The Design and Application of the Fine-Resolution Road Weather Information System to Improve Special Meteorological Services over the Greater Beijing Metropolitan Area in North China

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ABSTRACT

In the Greater Beijing metropolitan areas of North China, one fine-resolution road weather information system is designed and applied to improve the special meteorological services. This system is composed of four parts, that is: A local intense monitoring network; One rapid cycling numerical weather prediction system updated every 3 hours with WRF model coupled with Noah land surface model system, two domain two-way nested run with the fine-resolutions of 9/3km; A statistical interpretation sub-system for numerical products based on the nonlinear method of support vector machine; And an auto WEB deliver platform coupled with geographic information system (GIS). Furthermore, With the three-dimension variational data assimilation system WRFVAR, the local intense observations, such as atmospheric water vapour data of the ground-based GPS-MET network and surface observations of auto weather and road meteorological stations, are efficiently assimilated into forecasting system to improve prediction except of the routine meteorological data. In this paper, we briefly introduce the design of the fine-resolution road weather information system; especially, we conduct a thorough discussion the characteristic of atmospheric visibility's evolution and the corresponding physical analysis in the Beijing Expressway and the interpretation applications of nonlinear support vector machines.

Keywords:. road weather information, atmospheric visibility, special meteorological service, data assimilation, rapid update cycling system

1. INTRODUCTION

The safety of highway transport is sensible to the weather conditions. The targets of transportation, such as rapidity, efficiency, safety and punctuality, are restricted by the meteorological factors largely. With the rapid development of national economy and urbanization, the express traffic safety problem caused by weather factors has become an important issue to economy development. Developing and improving forecasting methods of road meteorological information always is a hot topic in meteorological field [2]. Recently, Zhang et al. (2007) [6]briefly reviewed the progress of Chinese and international research on major highway weather forecasting systems, and discussed their characteristics, difficulties and future developing tendencies. Furthermore, Zhang et al. pointed out that in china a good road weather information system should pay main attention to the fact of local weather conditions because road meteorological information is local and special. In the Greater Beijing metropolitan areas of North China (Beijing-Tianjin-Hebei Areas), the low atmospheric visibility events, especially such as heavy fogs that their visibilities are lower than 200 m, not only seriously affects the highway traffic safety and transportation, but also obviously increases the probability of traffic accidents. For practical design&application of a road weather information system, high forecasting skill on low atmospheric visibility events should be taken into account as the most important developing aim rather that on road ice/snow. In this paper, we briefly introduce the design of the developing fine-resolution road weather information system using in the Greater Beijing metropolitan areas of North China, and present major progress in applications.

2. DESIGN OF THE FINE-RESOLUTION ROAD WEATHER INFORMATION SYSTEM

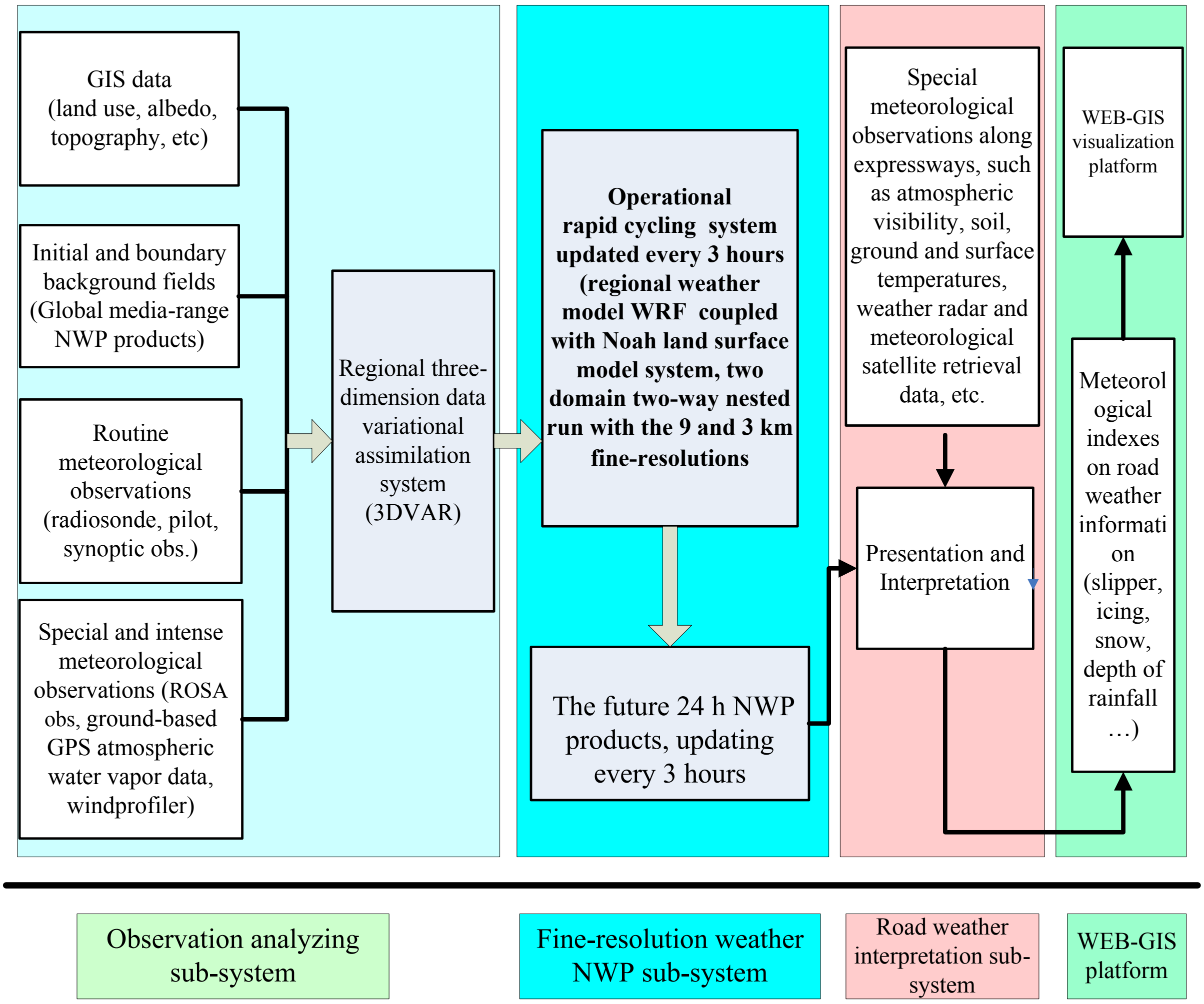

Fig. 1. Sketch map of the IUM road weather information system using in the Greater Beijing metropolitan areas of North China

Figure 1 gives the illustration of the road weather information system, which is design and developing at Institute of Urban Meteorology, Beijing. Now this system have been operationalized and used into the traffic weather services in the Greater Beijing metropolitan areas of North China (Beijing-Tianjin-Hebei Areas). As can be seen in Fig. 1, this system consists of 3 sub-systems and one WEB-GIS visualization operational platform. Based on the fine-resolution RUC system coupled with Noah land surface model, sophistical presentation&interpretation methods, and local density observations make it feasible to provide good and timely road weather information in practical.

3. BRIEF INTRODUCE TO ROAD METEOROLOGICAL MONITORING NETWORK

Fig. 2 Expressway network (red, white and blue lines) around the greater Beijing metropolitan areas.

Except of weather radars, wind profilers and routine weather observations, there is an intense road weather information monitoring network in the Greater Beijing metropolitan areas of North China. Now this network consistent of 18 ROSA observations of the Vaisala company of Finland, and 100 more auto weather stations partly with atmospheric visibility measurement. Figure 2 illustrates expressway network in the Beijing-Tianjin-Hebei areas, and Figures 3 and 4 presents the ground-based GPS-Met network in Beijing-Tianjin-Hebei Areas, and ROSA stations in downtown of Beijing city, respectively. All of three Figures show, partly but enough, the density distribution of the road meteorological monitoring network.

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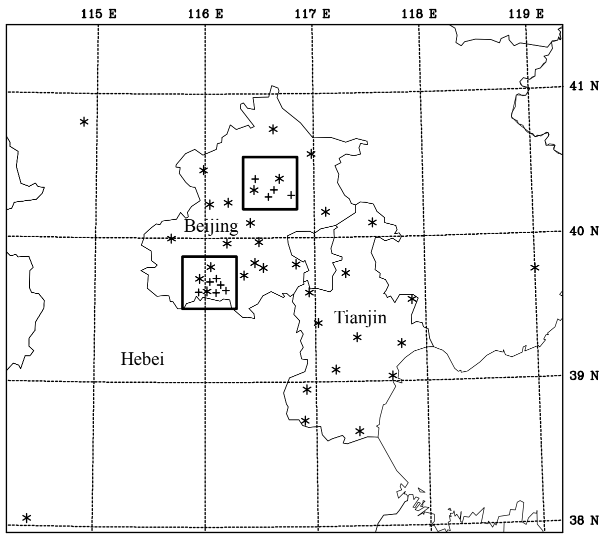


Fig. 3 Distribution of the ground-based GPS network for atmospheric water vapour. Single- and dual- frequency GPS station denotes with asterisk and plus sign, respectively. Tow bold squares highlight the intense observation sub-networks over the sensitive area to sever weather events (especially heavy rainfall) within Beijing using the mixed single- and dual-frequency ground-based GPS receivers.

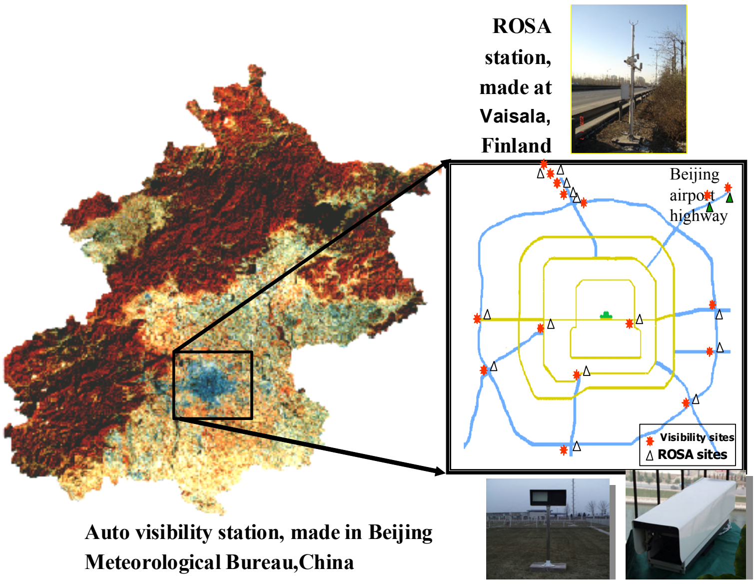


Fig. 4. ROSA Monitoring network for road weather information system

4. OBSERVATIONAL CHARACTERISTIC OF ATMOSPHERIC VISIBILITY

According to the continuous 21-months high temporal resolution data, which was observed by the special automatic weather stations ROSA at 5-min interval, in Beijing airport expressway (highlighted in Figure 4) from December 2004 to August 2006, the characteristic of atmospheric visibility's evolution and the corresponding physical factors in the Beijing expressway are studied. Results show that: (1) the visibility in the Beijing expressway has distinctly daily and monthly variation features, that is to say, the value of the summer/spring visibility is the highest/lowest of the year, and in 14:00 LST the value of visibility is the highest in a day, and the lowest time is uncertain in any day (see Figure 5 and Figure 6).

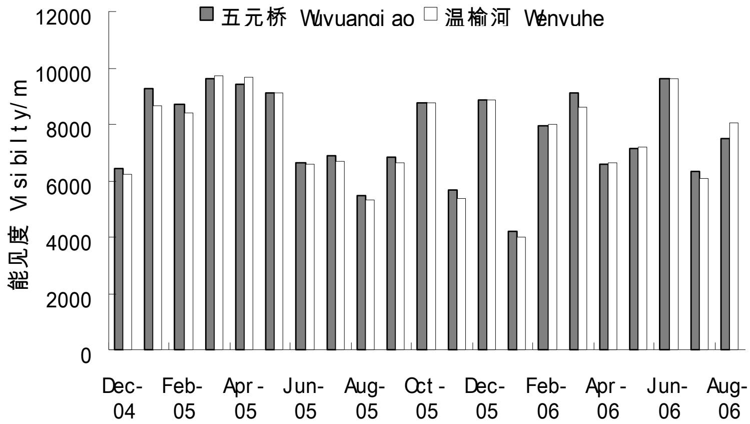


Fig.5 Monthly variation of visibility at Beijing airport expressway.

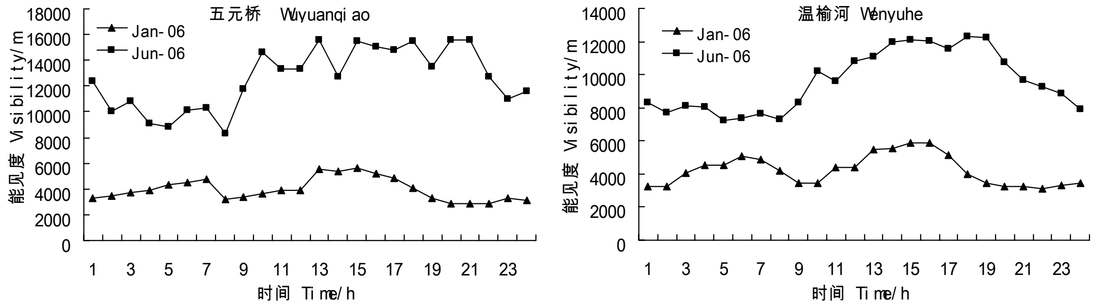
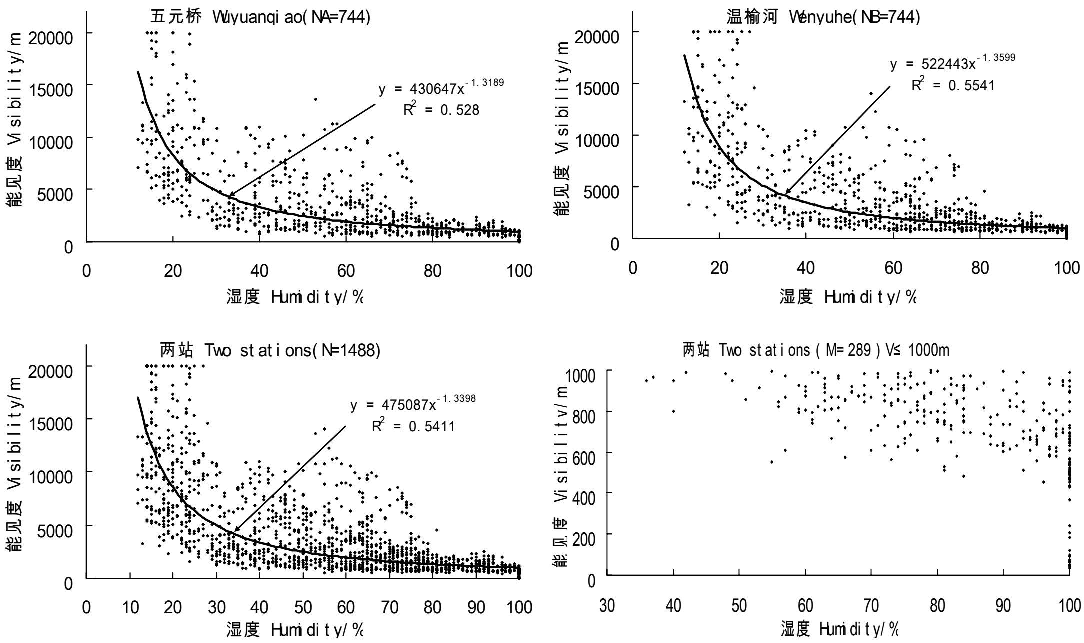


Fig.6 Daily variation at the two stations in January and in June, 2006

(2) Of monthly and daily variation , the relationship between the visibility and the meteorological factors is the complex nonlinear correlation (see Figure 7). Through analyzing the lowest monthly visibility in 21-month data, it is shown that the relationship between the visibility and the humidity is power, and is U type with the temperature. However, in the highest monthly visibility, the relationship between the visibility and the humidity changes to be exponential (Figure for the highest monthly visibility omitted). From the view of physics, the visibility reduction is effected by humidity through the water vapor's Rayleigh scattering and the fog's Mie scattering, is effected by the aerosol through the pressure resistance from the wind, and is effected by the water phase change through the Bergeron three-phase processes when the temperature is around 0℃.



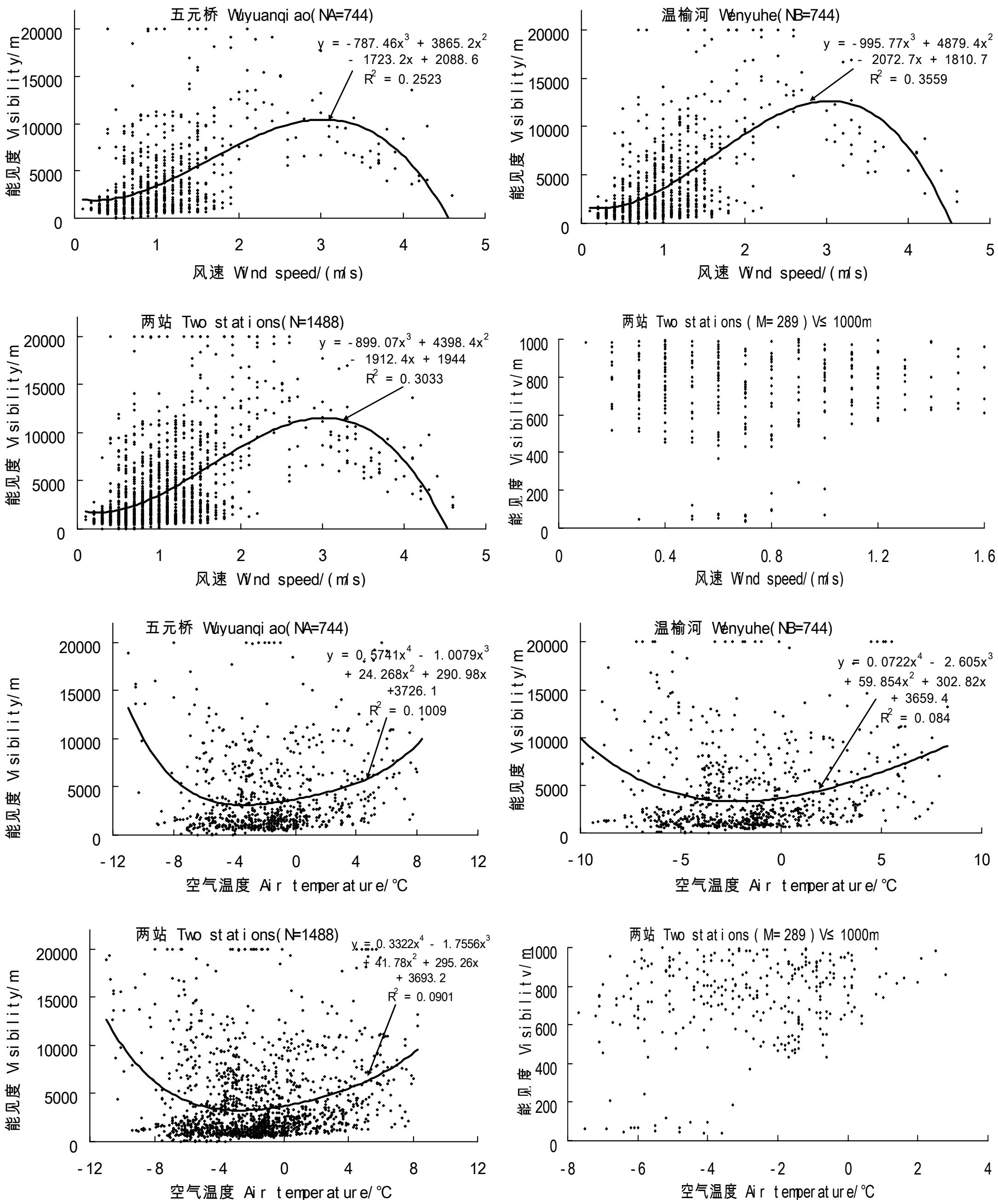


Fig.7 Discrete char of the relationship between the visibility and the humidity, wind speed as well as the temperature in January, 2006

(4) From Table 1 it clear shows that the visibility below 200 m happens mostly on the conditions that relative humidity of atmosphere is close to 100% (fog weather phenomenon), while the visibility above the 200 m is different. It is found that about 50% of visibility between 200 m and 1 000 m happens in the case of fog, and about 30% of 1～4km visibility is caused by fog. Thus, 1～4 km visibility mainly result from haze, sand storm and other weather phenomena.

Table 1 Times of visibility less than 4000 m as well as the corresponding distribution of humidity

Visibility/m	Times	Humidity100%		Humidity95%～100%		Humidity90%～100%	
		Times	Frequency	Times	Frequency	Times	Frequency
V＜50	84	81	96%	83	99%	83	99%
50≤V＜200	230	211	92%	230	100%	230	100%
200≤V＜1000	21706	7124	33%	11029	51%	13664	63%
1000≤V＜4000	121560	13539	11%	23555	19%	33559	28%

(4) The visibility below 1 000 m appears on the conditions that temperature is very low, humidity is very high and the wind velocity is very small, but it is only the essential condition not the full condition, especially for the heavy fog which visibility is below 200 m (See Figure 8).

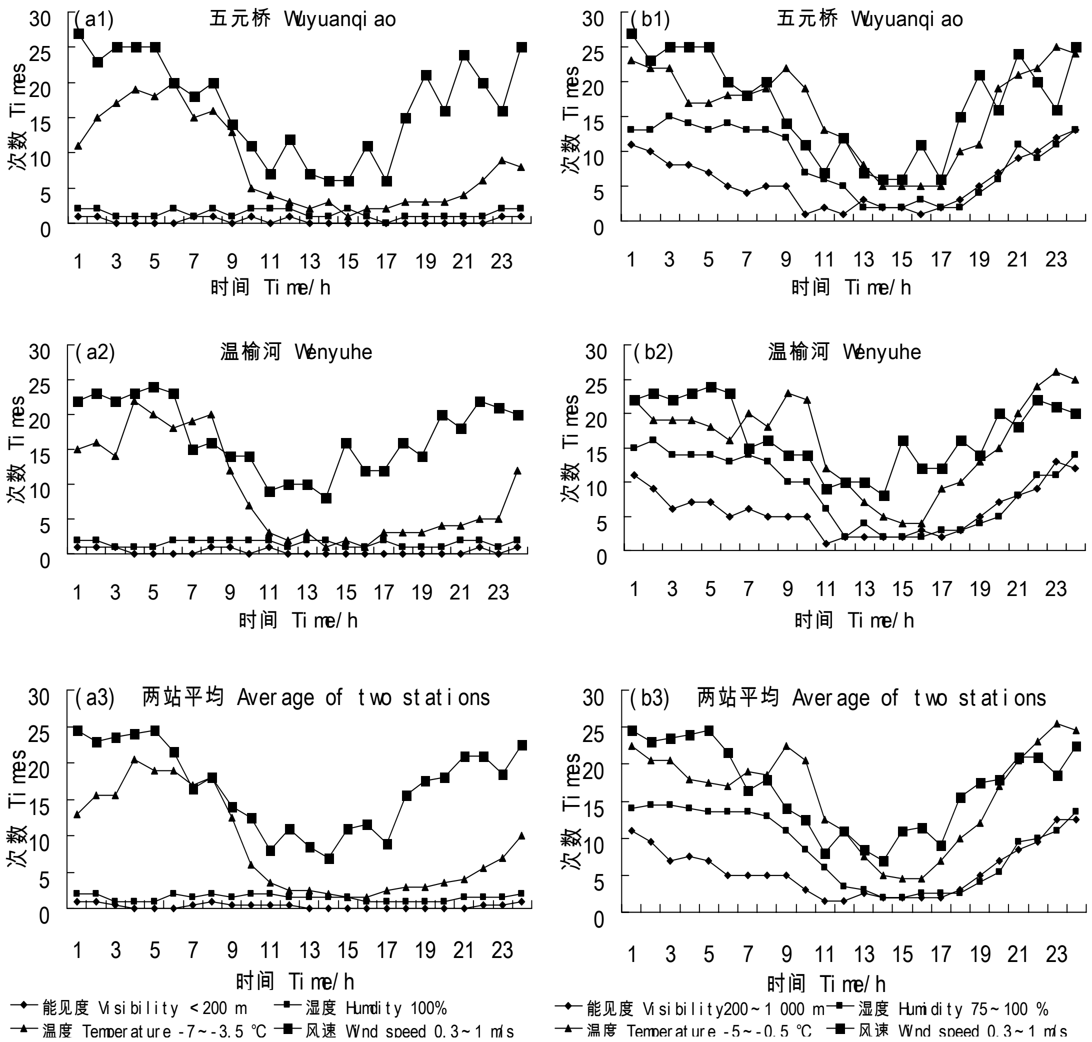


Fig.8 Times of the low visibility 0～200m（a）,200～1 000m (b) and the times of their corresponding meteorological factors respectively

5. Improvement on the fine-resolution numerical prediction system

To improve the forecasting skills of road weather information, many efforts are done to efficiently implement the local GIS information and intense meteorological data assimilation e.g. [6]-[8], [1]. Especially, the retrieved data of atmospheric precipitable vapour of ground-based GPS is successful assimilation into the fine-resolution RUC system coupled with Noah land surface model, numerical results show that assimilation of GPS/PW observations with the 3 dimension data variational assimilation method (3DVAR) significantly helps to improve the moisture analysis at the initial time of the numerical forecasting model, and then assists to improve the prediction upon location, intensity and evolution of heavy rainfall events. For example, Zhang et al. (2006)[8] assessed the impacts of the topographic effects and the individual components of meteorological observations (ground-based GPS PWV data, automatic and conventional meteorological observations) on the torrential rain event on 4 - 5 July, 2000 in Beijing (with 24 h accumulated precipitation reaching 240 mm), and found that the threat scores (TS) with thresholds of 1 , 5 , 10 and 20 mm are increased by 1 % - 8 % for 6 and 24 h accumulated precipitation observations by incorporating the PWV data of ground-based GPS network into the 3DVAR analyses at the initial time.

6. The sophistical presentation&interpretation method: nonlinear support vector machines SVM

Owing to the observational relationship between the visibility and the meteorological factors is the complex nonlinear correlation, the sophistical nonlinear SVM method is used to modelling the forecasting method of atmospheric visibility classification with visibility observations. The SVM method is a nonlinear and a few samples study method base on the statistic learning theory [3]-[4]. The final decision-function of SVM is only confirmed by a few of support vectors, and the complication of calculation depends on the number of support vectors rather than the dimension of sample space. The method is available to deal with nonlinear mathematical and physical problems. In operational application we use SVM nonlinear regression method, and select radial basis function as kernel function, that is:

$$K(X, X_i) = \exp(-r\|X - X_i\|^2)$$

Format of final regression function is defined as:

$$f(X) = \sum_{\text{support vector}} (\alpha_i - \alpha_i^*) K(X, X_i) + b$$

$$= \sum_{\text{support vector}} (\alpha_i - \alpha_i^*) \exp(-r\|X - X_i\|^2) + b$$

X_i is sample factors of support vector, X is pre forecast vector's factors, α_i, α_i^*, b are pending coefficients of founding SVM model, r is kernel parameter.

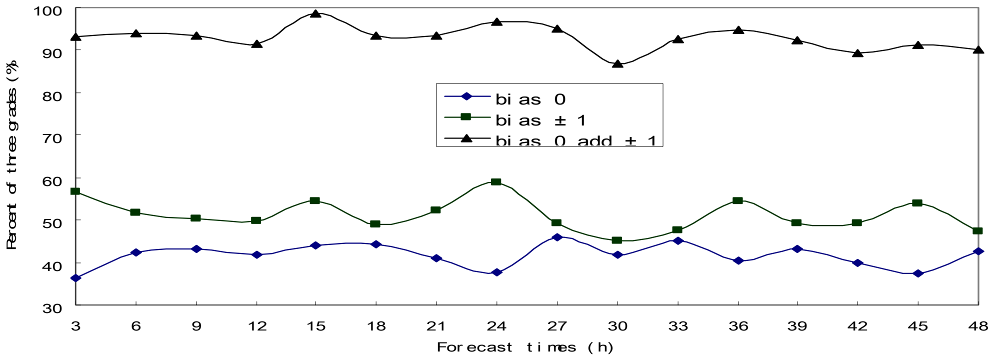


Fig. 9 The verification of 03-48h visibility classification forecast of Wuyuanqiao station in spring 2007. Verification of the atmospheric visibility classification is done at each forecasting time of the SVM model. The bias results have been divided into three kinds: the same classification (classification bias is 0), discrepancy is 1 (classification bias is ±1) and same classification add discrepancy is 1. Count the number of each verification score to get the percent of three forecasting skills in total forecast data. Atmospheric visibility is classificated into six grades ($V < 50$ $50 \le V < 200$ $200 \le V < 1000$ $1000 \le V < 4000$ $4000 \le V < 10000$ $V \ge 10000$).

Use the visibility data (ROSA station Wuyuanqiao at 39°59´45"N , 116°29´30"E), the NWP operational results of meso-scale model in Beijing areas, and the auto weather station (AWS) data as experimental data. The data of spring 2006 (March to May) has been used to modelling the forecasting method of atmospheric visibility classification, and the verification results of spring 2007 shown in Fig. 9, it indicates that the performance of forecast model basing on Support Vector Machine method is good. The verification indicates 40 percent of atmospheric visibility classification forecast agree with the observing data and more than 90 percent forecast classification's errors are within one level(include equal). In addition, the performance of 3–48 hours atmospheric visibility forecast is stable. The perfect forecast of atmospheric visibility classification provided by Support Vector Machine method attributes to its capability of processing the nonlinear relation between air visibility and metrological factors.

7. WEB-GIS VISUALIZATION OPERATIONAL PLATFORM

A WEB-GIS visualization operational platform has been developed. Figure 10 shows two representative products. With this platform, the road weather information can be more easily "SEE" and make service more rapidly and efficiently.

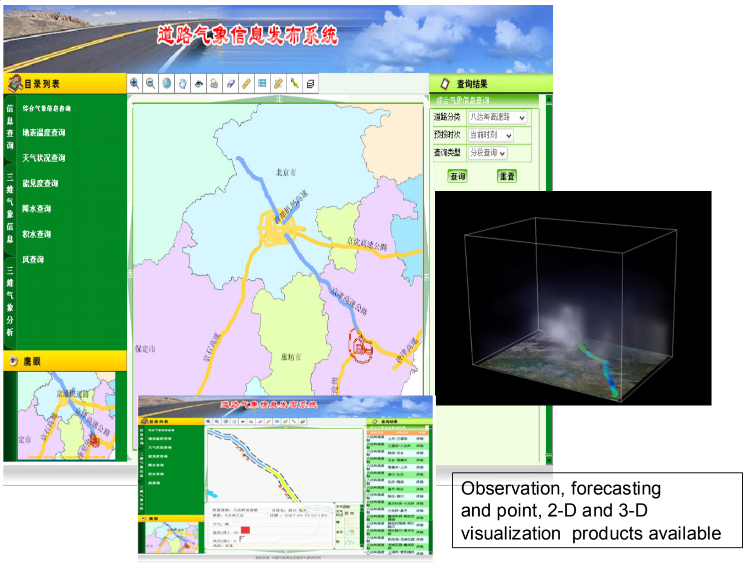


Fig. 10 The WEB-GIS visualization operational platform, site, road, region, and three-dimension products are available.

8. CONCLUDSION

In this paper major advances on the design&application of the fine-resolution road weather information system developed in the Beijing-Tianjin-Hebei areas are briefly introduced. Further investigations on special models of road temperature and depth of accumulated rainfall amount are still necessary in the future.

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