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Quality control and homogeneity of Turkish precipitation data

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Abstract:

Outlier trimming and homogeneity checking/correction were performed on the monthly precipitation time series of various lengths from 267 stations in Turkey. Outlier values are usually found during dry summer months, and are concentrated mostly over the southern parts of the country, where the dry period is most pronounced, implying natural extremes rather than wrong measurements. Homogeneity analysis was done using the Standard Normal Homogeneity Test, on an individual monthly basis, which led to many non-testable series due to lack of reference stations, especially during summer months. Yet, remaining testable months were usually helpful for the assessment of homogenity, revealing a well distributed set of stations that proved to be homogeneous. There were still a number of stations which either could not be tested efficiently, or were classified as inhomogeneous. Lack of metadata is argued to be largely responsible for inefficient homogeneity testing.

KEY WORDS station data; precipitation; Turkey; quality control; outlier; interpolation; homogeneity

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INTRODUCTION

Once 'climate change' became an issue of central importance, there arose a much needed skepticism about the results of data analysis work, which frequently indicated sharp or determined changes in regional climates. It is now well recognized that variations in many long-term station time series are caused not only by changes in weather and climate, but also by changes in location of the stations, instruments, formulae used to calculate means, observing practices and station environment (Karl and Williams, 1987; Heino, 1994). A homogeneous climate series is defined as one where variations are caused only by variations in weather and climate (Conrad and Pollak, 1950). Other, unnatural variations are called inhomogenities, which can lead to erroneous interpretations of the studied climate. Thus, before using climatological data in any kind of study—especially in climate change studies—a quality control and homogeneity assessment of data sets is mandatory (Peterson *et al.*, 1998).

Having been the primary emphasis of quality control work historically (Grant and Leavenworth, 1972), outliers are defined to be the marginal values of a climate time series, which are very distant from the mean value. They can be due to measurement errors or extreme meteorological events. Outliers that are known to be wrong measurements should be excluded from the data set (González-Rouco *et al.*, 2000), but for those that may have a physical background, whether correction should be made or not is an important question (Barnett and Lewis, 1994). These extreme values, if they are correct, carry valuable climatological information that should not be dismissed (Gonález-Rouco *et al.*, 2000). On the other hand, outliers can affect the estimation of sample statistics during the use of nonresistant techniques. These techniques are known to be sensitive to the presence of outliers (Lanzante, 1996). In order to retain the information of extreme events while not influencing nonresistant statistics too much, outliers can be replaced by a threshold value specific for each time series (Barnett and Lewis, 1994). This is the approach adopted as the quality control procedure in this work.

Peterson *et al.* (1998) give a comprehensive review of homogeneity assessment and adjustment methodologies. Of those, 'direct' ones mainly rely on station history files, known as metadata. 'Indirect' methods, which may also benefit from metadata, can either use single station data (Zurbenko *et al.*, 1996; Rhoades and Salinger, 1993), or construct a reference time series to be compared with the one being tested (Potter, 1981; Alexandersson, 1986; Hanssen-Bauer and Førland, 1994; Peterson and Easterling, 1994; Alexandersson and Moberg, 1997; Tayanç *et al.*, 1998, González-Rouco *et al.*, 2000). Erinç (1962) states that, since the climatic parameters may vary greatly in time at the same place, it is almost impossible to describe the inhomogeneity of a station time series by analysing it individually. However, stations exhibiting similar changes in time, form a reliable basis to assess homogeneity, no matter how big the change is. Thus, homogeneity assessment methods using reference series are usually considered superior to the others.

In this work, we deal with the outliers and inhomogeneities of monthly precipitation time series of Turkey. First, the outliers are trimmed by replacing them with a certain threshold value specific for each time series, a method which is outlined by Barnett and Lewis (1994).

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Then the inhomogeneities are detected and the time series corrected accordingly, following a procedure based on the Standard Normal Homogeneity Test developed by Alexandersson (1986), and later improved by Hanssen-Bauer and Førland (1994) with the purpose of using reference stations that proved to be homogeneous.

The main purpose of this study is to determine high quality precipitation time series which could be used in subsequent works of hydrology, hydrometeorology, statistical downscaling, and climate change and variability. To date, no comprehensive homogeneity analysis of a Turkish precipitation data set has been made, while Tayanç *et al*. (1998) studied the temperature data sets in detail.

Data are described in the next section, followed by presentation of the methodology. The final two sections include results and conclusions.

DATA

Early instrumental climate records in Turkey date back to the mid-nineteenth century. These consist of temperature data measured at private foreign schools in Istanbul. Some records were also kept by individuals, who were usually foreigners, before the establishment of 'Rasathane-i Amire' (meaning close to 'Royal Observatory') in Pera, Istanbul, in 1868. This was the first institution in Turkey to record meteorological data. In 1911 it moved to Icadiye Hill at Kandilli village on the Anatolian side of the Bosphorus Strait, and has been called 'Kandilli Observatory' since 1939. The State Meteorological Service of Turkey was established in 1936, based on the preliminary efforts of Antal Réthly, a Hungarian meteorologist who was in charge of installing meteorological stations in Turkey at the time and also collected the older climatic records of the country.

In this study, time series of monthly precipitation totals from 267 meteorological stations in Turkey were used. Station locations are shown in Figure 1. Except one station, data were provided by the State Meteorological Service of Turkey (SMST) under the contract of a joint research programme. Otherwise, data from SMST are not freely available to the international climate research community. Time series in this dataset have variable lengths, with many missing values in some of them. The longest series have records dating back to 1930. Almost all of the stations have their most recent records at 2004. Some missing values were completed utilizing a smaller data set, which was previously quality controlled by Murat Türkeş, Utku Sümer, Gönül Kılıç and İsmail Demir, of SMST. Metadata, a feature that only a few stations have in this dataset, are taken from Tayanç *et al.* (1998), as no metadata were available from SMST. They are composed only of relocation dates of a few stations, and proved to be useless for the final assessment. There is no information about the history of instruments used. The data from Kandilli station, which was obtained from Kandilli Observatory and Earthquake Research Institute of Bosphorus University, spans the period from 1912 to 2004. Earlier instrumental records, some of which are presented in Erinç (1962), are neither complete enough to be used in the analysis, nor fully available from any other source.

METHODOLOGY

In this section, the methods of outlier trimming, homogeneity adjustment and missing value interpolation are described.

Outlier trimming

Outliers are values greater than a threshold value specific for each time series, defined by

$$P_{out} = q_{0\cdot 75} + 3IQR \tag{1}$$

where $q_{0\cdot 75}$ is the third quartile and IQR is the interquartile range. Thus, P_{out} represents both the average magnitude and variance of the related variable. In order to reduce the size of distribution tails and make a safer use of the nonresistant homogenization technique used later (González-Rouco *et al.*, 2000), also to keep the information from extreme events, outlier values of each monthly

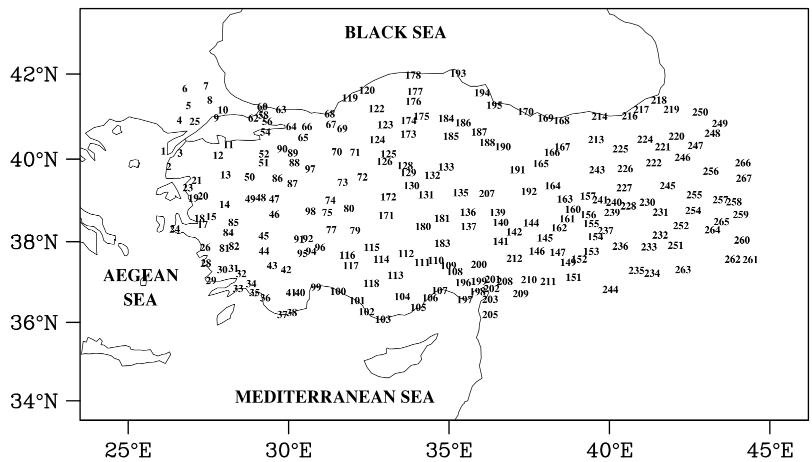

Figure 1. Distribution of the 267 precipitation stations used. Numbers which do not appear on the map belong to overlapping stations

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precipitation series were replaced by the unique P_{out} value.

Homogenization

Standard normal homogeneity test. A homogenization technique was employed based on the Standard Normal Homogeneity Test (SNHT hereafter) developed by Alexandersson (1986). The following outline of the test is taken from González-Rouco *et al.* (2000). SNHT assumes that precipitation amounts at the test station and some regional average amounts are proportional to each other through time. This proportionality is expressed as the ratio, q, of the test station normalized precipitation values to those of a regional time series, which is defined as a weighted average of several nearby stations. These neighbour stations are the references for the station being tested. The ratio q in any year is written as

$$q_i = F_i/G_i, \quad i = 1, \ldots, n \tag{2}$$

where n is the number of years and F_i and G_i are normalized values of precipitation at the test and reference stations defined as

$$F_i = P_i/\overline{P}, \quad G_i = \frac{\sum_{j=1}^{k_i} v_j Q_{ij}/\overline{Q}_j}{\sum_{j=1}^{k_i} v_j} \tag{3}$$

P_i being the precipitation at the test station, Q_{ij} the precipitation at the jth reference station, and ν_j a weight factor for the jth reference series. In this study, ν_j was defined as the square of the correlation coefficient between the test series and the jth reference series. k_i is the number of reference stations used in time step i, which may vary with time due to different lengths of time series and the existence of missing values. Overbars denote average values over the period of observation.

Next, q_i values are standardized using their sample mean $\overline{q}$ and, standard deviation s_q:

$$z_i = (q_i - \overline{q})/s_q \tag{4}$$

This series has a mean of zero and a standard deviation of 1, also is assumed to be normally distributed. An inhomogeneity in the tested time series would affect the ratio series, q_i, and z_i. Therefore, SNHT is based on the following two hypotheses:

Null hypothesis (H_0): Tested series is homogeneous. Any subset of z_i is normally distributed.
Alternative hypothesis (H_1): Tested series has an inhomogeneity in year m such that first m years of the z_i have mean value μ_1 and the last $(n - m)$ years have mean value μ_2, with unit standard deviation in both segments.

By using these definitions, only one inhomogeneity is detected in the original test series. A test statistic, T_m, is computed for each of the $(n - 1)$ possible change points:

$$T_m = m\overline{z}_1^2 + (n - m)\overline{z}_2^2, \quad m = 1, \ldots, n - 1 \tag{5}$$

where $\overline{z}_1$ and $\overline{z}_2$ are the mean values of z_i during the m first and n last years, respectively. A high T value in year m implies that μ_1 and μ_2 are significantly different from zero, making the null hypothesis, H_0, unlikely. T_x is the maximum T_m value in the time series, and if it exceeds a critical value which is determined by the length of the series, H_0 is rejected. Critical T values for 5% and 10% significance levels (T_{95} and T_{90}) are given by Alexandersson (1986). A series is then classified as inhomogeneous if (i) it contains an inhomogeneity significant at the 5% level, 5 year or more from either end of the series, or (ii) the series contains an inhomogeneity significant at the 10% level, but explainable by metadata. Unexplained inhomogeneities close to the ends of the time series are not accepted, since probability of having greater T values near the ends is higher (Hawkins, 1977).

An inhomogeneous series is corrected by multiplying its data before the inhomogeneity date by q_a/q_b, where q_a and q_b are the mean values of q_i after and before the inhomogeneity.

One important feature that distinguishes this work from previous studies is that, all the months are treated separately and the methodology is applied to each individual monthly series of a tested station, for the highest correlation values were generally observed between series of test and reference stations that belong to winter months (Table I). That is, the whole data set is divided into 12 separate data sets, each one including time series of a specific month. The inhomogeneities of individual monthly series of each tested station are then compared, and a check made whether the inhomogeneity dates are consistent among months. This approach, although it leads to many non-testable monthly series due to lack of reference stations, especially during dry months, enables the construction of more reliable reference series, which arises as a need in the absence of metadata. Moreover, correlations between annual precipitation series of candidate stations

Table I. Correlation coefficients between selected nearby stations

Station 1	Station 2	January correlation	Winter correlation	July correlation	Summer correlation	Annual correlation
Kandilli	Florya	0·87	0·86	0·75	0·91	0·75
Edirne	Kırklareli	0·86	0·87	0·63	0·63	0·70
Esenboğa	Etimesgut	0·94	0·92	0·64	0·79	0·85
Adana	Ceyhan	0·87	0·81	0·53	0·79	0·67
Rize	Pazar	0·88	0·79	0·65	0·60	0·67

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are frequently very different from the correlations of individual monthly series, in particular, annual values are much higher than summer month values except in a few cases. Relocation of a station may effect the local climatic records differently at different times of the year (Türkeş, 2003). Thus, use of annual correlations for homogeneity testing and correction was avoided. In order to further enhance the reliability of reference series, a lower threshold of 0·80 was used for the correlation value between test and candidate reference stations. Increasing this threshold value further would lead to more stations with no reference series and in turn many more non-testable stations, which is obviously not desirable. Also, series shorter than 20 years were not included in the homogeneity procedure as either test or reference series, since high correlations between very short series and longer ones would be misleading in the choice of reference stations.

The data set, which is described in the previous section, has many missing values and very little metadata. Thus, rather than trying to determine all the inhomogeneities exactly and to have lots of corrected precipitation series, the aim in this study is to obtain a modest number of high quality precipitation series, which can be used safely in future work. All the approaches and tight criteria are adopted in order to fulfil this goal.

Selection of reference stations. If none of the series in the dataset has been tested before and is known to be homogeneous, results of SNHT can be negatively affected by the use of non-homogeneous series as references. Thus, the 5-step technique developed by Hanssen-Bauer and Førland (1994) was used, with the purpose of employing homogeneous reference series as far as possible. The procedure, which is summarized in Figure 2, is as follows.

In step 1, all series are tested, using all series again as possible references. This leads to an initial classification of homogeneous (H1) and inhomogeneous (I1) series. After correction of the inhomogeneous I1 group, step 2 tests all series again, this time using the homogeneous (H1) and corrected (I1) series of step 1 as the pool of references. This results in a better classification of homogeneous (H2) and inhomogeneous (I2) series. In step 3, the I2 group is tested after having been adjusted using references selected from H2 and the corrected I2 groups. The output is two groups with corrections: homogeneous (HC3) and inhomogeneous (IC3) series. At step 4, all series, consisting of H2 and I2 groups are tested again, selecting the references only from those series which prove to be homogeneous so far, H2 and HC3 groups. Outputs of step 4 are two groups of homogeneous (H4 and HC4) and two groups of inhomogeneous (I4 and IC4) series. Finally, step 5 tests the inhomogeneous group of step 4 (I4) after its correction, using homogeneous H4 and HC4 groups as the reference candidates. At the end, we have a set of homogeneous (H4), two sets of homegenous after correction (HC4 and HC5), and two sets of inhomogeneous after correction (IC4 and IC5) series. Series corrected once and found to remain inhomogeneous, are not corrected once more and are classified as inhomogeneous.

Interpolation of missing data

Equations (2) and (3) of the SNHT procedure can also be used for the interpolation of missing data (Alexandersson, 1986). Assuming $q_t \simeq \overline{q} = 1$ for missing data, missing F_i values, $\hat{F}_i$ are estimated from

$$\hat{F}_i = q_i G_i \simeq \overline{q} G_i = G_i \tag{6}$$

thus the precipitation for the test station is estimated as $\hat{P}_i = \overline{P} G_i$.

RESULTS

Outlier distribution

Figure 3 shows the distribution of P_{out} (Equation (1)) values for January and July as representatives of winter and summer, respectively. In January, the highest

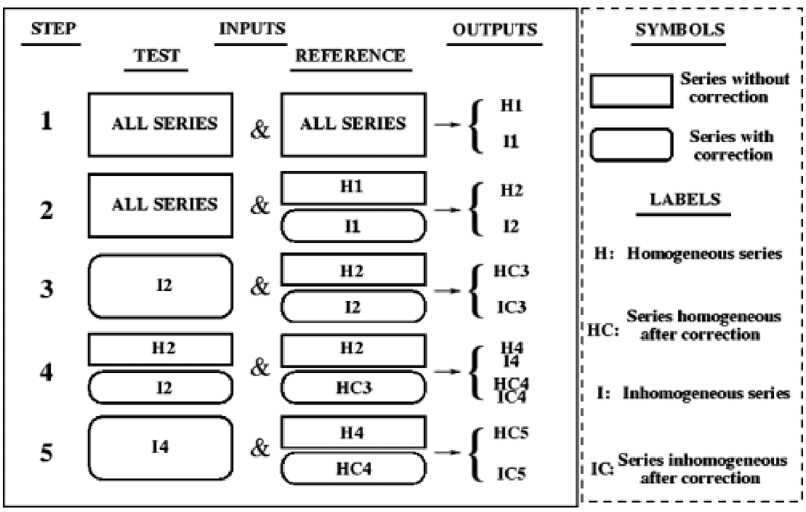

Figure 2. Five-step procedure for homogeneity testing developed by Hanseen-Bauer and Førland (1994). Figure adopted from González-Rouco *et al.* (2000)

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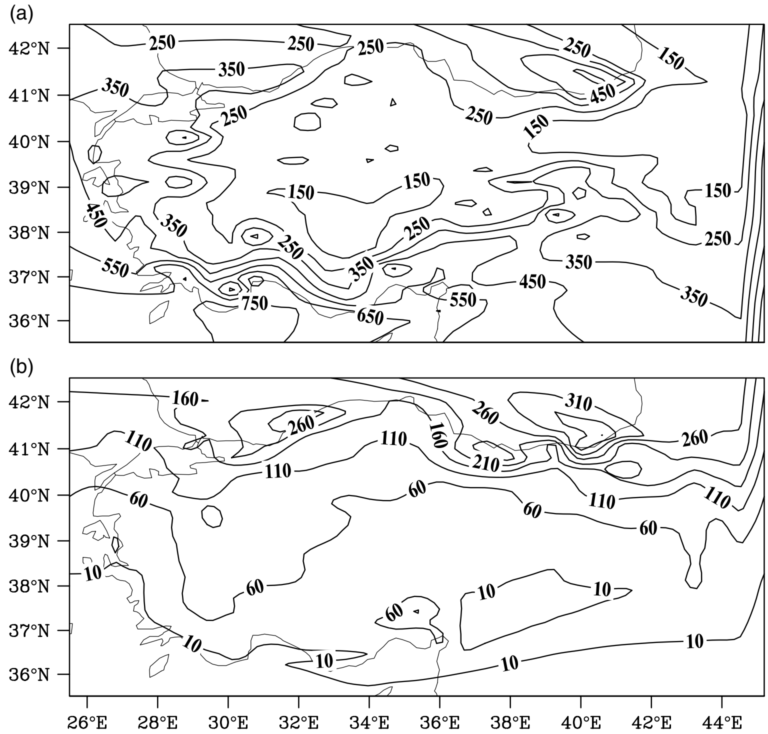

Figure 3. Distribution of outlier threshold, P_{out}, values in mm for (a) January, (b) July

P_{out} values are found on the southern (Mediterranean) coasts of Turkey. This is expectable, since in this part of the country, both the average amount and the variability of precipitation during winter is very high, with many extreme events, compared to the national average and other geographic districts (Figure 4). Other coastal regions also have high P_{out} values owing to their rainy climates in winter.

In July, high P_{out} values shift to the northern coasts, a region where no summer aridity is present. Very low P_{out} values are observed compared to January, leading to a generally high percentage of outliers during summer (Figure 5).

Annually averaged distribution of outlier percentages is shown in Figure 6. Higher percentages at the west and south coastlines of the country mainly arise from the outliers in summer, which is the dry season for these regions, yet featuring some precipitation anomalies in some years (not shown) due to non-frequent thunderstorm

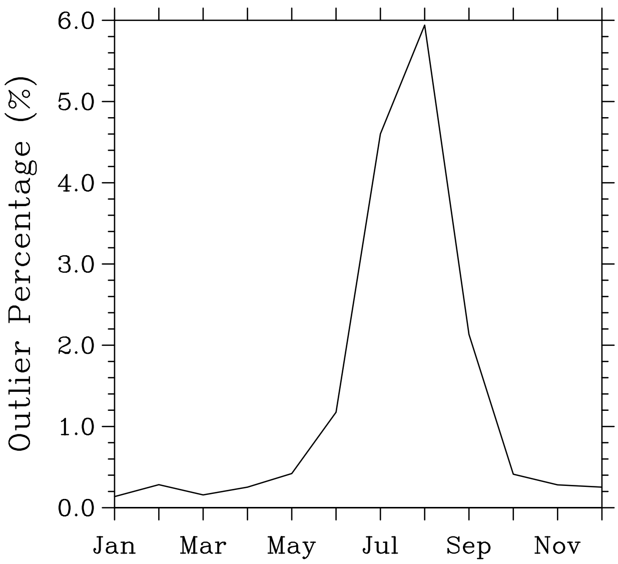

Figure 5. Monthly variability of averaged outlier percentage for all stations

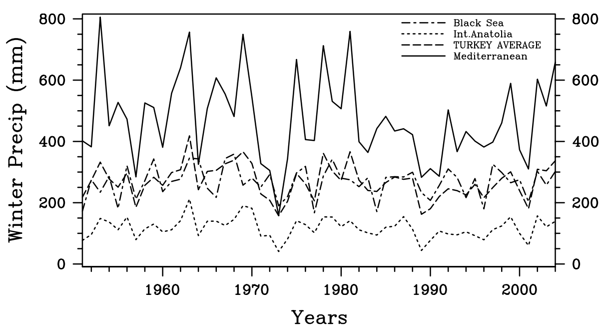

Figure 4. Winter precipitation variability of various geographical districts in Turkey through years. Solid line denotes Mediterranean, the region whose amount as well as variability of winter precipitation are the greatest

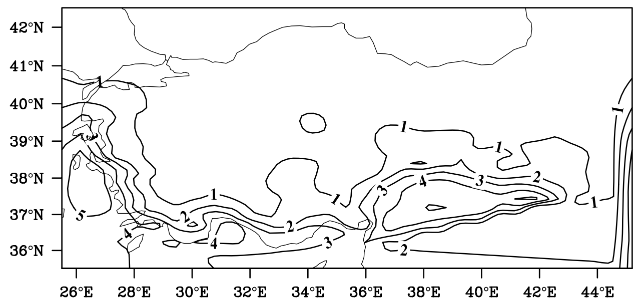

Figure 6. Annually averaged distribution of outlier percentages

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activity. Thus, summer months with high precipitation values are usually classified as outliers, due to very low P_{out} values, as explained earlier.

Both spatial and monthly distributions of outliers imply that they arise from natural variability rather than erroneous measurements.

Homogeneity

Since SNHT is based on reference series, the process of determination of reference stations is very important. It becomes even more important when very little metadata are available, as in this study. Therefore, individual monthly series were used, which give the highest correlation values, thus increasing the reliability of the reference series formed for each station. A homogeneity assessment of each station was made by checking the consistency among possible inhomogeneity years of all months. Reference series were chosen from those whose correlations with the test series were 0·80 or greater.

Figure 7 shows the spatial distribution of the number of reference stations for January and August. Although the correlation values are usually greatest between test and candidate reference series in winter and fall months, stations located over eastern parts of Turkey still have very few or no reference stations in January. This fact is largely due to topography-related variability of precipitation: Eastern Turkey is a high plateau with a relatively sparse network of stations that are seperated by topographic features leading to microclimates. Higher snowfall amounts in this region might also create some uncertainties in the precipitation measurements. Thus, correlations in this region are low, leading to many non-testable series because of the lack of references.

In August, reference series are nearly nonexistent throughout the country, except for a group of very few close stations located around Istanbul. This arises from the extremely variable distribution of thunderstorms in summer, both spatially and temporally, which are the only source of precipitation for the whole country at that time of year. Total number of reference series is maximum in fall and winter, while it decreases in spring and becomes minimum in summer. Fall and winter months therefore are the focus of homogeneity assessment for most of the stations.

Figure 8 shows the preliminary classification of stations with regard to the groups in Figure 2. Monthly variation of non-testable stations reflects the explained lack of reference series. Although the percentage of corrected series do not exceed approximately 10% of all stations for any month, since a corrected station of a month may not be a corrected station of another month, total corrected series percentage is somewhat higher. To overcome this sort of inconsistency and make an overall assessment of the usability of stations in future work, all stations were classified according to their testability and consistency among their inhomogeneity dates, following the subjective criteria:

(i) If none or only one of the monthly series of a station is testable, that station is designated as *non-testable*. Decision regarding the use of the station is left to user.

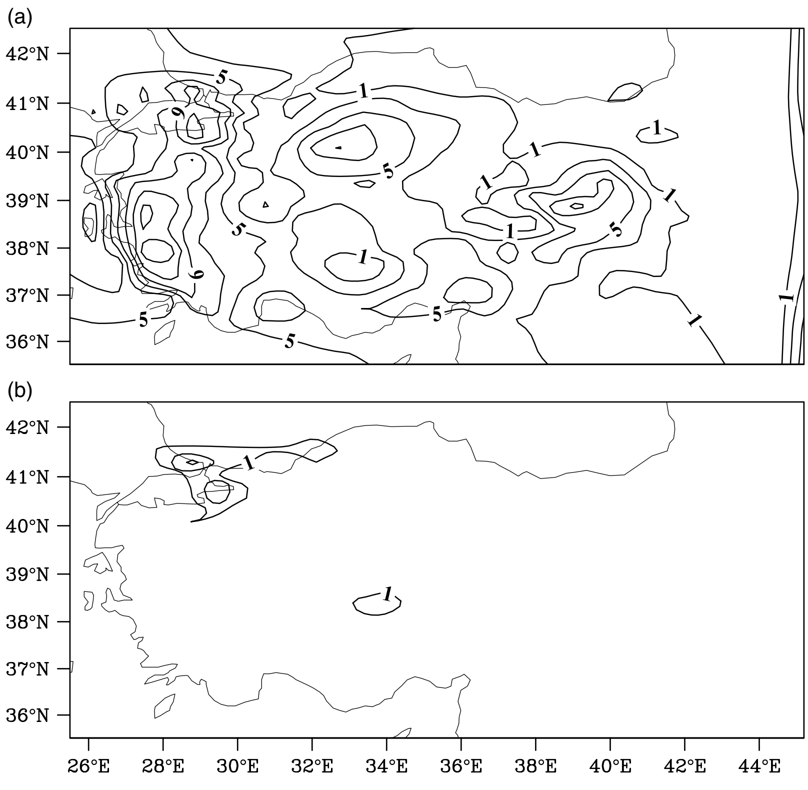

Figure 7. Distribution of number of reference stations for (a) January, (b) August

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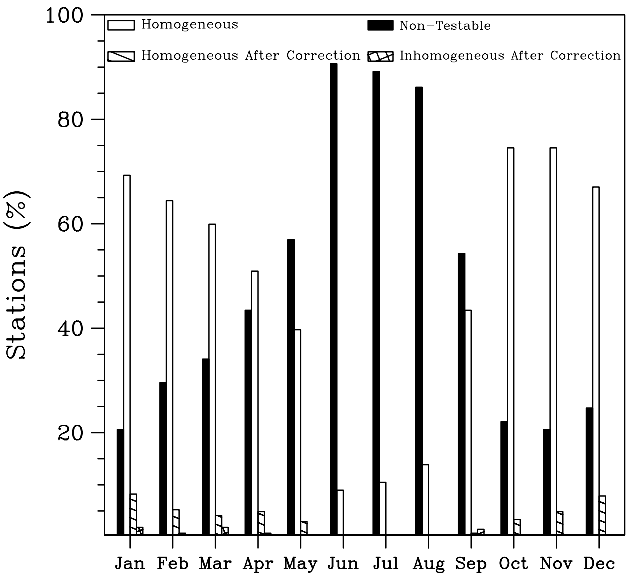

Figure 8. Preliminary classification of station time series according to the groups in Figure 2

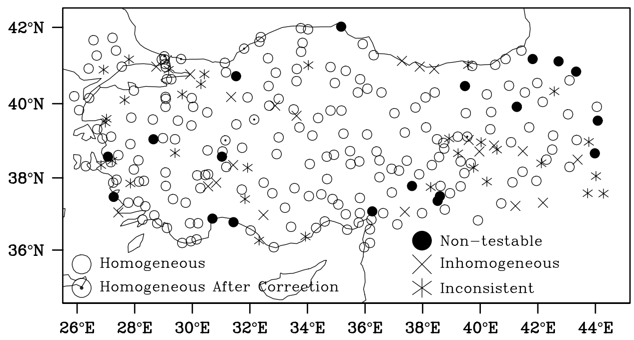

Figure 9. Final classification of precipitation stations with regard to their usability

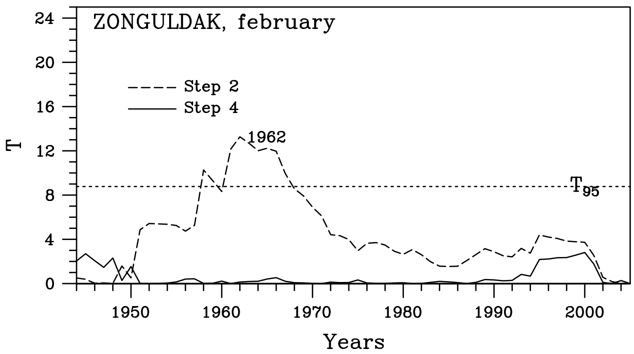

Figure 10. T statistic for February precipitation series from Zonguldak. Step 2 and Step 4 shows T values before and after the homogeneity correction, respectively

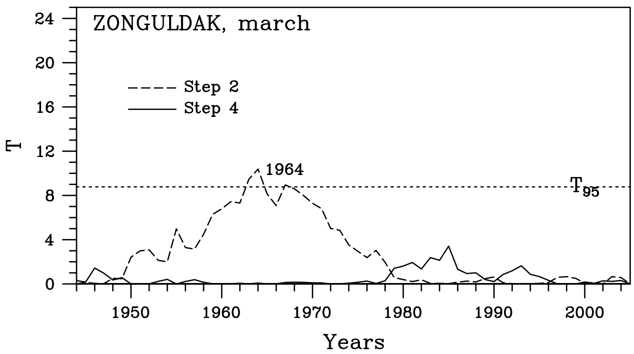

Figure 11. T statistic for March precipitation series from Zonguldak. Step 2 and Step 4 shows T values before and after the homogeneity correction, respectively

(ii) If none of the testable monthly series of a station has an inhomogeneity, then the station is designated as *homogeneous*.

(iii) If only one of the testable monthly series of a station has an inhomogeneity, no correction is made, and the correction factor for that single month is checked. If the correction factor is between 0·7 and 1·3, then that single month is ignored and the station is designated as *homogeneous*.
The values 0·7 and 1·3 are totally arbitrary here and they limit the range of correction factors which are close to 1·0, showing that it is safer to ignore inhomogeneities. On the other hand, if the correction factor is either above 1·3 or below 0·7, the station is designated as *inconsistent* and the decision regarding its use is left to the user.

(iv) If two or more of the monthly series of a station have an inhomogeneity, then the inhomogeneity years of different months are compared. If all of those years are within the same 5-year range, all the monthly series are corrected using the monthly series correction factor that has the earliest inhomogeneity year, and the station is designated as *homogeneous after correction*. Using the same correction factor for all monthly series is also recommended by Alexandersson (1986). Otherwise, the station is designated as *inconsistent*, no correction is made, and the decision regarding its use left to the user.

(v) If any of the testable monthly series of a station is from the *inhomogeneous after correction* preliminary group, all monthly series of the tested station are designated as *inhomogeneous after correction*.

One should note that, none of the stations having metadata exhibited an inhomogeneity in the analysis. That is why metadata could not be used in the above criteria.

Figure 9 shows the final classification of all stations. A well distributed set of stations are homogeneous with or without correction. However, other stations, that either have inconsistencies among their dates of inhomogeneity, or inhomogeneous at all, are not very few. Neither inconsistent stations nor inhomogeneous ones show a coherent enough distribution to suggest that there is a systematic mechanism behind the results, although some of the inhomogeneous stations seem to be closer to each other.

Figures 10 to 13 shows T statistics of two homogeneous stations with corrected monthly series: Zonguldak and Şile. For the February series of Zonguldak

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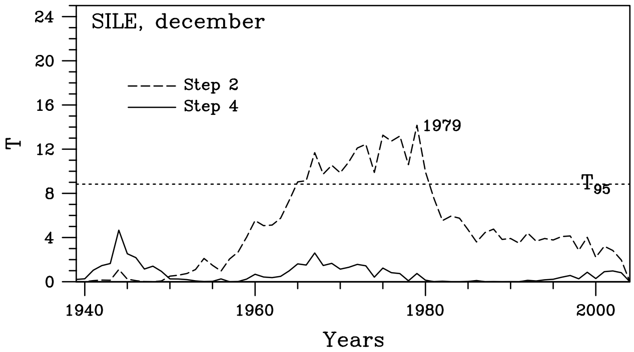

Figure 12. T statistics for December precipitation series from Şile. Step 2 and Step 4 shows T values before and after the homogeneity correction, respectively

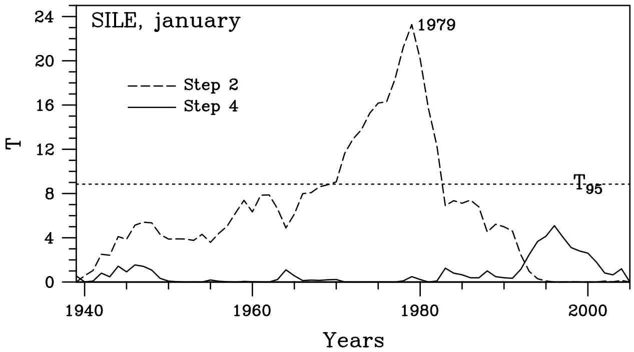

Figure 13. T statistics for January precipitation series from Şile. Step 2 and Step 4 shows T values before and after the homogeneity correction, respectively

(Figure 10) there is an inhomogeneity in 1962, disappearing at Step 4 after the correction made at Step 2. This inhomogeneity date (with only a 2 year difference) also appears in the March series of the same station. December and January series of Şile are again consistent with regard to the date of inhomogeneity. The maximum T values, surpassing the statistically significant T_{95} value at year 1979, are well below the inhomogeneity level after the correction.

SUMMARY AND DISCUSSION

In this work, an outlier analysis was conducted, and then a 20th-century precipitation data set from Turkey was homogeneity tested, for the purpose of obtaining a reasonable number of high quality series to be used in future studies of hydrometeorology, statistical downscaling, climate variability and climate change. This is the first comprehensive homogeneity assessment of a Turkish precipitation data set.

The outlier distribution implies that extreme values arise from natural extremities, which are in agreement with the precipitation regime of Turkey. Most of the outliers are values for anomalously wet summer months.

As a powerful method that employs reference stations, the *Standard Normal Homogeneity Test* developed by Alexandersson (1986) was used. Since station history documentation is very poor or totally absent for the data set, during the selection of reference stations, time series were sought that have the highest correlation with the tested time series, in order to enhance the reliability of references. Thus, the SNHT was applied twelve times, each time for a seperate month. On the other hand, doing the homogeneity analysis seperately for each month resulted in a lack of references, and thus in many non-testable series during the dry summer months, due to low correlations for that time of the year. At the end, for each station, inhomogeneity dates were compared for consistency, if they exist. Thus a final classification was made. Although tight criteria were used to classify a station as *homogeneous*, a much greater number of safe stations was obtained than the number of stations used in previous work concerning Turkey. Also, a number of stations exhibited inconsistency among their monthly inhomogeneity dates or were non-testable at all. The number of inhomogeneous stations was not large enough to disrupt the good geographical distribution of usable stations.

Very poor or nonexistent station history documentation seems to be the main obstacle to the homogeneity assessment of Turkish climate data sets. There is no means to check the accuracy of inhomogeneity dates found from the analyses, a fact which leads researcher to subjective approaches for the final decision regarding inhomogeinity existence and date. Therefore, tracing, collection and supply of metadata is an essential task for the Turkish State Meteorological Service, in order to contribute to climate research in Turkey. Since the particular way of using SNHT adopted here has proved to have some caveats, it is not wise to strictly discard stations that are in classes other than *homogeneous*. Stations classified as *inconsistent* or *non-testable* could also be employed by future users if needed, provided other homogeneity tests are applied properly or metadata are accessed, if they become available in the future.

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