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CASE STUDIES

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A monthly regression correction model for the Hargreaves–Samani method in Mainland China*

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Abstract

Reference crop evapotranspiration (ET_0) is an important parameter for irrigation engineering. It can be calculated using the Penman–Monteith method (PM), which results in $ET_{0\text{-PM}}$. This study uses $ET_{0\text{-PM}}$ to determine the availability of a monthly linear regression correction model for the Hargreaves–Samani method (HG). The data were obtained from 647 meteorological stations in mainland China, which are contained within the data set of monthly values of climate data from Chinese surface stations. For most stations, the correlation coefficient of $ET_{0\text{-PM}}$ and $ET_{0\text{-HG}}$ (determined by the HG method) ranges from 0.5 to 1.0. This provides the necessary conditions for the monthly linear regression correction of $ET_{0\text{-HG}}$. The mean relative change of the mean absolute error before and after the $ET_{0\text{-HG}}$ correction for each year indicates that the scheme adopted in this study yields improved correction results during autumn, winter and spring in mainland China and poor results during summer. However, the monthly regression correction model for the HG is only available for part of the stations in each season. This study supplements a case for the larger-scale $ET_{0\text{-HG}}$ monthly regression correction. This can be a reference for the further refinement of the $ET_{0\text{-HG}}$ spatio-temporal correction

KEYWORDS
reference crop evapotranspiration, Hargreaves–Samani method, linear regression model, Penman–Monteith method, mainland China

Résumé

L'évapotranspiration des cultures de référence (ET_0) est un paramètre important pour l'ingénierie de l'irrigation. ET_0 peut être calculé à l'aide de la méthode Penman–Monteith (PM), qui donne $ET_{0\text{-PM}}$. Cette étude utilise $ET_{0\text{-PM}}$ pour déterminer la disponibilité d'un modèle de correction de régression linéaire mensuel pour la méthode Hargreaves–Samani (HG). Les données ont été obtenues de 647 stations météorologiques en Chine continentale, qui sont contenues dans l'ensemble de données des valeurs mensuelles des données climatiques des stations de surface chinoises. Pour la plupart des stations, le coefficient de corrélation $ET_{0\text{-PM}}$ et $ET_{0\text{-HG}}$ (déterminé par la méthode HG)

*Un modèle de correction de régression mensuelle pour la méthode Hargreaves–Samani en Chine continentale.

varie de 0.5 à 1.0. Cela fournit les conditions nécessaires pour la correction de régression linéaire mensuelle de $ET_{0\text{-}HG}$. La variation relative moyenne de l'erreur absolue moyenne avant et après la correction $ET_{0\text{-}HG}$ pour chaque année indique que le schéma adopté dans cette étude donne de meilleurs résultats de correction en automne, en hiver et au printemps en Chine continentale et de mauvais résultats en été. Cependant, le modèle de correction de régression mensuelle pour le HG n'est disponible que pour une partie des stations à chaque saison. Cette étude complète un cas pour la correction de régression mensuelle à plus grande échelle de $ET_{0\text{-}HG}$. Cela peut être une référence pour le perfectionnement de la correction spatio-temporelle $ET_{0\text{-}HG}$.

MOTS CLÉS
evapotranspiration des cultures de référence, méthode Hargreaves–Samani, modèle de régression linéaire, méthode Penman–Monteith, Chine continentale

1 | INTRODUCTION

The reference crop water requirement, also known as the reference crop evapotranspiration (ET_0), is an important parameter when studying agriculture, climate and hydrology, especially for the planning, construction and operations of irrigation engineering (Allen *et al.,* 1998). To date, the Penman–Monteith method (PM), recommended by the Food and Agriculture Organization (FAO) of the United Nations, is considered to be the standard method for calculating ET_0 (Ma and Jiao, 2006). This method, which covers climate/meteorology variables, such as radiation, air temperature, vapour pressure and wind speed, is a comprehensive model in line with the mechanisms of climatology and aerodynamics (Allen *et al.,* 1998). However, the types of observation variables required by PM are too many for most areas of the globe (Peng *et al.,* 2017). Owing to the complexity of the Earth's surface environment and differences in regional socio-economic development, there is a lack of synchronization between the application and development of modern meteorological scientific observation technology. Missing or discontinuous observation data from meteorological stations exist at a global scale (Peng *et al.,* 2017). This makes it difficult for the data to meet the requirements of PM for a wide range of applications (Peng *et al.,* 2017). To solve this problem, numerous studies have proposed a series of simplified methods to estimate ET_0 (Doorenboos and Pruitt, 1977; Irmak *et al.,* 2003; Valiantzas, 2013). These include the Makkink (1957) and Priestley and Taylor (1972) methods based on radiation data, the Hargreaves and Samani (1985) method (HG), the Droogers and Allen (2002) method and the Berti *et al.* (2014) method based on temperature data. PM, in most cases, is only used in experimental research or as a standard algorithm to validate the applicability of other methods (Peng *et al.,* 2017). Many studies (Er-Raki *et al.,* 2010; Qingyu *et al.,* 2010; Todorovic *et al.,* 2013; Xiaoying *et al.,* 2006; Zhandong *et al.,* 2014) have confirmed that HG is a simplified method that yields better results. However, considering that HG is an empirical equation developed by Hargreaves and Samani (1985) in arid and semi-arid areas through observation and experiment, there are large deviations for wet and cold areas (Cobane, 2011; Temesgen *et al.,* 2005; Trajkovic, 2005, 2007; Wei *et al.,* 2014). Therefore, FAO 56 suggests that a linear regression correction should be performed when HG is applied to new areas (Allen *et al.,* 1998).

Irrigation is one of the main measures to ensure safe agricultural production in China. Consequently, ET_0 is an important reference index to design and implement irrigation projects and ensure adequate water supply for its agricultural production. The calculation methods for ET_0 have been the subject of extensive research. The research on HG has achieved fruitful results (Wang *et al.,* 2016; Xiaoying *et al.,* 2006; Zhao *et al.,* 2004). However, the validation studies of the linear regression correction program recommended by the FAO in China are limited to small regional experimental studies. This results in inconsistent spatio-temporal scales for correction coefficients. National scale research is focused on the partition optimization method (Hu *et al.,* 2011; Zhang *et al.,* 2012). To the best of our knowledge, there are no published studies available for linear regression corrections for the large spatial scale in China. In addition, although all existing case studies have good results, there are no corresponding data products. This indicates that the feasibility of these methods for a wide range of applications may not be strong. Therefore, simple and feasible business application methods require further discussion.

The main aim of this study is to explore the availability of a monthly regression correction program for HG in mainland China. Specifically, the study adopted the program recommended by FAO 56 (Allen *et al.*, 1998) and referred to CLIMWAT 2.0 of the FAO calculation case for the monthly mean daily $ET_{0\text{-}PM}$ (ET_0 based on the PM calculation) at a global scale. Afterwards, using the available meteorological station data of China with the help of the spatial interpolation method, HG was modified month by month. These results are expected to provide a reference for the development of large-scale ET_0 spatio-temporal data products.

2 | STUDY AREA AND DATA

The study area encompasses the entire mainland of China. There are various combinations of temperature and precipitation and a variety of climate types due to its unique sea and land location, along with its complex topography and geomorphology conditions. Based on the combined index of precipitation and evaporation, mainland China is divided into four zones with different humidity conditions (http://www.resdc.cn/data.aspx?DATAID = 273), i.e. humid, subhumid, semi-arid and arid zones (Figure 1).

The data used in this study include daily values of the following six variables: air pressure (kPa), minimum temperature (°C), relative sunshine duration (%), maximum temperature (°C), wind speed (m s^{-1}) and actual vapour pressure (kPa). These are averaged over each calendar month to obtain the monthly values of each meteorological variable. They were compiled directly from the data set of monthly values of climate data from Chinese surface stations (DMCD) that are downloaded by the China National Meteorological Data Service Centre (CMDC) (http://data.cma.cn/). The data set contains 756 stations, including basic stations, reference surface meteorological observation stations and automatic stations with records during the period 1951–2016.

According to the metadata description of the data set and algorithm requirements of each variable in PM and HG, this study conducted data screening and station filtering to eliminate invalid values, outliers and missing values. These may be caused by failures in the observation instrument or improper operation by observers. The 24-h wind speed was recorded at 10–12 m height. The necessary corrections were applied to convert it to a 2 m height to confirm its application in PM. In addition, the data series is 'broken' (e.g. 1961–1970 and 1992–2000) for almost all of the stations. In CLIMWAT 2.0 (http://www.fao.org/land-water/databases-and-software/climwat-for-cropwat/en/) from the FAO, the principle is followed that each station has at least 15 years of cumulative valid data. To reference CLIMWAT 2.0, this study follows that principle. After data and station filtering, 647 stations (Figure 1) were selected, which cover the period between 1951 and 2016. The series is 'broken'; however, this has at least 15 years of data. The number of stations in humid, subhumid, semi-arid and arid zones are 327,165, 73 and 82, respectively.

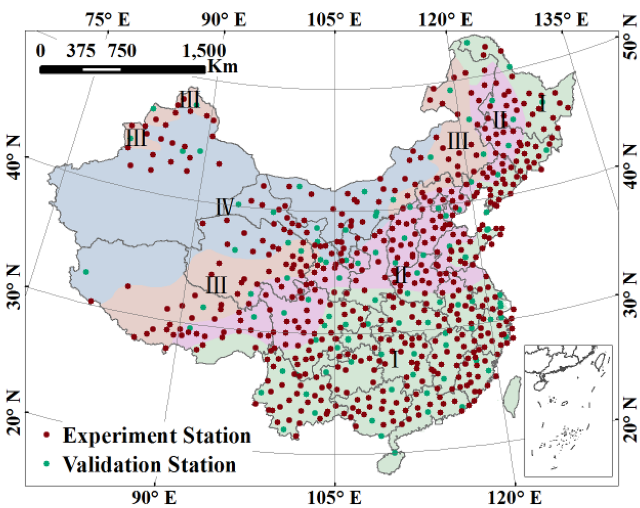

FIGURE 1 Locations of the selected meteorological stations for the available data. I: Humid zone. II: Subhumid zone. III: Semi-arid zone. IV: Arid zone [Colour figure can be viewed at wileyonlinelibrary.com]

3 | METHODS

3.1 | The FAO 56 Penman–Monteith method (PM)

The prototype of PM is the water surface evaporation equation derived by Penman in 1948. This combines energy balance and mass transfer with sunshine, temperature, humidity and wind speed for standard meteorological data. After continuous research and improvement via numerous studies, resistance factors for calculating the tension for crop surfaces were introduced to improve the equation, and PM was created (Monteith, 1965). Beginning in 1990, the FAO organized a panel of experts and researchers in collaboration with the International Commission for Irrigation and Drainage and the World Meteorological Organization. This collaboration demonstrated the scientific nature and global applicability of PM (Allen *et al.*, 1998). Further, in 1998, the FAO recommended PM (Equation 1) as a new standard method to determine ET_0

in FAO Irrigation and Drainage Paper No. 56: 'Crop evapotranspiration (guidelines for computing crop water requirements)' (Allen *et al.,* 1998):

$$ET_{0\text{-}PM} = \frac{0.408\Delta(R_n - G) + \gamma\frac{900}{T+273}u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \quad (1)$$

where $ET_{0\text{-}PM}$ is the reference crop evapotranspiration based on PM (mm day^{-1}); R_n is the net radiation at the crop surface (MJ m^{-2} day^{-1}); G is the soil heat flux density (MJ m^{-2} day^{-1}); T is the mean daily air temperature at a height of 2 m (°C); u_2 is the wind speed at a height of 2 m (m s^{-1}); e_s is the saturation vapour pressure (kPa); e_a is the actual vapour pressure (kPa);$e_s - e_a$ is the saturation vapour pressure deficit (kPa); Δ is the slope vapour pressure curve (kPa $°C^{-1}$); and γ is a psychrometric constant (kPa $°C^{-1}$). A complete set of equations, proposed by Allen *et al.* (1998) based on the available weather data and time step computation, constitutes PM. $G_{month,i} = 0.07$ $(T_{month,i+1} - T_{month,i-1})$ was used for estimating the soil heat flux density, where $T_{month,i-1}$ is the mean air temperature of the previous month (°C) and $T_{month,i+1}$ is the mean air temperature for the following month (°C). Since there were no solar radiation data available, R_n was estimated from the relative sunshine duration record, assuming the recommended (Shuttleworth, 1993) values for albedo equals 0.23 and the Angstrom coefficients, a_s and b_s, are 0.25 and 0.5, respectively. The detailed algorithm for the other variables can be found in FAO 56 (Allen *et al.,* 1998). This method has been widely used in hydrology, agriculture and climatological studies (Biazar *et al.,* 2019; Dinpashoh *et al.,* 2011, 2019; Jhajharia *et al.,* 2015).

3.2 | The FAO 56 Hargreaves–Samani method (HG)

HG is an empirical method (Equation 2) proposed by Hargreaves and Samani (1985) based on a study carried out in arid and semi-arid regions. After extensive research and application, the FAO recommends it as a simplified method to calculate ET_0 in the case where only temperature data are available. As HG is derived empirically, the FAO also recommends that, if necessary, it can be calibrated on a monthly or annual basis by determining the empirical coefficients (Equation 4). The coefficients a and b can be determined by the regression analysis method.

$$ET_{0\text{-}HG} = \alpha \times (T_{mean} + 17.8)(T_{max} - T_{min})^{0.5} \times R_a, \quad (2)$$

$$T_{mean} = \frac{T_{max} + T_{min}}{2}. \quad (3)$$

where $ET_{0\text{-}HG}$ is the reference crop evapotranspiration based on HG (mm day^{-1}); α is a constant equal to 0.0023 (Hargreaves and Samani, 1985); T_{max} is the average daily maximum temperature (°C); T_{min} is the average daily minimum temperature (°C); T_{mean} is the average daily temperature (°C); and R_a is the extra-terrestrial radiation (mm day^{-1}). The R_a algorithm is also a part of FAO 56 (Allen *et al.,* 1998).

Based on the calibration of HG in a distinct region, one can calculate ET_0 with more accuracy by using only temperature data. The calibration formula is as follows:

$$ET_0 = a + bET_{0\text{-}HG}, \quad (4)$$

where ET_0 is the reference evapotranspiration (mm day^{-1}), and a and b are the regression coefficients.

3.3 | Processing

For the processing of this study, $ET_{0\text{-}PM}$ and $ET_{0\text{-}HG}$ are calculated for each station on a yearly and monthly basis, respectively. Then, the stations were divided into two groups: experimental and validation stations. The validation stations group includes 103 basic stations with good data quality. The experimental stations group includes the remaining 544 stations. The experimental stations were used to directly obtain the correction coefficients, a and b, based on the regression correction scheme proposed by the FAO. The validation stations were used to validate the reliability of the correction coefficients obtained via spatial interpolation based on the correction coefficients of the experimental stations. Then, the correlation coefficient of the monthly $ET_{0\text{-}PM}$ and $ET_{0\text{-}HG}$ of the experimental stations was calculated. The stronger the correlation, the higher the correlation coefficient. Taking $ET_{0\text{-}PM}$ as the true value, the linear regression correction of the monthly $ET_{0\text{-}HG}$ was performed based on the 544 experimental stations by using the least squares method. The simple tension spline interpolation method without any parameter optimization and auxiliary variables was used to spatialize the a and b correction coefficients to obtain the spatially continuous correction coefficients. The correction coefficients a and b for 103 validation stations were extracted from the interpolation results. The interpolation and extraction algorithms were implemented by using the Arcgis10.2 toolkit. Finally, the corrected $ET_{0\text{-}HG}$ (ET_0) was calculated for the 103 validation stations based on the coefficients a and b that were previously obtained. By taking $ET_{0\text{-}PM}$ as the true values, the accuracy of the corrected results of $ET_{0\text{-}HG}$ was analysed by comparing the mean relative change (MRC) (Equation 5) of the mean absolute error (MAE) before and after the correction for 103 validation stations. This was done to demonstrate the feasibility of the monthly regression correction model for HG in mainland China.

$$\text{MRC} = \frac{\text{MAE before the } ET_{0\text{-}HG} \text{correction} - \text{MAE after the } ET_{0\text{-}HG} \text{correction}}{\text{MAE before the } ET_{0\text{-}HG} \text{correction}} \times 100\% \quad (5)$$

4 | RESULTS AND DISCUSSION

4.1 | Results

4.1.1 | Correlation analysis between $ET_{0\text{-}PM}$ and $ET_{0\text{-}HG}$

$ET_{0\text{-}PM}$ and $ET_{0\text{-}HG}$ are the reference crop evapotranspiration values obtained using different models based on the meteorological observation data. The monthly $ET_{0\text{-}HG}$ linear regression correction was first performed to ensure that it has a good correlation with $ET_{0\text{-}PM}$, which was taken as the standard value. Table 1 lists the proportional numbers of the experimental stations for the different $ET_{0\text{-}PM}$ and $ET_{0\text{-}HG}$ correlation coefficient intervals for each month. On average, there are more than 95% stations with a correlation coefficient of ≥0.5 per month, while 83% of the stations have a correlation coefficient between 0.7 and 1.0. For the 5% of residual stations with a correlation coefficient of less than 0.5, most of them suffer problems, such as a discontinuous data time series or small amounts of accumulated data. Therefore, if the 5% of stations containing poor data quality is excluded, the statistical result of the above correlation coefficient indicates that, in mainland China, $ET_{0\text{-}HG}$ can be corrected by using Equation 4 as recommended by the FAO.

4.1.2 | Error comparison before and after $ET_{0\text{-}HG}$ correction

Figure 2 shows the MRC of the MAE for the validation stations before and after the $ET_{0\text{-}HG}$ correction for each year in mainland China. For Figure 2, the positive values (black lines) represent the relative decreasing value of the MAE after $ET_{0\text{-}HG}$ correction, while the negative values (red lines) indicate the opposite. The correction error for autumn, winter and spring decreased except for the initial years when there was a small number of stations along with poor data quality. However, the correction error for summer increased for all of the years. Therefore, from the MRC perspective, the scheme adopted in this study delivered better correction results during autumn, winter and spring in mainland China; however, poor correction results were obtained during summer. This indicates that $ET_{0\text{-}HG}$ and $ET_{0\text{-}PM}$ in the summer may not have a good linear relationship at a national scale.

Figure 3 shows the MRC in the MAE for each season before and after $ET_{0\text{-}HG}$ correction at 103 validation stations, which differs slightly from the results shown in Figure 2. In Figure 3, the black dots represent the relative decrease in the MAE after $ET_{0\text{-}HG}$ correction, while the red dots indicate the opposite. Based on this figure, not all of the stations had an improved $ET_{0\text{-}HG}$ value after correction in comparison to their values before correction, i.e. $ET_{0\text{-}HG}$ before correction was better than $ET_{0\text{-}HG}$

TABLE 1 Monthly quantitative proportion of stations for each correlation coefficient interval (%)

Correlation coefficient interval	0.0–0.5	0.5–0.6	0.6–0.7	0.7–0.8	0.8–0.9	0.9–1.0
Jan.	5.53	6.87	10.1	31.2	38.0	8.38
Feb.	1.51	2.01	6.87	13.4	44.2	32.0
Mar.	1.01	2.68	6.20	14.6	44.7	30.8
Apr.	2.51	2.85	7.04	20.6	46.9	20.1
May	3.85	4.69	7.20	20.3	41.7	22.3
Jun.	4.52	3.52	7.20	17.4	45.1	22.3
Jul.	3.18	2.35	7.20	20.6	46.4	20.3
Aug.	5.19	4.19	6.53	16.8	42.4	25.0
Sep.	7.20	4.36	9.21	19.1	42.6	17.6
Oct.	6.20	5.03	11.4	19.3	40.2	17.9
Nov.	7.04	3.52	11.6	23.3	40.4	14.2
Dec.	9.88	5.19	13.4	26.3	38.9	6.37

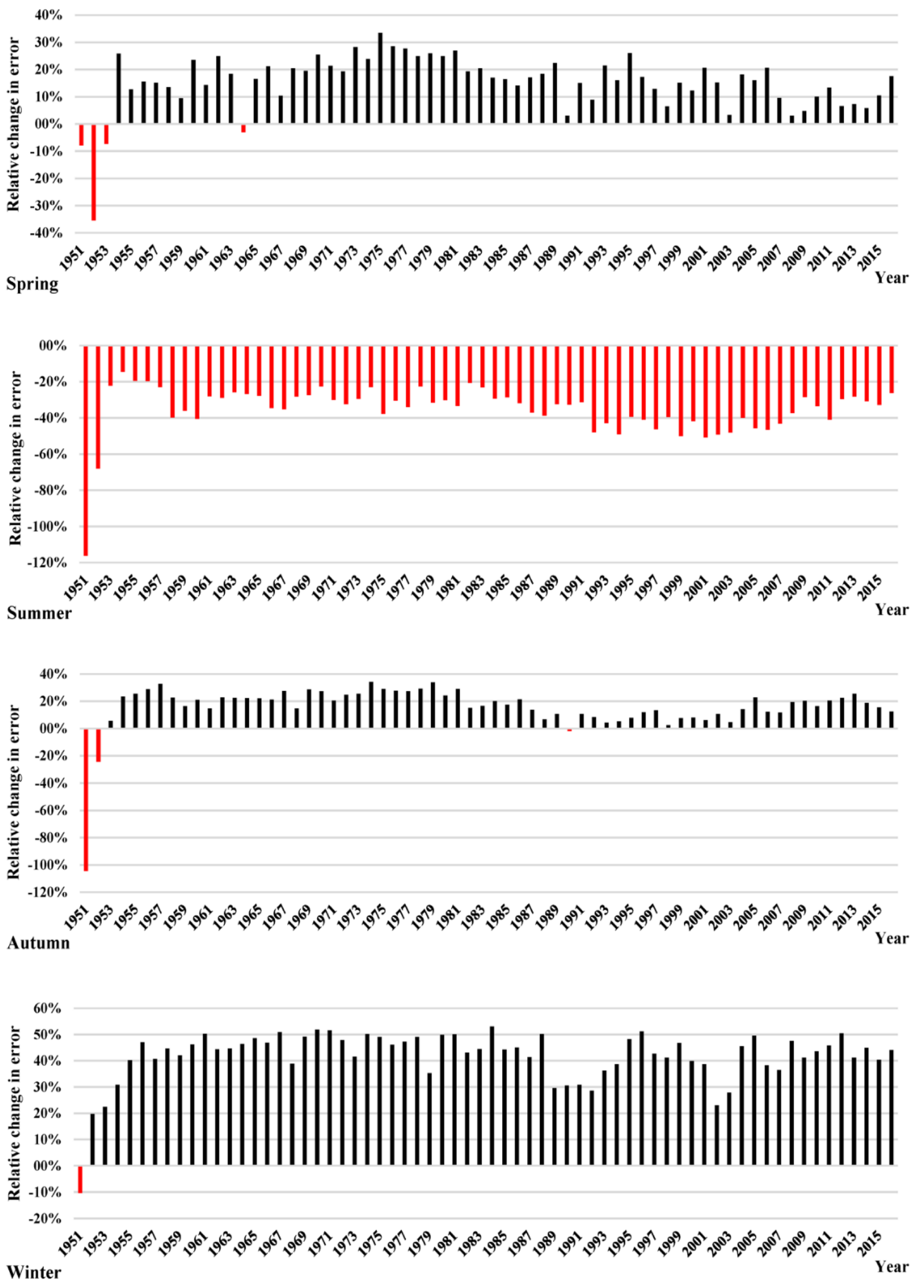

FIGURE 2 Mean relative change (MRC) of MAE before and after $ET_{0\text{-}HG}$ correction per year in mainland China. The positive values (black lines) represent the decreasing value of MAE after $ET_{0\text{-}HE}$ correction, while the negative values (red lines) indicate the opposite [Colour figure can be viewed at wileyonlinelibrary.com]

after correction. The number of stations at which $ET_{0\text{-}HG}$ after correction are better than $ET_{0\text{-}HG}$ before correction is highest in winter and spring, followed by autumn, and low in summer. For spatial distribution, the stations with a better $ET_{0\text{-}HG}$ before correction are mainly distributed in the southern coastal areas, along the lower Yangtze River and the Yellow River, during the winter and spring. In addition, the three above areas and the south-west, where the stations with a better $ET_{0\text{-}HG}$ before correction, are present in autumn. Finally, for the summer, the stations with a better $ET_{0\text{-}HG}$ before correction are scattered throughout mainland China. This indicates that the HG correction scheme adopted in this study is not applicable for certain local areas in each season.

4.2 | Discussion

Some existing published studies report on the linear regression correction for HG in many areas of China. For example: the experimental field of Northwest A&F University (Zhao *et al.*, 2004), the Weihe River basin (Zuo *et al.*, 2011), the Loess plateau region (Youqi *et al.*, 2013), the Qinghai Lake basin (Li *et al.*, 2015), Sichuan Province (Danyang *et al.*, 2017) and the Minjiang River headwater region (Yan *et al.*, 2018). These studies show that HG modified by linear regression can achieve good results on different time scales, such as daily, every 10 days and monthly. However, our results (Figure 2) indicate that HG modified by linear regression in autumn, winter and

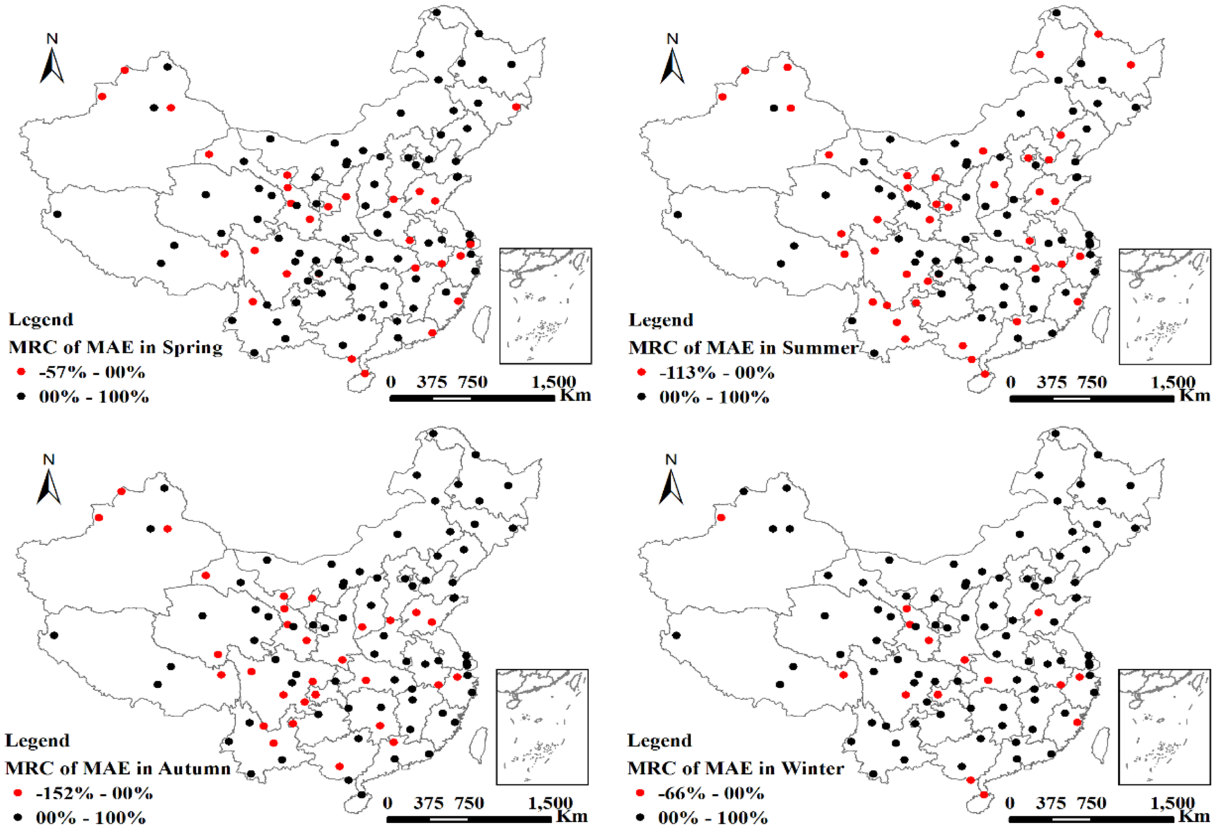

FIGURE 3 Mean relative change (MRC) in MAE for each season before and after $ET_{0\text{-}HG}$ correction at 103 validation stations. Black dots represent the relative decrease in MAE after $ET_{0\text{-}HG}$ correction, while red dots indicate the opposite [Colour figure can be viewed at wileyonlinelibrary.com]

spring in mainland China has better results than the original HG. In contrast, the results for summer are reversed. This might be due to the following factors.

First, there are differences in the time and space scales between the different studies. As stated earlier, the existing studies focused on a small regional scale and the time scales on which data were recorded were different. For example, Zhao *et al.* (2004) used 10-day average observation data between 1984 and 2002. Youqi *et al.* (2013) used daily meteorological data from 1981 to 1998 in Yulin. Danyang *et al.* (2017) used data from a daily climatological data set for international exchange stations in China during 1991–2010. Yan *et al.* (2018) used daily meteorological data between 1961 and 2010 from the Pansong National Meteorological Station, which is the only continuous meteorological observation station in the Minjiang River headwater region. This study used the monthly meteorological data of 647 stations from the DMCD during 1951–2016. The data quality varies from the different sources. For studies in smaller regions, the time scales are relatively short and most of them obtain time series data. Moreover, the geographical environment in a small region is relatively stable and the short-term data quality is relatively consistent. However, the spatio-temporal scale of this study is large and the geographical environment is complex. The data were calculated using the monthly average with valid observation values over at least 15 years since 1951 by referencing CLIMWAT 2.0 of the FAO. The establishment time inconsistencies of the meteorological stations, along with the migration, equipment updates, debugging and other factors, have led to differences in the spatial distribution of the data. This also includes discontinuities in the time series data and differences in the data quality over different time intervals. As a result, this is a source of error in the study. Therefore, further analysis and validation of $ET_{0\text{-}HG}$ correction accuracy at different climate scales, using a consistent spatio-temporal scale data set, are necessary.

As shown in Figure 3, the correction scheme adopted in this study is not available for every station for all of the seasons. The study by Danyang *et al.* (2017) in Sichuan Province also showed that the correction for HG might lead to the phenomenon of reversal of the relative errors of individual stations in individual months. That is, the relative errors of some stations after the correction are larger than before the correction. Thus, this research

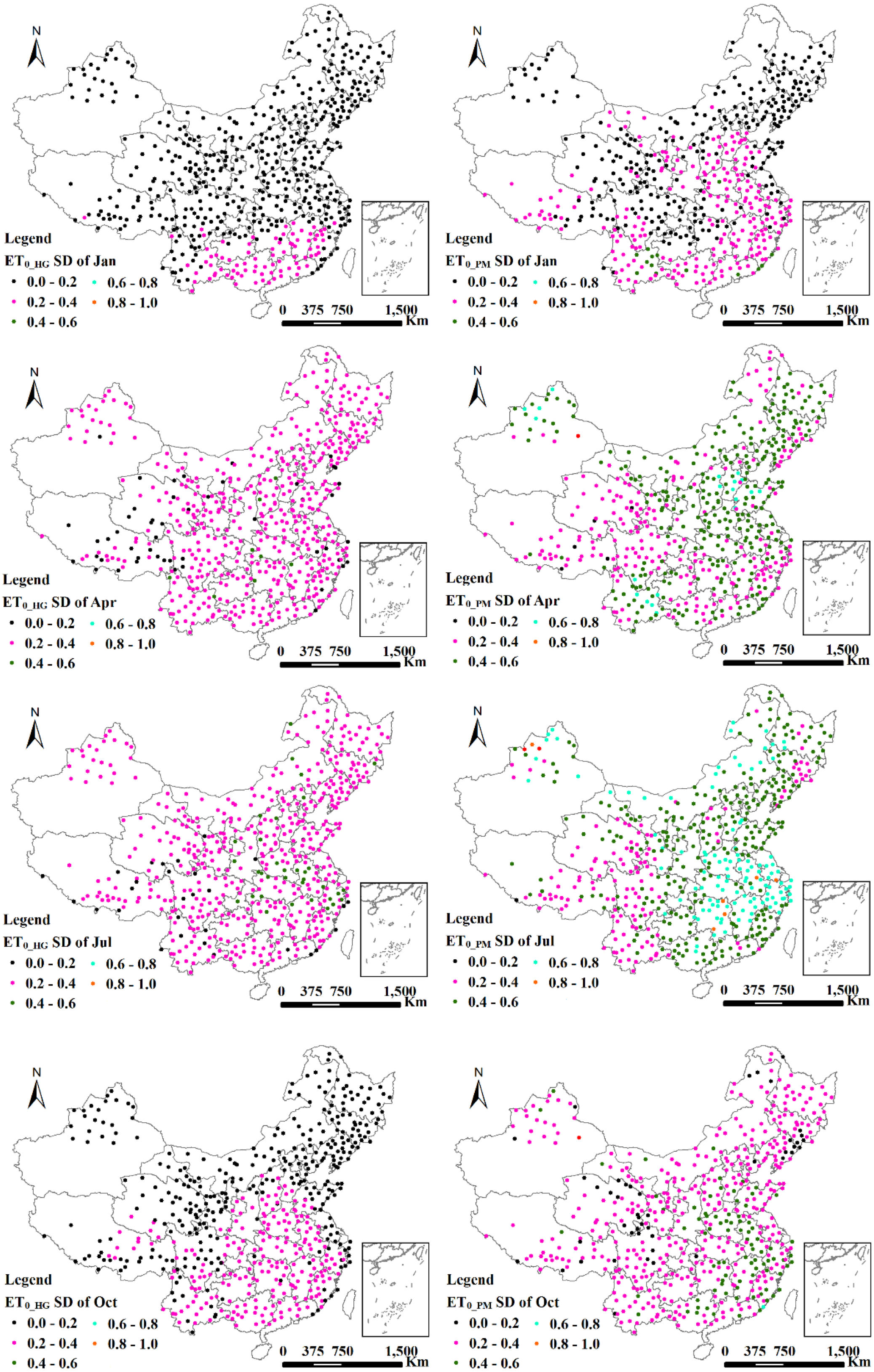

FIGURE 4 Spatio-temporal distribution of the standard deviation (SD) of $ET_{0\text{-HG}}$ and $ET_{0\text{-PM}}$ for the experimental stations in the second month of each season [Colour figure can be viewed at wileyonlinelibrary.com]

analysed the spatio-temporal stability of $ET_{0\text{-}PM}$ and $ET_{0\text{-}HG}$. Figure 4 presents the spatio-temporal distribution of the standard deviation (SD) of $ET_{0\text{-}HG}$ and $ET_{0\text{-}PM}$ for the experimental stations for 4 months (second month of each quarter). As illustrated in Figure 4, the SD of $ET_{0\text{-}HG}$ and $ET_{0\text{-}PM}$ at the same station for different months varies. Moreover, the SD in $ET_{0\text{-}HG}$ and $ET_{0\text{-}PM}$ during the same period do not have the same numerical range for each value at certain stations. There are also differences in the dispersion degree of the two values. This may lead to a lower correlation of the two values at these stations, while also introducing another source of error in this study.

In addition, the spatial interpolation of the regression coefficients may influence the results to some extent. In this study, simple tension spline interpolation without any parameter optimization and auxiliary variables was selected for spatial interpolation of the regression coefficients. Existing studies for the spatial interpolation of HG correction coefficients via kriging (Chuanyan *et al.,* 2004; Kamali *et al.,* 2015; Tang *et al.,* 2016) yield good results. The method used in this study should be further compared with other interpolation methods to determine the best spatial interpolation method for HG modified coefficients.

5 | CONCLUSIONS

This study explored the availability of HG modified by monthly regression in mainland China. Based on the data published by the CMDC and the ET_0 algorithm reported in FAO 56, we calculated the monthly $ET_{0\text{-}PM}$ and $ET_{0\text{-}HG}$ of 647 stations from 1951 to 2016, conducted a correlation analysis between $ET_{0\text{-}PM}$ and $ET_{0\text{-}HG}$, and compared the errors before and after the corrected $ET_{0\text{-}HG}$. The results of this study are as follows:

- at most stations, $ET_{0\text{-}PM}$ and $ET_{0\text{-}HG}$ had good correlation. This indicates that the monthly $ET_{0\text{-}HG}$ modified by the linear regression programme recommended by the FAO in mainland China has met the basic conditions sufficiently;
- the changes in average annual MAE before and after $ET_{0\text{-}HG}$ correction indicate that the scheme adopted in this study yields improved correction results during autumn, winter and spring in mainland China, although poor correction results were obtained during summer. However, changes for individual stations in MAE before and after $ET_{0\text{-}HG}$ correction show that the correction scheme adopted in this study is not suitable for all stations. The reason for the poor correction results in summer and the influence of global correction on local results require further exploration.

Finally, the validation of the correction scheme adopted in this study, in essence, is a *validation in the past.* This cannot reflect the availability of the correction scheme currently for the future. The spatial correction coefficient constructed based on historical data to correct current or future $ET_{0\text{-}HG}$ values is key to the practical application of this scheme and the core of future research. Furthermore, the influence of underlying surface factors on the correction coefficient of $ET_{0\text{-}HG}$, such as surface roughness and topographic relief, should be investigated. This can compensate for the limitations in HG that do not consider other factors except for temperature. The effects of different interpolation methods on the spatial results of correction coefficients of $ET_{0\text{-}HG}$ should also be discussed.

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