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A REVIEW OF THE ANALYSIS OF MOISTURE VARIABLES AND THE APPLICATION IN NUMERICAL MODELS

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Abstract: The application of the explicit microphysical process in the high-resolution mesoscale numerical models makes it necessary to analyze the moisture variables such as the cloud water, cloud ice and rain water to initialize the explicit predicted fields. While the inclusion of moisture variables in initial fields can influence the whole performance of the model significantly, it can also reduce the spin-up time and increase the short-term forecasting ability of the model since the dynamical fields become more accordant with the thermodynamic fields. Now the increase of the observing ability and the abundance of the data promote the development of ways to analyze the moisture variables. A review of some methods to analyze the moisture variables is presented, and the situation and problems of the application in the numerical models are also discussed in this paper.

Key words: mesoscale numerical model; microphysical process; moisture variable analysis; assimilation

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1 INTRODUCTION

Wet processes are those that involve with mutual transformation of water vapor and moisture variables in the model domain, or cloud formation and precipitation, and their associated dynamic and thermodynamic effects. The initialization of water variables such as cloud water and rainwater is very important for the simulation of physical processes like transformation between different phase states, development and attenuation of clouds. It is difficult for conventional surface and sounding data to capture information about mesoscale circulation while cloud water, cloud ice and rainwater are not something that can be measured directly. Traditional analysis systems do not work on such physical quantities as cloud water and rainwater, which affect the forecasting of circulation. The bias of mesoscale circulation forecast will in turn affect the forecast of water vapor and thermodynamic field [1]. The model prediction of precipitation is strongly dependent on the initial value of mesoscale water vapor. Due to the lack of sounding data, the forecast deviates much from the observation when objective analysis fails to reflect the existence of mesoscale areas of high humidity. With artificial adjustment of the humidity field based on real precipitation areas, the forecast is much improved to be close to reality [2]. It is due to this problem that earlier methods of non-linear initialization or physical initialization were studied mainly based on the application of satellite data [1, 3-5] to predict precipitation as accurately as possible and to shorten the initial spin-up time of the model.

Diabatic initialization has been developed to solve the problem of precipitation forecast by adjusting water vapor and relevant dynamic and thermodynamic fields rather than cloud water or rainwater. As there is no information about vertical structure in the observation of rainfall or cloud imagery, it is quite difficult to determine the vertical distribution of diabatic heating. Attempts have been documented to introduce predictive equations for cloud water and rainwater to study their initialization [5], but the assimilation and initialization cannot be sustainable, as the wet process is simple.

Rapid progress has been made in the development of mesoscale models in recent years [6 - 8]. For the dynamic framework, the development of non-hydrostatic equilibrium has increased the model

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resolution and simulation scale. Great progress has also been made in physical processes, especially, all kinds of micro-physical processes have been introduced, which make it possible to describe in detail the evolution of clouds and mutual transition between various moisture variables. In China, a new non-hydrostatic numerical model and its associated three-dimensional variational and assimilation system (GRAPeS) has also been established [8]. Existing mesoscale models can not only simulate large-scale stratiform cloud systems and their associated weather processes, but also the generation, evolution of convective clouds in them, especially having great advantage and application prospect for the simulation of severe meso-β scale convection and storms. However, the selection of parameters relating with clouds is a source of uncertainty for model prediction, for the distribution of simulated clouds and their radiative properties differ much from reality. In the meantime, observation capabilities have been improved greatly and an increasing spectrum of data can be acquired owing to the increase of satellite channels and denser deployment of Doppler radar sites. A series of methods have been formulated in the analysis of clouds and moisture variables thanks to the application of new observations. In this paper, one of the main methods for the analysis and application of moisture variables in mesoscale models will be introduced in the hope that the results can be useful in relevant research.

2 ELEMENTS IN THE ANALYSIS OF MOISTURE VARIABLES

Elements of moisture variables are related with wet physical processes used in numerical models. The latter is mainly about clouds and precipitation. Clouds are made up of water droplets and ice crystals. The ice crystals in nature are mainly of cells of ice crystal, snow, graupel and hail. Precipitable particles include water droplets in liquid state and snow, hail and graupel in solid form. The physical quantities associated with wet processes include cloud water and rainwater (in liquid state) and ice crystal, snow, graupel and hail (in solid state), apart from better-known liquid-state water and water vapor.

For model wet processes, there are schemes of explicit cloud physics and parameterization of cloud convection. In the processing of large-scale model precipitation, a mixed scheme, which consists of an implicit convection scheme and explicit cloud physics scheme, generally should be used at the same time depending on the resolution. Usually, there are a number of cloud physics schemes that can be chosen from for mesoscale numerical models. The large differences in cloud physics schemes can be displayed as the differences in the predicted precipitation from clouds as well as in the physical description and processing procedures of micro-physical processes [10].

Included in both simple and complicated physical processes, cloud water and rainwater are two basic elements to be analyzed. Our analysis is mainly for the distribution of clouds and cloud water and rainwater while the analysis of other moisture variables mainly depend on their transition. As shown in the numerical experiment, the initial concentration of cloud droplets have some influence on convective precipitation [13], though the concentration of counts are not studied much. The analysis methods presented hereafter are mainly for cloud water and rainwater, two variables in liquid state as well as for cloud ice.

3 METHODS FOR ANALYZING MOISTURE VARIABLES

One of the systems that analyze moisture variables is Local Analysis and Prediction System (LAPS) by the Forecast Systems Laboratory (FSL), U.S.A. Mainly based on the application of various local data, LAPS analyzes physical quantities such as cloud water / ice, with three-dimensional cloud analysis.

Specifically, one of the features of LAPS [14] is the analysis of clouds. It has complete description of cloud variables of cloud base, cloud top, cloud cover and cloud type. The scheme was put forward in 1996[15]. A few years later, LAPS expanded the cloud scheme to all phase states of water [16] to supply the model with complete initial field of water vapor and relevant analysis of dynamic and thermodynamic fields [17]. In the analysis, LAPS uses such multiple data as satellites, radars, wind profilers, aircraft and surface reports. The "sounding" of clouds as determined with surface data and aircraft report help form a preliminary three-dimensional analysis of clouds. With the latter, more analysis can be done of the moisture variables.

With LAPS, precipitation is studied to identify its types with reference to radar echo and wet-bulb temperature. The types include no rain, rain, snow, freezing rain, icy rain and hail. The analysis of precipitation types helps determine which moisture variables exist.

A variational method has also been developed recently [18], in which radiative transfer models applies multiple types of radiation data to analyze the field of water vapor at the same time. Variational analysis expands the types of data that can be used, like the GPS-derived data. Such data are free from the effect of clouds and applicable in places with clouds.

4 APPLICATION OF MOISTURE VARIABLES IN MODELS

With explicit equations for clouds and precipitation taken into account, the original equations for dynamics and thermodynamics also need to be adjusted due to the drag of moisture variables, in addition to new predictive equations for wet predictands. In the HLAFS model, for example, the thermodynamic and hydrostatic equations [11] are respectively.

$$\frac{\partial T}{\partial t}=-\frac{1}{p_s}[\frac{1}{a\cos q}(p_s u\frac{\partial T}{\partial l}+p_s v\cos q\frac{\partial T}{\partial q})+p_s\dot{s}\frac{\partial T}{\partial s}-\frac{kT^*}{s}w]+F_T+\frac{dT}{dt}$$

and

$$\frac{\partial f}{\partial(\ln s)}=-R_d T^*$$

Specifically, T^* has to be adjusted according to the scheme. For complicated schemes that include water vapor (Q_v), cloud water (Q_c), rainwater (Q_r), cloud ice (Q_i), snow (Q_s) and graupel (Q_g), $T^*=T_v\frac{1+Q_v}{1+Q_v+Q_c+Q_r+Q_i+Q_s+Q_g}$, in which T_v is the virtual temperature.

For the model initial values, the model's dynamic and thermodynamic fields also need to be adjusted in addition to the provision of initial distribution of moisture variables. For numerical weather prediction of heavy rains, precipitation simulation needs some time to adjust during the early stage of model integration due to inadequate match between the dynamic and thermodynamic conditions and the scheme for wet parameterization of the model. Consequently, the model has to wait a few hours before precipitation begins to take place, which is the so-called "spin-up".

In LAPS, the analyzed cloud water and rainwater are used in the model and given adequate dynamic and thermodynamic fields. Apart from it, the following steps have to be taken [17]. 1) In-cloud vertical velocity is estimated. 2) Variation adjustment is used. 3) Water vapor is adjusted to saturate the relative humidity in the cloud.

In the method presented above, the initial values of dynamics, thermodynamics and moisture variables of the model are adjusted all at the same time. Another way of doing it is through the nudging method to incorporate moisture variables to the model. After a time of integration adjustment in the model, dynamic and thermodynamic fields can be determined that are coordinated with the analyzed moisture variables.

For analyses of other aspects, refer to the Chinese edition of the journal.

4 CONCLUSIONS AND RESULTS

The methods for analyzing moisture variables and their implication in models are mainly introduced in this work. The methods are closely related with the increase of all kinds of observations and application. It is known from these methods that the principles and procedures of the analysis are not complicated. Clouds, cloud water and rainwater are studied and adjusted mainly based on satellite and radar data, together with conventional observation and model prediction. Model applications have indicated that the initialization of moisture variables improves the model prediction of precipitation and decreases the unwanted effect of spin-up.

In China, a number of distinctive methods have been developed on the modeling of convective clouds and do have schemes for cloud physics in mesoscale models [10], with successful application in operational predictive model of HLAFS [11-12]. Apart from improving physical processes, acquiring reasonable initial conditions is also very important. Much progress has also been made in China in the aspect of assimilation techniques. Examples include the setting-up of a three-dimensional assimilation system of GRAPES and research and application of four-dimensional assimilation techniques. In other words, it is technically capable of developing methods for analyzing moisture variables but realistically lagging behind. Such state of application not only affects the prediction skill, especially that of precipitation, for the mesoscale operation, but the ability of assimilating various types of data. In the atmosphere, there are complicated interactions between radiation and water, which exists in all kinds of phase states. If no adequate analyses are done of clouds and various moisture variables, assimilation will not achieve satisfactory results even if advanced variational methods are used [19].

The present weak analyses of moisture variables in China may be related with weak ability for data measurement. With the deployment of Doppler network and development of meteorological satellite in recent years, however, prerequisites are now available for the utilization and processing of the data. The commencement of refined prediction is just operational requirement based on improved measurement techniques and model techniques that describe detailed and complicated physical processes. It is believed that distinctive schemes for analyzing moisture variables will be formulated in China in the near future.

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