Developments in Atmospheric Science 1

F. VERNIANI

Structure and Dynamics of the Upper Atmosphere

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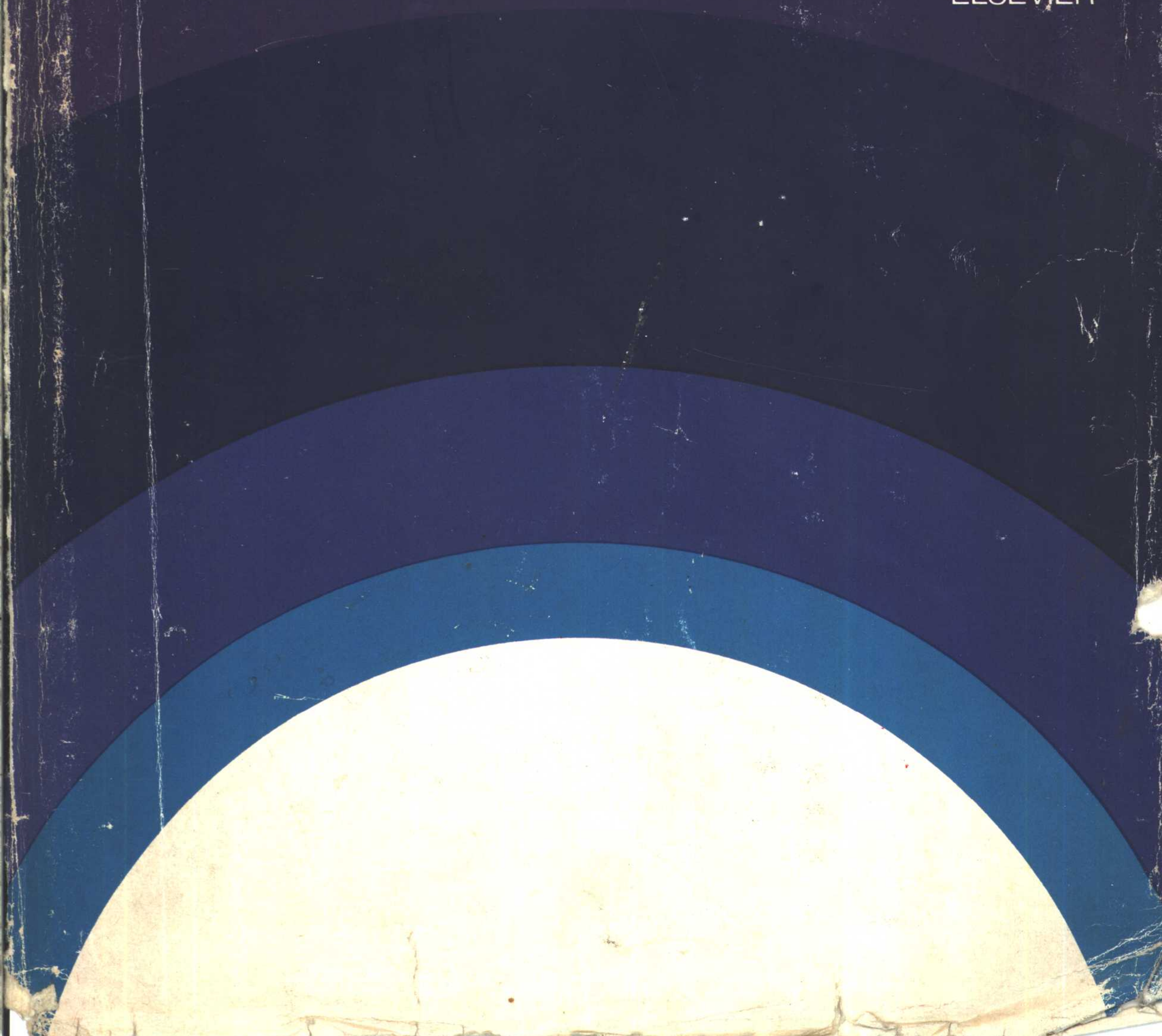

Developments in Atmospheric Science, 1

STRUCTURE AND DYNAMICS OF THE UPPER ATMOSPHERE

Proceedings of the 2nd Course of the International School of Atmospheric Physics, "Ettore Majorana" Centre for Scientific Culture, held in Erice (Italy), 13–27 June, 1971

edited by

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Foreword

Thanks to the initiative of Professor A. Zichichi, Director of the "Ettore Majorana" Centre for Scientific Culture, it was possible to set up the International School of Atmospheric Physics and hold its first Course in June 1970. This was followed in June 1971 by a second Course on "Structure and Dynamics of the Upper Atmosphere", that was sponsored by the Italian National Research Council, the Ministry for Public Education, the Ministry for Scientific and Technological Research and the Sicilian Regional Government.

The Course aimed at providing both a comprehensive survey of basic topics like photochemical atmosphere models, tides and gravity waves in the atmosphere, the structure of the various ionospheric regions, the source of atmospheric electrification and a review of some more specialized topics of great current interest and intrinsic importance, such as global observations of the upper atmosphere with meteorological sounding rockets and with remote sensing techniques from satellites, composition studies in the thermosphere by means of mass spectrometers, optical techniques for temperature determination, and radio meteor studies of winds and turbulence in the upper atmosphere.

The Course included ten cycles of lectures and ten seminars for a total of 50 hours. It was attended by 52 participants coming from 17 countries, namely: Argentina, Australia, Belgium, France, Germany, Hong-Kong, India, Israel, Italy, The Netherlands, Norway, Poland, Spain, Sweden, Turkey, The United Kingdom and The United States.

This volume includes most of the material that was presented and discussed at Erice, so I hope the readers will enjoy the book as much as the participants enjoyed attending lectures, seminars and discussions.

Putting together this book was quite a time-consuming task. Mrs. Angelica Ciampi helped me in the revision of the manuscripts, as far as the English language was concerned, Mrs. Maria Teresa Tibaldi typed most of the final typescripts and checked figures and references together with Mrs. Renata Malossi. I wish to thank them very warmly for their invaluable help. Mrs. Tibaldi also acted as secretary of the School and I am grateful to her for the intelligent cooperation in the various stages of the course organization.

Finally, I should like to express my gratitude to Professor Zichichi, Director of the "E. Majorana" Centre, for giving me the possibility to organize the International School of Atmospheric Physics.

Bologna, July 1972 F. VERNIANI

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Developments in Atmospheric Science, 1

Structure and Dynamics of the Upper Atmosphere

Contents

Opening Speech:
IMPACT OF MODERN TECHNOLOGY ON THE ATMOSPHERIC SCIENCES

GIORGIO FIOCCO

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I am going to restrict myself to some opening remarks that will be neither too specific nor too technical. I have chosen a title which is vague enough, perhaps a little banal, but which I hope describes some general aspects of the work in the atmospheric sciences.

The impact of technology means that a very substantial level of resources is now available to disciplines, some of which, only one or two decades ago, utilized rather simple instrumentation and, often, empirical methods of analysis. On the other hand, it may also mean that a very large part of those resources is used in solving technical problems, when a certain amount of ingenuity in the definition of the scientific aspects of the problem might have saved time and effort.

In our culture it is often not clear whether the offer of a product or a service is in response to a need, or whether demand is being artificially created. Judging the validity of scientific research is not simple. A criterion should be based on a reasonable compromise among originality, usefulness and cost. This does not mean that a piece of work should be trivial or useless as long as it is expensive. Rather the opposite! As far as usefulness goes, the atmospheric sciences come out rather honourably.

I assume that many of those attending this school are, like myself, from Western Europe. Since for the last several years most of the scientific effort has been carried out in the U.S. and the U.S.S.R., the choice among originality, usefulness and cost for the European scientist has been, and still is, more limited. With low cost being a sort of boundary condition, let us try at least to be original and useful.

In the atmospheric sciences, as in other sciences that have emerged from the stage of taxonomy, results are obtained by a competition between (analytic, numerical) models and experiments. One practical example is weather prediction. Numerical models are developed by digital computers; data are collected by a worldwide network, and now also by satellites. At least twice a day several weather bureaus turn out forecasts, the validity of which is tested by a multitude of users. Originality may not be too high, and individual contributions may disappear in much routine work, but the usefulness is great and the cost is high.

Although the mathematical and physical sophistication of the model utilized is not great, the organization necessary to carry out the scheme is very complex.

It appears, by the way, that the prediction of an experienced forecaster is not much worse than that carried out by the computer. On the basis of the preliminary computer analysis, the forecaster can make an even better prediction. Thus, one wonders whether some aspects of this extremely laborous computation could be replaced either by more powerful mathematical techniques or by better understanding of how the human mind works.

In practice, now, progress in weather forecasting is closely related to progress in computers. But notice that the cost of a commercially available, advanced computer of medium size can be 10^7\$ or a monthly rental of approximately $2 \cdot 10^5$\$. After considering, for example, that a reduction by a factor of 2 in the size of the computational grid involves an increase by a factor close to 2^4 in the computer size, it becomes obvious that many of the problems in the atmospheric sciences cannot be solved by sheer strength of computation in the foreseeable future. In this spiral of high costs, the question of international cooperation also becomes essential. At the moment there are more than ten agencies in the world that carry out detailed weather predictions. Several of these are in Europe; in this case there is an evident overlap even for short-term predictions. Therefore, the establishment of common centers is becoming mandatory. Of course, the establishment of large facilities should make global weather predictions possible and allow some of the available computer time to be dedicated to research. Thus, it should be possible to study in detail, for instance, the kind of problems that Professors Hesstvedt and Lindzen discuss in their contributions.

When global predictions are considered, one of the difficulties is lack of adequate data, especially for the Southern hemisphere, the oceans, and the less populated areas. Satellites perform very well as far as global coverage is concerned. The instruments carried by the present generation of meteorological satellites permit: (1) Continuous observation of the earth's cloud cover; (2) Infrared sounding of the atmosphere to allow quantitative deviation of vertical temperature profiles; (3) Infrared scanning to study the earth's radiative budget.

With this basic instrumentation, aided also by rocket campaigns, a fairly complete description of the mesospheric and stratospheric meteorology has emerged. The measurements at tropospheric levels are more difficult to interpret. Synoptic observations of cloud formations are of interest to the weather forecaster. They permit, for instance, the early detection of severe storms, especially since the area observed may not be adequately covered by ground stations. This information is of a qualitative nature and some scientists have tended to de-emphasize its importance. Cloud movements are, of course, an aid to the measurement of wind velocity, even though doubts may remain in some cases as to whether clouds move at the same velocity as the wind. Cloud heights, also, are not measured directly.

As we shall see in Dr. Nordberg's lectures, the measurement of atmospheric temperature profiles from the CO_2 15-μ emission band was one of the important results. The contributions to the total spectral density measured on the satellite come from different height levels, so that for each portion of the spectrum a different weighting function exists. The problem of data reduction involves the inversion of raw data—an operation which can be ambiguous. The contribution of clouds and aerosols sets a limit to the present accuracy of the technique. The problem arises of making observations through holes in clouds, or making use of different spectral regions.

The possibility of detecting minor atmospheric constituents is still at the experimental stage. This is also of importance to the circulation of pollutants and other ecological problems. I suspect that a good deal of work is still necessary in order to develop adequate sensors and to prepare the atmospheric models necessary for the interpretation of data. The study of more complex compounds, such as the polymers of water, clusters and aerosols, is also attracting great interest. Satellites can be used to communicate with buoys, to track floating balloons, and to relay data from ground stations and data centers. But just to give some idea about cost: an estimate for a satellite including the development of the sensors, ground stations, etc., may run over $5 \cdot 10^7$\$.

A rapid survey like this should not neglect the use of the manned orbiting laboratory, especially with regard to the testing of particularly complex instrumentation: but here, the question of costs may really get out of hand.

Last, but not least, I should call your attention to the important work that can be done with relatively inexpensive ground-based instruments, such as the meteor radars. In this connection, I will give a seminar on the laser as a tool for atmospheric studies. This is, of course, only one of the main tools that the atmospheric scientist has at his disposal today.

Let us remember that knowledge about the earth's atmosphere is important in many facets of human activity, from strictly economic ones to more speculative ones. For instance, exact geodetic surveys carried out from satellites equipped with corner reflectors, or from the moon itself, are limited by our knowledge of the refractive index of air. Fluctuations in air properties should be better known if accuracies of the order of a few cm, which are technically feasible, are to be achieved. I do not have to expound further on the vast importance of accurate climatological studies and weather predictions. Therefore, having established proper priorities, it is clear that the field of atmospheric study is not only scientifically valid, but also of great practical relevance.

PHOTOCHEMICAL ATMOSPHERE MODELS

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SUMMARY

The first section describes how a photochemical atmosphere model is built up. Definitions are given of basic concepts such as reaction and dissociation rate coefficients and lifetimes. The pure oxygen atmosphere model is used as an example. The necessity of considering atmospheric transport together with chemistry is emphasized.

In section 2 the principles given in section 1 are applied to an oxygen–hydrogen model in order to study the composition of the upper stratosphere and lower mesosphere. The computation of ozone is in fair agreement with observational dat and turns out to be of particular interest.

1. INTRODUCTION TO PHOTOCHEMICAL ATMOSPHERE MODELS

An efficient study of the upper atmosphere depends, to a large extent, upon our knowledge of its chemical composition. During the last few years a series of measurements has provided us with useful information, but the situation is still far from satisfactory, even for such important trace components as atomic oxygen, ozone, nitric oxide and water vapor.

In addition to experimental results, useful information can be obtained from photochemical models. In such models, one tries to simulate the chemistry of the real atmosphere by specifying a set of chemical reactions which are believed to be important for the problem to be studied. In the more recent models, the effect of vertical air transport has been included as well. There are two kinds of reactions:

(a) chemical reactions, e.g.:

$$O + O + M \rightarrow O_2 + M \qquad k_1 = 1.5 \cdot 10^{-34} \exp(1.4/RT) \mathrm{cm^6 sec^{-1}} \qquad (1)$$

$$O + O_2 + M \rightarrow O_3 + M \qquad k_2 = 5.8 \cdot 10^{-35} \exp(1.5/RT) \mathrm{cm^6 sec^{-1}} \qquad (2)$$

$$O + O_3 \rightarrow 2O_2 \qquad k_3 = 3.3 \cdot 10^{-11} \exp(-4.2/RT) \mathrm{cm^3 sec^{-1}} \qquad (3)$$