Precipitation plays a very significant role in the climate system, every bit as important as temperature, yet this is the first book that provides a comprehensive examination of the processes involved in the growth of clouds, rain, snow and hail. The book also shows how precipitation is measured and what these measurements tell us about its distribution around the globe.

The book begins by tracing our attempts to understand what precipitation is, starting with the ideas of the ancient Greeks, followed, after a long period of stagnation through the Middle Ages, by the improved insights of seventeenth-century scientists, leading to today’s detailed knowledge. The measurement of precipitation with rain gauges, radar and satellites is explained followed by what these measurements tell researchers about global annual means, trends, variability and extremes of precipitation. There are still very few rainfall measurements from any of the oceans, while coverage on land is extremely patchy. The concluding chapter outlines what needs to be done to correct these deficits, thereby making it possible to observe future climate change with more confidence.

Precipitation will be invaluable to researchers in environmental science and climatology, those concerned with water resources and flood management, and those planning action as the climate changes. It will also have an appeal to scientific historians.

Ian Strangeways is Director of TerraData, a consultancy in meteorological and hydrological instrumentation and data collection. He has also written Measuring the Natural Environment, now in its second edition (Cambridge University Press 2003).
PRECIPITATION
Theory, Measurement and Distribution

IAN STRANGEWAYS
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Preface

I was able to write most of this book directly from personal experience gained at the Institute of Hydrology (now the Centre for Ecology and Hydrology) in Wallingford from 1964 to 1988 and since then as a consultant in the same disciplines. This whole period has also been regularly interspersed with overseas travel, advising on data collection for water resources, flood warning and agricultural projects. These trips have taken me to about as many remote locations around the globe as David Attenborough has visited in his film making, places rarely seen by outsiders. On these many and diverse missions, from the Antarctic to tropical rainforests and deserts, I came face to face with the complex reality of environmental monitoring and the many problems that obtaining good measurements presents.

When it came to writing Part 4, I needed input from those directly involved in collating, homogenising and analysing the data collected by the global network of raingauges, and more recently by satellites. In this I was helped greatly by David Parker, Jen Hardwick and Chris Folland at the Hadley Centre in Exeter, who supplied me with data and graphs showing long-term precipitation trends in England and Wales, and who helped by passing on some of my questions to others with different specialised knowledge. In consequence I also had a useful and interesting exchange of emails with Aiguo Dai, Kevin Trenberth and Ping Ping Xie all at the National Center for Atmospheric Research in Boulder, Colorado. It is always a pleasure to experience the willingness of people working in science to exchange ideas and to do so with enthusiasm, and all of these co-workers lived up to this expectation.

But before getting to the present day I started by looking back to those times when just a handful of Greek philosophers brought a brief glimpse of light into the pervasive darkness of the ancient world to ponder on the nature of things, including rain and snow and clouds, and at their explanation of what they thought they were – their initiatives only to be extinguished very quickly by the dark ages for the next 2000 years. But then came a renaissance in the seventeenth century and the
modern world began, with all its new discoveries; this long history makes interesting reading.

I am grateful to the staff of Cambridge University Press for publishing the book, in particular to Matt Lloyd, who has assisted at every step along the way, and to Dawn Preston, who has managed the production of the book. I would like also in particular to thank my copy-editor, Hugh Brazier, for the way he has been through the book in fine detail, routing out very small, small and not so small errors and suggesting alternative ways of expressing some of the ideas. The result is a book that will be all the more accurate and readable for the close scrutiny it has received.

I should also like to thank the reader for reading the book, and hopefully also for buying it. I can assure you, however, that being an author does not make you rich – unless you write about the adventures of Harry Potter or the private life of a footballer. Fantasy and celebrity pay much better than science. But I would not exchange.
Acronyms and abbreviations

AAO Antarctic oscillation
ADC analogue-to-digital conversion
AMS American Meteorological Society
AMSU advanced microwave sounding unit
AO Arctic oscillation
ATD arrival-time difference
ATLAS autonomous temperature line acquisition system
AVHRR advanced very high resolution radiometer
AWS automatic weather station
BT brightness temperature
CCD charge-coupled device (image sensor)
CCN cloud condensation nucleus
CEH Centre for Ecology and Hydrology (formerly IH)
CERES clouds and the earth’s radiant energy system
CMAP climate prediction center merged analysis of precipitation
CMIS conical scanning microwave imager/sounder
CRDF cathode ray direction finder
CRU Climatic Research Unit (University of East Anglia)
DCP data collection platform
DF direction finder (lightning)
DFIR double-fence intercomparison reference (snow fence)
DSRT dual-frequency surface reference technique
DWD Deutscher Wetterdienst (German National Meteorological Service)
ELF extra low frequency (radio – lightning)
ENSO El Niño southern oscillation
ESA European Space Agency
**Acronyms and abbreviations**

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
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<tbody>
<tr>
<td>FRONTIERS</td>
<td>forecasting rain optimised using new techniques of interactively enhanced radar and satellite data</td>
</tr>
<tr>
<td>GANDOLF</td>
<td>generating advanced nowcasts for deployment in operational land-surface flood forecasting</td>
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<tr>
<td>GARP</td>
<td>global atmospheric research program</td>
</tr>
<tr>
<td>GATE</td>
<td>GARP Atlantic tropical experiment</td>
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<tr>
<td>GCOS</td>
<td>global climate observing system</td>
</tr>
<tr>
<td>GEOSS</td>
<td>global earth observation system of systems</td>
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<tr>
<td>GEWEX</td>
<td>global energy and water cycle experiment</td>
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<tr>
<td>GHCN</td>
<td>global historical climatology network</td>
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<tr>
<td>GMI</td>
<td>global precipitation measurement microwave imager</td>
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<tr>
<td>GMS</td>
<td>geostationary meteorological satellite</td>
</tr>
<tr>
<td>GOES</td>
<td>geostationary operational environmental satellite</td>
</tr>
<tr>
<td>GOMS</td>
<td>geostationary operational meteorological satellite</td>
</tr>
<tr>
<td>GPCC</td>
<td>Global Precipitation Climatology Centre</td>
</tr>
<tr>
<td>GPCP</td>
<td>global precipitation climatology project</td>
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<tr>
<td>GPI</td>
<td>GOES precipitation index</td>
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<tr>
<td>GPM</td>
<td>global precipitation measurement</td>
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<tr>
<td>GPROF</td>
<td>Goddard profiling algorithm</td>
</tr>
<tr>
<td>GPS</td>
<td>global positioning system</td>
</tr>
<tr>
<td>GTS</td>
<td>global telecommunication system</td>
</tr>
<tr>
<td>ICSU</td>
<td>International Council for Science</td>
</tr>
<tr>
<td>IH</td>
<td>Institute of Hydrology (now CEH)</td>
</tr>
<tr>
<td>IOC</td>
<td>Intergovernmental Oceanographic Commission</td>
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<tr>
<td>IPCC</td>
<td>Intergovernmental Panel on Climate Change</td>
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<tr>
<td>IR</td>
<td>infrared</td>
</tr>
<tr>
<td>JAXA</td>
<td>Japan Aerospace and Exploration Agency</td>
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<tr>
<td>LEO</td>
<td>low-earth orbit</td>
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<tr>
<td>LIS</td>
<td>lightning imaging sensor</td>
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<tr>
<td>LPATS</td>
<td>lightning position and tracking system</td>
</tr>
<tr>
<td>MSG-1</td>
<td>Meteosat Second Generation 1</td>
</tr>
<tr>
<td>MSS</td>
<td>multispectral scanner</td>
</tr>
<tr>
<td>MSU</td>
<td>microwave sounding unit</td>
</tr>
<tr>
<td>NAO</td>
<td>North Atlantic oscillation</td>
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<tr>
<td>NASA</td>
<td>National Aeronautical and Space Administration</td>
</tr>
<tr>
<td>NCDC</td>
<td>National Climatic Data Center</td>
</tr>
<tr>
<td>NOAA</td>
<td>National Oceanographic and Atmospheric Administration</td>
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<tr>
<td>NWS</td>
<td>national weather service</td>
</tr>
<tr>
<td>OTD</td>
<td>optical transient detector (lightning)</td>
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<td>PIP</td>
<td>precipitation intercomparison project</td>
</tr>
</tbody>
</table>
**Acronyms and abbreviations**

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td>PIRATA</td>
<td>pilot research moored array in the tropical Atlantic</td>
</tr>
<tr>
<td>PR</td>
<td>precipitation radar</td>
</tr>
<tr>
<td>RAM</td>
<td>random access memory</td>
</tr>
<tr>
<td>RH</td>
<td>relative humidity</td>
</tr>
<tr>
<td>RMS</td>
<td>Royal Meteorological Society</td>
</tr>
<tr>
<td>RS</td>
<td>remote sensing</td>
</tr>
<tr>
<td>SAFIR</td>
<td>(a French lightning direction finding system)</td>
</tr>
<tr>
<td>SEVIRI</td>
<td>spinning enhanced visible and infrared imager</td>
</tr>
<tr>
<td>SOI</td>
<td>southern oscillation index</td>
</tr>
<tr>
<td>SSM/I</td>
<td>special sensor microwave imager</td>
</tr>
<tr>
<td>SST</td>
<td>sea surface temperature</td>
</tr>
<tr>
<td>SVP</td>
<td>saturation vapour pressure</td>
</tr>
<tr>
<td>TAO/TRITON</td>
<td>tropical atmosphere ocean/triangle trans-ocean buoy network</td>
</tr>
<tr>
<td>TMI</td>
<td>tropical rainfall measuring mission microwave imager</td>
</tr>
<tr>
<td>TOA</td>
<td>time of arrival</td>
</tr>
<tr>
<td>TRMM</td>
<td>tropical rainfall measuring mission</td>
</tr>
<tr>
<td>UHF</td>
<td>ultra-high frequency</td>
</tr>
<tr>
<td>UNEP</td>
<td>United Nations Environment Programme</td>
</tr>
<tr>
<td>UV</td>
<td>ultraviolet</td>
</tr>
<tr>
<td>VHF</td>
<td>very high frequency</td>
</tr>
<tr>
<td>VISSR</td>
<td>visible and IR spin-scan radiometer</td>
</tr>
<tr>
<td>VLF</td>
<td>very low frequency (lightning detection)</td>
</tr>
<tr>
<td>VP</td>
<td>vapour pressure</td>
</tr>
<tr>
<td>WCRP</td>
<td>world climate research programme</td>
</tr>
<tr>
<td>WMO</td>
<td>World Meteorological Organization</td>
</tr>
<tr>
<td>WV</td>
<td>water vapour</td>
</tr>
</tbody>
</table>

For a fuller list of abbreviations and acronyms, see Padgham, R. C., *A Directory of Acronyms, Abbreviations and Initialisms* (Swindon: Natural Environment Research Council, 1992).