Representativeness of Four Precipitation Observational Networks of China

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ABSTRACT

Four precipitation observational networks with varied station densities are maintained in China. They are: the Global Climate Observation System (GCOS) Surface Network (GSN), the national Reference Climate Network (RCN), the national Basic Meteorological Network (BMN), and the national Ordinary Meteorological Network (OMN). The GSN, RCN, BMN, and the merged network of RCN and BMN (R&B) have been widely used in climatology and climate change studies. In this paper, the impact of the usage of different networks on the precipitation climatology of China is evaluated by using the merged dataset of All Station Network (ASN) as a benchmark. The results show that all networks can capture the main features of the country average precipitation and its changing trends. The differences of average annual precipitation of the various networks from that of the ASN are less than 50 mm ($\leqslant$ 10%). All networks can successfully detect the rising trend of the average annual precipitation during 1961–2009, with the R&B exhibiting the best representativeness (only 2.90% relative difference) and the GSN the poorest (39.77%). As to the change trends of country average monthly precipitation, the networks can be ranked in descending order as R&B (1.27%), RCN (2.35%), BMN (4.17%), and GSN (7.46%), and larger relative differences appear from August to November. The networks produce quite consistent spatial patterns of annual precipitation change trends, and all show an increasing trend of precipitation in Northwest and Southeast China, and a decreasing trend in North China, Northeast China, and parts of central China. However, the representativeness of the BMN and R&B are better in annual and seasonal precipitation trends, in spite of the fact that they are still far from satisfactory. The relative differences of trends in some months and regions even reach more than 50%. The results also show that the representativeness of the RCN for country average precipitation is higher than that of the BMN because the RCN has a more homogeneous distribution of stations.

Key words: climate stations, observational network, monitoring, precipitation climatology, precipitation change

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1. Introduction

In mainland China, a surface observational system consisting of different station networks with varied station densities and observation standards has been established to monitor the weather and climate variations (Zhang and Xu, 2008). The system includes the Global Climate Observation System (GCOS) Surface Network (GSN), the national Reference Climate Network (RCN), the national Basic Meteorological Network (BMN), and the national Ordinary Meteorological Network (OMN). Operation of the meteorological observation networks has laid a solid foundation for weather forecast and climatology studies, and some networks are being used for the monitoring and studies of regional climate change.

However, the observational networks under operation were mostly initiated without taking full consideration of the need to accurately monitor long-term climate change. In addition to the observational standards related to instruments and micro-environmental conditions, which can significantly affect the accuracy

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and reliability of the long-term climate data (Karl et al., 1988; Zhou et al., 2004; Ren et al., 2008; Zhang et al., 2010), the density and the spatial deployment of observational stations also matter for regional and global climate change monitoring (Karl et al., 1995; Jones and Moberg, 2003). Zhao et al. (2007) and Ren et al. (2012) showed that the climate monitoring with different objectives requires significantly different observational density for the same region. It is obvious that some of the currently operated observational networks may deliver biased monitoring results for key climatic variables including precipitation.

Relevant studies on the representativeness of precipitation observational networks in China are rare. Previous analyses on the representativeness of various levels of precipitation station networks in regions other than mainland China suggest that not all the station networks can capture the real climatological and climatic change information (Hubbard, 1994; DeGaetano, 2001; Janis et al., 2002, 2004; von Storch and Zwiers, 1999). For example, Hubbard (1994) indicated that one station for every 60 km could represent 90% of the spatial variation of diurnal temperature variability in flat regions, but for precipitation, a higher observation density of 5 km was needed. DeGaetano (2001) analyzed the seasonal precipitation from 814 stations in the US Historical Climate Network and found that the statistics from a minimum of 321 stations could represent the whole spatial distribution of seasonal precipitation variability in the US. As for the US Climate Reference Network (CRN), Janis et al. (2002, 2004) found that 250 stations, i.e., one station for every 180 km, could meet the needs for monitoring regional climate change in the country. Hu et al. (2012) applied the US station density strategy to mainland China, and recommended a proper layout of the national reference climate network. Vose and Menne (2004) investigated the influence of station density on climate change monitoring in the US.

There are 33 GSN stations, 143 RCN stations, 682 BMN stations, and 1592 OMN stations in China. It is important to understand the difference between different observation networks and to which degree the choice of dataset can affect the regional climate change monitoring and detection in mainland China.

In this paper, a statistical analysis based on data from the current observation networks is conducted so as to compare the results from different observational networks in documenting climatological characteristics of precipitation and monitoring precipitation change. A merged dataset of all station networks is used as a benchmark for the comparison. The results of the analysis will be useful for choice of datasets in precipitation studies and for the design and management of the national and regional climate observational systems.

2. Data and methods

At present, there is no consensus about the suitability of precipitation data of various meteorological station networks for studies of regional climatology and climate change. It generally holds that the denser the station network, the more reliable the monitoring result, given that the data quality maintains high. Therefore, a monthly precipitation dataset with preliminary quality control and with data from all kinds of China meteorological stations is considered as most reliable, and it is used as the reference for comparison with the datasets of component meteorological station networks in the study region.

The monthly data from the stations with no missing records during the reference period 1971–2000 and with the missing records of no more than 10 yr during the whole analysis period 1961–2009 are chosen in this study. Altogether, there are 2070 stations from the four observational station networks. These are hereafter referred to as the All Station Network (ASN). The ASN comprises 131 RCN stations, 628 BMN stations, 1311 OMN stations, and 32 GSN stations. A merged dataset of 740 stations from both the RCN and BMN is referred to as R&B for short and considered as a separate observational network in this paper. The distributions of stations of all the observational networks are shown in Fig. 1. Taiwan Region is not included in this study due to the unavailability of observational data.

Janis et al. (2002, 2004) reported that one station every 180 km can meet the need to monitor long-term temperature and precipitation changes in the US. Con-

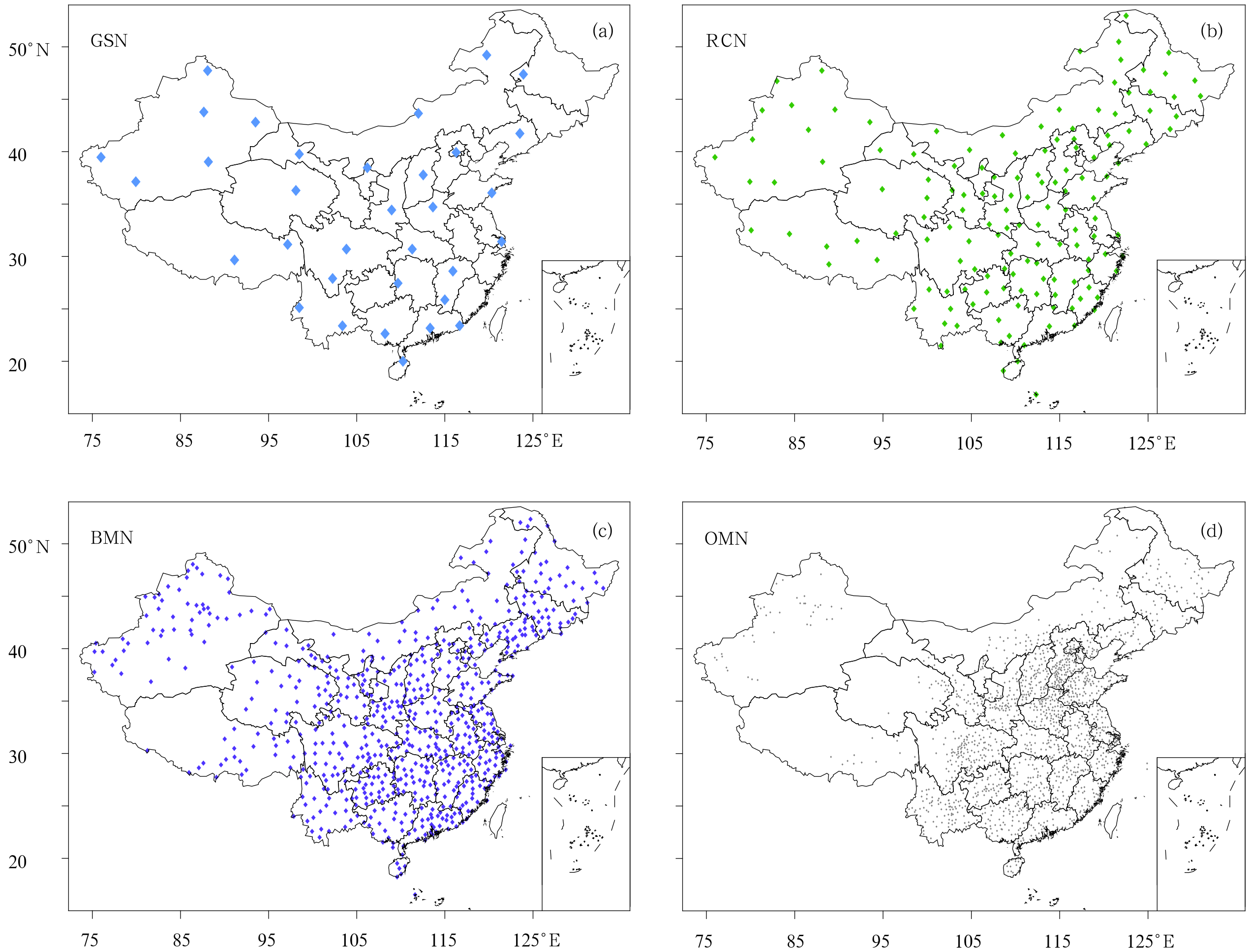

Fig. 1. Distributions of various observation networks used in this study. (a) GSN, (b) RCN, (c) BMN, and (d) OMN.

sidering the good similarity of geographical and climatic characteristics between the US and China, the requirement for station density for monitoring climate change in the US might be also applicable in China to a certain extent. Figure 2 shows the distribution of ASN station density (number of stations) for each latitude-longitude grid of 2.5°×2.5°. The ASN station density is much higher in eastern China. Most 2.5°×2.5° grids in western China have also enough data. About 1/6 of the grids are not covered by observational data and they are mainly located in central to northern Tibetan Plateau and central to eastern parts of the Taklimakan Desert. A division of 5°×5° latitude-longitude grids can guarantee that there is at least one station in each of all the complete grids over mainland China (Fig. 2).

It is understandable that daily station precipitation data represent a relatively small spatial coverage. For monthly and annual precipitation data, however, the values of precipitation average and variance at adjacent stations within a given distance would be more similar. In addition, the long-term change and variab-

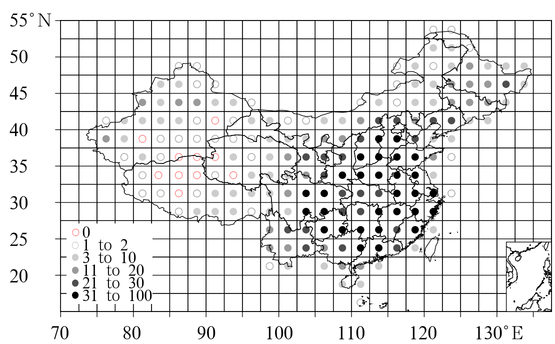

Fig. 2. Distribution of the ASN station density (number of stations) for each 2.5°×2.5° grid box.

ility are not so sensitive to the terrain as average. It is thus reasonable to assume that the ASN data can satisfy the demand when monitoring monthly, seasonal, and annual climate change and climate variability. Therefore, in this paper, we assume that the observation data series of the ASN could best represent climatological characteristics and long-term trends of annual and seasonal precipitation in every region of China. The ASN data and their averages at any grid are taken as benchmark or reference data for comparison with other observation networks.

Subtraction of the ASN data series from the other network data series (absolute difference) and the percentage ratio of the difference to the ASN value (relative difference) are used to assess the deviation of the network from the reference records, and they are marked as ad_{ij} and rd_{ij}, respectively. The average of the monthly absolute values of rd are obtained and called comprehensive difference (cd_i). Variables ad_{ij}, rd_{ij}, and cd_i are calculated for monthly and annual precipitation to characterize the impacts of different network densities and spatial distributions on the estimates of region-averaged precipitation amounts and precipitation trends.

$$\mathrm{ad}_{ij} = P_{ij} - P_{\mathrm{ASN}j}, \tag{1}$$

$$\mathrm{rd}_{ij} = |\mathrm{ad}_{ij}/P_{\mathrm{ASN}j}| \times 100\%, \tag{2}$$

$$\mathrm{cd}_i = \sum_{j=1}^{12} \mathrm{rd}_{ij}/12, \tag{3}$$

where ad_{ij} is the absolute difference between station network i and the ASN in month j, P_{ij} is the precipitation (monthly mean value or linear trend) for station network i in month j, $P_{\mathrm{ASN}j}$ is the precipitation (monthly mean value or linear trend) for ASN in month j, rd_{ij} is the relative difference between station network i and ASN in month j, and cd_i is the comprehensive difference between station network i and ASN.

The various observational networks all exhibit a higher density and a more homogeneous pattern in eastern China, but the station density is not so good in the west, especially over central and western Qinghai-Tibetan Plateau in 30°–37°N, 80°–95°E. A large station gap in western China can be seen for OMN, and this is the reason why OMN will not be taken as an independent network for the comparison.

There is an obviously varied precipitation distribution in China. To minimize the impact of spatial difference of precipitation on the analysis results, the precipitation anomaly percentage is used to reflect the relative change of precipitation. The reference period for the calculation of precipitation anomaly percentage is 1971–2000. For climatological analysis, the grid- and country-averaged annual and monthly precipitation amounts are calculated and compared for different observational networks.

The uneven distributions of stations can also exert an impact on the analysis results. The study domain is divided into 5°×5° grids, and the grid- and country-averaged precipitation amounts and anomaly percentages are obtained. Firstly, arithmetic averages of precipitation and anomaly percentages are calculated for each month of 1961–2009 at each grid, with 1971–2000 as the reference period. Then, the area-weighted average of the grid values is calculated to obtain the country-averaged precipitation amount and precipitation anomaly percentage for each month (Jones and Moberg, 2003).

It is better to use the grids on a resolution finer than 5°×5° latitude and longitude in the calculation of regional averaged precipitation. Due to the low-density of the GCOS, however, latitude and longitude grids of smaller scales would leave too many blanks. Therefore, the 5°×5° horizontal grid points are selected uniformly throughout this study.

3. Results

3.1 Average annual and monthly precipitation

The time series of average annual precipitation of mainland China from 1961 to 2009 calculated from different observational networks are shown in Fig. 3. The largest annual precipitation is from the GSN, followed by the BMN and RCN. The smallest absolute difference of the annual precipitation from the reference station network is found with the R&B, which is only 4.3 mm, followed by those from RCN (11.8 mm) and BMN (21.2 mm). The largest absolute difference of 40.9 mm is seen with the GSN. The relative differences of the country-averaged annual precipitation for the R&B, RCN, BMN, and GSN are –0.63%, 1.71%,

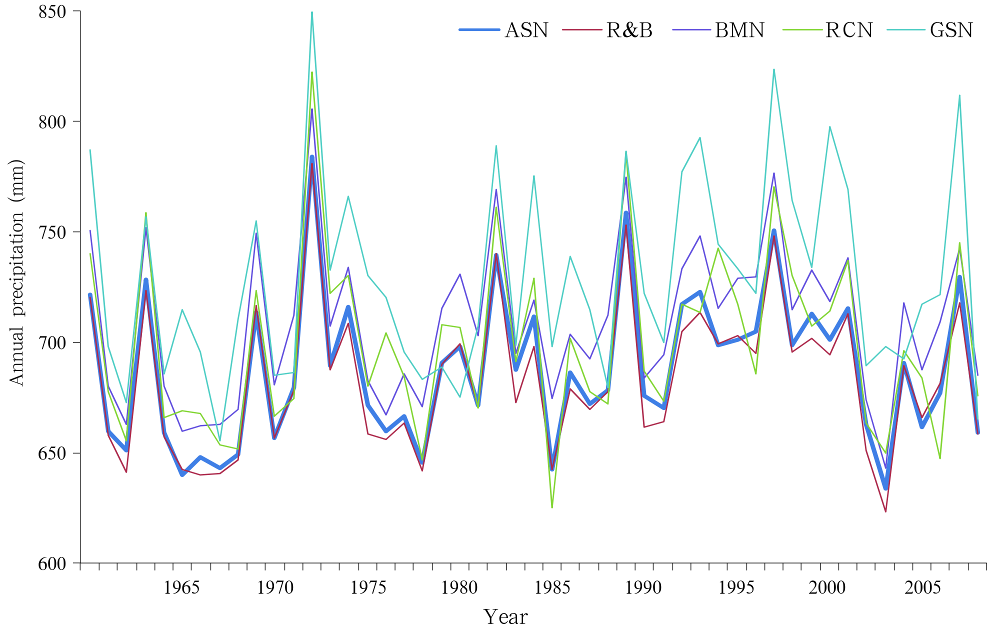

Fig. 3. Time series of mainland China average annual precipitation from various observation networks during 1961–2009.

3.08%, and 5.95%, respectively, with none exceeding 10%, indicating that the deviations of the R&B, RCN, BMN, and GSN from the reference network are small (Table 1).

Table 1. Country-averaged annual and monthly precipitation (mm) from various observation networks in China (1961–2009)

	ASN	R&B	BMN	RCN	GSN
Jan	13.47	13.39	13.96	14.04	14.95
Feb	18.16	17.94	18.95	18.25	20.43
Mar	29.35	29.32	30.97	29.56	31.91
Apr	48.13	47.41	49.93	47.97	53.71
May	74.74	74.08	77.97	73.84	80.87
Jun	105.30	104.65	108.05	108.36	114.48
Jul	123.65	121.92	124.70	125.47	132.37
Aug	116.30	113.97	116.16	118.32	122.96
Sep	77.46	77.06	80.06	79.11	76.33
Oct	46.25	47.70	50.60	47.03	43.54
Nov	23.07	23.65	24.72	24.42	23.84
Dec	12.55	12.65	13.18	13.23	13.22
Annual	687.68	683.39	708.87	699.47	728.60

With regard to the monthly precipitation, the absolute differences range from –4 to 10 mm. The GSN witnesses the largest differences from the ASN, especially during summer months, reaching 6–9 mm in May to August, and the R&B exhibits the smallest absolute differences (Fig. 4). Figure 5 shows the relative differences of monthly precipitation for the networks.

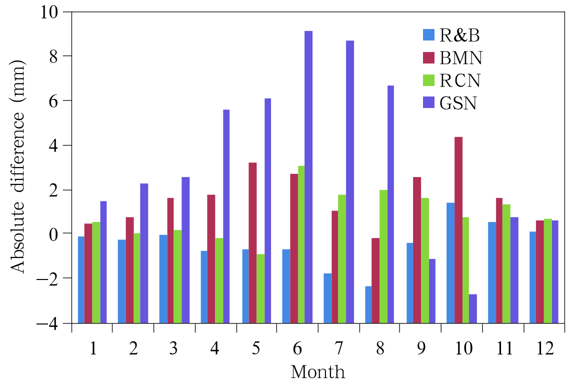

Fig. 4. Absolute differences of monthly precipitation (mm) of various observational networks from the ASN in mainland China (1961–2009).

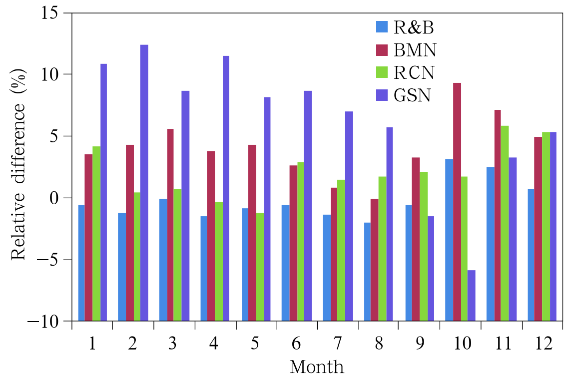

Fig. 5. As in Fig. 4, but for relative differences.

It is clear that the monthly relative differences of the R&B are all less than 5%, and those of the RCN and BMN are all less than 10%. However, the relative differences of the GSN for January, February, and April are well above 10% (Fig. 5).

The R&B has the smallest comprehensive difference of 1.27%, followed by the RCN (2.35%) and BMN (4.17%). It is notable that the deviation of the RCN is smaller than that of the BMN, implying that the station density of an observational network might have not been the dominant factor for accurate monitoring of regional precipitation. The balance between monitoring capability and constructing/maintaining costs of a specific network needs to be further investigated. However, the above result shows that the density and distribution of a network like the RCN, which has a higher capability and a more reasonable cost, are better than the BMN for estimating regional average precipitation.

Figure 6 shows the distributions of annual total

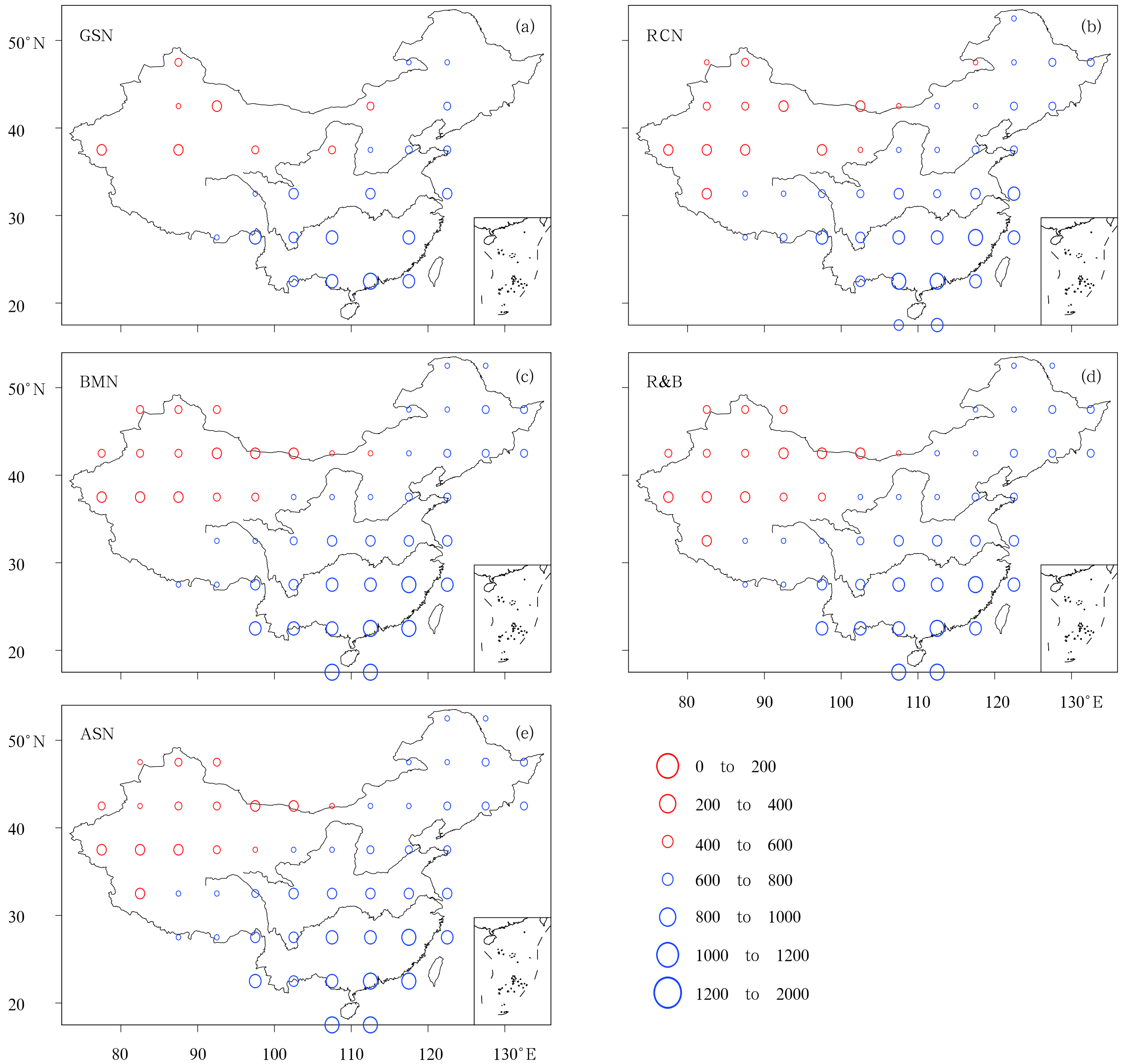

Fig. 6. Distributions of annual total precipitation (mm) from various observation networks (1961–2009). (a) GSN, (b) RCN, (c) BMN, (d) R&B, and (e) ASN.

precipitation from various station networks for the period 1961–2009. The spatial features from all the networks bear a similar and consistent pattern, and all of the networks are able to reflect the gradual increase of precipitation from Northwest to Southeast China. The highest similarity to the ASN seems from the R&B. However, the annual precipitation in specific grid boxes exhibits larger differences among the networks.

Figure 7 shows the relative differences of the networks from the ASN at each grid box. The absolute values of the relative differences obtained from RCN, BMN, and R&B are generally less than 10% except for Northwest China for all of the three networks and for central Inner Mongolia from the BMN, where more than 10% absolute differences are produced. The annual precipitation amounts estimated from the BMN, the RCN, and the R&B in northwestern China are usually less than those from the ASN, mostly less than –10%, indicating relatively poor representativeness of the three networks. The underestimated values are mainly located around 45°N, corresponding to the location of the Tianshan Mountain. The lower station density and the highly varied landforms in the area might be the factors for the poor representativeness of the networks.

For the regions south of the Yangtze River, the situation is much better, with absolute values of the relative differences all below 10%, indicating that the networks can well record the "real" annual precipitation, and each of them except the GSN, which was established for global-scale research and monitoring (Gandin, 1970), can be confidently used for climatological research of regional precipitation. The GSN

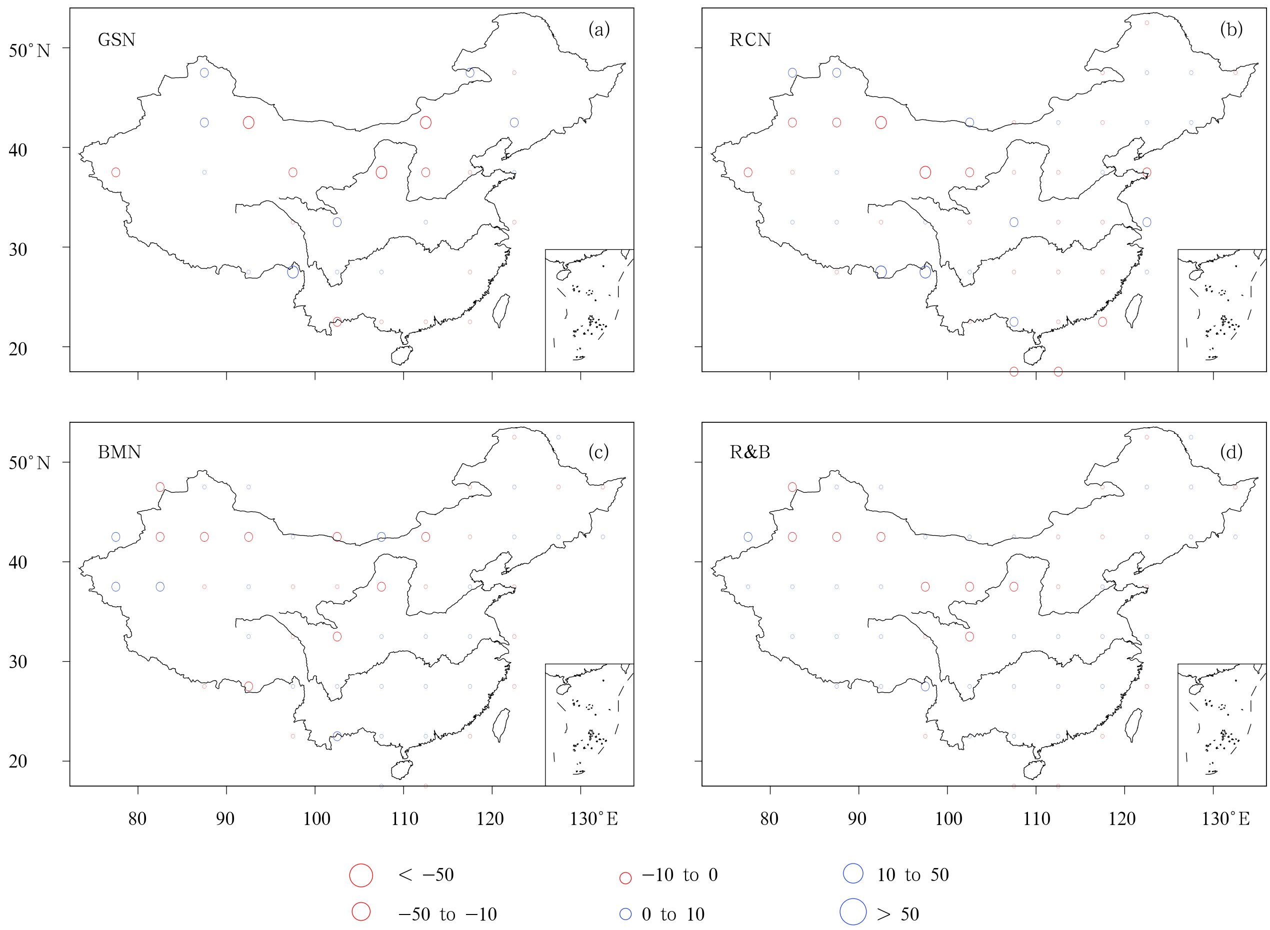

Fig. 7. Distributions of the differences of annual precipitation (%) of various networks relative to the reference network. (a) GSN, (b) RCN, (c) BMN, and (d) R&B.

presents a similar pattern of the relative differences to that of the BMN except that there are more blank boxes.

3.2 Trend of precipitation

Figure 8 gives the time series of the annual precipitation anomaly percentage of mainland China for various networks during 1961–2009. The time series curves are very close to each other, and the correlation coefficients among them all pass the significance test at the 0.01 confidence level. There are some differences, however, especially between the GSN and other networks, with the former showing a larger annual variability due to the much smaller number of stations. Increasing trends in the precipitation anomaly percentage series can be seen for all of the networks, in spite of the fact that the increasing rates are somehow different. The GSN witnesses the largest rising trend, and the BMN exhibits the smallest increase.

The time series of the R&B bears the best similarity to that of the ASN in terms of linear trends of annual precipitation, with a negligible relative difference of –0.04% per decade, or about –2.74% of the ASN trend (Table 2 and Fig. 9). The trend differences of the RCN, BMN, and GSN relative to the ASN are –0.40%, –0.33%, and 0.58% per decade, respectively. The relative differences, however, are large, reaching –22.60%, –27.40%, and 40.41% respectively for the BMN, RCN, and GSN. Meanwhile, the trends for the BMN and RCN do not pass the significance test. Therefore, only the R&B dataset can reliably capture the change trends of annual and monthly precipitation in regions like mainland China. This shows that the linear trends of annual precipitation are more sensitive than the regional average annual total precipitation to the datasets used. The density and distribution of observation stations might have been important in this regard.

The estimated linear trends of monthly precipitation anomaly percentage series from 1961 to 2009 show that, for the series of all the networks except the GSN, the rising trends of the monthly precipitation anomaly percentage in January, March, May, and December are consistently more significant, while the small negative trends are registered for August for the BMN and for November for the RCN (Table 2).

Figure 9 shows the absolute differences of the linear trends of annual and monthly precipitation ano-

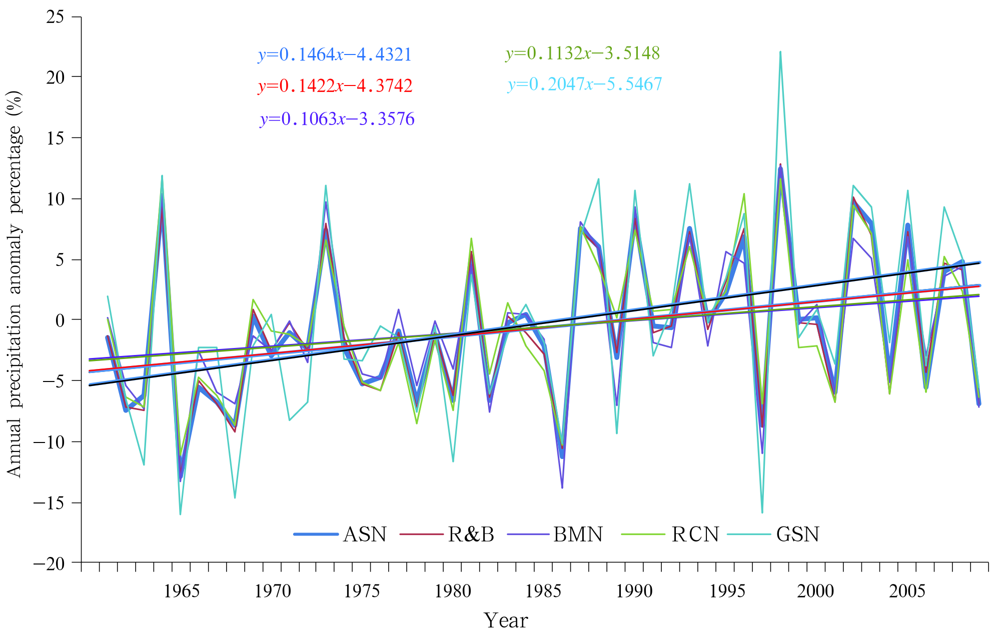

Fig. 8. Country-averaged annual precipitation anomaly percentages of mainland China for the various observation networks during 1961–2009.

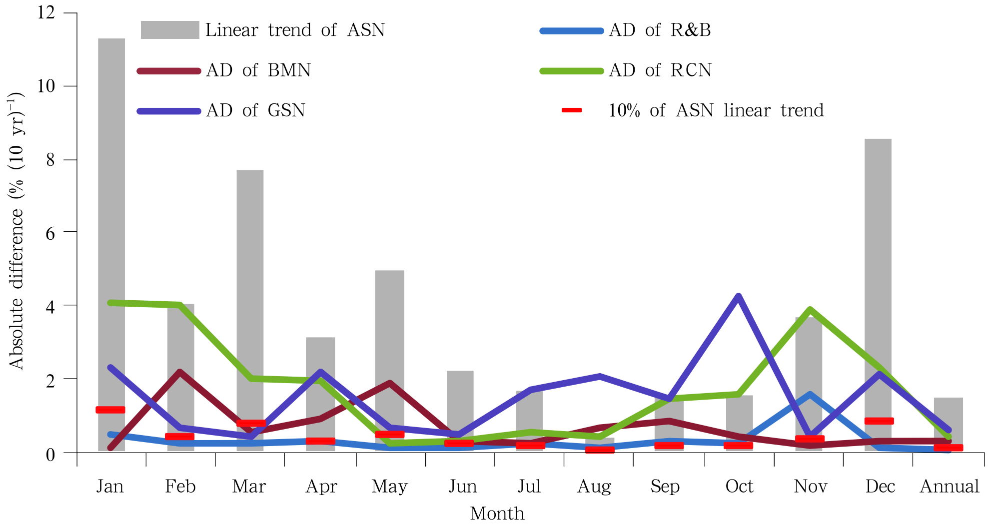

Fig. 9. Absolute differences of linear trends (% (10 yr)$^{-1}$) of monthly and annual precipitation anomaly percentages of various observation networks in mainland China for the period 1961–2009 (AD denotes absolute difference).

Table 2. Linear trends (% (10 yr)$^{-1}$) of annual and monthly precipitation anomaly percentages of various observation networks in mainland China for the period 1961–2009

	ASN	R&B	BMN	RCN	GSN
Jan	11.28**	10.82**	11.14*	7.20	8.98*
Feb	4.04	3.81	6.24*	0.03	3.39
Mar	7.67*	7.41*	7.11*	5.65	7.26*
Apr	3.12	2.85	2.22	1.15	0.96
May	4.99*	4.9*	3.12	4.77*	4.34
Jun	2.24	2.35	1.95	1.91	2.71
Jul	1.65	1.43	1.43	1.10	3.34*
Aug	0.37	0.26	–0.33	0.79	2.46
Sep	1.56	1.25	0.70	0.10	0.10
Oct	1.56	1.79	1.97	0.00	–2.72
Nov	3.66	2.10	3.82	–0.25	4.07
Dec	8.56*	8.67*	8.89*	6.27	6.43
Annual	1.46*	1.42*	1.13	1.06	2.05*

** Significant at the 0.01 confidence level by t-test;

* Significant at the 0.05 confidence level by t-test.

maly percentage for the various networks compared to those for the ASN during 1961–2009. Figure 9 also gives the linear trends of monthly and annual precipitation of the ASN and the 10% level of the trends. The smallest absolute differences are found for the R&B, with all the months except November below 1% per decade. The BMN owns relatively small absolute differences as well, and the GSN and RCN have larger absolute differences in summer and winter respectively. However, the absolute values of all the monthly relative differences from July to October are more than 10%. The monthly precipitation anomaly percentage of the ASN rises by 1.56% per decade in October, for example, but that of the GSN drops by 2.72% per decade, and the absolute difference between them reaches 4.28% per decade, two times higher than the trend of the ASN. Also, the absolute difference of the linear trend of February precipitation anomaly percentage for the BMN is 2.20% per decade, more than half of the linear trend for the ASN.

In view of the comprehensive differences of linear trends of annual precipitation, the R&B once again owns the best representativeness, followed by the BMN and the RCN, and the largest comprehensive difference of linear trends of annual precipitation is registered for the GSN, indicating that the GSN dataset is relatively poor in monitoring regional average trends of annual precipitation in mainland China.

Figure 10 shows the distributions of the linear trends of annual precipitation anomaly percentages from 1961 to 2009 for the various networks. It is obvious that the spatial distributions all exhibit a previously recognized pattern of change trends of annual precipitation, with increase in Northwest and Southeast China, and decrease in North China, southern Northeast China, and central parts of the country

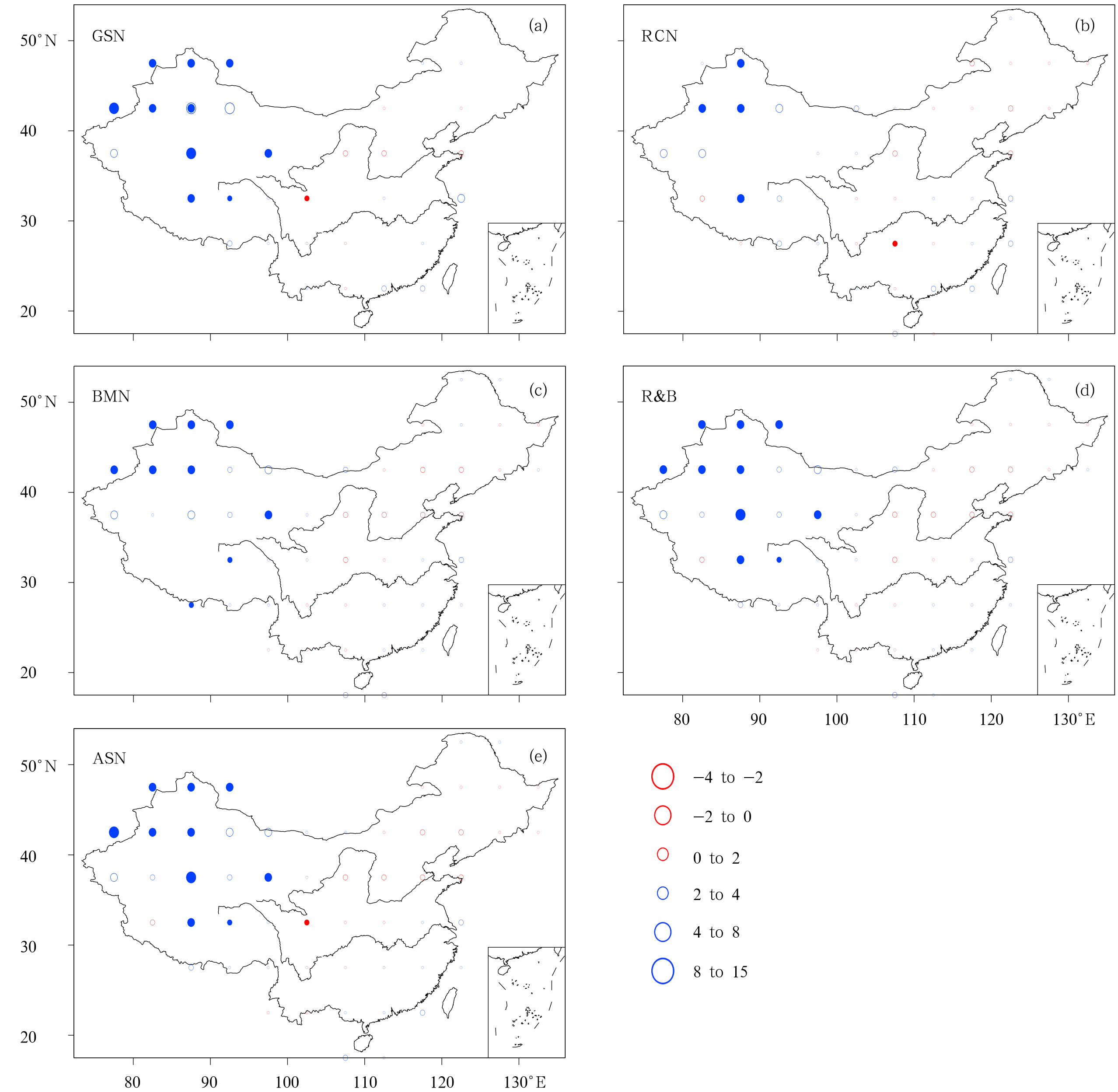

Fig. 10. Linear trends of grid precipitation anomaly percentages (% (10 yr)$^{-1}$) of various observation networks from 1961 to 2009. Solid circles denote that the trends are significant at the 0.05 confidence level. (a) GSN, (b) RCN, (c) BMN, (d) R&B, and (e) ASN.

(Ren et al., 2005). It seems that the networks are able to capture better the spatial pattern of the precipitation trends than their temporal changes. Of course, there are considerable variations in magnitudes for certain grids among the networks. The R&B bears the highest similarity to the ASN, with regard to the spatial patterns of the precipitation trends. It is interesting to note that the GSN also has a good similarity to the ASN in the west in spite of more blank grids there.

Figure 11 shows the distributions of the relative differences of linear trends of grid precipitation ano-

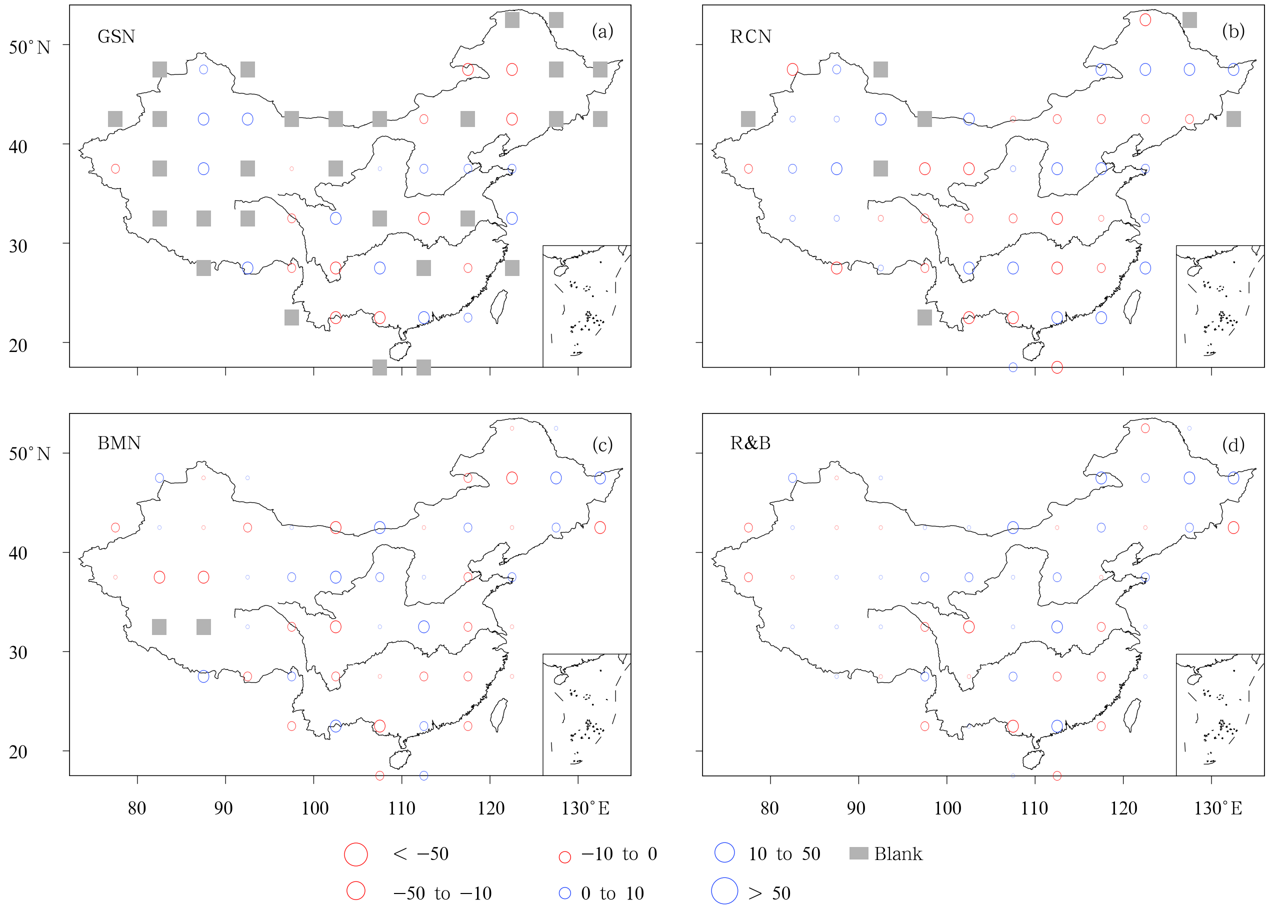

Fig. 11. Relative differences of linear trends of grid precipitation anomaly percentages (%) for various networks from 1961 to 2009. Grey diamonds denote the grids without data. (a) GSN, (b) RCN, (c) BMN, and (d) R&B.

maly percentages. The linear trends of annual precipitation for the various observational networks are mostly smaller than those for the ASN, leading to negative relative differences for most grids. However, the absolute differences and the relative differences obviously vary from region to region.

Most of the GSN grids with data have larger absolute values of the relative differences, especially in western China, indicating relatively low reliability for the network to monitor precipitation trends of that region. The representativeness of the RCN is better in Northwest China, but not so good in central Northeast China. For most of the networks, their consistencies with the ASN are poor in South and Southwest China. Although the best representativeness can be found for the R&B, it is far from satisfactory in central and eastern Northeast China, and in northern parts of the middle reaches of the Yangtze River. Compared to the distribution of the relative differences of annual precipitation, the trend consistency of the networks with the ASN in Northwest China seems better. It is notable that the consistency of the networks with a low station density is also better in Northwest China than in South China, where the station density is higher. This can be explained by the fact that a more significant rising trend of precipitation occurs in Northwest China during the last five decades, and the precipitation trends during the same time period in South China are more diverse in spatial distribution.

4. Conclusions and discussion

Generally, the higher the station density of an observational network is, the higher the representativeness of the observation will be. Therefore, it was assumed in this study that the ASN, composed of all network stations, could produce the most accurate estimates of precipitation climatology and precipitation change, and it could be taken as a reference network. Based on this assumption, we analyzed the consistency of precipitation climatology and precipitation change obtained using the data from different observational networks in mainland China. The following conclusions are drawn:

(1) Among the observation networks used for studies of precipitation climatology and climate change in mainland China, there are some differences in their representativeness for the country-averaged annual precipitation, but the relative differences are below 10%. The spatial distributions of annual precipitation for different networks are considerably consistent, characterized by a gradual increase from Northwest to Southeast China. The observation representativeness is poor in Northwest China and central Inner Mongolia, and is better in the region south of the Yangtze River.

(2) Observation networks at all levels could successfully detect the rising trend of annual precipitation in mainland China as a whole during 1961–2009, with the R&B (ad: –0.04% per decade; rd: –2.74%) being the closest to the ASN, and the GSN (ad: 0.58% per decade; rd: 40.41%) the most deviated. The trend differences of monthly precipitation from the ASN indicate a better capacity of the RCN than that of the BMN. In view of the representativeness for country-averaged monthly precipitation trends, the observational networks can be ranked as the R&B (rd: 1.27%), the RCN (rd: 2.35%), the BMN (rd: 4.17%), and the GSN (rd: 7.46%), in descending order.

(3) The observation networks produce quite consistent spatial patterns of linear trends of annual precipitation. They all show a general pattern of increasing trends in Northwest and Southeast China, and decreasing trends in North, Northeast, and parts of central China.

(4) In view of the linear trend patterns and their similarity to the ASN, the BMN and R&B are better, though they are still unsatisfactory in central and eastern Northeast China, and in parts of Southeast China. The relative differences of GSN and RCN exceed 10% at all grids, so the representativeness of the GSN and RCN are not satisfactory in mainland China as a whole.

It was also found that higher station density does not always lead to more satisfactory estimates of region average precipitation and precipitation change. For example, in some areas of Northwest and central China, the RCN data could meet the requirement for the analysis of annual precipitation change; so in this case, it is unnecessary to use the observational networks with denser stations like the BMN or R&B. In the construction and management of the regional climate observational networks, and in the studies of regional precipitation, the cost-benefit should be considered in order to adopt the most appropriate dataset from the observational networks with higher representativeness and availability, and lower station density.

One of the reasons for the higher sensitivity of the analysis results to choices of the networks lies in the fact that the station distributions of certain observational networks are spatially uneven. This might have been especially true for the estimate of the regional average annual total precipitation or monthly total precipitation when a larger-size grid is chosen. It is thus understandable why the observation representativeness of the country average precipitation by using the RCN data is higher than that by using the BMN data. A relatively more homogeneous distribution of stations is guaranteed in the former case. Therefore, caution should be kept in mind when applying the general principle that higher station density will lead to better estimates of regional average precipitation and precipitation change.

Compared to the regional average precipitation amount and precipitation trends, the estimates of frequency and magnitude of extreme precipitation events would be more sensitive to the density and distribution of stations. The ASN as applied in this study cannot satisfy the need for monitoring daily precipitation change and variability, and the capability of the current observational networks in capturing the extreme precipitation events and their trends should be evaluated independently.

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