

“Barry and Hall-McKim have produced the ultimate book on the polar regions. It serves both as an excellent scientific/academic contribution and as a highly accessible source for the wider public concerned about the Polar environments, past history, and future potentially serious impacts of the current climate warming on the entire world. The authors have unsurpassed experience to undertake such an immense and important task. The book is replete with highly relevant maps, diagrams, tables, and photographs. It also provides easy access to the vast amount of research and data sets scattered through an immense literature.”

- Jack D. Ives,  
*Carleton University*

“The book is well structured with a flow from chapter to chapter, which leads the reader constructively through a set of themes and trends in the changing role that the polar regions play in the planet’s changing climate. The nine chapters provide this flow of important understanding to a book that has the clear potential as a textbook and a ‘good’ read for a broader audience. The development of and use of figures, boxes, and graphics is well done and very usefully connected to the text. Further, the references, chapter by chapter, are extensive and well thought through to give the reader additional material that enhances the value of the book as a textbook and provides the broader readership with particularly important added information. The summaries at the end of each chapter are a clear composite of what is in the chapter: just reading these can provide the reader with a substantive understanding of the polar regions and climate change. Finally, the listing of important questions at the end of each chapter is excellent.

It is, in my view, a book that will be an excellent textbook, but, of equal importance, a ‘good solid’ read for a broader audience. I highly recommend the book to Cambridge University Press, with the hope that it will be published soon. It is deeply a moment of sadness that Roger passed away so near to the end of the review period and close to – what I hope will be – its publication. I hope that Dr. Eileen A. Hall-McKim will both carry the effort to its completion and honor Roger by fostering its use as a textbook and as a book for that ‘good read’ by a broader audience. I hope too, that she will follow his incredible leadership in polar science and understanding by picking up his remarkable professional mantle.”

- Robert W. Corell,  
*Principal, Global Environment and Technology Foundation,  
and its lead at its Center for Energy and Climate Solutions (US);  
Adjunct Professor, University of Miami;  
and Professor at the University of the Arctic (Norway)*

“Roger Barry and Eileen Hall-McKim have produced a compelling, state-of-the-art synthesis of the current state of the physical components of the Arctic and Antarctic climate systems. Complementary perspectives from the paleoclimate record, climate change

projections, and the ThirdPole expand upon the primary material. Extensive use of contemporary literature, chapter summaries, and chapter questions that probe understanding make this text ideal for a graduate course on polar environments.”

- David Bromwich,  
*Byrd Polar Research Center, Ohio State University*

“*Polar Environments and Global Change* by Barry and Hall-McKim focuses on the environmental change in the polar regions that comes as a consequence of global climate change. One of the very few currently available, this timely book could easily be the foundation textbook for an upper-level undergraduate or a graduate-level class on environmental change in the polar regions. It is comprehensive, providing a wealth of information, and giving much of the necessary scientific and historical background which allows the student to view and understand the contemporary change. Barry and Hall-McKim set the stage with a strong, historical component which touches on polar discovery and exploration. They also examine the polar climate over an arc of time linking the paleoclimatic to the contemporary, effectively placing present-day climate change within the context of the distant, past climate. Their detailing of how the environment developed, before moving to an exposition of how present-day practices induced change, fosters a fuller comprehension of the material.

As is normal in textbooks written/led by Barry, this book is very lucidly written. The authors managed quite successfully to provide a wealth of information in a very accessible way. It reads easily and is well illustrated. The summary pieces at the end of each chapter tie together the major ideas expressed in the chapter, allowing the reader to get a large-scale view of how these ideas are linked. It is also very well referenced; its comprehensive bibliography includes research very recently published.

I should also say that I am preparing a course on polar environmental change and this textbook is a prime candidate for use in this class.”

- Marilyn Raphael,  
*University of California, Los Angeles*

“Packed with a wealth of important and fascinating information, this is a timely, valuable, and highly readable synthesis of our current understanding of diverse aspects of polar environments and their significance and vulnerability – including the Third Pole. Though aimed particularly at tertiary students, this book will be of great interest to all those who care about our planet and its future.”

- Robert Massom,  
*Antarctic Climate and Ecosystems Cooperative Research Centre,  
University of Tasmania*

“This is another excellent book from Roger Barry and Eileen Hall-McKim, discussing the three most important cold regions of the world: Arctic, Antarctic, and the Third Pole (encompassing the mountains of Central Asia, Hindukush-Himalayas system and Tibet). The book provides a comprehensive account of the interactions between

climate, ocean, and the cryosphere, and an excellent review of the observational systems collecting data in these remote regions. The book is written in an engaging and very understandable way with plenty of useful references and self-check questions and will be indispensable in teaching undergraduate and master's courses in geography, glaciology, and climate science."

- *Maria Shahgedanova,*  
*University of Reading*

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## Polar Environments and Global Change

The polar regions are the “canary in the coal mine” of climate change: They are likely to be hit the hardest and fastest. This comprehensive textbook provides an accessible introduction to the scientific study of polar environments against a backdrop of climate change and the wider global environment. The book assembles diverse information on polar environmental characteristics in terrestrial and oceanic domains, and describes the ongoing changes in climate, the oceans, and components of the cryosphere. Recent significant changes in the polar region caused by global warming are explored: shrinking Arctic sea ice, thawing permafrost, accelerating loss of mass from glaciers and ice sheets, and rising ocean temperatures. These rapidly changing conditions are discussed in the context of the paleoclimatic history of the polar regions from the Eocene to the Anthropocene. Future projections for these regions during the twenty-first century are discussed. The text is illustrated with many color figures and tables, and includes further reading lists, review questions for each chapter, and a glossary.

**Roger G. Barry** was Distinguished Professor Emeritus of Geography at University of Colorado at Boulder and was the former director of the National Snow and Ice Data Center. He published 29 textbooks and 260 research articles, and supervised 65 graduate students. He was a Guggenheim Fellow, a Fulbright Teaching Fellow, and a visiting professor in eight countries.

**Eileen A. Hall-McKim** is a climatologist receiving her doctorate from the University of Colorado at Boulder. Her interdisciplinary degrees include work in the geological sciences, paleoclimatology, meteorology, oceanography, and water resources. She is the co-author, with Roger G. Barry, of *Essentials of the Earth's Climate System* (Cambridge University Press, 2014).

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# Polar Environments and Global Change

Roger G. Barry

UNIVERSITY OF COLORADO AT BOULDER

Eileen A. Hall-McKim

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## In memoriam

Roger G. Barry, Distinguished Professor Emeritus at the University of Colorado (CU) Geography Department, longtime CU faculty member, colleague, and friend to many, passed away on March 19, 2018, concluding a distinguished career in the study of the cryosphere and mountain climates. His work as a scientist and professor, and his dedication to the formation of centers for the study of the cryosphere, helped shape the evolution of climate science. He was the founder of the National Snow and Ice Data Center (NSIDC) and director there for more than 30 years.

Along with training and recruiting a dedicated staff at NSIDC, Dr. Barry also fostered international collaboration with many countries, and from 1971-2011, he supervised 67 graduate students, 36 of whom earned Ph.D. degrees. Over the course of his career, he authored hundreds of research papers and review articles, and was a prolific author of textbooks, some of which are: *Atmosphere, Weather and Climate (9<sup>th</sup> edition)*, *Mountain Weather and Climate*; *The Global Cryosphere: Past, Present and Future*; *Essentials of the Earth's Climate System*; *Microclimate and Local Climate*; and his final text, *Polar Environments and Global Change*.

Roger Barry was recognized around the world for both his scientific accomplishments and service to the community, receiving many prestigious awards throughout his career.

Further information is available at the following websites:

## References and Tributes

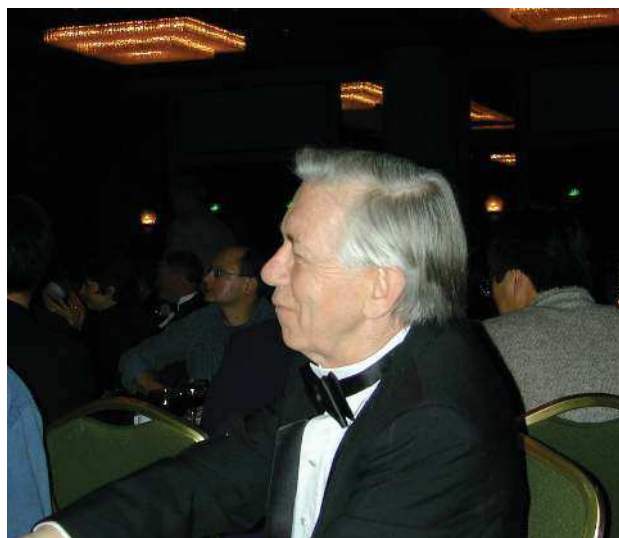
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1. Roger Barry on the Boas Glacier on Baffin Island, Canadian Arctic, in August 1970  
(photo: Ronald Weaver)



2. Roger Barry at his initiation as a Fellow of the American Geophysical Union, San Francisco, December 1999  
(photo: Ronald Weaver)

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## About the Authors

We believe it is appropriate to outline our scientific history as it relates to the polar regions.

Roger has been fascinated by cold environments since spending a year at the McGill Subarctic Research Station in Schefferville, Quebec, as a graduate student and weather observer during the International Geophysical Year, 1957–1958. Professor Jack Ives introduced him to the history of glaciation and the Laurentide ice sheet, a topic that became a part of his MSc thesis and subsequent PhD dissertation.

In summer 1963 and spring 1964, Roger took part as a meteorologist in Operation Tanquary, a Canadian Defense Research Board program on Ellesmere Island led by Dr. Geoff Hattersley-Smith. In 1966–1967, he worked at the Geographical Branch, Department of Energy Mines and Resources, in Ottawa studying the climate of Baffin Island. This included a two-week spell at the Branch's base camp in Inugsuin Fiord with a visit to the Barnes ice cap.

In October 1968, Roger accepted a faculty position at the University of Colorado, Boulder, in the Geography Department, rostered in the Institute of Arctic and Alpine Research. In 1969, along with John Andrews, he directed the work of a group of graduate students studying glaciology and glacial geomorphology in eastern Baffin Island. The “Boas” glacier, near Narpaing Fiord, was the object of glacier–meteorological research with John Jacobs and Ron Weaver. Subsequently, they shifted their attention to the landfast ice at Broughton Island. In May 1970, Roger and John Jacobs conducted aircraft measurements over the Davis Strait sea ice from a Queenair of the National Center for Atmospheric Research in Boulder.

A team-taught course on arctic and alpine environments at the Institute of Arctic and Alpine Research led to a multiauthored book, of the same title, that was edited by Jack Ives and Roger.

In 1981, Roger transferred his faculty position to the Cooperative Institute for Research in the Environmental Sciences (CIRES) in partnership with the World Data Center for Glaciology, of which he was director until 2008. This center was granted the title National Snow and Ice Data Center (NSIDC) by the National Oceanic and Atmospheric Administration (NOAA) in 1981. As part of the International Tundra Biome Programme, Roger was able to visit tundra sites at Toolik Lake, Eagle Summit, and Barrow, Alaska. The award of a J. S. Guggenheim Fellowship in 1982–1983 enabled him to spend time at the National Institute

## ABOUT THE AUTHORS

for Polar Research in Tokyo, the University of Bern, Switzerland, and the Scott Polar Research Institute in Cambridge, United Kingdom, researching snow and ice data.

Roger has also visited various parts of Central Asia. In 1979 and again in the 1990s, he visited the Abramov Glacier in the Pamir. In 1981, he traveled with Jack Ives and Gordon Young, together with Professor Shi Yafeng, Qiu Jiachi, and Kang Ersi, to No. 1 glacier in the Tien Shan. In 2005, he traveled by road from DunHuang in northwest China to Golmud and Lhasa. The railroad was under construction at the time, and the party inspected the embankments designed to prevent thawing of the permafrost. In 2009, he traveled to the terminus of No. 12 glacier at 4,250 meters in the Qilian Shan, following a meeting in Lanzhou.

In 1990, and again in 1997, Roger spent six months at the Institute of Geography, ETH, Zurich, where he lectured on mountain climates and cryospheric topics. In 1994, Roger spent four months at the Alfred Wegener Institute for Polar and Marine Research, Bremerhaven, Germany, writing a paper about snow and sea ice albedo. In spring 2000, he spent four months at Moscow State University lecturing on snow and ice. In 2004, he spent four months at the Laboratoire de Géophysique et Glaciologie in Grenoble, France, writing a paper on glacier research. In 2005, Mark Serreze and Roger published *The Arctic Climate System* through Cambridge University Press, with a second edition appearing in 2014.

Roger received a Humboldt Prize Fellowship in 2009–2010 at the Bavarian Academy of Sciences Commission on Glaciology while writing *The Global Cryosphere: Past, Present, and Future* with Thian Gan of the University of Alberta for Cambridge University Press.

In September 2005, Roger was a lecturer for a Summer School of the University of Alaska, Fairbanks, on the Russian icebreaker *Kapitan Dranitsin* as it sailed from Kirkenes, Norway, into the Laptev Sea, where it conducted research at an ice station. In February 2012, he had the opportunity to lecture on a cruise ship that sailed from Ushuaia, Argentina, across Drake Passage to the South Shetland Islands, with a landing on the Antarctic peninsula. This provided some impressions of Antarctica and the Southern Ocean. Roger continues to work on scientific papers at the NSIDC, gives invited lectures internationally, and consults on climate and cryospheric topics.

Eileen Hall-McKim is a PhD climatologist, receiving her doctorate from the University of Colorado, Boulder. Her interdisciplinary degrees include work in the geological sciences, paleoclimatology, meteorology, hydrology, oceanography, and water resource research.

Eileen's interest in weather began early. Growing up on the high plains of Kansas, she became fascinated by big sky horizons filled with supercell thunderstorms and cloud formations. Her interest in geology and paleoclimate was largely initiated by visits to Utah's Canyonlands in early 1970s. Her intrigue with

the World of Ice was fueled while she engaged in an undergraduate astronomy class with astrophysicist Dr. Joe Romig, University of Colorado, as he discussed the Milankovitch cycles and the coming and going of ice ages. Emeritus Professor Gary Thomas, working in the field of astrophysics and planetary sciences, also greatly encouraged Eileen's interest in meteorology and climate and helped facilitate undergraduate research into high-altitude noctilucent clouds as possible harbingers of climate change in early 1990s.

In 1993, during a University of Colorado INSTARR/Geography program, Eileen did extensive fieldwork in glacial geology on an Arctic River Expedition, exploring the Mara and Burnside Rivers by inflatable canoe and following the flow of springtime ice breakup of the rivers, into the Arctic Ocean near Bathurst Inlet, in Canada's Northwest Territories. Throughout the expedition, she conducted research/data collection for paleoclimate indicators of the ice flow of the Laurentide Ice Sheet through mapping of glacial striations and other landform features on the northern Canadian Shield bedrock.

Other interesting fieldwork followed observing glacial landscapes on Colorado's Niwot Ridge and Sangre de Cristo Mountain Range of the southern Rockies through the University of Colorado's Arctic and Alpine Mountain Research Station.

Eileen completed her MSc at the National Snow and Ice Data Center, Boulder, and her PhD while working as editor and writer for the Intermountain West Climate Summary of the NOAA/Western Water Assessment. Her honors include being elected a member of the Phi Beta Kappa National Honor Society; the Outstanding Women in Geosciences Student Award from the American Association of Women in Geosciences; the Graduate Research Fellowship Award from the Cooperative Institute for Research in Environmental Sciences (CIRES); and membership in the Magna Cum Laude National Honor Society, University of Colorado.

In 2008, Eileen traveled to the No. 12 glacier in the Qilian Shan in northwest China following a meeting on the World Glacier Inventory. In 2012, she sailed on the *Antarctic Dream* across Drake Passage to the South Shetland islands and Antarctic peninsula, followed by travels through Argentina and the Perito Moreno Glacier. Other travel includes visiting glaciers and periglacial landscapes in Iceland, Norway, Switzerland, Canada, and Alaska.

Eileen completed professional certification in Sustainable Community Management from the University of Colorado Sustainable Practices Program in 2011–2014 and has continuing interest in methods of carbon sequestration, with special interest in biomimetic techniques. She co-authored *Essentials of the Earth's Climate System* (with Roger G. Barry, Cambridge University Press, 2014).

Roger G. Barry and Eileen A. Hall-McKim

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## Preface

The polar world is undergoing unprecedented changes as a result of global warming and its amplification in high latitudes. Arctic sea ice is shrinking and thinning at an unprecedented rate, permafrost is thawing, glaciers and the polar ice sheets are losing mass at an accelerating rate, and ocean temperatures are rising. These changes are beginning to have large impacts on plants, animals, and human society that will increase in the future, whether or not greenhouse gas emissions are reduced.

The Third International Conference on Arctic Research Planning (ICARP 3) lists as the first of its three themes “The Arctic system and its transformation.” The first key finding of the 2017 Arctic Monitoring and Assessment Programme (AMAP) report *Snow, Water, Ice, and Permafrost in the Arctic (SWIPA)* is that “the Arctic’s climate is shifting to a new state.” It seems timely, therefore, to assemble the diverse information on polar environmental change for the benefit of students in environmental sciences, geography, biology, and climate sciences, as well as planners and northern residents.

Following an introduction that outlines the setting and research history of the polar regions, Chapter 2 describes the broad outlines of climatic history from the Eocene to the Anthropocene. Chapter 3 gives an overview of in situ and remote sensing observations of polar regions. Chapter 4 surveys the atmospheric and oceanic circulations and climatic conditions. Chapter 5 details the characteristics of the terrestrial environments and the processes at work in them. Chapter 6 examines the ice sheets of Greenland and Antarctica and ice shelves. Chapter 7 treats oceanic and sea ice environments. Chapter 8 introduces the Third Pole in the Central Asian highlands. Finally, Chapter 9 discusses projections for the future environments of the polar regions during this century. Each chapter concludes with a summary of the main points and a mixture of review and discussion questions that encourage students to check their understanding and think critically.

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