

1 *Type of the Paper (Article)*

## 2 **Simulation of Evapotranspiration at a 3-minute Time** 3 **Interval Based on Remote Sensing Data and SEBAL** 4 **Model**

5 **Guoqing Li<sup>1\*</sup>, Alona Armstrong<sup>2</sup> and Xueli Chang<sup>2</sup>**

6 <sup>1</sup> School of Resources and Environmental Engineering, Ludong University, Yantai, Shandong Province,  
7 China 264025; ligqing@foxmail.com

8 <sup>2</sup> Lancaster Environment Centre, Lancaster University, Lancaster, UK, LA1 4YQ; Alona\_Armstrong@163.com

9 \* Correspondence: ligqing@foxmail.com;

10 Received: 06-24-2020; Accepted: ; Published:

11 **Featured Application:** Our research not only provides a method for estimating  
12 evapotranspiration, but also provides the possibility for additional remote sensing models to  
13 appear on a “minute” or even “second” time scale .

14 **Abstract:** Using remote sensing to estimate evapotranspiration minute frequency is the basis for  
15 accurately calculating hourly and daily evapotranspiration from the regional scale. However, from  
16 the existing research, it is difficult to use remote sensing data to estimate evapotranspiration  
17 minute frequency. This paper uses GF-4 and moderate-resolution imaging spectroradiometer  
18 (MODIS) data in conjunction with the Surface Energy Balance Algorithm for Land (SEBAL) model  
19 to estimate ET at a 3-minute time interval in part of China and South Korea, and compares those  
20 simulation results with that from field measured data. According to the spatial distribution of ET  
21 derived from GF-4 and MODIS, the texture of ET derived from GF-4 is more obvious than that of  
22 MODIS, and GF-4 is able to express the variability of the spatial distribution of ET. Meanwhile,  
23 according to the value of ET derived from both GF-4 and MODIS, results from these two satellites  
24 have significant linear correlation, and ET derived from GF-4 is higher than that from MODIS.  
25 Since the temporal resolution of GF-4 is 3 minutes, the land surface ET at a 3-minute time interval  
26 could be obtained by utilizing all available meteorological and remote sensing data, which avoids  
27 error associated with extrapolating instantaneously from a single image.

28

29 **Keywords:** GF-4; evapotranspiration; SEBAL model; MODIS; minute frequency

30

---

### 31 **1. Introduction**

32 Evapotranspiration (ET) is an important climatic factor besides solar radiation and atmospheric  
33 circulation, which controls the energy and mass exchange between the earth's ecosystem and the  
34 atmosphere, thus affecting the water balance of the ecosystem [1-3]. The accurate estimation of ET  
35 minute frequency at a regional scale is crucial to better understand detailed surface hydrological  
36 processes and provide more efficient catchment water management [4,5]. Traditionally ET is

37 estimated for points or patches on the land surface but spatial heterogeneity in land surface  
38 characteristics precludes robust upscaling to the regional scale[6-8]. However, surface energy  
39 balance models using remote sensing data (specifically terrain, soil humidity, air and land surface  
40 temperature) enables accurate ET estimates at the regional scale [6,9-11]. For example, in the Haihe  
41 River Basin of China, ground verification studies suggested the root mean square error associated  
42 with estimates of ET was approximately 0.32mm/3h [12]. Further, land-atmosphere interactions in  
43 California Delta of USA, showed that the root mean square error was within 0.98mm/day when  
44 calculating the one-day ET value [13].

45 Accurate estimation of evapotranspiration in irrigation areas is the basis for optimal  
46 management of water resources and water-saving irrigation. Remote sensing evapotranspiration  
47 model is of great significance for improving irrigation water use efficiency and simulating crop yield  
48 [14,15]. At present, remote sensing evapotranspiration model is mainly combined with  
49 meteorological data to evaluate irrigation water demand, irrigation efficiency and crop water  
50 monitoring in water resources management in irrigation areas [16-18]. In the above research, the  
51 input data with high temporal resolution played a very important role in the fine description of the  
52 above process. At present, the precipitation and temperature at minute frequency can already be  
53 obtained through the measured data of meteorological stations, and then the spatial distribution of  
54 temperature and precipitation in the irrigation area can be obtained through spatial interpolation,  
55 but the evapotranspiration is "cumulative data", which is different from "instantaneous data" such as  
56 temperature and precipitation, and the change at minute frequency is difficult to measure[19-22]. At  
57 present, most of the data measured by meteorological stations are the evaporation measured by the  
58 evaporation pan, not the evapotranspiration. Although lysimeter, scintillometer, flux tower and  
59 other methods can be used to measure the evapotranspiration with time interval of minutes, the cost  
60 of measuring instruments is huge and it is difficult to realize widespread arrangement like  
61 meteorological stations [21,23]. Therefore, using remote sensing data to simulate evapotranspiration  
62 at minute frequency has very significant potential applications.

63 However, limited by the current temporal resolution of satellites, the minimum time interval  
64 for simulating evapotranspiration using remote sensing data is hourly. Moreover, estimating ET  
65 with 1 hour interval is at the expense of expanding the spatial resolution of ET, for example (Liu et al,  
66 2015) using FY meteorological satellite images simulated the evapotranspiration of Tibetan Plateau  
67 at 1 hour interval, but the spatial resolution of ET was 1000 m, and the result could not accurately  
68 reflect the spatial diversity of ET[24]. Ideally, to obtain accurate ET at a regional scale, satellite data  
69 with both high temporal (i.e. hourly) and spatial (i.e. <100 m) resolution would be used. However,  
70 current satellite imagery either has a high temporal resolution and low spatial resolution (e.g. The  
71 time resolution of moderate-resolution imaging spectroradiometer is less than half a day, but its  
72 spatial resolution is 250 m to 1000 m.) or has a low temporal resolution and high spatial resolution  
73 (e.g. The spatial resolution of Landsat-8 is 15 m to 100 m, but its time resolution is 16 days).  
74 Consequently, it's almost impossible to use remote sensing data to obtain ET within 100m spatial  
75 resolution with a temporal resolution of less than 1 hour.

76 The high temporal and spatial resolution, and large width of the GF-4 data, offers significant  
77 potential to advance understanding of ET on a regional scale, in addition to more accurate  
78 understanding of land surface energy balances and exchanges. However, due to the lack of thermal  
79 infrared band of GF-4, we cannot obtain the land surface temperature at the coincidence time with  
80 the visible bands of GF-4. In addition, we find that because there was no remote sensing data with  
81 time resolution of minutes, the existing evapotranspiration models do not consider using these  
82 remote sensing data, and the existing evapotranspiration models are not suitable for simulating ET  
83 with time interval of minutes. Researchers have been unable to take advantage of GF-4 application  
84 in simulating ET, and most of the papers were focused on weather monitoring and land target  
85 recognition[25,26]. Consequently, the aim of this research was to simulate ET based on GF-4, MODIS  
86 data and SEBAL (Surface Energy Balance Algorithm for Land) model, and compared the ET

87 estimates derived from both MODIS and GF-4 imagery. The objectives are: (1) to characterize the  
 88 variation at 3-minute interval in ET estimated based on GF-4, MODIS and meteorological data across  
 89 different land covers. (2) To compare ET estimates derived from MODIS and GF-4 captured at  
 90 approximately the same time. (3) To verify MODIS and GF-4 simulated ET using field measured  
 91 data.

92 **2. Materials and Methods**

93 *2.1 Materials*

94 *2.1.1 Remote sensing data*

95 The GF-4 satellite (launched on 29 December 2015) has a geosynchronous orbit fixed at 105.6°E,  
 96 altitude of 36,000 km and swath width of 400 km [27] . GF-4 can acquire remote sensing images in  
 97 the extent of 2° s -68° N and 20° E-180° E. The GF-4 satellite is an important addition to the civil series  
 98 of Chinese high-resolution earth observing satellites, as it provides both high spatial resolution (<100  
 99 m) and temporal (20 seconds) resolution visible, and near and medium wave infrared imagery with  
 100 a pixel resolution of down to 50m (table 1).

101 **Table 1.** Primary characteristics of each payload of GF-4

	<b>Band</b>	<b>Spectral range (<math>\mu\text{m}</math>)</b>	<b>Spatial resolution(m)</b>
Visible and near infrared(VNIR)	1	0.45~0.90(pan)	50
	2	0.45~0.52(blue)	
	3	0.52~0.60(green)	
	4	0.63~0.69(red)	
	5	0.76~0.90(near-infrared )	
Medium-wave infrared (MWIR)	6	3.5~4.1	400

102 GF-4 images were obtained from (<http://data.cma.cn/>). Land surface temperature (LST)  
 103 products and surface reflectance products of MODIS were obtained from  
 104 (<https://ladsweb.modaps.eosdis.nasa.gov/>). Digital elevation model (DEM) was obtained from  
 105 (<https://search.earthdata.nasa.gov/>). Considering that weather should be sunny or cloudless at the  
 106 imaging time, the imaging time should be close enough, and the imaging area of two images should  
 107 be overlapped as much as possible. The imaging time of MODIS and GF-4 were shown in table 2.  
 108 LST and DEM data were resized or resampled, using the nearest neighbor method, to either 50 or  
 109 250 m to match the spatial resolution of the GF-4 and MODIS imagery, respectively.

110 **Table 2.** Imaging time of MODIS and GF-4<sup>1</sup>

<b>Region</b>	<b>CB,CG,CF</b>	<b>KB,KE,KD</b>
<b>Imaging time of MODIS</b> (Local solar time)	2016-12-02	2017-04-29
	11:35 (MT <sub>0</sub> )	12:10(MT <sub>0</sub> <sup>'</sup> )
	13:10(MT <sub>1</sub> )	13:45 (MT <sub>1</sub> <sup>'</sup> )
<b>Imaging time of GF-4</b> (Local solar time)	2016-12-02	2017-04-29
	11:14 (T <sub>1</sub> )/11:17 (T <sub>2</sub> )/11:20 (T <sub>3</sub> )	11:14 (T <sub>1</sub> <sup>'</sup> )/11:16(T <sub>2</sub> <sup>'</sup> )/11:19(T <sub>3</sub> <sup>'</sup> )
	/11:23 (T <sub>4</sub> )/11:26 (T <sub>5</sub> )/11:29 (T <sub>6</sub> )	/11:22(T <sub>4</sub> <sup>'</sup> )/13:50(T <sub>5</sub> <sup>'</sup> )/13:55(T <sub>6</sub> <sup>'</sup> )
	/11:32(T <sub>7</sub> )/11:36(T <sub>8</sub> )/11:39(T <sub>9</sub> )	/13:58(T <sub>7</sub> <sup>'</sup> )
	/11:42(T <sub>10</sub> )/11:45(T <sub>11</sub> )/11:48(T <sub>12</sub> )	

/11:51(T<sub>13</sub>)/11:54(T<sub>14</sub>)/11:57(T<sub>15</sub>)

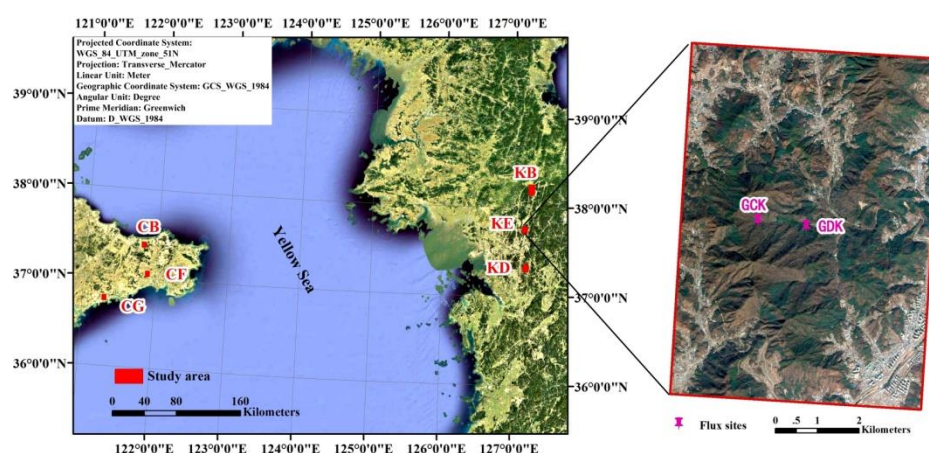
111 <sup>1</sup> Although the temporal resolution of GF-4 is 20 seconds, these data are only provided to specific institutions.  
 112 The GF-4 data for the 3-minute time interval used in this paper is open to all researchers, but the number of  
 113 images and imaging time in each region will not be the same. Therefore, the number of GF-4 images in Table 2 is  
 114 different between China and South Korea.

### 115 2.1.2 Meteorological and Flux data

116 The time of sunrise, sunset was obtained from (<http://www.sunrisesunset.com/>). Daily  
 117 maximum LST, maximum wind speed, mean wind speed, minimum air temperature, and maximum  
 118 air temperature at 6 km resolution were obtained from the China Meteorological Administration  
 119 (<http://new-cdc.cma.gov.cn>). Meteorological data were resized, using the nearest neighbor method,  
 120 to either 50 or 250 m to match the spatial resolution of the GF-4 and MODIS imagery, respectively.  
 121 The flux data of GDK and GCK sites were provided by Korea Flux Monitoring Network (KoFlux),  
 122 they were used to verify simulated ET, with a 30 minutes measuring interval. The position of GDK  
 123 is 37° 44' 56" N, 127° 08' 57" E, and the position of GCK is 37° 44'54" N, 127°09'44" E (Figure 1). More  
 124 details about GDK and GCK sites can be obtained from Asia Flux website (<http://asiaflux.net/>).

### 125 2.1.3 Location and study area

126 The study area is located in China and South Korea (Figure 1). The study area ranges from an  
 127 altitude of 100-1100 m, comprising a hilly area and regions of flat terrain. Climatologically, it belongs  
 128 to the north temperate continental monsoon climate, and experiences distinct seasonal variation as  
 129 well as impacts from the monsoon advancing and retreating. To minimize the influences of  
 130 undulating terrain and hill shade, six study areas were selected: (CB) mainly cultivated land and  
 131 built-up areas, (CG) mainly of garden and urban construction land, (CF) mainly cultivated land and  
 132 forest land, (KB) mainly cultivated land and village construction land, (KE) mainly forest land and  
 133 river wetland (GDK and GCK Flux sites were in KE region), and (KD) mainly cultivated land and  
 134 forest land (Figure 1).



135

136

Figure1. Location of the study area

## 137 2.2 Methods

### 138 2.2.1 SEBAL Model

139 The SEBAL model is a physically based land surface energy balance model that uses remotely  
 140 sensed input and has been widely used to calculate ET [28-32]. Input data to the SEBAL model  
 141 include: ground elevation, visible light and near infrared bands from remote sensing images (used to  
 142 calculate the Normalized Difference Vegetation Index, NDVI value), the thermal infrared band  
 143 (used to calculate the land surface temperature, LST), and temperature and wind speed at the  
 144 imaging time. The two papers were referred for the sensible heat calculation, hot and cold pixel  
 145 selection, net radiation and soil head flux calculation[33,34]. Then we calculated the ET of MODIS  
 146 and GF-4 at imaging time in Table 2 using SEBAL model.

147 2.2.2 Calculation of NDVI

148 The MODIS NDVI was calculated by[35]:

$$NDVI = \frac{\rho_{nir} - \rho_{red}}{\rho_{nir} + \rho_{red}}, \quad (1)$$

149 in Equation (1), the NDVI denotes the normalized vegetation index, and  $\rho_{nir}$  and  $\rho_{red}$  denote  
 150 surface reflectance in the near infrared band and the red band, respectively.

151 The GF-4 NDVI was calculated as for the MODIS NDVI, shown in Equation (1), but the  
 152 apparent reflectance of the near infrared (the red band) was derived by[36]:

$$\rho_{\lambda} = \frac{\pi L_{\lambda} d^2}{\cos \theta_s ESUN_{\lambda}}, \quad (2)$$

153 in Equation (2), where  $\rho_{\lambda}$  is the at-satellite reflectance,  $ESUN_{\lambda}$  is the mean solar exoatmospheric  
 154 irradiance in  $W \cdot (m^2 \cdot ster \cdot \mu m)^{-1}$ ,  $\theta_s$  is the solar zenith angle in degrees, and  $d$  is the earth-sun distance  
 155 in astronomical units.  $L_{\lambda}$  is the at-satellite spectral radiance in  $W \cdot (m^2 \cdot ster \cdot \mu m)^{-1}$ .  $\theta_s$  can be obtained  
 156 from the head file. The  $ESUN$  value for each GF-4 band has not been published yet, but can be  
 157 calculated using the spectral response function of the solar spectrum curve and the sensor, as shown  
 158 in Equation (3) [37].

$$ESUN = \frac{\int_{\lambda_1}^{\lambda_2} E(\lambda) S(\lambda) d\lambda}{\int_{\lambda_1}^{\lambda_2} S(\lambda) d\lambda}, \quad (3)$$

159 In Equation (3),  $ESUN$  denotes the band average solar radiation outside of the atmosphere;  $\lambda_1$   
 160 and  $\lambda_2$  denote the upper and the lower integration limit of wavelength of band range;  $E(\lambda)$  denotes  
 161 the solar spectrum radiation of the remote sensor out of the atmosphere at band  $\lambda$ , where different  
 162 solar spectrum curves have different  $E(\lambda)$  values. Current studies show that the World Radiation  
 163 Center (WRC) solar spectrum curve is the most favorable for the calculation of the  $ESUN$  using this  
 164 sensor at a medium resolution in China [38]. According to the WRC solar spectrum curve, the  $E(\lambda)$   
 165 value could be in the range of  $\lambda_1$  and  $\lambda_2$ ; and  $S(\lambda)$  denotes the spectral response function of the  
 166 remote sensor at band  $\lambda$ . The  $ESUN$  values for all GF-4 bands calculated using Equation (3) are  
 167 shown in table 3.

168 **Table 3.** Calculated  $ESUN$  values for all GF-4 bands

Bands	B1	B2	B3	B4	B5
ESUN	1609.81	1634.44	1839.33	1578.12	1104.77
$W \cdot (m^2 \cdot ster \cdot \mu m)^{-1}$					

169

170 The equation converting the DN value of satellite images to radiance images using the absolute  
 171 calibration coefficient is[39]:

$$L_{\lambda} = A \times DN, \tag{4}$$

172 where GF-4 provides gain values (A) under 5 statuses, for example, status 2-6-4-6-6 denotes an  
 173 integration time for full color, blue, green, red, and near infrared of 2, 6, 4, 6, and 6 ms, respectively,  
 174 the other statuses please see table 4. Users need to determine the status of image bands according to  
 175 the appropriate XML file parameters of GF-4 images, and then select the corresponding calibration  
 176 coefficient.

177 **Table 4.** Gain values of all GF-4 bands under different statuses

Status	Gain Values (A)				
	B <sub>1</sub>	B <sub>2</sub>	B <sub>3</sub>	B <sub>4</sub>	B <sub>5</sub>
2-6-4-6-6	0.5215	0.9400	0.9885	0.7847	0.5641
4-16-12-16-16	0.3100	0.3484	0.3484	0.3095	0.2257
6-20-16-20-20	0.1681	0.3263	0.2472	0.2806	0.1997
6-40-30-40-40	0.1681	0.1252	0.1226	0.1102	0.0796
6-30-20-30-30	0.1235	0.1784	0.1878	0.1515	0.1080

178

179 2.2.3 Calculation of Land Surface Temperature

180 Unlike MODIS, GF-4 has no thermal infrared band to directly obtain LST at imaging time. Thus,  
 181 in order to attain the LST of GF-4 at imaging time, it is necessary to utilize two daily LST images to  
 182 simulate LST at any time using following equations [40-42]. In this paper, two daily LST images after  
 183 sunrise were as input from MODIS (table 1).

184 Daytime LST variation after sunrise was derived by:

$$T(t) = T_{B,set} + (T_{B,max} - T_{B,set}) \times \sin(W_2 t + \varphi_2), \tag{5}$$

185 in which: T(t) denotes the LST at the time t; T<sub>B,set</sub> denotes the LST at sunset; T<sub>B,max</sub> denotes the  
 186 daily maximum LST; W<sub>2</sub> = π / (DL - 2p) denotes the angular frequency of the sinusoid in the second  
 187 stage; DL denotes the daytime length; p = TIME<sub>x</sub> - NOON, TIME<sub>x</sub> denotes the time when the  
 188 maximum LST appears, TIME<sub>x</sub> can be attained from meteorological stations, NOON denotes the  
 189 time when the largest solar altitude appears, which is usually selected as 12.0; and  
 190 φ<sub>2</sub> = π / 2 - W<sub>2</sub> × TIME<sub>x</sub> denotes the phase angle.

$$T_{B,set} = \frac{4p \times T_{B,max} + (DL - 2p) \times T_{B,min}}{DL + 2p}, \tag{6}$$

191 This paper used the MODIS LST at the overpass time as inputs to calculate TB,max, TB,min, and  
 192 TB,set, and then calculated the LST at GF-4 imaging time using Equations (5) and (6).

193 2.2.4 Calculation of Daytime Air Temperature

194 Since GF-4 do not take images at night, the general formula to calculate daytime air temperature  
 195 is [42]:

$$T_a = T_{min} + (T_{max} - T_{min}) \times S(t), \tag{7}$$

196 in which, T<sub>a</sub> denotes daytime air temperature, and T<sub>min</sub> and T<sub>max</sub> denote daily minimum and  
 197 daily maximum air temperature. In Equation (11), S(t) is a function of time (t) with data range of  
 198 0-1, represented as:

$$S(t)=\sin\left(\pi\times\frac{t-\text{NOON}}{\frac{\text{DL}}{2}+2P}\right), \quad (8)$$

199 in which,  $t$  denotes any time, NOON denotes the time when the largest solar altitude appears,  
 200 DL denotes the daytime length, and  $P$  denotes the time difference between the highest air  
 201 temperature and the largest solar altitude. The time difference results from the intrinsic difference  
 202 in heat storage of soil and air. When air temperature rises,  $T_{\min}$  denotes the lowest air temperature  
 203 at present day in Equation (11); when air temperature decreases,  $T_{\min}$  denotes the lowest air  
 204 temperature on the next day.

### 205 2.2.5 Calculation of Wind Speed

206 Daily variation in wind speed has the following features: the wind speed is low from nighttime  
 207 to a time ( $t_1$ ) in the morning, at which point the wind speed gradually increases to the maximum  
 208 value until a time ( $t_2$ ) in the afternoon, then gradually decreases to the minimum value until a time  
 209 ( $t_3$ ) at night. The  $t_1$ ,  $t_2$ , and  $t_3$  vary with location: in the study area,  $t_1=1.0$ ,  $t_2=14.0$ , and  $t_3=0.0$ , and the  
 210 variation of wind speed with time is expressed by the following equation [42]:

$$W_a=W_{\min}+W_{\max}\times\sin\left(2\pi\times\frac{t_a-t_{w1,2}}{\text{SF}_{1,2}}\right), \quad (9)$$

211 in which:  $W_a$  denotes wind speed at any time (m/s),  $W_{\max}$  and  $W_{\min}$  denote daily maximum and  
 212 daily minimum wind speed (m/s), respectively,  $t_a$  denotes any time,  $t_{w1}=t_1$ ,  $t_{w2}=2(t_2-t_3)$ ,  $\text{SF}_1=4(t_2-t_1)$ ,  
 213 and  $\text{SF}_2=4(t_3-t_2)$ .

214 The daily minimum wind speed can be calculated by using the daily air movement distance  
 215 and the daily maximum wind speed as input data:

$$W_{\min}=\frac{1000\times[\text{TOT}_w-W_{\max}\times(\text{SF}_1+\text{SF}_2)\times3600/2000/3.1415926]}{24.0\times3600.0}, \quad (10)$$

216 in Equation (10):  $\text{TOT}_w$  denotes daily air movement distance (km/d), which can be calculated  
 217 from the daily average wind speed (m/s) available from meteorological stations and the length of a  
 218 day (24 h $\times$ 3600 s/h).

### 219 2.2.6 Verification and evaluation of simulation results

220 We estimated ET from SEBAL model using MODIS and GF-4 at imaging time in table 2 per  
 221 minute by using the methods in section 2.2. The following methods were used for verifying ET: (1)  
 222 Cross-validation ET obtained from different remote sensing data; (2) Verify with ET data measured  
 223 in field. In this paper, we first cross-verified ET of GF-4at 11:36( $T_8$ ) using ET of MODIS at 11:35 ( $MT_0$ ).  
 224 Then ET at 13:50( $T_5$ ) of GF-4 and 13:45( $MT_1$ ) of MODIS were cross-verified. Finally, we used the field  
 225 measured ET data to verify them from the Flux sites in South Korea, which was close to the imaging  
 226 time of remote sensing images. Since the measuring time interval at KoFlux sites was 30 minutes, we  
 227 chose the measured ET at 11:30 and 14:00 to verify the simulated ET at 11:22( $T_4$ ) and 13:58( $T_7$ ) of  
 228 GF-4 respectively. Then the field measure ET at 12:00( $MT_0$ ) was used to verify the simulated ET of  
 229 MODIS at 12:10( $MT_0$ ).

230 In order to evaluate the difference between measured ET and remote sensing data, we use root  
 231 mean square error (RMSE) and mean relative error (MRE) to analyze the error.

$$\text{RMSE}=\sqrt{\frac{\sum(y_i-y'_i)^2}{N}}, \quad (11)$$

$$\text{MRE}=\sqrt{\frac{\sum[(y_i-y'_i)/y'_i]^2}{N}}, \quad (12)$$

232 In equations (11) and (12),  $Y_i$  is the measured value,  $Y_i'$  is the simulated value obtained from  
233 the model, and  $n$  is the number of sample points [43,44]. The smaller the values of RMSE and MRE,  
234 the higher the simulation accuracy of the model [43,44].

### 235 3. Results

236 When NDVI of GF-4 is taken as the input of SEBAL model, the spatial resolution of ET is 50 m,  
237 while when NDVI of MODIS is taken as the input of SEBAL model, the spatial resolution of ET is 250  
238 m. Figure 2, figure 3 and figure 4 were the comparison of ET at 11:36( $T_8$ ) of GF-4 and ET at 11:35 ( $MT_0$ )  
239 of MODIS in CB, CF and CG regions respectively.

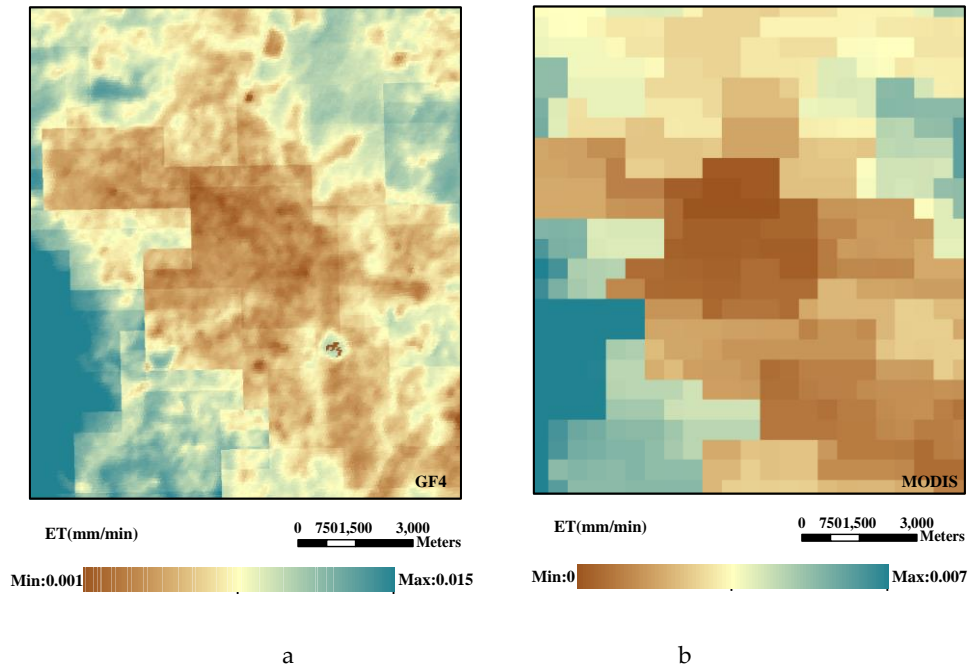
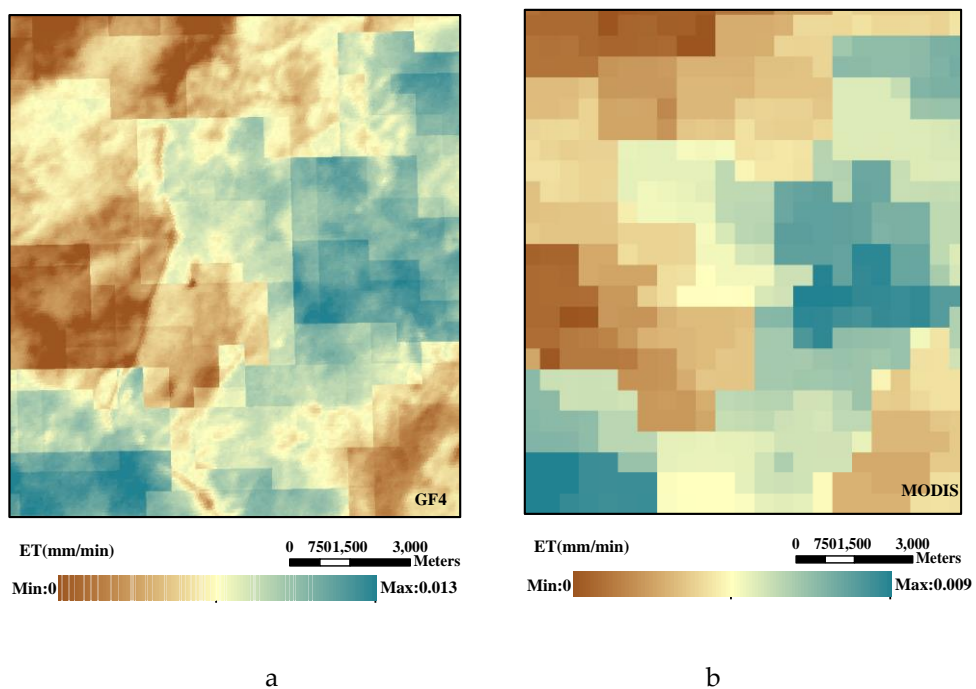


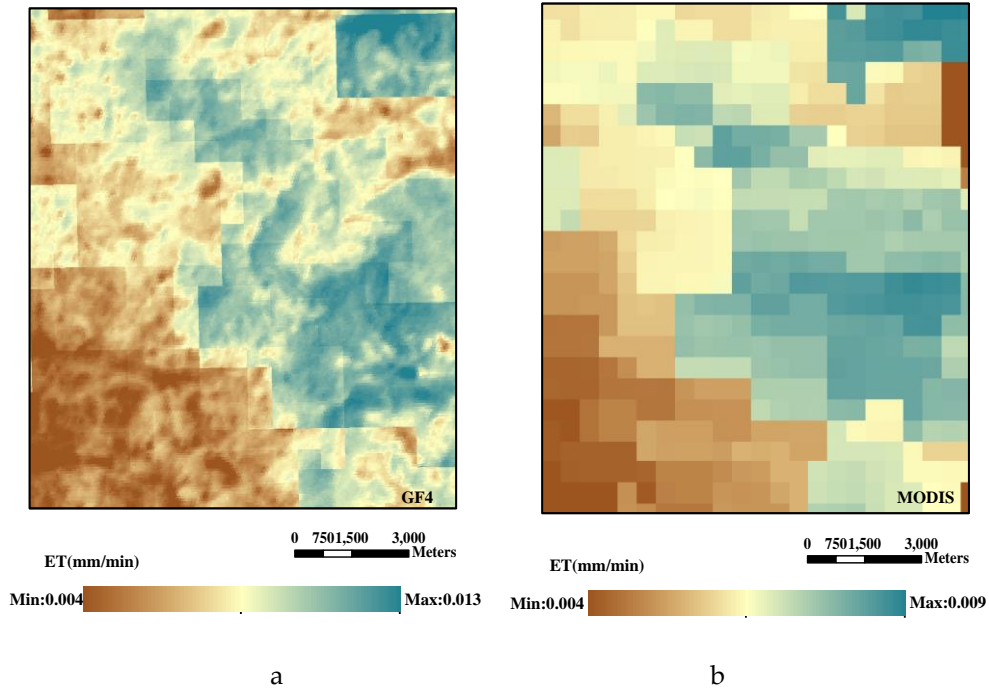
Figure 2. ET of GF-4 at 11:36(a) and ET of MODIS at 11:35 (b) in area CB





245

**Figure 3.** ET of GF-4 at 11:36(a) and ET of MODIS at 11:35 (b) in area CF



246

247

248

**Figure 4.** ET of GF-4 at 11:36 (a) and ET of MODIS at 11:35(b)in area CG

249

250

251

252

253

254

255

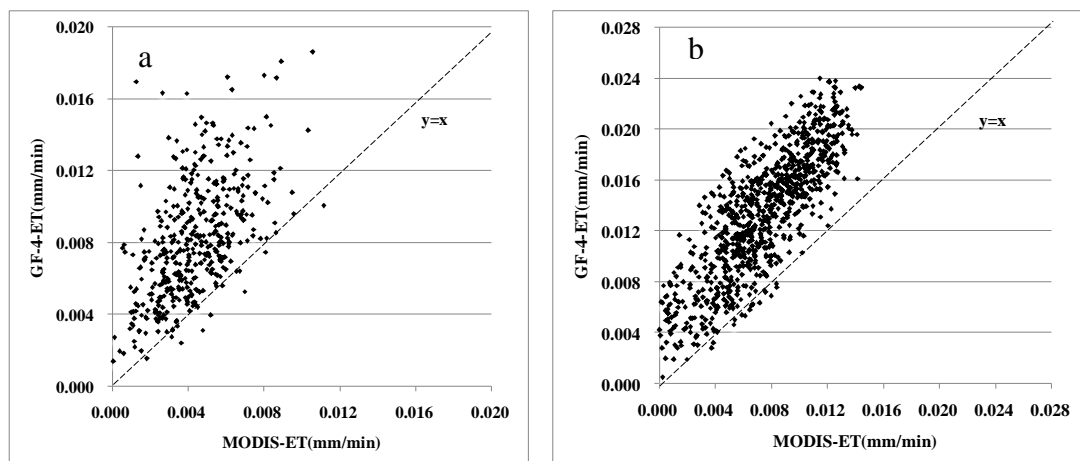
256

As seen in Figure 2, Figure 3 and Figure 4, since the spatial resolution of NDVI of GF-4 is higher than that of MODIS, the derived texture of ET is more obvious than that from MODIS. In order to cross-verify ET obtained from MODIS and GF-4, the bilinear method was used and GF-4 ET data was resampled to 250 m, which was identical to the spatial resolution of MODIS. As shown in Figure 5, 420 total sampling points were randomly selected in areas CB, CG and CF (Figure 5a.) and 870 total sampling points were randomly selected in areas KB, KE and KD (Figure 5b.) to find variability between the two ETs. Meanwhile we verified the simulated ET with the measured ET data of KoFlux as shown in figure 6.

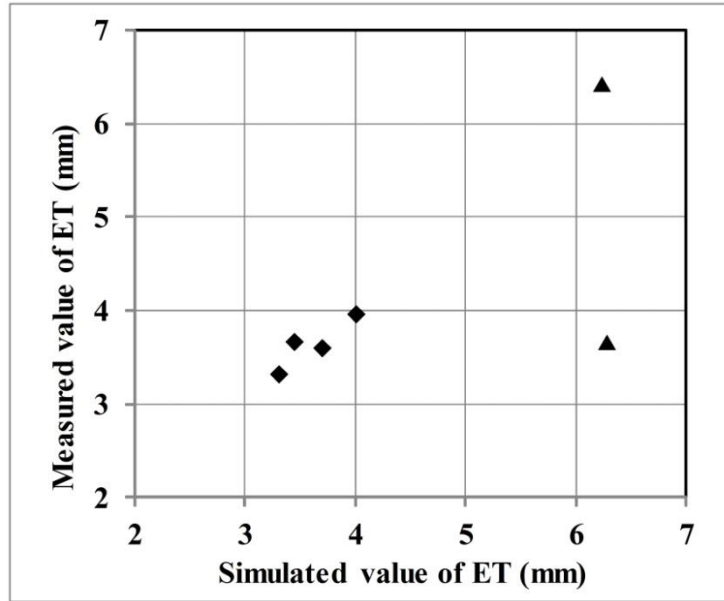
257

258

259



**Figure 5.** Cross-validation of Simulated ET of GF-4 and MODIS; (a) ET at 11:35 of MODIS and 11:36 of GF-4 in areas CB, CG and CF; (b) ET at 13:45 of MODIS and 13:50 of GF-4 in areas KB, KE and KD)



260

261

Figure 6. Comparison of Simulated and Measured ET at KoFlux Sites

262

(Black squares are ET values simulated by GF4, while black triangles are ET values simulated by MODIS).

263

264

265

266

267

268

269

As can be seen from figure 5, most ET simulation values of MODIS are less than that of GF-4's, but there is a strong correlation between the ET derived from GF-4 and MODIS,  $R = 0.581$  ( $p < 0.001$ ) in areas CB, CG and CF, and  $R = 0.810$  ( $p < 0.001$ ) in areas KB, KE and KD. While the difference in imaging time of MODIS and that of GF-4 is 1 to 5 minutes, it is certain that the ETs derived from both satellites have a significant linear correlation at the same imaging time. In addition, as can be seen from figure 6, the difference between the simulated and measured values of ET was not obvious.

270

271

272

273

The following two methods were used to verify the simulated ET. Firstly, we used the field measured data of KoFlux to verify the simulated ET of MODIS and GF-4. Then we took the ET calculated by MODIS as the measured value, and the ET calculated by GF-4 as the simulated value. The verification results were shown in table 5.

274

Table 5. Using Flux Data and MODIS to Verify the Accuracy of Simulated ET

Region	Data of verification	MRE(%)	RMSE(mm/min)
KE	KoFlux data	16.95	0.00072
CB,CG and CF	MODIS	48.64	0.00451
KB,KE and KD	MODIS	48.33	0.00655

275

276

277

278

279

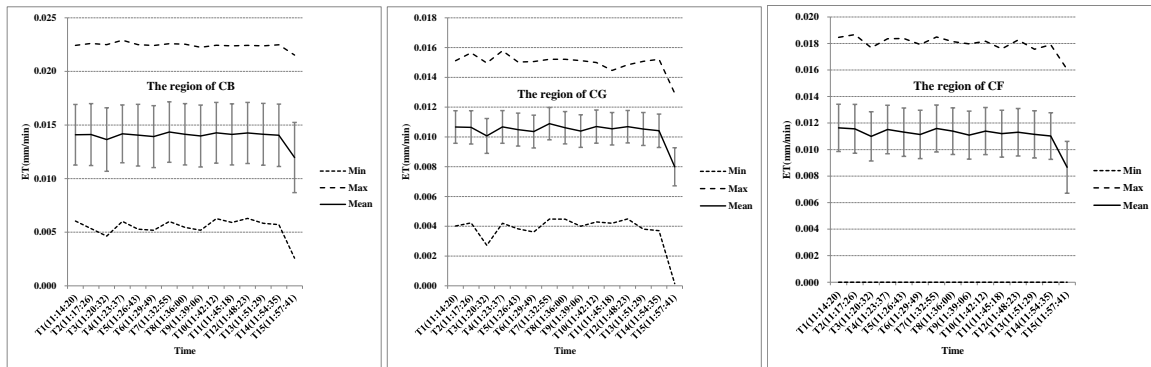
As can be seen from figure 6 and table 5,  $RMSE = 1.04$  (mm/day) and the MRE was 16.95% when validating simulated ET values using KoFlux data, which showed that it was feasible to simulate ET using the methods in this paper, while most GF-4 simulated ET values were higher than those of MODIS's, the MRE of ET when validating GF-4 using MODIS was less than 50%.

280

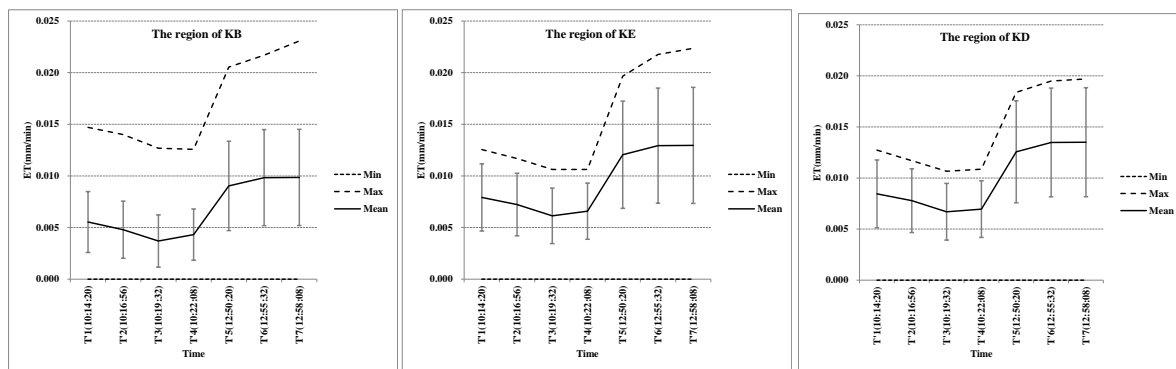
281

In order to further analyze the variation of ET in all study areas at time  $T_1 - T_{15}$  in areas CB, CG and CF,  $T'_1 - T'_7$  in areas KB, KE and KD, the minimum, maximum, and average values, and the

282 standard error of ET at above time was calculated by ArcMAP 10.3 for all pixels, as shown in Figure  
 283 7 and Figure 8.



284  
 285 **Figure 7.** ET of GF-4 at time T<sub>1</sub>-T<sub>15</sub> in areas CB, CG, and CF (the minimum value, the maximum value, the  
 286 average value, and the standard error)



287  
 288 **Figure 8.** ET of GF-4 at time T<sub>1</sub>' - T<sub>7</sub>' in areas KB, KE, and KD (the minimum value, the maximum value, the  
 289 average value, and the standard error)

290 As shown in Figure7, the trends of the average, minimum, maximum and average ET in  
 291 different study areas have significant differences, but the minimum ET in areas CF at time T<sub>1</sub>-T<sub>15</sub>  
 292 does not. The minimum ET does not vary in study area at time T<sub>1</sub>-T<sub>15</sub>, and the pixel with ET=0  
 293 always exists. As shown in Figure7 and Figure 8, the maximum value trend in all areas is the same  
 294 as that of the average values, while the fluctuation in trend of the maximum and minimum value in  
 295 all areas is different. This is mainly due to the difference among soil types and meteorological  
 296 conditions in the six areas, causing the impacts on ET to vary[3,45]. This validates that due to the  
 297 different of surface types and meteorological conditions, even 2 MODIS remote sensing images  
 298 show daily variation in remote sensing pixel ETs. This daily variation does not follow the constant  
 299 linear rule, meaning that extrapolating instantaneous ET at the imaging time to a hourly or daily  
 300 time scale will cause relatively large errors[46,47]. Although GF-4 is with no thermal infrared band  
 301 and the LST at imaging time could not be obtained, its temporal resolution is relatively high and the  
 302 land surface ET at a three-minute time interval can be attained by using all available meteorological  
 303 and MODIS data. By using this method, the error associated with extrapolating instantaneous ET  
 304 from one remote sensing image could be avoided and the real spatial diversity of ET at various  
 305 imaging time could be obtained.

306 **4. Discussion**

307 While this paper compared ETs derived from GF-4 and MODIS using the SEBAL model, the  
 308 extent of the differences from SEBAL model ET input data needs further analysis. The reason for

309 the difference in ET simulation results between the two sensors needs further discussion, and the  
310 validation of ET simulation results requires careful consideration as well:

311 (1) Errors in SEBAL model input data lead to a decrease in ET simulation accuracy. However, in  
312 many areas, simulation is limited by available data, and often, the wind speed, LST, air temperature,  
313 and other data cannot be attained. While simulating the above parameters using the present model,  
314 various kinds of error must exist. If the above meteorological data could be replaced by observed  
315 data, the model accuracy could be significantly improved. In addition, the ESUN of GF-4 is not  
316 published yet, and the subsequent ESUN simulation that was used has errors which affected both  
317 the calculation of NDVI and the simulated values of ET.

318 (2) Besides the errors associated with SEBAL input data, the dependence on remote sensing  
319 data can lead to different ETs derived from the GF-4 and MODIS Sensors. Many researchers have  
320 pointed out that the local variables of the SEBAL model would change with the scope of the remote  
321 sensing image, which could lead to additional uncertainty associated with the domain dependence  
322 of the remote sensing model accuracy[7,28,34,48]. On the other hand, remote sensing images with  
323 different spatial resolutions would also cause differences in local variables, and thus could lead to  
324 completely different dry-wet conditions, dependent upon the resolution of the remote sensing  
325 models. For all established models based on remote sensing images, the model outputs may have  
326 uncertainties if the determination of variables or input parameters depends on the scope and  
327 resolution of those images.

328 (3) The objective of this paper was not to validate whether the GF-4 or MODIS remote sensor  
329 has higher accuracy in ET retrieval, but to quantify the similarities and differences between ETs  
330 derived from both satellites by comparing their retrievals. It is clear that more efficient ground  
331 observations are essential to validate model results. Currently, widely used ET remote sensing  
332 model validation techniques include the lysimeter method, the field water balance method, the  
333 Bowen ratio method, the eddy covariance method and the large aperture scintillometer method  
334 [23,49-52]. However, in practical operation, the spatio- temporal scale of the observed data does not  
335 always match with that of the model retrievals. Therefore, we can only use KoFlux data with 2-10  
336 minutes difference in remote sensing images for verification. The GF-4 is only the beginning of high  
337 orbit and high temporal-spatial resolution satellite technology, and as more research and data are  
338 gathered, new observational approaches will emerge.

339 (4) It is also necessary to consider cross-validation using remote sensing data with higher spatial  
340 resolution. We tried to verify GF-4 imaged at 11:14 in regions CB,CG and CF by using Landsat 8  
341 imaged at 10:29. Meanwhile in regions KB, KE and KD, Landsat 8 imaged at 10:04 was used to  
342 verify GF-4 imaged at 11:14, the verification results of ET were shown in table 6.

343 **Table 6.** Using Landsat 8 Data to Cross-Verify the Simulated ET of GF-4

Region	Data of verification	MRE (%)	RMSE(mm/min)
CB,CG and CF	Landsat 8	79.21	0.00462
KB,KE and KD	Landsat 8	190.36	0.00383

344 As can be seen from table 6, when the simulated ET of GF-4 was verified by Landsat 8, the MRE  
345 of ET of GF-4 was very large. Since the imaging time of Landsat8 was 44 minutes earlier than that  
346 of GF-4 in regions CB,CG and CF; and the imaging time of Landsat 8 was 70 minutes earlier than that  
347 of GF-4 in region KB,KE and KD. On such a long time difference, we think that the results of table 6  
348 can not accurately represent the actual accuracy of GF-4. However there is still a strong correlation  
349 between the ET derived from GF-4 and Landsat 8,  $R=0.548$  ( $p<0.001$ ).

## 350 5. Conclusions

351 (1) The spatial distribution of ET derived from MODIS and GF-4 showed that the texture of ET  
352 derived from GF-4 was more obvious than that from MODIS, and GF-4 was able to express the  
353 variability of ET spatial distribution. The correlation between ETs derived from two sensors showed  
354 significant linear correlation; and ET values derived from GF-4 was higher than that of MODIS.

355 (2) Even in the same study area, trends in the maximum value, the average value, and the  
356 standard error of ET at different times were not the same. This validates that even if in 2 MODIS  
357 remote sensing images scope, due to different surface types and meteorological conditions, the daily  
358 variation of ET in the remote sensing pixel scale does not follow the constant linear rule.

359 (3) Since the temporal resolution of GF-4 is 3 minutes in our paper, the land surface ET every  
360 three-minutes could be obtained by using all available meteorological data and other remote sensing  
361 data. At this scale, the extrapolation of instantaneous ET from a single image was avoided, and the  
362 spatial diversity at each imaging time was attained.

363 (4) This paper has validated ET derived from GF-4 and MODIS, and the verification results also  
364 showed that the error was within the normal range, but more observational methods to validate ET  
365 estimation results of GF-4 is needed, and should be a major goal for future studies.

## 366 6. Perspectives

367 The GF-4 satellite can not only collect images with a large scope and at high temporal and  
368 spatial resolutions, but also carry out "staring observation" in a specific region according to user  
369 instructions, which will play an important role in disaster reduction, meteorology, earthquake,  
370 forestry, and obtaining precise measurements in other fields. For example, GF-4 could practically  
371 observe a typhoon, since middle and low orbit satellites have high spatial resolution, but the  
372 retrogression time is relatively long, and the continuous observation of interesting areas is difficult.  
373 Compared with present high orbit continuous observation meteorological satellites, GF-4 could not  
374 only continuously provide information on the development of a typhoon, but could also take  
375 observations and measurements of details like typhoon textures.

376 In addition, GF-4 will further accelerate the development of advanced models supported by  
377 remote sensing data. Currently, models in disparate fields like ecology, hydrology, geochemistry,  
378 and meteorology are driven by remote sensing data, but are limited by the temporal and spatial  
379 resolution of available remote sensing data, and face issues of fulfilling simultaneous goals such as  
380 having "short time", "high accuracy", and "large space" [53-55]. Most models driven by remote  
381 sensing are on time scales of days, months, or years. Even if a part of these models could realize  
382 hourly time scales from meteorological satellites such as ones available from NOAA, the spatial  
383 resolution of their simulation results is over 1 km, which could not accurately estimate the spatial  
384 diversity of observation pixels [56-58]. Comprehensive advantages of GF-4 on increased temporal  
385 and spatial resolution and large widths would facilitate the appearance of various kinds of remote  
386 sensing models on fine time scales at minutes or even seconds.

387 **Author Contributions:** Conceptualization, Guoqing Li; methodology, Guoqing Li; software, Xueli Chang;  
388 validation, Xueli Chang; writing—original draft preparation, Guoqing Li; writing—review and editing, Alona  
389 Armstrong. All authors have read and agreed to the published version of the manuscript.

390 **Funding:** This research was funded by the National Natural Science Fund of China, grant number: 41601598,  
391 the Talent Project of Ludong University, grant number: LY2014020, and an NERC Industrial Innovation  
392 Fellowship awarded to AA (grant number: NE/R013489/1).

393 **Acknowledgments:** Thanks to the help of Dr. Youngryel Ryu and Dr. Minseok Kang of Seoul National  
394 University. Without their data from Korea Flux Monitoring Network (KoFlux), we would not have been able to  
395 complete the verification of ET.

396 **Conflicts of Interest:** The authors declare no conflict of interest.

## 397 **References**

- 398 1. Wei, Z.; Yoshimura, K.; Wang, L.; Miralles, D.G.; Jasechko, S.; Lee, X. Revisiting the contribution of  
399 transpiration to global terrestrial evapotranspiration. *Geophysical Research Letters* **2017**, *44*, 2792–2801,  
400 doi:10.1002/2016GL072235
- 401 2. Borges Júnior, J.C.F.; Pinheiro, M.A.B. Daily Reference Evapotranspiration Based on Temperature for  
402 Brazilian Meteorological Stations. *Journal of Irrigation and Drainage Engineering* **2019**, *145*, 04019029,  
403 doi:10.1061/(ASCE)IR.1943-4774.0001437.
- 404 3. Karimi, S.; Kisi, O.; Kim, S.; Nazemi, A.H.; Shiri, J. Modelling daily reference evapotranspiration in  
405 humid locations of South Korea using local and cross-station data management scenarios.  
406 *International Journal of Climatology* **2017**, *37*, 3238–3246, doi:10.1002/joc.4911
- 407 4. Karlsen, R.H.; Bishop, K.; Grabs, T.; Ottosson-Löfvenius, M.; Laudon, H.; Seibert, J. The role of  
408 landscape properties, storage and evapotranspiration on variability in streamflow recessions in a  
409 boreal catchment. *Journal of Hydrology* **2019**, *570*, 315–328, doi:10.1016/j.jhydrol.2018.12.065.
- 410 5. Lian, X.; Piao, S.; Huntingford, C.; Li, Y.; Zeng, Z.; Wang, X.; Ciais, P.; McVicar, T.R.; Peng, S.; Oettle, C.  
411 Partitioning global land evapotranspiration using CMIP5 models constrained by observations. *Nature*  
412 *Climate Change* **2018**, *8*, 640, doi:10.1038/s41558-018-0207-9.
- 413 6. Zhang, B.; He, C.; Di, X.; Li, F. Methods to estimate daily evapotranspiration from hourly  
414 evapotranspiration. *Biosystems Engineering* **2017**, *153*, 129–139, doi:10.1016/j.biosystemseng.2016.11.008
- 415 7. Bastiaanssen, W.G.M.; Noordman, E.J.M.; Pelgrum, H.; Davids, G.; Thoreson, B.P.; Allen, R.G. SEBAL  
416 model with remotely sensed data to improve water-resources management under actual field  
417 conditions. *Journal of irrigation and drainage engineering* **2005**, *131*, 85–93,  
418 doi:10.1061/(ASCE)0733-9437(2005)131:1(85).
- 419 8. Awada, H.; Ciralo, G.; Maltese, A.; Provenzano, G.; Hidalgo, M.A.M.; Còrcoles, J.I. Assessing the  
420 performance of a large-scale irrigation system by estimations of actual evapotranspiration obtained  
421 by Landsat satellite images resampled with cubic convolution. *International Journal of Applied Earth*  
422 *Observation and Geoinformation* **2019**, *75*, 96–105, doi:10.1016/j.jag.2018.10.016.
- 423 9. Ramírez-Cuesta, J.M.; Cruz-Blanco, M.; Santos, C.; Lorite, I.J. Assessing reference evapotranspiration  
424 at regional scale based on remote sensing, weather forecast and GIS tools. *International journal of*  
425 *applied earth observation and geoinformation* **2017**, *55*, 32–42, doi:10.1016/j.jag.2016.10.004
- 426 10. Talsma, C.; Good, S.; Miralles, D.; Fisher, J.; Martens, B.; Jimenez, C.; Purdy, A.J.R.S. Sensitivity of  
427 Evapotranspiration Components in Remote Sensing-Based Models. *Remote Sensing* **2018**, *10*, 1601,  
428 doi:10.3390/rs10101601
- 429 11. He, M.; Kimball, J.S.; Yi, Y.; Running, S.W.; Guan, K.; Moreno, A.; Wu, X.; Maneta, M. Satellite  
430 data-driven modeling of field scale evapotranspiration in croplands using the MOD16 algorithm  
431 framework. *Remote Sensing of Environment* **2019**, *230*, 111201, doi:10.1016/j.rse.2019.05.020.
- 432 12. Zhao, J. Estimate hourly and daily evapotranspiration using remote sensing technology for Haihe  
433 River basin. Twente Universiteit, Netherland, 2017.
- 434 13. Anderson, M.; Diak, G.; Gao, F.; Knipper, K.; Hain, C.; Eichelmann, E.; Hemes, K.S.; Baldocchi, D.;  
435 Kustas, W.; Yang, Y. Impact of Insolation Data Source on Remote Sensing Retrievals of  
436 Evapotranspiration over the California Delta. *Remote Sensing* **2019**, *11*, 216, doi:10.3390/rs11030216.
- 437 14. Knipper, K.R.; Kustas, W.P.; Anderson, M.C.; Alfieri, J.G.; Prueger, J.H.; Hain, C.R.; Gao, F.; Yang, Y.;  
438 McKee, L.G.; Nieto, H. Evapotranspiration estimates derived using thermal-based satellite remote

- 439 sensing and data fusion for irrigation management in California vineyards. *Irrigation Science* **2019**, *37*,  
440 431-449, doi:10.1007/s00271-018-0591-y.
- 441 15. Mahmoud, S.H.; Gan, T.Y. Irrigation water management in arid regions of Middle East: assessing  
442 spatio-temporal variation of actual evapotranspiration through remote sensing techniques and  
443 meteorological data. *Agricultural Water Management* **2019**, *212*, 35-47, doi:10.1016/j.agwat.2018.08.040.
- 444 16. Glenn, E.P.; Neale, C.M.U.; Hunsaker, D.J.; Nagler, P.L. Vegetation index-based crop coefficients to  
445 estimate evapotranspiration by remote sensing in agricultural and natural ecosystems. *Hydrological*  
446 *Processes* **2011**, *25*, 4050-4062, doi:10.1002/hyp.8392.
- 447 17. Foster, T.; Gonçalves, I.Z.; Campos, I.; Neale, C.M.U.; Brozović, N. Assessing landscape scale  
448 heterogeneity in irrigation water use with remote sensing and in situ monitoring. *Environmental*  
449 *Research Letters* **2019**, *14*, doi: 024004. 10.1088/1748-9326/aaf2be
- 450 18. Dalezios, N.R.; Blanta, A.; Loukas, A.; Spiliotopoulos, M.; Faraslis, I.N.; Dercas, N. Satellite  
451 methodologies for rationalising crop water requirements in vulnerable agroecosystems. *International*  
452 *Journal of Sustainable Agricultural Management and Informatics* **2019**, *5*, 37-58,  
453 doi:10.1504/IJSAMI.2019.101376.
- 454 19. Ochoa-Sánchez, A.; Crespo, P.; Carrillo-Rojas, G.; Sucozhañay, A.; Célleri, R. Actual  
455 evapotranspiration in the high Andean grasslands: a comparison of measurement and estimation  
456 methods. *Frontiers in Earth Science* **2019**, *7*, 55, doi:10.3389/feart.2019.00055.
- 457 20. Carlson, T.N.; Petropoulos, G.P. A new method for estimating of evapotranspiration and surface soil  
458 moisture from optical and thermal infrared measurements: the simplified triangle. *International journal*  
459 *of remote sensing* **2019**, *40*, 7716-7729, doi:10.1080/01431161.2019.1601288.
- 460 21. Alfieri, J.G.; Kustas, W.P.; Anderson, M.C. A Brief Overview of Approaches for Measuring  
461 Evapotranspiration. *Agroclimatology: Linking Agriculture to Climate* **2020**, *60*, 109-127,  
462 doi:10.2134/agronmonogr60.2016.0034.
- 463 22. Pütz, T.; Hannesd, M.; Wollschlägere, U. Estimating precipitation and actual evapotranspiration  
464 from precision lysimeter measurements. *Procedia Environmental Sciences* **2013**, *19*, 543-552, doi:  
465 10.1016/j.proenv.2013.06.061
- 466 23. Rosa, R.; Dicken, U.; Tanny, J. Estimating evapotranspiration from processing tomato using the  
467 surface renewal technique. *Biosystems engineering* **2013**, *114*, 406-413,  
468 doi:10.1016/j.biosystemseng.2012.06.011
- 469 24. Liu, R.; Wen, J.; Wang, X.; Hu, Z.Y.; Kang, Y. Hourly variation of evapotranspiration estimated by  
470 visible infrared and microwave data over the northern Tibetan Plateau. *Journal of Infrared & Millimeter*  
471 *Waves* **2015**, *34*, 211-217, doi:10.11972/j.issn.1001-9014.2015.02.015
- 472 25. Liu, Y.; Yao, L.; Xiong, W.; Zhou, Z. GF-4 Satellite and Automatic Identification System Data Fusion  
473 for Ship Tracking. *IEEE Geoscience and Remote Sensing Letters* **2019**, *16*, 281-285,  
474 doi:10.1109/LGRS.2018.2869561.
- 475 26. Liu, J.; Zheng, G.; Yang, J.; Wang, J. Top Cloud Motion Field of Typhoon Megi-2016 Revealed by GF-4  
476 Images. *IEEE Transactions on Geoscience and Remote Sensing* **2019**, *In pressing*, 1-18, doi:DOI:  
477 10.1109/TGRS.2019.2891207.
- 478 27. Wang, M.; Cheng, Y.; Tian, Y.; He, L.; Wang, Y. A New On-Orbit Geometric Self-Calibration  
479 Approach for the High-Resolution Geostationary Optical Satellite GaoFen4. *IEEE Journal of Selected*  
480 *Topics in Applied Earth Observations and Remote Sensing* **2018**, *11*, 1670-1683,  
481 doi:10.1109/JSTARS.2018.2814205

- 482 28. Li, S.; Zhao, W. Satellite-based actual evapotranspiration estimation in the middle reach of the Heihe  
483 River Basin using the SEBAL method. *Hydrological Processes* **2010**, *24*, 3337-3344, doi:10.1002/hyp.7748.
- 484 29. Bastiaanssen, W.G.M.; Menenti, M.; Feddes, R.A.; Holtslag, A.A.M. A remote sensing surface energy  
485 balance algorithm for land (SEBAL). 1. Formulation. *Journal of Hydrology* **1998**, *212-213*, 198-212,  
486 doi:10.1016/S0022-1694(98)00253-4
- 487 30. Timmermans, W.J.; Kustas, W.P.; Anderson, M.C.; French, A.N. An intercomparison of the Surface  
488 Energy Balance Algorithm for Land (SEBAL) and the Two-Source Energy Balance (TSEB) modeling  
489 schemes. *Remote Sensing of Environment* **2007**, *108*, 369-384, doi:10.1016/j.rse.2006.11.028
- 490 31. Grosso, C.; Manoli, G.; Martello, M.; Chemin, Y.; Pons, D.; Teatini, P.; Piccoli, I.; Morari, F. Mapping  
491 Maize Evapotranspiration at Field Scale Using SEBAL: A Comparison with the FAO Method and  
492 Soil-Plant Model Simulations. *Remote Sensing* **2018**, *10*, 1452, doi:10.3390/rs10091452.
- 493 32. Gobbo, S.; Lo Presti, S.; Martello, M.; Panunzi, L.; Berti, A.; Morari, F. Integrating SEBAL with in-Field  
494 Crop Water Status Measurement for Precision Irrigation Applications—A Case Study. *Remote Sensing*  
495 **2019**, *11*, 2069, doi:10.3390/rs11172069.
- 496 33. Rahimzadegan, M.; Janani, A. Estimating evapotranspiration of pistachio crop based on SEBAL  
497 algorithm using Landsat 8 satellite imagery. *Agricultural Water Management* **2019**, *217*, 383-390,  
498 doi:10.1016/j.agwat.2019.03.018.
- 499 34. Yang, Y.; Zhou, X.; Yang, Y.; Bi, S.; Yang, X.; Li Liu, D. Evaluating water-saving efficiency of plastic  
500 mulching in Northwest China using remote sensing and SEBAL. *Agricultural water management* **2018**,  
501 *209*, 240-248, doi:10.1016/j.agwat.2018.07.011.
- 502 35. Huete, A.; Didan, K.; Miura, T.; Rodriguez, E.P.; Gao, X.; Ferreira, L.G. Overview of the radiometric  
503 and biophysical performance of the MODIS vegetation indices. *Remote Sensing of Environment* **2002**,  
504 *83*, 195-213, doi:https://doi.org/10.1016/S0034-4257(02)00096-2.
- 505 36. Li, G.; Li, X.; Li, G.; Wen, W.; Wang, H.; Chen, L.; Yu, J.; Deng, F. Comparison of Spectral  
506 Characteristics Between China HJ1-CCD and Landsat 5 TM Imagery. *IEEE Journal of Selected Topics in*  
507 *Applied Earth Observations & Remote Sensing* **2013**, *6*, 139-148, doi:10.1109/JSTARS.2012.2206800.
- 508 37. Pandya, M.R.; Singh, R.P.; Murali, K.R.; Babu, P.N.; Kirankumar, A.S.; Dadhwal, V.K. Bandpass solar  
509 exoatmospheric irradiance and Rayleigh optical thickness of sensors on board Indian remote sensing  
510 satellites-1B,-1C,-1D, and P4. *IEEE Transactions on Geoscience and Remote Sensing* **2002**, *40*, 714-718,  
511 doi:10.1109/TGRS.2002.1000331
- 512 38. Zhang Lu, S.R., Xu Yongming, Li Long, Gao Wei. Calculation of Mean Solar Exoatmospheric  
513 Irradiances of Several Sensors Onboard of Chinese Domestic Remote Sensing Satellites. *Journal of*  
514 *Geo-information Science (in Chinese)* **2014**, *16*, 621-627, doi:10.3724/sp.J.1047.2014.00621.
- 515 39. Yang, A.; Zhong, B.; Wu, S.; Liu, Q. Radiometric cross-calibration of GF-4 in multispectral bands.  
516 *Remote Sensing* **2017**, *9*, 232, doi:10.3390/rs9030232
- 517 40. Cong, Z.t. Study on the coupling between the winter wheat growth and the water-heat transfer in  
518 soil-plant-atmosphere continuum. Tsinghua University, Beijing, Beijing, 2003.
- 519 41. Parton, W.J.; Logan, J.A. A model for diurnal variation in soil and air temperature. *Agricultural*  
520 *Meteorology* **1981**, *23*, 205-216, doi:10.1016/0002-1571(81)90105-9.
- 521 42. Ephraim, J.E.; Goudriaan, J.; Marani, A. Modelling diurnal patterns of air temperature, radiation wind  
522 speed and relative humidity by equations from daily characteristics. *Agricultural systems* **1996**, *51*,  
523 377-393, doi:10.1016/0308-521X(95)00068-G



- 524 43. Trajkovic, S.; Gocic, M.; Pongracz, R.; Bartholy, J. Adjustment of Thornthwaite equation for estimating  
525 evapotranspiration in Vojvodina. *Theoretical and Applied Climatology* **2019**, 10.1007/s00704-019-02873-1,  
526 1-10, doi:10.1007/s00704-019-02873-1.
- 527 44. Khedkar, D.; Singh, P.; Bhakar, S. Estimation of evapotranspiration using neural network approach.  
528 *Journal of Agrometeorology* **2019**, *21*, 233-235.
- 529 45. Wang, S.; Fu, B.J.; Gao, G.Y.; Yao, X.L.; Zhou, J. Soil moisture and evapotranspiration of different land  
530 cover types in the Loess Plateau, China. *Hydrology and Earth System Sciences* **2012**, *16*, 2883-2892,  
531 doi:10.5194/hess-16-2883-2012
- 532 46. Ebenezer, A.O.; Okogbue Emmanuel, C.; Akinluyi Frank, O. Mapping evapotranspiration for  
533 different landcover in the Lake Chad region of Nigeria using landsat datasets. *Journal of Remote*  
534 *Sensing Technology* **2016**, *4*, 58-69, doi:10.18005/JRST0401005
- 535 47. Peng, L.; Zeng, Z.; Wei, Z.; Chen, A.; Wood, E.F.; Sheffield, J. Determinants of the ratio of actual to  
536 potential evapotranspiration. *Global change biology* **2019**, *00*, 1-18, doi:10.1111/gcb.14577
- 537 48. Long, D.; Singh, V.P. A modified surface energy balance algorithm for land (M-SEBAL) based on a  
538 trapezoidal framework. *Water Resources Research* **2012**, *48*, 2528, doi:10.1029/2011WR010607
- 539 49. Qiu, G.Y.; Momii, K.; Yano, T.; Lascano, R.J. Experimental verification of a mechanistic model to  
540 partition evapotranspiration into soil water and plant evaporation. *Agricultural and Forest Meteorology*  
541 **1999**, *93*, 79-93, doi:10.1016/S0168-1923(98)00115-4
- 542 50. Pelosi, A.; Medina, H.; Villani, P.; D'Urso, G.; Chirico, G.B. Probabilistic forecasting of reference  
543 evapotranspiration with a limited area ensemble prediction system. *Agricultural water management*  
544 **2016**, *178*, 106-118, doi:10.1016/j.agwat.2016.09.015
- 545 51. Lee, Y.; Kim, S. The modified SEBAL for mapping daily spatial evapotranspiration of South Korea  
546 using three flux towers and terra MODIS data. *Remote Sensing* **2016**, *8*, 983, doi:10.3390/rs8120983.
- 547 52. VH da Motta Paca, V.H.; Espinoza-Dávalos, G.E.; Hessels, T.M.; Moreira, D.M.; Comair, G.F.;  
548 Bastiaansen, W.G. The spatial variability of actual evapotranspiration across the Amazon River Basin  
549 based on remote sensing products validated with flux towers. *Ecological Processes* **2019**, *8*, 6,  
550 doi:10.1186/s13717-019-0158-8
- 551 53. Lees, K.J.; Quaipe, T.; Artz, R.R.E.; Khomik, M.; Clark, J.M. Potential for using remote sensing to  
552 estimate carbon fluxes across northern peatlands—A review. *Science of the Total Environment* **2018**, *615*,  
553 857-874, doi:10.1016/j.scitotenv.2017.09.103.
- 554 54. Frohn, R.C.; Lopez, R.D. *Remote sensing for landscape ecology: new metric indicators: monitoring, modeling,*  
555 *and assessment of ecosystems*; CRC Press: Boca Raton, 2017.
- 556 55. Lekula, M.; Lubczynski, M.W. Use of remote sensing and long-term in-situ time-series data in an  
557 integrated hydrological model of the Central Kalahari Basin, Southern Africa. *Hydrogeology Journal*  
558 **2019**, *27*, 1-22, doi:10.1007/s10040-019-01954-9.
- 559 56. Fallahi, S.; Amanollahi, J.; Tzanis, C.G.; Ramli, M.F. Estimating solar radiation using NOAA/AVHRR  
560 and ground measurement data. *Atmospheric Research* **2018**, *199*, 93-102,  
561 doi:10.1016/j.atmosres.2017.09.006.
- 562 57. Chao, Y.; Farrara, J.D.; Zhang, H.; Armenta, K.J.; Centurioni, L.; Chavez, F.; Girton, J.B.; Rudnick, D.;  
563 Walter, R.K. Development, implementation, and validation of a California coastal ocean modeling,  
564 data assimilation, and forecasting system. *Deep Sea Research Part II: Topical Studies in Oceanography*  
565 **2018**, *151*, 49-63, doi:10.1016/j.dsr2.2017.04.013

- 566 58. Ford, T.W.; Quiring, S.M. Comparison of Contemporary In Situ, Model, and Satellite Remote Sensing  
567 Soil Moisture With a Focus on Drought Monitoring. *Water Resources Research* **2019**, *55*, 1565-1582,  
568 doi:10.1029/2018WR024039.  
569



© 2020 by the authors. Submitted for possible open access publication under the terms and conditions of the Creative Commons Attribution (CC BY) license (<http://creativecommons.org/licenses/by/4.0/>).

570