Well below 2ºC: Mitigation strategies for avoiding dangerous to catastrophic climate changes

Xu and Ramanathan, Proc. Nat'l. Acad. Sci. (14 September 2017)

(1) Because of the cumulative emissions thus far, the planet is likely to reach dangerous warming levels (with 50% probability) in less than 15 years. Without fast and much more aggressive mitigation beyond the Paris pledges, we risk experiencing catastrophic climate change by 2050 (5% probability) and approaching an existential/unknown threat by 2100.

- For the first time, scientists have categorized climate change warming in terms of being dangerous, catastrophic, and existential ("unknown"), with "dangerous" designating warming above 1.5ºC above pre-Industrial level, "catastrophic" for warming above 3ºC, and "existential/unknown" for warming in excess of 5ºC. *See* Box 2 of the study for further characterization; and note, current warming is already 1ºC.
  - **Catastrophic warming** far outpaces humanity's ability to adapt, with more than ~70% of the population (5.5 billion people) exposed to deadly heat, and ~2.4 billion people exposed to vector borne diseases.
  - **Existential/"Unknown??" warming** in excess of 5ºC, which has not been experienced in the last 20+ million years, poses existential threats to a majority of the population. (The question marks denote the subjective nature of the authors' deduction and the fact that catastrophe may strike at even lower warming levels.)

- Beyond looking at the median (50% probability) of passing a temperature target, Xu and Ramanathan consider the lower-probability (5%) but higher-impact warming, which accounts for uncertainties of future emissions, self-reinforcing climate feedbacks (water vapor, clouds, and snow/ice albedo), carbon cycle feedbacks (decrease in land/ocean uptake, soil carbon release from permafrost, and carbon emissions from wetlands), and aerosols. This 5% probability—a 1 in 20 chance—is referred to as the "fat tail."

(2) By pulling three levers for climate mitigation—carbon neutrality (net zero emissions, plus reduced energy intensity), super pollutants/short-lived climate pollutants (SLCPs), and carbon extraction and sequestration—we still have the possibility of avoiding catastrophic climate change, with SLCPs *essential* for staving off catastrophic warming in the near-term (before 2050) and the trio of levers essential for avoiding catastrophic and existential threats in the long-term (up to 2100).

- SLCPs (methane, tropospheric ozone, black carbon, and hydrofluorocarbons (HFCs)) have the largest contribution to warming through mid-century. From 1850 to 2015, SLCPs were responsible for 1.1ºC of warming compared to the 0.8ºC due to CO_2. (Cooling aerosols have masked 0.9ºC of this warming, and thus we have only experiences about 1ºC above pre-Industrial levels.)
- The three-lever approach is necessary to limit the probability of dangerous and catastrophic warming, and can keep the temperature well below the 2ºC target (Target-WB2C):
  - Pulling Lever One can achieve carbon neutrality by 2060–2070—zero anthropogenic CO_2 emission such that no additional CO_2 is added to the

atmosphere—through reducing energy intensity of the economy and decarbonization of energy sources. This will limit the cumulative CO_2 emissions to 3.7 trillion tons (since pre-Industrial) (CN2030). (Cumulative CO_2 emissions represent the total amount of CO_2 that can enter the atmosphere for a certain chance of remaining under a specified temperature threshold, and in this case, 3.7 trillion tons of CO_2 yields a 50% chance of staying below 2ºC of warming.)

  - Pulling Lever Two can bend SLCP emissions downward by 2020 and reach full potential by 2060—mitigating 0.6ºC by 2050 and 1.2ºC by 2100—utilizing maximum deployment of existing technologies (SLCP2020).
  - Pulling Lever Three can deploy carbon extraction and sequestration strategies by 2030 to pull down 16 billion tons of CO_2 per year (approximately half of the annual fossil fuel CO_2 emissions from 2010). This, combined with the other two levers, will limit cumulative CO_2 emissions to 2.2 trillion tons and create about a 50% chance of staying under 1.5ºC and drastically reduce the likelihood of catastrophic warming in the long-term.
- Absent carbon removal strategies, the carbon neutrality and super pollutant levers will only be able to limit the 50% probability warming to below 2ºC (*see* Target-2C in Figure 3) while still risking dangerous warming in both the near-term and long-term.
- Xu and Ramanathan show that the median of Target-WB2C can keep warming to less than 1.5ºC, while the fat tail—the extension of the curve to the right—continues into the dangerous and catastrophic range. This highlights that even the best solutions still face some risk of excessive warming though far less risk than baseline scenarios that fail to include faster and much more aggressive mitigation.
  - Baseline-default "adopts the current rate of reduction in energy intensity until 2100, achieving a 50% reduction from the 2010 level" and has its median (50% probability) within the existential/unknown range for 2100.
  - Baseline-fast "assumes an aggressive 80% reduction in the energy intensity of the economy (still using fossil fuels) compared with the 2010 energy intensity" and has its median (50% probability) within the catastrophic range at 2100.
  - For both baselines at 2100, the fat tails tell worse tales and extend well into the unknown ranges.
- Figure 2 (below) shows the probability density functions (PDFs) of Target-WB2C and the baseline scenarios. These PDFs represent the outcomes of 1500 model runs whereby each temperature result is plotted as its probability of occurrence given the uncertainties in modeling the climate feedbacks that are often underestimated. The median is close to the peak of the curve, but these PDFs reveal the rest of the story as a range of possibilities.

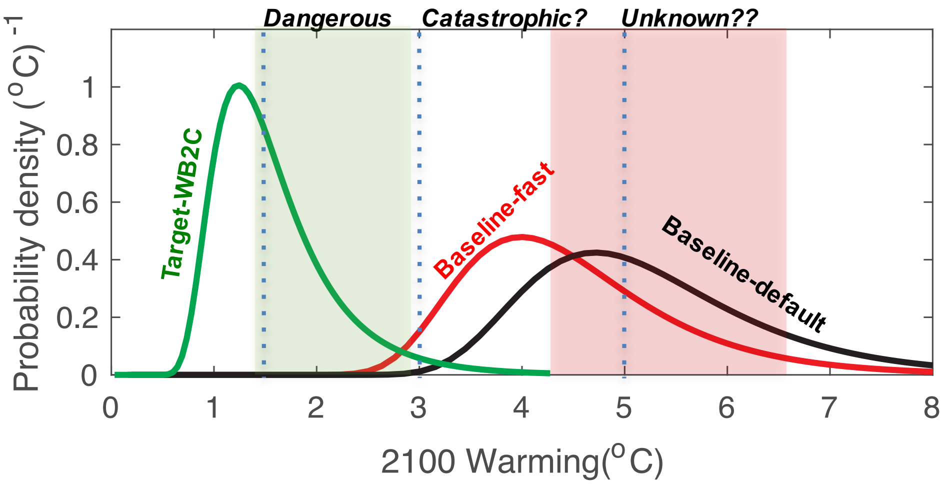

Fig. 2. *Probability density function of projected warming in 2100 for the baseline-default, baseline-fast, and Target-WB2C (CN2030 + SLCP2020 + CES1t) scenarios. The green and red color shading shows the 50%–95% range of the projection for the Target-WB2C and baseline-fast scenarios due to uncertainty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

(3) The avoided warming at 2100 from these climate policy measures are as follows: 1.2ºC from reducing super pollutants/SLCPs, 0.9ºC from reducing energy intensity, and 1.6–1.9ºC from achieving carbon neutrality.

- Cuts to SLCPs have the most dominant effect in the near-term.

Adapted from Table S1. *The contribution of individual mitigation measures to the warming in the 21st century.*

Policy Measure	2050 Avoided Warming	2100 Avoided Warming	Estimated in
Reducing Energy intensity	–0.2 ºC	–0.9 ºC	Fig. 1, Fig. S1
Cutting CO_2 due to CN2020	–0.3 ºC	–1.9 ºC	Fig. 3
Cutting CO_2 due to CN2030	–0.1 ºC	–1.6 ºC	Fig. S3
Extracting CO_2 due to CES1t	0 ºC	–0.3 ºC	Fig. S3, Fig. S6
Cutting SLCPs	–0.6 ºC	–1.2 ºC	Fig. S3, Fig. S6
Aerosol unmasking	+0.3 ºC	+0.6 ºC	Fig. S7

Mitigation measures included in Target-WB2C include all except CN2020, which is included to show difference between carbon neutrality policies beginning in 2020 versus 2030. SLCPs include contributions from black carbon, methane (CH_4) and tropospheric ozone (O_3), and hydrofluorocarbons (HFCs).

- Figure 2 was adopted (Figure 5, below) for the *Well Under 2 Degrees Celsius: Fast Action Policies to Protect People and the Planet from Extreme Climate Change*, Report of the Committee to Prevent Extreme Climate Change, to further illustrate the conclusions of the Committee. Here, the Target-WB2C scenario of Xu and Ramanathan 2017 assumes similar actions as the “four building blocks + three levers” approached discussed in the Report, thus yielding similar results of the ability to limit warming to well under 2ºC with minimized risk of reaching catastrophic or existential threat. The *Well Under 2 Degrees* Report provides additional details on each of the three levers, outlining feasible solutions that can be implemented immediately to start bending the curve.

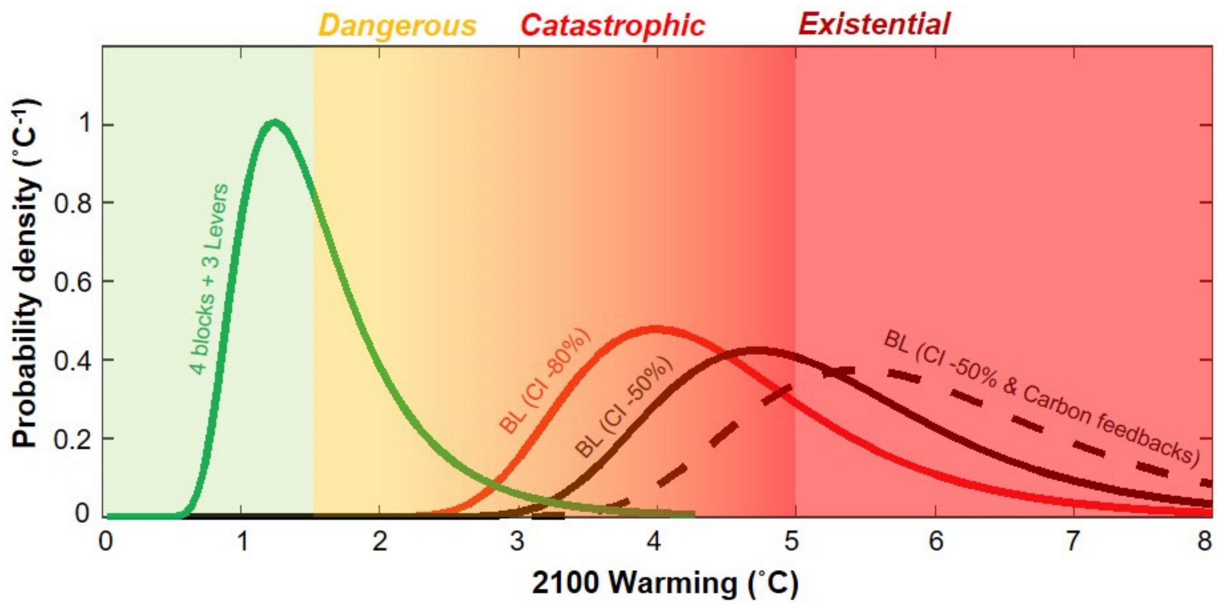

Fig. 5. *Projected warming for 4 different scenarios from pre-industrial to 2100 as adopted from Xu and Ramanathan (2017). The warming is given in terms of probability distribution instead of a single value, because of uncertainties in climate feedbacks, which could make the warming larger or smaller than the central value shown by the peak probability density value. The three curves on the right side indicated by BL (for baseline), denote projected warming in the absence of climate policies. The BL (CI-80%) is for the scenario for which the energy intensity (the ratio of energy use to economic output) of the economy decreases by 80% compared with its value for 2010. For the BL (CI-50%), the energy intensity decreases by only 50%. These scenarios bound the energy growth scenarios considered by IPCC–WGIII (2014). The right extreme curve, BL (CI-50% & C feedback), includes the carbon cycle feedback due to the warming caused by the BL (CI-50%) case. The carbon cycle feedback adopts IPCC recommended values for the reduction in* CO_2 *uptake by the oceans as a result of the warming; the release of* CO_2 *by melting permafrost; and the release of methane by wetlands.*

The green curve adopts the 4 building blocks and the 3 levers proposed in this report. There are four mitigation steps:

1. *Improve the energy efficiency and decrease the energy intensity of the economy by as much as 80% from its 2010 value. This step alone will decrease the warming by 0.9°C (1.6°F) by 2100.*
2. *Bend the Carbon emission curve further by switching to renewables before 2030 and achieving carbon neutrality in 3 decades. This step will decrease the warming by 1.5°C (2.7°F) by 2100.*
3. *Bend the Short-Lived Climate Pollutants curve, beginning 2020, following the actions California has demonstrated. This step will decrease the warming by as much as 1.2°C (2.2°F) by 2100.*
4. *In addition, extract as much as 1 trillion tons (about half of what we have emitted so far) from the atmosphere by 2100. This step will decrease the warming by as much as 0.3ºC to 0.6ºC (0.5ºF to 1ºF).*

The 50% probable warming for the 4 scenarios are respectively from left to right: 1.4°C (2.5°F); 4.1°C (7.4°F); 5°C (9°F); 5.8°C (10.4°F). There is a 5% probability, the warming for the 4 scenarios can exceed respectively (left to right): 2.2°C (4°F); 5.9°C (10.6°F); 6.8°C (12.2°F); 7.7°C (14°F).

The risk categories shown at the top largely follow Xu and Ramanathan (2017) with slight modifications. Following IPCC and Xu and Ramanathan (2017), we denote warming in excess of 1.5°C as Dangerous. Following the burning embers diagram of IPCC as updated by O'Neill et al. (2017), warming in excess of 3°C is denoted as Catastrophic. We invoke recent literature on health effects of warming >4°C, impacts on mass extinction of warming >5°C and projected collapse of natural systems for warming in excess of 3°C, to denote warming >5°C as exposing the global population to Existential threats.