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The personal difference in absolute geomagnetic measurements

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Abstract. Absolute geomagnetic measurement is very important work in geomagnetic observatories. It plays a decisive role in data quality control and instrument calibration. As modern fluxgate theodolite in absolute geomagnetic measurements has a high precision, usually with 1 second of arc, the measurement results are susceptible to external factors. The personal difference is one of these factors, and it has become an important factor that cannot be ignored in measurement results. In order to estimate the personal difference, an experiment has been designed. Six fluxgate theodolites were used and six observers who were proficient in absolute measurements were invited to this experiment. Then observers made the absolute geomagnetic measurements in turns, and the personal difference among the observers for each instrument was computed by comparing baseline values. Finally, the personal difference can be estimated by a statistical method.

1 Intruduction

The geomagnetic field is an intrinsic characteristic of the earth, and it is a vector which has a direction as well as size. To determine a vector field, at least three independent elements are required, and they are different in different coordinates. They may be expressed by X (north component), Y (eastern component) and Z (vertical component) in Cartesian coordinates, described by H (horizontal component), D (declination) and Z (vertical component) in cylindrical coordinates, or represented by D (declination), I (inclination) and F (total field) in spherical coordinates. Nowadays, D, I and F are recommended as the three independent elements, and extensively adopted in most geomagnetic observatories in the world (Bitterly et al., 1984; Jankowski et al., 1996). And the fluxgate theodolite (to measure D and I) combined with one proton magnetometer (to measure F) are the recommended pair as absolute geomagnetic measurements instruments. The procedure of measuring the absolute value of the geomagnetic field is called absolute geomagnetic measurements.

As known, the absolute value of the geomagnetic field is usually in tens of thousands of nanotesla. The geomagnetic observatories use variometers to record the continuous variations of the geomagnetic field. The range of the geomagnetic variometers are usually within ±3000 nT, may be as great as ±4000 nT at high latitudes (Jankowski et al., 1996). Therefore,

the continuous absolute geomagnetic field can be obtained by adding a value, called baseline value, to the variations. The baseline value is calculated by the absolute measurement results. This is meaning that the absolute measurements play a decisive role in the quality of continuous absolute value of the geomagnetic field. Now, the variometers are rather stable and have a high precision, but there are also some slight changes, which may be caused by the orientation setting error, the scale factor nonlinearity or the non-orthogonality of variometers, or the unstability of observation pillars (Zhang et al., 2011). So the absolute measurements of a certain frequency are necessary. Twice a week is practice in most Chinese geomagnetic observatories. That is a better way to monitor the changes and to control the data quality (Li et al., 2012).
Now, the declination and inclination are measured manually using fluxgate theodolite at most geomagnetic observatories. Some artificial observation errors are unavoidable during the measurement processing, and they will affect the final results. Sometimes, there are more than one observer working in an observatory, they make absolute geomagnetic measurements in turns. So the influence on the final results may become stronger, because more artificial observation errors were included.

Since the data quality is an important guarantee for scientific research, it is useful work to accurately evaluate these errors (Zhang et al., 2016). This work is helpful to understand their influence on the final observation results, to control the quality of observation data, and to identify and analyse their performance in research results. The technology of proton magnetometer is very mature. There is nearly no personal influence on the total field measurements. So only the artificial observation errors in absolute geomagnetic measurements are analysed here.

2 Personal difference and estimate method

There are many errors in absolute geomagnetic measurements, for example index error, horizontal-axis error, collimation error, positioning errors, the artificial observation error and so on (Newitt et al., 1996). Some are instrumental errors, while others are artificial observation errors. Most of the instrumental errors can be eliminated by choosing specific measurement procedure, but the artificial observation errors are difficult to remove (Deng et al., 2010). Because the artificial observation errors may be caused by the magnetic objects (e.g. magnetic parts of clothing), may come from the observer's observation method or skill, and may arise from the observer's minimum resolution in physiology or reading error and so on. They are uncertain and difficult to estimate. Especially, when come to the observatory where the absolute geomagnetic measurements were made by more than one observer, the artificial observation errors will become more complex. Here, the difference between the observation results, measured by two observers with the same instrument, is defined as the personal difference. It is not a constant value, so it is hard to estimate.

In order to estimate the personal difference, an observation experiment was designed. Six fluxgate theodolites were used and six skilful observers from different geomagnetic observatories were invited to this experiment. Then the fluxgate theodolites were placed on the observation pillars respectively, and the observers made the absolute geomagnetic measurements in turns.

After completing the measurement, the baseline values measured by the same instrument were calculated one by one. Then, the personal difference between the observers for each instrument was computed by comparing baseline values. Finally, all the personal differences were collected together and analysed by statistical method. In this way, the effect of instrument and pillar differences can be effectively excluded; the personal difference in absolute geomagnetic measurements can be estimated.

The type of the fluxgate theodolites used in this experiment is Zeiss 010B with a precision of 1 second of arc. The measurement procedure followed the guide published by IAGA (Newitt et al., 1996). The baseline value computing method followed equation given by St-Louis (St-Louis, 2011). The experimental results are displayed in sect. 3.

3 Experimental results

The experiment was carried out in an absolute house at Lanzhou observatory, where the observation environment for geomagnetic field was very good. And it was performed on quiet solar day when the geomagnetic field varied slowly. Theoretically, the daily variation of the geomagnetic field has no effect on the baselines. But in practice, there may be some slight changes due to a setup error (possible orientation or scale factor). So sets of absolute measurements were made early in the morning and late in the evening. This effectively avoids the potential impact of the principal part of the daily variation. The fluxgate theodolites were installed on the correct position of observer pillars, and they were forbidden to move during the experiment. That avoided introducing an azimuth error of the reference marker caused by inexact positioning. Also the magnetic objects or magnetic parts of clothing of the observers were carefully checked before beginning measurement. So the influences from these magnetic contaminations can be removed.

The plan of the absolute house is displayed in Fig. 1. The six fluxgate theodolites are fixed on these observation pillars respectively. The observers take turns to operate them in this experiment. The fluxgate theodolites code, pillars number and observers order are list in table 1. The black dots represent the observer made an absolute measurement with this instrument, while the short lines indicate that no operation was done.

The baselines determined by each fluxgate theodolite and by each observer were calculated. All the declination and inclination baselines were shown in fig. 2 and fig. 3, respectively. The different symbols (or colors, easier to distinguish) represent different observers, while the different line styles represent different observation dates. The baselines for each instrument were separately plotted in different panels, so there are six panels for each figure. As shown in the two figures, each observer has made several sets of measurements on the same day. These baselines were rather stable, except for individual large values. This means that the absolute measurements results in this experiment have a high observation quality.

To check the reliability of this experiment, the standard deviations of sets of the baseline values for each person were also computed, listed in Table 2 and Table 3. The standard deviation can reflect the degree of dispersion of data set, and the smaller the standard deviation, the less the value deviate from the average value. To an extent, it represents the absolute measurements level of observer. The results indicate that the observers have a high level of observation.

In addition, the observer at Lanzhou observatory made the synchronous absolute measurements with their own fluxgate theodolite. In this way, the observation environment changes of Lanzhou observatory can be monitored during the experiment. The declination and inclination baselines of Lanzhou observatory were displayed in Fig. 4. As shown in the figure, the baselines were stable during the experiment period. All these results suggest that the experimental results are very reliable. However, there is a sudden change on the second day (the dark red ball), when the variation of declination baseline is about 0.2 ' comparing to the day before. The difference may be caused by artificial observations error from observer self. This is similar to both Yang’s results (the pink diamond in second panel, LZH) and He’s results (the light blue ball in fourth panel, BJI) in Fig. 2. The observer's self-differences are also part of the personal difference.

In the process of the personal difference calculation, sets of the baseline values, determined by the same fluxgate theodolite and same person on the same day, were averaged. Then the personal differences were calculated by comparing these average values. At last, all the personal difference values were collected together. Since we only focus on the magnitude of the personal difference rather than the sign, we take the absolute values of the personal differences. Finally, these absolute values were used to estimate the personal differences.

Table 4 and table 5 have respectively listed all the personal differences of declination and inclination. The number in the brackets behind the personal difference is the pillar number. As listed in the tables, the maximum of the personal difference of declination is 0.22 '; the maximum value of the inclination is 0.09 '.

Figure 5 shows the statistical result of all the personal differences. The frequency distribution (corresponding to left vertical axis) and the cumulative probability (corresponding to right vertical axis) are represented by dotted line and solid line, respectively. The histogram is the count of the personal difference. The statistical results of the personal difference for the declination and inclination are respectively displayed in Fig. 5 (a) and Fig. 5 (b). The personal differences of declination almost evenly distribute between 0 ' and 0.22 '; while the personal differences of inclination distribute between 0 ' and 0.1 ', and most data are distributed near zero.

Usually, the accuracy of less than 0.1 ' (for directional elements) and less than 1 nT (for intensity elements) is considered as the standard for data quality control at geomagnetic observatory (Zhang et al., 2016). This is also the aim what the global geomagnetic observatories desire to achieve. If this accuracy is used to investigate personal difference in this experiment, the cumulative probability of declination corresponding to 0.1 ' is only 55%. When it comes to the inclination data, the percentage is 100%. That is to say, it is still difficult to achieve the accuracy of less than 0.1' in declination measurement.

In order to reasonably estimate the personal difference, 90% of the cumulative probability is adopted as an evaluation criterion in this work. The obvious wrong data can be excluded. Then the personal difference value corresponding to 90% of the cumulative probability is considered as the estimation value. As seen in Fig. 5, when the 90% was adopted to estimate personal difference, the estimation values of declination and inclination are 0.18 ' and 0.08 ', respectively. And the personal difference of declination is much larger than that of the inclination. This means that more artificial observation errors might be brought in during the declination measurements, the quality of inclination is better than that of declination.

There are two possible reasons for the distinction of personal differences between declination and inclination. First, the first step of the declination measurement is to measure the position of the azimuth mark. The observer should adjust the telescope to ensure that the optical axis is aligned with the azimuth mark. It is hard for an observer to adjust the optical axis to the exactly the same position every time, let alone different observers. This may be the main reason for the distinction. Second, in general, it will take several ten minutes for a skilled observer to finish a set of absolute measurements. The declination of geomagnetic field has changed during the observation period. This change has less effect on inclination measurements than on the declination. In any case, both of the personal differences will be introduced to the final results in absolute geomagnetic measurements.

4 Conclusion and Outlook

Geomagnetic observatory is the main sites to measure the secular variation of the magnetic field. It is desirable to aim for the accuracy of less than 0.1 ' (for directional elements) and 1 nT (for intensity elements). In principle, the modern instrument such as the Zeiss 010B fluxgate theodolite with 1 second of arc has sufficient precision to make this aim possible. In practice, its accuracy is not better than 3 second (according ISO 17-123). This means that a possible error of 0.05 ' will be brought to the results. Moreover, the existence of various errors in measurement, especially artificial observation errors, makes this goal difficult to achieve. The personal difference is one of the artificial observation errors, and it is difficult to estimate.

The measurement experiment in this paper is a feasible way to estimate the personal difference. The results are reliable, and they clearly display the personal difference in absolute geomagnetic measurements. According to the estimation results, the personal difference of declination and inclination are 0.18 ' and 0.08 ' respectively. If the absolute measurements were made by different observers in one observatory, the personal difference will be introduced to the final results. However, we should be aware that the observer's self-difference and the error of instrument accuracy may be contained in the personal difference.

We also found that the results of declination are more susceptible than that of inclination. Two possible reasons have been given in this paper.

This work is helpful to understand and estimate the personal difference in absolute measurements. It gives us an advice that a fixed observer responsible to absolute geomagnetic measurements is useful for improving the observation data quality. It is also helpful for the scientists who using these data to carefully analyse their research results.

In recent years, lots of efforts have been plunged into the new observation technology and automatic fluxgate theodolites (Auster et al., 2003; Rassion et al.,2011; Gonsette et al., 2017; Hegymegi et al.,2017; Brunke et al., 2018; and so on). Now, a few of them have come true and are operating in observatories. With the increasing of the instrument precision and the using around the world, we hope the personal difference will disappear and the high quality observation data will be obtained in the future.

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Table 1: The code and position of fluxgate theodolites and the order of observers.

No.	Code	Pillar No.	Observers						Computing
			Xin	Yang	Li	He	Yan	Tian	Wang
1	QIX	1#	–	●	●	●	–	–	●
2	LZH	3#	●	●	●	–	●	–	●
3	THJ	4#	●	●	●	–	●	–	●
4	BJI	5#	●	–	–	●	●	–	●
5	GNC	6#	●	●	–	●	–	–	●
6	MKP	2#	–	–	–	–	–	●	●

Table 2: The standard deviation of declination baselines for each observer.

No.	Xin	Yang	Li	He	Yan	Tian
1	0.09(3#)	0.02(1#)	0.04(1#)	0.08(1#)	0.07(3#)	0.06(2#)
2	0.04(4#)	0.03(1#)	0.07(3#)	0.07(5#)	0.03(3#)	0.03(2#)
3	0.03(5#)	0.10(3#)	0.06(4#)	0.06(5#)	0.07(4#)	0.06(2#)
4	0.08(6#)	0.10(4#)	0.04(4#)	0.04(6#)	0.07(5#)	0.05(2#)
5	0.03(6#)	0.07(6#)				0.05(2#)
Means	0.05	0.06	0.05	0.06	0.06	0.05

Table 3: The standard deviation of inclination baselines for each observer.

No.	Xin	Yang	Li	He	Yan	Tian
1	0.02(3#)	0.01(1#)	0.03(1#)	0.02(1#)	0.03(3#)	0.03(2#)
2	0.02(4#)	0.01(1#)	0.03(3#)	0.04(5#)	0.03(3#)	0.03(2#)
3	0.02(5#)	0.01(3#)	0.02(4#)	0.07(5#)	0.03(4#)	0.02(2#)
4	0.02(6#)	0.03(4#)	0.03(4#)	0.02(6#)	0.08(5#)	0.02(2#)
5	0.01(6#)	0.02(6#)				0.03(2#)
Means	0.02	0.02	0.03	0.04	0.04	0.03

Table 4: The personal differences of declination.

	Xin	Yang	Li	He	Yan
Xin	0.05(6#)	0.01(3#) 0.06(4#) 0.10(6#)	0.07(3#) 0.12(4#) 0.06(4#)	0.09(6#) 0.04(6#) 0.18(5#) 0.05(5#)	0.06(3#) 0.14(3#) 0.04(4#) 0.03(5#)
Yang	0.15(6#)	0.01(1#)	0.07(3#) 0.12(4#)	0.19(1#) 0.18(1#) 0.19(6#)	
Li		0.02(1#) 0.01(1#) 0.18(4#)	0.06(4#)	0.17(1#)	
He				0.13(5#)	
Yan		0.06(3#) 0.15(3#) 0.10(4#)	0.13(3#) 0.22(3#) 0.08(4#) 0.02(4#)	0.20(5#) 0.08(5#)	0.09(3#)

Table 5: The personal differences of inclination.

	Xin	Yang	Li	He	Yan
Xin	0.02(6#)	0.08(3#) 0.03(4#) 0.02(6#)	0.08(3#) 0.01(4#) 0.01(4#)	0.04(6#) 0.03(6#) 0.05(5#) 0.06(5#)	0.07(3#) 0.07(3#) 0.01(4#) 0.03(5#)
Yang	0.03(6#)	0.01(1#)	0.00(3#) 0.04(4#)	0.03(1#) 0.02(1#) 0.06(6#)	
Li		0.01(1#) 0.01(1#) 0.02(4#)	0.02(4#)	0.01(1#)	
He				0.01(5#)	
Yan		0.01(3#) 0.01(3#) 0.04(4#)	0.01(3#) 0.01(3#) 0.00(4#) 0.02(4#)	0.09(5#) 0.08(5#)	0.00(3#)

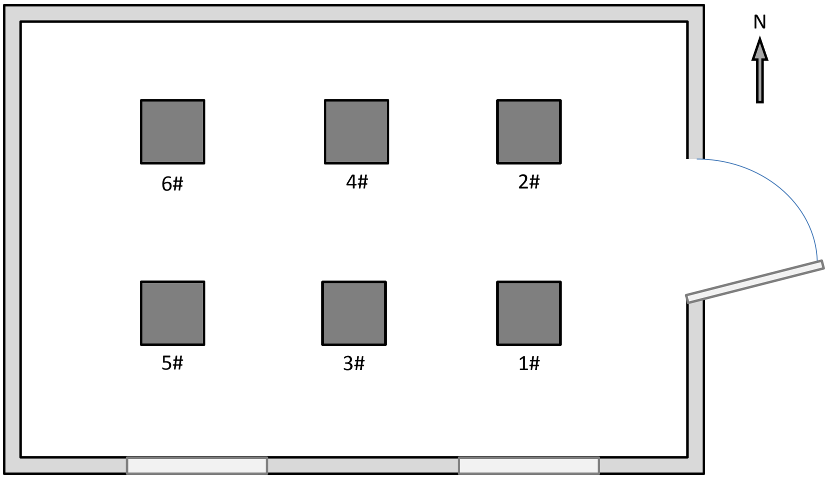

Figure 1: The plan of absolute measurement house.

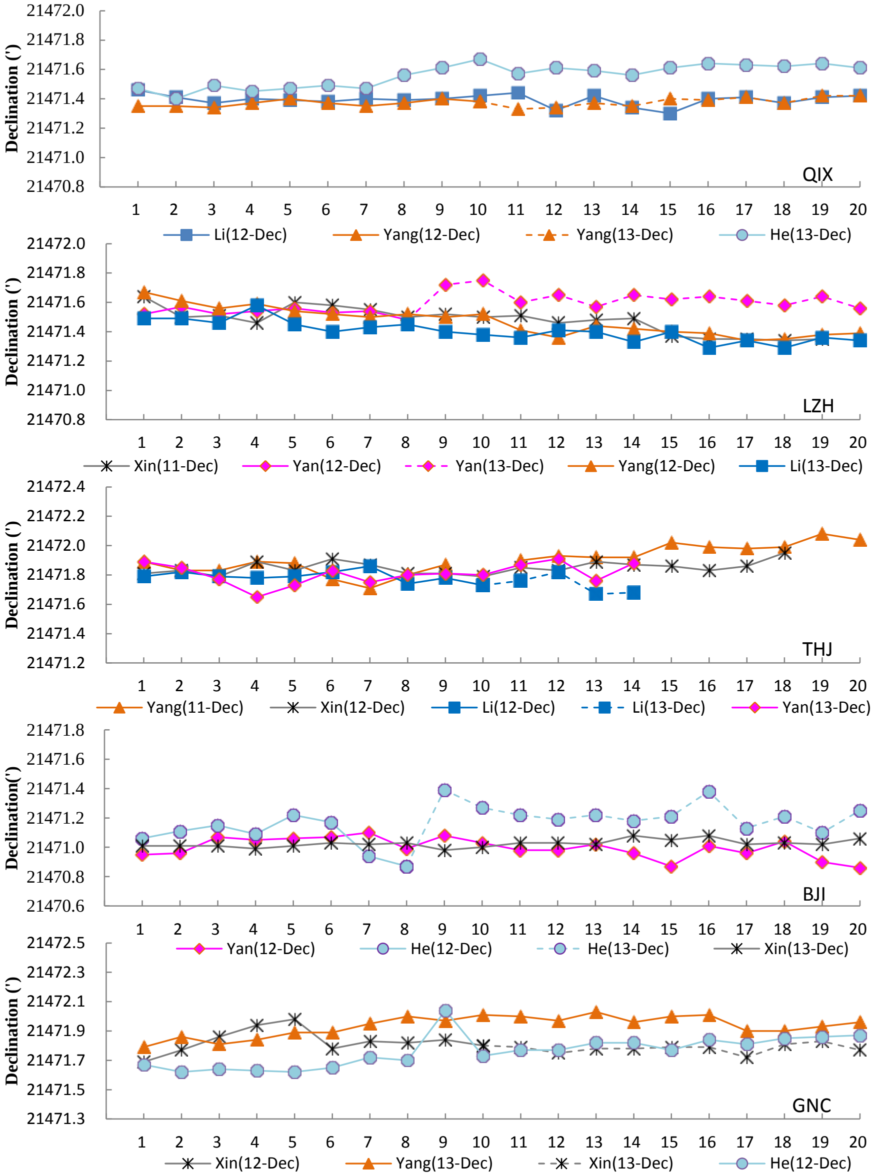

Figure 2: The baselines of declination. Different symbols (or colors) represent different observers, and different line styles represent different observation dates.

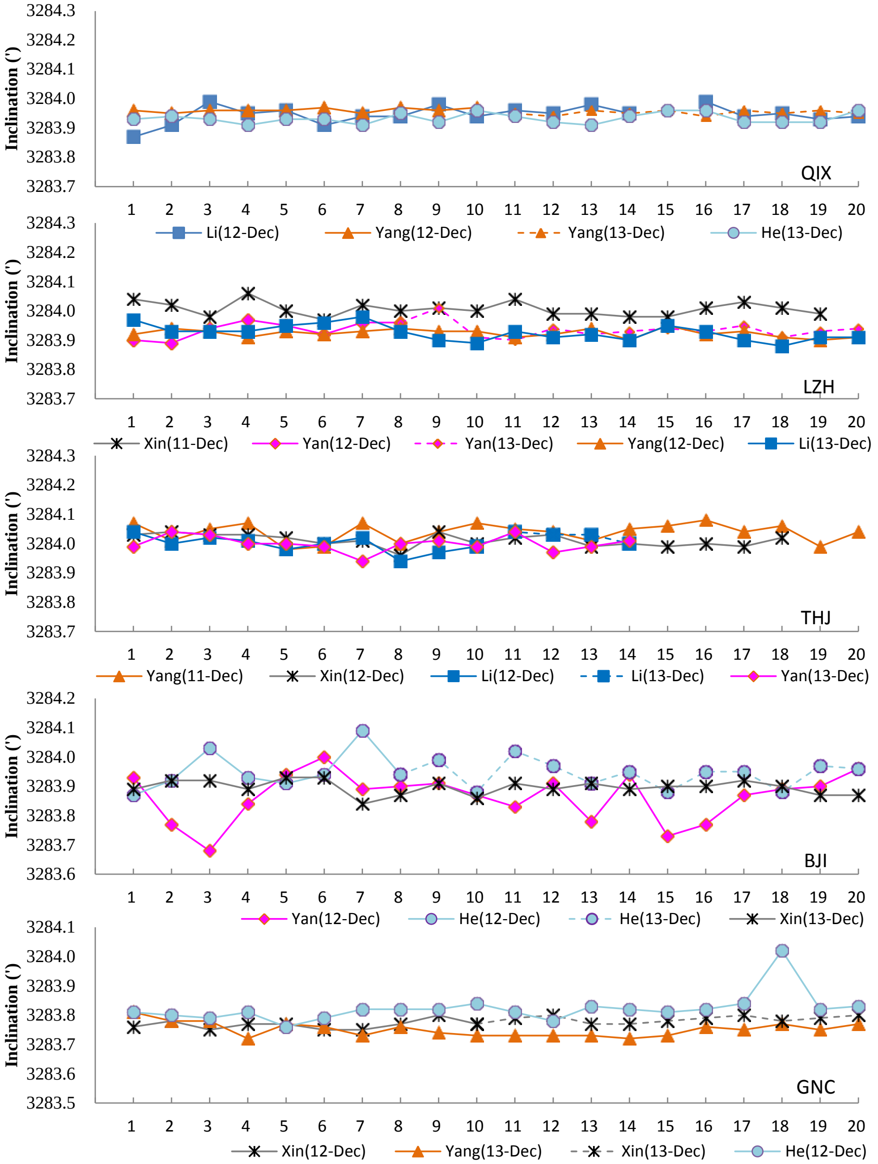

Figure 3: The baselines of inclination. Different symbols (or colors) represent different observers, and different line styles represent different observation dates.

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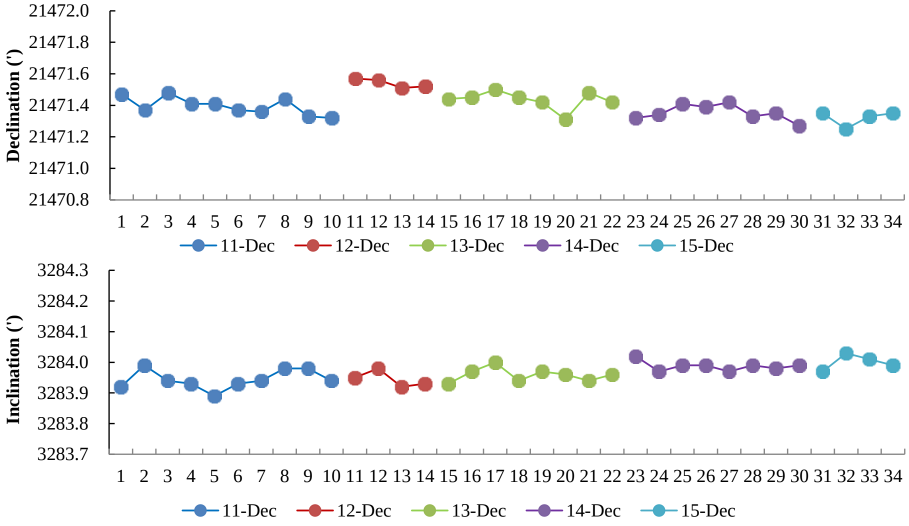

Figure 4: The declination and inclination baselines of LanZhou observatory.

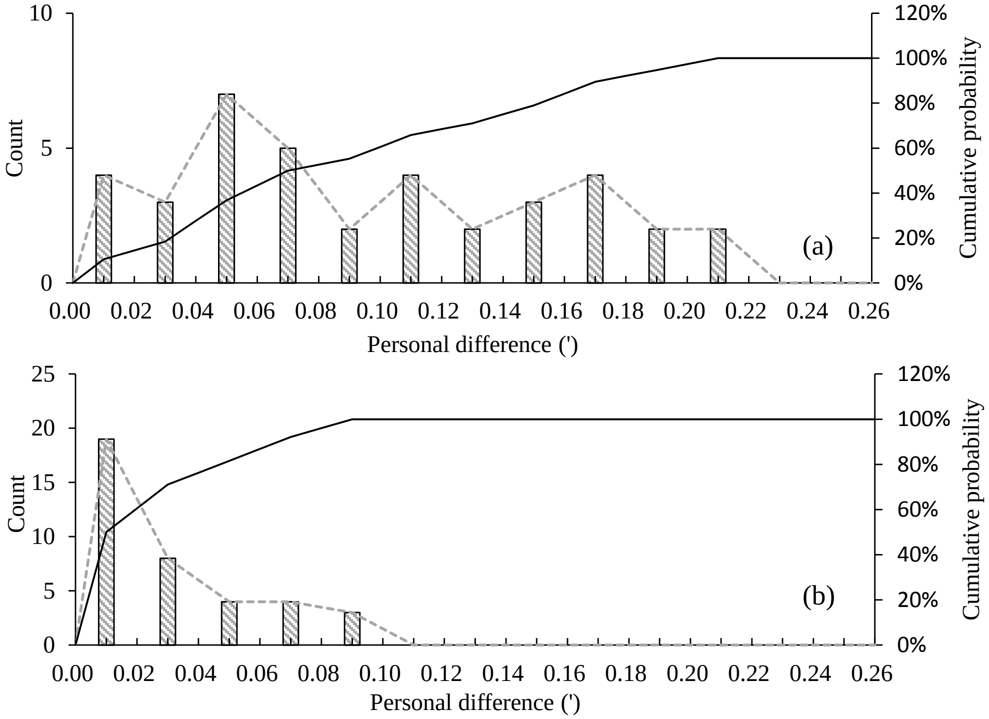

Figure 5: The frequency distribution and the cumulative probability. The histogram is the count of the personal differences. The dotted line and solid line respectively represent the frequency distribution (corresponding to left vertical axis) and the cumulative probability (corresponding to right vertical axis).