

# Table of Contents

**Title Page**

**Foreword**

**Acknowledgements**

**Dedication**

**Preface March 22, 2024**

**Preface December 2, 2022**

**Preface August 14, 2021**

**Preface January 18, 2021**

**Table of Contents**

**List of Figures**

**List of Tables**

**Chapter 1 Introduction**

**1.1 Overview of Guide**

**1.2 Special note on Nobel Prize winners**

**1.3 International organizations**

**1.3.1 World Meteorological Organization**

**1.3.2 United Nations Environment Programme, UNEP**

**1.3.3 World Climate Research Program**

**1.3.4 Future Earth**

**1.4 Information support**

**Chapter 2 History of the Scientific Study of Climate Change**

December 12, 2020 – Fifth Anniversary of the Paris Agreement

August 9, 2021 – Publication of IPCC AR6 WGI, Climate Change, The Physical Science Basis, February 28, 2022 IPCC AR6 WGII, Climate Change: Impacts, Adaptability and Vulnerability and April 4, 2022 IPCC AR6 WGIII, Climate Change: Mitigation

Guide to the Science of Climate Change in the 21<sup>st</sup> Century, August 14, 2021

xiv

	<b>2.1 Information support</b>
<b>Chapter 3</b>	<b>Weather vs. Climate</b>
	<b>3.1 Introduction</b>
	<b>3.2 Weather observation and interpretation</b>
	<b>3.3 Canada – meteorological data availability</b>
	<b>3.4 Forecasting</b>
	<b>3.4.1 Stochastic forecasting</b>
	<b>3.4.2 Real-time forecasting</b>
	<b>3.4.3 Distributed models</b>
	<b>3.5 Information support</b>
<b>Chapter 4</b>	<b>Earth’s Energy Budget</b>
	<b>4.1 Introduction</b>
	<b>4.2 Concept of energy</b>
	<b>4.3 Solar energy</b>
	<b>4.4 Energy budget</b>
	<b>4.5 Conservation of energy</b>
	<b>4.6 Greenhouse effect</b>
	<b>4.7 Impact of human activities on the energy budget</b>
	<b>4.8 Information support</b>
<b>Chapter 5</b>	<b>Carbon Cycle</b>
	<b>5.1 Introduction</b>
	<b>5.2 Units</b>
	<b>5.3 Carbon in the atmosphere</b>
	<b>5.4 Plant biomass (terrestrial)</b>

**5.5 Oceans**

**5.6 Fossil pool**

**5.7 Fossil fuels, cement and land use change**

**5.8 Weathering**

**5.9 Carbon waste**

**5.10 Information support**

**Chapter 6 Hydrological Cycle**

**6.1 Introduction**

**6.2 Basic elements of the hydrological cycle**

**6.3 Evaporation and evapotranspiration**

**6.4 Convection and cloud formation**

**6.5 Precipitation**

**6.6 Snow and ice**

**6.7 Runoff**

**6.8 Distribution of water on Earth**

**6.9 Ice caps, glaciers, ice streams, ice field, ice sheets, ice shelves,  
and sea ice**

**6.10 Isotopes of oxygen, hydrogen, deuterium and water**

**6.11 Hydrologic data availability**

**6.12 Forecasting**

**6.12.1 Stochastic forecasting**

**6.12.2 Real-time forecasting**

**6.12.3 Distributed forecasting**

**6.13 Flood Plain Delineation**

**6.14 Information support**

December 12, 2020 – Fifth Anniversary of the Paris Agreement

August 9, 2021 – Publication of IPCC AR6 WGI, Climate Change, The Physical Science Basis, February 28, 2022 IPCC AR6 WGII, Climate Change: Impacts, Adaptability and Vulnerability and April 4, 2022 IPCC AR6 WGIII, Climate Change: Mitigation

Guide to the Science of Climate Change in the 21<sup>st</sup> Century, August 14, 2021

xvi

<b>Chapter 7</b>	<b>Global Circulation of the Atmosphere</b>
	<b>7.1 Introduction</b>
	<b>7.2 Characteristics of the atmosphere</b>
	<b>7.3 Early perception of global circulation of the atmosphere</b>
	<b>7.4 Actual global circulation of the atmosphere</b>
	<b>7.5 Atmospheric rivers</b>
	<b>7.6 Ozone and the ozone hole</b>
	<b>7.7 Heat dome</b>
	<b>7.8 Information support</b>
<b>Chapter 8</b>	<b>Global Circulation of Water in the Ocean</b>
	<b>8.1 Introduction</b>
	<b>8.2 Ocean currents</b>
	<b>8.3 Gulf Stream</b>
	<b>8.4 Information support</b>
<b>Chapter 9</b>	<b>Climate and Seasons</b>
	<b>9.1 Temperate zones – northern and southern hemispheres</b>
	<b>9.2 Tropical zones</b>
	<b>9.3 Monsoons</b>
	<b>9.3.1 Southwest Indian monsoon</b>
	<b>9.3.2 West African monsoon</b>
	<b>9.3.3 West coast North America monsoon</b>
	<b>9.4 Intertropical convergence zone (ICZ)</b>
	<b>9.5 Predictability</b>
	<b>9.6 Information support</b>
<b>Chapter 10</b>	<b>Hurricanes, Typhoons and Cyclones</b>
	<b>10.1 Introduction</b>

December 12, 2020 – Fifth Anniversary of the Paris Agreement

August 9, 2021 – Publication of IPCC AR6 WGI, Climate Change, The Physical Science Basis, February 28, 2022 IPCC AR6 WGII, Climate Change: Impacts, Adaptability and Vulnerability and April 4, 2022 IPCC AR6 WGIII, Climate Change: Mitigation

Guide to the Science of Climate Change in the 21<sup>st</sup> Century, August 14, 2021

xvii

- 10.2 Hurricanes and tropical cyclones**
- 10.3 Monitoring tropical cyclones**
- 10.4 Effect of ENSO on tropical cyclones**
- 10.5 Information support**

**Chapter 11 El Niño-Southern Oscillation**

- 11.1 Introduction**
- 11.2 ENSO normal conditions**
- 11.3 El Niño**
- 11.4 La Niña**
- 11.5 Global impact of ENSO**
- 11.6 Prediction of ENSO events**
- 11.7 Information support**

**Chapter 12 Climate Change – Natural Forces**

- 12.1 Introduction**
- 12.2 Tectonic activity**
- 12.3 Solar radiation, sun spots and cosmic radiation**
- 12.4 Milankovitch Cycles – changes in Earth’s orbit and orientation to the sun**
- 12.5 Volcanic activity**
- 12.6 Global dimming**
- 12.7 Information support**

**Chapter 13 Paleoclimatology**

- 13.1 Introduction**
- 13.2 Variation of Earth’s temperature over the last 500 million years**
- 13.3 Climatic data obtained from proxy sources**

- 13.3.1 Historical records**
- 13.3.2 Tree rings**
- 13.3.3 Lake sediments**
- 13.3.4 Corals**
- 13.3.5 Ice cores – Antarctica and Greenland**
- 13.3.6 Ice cores – ice caps**
- 13.3.7 Speleothems**
- 13.3.8 Loess**
- 13.3.9 Boreholes**
- 13.3.10 Marine sediments**
- 13.3.11 Geomorphic features**
- 13.3.12 Pollen**
- 13.3.13 Oxygen isotopes and hydrogen isotopes**
- 13.3.14 Stomatal density (Stomata Density Index, SDI)**
- 13.3.15 Radiocarbon or Carbon-14 dating**
- 13.3.16 Beryllium 10 and 7**
- 13.3.17 Radiometric dating or radioactive dating**
- 13.3.18 Leaf wax**
- 13.3.19 Anecdotal and ad hoc historical data**

#### **13.4 Ice ages**

#### **13.5 Little ice age**

#### **13.6 Information support**

### **Chapter 14 Modern Instrumental Period**

#### **14.1 Introduction**

#### **14.2 Instrumental temperature record**

#### **14.3 Modern instrumentation**

December 12, 2020 – Fifth Anniversary of the Paris Agreement

August 9, 2021 – Publication of IPCC AR6 WGI, Climate Change, The Physical Science Basis, February 28, 2022 IPCC AR6 WGII, Climate Change: Impacts, Adaptability and Vulnerability and April 4, 2022 IPCC AR6 WGIII, Climate Change: Mitigation

Guide to the Science of Climate Change in the 21<sup>st</sup> Century, August 14, 2021

#### **14.4 Satellites**

#### **14.5 Information support**

### **Chapter 15 Greenhouse Gases and Aerosols**

#### **15.1 Introduction**

##### **15.1.1 Greenhouse gas emissions – an overview**

##### **15.1.2 Aerosols**

#### **15.2 Types of greenhouse gas emissions**

#### **15.3 Carbon dioxide emissions by fuel type**

#### **15.4 Carbon dioxide emissions from cement production**

#### **15.5 Methane (CH<sub>4</sub>) emissions**

#### **15.6 Sources of greenhouse gases**

##### **15.6.1 World greenhouse gas emissions by sector in 2018**

##### **15.6.2 Global historical emissions**

##### **15.6.3 Comparison of global greenhouse gas emissions by country by Johannes Friedrich.**

##### **15.6.4 Global historical comparison of emissions by the top ten emitting countries.**

#### **15.7 Greenhouse gas emissions – reported**

##### **15.7.1 UNFCC country reports by country projected to 2030**

##### **15.7.2 Global Carbon Project**

##### **15.7.3 US National Academies of Science, Engineering and Medicine**

#### **15.8 Greenhouse gas emissions – observed**

##### **15.8.1 Land and ocean-based GHG monitoring and sampling**

December 12, 2020 – Fifth Anniversary of the Paris Agreement

August 9, 2021 – Publication of IPCC AR6 WGI, Climate Change, The Physical Science Basis, February 28, 2022 IPCC AR6 WGII, Climate Change: Impacts, Adaptability and Vulnerability and April 4, 2022 IPCC AR6 WGIII, Climate Change: Mitigation

Guide to the Science of Climate Change in the 21<sup>st</sup> Century, August 14, 2021

**15.8.2 Aircraft GHG sampling**

**15.8.3 Satellite based monitoring**

**15.9 Natural and anthropogenic radiative forcing**

**15.10 Carbon footprint and auditing**

**15.11 Emission intensity or carbon intensity**

**15.12 Carbon neutral, decarbonizing, net zero, carbon efficiency**

**15.13 Carbon management**

**15.13.1 Cap-and-trade (carbon allowance, carbon cap, carbon credits, carbon offsets, negative emissions, carbon insets)**

**15.13.2 Carbon tax**

**15.13.3 Carbon dividend**

**15.13.4 Carbon leakage**

**15.13.5 Carbon tariff**

**15.13.6 Carbon pricing**

**15.13.7 Avoided emissions**

**15.13.8 Renewable energy certificate**  
**15.12 Carbon neutral, decarbonizing, net zero, carbon efficiency**

**15.14 Net zero by 2050 objective and committed warming**

**15.15 Super pollutant concepts**

**15.16 Immortal pollutants**

**15.17 Information support**



## **Chapter 16 Observation and Impacts of Recent Climate Change – Attribution Science**

### **16.1 Attribution**

### **16.2 Temperature and greenhouse gas**

### **16.3 Ocean acidification**

### **16.4 Arctic**

#### **16.4.1 Sea ice**

#### **16.4.2 Permafrost**

#### **16.4.3 Loss and change of habitat**

#### **16.4.4 Transportation**

#### **16.4.5 Territorial claims**

#### **16.4.6 Methane and GHG's**

#### **16.4.7 Glaciers**

### **16.5 Greenland**

### **16.6 Antarctica**

#### **16.6.1 Loss of ice mass.**

#### **16.6.2 Break up of Larson C ice shelf**

#### **16.6.3 Break up of ice shelf at the terminus of Thwaites Glacier in West Antarctica**

#### **16.6.4 Sea ice**

#### **16.6.5 Effect of climate change on the ecology of Antarctica**

### **16.7 Oceans**

#### **16.7.1 Warming**

#### **16.7.2 Sea level**

#### **16.7.3 AMOC – Atlantic Meridional Overturning 2022**

### **16.8 Coral reefs**

### **16.9 Thermal habitat of oceans and lakes**

### **16.10 Droughts**

December 12, 2020 – Fifth Anniversary of the Paris Agreement

August 9, 2021 – Publication of IPCC AR6 WGI, Climate Change, The Physical Science Basis, February 28, 2022 IPCC AR6 WGII, Climate Change: Impacts, Adaptability and Vulnerability and April 4, 2022 IPCC AR6 WGIII, Climate Change: Mitigation

Guide to the Science of Climate Change in the 21<sup>st</sup> Century, August 14, 2021

xxii

- 16.11 Desertification**
- 16.12 Wildfires**
- 16.13 Tropical cyclones**
- 16.14 Intergovernmental Panel on Biodiversity and Ecosystem Services, IPBES**
- 16.15 Biological Diversity (Biodiversity)**
  - 16.15.1 Convention on Biological Diversity, CBD**
  - 16.15.2 International Union for Conservation of Nature**
  - 16.15.3 World Wildlife Fund (WWF) – Living Planet Report 2020**
  - 16.15.4 World Wildlife Fund – Living Planet Report 2022**
- 16.16 Habitat change – natural environment – general**
  - Comments**
- 16.17 Glaciers**
- 16.18 Regional impacts of climate change**
  - IPCC Climate Change 2014, Synthesis Report, AR5**
- 16.19 Extreme weather**
  - 16.19.1 Heat dome - heatwave Pacific Northwest 2021**
  - 16.19.2 Atmospheric river - extreme rainfall caused by multiple atmospheric rivers British Columbia, Canada 2021**
  - 16.19.3 Increasing major snowstorms**
  - 16.19.4 USEPA climate change indicators**
  - 16.19.5 Double jet streams – heatwaves over Europe 2022**
  - 16.19.6 Extreme weather 2022**
- 16.20 US EPA Report May 2021**
- 16.21 Health**
  - 16.21.1 Heat and hot weather**

**16.21.2 Present and potential health impacts of climate change**

**16.21.3 Stress and anxiety among our children and youth and everyone else.**

**16.22 Forecasting**

**16.22.1 Overview**

**16.22.2 Climate change models**

**16.22.3 Stochastic**

**16.22.4 Insurance and insurability**

**16.23 Social impacts**

**16.23.1 Economic impacts**

**16.23.2 Poverty**

**16.23.3 Migration**

**16.23.4 War**

**16.24 Tipping points, domino effects, knock-on effects, runaway global warming and hothouse Earth**

**16.25 Climate action and climate activism**

**16.26 Comments**

**16.27 Future updates**

**16.28 Information support**

**Chapter 17 Climate Models**

**17.1 Introduction**

**17.2 Climate models**

**17.3 Data available for climate models**

**17.4 Climate models**

**17.4.1 Atmosphere-ocean general circulation models (AOGCM)**

**17.4.2 Earth system models (ESM)**

**17.4.3 Regional climate models**

December 12, 2020 – Fifth Anniversary of the Paris Agreement

August 9, 2021 – Publication of IPCC AR6 WGI, Climate Change, The Physical Science Basis, February 28, 2022 IPCC AR6 WGII, Climate Change: Impacts, Adaptability and Vulnerability and April 4, 2022 IPCC AR6 WGIII, Climate Change: Mitigation

Guide to the Science of Climate Change in the 21<sup>st</sup> Century, August 14, 2021

xxiv

**17.4.4 Emulator models**

**17.4.5 Ensemble models**

**17.5 CMIP5 Coupled model intercomparison project AR5**

**17.6 CMIP5 model predictions of surface temperature change compared to observed**

**17.7 CMIP6 Coupled model intercomparison project AR6**

**17.8 CMIP6 model predictions of surface temperature change compared to observed**

**17.9 CORDEX regional climate model**

**17.10 CMIP6 models and CORDEX model results**

**17.11 Confidence, agreement and likelihood terminology - assessment of model predictions**

**17.12 Integrated assessment models, IAMs**

**17.13 Earth Virtualization Engines (EVE)**

**17.14 Information support**

**Chapter 18 IPCC 2014 AR5 - Impacts of Climate Change on Physical Systems**

**18.1 Introduction**

**18.2 Scenarios**

**18.3 Projected impacts physical impacts**

**18.3.1 Temperature**

**18.3.2 Water – soil moisture, runoff, precipitation, evaporation**

**18.3.3 Cryosphere**

**18.3.4 Sea level**

**18.3.5 Ocean chemistry**

**18.3.6 Jet stream**

**18.3.7 Atlas of global and regional climate projections**

December 12, 2020 – Fifth Anniversary of the Paris Agreement

August 9, 2021 – Publication of IPCC AR6 WGI, Climate Change, The Physical Science Basis, February 28, 2022 IPCC AR6 WGII, Climate Change: Impacts, Adaptability and Vulnerability and April 4, 2022 IPCC AR6 WGIII, Climate Change: Mitigation

Guide to the Science of Climate Change in the 21<sup>st</sup> Century, August 14, 2021

xxv

**18.4 Climate phenomena and regional climate change**

**18.5 Tipping points, domino effects, knock-on effects, runaway global warming and hothouse Earth**

**18.6 Snow melt from mountainous regions**

**18.8 Water management infrastructure**

**18.8 Atmospheric rivers**

**18.9 Net-zero by 2050 objective and committed warming**

**18.10 Earth Visualization Models**

**18.11 Information support**

**Chapter 19 IPCC 2014 AR5 - Adaptation**

**19.1 Introduction**

**19.2 Nature**

**19.3 Humans and human managed systems**

**19.4 Financial implications of global warming and climate change**

**19.5 Insurance and the impact of climate change**

**19.6 Climate justice**

**19.7 Information support**

**Chapter 20 IPCC 2014 AR5 - Mitigation**

**20.1 Introduction**

**20.2 The science**

**20.3 Consequences of unconstrained continued emission of greenhouse gases.**

**20.4 Strategies for limiting temperature increases to between 1-2 °C**

**20.5 Mitigation strategies**

**20.6 Paris Agreement**

**20.7 Net-zero by 2050 objective and committed warming**

December 12, 2020 – Fifth Anniversary of the Paris Agreement

August 9, 2021 – Publication of IPCC AR6 WGI, Climate Change, The Physical Science Basis, February 28, 2022 IPCC AR6 WGII, Climate Change: Impacts, Adaptability and Vulnerability and April 4, 2022 IPCC AR6 WGIII, Climate Change: Mitigation

Guide to the Science of Climate Change in the 21<sup>st</sup> Century, August 14, 2021

xxvi

## **20.8 Information support**

### **Chapter 21 IPCC 2021 AR6 WGI: The Physical Science Basis**

#### **21.1 Introduction**

#### **21.2 Outcomes of note**

#### **21.3 Shared socio-economic pathways, SSPs**

#### **21.4 AR6**

##### **21.4.1 Validity of AR6 simulations**

##### **21.4.2 Details of emission scenarios used in AR6 simulations**

##### **21.4.3 Global impact of human activities (also taken from AR6 WG1 SPM)**

##### **21.4.4 Climatic impact-drivers**

##### **21.4.5 Limiting future climate change to 1.5°C**

##### **21.4.5 IPCC WG1 Interactive Atlas <https://interactive-atlas.ipcc.ch/>**

##### **21.4.6 NASA/ IPCC Sea level projection tool**

##### **21.4.7 Climate Information web site <https://climateinformation.org/>**

##### **21.4.8 Climate data for a resilient Canada <https://climatedata.ca/>**

##### **21.4.9 Carbon Brief's In-depth Q&A: The IPCC's sixth assessment report on climate science**

#### **21.5 Net zero by 2050 objective and committed warming**

#### **21.6 Information support**

### **Chapter 22 IPCC 2022 AR6 WGII: Impacts, Adaptation and Vulnerability**

### **Chapter 23 IPCC 2022 AR6 WGIII: Mitigation**

### **Chapter 24 IPCC 2023 AR6 Synthesis Report**

#### **24.1 AR6 Synthesis Report**

#### **24.2 Carbon Brief Q&A**

December 12, 2020 – Fifth Anniversary of the Paris Agreement

August 9, 2021 – Publication of IPCC AR6 WGI, Climate Change, The Physical Science Basis, February 28, 2022 IPCC AR6 WGII, Climate Change: Impacts, Adaptability and Vulnerability and April 4, 2022 IPCC AR6 WGIII, Climate Change: Mitigation

Guide to the Science of Climate Change in the 21<sup>st</sup> Century, August 14, 2021

xxvii

	<b>24.3 World Resources Institute</b>
	<b>24.3 Information Support</b>
<b>Chapter 25</b>	<b>Comments</b>
<b>Chapter 26</b>	<b>Discussion Presentation #11, Climate Change Canada and Alberta</b>
	<b>26.1 Introduction</b>
	<b>26.2 Selected web sites</b>
<b>Chapter 27</b>	<b>Discussion Presentation #12, Climate Change Denial</b>
	<b>27.1 Introduction</b>
	<b>27.2 Selected web sites</b>
<b>Chapter 28</b>	<b>Glossary</b>
<b>Chapter 29</b>	<b>Selected Web Sites</b>
	<b>29.1 Educational</b>
	<b>29.2 Newsletters</b>
	<b>29.3 International organizations</b>
	<b>29.3.1 World Meteorological Organization</b>
	<b>29.3.2 United Nations Environment Programme, UNEP</b>
	<b>29.3.3 World Climate Research Program</b>
	<b>29.3.4 Future Earth</b>
	<b>29.3.5 United Kingdom Met Office</b>
	<b>29.3.6 United Nations Office for Disaster Risk Reduction</b>
	<b>29.3.7 Urban Climate Change Research Network</b>

December 12, 2020 – Fifth Anniversary of the Paris Agreement

August 9, 2021 – Publication of IPCC AR6 WGI, Climate Change, The Physical Science Basis, February 28, 2022 IPCC AR6 WGII, Climate Change: Impacts, Adaptability and Vulnerability and April 4, 2022 IPCC AR6 WGIII, Climate Change: Mitigation

Guide to the Science of Climate Change in the 21<sup>st</sup> Century, August 14, 2021

xxviii