MEASURING GLOBAL TEMPERATURES

Temperature is probably the most influential of all climatic variables. Our only direct, quantitative knowledge of global temperatures (and indeed of any climate variable) comes from instruments invented and operated over the last 150 or so years. Crucial as these data are to our understanding of the climate, they are largely taken for granted, even by many of those using them, with little appreciation of how they came into being, how accurate they are, or how urgently they need to be improved for the future.

Measuring Global Temperatures will fill this gap by explaining how global temperatures are measured, how the data are analysed, what the potential errors are, and what needs to be done to improve temperature measurement in the future. After looking at how temperature measurements are made, Ian Strangeways shows how they are then processed to give average temperatures over the globe, explaining that global values may be misleading because they merge many different climates and seasons into one and so may hide vital details. Using some of the best datasets currently available, the book shows that temperature change is complex, and not reducible to one single graph or global truth: we need to look at the local scale for clues as to how and why the climate is changing.

This book will be of great interest to all meteorologists, climatologists and hydrologists, especially those concerned with climate change and global warming. It is written in accessible language with little mathematics, and will also appeal to students and anyone with an interest in weather and climate.

IAN STRANGEWAYS obtained his degree in electronic engineering, physics and mathematics from Bangor University, followed some years later by a PhD in meteorological instrumentation from Reading. After 24 years at the Institute of Hydrology as head of the Applied Physics Section, measuring the hydrometeorological environment, he became Director of TerraData, a consultancy in meteorological and hydrological data collection. He is the author of *Measuring the Natural Environment*, now in its second edition (2003, Cambridge University Press) and *Precipitation: Theory, Measurement and Distribution* (2007, Cambridge University Press). He has published many papers on the topic of data collection, climate measurement and instrumentation, and has written extensively for the Royal Meteorological Society's (RMetS) magazine *Weather*, for which he received the Gordon Manley Award in 2005. He is on the committee of the RMetS Special Interest Group on Meteorological Observing Systems, which he chaired for three years. He has travelled extensively to many remote areas of the world, advising on the monitoring of the weather and rivers, and has given talks at major international conferences. He has been an external lecturer on the subject at Newcastle University, and has also taught at the Open University and instructed students overseas. He is a Fellow of the RMetS and an Associate Member of the British Hydrological Society and the Institution of Civil Engineers.

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Their Analysis and Interpretation

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In writing this book, I have adopted the Royal Society's motto:

Nullius in verba

(*Nothing upon another's word*)

(Horace, Epistles I.i, 1.13–14)

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Preface

In the course of my work measuring the weather and rivers, I have had the good fortune to visit many remote locations around the world that few people get to see. The purpose of these journeys was to advise on how the meteorological and hydrological environments should be measured for applications ranging from a country's water resources, through flood prediction and warning, agriculture and irrigation in deserts, plant diseases in the tropics, water for hydroelectric schemes, the transmission of measurements to remote bases via telephone, radio and satellite, and a wide variety of meteorological measurements for diverse applications. When not thus occupied I spend my time in laboratories in the UK developing new ways to measure the natural environment and writing up the accumulated knowledge gained in this way over four decades.

This work has taken me into the rainforests of Papua New Guinea, Indonesia and Malaysia, into the deserts of Libya and Oman, to the Cairngorm mountain-tops in winter, to hydroelectric generator halls inside the mountains of Honduras and to remote islands off the Antarctica peninsula, testing experimental instruments, and by small plane to grass airstrips in the Mato Grosso of the Brazilian interior, to India, Malaysia, Indonesia and to many other impressive locations. Such journeys are not without stress, for it was vital that what I did there had to work and I had to 'hit the ground running' despite jet lag and had to avoid getting ill despite some primitive living conditions.

Seeing at first hand the way in which different countries undertook the task of making their measurements, and the field conditions in diverse climates, expanded my view beyond the comfortable confines of laboratories and offices out into many corners of the globe where scientific standards vary greatly and where you are on your own without any help immediately to hand. Travel to these places has coloured my view of the world profoundly.

Out of these many journeys came my first book, *Measuring the Natural Environment*, and two years later its second edition, describing how meteorological and hydrological variables are measured. The next book was *Precipitation*, which concentrated on just that one topic in detail; on a history of our understanding of what it is, on the way it is measured and on what the measurements tell us about rainfall and snowfall around the globe. After that I felt it was time to turn my attention to what is now undoubtedly the most important of all climate variables, temperature. The present book is the end-product of two years' writing and research.

I begin with a history of thermometer development in Italy, France, Holland, Denmark, Sweden and England at the start of the modern age of scientific enquiry. After describing how temperatures have been measured over the land and the sea, and how reliant we still are on measurements made by simple old instruments, I move on to show how these measurements are processed to give average temperatures over small areas and how these are then converted into hemispheric and global averages. Throughout this enquiry, I avoid complex statistics in order to make the book intelligible to a wide audience, but with references for those who want more details of the maths.

Finally, I look into the pressing matter of what these measurements actually tell us about temperature change over the last few hundred years – coming to some unexpected and counter-intuitive conclusions. Using some of the best datasets currently available, I demonstrate that the situation regarding temperature change is complex and not reducible to one single graph or to one simple global truth. I show how we need to look at the local scale for clues as to how, and why, the climate is changing. Hemispheric and global values can be misleading because they merge many different climates and all four seasons, north and south, into one, thereby masking crucial details. I also explore doubts as to whether the merging of data from diverse climates and different times of the year has any validity in the real world.

In writing the book, I became increasingly aware that by stressing the complexity of the climate system, the uncertainty of the measurements and the intricacy of what they show, I run the risk of offending the committed hardline environmentalist and of adding fuel to the sceptics' case. I sit in the middle, unhappy with the often petulant tones of the sceptical debate while being unable to support the impression of certainty that many climatologists want to project, however worthy they may feel their motives are. But I end the book with positive suggestions as to how we might now proceed.

Acknowledgements

To avoid errors and the risk of being out of date, I sought advice and help from the following top experts in climate research:

Phil Jones (Climatic Research Unit, University of East Anglia) read four of my draft chapters and annotated them liberally, occasionally forcibly, for which I am most grateful; plain-speaking is what I wanted and is what I got. Many of his remarks, however, were exceedingly useful and I modified the text appropriately. On a few points we didn't agree, so any remaining mistakes or errors are mine. The book is very much the better for his contribution, so I hope we do not fall out over our disagreements.

David Parker (Hadley Centre, Met Office) also took the time to read some of the original drafts, including the chapter on sea surface and marine air temperature. David also gave valuable help with my questions regarding Central England Temperature and the diurnal temperature range, as well as on the latest research on warming in the troposphere. Like Phil Jones, I am sure David will not agree with everything I have written but would probably say that any remaining errors are mine.

Chris Folland (Hadley Centre, Met Office) has helped by supplying relevant recent papers and referring me to other researchers both in the UK and the USA where appropriate. Chris also suggested changing the subtitle of the book from my original *Past, Present and Future*, to the much better *Their Analysis and Interpretation*, which he believes conveys more accurately what the book is about – for the measurements are just the start, not the end. I think this is correct and I hope it encourages more people to read the book.

John Kennedy (Hadley Centre, Met Office) advised me on details of sea surface temperature measurements from ships and drifting buoys and on comparisons between them, supplying many relevant papers that ensured I was up to date. Climate science changes quickly and it is important to keep abreast of everyone's work.

Jon Turton (Hadley Centre, Met Office) read my draft section on the Argo float network, suggested changes and helped establish its temperature accuracy. Jon also advised on sea surface temperature and drifting buoys, augmenting what John Kennedy had provided, again ensuring I was up to date in what I said.

I am very indebted to all the above, who took the trouble to read what I had written. I appreciate the care they took and the time they spent doing this. Receiving their help made the task of writing the book more complex, since I had to rethink and rewrite several sections, but the book is that much the better for it. I have not agreed with all their comments, but that is no bad thing. I am sure I will be criticised for some of my comments and suggestions. Indeed I already have been.

I would also like to thank **Russell Vose** (National Oceanic and Atmospheric Administration, NOAA) for sending me the latest datasets on changes in the diurnal temperature range and for agreeing that I can use them in the book. These are invaluable data and I am very grateful to Russell for being so open and helpful. Indeed I have found that everyone I have approached has responded very positively, even when they disagreed with me.

I would like to thank my copy-editor, **Nancy Boston**, for the way she has picked up many small and not so small errors in what I had written. In effect, Nancy has been the first reader of the book and was able to draw my attention to points that I had not expressed clearly enough and mistakes I had overlooked. The book is very much the better for her care and attention, and the more readable for it.

I am also grateful to the staff of Cambridge University Press for publishing the book, especially to **Matt Lloyd**, who has been very supportive throughout the long process, from my initial proposal a few years ago, through the reviewing stage, followed by acceptance and, finally, publication.

Acronyms

AAO	Antarctic Oscillation
AMO	Atlantic Multidecadal Oscillation
AMSU	Advanced Microwave Sounder Unit
AO	Arctic Oscillation
AR4	Fourth Assessment Report (of the IPCC)
ATMS	Advanced Technology Microwave Sounder
ATSR	Along Track Scanning Radiometer
AVHRR	Advanced Very High Resolution Radiometer
AWS	automatic weather station
AXBT	airborne expendable bathythermograph
CAM	climate anomaly method
CDIAC	Carbon Dioxide Information Analysis Center
CEH	Centre for Ecology and Hydrology
CET	Central England Temperature
CLIVAR	Climate Variability and Predictability
CNES	French Space Agency
CRU	Climatic Research Unit
DBCP	Data Buoy Cooperation Panel
DCP	data collection platform
DTR	diurnal temperature range
ENSO	El Niño Southern Oscillation
ERI	engine-room intake
FD	first difference
FDM	first difference method
GCOS	Global Climate Observing System
GCR	galactic cosmic ray
GDP	Global Drifter Program

GEOSS	Global Earth Observation System of Systems
GHCN	Global Historical Climatology Network
GHG	greenhouse gas
GHRSST-PP	Global Ocean Data Assimilation Experiment High Resolution Sea Surface Temperature Pilot Project
GISS	Goddard Institute for Space Studies
GODAE	Global Ocean Data Assimilation Experiment
GOES	Geostationary Operational Environmental Satellite
GOOS	Global Ocean Observing System
GOSAMOR	Global Ocean Salinity Monitoring
GPS	Global Positioning System
GTS	Global Telecommunications System
ICOADS	International Comprehensive Ocean–Atmosphere Data Set
ICSU	International Council for Science Unions
IH	Institute of Hydrology
IOC	Intergovernmental Oceanographic Commission
IOD	Indian Ocean Dipole
IPCC	Intergovernmental Panel on Climate Change
IPO	Inter-decadal Pacific Oscillation
IPTS	International Practical Temperature Scale
IR	infrared
LAT	land air temperature
LEO	low Earth orbit
LIA	Little Ice Age
MAT	marine air temperature
MCDW	Monthly Climatic Data for the World
MHS	Microwave Humidity Sensor
MSS	multispectral scanner
MWP	Medieval Warm Period
NAM	North Annular Mode (or Arctic Oscillation)
NAO	North Atlantic Oscillation
NCAR	National Center for Atmospheric Research
NCDC	National Climatic Data Center
NMAT	night marine air temperature
NMS	National Meteorological Service
NOAA	National Oceanic and Atmospheric Administration
NOCS	National Oceanography Centre, Southampton
NODC	National Oceanographic Data Center
NORPEX	North Pacific Experiment

OWS	ocean weather ships
PDO	Pacific Decadal Oscillation
PMO	Port Meteorological Officer
PNG	Papua New Guinea
PRT	platinum resistance thermometer
QDO	quasi-decadal oscillation
RAM	random access memory
RCS	Reference Climatological Station
RH	relative humidity
RS	remote sensing
RSM	reference station method
RSS	remote-sensing systems
RTE	radiative transfer equation
SAM	Southern Annular Mode (or Antarctic Oscillation)
SAR	Second Assessment Report (of the IPCC)
SAR	synthetic aperture radar
SEVIRI	Spinning Enhanced Visible and Infrared Imager
SIO	Scripps Institution of Oceanography
SOC	Southampton Oceanography Centre
SOHO	Solar and Heliospheric Observatory
SOI	Southern Oscillation Index
SST	sea surface temperature
SVP	Surface Velocity Program
SVP	saturation vapour pressure
TAO	Tropical Atmosphere Ocean array
TAR	Third Assessment Report (of the IPCC)
TOGA	Tropical Ocean Global Atmosphere
TOPEX	Ocean Topography Experiment
UAH	University of Alabama in Huntsville
UHI	urban heat island
UNEP	United Nations Environment Programme
USHCN	US Historical Climate Network
UV	ultraviolet
VISSR	Visible and Infrared Spin-Scan Radiometer
VMO	voluntary marine observer
VOF	voluntary observing fleet
VOS	voluntary observing ships

VOSClim	VOS Climate Project
WCRP	World Climate Research Programme
WIS	WMO Information Service
WMO	World Meteorological Organization
WOCE	World Ocean Circulation Experiment
WV	water vapour
WWR	World Weather Records
XBT	expendable bathythermograph