Backgrounder:

Comparing climate impacts at 1.5°C, 2°C, 3°C and 4°C

1. Projected levels of temperature rise

Climate change has already caused global temperatures to rise about 1°C above pre-industrial levels. Unless emissions are rapidly reduced, temperatures could rise 1.5°C by 2040, 2°C by 2065 and 4°C by 2100.[1]

The 2015 Paris climate agreement saw world leaders commit to limit temperature rise to 2°C above pre-industrial levels and to aim to limit the increase to no more than 1.5°C by the end of the century. Governments also produced a set of pledges detailing how they intend to reduce emissions. If governments deliver on these pledges but do no more, temperatures will rise by about 3°C by the end of the century.[2]

It's hard to be certain what this level of temperature rise will mean for the world's natural systems, economy and human society. In the past, it has taken thousands of years for temperature to rise by a few degrees, and big changes are already occurring as a result of a 1°C increase. The climate system may have many unpleasant surprises in store for us, and scientists are calling for climate change to be limited as much as possible.[3]

2. How climate will change the planet

Most of the projections in this briefing are based on Intergovernmental Panel on Climate Change (IPCC) scenarios. The IPCC's Representative Concentration Pathways (RCPs) and Special Report on Emissions Scenarios (SRES) model different scenarios for how temperatures might change over the course of the 21st Century.[4] The IPCC also considers a set of societal scenarios - the Shared Socioeconomic Pathways (SSPs) - which map how these projections are changed by different social and economic factors, including whether the world becomes more equitable, or less so, levels of conflict and gender issues.

Overall, climate change is likely to cause wet places to get wetter and dry places to get drier. Tropical countries are likely to experience the most severe impacts of climate change, partly because temperatures will change the most dramatically at the tropics, but also because they have less capacity to adapt.

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[1] Before 2015, global carbon emissions were tracking above the highest emissions scenarios produced by the IPCC (RCP8.5). The fall since 2015 means emissions are now tracking between the top two sets of scenarios - RCP6.0 andRCP 8.5. This suggests a temperature rise of about 4°C by 2100. https://www.researchgate.net/publication/325164113_Projected_Changes_in_Wet-Bulb_Globe_Temperature_under_Alternative_Climate_Scenarios#pfb

[2] A range of analyses show that, if the world's governments collectively deliver on current, and insufficient, pledges to reduce emissions, global temperatures will rise by 2.8-3.5°C by the end of the century. Without these efforts, they will rise by more than 4°C. https://www.carbonbrief.org/analysis-meeting-paris-pledges-would-prevent-at-least-one-celsius-global-warming

[3] Table SPM.1 in the IPCC's 2014 report concludes that RCP6.0 leads to a temperature rise of 3.1-3.7°C and RCP8.5 leads to a temperature rise of 4.1-4.8°C by the end of the century.

[4] RCP1.9 models pathways roughly consistent with a 1.5°C temperature rise by the end of the century; RCP2.5 model those consistent with a 2°C temperature rise and RCP4.5 model those consistent with a 3°C by the end of the century. A 4°C temperature rise by the end of the century lies between the projections for RCP4.5 and those for RCP8.5. See Table SPM.1, p.13. http://www.ipcc.ch/pdf/assessment-report/ar5/wg3/ipcc_wg3_ar5_summary-for-policymakers.pdf

Temperatures will also change at different rates in different parts of the world. Temperatures across Africa, for example, could go up 1.5 times faster[5] than the global average.

3. Temperature rise of 1.5°C: how likely is it, and what does it mean?

On current trends, global average temperature will rise 1.5°C above pre-industrial levels by 2040. Limiting temperature rise to 1.5°C by 2100 means immediate and radical cuts in global emissions on a scale never seen before. It's very likely that it also means using measures to suck carbon dioxide out of the atmosphere. If this happens, temperatures will probably 'overshoot' the 1.5°C target at some point during this century, and then fall again by 2100. Whatever happens, it is very unlikely that the world can avoid the impacts detailed below at some point this century.

- **Rising heat:** The world is already experiencing the effects of a 1°C temperature rise. In 2015 for example, a heatwave in Karachi, Pakistan, killed 1300 people. According to one projection, a 1.5°C temperature rise would mean it experienced the same temperature about once every 3.6 years. In today's climate the average African region experiences one to three heatwaves a year - where temperatures rise into the top 5% of the average for the region for 2-3 days. In a world that is 1.5°C warmer by 2100 this frequency could more than double by the middle of the century.

- **Water shortages in vulnerable regions:** The amount of freshwater available in rivers and lakes could decrease by 9% in the Mediterranean,[6] 10% in Australia, and 7% in in north-east Brazil as a result of a 1.5°C temperature rise. Glaciers in the high mountains of Asia play an important role in the water supply of millions of people living downstream. 800 million people are at least partly dependent on meltwater from these glaciers. In a world where temperatures are limited to 1.5°C by the end of the century, around a third of the ice stored in these glaciers would be lost.

- **Nearly all coral reefs lost:** Between 2014 and 2017, 21 of the 29 reefs listed as World Heritage Sites suffered[7] from heat stress as a result of rising ocean temperatures. In a scenario where temperatures rise 1.5 °C by the end of the century, nine out of ten of coral reefs are at risk from severe degradation from 2050 onwards. This declines to 70% by 2100 - meaning that some coral reefs have a chance of survival. At the moment, coral reefs provide about US$30 billion annually to the world economy, in coastal protection, building materials, fisheries and tourism.

- **Food production suffers:** Rising temperatures, drought and unstable weather patterns have serious implications for global food production. Every degree of global temperature rise reduces global yields of wheat by 6.0%, rice by 3.2%, maize by 7.4%, and soybean by 3.1%. Some regions are more affected than others - for example in West Africa, wheat yields could fall by up to 25% if temperatures rise 1.5°C.[8] Fishing will also be affected. Every year, about 82 million tonnes of fish[9] are caught in the sea. For every degree of warming, this could decrease by 3 million tonnes. This may be an underestimate, as it doesn't take into account the potential impact of coral reef collapse, ocean acidification or overfishing on fish populations.

- **Rising sea levels displace people:** Climate change causes sea level rise for two reasons: because water expands as it warms, and because melting ice sheets add water to the seas. 46 million people[10] currently live in areas that are at risk of permanent inundation from sea level rise if temperatures rise by

[5] IPCC, AR4, WG1, Chapter 11, p.867.

[6] Differential climate impacts for policy-relevant limits to global warming: the case of 1.5C and 2C (Earth System Dynamics, 2016) Table S4.

[7] Impacts of Climate Change on World Heritage Coral Reefs (2017), UNESCO, p.4.

[8] Differential climate impacts for policy-relevant limits to global warming: the case of 1.5C and 2C (Earth System Dynamics, 2016), p.337.

[9] The state of world fisheries and aquaculture (2016), Food and Agriculture Organization of the United Nations, p.4.

[10] These are median estimates. The ranges are 31.87–68.83 for 1.5°C and 31.99–78.38 for 2C. The estimates are based on the 2010 population.

1.5°C, equivalent to about 70% of the number[11] of people currently displaced from their homes globally by war, instability or human rights violations. About half of this at-risk population is in China, Vietnam or Japan.

4. Temperature rise of 2°C: how likely is it, and what does it mean?

On current trends, global average temperature will rise 2°C above pre-industrial levels by about 2065. Limiting temperature rise to 2°C means sharp reductions in global emissions and the rapid reversal of economic and population growth trends observed the last 50 years. Nearly all scenarios that limit temperature rise to 2°C by the end of the century also require measures to remove carbon dioxide from the atmosphere.

- **Heat extremes that kill and damage agriculture:** The European summer heatwave of 2003, which killed 70,000 people, was an example of a three sigma heatwave. Most heatwaves of this level result in serious impacts to society, causing deaths, serious forest fires or harvest losses. If temperatures rise 2°C above pre-industrial levels, heat extremes of this level could be experienced in half the summer months in tropical countries, while in Western Europe they will be experienced in a fifth of summer months. In the Middle East and North Africa, temperatures could rise to 46°C on the hottest days. Temperatures of this level pose a serious threat to life and could make some parts of the region uninhabitable.

- **Changes to rainfall and water shortages:** In a world where temperatures rise by 2°C, heavy rainfall will increase across Europe in all seasons, except in southern Europe in the summer. The amount of rain falling in central and northern Europe in winter could increase by as much as 20%. But at the same time rain could decrease by 20% in central and southern Europe in the summer. Overall, 8% of the global population would face severe water shortages.

- **All coral reefs disappear:** If temperatures rise to 2°C, virtually all the world's tropical coral reefs are at risk of severe degradation and collapse. Coral reefs account for 10 to 12% of the fish caught in tropical countries, and 20 to 25% of the fish caught by developing nations.[12] They provide food, income and protection from storms for millions of people along coastal areas.

- **Arctic sea ice melt:** The Arctic is warming at twice the rate of the rest of the world, and the area sea ice covers has rapidly declined over the last decade. If global temperatures rise by 2°C, Arctic sea ice is likely to melt completely - possibly for several months of the year, for several years in a row. This could in turn speed up warming by decreasing the amount of sunlight that is reflected away from the planet.

- **Food supplies at risk:** Worldwide, agricultural yields fall rapidly as global temperatures rise from 1°C to 3°C above pre-industrial levels.

- **Multiple risks affect Africa and Asia:** In a scenario where temperatures rise to 2°C by the end of the century, 29% of the global population face 'beyond tolerable' risk in at least two out of the three main sectors - water, energy and food, and environment. 91-98% of the exposed and vulnerable people are in Africa and Asia, with about half in south Asia alone.

- **Animals go extinct, and protected areas disappear:** As temperatures rise protected areas start to disappear. In a 2°C world, 25% of the 80,000 plant and animal species in the world's most naturally rich areas, such as the Amazon and the Galapagos, could face local extinction by the end of the century.

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[11] By the end of 2016, 65.6 million people had been displaced from their homes as a result of persecution, conflict, violence, or human rights violations. http://www.unhcr.org/5943e8a34.pdf

[12] IPCC, AR5, WGII, CC Boxes, p.99.

Warming temperatures may affect the behaviour of insects and animals, causing a cascade effect that affects entire ecosystems.

- **Abrupt change is possible:** There are a number of potential 'tipping points' at which abrupt change may occur. The Arctic could become ice-free even in winter, the Amazon rainforest could die off, or the Tibetan Plateau could see the total disappearance of snow and ice cover. It is extremely difficult to know if and when such sudden events will occur - so scientists can only assess changing levels of risk. But in a recent study, half of the potential tipping points identified could be triggered by a global temperature rise of 2°C or less.

5. 3°C temperature rise - how likely is it, and what does it mean?

If emissions keep going up at current rates, global average temperature will rise 3°C above pre-industrial levels sometime in the second half of this century. If governments deliver on the pledges made to reduce emissions as a part of the Paris climate change agreement, but go no further, temperatures will climb at a slower rate, reaching 3°C above pre-industrial levels by about 2100. Achieving the pledges means a shift to more renewable power, the use of carbon capture and storage technology to limit emissions from fossil fuels, and an increase in global forest area by the end of the century.

- **Heat extremes:** In today's climate the average African region experiences one to three heatwaves per year. Under a scenario where temperatures rise 3°C by the end of the century, heatwaves could increase by a factor of five by the middle of the century. Droughts are likely to become increasingly frequent and severe in the Mediterranean area, western Europe, and Northern Scandinavia.

- **Significant water shortages:** A 3°C temperature rise is likely to reduce the amount of water stored underground, known as groundwater. Groundwater supplies about a third of US drinking water, the majority of public water supply in England, and about two-thirds of public water supply in western Australia. A 3°C temperature rise would be very likely to reduce groundwater recharge to half of 1990 levels by 2050 in some parts of Australia.[13] The amount of groundwater recharge in East Anglia, England - where groundwater is used for irrigation of crops - could fall to 22% below current levels by the middle of the century.[14] A 3°C temperature rise could also cause 43% of Himalayan high mountain glaciers - which currently provide water for 800 million people - to be lost.

- **Marine ecosystems may collapse:** 3°C of temperature rise poses "substantial risks"[15] to marine ecosystems. Simultaneous threats - like ocean warming and ocean acidification - may interact, increasing the impacts on species and ecosystems and making them hard to predict.

- **Extinctions of plants and animals:** At 3°C temperature rise and above, many trees, plants and smaller animals will be unable to migrate fast enough to keep up with the rate of temperature change, resulting in local extinctions.

- **Potential for catastrophic sea level rise:** At some point rising temperatures will trigger the near-complete melting of the Greenland ice sheet. The whole process could take more than 1,000 years, but it would ultimately lead to a sea level rise of seven metres or more.[16] The temperature threshold triggering this level of melt is somewhere between 1°C and 4°C above pre-industrial levels. The West Greenland ice sheet is already melting at the fastest rate in centuries, and scientists are worried that it will melt faster than projected.

[13] IPCC, AR5, WGII, Chapter 3, Table 3-2.

[14] IPCC, WGII, AR5, Chapter 3, p.249.

[15] IPCC, AR5, WGII, SPM, p.17.

[16] IPCC, AR5, WG1, SPM, p.29.

- **High risk of hitting tipping points:** A 3°C temperature rise increases the possibility that fragile natural systems like the Arctic or Amazon experience "abrupt and irreversible changes" by melting entirely, or drying out, for example. The risks of these 'tipping points' are moderate from 0 to 1°C temperature rise, but "increase disproportionately" as temperature increases from 1–2°C, becoming "high" above 3°C,[17] according to the IPCC. The inclusion of these risks in to an economic model raises the social cost of carbon from $15/tCO2 to $116/tCO2.

- **Rapid fall in food production:** Globally, agricultural yields fall rapidly between 1°C and 3°C of warming. Once local temperatures reach 3°C above pre-industrial levels, all crops are negatively affected, wherever they are in the world - including in temperate regions.[18] Fish species go locally extinct, with serious impacts on fisheries.[19]

6. 4°C temperature rise - how likely is it, and what does it mean?

Until 2015, global carbon emissions were tracking above the highest emission scenario produced by the Intergovernmental Panel on Climate Change (IPCC). A fall in emissions since 2015 means emissions are now tracking between the top two sets of scenarios, suggesting temperatures will rise by about 4°C above pre-industrial levels by 2100.

- **Unbearable heat:** If temperatures rise 4°C above pre-industrial levels, three sigma heat could cover about 85% of the global land area and five sigma heat about 60% of the global land area. Three quarters of the world's population could experience potentially deadly temperatures for at least 20 days a year. A heatwave in Karachi, Pakistan, killed 1300 people in 2015. Projections suggest that if temperatures rise by 4°C, Karachi would experience the same temperatures for 40 days every year. In the Middle East and North Africa (home to 500 million people) - summer temperatures rise by more than 5°C and some areas would become uninhabitable as a result of extreme heat.

- **Food disaster:** A temperature rise of 4°C or above means significant parts of the world could experience medium to high levels of food insecurity by the 2080s, reversing the whole development path of those regions.

- **Water shortages and droughts:** The whole European continent, with the exception of Iceland, will be affected by more frequent and severe extreme droughts.

- **Arctic sea ice melts in two decades' time:** On current trends, the Arctic could be largely ice-free in the summer by the late 2030s - earlier than most models suggest. An ice-free Arctic means less sun is reflected back into the atmosphere, resulting in temperatures going up quicker. This could decrease the global carbon budget available for limiting temperatures to 2°C by 20%–51%.

- **Hundreds of millions at risk from sea level rise:** A 4°C temperature rise is estimated to lead to sea level rise of nearly nine metres over several hundred years as it triggers melting of the Antarctic and Greenland ice sheets. This level of sea level rise would inundate all the world's coastal city locations. 470 to 760 million people currently live in at-risk areas, including 145 million people in China. India, Bangladesh, Vietnam, Indonesia, Japan, the United States, Philippines, Egypt, Brazil, Thailand, Myanmar and the Netherlands all have more than 10 million people living in areas at risk. Some scientists argue the melt could happen much quicker than projected, adding several metres to sea level over the next 50-150 years, but this argument is controversial amongst the scientific community.

[17] IPCC, AR5, WGII, SPM, p.12.

[18] IPCC, WGII, AR5, Chapter 7, p.497.

[19] IPCC, WGII, AR5, Chapter 7, p.508.

- **Half of all plant animal species in valuable areas at risk:** Half of plant and animal species in the world's most naturally rich areas, such as the Amazon and the Galapagos, could face local extinction by the end of the century if temperatures rise by 4°C. In the average ecosystem 25-35%[20] of vertebrate species would be at risk of extinction, as a result of the interaction between climate change and land use change.

- **Economic damage:** Unmitigated global warming could reduce global average incomes by 23% by 2100, compared to what they would have been.

- **Adaptation to 4°C may not be possible:** A 4°C world is likely to create a set of interacting pressures, making it hard to project what will happen as a result. Computer models, for example, don't take into account what might happen if reduced water availability, new diseases and heat extremes happen at the same time. In its 2012 report in to the impacts of a 4C temperature rise, the World Bank concluded: "there is no certainty that adaptation to a 4°C world is possible … the projected 4°C warming simply must not be allowed to occur."[21]

7. Particularly vulnerable regions

- **Mediterranean Basin:** Southern Europe is particularly vulnerable to climate change, and likely to be more affected than other parts of Europe. A 2°C temperature rise could lead to summer rain decreasing by 20%. Water availability in the region could decrease by 9% if temperatures rise by 1.5°C, and 17% if they rise by 2°C. As temperatures rise, droughts are likely to become increasingly frequent and severe. Multiple sectors[22] - tourism, agriculture, infrastructure, energy and health - could be affected.If temperatures rise by more than 4°C, much of southern Spain[23] could become a desert by the end of the century.

  Almost half of the plants and animals and more than half of the habitats protected by the EU Habitats Directive occur in the Mediterranean region. If temperatures rise by 1.5°C, Mediterranean ecosystems may survive, but if temperatures rise by 2°C or more, they will change more dramatically than at any point in human history.

- **Middle East and North Africa:** More than 500 million people currently live in the Middle East and North Africa. This part of the world is likely to warm faster than the global average. If global temperatures rise by 2°C, summer temperatures in this region could more than double. By 2050, daytime temperatures could rise to 46°C on the hottest days. Temperatures of 30-40°C can be deadly and this could make parts of the region uninhabitable. Rising temperatures are also likely to lead to water shortages. The Al-Wehda dam between Jordan and Syria for example is designed to provide Jordan with water for both human consumption and agriculture. At 3°C temperature rise, the amount of water available from the dam is likely to half.

  Changes of this magnitude are likely to contribute to instability in the region. It is possible this has already happened. The Syrian conflict followed the longest and the most intense drought in the region in the last 900 years. While a complicated series of social and economic factors triggered the crisis in Syria, research suggests a drought played a role.

- **Small Island Developing States (SIDS):** Small islands are extremely vulnerable to the impacts of climate change. People living on small islands are very exposed to the weather, often live on the coast,

[20] Read off Figure 1b

[21] Turn down the heat: why a 4°C warmer world must Be avoided (2012), The World Bank, p.xviii.

[22] IPCC, WGII, AR5, Chapter 23, p.1270.

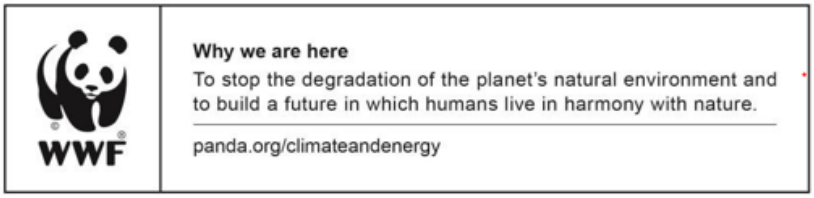
[23] RCP8.5 emissions scenario.

are dependent on fisheries based on corals, and only have limited resources and options for employment available. One extreme weather event can have a significant effect. More than 4,600 people died on the island of Puerto Rico for example as a result of a hurricane in November 2017, which has also triggered a healthcare and humanitarian crisis.

As sea levels rise, large waves are also likely to inundate the low lying islands more and more often, contaminating groundwater supplies of drinking water with salt. In a high emissions scenario where temperatures rise by more than 4°C by the end of the century, this could make these islands uninhabitable by around 2030-40, according to one study. In a scenario where temperature rise is limited to 3°C, they could be uninhabitable by 2055-65. Previous studies are more optimistic, suggesting they could be uninhabitable by the end of the century.

The difference between a 1.5°C to 2°C temperature rise are important for small island states. For several SIDS, particularly across the Caribbean, about a quarter of the overall freshwater stress projected under a 2°C temperature rise can be avoided if temperatures only rise by 1.5°C.

This paper was prepared by GSCC to support understanding of issues arising from the IPCC's Special Report on 1.5°C warming.



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