Preface

The Working Group I (WGI) contribution to the Sixth Assessment Report (AR6) of the Intergovernmental Panel on Climate Change (IPCC) focuses on a full and comprehensive assessment of the physical science basis of climate change, based on evidence from more than 14,000 scientific publications available by 31 January 2021.

This Report reflects recent climate science advances resulting from progress in, and the integration of, multiple lines of evidence, including: in situ and remote observations; paleoclimate information; understanding of climate drivers and physical, chemical and biological processes and feedbacks; and global and regional climate modelling; as well as advances in methods of analyses and insights from the growing field of climate services.

The AR6 WGI Report builds on the WGI contribution to the IPCC's Fifth Assessment Report (AR5) in 2013, and the AR6 Special Reports[1] released in 2018 and 2019.

The report considers the current state of the climate in the long-term context, the understanding of human influence, the state of knowledge about possible climate futures, climate information relevant for climate-related risk assessment and regional adaptation, and the physical science basis on limiting human-induced climate change.

Scope of the Report

As part of the scoping process and approval of the outline of the IPCC Sixth Assessment Report, the WGI contribution evolved from the structure of past WGI assessment reports, reflecting developments in climate science and the assessment of global and regional climate information that is relevant to inform decision-making.

Some key new topics assessed by WGI include the global response to new illustrative emissions scenarios, physical climate storylines, low-likelihood, high-impact outcomes, and physical climate conditions that affect society and/or ecosystems (defined as climatic impact-drivers).

The integration of multiple lines of evidence strengthens the understanding of past, current and possible future changes in the climate system and the distillation of regional climate change information at regional scale. The new structure of the WGI Report is designed to facilitate this integration for end-to-end assessment of key topics and to enhance the visibility of knowledge developments for global and regional climate change. This includes climate information that is relevant for risk assessment, regional adaptation and for mitigation. It is also designed to inform decision-making without being policy prescriptive and to facilitate the integration of the WGI key findings with the other AR6 Working Group reports.

Structure of the Report

This Report consists of thirteen thematic chapters with their supporting supplementary material, ten annexes (including the report Glossary, which is developed in coordination with Working Groups II and III where relevant), an integrative Technical Summary, and a Summary for Policymakers. An innovation in this Working Group I assessment is the online Interactive Atlas (https://interactive-atlas.ipcc.ch), a novel tool for flexible spatial and temporal analyses of observed and projected climate change information, which enhances accessibility for stakeholders and users to the data assessed in the Report.

The Summary for Policymakers and Technical Summary include the line of sight, indicated in curly brackets, to the chapters and the specific sections therein where the detailed assessment can be found. In this way, these summary components of the Report provide a roadmap to the contents of the entire report and a synthesis of the major findings that is traceable to the underlying literature and assessment.

The introduction (Chapter 1) of the Report frames the WGI assessment within the broader AR6 and global climate policy context and introduces the key concepts, lines of evidence, and major developments. The remainder of the Report is structured in three segments. The first segment focuses on large-scale climate change (Chapters 2–4). These chapters provide an updated and comprehensive assessment of knowledge about the current state of the climate system, human influence and projections of future change on key large-scale indicators of the climate system. Chapter 2 assesses observed large-scale changes in the climate system in the long-term paleoclimate context. Chapter 3 updates the assessment of human influence on the climate system, considering natural variability, model performance and detection and attribution. Chapter 4 covers global climate projections spanning time horizons from the near term (2021–2040) to the mid-term (2041–2060), long term (2081–2100) and beyond.

The second segment of the report is dedicated to climate system components and processes that play key roles in global and regional climate (Chapters 5–9), including carbon and other biogeochemical cycles, energy, and water; short-lived climate forcers (SLCFs) and their link to air quality; and changes in the ocean, cryosphere and sea level. Chapter 5 addresses the assessment of the global biogeochemical budgets for carbon dioxide, methane, and nitrous

1 Global warming of 1.5°C: an IPCC special report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty (SR1.5); Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems (SRCCL); IPCC Special Report on the Ocean and Cryosphere in a Changing Climate (SROCC).

Downloaded from https://www.cambridge.org/core. UNIVERSIDAD AUTONOMA METROPOLITANA, on 14 Nov 2026 at 21:43:44, subject to the Cambridge Core terms of use, available at https://www.cambridge.org/core/terms. https://doi.org/10.1017/9781009157896

oxide and the assessment of carbon and other biogeochemical feedbacks. Chapter 6 assesses changes in the emissions and abundances of individual SLCFs, how these changes affect Earth's energy balance through radiative forcing and feedback in the climate system, the implications of changing climate on air quality, and the implications of SLCF mitigation for climate and for air quality. Chapter 7 addresses Earth's energy budget through advances in observations, understanding and quantification of effective radiative forcing, and the assessment of feedbacks and climate sensitivity. Chapter 8 assesses observed and projected changes in the global water cycle, the physical understanding of the complexity of its response to multiple drivers, and implications for water availability. The physical processes underlying global and regional changes in the ocean, cryosphere and sea level and the understanding of observed and projected future changes since the AR5 and Special Report on the Ocean and Cryosphere in a Changing Climate are assessed in Chapter 9.

The final four chapters of the Report (Chapters 10–12 and the Atlas) are dedicated to the assessment and distillation of regional climate information from multiple lines of evidence at sub-continental to local scales (including urban climate), building on information from previous chapters on large-scale climate and process understanding, with a focus on recent and projected regional changes in mean climate, extremes, and climatic impact-drivers. Chapter 10 assesses the foundations of how regional climate information is distilled from multiple lines of evidence and the interplay between anthropogenic causes and internal variability at regional scales. Chapter 11 addresses changes in weather and climate extremes on global and regional scales, including observed changes and their attribution, as well as projected changes. Chapter 12 assesses the climatic conditions that may lead to impacts and risks across the world's regions. Changes in mean climate at regional scales, in particular observed trends and their attribution and projected future changes in temperature and precipitation, are assessed in the Atlas chapter.

The Interactive Atlas allows flexible spatial and temporal analyses of climate variables, extreme indices and climatic impact-drivers, including datasets underpinning assessment findings across report chapters and syntheses of regional changes.

Specific regional case studies are considered in different chapters, including rainfall changes in the Sahel and Western Africa, South-Western North America, and South-Eastern South America; climate information relevant for water resources in small islands, for Cape Town drought, for the Indian summer monsoon, for Mediterranean summer warming, and for the Hindu Kush Himalaya region; urban climate processes and trends; and the influence of the Arctic on mid-latitude climate.

All chapters contain Frequently Asked Questions, which are grounded in the assessment and written in language that is more accessible to a broad readership and can serve as a resource for teaching and outreach.

Each chapter is accompanied by Supplementary Material, which is available online and provides traceability and transparency for technical aspects of the assessment, such as descriptions of datasets, models or methodologies supporting chapter analyses.

The Process

This WGI Assessment Report represents the combined efforts of hundreds of leading experts in the field of climate science and has been prepared in accordance with principles and procedures of the IPCC.

A scoping meeting for the Sixth Assessment Report was held in May 2017, and the outlines for the contributions of the three Working Groups were approved at the 46th Session of the Panel in September 2017. Governments and IPCC observer organizations nominated experts for the author team. The team of 198 Coordinating Lead Authors and Lead Authors plus 36 Review Editors selected by the WGI Bureau was accepted at the 55th Session of the IPCC Bureau in January 2018. During the report preparation, a few changes have taken place to address core expertise gaps and to replace authors who were not available anymore. In addition, 615 Contributing Authors provided information to the author teams at their request.

Drafts prepared by the authors were subject to two rounds of formal review and revision followed by a final round of government comments on the Summary for Policymakers. A total of 78,007 written review comments were submitted by 1891 individual expert reviewers and 47 governments. The Review Editors for each chapter monitored the review process to ensure that all review comments received appropriate consideration. All review comments and responses are available online on the report website.

Three in-person Lead Author Meetings took place to enhance progress and coordination in the assessment process. These were particularly critical for the intense cross-chapter coordination implied by the new report outline.

We strived to foster an inclusive environment that achieves a rigorous and transparent assessment process. These efforts included greater attention to addressing implicit biases and technical considerations to enhance the participation in the process and increasing the accessibility of the assessed information.

For the first time in the IPCC, WGI recommended the implementation of FAIR (findable, accessible, interoperable, reusable) data principles in the assessment to document and curate the data assessed and included in report figures. The motivation was to increase transparency and accessibility of the assessment, support implementation of the IPCC Error Protocol, and provide for the long-term curation of the assessed digital information. This process was supported by our close collaboration with the IPCC Task Group on Data Support for Climate Change Assessments (TG-Data) established in March 2018.

The COVID-19 pandemic was declared by the World Health Organization at the start the Second Order Draft review. Following an extensive consultation process with IPCC member countries, authors and the scientific community, including editors of relevant

Downloaded from https://www.cambridge.org/core. UNIVERSIDAD AUTONOMA METROPOLITANA, on 14 Nov 2026 at 21:43:44, subject to the Cambridge Core terms of use, available at https://www.cambridge.org/core/terms. https://doi.org/10.1017/9781009157896

science journals, the timeline of the report was extended by four months to balance the delays and challenges faced by authors and the scientific community with maintaining momentum and timeliness in the assessment process. The review process is critical for the rigor, objectivity and comprehensiveness of the assessment. The adjustments to the timeline facilitated broad participation from scientists and governments in the review process. Stringent scientific rigor and quality of the assessment were maintained despite the pandemic.

The fourth Lead Author Meeting, due to be held in June 2020, was replaced by extensive virtual activities to address the Second Order Draft review comments and topics that cut across multiple chapters. A final virtual Lead Author Meeting was held in February 2021 to finalize the report. Drafting meetings for the Summary for Policymakers also took place through virtual meetings.

Addressing the implications of the COVID-19 pandemic on the assessment process required innovation to facilitate international virtual collaboration, including extra support and training for participants and facilitators, support for participants with internet connectivity challenges, additional advance preparation, shorter and more focused meetings with clear agendas and objectives and duplicated to account for time zones of participants, high levels of transparency – including the provision of written summaries of meetings and decisions, and allotting time for asynchronous contributions to the discussion and decision-making process.

Documenting and understanding barriers to participation due to an increased reliance on online activities and the use of inclusive practices required priority attention in these novel conditions. We gained experience in applying methods to facilitate participatory and inclusive processes in the assessment and recognized the necessity of fostering these approaches over the course of the assessment process, both during and in-between meetings, to build a stronger community of practice within this unique international context. This will be an important legacy for future assessment cycles.

The preparation of the WGI AR6 report was also informed by recommendations from several IPCC expert meetings. The first meeting focused on assessing climate information for regions (in 2018, co-organized by WGI and WGII, and hosted at ICTP, Trieste, Italy), which provided a scoping of the Interactive Atlas. A second meeting focused on short-lived climate forcers (in 2018, co-organized by TFI and WGI, and hosted by the World Meteorological Organization in Geneva, Switzerland), which identified science advances in the understanding of emissions and climate effects of SLCFs and needs for improvements in emission inventories and methodologies. A third meeting on mitigation, sustainability, and climate stabilization scenarios (in 2019, organized by WGIII in Addis Ababa, Ethiopia), led to cross-WG coordination related to scenarios. Recommendations for clarity and readability from the 2016 IPCC Expert Meeting on Communication (organized by the IPCC Secretariat in Oslo, Norway) were taken into account in developing technical guidance, training and resources provided to authors and in particular for the preparation of the text and figures of the Frequently Asked Questions and the Summary for Policymakers.

The Summary for Policymakers was approved line-by-line during the first-ever virtual IPCC approval session, the 14th Session of IPCC Working Group I from 26 July – 06 August 2021, and the underlying Report was accepted during the 54th Session of the IPCC on the 6th August 2021.

Acknowledgements

We are very grateful for the exceptional rigor and dedication of the volunteer Coordinating Lead Authors and Lead Authors throughout this process, who delivered the most comprehensive assessment ever of our physical understanding of climate change. We thank the Review Editors for working alongside the author teams to ensure that the chapters are fully reflective of the input provided through the review process. We express our sincere appreciation to all the government and expert reviewers, including several group reviews from early-career scientists. We thank the many Contributing Authors who provided input and important support to the authors.

A special thanks goes to the Chapter Scientists of this report who went above and beyond what was expected of them: Kari Alterskjaer, Lisa Bock, Katherine Dooley, Gregory Garner, Mathias Hauser, Tim Hermans, Lijuan Hua, Carley Iles, Maialen Iturbide, Laurice Preciado Jamero, Martin Jury, Megan Kirchmeier Young, Chaincy Kuo, Hui-Wen Lai, Alice Lebehot, Elizaveta Malinina Rieger, Sebastian Milinkski, Therese Myslinski, Tamzin Palmer, Browdie Pearson, Stephane Senesi, Jérôme Servonnat, Chris Smith, David Smyth, Sabin Thazhe Purayil, Emilie Vanvyve, Tania Villasenor Jorquera, Hui Wan and Kyung-Sook Yu. Chapter scientists were recruited by and reported directly to the Coordinating Lead Author(s) and provided technical support to the chapters, including reference checking and compilation, figure drafting, traceability checking, identification of overlaps or inconsistencies across chapters, and technical editing.

We thank the Vice Chairs of the WGI Bureau for their dedication, guidance and wisdom throughout the preparation of the Report and their support for cross-Working Group coordination: Edvin Aldrian, Fatima Driouech, Gregory Flato, Jan Fuglestvedt, Muhammad I. Tariq, Carolina Vera and Noureddine Yassaa.

We gratefully acknowledge the support from the host countries and institutions of the WGI Lead Author Meetings (LAMs): China Meteorological Administration (CMA), China, for hosting the first LAM; Environment Canada, Canada, for hosting the second LAM; and Météo France, France, for hosting the third LAM. We also thank the Ministerio de Ciencia, Tecnologia, Conocimiento e Innovación and the Ministerio del Medio Ambiente, Chile, for offering to host the fourth LAM meeting that we were unable to hold in person due to the COVID-19 pandemic.

The support provided by governments and institutions, as well as through contributions to the IPCC Trust Fund, is thankfully acknowledged as it enabled the participation of the author teams in the preparation of the Report. The efficient operation of the WGI Technical Support Unit (TSU) was made possible by the generous financial support provided by the government of France

Downloaded from https://www.cambridge.org/core. UNIVERSIDAD AUTONOMA METROPOLITANA, on 14 Nov 2026 at 21:43:44, subject to the Cambridge Core terms of use, available at https://www.cambridge.org/core/terms. https://doi.org/10.1017/9781009157896

and administrative and information technology support from the Université Paris Saclay (France), Institut Pierre Simon Laplace (IPSL) and the Laboratoire des Sciences du Climat et de l'Environnement (LSCE). We thank the Norwegian Environment Agency for supporting the preparation of the graphics for the Summary for Policymakers. We thank the United Nations Environment Programme Library for providing a service for authors to access literature.

The approval of the WGI Summary for Policymakers took place in an unprecedented context, with travel restrictions caused by the COVID-19 pandemic rendering an in-person IPCC Plenary session impossible. We thank the support and advice of the IPCC Executive Committee and the tireless work of the ad-hoc task group that was established to advise us as Co-Chairs in preparing for the approval session. The task group was led by IPCC Vice-Chair Ko Barrett and included WGI Vice-Chairs Fatima Driouech, Greg Flato and Edvin Aldrian; Anna Pirani and Sarah Connors of the WGI TSU; and Ermira Fida of the IPCC Secretariat. The task group prepared guidance for participants on the modalities of the session and a carefully structured meeting schedule to implement a virtual approval process.

The approval took place virtually for the first time and involved more than 186 hours of online meetings. We thank all participants for the remarkable collaborative spirit and rigorous work undertaken during the session. IPCC Vice Chairs Ko Barrett, Thelma Krug and Youba Sokona brought their unwavering support to facilitate discussions amongst authors and delegations and provided core support for the success of the approval process. We are also grateful to the Vice Chairs of WGI, as well as Mark Howden and Andy Reisinger, Vice Chairs of WGII and WGIII respectively, and Jim Skea, Co-Chair of WGIII, for their support to facilitate the discussions. The WGI TSU was joined by members of the WGII and WGIII TSUs, as well as past interns and chapter scientists to staff this Herculean coordination effort.

Our warmest thanks go to the collegial and collaborative support provided by Melinda Tignor, Elvira Poloczanska, Katja Mintenbeck, Bard Rama, Almut Niebuhr, Vincent Möller, Sina Löschke, Komila Nabiyeva, Andrés Alegría, Stefanie Langsdorf, Andrew Okem, Marlies Craig, Anka Mühle, Philisiwe Manqele, Stefan Weisfeld, Jussi Savolainen and Mallou from the Working Group II Technical Support Unit; Roger Fradera, Raphael Slade, Alaa Al Khourdajie, Minal Pathak, Sigourney Luz, Malek Belkacemi, David McCollum, Renée van Diemen, Shreya Some, Purvi Vyas, Juliette Malley and Géninha Lisboa from the Working Group III Technical Support Unit; and Noémie Le Prince-Ringuet from the Synthesis Report Technical Support Unit.

We are grateful for the close collaboration with authors and Bureau members from Working Group II and III, including as contributing authors in many parts of the report. We thank the Co-Chairs Debra Roberts, Hans-Otto Portner, Jim Skea and Priyadarshi R. Shukla for the collegial teamwork across Working Groups that has characterized the AR6. We also thank Eduardo Calvo Buendía and Kyoto Tanabe, Co-Chairs of the Task Force on Greenhouse Gas Inventories, for their support and collaboration.

We thank Hoesung Lee, Chair of the IPCC, Abdalah Mokssit, Secretary of the IPCC, and the staff of the IPCC Secretariat: Ermira Fida, Jonathan Lynn, Judith Ewa, Mxolisi Shongwe, Jennifer Lew Schneider, Jesbin Baidya, Werani Zabula, Nina Peeva, Melissa Walsh, Joelle Fernandez, Laura Biagioni and Oksana Ekzarkho for their guidance and support to implement the many facets of the IPCC process. We were grateful that we could work together extensively on communication activities. We thank Sue Escott for her tireless work to strengthen how we communicate the outcomes of the assessment.

We would like to acknowledge the support of the SHIFT Collaborative team – Stacy Barter and Michelle Colussi – and the generous support of the Canadian government for training and tools on inclusive practices in a consensus-based decision-making context, which we have been able to use for a more inclusive assessment process, including when we moved to purely online approaches. We appreciated the presence of Jessica O'Reilly and Mark Vardy, who have been with us throughout, working on an ethnographic study of how authors undertake the IPCC assessment, and we look forward to the insights from their research.

A core outcome of the report has been the development of the WGI Interactive Atlas produced by the Atlas chapter team. The Atlas is dedicated to the memory of Gemma Teresa Narisma, who co-led this innovative chapter with her extensive experience in regional climate research and outstanding leadership. The development and technical implementation have been supported with in-kind contribution from the Spanish government through the Spanish Research Council (CSIC) Instituto de Física de Cantabria, in partnership with Predictia Intelligent Data Solutions. Funding from the Spanish Research & Development program is acknowledged (ref. PID2019-111481RB-I00). We thank the modelling centres and institutions that produce and make available the datasets used in this work. The Interactive Atlas was first made available along with the rest of the Report on 9 August 2021 and was visited by more than half a million users worldwide during the first month.

The WGI TSU has initiated the process to archive the data and code from the report, building on the guidance and support from a large group of contributors. We are indebted to the members of the IPCC Task Group on Data Support for Climate Change Assessments (TG-Data) for their oversight, expert guidance and constant encouragement, including the Co-chairs of the Task Group, David Huard and Sebastian Vicuna, and members representing the WGI science community, Michio Kawamiya, Silvina Solman, José Manuel Guttierez and Nana Ama Browne Klutse. For the preparation of the figure data and code for archival, we especially thank to our dedicated contractor, Lina Sitz.

The IPCC Data Distribution Centre (DDC) has been indispensable for this effort. For the archival of figure data, we are indebted to Charlotte Pascoe, Kate Winfield, and Martin Jukes from the UK Centre for Environmental Data Analysis (CEDA). For the archival of the climate model data used as input to the report and intermediate assessed datasets, we gratefully acknowledge Martina Stockhause of the German Climate Computing Centre (DKRZ). For the transfer of metadata on archived data/code into the IPCC data catalogue, we thank MetadataWorks. Finally, we gratefully acknowledge funding

Downloaded from https://www.cambridge.org/core. UNIVERSIDAD AUTONOMA METROPOLITANA, on 14 Nov 2026 at 21:43:44, subject to the Cambridge Core terms of use, available at https://www.cambridge.org/core/terms. https://doi.org/10.1017/9781009157896

support from the Governments of the United Kingdom and Germany, without which data archival at the DDC would not have been possible.

A special thanks goes to the visual design team of the Summary for Policymakers: Tom Johansen and Angela Morelli of Information Design Lab and Jordan Harold and Irene Lorenzoni of the Tyndall Centre for Climate Change Research, as well as to Nigel Hawtin for graphical design support of the Report. We would like to thank Alisa Singer for creating the "Changing" artwork inspired by one of the scientific figures for the front cover of the Report.

Our particular appreciation goes to the WGI TSU, whose tireless dedication, professionalism and enthusiasm underpinned the production of this Report. The Report could not have been prepared without the commitment of members of the TSU, all new to the IPCC, who rose to the unprecedented Sixth Assessment Report challenge and were pivotal in all aspects of the preparation of the Report: Anna Pirani, Clotilde Péan, Sarah Connors, Yang Chen, Robin Matthews, Melissa Gomis, Sophie Berger, Leah Goldfarb, Rong Yu, Baiquan Zhou, Ozge Yelekci, Nada Caud, Katherine Leitzell, Tom Maycock, Mengtian Huang, Elisabeth Lonnoy, Tim Waterfield and Diego Cammarano. We thank our past WGI TSU team members: Wilfran Moufouma-Okia, Roz Pidcock, and Rodrigro Manzanas. We also thank the contributions of Margot Eyraud, Evéa Piedagnel, Mathilde Mousson and Felix Chavelli, who joined the TSU as interns.

We wish to express our sincere recognition to all those who contributed to the WGI assessment given the implications of undertaking this during the COVID-19 pandemic, all of whom have worked from home under such challenging conditions.

Finally, on behalf of all the participants to this unprecedented experience, we would like to thank colleagues, friends, and families who have also been part of this intense journey for their understanding and support.

This report shows that how much climate change we experience in the future depends on our decisions now, and what to prepare for. We wish that this report is widely used to provide evidence-based knowledge to inform decision-making, for teaching and training, and to enhance climate literacy worldwide.



Valérie Masson-Delmotte
IPCC Working Group I Co-Chair



Panmao Zhai
IPCC Working Group I Co-Chair

Downloaded from https://www.cambridge.org/core. UNIVERSIDAD AUTONOMA METROPOLITANA, on 14 Nov 2026 at 21:43:44, subject to the Cambridge Core terms of use, available at https://www.cambridge.org/core/terms. https://doi.org/10.1017/9781009157896

Downloaded from https://www.cambridge.org/core. UNIVERSIDAD AUTONOMA METROPOLITANA, on 14 Nov 2026 at 21:43:44, subject to the Cambridge Core terms of use, available at https://www.cambridge.org/core/terms. https://doi.org/10.1017/9781009157896