



Guide to the Science of Climate Change in the 21st Century

Chapter 1 Introduction

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1. Introduction

Everything on Earth has a close relationship with climate including humans. It is interesting to reflect on what the human relationship with climate has been and how it has evolved. For the first time in the multi-billion-year history of our planet the human relationship with climate is the most important factor in the evolutionary process. A term, the anthropogenic era, has been created to identify this time.

Humans' activities are causing climate changes which appear to be determining the biologic future of Earth. It is possible to make these attributions because of the knowledge gained as a result of the study of the science of climate change. It is possible to forecast the implications of future human activities on climate, the environment and nature, and develop strategies to avoid the most undesirable outcomes. Failure to respond in a timely fashion will result in the next great extinction of life the Earth, the Holocene or sixth extinction. This is a legacy the current generation does not want.

A guest post in the newsletter Carbon Brief 11.10.21, <https://www.carbonbrief.org/guest-post-what-100000-studies-tell-us-about-climate-impacts-around-the-world>, concludes after reviewing 100,000 studies: "Our findings show that the influence of human-caused warmings on average temperature and rainfall can already be felt for 85% of the world's population and 80% of the world's area."

The science of climate change is accepted by the scientific community. In Environmental Research Letters published 19 October 2021, https://iopscience.iop.org/article/10.1088/1748-9326/ac2966?utm_campaign=Carbon%20Brief%20Daily%20Briefing&utm_content=20211020&utm_medium=email&utm_source=Revue%20Daily, it was stated that there is "greater than 99% consensus on human caused climate change in peer-reviewed scientific literature".

This Guide follows directly from a short course on the science of global warming and climate change given through the University of Calgary, Canada, over the past twelve years. There were several other presentations on the subject given to consulting engineering groups, public school groups and faith-based organizations. The students and audiences have been very diverse with respect to education, age (twelve to eighty years), profession, work experience and life experience. To the knowledge of the author the course and presentations were well received.

There are many sources which describe the science of climate change. Most have their origins in the various publications of the United Nations Intergovernmental Panel on Climate Change (UN IPCC) or sources that have contributed to them. The IPCC was created to provide policymakers with regular scientific assessments on climate change, its implications and potential future risks as well as to put forward adaptation and mitigation options. The IPCC was created by the United Nations Environment Program (UNEP) and the World Meteorological Organization (WMO) in 1988 and has 195 members. The IPCC does not conduct its own

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research. IPCC reports are neutral, policy-relevant, but not policy-prescriptive. In 2007 the Intergovernmental Panel on Climate Change and Albert Arnold (Al) Gore Jr. were awarded the Nobel Peace Prize “for their efforts to build up and disseminate greater knowledge about man-made climate change, and to lay the foundations for the measures that are needed to counteract such change.”

The IPCC has produced five assessment reports since 1990 and is in the final stages of producing a sixth assessment report. Each assessment report has three components; first, the physical science basis, second, impacts, adaptation and vulnerability and third, mitigation of climate change. The working groups, composed of reputable scientists, for each of the reports are referred to as WG1, WG2, and WG3 respectively. Web sites for each of the full reports and the physical science basis are provided. There are a variety of supplementary reports which provide synthesis, policy maker summaries and supplements. Other reports and conference proceedings are available which support the full reports and are very important for the background information they provide. The various IPCC publications provide information to the United Nations Framework Convention on Climate Change (UNFCCC) that was formed in 1992. Periodically, the UNFCCC holds meetings, known as ‘conference of the parties’ (COP) referring to the membership in the UNFCCC in which they develop global strategies to aid in adaptation and mitigation of the recommendations of the IPCC.

Three IPCC Special Reports were published in 2019 with the hope of pre-strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty prior to Conference of the Parties 26, COP26, to be held in Glasgow, Scotland 31 October – 12 November, 2021. IPCC has published the Assessment Report AR6 WG1 Climate Change 2021: The Physical Science Basis on August 9, 2021. Report AR6 WG2 Climate Change 2021: Impacts, Adaptation and Vulnerability and report AR6 WG3 Climate Change 2021: Mitigation of Climate Change are expected to be available February 2022 and March 2022 respectively.

A complete list of reports from the different working groups of the IPCC Sixth Assessment Report, AR6, <https://www.ipcc.ch/assessment-report/ar6/> are as follows:

- AR6 WG1 Climate Change 2021: The Physical Science Basis was published August 9, 2021 <https://www.ipcc.ch/report/ar6/wg1/#FullReport>.
- AR6 WG2 Climate Change 2021: Impacts, Adaptation and Vulnerability is expected to be available February 2022.
- AR6 WG3 Climate Change 2021: Mitigation of Climate Change is expected to be available March 2022.
- AR6 Synthesis Report: Climate Change 2022 is expected to be available September 2022.

Four other reports that have been published since AR5 are:

- Special Report Global Warming of 1.5°C was approved by the IPCC on October 8, 2018 <https://www.ipcc.ch/sr15/>.

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- Special Report Climate Change and Land was published August 8, 2019 <https://www.ipcc.ch/srccl/>.
- Special Report Ocean and the Cryosphere was published September 24, 2019, <https://www.ipcc.ch/srocc/>.
- 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories was published May 2019 <https://www.ipcc.ch/report/2019-refinement-to-the-2006-ipcc-guidelines-for-national-greenhouse-gas-inventories/> .

A fifth report that is currently in preparation is ‘Methodology Report on Short-lived Climate Forcers’ <https://www.ipcc.ch/report/methodology-report-on-short-lived-climate-forcers/>.

On December 12, 2015, COP21 in Paris, reached ‘a landmark agreement to combat climate change and to accelerate and intensify actions and investments needed for a sustainable low carbon future’. This is known as the ‘Paris Agreement’. Its objective is ‘to pursue efforts to limit the (global) temperature rise this century well below 2 degrees Celsius above pre-industrial levels and to pursue efforts to limit the temperature increase even further to 1.5 degrees Celsius. Additionally, the agreement aims to increase the ability of countries to deal with the impacts of climate change, and at making finance flows consistent with a low GHG emissions and climate-resilient pathway’. (<https://unfccc.int/process-and-meetings/the-paris-agreement/what-is-the-paris-agreement>) Several conventions have followed with the purpose to make the Paris Agreement fully operational. COP26 will be taking place in Glasgow, Scotland on 1 to 12 of November, 2021 (<https://www.ukcop26.org/>).

For reasons of accuracy and completeness the IPCC publications are substantial documents. For most people these reports are a challenge to read and understand even in a synopsis form. If its any comfort there are few if any scientists who can say they understand all of the subjects included in the science. But scientists believe scientists.

The purpose of this Guide is to provide a comprehensive introduction to the science of climate change. The material is presented requires little or no previous education or knowledge on any of the subjects beyond junior high school. Terminology is introduced that can be further searched on the internet or elsewhere as desired or required.

The Chapters of the Guide can be read one at a time, in any order – more-or-less. It is not necessary to start at Chapter 1 and continuing to the end. The Chapters do flow one to the next, but some of the them might be difficult reading. For example, one may wish to read about climate models or observations of climate change which is perfectly reasonable and possible without reading other chapters.

The Guide is separated into twenty-four chapters. The sequence is consistent with the IPCC approach. Content for Chapters 2 to 15 are taken from a wide variety of sources including some from the IPCC reports. From Chapter 16 to 21 IPCC content dominates because of their role in

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the development and application of climate models, predictions and discussions on adaptation and mitigation.

Chapter 2 provides an overview of the history of the scientific study of climate change. It is important to know that the science was discovered at a time when Darwin and the theories on evolution were being developed. It is not a recent construct to serve other interests.

Chapter 3 clarifies the differences between weather and climate.

Chapter 4 is perhaps one of the most important and difficult for scholars of climate to understand. The global energy budget forms the framework for all further discussion on global warming and climate change. It is worth the effort to thoroughly understand the energy budget as it is the basis for the science.

Chapter 5 discusses the carbon cycle which is essential when considering the storage, movement, origins, fate and opportunities for management of the most important greenhouse gas, carbon dioxide.

Chapter 6 discusses the hydrological cycle, water occurrence, movement and storage.

Chapter 7 outlines present basic understanding of the very complex global circulation of the atmosphere, the development of weather and movement of energy around the globe.

Chapter 8 outlines present basic knowledge of circulation of water in the ocean. It provides some idea of how energy moves throughout the globe and how it will inevitably affect climate and ocean habitat.

Chapter 9 discusses regional climate variations known as seasons around which all life on Earth has adjusted to, and how changes in climate might affect their occurrence and characteristics.

Chapter 10 discusses a significant weather phenomenon collectively known as cyclones which are significant because of their destructive potential. It is important to understand the factors that determine their occurrence and strength and how these might be connected to climate change.

Chapter 11 discusses the El Niño-Southern Oscillation (ENSO), an important atmosphere-ocean system, which occurs in the south Pacific but affects weather systems around the world through a process known as teleconnection. Several other atmosphere-ocean systems have been identified and known to have significant short and long effects on regional weather and ocean characteristics. ENSO is the most dramatic.

Chapter 12 identifies and discusses the natural forces which cause climate change that is

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evident in studies of paleoclimatology, the subject of Chapter 13. The fact that climate change has occurred since Earth was formed is evident in the geology. The study of paleoclimatology helps identify when the various changes occurred and what they were. There is considerable, reliable, and detailed knowledge on how Earth's climate has changed over the past 800,000 years. Palaeoclimatological studies allow characterization of Earth's climate before actual measurements were being made.

Chapter 14, the modern instrumental period, discusses how methodology for observing weather has evolved since the beginning of the use instruments to measure temperature and precipitation and how the observation of most of the elements in the energy budget, on a global scale, is achieved using satellite technology and advanced data management techniques only possible with advances in computer technology.

Chapter 15 discusses greenhouse gases, what they are and how they are quantified and introduces how they are measured locally and on a global scale.

Chapter 16 describes observed impacts of recent climate change, the motivating force behind the development of climate science and climate models which is discussed in Chapter 17. The development of climate models was necessary to consider all of the factors that affect climate, worldwide. The capability, validity and use of the numerous climate models are discussed.

Chapter 18 discusses how the projected impacts of climate change on physical systems were arrived at, including the scenarios, known as representative concentration pathways (RCPs), were used.

Chapter 19 provides an overview of how the projected physical impacts are used to identify impacts on nature (biological systems) and on humans and human managed systems and how opportunities for adaptation may be identified.

Chapter 20 introduces climate change mitigation and the various strategies available to perform mitigation.

Chapter 21 introduces the Sixth Assessment Report, AR6 WG1 Climate Change 2021: The Physical Science Basis published August 9, 2021.

(Note that two new chapters will be produced as reports from working groups AR6 WG2 and WG3 are published.)

Chapter 1.0 Introduction

Chapter 2.0 History of the Scientific Study of Climate Change

Chapter 3.0 Weather and Climate

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- Chapter 4.0 Earth’s Energy Budget
- Chapter 5.0 Carbon Cycle
- Chapter 6.0 Hydrological Cycle
- Chapter 7.0 Global Circulation of the Atmosphere
- Chapter 8.0 Global Circulation of Water in the Ocean
- Chapter 9.0 Climate and Seasons
- Chapter 10.0 Hurricanes, Typhoons and Cyclones
- Chapter 11.0 El Niño-Southern Oscillation (El Niño and La Niña)
- Chapter 12.0 Climate Change – Natural Forces
- Chapter 13.0 Paleoclimatology
- Chapter 14.0 Modern Instrumental Period
- Chapter 15.0 Greenhouse Gas
- Chapter 16.0 Observation and Impacts of Recent Climate Change
- Chapter 17.0 Climate Models
- Chapter 18.0 AR5 - Impacts of Climate Change on Physical Systems
- Chapter 19.0 AR5 - Adaptation
- Chapter 20.0 AR5 - Mitigation
- Chapter 21.0 Sixth Assessment Report, August 9, 2021 – AR6 WG1 Climate Change 2021:
The Physical Science Basis
- Chapter 22.0 Comments
- Chapter 23.0 Glossary
- Chapter 24.0 Selected Web Sites

Table 1.1 Summary of table of contents.

The United Nations Department of Economic and Social Affairs, Sustainable Development lists seventeen sustainable development goals (SDGs) (<https://sdgs.un.org/goals>) listed in Table 1.2. These cannot be successfully addressed without resolving the climate change crisis.

1. No poverty.
2. Zero hunger.
3. Good health and well-being.
4. Quality education.
5. Gender equality.
6. Clean water and sanitation.
7. Affordable and clean energy.
8. Decent work and economic growth.
9. Industry, innovation and infrastructure.
10. Reduced inequalities.
11. Sustainable cities and communities.
12. Responsible consumption and production.
13. Climate action.

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14. Life below water.
15. Life on land.
16. Peace, justice and strong institutions.
17. Partnerships for the goals.

Table 1.2 United Nations ‘Sustainable Development Goals’.

It is hoped that readers will wish to continue their studies on the science of climate change by engaging in further exploration of the concepts presented in this Guide and begin to study the various IPCC reports themselves. To meet this need, a content support section is included at the end of each chapter which provides a limited list of useful web sites, useful books, videos and selected references if available or relevant.

As already mentioned, access to quality information on almost any subject is available in a timely fashion on the internet. There is also questionable and misleading information. The internet has the advantage of being able to provide the most up-to-date knowledge from the best sources – once you know how to identify them. The veracity of information can be cross-checked easily by also accessing other web sites, particularly those supported by reputable organizations. Peer reviewed published articles may also be found – information that would be very difficult to come by any other way. Web sites appear, disappear and change and for this reason only a few web sites that are considered the best available long-term sources are listed.

There are several [on-line courses on the science of climate change](#) supported by very reputable universities and government agencies that can provide other perspectives on the topics introduced in this Guide. Several are listed in Chapter 24. A word of caution about published articles, peer reviewed or otherwise. Simply because the research is published does not mean it was or remains ‘fact’. Papers and research reported may be superseded by recent thought and research. New research might make the previously published work irrelevant, obsolete and even prove that previous research was not completely correct. Care must always be taken. The screening process used by the IPCC in the preparation of their reports is particularly useful in this regard. Information in published articles can usually be further explored on the web.

Additional information on all of the subjects covered in this Guide is constantly being published. To the extent possible the Guide is updated regularly. Readers may wish to participate in this process by subscribing to one or more of the newsletters listed in Chapter 24.

1.1 Special note on Nobel Prize winners

The 2021 Nobel Prize in Physics was awarded to Syukuro Manabe and Klaus Hasselmann who each shared ¼ of the prize “for the physical modelling of Earth’s climate, quantifying variability and reliability of predicting global warming”. The other half of the prize was awarded to Georgio Parisi “for the discovery of the interplay of disorder and fluctuations in physical systems

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from atomic to planetary scales”. See

<https://www.nobelprize.org/prizes/physics/2021/summary/>,
<https://www.nobelprize.org/prizes/physics/> and https://www.nature.com/articles/d41586-021-02703-3?utm_source=Nature+Briefing&utm_campaign=38fd982e90-briefing-dy-20211008&utm_medium=email&utm_term=0_c9dfd39373-38fd982e90-46124954.

The 2007 Nobel Peace Prize was awarded jointly to the IPCC and Al Gore “for their efforts to build up and disseminate greater knowledge about man-made climate change, and to lay the foundations for the measures that are needed to counteract such change”. See

<https://www.nobelprize.org/prizes/peace/2007/summary/> and
<https://www.nobelpeaceprize.org/laureates/2007>.

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1.2 Information support

Key web sites:

1. Paris Agreement, COP21. <https://unfccc.int/process-and-meetings/the-paris-agreement/what-is-the-paris-agreement>.
2. UNFCCC. <https://unfccc.int/>.
3. UN IPCC. <https://www.ipcc.ch/>.
4. IPCC First assessment report science. <https://www.ipcc.ch/report/ar1/wg1/>.
5. IPCC Second assessment report science. <https://www.ipcc.ch/report/ar2/wg1/>.
6. IPCC Third assessment report science. <https://www.ipcc.ch/report/ar3/wg1/>.
7. IPCC Fourth assessment report science. <https://www.ipcc.ch/report/ar4/wg1/>.
8. IPCC Fifth assessment report science. <https://www.ipcc.ch/report/ar5/wg1/>.
9. IPCC Sixth Assessment Report, WG1 Climate Change: The Physical Science Basis, <https://www.ipcc.ch/report/ar6/wg1/#FullReport>.
10. IPCC First assessment report. https://www.ipcc.ch/site/assets/uploads/2018/05/ipcc_90_92_assessments_far_full_report.pdf.
11. IPCC Second assessment report. <https://archive.ipcc.ch/pdf/climate-changes-1995/ipcc-2nd-assessment/2nd-assessment-en.pdf>.
12. IPCC Third assessment report. <https://www.ipcc.ch/assessment-report/ar3/>.
13. IPCC Fourth assessment report. <https://www.ipcc.ch/assessment-report/ar4/>.
14. IPCC Fifth assessment report. <https://www.ipcc.ch/assessment-report/ar5/>.
15. IPCC Sixth Assessment Report, AR6, <https://www.ipcc.ch/assessment-report/ar6/>.
16. IPCC Special Report 2019. https://www.ipcc.ch/site/assets/uploads/sites/2/2019/06/SR15_Full_Report_High_Re

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[s.pdf](#)

17. IPCC Special Report Global Warming of 1.5 degrees Celsius. <https://www.ipcc.ch/sr15/>.
18. IPCC Special Report on the Ocean and Cryosphere in a Changing Climate. <https://www.ipcc.ch/srocc/>.
19. IPCC Special Report on Climate change and Land. <https://www.ipcc.ch/srccl/>.
20. 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories was published May 2019 <https://www.ipcc.ch/report/2019-refinement-to-the-2006-ipcc-guidelines-for-national-greenhouse-gas-inventories/>.
21. COP26. <https://www.ukcop26.org/>.
22. United Nations sustainable development goals. <https://sdgs.un.org/goals>.
23. Sixth extinction. https://en.wikipedia.org/wiki/Holocene_extinction.
24. Consensus on climate science, Environmental Research Letters, Volume 16, Number 11. https://iopscience.iop.org/article/10.1088/1748-9326/ac2966?utm_campaign=Carbon%20Brief%20Daily%20Briefing&utm_content=20211020&utm_medium=email&utm_source=Revue%20Daily.
25. Climate change impacts around the world, Guest Post, Carbon Brief 11.10.2021. <https://www.carbonbrief.org/guest-post-what-100000-studies-tell-us-about-climate-impacts-around-the-world>.
26. Nobel Prize 2007. <https://www.nobelprize.org/prizes/peace/2007/summary/> and <https://www.nobelpeaceprize.org/laureates/2007>.
27. Nobel Prize, Climate Modellers, Nature 2021 October 5. https://www.nature.com/articles/d41586-021-02703-3?utm_source=Nature+Briefing&utm_campaign=38fd982e90-briefing-dy-20211008&utm_medium=email&utm_term=0_c9dfd39373-38fd982e90-46124954.
28. Nobel Prize 2021. <https://www.nobelprize.org/prizes/physics/2021/summary/> and <https://www.nobelprize.org/prizes/physics/>.

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