Influence of changes of sensor and shelter on air temperature observation, and analysis to its causes

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Abstract

By selecting parallel observation data of five national reference stations recorded by manual and automatic systems with the same radiation-proof instrument shelter and different sensors at the same observation site, differences in observed and statistical values at different time scales (hour, day, month) were analyzed; deviations of air temperature measured by the two systems were revealed; causes for the deviations were analyzed; and deviations caused by influence factors including instrument precision, instrument sensitivity, solar radiation and infrared radiation, etc., were estimated approximately. Variation of observation sensors has prominent influence on measured air temperature. The differences in observed daily, monthly and annual mean air temperatures are about 0.2℃. The difference induced by influence of solar radiation on different sensors is the main cause, meanwhile, systematic observation difference of about 0.1 exists in the two kinds of instruments, and the different sensitivity to environmental temperature change may also cause difference of 0.1-0.15 at different time of a day. Comparative analysis to observation data of three stations with different radiation-proof shelters and the same sensors revealed that as a whole, variation of shelter has little influence on observed air temperature, however, air temperature in fiberglass shelter is more sensitive to environmental temperature than that in wooden shelter.

1. Data

1.1 Comparative observation data recorded by different sensors

Five reference climatic stations were selected with hourly observations for more than three years. The stations are given in table 1.

Observation data used in the research include: hourly air temperature and wind speed, daily mean, maximum and minimum air temperatures parallelly observed by manual and automatic stations; manually observed hourly total cloud amount and precipitation. Daily mean air temperature is arithmetic mean of 24 punctually recorded air temperatures. Parallel observations were made at the same observation site, and all adopt wooden shelter used in traditional manual observation in China. Automatic observation adopts Milos500-type AWS, and HMP45D temperature/humidity sensor produced by Vaisala as air temperature sensor, which is also the temperature/humidity sensor prevalent in other automatic stations in China Manual observation adopts glass mercury thermometer.

Table 1 List of stations for comparative observation

Station	Station ID	Lat	Lon.	Alt（m）	Time interval
Gangcha	52754	37°20´	100°08´	3301.5	2001-2003
Minhe	52876	36°19´	102°51´	1813.9	2001-2003
Xinghai	52943	35°35´	99°59´	3323.2	2001-2003
DaEr	56046	33°45´	99°39´	3967.5	2001-2003
Nangqian	56125	32°12´	96°29´	3643.7	2001-2003

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1.2 Comparative observation data recorded by different shelters

In order to examine the possible influence of the fiberglass-reinforced plastic shelter popularized among AWS all over the country on observation of surface air temperature/humidity, the comparative observations were made for a half-year (February-July of 2005) using the same kind of sensors and three different shelters (traditional wooden shelter, BB-1 fiberglass-reinforced plastic shelter, and DPX1 fiberglass-reinforced plastic shelter, wherein the BB-1 instrument shelter has been put into practical application) simultaneously in Changchun, Yichang, and Beijing. Beside hourly surface air temperature, the data for analysis also include hourly cloud amount and wind speed observed by the stations.

Table 2 List of stations for shelter comparison

Station	Station ID	Lat.	Lon.	Alt. (m)	observation times per day
Changchun	54161	43°54´	125°13´	236.8	24
Yichang	57461	30°42´	111°18´	133.1	8-24
Beijing	54511	39°48´	116°28´	31.3	8-24

2. Analysis to the difference of temperature caused by different sensors

2.1 Differences of daily temperature

Statistics of the differences between manually and automatically observed daily mean, maximum and minimum air temperatures of each station between 2001 and 2003 were made. As a whole, manually observed values are smaller than automatically observed values, and this difference is shown in each month for each station. The difference in average daily mean air temperature in three years is about (-0.2)-(-0.3)℃. Monthly and annual mean air temperatures are arithmetic means of daily mean air temperatures, furthermore, signs of the differences in daily mean air temperatures of each month are consistent, therefore, introduction of automatic air temperature observation instrument will cause an increase of 0.2-0.3℃ in monthly and annual mean air temperatures observed by stations.

Signs of the differences in maximum and minimum air temperatures are consistent, but greatly different in value. Except for Minhe station, all other stations show the same character: the difference in maximum air temperature is the largest, and the difference in monthly mean daily maximum air temperature is up to –0.79℃; while the difference in minimum air temperature is small, close to or smaller than the difference in daily mean air temperature, as shown in fig. 1.

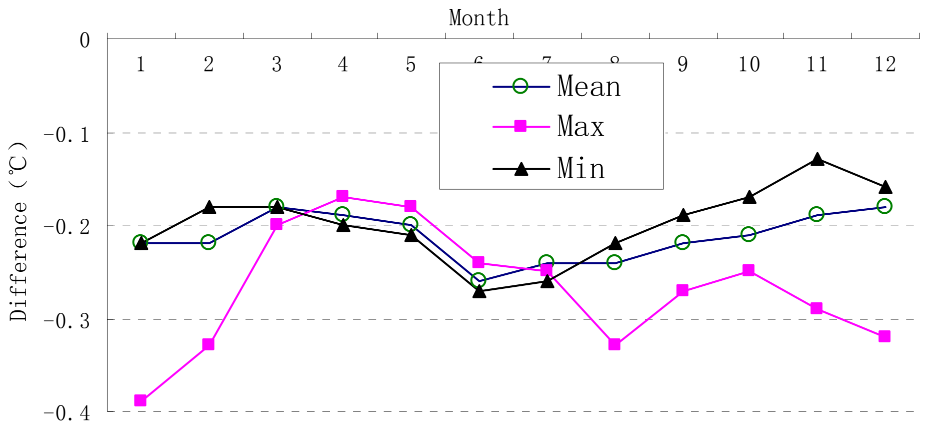

Fig. 1 Differences in daily mean, maximum and minimum temperatures for GangCha

2.2 Diurnal variation of differences

It can be seen from fig. 3 that each station is dominant with negative difference in most time of a day, i.e., automatically observed value is higher than manually observed value. Meanwhile, prominent diurnal variation exists in value of difference, daytime difference is large, and nighttime difference is small. The difference from 9 pm to 7 am is normally ±0.1℃; maximum value of daytime negative difference occurs at 10-11 am, and is about (-0.5)-(-0.8)℃.

Compared with the difference in daily mean air temperature, the nighttime difference in hourly air temperature is smaller, while the daytime difference in hourly air temperature is prominently larger.

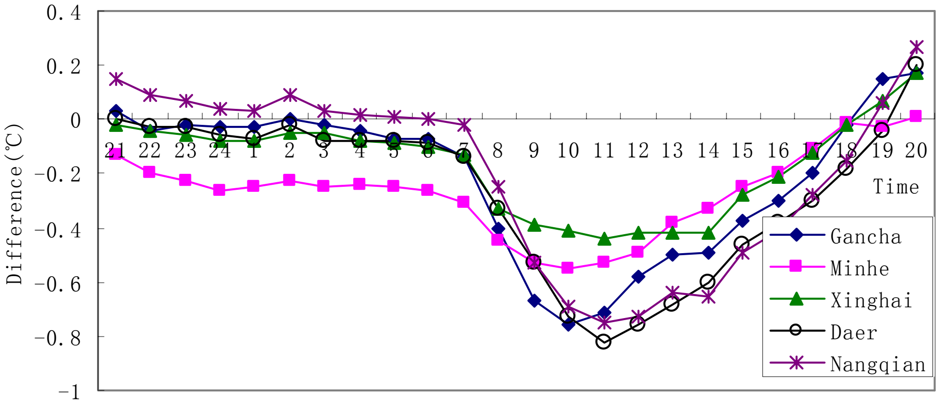

Fig. 3 Differences in hourly air temperature observed by AWS and manual observation

2.3 Cause analysis to differences

2.3.1 Systematic measuring deviation between instruments

We respectively calculated differences in hourly air temperature observed at night under the following four conditions:

C1: hourly variation of automatically observed air temperature (absolute value of the difference between current and previous hourly air temperatures) is less than 0.3℃.

C2: precipitation occurred in the previous hour;

C3: total current hourly cloud amount is 10;

C4: conditions C1 and C3 are satisfied simultaneously.

The above four conditions all express the same meaning, i.e., there is no influence of solar radiation, little variation of air temperature with time, and little influence of infrared radiation. Therefore, air temperature differences observed under these conditions can be approximately taken as systematic deviation between the two kinds of instruments.

Mean hourly air temperature differences between 9 pm and 6 am of each station are given in table 3. For the same station, results under the four conditions are similar, except for the large deviation of –0.3℃ of Minhe (52876) station, deviations of other several stations are all about –0.1℃. Therefore, the systematic deviation between observation instrument of automatic station and normal mercury thermometer is not large at all, and similar to the situation in America, the only difference lies in the different signs of deviation: in our country, observation value of normal mercury thermometer is lower than that of automatic observation instrument, while the situation is contrary in America.

Table 3 Mean hourly temperature differences under different conditions (℃)

Station	C1	C2	C3	C4
56125	-0.01	-0.05	-0.03	-0.06
56046	-0.11	-0.11	-0.11	-0.14
52943	-0.10	-0.13	-0.06	-0.10

52876	-0.26	-0.30	-0.24	-0.28
52754	-0.07	-0.11	-0.08	-0.10

2.3.2 Difference in instrument sensitivity

In order to analyze why the difference between manually and automatically observed values varies with time in a day, we calculated hourly temperature variations (absolute value of the difference between current and previous hour) with automatically observed hourly air temperatures. Result of DaEr station is given in Fig. 4. At daytime, air temperature began to rise at before 8 am, meanwhile difference also began to rise. By 10 am, air temperature variation reached the climax, while air temperature difference was maximum at 11 am, thereafter, both air temperature variation and air temperature difference began to fall. That is, the higher is the variation of air temperature, the larger will be the absolute value of negative difference between manually and automatically observed temperatures. Diurnal variations of manually and automatically observed air temperatures are similar, but different in phase, there are mainly two causes: first, compared with temperature sensor used in automatic observation, the mercury thermometer used in manual observation has hysteresis, manually observed air temperature at certain time is in fact the air temperature at one certain earlier time, while sensitivity of automatic temperature sensor is very high, and this leads to the large difference at fast rising stage (certain time interval after sunrise) and fast falling stage (certain time interval after sunset) of diurnal variation of air temperature; second is the influence of solar radiation on difference, the difference in presence of solar radiation and the difference in absence of solar radiation is greatly different, furthermore, the diurnal variation of difference is very similar to that of solar radiation.

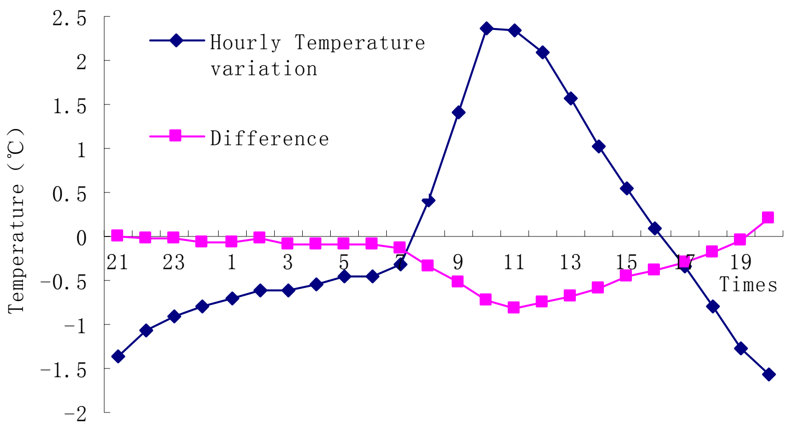

Fig.4 hourly temperature variations and temperature differences at DaEr

In order to explain the influence of instrument sensitivity on observation value quantitatively, we respectively calculated the hourly temperature difference (TG) when absolute value of hourly temperature variation is higher than 0.3℃ and the hourly temperature difference (TL) when absolute value of hourly temperature variation is lower than 2℃. Fig. 5 is the result of Daer station. During warming period (8 am to 3 pm), TG is inclined to be more negative than TL, absolute value of hourly TG is larger than absolute value of hourly TL, i.e., with the acceleration of temperature rise, due to the hysteresis of manual instrument relative to automatic instrument, the negative value of difference becomes larger. During cooling period (5 pm-6 am), TG is inclined to be more positive than TL, that is, due to the different hysteresises of the two kinds of instruments, partial negative value of the deviation between instruments is counteracted.

The difference between TG and TL is expressed by DT, in which influence of systematic deviation between instruments is already removed. Meanwhile, despite the variation of the influences of solar radiation and infrared radiation on air temperature difference with time, it can be seen from fig. 6 that absolute value of DT is basically invariable with time, so we can say that the influences of solar radiation and infrared radiation on air temperature difference are also removed in DT, therefore, we can approximately take DT as the temperature observation deviation caused by different sensitivities of the two kinds of instruments.

Table 5 Mean differences between TG and TL in the warming and cooling periods

	56125	56046	52943	52876	52754
Warming period	-0.13	-0.15	-0.17	-0.11	-0.15
Cooling period	0.11	0.13	0.08	0.07	0.13

Results of each station are given in table 5. It can be seen, due to the different sensitivities of the two kinds of instruments to environmental temperature, during warming period of a day (8 am-4 pm), manually observed value will be 0.15℃ lower than automatically observed value; while during cooling period (5 pm-7 am), manually observed value will be 0.1℃ higher than automatically observed value. However, the difference in sensor sensitivity has little influence on observed daily mean air temperature.

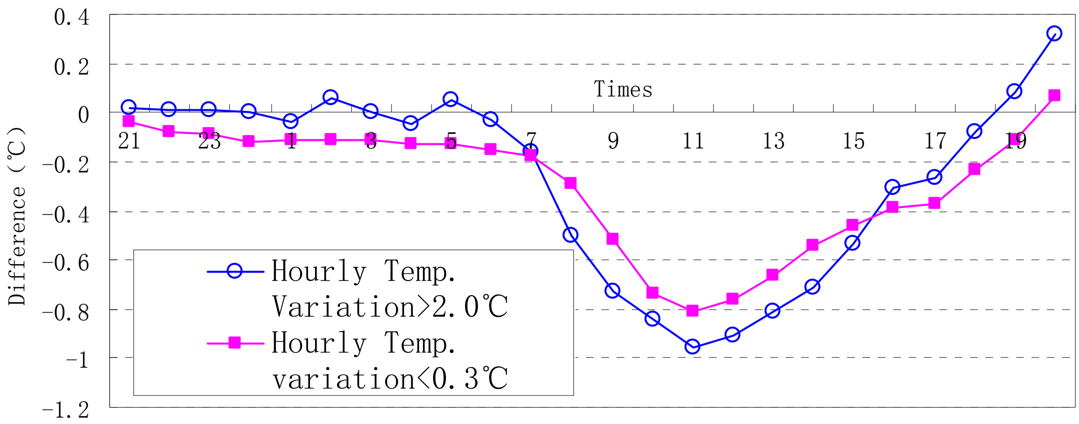

Fig. 5 Hourly temperature difference under different conditions for DaEr (Circle for temperature variation >2.0℃, and square for temperature variation <0.3℃)

2.3.3 Influences of solar radiation and infrared radiation

The different daytime and nighttime temperature differences reflect the different contributions of solar radiation and infrared radiation to temperature difference. Obviously, daytime solar radiation has far higher influence on temperature difference than nighttime infrared radiation.

Top and bottom of instrument shelter are all sealed, so the radiation exchange between temperature sensor and environment outside instrument shelter can only be realized in horizontal direction of instrument shelter. We calculated hourly mean horizontal component of direct solar radiation at GeErMu station (north latitude 36°25´, east longitude 94°54´, altitude 2807.6 m) of Qinghai province between 2001 and 2003. It can be seen that horizontal component of direct solar radiation is the highest at about 11 am, which is consistent with the time when extreme value of diurnal variation of temperature difference occurs. By combining the above analysis, we can draw a conclusion that diurnal variation of temperature difference at daytime is mainly caused by influence of solar radiation, the stronger is solar radiation, the larger will be temperature difference.

If influence of infrared radiation is neglected, the temperature difference at daytime (8 am-6 pm) after subtracting the differences caused by influences of sensor and sensitivity is just the influence of solar radiation. The temperature difference at nighttime (8 pm-7 pm) after subtracting the differences caused by influences of sensor and sensitivity is just the influence of infrared radiation cooling. Hourly temperature difference induced by solar and infrared radiations at Nangqian station are given in Fig. 7. The temperature difference caused by nighttime infrared radiation is very small, within ±0.1℃, and dominant with negative difference; while daytime solar radiation has prominent influence on temperature difference, and the highest difference can reach -0.6℃.

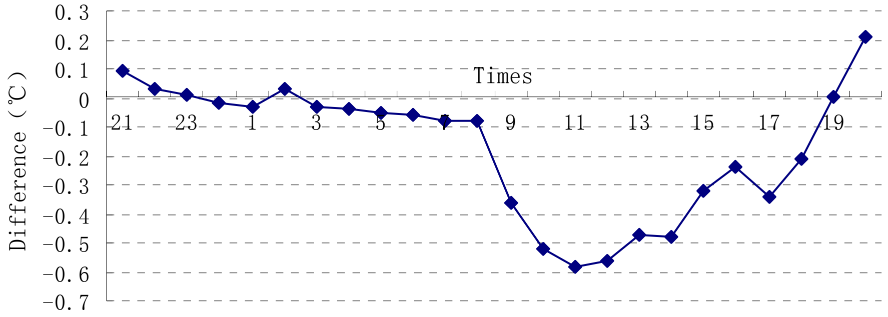

Fig. 7 Hourly temperature difference induced by solar and infrared radiations (Nangqian station)

3. Analysis to the influence of different shelters on temperature

3.1 Overall temperature difference between different shelters

Table 6 temperature difference between two kinds of fiberglass-reinforced plastic shelters and wooden shelter

Element	Station		Hourly mean difference	Standard deviation	Daily mean difference	Standard deviation
Mean temperature（℃）	Changchun	T1-T0	0.02	0.12	0.02	0.07
		T2-T0	0.03	0.12	0.03	0.07
	Beijing	T1-T0	-0.08	0.12	-0.08	0.07
		T2-T0	-0.1	0.19	-0.1	0.1
	Yichang	T1-T0	-0.06	0.17	-0.07	0.09
		T2-T0	-0.09	0.2	-0.09	0.1
Maximum temperature（℃）	Changchun	T1-T0			-0.08	0.2
		T2-T0			-0.05	0.23
	Beijing	T1-T0			0	0.14
		T2-T0			0.07	0.19
	Yichang	T1-T0			0.07	0.2
		T2-T0			0.09	0.18
Minimum temperature（℃）	Changchun	T1-T0			0.01	0.15
		T2-T0			-0.02	0.18
	Beijing	T1-T0			-0.28	0.27
		T2-T0			-0.37	0.31
	Yichang	T1-T0			0.03	0.26
		T2-T0			-0.05	0.17

(T0:for wooden shelter; T1: for DPX-1 plastic shelter; T2 : for BB-1)

2872-4344 comparative observations were respectively made at three selected stations between February-July, 2005. Temperature differences between different shelters were calculated, and differences with more than 3 times of standard deviation were weeded out. Mean values and standard deviations of temperature difference in each observation, daily mean temperature difference, daily maximum temperature difference and daily minimum temperature difference were calculated as table 6, in which T0 represents result observed in wooden shelter; T1 represents result observed in DPX-1 fiberglass-reinforced plastic shelter; T2 represents result observed in BB-1 fiberglass-reinforced plastic shelter. It can be seen, hourly and daily mean temperature differences between two kinds of fiberglass-reinforced plastic shelters and wooden shelter are all below measurement precision of instrument (0.1℃), and standard deviations of difference are within 0.2℃. Mean differences of daily maximum air temperature are also very small, all below 0.1℃ for each station. Except for Beijing, mean differences of daily minimum air temperature are below 0.1℃, while the differences of Beijing station are also below the allowed precision (0.4℃) stated in observation regulation[7] for extreme air temperature measurement. Therefore, variation of instrument shelter will not influence the observation values of mean air temperature and extreme air temperature.

3.2 Analysis to the sensitivity of thermometer in different shelters

Diurnal variation of hourly mean temperature difference was analyzed. It can be seen that shortly after sunrise, the difference between fiberglass-reinforced plastic shelter and wooden shelter begins to show an obvious trend of positive value, that is, air temperature rising speed in plastic shelter is higher than that in wooden shelter; after 5 pm, the difference begins to show an obvious trend of negative value, that is, air temperature falling speed in plastic shelter is higher than that in wooden shelter. The same rule is shown in all the three stations. This indicates that air temperature observed in wooden shelter is lagged behind the air temperature observed in plastic shelter, i.e., air temperature in plastic shelter is more sensitive to environmental temperature. Main reason for this difference is that wooden shelter has larger thermal capacity than plastic shelter.

4. Conclusion

(1) The daily, monthly and annual mean air temperatures recorded by new automatic surface observation system will be about 0.2℃ higher than that recorded by traditional manual observation.

(2) Obvious diurnal change exists in the difference between manually and automatically observed air temperatures, the temperature difference is large (up to (-0.5)-(-0.8)℃) at daytime, and small (generally around ±0.1℃)at nighttime.

(3) Systematic deviation between mercury thermometer used in manual observation and Pt thermistor temperature sensor used in automatic station is generally -0.1℃， and up to -0.3℃ for exceptional stations.

(4) Temperature sensor used in automatic station is more sensitive than mercury thermometer used in manual observation. As a result, during warming period of a day, manually observed value will be 0.15℃ lower than automatically observed value; while during cooling period, manually observed value will be 0.1℃ higher than automatically observed value. However, the difference in instrument sensitivity has little influence on observed daily mean air temperature.

(5) Among the several influence factors, solar radiation has the largest influence on observation difference induced by variation of sensor, which can be up to 0.6℃ averagely at daytime. Nighttime infrared radiation has little influence on observation difference.

(6) As a whole, the replacement of wooden shelter by fiberglass-reinforced plastic shelter has little influence on observed mean air temperature. However, the air temperature in plastic shelter is more sensitive to environmental temperature than that in wooden shelter.

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