Atmospheric Modeling, Data Assimilation, and Predictability

Eugenia Kalnay, 2002, 341pp., $45.00, paperbound, Cambridge University Press, ISBN 0-521-79629-6

Numerical weather prediction (NWP) now provides major guidance in our daily weather forecast. The accuracy of NWP models has improved steadily since the first successful experiment made by Charney, Fj∅rtoft and von Neuman (1950). During the past 50 years, a large number of technical papers and reports have been devoted to NWP, but the number of textbooks dealing with the subject has been very small, the latest being the 1980 book by Haltiner & Williams, which was dedicated to descriptions of the atmospheric dynamics and numerical methods for atmospheric modeling. However, in the intervening years much impressive progress has been made in all aspects of NWP, including the success in model initialization and ensemble forecasts. Eugenia Kalnay's recent book covers for the first time in the long history of NWP, not only methods for numerical modeling, but also the important related areas of data assimilation and predictability. It incorporates all aspects of environmental computer modeling including an historical overview of NWP, equations of motion and their approximations, a modern description of the methods to determine the initial conditions using weather observations and a clear discussion of chaos in dynamic systems and how these concepts can be applied to atmospheric and oceanic systems. The book is written in a textbook style. Yet it is also a useful reference for the scientists in atmospheric and other associated fields.

The book begins with an introductory historic overview, tracing the development of NWP from the first success with ENIAC integrations up to the present ensemble forecasting system on modern supercomputers, and ending up with a glance into future developments. The author explains with great enthusiasm how rapid progress of NWP was achieved at U.S. National Centers for Environmental Prediction (NCEP) during the last half-century. She provides an overview of the major developments and achievements and presents a clear and broad landscape of NWP and its basic components and concepts. A solid foundation in all aspects of NWP is described in detail in subsequent chapters.

Chapter 2 is a concise but complete presentation of the basic equations used for NWP. Through simple examples, the types of waves which can occur with different levels of simplification and the various filtering approximations are discussed. Chapter 3 is equally thorough in covering the numerical techniques used to construct forecast models. Traditional discretization schemes and spectral methods are introduced, as well as staggered grid structures, and recently developed semi-Lagrangian and finite volume schemes.

Chapter 4 gives a short summary of physical parameterization methods, with references for more details. In contrast, Chapter 5 on data assimilation is the longest in the book. Early empirical methods such as successive correction and nudging are described. By using simple examples, the least-square and Bayesian derivations of modern statistical methods are introduced. The relationship and differences between traditional optimal interpolation (OI) and current three-dimensional variational data assimilation (3DVAR) schemes are discussed. Advanced methods with evolving forecast error covariance as well as four-dimensional variational data assimilation (4DVAR) technique are covered, with a mention of current research activities in the ensemble Kalman filter. In addition, the methods for quality control of observations are also introduced with detailed discussion on their applications.

Chapter 6 on predictability is another highlight of the book, going from Lorenz's butterfly, through chaos in dynamic systems, to the development in modern ensemble forecasting systems. The fundamentals of predictability and the different ensemble forecasting methods are introduced. The role of the oceans in long-range forecasting and climate change is also included in the concluding sections.

The book forms a comprehensive text and reference work on modern NWP. The author's primary intention to make a textbook is clear in its effort to provide not only an introductory knowledge base, but also an application orientated component. In each chapter the emphasis is on clear and intuitive explanations of all the fundamental concepts, followed by a complete and sound development of the theory and applications. The book uses many simple graphical sketches that illustrate the important relations and definitions. Real examples and comprehensive discussion are usually presented after the concepts are introduced. For instance, an example of complex quality control is given after a comprehensive description of the scheme (Chapter 5). A method for coding and checking the tangent linear and the adjoint models is included in Appendix B. With all these features, the book achieves a commendable balance between comprehensiveness and readability.

Without any doubt, the overall text of the book is excellent for a complete graduate level NWP course. But, the benefit of the book is not limited only to NWP subjects. The reader will soon realize that each of the six chapters is self-contained. Thus, each chapter can be used as an independent text for an individual course in the related fields. For instance, Chapter 1 is complete in itself and forms a fundamental introduction to NWP. With use of few equations, it can be used as an introductory class for undergraduate students. Chapter 2 and 3 alone are useful for undergraduate and graduate level classes in numerical methods, applied mathematics, as well as environmental computer modeling. Chapter 5 provides adequate material for a complete class in earth system data assimilation. Chapter 6 is very suitable for any courses in predictability of weather and climate and chaos in dynamic systems.

Besides its function as a textbook, the book offers a unique reference for scientists in atmospheric and associated fields, especially for those who work on the data assimilation and predictability. Data assimilation was a minor and often neglected sub-discipline of NWP before the late of 1970s. However, it has become an active area since the early of 1980s, along with the maturity of the global observing system (GOS) and rapid development of satellite and other remotely sensed instruments. A book by Roger Delay published in 1991 marked the data assimilation as an independent science, but much progress and many new techniques have been made in both the operational and research community during the past ten years. It is difficult to make clear description of different techniques, taken from broad literature and technical report reviews (including internal office notes). Obviously, the author has done a creative job in this respect, and she uses only about 75 pages to summarize almost all new techniques we use now and should be working on in the future. In the meantime, she did not forget all the traditional simple methods that were used before. Strong links are drawn between the current data assimilation schemes (e.g., 3DVAR) and old techniques (e.g., OI). The similarity and differences between different methodologies are also presented clearly.

Compared with any recent papers and reports, Chapter 6 is an unprecedented summary on atmospheric predictability. It provides for the first time a complete overview on chaos in dynamic systems, predictability of weather climate systems and operational practice in ensemble forecasts.

Of course a book of this length cannot cover everything in depth; Chapter 4 leaves out details of physical parameterization. Fortunately, the reader will soon realize that the references contained in this chapter could lead them to further explore the details in this topic. Overall, there has been a very comprehensive citation in the whole text. The bibliography of the book runs over 44 pages: this makes the book is very informative.

The book has already been adopted for many graduate and undergraduate level courses in NWP, data assimilation, predictability as well as the applied mathematics around world. Up to now, about three years after this book was first published, it has been re-printed twice to fill the increasing needs from the educational and research community. It has also been translated into Chinese and published by China Meteorological Press in 2005.

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