

## Predicting Daily Reference Evapotranspiration in a Humid Region of China by the Locally Calibrated Hargreaves-Samani Equation Using Weather Forecast Data

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### ABSTRACT

The Hargreaves-Samani (HS) equation, which estimates reference evapotranspiration ( $ET_0$ ) using only temperature as input, should be most suitable for  $ET_0$  prediction based on weather forecasting data. In the current study, the HS equation is calibrated with daily  $ET_0$  by the Penman-Monteith equation, and is evaluated to check the possibility of predicting daily  $ET_0$  based on weather forecast data. The HS equation is likely to overestimate daily  $ET_0$  in the humid regions of China. Coefficients  $a$  and  $c$  are calculated as 0.00138 and 0.5736 according to local calibration. The calibrated HS equation performs considerably better than the original one. The proposed equation could be an alternative and effective solution for predicting daily  $ET_0$  using public weather forecast data as inputs. The error of daily  $ET_0$  prediction increases with the increase in the error of daily temperature range (TR) or daily mean temperature ( $T_{mean}$ ). This error is likely to be more sensitive to the error in TR than in the  $T_{mean}$ . Ensuring that TR errors are less than 2°C is necessary for perfect estimations of  $ET_0$  based on public weather forecast data using the calibrated HS equation.

**Keywords:** Hargreaves-Samani equation, Humid region, Local calibration, Reference evapotranspiration, Sensitivity analysis, Weather forecast data.

### INTRODUCTION

The prediction of daily crop evapotranspiration ( $ET_c$ ) is the basis for real-time irrigation forecasting. The estimation of  $ET_c$  often involves calculating the reference evapotranspiration ( $ET_0$ ), which is defined as the evapotranspiration rate from a hypothetical crop with an assumed height of 0.12 m, a fixed surface resistance of 70 s·m<sup>-1</sup>, and an albedo of 0.23 (Allen *et al.*, 1998). Subsequently, a suitable crop coefficient ( $K_c$ ) is applied. The prediction of daily  $ET_0$ , which is the basis for estimating the daily  $ET_c$  and determining crop irrigation requirements, is essential for real-time irrigation forecasting.

The prediction of  $ET_0$  is always realized based on either the weather forecast data (Duce *et al.*, 1999; Xu *et al.*, 2006; Cai *et al.*, 2007; Er-Raki *et al.*, 2010) or time series analysis (Mariño *et al.*, 1993; Mao, 1994; Mohan and Arumugam, 1995; Gu *et al.*, 1998; Trajković, 1998; Luo *et al.*, 2005; Landaras *et al.*, 2009). Duce *et al.* (1999) calculated the hourly  $ET_0$  using the modified Penman-Monteith (PM) equation, with outputs of a mesoscale weather forecast model as inputs. Xu *et al.* (2006) established a back propagation neural network model (BP-ANN) for the real-time prediction of  $ET_0$  based on daily public weather forecast data. Cai *et al.* (2007) presented a complex analytical method for the estimation of  $ET_0$

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by the FAO-56 PM equation using daily weather forecast messages, by which weather forecast messages were firstly transformed into data required before  $ET_0$  was calculated by FAO-56 PM equation. Er-Raki *et al.* (2010) used the Hargreaves method to predict the daily  $ET_0$  in semi-arid regions in the Tensift basin with climatic data generated by numerical weather prediction models as inputs. Thus, weather forecasting data are useful for the real prediction of  $ET_0$  with different methods.

A number of methods have been developed for the estimation of  $ET_0$  based on either (i) aerodynamic principles; (ii) energy budget; (iii) a combination of (i) and (ii); or (iv) empirical principles. The FAO PM combination equation (FAO-56 PM) has been proposed as the only standard method for calculating  $ET_0$ , and evaluating other equations (Allen *et al.*, 1998). It is accepted worldwide as the optimum method and the standard for evaluating other methods (e.g., Jacovides and Kontonyiannis, 1995; Antonio, 2004; Hossein *et al.*, 2004; Xu and Chen, 2005; López-Urrea *et al.*, 2006; Trajkovic, 2007; Meshram *et al.*, 2010; da Silva *et al.*, 2011; Mohawesh, 2011). An issue that confronts us is that weather forecast data cannot meet the requirements for  $ET_0$  calculation in many complex methods. The Hargreaves-Samani (HS) equation (Hargreaves and Samani, 1985), proposed as an alternative by Allen *et al.* (1998), may be most suitable for  $ET_0$  prediction using weather forecast data because its estimated  $ET_0$  merely uses temperature as input. However, debates continue regarding the HS equation. Several studies have reported that this equation may provide reasonable estimates of  $ET_0$  (Hargreaves, 1994; Martinez-Cob and Tejero-Juste, 2004; Xu and Singh, 2002; Dinpasiogh, 2006; Er-Raki *et al.*, 2011); however, others argue that this equation tends to overestimate  $ET_0$  in humid regions but underestimate  $ET_0$  in very dry and windy regions (Samani, 2000; Droogers and Allen, 2002; Bakhtiari *et al.*, 2011). Local calibration is strongly recommended prior to

its application (Temessgen *et al.*, 2005; Gavilan *et al.*, 2006; Fooladmand and Haghighat, 2007; Er-Raki *et al.*, 2010; Hu *et al.*, 2011).

The objectives of the current study include providing an improved local calibration of the HS equation using the daily  $ET_0$  by the FAO-56 PM equation in a humid region of China and evaluating its potential to use weather forecast data as inputs in the daily  $ET_0$  prediction by the calibrated HS equation.

## MATERIALS AND METHODS

### Site Description and Data Collection

The Nanjing climate station (31°15'15"N, 120°57'43"E) was selected as the typical climate station in humid region in East China. The study area has a subtropical monsoon climate with an average annual air temperature of 16.3°C and a mean annual precipitation of 1,062.4 mm. Historical observed meteorological data (1995–2007) and public weather forecast data (2004–2005) were collected. The observed data set used in the current study was collected from the Chinese Meteorological Data Sharing Service System (<http://cdc.cma.gov.cn>). The data set is composed of daily values of the maximum air temperature ( $T_{\max}$ ), minimum air temperature ( $T_{\min}$ ), average temperature ( $T_a$ ), atmospheric pressure ( $P$ ), air humidity ( $RH_a$ ), solar radiation ( $R_s$ ), net radiation ( $R_n$ ), and 24 hours wind speed at a height of 2 m ( $u_2$ ). The data were measured following the Surface Meteorological Observation Standard of China Meteorological Administration (CMA, 2003) over a "25×25 m<sup>2</sup>, well-watered, uniform height (less than 20 cm)" surface. Data quality was checked according to Quality Control of Surface Meteorological Observational Data (CMA, 2010) before it was published on the Chinese Meteorological Data Sharing Service System. The meteorological data have good quality and integrity. Statistics of the historical observed meteorological data from 1995 to

2007 are listed in Table 1. The observed meteorological data are divided into two groups. Data from 1995 to 2005 were used for the local calibration of the HS equation, and the remaining data (2006 to 2007) were set apart for validation. Before the data were used for daily  $ET_0$  calculation using the FAO-56 PM equation (Allen *et al.*, 1998), they were checked according to Allen (1996) by comparing the clear sky radiation ( $R_{so}$ ) with solar radiation ( $R_s$ ), as indicated in Figure 1.

Daily public weather forecast data, collected from Nanjing Daily, were composed of daily values of the  $T_{max}$  and  $T_{min}$ . Prediction errors of the forecast  $T_{max}$  and  $T_{min}$  are plotted in Figure 2, compared with the observed meteorological data. Errors of the daily  $T_{max}$  and  $T_{min}$  ranged from -3.3 to 3.0°C and -3.2 to 2.8°C, with an average of -0.244 and -0.242°C, respectively. Statistical analysis revealed that 51.3% of the forecast daily  $T_{max}$  and 51.3% of the forecast daily  $T_{min}$  had an error of no more than 1°C, and that 89.9% of the

forecast daily  $T_{max}$  and 91.8% of the forecast daily  $T_{min}$  had an error no more than 2°C.

### HS Equation: Calibration and Validation

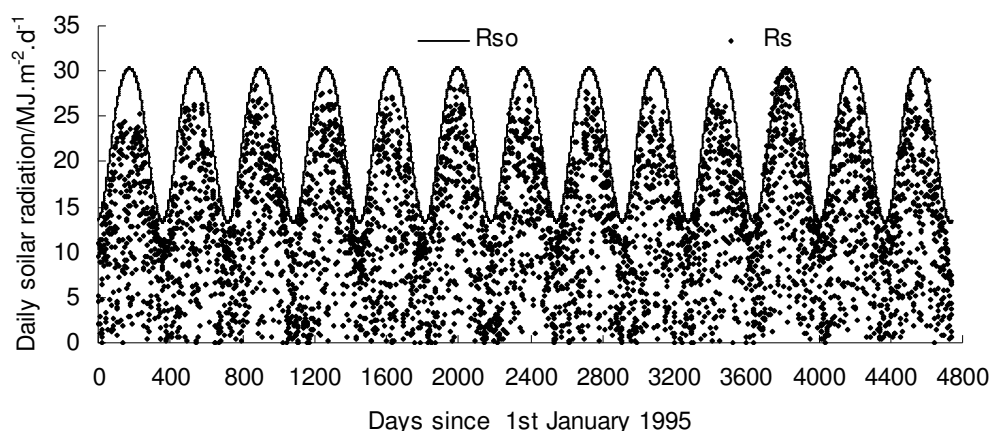
The HS equation (Hargreaves and Samani, 1985) is as follows:

$$ET_0 = 0.408 \times a \times (T_{mean} + b) \times TR^c \times R_a \quad (1)$$

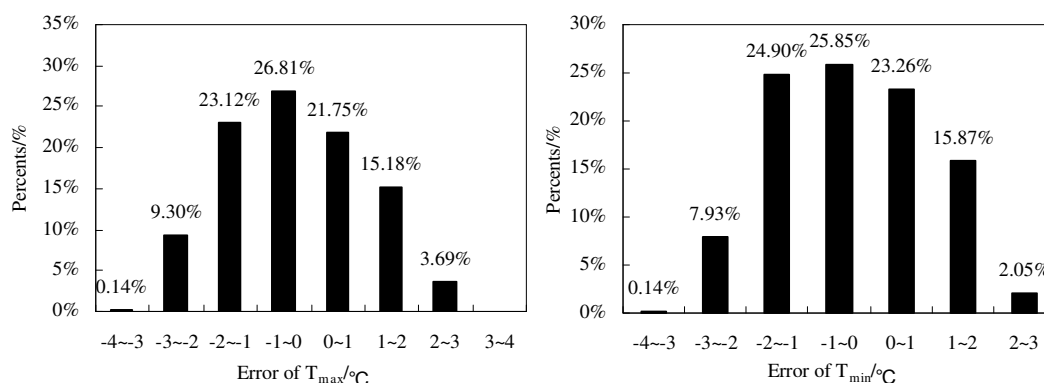
Where,  $T_{mean}$  and  $TR$  are the daily mean air temperature and daily temperature range (°C), respectively. Here,  $T_{mean}$  and  $TR$  are calculated based on the daily  $T_{max}$  and  $T_{min}$ , with  $T_{mean} = (T_{max} + T_{min})/2$  and  $TR = (T_{max} - T_{min})$ . The parameter  $R_a$  is the extraterrestrial radiation ( $MJ\ m^{-2}\ d^{-1}$ ) that depends on the day of the year and the latitude. It can be computed according to the method described by Allen *et al.* (1998). The coefficient  $b = 17.8$  is used to convert the temperature  $F$  into °C. However, the coefficients  $a$  and  $c$ , with the original values of 0.0023 and 0.5, respectively, should be determined according to the local calibration.

**Table 1.** Statistics of historical observed meteorological data from 1995 to 2007.

Statistics		$T_{max}$ (°C)	$T_{min}$ (°C)	$T_a$ (°C)	$P$ (Kpa)	$RH_a$ (%)	$R_{so}$ ( $MJ\ m^{-2}\ d^{-1}$ )	$R_n$ ( $MJ\ m^{-2}\ d^{-1}$ )	$u_2$ ( $m\ s^{-1}$ )
Calibration data (1995 - 2005)	Maximum	40.0	30.0	34.3	104.3	98	32.3	17.9	5.83
	Minimum	-2.6	-8.0	-4.5	99.1	19	0	-2.2	0
	Average	20.9	12.6	16.3	101.5	74	12.2	5.42	1.46
Validation data (2006- 2007)	Maximum	38.2	29.0	33.1	104.0	95	28.2	15.2	5.70
	Minimum	0.7	-5.6	-2.0	99.6	31	0	-1.8	0.2
	Average	21.8	13.4	17.2	101.5	71	12.3	5.1	1.96



**Figure 1.** Comparison between daily solar radiation ( $R_s$ ) and clear sky radiation ( $R_{so}$ ).



**Figure 2.** Prediction errors of  $T_{max}$  and  $T_{min}$  in public weather forecast compared with observed data.

Based on historical observed meteorological data from 1995 to 2005, local calibration was performed to determine the values of coefficients  $a$  and  $c$  through nonlinear multiple regression between the  $ET_0$  calculated using the FAO-56 PM equation and  $T_{mean}$ ,  $T_{max}$ ,  $T_{min}$ , and  $R_a$ . The nonlinear multiple regressions were realized by the 1stOPT software with Levenberg-Marquart (LM) algorithm. The locally calibrated HS equation was validated for the data from 2006 to 2007 by comparing the results with those using the FAO-56 PM equation.

#### Performance of Calibrated HS Equation Based on Weather Forecast Data

The  $ET_0$  was predicted based on public weather forecast data (2004 to 2005) using Equation (1), with the locally calibrated

coefficients of  $a$  and  $c$ . The prediction results with the calibrated HS equation were evaluated by comparing them with those calculated using the FAO-56 PM equation based on the historical observed climatic data.

#### Sensitivity Analysis of $ET_0$ Prediction to Weather Forecast Error

Errors on the weather forecast data and its influence on the accuracy of  $ET_0$  predication must be discussed before they are used as inputs of the locally calibrated HS equation. Eighteen combinations of errors in the  $T_{max}$  and  $T_{min}$  were designed (Table 2), and the polluted data groups were acquired by imposing combinations of errors in the  $T_{max}$  and  $T_{min}$  of the historical observed climatic data (2004 to 2005). The  $ET_0$  was then calculated using the calibrated HS equation with the polluted data groups as inputs, and

**Table 2.** Eighteen combinations of errors in  $T_{max}$  and  $T_{min}$  for sensitivity analysis of  $ET_0$  prediction to weather forecast error.

Error in $TR(T_{mean})$		Error in $T_{max}$				
		-2 $^{\circ}\text{C}$	-1 $^{\circ}\text{C}$	0 $^{\circ}\text{C}$	1 $^{\circ}\text{C}$	2 $^{\circ}\text{C}$
Error in $T_{min}$	-2 $^{\circ}\text{C}$	0(-2)	1(-1.5)	2(-1)	3(-0.5)	4(0)
	-1 $^{\circ}\text{C}$	-1(-0.5)	0(-1)	1(-0.5)	2(0)	3(0.5)
	0 $^{\circ}\text{C}$	OM	-1(-0.5)	0 (0)	1(0.5)	2(1)
	1 $^{\circ}\text{C}$	OM	OM	-1(0.5)	0 (1)	1 (1.5)
	2 $^{\circ}\text{C}$	OM	OM	OM	-1(1.5)	0 (2)

OM means omitted, because those combinations of error in  $T_{max}$  and  $T_{min}$  are likely to lead to contradiction.

compared with those calculated by the FAO-56 PM equation based on historical observed climatic data.

### Statistical Analysis

For the comparison of the  $ET_0$  calculated by different equations or different input data sets, linear regressions with zero interception were made, and slopes and determination coefficients ( $R^2$ ) were calculated. The average absolute errors (AE) and root mean square error (RMSE) were also calculated using the following expressions:

$$AE = \frac{1}{n} \sum_{i=1}^n (|P_i - O_i|) \quad (2)$$

$$RMSE = \sqrt{\frac{1}{n} \sum_{i=1}^n (P_i - O_i)^2} \quad (3)$$

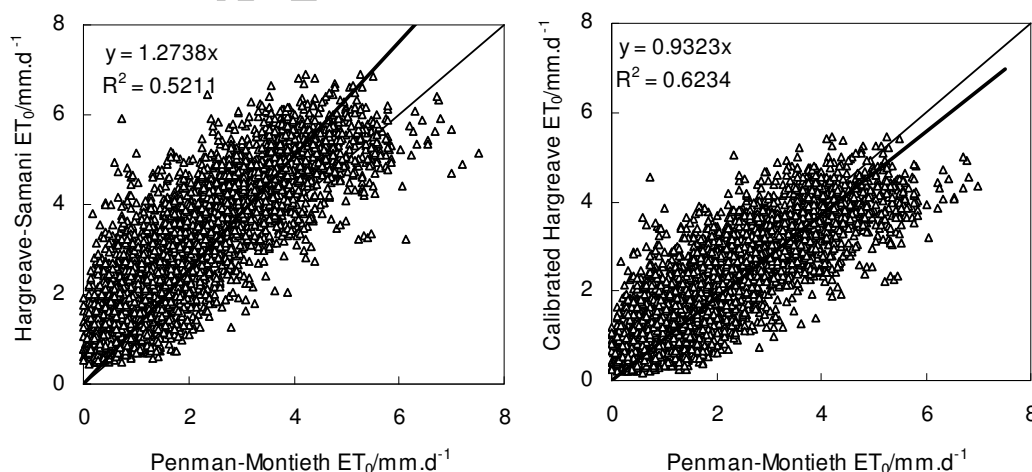
## RESULTS AND DISCUSSION

### Calibration and Validation of HS Equation

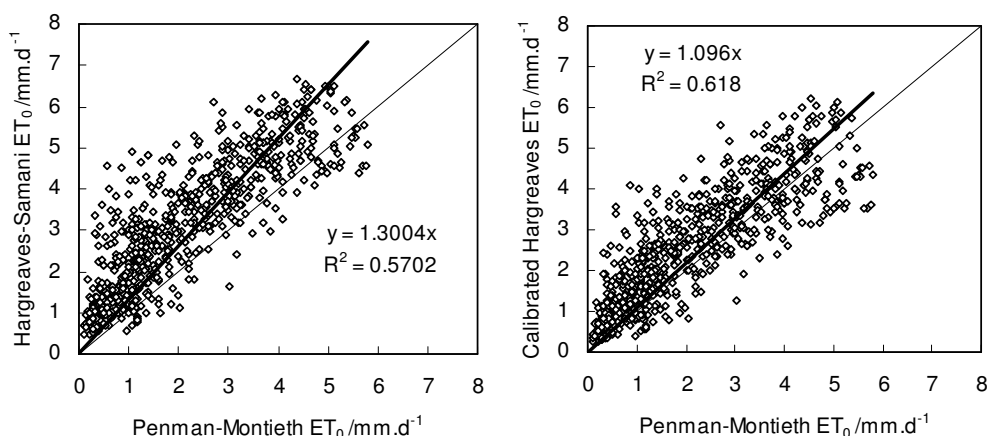
The HS equation is likely to overestimate daily  $ET_0$  in a humid region in China,

compared with the  $ET_0$  by the FAO-56 PM equation. Approximately 88.7% of all the results overestimated daily  $ET_0$ . The average overestimation is  $1.12 \text{ mm d}^{-1}$ . Thus, local calibration was carried out with the  $ET_0$  by the FAO-56 PM equation as a standard. The coefficients  $a$  and  $c$  were calculated as 0.00138 and 0.5736. Coefficient  $a$  in the current study is much lower than the original value suggested by Hargreaves and Samani (1985) and results of Gavilan *et al.* (2006), but falls within the range suggested by Moges *et al.* (2003) and Hu *et al.* (2011). The coefficient  $c$  in the current study is higher than the original value suggested by Hargreaves and Samani (1985) and by Trajkovic *et al.* (2007), but lower than the results of Hu *et al.* (2011). The daily  $ET_0$  calculated by the HS equation and the locally calibrated equation were compared with those obtained by the FAO-56 PM equation (Figure 3). The results show the slopes to be 1.2738 and 0.9323, and the  $R^2$  to be 0.5211 and 0.6234 for the original and locally calibrated HS equations, respectively. The average AEs are 1.05 and  $0.56 \text{ mm d}^{-1}$ , and the RMSEs are 1.26 and  $0.71 \text{ mm d}^{-1}$  for the original and locally calibrated HS equations, respectively.

The locally calibrated HS equation was validated with data from 2006 to 2007



**Figure 3.** Comparison between the daily  $ET_0$  calculated by the FAO-56 Penman-Monteith equation and the Hargreaves-Samani equation with the original and locally calibrated parameters for calibration data (1995-2005, N=3985).



**Figure 4.** Comparison between the daily  $ET_0$  calculated by the FAO-56 Penman-Monteith equation and the Hargreaves-Samani equation with the original and locally calibrated parameters for validation data (2006-2007,  $N=729$ ).

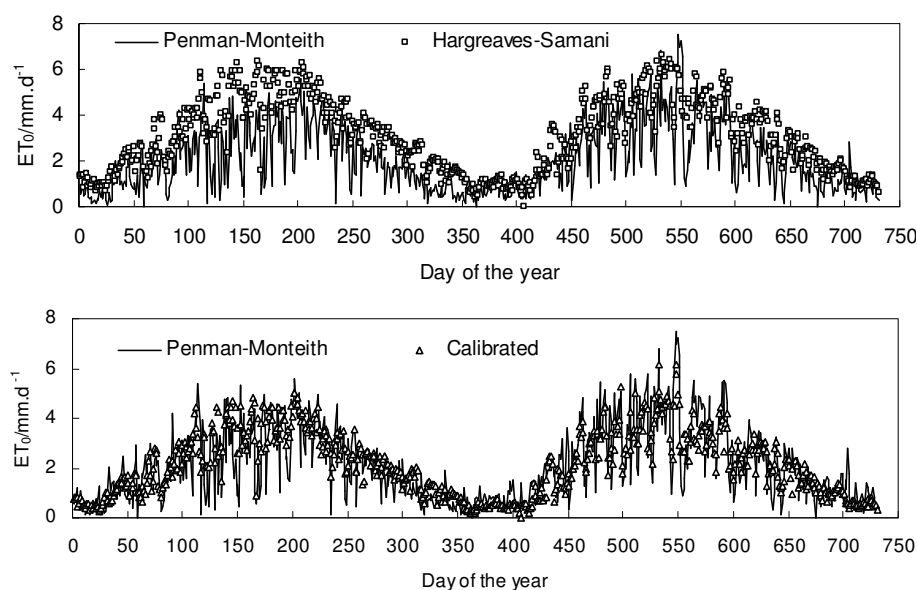
(Figure 4), by comparing with the  $ET_0$  by the FAO-56 PM equation. The slope and  $R^2$  of the linear regression between the  $ET_0$  by the locally calibrated  $HS$  equation and the FAO-56 PM equation are 1.096 and 0.618, respectively. However, the slope and  $R^2$  of the linear regression between the  $ET_0$  by the original  $HS$  equation and the FAO-56 PM equation are 1.300 and 0.570, respectively. The  $AE$  and  $RMSE$  between the  $ET_0$  by the locally calibrated  $HS$  equation and the FAO-56 PM equation are 0.61 and 0.77 mm d<sup>-1</sup>, lower than the  $AE$  (0.97 mm d<sup>-1</sup>) and  $RMSE$  (1.22 mm d<sup>-1</sup>) between the  $ET_0$  by the original  $HS$  equation and the FAO-56 PM equation. The locally calibrated  $HS$  equation performs considerably better than the original  $HS$  equation. The locally calibrated  $HS$  equation performs much better than the original  $HS$  equation for  $ET_0$  calculation in the humid regions of East China.

For validation data sets, 66 and 171 data groups underestimate the  $ET_0$  by the  $HS$  and the calibrated  $HS$  equations, respectively, compared with the  $ET_0$  by the FAO-56 PM equation. However, 662 and 557 data groups overestimate  $ET_0$ . The underestimated  $ET_0$  most likely occurred during windy days. The average wind speeds are 2.9 and 2.7 m s<sup>-1</sup> for the underestimated cases, but 1.8 and 1.7 m s<sup>-1</sup> for the overestimated cases. More than 80% of the underestimated cases have a

wind speed higher than 2.5 m s<sup>-1</sup>, and more than 80% have a wind speed lower than 2.0 m s<sup>-1</sup>. These findings are consistent with the conclusion that the  $HS$  equation underestimates the  $ET_0$  in very dry and windy regions (Samani, 2000; Droogers and Allen, 2002; Bakhtiari *et al.*, 2011). This can be ascribed to the advection phenomena related to the high aerodynamic term during windy days, which has been omitted in the  $HS$  equation.

#### Performance of Calibrated $HS$ Equation Based on Weather Forecast Data

The  $ET_0$ s were predicted using the original and calibrated  $HS$  equations (Equation 1) based on the weather forecast data (2004 to 2005). The results plotted in Figure 5 were compared with the  $ET_0$  calculated using the FAO-56 PM equation based on measured climatic data (2004 to 2005). The total predicted  $ET_0$ s by the original and calibrated  $HS$  equations during from 2004 to 2005 are 2262.1 and 1576.5 mm, 45.2 and 1.1% higher than the  $ET_0$  by the FAO-56 PM equation. The slope for linear regressions between the predicted  $ET_0$  by the calibrated  $HS$  equation and the  $ET_0$  by the FAO-56 PM equation ( $R^2=0.6497$ ) is 0.9247, and 1.267



**Figure 5.** Comparison between the  $ET_0$  predicated by using the Hargreaves-Samani equation based on weather forecast data and  $ET_0$  calculated by the FAO-56 Penman-Monteith equation based on measured climatic data( 2004-2005, N= 728).

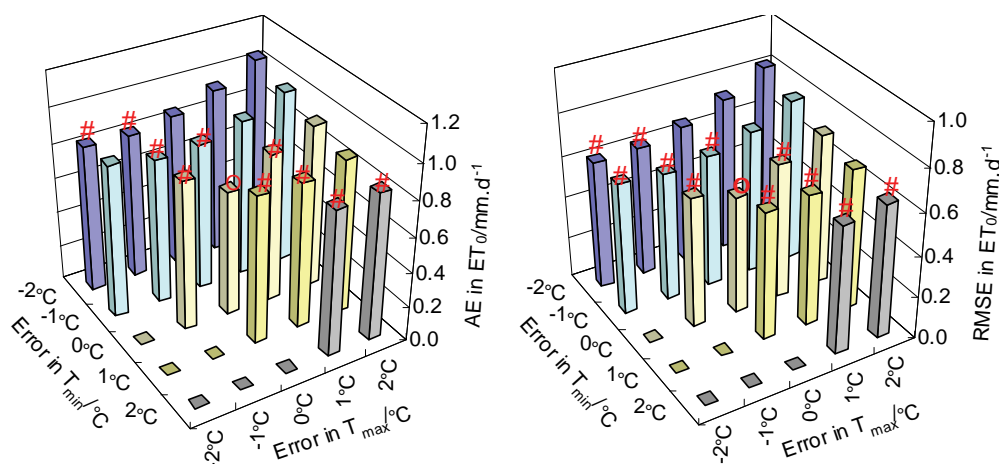
for linear regressions between the predicted  $ET_0$  by the original *HS* equations and the  $ET_0$  by the FAO-56 PM equation ( $R^2 = 0.4810$ ). The average *AE* are 1.09 and 0.61  $\text{mm d}^{-1}$ , and the *RMSE* are 1.33 and 0.79  $\text{mm d}^{-1}$ . The average values of the *RMSE* are larger than the results by the analytical method in humid and semi-humid regions in China (Cai *et al.*, 2007). This result is near to that by the neural network model (Xu *et al.*, 2006) in humid regions in China and by the *HS* method (Er-Raki *et al.*, 2010) in semi-arid regions in Morocco. Thus, the *HS* equation always overestimates the  $ET_0$  based on weather forecast data, compared with those calculated by the FAO-56 PM equation. Moreover, the calibrated *HS* equation performs considerably better than the original one in humid regions in China.

Both average *AE* and *RMSE* of the  $ET_0$  prediction by the calibrated *HS* equation are relatively high, with 0.61 and 0.79  $\text{mm d}^{-1}$  for the one using weather forecast data as input, and 0.61 and 0.77  $\text{mm d}^{-1}$  for the one using observed meteorological data. Thus, both the original and locally calibrated *HS* equations are not good solutions for  $ET_0$  calculation in humid regions in East China.

However, assuming the simplicity and minimum data requirements of the *HS* equation, as well as the fact that public daily weather forecast data are always composed of limited information for the maximum temperature, minimum temperature, wind scale, and climate conditions, the locally calibrated *HS* equation could be an alternative and effective solution for predicting daily  $ET_0$  using public weather forecast data as inputs. The proposed method may be useful for real-time irrigation forecasting. Nevertheless, further efforts should be made to improve the calibration of the *HS* equation and the accuracy of the weather forecast.

#### Sensitivity of $ET_0$ Prediction to Weather Forecast Error

Slopes, determination coefficients ( $R^2$ ), average *AE*, and *RMSE* were calculated by comparing the  $ET_0$  by the calibrated *HS* equation based on polluted data groups (see Table 2) and the results by the FAO-56 PM equation based on historical observed climatic data (Figure 6). The slopes range



**Figure 6.** Average absolute errors (AE) and root mean square errors (RMSE) between  $ET_0$  calculated by the calibrated Hargreaves-Samani equation based on polluted data groups and by the FAO-56 Penman-Monteith equation based on historical observed climatic data. (O on the column means the case with zero error in temperature prediction. # on the column indicates the AE less than  $0.85 \text{ mm d}^{-1}$  or RMSE less than  $0.65 \text{ mm d}^{-1}$ ).

**Table 3.** Slopes and determination coefficients of regressions between  $ET_0$  by the calibrated Hargreaves-Samani equation based on polluted data groups and that by the FAO-56 Penman-Monteith equation based on historical observed climatic data.

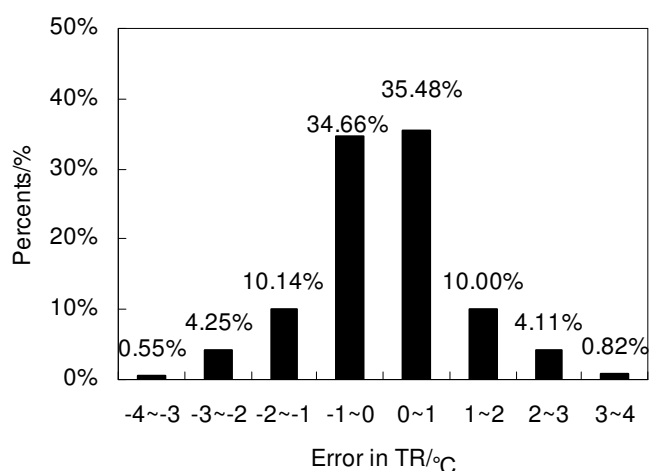
Slope ( $R^2$ )		Error in $T_{\max}$				
		-2°C	-1°C	0°C	1°C	2°C
Error in $T_{\min}$	-2°C	0.8496(0.6346)	0.9207(0.6196)	0.9912(0.6041)	1.0612(0.5887)	1.131(0.5735)
	-1°C	0.8043(0.6416)	0.8784(0.6272)	0.9514(0.6115)	1.0237(0.5953)	1.0954(0.5972)
	0°C	OM	0.8311(0.6347)	0.9247(0.6497)	0.9821(0.6031)	1.0562(0.5862)
	1°C	OM	OM	0.858(0.6276)	0.9361(0.6116)	1.0128(0.5944)
	2°C	OM	OM	OM	0.8848(0.6202)	0.9649(0.6035)

OM means omitted, because those combinations of error in  $T_{\max}$  and  $T_{\min}$  are likely to lead to contradiction. Shaded cell indicates that the polluted data group results in increased slope.

from 0.8043 ( $T_{\max} -2^\circ\text{C}$ ,  $T_{\min} -1^\circ\text{C}$ ) to 1.131 ( $T_{\max} +2^\circ\text{C}$ ,  $T_{\min} -2^\circ\text{C}$ ). The shaded cell in Table 3 indicates that the polluted data group results in the increased slope. The slope increases with the increase in the daily maximum temperature or the reduction in the daily minimum temperature. The error in  $T_{\max}$  and  $T_{\min}$  is converted into the change in temperature range  $TR$  and daily mean temperature  $T_{\text{mean}}$  (as listed in Table 2). Clearly, the slope increases with the increase in error in  $TR$  or  $T_{\text{mean}}$ , and the slope is likely to be more sensitive to error in  $TR$  than  $T_{\text{mean}}$ . The RMSE ranges from 0.827 ( $T_{\max} -1^\circ\text{C}$ ,  $T_{\min} -1^\circ\text{C}$ ) to 1.057  $\text{mm d}^{-1}$  ( $T_{\max} +2^\circ\text{C}$ ,  $T_{\min} -2^\circ\text{C}$ ), and average AE ranges from 0.612 ( $T_{\max} +1^\circ\text{C}$ ,  $T_{\min} +2^\circ\text{C}$ ) to 0.833  $\text{mm d}^{-1}$

( $T_{\max} +2^\circ\text{C}$ ,  $T_{\min} -2^\circ\text{C}$ ). RMSE and AE also increase with the increase in the errors of the  $TR$  or  $T_{\text{mean}}$ , and are more sensitive to errors in  $TR$  than those in  $T_{\text{mean}}$ . If the setting for AE that is less than  $0.65 \text{ mm d}^{-1}$  and RMSE that is less than  $0.85 \text{ mm d}^{-1}$  are permissible in the  $ET_0$  prediction based on weather forecast data, acceptable polluted data groups are likely to fall in a narrow range with errors in  $TR$  of no more than  $1^\circ\text{C}$  along the diagonal line ( $TR$  error equals  $0^\circ\text{C}$ ) in Table 2. If the setting for AE that is less than  $0.70 \text{ mm d}^{-1}$  and RMSE that is less than  $0.90 \text{ mm d}^{-1}$  are permissible, the acceptable polluted data groups are likely to fall in the range in which the error in  $TR$  is no higher than  $2^\circ\text{C}$ . In fact, approximately 70 and 90%





**Figure 7.** Prediction errors of daily temperature range (TR) in public weather forecast.

of the weather forecast fall in this range, with a  $TR$  error within  $-1$  to  $1^{\circ}\text{C}$  and  $-2$  to  $2^{\circ}\text{C}$ , respectively (see Figure 7).

## CONCLUSIONS

The  $HS$  equation was tested and calibrated with the daily  $ET_0$  calculated by the FAO-56 PM equation, and its capability to predict the daily  $ET_0$  by this equation based on weather forecast data was evaluated. The  $HS$  equation is likely to overestimate the daily  $ET_0$ , as indicated in other studies carried out in humid regions. Local calibration of the  $HS$  equation is quite essential for  $ET_0$  estimation in humid regions in China. The coefficients of  $a$  and  $c$  are calculated as 0.00138 and 0.5736, according to the local calibration. The average  $AE$  and  $RMSE$  of the  $ET_0$  by the calibrated  $HS$  equation based on either observed climatic data or public weather forecast data are much lower than those by the original  $HS$  equation. The locally calibrated  $HS$  equation performs much better than the original  $HS$  equation. Furthermore, it could be an alternative and effective solution for predicting daily  $ET_0$  using public weather forecast data as inputs, especially in real-time irrigation forecasting. The influence of weather forecast accuracy on daily  $ET_0$  predication using the locally calibrated  $HS$  equation was also discussed.

The error in the daily  $ET_0$  predication increases with the increase in the error of the daily  $TR$  or daily  $T_{\text{mean}}$ . This error is apparently more sensitive to the error in  $TR$  than that in the  $T_{\text{mean}}$ . Ensuring a  $TR$  error of less than  $2^{\circ}\text{C}$  is necessary for perfect estimation of  $ET_0$  based on public weather forecast data using the calibrated  $HS$  equation.

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پیش بینی تبخیر و تعرق مرجع روزانه منطقه‌ای مرطوب در چین با کالیبراسیون  
محلی معادله هارگریوز-سامانی با استفاده از داده‌های پیش‌بینی آب و هوا

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### چکیده

معادله هارگریوز-سامانی (HS)، که تبخیر و تعرق مرجع ( $ET_0$ ) را فقط با استفاده از درجه حرارت به عنوان ورودی برآورد می‌کند، باید مناسب‌ترین راه برای برآورد  $ET_0$  بر اساس اطلاعات پیش‌بینی وضع هوا باشد. در مطالعه حاضر، معادله HS با  $ET_0$  روزانه به‌دست آمده از معادله پنمن-مونتیث کالیبره شده و ارزیابی شده است تا امکان پیش‌بینی  $ET_0$  روزانه بر اساس اطلاعات پیش‌بینی وضع هوا بررسی گردد. معادله HS به احتمال زیاد  $ET_0$  روزانه در مناطق مرطوب چین را زیاد برآورد می‌کند. با



توجه به کالیبراسیون محلی، ضرایب  $a$  و  $c$  به میزان  $0/00138$  و  $0/5736$  محاسبه شدند. معادله HS کالیبره شده به طور قابل توجهی بهتر از معادله اصلی عمل نمود. معادله پیشنهادی می تواند یک راه حل جایگزین و موثر برای پیش بینی  $ET_0$  روزانه با استفاده از داده های پیش بینی آب و هوای عمومی به عنوان ورودی باشد. خطای پیش بینی  $ET_0$  روزانه با افزایش خطای دامنه دمایی روزانه (TR) و یا درجه حرارت متوسط روزانه ( $T_{mean}$ ) افزایش می یابد. این خطا به احتمال زیاد نسبت به خطا در TR از خطا در  $T_{mean}$  حساس تر است. برای برآورد صحیح  $ET_0$  بر اساس داده های عمومی پیش بینی هوا با استفاده از معادله HS کالیبره شده، اطمینان از خطای کمتر از ۲ درجه سانتی گراد TR لازم است.

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