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Characteristics of Road Surface Temperature in Beijing Winter and its statistic forecasting models Based on the RMAPS Product

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Abstract. An analysis of the inter-diurnal variation of road surface temperature in the different weather conditions in Beijing winter is done, based on the data of the road stations from 2012 to 2017 and the outcomes from the numerical forecasting model, Rapid-refresh Multi-scale Analysis and Prediction System (RMAPS), which are constructed in this paper. First, the correlation coefficients between road surface temperature and the meteorological factors output by the RMPAS model are investigated. We used the stepwise regression model methods to build three kinds of types of statistical models for hourly road surface temperature in 24 h in winter. Then the best forecasting models are chosen to build for forecasting road minimum temperature in winter from A1027 road station selected. The results show that there exists a significant diurnal variation for the road surface temperature, suggesting that the road surface temperature is obviously different under the different kind of weather conditions. The road surface temperature is correlated with air temperature, atmospheric radiation, and sunshine duration. Compared to the type of statistical model with the only one factor for the road temperature of previous day, the type of regression model with meteorological elements of remarkable correlation inserted performs better in terms of the road surface temperature forecast accuracy by more than 25%, and the prediction error decreases by 1℃.

Keywords: road surface temperature, RMAPS, forecasting model

1. Introduction

As an important transportation hub, Beijing of China is the starting point of several expressways and one of the transportation transit stations connecting various provincial capitals. There exists circle roads and the highways radiate in all directions, leading the municipal government to assume the heavy responsibility of transportation security. Affected by severe weather in recent years, the requirements for weather information of influencing transportation is growing. It is found that the extreme road surface temperature is one of the most important factors. The analyses point out that the minimum temperature in winter appears at night most often, and, in addition, snow can easily cause ice on the road

and affect the normal operation of the traffic line (Li Xun, 2012). The minimum temperature in winter would lead to ice on the pavement, which would reduce the friction coefficient of the pavement, and then causing traffic congestion and even accidents. It is therefore vital that the meteorological department accurately provides the related highway weather forecast to improve road traffic safe driving (Yin Zhicong, 2015; Zhai Liang, 2108; Sun Jun, 2018).

In the 1950s, the United States, Canada and the Netherlands had developed models for calculating the maximum and minimum temperatures of the pavement (BARBER E S,1957).   After entering the 21st century, based on the road surface temperature and air temperature, the prediction models of the maximum and minimum temperatures of the pavement in the different areas as well as GIS prediction model (Chapman L,2010a,2010b) were established according to the division of seasons (Shao et al,1996; DIEFEN DERFER B K,2003) . Some international meteorological departments used high-density detection models to provide road surface temperature, and used the numerical analysis method to combine meteorology and heat transfer. There are many parameter factors among which most of them were detected by special instruments, so it is difficult to realize localization in a short time (Hertl S et al,2010; Hermansson et al,2000; Kr ˇ smanc et al,2014). Many scholars established the road surface temperature forecasting models by using the heat conduction differential equation via the theoretical analysis method (Wu Ganchang,1998; Feng Tao,2012), including land surface models with combining the multi-source data results as its forced fields (Meng Chunlei,2012;Feng Lei,2017). On the other hand, the statistical analysis method is also employed to integrate the physical models for forecasting the road surface temperature in space, line and point. However, most of the meteorological factors come from the observation among which main ones are based temperature, including (e.g.) the maximum, minimum, and average temperature. Other observed data such as wind, cloud cover, precipitation and pressure are supplemented (Ma Shaiyan, 2012; Shu Si, 2016; Liu B, 2018). Both manual and automatic observation of these factors will inevitably contain some record error information. As far as the regularities of distribution of the asphalt pavement analyzed is concerned, the surface temperature, temperature and solar radiation intensity should be the main factors. In fact, radiation data were usually not observable so the model data are employed to assist the analysis. Li Naijing (2017) used mechanism analysis method to improve the land surface model and introduced the radiation factor in the Beijing regional model data, and it is found that the predictive effect was better than before (Feng Tao,2012).

Recently, Rapid-refresh Multi-scale Analysis and Prediction System (RMAPS) was developed widely in business application (Dong Yan,2017). In this study, RMAPS output data would be used to establish statistic forecasting models based on the analysis of characteristics of road surface temperature in winter in Beijing. In addition, we took account on the surface road temperature on the day before, which was applied to judge whether meteorological factors participates or not in terms of the prediction accuracy. Finally, we would built the hourly prediction model. The statistic forecasting model as a supplement to the land surface model, incorporated into it and then combined these two kinds of models for forecasting road surface temperature from point to line, as well as from grid to road line.

2. Data and Methods

2.1. Road stations data
There are 28 road stations in Beijing, which are mainly located on import and export of highway port (Beijing-Tibet, Beijing-Harbin, Beijing-Tianjin-Hebei Expressways), fifth ring road with the trunk roads centered on the capital.

In this study, we focus on the hourly road surface elements from January 1, 2008 to December 31, 2017. We choose A1027 road station, located out of Beijing airport expressway of 12.8 km, as representative standing modeling. To distinguish the different weather types, another important dataset is the observational data on 20 National observation station in Beijing, involving sunshine duration, daily rainfall, daily snowfall, via the difference value disposal to correspond the station position.
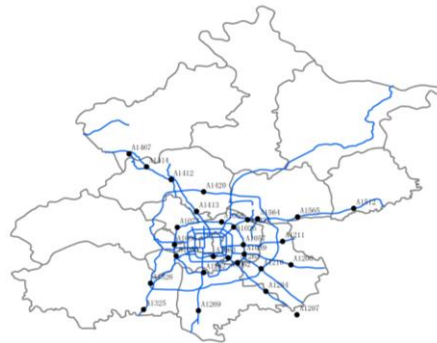
Figure 1. Spatial distribution of the road stations in Beijing

2.2. RMAPS model

The Rapid-refresh Multi-scale Analysis and Prediction System (RMAPS) with its predecessor being the Rapid updated cycle system for the Beijing areas (BJ-RUC), comprise the WRF3DVAR system and 3D Assimilation System, used as daily operational application in the Beijing Meteorological Bureau. The model operation is steady with a high accuracy on conventional forecast and precipitation. The RMAPS output products scroll to update by every 3 hours, in which the 08 h as the model comparative time with the spatial resolution of 3 km. Benefitting from the abundant RMAPS outputs, Long wave radiation (GLW), surface pressure (P_{sfc}), Air Temperature (T_2), Relative Humidity at 2 m (RH_2), Shortwave radiation (SWDOWN), radial wind at 10 m(U_{10}), zonal wind at 10 m(V_{10}), hourly accumulation precipitation(P_{t_total}) were included.

2.3. Methods

For a high accuracy sake, we calculated the average of the bias 0.5 degree of longitude and latitude region from all grid of RMAPS output products, used to fit the road station position. For example, the 0.5 degree deviation of A1027 (116.56E, 40.03N) distance is 116.06~117.06E, 39.53~40.53N. There are total 989 grid data of RMAPS matching up it. Then the average of the chosen grid data would be the forecast of the road station.

Taking the contrast date of RMAPS ground with the road station, as well as adding the surface temperature corresponding hour to the day before (T_{ex_day}), we build hourly road surface temperature forecasting models to forecast next 24 hours.

During the modeling process, in order to estimate the prediction accuracy of the statistic forecasting models whether involved meteorological elements or not, we choose the different factors to take part in building three kind of statistic models. First, the model only adds the surface temperature corresponding hour to the day before, which propose to measure the weight ratio and the influence of itself. Second, the model screens out the main meteorological factors on the preceding. Third, the model takes all of meteorological factors. Then we compare to three kind of models from fitting checking, electing the best one to comparatively analysis with observed value.

3. Characteristics of Road Surface Temperature

It is verified remarkably diurnal variation on the road surface temperature and air temperature in winter (Figure 2). According to the statistics, the minimum temperature appears from 06 to 07am. With the sunrise, the temperature presents on upward trend and go to peak around 14 to 15pm, then falls in the afternoon. While the rise or fall speed of the road surface temperature is faster than air temperature the phase error of the maximum road surface temperature is ahead 2 hours of air temperature, in spite of little temperature difference in the evening.
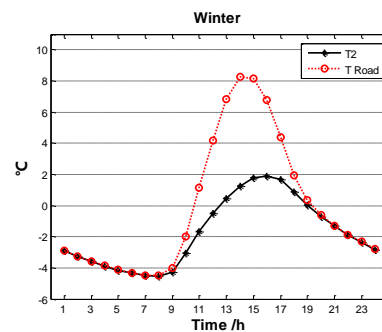
Figure 2. Diurnal variation of the road surface temperature and air temperature in winter
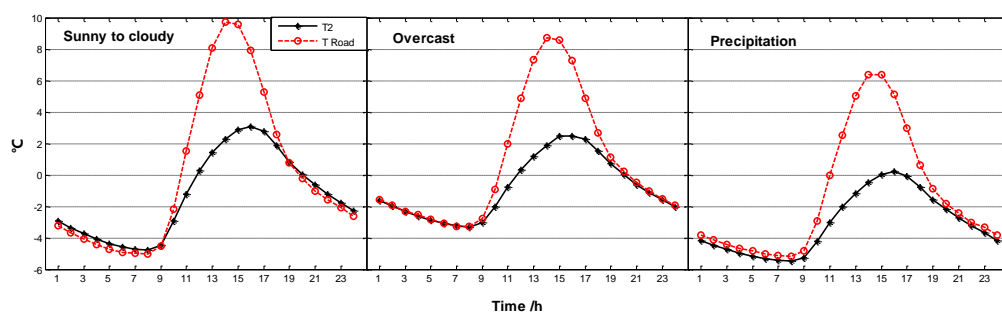

Figure 3. Diurnal variations of the road surface temperature and air temperature in the different weather conditions in winter

There is a litter difference for diurnal variations of the road surface temperature and air temperature in the different weather conditions in winter (Finger 3). The temperature presents higher on sunny to cloudy than overcast in the daytime, while opposite in the nighttime. It would be lower by 3 to 4 ℃ on rainy than other weather conditions. Linking the finger 2, it is found that the surface road temperature and air temperature emerge significant difference between 1.5 hours on sunrise and sunset. Specifically, the phase of road surface temperature ahead to air temperature on sunrise, because of the difference of heating source. The heating of air temperature is mainly from the long-wave radiation by the underlying surface, while the short-wave radiation acts as the primary heating source of road surface temperature. In addition, the heavy traffic flow causes friction, leading heat the bituminous pavement to thermal function during the daytime. The road surface temperature would fall faster than air temperature after sunset, because the long-wave radiation plays a dominant role. It was stronger during clear-sky nights, which lead to colder road surface.

4. Model Establishment and Assessment

The road surface temperature principally is affected by the natural environment including meteorological factors. After the statistical analysis correlation between RMPAS outputs and the road surface temperatures, with the road surface temperature the day before imported, we build hourly temperature forecasting 24 hours by month and the minimum temperature statistic forecasting models with the different road stations on different updated. A1027 as an example to elaborate, then other stations using the same methods to build forecasting models.

4.1. The linear correlativity

As expected, the road surface temperature is highly associated with itself at the different periods. The most relevant factor is the road surface temperature the day before. The major significantly correlative of meteorological factors are $SWDOWN, T_2$, with above 0.5 correlation, and GLW, RH_2 as the second place. However, U_{10}, V_{10}, P_t present the lowest correlation. P_s, RH_2 reveal the negative correlation. As a result, different factors input to build forecasting statistic models is considered.

Table 1. The correlation coefficients between the road temperature and the meteorological factors output by the RUC in the winter half year for 2012 to 2013.

Factors	GLW	P_s	RH_2	SWDOWN	T_2	U_{10}	V_{10}	P_t	T_{ex_day}
Correlativity	0.41[**]	-0.04[*]	-0.39[**]	0.59[*]	0.86[**]	0.01	0.08[*]	0.02[*]	0.91[**]

Degree of freedom = 3369, ** and * represent beyond 0.01 and 0.05 significance testing, respectively

4.2. Models building
Considering different factors effect, three kinds of statistic model are established. First, the Y1 model only adds T_{ex_day}, which propose to measure the weight ratio and the influence of itself. Second, the Y2 model Inputs the major meteorological factors, SWDOWN and T_2, on the preceding. Third, the Y3 model takes all of meteorological factors. The results evaluate prediction accuracy of three kind of forecasting models, including the contributing ratio of meteorological factors via Y1 contrast to Y2 and Y3, then to select the best one to comparatively analysis with the observed value.

Comparing between the forecasts by the three regression models is made with the observations for A1027 at 08 h in the winter half year from November 2012 to March 2013 (Finger 4). The three kind of monthly models could fit the tendency of the diurnal variation of temperature, especially the fitting result of Y3 model in which the wave peak and hollow of variation temperature approach the observation. With the monthly variation, the simulation results could response the climate temperature changes in winter. However, the simulated result appeared high side by contrast with the observation on 11 January . In fact, the reason for the inaccuracy is that the air condition was not well on that day. Therefore, the models forecast temperature tends to becomes worse under the air condition like precipitation or cloudy one.
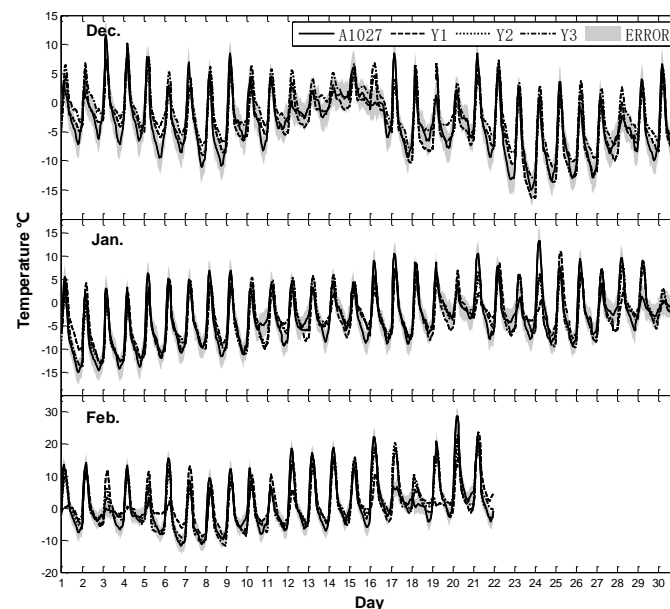

Figure 4. Comparison between the forecasts by the three regression models with the observations for A1027 at 08 h in the winter half year from November 2012 to March 2013.

It was showed that the case with the meteorological significant factors added, Y3 model, was simulated best (Table 2). Y3 model represents the improvement of fitting and the results is obviously better as done through the comparative analysis with other models. The predictive accuracy was enhanced by 25%, and the mean absolute error (MAE) would be controlled within 2.5 ℃.

Table 2. The comparison of the forecast results among the different regression models from November 2012 to 30 March 2013

models		Y1	Y2	Y3	Effect increasing
Dec.	**R**	0.759	0.927	0.932	
	MAE	4.452	1.447	2.054	46.1%
	RMSE	5.487	1.778	2.493	45.4%
Jan.	**R**	0.866	0.924	0.928	
	MAE	2.002	1.522	1.515	24.3%
	RMSE	2.671	2.045	1.993	25.4%
Feb.	**R**	0.769	0.911	0.926	
	MAE	3.473	2.326	2.241	35.5%
	RMSE	4.793	3.099	2.833	40.9%

As expected, we finally chose the Y3 model to forecast the road surface temperature and assess the predictive accuracy via the model contrast with the observation (Figure 5). With longer leading time, it presented a good correlation between the model and observation. The diurnal variation trend of the track temperature would be predicted with the statistic model, where the peak between forecast and observed value occurred mismatch, causing some individual points deviated sharply from the diagonal in scatter plot. It was significantly different for the minimum temperature during the nighttime. On the basis of the perspective of atmospheric forcing, long-wave radiation at night plays a key role, and, on the other hand, the influence of long wave radiation on track temperature is not as great as short wave radiation. Therefore, the forecast result on daytime is better than that on night. The peak of error density was below 0℃, which explained that the average value of forecast was lower than that the observed. The MAE with longer leading time became weaker, the float of MAE sharply changed after 10 hours.
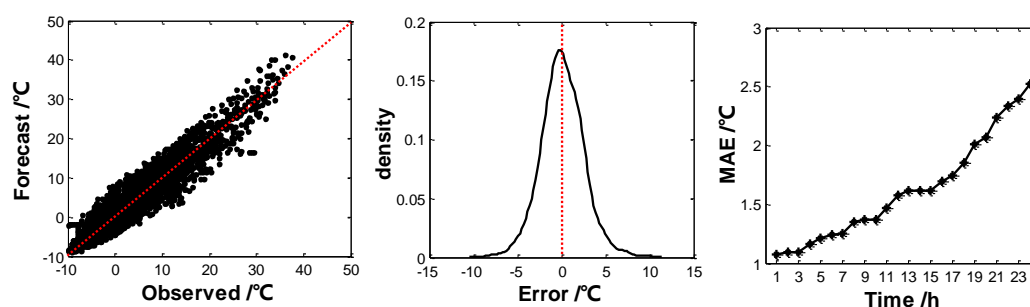
Figure 5. Error estimation between the forecast and the observation at 08 h

(The left panel is for the observed-forecast scatter, the middle one for the error-density plot, and the right one for the mean absolute error)

5. Conclusion

The main aim of this study was to analysis the characteristics of road surface temperature and establish the statistic forecast models based on the RMAPS outputs. In the light of the results, there were obvious diurnal changes in road surface temperature, which was different from air temperature, especially under the different weather conditions. Our results show that there is a good correlation between road surface temperature and meteorological factors, with the air temperature having the greatest correlation, and radiance factor and sunshine duration as the second place as shown in the statistic model.

The established statistic forecasting models could fit the tendency of the diurnal variation of temperature, especially the fitting result of Y3 model where the wave peak and hollow of variation temperature approach the observation. It explained the meteorological factors became more important. Compared to the Y1 model in which input the significant factor was only road surface temperature the

day before, the predictive accuracy of Y3 model was enhanced by 25% with the error reduced by above 1℃.

The meteorological factors of statistic forecasting models depended on the RMAPS output, whose predecessor named Beijing Rapid Update Cycle (BJ-RUC) before 2017. The predictive accuracy of precipitation and temperature was enhanced owing to the model technology improvement. However, the station environment changed deeply, leading the record of observed data missed or error, which influenced distinctly the accuracy of forecasting models.

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