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REVIEWS

Numerical Prediction and Dynamic Meteorology, 2nd Edn. By G. J. HALTINER and R. T. WILLIAMS. Wiley, 1980. 477 pp. £26.90.

This book is best described as a textbook of modern numerical weather-prediction models. The title places numerical prediction before dynamic meteorology, and this is a fair reflection of the book's emphasis. The structure of the text very much follows the organization of prediction models, and its strengths and weaknesses as a book on dynamic meteorology reflect the current state of the art in modelling. Most of the book is concerned with describing techniques as used now, rather than the historical development that led to the present design of models. It is thus a very useful reference for workers coming into the subject who have to work with an established model, but less useful for those who wish to relate the model design to new developments in dynamical theory. Since, however, there are other books on dynamical meteorology available, but no comparable easily available textbook that describes models, the authors have clearly chosen to give priority to filling an obvious gap. The authors are both based at the Naval Postgraduate School in Monterey, California, and most of their examples are taken from models developed in the USA; in particular that at UCLA. This may give the impression that model-development work is more concentrated in the USA than is in fact the case. However, this is perhaps a criticism more appropriate to a review article than a textbook.

The authors start by describing the equations of motion in Chapter 1. The treatment is very elementary and most of it would serve as a good introduction to the equations of any branch of fluid dynamics, since the scale analysis that defines the problem to be solved as meteorology is postponed to Chapter 3. Thus the introduction of the hydrostatic assumption in Section 1.6 seems premature, it would have been better treated along with the rest of the scale analysis. This perhaps reflects a bias inevitable in workers concerned with large-scale models where the hydrostatic approximation is usually the only one made. The equations of motion for a hydrostatic fluid are regarded as the fundamental ones, and other approximate systems are only used for specialized theoretical studies. However, the use of non-hydrostatic models to describe small-scale weather systems is increasing, and a book with this title should not restrict its scope to models describing only large scales.

Chapter 1 continues with a derivation of the equations in spherical coordinates and on various map projections. It is again unfortunate that some scale analysis is swept under the carpet in Section 1.7. Experienced meteorologists would not need to read this chapter in any case and newcomers would benefit from a fuller explanation of why several terms have been ignored. A detailed description of the different vertical coordinate systems used is followed by an introduction to the energy equations. This is very important, as understanding the nature of the energy transfers in the atmosphere is essential to any knowledge of the dynamics, and correct representation of them in numerical models is necessary if realistic solutions are to be obtained. The chapter concludes with derivations of equations for the vorticity and divergence.

Before describing the scale analysis specializes the equations to atmospheric motions, the authors give an elementary description of some types of wave motion that can be represented by the equations. This is useful material for undergraduate-level students and for those coming into meteorology from other subjects. There is also a table at the beginning showing some typical scales of atmospheric motion which

would have been better placed in Chapter 3 with the scale analysis. Such tables can easily be misused if they are read separately. The chapter concludes with a discussion of the geostrophic adjustment process. This again would be better placed after the scale analysis which motivates the search for quasi-geostrophic solutions of the governing equations.

Chapter 3 presents the scale analysis for atmospheric motions. Most of the descrition applies to middle and high latitudes where the constraints imposed by rapid rotation are very strong. The concepts are first described for the shallow-water equations used in Chapter 2. Most of the derivation is systematic and elementary, but a few technical terms are used without definition; for instance 'baroclinic' on pages 54 and 59. After describing the analysis for mid-latitude weather systems, a brief description is given of an analysis for equatorial regions and for global scale motions. Neither of these sections is very satisfactory since it is not clear what observed phenomena are being discussed. In the tropics it is necessary to list the types of phenomena observed, and describe the scaling appropriate to each. There must be doubt as to whether it is sensible to discuss planetary-scale waves as a separate physical phenomenon at all; they may sometimes be an artefact of decompositions of atmospheric data into spherical harmonics. The chapter concludes with a statement of the balanced system of equations, which describe only motions selected by the scale analysis as important for meteorological systems. It would have been logical if the rest of the discussion of reduced systems of equations resulting from the scale analysis were placed here instead of in Chapter 7. It is also a pity that the scaling appropriate to smaller scale systems such as fronts and jet streams could not be discussed.

Chapter 4 builds on the scale analysis and describes more types of wave motions and also the instabilities that are believed to give rise to such phenomena as cyclones. Profiles of maximum growth rate are shown, and the scales for which this occurs related to the scale of observed disturbances. The energetics of unstable waves is analysed in detail, which is very helpful for an understanding of the dynamics of the finite-amplitude systems and compensates to some extent for the lack of proper nonlinear solutions. This chapter is a very readable introduction to the concepts of barotropic and baroclinic instability, and also equatorial waves.

This chapter conludes most of the treatment of atmospheric dynamics in the book. It is an adequate introduction for those whose primary interest is working with existing models. It would not be suitable as an introduction for those interested in the dynamics of particular observed weather systems, since the bias is very much towards knowledge required for modelling large-scale systems. There is very little discussion of actual weather patterns; considerable knowledge appears to be taken for granted. This would make the text difficult to follow for non-meteorologists taking up the subject.

Chapters 5–7 describe the basic numerical techniques used to solve the hydrostatic primitive equations. Chapter 5 gives an elementary introduction to numerical techniques, including methods of analysing their stability. The advection and wave equations are treated first, and standard finite-difference schemes for approximating them are analysed. This section is suitable as an introduction for numerical analysts as well as meteorologists, since the matrix method, Von Neumann's method and the energy method of analysis are all described and illustrated in simple examples. Methods of solving elliptic equations are then described in equally practical terms. The last part of Chapter 5 concerns the stability of approximations to nonlinear equations. This is quite adequate as an introduction to current knowledge in

meteorology, but falls far short of what is required for rigorous stability analysis for such equations. The current practice in weather-prediction models is to enforce discrete analogues to global conservation properties satisfied by the continuous equations, and this is illustrated by several examples. However the questions of whether solutions to the continuous equations exist, and, if so, how discrete approximations can be proved to converge to them is not mentioned. This is a weakness in current knowledge, not in the content of this book.

Chapter 6 describes Galerkin methods for approximating (mostly two-dimensional) equations, and applies in particular to the spectral and finite-element methods. The transform technique developed by Orszag and Machenhauer is explained as the essential step in making the spectral method economical in high-resolution models. Only a very brief description of the simplest forms of finite-element methods is given.

Chapter 7 completes the description of numerical methods by describing the remaining tasks that have to be carried out in designing forecast models. It begins by reviewing some simplified systems of equations, which would have been better dealt with in Chapter 3. The important constraints of ensuring consistency of the conversions between kinetic and potential energy is discussed, and the effect on the choice of vertical differencing thus treated. The questions of how to arrange the different variables on a grid, how to design grids on a sphere and how to choose boundary conditions for a limited area model are treated. In the latter case it is known that the equations usually solved are ill-posed with any set of local boundary conditions, and various *ad hoc* procedures are described. The chapter ends with a very cursory mention of the upper boundary condition and mountain effects. Both these are important subjects of current research and deserve more than the two pages devoted to them.

Chapters 8–10 deal with what numerical modellers call the 'physics'. These include ways of representing effects that cannot be treated properly with current model resolutions, and treatment of the forcing terms in the equations. The basic theory of the atmospheric boundary layer is described. In numerical models the resulting stresses are usually represented by eddy flux terms with coefficients calculated from experimental data. It is therefore difficult to see why the use of formulae expressed to four significant figures as on page 292 is justified. The second part of Chapter 8 is mostly a technically detailed description of some schemes actually used. In view of the simple and general treatment of topics earlier in the book, this seems unnecessary.

Chapter 9 describes moist processes. The reason why convection has to be specially treated is not explained properly on page 312. The early sections describe the principles by which the effect of sub-grid-scale convection can be modelled, but the latter sections are very detailed descriptions of a few current schemes. As in Chapter 8, this seems unnecessary, many of the schemes described having been modified or superseded. A newcomer to the field would need to read the first few sections of the chapter for basic techniques and then up-to-date review papers for detailed technical information.

Much of the same criticism applies to Chapter 10 on radiation. Though the chapter only has 15 pages, they consist almost entirely of equations. The basic introductory material is included, but confused with technical detail throughout.

The remaining chapters deal respectively with objective analysis and initialization, ocean modelling, and a general chapter on current forecasting skill. Chapter 11, on analysis, introduces the standard techniques for interpolating an irregularly spaced set of observations to a grid, allowing for expected observational errors. The resulting

pressure and wind fields may well not satisfy the constraints suggested by the scale analysis of Chapter 3, and so must be modified. Techniques for doing so are described. These are mostly based on linear theory and are not entirely satisfactory. The last section on smoothing would have been better treated with basic numerical techniques in Chapter 5.

Chapter 12 gives a brief introduction to the principles of ocean modelling. The two separate areas of modelling the ocean circulation and of modelling the evolution of sea surface temperature using simple mixed-layer models are described.

The last chapter is a general review of the state of the art in numerical forecasting as in 1980. This section, it is to be hoped, will date rapidly as the standard is improved. The question of predictability is discussed. Perhaps the main omission here is the fact that initial data for forecasts can be improved by improving the first guess taken from the previous forecast, and so improvements to forecast models will also improve the initial data. This may allow a more optimistic view to be taken.

In summary, though this book has some weaknesses, these are mostly those of current models; the input of knowledge of atmospheric dynamics is confined to writing down the Navier–Stokes equations, and many physical processes are handled by very crude *ad hoc* methods. There is a clear lack of rigorous theory behind much existing practice, but the authors of this book cannot be blamed for that. The book does the important job of describing the state of the art very well, it is an excellent introduction to large-scale forecast models, and incidentally to numerical methods for partial differential equations.

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Multiphase Science & Technology, Volume 1. Edited by G. F. HEWITT, J. M. DELHAYE and N. ZUBER. McGraw-Hill, 1982. 513 pp. $49.75.

Multiphase flow as a subject for research requires knowledge from many disciplines, notably physics, mathematics, physical chemistry. There are many symposia proceedings available but textbooks are rare. This is perhaps not surprising if one realizes how broad the field is and how many abilities are needed to write about it.

The editors of the series (of which the present volume is the first), all three of them distinguished researchers in multiphase flow, asked specialists to write 'authoritative overviews of important areas in multiphase systems'. They aim, not so much at the specialist, but rather at the nonspecialist reader and the articles are supposed therefore to have a tutorial aspect. This volume has four chapters:

(1) Spray cooling of hot surfaces, 99 pages, by L. Bolle and J. C. Moureau (Université Catholique de Louvain, Belgium);

(2) The spherical droplet in gaseous carrier streams: Review and Synthesis, 180 pages, by George Gyarmathy (BBC Brown Boveri & Co. Ltd., Baden, Switzerland);

(3) Boiling in multicomponent fluids, 105 pages, by R. A. W. Shock (Harwell, Didcot, Oxon U.K.);

(4) Contact angles, 105 pages, by Jacques Chappuis (Laboratoire de Technologie des Surfaces, Ecole Centrale de Lyon, Ecully, France).

As compared with the *Annual Reviews of Fluid Mechanics*, well known to readers of this journal, the articles are much longer, which permits an author to adopt a slow pace in agreement with the needs of a tutorial presentation. Some comments on the four chapters follow.

The authors of chapter 1 emphasize the rôle of the atomizer and give a useful discussion of various types used in practice. When drops impinge on a hot surface

for example on the run-out table of a hot strip mill, the heat transferred from the hot surface exceeds a million Watt per m^2 at temperature differences of several thousands of degrees centigrade.

The associated heat transfer coefficients are huge and there is difficulty in understanding how this transfer occurs. Theories assuming that a vapour film appears when a drop reaches the vicinity of a hot plate cannot account for these observed heat transfer rates. Bolle & Moureau show that they can be explained if one assumes that during a fraction of the impact direct contact between liquid and hot plate takes place.

Associated with spray cooling is the following problem: A metal sample is rapidly cooled from a temperature of 1000 °C, say. Knowing the initial conditions and the time history of the temperature of a point near the surface, find the temperature and the heat flux at the surface. Bolle and Moureau call this 'the inverse heat conduction problem'.

In chapter 2, exceeding the others in length by almost a hundred pages, momentum, heat and mass transfer from a spherical droplet to a carrier gas are discussed in great detail. Droplet number densities are supposed to be high enough to have a significant effect on the temperature of the gas. The author attempts completeness and includes everything in his discussion – surface tension, relaxation, evaporation, compressibility. Laudable as this is, in some places it is a disadvantage because the text is heavily loaded with dimensionless numbers, some of which are familiar and others which are not, like for example the Stodola number which aerodynamicists would write as $(\text{Mach} \times \text{Knudsen})^{-1}$, and there is a serious risk of a reader losing track of the argument.

In chapter 3 boiling in multicomponent fluids is discussed. Boiling of mixtures is important in the chemical and petroleum industries. The home of the subject is therefore chemical engineering and it is no surprise that most of the references come from that field. Nevertheless reference to the important work by Plesset and his associates would have been in order, reviewed for example by M. S. Plesset & A. Prosperetti in *Annual Review of Fluid Mechanics*, vol. 9, 1977. To my taste this chapter is too descriptive and not sufficiently aimed at providing an understanding.

Chapter 4 is about surface tension and contact angles, occurring for instance when a liquid drop sits on a solid in equilibrium position. An entertaining and informative account of surface phenomena is given. I learned, for example, that solids have a surface tension which can be measured. Another interesting experiment, discussed in this chapter, is the one in which it is shown that a sessile drop exerts a vertical force on a solid, which is used as experimental evidence of Young's vectorial model. Strange enough, the author avoids vector notation, although this might have considerably simplified the description of forces and such things as surface curvature.

The author restricts himself to contact lines in static equilibrium situations. Maybe we can learn from another volume in the series what happens in the notoriously difficult case of moving contact lines?

In summary, certainly in chapters 1 and 4 and to a lesser extent in chapters 2 and 3 the editors have succeeded in their attempt to get presentations which may give 'the nonspecialist reader an up-to-date idea of the present stage of development'.

L. VAN WIJNGAARDEN