CLIMATE CHANGE IN THE POLAR REGIONS

The polar regions have experienced some remarkable environmental changes in recent decades, such as the Antarctic ozone hole, the loss of large amounts of sea ice from the Arctic Ocean and major warming on the Antarctic Peninsula. The polar regions are also predicted to warm more than any other region on Earth over the next century if greenhouse gas concentrations continue to rise. Yet trying to separate natural climate variability from anthropogenic forcing still presents many problems. This book presents a thorough review of how the polar climates have changed over the last million years and sets recent changes within the long-term perspective, as determined from ice and ocean sediment cores. The approach taken is highly cross-disciplinary and the close links between the atmosphere, ocean and ice at high latitudes are stressed. The volume will be invaluable for researchers and advanced students in polar science, climatology, global change, meteorology, oceanography and glaciology.

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Preface

The last few years have seen an unprecedented level of interest in the climate of the polar regions. The discovery of the Antarctic ozone hole, the reduction in extent of Arctic sea ice, the disintegration of floating ice shelves around the Antarctic and the high levels of aerosols reaching the Arctic have all been reported extensively in the media. This has been coupled with climate model predictions showing that the high latitude areas will warm more than any other region on Earth over the next century if 'greenhouse gas' concentrations continue to rise. Yet some have pointed to rapid climatic fluctuations that have taken place in the polar regions over the last few centuries and millennia and questioned whether the recent changes that we have seen are not simply a result of natural climate variability. Hence the time is right for a reappraisal of our understanding of recent high latitude climate change in the context of increasing anthropogenic influence on the Earth and our greater understanding of the reasons for past climate variability.

This book seeks to assess the climatic and environmental changes that have taken place over the last century and set these in the context of our understanding of natural climate variability in the pre-industrial period. We will draw on many of the new climate data sets that have become available in recent years and also make use of the results of modelling experiments. The last few years have seen great advances in our ability to observe, monitor and model the present and past polar climates. In particular, the International Polar Year of 2007–08 gave us an unprecedented amount of data from the two polar regions and increased our understanding of the mechanisms responsible for climate variability and change at high latitudes.

The record of in-situ meteorological measurements from observatories and research stations extends back about a century in many parts of the Arctic and about 50 years in the Antarctic. These observations provide us with the most accurate measurements of atmospheric conditions, yet the early observations are widely separated in many areas, with few observations from the ocean areas. However, from the mid 1970s an increasing number of observations became available from polar-orbiting satellites, which allowed the production of increasingly reliable atmospheric analyses of the high latitude areas. Over the past few decades the historical archive of in-situ and satellite observations have been reprocessed using current data assimilation schemes to produce so-called 'reanalysis' data sets. These provide a particularly valuable source for investigation of climate variability and change in the polar regions over approximately the last 30 years.

In the pre-instrumental period the most valuable data on climate variability comes from analysis of chemical species and accumulation in ice cores drilled on high latitude ice sheets. Annual layers and/or specific events, such as volcanic eruptions, can often be identified in these cores, allowing the dating of the core. Many short cores covering a few years to a few decades have been collected in the Arctic and Antarctic but there are far fewer longer cores extending back several centuries or more. However, the Vostok, Dome C and Dome F cores from East Antarctica and several long cores collected from the plateau of Greenland provide extremely valuable records of climatic conditions extending back over one or more ice ages.

The proxy data described above provide us with a reasonable picture of changes in atmospheric conditions in the past, although with decreasing resolution in the earlier part of the record. However, even today we do not have a synoptic picture of the distribution of water masses across the world's ocean and of ocean circulation, so understanding oceanic conditions in the past presents a number of difficulties. Nevertheless, analysis of ocean sediment cores has provided key information on past oceanic conditions to complement the palaeoclimatic atmospheric data.

Complementary to the climate observations from the polar regions that are used in investigating high latitude climate change are atmospheric and coupled atmosphere–ocean models. These have developed rapidly over the last couple of decades from relatively coarse resolution atmosphere-only models, which were only able to simulate the broadest features of the polar climates, to complex, high-resolution models capable of simulating the non-linear interactions between the atmosphere, ocean and cryosphere. Moreover, they have been applied to the present-day climate, and conditions during previous climatic regimes. They are the only tool that we have for predicting how the Earth's climate will evolve in the future.

In this volume we have used the data discussed above to describe past and possible future climate scenarios for the polar regions. The emphasis is on explaining the forcing mechanisms behind the observed changes and the difficulties in differentiating natural climate variability from anthropogenic effects. A priority is to integrate our understanding of the atmospheric, oceanic and cryospheric changes and to present the polar regions within the context of Earth System Science studies.

The geographical focus is obviously the Arctic and Antarctic, but research has shown that there is a close, but non-linear, coupling between the climates of the polar regions and lower latitudes. For example, recent analysis of chemical species in Antarctic ice cores has shown that signals of the El Niño–Southern Oscillation (ENSO) are present in temperature and precipitation data, but that the high latitude response varies between different ENSO events. So, where appropriate, we will not limit our coverage to just the polar regions, as defined as the areas poleward of the Arctic and Antarctic circles, but set the climatic changes of the polar regions in a global context.

Regarding the time period that the book should cover in terms of the past, we will obviously deal with the period when in-situ meteorological observations are available, approximately the last 100 years. The Holocene, which covers approximately the last 11.7 kyr, had roughly the same solar forcing as today and the Mid Holocene warm period was when some of the ice shelves around the Antarctic Peninsula disintegrated in a similar fashion to the way they have collapsed in recent decades. However, the most dramatic climatic changes at high latitudes have been the ice ages, and the latest Antarctic ice cores provide a unique record of such events through a significant part of the Pleistocene. We therefore felt that it would be logical to cover the period covered by the Dome C ice core and consider the last million years. In terms of future changes, we will deal with the Intergovernmental Panel on Climate Change (IPCC) scenarios considering the next 100 years.

As a practical note on timing within this book, for periods of more than 2000 years ago we will use the 'before present (BP)' notation, where the present is taken as AD 1950; thus the start of the Holocene will be indicated as 11.7 kyr BP.

In the first chapter we provide an introduction to the environments of the Arctic and Antarctic and consider the role of the polar regions in the global climate system. Although the book does not generally deal with the societal consequences of climate change, here we provide a brief account of the possible implications of major changes to the high latitude icecaps.

Chapter 2 is concerned with the data and the models that we have available to investigate the past and present polar climates and how they will evolve in the future. We review the availability and quality of the instrumental observations and assess the climatic information that can be derived from ice cores and ocean sediment cores. We also review the reliability of the meteorological reanalysis fields.

In Chapter 3 we consider the mechanisms that are responsible for variability and change in the high latitude climates on a range of timescales and explain why the climates of the two polar regions have their particular form. We deal with the radiation regime, ice/atmosphere feedbacks, the impact of the different land–sea distributions and orography in the two hemispheres and, in particular, the role of the Arctic Ocean compared with the Antarctic continent. We also present some mean meteorological/cryospheric fields for the two areas based on data from recent decades. These provide reference fields for the discussion on past conditions and future predictions.

Chapter 4 discusses our understanding of climate change over the last one million years, which is the most recent half of the Pleistocene. We describe the broadscale climate changes associated with the different ice ages and examine some of the more recent episodes of major change in detail, including the peak of the most recent ice age, the Last Glacial Maximum.

The Holocene is dealt with in Chapter 5. For this period we have much more detailed climatic information as there is greater temporal resolution in the available ice and ocean sediment cores. We consider our current knowledge of atmospheric and oceanic circulation, along with changes in temperature, precipitation, sea ice and the ice sheets.

The instrumental period of the last 50–100 years is covered in Chapter 6. Over this period increasingly sophisticated observations have been obtained of many aspects of the polar environment and these are used to examine variability and change. We consider the main meteorological elements, as well as the ocean environment, sea ice and the icecaps.

Although a great deal of atmospheric and cryospheric data are now available, a major gap in our knowledge is still the oceans, where many records are short.

Chapter 7 examines the prospects for the evolution of the polar climates over the next 100 years. The atmospheric and oceanic predictions come from state-of-the-art climate models, many of which were used in the production of the IPCC Fourth Assessment. Such models can also provide information on future changes in sea ice extent; however, prediction of changes in the major ice sheets is still very difficult to quantify.

In Chapter 8 we summarise our current understanding of high latitude climate change and consider future research and data collection needs.

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