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ASSIMILATION OF OBSERVED SURFACE WIND WITH GRAPES

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Abstract: With the advances of numerical weather simulation and reduced data assimilation updating cycle, surface observation data assimilation becomes more and more important in data assimilation systems. It is widely accepted that a better data assimilation system should contain the restriction of thermodynamic processes in the surface layer. Therefore, in this paper, a new surface wind observation operator is utilized in Global and Regional Assimilation PrEdiction System_3D-Variance (GRAPES_3D-Var), with the restriction of thermodynamic process in the planetary boundary layer (PBL). In order to research the ability of this new surface wind observation operator in assimilation and forecasting, a series of experiments are operated by using the GRAPES model. The main results indicate that this new method of surface wind observation operator has positive impact on the forecast with the GRAPES model.

Key words: numerical weather simulation; forecast; surface wind; data assimilation; restriction of thermodynamic processes; GRAPES

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1 INTRODUCTION

The aim of data assimilation is to provide the best initial value possible for northern West Pacific (NWP) from a large variety of observations and model background information. Currently, there are many sources of observation information, and one of the most important sources is the Surface Observation Data (SOD). It is of great significance for three-dimensional data assimilation to effectively assimilate the SOD. Furthermore, the SOD with high spatial and temporal resolution can make surface variable analysis valuable for mesoscale forecasting. Over the land, conventional observation stations and automatic weather stations (AWS) are the main sources of surface observation. Presently, there are more than 2000 AWS's in China, with more than 600 AWS's in Guangdong province, and the number is still increasing. Moreover, the spatial coverage of SOD is much larger than soundings, and the AWS can supply the basic element observation on an hourly basis, with precipitation available every 10 minutes. Hence, high-frequency observation has become one of the most important sources for nowcasting. However, the utilization ratio of SOD is still low even though the data density has been high in China. The SOD is usually archived and used for qualitative analyses, instead of being used for NWP to improve numerical prediction, resulting in a large waste of resources.

It has been recognized that SOD includes high frequency boundary forcing information and a good boundary forecast will be produced by assimilating SOD into the model. In view of the fact that the boundary layer can influence the model forecasting differently, it is very important to use a fine boundary layer, which can be used to smooth and transit analysis from the model's lowest layer to the upper layer, ensuring that there is a consistent field in the vertical direction in the process of initialization and the deviation information produced in the analyses is saved. Yee and Jackson[5] emphasized that although SOD does not contain the information in the upper level atmosphere, we can use the difference between surface observation value and the model's lowest layer forecast value to modify other layers.

However, the SOD is greatly influenced by topography, which is very complex in its distribution, and there still exists difference in elevation between surface observation station measurement and numerical model surface. Therefore, compared to the assimilation

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work for unconventional data such as radar and satellite, studies on incorporating most of the surface data into NWP are relatively less and the progress is also limited. How to solve the difference in elevation between surface observation data and numerical model surface has become a fundamental problem in SOD assimilation.

Previous studies in the 1980s mostly focused on the assimilation of temperature. Meteorologists such as Hessler, Hutchinson, Andersson and Benjamin all assimilated temperature with univariate optimum interpolation methods, but the surface wind field was paid less attention to [1-4].

In 1996, Ruggiero et al. [5] adopted successive corrections methods[6] for surface analysis. The basic idea is to interpolate the surface wind data from AWS measurements to model surface by using the constraint condition in the boundary-layer similarity theory to transfer the surface data properties on to the upper layers. In 2000, Ruggiero [7] improved his assimilation schemes developed in 1996. The existing problem is that all these schemes are simple interpolation, with relatively low accuracy of calculation.

In 2002, Guo et al.[8], collaborating with NCAR and Korea, pointed out the merits and the flaws of his old scheme about AWS, and proposed a new scheme to overcome the flaws in the old scheme. The new scheme is summarized as follows. By assuming that all observation stations are on the model level, a forward observation operator with tangent linearity and adjoint codes for 10-m wind fields was set up based on the Medium Range Forecast planetary boundary layer (MRF PBL) scheme[9]. This new scheme had the ability of assimilating 10-m wind data, but it assumed all stations on the model surface, which ignored the difference in elevation between the measurements from surface observation stations and numerical model surface. In addition, in view of the fact that the distribution of terrain in China is complex and there are relatively large differences in the elevation of terrain between the model and observations, and the wind field also varies with the distribution of elevation and terrain changes, this new program does not apply in China.

2 THE SCHEME OF NEW SURFACE OBSERVATION OPERATOR

Based on the GRAPES_3D-Var framework, a new surface observation operator is built using the Monin-Obukhov surface similarity theory. The major steps are summarized as follows (Fig. 1).

A. If the elevation of an observed site is lower than the height of the model's lowest level by more than 50 m, this station is discarded.

B. If the elevation of an AWS is above the height of the model's lowest level by more than 750 m, then the measurements from this station are used in the same way as upper air data, with the data assimilated with the cubic spline interpolation method.

C. If the elevation of an AWS is below the model's lowest level, but not more than 50 m, and the elevation of an AWS is above the model's lowest level but not more than 750 m, the measurements are used, following the surface similarity theory, to modify the surface wind field from the model's lowest level to observation level. It mainly uses the Bulk Richardson No.(R_i) to estimate the atmospheric static stability [9] and gives the different expression of wind profiles[10] according to atmospheric static stability.

Choosing 750 m as a critical difference elevation is based on considerations of the test effect and elimination rate of the stations number. Through a series of tests, a better result can be obtained and nearly 93% of the stations are retained when 750 m is used as a critical difference in elevation.

3 THE TEST

In an assimilation system, the error of analysis residual should be less than that of innovation. Based on this feature, a test has been done to compare the mean and root mean square (rms) of innovation and analysis residual of the new scheme. The figures (Fig. 2 and Fig. 3) show that the mean of innovation has a large disturbance. Through the assimilation analysis, the disturbance is substantially reduced, and approaches the zero line furthermore. Similar to the mean disturbance, the change in rms is also greatly decreased. It indicates that the characteristics of assimilation analysis still remain by using the new surface observation operator.

We focus on three aspects to compare the new scheme with the old one. First, in the case study (Fig. 4 – Fig. 6), there is a cyclone in the boundary region between the southeast of Zhejiang province and Fujian province in the real-time analysis, with a geopotential height of 510 geopotential meter in the center. For the basic description of this cyclone, the positions forecasted in both the schemes are almost the same and both of them are located west of the real position. However, the center geopotential height in the old scheme is 620 geopotential meter while the new one is 600 geopotential meter, i.e. the new scheme is closer to the observed intensity of the cyclone. For the description of the wind field, the wind speed in the north of the cyclone is larger in the new scheme than in the old scheme and closer to the observation.

Second, from the comparison of statistical characteristics of the innovation in both the new and old schemes, it is known that the former is smaller than the latter. It indicates that a more realistic statistical characteristic of the innovation can be obtained by using the new surface observation operator. The superiority of this operator may arise from the consideration of the earth's surface characteristics, such as roughness and static stability of the atmosphere. In the old scheme, a simple interpolation method is used near the surface, which does not conform to the real atmospheric distribution; but in the new scheme, the background is much closer to the observation due to the consideration of the influence of PBL processes.

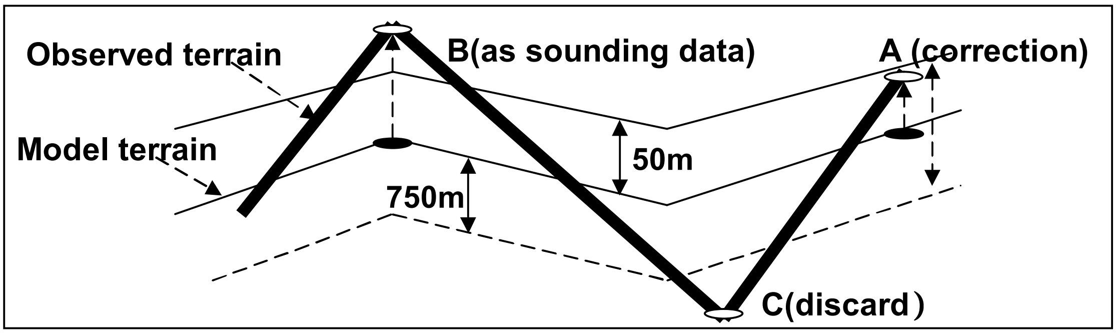

Fig.1 Sketch map of the new method. See text for further detail.

Finally, as the change in the wind field can greatly affect the atmospheric circulation and also has impacts on the water vapor transportation, we design a continuous test (Table 1) to examine the influence of the new scheme on precipitation forecasting, and also present the TS scores, miss rates and false alarm rates of 24-h accumulative precipitation.

Table 1 Design of the three tests.

test	Data	methods
test 1	SYNOP +TEMP	New
test 2	SYNOP +TEMP	Old
test 3	TEMP	

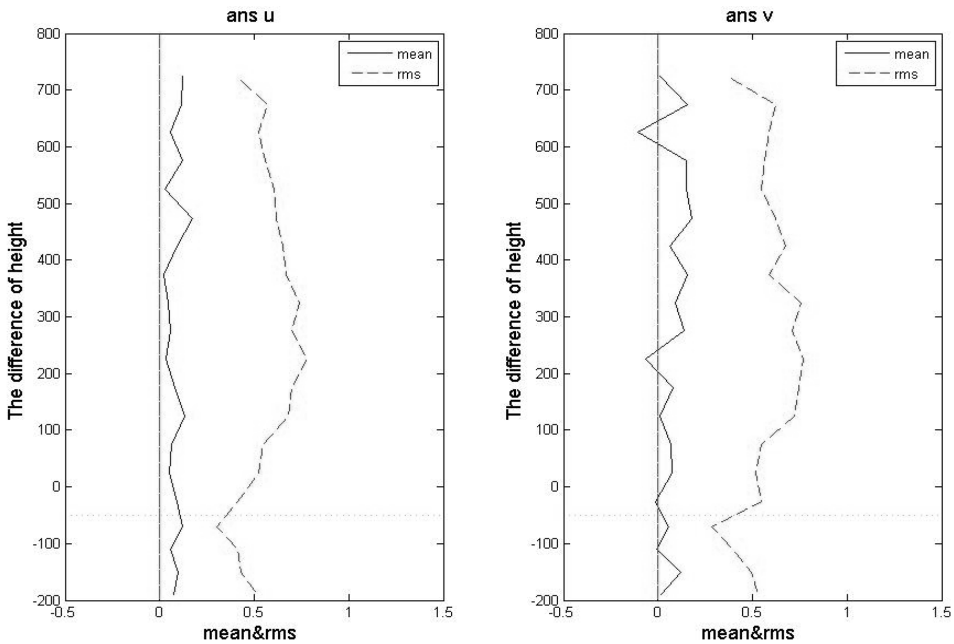

Fig.2 Distribution of the mean and root mean square of analysis residual with the difference between the observation and model height. (Vertical line: the zero line; real curve: the mean; broken curve: the root mean square)

As revealed from comparisons of the three different groups of data and assimilation methods, it is shown as follows. First, for the whole country of China, the precipitation TS scores of light rain and moderate rain with the new scheme are better than those with the old scheme, and there is not much difference in the scores of heavy rain with the two schemes. For different regions in China, the TS scores of light rain, moderate rain and heavy rain with the new scheme are almost all better than those with the old scheme. Second, for the light rain, the precipitation miss rates in the three tests are almost the same for the whole country except in some areas of northern China and southern China. The miss rates for the other areas with the new scheme are smaller than with the old one or are without much difference between them. For the moderate rain and heavy rain, the new scheme does not exhibit apparent advantage on the miss rate compared to the other two schemes. Lastly, the precipitation false alarm rates of light rain, moderate rain and heavy rain with the new scheme are mostly smaller than those in the old scheme.

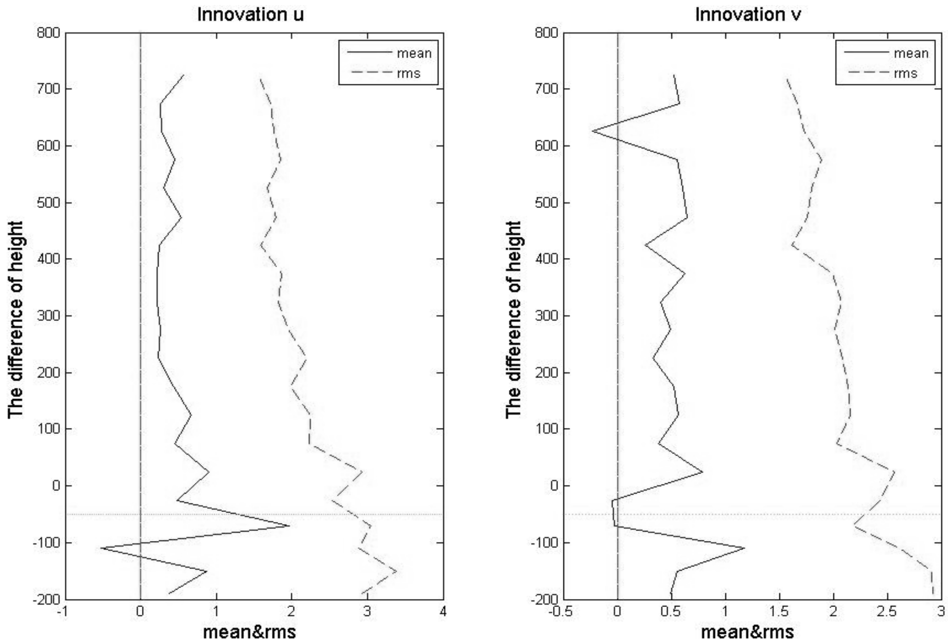

Fig.3 Distribution of the mean and root mean square of innovation with the difference between the observation and model height. (Vertical line: the zero line; real curve: the mean; broken curve: the root mean square)

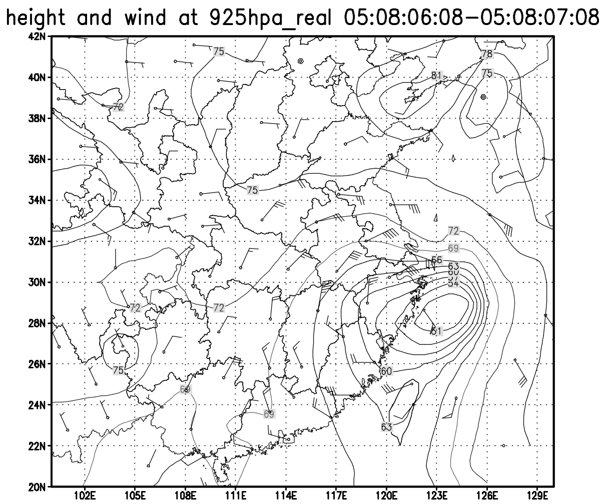

Fig.4 Observed 925-hPa height and wind field at 0000 UTC 7 August 2005.

4 CONCLUSIONS

The old scheme in the GRAPES_3D-Var does not consider PBL processes and only uses surface data as sounding data, which also has a large deviation. Therefore, the GRAPES_3D-Var has not assimilated the surface wind field data into the model. This paper describes the foundation of a new surface observation operator, which contains thermodynamic processes in PBL. Based on the Monin-Obukhov surface similarity theory, it modifies the model value from the model's lowest layer to the surface observation elevation for a 10-m wind field and takes into account the difference in elevation between surface observation station measurements and the numerical model surface. In order to investigate the ability of assimilation and forecasting with the new surface observation operator, a series of experiments have been conducted by using the GRAPES model and the main results and conclusions are summarized as follows.

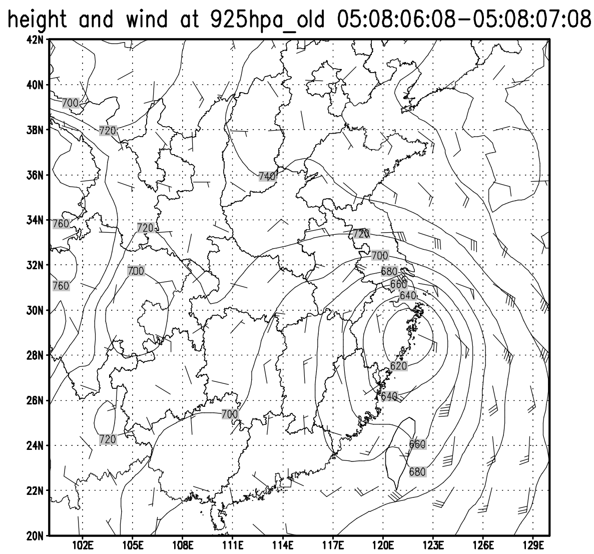

Fig.5 Simulated 925-hpa height and wind field at 0000 UTC 7 August 2005 with the old method.

(1) Based on the GRAPES_3D-Var framework, a

new surface observation operator is built by using surface similarity theory, which considers the influence of thermodynamic processes on the atmospheric boundary layer. In this new scheme, the difference in elevation between the measurements of surface observation stations and numerical model surface is the major factor determining the assimilation method. Theoretically, the new surface observation operator can better describe the function of surface observation in data assimilation.

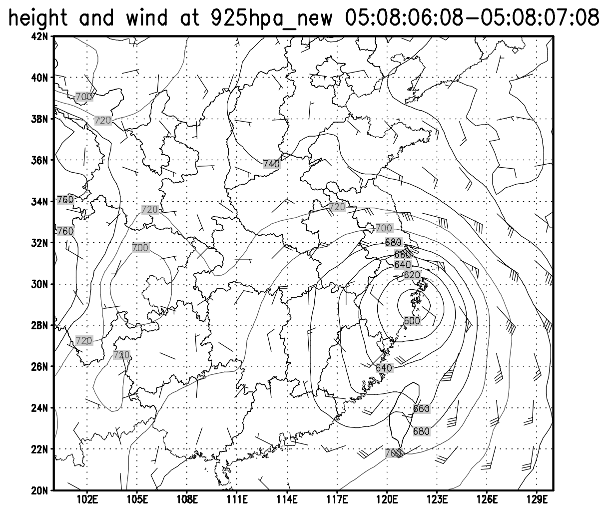

Fig.6 Simulated 925-hpa height and wind field at 0000 UTC 7 August 2005 with the new method.

(2) Strict examination and tests have been performed for the surface observation operator, including an accuracy test of the tangent linear and adjoint codes and the results are reasonable. In addition, through the test on the statistic character of innovation and analysis residual, we can conclude that the characteristics of assimilation analysis still remain with this new surface observation operator.

(3) From the comparison of the statistic characteristics of innovation in the new and the old scheme, it indicates that a more ideal statistic characteristic of innovation can be obtained using the new surface observation operator. This improvement may be due to the consideration of earth's surface character, such as roughness and static stability of the atmosphere.

(4) Considering that the change in the wind field can affect the change of atmospheric circulation and also has an impact on the water vapor transportation, two continuous precipitation experiments have been designed in this paper that analyze the TS scores, miss alarm rate and false alarm rate of 24-h accumulative precipitation. The results indicate that in general, the new scheme for the surface wind observation data assimilation has a positive influence on precipitation.

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