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GIS-based Meteorological Data Processing Technology for Forest Fire Danger Rating Forecast System of China

Yinghui Zhao, Zhen Zhen and Fengri Li[1]*

School of Forestry, Northeast Forestry University, Harbin 150040, P. R. China

Abstract : The data of average temperature, average relative humidity, precipitation and average wind speed were collected from 674 meteorological stations in China. A specific procedure that processes original data into a new data format needed in forest fire danger rating forecast system of China was introduced systematically, and the feasibility of this method was validated in this paper. In addition, a set of meteorological data processing software was constructed by the secondary development of GIS in order to realize automation of processing data for the system. Results showed that the approach preformed well in handling temperature, average relative humidity and average wind speed, and the processing effect of precipitation was acceptable. Moreover, the automated procedure could be achieved by GIS and the working efficiency was about 3 times as much as that of manual handling. The informationization level of processing meteorological data was greatly enhanced.

Key words **:** *GIS, forest fire danger rating forecast system, ArcGIS Engine, VBA*

Introduction

Forest fire forecast refers to forecast possibility of fire outbursts, index of forest fire behaviors after fire and difficulty level of controlling fire through measuring and calculating some nature and human factors (Hu, 2005). It experienced a development history of nearly a hundred. Owing to the strong scale effect of forest fire forecast, different regions or scales require various forecasting methods. Forest fire danger rating forecast is a kind of weather forecast of potential of forest fire (Yan, 2001), and an effective method for reducing fire outbursts and concomitant damage. It enhanced the level of forecasting techniques that focused on qualitative fire weather forecast in the beginning of 20th century. Since 1960s, an expanding number of countries have paid more attention to this method. The Fire Danger Rating System produced by A.G. McArthur has been used as the standard forest fire danger rating system in eastern Australia in 1960's (Hu, 2005). In 1972, the National Fire Danger Rating System (NFDRS) was released for general use by agencies throughout the United States. The current form of the Canadian Forest Fire Danger Rating System (CFFDRS) has been under development by the federal forestry service in Canada since 1968 (Tian *et al.*, 2005). Nevertheless, spatial variation in fuels and terrain is a fire management information problem not easily handled by most systems, unless linked by computer technology to a geographic information system (GIS) (Lee *et al.*, 2002). To some extent, meteorological data used in forest fire danger rating forecast system are defined as a sort of geographic information since temperature, humidity, wind speed and precipitation should be serviced for specific spatial and time domain. And, GIS, which is a type of computer system of visualization of spatial information (Li, 2002) just finds a breakthrough for processing and operating meteorological data. In the 1990s, popularization of GIS brought a radical revolution to forest fire forecast (Hu, 2005).

With continual improvement, nowadays the CFFDRS is one of the most well developed and widely applied schemes in the world (Harris *et al.*, 2001), including two major subsystems---the Canadian Forest Fire Weather Index (FWI) System and the Canadian Forest Fire Behavior Prediction (FBP) System. CFFDRS, which is applicable to any scale, has been used in New Zealand, Fiji, Mexico, Alaska, Florida and Southeast Asia nations successfully. Due to its favorable adaptability, it is better to develop the fire danger rating system of China based on the technologies of the CFFDRS (Tian *et al.*, 2005). However, CFFDRS is a non-spatial system, which provides the science framework for fire danger rating in Canada (Lee *et al.*, 2002). It deals with the prediction of fire occurrence and behavior from point-source weather measurement and does not account for spatial variation

*Corresponding author
E-mail: fengrili@live.com

in weather elements between points of measurement. Models and other systems external to the CFFDRS must handle such interpolation (Lee *et al.*, 2002).

To solve this problem, this study researched an approach that could convert original data to a new data format needed in Forest Fire Danger Rating Forecast System of China, which based on fire weather index (FWI) model in CFFDRS and combined mathematical analysis and field experiments. This method was validated daily by data from 168 independent meteorological stations. In view of abundance and complexity of data, meteorological data processing software for auto-processing meteorological data for the system was constructed through secondary development of GIS. In addition, taking other 506 meteorological stations as example, forest fire danger rating of China from July 21 to July 31, 2009 was forecasted efficiently. The application of the software greatly enhanced process speed and ameliorated display effect of meteorological data.

Materials and Method

1. Study area

China, ranging across 73° 40' E-135° 2' E and 3° 52' N-53° 33' N, possesses 96,000,000 (sq.km) and covers approximately one fifths of total terrestrial area on the Earth. The immense coverage area results in a span of six temperature zones, of which, the area of subtropical zone, warm temperate zone and middle latitude temperate zone accounts for 70% of that of the whole country.

The dominant factors of formation of climates in China are geographical latitude, solar radiation, ocean current, terrain, and atmosphere circulation. The interaction and mutual checks among them engender diverse climate types of China. The east is mainly dominated by monsoon climate, that is, continental monsoon climate leads to chilliness and desiccation in winter, while maritime monsoon climate brings on torridity, humidity and raininess in summer. Particular frigid climate is formed in Qinghai-Tibetan Plateau for its high elevation and enormous area. The west, which is far from ocean, is under the control of inland acid climate instead.

2. Data collection

Data for this study were collected from 674 meteorological stations, which were distributed in 31 districts, including 22 provinces, 4 municipalities and 5 autonomous regions (Figure 1). Financing by Planning Programs for Science and Technology Support of China, core user of China meteorological data sharing service system (http://cdc.cma.gov.cn/) was applied and meteorological data were downloaded from surface daily climate dataset of China. The data, comprising meteorological

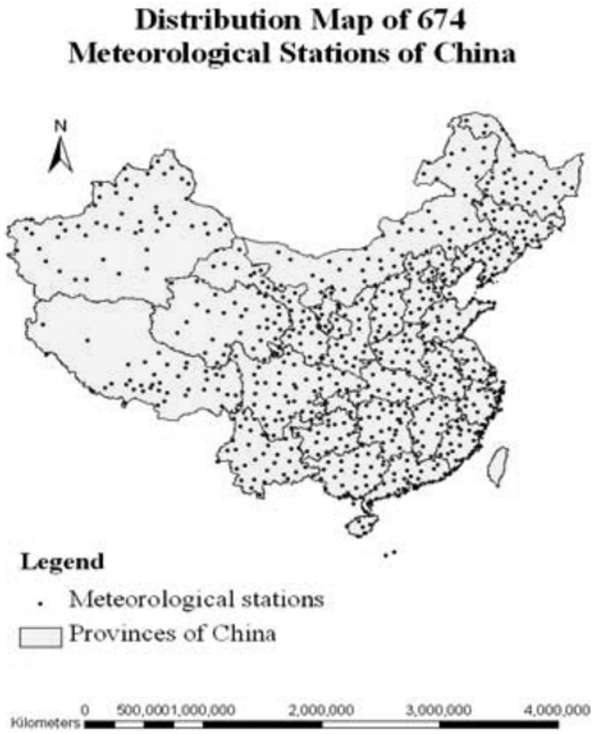

Figure 1. The distribution map of meteorological stations used in this paper.

station index number, date, average temperature, average relative humidity, precipitation and average wind speed, were TXT format and recorded daily.

Geographic information is the premise of processing and manipulating meteorological data, that is, meteorological data should be attached to geographic location. However, few of meteorological stations supply this kind of data. Therefore, before processing data, pre-processing was demanded, including converting units, processing outlier and connecting meteorological stations to data. After preparation procedure, 674 simple meteorological stations divided into two groups: fitting data set (506 stations) and test data set (168 stations). The statistical results of 674 meteorological stations from 07/21/2009 to 07/31/2009 are presented in Table 1.

3. Data processing

In order to acquire reliable forecasting results, the nationwide meteorological data in a certain resolution should be predicted by interpolation algorithms. Interpolation can be defined succinctly as the process of predicting the value of a given variable at an unknown location from values of the same variable at surrounding, known locations (Harris *et al.*, 2001). The interpolation method used in this study is Thiessen polygon interpolation. Thiessen polygon was originally employed for calculating average precipitation from discrete meteorological stations (Huang and Li, 1996; Zhang and Cui, 1991). At present, this

Table 1. The statistical results of 674 meteorological stations from 07/21/2009 to 07/31/2009.

Data Group	N	Variables	Mean	Std.error	Minimum	Maximum
Fitting data set	506	Average temperature (ºC)	23.29	0.07	3.90	35.10
		Average relative humidity (%)	0.71	0.00	0.12	1.00
		Precipitation (mm)	4.64	0.17	0.00	165.20
		Average wind speed (m/s)	1.95	0.02	0.00	15.50
		Latitude (°)	34.12	0.10	16.53	52.97
		Longitude (°)	109.15	0.16	75.23	132.97
Test data set	168	Average temperature (ºC)	23.1	0.1	5.4	34.5
		Average relative humidity (%)	0.69	0.00	0.08	1.00
		Precipitation (mm)	4.3	0.3	0.00	194.0
		Average wind speed (m/s)	2	0.00	0	12
		Latitude (°)	34.61	0.17	16.53	52.97
		Longitude (°)	108.87	0.28	75.23	132.97

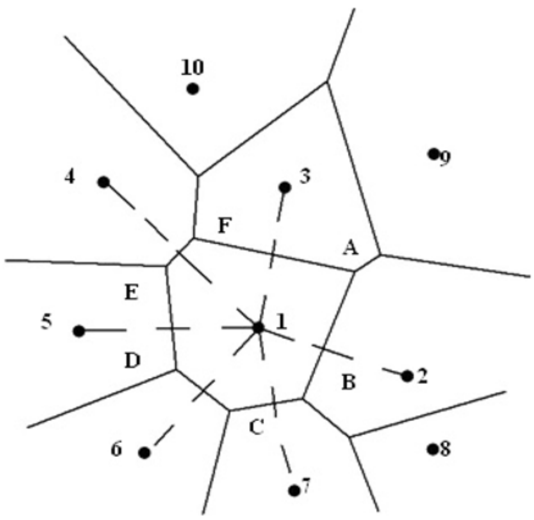

Figure 2. The construction of Thiessen polygons.

approach, which can obtain polygon by point sources, is widely used in fields of geoscience, resource science, environmental science, meteorology and so forth.

The principle of Thiessen polygon interpolation was showed by Figure 2. The perpendicular dissectors of the lines joining No.1 station and its adjacent stations (No.2 to No.7) form the Thiessen polygon and define which stations are neighbors. Obviously, No.8-10 stations are not neighbors. Therefore, Thiessen polygon (polygon ABCDFE) presents neighborhood region of No.1 station and share its attributes. Considering a certain amount of meteorological stations (506) as generators, data covered the whole research area were gained by constructing Thiessen polygon.

In order to generate ASCII file of each meteorological factor precisely, triangulated irregular networks (TIN) that Z value is meteorological factor should be constructed based upon Thiessen polygon (SHAPE file). TIN model is a sort of methods for fitting terrain by applying a series of plant triangles with the same slope (Fan and Zhou, 2003). This idea was adopted in this study: every meteorological factor (average temperature, average relative humidity, precipitation and average wind speed) was fitted by a chain of plant triangles with the same value. Due to avoiding limitation of distribution of meteorological stations, this kind of TIN model expressed meteorological characteristics well. After that, TIN model of each meteorological factor should be converted to raster model since attribution can be expressed in explicit form (Fan and Zhou, 2003), and then to ASCII file. Owing to cell size of GRID model can be set up as required, we define cell size as 10000 m according to display effect of forecast map. The GRID model of 10000 m resolution, dividing the research area into 506×700 cells, could meet the requirement of forecast results. In this way, meteorological factors in each cell will be described readily and conveniently.

4. Validation

After data processing, cross-validation is needed to analyze the results of processing, that is, 75% of meteorological stations are involved into interpolation while the others are used to verify precision estimation (Feng, 2002). Hence, 168 independent stations were drawn randomly from 674 stations in daily validation and processing results of 11 days were verified. The validation is performed by Mean Error (ME), Mean Absolute Error (MAE) and Precision Estimation (P%).

5. Techniques of automated data processing

Recent years, diverse professional development kits of GIS swarm into GIS market. And component GIS best represents the development trend of GIS. Based on Component Object Model (COM), Microsoft released ActiveX component technique, which was employed in most of component GIS. It provides developers a more

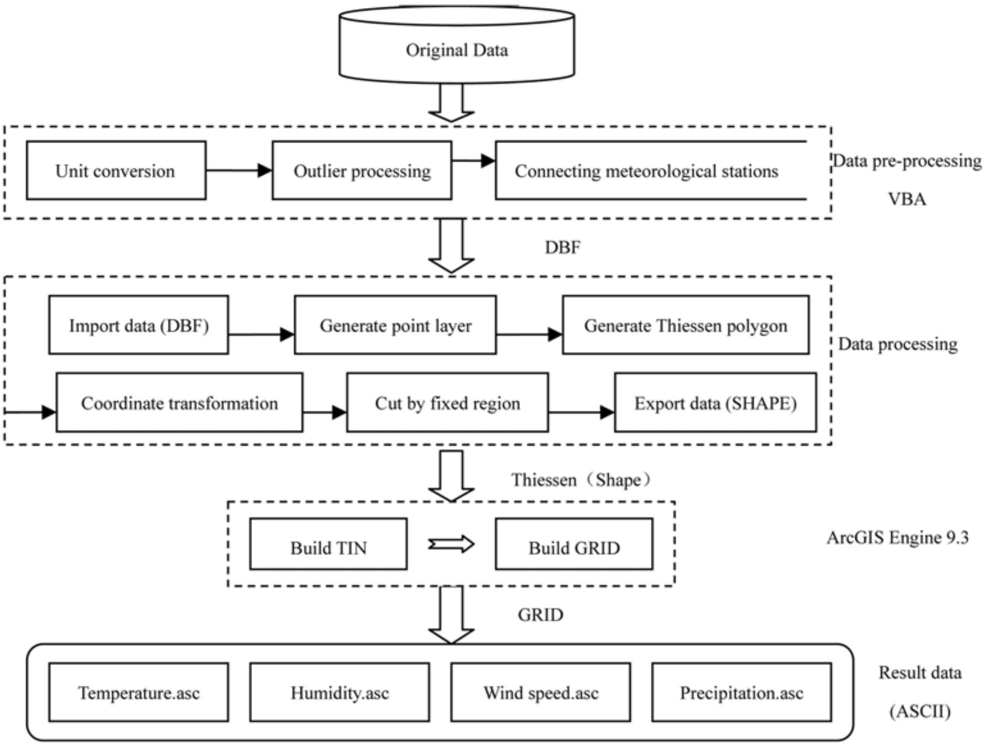

Figure 3. Software development framework.

efficient and flexible approach to achieve GIS functions using various program languages. In this study, meteorological data processing software was constructed by component GIS and programmed in Visual Basic 6.0 (VB6.0) development platform, including data pre-processing and processing module. In data pre-processing module, software fulfilled unit conversion, outlier processing and connection of meteorological data and stations by Visual Basic for Application (VBA); in data processing module, interpolation, coordination transformation, data convertion etc were accomplished by ArcGIS Engine 9.3.

According to principles and techniques above, the development framework of meteorological data processing software was designed (Figure 3).

Figure 4. Interface of data pre-processing.

Results

Meteorological data processing software was constructed in order to validate the practicability of the method above. Taking data of July 23th, 2009 for example, the data processing will be demonstrated following.

1. Data pre-processing

Meteorological data processing software provided processing methods for two main kinds of data. One was downloaded from China meteorological data sharing service system (http://cdc.cma.gov.cn/); the other was input by manual from other ways, including electrical transmission, telephone, text message, etc. Whichever kinds of data, they must contain four meteorological factors (average temperature, average relative humidity, precipitation and average wind speed) and date. The downloaded data were needed unit conversion and outlier correction in pre-processing.

The main interface of meteorological data processing software furnished two buttons, named “data pre-processing” and “data processing”. In the interface of data pre-processing, two main menus called “data acquisition” and “data pre-processing” were offered (Figure 4). The functions of each menu were listed in Table 2.

Table 2. Menus and functions provided by data pre-processing interface.

Menu name	Submenu name	Functions
Data acquisition	Manual Input (Ctrl+H)	Open a specific Excel book that used for inputting data manually
	Auto-separation by date (For downloaded data) (Ctrl+D)	Auto-separate the downloaded data in consecutive period by date
Data pre-processing	Pre-process manual inputting data (Ctrl+B)	Pre-process manual inputting data (EXCEL format) and output DBF format data
	Pre-process downloaded data (Ctrl+L)	Pre-process downloaded data (TXT format) and output DBF format data

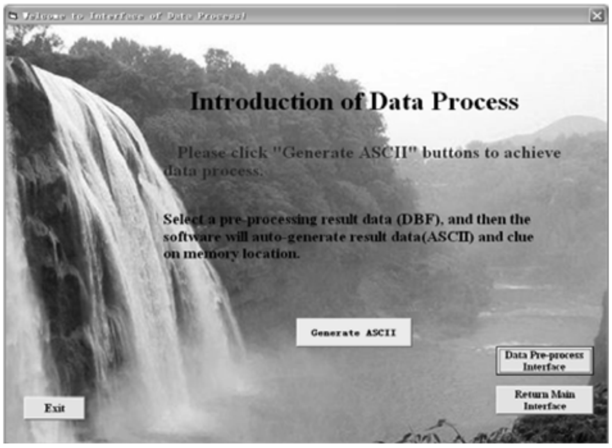

Figure 5. Interface of data processing.

2. Data processing

After data pre-processing, users can click into data processing interface. Click "generate ASCII" button and select a pre-processing result data (DBF format), and then the software will auto-generate result data, including a folder for storing ASCII and the other for processing data (TIN, GRID format). Finally, a message box will pop up and present memory location. Figure 5 presents the interface of data processing.

Result data will be read automatically by forest fire danger rating forecast system of China, which continues to use the FWI system of CFFDRS. Figure 6 presented structure of the FWI system.

According to Figure 6, FWI is computed by forest fire danger rating forecast system of China hierarchically. Firstly, fire moisture codes, including FFMC, DMC, DC are calculated by four meteorological factors. Secondly, fire moisture codes and wind speed are used to compute ISI and BUI. Finally, FWI is computed by ISI and BUI using following formulae.

$$F=\begin{cases}0.1\cdot I_{s,j}\cdot(0.626B_{u,j}^{0.809}+2) & B_{u,j}\le 80\\ 100\cdot I_{s,j}/(25+108.64e^{-0.023B_{u,j}}) & B_{u,j}>80\end{cases} \quad (1)$$

$$\begin{cases}\text{In }F_{w,i}=2.72(0.434\text{In}F)^{0.647} & F>1\\ F_{w,i}=F & F\le 1\end{cases} \quad (2)$$

Where $I_{s,j}$ is initial spread index (ISI), $B_{u,j}$ is buildup index (BUI), F is an intermediate value of $F_{w,j}$ and $F_{w,j}$ is fire weather index. Hence, daily fire danger rating (DSR) will be obtained by equation (3).

$$DSR=0.0272(F_{w,j})^{1.77} \quad (3)$$

After reading ASCII file, Forest fire danger rating

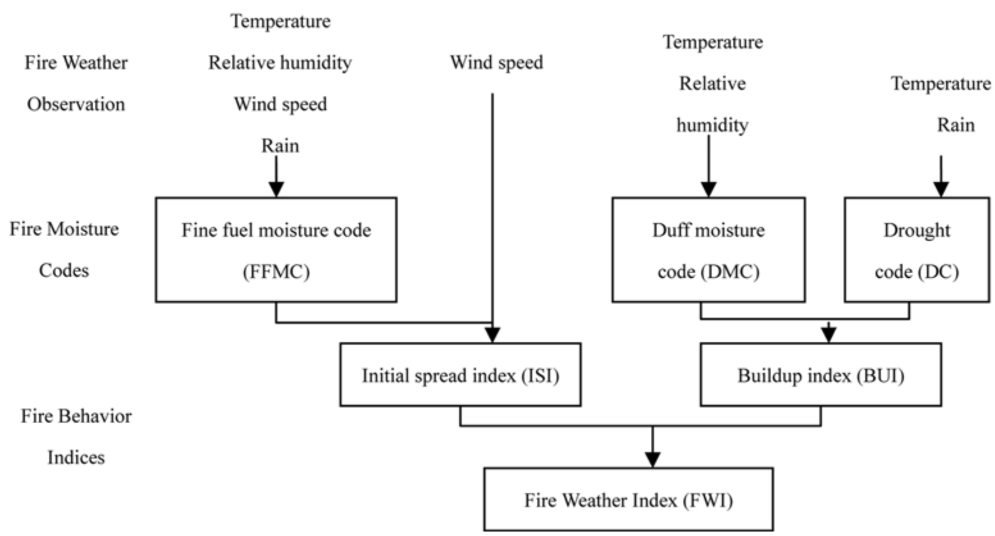

Figure 6. Simplified structural diagrams for the FWI system of CFFDRS.

Figure 7. The forecast map of forest fire danger rating of China, July 23th, 2009.

Table 3. Fire danger rating, the corresponding $F_{w,i}$ and danger level.

Fire danger rating	$F_{w,i}$	Danger level
Rank I	0-2	Extremely low
Rank II	2-6	Low
Rank III	6-12	Middle
Rank IV	12-24	High
Rank V	>24	Extremely high

forecast system of China auto-calculated fire $F_{w,i}$ and DSR and formed forecast map of forest fire danger rating (Figure 7). In this study, we adjusted corresponding value of $F_{w,i.}$ for each fire danger rating according to actual situation of China. Table 3 presents forest fire danger rating in forecast map, the corresponding $F_{w,i}$ and danger level.

3. Validation

In validation procedure, meteorological factors interpolated by fitting data set (506 meteorological stations) and located in the same position of testing stations (168) were worked out. In order to compare predicted value with true value, the performance evaluation criteria were calculated in daily validation. The validation results of meteorological factors were summarized in Table 4.

From Table 4, it was conclusion that process effects of all meteorological factors were performed well. The estimated precisions of average temperature and average relative humidity for testing data set were above 97% and much better than that of average wind speed and precipitation. The estimated precision of precipitation was the lowest one because of its strong heterogeneity of spatial distribution. Though process effect of precipitation was lower, it was above 70% and acceptable. Therefore, the procedure, including Thiessen polygon interpolation, TIN model and raster with a resolution of 10000 m, is acceptable.

Discussion

In ecology, meteorology and hydrology, daily meteorological factors, such as precipitation, temperature and so forth, play a significant role in driving various models. However, because it is difficult to obtain adequate data from the limited meteorological stations, it is necessary to find out an appropriate interpolation method to over come the limitation of distribution of stations. Thiessen polygon provides an easy and expeditious means to interpolate data. Though it is acceptable to employ Thiessen polygon interpolation in this study, interpolation effect should be improved in future, especially that of precipitation. Therefore, in next stage, different interpolation aiming at different meteorological factors should be studied to acquire more accurate results.

Although it is possible to process meteorological data for forest fire danger rating forecast system by manual handling with help of conventional software, such as

Table 4. The validation results of meteorological factors.

Date	Average temperature			Average relative humidity			Precipitation			Average wind speed		
	ME	MAE	P	ME	MAE	P	ME	MAE	P	ME	MAE	P
07/21/2009	0.20	1.37	98.60	0.00	0.07	97.94	-0.30	1.93	76.03	0.08	0.67	91.57
07/22/2009	-0.15	2.25	97.88	-0.02	0.08	97.58	0.56	1.39	85.71	0.13	0.60	93.47
07/23/2009	0.19	1.91	98.13	-0.03	0.07	97.67	1.16	2.85	73.89	0.13	0.59	93.74
07/24/2009	0.04	2.00	97.95	-0.02	0.08	97.62	0.19	3.11	70.62	0.18	0.56	93.54
07/25/2009	0.17	1.78	98.40	0.00	0.06	98.21	-0.03	2.41	82.61	0.12	0.51	93.04
07/26/2009	-0.30	1.97	97.83	-0.01	0.06	98.23	0.60	3.43	73.46	0.32	0.58	92.62
07/27/2009	0.15	2.03	97.84	0.00	0.06	98.23	-0.19	2.83	81.30	0.02	0.53	91.63
07/28/2009	0.31	1.94	97.96	-0.20	0.07	98.05	0.66	2.69	78.54	0.15	0.52	93.12
07/29/2009	-1.43	1.89	97.97	-0.01	0.07	97.85	0.73	1.87	70.26	0.21	0.48	93.87
07/30/2009	-0.02	1.94	98.21	-0.01	0.07	98.21	-0.22	1.85	80.09	0.12	0.53	93.60
07/31/2009	-0.02	1.75	98.38	0.00	0.06	98.40	-0.19	1.22	86.80	0.07	0.47	94.05

ME: Mear Error, MAE: Mean Absolute Error; P(%): Precision Estimation

Excel, ArcGIS and so on, the operational process is quite complex. However, the meteorological data processing software provides a novel approach to auto-process data. About 6 min will be spent for an experienced worker to process data of 674 meteorological stations by utilizing meteorological data processing software instead of 20 min by manual handling. The working efficiency was approximate 3 times as much as that of traditional method. Taking full advantages of GIS in meteorology field, the informationization level of processing meteorological data was greatly enhanced.

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