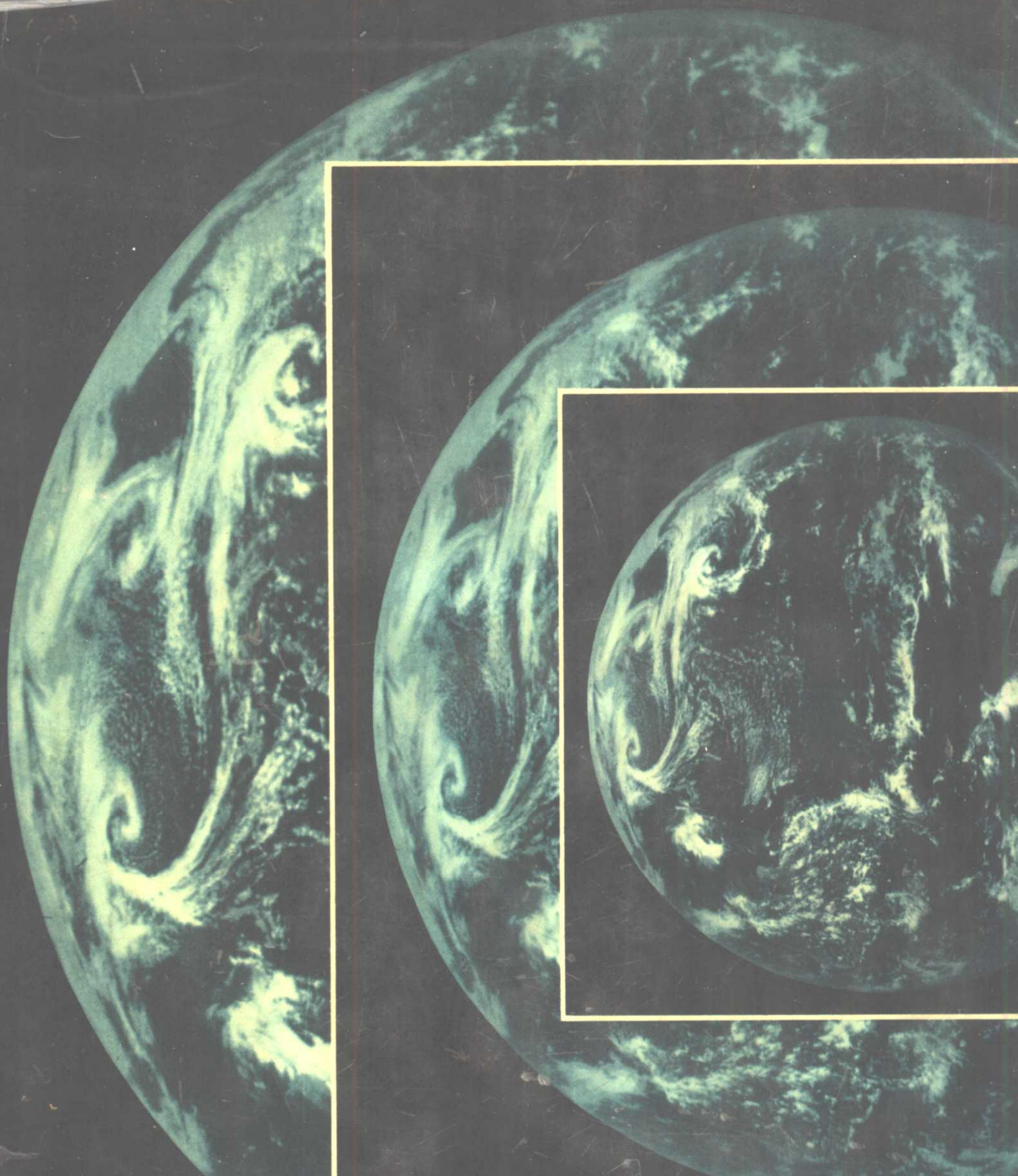

Global Weather Prediction

The Coming Revolution

EDITED BY BRUCE LUSIGNAN AND JO N KIEL

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Preface

WITHIN the next decade, there will be a revolution in the science of weather prediction, for within five to ten years it should be possible to make accurate 10- to 14-day weather forecasts. This amounts to a quantum jump beyond the current forecasting ability, and its benefits will involve saving millions of dollars and hundreds of lives which are lost each year in unexpected floods and storms, and will have far-reaching consequences for large segments of the world's population. Hence, a book about this revolution, written by some of the men who make it possible, may be of interest to a wide range of readers.

This book grew out of a series of some 30 lectures given over a period of four months in 1966 to a graduate Space Systems Engineering course at Stanford University. The goal of the class, which consisted of some 50 engineers, lawyers, businessmen, economists, and one philosopher, was to design a global weather satellite system. Since a knowledge of meteorology was not a prerequisite for the course, the aim of the lectures was to provide an extensive introduction into the many aspects of a global weather prediction system. The members of the class then proceeded with their own research. The final weather satellite system design has been published by Stanford in a volume entitled *SPINMAP*, sections of which are included in this book.

Among the lecturers were many of the leading meteorologists, physicists, businessmen, and statesmen involved in the field of weather prediction. Among the many topics they dealt with were the history and future of meteorology, the costs and benefits of improved weather forecasts, the TIROS and Nimbus satellite systems, numerical models for the atmosphere, and the use of the laser for atmospheric observations. This book came about as a result of the excitement generated by the individual concepts and by the overall possibilities for the next decade which grew out of these lectures.

Many people with a diversity of backgrounds enjoyed these lectures, and they have been edited into the articles of this book for readers who are interested in the concepts of weather prediction in the 1970's. The major portion of the book has been written for readers with a general engineering or scientific background. However, a substantial part of the first five parts should be intelligible to any man of letters, while parts of Part 6, on numerical models, require a reasonable mathematical competency.

The articles of the book fall naturally into two unequal sections. The first, consisting of Parts 1 to 3, provides a general introduction to the concepts, problems, cost, and benefits of weather prediction, while the second, Parts 4 to 7, describes the technology, the satellite data systems, and the models which will enable man to comprehend the motions and properties of the atmosphere on a global basis well enough to begin to make the long-term forecasts.

The problem of measuring such simple variables as temperature, pressure, and water vapor content at a certain point in the atmosphere remotely from an orbiting satellite has yet to be completely solved. Part 7 contains a discussion of problems of this nature together with a description of the French EOLE weather satellite system by Professor Pierre Morel of the University of Paris.

The 18 articles in this book cover a wide range of topics and represent the thinking and research of the individual authors. This book is not a text in meteorology, nor is it a comprehensive design of a weather forecasting system, but rather its aim is to present an overall view of the exciting possibilities as well as the technical and political problems involved in bringing about the revolution in weather prediction.

The editors wish to thank the 16 authors who gave the initial lectures and who gave freely of their time and interest to the sometimes difficult job of transforming the spoken word of a lecture to the written word of an article for a book. We are also grateful to the Department of Engineering of Stanford University for their generous support of the Space Systems Engineering course within which this book had its beginnings and grew to maturity. We also wish to thank Wendy Meara, Jan Jeffery, Betty Griffiths, Mary Beard, and Sally Burns for their advice and interest in the typing and preparation of the manuscript.

Bruce Lusignan
John Kiely

Contents

Acronyms, Titles, and Unit Abbreviations

APT	Automatic Picture Transmission *Camera systems on board TIROS and other meteorological satellites*
ATS	Applications Technology Satellites *A series of multipurpose research satellites*
AVCS	Advanced Vidicon Camera System *Used first on TOS*
BUV	Backscatter Ultraviolet Spectrometer
CDA	Command and Data Acquisition Station (*TIROS*)
COMSAT	*An early Communications Satellite Project which developed into SYNCOM* (*Part 4, Rosen*)
COSPAR	Committee on Space Research
CRT	Cathode Ray Tube
dB	Decibel
Early Bird	*A spin stabilized synchronous communications satellite in an equitorial orbit*
ekW	Electrical kilowatt
EOLE	*A French weather data system using free floating constant level balloons and a tracking satellite* (*similar to the U.S. GHOST system*)
ESSA	Environmental Science Services Administration. Washington, D.C.

ETS	Educational Television Satellite
eV	Electronvolt
GARP	Global Atmospheric Research Program
GHOST	Global Horizontal Sounding Technique *A balloon satellite data system sponsored by the U.S. Weather Bureau*
TROMEX GLOMEX	Global Meteorological Experiments
HRIR	High Resolution Infrared Radiometer
Hz	Hertz (cycles per second)
ICAU	A treaty for International Commercial Aircraft Operations
ICSU	International Council of Scientific Unions
IR	Infrared *Radiation with wavelengths just longer than visible light*
km	Kilometer
kW	Kilowatt
LARC	*A computer used at the Lawrence Radiation Laboratory* (*Part 6, Leith*)
LIDAR	Laser Radar *An instrument capable of measuring the radiation backscattered from a ruby laser beam* (*Part 7, Ligda*)
MHz	Megahertz
mb	Millibar
MRIR	Medium Resolution Infrared Radiometer
NASA	National Aeronautics and Space Administration
NCAR	The National Center for Atmospheric Research
NESC	National Environment Satellite Center in Suitland, Maryland

Nimbus	*A meteorological observatory spacecraft (a successor to the TIROS/TOS series)*
NOMAD	*A Navy Buoy anchored in the Gulf of Mexico used for gathering and transmitting meteorological data*
nmi	Nautical miles
OAO	Orbiting Astronomical Observatory
OMEGA	*A U.S. Navy navigational service*
RTG	Radioisotope Thermoelectric Generator (*SNAP-19*)
SIRS	Satellite Infrared Spectrometer
SNAP	*A series of nuclear thermoelectric generators for satellite power supplies*
Solomon STRETCH	*Computers used with the numerical models of the atmosphere*
SPINMAP	Stanford Proposal for an International Network for Meteorological Analysis and Prediction
SSCC	Spin-Scan Cloud Camera
SYNCOM	A Spin Stabilized Synchronous Communication Satellite
TIREC	TIROS Ice Reconaissance Program
TIROS	*An early weather satellite system*
TOS	TIROS Operational System
WMO	World Meteorological Organization (*An agency of the United Nations*)
WWW	The World Weather Watch

PART 1

introduction

THE weather affects all aspects of man's life. It determines when farmers plant and harvest their crops; it affects the price a housewife pays for fruits and vegetables; it determines what route an ocean liner or an airplane should take between cities; it influences the timing of a manned space shot from Cape Kennedy; it determines whether we take an umbrella or an overcoat to work. Fuel companies must decide whether a coming winter will be harsh or mild to estimate the size of their coal and fuel-oil reserves. Construction companies, picnickers, field generals, farmers cutting hay, and brides-to-be would all very much like to know whether it will rain next Tuesday or two weeks from today.

Hence, for thousands of years man has been trying with every means at his disposal to predict, change, and cajole the moving masses of air and moisture which make up the atmosphere. But for all these years the movement of storms and the large-scale energy sources and sinks of the atmosphere have remained a mystery.

Today, however, we are on the threshold of a new era when global satellite and balloon data systems together with sophisticated atmospheric models and high-speed computers will enable man to begin to understand the complex motions and energies of the atmosphere and hence to begin to make accurate long-range weather predictions. Within a decade it should be possible to make 10-to-14-day weather forecasts with an accuracy greater than that of the 2-to-3-day forecasts we now receive. The following articles attempt to describe various facets of this new era.

The word "meteorology" will come up frequently in this book. Meteorology as we use the term is concerned with the physics, chemistry, and dynamics of the atmosphere and with its effects on the oceans, the earth's surface, and life in general. It assumes a physical understanding of the atmosphere, and it strives toward accurate prediction and eventual control of the atmospheric environment.

In this book meteorology is viewed primarily from the standpoint of weather prediction and its supporting research programs. Bounded by the ocean and solid earth below and by the ionosphere above, the "meteorological atmosphere" considered here extends to about 50 miles above the earth's surface.

One of the most troublesome characteristics of storms and high-and low-pressure areas is that they move over large areas in relatively short periods of time. A certain mass of air may travel around the globe two, three, or even four times in a period of two weeks. Now for several centuries men have been able to measure the basic meteorological variables of pressure, temperature, and water-vapor content at the surface of the earth. Such measurements have of necessity been taken in the scattered centers of population. There have been very few measurements taken in uninhabited areas and over the three quarters of the earth covered by oceans, and until quite recently none in the important upper levels of the atmosphere. It has been estimated that less than 20 percent of the earth's surface is adequately covered by upper-air observing stations, and unless this situation is corrected, it is hopeless to expect a substantial advancement in weather forecasting. Meteorologists have been making weather forecasts with data which are marginally acceptable for short-range forecasts but which would be seriously inadequate for longer-range predictions.

In addition to this lack of data meteorologists have had only an imperfect understanding of the physics of the atmosphere. The atmosphere is basically an initial state problem; that is, if one knew the initial temperature, pressure, and velocities of the air over all the earth, then by solving a certain set of differential equations it should be possible to predict the entire future pattern of air movement. To a certain extent this can now be done with the atmospheric models available (Part 6). However, there are an enormous number of complexities (such as the turbulent energy exchange between large- and small-scale weather systems) which quickly make the predictions of the model invalid.

The goal of the next decade is to remedy these two obstacles; to set up a global data-collection system and to perfect our physical understanding of the atmosphere. There are numerous other problems, such as communication links, the optimum form for presenting the data, and rapid preparation and dissemination of local forecasts to individual users, but these require wise administrative decisions rather than the more lengthy development of new techniques.

It is generally accepted that for weather predictions in excess of a few days, the earth's atmosphere must be treated as a single dynamic system. At present, numerical forecasts are prepared routinely for periods of three to four days, and for areas covering about one-third of the earth. To extend forecasts to longer periods or to larger areas requires knowledge of the initial state of the atmosphere on a global or at least hemispheric scale. Otherwise, unknown disturbances will migrate into the prediction areas and contaminate the forecast.

Ultimately it is likely that the global meteorological network will consist of a system of satellites to gather data throughout the atmosphere remotely, tracking stations, and one or more large meteorological centers which will use the atmospheric models and the largest computers available to analyze the satellite data and to prepare the predictions. Local weather forecasts for periods ranging from 6 hours to 14 days could then be sent to the various national or regional distribution centers.

For the immediate future, however, it does not appear feasible to measure temperature, pressure, wind velocity, or water-vapor content remotely from satellites. The various technologies have been proposed and widely discussed, but it will be several years before such systems are operable. All the systems now being built involve some intermediate network present in the atmosphere to collect data and transmit it either directly to earth or to monitoring satellites. The French EOLE system and the United States GHOST systems both propose the use of light-weight free-floating constant-level balloons. Part 7 contains descriptions of these systems by Pierre Morel and Stanley Ruttenberg.

In all the numerical models now in use the atmosphere is divided up into boxes and data is read in at each of the corners or grid points. The model uses a numerical integration scheme to advance the variables at each grid point through one time step. This basic process is repeated over and over again to predict a future state of the atmosphere. The choice of the box or mesh size and the time step are two of the most important parameters of the entire network.

The mesh size determines the size of atmospheric phenomena which may be dealt with in the model. For instance, with a box of 1000 km on a side one could not hope to predict the occurrence of any storms whose dimensions were less than 1000 km because the model receives data at only one point in every box—every 1000 km. Hence the weather maps produced by the model might predict a large low-pressure area or a hurricane but they would never be able to predict a tornado or a thunderstorm.

From this viewpoint it is desirable to have the smallest possible grid spacing. Ideally this might be only a few kilometers. However, the amount of data and the amount of computer time required to advance the variables through one time step increase rapidly with the number of grid points.

At present, for a global model, a grid spacing of 300 to 500 km is at the upper limit of computer capabilities. This figure will of course become smaller as larger and faster machines are available. The time step for each integration affects, among other things, the accuracy of the predicted states. At present, for the computer calculation to run at about 10 times faster than real time (which is a lower limit if the model is to make useable predictions) a time step of about 10 minutes is generally used.

Most of the work now going on is devoted to developing hardware, building systems, and testing systems. The pioneer TIROS and Nimbus satellite systems, in addition to sending back a wealth of cloud-cover pictures, have been testing many of the cameras and sensors which will ultimately be used on the data satellites. The development of the constant-level balloons and the ultra-lightweight electronic circuitry (to eliminate the danger of collisions with high flying aircraft) is essentially complete. However, as mentioned earlier, there is a great deal of work yet to be done on the remote sensors to measure temperature, pressure, and wind velocities from orbiting satellites.

The global weather-prediction network is still in its infancy, but it is a healthy child and growing rapidly. The articles which follow describe its current appearance and indicate in some detail the directions of its future development.

PART 2

goals