Test and analysis of high resolution regional model precipitation forecast based on wavelet

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Abstract. In order to avoid the double punitive disadvantage of traditional test methods, based on the advantages of wavelet in multi-resolution analysis the precipitation forecast products of RMAPS (Rapid-refresh Multi-scale Analysis and Prediction System) system are tested objectively. In this study, Haar is used as basis function. The test results show that the hourly precipitation forecast error of the 3km discriminant ratio of the forecast system is less than 15% for the precipitation process with the horizontal scale exceeding 94 km. As the wavelet analysis scale decreases, the precipitation error gradually increases.

1. Introduction
Conventional objective test methods, such as TS score, False alarm rate, Missing alarm rate and Hit rate, cannot describe the space-time scale properties of the prediction field. On the other hand, with the rapid improvement of computing power and the modernization of local observation data network in recent years, the horizontal resolution of regional numerical prediction model has been gradually improved. A number of units have realized the operationalization of a numerical prediction system with a horizontal resolution of up to 3km. Taking Beijing regional forecast center as an example, its RMAPS-st (short term) system provides users with hourly forecast products in a way that 9 km nested 3 km for 24-hour forecast. How to evaluate the high resolution finite model becomes a problem to be solved urgently. Wavelet analysis has unique advantages in scale decomposition. It is widely used in the field of signal system [1-10]. Internationaly, Casati [11,12] was introduced into the field of meteorology in 2004. In China, Xu [13] intensity scale inspection technology is introduced into the quantitative precipitation forecast of WRF 9 km resolution, Kong Rong [14] intensity scale testing technique is applied to, such as the "world meteorological organization weather research program -- forecast demonstration projects for the Beijing Olympic Games" (WWRP08FDP) project four approaches in forecast in system (BJANC, GRAPES SWIFT, STEPS, CARDS) decomposition of quantitative precipitation forecasts for 1 h scale test, the precipitation forecast techniques and time and space, the relationship between the scale and intensity of precipitation. The horizontal resolution of the model is 12 km. Hu \textit{et al.} [15] compared and tested four types of quantitative precipitation forecast (QPF) products of radar extrapolation, WRF, T639 and ECMWF, and drew a comparison conclusion of precipitation capacity of various products in different spatial scales. All of the work mentioned above, did not evaluate the forecasting ability of finite regional model in short-term forecast (0-24 hour).
Based on the work, this study investigated the prediction ability of hourly precipitation forecast of numerical prediction model in different spatial scales.

2. Data

2.1. Observation field
The observation field named CMORPH, adopts the national intelligent grid real-time fusion analysis product developed by the national meteorological information center [16], with a horizontal resolution of 5 km and a time resolution of 1 hour. The fusion data of observations on grids with high spatial and temporal resolution provide the necessary observation fields for the wavelet analysis to test high resolution numerical models. The data adopts "PDF+BMA+OI" ground-satellite-radar three-source precipitation fusion idea: first, PDF technology is used to correct the systematic error of radar and satellite precipitation; Then, Bayesian Model Averaging (BMA) method was used to dynamically estimate the fusion weights of radar and satellite data according to the sample matching in the sliding live window, so as to form the optimal radar-satellite joint background field. Finally, OI fusion ground observation was used for correction to generate a precipitation fusion product with a resolution of 5km. The results of independent sample test show that the accuracy of precipitation from three sources is better than that from any single source.

2.2. Forecast field
Institute in Urban Meteorological of Beijing in BJ-RUC researches, on the basis of the preliminary built in 2015 is a new generation of multi-scale Analysis and Prediction System - rapid update short-term forecasting subsystem (Rapid - refresh Multiscale Analysis and Prediction System, ShortTerm RMAPS - st for short), as the core of a new generation of numerical forecast System, focus on 2-12 hours short-time forecast, improve city high resolution was numerical weather Prediction ability. On June 25, 2015, RMAPS-st system v1.0 (RMAPS-stv1.0) started real-time operation on dawn high-performance computer in Beijing bureau. On June 1, 2016, the system realized quasi-business operation, and has been running steadily for 18 months. Related numerical forecast service products in Beijing meteorological information integrated display system LDAD platform, providing business trial, "track and field world championships in 2015," Anti-Japanese War victory parade "and other major activities and on July 19 and 20, 2016 in north China area in the process of severe storms and other major weather forecast service has been very good applications. RMAPS-stv1.0 system applies the international advanced hot start cycle technology and develops a new system operation process. The assimilation of 7 new-generation weather radars in the beijing-tianjin-hebei region was expanded, and the assimilation of 3d digital jigsaw data of 29 new-generation weather radars in the north China region was realized. China takes the lead in realizing the transition from the assimilation of the total GPS water vapor in the ground to the direct assimilation of the total delay data of the GPS signal in the ground, eliminating the errors caused by the calculation of the total GPS water vapor based on the ground observation. According to the test of precipitation forecast in the flood season of 2015 and 2016, compared with BJ-rucv3.0, the RMAPS-stv1.0 system has significantly improved TS scores in most precipitation thresholds and most forecast time periods.

The RMAPS-stv1.0 system consists of a 6-hour thermal start cycle subsystem with a 9 km resolution and a 3-hour rapid update cycle assimilation and prediction subsystem with a 3 km resolution, while the RMAPS-stv1.0 stile exist many errors in precipitation area in time and space. Wavelet analysis tools can objectively display the problems of mismatch between forecast precipitation area and real space and time inconsistency, which can not be achieved by traditional test methods.

3. Inspection methods
The two-dimensional discrete wavelet basis of Haar described in [13] is adopted, but the precipitation elements tested have higher spatial and temporal accuracy than [13]. The spatial resolution of the mother wavelet was set as 3, 6, 12, 24, 48, 96, 192 and 384km. This paper
focuses on the analysis of the rule of binary mean square error of the precipitation forecast of the ris-graph system changing with time, so the following test indexes are adopted:

### 3.1. Binary mean square error

First, transform the forecast and observation field into threshold value.

\[
\begin{align*}
    f_i & = \begin{cases} 
    1 & F_i > \mu \\
    0 & F_i \leq \mu
    \end{cases} \\
    o_i & = \begin{cases} 
    1 & O_i > \mu \\
    0 & O_i \leq \mu
    \end{cases}
\end{align*}
\]

The threshold \( \mu \), here is set to 0, 1, 2, 5..., 50 mm/h. \( I_F \) means binary field of Forecast, \( I_O \) means binary field of OBS. \( Z = I_F - I_O \), means the binary error field, can be expressed as the member sum after two-dimensional discrete wavelet decomposition, and the expression is:

\[
Z = \sum_{l=1}^{L} Z_l
\]

\( L \) is the decomposition scale number, where \( L=8 \). The size of each spatial scale can be expressed as: \( dx \times 2^{L-1} \), \( dx \) is the spatial resolution of the mode.

Then, the binary mean square deviation is defined as:

\[
MSE = Z^2
\]

According to MSE, the model can be used to evaluate the prediction errors of precipitation rate thresholds at different spatial scales.

### 3.2. Energy square

In order to investigate the number of weather events on each characteristic scale and precipitation rate threshold in the prediction field and observation field, the concept of energy square is introduced, which is defined as:

\[
EN2(X) = \sum_{i=1}^{L} X_i^2
\]

Energy deviation is defined as the standardization of the sum of the squared energy variance of the predicted field and the observed field. The formula is expressed as follows:

\[
EN2 \text{BIAS} = \left[ \frac{EN2(F) - EN2(O)}{EN2(F) + EN2(O)} \right]
\]

The value range of the energy deviation is [-1, 1], and a positive value indicates more forecast events, while a negative value indicates less forecast events.

### 4. Check individual cases

Take a precipitation process in the Beijing-Tianjin-Hebei region on August 6, 2018 as an example. From 20:00 on August 5 to 20:00 on August 6, the heaviest rainfall occurred in Baoding waterfall river, Hebei province. The hourly rainfall intensity was 118.4 mm. The time of occurrence was 03:00:00 on August 6. The Beijing-Tianjin-Hebei average is 9 mm. The maximum cumulative precipitation occurred in: Beiloushan, Baoding, and the cumulative rainfall was 212.0 mm. There were 2,107 stations with cumulative precipitation greater than or equal to 0.1 mm, 705 stations greater than or equal to 10 mm, 327 stations greater than or equal to 25 mm, 149 stations greater than or equal to 50 mm, 46 stations greater than or equal to 100 mm, and two stations greater than or equal to 200 mm. As can be seen from Figure 1 and Figure 2, RMAPS-ST is located in Wulanchabu League, Xilinguole League and Xing’an League at 00:00 on Aug. 6. Compared with the actual precipitation area, it is more northwest. With the increase of forecast effect pair, the precipitation forecast and the actual precipitation forecast are closer to the actual precipitation area and magnitude.
Figure 1. RMAPS-st 00-09 forecast on 2018080600 versus CMORPH precipitation.
Figure 2. RMAPS-st 00-09 forecast on 2018080600 versus CMORPH precipitation.
The process was decomposed by wavelet. As shown in Figure 3, firstly, the forecast error of precipitation at all scales changed correspondingly with the change of precipitation, that is, the precipitation were about small, and the error was smaller. Secondly, as shown in Figure 4, the precipitation errors of each scale are sensitive to the shape changes of the precipitation area.

Figure 3. MSE of RMAPS on 2018080600 for 24 hour forecast, compared with CMORPH.

Figure 4. BIAS of RMAPS on 2018080600 for 24 hour forecast.

5. Summary

The wavelet analysis technology can decompose the precipitation forecast products of the numerical model in different scales.

Through the wavelet scale decomposition analysis of individual cases of precipitation, it is found that the hourly precipitation forecast of RMAPS-st system has the following characteristics within the 24-hour prediction time limit:

1) Overall, the hourly cumulative precipitation prediction error of RMAPS-st 3KMkm resolution decreases with the increase of the test scale. The percentage of precipitation error is about 15% in the range of 96 km length error.

2) The analysis of precipitation forecast of RMAPS-st at different times shows that the order and magnitude of some scale test errors have changed, because the results of different reporting times are different in the precipitation area, which shows that the precipitation area affects the results of precipitation error calculation at different scales.

3) From the distribution of energy deviation, it can be seen that with the increase of scale, the number of missed time periods increases first, and at scale-5 (96km) scale, the number of missed time periods is the largest. Thereafter, with the increase of scale, the number of missed reporting periods decreases, especially over 2mm/h magnitude, without missed reporting
periods. It shows that RMAPS-ST can be fully predicted when the precipitation scale is greater than 96 km and the precipitation is more than 1 mm/h.

Of course, the wavelet analysis technology also has limitations, when the actual precipitation range is small, the wavelet analysis effect is not ideal. The next step is to use the wavelet analysis technique to decompose and examine the numerical model in time scale.

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