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Analysis of solar radiation variations over Nanjing region in recent 40 years

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The data utilized in this analysis consisted of extraterrestrial radiation, global radiation, diffuse radiation, direct radiation, total cloud cover and relative sunshine. The annual variations and trend were analyzed for monthly mean daily total global, direct, and diffuse radiation on a horizontal surface and for the relations between global, direct, diffuse radiation and relative sunshine, total cloud cover. The climatological calculation equations of global and direct radiation are put forward. The results show that global and direct radiations are characterized by decrease and diffuse radiation by increase. The main causes are due to the increase of concentration of suspended particles and atmospheric turbidities rather than cloud cover variations.

Analysis of solar radiation variations over Nanjing region in recent 40 years ZHANG Yunlin, QIN Boqiang, CHEN Weimin (Nanjing Institute of Geography and Limnology, CAS, Nanjing 210008, China) Abstract: Key words: CLC number: 1 Introduction The knowledge of solar radiation of an area is important for assessing the potential use of solar energy to be concerted to either thermal or electric energy, as a power source. Solar radiation is the main energy source of the ground surface, and also the main component of surface radiation balance and heat balance. Its magnitude and variations have a significant effect on heat regimes of the atmosphere and geoshpere, the growth of biology, and human activities. Solar radiation which reaches the ground surface is closely related to the sunshine, atmospheric components, cloud cover, the water vapor content of atmosphere and concentration of atmospheric suspended particles. Solar radiation data for a period of 40 years from 1961 to 2000, including global radiation, direct radiation, diffuse radiation, and sunshine hours, recorded by meteorological observatory in Nanjing have been collected and properly processed. These solar radiation data have been extensively analyzed separately in conjunction with relative sunshine and turbidity. The aim of this work is to obtain middle- and long-term variation law of the solar radiation and the climate variation law in recent 40 years over Nanjing region. As the atmospheric transparence decreases due to the absorption and diffuse of the atmospheric pollutants, it is also possible to get to know the atmospheric conditions and the degree of air pollution indirectly. 2 Study site The Nanjing Meteorological Station belongs to the second level national solar radiation station, which is situated in the suburb of Xiaojiaochang of Honghua town in Qinhuai district of Nanjing. The station lies at 32o00´N, 118o48´E, with a height of 7.1 m above sea level. The global radiation, direct radiation, diffuse radiation and net radiation were observed before 1991; however, the direct radiation and diffuse radiation were no longer observed after the adjustment of the radiation stations all over the country. Now, the model DFY4 global radiation meter, the model DFY5 net radiation meter and FJ2 sunshine meter have been installed at the Nanjing station which enabled the acquisition of the global radiation, net radiation and regular meteorological data. 3 Results and discussion 3.1 Analysis of features of radiation climate 3.1.1 Global radiation Based on yearly anomaly of annual mean daily total global radiation in recent 40 years from 1961 to 2000 over Nanjing region, the results show that the values of only 4 years are higher than zero in the 26 years since 1974, however, the value of only one year is lower than zero before 1974. Therefore, the variation of global radiation can be divided into two stages: from 1961 to 1974 and from 1975 to 2000. In the first stage, the annual mean daily total global radiation is high. Since 1974, the annual daily global radiation has been decreasing obviously. The variation trend of annual mean daily total global radiation in recent 40 years is given in Figure 1. The result shows that there has an obvious decrease in annual daily global radiation whose variation trend is similar to that of other regions in China (Li et al., 1998; Zhang et a l., 1999). Figure 2 shows the annual variation curves of monthly mean total global radiation from 1961 to 2000 whose variation trend is similar to extraterrestrial radiation´s with the highest value in summer and the lowest value in winter. However, the extraterrestrial radiation value is the highest in June, but the measured global radiation is relatively low in June than in May, July and August. The main causes are due to the large amount of precipitation, relative sunshine hours (Figure 3), and increase of total cloud cover with the highest value of total cloud cover (Figure 5b). Figure 3 shows the seasonal variation of the ratio of measured global radiation to extraterrestrial radiation and relative sunshine over a period from 1961 to 2000. It can be seen that the ratio of measured global radiation to extraterrestrial radiation varies almost linearly with relative sunshine. For example, both curves turn up relative low value in June and September, which demonstrates that sunshine hour is the main factor affecting actual global radiation and it is the reason for estimating global radiation with relative sunshine. 3.1.2 Direct and diffuse radiation For a proper understanding of the radiation climatology of a region, apart from information on global solar radiation, the knowledge on direct and diffuse radiation is required. The direct radiation is the solar radiation which reaches the ground surface directly. If there were no atmosphere around the earth, the amount of direct radiation would be the amount of extraterrestrial radiation, whose value relates to the latitude of the region and of the day. However, the amount of radiation reaching the ground surface varies greatly in different regions due to the difference of absorption and diffusion of the cloud to solar radiation. The intensity of direct radiation rests with cloud cover, cloud condition and atmospheric transparent coefficient. The diffuse solar radiation represents the shortwave energy of solar origin scattered downwards by gas molecules, aerosols (or suspended particulate matter), water vapor and clouds in the atmosphere. The variability in the amount and type of cloud plays a dominant role in the value of diffuse radiation (Lu and Gao, 1987). The variation curves of the annual average daily direct radiation and diffuse radiation over a period from 1961 to 1989 over Nanjing region are shown in Figure 4. From Figure 4 one can see a general decreasing trend for direct radiation and a little increasing trend for diffuse radiation in 29 years. This confirms that global radiation decreases at a higher rate than the increase of diffuse radiation. In general, the relation between direct radiation and diffuse radiation is a model of one falling after another rising. The annual anomaly of the mean daily total direct radiation averaged over many years is 6.3368 MJ/m2d, which accounts for 50.44% of the global radiation. The calculation of the annual anomaly of the mean daily total direct radiation shows that there exist two stages of direct radiation variations: 1) from 1961 to 1974, the value was basically less than zero, only one year more than zero; and 2) from 1975 to 2000, the value was mostly more than zero, only two years less than zero in 15 years. However, the increasing trend of annual anomaly of the mean daily total diffuse radiation is not as obvious as the decreasing trend of direct radiation with two stages. But from 1981 to 1989, the annual anomaly is basically positive, which indicates the increasing trend of diffuse radiation. The consequence is probably due to the increase in air pollutants, cloud cover and sand storm occurrence frequency which exert great effects on the decrease in global radiation and the increase in diffuse radiation. Figure 5a and 5b show the annual variation of direct, diffuse radiation and total cloud cover. Figure 5a shows a regular annual variation with a maximum in August and a minimum in January, which shows the variation trend of direct radiation according to extraterrestrial radiation. However, the variation of direct and extraterrestrial radiation is not completely unanimous because of the effect of atmospheric component, cloud cover, vapor and suspended matter. There exists a relatively low value in June, due to the occurrence of rain, with more precipitation, less sunshine duration, more cloud cover. Inversely, there exists a relatively high value in October due to the less rainfall, cloud cover in autumn which causes the increase of direct radiation in October than in September. The annual variation of diffuse radiation is similar to that of direct radiation, only with the difference of turn-up time of maximum. The maximum of diffuse radiation turns up in June instead of in August whose causes are related to the plum rain season. 3.1.3 Diffuse fraction (D/Q) Diffuse fraction (D/Q) renders the proportion of diffuse radiation to global radiation (Li and Mou, 1994). Because of air pollution and the ascent of the concentration of aerosols and suspended particulate matter, the turbidity increases and transparency decreases, which leads to the mitigation of the direct radiation and amplification of scattering radiation on clear day. However, the increasing of scattering radiation cannot counteract the decreasing of direct radiation. Thus, with the aggravation of air pollution, the global radiation decreases and scattering radiation increases, which results in the value of D/Q increasing. Ratios of yearly mean daily values of diffuse to global solar radiation (D/Q) from 1961 to 1989 are given in Table 1. Taking all the years, the values of D/Q are seen to vary between 39.58% and 59.09%. The variation curves of ratios of yearly mean daily values of diffuse to global solar radiation in 29 years are given in Figure 6. Table 1 and Figure 6 show that the ratio increase takes 1980 as a demarcation line. Before 1980, the ratios are almost less than 0.5 in 20 years but more than 0.5 in 1970, 1975 and 1976. To the contrary, the ratios are all more than 0.5 from 1981 to 1989. I t can be seen that the variation is due to the obvious increase of turbidity during this period over Nanjing region, which is related to the development of industry and economy. Since the opening up, the industries developed rapidly with aggravation of air pollution, decrease of atmospheric transparence, which causes the increase of diffuse radiation, the decrease of direct radiation and the increase of ratios of yearly mean daily values of diffuse to global solar radiation. 3.2 Climatological calculation of global radiation There are no unified models for climatological calculation of global radiation. Several expressions have been used to estimate global solar radiation (Peman, 1948; Iqbal, 1983; Weng, 1997). However, in general, the climatological calculation of global radiation is mainly based on relative sunshine and cloud cover related to some meteorological parameters. In this paper, the only meteorological parameter-relative sunshine is used to calculate global radiation whose causes are analyzed in the text. Eqn. (1) is written as the following: Q = Q0 (a + bs1) (1) where Q, Q0 are monthly average daily measured global and extraterrestrial radiation in MJ/m2, respectively, s1 is relative sunshine and a, b are empirical coefficients to be determined. The extraterrestrial radiation but not an average cloud-free global radiation is used to calculate measured global radiation because Weng Duming and Zhu Changhan made an overall and detailed discussion about the basic problems of climatological calculation of radiation and demonstrated the rationalization substituting with extraterrestrial radiation by global radiation in clear sky (Weng, 1964; Zhu, 1982a, b). Extraterrestrial radiation is the solar irradiance on the horizontal surface at the top of the atmosphere as a function of latitude and month. The daily total extraterrestrial radiation is given below (Lu and Gao, 1987): Q = (?棕sin?渍sin?啄 + con?渍con?啄sin?棕) (2) where T is the length of a day (=24 hours), I0 is the solar constant (=1367w/M2), ?渍 is the latitude of the place, ?啄 is the solar declination, ?棕0 is the sunset-hour angle and ?籽 is the mean Earth-Sun distance. The monthly average value of extraterrestrial radiation is substituted by the value on the 15th of every month. Using the monthly average values of Nanjing station in recent 40 years, the equation for calculating mean value in decades of years is given by: Qj = Qij (j =1, 2, 3…, M) (3) Empirical coefficients are determined by using the method of mathematical statistics. a = y - bx (4) b = (5) Using eqns. (4) and (5), the values of every month of Nanjing station can be obtained (Table 3). Table 3 shows that with the exception of March having relative great b value and May, September and November having relative small b values, the b values of other months do not vary much, fluctuating around 0.6. The distinction of yearly anomaly is small. From the above analysis, the climatological calculation equation of the global radiation can be given: Q = Q0 (0.1211 + 0.5951s1) (6) where Q0 and s1 are the monthly mean of extraterrestrial radiation and relative sunshine, respectively. The related coefficient of regression formula is 0.89 and specimen capacity n is 40. In order to testify the error of regression equation, the measurement data of the recent 40 years were compared with calculation result, which are listed in Table 4. 3.3 Climatological calculation of direct radiation The direct global radiation can only be obtained through climatological calculation because no measurement had been done since 1990 at Nanjing station. The direct radiation was calculated using different equations by many scholars according to different data (Weng, 1964, 1985; Zhu, 1985). In this paper, the following equation is adopted to calculate direct radiation (Lu and Gao, 1987). S = a + bQ0s1 (7) where S, Q0 and s1 are monthly mean direct radiation, extraterrestrial radiation and relative sunshine, respectively, a and b are empirical coefficients which indicate the transparent extent of atmosphere. Just as Lu Yurong discussed, the values of a and b are not possibly constant, which vary according to geographical features, vapor content and seasonal variations. The equation similar to that of global radiation calculation is adopted by author here. S = Q0 (a´ + b´) (8) The parameters are determined in accordance with the above method with the period just from 1961 to 1989. The calculated results are given in Tables 5 and 6. From the above analysis, the climatological calculation equation fitting in with this region can be given: S = Q0 (-0.0595 + 0.5621s1) (9) where Q0 and s1 are the monthly mean of extraterrestrial radiation and relative sunshine, respectively. The related coefficient of regression formula is 0.89 and specimen capacity n is 29. The estimated direct radiation can be obtained through eqn. (9). And so, the results of error tests are presented by using the data of measured direct radiation and extraterrestrial radiation from 1961 to 1989 (Table 7). 4 Conclusions The solar climate of Nanjing region has been reported in detail. The following results can be gained by statistical analyses on solar radiation, relative sunshine and cloud cover of Nanjing station from 1961 to 2000. (1) Direct radiation has declined in recent 40 years over Nanjing region and the trend of descendent was more obvious especially since 1974. Diffuse radiation has increased somewhat in recent 40 years, whose increasing quantity can not make up for the decease of direct radiation. In general, there exists the relation of one falling after another rising between direct radiation and diffuse radiation. Global radiation also decreased in the last 40 years, whose variation trend is similar to direct radiation. (2) The annual variations of global radiation, direct radiation and diffuse radiation are basically consistent with extraterrestrial radiation with a maximum in summer and a minimum in winter. However, the variation of three parameters is not totally identical with a ma

ximum in August and a relatively low value in June of global and direct radiation but with a maximum in June of diffuse radiation. Considering the causes, the precipitation increases, sunshine hours decrease and cloud cover reaches a maximum of a year due to the plum rain season of Nanjing region. (3) The ratio of measured global radiation to extraterrestrial radiation varies almost linearly with relative sunshine, which is the basis of using relative sunshine to calculate global radiation. (4) Using the global radiation and relative sunshine in suit of Nanjing station in recent 40 years, the monthly global radiation climatological formula can be obtained: $Q = Q_0 (0.1211 + 0.5951s_1)$ Through analysis of error, it has been found that yearly mean calculation error is only 0.15%, which proves that it is credible to use the empirical equation to calculate the global radiation of Nanjing region and vicinity. (5) According to Lu Yurong´s direct radiation equation, the similar calculation equation just like global radiation is presented. Based on the data of Nanjing station from 1961 to 1989 to regression analysis, the climatological calculation equation of direct radiation is given: $S = Q_0 (-0.0595 + 0.5621s_1)$ References

关键词： Nanjing region; global radiation; direct radiation; diffuse radiation; relative sunshine

