Solar Radiation at Surface for Typical Cities in the Arid and Semi-Arid Area in Xinjiang, China Based on Satellite Observation

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Abstract: Xinjiang, a region of China with arid and semi-arid areas, has abundant solar incidence with 166.5×10⁴ km² and diverse underlying surface. The meager number of surface radiation observatories cannot meet the need for efficient exploration of solar energy. In this study we classified Xinjiang into three regions: southern Xinjiang, northern Xinjiang and Tu-Ha region and applied satellite data to provide the surface solar radiation’s temporal distribution for 10 typical cities. The study is focused on seasonal, annual and variations of all sky downward shortwave radiation flux at surface based on 24-year satellite dataset GEWEX-SRB from the WCRP/GEWEX (World Climate Research Program/Global Energy and Water Cycle Experiment) from 1984 to 2007. The results are as follows. In general, the monthly average solar radiation flux for the cities in the Tu-Ha region was the largest followed by the south Xinjiang and northern Xinjiang. The solar radiation in the most northern cities were less than 150.0 W/m² in winter, the minimum is 138.7 W/m², while the other cities were greater than 150.0 W/m². The maximum of monthly solar flux for the Tu-Ha region, southern and northern Xinjiang was 400.0 W/m².

1. Introduction

Excessive depletion of fossil fuels results in severe global energy crisis with a large amount of greenhouse gas from combustion emissions leading to global warming and serious threats to the environment and human health. Solar radiation has been internationally recognized as one of the preferred sources of clean energy due to its wide distribution, in situ availability, no need for transport and small impact on the environment [1-4].

Scholars in China and overseas have utilized global surface observation, numerical simulation and satellite remote sensing to estimate solar radiation reaching the earth’s surface for research areas including global and cities [5-6], focusing on distribution of solar radiation [7-10], its long-term change trend in time and space [11-12], and its influencing factors [13-15].
Xinjiang Uygur Autonomous Region is located in northwestern China. It accounts for about 1/6 of the total land area of China. It is in the arid and semi-arid climate zone with abundant solar energy. Its annual total radiation is up to 5430-6676 MJ/m², and the theoretical annual solar energy is 1450-1720 kWh/m², which suggests a powerful potential for future development of electricity [16].

Although there has been some research on solar radiation in Xinjiang [17-20], it was mainly based on a few surface observations that limited the results. Therefore, in this study SRB satellite data from 1984 to 2007 for 10 typical cities of Xinjiang was used to study seasonal, annual and inter-annual variations of shortwave radiation flux in order to provide better scientific understanding of solar radiation in Xinjiang.

2. Materials and Methodology

In this paper, the northern area to the Tianshan Mountains in Xinjiang is defined as the northern Xinjiang and the southern area is defined as the southern Xinjiang. The Turpan and Hami area is defined as the Tu-Ha region (Figure 1). Because of differences in geographical locations, climate and terrain conditions, we selected representative cities in each region for research: Altay, Yining, Urumqi for the northern Xinjiang; Korla, Aksu, Kashgar, Qiemo, and Hotan for the southern Xinjiang; Turpan and Hami for the Tu-Ha region. Seasonal, annual and inter-annual variations based on monthly solar radiation flux are presented in this paper.

Radiation measurements often contain erroneous and spurious values due to technical failures and/or operation-related problems. As a result, lack of adequate and high-quality solar radiation data has become a universal problem [21, 22]. GEWEX-SRB is a series of long-term Surface Radiation Budget (SRB) dataset provided by NASA's WCRP/GEWEX (World Climate Research Program/Global Energy and Water Cycle Experiment). An improved (by Pinker/Laszlo) algorithm on shortwave to calculate shortwave radiation was used in the dataset [23]. The algorithm was used to calculate the broadband solar radiation for every time indicated. The Double-flow Eddington approximation model was used to map broadband reflected radiation flux from the top of the atmospheric radiation to ground surface. Furthermore, total reflected radiation flux at the top of the atmosphere was calculated through conversion of narrow-band to broadband in the visible radiation. The angle distribution model was from Earth Radiation Budget Test (ERBE). The satellite observation dataset, SRBREL3.0 shortwave 3 hourly data product [24-26] in the time period from January 1984 to December 2007 was adopted in this research. The spatial resolution is 1° × 1°, and the temporal resolution is 3 hours. All Sky Downward shortwave radiation flux was analyzed.

![Figure 1. Locations of the ten typical cities in Xinjiang](image)

3. Results and Discussion

Comparison of annual variations of shortwave radiation among the three regions. Generally, in Fig.2, the monthly average solar radiation in northern cities was the smallest among the three region sand those in winter were below 200.0 W/m², with a minimum of 138.7 W/m²; it was greater than 150.0
W/m² in the other cities, also the values were relatively concentrated. For both southern and northern cities, the maximums were all close to 400.0 W/m². Differences among cities were significant in spring and summer; it could reach to 150.0 W/m² from maximum to minimum. In autumn and winter, however, radiation value lines of each city almost overlap due to the relatively small differences among cities.

**Figure 2.** (a) Annual variations of solar radiation flux in 5 typical cities in northern Xinjiang and the Tu-Ha Region averaged for the period from 1984 to 2007; (b) Annual variations of solar radiation flux in 5 typical cities in the southern Xinjiang averaged for the period from 1984 to 2007.

Figure 2 (a) shows, in general, Hami had the maximum monthly values followed by Turpan, Urumqi, Yining, Altay. This is mainly related to the cities’ latitudes; the higher the latitude, the smaller the city’s radiation, generally. In June, for example, the largest value appeared in Yining. Maximum values for each city were in different months: April for Turpan, Altay and Urumqi, while August for Hami, and June for Yining.

From Figure 2 (b), the five southern cities in order of radiation values from larger to smaller were Qiemo, Korla, Aksu, Hotan and Kashgar. The gap between Hotan and Kashgar was especially small. In contrast with the values for northern Xinjiang, the radiation values for southern cities were hardly related to their latitudes. Korla has the highest latitude, but its average radiation value ranked second in the five cities, and even first in April, May and June. Hotan has the lowest latitude, but the largest radiation values. Because Hotan is located in the Tarim Basin, under the influence of high concentration desert aerosols, a large part of radiation will be scattered, so the part that reaches the ground will decrease accordingly. Maximum values for two cities appeared in April, Kashgar in July, and Aksu in May.

The monthly average radiation flux for the whole Xinjiang area for the 24 years was 281.0 W/m², with monthly average radiation flux values from 116.78 to 358.97 W/m² shown in Table 1. The maximum appeared in June and minimum in December.

**Table 1.** Monthly solar radiation flux averaged for 10 cities in Xinjiang from 1984 to 2007

| Months | Jan | Feb | Mar | Apr | May | Jun |
|--------|-----|-----|-----|-----|-----|-----|
| Average radiation flux (W/m²) | 131.24 | 180.06 | 242.55 | 304.84 | 346.23 | 358.97 |

Figure 3. The annual variations of solar radiation flux anomalies for the 5 cities in northern Xinjiang and the Tu-Ha Region averaged for the period from 1984 to 2007
The monthly anomalies of solar radiation flux for the five cities in northern and the Tu-Ha Region in Figure 3. In general, radiation flux values for northern cities for most months are lower than that for the whole-Xinjiang average; in southern cities the situation is quite the opposite. Yining and Altay in northern Xinjiang are below the average in all months for the whole of Xinjiang. Radiation flux anomaly in July for Altay in particular, located in most north part of Xinjiang and in the Altai Mountains, can reach up to 78.7 W/m².

The result of five southern cities are shown in Figure 4. In May, June and July, almost all their radiation values are lower than that for the whole Xinjiang; in northern cities the situation is quite the opposite. Yining and Altay in northern Xinjiang are below the average in all months for the whole of Xinjiang. Radiation flux anomaly in July for Altay, located in most north part of Xinjiang and in the Altai Mountains, can reach up to 78.7 W/m².

Specific values of climate tendency rates for each city for each month are shown in Table 2 below, each months’ maximum was shown in bold. We can see that the changing trend in Urumqi was the most obvious with several months’ maximum rate values among all the cities.

### Table 2. Climate tendency rates (W/m²/10) of solar radiation for the ten cities in each months

|       | Jan | Feb | Mar | Apr | May | Jun |
|-------|-----|-----|-----|-----|-----|-----|
| Altay | 0.313 | 5.123 | 5.08 | -4.233 | -2.872 | -6.465 |
| Yining | -1.058 | 3.781 | 1.552 | -0.126 | -4.845 | -10.467 |
| Urumqi | -3.325 | -0.675 | 1.965 | -9.652 | -19.464 | -15.478 |
| Turpan | -1.811 | -1.908 | 2.815 | -2.408 | -10.342 | -4.103 |
| Hami | -0.465 | 0.263 | 1.012 | -0.858 | -0.582 | 4.316 |
|       | Jul | Aug | Sep | Oct | Nov | Dec |
| Altay | -7.978 | 0.96 | 3.967 | 3.19 | -0.463 | -1.59 |
| Yining | -2.1 | 3.513 | 2.803 | 1.148 | -2.296 | -2.088 |
| Urumqi | -13.779 | -11.001 | -4.928 | -3.319 | -3.14 | -1.985 |
| Turpan | -8.804 | -3.622 | 0.481 | 1.946 | 1.756 | 0.171 |
| Hami | 4.525 | 5.366 | 5.789 | 5.94 | 2.871 | 0.873 |
| Korla | -8.024 | -3.51 | 5.847 | 0.544 | 0.145 | 3.542 |
| Aksu | -7.097 | -3.458 | -0.985 | 4.441 | 0.848 | 2.867 |
| Kashgar | -0.193 | -1.2 | 3.984 | 7.974 | 0.666 | 1.296 |
| Qiemo | -6.67 | -3.495 | -1.288 | 5.471 | 3.411 | 0.289 |
| Hotan | -8 | -14.828 | -5.225 | -0.943 | -1.935 | 0.431 |

### 4. Conclusions

As the lack of surface observations limited the scientific basis for exploration of solar energy, in this study GEWEX-SRB dataset from the WCRP/GEWEX (World Climate Research Program / Global Energy and Water Cycle Experiment) from 1984 to 2007 was used to help fill in the information gap over the data-sparse area. The seasonal, annual and inter-annual variations of all sky downward shortwave radiation flux at surface for 10 typical cities in Xinjiang, which is an arid and semi-arid area,
were studied. The main results are summarized as follows.

1) The monthly solar radiation flux average for the 24 years for the 10 cities in Xinjiang was from 116.8 W/m² to 359.0 W/m² with the average value for the whole Xinjiang area was 281.0 W/m². The maximum appeared in June and minimum in December. In general, among the three regions it was the largest for the cities in the Tu-Ha region, the second largest in the south Xinjiang and the smallest in northern Xinjiang.

2) For annual variation, in winter (November, December and January) the solar radiation flux was the smallest. In the northern cities the monthly solar radiation flux was less than 200.0 W/m² with the minimum 138.7 W/m² which occurred in Altay and greater than 200.0 W/m² in the other cities. The maximum of monthly solar flux was between 340.0 W/m² and 400.0 W/m² which most occurred in April, Jun and August.

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