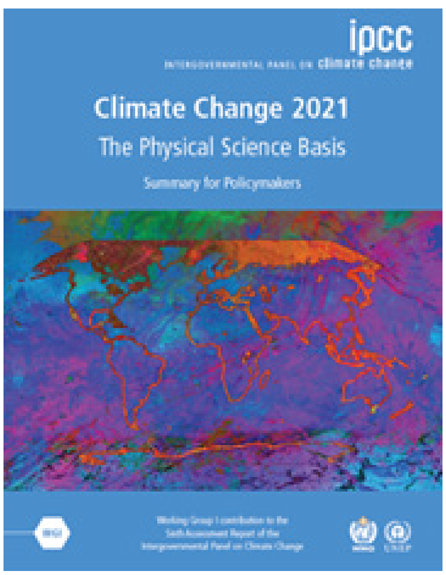
IPCC'S 2021 CLIMATE SCIENCE ASSESSMENT REPORT

High-Level Technical Summary and Perspectives

Key Insights and Perspectives

- Climate change is occurring, and humans are definitively contributing
- Additional climate change is unavoidable
- Extreme weather is changing with both climate and non-climate drivers

Introduction



"Changing" by Alisa Singer. © 2021 All rights reserved. Source: IPCC (2021).

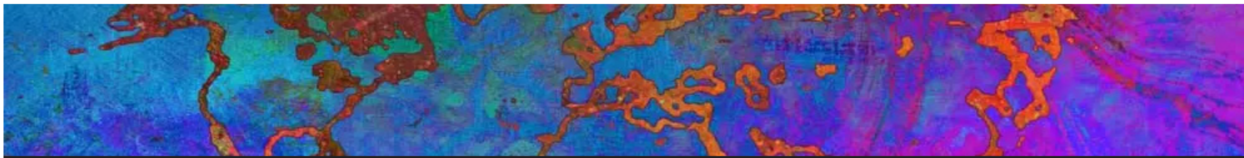
This brief provides technical perspectives on the recently released Intergovernmental Panel on Climate Change's (IPCC's) Sixth Assessment Report (AR6) assessing climate-related physical scientific knowledge (LINK). The report is authored by the IPCC's Working Group I (WGI) and is the first of four AR6 reports. The Working Group II report on *Climate Impacts, Adaptation, Vulnerability* is expected in February 2022 and the Working Group III report on *Mitigation of Climate Change* is expected in March 2022. A *Synthesis Report* is expected later in 2022.

The IPCC assessment reports assess the expansive, climate research literature. The Sixth Assessment updates the Fifth Assessment (2013-2014), incorporating more recent data and scientific advances. It also utilizes and updates a series of IPCC Special Reports produced in recent years on 1.5°C, land, and the ocean and cryosphere. Many stakeholders referred to the 1.5°C report (2018) to motivate net-zero strategies. AR6, however, has broader scope than the Special Reports, such as assessing potential climates, impacts, and mitigation for global average temperatures above 2°C, as well as for 2°C and 1.5°C.

This brief highlights key WGI AR6 findings with regard to observed climate change, human attribution, future climate change, and weather extremes (observed and projected) and provides perspectives on the implications of the findings for company and industry planning and other research.

Table of Contents

December 2021



Observed Climate Change and Attribution

Based on historical evidence, the IPCC WGI report finds that widespread and rapid **changes in large-scale climate systems are occurring**, some of which are unprecedented. For instance, the report concludes, with high confidence to certainty, that there have been increases in global average surface temperature, ocean heat content, ocean salinity and acidification, global average sea level, glacial retreat, and ice sheet mass loss.

The report also reevaluates global average warming to date and finds it to be **0.1°C greater than previously thought** based on methodological and data advances. Furthermore, temperature has increased steadily, with the **past four decades** the warmest on record since preindustrial times, and each of the decades warmer than the one before. Warming over land has been greater than over the ocean, and some regions (e.g., the Arctic, Europe, North-Eastern North America, Arabian Peninsula, and West Central Asia) have warmed faster than others.

These findings have important implications for company and societal planning—affecting the timing for when the Earth might reach potential future global warming levels and highlighting the many types of global system changes occurring, in addition to the relative magnitude and differences in potential local warming and other climatic changes.

The IPCC also states that it is "unequivocal" that **humans are contributing** to climate change. Thus, for the first time, the IPCC concludes that the evidence is definitive. (See the final section below for a discussion of observed changes in weather extremes.)

Future Climate Change

Additional climate change is shown to be unavoidable (Figure 1). Even with rapid, deep decarbonization, as captured by the lowest emission projection evaluated by WGI (SSP1-1.9), a **global average temperature increase of 1.5°C from the pre-industrial levels is likely to be exceeded** in the next few decades or soon after (Table 1). Note that this projection is associated with a global greenhouse gas emissions pathway that has been shown to be challenging and likely unattainable (Rose and Scott, 2020).

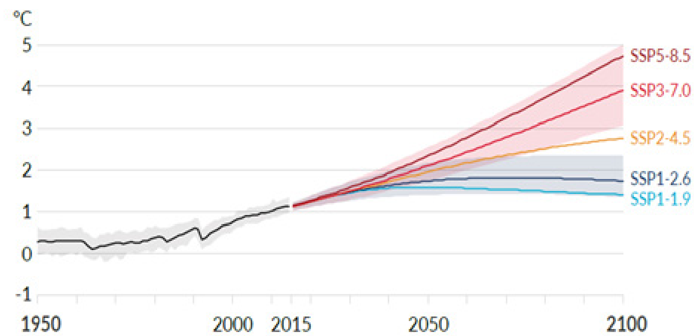


Figure 1. IPCC (2021) assessed projected changes in global average surface temperature for prescribed global emissions pathways (SSPs). Results based on multiple lines of evidence. Developed from IPCC (2021) Figure SPM.8 and Table SPM.1.

The impact of emissions reductions on climate are projected to be realized primarily after mid-century (Table 1), with the broad range of emissions futures evaluated producing **nearly identical projected near-term climate changes through 2040,** with significant overlap through 2060. They more clearly differentiate themselves after

Table 1. IPCC (2021) assessed projected changes in global average surface temperature for prescribed global emissions pathways (SSPs). Results based on multiple lines of evidence. Very likely range' refers to the 90% interval. Red highlights added. Developed from IPCC (2021) Figure SPM.8 and Table SPM.1.

	Near term, 2021-2040		**Mid-term, 2041-2060**		**Long term, 2081-2100**	
Scenario	Best estimate (°C)	*Very likely* range (°C)	Best estimate (°C)	*Very likely* range (°C)	Best estimate (°C)	*Very likely* range (°C)
SSP1-1.9	1.5	1.2 to 1.7	1.6	1.2 to 2.0	1.4	1.0 to 1.8
SSP1-2.6	1.5	1.2 to 1.8	1.7	1.3 to 2.2	1.8	1.3 to 2.4
SSP2-4.5	1.5	1.2 to 1.8	2.0	1.6 to 2.5	2.7	2.1 to 3.5
SSP3-7.0	1.5	1.2 to 1.8	2.1	1.7 to 2.6	3.6	2.8 to 4.6
SSP5-8.5	1.6	1.3 to 1.9	2.4	1.9 to 3.0	4.4	3.3 to 5.7

2060, making the **respective likelihoods of the potential futures important considerations** for planning (e.g., EPRI, 2021a; Rose and Scott, 2018).

The IPCC finds that limiting human-induced global warming requires limiting **cumulative carbon dioxide (CO_2)** emissions over time, as well as other greenhouse gas emissions, including **methane (CH_4),** which has a higher global warming potential than CO_2.

The IPCC also concludes that uncertainty about the **responsiveness of the climate system** to greenhouse gas emissions (equilibrium climate sensitivity) has narrowed, lowering the likelihood that the climate system behaves favorably and is less responsive to emissions, as well as lowering the likelihood of a particularly unfavorable climate response to emissions. However, raising the lower end of this range also implies that the climate system will be more challenging to manage, and each unit of emissions will have a larger climate signal that, among other things, affects estimates of potential climate damages like the social cost of carbon. (See the final section of this brief for a discussion of projected changes in weather extremes.)

Global Warming Levels

For the first time, in addition to climate projections, the IPCC WGI report evaluates and presents changes to climate variables with respect to a common set of global average temperature change levels—1.5˚C, 2˚C, 3˚C, and 4˚C (relative to 1850-1900). These levels are referred to as Global Warming Levels (GWLs).

GWLs are an **alternative way of communicating potential future climate change**, in addition to projections based on emissions scenarios, such as RCP4.5, and more recently SSP2-4.5. See, for instance, Table 2 with information on the assessed timing for surpassing GWLs.

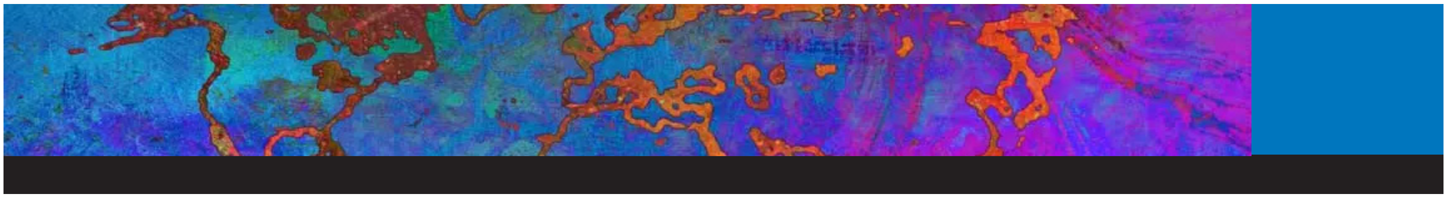
Communicating potential changes in climate variables relative to **GWLs offers various benefits** over scenario-specific projections. GWLs can be more intuitive for decision-makers, and functional for contemplating, evaluating, and communicating potential climates and risk (e.g., what might happen at 1.5˚C, 2˚C, and 3˚C). See, for example, Figure 2 with projected changes in regional climates and global patterns by GWL.

Furthermore, GWLs help isolate and define uncertainty for other physical elements of climate change (e.g., Table 3 illustrates continental climate change ranges by GWL), and facilitate cross-science integration, such as integrating potential climate impacts by GWL with GWLs along a potential decarbonization emissions pathway. Overall, GWLs are useful to climate risk and resiliency analyses, as well as social cost of greenhouse calculations by defining climate variable dynamics relative to global average temperature.

GWLs also have limitations. Some climate variables depend on the path to a GWL, such as sea-level rise and earth-system and ecosystem thresholds that depend on how a particular GWL is reached. Regional air quality is also path dependent – determined by both air pollutants and climatic conditions, that in turn influence climate. In addition, WGI *assesses* global future average temperatures using multiple lines of evidence (i.e., more than model projections), which creates an inconsistency with the GWL-climate variable relationships that are defined by projections alone.

Table 2. IPCC (2021) assessed timing for surpassing GWLs for AR6 climate projections. Shown are very likely (5-95%) ranges for timing when 20-year average GWLs are reached. "n.c." indicates that the GWL is not crossed before 2100. Developed from IPCC (2021) Cross-Section Box TS.1 Table 1.

Projection	Global Warming Level							
	1.5˚C		2˚C		3˚C		4˚C	
	5%	95%	5%	95%	5%	95%	5%	95%
SSP1-1.9	2013-2032	n.c.	n.c.	n.c.	n.c.	n.c.	n.c.	n.c.
SSP1-2.6	2012-2031	n.c.	2031-2050	n.c.	n.c.	n.c.	n.c.	n.c.
SSP2-4.5	2012-2031	2037-2056	2028-2047	2075-2094	2061-2080	n.c.	n.c.	n.c.
SSP3-7.0	2013-2032	2033-2052	2026-2045	2053-2072	2050-2069	n.c.	2070-2089	n.c.
SSP5-8.5	2011-2030	2029-2048	2023-2042	2044-2063	2042-2061	2074-2093	2058-2077	n.c.



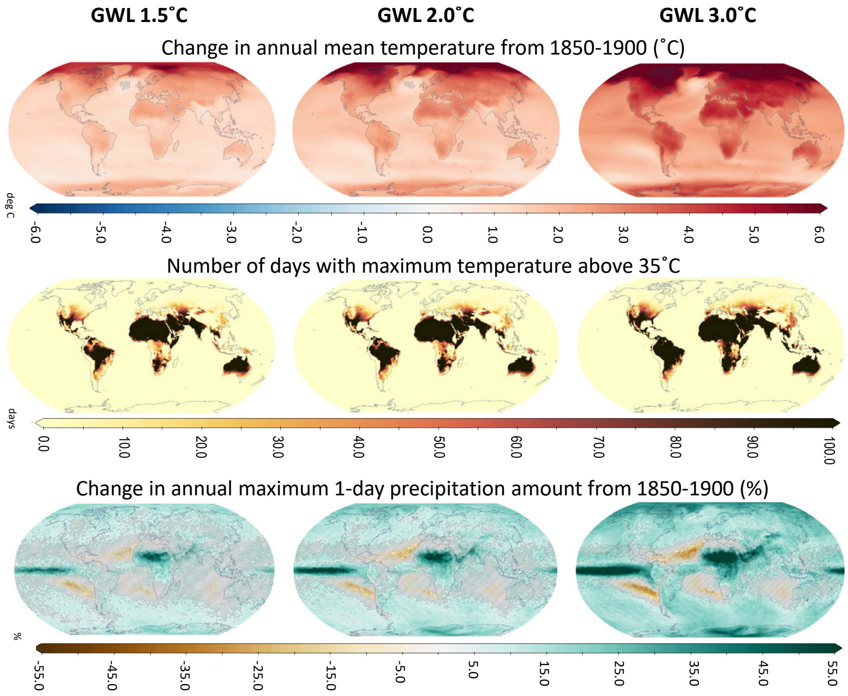


Figure 2. Sample of physical climate change indicators by GWL. Constructed from IPCC (2021) Interactive Atlas.

Extreme Weather

The IPCC finds greater **evidence that human-induced climate change is contributing** to observed extreme weather changes, but the **evidence varies by type of extreme** (e.g., Table 4 for North America). For example, evidence of the human contribution is greater for observed changes in heat extremes and heavy precipitation events than for droughts. Science assessing links between extreme weather and climate change is a rapidly developing area of research; however, the ability to evaluate the relationship between extreme weather and human-induced climate change is in some cases constrained by current capabilities for simply detecting changes (EPRI, 2021b). For most types of extreme weather, it is important to recognize that non-climate factors (e.g., where and how homes are built, fire ignition) are also important contributors to risk, and important considerations for managing extreme weather risk.

Table 3. Sample of continental temperature and precipitation ranges by GWL. Ranges are 5th and 95th percentiles from climate model inter-comparison results. Constructed from IPCC (2021) Interactive Atlas.

Climate Variable	Region	Global Warming Level			
		1.5ºC	2ºC	3ºC	4ºC
Mean temperature (ºC)	North America	4 to 8	5 to 9	6 to 11	8 to 11
	Africa	24 to 26	24 to 27	25 to 28	26 to 29
Minimum of daily low temperature (ºC)	North America	-32 to -20	-30 to -18	-27 to -15	-25 to -15
	Africa	6 to 12	7 to 13	8 to 14	10 to 14
Number of days above 35ºC – bias adjusted	North America	16 to 24	19 to 29	27 to 40	36 to 50
	Africa	107 to 133	116 to 151	131 to 183	153 to 210
Maximum 1-day precipitation (mm)	North America	31 to 47	32 to 48	34 to 50	40 to 53
	Africa	21 to 58	22 to 59	25 to 66	29 to 67
Maximum 5-day precipitation (mm)	North America	63 to 83	65 to 84	68 to 87	75 to 93
	Africa	52 to 105	55 to 107	60 to 118	68 to 113

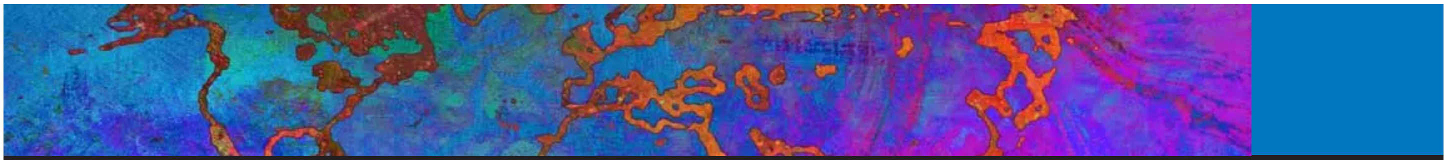


Table 4. Sample of IPCC (2021) assessed observed trends, and attribution to climate change, and future changes for select weather extremes for North America (NA). Constructed from IPCC (2021) Interactive Atlas results for IPCC WGI's four NA regions.

	Weather Extreme	Observed Trend (and Attribution)	Future Changes
	Extreme heat	Upward trend with medium confidence of attribution in Western NA	High confidence of increase
	Cold spell	Downward trend with medium confidence of attribution in Western NA	High confidence of decrease
	Heavy precipitation	Upward trend with medium confidence of attribution in Central NA	High confidence of increase
	Drought	No assessment given	Medium confidence of increase
	Fire weather	Upward trend without attribution in Western NA	High confidence of increase in Western NA, medium confidence of increase in Central and Eastern NA
	Coastal and river flooding	Upward trend without attribution	High confidence of increase
	Tropical cyclone, severe wind	No assessment given	Medium confidence of increase

Increases in the **frequency and intensity** of many extremes is expected with additional future climate change (Figure 3 and Table 4), as is increased **variability** in local water cycles (e.g., precipitation and events severity). Furthermore, changes in extreme weather with warming vary significantly geographically—for a given warming level and in terms of the responses to greater warming and response uncertainty. See Figure 2 and Table 3 for quantitative extreme temperature and precipitation examples.

With greater future warming, every region is projected to increasingly experience **concurrent and multiple changes** in climatic impact-drivers, such as concurrent heatwaves and droughts, combinations of hot, dry, windy conditions that are conducive to wildfire (fire weather), and storm surge combined with rainfall-driven flooding.

Decadal variation, in addition to longer-run climate trends, is also important to consider in risk planning, and for resiliency and reliability.

Relevance to EPRI Research

EPRI is assessing and integrating this science into our research:

- Climate resiliency. Factoring this information into climate data resources, as well as asset and power system design resilience research.
- Climate-related risk and disclosure. Informing the scientific basis for physical climate risk assessment, research design, methodological guidance, and company and stakeholder education.
- Social costs of carbon and other greenhouses. Assessment of the climate and earth system science related to estimation of the economic costs of emitting a unit of carbon dioxide, methane, or other greenhouse gas that inform regulatory and other policy decisions.

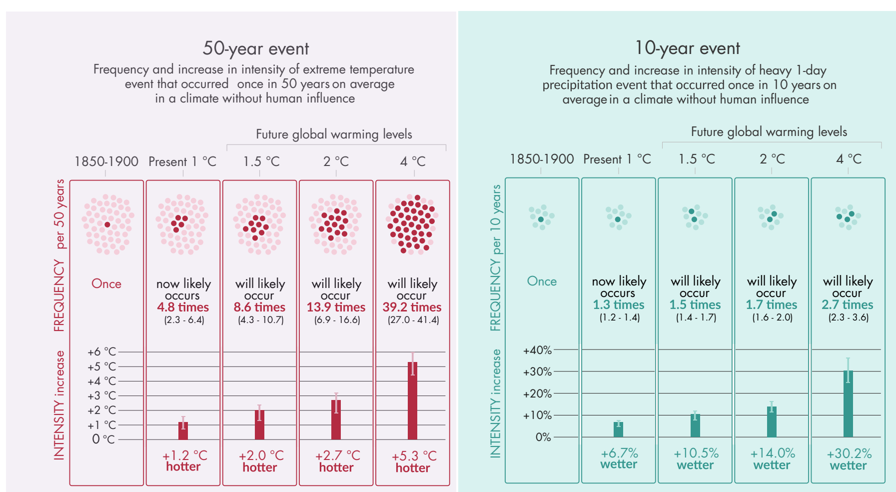


Figure 3. IPCC (2021) projected average changes by GWL in frequency and intensity of hot temperature extremes over land 50-year events (left panel), and heavy precipitation over land 10-year events (right panel). Developed from IPCC (2021) Figure SPM.6.

Additional References

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