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Chapter 1

Introductory Chapter: Understanding of Atmospheric Systems with Efficient Numerical Methods for Observation and Prediction

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http://dx.doi.org/10.5772/intechopen.82468

1. Introduction

In this book, advances in numerical methods for better understanding of atmospheric systems are introduced in eight chapters, with five chapters focusing on numerical weather prediction (NWP) and three chapters on observation. By using math to model the future state of the atmosphere, NWP relies upon observations to provide both initial and verification data so as to conduct and verify a forecast. In this sense, knowing the current state of the weather by various observations is as important as developing numerical models. Remote sensing techniques, which are crucial for observation on the occurrence and development of severe weather systems over data-sparse area, are considered as some of the best choices for global observation on atmospheric and ocean systems, e.g., tropical cyclones, clouds, dust storms, etc. Thus, Chapter 1 presents an efficient algorithm for tropical cyclone (TC) center determination by using texture and gradient of infrared remote sensing image from geostationary satellite. Because remote sensing approach faces dilemma in identifying atmospheric objects from its environment, a new polarization method is presented in Chapter 2 to solve this problem. Chapters 3–8 then attempt to enhance the performance of NWP models in prediction of atmospheric systems, by using radar remote sensing data (Chapter 3), spectral method (Chapter 4), parameterization schemes (Chapters 5, 6), and atmospheric chemistry models (Chapters 7, 8), which should be valuable for reference to researchers and forecasters in the field of NWP.

2. The advances of NWP

Before going into the details of the book, we need to make a brief introduction on the background of NWP and its relation with each of the chapters. The advances of NWP in the past were based on the achievements in the development of theoretical principles of meteorology and computational mathematics. These achievements enable us today to create powerful systems to perform high-quality forecast of atmospheric systems by using atmospheric datasets in high spatial-temporal resolution. The first breakthrough in NWP started at the end of the 1940s, when Charney et al. [1] got the first numerical simulation by solving the barotropic vorticity equation over a single layer of the atmosphere. Then, in 1954, the first operational forecast was conducted in Stockholm by Rossby et al. by using barotropic equation. Later models employed more complete equations for atmospheric dynamics and thermodynamics to improve the performance of NWP models [2]. Updates to primitive equation models were persistently conducted based on detailed consideration of various important physical processes, for example, solar radiation, moisture, latent heat, sea surface temperature, and rainfall-convection feedback, etc. The particular role of each kind of these processes in prediction was usually evaluated with sensitivity experiments, which demands a huge amount of computer resources. To avoid this problem, in Chapter 4, a new scheme called Generalized Weighted Residual Method (GWRM) is proposed to efficiently identify the parameter dependency of NWP model. The physical processes identified above are usually considered by model based on parameterization schemes [3], as there always are certain scales that are unresolved by the model grids. To first order, parameterization involves the representation of a process in terms of its known relationships to dependent variables resolved on the model grid. Some common processes that are parameterized by modern NWP models include radiation, planetary boundary layer, surface layer, shallow and deep cumulus convection, and cloud microphysics. One typical example is cloud parameterization, which can infer the properties of unresolved clouds and determine whether or not they should be present. Another example is about turbulent motion. Given wind shear and stability in grid scale, a turbulent parameterization scheme can infer the properties of subgrid-scale turbulent motions. Usually, there are many ways that physical processes can be parameterized, each with assumptions, strengths, and weaknesses. It is noticed that, for any parameterized process, the parameterization is just an approximation and thus a major source for model error. Chapters 5 and 6 will introduce in detail the design of new parameterization schemes and its application in prediction of atmospheric systems.

The advances of numerical methods on physical parameterization and observation greatly contribute to the development of numerical models, including global model for prediction of large scale processes and regional models for mesoscale application. Currently there are more than 13 centers worldwide with operational global NWP capability (BoM—Australia, CMA—China, CMC—Canada, CPTEC—Brazil, DWD—Germany, ECMWF—Europe, IMD/NCMRWF—India, JMA—Japan, KMA—Republic of Korea, MF—France, NOAA/NCEP—USA, ROSHIDROMET—Russian Federation, and UKMO—UK). Most of these global NWP centers are typically running a combination of global models at grid spaces less than 30 km and high resolution regional models with grid spaces less than 12 km, according to the

http://dx.doi.org/10.5772/intechopen.82468

Annual WMO Technical Progress Reports. Regional models, which is more convenient and flexible than global model for its relative low requirement on computational resources and datasets, are generally run for national or regional domains centered around the immediate area of the NWP center. Here, most of the regional models used in this book employed the background fields provided by one of the global models mentioned above. Among them, the Weather Research and Forecasting (WRF) model developed by National Center for Atmospheric Research (NCAR) might be one of the regional models most popularly used by the NWP community in the world. The WRF model features dynamical cores, a data assimilation system, and a software architecture allowing for parallel computation and system extensibility. In this book, Chapter 3 will incorporate radar remote sensing data into high-resolution WRF model and evaluate its performance in numerical prediction of local weather systems.

In addition to the application in weather prediction, WRF model can also be coupled with atmospheric chemistry, namely WRF-Chem, for simulation on the emission, transport, mixing, and chemical transformation of trace gases and aerosols simultaneously with the meteorology. The WRF-Chem model has been successfully employed for investigation of regional-scale air quality, field program analysis, and cloud-scale interactions. In Chapter 7, the authors will share their experience on using WRF-Chem model for air quality numerical forecast over eastern China. Similar to the use of WRF-Chem in chemical weather prediction, another numerical model, the Community Multiscale Air Quality (CMAQ) model has been developed in US since 1998, to provide fast, technically sound estimates of ozone, particulates, toxics, and acid deposition. Because it includes information about the emissions and properties of compounds and classes of compounds, CMAQ can inform users about the chemical composition of a mixture of pollutants. This is particularly useful when measurements only give insight into aggregate details, like total particulate mass. CMAQ's generalized and flexible formulation has enabled incorporation of alternate process algorithms and numerical solution methods. This has allowed inclusion of new science in the model to address increasingly complex air pollution issues. In Chapter 8, the author will use a coupled WRF/CMAQ model to simulate the effects of increasing urban albedo on air temperatures and quality over Madrid city of Spain.

3. Future work

With the increase of computer resources, the horizontal resolution of operational global numerical models reaches the gray-zone resolution at tens of km or finer, even within several 100 m. A significant focus of research over the coming years is likely to be on improving the depiction of cloud with cloud resolving models, equipped by high resolution observations of cloud and its environment. However, the implementation of cloud resolving model into operational systems is a highly complex task, and is increasingly undertaken in a collaborative framework of national centers, in collaboration with academic partners in universities and other research institutes.

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