United in Science 2022

A multi-organization high-level compilation of the most recent science related to climate change, impacts and responses

Photographer: Alkis Konstantinidis/Reuters

WORLD METEOROLOGICAL ORGANIZATION

UN environment programme

GLOBAL CARBON project

Met Office

ipcc INTERGOVERNMENTAL PANEL ON climate change

UNDRR UN Office for Disaster Risk Reduction

This report has been compiled by the World Meteorological Organization (WMO) under the direction of the United Nations Secretary-General to bring together the latest climate science-related updates from key global partner organizations – WMO, Global Carbon Project (GCP), UN Environment Programme (UNEP), Met Office (United Kingdom), Urban Climate Change Research Network (UCCRN), UN Office for Disaster Risk Reduction (UNDRR), World Climate Research Programme (WCRP, jointly sponsored by WMO, IOC-UNESCO and the International Science Council (ISC)) and the Intergovernmental Panel on Climate Change (IPCC). The content of each chapter is attributable to each respective organization.

The report is available electronically at: https://public.wmo.int/en/resources/united_in_science

Cover Illustration: A man works on a destroyed house in the aftermath of Cyclone Batsirai in the town of Mananjary, Madagascar, 8 February 2022 (REUTERS/Alkis Konstantinidis).

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IPCC boxes: content taken from the Summary for Policymakers (SPM) reports from the most recent IPCC 6th Assessment Report, including Working Group I: The Physical Science Basis, Working Group II: Impacts, Adaptation and Vulnerability and Working Group III: Mitigation of Climate Change.

Foreword by Antonio Guterres, Secretary-General of the United Nations

Rapidly accelerating climate disruption means that no one is safe from disasters such as floods, droughts, heatwaves, extreme storms, wildfires or sea level rise. The answer lies in urgent climate action, yet we continue to feed our fossil fuel addiction and to compromise the livelihoods of future generations.

In the Paris Agreement on climate change, governments pledged to limit global temperature rise to 1.5 degrees and to build climate-resilient communities. This year's United in Science report shows that we are way off track. It is time to turn pledges into action.

We need a renewable energy revolution to bring down carbon emissions. We must also double investment in adaptation. A first necessary step, which is both quick and cost-effective, is early warning.

Early warnings save lives and livelihoods from climate threats. Yet, many developing countries still lack such systems. Ensuring early warnings is essential to help people prepare for extreme weather events, droughts and other climatic impacts. I am pleased that the World Meteorological Organization is developing a plan to ensure universal global early warning coverage within the next five years.

However, we need much more if we are to rise to the existential climate challenge. I urge all leaders to heed the facts in this report, to unite behind the science and to take ambitious urgent climate action.

A. Guterres, Secretary-General UN

Foreword by Prof. Petteri Taalas, Secretary-General of the World Meteorological Organization

The science is unequivocal: we are going in the wrong direction.

Greenhouse gas concentrations are continuing to rise, reaching new record highs. Fossil fuel emission rates are now above pre-pandemic levels. The past seven years were the warmest on record. Cities, which contribute 70% of global emissions, are highly vulnerable to climate impacts.

These trends will continue if we do not act urgently to reduce fossil fuel emissions. Ambition of emissions reduction pledges for 2030 needs to be seven times higher to meet the 1.5 °C goal of the Paris Agreement.

The combined effects of higher temperatures and humidity in some regions could have dangerous consequences for human health in the next few decades. This could lead to physiological tipping points beyond which outdoor human labor is no longer possible without technical assistance. Research on this and other climate tipping points, such as the melting of polar ice sheets, will help society better understand the costs, benefits and potential limitations of climate mitigation and adaptation in the future.

Climate science is increasingly able to show that many of the extreme weather events that we are experiencing have become more likely and more intense due to human-induced climate change. It is more important than ever that we scale up action on early warning systems to build resilience to current and future climate risks in vulnerable communities.

I thank the many expert teams involved in creating this report for their collaboration, uniting the climate science community to deliver the latest essential information, in these unprecedented times.

Prof. P. Taalas, Secretary-General WMO

Summary

United in Science provides an overview of the most recent science related to climate change, impacts and responses from the World Meteorological Organization (WMO) and partner organizations. At a time when urgent action to address climate change is needed, the report provides unified scientific information to inform decision-makers and highlights some of the physical and socioeconomic impacts of the current and projected climate.

According to the WMO Global Atmosphere Watch (GAW), atmospheric greenhouse gas (GHG) concentrations continue to rise, despite emissions reductions in 2020 resulting from the COVID-19 pandemic lockdowns. The Global Carbon Project (GCP) also notes that, in 2021, global fossil CO_2 emissions returned to 2019 pre-pandemic levels after a large, but temporary, absolute drop in emissions due to widespread lockdowns. These conditions are leading to increasing global surface temperature and other climatic changes, as highlighted by the WMO *State of the Global Climate 2021* report, which found the most recent seven years, 2015 to 2021, to be the warmest on record.

Looking forward, the Met Office (UK), in partnership with the World Climate Research Programme (WCRP), found that there is a 48% chance that annual mean temperature will temporarily be 1.5 °C higher than in 1850-1900 during at least one year in the next five years. Additionally, there is a 93% chance that at least one year in the same time period will be the hottest on record.

The UN Environment Programme's (UNEP) latest *Emissions Gap Report* found that full implementation of mitigation pledges made by countries (as of 4 November 2021) are insufficient and will not keep global warming below 1.5 °C above pre-industrial levels. The report also found that the ambition of these pledges would need to be four times higher to keep global temperature rise below 2 °C above pre-industrial levels and seven times higher to limit warming to 1.5 °C. Enhanced mitigation action is needed to prevent the goals of the Paris Agreement from slipping out of reach.

Without ambitious action, the physical and socioeconomic impacts of climate change will be devastating. Irreversible physical changes in the climate system, known as tipping points, can not be ruleld out and could have significant global and regional consequences. According to the Urban Climate Change Research Network, cities – responsible for up to 70% of human-caused emissions – will face increasing climate impacts that will intersect with socioeconomic inequalities. Additionally, the WMO World Weather Research Programme highlights that it is the world's most vulnerable populations that will suffer the most, as has already been observed during recent extreme weather events.

Billions of people around the world are highly vulnerable to the impacts of climate change. As a result, adaptation and disaster risk reduction are crucial to lower the risks to climate impacts. According to WMO and the UN Office for Disaster Risk Reduction (UNDRR), early warning systems not only save lives and reduce losses and damages, but also contribute to disaster risk reduction, and support climate change adaptation. However, less than half of all countries in the world have these crucial systems and coverage is particularly low in vulnerable countries. To address this issue, the United Nations Secretary-General António Guterres called for new action to ensure every person on Earth is protected by early warning systems in the next five years.

Additionally, the Intergovernmental Panel on Climate Change (IPCC) recently released highly anticipated Working Group reports covering *The Physical Science Basis*; *Impacts, Adaptation and Vulnerability*; and *Mitigation of Climate Change*, which are an integral part of its Sixth Assessment Report. These important reports identify the strength of scientific agreement in these different areas and identify where further research is needed.

The science is clear – urgent action is needed to mitigate emissions and adapt to our changing climate. The United Nations system, along with its partners, will continue to provide world-leading science to inform decision-making and support global climate action.

Key messages

- **Atmospheric greenhouse gas concentrations continue** to rise and fossil fuel emissions are now above pre-pandemic levels after a temporary drop due to lockdowns associated with the COVID-19 pandemic in 2020 and 2021
- **Recent years saw record high temperatures and ocean heat.** Looking forward, there is a 48% chance that, during at least one year in the next five years, annual mean temperature will temporarily be 1.5 °C higher than in 1850-1900
- **Mitigation pledges are insufficient to achieve the Paris Agreement.** Enhanced action is needed to prevent the continued warming that is increasing the likelihood of irreversible changes in the climate system, known as tipping points
- **Billions of people around the world are exposed to climate change impacts.** Cities – responsible for up to 70% of human-caused emissions – will face increasing socioeconomic impacts and the world's most vulnerable populations will suffer most, as seen in recent extreme weather events
- **Adaptation is crucial to lower the risks to climate impacts.** Early warning systems can save lives, reduce losses and damages, contribute to disaster risk reduction, and support climate change adaptation.

Tipping Points in the Climate System

WMO/World Climate Research Programme
(WMO/International Science Council/IOC-UNESCO)

Key messages

- Major tipping points include changes in the Atlantic Meridional Overturning Circulation, the melting of polar ice sheets, the migration of large-scale weather and climate patterns, drying of the Amazon rainforest, or disruptions of major weather systems, such as the monsoon
- The combined effects of higher temperatures and humidity during hot spells in some regions could reach dangerous levels in the next few decades, which could lead to physiological tipping points, or thresholds beyond which outdoor human labor is no longer possible without technical assistance
- Further research on tipping points will be crucial to help society better understand the costs, benefits and potential limitations of climate mitigation and adaptation in the future.

"Tipping points" have become a widely-used shorthand for many aspects of non-linear changes in a complex system. What we now refer to collectively as "tipping points in the climate system" were first addressed in the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) as "surprises" (Stocker et al., 2001) and subsumed under the "Reasons for Concern" as "large-scale singular events" or "discontinuities in the climate system" (IPCC, 2001). These tipping points have both global and regional consequences and include changes in the Atlantic Meridional Overturning Circulation (AMOC), the melting of polar ice sheets, the migration of large-scale weather and climate patterns, and dieback of the Amazon rainforest.

Tipping points with global consequences

AMOC is an important driver of the distribution of heat, salt, and water in the climate system, both regionally and globally. Based on paleoclimate proxy data, it has been suggested that AMOC may be weaker in the current climate than at any other time in the last millennium (Caesar et al., 2021). In addition, recent models consistently indicate that the AMOC will weaken as CO_2 continues to increase (Weijer et al., 2020). Although direct measurements since 2004 show no significant trends (Worthington et al., 2021), continuous long-term weakening of the AMOC, as robustly suggested by models (Jackson et al., 2022), may increase its vulnerability to other changes, such as freshwater delivery from melting ice sheets and glaciers. As a result, the continued study, identification, and observation of early warning signals of a potential tipping point in the AMOC is crucial (Boers, 2021).

The melting of the polar ice sheets on Greenland and Antarctica have been considered tipping elements for many years (Figure 1). Their tipping would be particularly dangerous as they would have global consequences due to substantial additional sea-level rise on the timescales of centuries to millennia (Clark et al., 2016). The IPCC Fifth Assessment Report communicated that crossing a critical global warming threshold between 1 °C and 4 °C would lead to significant and irreversible melting of the Greenland Ice Sheet (Stocker et al., 2013). However, this range was reassessed and found to be at or slightly above 1.5 to 2 °C – that is, the global warming limits of the Paris Agreement (Pattyn et al., 2018). At this warming level, the West Antarctic Ice Sheet would also be at increasing risk of irreversible ice loss (Garbe et al., 2020). While the underlying physical mechanisms are well-researched and theoretically understood, determination of the critical thresholds for the individual ice basins under realistic conditions and topography is very difficult, and large uncertainties remain (Pattyn and Morlighem, 2020).

Figure 1. Crossing tipping points associated with ice-sheet instabilities in Antarctica, or with rapid discharge from ice streams in Greenland, can have serious global impacts. (Terminus of Jakobshavn Isbrae, Greenland, Photo T.F. Stocker).

Regional tipping points

Recently, regional tipping points, such as migration of large-scale weather and climate patterns, changes in extreme and compound events, and drying of the Amazon rainforest, have moved into focus. There is concern that their impacts may have serious consequences for local communities (Figure 2) and could cause further cascading impacts, including global feedbacks, such as potential effects of regional droughts on the global carbon cycle (Humphrey et al., 2018). Overall, while these tipping points may first occur regionally in several locations, over time they may add up to a global scale with cumulative and compounding impacts (e.g., Kornhuber et al., 2020).

A gradual migration of large-scale weather or climate patterns may be registered regionally as tipping into a new regime. The paleoclimate record, for example, has pointed to phases when the monsoon belt has shifted or changed in intensity in response to large-scale hemispheric climate changes during the last 30 000 years (Brovkin et al., 2021). A recent analysis suggests that future warming could lead to an intensification of the Indian monsoon and its variability, expressed possibly as shorter and heavier rains (Katzenberger et al., 2021).

In mid-latitude regions, changes in soil moisture can lead to threshold effects in evaporative regimes, and to an associated non-linear amplification of heat extremes (Seneviratne et al., 2010; Miralles et al., 2014; Vogel et al., 2018). Furthermore, the frequency of threshold-based climate extremes generally increases non-linearly with increasing global warming, with the largest relative changes for the most extreme events (Kharin et al., 2018). Changes in regional mean climate and the intensity of climate extremes tend to vary linearly as a function of global warming (Wartenburger et al., 2017). However, they can also lead to the crossing of regional ecosystem thresholds (Guiot and Cramer 2016; Warren et al., 2018; Ratnayake et al., 2019; Breshears et al., 2020) and to climate regime shifts in combination with vegetation changes and societal responses. An example of this is the dust bowl period in the United States (e.g., Cowan et al., 2020).

The marine environment is also prone to regional tipping. Marine heat waves, for example, could occur more frequently and more intensely (Frölicher et al., 2018). Ocean acidification, caused by the ocean's absorption of increasing atmospheric carbon dioxide concentrations in its role as a carbon sink, could cross thresholds with consequent coral bleaching and other marine ecosystem impacts (Hoegh-Guldberg et al., 2019). Regional tipping points of marine systems due to warming, ocean acidification, and deoxygenation can, in combination, cause global impacts (Heinze et al., 2021).

The Amazon rainforest, a unique ecosystem of global significance and value, is under pressure from deforestation and anthropogenic climate change. Although projections of its future evolution are highly uncertain, studies point to the likelihood of further drying (Baker et al., 2021). More extended dry seasons and extreme drought events, and self-reinforcing feedbacks, could further reduce the forest extent (Zemp et al., 2017) with a potential approach to a tipping point (Boulton et al., 2022) where the forest is unsustainable. Loss of the Amazon rainforest would have potentially devastating consequences on regional climate, biodiversity and social systems as well as potentially wider impacts through changes of the hydrological and carbon cycles.

Figure 2. Thresholds and tipping points may be increasingly encountered in regional weather patterns and extremes with consequences for local communities and ecosystem services (Drought and developing storm in the Ebro Delta, Spain, 2020. Photo WMO/Agusti Descarrega Sola).

Consequences of tipping points on human health and well-being

The impact of climate change on human health is receiving greater attention (Romanello et al., 2021) as the potential threats are multiple. The combined effects of higher temperatures and humidity during hot spells in some regions could reach dangerous levels in the next few decades (Pal and Eltahir, 2016), which could lead to physiological tipping points, or thresholds beyond which outdoor human labor is no longer possible without technical assistance. Already, a substantial fraction of heat-related mortality today can be attributed to anthropogenic warming (Vicedo-Cabrera et al., 2021) and this trend is increasing in extent and magnitude. Hence these events can cause tipping points and threshold behaviour in the Earth system, which includes the biosphere, the carbon cycle, and society, as socioeconomic impacts are expected to be strong and irreversible on intermediate timescales.

Taken together, tipping points in the climate system are a scientific topic of great public interest. The WCRP, for example, is addressing this issue in one of their Lighthouse Activities through an international platform to combine theoretical-mathematical approaches, observational monitoring, and comprehensive climate modelling efforts. Non-linear processes in the climate system are at the origin of tipping elements, so a concerted international effort in high-resolution coupled Earth system modelling developing and utilizing exa-scale computing infrastructure (Slingo et al., 2022; Hewitt et al., 2022) will provide an improved representation of climate feedbacks and of dynamical responses responsible for tipping elements.

Finally, a formal scientific consensus on tipping points and irreversible climate change, which is central to estimating climate risk, yet fraught with deep uncertainty, is policy-relevant. The latest IPCC report has assessed tipping points and outlines the limits of the current status of knowledge. A cross-working group IPCC Special Report on "*Climate Tipping Points and Consequences for Habitability and Resources*" would help strengthening a consensus on this topic and trigger the much needed advances in scientific understanding to more comprehensively inform adaptation and mitigation strategies.

IPCC headline statements

- Many changes due to past and future greenhouse gas emissions are irreversible for centuries to millennia, especially changes in the ocean, ice sheets, and global sea level (IPCC Working Group I, 2021)
- The probability of low-likelihood, high impact outcomes increases with higher global warming levels (*high confidence*). Abrupt responses and tipping points of the climate system, such as strongly increased Antarctic ice-sheet melt and forest dieback, cannot be ruled out (*high confidence)* (IPCC Working Group I, 2021)
- The rise in weather and climate extremes has led to some irreversible impacts as natural and human systems are pushed beyond their ability to adapt (*high confidence*) (IPCC Working Group II, 2022).

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