The Global Circulation of the Atmosphere

THE GLOBAL CIRCULATION OF THE ATMOSPHERE

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Foreword

It is a pleasure to be able to contribute to this volume devoted to the global circulation of the atmosphere, even though I was unable to attend the conference that gave rise to it. I look at the conference as the most recent in an extended series. This has not been a planned series; there have been no *First Symposium on the General Circulation of the Atmosphere, Second Symposium* . . . , etc. Individual meetings have taken place when the various organizers have felt that the occasion has arisen. What gives continuity to the succession of meetings, and what makes it possible to look at them as constituting a series, is the not-surprising fact that to a considerable extent the participants in any one meeting were those in the previous one, and the ideas that they offered were often extensions of those presented before. Of course, there have generally been a few welcome newcomers, while some contributors of longer standing have retired or acquired new primary interests. Sometimes the organizers have invited specialists in specific related fields.

I shall not attempt to enumerate the many meetings that have taken place at many institutions in quite a few nations. Instead I shall mention just two; these seem especially relevant because each one gave rise to a volume not unlike the present one.[1,2] Also, having attended each of them, I feel a bit more qualified to describe them.

The first of these, which was more specialized than most and was particularly concerned with numerical integration, took place in 1955 at the Institute for Advanced Study in Princeton, New Jersey. Here we were honored by the presence of John von Neumann, possibly the world's greatest then-living mathematician, who had become a champion of the application of computers to mathematical problems—an activity then frowned upon by many prominent mathematicians—and had identified the weather-forecasting problem as especially amenable to this approach. A highlight of the conference was Norman Phillips's account of his now famous experiment—the first attempt to model the general circulation numerically. His description, shortly afterward enlarged and published in the standard literature[3], earned him the then recently established Napier Shaw Prize of the Royal Meteorological Society.

Nevertheless, many of the papers presented were like what might have appeared at any other general-circulation meeting of that day. Indeed, many participants did not have ready access to computers, and had never contemplated performing numerical integrations.

The other meeting took place in 1969 in the Rooms of the Royal Society of London. I had the honor, if it is an honor, of being the first speaker, and I presented what was to me an up-to-date account of the workings of the general circulation, noting a few problems that remained to be solved. I was followed by Joseph Smagorinsky, who described in detail a great many problems that needed to be solved in the still-young field of numerical general-circulation modeling, before results from the models could be considered definitive. Some of the other papers considered the roles of restricted portions of the atmosphere—the lower boundary layer, the stratosphere, and the Tropics—that had generally received less attention in earlier studies, at least partly because suitable observations had not been plentiful. By this time access to computers had become more common, but most of the papers presented did not make much use of computers, other than to speed up some data processing.

Both conferences were attended by a large number of those whom one would have expected to encounter at a general-circulation meeting, and one might have supposed that the proceedings would in due time become the works that would be most frequently cited. Possibly they enjoyed this status for a short while, but in preparing this foreword I decided to count the number of references in the present volume to the papers in those proceedings. Out of a total of 752 references (not eliminating duplications), the count came to zero. There are a few references to Phillips's published paper, which had appeared in shorter form in the Princeton proceedings.

How are we to account for this absence? Perhaps many of the same ideas were to be found in more-widely disseminated publications such as journals, which were more conveniently quoted; but, more importantly I believe, our ideas as to what constitutes the general circulation, or what are its relevant aspects, are continually changing over the years, and the last forty or fifty years have been no exception.

Almost anyone today would agree that the average or typical tropospheric lapse rate of temperature and the average tropospheric relative humidity, for example, are significant features of the global circulation. Fifty years ago almost anyone, if asked, would probably have agreed, yet these features received little attention then among general-circulation theorists. Possibly their magnitudes were taken for granted. In the present volume they receive some of the recognition that they deserve, in the first, third, and sixth chapters.

Likewise, in earlier studies we often treated atmospheric water in its various phases by omitting any explicit reference to it, aside from subsequently acknowledging that it might be a modifying influence. At the London meeting, after noting a reidentification of pressure systems as circulation systems, I concluded my talk by speculating that a future generation might be talking about water systems. While the term “water system" has not invaded the present volume, the presence of water plays an essential role in the arguments presented in at least nine of the twelve chapters.

Methods of dealing with the general circulation have also changed. At the earlier meetings there were talks devoted to the new or growing field of numerical simulation, and implicitly hailing it as another approach to the problem. Today numerical modeling appears to have become the approach of choice. Much of what we know or believe that we know about the global circulation as it is, as opposed to knowing why, is actually what we have observed in the output of numerical models.

Perhaps the most timely change in attitude, however, is our identification of the global circulation with the climate. This might be just a matter of semantics, except for the fact that our view of the climate itself has changed. Richard Pfeffer, who edited the proceedings of the Princeton meeting, was ahead of his time in titling the volume “Dynamics of Climate"; this was still the age when “climatology" was often irreverently defined as adding up thirty numbers and dividing by thirty. Some standard textbooks, including the one that I best recall from my student days,[4] bore no suggestion that the climate had ever deviated from its present arrangement. By the time of the meeting we all recognized that the climate during the recurring ice ages must have differed from the present one, and we generally assumed that some day the ice might come back. Harry Wexler offered a paper on the possible causes of climatic change, but there was little mention of climate in the remaining contributions. Today the study of climate seems to be dominated by the problem of climate change, and we are acutely aware of the possibility that a new climate may well appear within our own lifetimes.

It therefore seems quite appropriate that this volume should conclude with a chapter on abrupt climate change. Such a phenomenon was unanticipated forty years ago, and, indeed, the proxy observations that revealed its presence were altogether unavailable then. When the observations did appear some twenty years ago, their interpretation was seriously questioned; slow climate changes were easier to accept.

The existence of climates as different as those typifying glacial and interglacial periods, following one another by intervals as short as two decades, is now fairly well accepted. Great advances have been made since several generations ago, when experts were still attempting to show, by nonquantitative reasoning from basic physical principles, that the atmosphere must circulate in the particular manner that was then observed. The present volume leaves little doubt that great advances will continue to be realized.

Edward N. Lorenz

Notes

1. Pfeffer, R.L. (Ed.), 1960: *Dynamics of Climate*. New York, Pergamon Press, 137 pp.

2. Corby, G.A. (Ed.), 1969: *The Global Circulation of the Atmosphere*. London, Royal Meteorological Society, 257 pp.

3. Phillips, N.A., 1956: The general circulation of the atmosphere: A numerical experiment. *Q. J. Roy. Meteor. Soc.*, 82, 123–164.

4. Kendrew, W.G., 1942: *The Climates of the Continents*. New York, Oxford University Press, 473 pp.

Preface

This book is an attempt to summarize our current understanding of the mechanisms controlling the global circulation of the atmosphere and to define questions for future research. The book is an outgrowth of a three-day conference held at the California Institute of Technology in Pasadena, California, in November 2004. The centerpiece of the conference was a set of ten invited lectures. Each of the invited lecturers was asked to write a chapter of this book based on the lecture material. We contributed another two lectures and two chapters.

The global circulation of the atmosphere is a broad topic, and current research uses a variety of approaches. Observations and the phenomena they describe form the first pillar of our knowledge, and observational work employs a large fraction of our field's material and intellectual resources. Numerical simulations with the most comprehensive and complex climate models form the second pillar, and their importance continues to grow. The models are continually improving, as are the computers used to run them, and in response to this, as well as to the rapidly increasing prominence of climate change in the public eye, the demands on these simulations have never been greater.

Theory forms the third pillar of our knowledge. By theory, we mean that stage of scientific investigation in which mechanisms based on general principles are posited as responsible for observed or simulated phenomena. Theory in our field generally involves the construction of idealized mathematical models that (unlike comprehensive climate models) omit many details, rendering them simple enough that the chain of cause and effect in them can be laid bare, but that still retain sufficient complexity to be relevant for understanding the atmosphere.

This book focuses on theory. Key aspects of the observations motivating the theoretical issues at hand are presented in many of the chapters, but a comprehensive treatment of the observations is not contained here. Numerical simulations with comprehensive climate models are discussed in detail only in a small subset of the chapters, particularly chapters 11 and 12.

The tropical and extratropical atmospheres have historically been and to some extent still are studied separately by relatively distinct groups of scientists. The global circulation is one area in which the two should be brought together, and we have done that here. The tropics and extratropics are given approximately equal weight, with some chapters, particularly chapters 5, 6, and 12, addressing tropical-extratropical interactions.

This is not a textbook. Some prior knowledge of the field on the part of the reader is assumed. We hope the book captures the state of the field but communicates it in a more condensed form and with more context, breadth, and perspective than one would find in the primary research literature. We hope the book will be useful to graduate students in atmosphere, ocean, and climate science. When we were graduate students, we enjoyed reading books like this, learned a lot from them, and wished there were more. Of course, more advanced researchers in the field should find the book accessible, and those from related fields may be able to use it to gain a foothold in ours.

Many people contributed to this book. First and foremost, of course, are the authors, who have our gratitude. In addition to writing the chapters, the authors also served as reviewers, each reviewing a chapter by another author. We also solicited reviews from a few additional reviewers and thank Michela Biasutti and Edmund Chang for their constructive suggestions on the chapters they reviewed. We are very grateful to William and Sonja Davidow, whose financial support made the conference and this book possible.

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