Temporal and spatial distribution of cloud microphysical parameters and surface shortwave radiation over the Tibetan Plateau based on Himawari-8 satellite data

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ABSTRACT: Cloud plays an important role in the energy budget and water cycle process of the earth atmosphere system. Cloud radiation forcing represents the change of radiation balance caused by cloud, which represents the overall effect of cloud on radiation balance. It is an effective method to study the interaction between cloud and radiation and quantitatively describe the influence of cloud on radiation balance of earth atmosphere system. Based on the Himawari-8 geostationary meteorological satellite data, the Clouds and the Earth's Radiant Energy System (CERES) data and ERA5 data, this paper systematically analyzes the temporal and spatial distribution of cloud microphysical parameters combined with the surface downward shortwave radiation characteristics in the Tibetan Plateau, and preliminarily analyzes the spatial and temporal distribution characteristics of cloud shortwave radiation forcing. The results show that: The downward shortwave radiation flux in spring and summer is significantly higher than that in autumn and winter, and the radiation duration in spring and summer is longer than that in autumn and winter. The highest value is in the southwest of the plateau, and the lowest value is in the southeast.

1. Introduction

The existence of cloud greatly affects the accuracy and stability of the extraction of surface and atmospheric information in remote sensing applications(Nakajima et al., 1990 1991). The high-precision and high-efficiency cloud products provide the basis for the study on the mechanism of environmental change in the second scientific examination of the Qinghai Tibetan Plateau (Bao et al., 2019). Among them, the sun synchronous orbit satellite has a very high spatial discrimination, which can distinguish the geostationary satellite data of 1 to 4 km, and can also reflect the changes of cloud layer in different time periods. Clouds will change with time and space. When the weather conditions are relatively difficult during monitoring, the stationary satellite is usually preferred for monitoring (Shang et al., 2018; Randall et al., 2003). Due to the complex terrain and meteorological conditions in the Qinghai Tibetan Plateau, there are few effective observation stations and it is difficult to observe. Satellite observation is one of the effective means of energy balance observation in plateau area. However, due to the low spatial-temporal resolution and the difficulty of radiometric calibration, the previous geostationary satellite data are difficult to be effectively used in the study of radiation balance parameters. Therefore, the existing satellite observations in the plateau mainly focus on the polar orbit satellite data with one or two observations. It leads to the uncertainty of daily mean value and seasonal variation analysis parameters. The new generation of Himawari-8 geostationary satellite has the characteristics of high spatial-temporal resolution and spectral resolution. The cloud microphysical characteristics and shortwave radiation products of Himawari-8 provide new opportunities and important data for the study of the balance of radiation energy budget in the Tibetan Plateau.

2. Data and Methods

2.1. Data

Himawari-8 geostationary meteorological satellite carries the world's advanced next generation meteorological observation sensor AHI (Advanced Himawari Imager). Compared with previous stationary satellite sensors, Himawari-8 achieves higher spatial, temporal and spectral resolutions. The specific parameters are shown in Table 1.

Table 1 Himawari-8 satellite products

Product	Parameter	Unit	Resolution
H-8 L2 cloud products	COT	-	10 min, 5km
	CER	μm	
H-8 L2 radiation products	SSR	Wm^{-2}	

ERA5 is derived from the reanalysis data set (ERA-Interim) of European Center for medium range weather forecasts (ECMWF). The ERA5 dataset consists of a high-resolution implementation (called "reanalysis") and a reduced resolution set of ten members (called "sets"). In general, these data are provided on a daily and monthly basis and consist of analysis and short (18 hour) forecasts, initialized twice a day from the analysis of 06 and 18 UTC. The parameters of SSR, SSRC, ssrd and ssrdc of ERA5 data are used in this paper. The horizontal resolution is (0.25° × 0.25°).

The CERES energy budget and fill dataset is generated using measurement data from multiple instruments. It includes CERES and MODIS instruments (descending sun synchronous orbit, crossing the equator at 10:30 a.m. local time) and aqua (rising sun synchronous orbit, crossing the equator at 1:30 p.m. local time), and geosynchronous imager, which provides daytime information between 60° and 60° N per hour, CERES instruments measure shortwave (SW, wavelength between 0.3 and 5 μm). The CERES instrument provides global coverage every day, while the monthly average regional flow is based on daily complete samples of the whole world with a horizontal resolution of (1° x 1°).

2.2. Research contents and methods

In order to improve the understanding of cloud microphysical parameters and radiation characteristics over the Tibetan Plateau, this study intends to systematically analyze the temporal and spatial distribution of cloud microphysical parameters and surface downward shortwave radiation characteristics over the Tibetan Plateau based on the Himawari-8 geostationary meteorological satellite data, and verify with ERA5 data and CERES data in the same period. At the same time, the temporal and spatial distribution characteristics of radiative forcing are calculated and analyzed. The specific flow chart is shown in Fig. 1.

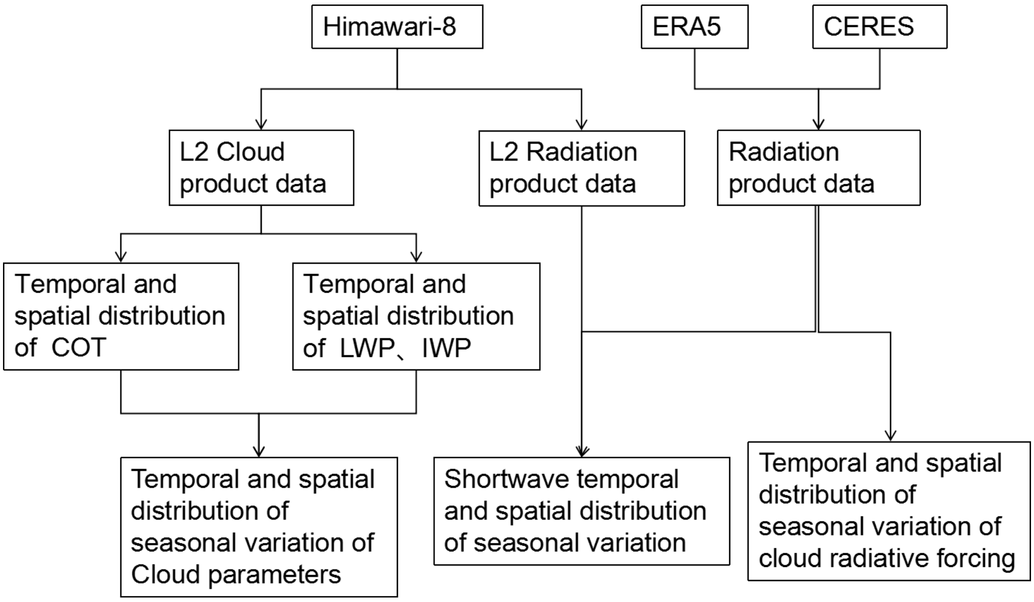


Figure 1 flow chart of the research

Cloud water quantity is the main physical quantity reflecting cloud water resources. The research on the characteristic mechanism and evolution law of cloud water amount can provide reference for climate change research and reducing the uncertainty of cloud simulation in climate model. Cloud water content refers to the sum of liquid and solid cloud water content in unit atmospheric column. It is the physical quantity of cloud water content in the atmosphere, and its size can reflect the abundance of cloud water resources in the region.

If the climate system is in equilibrium, the solar energy it absorbs will be exactly equal to the infrared radiation emitted from the earth and the atmosphere. Any factor that can disturb this balance and thus change the climate is called radiative forcing factor, and the forcing on the earth and atmosphere system caused by them is called forced radiation (IPCC, 1990). CRF (radiative forcing of clouds) is defined as the difference between the net solar radiation flux (downward flux minus upward flux) of a given atmosphere and the net solar radiation flux of the same atmosphere when the cloud does not exist. This definition is applicable to both the surface and the atmospheric top (TOA).This study is based on the surface downward shortwave radiation data of ERA5 in 2016, and calculates the shortwave radiation forcing according to formula (1), where the four terms on the righthand are surface clear-sky upward shortwave flux, cloudy upward shortwave flux, clear-sky downward shortwave flux and cloudy downward shortwave flux, respectively.

$$W = S_{clr\uparrow} + S_{\uparrow} + S_{clr\downarrow} - S_{\downarrow} \quad (1)$$

3. Results

As shown in Figure 2, the shortwave radiation in spring and summer is significantly higher than that in autumn and winter, and the radiation duration in spring and summer is longer than that in autumn and winter. In terms of spatial resolution, the highest value is in the southwest of the plateau, and the lowest value is in the southeast of the plateau. Among them, rivers and lakes in some areas will lead to weak surface radiation. In terms of time resolution, the shortwave radiation is the strongest from 11:00 to 13:00 in all seasons of the Qinghai Tibetan Plateau, and summer > spring > autumn > winter. Compared with the cloud optical thickness map, the shortwave radiation is also weak in the places with large cloud optical thickness, especially in the Himalayas and Hengduan Mountains. In some special terrain, such as Sichuan Basin, due to the blocking of Himalayas, more rainfall is formed, and the cloud layer is thick, which leads to poor solar radiation reduction, resulting in weak radiation (Gui et al., 2010). However, on the whole, the altitude of Qinghai Tibetan Plateau is higher, the atmosphere is thinner, the solar radiation is stronger than other plain areas, and the higher the altitude, the stronger the solar radiation(Chen et al., 2014).

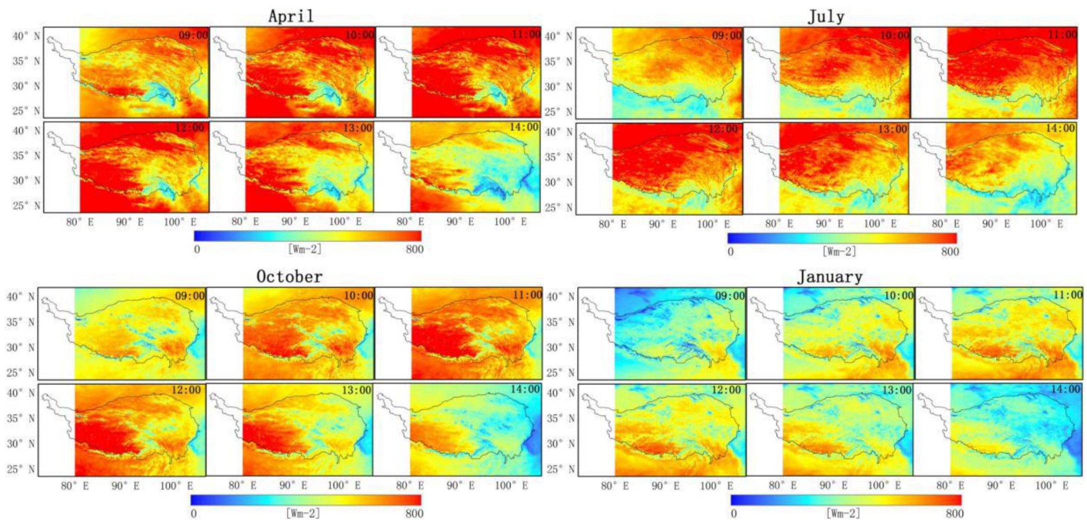
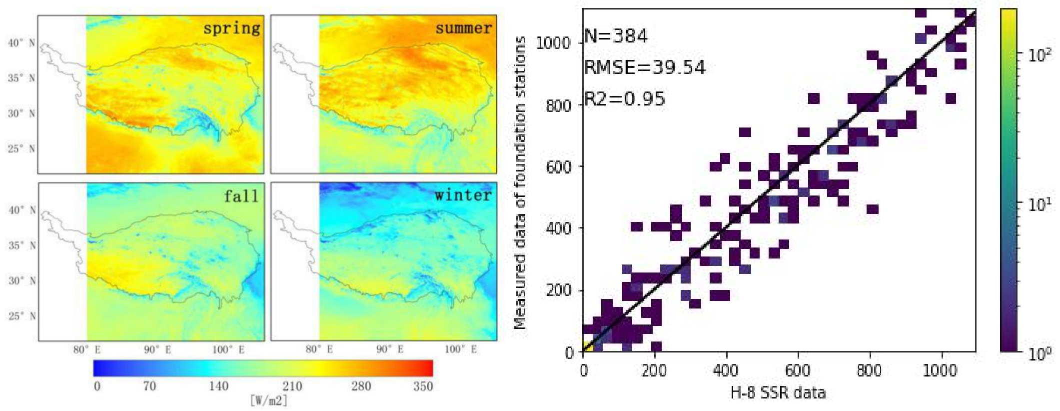


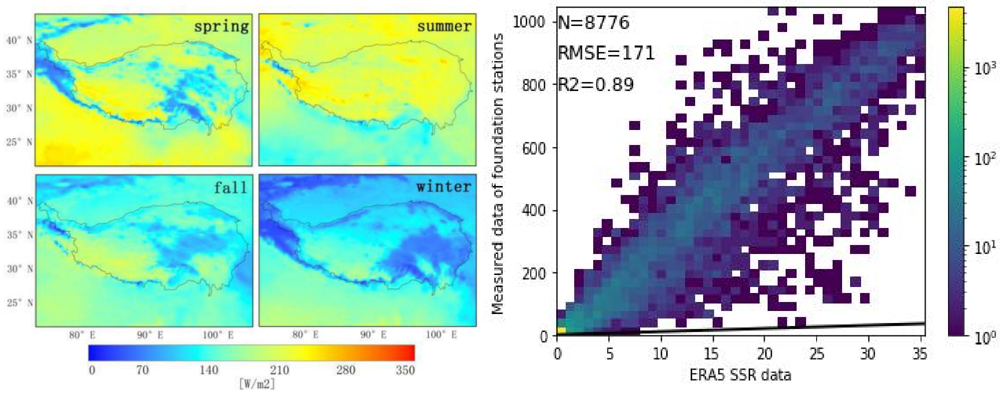
Fig. 2 the average radiation map of Himawari-8 L2 shortwave radiation product data in January, April, July and October 2016 in Qinghai Tibetan Plateau from 9:00 to 14:00(LT).

As shown in Figure 3, the seasonal variation of surface shortwave radiation calculated by Himawari-8 data, ERA5 data and CERES data. In summer, the radiation flux is generally high due to the long sunshine time, while it is generally low in winter. In spring and autumn, it is high in the southwest, low in the East and south, low in the South and high in the north in summer, high in the South and low in the North in winter, which is consistent with the previous analysis. There is a big difference between the new generation geostationary satellite data and reanalysis data. The surface shortwave radiation flux of Himawari-8 data is higher than that of ERA5 data in each season. CERES data and Himawari-8 data are relatively close, ERA5 data resolution is higher, CERES data resolution is lower, but the spatial and temporal distribution of the three data are relatively similar.

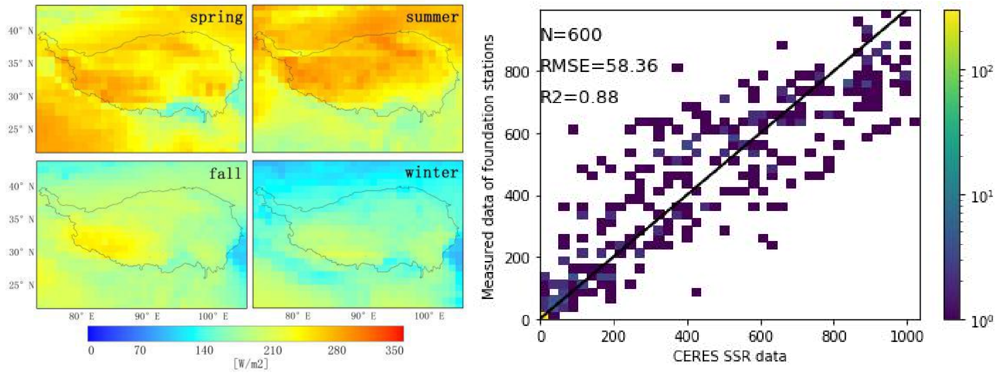
Comparing the three satellite data with the measured data of ground-based stations, the number of samples of Himawari-8 data is at least 384, R^2 is 0.95, and RMSE (root mean square error) is 39.45. ERA5 data had 8776 samples, R^2 was only 0.89, RMSE was 171, the accuracy was the lowest. The number of CERES samples was 600, R^2 was 0.88, and RMSE was 58.36. It can be seen that the Himawari-8 data is the closest to the curve value of the foundation station, and the change trend is the same. The next is CERES data, and ERA5 data has the largest difference.



(a)Himawari-8



(b)ERA5



(c)CERES

Fig. 3 seasonal map of surface downward shortwave radiation (a) himawari-8, (b) ERA5, (c) CERES.

4. Conclusion

In this study, the spatial and temporal distribution of cloud microphysical parameters combined with the characteristics of the surface down wave radiation is systematically analyzed by using the Himawari-8 geostationary meteorological satellite data, and the spatial and temporal distribution characteristics of the cloud's shortwave radiation forcing are analyzed. The seasonal map of shortwave radiation distribution shows that the shortwave radiation in the Qinghai Tibetan Plateau is significantly higher in spring and summer than in autumn and winter, and the radiation duration in spring and summer is longer than that in autumn and winter. The highest value is in the southwest of the plateau, and the lowest value is distributed in the southeast, and shows the trend of the West High and low East, and the radiation from west to East is gradually weakening. Some of the rivers and lakes in some areas will cause the surface radiation to be weak. The shortwave radiation in the Qinghai Tibetan Plateau is the strongest in the four seasons from 11:00 to 13:00, and there is obvious daily variation law. The new generation of static satellite data is different from reanalysis data, and the surface shortwave radiation flux of Himawari-8 data is higher than that of ERA5 data in each season. CERES data is close to Himawari-8 data, ERA5 data has higher resolution and lower resolution of CERES data, but the spatial and temporal distribution of CERES data is similar as a whole.

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