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Estimation of Reference Crop Evapotranspiration in Northwest China

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Abstract: Based on the daily meteorological data from 1956 to 2011 in Northwest (NW) China and the Penman-Monteith (PM) equation, the regional reference crop evapotranspiration (ET0) is estimated. The ET0 variations in time series and spatial distributions are analyzed. The trend analysis, Mann-Kendall (M-K) test, wavelet analysis, stepwise regression and EOF analysis methods are used to investigate the spatiotemporal variability of ET0 and its contributing climatic factors, the mutation of ET0, the period of ET0, and the main influencing meteorological factors, respectively. Major conclusions are obtained as follows: (1) In the past 56 years, the trend of average annual ET0 time series in the NW China is significantly reduced, the differences exists in different seasons, i.e., the trends of ET0 in spring (-0.26mm/a), summer (-0.72mm/a) and autumn (-0.31mm/a) are decreased, respectively, the ET0 in winter is slowly increased (0.02mm/a). (2) The region which ET0 decreased most is located at the field from Kumul to Hotan (from northeast to southwest). ET0 has a sharply decrease around the 1980s, with a multiple-time scale nesting complex structure in the period. The first, second and third EOF models account 36.84%, 13.87% and 9.04% for the explained variance, respectively. The summer EOF model is the main contributor to the annual first model. (3) The upward trend of mean surface air temperature (T) and the decreased trend of sunshine duration (SD), relative humidity (RH) and wind speed at 2 m high (U_2) induce ET0 to decline. The variability of annual ET0 rate is most influenced by the variations of U_2, followed by SD, RH and T, which is influenced by various climatic variables. The investigation of spatiotemporal variability of ET0 and its contributor meteorological factors may help us better understand how ET0 responds to regional climate change.

Keywords: Climate Change, Penman-Monteith (PM) Model, Reference Crop Evapotranspiration (ET0), Northwest China, EOF Analysis

1. Introduction

Evapotranspiration (ET) is an important flux term in the water cycle that integrates atmospheric demand and surface conditions, which serves as an important element of the hydrological cycle in reflecting the maximum water demand of environment to maintain water balance. Evaporation accounts for the movement of water to the air from sources such as the soil, canopy interception, and water bodies. Transpiration accounts for the movement of water within a plant and the subsequent loss of water as vapor through part of the water cycle [1]. The evaporation is directly to the water balance and surface energy balance. Climate change not only have an impact on the hydrological cycle in both changing of precipitation and temperature and affecting the spatial and temporal changes of river runoff, but also change the ability of evaporation through different ways [2-4]. Evaporation is of particular concern in Asia where the convection above the Tibetan Plateau and hence the transfer of latent energy to the atmosphere directly influences the intensity of the Asian monsoon system [5]. Thus, understanding the spatiotemporal variations of evaporation is a vital component in regional hydrological studies in Asia. The study of the variability of evaporation and its contributing factors is extremely important for understanding the rule of climate change [6-8]. According to the Clausius-Clapeyron equation a warmer atmosphere will be able to hold more water and hence allow for higher evaporation. However, at present, many observations and research results show that, under the global and regional scale, the observed evaporation and the calculated potential evaporation are shown to decrease year by year. This phenomenon is called 'evaporation paradox' in meteorology and hydrology [9-10]. The decrease of evaporation means the changes in atmospheric water demand and therefore to changes the climatic parameters driving evapotranspiration. Yin et al [4] explored the variability of evaporation and its contributor at different climate region in China, and they found that the wind speed has the most important impact on reduced ET0 rate, the most sensitive climatic variable is the relative humidity, the upward trend of temperature positive contribution and the downward of wind speed and sunshine duration are offset. The wind speed has an important effect on the variability of evaporation in Western and Northern part of China. It plays an important role in the area of tropical and subtropical regions of South China. Of course, on the global or regional scale, whichever factor or a few meteorological factors play the major role in determining the variability of evaporation, there is no a consistent conclusion. Thomas [5] pointed that the changes of sunshine duration mainly determining the variation of evaporation in the south of 35°N China, while the wind speed, relative humidity and the maximum temperature are the contributing factors in the northwest of China, the central region and the northeast China regions, respectively. Zhang [8] showed that, in the east of 100°E China, the net radiation is the most contributing factor to the reduction of evaporation, and in the northwest China, the relative humidity is the main sensitive meteorological factor. In the east and south of China, the reduction of evaporation is mainly determined by the reducing solar radiation, this study showed that the human activities have an important influence on climate change, which in turn the climate change will affect the human life and production activities. Liang et al [11] investigated the potential evapotranspiration in Northeast China. They found that the relative humidity is the most sensitive factor, followed by sunshine durations, wind speed and mean surface air temperature. Fan et al [31] studied the temporal and spatial variation of the potential evapotranspiration and its contributing factors in Yunnan Province, and they obtained the conclusion that on the seasonal and annual scales, the variability of evaporation rates is most sensitive to the variations of sunshine duration, followed by relative humidity, maximum temperature and wind speed.

To compare the different climatic region's evapotranspiration, Penman [12] proposed the concept of 'potential evapotranspiration' in 1956 which defined as 'the amount of water transpired in a given time by a short green crop, completely shading the ground, of uniform height and with adequate water status in the soil profile'. Reference crop evapotranspiration (ET0) (Allen et al., 1988), defined as 'the rate of evapotranspiration from a hypothetical reference crop with an assumed crop height of 0.12 m, a fixed surface resistance of 70 s m^{-1} and albedo of 0.23, closely resembling the evapotranspiration from an extensive surface of green grass of uniform height, actively growing, well-watered, and completely shading the ground'. The PM equation has been recommended as the reference method for determining the ET0 by FAO. The method has been selected because it is physically based and explicitly incorporates both physiological and aerodynamic parameters. Some other methods used to calculate the potential evapotranspiration [13-15], which could not describe the radiation process of evaporation and the dynamic mechanical process, are applied in specific climatic region. It is of great significant to study the ET0 influencing factors for both understanding the regional hydrological cycle and mastering the rule of climate change.

In this study, we restrict our studies to the NW China which is a climatically complex region. NW China is mostly arid or semi-arid regions, and the precipitation is scale, and the sand storms frequently occur, this region is one of the most obvious influencing responses to the global climate change. In recent years, many scholars and scientists have been carried out numerous researches on the arid and semi-arid conditions in NC [8, 16-19]. It is necessary to investigate and analyze the temporal and spatial variation of ET0 and its influencing factors.

The objectives of this study are (1) to analysis and discuss the spatiotemporal variability of ET0 and its contributing factors in NW China from 1956-2011 under the background of global warming, (2) to explore the main meteorological factors which determining the variability of ET0, and (3) to provide the basic accumulative data for the study of ecological system and hydrological cycle.

The remainder of the paper is organized as follows. Section 2 provides a brief description of the methodology which includes study area, selection of data, methods. Section 3 introduces the results. Section 4 describes the discussion. Concluding remarks are presented in Section 5.

2. Data and Methodology

2.1. Study Area

The Northwest (NW) China, (NW: including the Xinjiang, Gansu, Qinghai, Ningxia and Shanxi Provinces) as bounded by 34°54′N and 49°19′N, is about 2.5 million km^2 in size, accounting for about 26% of China's total terrestrial area. It is located in an oasis with the Gobi desert areas in its surrounding region within the center of Eurasia continent, where the arid and semi-arid continental climate prevails which is characterized with drought, water shortage and dust storms. The primary driven factor for the water vapor transport is Westerly Circulation [20]. As NW China is surrounded by massive mountains such as Altai Mountain, Kunlun Mountain, Qilian Mountain and Helan Mountain, the air masses will be blocked by these mountains through the atmospheric circulations. Due to far away from the ocean, the water vapor is extremely difficult to reach NW China, which results in the extreme events such as drought, sand storms occur frequently. The spatial distribution of precipitation is largely determined by the regional physiographical features. The NW China has a typical continental climate. Due to the long distance to the surrounding oceans, the annual precipitation in the arid NW China is generally less than 200 mm. In winter, the NW China is largely controlled by Mongolia-Siberian High pressure and the average temperature in winter varying from -5.8°Cto -11°C. In summer, the land surface rapidly warms up, due to the vast desert and sand storms. The weather in NW China transitions in the spring and autumn are rapid.

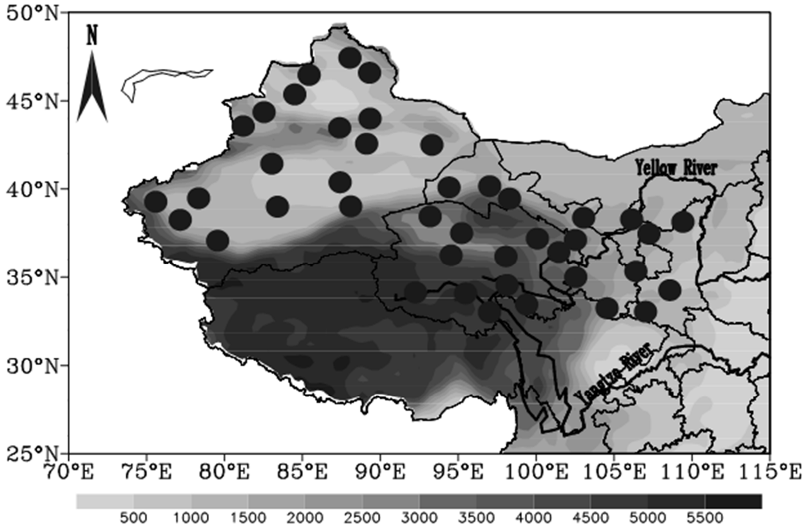

Figure 1. *Spatial distribution of study stations in NC. Topographic data are from ETOPO20.*

2.2. Data

In this paper, the daily meteorological data are performed by routine quality assessment and necessary error correction. Daily data on sunshine duration (SD), relatively humidity (RH), mean surface air temperature (T) and wind speed at 2 m (U_2) for 42 stations in NW China (Figure 1) were obtained during 1956-2011 for the National Meteorological Information Center of China (NMIC) of China Meteorological Administration (CMA). The study seasons include spring (MAM), summer (JJA), autumn (SON) and winter (DJF). The missing data account for about 0.2-0.5%, which was replaced by with estimated values from neighboring and high correlated stations.

2.3. Methods

2.3.1. Penman-Monteith Method

The Food Agriculture Organization (FAO) of United Nations Penman-Monteith PM method is recognized as a global standard computation of ET0 [21]. Many experts and scholars in different regions verify this method, and they obtain that the PM method has the highest precision and generality in current estimated methods. The P-M method consists of two terms, the radiative (first) and ventilation (second) contribution.

$$ET0(PM) = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T_a + 273} U_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34U_2)} \quad (1)$$

where *ET0 (PM)*=reference crop evapotranspiration [mm d^{-1}], R_n=net radiation at the crop surface [MJ m^{-2} d^{-1}], G=soil heat flux density [MJ m^{-2} d^{-1}], U_2=wind speed at 2 m height [m s^{-1}], e_s=saturation vapour pressure [kPa], e_a=actual vapour pressure [kPa], e_s-e_a=saturation vapour pressure deficit [kPa], Δ=slope vapour pressure curve [kPa°C^{-1}], γ=psychrometric constant [kPa°C^{-1}].

2.3.2. Mann-Kendall Mutation Test

Test for the detection of trend significance in data are categorized into the parametric and nonparametric approaches. Data should be distributed and be independent for the parametric approach while only independent data are the requirement of nonparametric approach. The Mann-Kendall (*M-K*) is a non parametric test method. Non parametric test method is known as non distribution test, which has the advantage of eliminating the researching values' abnormality. As it is originally proposed by Mann-Kendall, it is called the Mann-Kendall method. At present, the *M-K* test method has been widely used in the field of hydrology and meteorology [22-24].

2.3.3. Wavelet Spectrum Analysis

Wavelet analysis has good local property in time and space domain. It can analyze the local characteristics of the periodic variation of data in time series. The wavelet power spectrum analysis has been widely used in meteorological and hydrological research. Morlet wavelet is a complex form of wavelet function, which is used to investigate the periodic oscillation of ET0. In this paper, the wavelet analysis is based on Torrence Gilbert and P. Compo [25].

2.3.4. Multiple Liner Regression and Trend Analysis

In this paper, a multiple linear regression model is established by SPSS19.0.

2.3.5. EOF Analysis

Empirical orthogonal function (EOF) analysis is a method to extract the data main characteristics, which analysis the structural characteristics of matrix data. The method was firstly proposed by Pearson [26] and introduced by Lorenz [27] in meteorology and climate studies. The data analysis is usually characterized by a spatial sample, so it is called the spatial feature vector or spatial mode. The main component is the time variation, and it is called the time coefficient. Therefore, the EOF analysis is also called time and space disintegration in the geographical researches.

3. Results

3.1. Spatiotemporal Variation of ET0

3.1.1. Time Series Variation of ET0

Figure 1 gives the 42 stations in NW which contained the ETOPO20 topographic data. Figure 2 shows the average monthly variation of ET0 in NW China, and the seasonal distribution is given in Table 1. It can be seen from figure 2 that, on the monthly scale, ET0 increased gradually from January (20.2mm/month) to July (163.8mm/month), and monthly ET0 decreased from August to December (19.0mm/month). On the seasonal scale, ET0 in summer, spring, autumn and winter decreased with values of 467.4mm, 330.6mm, 193.2mm and 72.8mm, respectively. Because ET0 is influenced by various climatic variables, and the climatic variables influence each other, the distribution of ET0 on monthly and seasonal scales is not even. Figure 3 presents the variation of seasonal and annual ET0 in NW China during 1956-2011. In spring (Figure 3a), the maximum ET0 value appeared in 1974 (350.1mm), and the minimum value is 309.7 mm in 1996 during 1956-2011. The mean value is 331.2 mm, and the standard deviation is 10.8 mm. In summer (Figure 3b), because of the increase of summer temperature and the sunshine duration, ET0 in summer has the maximum value and the decreasing rate in summer is also the maximum in all seasons. Similar to the spring, the most ET0 values is smaller than the 56 years' average value. In autumn (Figure 3c), the maximum value appeared in 1956 (223.5mm), and the minimum value is 182.0mm in 1992. The average value in autumn of 56 years is 198.8 mm, and the standard deviation is 7.9 mm. During 1956 to 1992 in autumn, the ET0 rating showed a decreasing trend, and the upward trend fluctuated after 1992. Similar to the spring and summer, the average value of ET0 is smaller than most 56 years' average value. In winter (Figure 3d), the ET0 value is the smallest, and it showing the lightly increasing trend (0.02mm/a). The maximum value (82.5mm) appeared in 2010, and the minimum value is 63.9mm in 1964. The average value in winter is 72.3mm, and the standard deviation in winter is 4.3mm. From the time series and trend of a significant decreasing trend.

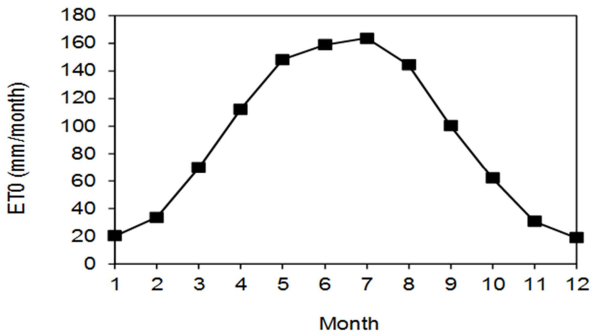

Figure 2. *Variation of monthly ET0 in NC from 1956 to 2011.*

To further analyze the ET0 changes' rate on different time scale, the PM ET0 in corresponding time period is accumulated (Table 1). In spring, summer and autumn, the changing trend is consistent with the annual changing trend. The ET0 presented a decreasing trend before 1990s, and it showed increasing trend after 1990s. The ET0 of the NW.

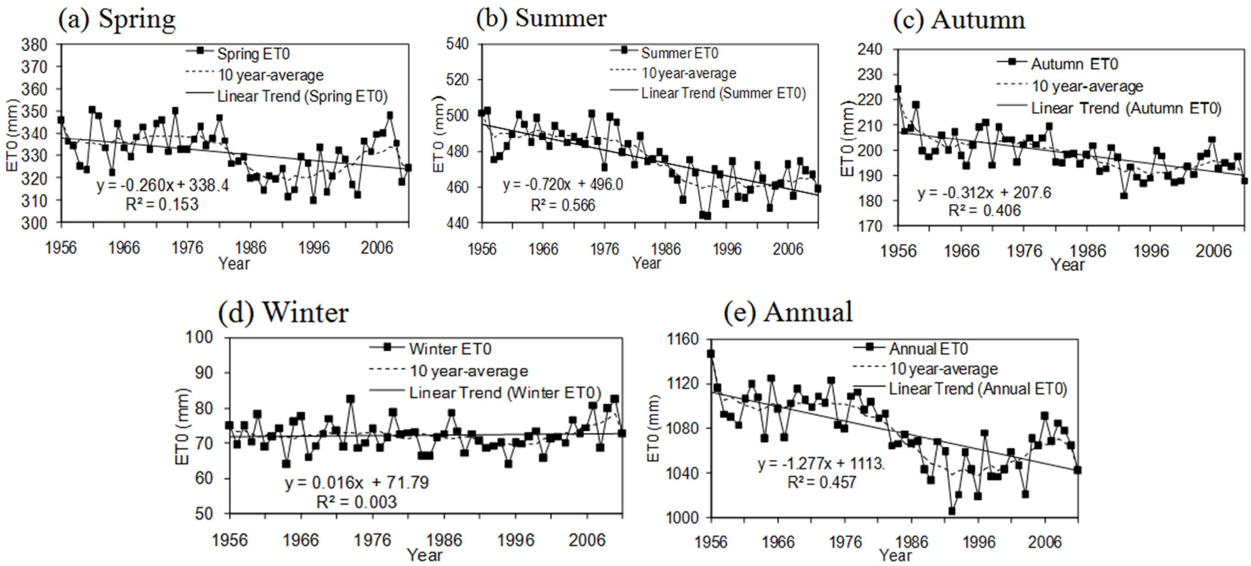

Figure 3. *Regional averaged monthly and annual ET0 totals (mm/decade per month or per year, resp.) from 1956 to 2011 for 42 stations in the NC. The straight line (bold) shows the linear trend from 1956-2011, the dashed line represents a smoothing 10 year-average from 1956 to 2011.*

China during 1956-2011 showed a decreasing trend and then increasing trend. It presented decreasing fluctuation trend (-17.0mm/a) before 1980s, and showed increasing fluctuation trend (15.7mm/10a). It is worth noting that there is a difference in the magnitude of the variations in different decadal variations, i.e., the minimum value appeared in 1986-1995 and the decreasing mostly is in the middle of 1970s and 1980s. From above analysis, the ET0 showed decreasing trend before 1980s and then increasing trend after 1980s, and the cut-off point appeared in the middle of 1980s.

Table 1. *Distribution of ET0 in NC (1956-2011).*

Time	Spring	Summer	Autumn	Winter	Annual
Pro (%)	31.1	43.9	18.1	6.9	100

Figure 4 shows the M-K mutation curves at given significant level (α=0.05, Z_α=1.96 and $-Z_\alpha$=-1.96). The UF curve represe、nts sequencing curve and the UB curve means sub-sequencing curve. As can be seen from Figure 4e, the UF curve and UB curve in 1980s get through the two critical curves intersect test, then the UF curve is exceed the critical line $-Z_\alpha$=-1.96. The ET0 has a mutation change about the middles of 1980s, which is consistent with the results of Figure 3e. It is worth noting that the M-K test results of seasonal average ET0 in spring, summer and autumn (Figures 4a, 4b and 4c) are consistent with the previous analysis, i.e., there is decreasing trend before 1980s and increasing trend after 1980s, while the ET0 presents slightly increasing trend in the middle age of 1980s.

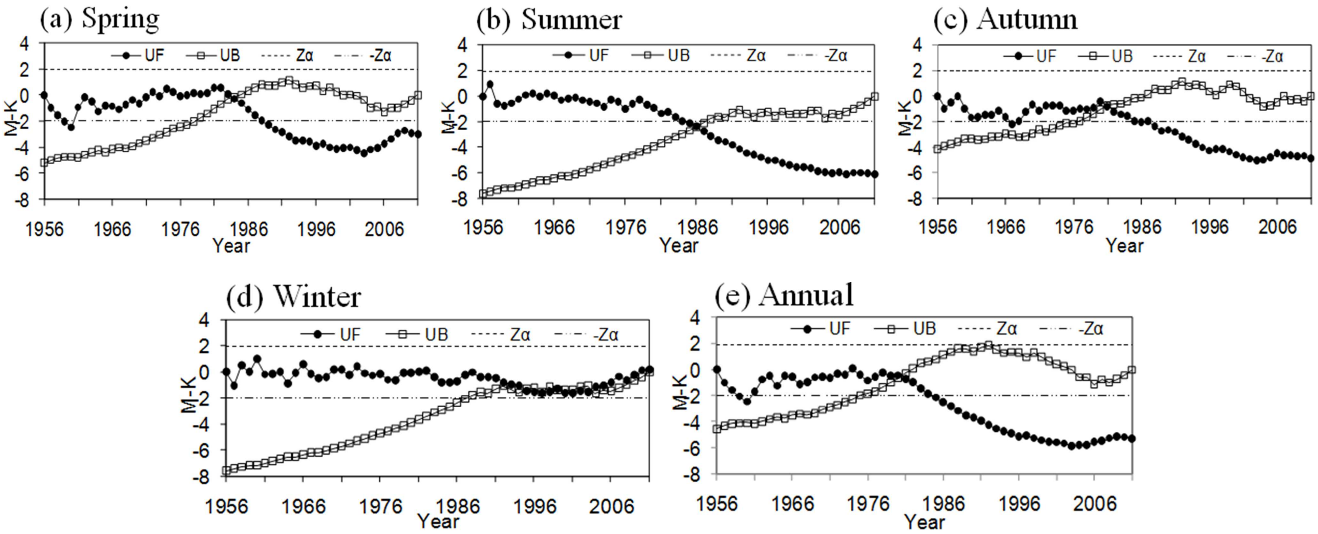

Figure 4. *M-K trend test of monthly ET0 in NC from 1956 to 2011 (α=0.05).*

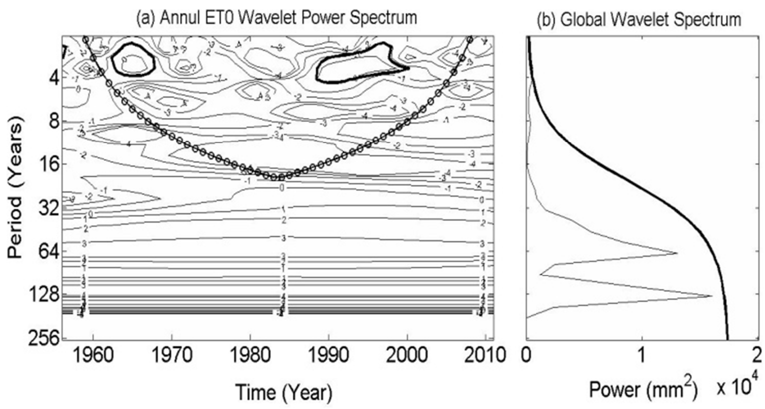

Figure 5. *Wavelet power spectrum (using the Morlet wavelet) of the annual ET0 in NC.(The thick black contour is the 5%significance level from a Monte Carlo simulation and plus sign line denotes the period scale after the boundary effect removal).*

To further explore and analysis the local characteristic of ET0, the wavelet power analysis method is adopted to analyze the period of ET0 in the NW China during 1956-2011 (Figure 5). In Figure 5, the contour map of wavelet transform in the center of the corresponding point mutation, the black thick part means get through 95% confidence testing, and the plus solid line represent the periodic boundary effect after removing scale. The results of wavelet power transform shows that the ET0 has multiple time periodic scale with the nested complex structures. It can be seen from the figure 8 that the average annual ET0 in NW China region during 1956-2011 presents the periodical characteristics of 2-3 years and 4-8 years. For the period of 2-3 years, the ET0 value wavelet transformation gets through the 95% significant test and the

ET0 present deceasing trend after 2005. While for the period of 4-8 years, the wavelet power transformation fails to get through the 95% significant test, and the maximum value appears about the year of 2006. These results are consistent with the current researches about ET0, i.e., the ET0 presents the deceasing trend before 1980s and increasing trend after 1980s. It is worth noting that the contour has no closed center in the analysis of more than 28 years, this is mainly due to the ET0 time series are only 56 years, which cannot be clearly expressed in our analysis.

3.1.2. Spatial Distribution of ET0

In the NW China, the seasons are significant different. The ET0 variation in different seasons is significant. Figure 6 presents the spatial distribution of seasonal and annual average ET0 values. The summer (JJA) ET0 has the maximum variation in all seasons, which is the main contributor to the variation of annual ET0. The variation of ET0 in autumn is slightly greater than that of spring, and the winter ET0 has the minimum variation in all seasons. The NW China region is belongs to the temperate continental arid climate which has the characteristic of the wind in spring is strong, the evaporation in summer is great than other seasons, the temperature deceases rapidly in autumn, and the weather is cold and low air stability in winter. Thus, on the annual scale, the ET0 maximum value in NW China is mainly distributed from Hami to Haitian (Northwest to Southeast), e.g., for the period of 1956-2011 in Kuche, the annual ET0 deceasing rating is -75.9mm/10a, the summer decreasing rate in is -34.5mm/10a which accounts for about half of the annual decreasing rate, the decreasing rate in spring and autumn are -20.0mm/a and -17.3mm/10a, respectively, and the winter decreasing rate (-4.1mm/10a) is the minimum. In addition, from the distribution of ET0 variation trend (Figure 6), the spring (Figure 6.a), summer (Figure 6.b), autumn (Figure 6.c) and annual (Figure 6.e) ET0 variation rates are all presented decreasing trend except for the rate in winter (Figure 6.d) is slightly increased where increase most in Ningxia, southeast of Qinghai and south of Shanxi and Gansu. Related researches of ET0 shows that under the background of global warming, the 'cold island effect' is gradually significant in recent years which is characteristic by the summer temperature presents decreasing trend and the relatively humidity increases obviously. The Kuche rapidly increasing ET0 values are mainly due to the significant variations of summer temperature and relative humidity.

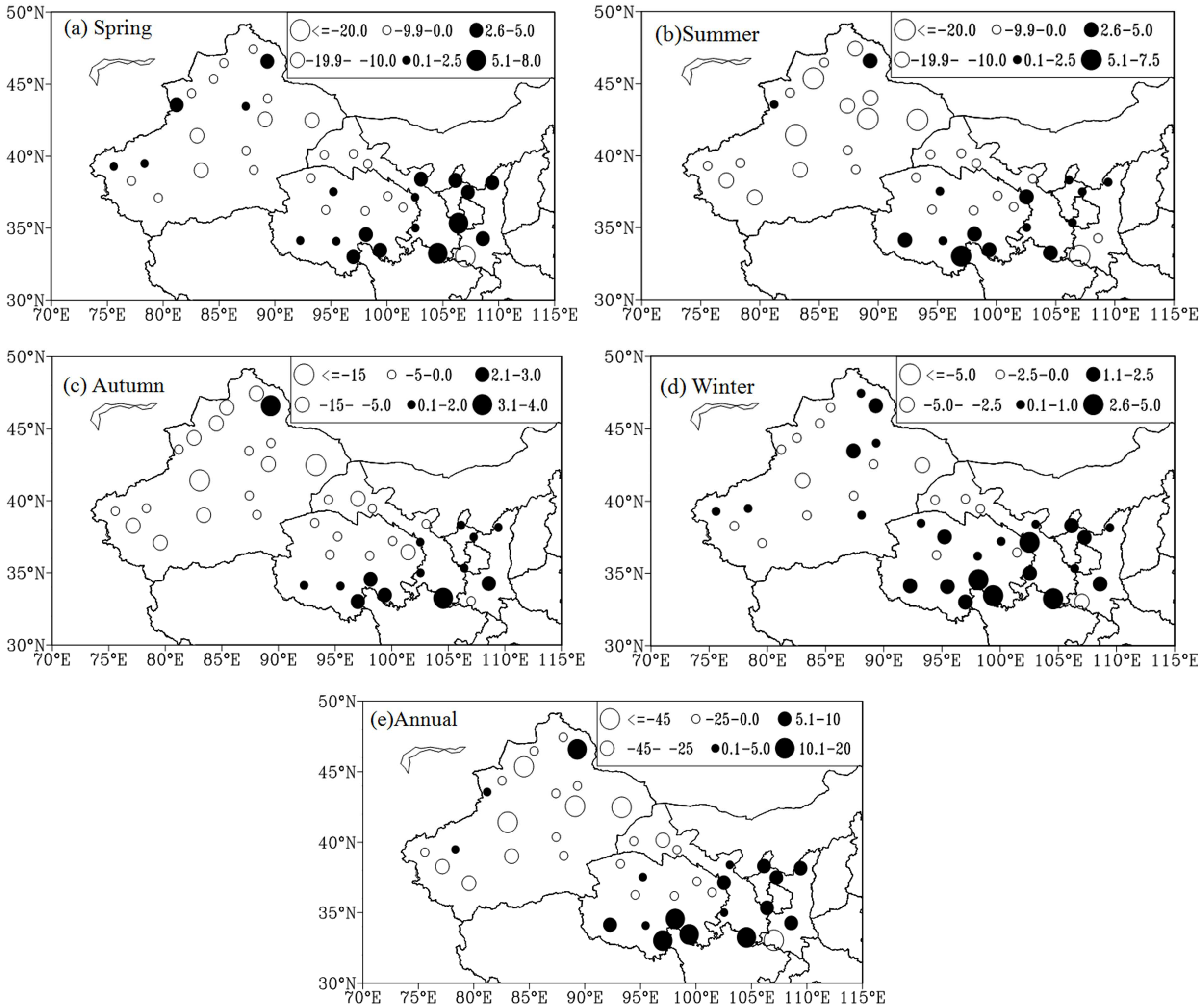

Figure 6. *Trends of ET0 for the period 1956-2011 of 42 meteorological stations in NC (unit mm 10a).*

3.1.3. EOF Analysis

Since the Empirical Orthogonal Function (EOF) method has been applied in the field of atmospheric science by Lorenz in 1956, it is simple and efficient that has been widely used in the field of atmosphere, ocean and climate researches. At present, this method has been fully developed in the diagnosis of climate change, and has become an important tool for the analysis of the main characteristics in the atmosphere researches. There are numerous fruitful researches results about this method. This paper adopted the characteristics of error range tested standard which was proposed by North and Bell [28] to test the significant of EOF results.

The first three models' explained variances are 36.84% (EOF1), 13.87% (EOF2), and 9.04% (EOF3), which can reflect the spatiotemporal distribution of ET0 in NW China.

The EOF1's explained variance is 36.84%, which is the typical field in the EOF analysis. The EOF1 is almost positive except in the field on the south of the Qinghai and north of the Xinjiang, which indicate that the entire NW China area is characterized by arid and semi-arid climate. According to the spatial distribution of EOF1 (Figure 8), there is a significant difference of ET0 in the north and south area (northeast to the southeast). The high values are mainly distributed in the northwest and center of Xinjiang and the low values are mainly distributed in the southern part of the study area which is similar to the ET0 variation (Figure 4). It is worth noting that the spatial distribution of annual EOF1 is most similar to the summer EOF1 model, which proves that the summer ET0 is the main contributor to the annual EOF1 model. In addition, the time coefficient (TC) during 1956-1983 is positive and it is negative from 1984 to 2011. It indicates the ET0 presents the decreasing trend in the middle of 1980s which also consistent with the trend of the 10 moving average curve. In addition, it is worth noting that the summer TC1 trend is consistent with the annual TC1. The autumn also presents the same trend which has the decreasing trend in the 1980s.

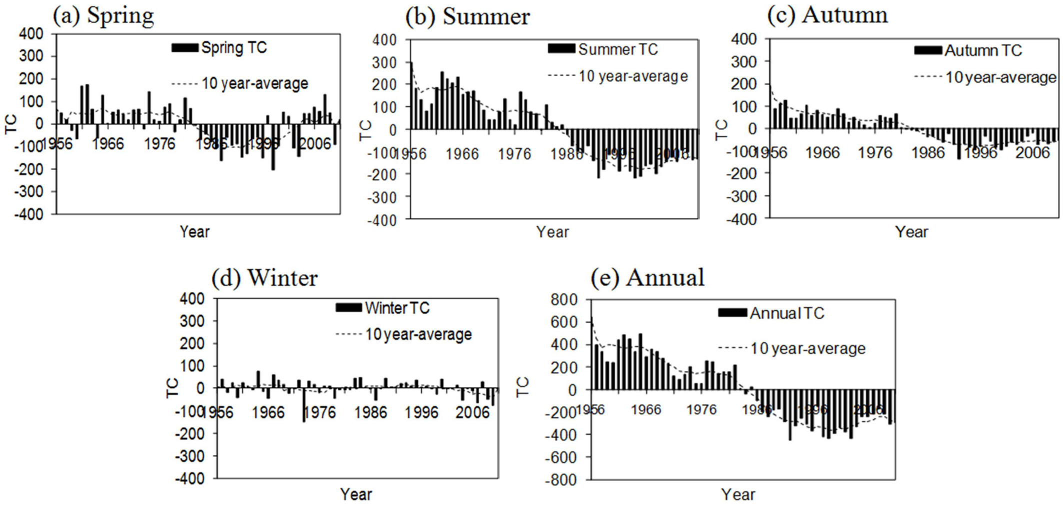

Figure 7. *The time coefficient (TC) based on EOF analysis of seasonal and annual ET0 for the period 1956-2011. Ten-year moving average filter (dashed) is applied for the EOF TC.*

The EOF2 model's explained variance is 13.87%, which is significant separated from the EOF1 and EOF3. Different from the EOF1, the southern part of Xinjiang has a negative a center. However, there is a positive center in the north area. In addition, the TC2 presents the fluctuation with the increasing amplitude.

The EOF1 has the maximum explained variance (36.84%), which is the main contributor. The single EOF model information is limited, so it should consider more models' information on the basis of the main model.

The EOF2 model's explained variance is 13.87%, which is significant separated from the EOF1 and EOF3. Different from the EOF1, the southern part of Xinjiang has a negative a center. However, there is a positive center in the north area. In addition, the TC2 presents the fluctuation with the increasing amplitude.

The EOF3 model's explained variance is only 9.04%, which is tested significant and has a certain physical means. The EOF3 present '-', '+' and '-'characteristic which has three phases. The TC3 also presents two peak fluctuation phases which is different from the TC2.

3.2. Spatiotemporal Variation of Meteorological Variables

The mean surface air temperature (T) presents increasing trends in this study area especially in the north and south area. The wind speed at 2 m high decreases most in the north and center area. The sunshine duration (SD) presents decreasing trend in most study area. The relative humidity (RH) also presents decreasing trend except in north and south area. In this study, we found that the U_2 decreasing rate is -0.07ms^{-1} decade^{-1} (95% significant test). U_2 gradually decreases after 1971, while SD decreases from 1956. RH decreases about -0.14% decade^{-1}, and its minimum value is in the year of 2009. Under the background of global warming, T gradually increases about 0.28° Cdecade^{-1} and reaches its maximum value in 2006. In addition, on the seasonal scale, the variation of these meteorological factors is different, i.e., the trend of T increases all the time, and that of U_2 decreases in the study time, SD shows decreasing trend except in the spring (MAM), and RH tends to decrease in the spring and winter.

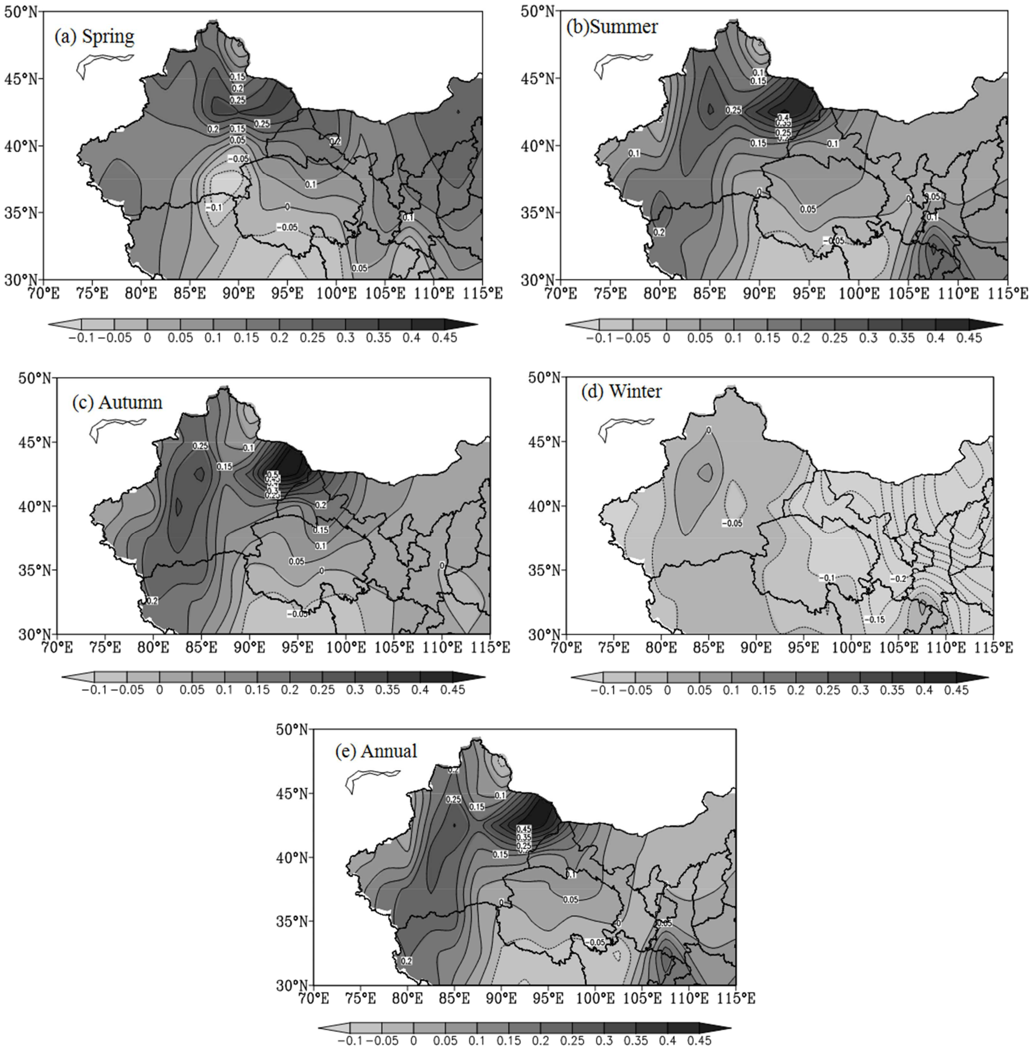

Figure 8. *EOF first model of seasonal and annual ET0 for the period 1956-2011 of 42 meteorological stations.*

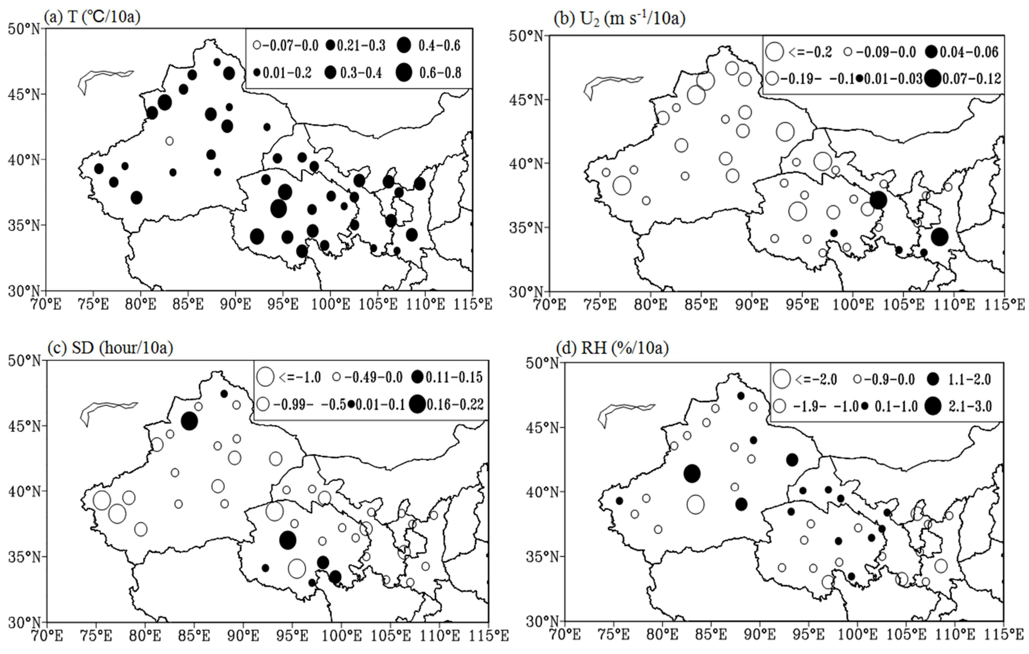

Figure 9. *Spatial patterns of meteorological factors linear trends per 10a.*

3.3. Main Influencing Meteorological Factors-ET0

We can obviously get the results that U_2 has a significant positive relationship with ET0 (CC=0.81 and PCC=0.71) (Table 2).

Table 2. *Statistical results. CC: Correlation Coefficient, and PCC: Partial Correlation Coefficient.*

Statistical	ET0-SD	ET0-T	ET0-U_2	ET0-RH
CC	0.67	-0.36	0.81	-0.42
PCC	0.38	0.22	0.71	-0.46

The decreased U_2 induces NW China ET0 to decrease. SD also has a positive relationship with ET0 (CC=0.66 and PCC=0.38). SD firstly influences the solar radiation and then controls the energy supply conditions of the evaporation process. Generally speaking, the more SD, the greater net radiation will reach to the earth, thus, it will intensify the evapotranspiration process and vice versa. However, RH has a negative relationship with ET0 (CC=-0.42 and PCC=-0.46). RH is the primacy meteorological factor which affects the water vapor in the process of evaporation. If the RH increases, the air saturation will decrease. Thus, the RH is also a very important factor in the process of evaporation. It is worth noting that the T has a weak negative relationship with ET0 (CC=-0.36, not significant), which indicates that the increasing T contribute a little to the decreasing ET0 in the study area. The residual analysis shows that the 56 years data in 3 years is more than the error range, which means the results have certain physical meanings. We can easily obtain the result that the RMSE of K scheme is minimum in all regression equations, and the equation is

$$ET0=1016.8+8.6SD+7.9T+133.2U2-5.9RH \quad (2)$$

From above analysis, the main meteorological factor for estimation of ET0 is U_2, followed by SD and RH, T contributes the minimum. On the whole, the variation of ET0 is caused by numerous meteorological factors. The main influencing factors play a key role in determining the variation of ET0, and meteorological factors will play a certain role in estimation of ET0.

4. Discussion

The NW China ET0 varieties in extensive ranges. It is mainly ascribed to the complex terrain and the monsoon circulation. The maximum ET0 value (1200mm) is mainly distributed in the basin and river region. Combined with the ET0-elevation fitting analysis (Figure 10), we found the ET0 presented decreased trend with the increase of elevation. It is worth noting that the winter ET0 shows slightly increasing trend, which is mainly caused by the winter monsoon circulation and more sunshine hours.

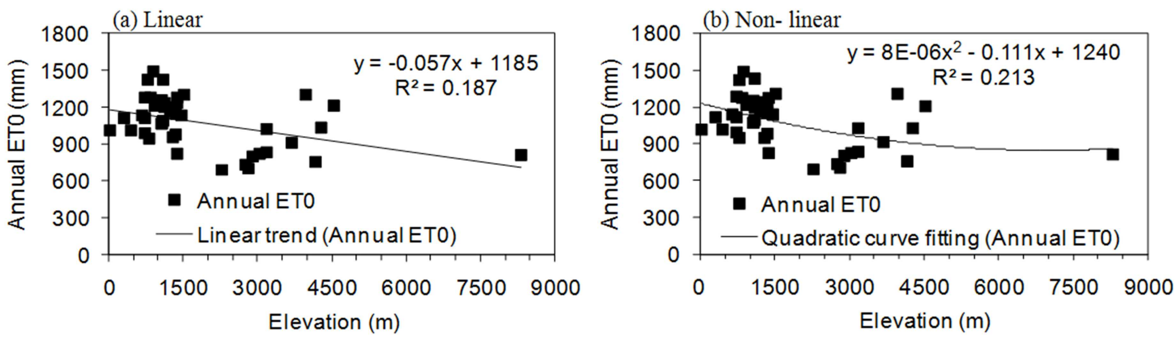

Figure 10. *Relationship between the annual ET0 and elevation in NC during the period of 1956-2011.*

On the annual and seasonal scale, the NW ET0 shows decreasing trend. Its value is higher before 1980s than which is after 1980s. Current researches are all shown to reducing trend of ET0 on the global and China region [6, 8]. As the main meteorological factor is the wind speed in the Tibet Plateau, the wind speed at 2 m high also plays a key role in determining the variation of Northwest China ET0.

In the past 56 years, SD, RH and U_2 are all showed decreasing trend, while T presented increasing trend year by year. The main influencing meteorological is decreasing wind speed. Many existing studies have indicated that SD is the main important meteorological factor due to vast territory in China. In the NW China region, the wind speed at 2 m high during 1956-2011 has the decreasing rate of -0.07 m s^{-1} decade^{-1}, which is consistent with the trend of global wind speed [9]. Wang et al. [29] ascribed this result to the weak of winter and summer monsoon.

With the decrease of sunshine hours and wind speed, ET0 present the decreasing trend year by year. In addition, numerous researchers indicated that the wind speed is the main influencing factor in determining the variation of ET0. According to the correlation analysis, ET0-U_2 has the maximum CC and PCC (CC=0.81 and PCC=0.71). From the result of multiple linear regression, when added in the U_2 in the H model, the performance of K model is better than H (H-K in RMSE=20.19-14.28=5.91, and K-H Adj R-sq=0.79-0.57=0.22). RH and SD also have a great influence on the ET0 variation. T is the weakest related with ET0 (not significant). IPCC [30] indicates that the gradually increasing temperature is the main cause of the ET variation. But we find the T in Northwest China has no significant relationship with ET0, this result is consistent with Fan's [31] investigation of Yunnan ET0 and its contributing meteorological factors. Many scientists selected a series of meteorological factors to establish numerous models to estimate the ET0 [13-15]. In practice, the model which considers the dynamic and radiative process can provide the accurate estimation than other models.

In addition, this research on ET0 only considers the regions in the arid and semi-arid over NW China. Our further main research directions are focus on: (1) to expand the research area on a wide range and about more complex climate characteristics, (2) to provide the reference for improving the performance of regional climate models (e.g., WRF model), (3) to study the relationship between ET0 and pan evaporation, (4) and analysis the relationship between ET0 and atmospheric circulation

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