S2*C*)
FixedConcentration2020	2020, but the reduction rate is slower than CN2020 (*SI Appendix*, Fig. S8*A*)	No	No
ZeroEmission2020	2020, but the CO_2 emission is reduced to zero abruptly (*SI Appendix*, Fig. S8*B*)	No	No
CN2020 + SLCP2020-dependent	2020 (*SI Appendix*, Fig. S2*B*)	2020, but only includes the portion that is coemitted by CO_2 sources (*SI Appendix*, Fig. S5)	No

Mitigation strategies for avoiding dangerous to catastrophic climate changes

'Three lever' strategy to limit warming for both the near (<2050) & long term (2100):

- Central warming below the dangerous level
- LPHI warming below the catastrophic level

1. Carbon neutral (CN) lever => zero net CO_2 emissions
2. Super pollutant (SP) lever => mitigate short-lived climate pollutants
3. Carbon extraction and sequestration (CES) lever => atmospheric CO_2 removal

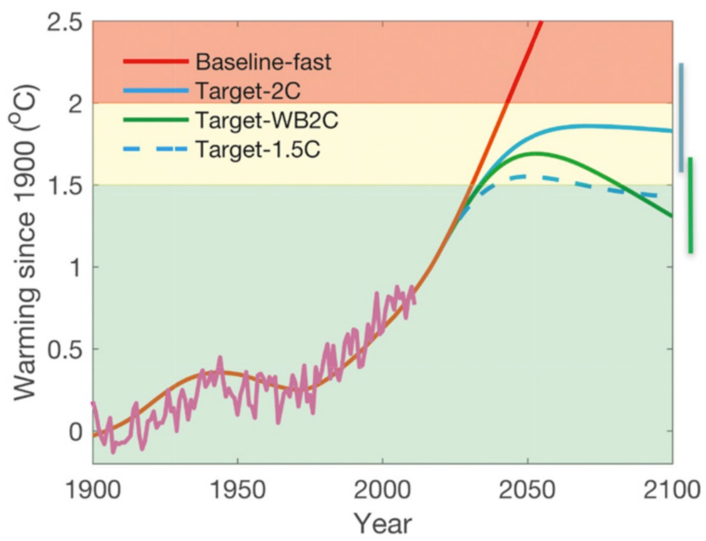


Fig. 3. Model-simulated temperatures for the 20th century (observations are shown in magenta) and their projections into the 21st century under four different scenarios: baseline-fast (red line);

(Xu and Ramanathan, 2017)

Case: central warming below dangerous levels

- CN and SP levers
- bend emissions curve by 2020

Case: LPHI warming below dangerous levels

- CES to extract as much as 1 trillion tons of CO_2 before 2100 => limit cumulative net CO_2 emissions to 2200 $GtCO_2$

IPCC – Understatements & underpredictions

- "IPCC reports have underplayed high-end possibilities and failed to assess risks in a balanced manner. The failure to fully account for potential future changes to permafrost and other carbon-cycle feedbacks is just one example." (Spratt, 2018)

- "Some of the key attributes of global warming from increased atmospheric greenhouse gases have been under-predicted, particularly in IPCC assessments of the physical science." (Brysse *et al*., 2013)

- "The affliction [of scientific reticence] is widespread and severe. Unless recognized, it may severely diminish our chances of averting dangerous climate change." (Hansen, 2007)

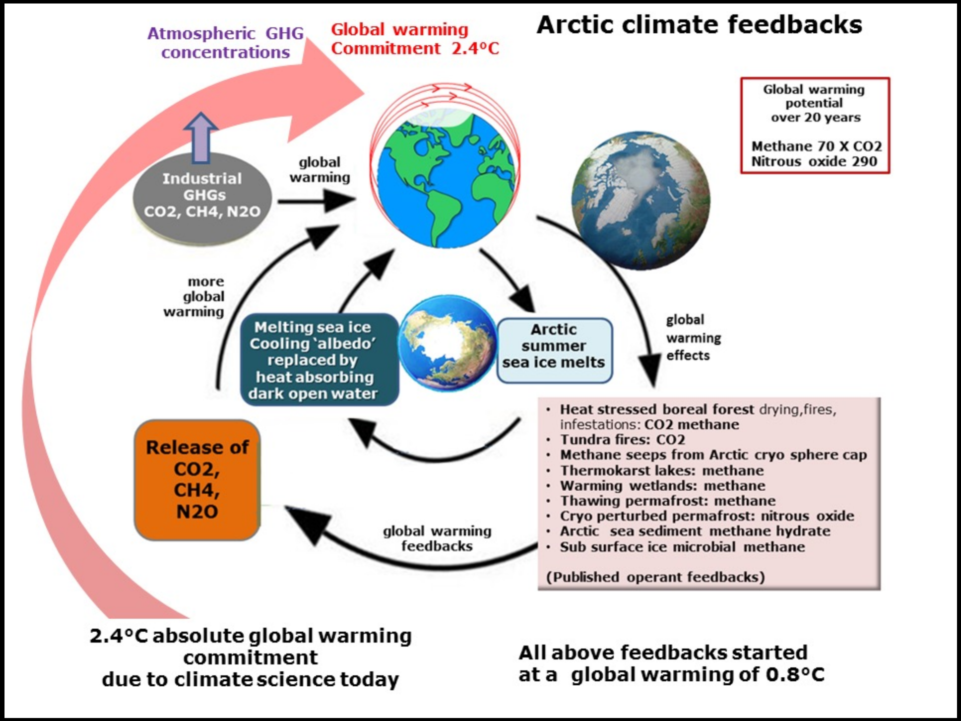
- "We're underestimating the fact that climate change is rearing its head... and we're underestimating the role of humans, and this means we're underestimating what it means for the future and what we should be planning for." – Trenberth, NCAR (Scherer, 2012)

Arctic climate feedbacks

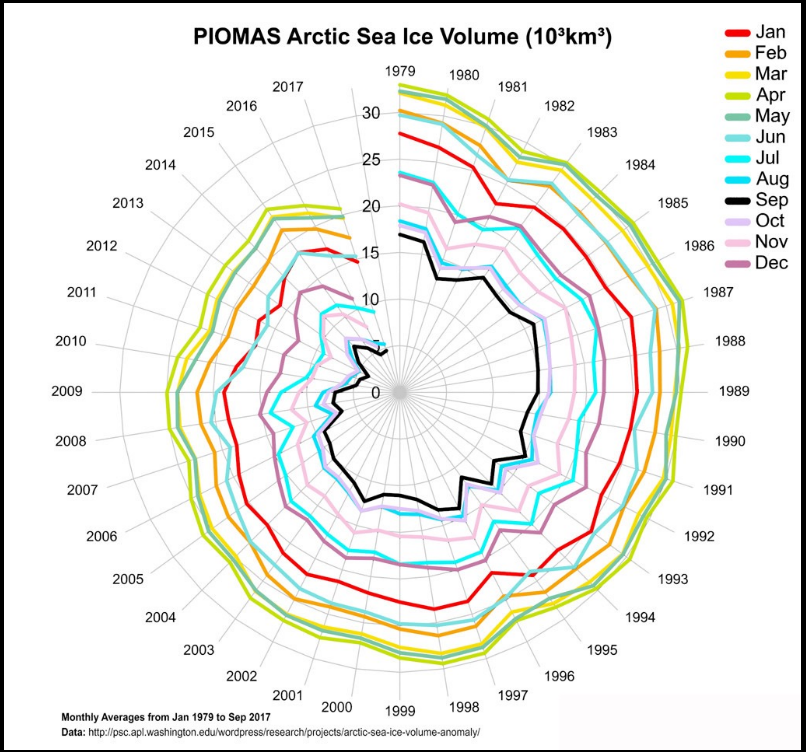
'Blue ocean event' = Ice-free arctic ocean

- 2020 – may occur in September
- 2025 – may occur from Aug – October
- 2030+ – year round?

Blue ocean event will accelerate global climate change…
(Wadhams, 2016)



(Carter, 2019)



Tipping point/critical threshold

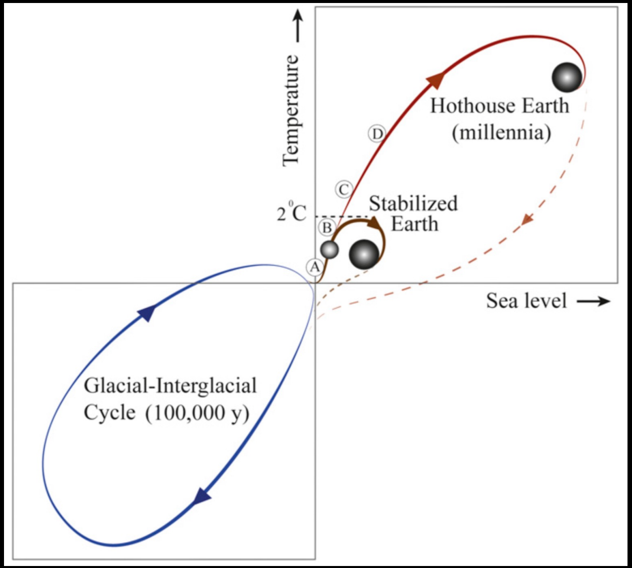
A level of change in system properties beyond which a system reorganizes, often abruptly, and does not return to the initial state, even if the drivers of the change are abated.

For the climate system, it refers to a critical threshold when global or regional climate changes from one stable state to another stable state. The tipping point event may be 'irreversible' (*i.e.* 100s – 1000s of years).

(IPCC AR5 WG I)

"We suggest 2 °C because of the risk that a 2 °C warming could activate important tipping elements, raising the temperature further to activate other tipping elements in a domino-like cascade that could take the Earth System to even higher temperatures (Tipping Cascades)."

(Steffen *et al.*, 2018)



(Steffen *et al.*, 2018)

Possible future pathways of the climate against the background of the typical glacial–interglacial cycles. Time periods that may give insights into positions along these pathways:

A) Mid-Holocene (~6–7 ka)
B) Eemian (~125 ka)
C) Mid-Pliocene (~3–4 Ma)
D) Mid-Miocene (~15–17 Ma)

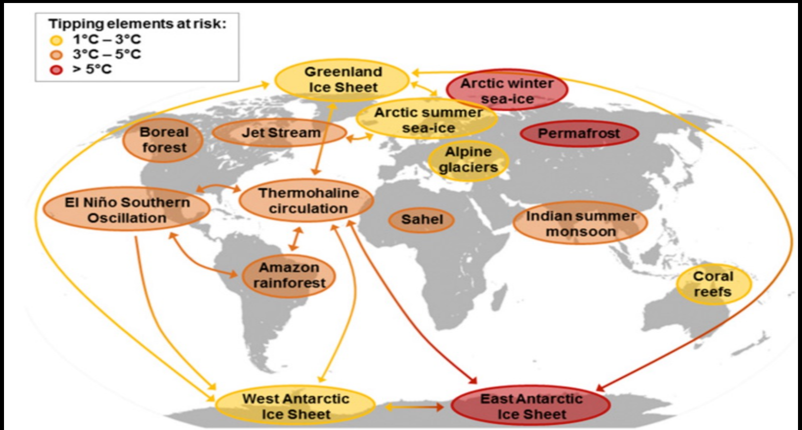


Fig. 3. Global map of potential tipping cascades. The individual tipping elements are color- coded according to estimated thresholds in global average surface temperature (tipping points) (12, 34). Arrows show the potential interactions among the tipping elements based on expert elicitation that could generate cascades. Note that,

(Steffen *et al.*, 2018)

Risks of self-reinforcing feedbacks

Steffen *et al.* explore the risk that self-reinforcing feedbacks could push the Earth System toward a planetary threshold

If crossed:

- stabilization of the climate at intermediate temperature rises may be impossible
- continued warming on a "Hothouse Earth" pathway (higher global average temperature than any interglacial in the past 1.2 million years and to sea levels significantly higher than at any time in the Holocene).

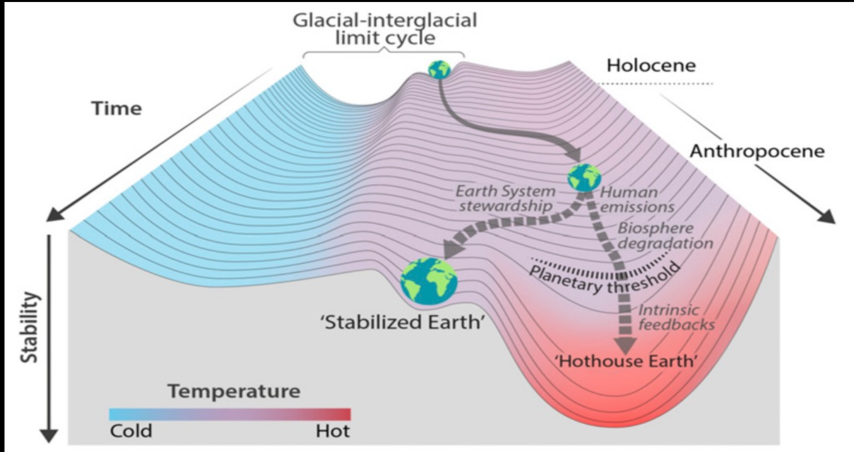


Fig. 2. Stability landscape showing the pathway of the Earth System out of the Holocene and thus, out of the glacial–interglacial limit cycle to its present position in the hotter Anthropocene. The fork in the road in Fig. 1 is shown here as the two divergent pathways of the Earth System in the future (broken arrows). Currently, the Earth System is on a Hothouse Earth pathway driven by human emissions of greenhouse gases and biosphere degradation toward a planetary threshold at ∼2 °C (horizontal broken line at 2 °C in Fig. 1), beyond which the system follows an essentially irreversible pathway driven by intrinsic biogeophysical feedbacks. The other pathway leads to Stabilized Earth, a pathway of Earth System stewardship guided by human-created feedbacks to a quasistable, human-maintained basin of attraction. "Stability" (vertical axis) is defined here as the inverse of the potential energy of the system. Systems in a highly stable state (deep valley) have

(Steffen *et al.*, 2018)

Existential risk management

“A prudent risk-management approach means a tough and objective look at … high-end events whose consequences may be damaging beyond quantification, and which human civilization as we know it would be lucky to survive.”

“Focusing on middle-of-the-road outcomes, and ignoring the high-end possibilities, may result in an unexpected catastrophic event that we could, and should, have seen coming.”

“The failure of both the research community and the policymaking apparatus to consider, advocate and/or adopt an existential risk-management approach is itself a failure of imagination with catastrophic consequences.”

“Since it is not possible to recover from existential risks, we cannot allow even one existential disaster to happen; there would be no opportunity to learn from experience, but at the moment we are facing existential disasters on several climate fronts, seemingly without being able even to articulate that fact.”

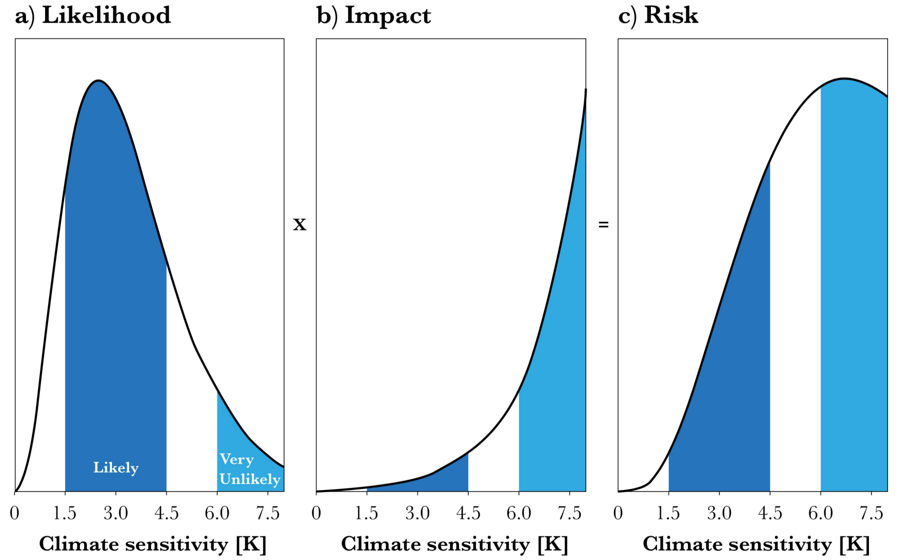


Figure 2: Schema of climate-related risk. (a) Event likelihood and (b) Impacts produce (c) Risk. Lower likelihood events at the high end of the probability distribution have the highest risk (Credit: RT Sutton/E Hawkins).

Fat-tail risks

“Lower-probability, high-impact consequences in which the likelihood of very large impacts is actually greater than we would expect under typical statistical assumptions.” (Spratt, 2018)

Summary

If business-as-usual continues, then climate & biosphere tipping points are expected to become *high impact* & *high probability* events => existential threat to our life support system (Lenton, 2018)

Stewardship of the entire Earth System is necessary — biosphere, climate, and societies.

- decarbonization of the global economy
- enhancement of biosphere carbon sinks

(Steffen *et al.,* 2018)

RCP 8.5 => [Existential risks, especially crossing irreversible tipping points(?)]

RCP 2.6 => [Sufficient to stabilize climate(?)]

CES => [Necessary to reduce atmospheric CO_2 to 350–300 ppm (or below)]

References

- IPCC AR5 WG I, 2013: Climate Change 2013 – The Physical Science Basis
- Bednaršek *et al*., 2012: Extensive dissolution of live pteropods in the Southern Ocean, *Nature Geoscience*, Vol. 5
- Bereiter *et al.*, 2014: Revision of the EPICA Dome C CO_2 record from 800 to 600 kyr before present, *Geophysical Research Letters,* Vol. 42
- Brysse *et al*., 2013: Climate change prediction: Erring on the side of least drama?, *Global Environmental Change*, Vol. 23
- Carter, 2019: www.climateemergencyinstitute.com
- Global Carbon Project, 2018: globalcarbonproject.org/carbonbudget/18/highlights.htm
- Hansen, 2007: Scientific reticence and sea level rise, *Environmental Research Letters*, Vol. 2
- Jouzel *et al*., 2007: Orbital and Millennial Antarctic Climate Variability over the Past 800,000 Years, *Science*, Vol. 317
- Lenton, 2018: Tipping points in climate and biosphere function, *NAS*, youtube.com/watch?v=_F4ET3sQXW4
- Mann and Bradley, 1999: Northern Hemisphere Temperatures During the Past Millennium: Inferences, Uncertainties, and Limitations, *Geophysical Research Letters*, Vol. 26
- NASA, Muir Glacier, www.climate.nasa.gov/climate_resources/4/graphic-dramatic-glacier-melt
- NOAA temperature anomalies, www.ncdc.noaa.gov/cag/global/time-series
- Orr *et al*., 2005: Anthropogenic ocean acidification over the twenty-first century and its impact on calcifying organisms, *Nature*, Vol. 437
- Scherer, 2012: How the IPCC underestimated climate change, *Scientific American*, 2012.12.06
- Sosdian *et al.*, 2018: Constraining the evolution of Neogene ocean carbonate chemistry using the boron isotope pH proxy, *Earth and Planetary Science Letters*, Vol. 498
- Spratt & Dunlop, 2018: What lies beneath – The understatement of existential climate risk, *National Centre for Climate Restoration*
- Steffen *et al.*, 2018: Trajectories of the Earth system in the Anthropocene, *PNAS*, Vol. 115
- USGCRP, 2017: Climate Science Special Report: Fourth National Climate Assessment, Volume I
  U.S. Global Change Research Program
- Wadhams, 2016: A Farewell to Ice: A Report from the Arctic, Oxford University Press
- Warren, 2011: The role of interactions in a world implementing adaptation and mitigation solutions to climate change, *Philosophical Transactions of the Royal Society A*, Vol. 369
- Xu and Ramanathan, 2017: Well below 2 °C: Mitigation strategies for avoiding dangerous to catastrophic climate changes, *PNAS*, Vol. 114