International Journal of the Physical Sciences Vol. 5(7), pp. 1023-1033, July 2010
Available online at http://www.academicjournals.org/IJPS
ISSN 1992 - 1950 ©2010 Academic Journals

Full Length Research Paper

Relationship between global solar radiation and sunshine duration for Northwest China

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Accepted 5 July, 2010

The monthly mean daily data of global solar radiation and sunshine hours for a period of 40 years (1961 - 2000) at 15 stations in Northwest China have been used to study their long-term, seasonal, and inter-annual variations. The variation of clearness index (K_T), relative sunshine (R_S) and the correlations have been analyzed. The results show that there are significant declining trends of both clearness index (~ 2.56%/decade) and relative sunshine duration (~ 1.36%/decade) with confidence level larger than 99% during 1961 to 2000 in Northwest China. The 40 years averaged clearness index and relative sunshine duration are higher than 0.40 and 40% at all 15 stations. In some remote sites such as Hami Dunhuang and Golmud, clearness index and relative sunshine duration are even higher than 0.60 and 70%, respectively. Linear and quadratic function fitting methods have been used to estimate the clearness index based on the measured sunshine duration data. According to the correlation coefficient (*R*), coefficient of determination (R^2), Mean Bias Error (*MBE*), Root Mean Square Error (*RMSE*) and Mean Percentage Error (*MPE*), both methods could be employed in estimating global solar radiation of location that has the same geographical location information as Northwest China.

Key words: Global solar radiation, sunshine hours, clearness index, relative sunshine duration, Northwest China.

INTRODUCTION

Global solar radiation is important for the study of climate change and global warming because of its indication of anthropogenic activities (Ramanathan et al., 2001). Moreover, it is of economic importance as a renewable energy alternative (Falayi et al., 2008). The knowledge of global solar radiation is very worthful for the optimal design and the prediction of the system performance in solar energy conversion system (Ibrahim, 1985). The best way of knowing the amount of global solar radiation over one region is to use pyranometer measurement data. And another approach is to correlate the global solar radiation with the meteorological parameters (Iqbal, 1983). The correlation could be used for estimation of global solar radiation (Augustine and Nnabuchi, 2009). Recently there are many studies about the applicability of estimation of global solar radiation based on the meteorological parameter of sunshine duration data (Ideriah and Suleman, 1989; Udo, 2000; Ogunjobi et al., 2002; Falayi and Rabiu, 2005; Skeiker, 2006).

As the largest developing country with a population of 1.3 billion in the world, the dominant energy sources used in China are coal, oil, natural gas and their derivatives which account for over 90% of the total energy consumption. China will consume more energy to keep a sustainable development in future. It is therefore important to consider the development of renewable energy sources such as biomass, solar, wind and hydro energy, etc. As for the solar energy development, there have been some studies about the estimation of global solar radiation in China (Zhou et al., 2004; Zhang et al., 2004; Che et al., 2007), which will be valuable for the solar energy evaluation in future. However there are limited studies focusing on the region of Northwest China. Northwest China is about 3.4 million km^2, accounting ~ 35% of the total area of China. There is abundant solar energy falling on the surface of the earth. Investigation of global solar radiation will be essential in assessing the climatologically potential solar energy utilization for this region (Che et al., 2007). There are more than 40 meteorological sta-

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tions with sunshine duration measurement in Northwest China. But only 15 stations take solar radiation measurements. It will be helpful to research the special and temporal distribution and variation of surface solar radiation over Northwest China deeply by using sunshine duration data in the future.

This article aims at investigating the distribution and variation of global solar radiation based on 40 years solar radiation and sunshine duration data at 15 observation sites located in Northwest China and trying to find suitable models that can be used to relate global solar radiation and sunshine hours for Northwest China.

METHODOLOGY

Data introduction

In this study, monthly global solar radiation G (MJ· m^{-2}· day^{-1}) and sunshine duration (hour) data of 15 radiation stations in Northwest China were collected during the period 1961 - 2000. Two indexes of clearness index (K_T) and relative sunshine duration (R_S) were calculated using the global solar radiation and sunshine duration data, respectively. Information on site locations is shown in Figure 1.

Analysis methods

The clearness index (K_T) is calculated as:

$$K_T = G/G_0$$

Where G is the measured global solar radiation (MJ· m^{-2}· day^{-1}), and G_0 is the total extraterrestrial radiation (MJ· m^{-2}· day^{-1}).

The G_0 can be calculated by the following formula:

$$G_0 = \frac{24 \cdot I_{SC}}{\pi\rho^2}(\omega_0 \sin\varphi \sin\delta + \cos\varphi \cos\delta \sin\omega_0)$$

Where I_{SC} is the solar constant (1367 W/m^2), φ is latitude of the location, δ is solar declination and can be calculated by using Julian day, ρ is distance of the sun from the earth, and ω_0 is sunset hour angle, which can be calculated from the following equation:

$$\cos\omega_0 = -\tan\varphi \tan\delta$$

The relative sunshine duration (R_S) is calculated as:

$$R_S = S/S_0$$

Where S is the monthly mean of diurnal sunshine duration (h), and S_0 is maximum possible sunshine duration that can be calculated as (Duffie and Beckman, 1991):

$$S_0 = {}^{2\omega_0}\!/_{15}$$

Simulation of K_T by using R_S data

In this article, the linear function fitting method (Angstrom, 1924) and the quadratic function fitting method (Black et al., 1954) has been used to simulate clearness index based on the relative sunshine duration, respectively:

Linear function fitting method:

$$K_T = a + b * R_S$$

Quadratic function fitting method:

$$K_T = a + b * R_S + c * R_S{}^2$$

The accuracy of the simulated K_T values was tested by calculating the Mean Bias Error (*MBE*), Root Mean Square Error (*RMSE*) and Mean Percentage Error (*MPE*).

The Mean Bias Error (*MBE*) can be calculated as following:

$$MBE = \frac{\sum_{i=1}^{N} D_{ie} - D_{im}}{N}$$

The Root Mean Square Error (*RMSE*) can be calculated as following:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N} (D_{ie} - D_{im})^2}{N}}$$

The Mean Percentage Error (*MPE*) can be calculated as following:

$$MPE = \frac{\sum_{i=1}^{N} \frac{D_{im} - D_{ie}}{D_{im}} \times 100}{N}$$

Where N is the number of data, D_{ie} is the i th estimated value, D_{im} is the i th measured value.

RESULTS ANALYSIS

Long-term variations of K_T and R_S in Northwest China

Figure 2a and b shows time-series of the annual mean K_T and R_S of all 15 radiation stations for a 40-year period from 1961 to 2000 in Northwest China. One can see that K_T decreased from 1960s to late 1980s but increased from late 1980s to 2000. The decreasing trends of K_T are ~ 2.56% per decade with confidence level larger than 99% during 1961 to 2000. R_S also showed a decreasing trend about 1.36% per decade with confidence level larger than 99%. Due to the clearness index gives the percentage attenuation by the atmosphere of the incoming global solar radiation (Udo, 2000), it could be speculated both the global solar radiation and the sunshine duration decreased during the last 40 years in Northwest China. From Fig 2c and d, one can see that all stations except Minqin showed decreasing trends of K_T during 1961 to 2000. Two stations of Lanzhou and Xi'an (population > 3 million) showed larger decreasing trends of both K_T and R_S than other stations. Different from K_T, there were eight stations with decreasing trend of R_S and

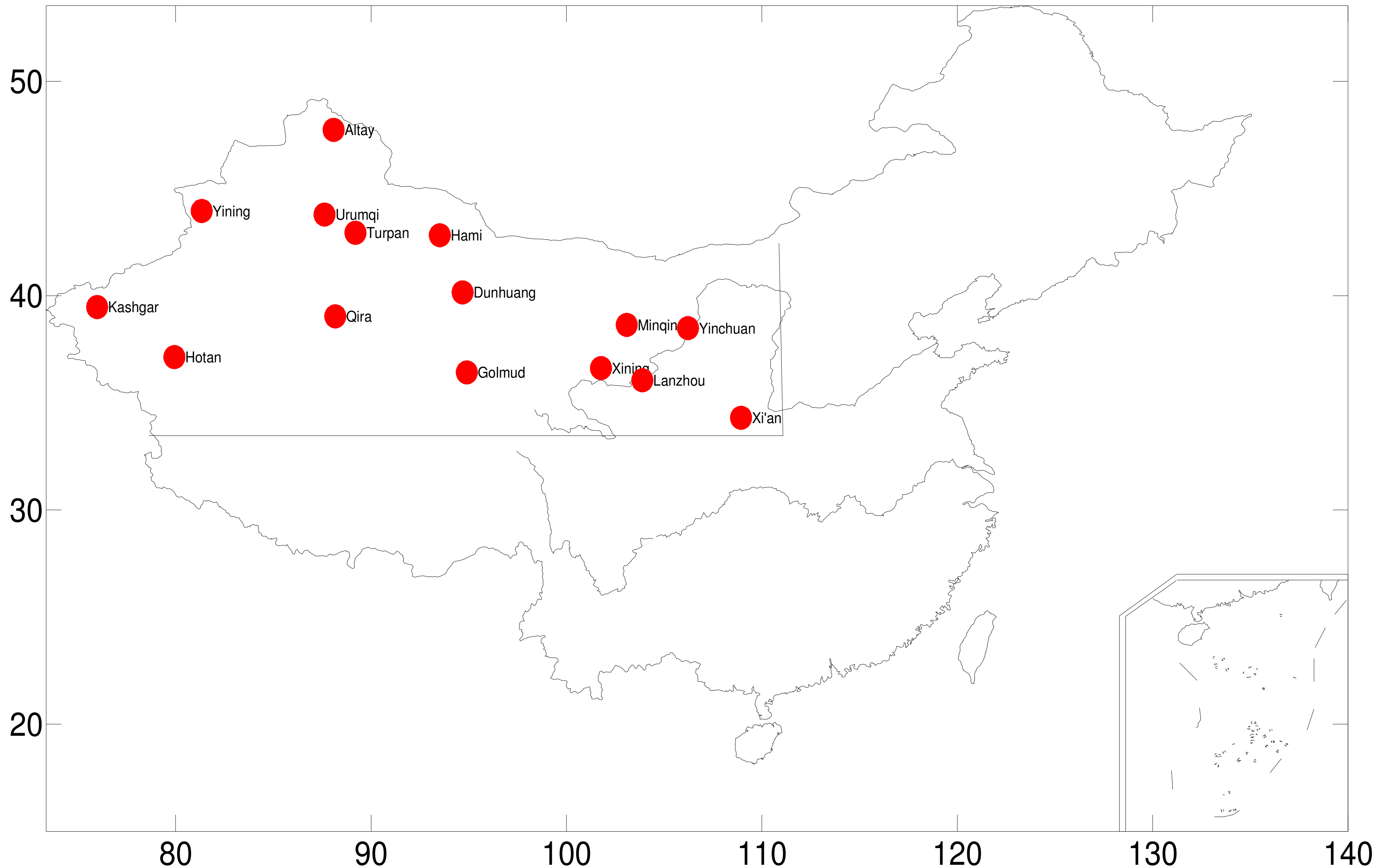


Figure 1. Geographical distribution of the 15 global solar radiation stations in Northwestern China.

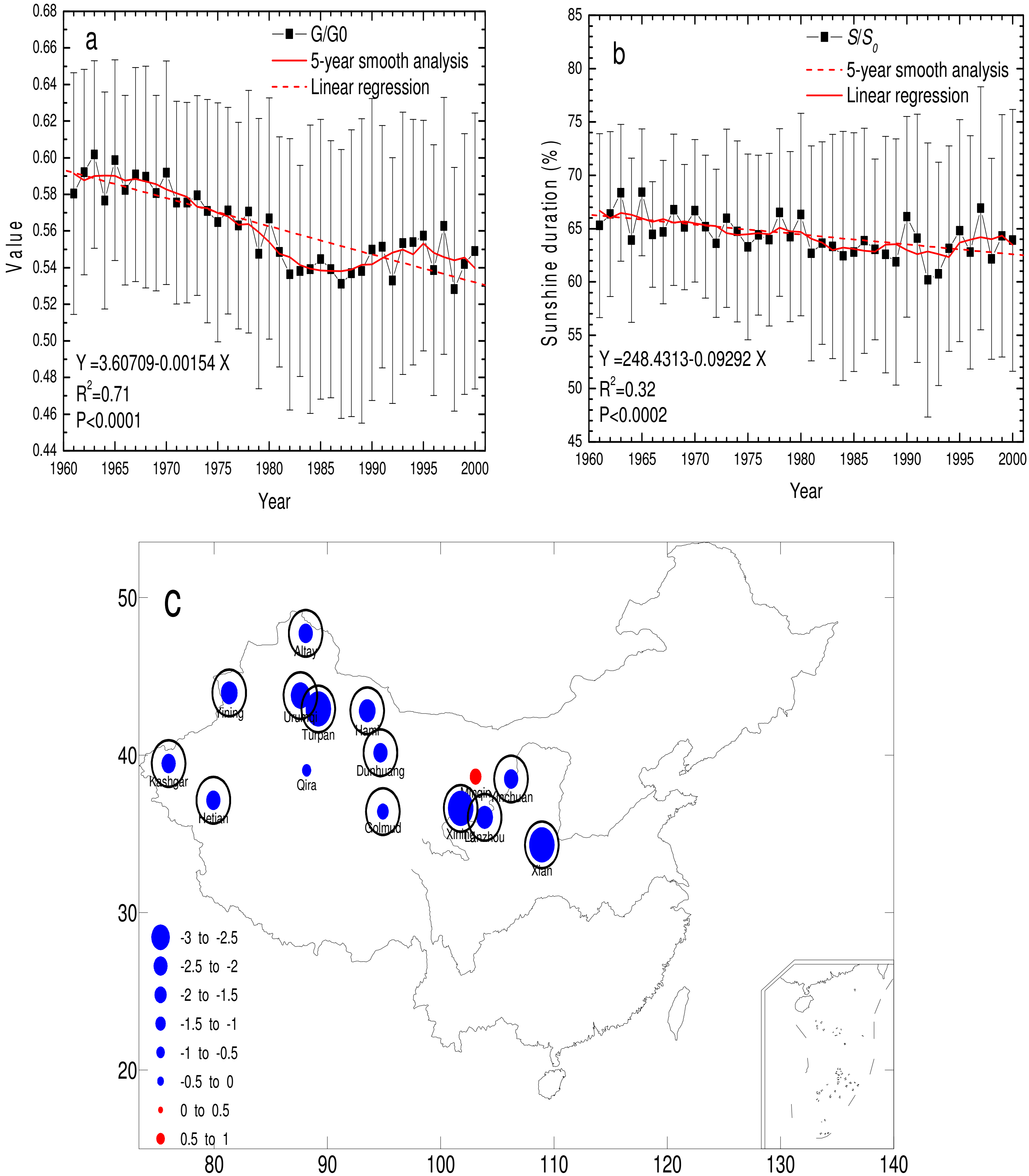


Figure 2. (a) Secular variation of annual mean daily K_T, (b) Secular variation of annual mean daily R_S, (c) Trends in annual mean K_T, (d) Trends in annual mean R_S. Station trend indicators with circles around them are significant at the 95% confidence level.

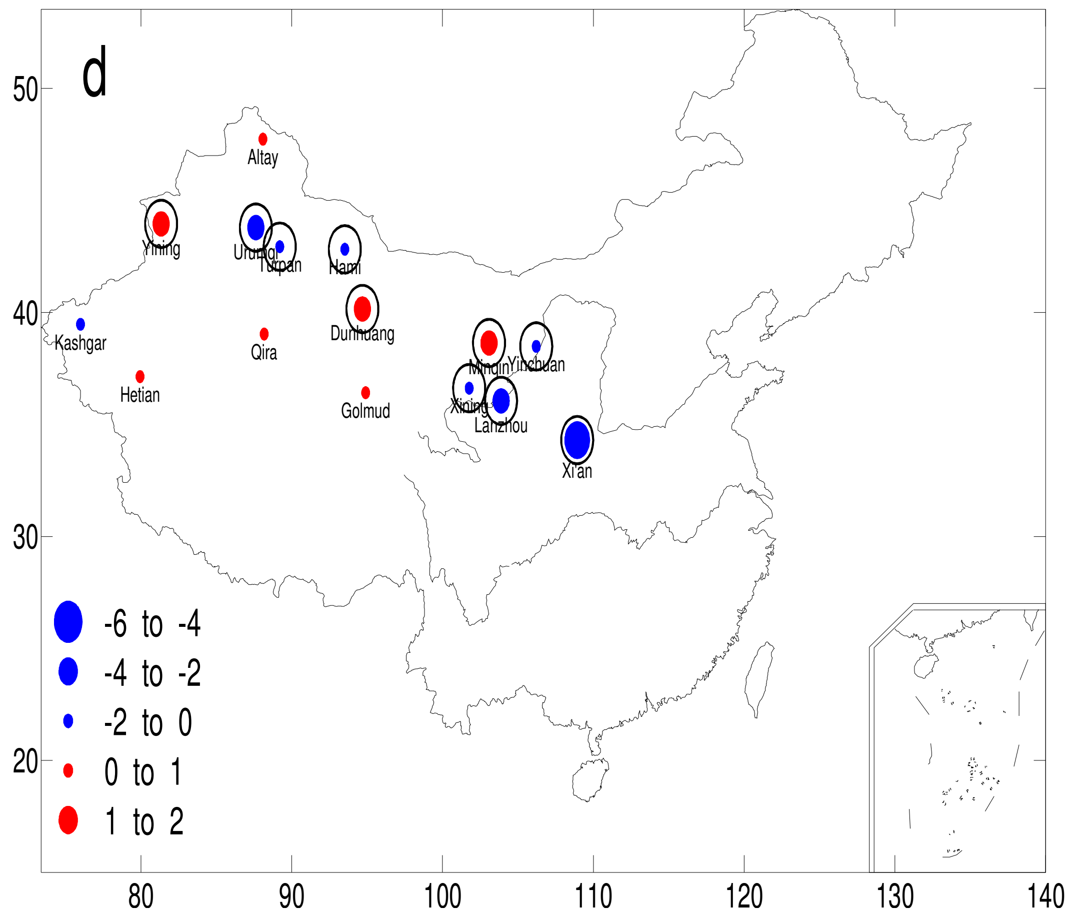


Figure 2. Contd.

seven of them with confidence level larger than 95%. Although there were seven stations with increasing trends of R_S but only three stations of Minqin, Dunhuang and Yining with confidence level larger than 95%.

Secular and seasonal averaged K_T and R_S in Northwest China

The 40 years averaged K_T and R_S are higher than 0.40 and 40% at all fifteen sites (Table 1). However, the lower K_T less than 0.55 occurs at Xi'an (0.41 ± 0.04), Lanzhou (0.49±0.03), Urumqi (0.51±0.04), and Kashgar (0.54±0.04), in which cities there have more anthropogenic activities. At the same time, the R_S is lower than 65% with about 40%±8%, 57%±5%, 60%±5%, 63%±4% at Xi'an, Lanzhou, Urumqi, and Kashgar, respectively. In some remote sites such as Hami Dunhuang and Golmud, K_T and R_S are higher than 0.60 and 70%, respectively. It means there are many clear days and plenty of potential solar energy at these regions. Generally, K_T and R_S in summer and fall are higher than those in winter and spring (Table 1). Except three stations of Xi'an, Lanzhou, and Urumqi, the other stations have fewer anthropogenic activities (population less than 500,000) but more dust events during winter to early summer, which could probably cause lower K_T and R_S in winter and spring at these stations.

Inter-annual variations of monthly averaged K_T and R_S in Northwest China

The inter-annual changes of K_T have tight relations to the climate at the locality. For nine stations such as Altay, Yining, Urumqi, Turpan, Kashgar, Qira, Hotan, Hami and Dunhuang, R_S has high values in August and November (Table 2).

For four stations such as Minqin, Golmud, Xining, and Yinchuan, R_S keeps high values (> 65%) during November to February. For some sites near deserts like Qira, Hotan, Kashgar, Hami, Dunhuang, and Minqin, low R_S usually occurs during March to May when frequent dust events happened comparing with other months. There seems no obvious inter-annual variation of R_S in Lanzhou, which could probably be due to the effect of heavy pollution there. The inter-annual variation of R_S in Xi'an is different from other stations; the maximum of R_S

Table 1. Longterm and seasonal averaged R_S and K_T for individual station.

Station	All		Spring		Summer		Autumn		Winter	
	R_S(%)	K_T	R_S(%)	K_T	R_S(%)	K_T	R_S(%)	K_T	R_S(%)	K_T
Altay	68(±2)	0.58(±0.02)	69(±8)	0.61(±0.05)	73(±5)	0.59(±0.04)	65(±11)	0.55(±0.06)	60(±11)	0.58(±0.08)
Yining	65(±4)	0.56(±0.04)	62(±8)	0.54(±0.07)	70(±7)	0.59(±0.06)	67(±10)	0.55(±0.07)	56(±10)	0.55(±0.08)
Urumqi	60(±5)	0.51(±0.04)	60(±9)	0.53(±0.06)	66(±6)	0.56(±0.04)	63(±12)	0.53(±0.07)	43(±15)	0.45(±0.08)
Turpan	67 (±3)	0.56(±0.04)	66(±6)	0.56(±0.04)	69(±5)	0.58(±0.04)	72(±8)	0.58(±0.05)	59(±12)	0.51(±0.08)
Kashgar	63(±4)	0.54(±0.04)	56(±9)	0.51(±0.06)	70(±6)	0.59(±0.06)	69(±10)	0.57(±0.06)	54(±11)	0.50(±0.06)
Qira	70(±3)	0.59(±0.03)	64(±7)	0.57(±0.05)	69(±6)	0.58(±0.04)	79(±6)	0.63(±0.05)	68(±9)	0.58(±0.06)
Hetian	60(±5)	0.55(±0.03)	53(±10)	0.52(±0.05)	57(±9)	0.54(±0.04)	72(±10)	0.61(±0.05)	58(±12)	0.55(±0.07)
Hami	75(±2)	0.63(±0.02)	74(±5)	0.63(±0.04)	74(±5)	0.62(±0.03)	79(±5)	0.64(±0.04)	73(±7)	0.63(±0.05)
Dunhuang	74(±3)	0.62(±0.03)	71(±7)	0.61(±0.04)	72(±6)	0.61(±0.05)	80(±6)	0.65(±0.05)	73(±8)	0.63(±0.05)
Minqin	69(±3)	0.58(±0.04)	66(±7)	0.56(±0.05)	66(±7)	0.54(±0.06)	73(±9)	0.58(±0.06)	76(±6)	0.62(±0.06)
Golmud	70(±2)	0.65(±0.02)	69(±5)	0.64(±0.04)	65(±7)	0.62(±0.04)	77(±7)	0.69(±0.04)	73(±7)	0.66(±0.04)
Xining	62(±3)	0.55(±0.05)	61(±6)	0.55(±0.05)	57(±8)	0.53(±0.06)	62(±11)	0.53(±0.08)	70(±7)	0.58(±0.07)
Lanzhou	57(±5)	0.49(±0.03)	58(±7)	0.51(±0.05)	57(±8)	0.51(±0.06)	55(±10)	0.47(±0.06)	57(±11)	0.46(±0.06)
Yinchuan	67(±4)	0.58(±0.02)	65(±7)	0.57(±0.04)	65(±7)	0.56(±0.04)	68(±9)	0.57(±0.05)	70(±9)	0.60(±0.05)
Xi'an	40(±8)	0.41(±0.04)	39(±12)	0.42(±0.06)	48(±13)	0.46(±0.07)	35(±14)	0.39(±0.07)	36(±15)	0.40(±0.07)

Table 2. Monthly averaged R_S and K_T for individual station.

		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Altay	R_S	61.27	66.50	67.50	70.28	70.33	71.68	71.54	74.28	74.80	65.55	55.40	52.39
	K_T	0.58	0.63	0.63	0.60	0.59	0.60	0.59	0.59	0.60	0.55	0.52	0.52
Yining	R_S	56.58	59.01	58.10	62.52	64.12	65.55	70.28	73.98	73.52	67.67	59.17	53.37
	K_T	0.56	0.57	0.53	0.54	0.56	0.58	0.59	0.60	0.59	0.55	0.52	0.51
Urumqi	R_S	43.61	50.55	53.15	63.03	64.06	62.61	65.94	70.45	71.09	68.32	49.84	36.34
	K_T	0.45	0.48	0.49	0.54	0.55	0.55	0.56	0.58	0.57	0.55	0.46	0.41
Turpan	R_S	57.37	66.72	66.49	64.46	66.70	66.83	68.31	72.51	75.67	74.71	65.80	53.00
	K_T	0.50	0.55	0.56	0.56	0.57	0.57	0.57	0.59	0.60	0.59	0.54	0.48
Kashgar	R_S	53.40	53.01	52.68	54.08	59.81	69.75	70.26	69.01	68.94	71.24	67.07	56.07
	K_T	0.50	0.49	0.49	0.50	0.54	0.60	0.59	0.57	0.58	0.59	0.55	0.50
Qira	R_S	69.14	67.44	63.24	63.45	66.40	67.59	67.30	72.57	78.70	83.19	76.54	67.95
	K_T	0.58	0.58	0.56	0.56	0.57	0.58	0.57	0.60	0.63	0.65	0.62	0.58
Hotan	R_S	57.13	53.57	52.88	52.40	54.83	59.29	55.41	56.81	65.18	76.25	73.64	62.29
	K_T	0.55	0.53	0.52	0.52	0.53	0.55	0.53	0.53	0.58	0.64	0.62	0.56
Hami	R_S	73.31	76.43	73.27	73.16	75.92	74.09	72.67	76.60	80.94	80.96	75.90	70.63
	K_T	0.63	0.65	0.63	0.63	0.64	0.62	0.61	0.62	0.65	0.65	0.63	0.60
Dunhuang	R_S	73.78	73.24	69.39	70.45	72.00	71.14	70.40	75.36	79.48	82.12	77.35	72.53
	K_T	0.63	0.63	0.61	0.61	0.62	0.61	0.60	0.62	0.64	0.66	0.63	0.62
Minqin	R_S	76.74	72.44	66.92	65.45	65.54	66.06	64.25	67.24	68.29	72.66	77.71	79.11
	K_T	0.63	0.61	0.57	0.56	0.56	0.55	0.53	0.55	0.55	0.58	0.61	0.62
Golmud	R_S	72.42	69.46	68.28	70.27	67.80	64.13	63.06	68.35	70.44	80.28	81.23	76.76
	K_T	0.66	0.65	0.64	0.66	0.64	0.62	0.61	0.64	0.65	0.70	0.70	0.68
Xining	R_S	70.43	68.70	62.08	61.60	58.64	56.16	55.60	59.06	53.23	61.13	70.59	70.02
	K_T	0.58	0.58	0.55	0.55	0.54	0.52	0.52	0.54	0.49	0.53	0.58	0.58
Lanzhou	R_S	54.93	61.73	56.13	58.34	58.08	56.81	56.24	59.14	51.91	55.38	58.61	54.75
	K_T	0.45	0.50	0.49	0.51	0.52	0.52	0.51	0.51	0.47	0.47	0.47	0.43
Yinchuan	R_S	70.37	68.85	64.71	64.21	65.85	65.99	63.40	64.50	65.06	67.96	72.23	72.27
	K_T	0.60	0.60	0.57	0.57	0.58	0.57	0.55	0.56	0.55	0.57	0.59	0.60
Xi’an	R_S	37.23	36.87	36.52	39.58	42.32	47.17	46.56	51.27	35.70	34.15	35.25	35.10
	K_T	0.40	0.40	0.39	0.42	0.44	0.45	0.45	0.47	0.39	0.38	0.39	0.39

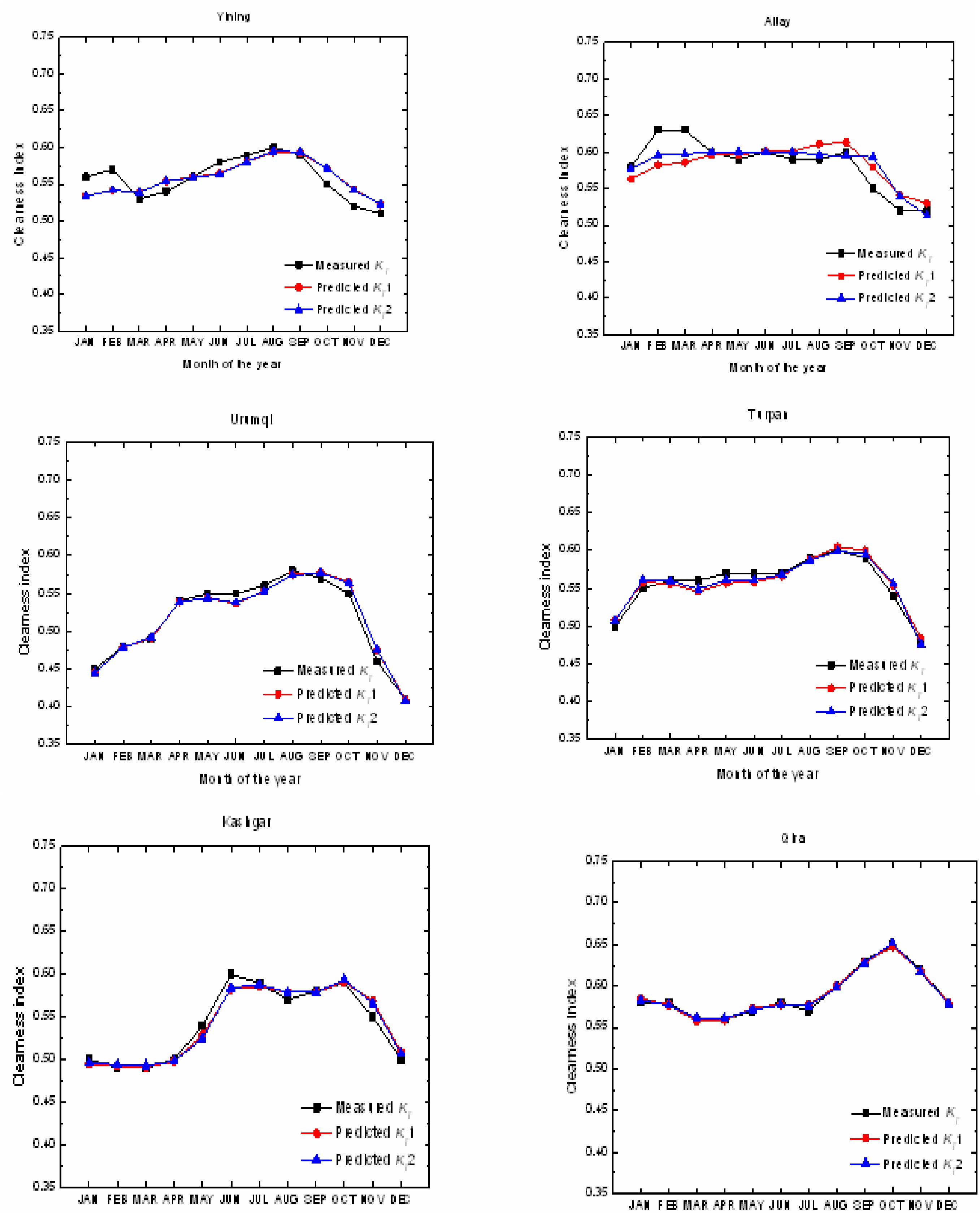
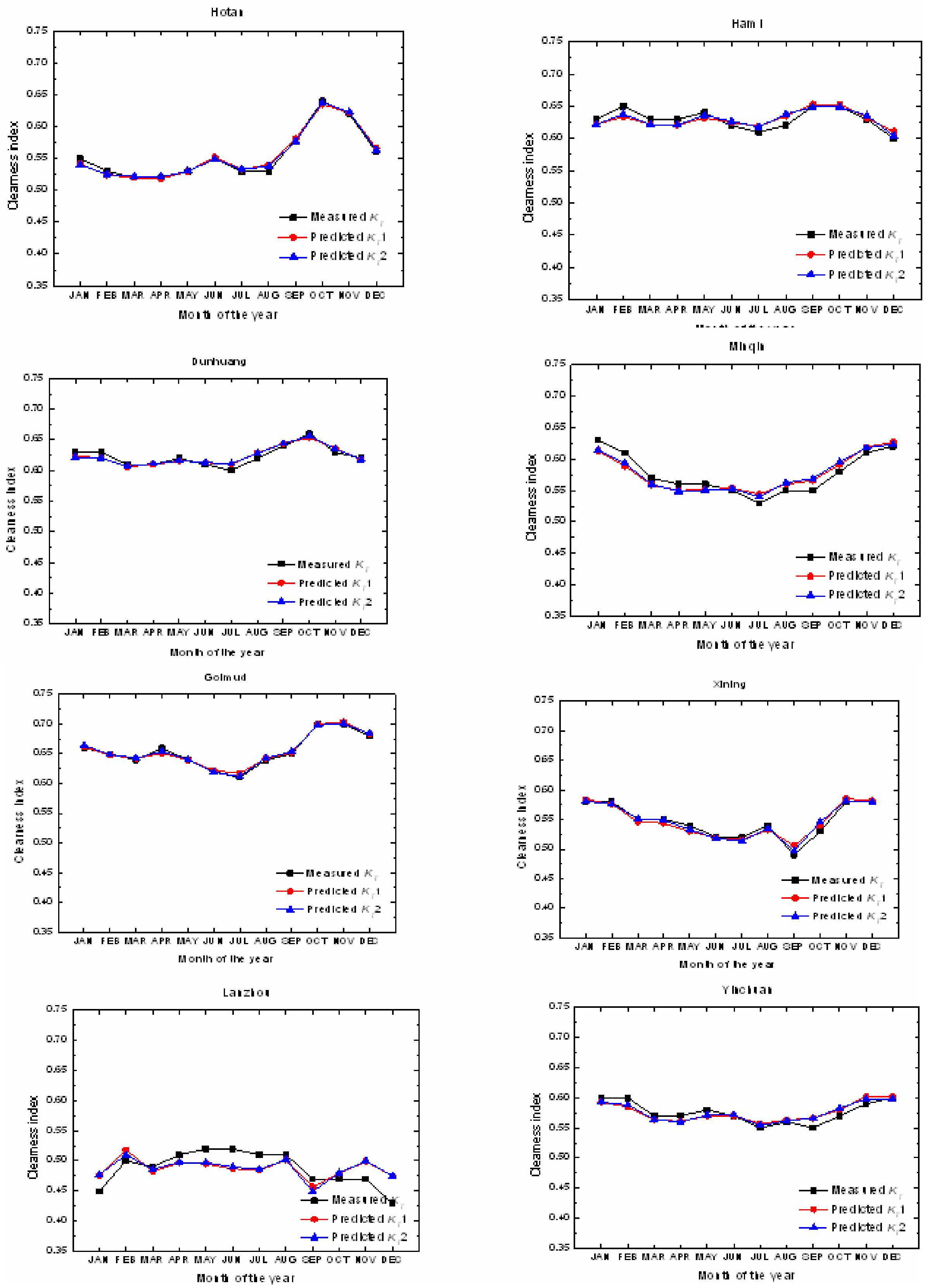


Figure 3. The measured monthly mean K_T and the simulated ones by using linear (Predicted K_T1) and quadratic (Predicted K_T2) fitting functions.



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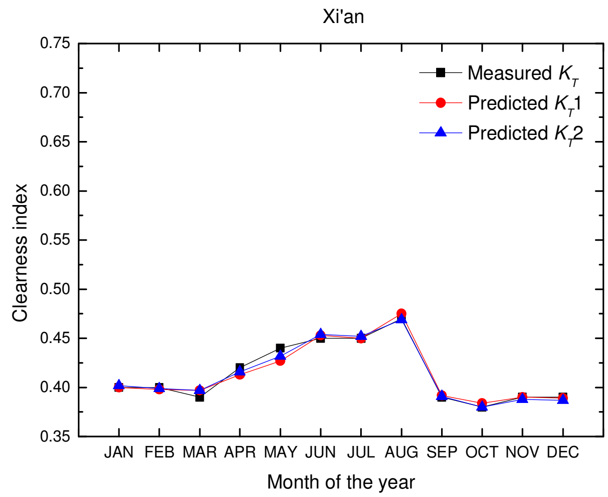

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Table 3. Linear function fitting parameters of K_T versus R_s at 15 stations in Northwest China.

$K_T = a + b * R_S$							
Station	***a***	***b***	***R***	R^2	***MBE***	***RMSE***	***MPE***
Altay	0.336	0.370	0.747	0.557	-5.064E-04	2.469E-02	-9.728E-02
Yining	0.335	0.350	0.807	0.651	-9.040E-04	1.674E-02	7.241E-02
Urumqi	0.234	0.484	0.988	0.976	9.047E-04	8.854E-03	-2.115E-01
Turpan	0.202	0.533	0.965	0.931	-8.523E-04	9.329E-03	1.229E-01
Kashgar	0.204	0.543	0.978	0.956	-6.977E-05	8.779E-03	-3.222E-03
Qira	0.273	0.451	0.995	0.989	-1.658E-05	2.519E-03	-6.546E-03
Hetian	0.260	0.491	0.991	0.982	4.924E-05	4.402E-03	1.437E-03
Hami	0.325	0.405	0.803	0.645	1.756E-04	8.573E-03	-4.771E-02
Dunhuang	0.345	0.377	0.918	0.843	-3.918E-04	5.703E-03	4.975E-02
Minqin	0.185	0.559	0.920	0.846	-5.202E-04	1.144E-02	4.094E-02
Golmud	0.312	0.484	0.989	0.978	1.950E-03	4.075E-03	-3.078E-01
Xining	0.263	0.455	0.965	0.931	-1.563E-03	7.520E-03	2.550E-01
Lanzhou	0.136	0.619	0.537	0.288	1.248E-04	2.288E-02	-2.533E-01
Yinchuan	0.234	0.509	0.850	0.723	-1.527E-03	9.342E-03	2.441E-01
Xi'an	0.203	0.531	0.982	0.964	-1.767E-04	4.224E-03	1.283E-02

occurs in summer time with the value about 51.27%.

Generally, K_T values in December are low at many stations like Altay, Yining, Urumqi, Turpan, Kashgar, Hami, Lanzhou and Xi'an (Table 2). High values occur during June to October at these stations. For some other stations such as Minqin, Golmud, Xining and Yinchuan, the K_T values are low during July to September but high during November to February which is similar to the inter-annual variation of R_S.

Comparison of the measured and simulated K_T values

Both the linear and quadratic function fitting results of K_T are shown in Figure 3. From Figure 3, one can see that the simulation results obtained from two methods are consistent to the measured ones at almost all stations except Altay and Yining, Lanzhou. Thus, it can be concluded that the simulated results could describe the inter-annual variation reasonably.

Linear function fitting analysis

The linear function fitting coefficients of *a*, *b*, *R*, R^2, *MBE*, *RMSE* and *MPE* for each site are shown in Table 3. The correlations coefficient of > 0.80 existing between the K_T and R_S at 13 of 15 stations except Altay and Lanzhou indicates that there is a high positive correlation between

Table 4. Quadratic function fitting parameters of K_T versus R_s at 15 stations in Northwest China.

$K_T = a + b * R_S + c * R_S^2$								
Station	***a***	***b***	***c***	***R***	***R^2***	***MBE***	***RMSE***	***MPE***
Altay	-0.713	3.722	-2.637	0.819	0.671	1.369E-04	2.151E-02	-1.723E-01
Yining	0.397	0.157	0.150	0.807	0.652	-9.004E-04	1.676E-02	7.157E-02
Urumqi	0.213	0.562	-0.070	0.988	0.976	9.018E-04	8.737E-03	-2.091E-01
Turpan	-0.150	1.632	-0.849	0.973	0.946	-8.530E-04	7.806E-03	1.338E-01
Kashgar	0.520	-0.497	0.843	0.979	0.958	-6.145E-05	8.737E-03	-3.820E-03
Qira	0.532	-0.268	0.494	0.997	0.993	-1.233E-04	1.849E-03	1.282E-02
Hetian	0.445	-0.097	0.459	0.993	0.986	4.823E-05	4.077E-03	1.748E-03
Hami	-1.551	5.332	-3.230	0.831	0.690	1.625E-04	8.175E-03	-4.325E-02
Dunhuang	0.669	-0.485	0.570	0.920	0.846	-3.878E-04	5.770E-03	4.901E-02
Minqin	-0.559	2.646	-1.458	0.923	0.852	-3.636E-04	1.133E-02	1.546E-02
Golmud	-0.084	1.583	-0.759	0.993	0.985	1.992E-03	3.852E-03	-3.134E-01
Xining	-0.322	2.336	-1.496	0.976	0.953	-1.569E-03	6.605E-03	2.629E-01
Lanzhou	-1.311	5.719	-4.488	0.553	0.305	1.069E-04	2.258E-02	-2.445E-01
Yinchuan	-1.352	5.199	-3.459	0.862	0.743	-1.686E-03	8.708E-03	2.724E-01
Xi'an	-0.014	1.583	-1.249	0.987	0.974	-2.264E-04	3.449E-03	2.875E-02

the measured R_S and K_T. Also, the values of coefficients of determination at 10 of 15 stations are larger than 0.80 ($R^2 > 0.90$ at 8 stations), which implies more than 80% of K_T can be accounted using fraction of sunshine at these stations such as Urumqi (97.6%), Turpan (93.1%), Kashgar (95.6%), Qira (98.9%), Hotan (98.2%), Dunhuang (84.3%), Minqin (84.6%), Golmud (97.8%), Xining (93.1%) and Xi'an (96.4%).

Quadratic function fitting analysis

The quadratic function fitting coefficients of *a*, *b*, *c*, *R*, R^2, *MBE*, *RMSE* and *MPE* for each site are shown in Table 4. The correlations coefficient (*R*) of > 0.80 existing between the K_T and R_S at 14 of 15 stations ($R > 0.90$ at 10 stations) indicates that there is a high positive correlation between the measured R_S and K_T. Meanwhile, the values of coefficients of determination (R^2) at 10 of 15 stations are larger than 0.80 ($R^2 > 0.90$ at 8 stations), which implies more than 80% of K_T can be accounted using fraction of sunshine at these stations such as Urumqi (97.6%), Turpan (94.6%), Kashgar (95.8%), Qira(99.3%), Hotan(98.6%), Dunhuang (84.6%), Minqin (85.2%), Golmud (98.5%), Xining (95.3%), and Xi'an (97.4%).

Comparing with linear function fitting method, the quadratic function fitting results have larger values of *R* and R^2 at most stations in Northwest China. However, the values of *R* and R^2 at Lanzhou are low for both the linear and the quadratic function fitting methods. Based on the high values of *R*, R^2 and low values of *MBE*, *RMSE* and *MPE* occurring at most stations in Northwest China, there are remarkable agreements between the measured and the simulated values of K_T for forty years from the correlations of this study (Figure 3).

In other words, both the linear and the quadratic function fitting methods can be used to estimate the global radiation properly at most of 15 radiation stations in Northwest China. The values of the regression coefficients (*a*, *b*, and *c* in Tables 3 and 4) obtained for these 15 stations were different, which suggests that regression coefficients associated with meteorological data changed with latitude and atmospheric conditions. However, further investigations are needed to comprehend this phenomenon in future.

CONCLUSION AND DISCUSSION

Relationship between global solar radiation and sunshine duration were studied at 15 global solar radiation stations in Northwest China with following conclusions:

(1) A general decreasing trend of the clearness index and relative sunshine duration have been observed in Northwest China based on 40 years' global solar radiation and sunshine duration data analysis. Almost all stations showed decreasing trends of clearness index during 1961 to 2000. Different from clearness index, there were about 50% stations with decreasing trend of relative sunshine duration.

(2) The lower clearness index and relative sunshine duration occur at those stations where there have been more anthropogenic activities. Generally, clearness index and relative sunshine duration in summer and fall are higher than those in winter and spring. Relative sunshine duration of many stations have high values during August and November. For some stations near deserts, low relative sunshine duration usually occurs during March to May which could be due to the effect of frequent dust

events.

(3) Two fitting methods have been used to estimate the clearness index based on sunshine duration data. It was found that both the linear and the quadratic function fitting methods are suitable to estimate the global radiation properly in Northwest China. The predicted results are consistent to the measured ones at almost all stations.

The regression equations could be employed in estimating global solar radiation of location which has the same geographical location information in Northwest China.

ACKNOWLEDGEMENTS

This work is financially supported by the grant of NSFC (NO: 40830957) and China Meteorological Administration (CMA) open foundation project, Institute of Arid Meteorology, Lanzhou (IAM 200816), for presenting the global solar radiation data and sunshine duration data.

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