Comparing FY-2F/CTA products to ground-based manual total cloud cover observations in Xinjiang under complex underlying surfaces and different Weather Conditions

Shuai Li[1, 2], Hua zhang[2*], Yonghang Chen[1], Zhili Wang[2, 3], Xiangyu Li[4], Yuan Li[5] Yuanyuan Xue[5]

5   [1]College of Environmental Science and Engineering Donghua University, Shanghai 201620, China
[2]State Key Laboratory of Severe Weather, Chinese Academy of Meteorological Sciences, Beijing 100081, China
[3]Key Laboratory of Atmospheric Chemistry of CMA, Chinese Academy of Meteorological Sciences, Beijing 100081, China
[4] School of Materials and Chemical Engineering, Pingxiang University, Pingxiang, Jiangxi 337000, China
[5]China energy Xinjiang Jilintai Hydropower Development Co., Ltd, Nilka, Xinjiang 835716, China

10   *Correspondence to:* Hua zhang (huazhang@cma.gov.cn)

Abstract. Clouds are an important parameter of artificial water augmentation, which are of substantial significance to judge the precipitation capacity. Xinjiang is an arid region in Northwest China, where weather stations are sparsely distributed, the types of underlying surface are complex and the climate difference between southern and northern Xinjiang varies greatly. However, the retrieval of the total cloud cover (TCC) from satellite in arid areas is a challenging task. Based on the hourly

15   data of TCC observed by ground observation stations from June 2015 to May 2016, considered the complex underlying surfaces and different weather conditions, the precision, consistency and error between the cloud total amount products of FengYun-2F stationary satellite (FY-2F/CTA) and manually observed TCC are compared and evaluated in Xinjiang region. The findings of this study are as follows: (1) The precision rate (PR) of FY-2F/CTA in Xinjiang region is 74.6 %, which gradually decreases from north to south, demonstrating a high false rate (FR) and a low missing rate (MR); The consistency

20   rate (CR) is 51.5 %, with little difference among three sub-regions of Xinjiang, all showing high weak rate (WR) and low strong rate (SR), which means that the TCC inverted from FY-2 satellite data are generally lower than that observed by ground observation stations, especially in Southern Xinjiang; The Bias is -20 %, and all the error indexes (EIs) including Bias, AE and RMSE increase from central to the north and south of Xinjiang, that means the EIs are the lowest in Tianshan Mountains, and the highest in Southern Xinjiang. The PR and CR of FY-2F/CTA in the vegetation underlying surface are

25   better than those of non-vegetation, that is to say, FY-2F/CTA have the best identification effect on the forest and plowland underlying surfaces, and the worst effect on the snow and ice underlying surface. (2) With the increase of temperature, the PR and CR of FY-2F/CTA increase, while the EIs decrease; Under various temperature conditions, FY-2F/CTA have always been exhibiting high MR, low FR (on the contrary in January), high WR and low SR. From low elevation to high elevation, the PR and CR of FY-2F/CTA decrease, but the PR increases significantly when the altitude is higher than 2000 m. (3) Dust

30   reduces the CR of FY-2F/CTA, increases the SR, but it has little effect on the identification of cloud and non-cloud. (4) Under different cloud cover levels, the PR and EIs of FY-2F/CTA are proportional to the amount of TCC, while the CR is inversely proportional to it, that is, the CR is higher, the PR and EIs are lower under clear sky and partly cloudy conditions, and the CR is lower, the PR and EIs are higher under cloudy and overcast conditions. This study is the first to evaluate the

35 FY-2F/CTA on the scales of complex underlying surface, various temperature and altitude, dust effects and different cloud cover levels in arid areas of Xinjiang. Thus, the results would provide an important reference for satellite retrieval and application of TCC in arid areas.

1 Introduction

Clouds are one of crucial element of weather and climate characteristics, they affect atmospheric movement and the earth's climate through three mechanisms: radiative forcing (Li et al., 2019; Kiran et al., 2015; Haynes et al., 2013), latent heat

40 forcing (Loeb et al., 2018) and convective forcing (Slingo and Slingo, 1988; Guo et al., 2015; Li et al., 2017) . In addition, clouds can influence the climate system indirectly through interactions with aerosols (Boers et al, 2006; Zhou et al, 2020), the feedback effect of climate change can also directly lead to change in cloud characteristics simultaneously(Harrison et al., 1990; Errico et al., 2007; Chepfer et al., 2014), for every 1 ℃ increase in global temperature, the content of water vapor in the atmosphere will increase by about 7 % (Boucher et al., 2013), the variation of water vapor can affect the occurrence,

45 development and extinction of clouds, and change cloud cover, cloud albedo and cloud microphysical properties (Zhang et al., 2022). The World Climate Research Programme (WCRP) lists understanding clouds, atmospheric circulation and climate sensitivity as one of the key scientific challenges currently facing the climate community (Bony et al., 2015), as an important component of climate feedbacks, cloud feedbacks are one of the largest sources of uncertainty in simulating current climate and predicting future climate change (Bony et al., 2006; Zelinka et al., 2017). Cloud cover, as one of significant cloud

50 parameters, can directly or indirectly affect the research on climate change, weather or climate models by taking advantage of the cloud macro and micro parameters, radiation parameters, water vapour and precipitation, aerosols and other physical quantities (Chen et al., 2000; Betts et al., 2014; Ceppi et al., 2017). An accurate understanding of the spatial distribution and temporal evolution of cloud cover is the basis for conducting research on atmospheric radiation, energy and water cycles, climate analysis and numerical models. It is of great significance for gaining insight into the complex interactions between

55 clouds and the terrestrial system, and thus for better understanding climate change (Pavolonisand Key, 2003; Ronald et al., 2007; Guo et al., 2015b).

At present, the conventional ground-based cloud cover observations, global reanalysis cloud products (NECP, ERA, etc.) and the total cloud cover (TCC) retrieved by satellite remote sensing (including ISCCP, MODIS, NOAA series and CloudSat, etc.) are the most common cloud cover data. They are extensively applied in analysis of cloud parameters and climatological

60 characteristics (Sun, 2003; Ding et al., 2004; Danso et al., 2019), satellite inversion and validation (Yousef et al., 2020; Yang et al., 2020), in particular, the cloud parameters of satellite inversion are usually compared with those of cloud radar, lidar, spectral imager and ground observations (Kotarba, 2009; Wang and Zhao, 2017). A great deal of research has been carried out by experts in the field of inspection and evaluation of cloud products. Werkmeister et al. (2015) compared cloud

fractional cover (CFC) measured by radiometers on polar satellites AVHRR and on one geostationary satellite SEVIRI to
ground-based manual SYNOP and automated observations by a cloud camera Hemispherical Sky Imager (HSI), and found in
general good agreement between satellite-derived estimated compared to HSI with biases ranging from 2 % (AVHRR) to
8 % (SEVIRI) and standard deviations of 22 % (AVHRR) and 29 % (SEVIRI) for instantaneous results, and also found that
SYNOP underestimated CFC by 6±19 % compared to HSI and SEVIRI. Free et al. (2016) compared a homogeneity-adjusted
dataset of TCC from weather stations in the contiguous United States with cloud cover in four global reanalysis products,
including the Climate Forecast System Reanalysis from NCEP (CFSR), the Modern-Era Retrospective Analysis for Research
and Applications from NASA (MERRA), ERA-Interim from ECMWF (ERA-Interim), and the Japanese 55-year Reanalysis
Project from the Japan Meteorological Agency (JAR-55), the result showed that TCC from ERA-Interim and CFSR had the
best correlation with weather station, followed by JRA-55 and MERRA had the lowest correlation. Sun et al. (2015)
concluded that average cloud cover in the United States from AVHRR Pathfinder Atmospheres Extended (PATMOS-x) with
station observations, including 54 National Weather Service (NWS), Federal Aviation Administration (FAA) stations and 101
military stations, showed the closest trend, followed by ISCCPs, with CLARA-A1 (AVHRR Data Edition 1) showing a
larger negative trend. Wu et al. (2014) found that in the United States, Active Remote Sensing of Clouds (ARSCL) and
International Satellite Cloud Climatology Project (ISCCP) have higher cloudiness than surface observations, this was the
same as the research results in China, where the ISCCPD2 total cloud cover products (TCCPs) were 8.46 % higher than the
ground observation (Wang and Wang, 2009), the accuracy of ISCCP TCCPs in January is better than that of MODIS, while
the MODIS TCCPs in July was slightly better than that of ISCCP (Liu et al, 2009), NOAA/AVHRR TCCPs could better
reflect the variation characteristics of TCC in China, However, the amount of TCC was slightly lower than that observed at
the ground observations (Liu et al., 2016). In addition, many experts have done a lot of research in the development and
validation of TCCPs of FY-2 series satellite, and some research results indicate that in China, FY-2 satellite observed cloud
products were lower relative to ground-based manual observations and also slightly lower than the MODIS calculated
TCCPs, but the overall trend was comparable (Li et al., 2018; Liu et al., 2017; Han et al. , 2015). However, the results of Xi
et al. (2013) showed the data set of TCCPs in East Asia retrieved by FY-2 and GMS were higher in magnitude than that
observed by the ground-based observations in the north of 40°N. Few studies related to clouds in the Xinjiang region, and
only some scholars have analyzed the cloud characteristics of Xinjiang, Feng et al. (2014) analyzed the characteristics of
different types of cloud heights in Xinjiang mountainous area by using CloudSat data; Based on FY-2F data, Li et al. (2019)
analyzed the distribution and difference of cloud cover in mountainous and basins of Xinjiang.

Xinjiang is a typical arid and semi-arid region, and the shortage of water resources has become a "bottleneck" problem in the
development of social economy and ecological construction in Xinjiang. Clouds are an important parameter of artificial
water augmentation, which are of substantial significance to judge the precipitation capacity. TCC observed by satellite is
more suitable for revealing the cloud climate characteristics on a large range, and has absolute advantages in the regions

where stations are scarce and data are lacking, such as plateau, desert and ocean. Xinjiang is a vast and sparsely populated area with extremely low spatial coverage rate of ground-based conventional observation stations, which is more suitable for satellite observation. How to use satellite observations to complement ground-based observation has become an urgent issue. The accuracy assessment of cloud cover retrieved by satellite is the basis of application and also a challenging task.

100   FengYun-2F (FY-2F) is the fourth geostationary satellite developed by China independently, which can provide observation data every half an hour, enabling better monitoring of the whole process of cloud formation, development and extinction. In this paper, the examination and evaluation of the cloud total amount products of FengYun-2F stationary satellite (FY-2F/CTA) are carried out using ground-based manually observed TCC and considering complex underlying surface (subsurface types, temperature and altitude conditions) and different weather conditions (dust effects and different cloud cover levels) with

105   Xinjiang as the examination region, with a view to providing valuable references for the application and research of FY-2 cloud products.

2. Research area, data and methods

2.1 Research area

Xinjiang (Figure 1) is located in the hinterland of the Eurasia and characterized by a typical temperate continental arid

110   climate. It is a core component of the world's largest non-zonal arid zone (the Central Asian arid zone) and occupies an extremely important position in the northern hemisphere climate system, with an average annual precipitation of only about 150 mm, which is representative of the global arid zone (Yao et al., 2018). With a complex topography of "three mountains sandwiched by two basins" and a unique landscape, mountains and basins account for 42.7 % and 57.3 % of the total area of Xinjiang region, respectively. The annual average TCC in Xinjiang is 37.7 %, showing a pattern of "less in the east and more

115   in the west; less in the south, more in the north; less in plains and basins, more in mountains "(Li et al., 2019).

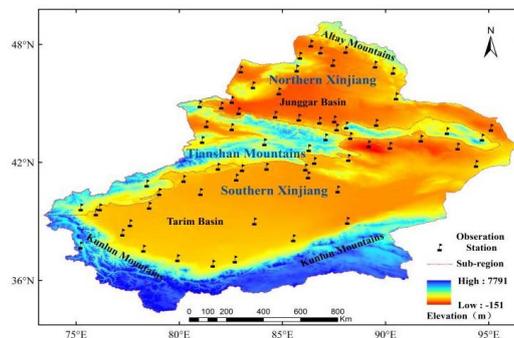



Figure 1. Overview of the geographic location and topography of Xinjiang with three mountain.

ranges (Altai Mountains, Tianshan Mountains and Kunlun Mountains) and two basins (Tarim Basin and Junggar Basin). The

red dashed polygons indicate the three sub-regions (NX, SX, and Tianshan).

2.2 Research data

The data used in this paper mainly include: hourly data of manually observed TCC by 66 ground observation stations in Xinjiang from June 1, 2015 to May 30, 2016 obtained from the information center of Xinjiang; FY-2F/CTA customized from the data service network of National Satellite Meteorological Center (http://satellite.nsmc.org.cn/portalsite/default.aspx)from June 1, 2015 to May 30, 2016, with a spatial resolution of 0.1º×0.1º, the time resolution is 1h.

2.3 Research methods

FY-2F/CTA is calculated by formula Eq. (1). That is, firstly, by calculating the radiation value of clear sky and full cloud for a certain pixel; Secondly, by using the radiation formula according to the actual radiation value of the pixel at a certain time (Liu et al., 2017).

$$Ac = (I-I_{clr})/(I-I_{cld}) \qquad\qquad (1)$$

Where Ac is the TCC; I_{clr} is the radiation value of full cloud pixels; I_{cld} is the radiation value of clear sky pixels, I is the actual radiation value of the pixel at a certain time.

The specific data processing methods are as follow. Firstly , the FY-2F/CTA hourly products are spliced, projected, resampled and cropped, where the projection method is Mercator projection, the nearest neighbor method is used for resampling. Secondly, selecting ground-based observations that match the timing of satellite observations, and the abnormal observations are eliminated through the spatial distribution of the ground observation stations, and the stations with continuous observation for more than 20 days are selected for the preliminary quality control of the ground observation data; Finally, the satellite cloud cover data are extracted according to the time, longitude and latitude information of the ground observation stations, and the TCC observed by the ground observation stations are matched with those observed by the satellite.

The matching principles are as follows. ① When the observation of ground station is clear sky and the satellite observation is also clear sky, it would be judged as an effective clear sky detection point of satellite, which is recorded as Nn; ② When the observation of ground station is cloud and the satellite observation is also cloud, it would be deemed as an effective cloud detection point of satellite, which is recorded as Yy; ③ When the observation of ground station is clear sky but the satellite detection result is cloud, it would be judged that the satellite misjudgment and be recorded as Ny; ④ When the observation of ground station is clear sky, but the satellite detection result is cloud, then the effective cloud arithmetic average is performed on the points in a certain area around the point, and if it is still clear sky, then the satellite is judged to have missed the detection, this point is recorded as Yn.

The precision analysis of FY-2F/CTA include precision rate (PR), False rate (FR) and missing rate (MR), which are calculated by Eq. (2) to Eq. (4) respectively:

$$PR = \frac{Yy+Nn}{Yy+Yn+Ny+Nn} \times 100\% \qquad (2)$$

$$FR = \frac{Ny}{Yy+Yn+Ny+Nn} \times 100\% \qquad (3)$$

$$MR = \frac{Yn}{Yy+Yn+Ny+Nn} \times 100\% \qquad (4)$$

For the consistency analysis of FY-2F/CTA, they are considered to be correct that absolute values of the difference between FY-2F/CTA and ground-based manual TCC observations are less than or equal to 2; they are considered to be stronger that the values of difference are greater than 2, they are considered to be weaker that the values of difference are less than -2; Then the consistency rate (CR), strong rate (SR) and weak rate (WR) can be expressed as Eq. (5) to Eq. (7) respectively:

$$CR = \frac{NR_k}{NR_k+NS_k+NW_k} \times 100\% \qquad (5)$$

$$SR = \frac{NS_k}{NR_k+NS_k+NW_k} \times 100\% \qquad (6)$$

$$WR = \frac{NW_k}{NR_k+NS_k+NW_k} \times 100\% \qquad (7)$$

Where NR_k represents the number of times that FY-2F/CTA are correct for a station during the test period, NS_k means the number of times that FY-2F/CTA are stronger and NW_k means the number of times that FY-2F/CTA are weaker.

Using the ground-based manual TCC observations as true values, the error analysis between FY-2F/CTA and ground-based manual TCC observations include Bias, absolute error (AE) and root mean square error (RMSE), which are calculated by Eq. (8) to Eq. (10) respectively:

$$Bias = \frac{1}{N}\sum_{i=1}^{N}(X - X_0) \qquad (8)$$

$$AE = \frac{1}{N}\sum_{i=1}^{N} abs(X - X_0) \qquad (9)$$

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(X - X_0)^2} \qquad (10)$$

Where N represents the number of matched samples, X is the data being tested and X_0 is the test source data.

3 Result and discussion

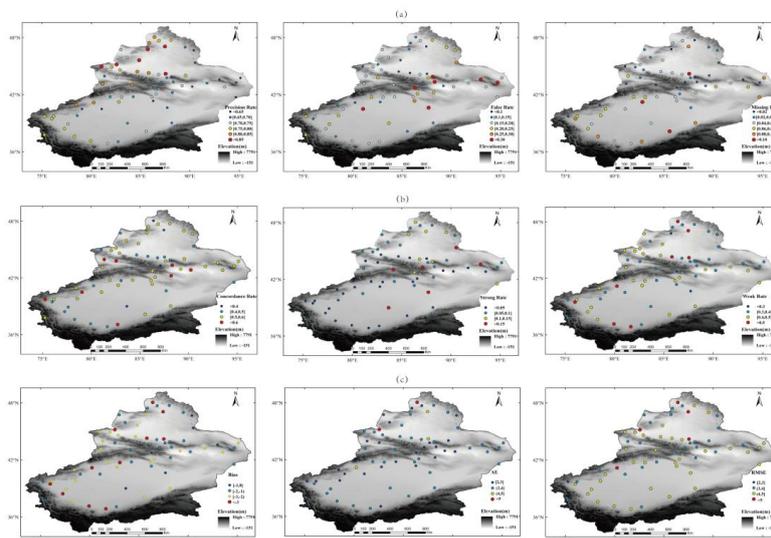
3.1 The difference between FY-2F/CTA products and Manual observed TCC in complicated underlying surface of Xinjiang

3.1.1 Different underlying surface types

Due to the fragmentation of complex terrain, the climate in different regions of Xinjiang varies widely, therefore, this paper calculates and analyzes the precision, consistency and error of FY-2F/CTA in Northern Xinjiang (NX), Tianshan Mountains (Tianshan) and Southern Xinjiang (SX) (Figure 2). It can be seen that the PR of FY-2F/CTA in Xinjiang region is about 74.6 %, and that in NX, Tianshan and SX is 79.5 %, 75.5 % and 72.6 % respectively, showing a decreasing trend from north

to south. The FR is higher than the MR overall, with the highest FR in the Tianshan and the highest MR in the SX. This conclusion is consistent with MODIS TCCPs, in contrast to the NOAA/AVHRR TCCPs. The study shows (Liu et al., 2017) that MODIS/Aqua TCCPs present high FR and low MR, mainly due to the 1.375 gm channel of MODIS, which is dedicated to detecting cirrus cloud in the upper atmosphere. In addition, several channels such as 6.715, 7.325 and 13.935 gm channels, can be used to assist in the detection of cirrus cloud, which reduce the MR of cirrus cloud detecting. However, the TCCPs that calculated by NOAA/AVHRR show high MR, mainly due to the translucent characteristics of thin cirrus cloud, whose reflectance of visible channels and bright temperature of infrared channels are not obvious. Of the five detection channels available to NOAA/AVHRR, although it is possible to detect thin cirrus cloud with the bright temperature difference of the infrared split window, the detection accuracy is not high.

The CR of FT-2F/CTA does not vary significantly among three sub-regions of Xinjiang, maintaining at about 51.5 %. The TCCPs observed by FY-2 satellite are lower than that observed by the ground observation stations on the whole, that is, FT-2F/CTA products show high WR and low SR, and the WR is highest in SX, and the SR is highest in Tianshan. FY-2F/CTA products are calculated in a certain field of view by using the radiation value,which takes into account the emissivity of cloud and solves the problem of some sub-pixel cloud, but the effective cloud cover obtained from the calculation is relatively small; The ability of satellite to detect high cloud is better than that of low cloud, the main reason is that low cloud is closer to the ground and have less variability, the result of satellite cloud detection algorithm could easily misjudge low cloud as surface, which would underestimate the cloudage, while the Tarim Basin, which occupies most of SX, is dominated by stratocumulus (Li et al., 2019), so WR is much higher than SR in SX. This conclusion is the same as the NOAA/AVHRR TCCPs, and contrary to the MODIS/Aqua TCCPs. Compared with the TCC observed by the ground observation stations, TCCPs calculated by NOAA/AVHRR are smaller, but TCCPs obtained by MODIS/Aqua present larger, and the TCCPs retrieved by FY-2 are lower than that retrieved by MODIS/Aqua (Liu et al., 2017)。

The errors of FT-2F/CTA in three sub-regions of Xinjiang are high overall, and all the error index (EIs) including Bias, AE and RMSE show increasing trend from the central to the north and south of Xinjiang, that is, the EIs are the lowest in Tianshan, and the correlation coefficient between FY-2F/CTA and ground-based manual TCC observations is high, about 0.65; While the EIs in NX and SX are high, and the correlation coefficients are slightly low, especially in NX, only 0.52 (Figure 3). This may be mainly due to the fact that satellite cloud observation is to observe from upper air downwards, and what is observed is mostly high cloud, while ground-based observation is to observe cloud from the ground upwards, and what is observed is mostly medium and low cloud. In addition, there is a certain subjectivity in the ground-based manual cloud observation, and when the cloud in the sky cannot be identified or not fully identified due to snow, fog, sand and other weather phenomena, they would affect the accuracy of cloud observation, make the difference between satellite observation and ground-based manual TCC observation larger. In this study, the reasons for the differences will be analysed in detail in terms of complex subsurface types, various temperature and altitude conditions, dust effects, and different cloud levels.

210   **Figure 2. The precision, consistency and error spatial distribution map of FY-2F/CTA products in Xinjiang.**

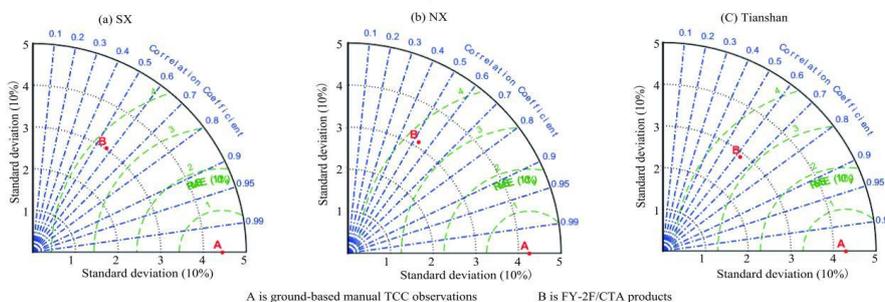



Figure 3. Taylor diagrams between FY-2F/CTA products and ground-based manual TCC observations

in different regions of Xinjiang.

215

Xinjiang is a vast territory with complex underlying surface types, in order to investigate the influence of diverse underlying

surfaces on the difference between FY-2F/CTA and ground-based manual TCC observations, this study selects typical

underlying surfaces in Xinjiang, including snow and ice, desert, city in non-vegetated region, grassland, forest and plowland

in vegetated region, compares and analyzes the precision, consistency and error of FY-2F/CTA under complex underlying

220   surfaces (Figure 4). It can be seen that the PR, CR and EIs of vegetation region are better than those of non-vegetation region,

with the highest accuracy in the underlying surface of forest and plowland, and the lowest accuracy in the underlying surface

of snow and ice; The MR in the vegetation area is higher (grassland is the highest), and the FR in the non-vegetation area is

higher (snow and ice is the highest); The WR is higher than the SR in all kinds of underlying surfaces, but the difference is

not significant in the underlying surface of snow and ice.This is mainly due to the fact that the approximate distribution of

225   albedo for different underlying surfaces range from 0.2-0.46 for desert, 0.15-0.25 for grassland, 0.1-0.2 for forest, 0.75-0.95

for snow (clean), 0.25-0.75 for snow (wet and dirty). And according to the extracted temperature results of Kang et al. (2022)

using MOD11C3, the annual mean values of land surface temperature (LST) for different underlying surfaces are 2.57℃ for

grassland, 9.03℃ for forest, 10.27℃ for plowland, 11℃ for city and -7.01℃ for snow and ice respectively. In the process of

FY-2 TCCPs retrieval, the underlying surface of snow and ice has a high reflectance and low surface temperature, and the

230   difference between it and cloud is small, making it hard to distinguish snow and ice from cloud, especially at night, when it

will be more hard to identify without visible channel data. Therefore, the PR of FY-2F/CTA in snow and ice underlying

surface is low, and the FR is high; The characteristics of forest are opposite to those of snow and ice underlying surface, and

the difference between forest and cloud is great, so the effect of identification is relatively good.

235

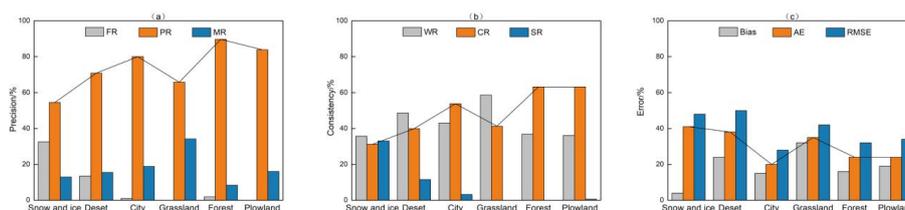



Figure 4. The precision, consistency and error of FY-2F/CTA products in complicated underlying surface of Xinjiang.

3.1.2 Under different temperature conditions

Xinjiang belongs to temperate continental climate and plateau mountain climate with average temperatures of -4.46℃ in

240   January, 26.73℃ in April, 38.66℃ in July and 19.52℃ in October (Kadiayi Alemu, 2021). In this paper the precision,

consistency and error of FY-2F/CTA under different temperature conditions are analyzed by using January, October, April

and July to represent winter, spring, summer and autumn respectively. Figure 5 is the scattered point of the FY-2F /CTA and

ground-based manual TCC observations in Xinjiang region. It can be seen that the of FY-2F/CTA are lower than those of

ground-based manual TCC observations in general, especially in April; The correlations between FY-2F/CTA and

245   ground-based manual TCC observations are best in July and October, and worst in January. The amount of TCC inverted

from FY-2 satellite data are generally lower than that observed by ground observation stations, with the greatest degree of

underestimation in April; the correlation between the two is best in July and October, and worst in January. This is basically

consistent with the test results of the North China and Huanghuai regions carried out by Han et al. (2015), that is, the

correlation coefficient between FY-2/CTA and ground-based manual TCC observation is the largest in May at 0.92 and the

250   smallest in January at 0.56 .

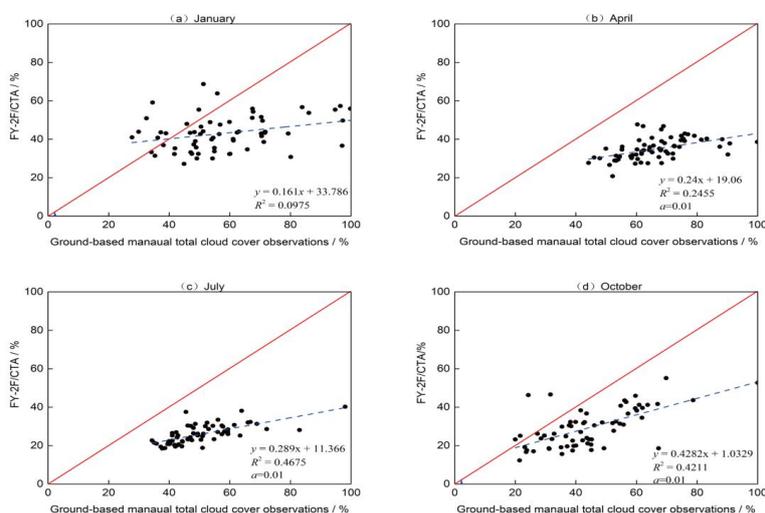



Figure 5. The scatter plot of FY-2F /CTA and ground-based manual TCC observations in Xinjiang

Figure 6 shows boxplot of the precision, consistency and error of FY-2F/CTA under different temperature, it can be seen that

255   the PR of FY-2F/CTA in Xinjiang region increases with the increases of temperature, that is, it is high in July, about 76 %, and low in January, about 66 %, and decreases from the central region to the north and south regions; When the temperature is above 0℃, it presents a high MR and a low FR, and when it is below 0℃, it is on the contrary, that is, it shows a high FR and a low MR in January. The CR is higher in July and October (52 % and 67 %, respectively) than in January and April (50 % and 45 %, respectively), and it decreases from the central to the north and south of Xinjiang in April, increases from

260   the north to the south of Xinjiang in July. Under various temperature conditions, it shows a high WR and a low SR. The EIs are high in January and low in July, which increase from the central to the north and south of Xinjiang. That is, the EIs are the lowest in Tianshan and highest in SX, but they are high in January in three sub-regions of Xinjiang. This mainly caused by the fact that the higher the temperature, the greater the difference in temperature between land and the cloud top, and the better the discrimination. Moreover, in January, the region north of Tianshan and some mountainous areas in SX are covered

265   by snow, therefor, the PR of FY-2F/CTA in Xinjiang in January is low and it's EIs are large, which may also be related to the misjudgment between cloud and snow.

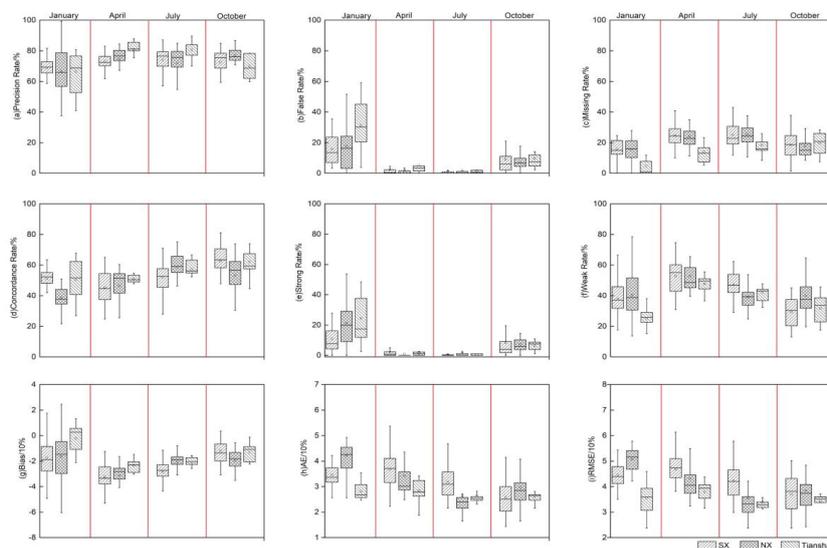



Figure 6. The precision, consistency and error box plot of FY-2F/CTA products in different temperature conditions of Xinjiang

270

3.1.3 Under different altitude conditions

The altitude will affect the LST, for every 100m increase in altitude, the LST would drop by approximately 0.52°C. When the temperature difference between cloud top and underlying surface in clear sky is very small, it is difficult to distinguish between the cloud pixels and the non-cloud pixels, which could affect the cloud recognition. The altitude of Xinjiang is

275   divided into four levels: less than 1000 m, 1000-1500 m, 1500-2000 m and greater than 2000 m in this paper. Figure 7 shows the precision, consistency and error of FY-2F/CTA products at different altitude of Xinjiang. It is observed that with the increase of altitude, the PR and CR of FY-2F/CTA present a decreasing trend, but the PR increases significantly when the altitude is greater than 2000 m. The reason for this may be mainly due to the fact that in mountainous areas with higher altitude, the cloud cover is high, and the cloud pattern mainly consists of altostratus or nimbostratus, cirrostratus, and the

280   cloud layer is thicker, so it is more accurate to identify the cloud and non-cloud, but less effective in the discerning of the amount of TCC .

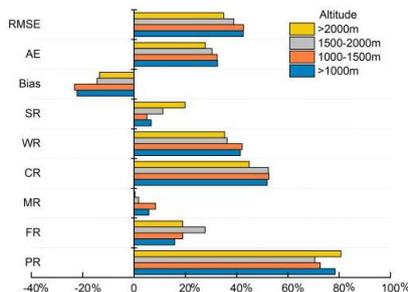



Figure 7. The precision, consistency and error of FY-2F/CTA products at different altitude conditions of Xinjiang.

3.2 The difference between FY-2F/CTA products and Manual observed TCC in dust and non-dust effect period of Xinjiang

As the seasons change, the types of underlying surface also change in most areas of Xinjiang, from vegetation in spring and summer, to bare land in autumn and snow in winter. Studies have shown that dusty weather occurs frequently in the Taklimakan Desert (Figure 9b), mainly in spring and summer, accounting for 88.3 % of the total number of dusty events, with winter being the season with the fewest dusty weather occurs throughout the year, accounting for only 2.3 % of the total (Zhou et al., 2017). In addition, the EOS/MODIS satellite remote sensing snow cover thematic map of Xinjiang in January (Figure 9a) shows that there is no stable snow cover in the Taklimakan desert in January, and the underlying surface changes little in the four seasons. In order to reduce the influence of underlying surface changes, only the influence of dust on cloud identification is considered, therefore, the precision, consistency and error of FY-2F/CTA are analysed by selecting January as the non-dust period and April as the dust period in Tazhong and Qiemo (Figure 8). It shows that dust can reduce the CR of FY-2F/CTA discrimination by about 15 %, but it has little effect on the PR, and the MR and WR in dust period are higher than those in non-dust period, and the FR and SR in dust period are lower than those in non-dust period. This might be caused by the fact that dust period is mainly dominated by low cloud, and the detection ability of satellites to low cloud is worse than that of high cloud, so the MR and WR during dust period are much higher than those during non-dust period. And beyond that dust storm often accompanied by precipitation, so the dusty weather has little effect on the identification of cloud and non-cloud, however, dusty weather has a greater effect on the recognition of cloudage due to uncertain sky conditions and poor visibility.

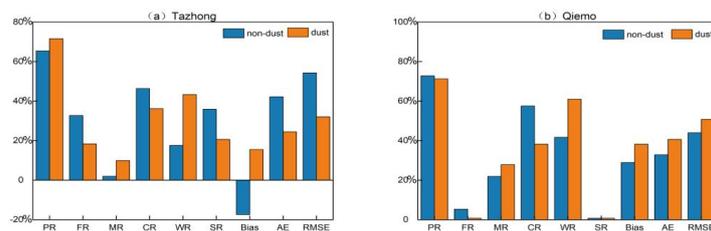



Figure 8. The precision, consistency and error box plot of FY-2F/CTA products in dust and non-dust effect period of Xinjiang.

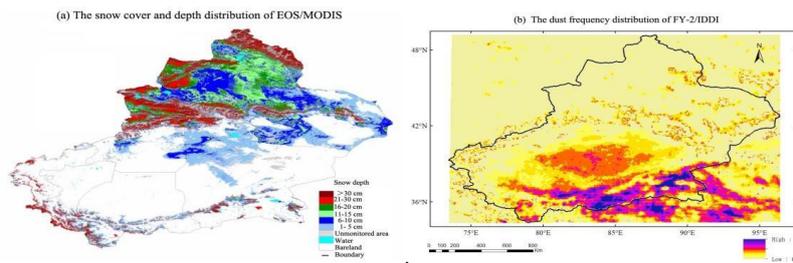



Figure 9. Distribution of snow cover (in January 2016) and dust frequency (in 2016) in Xinjiang

(a) the snow cover and depth distribution of EOS/MODIS, (b) the right picture is the dust frequency distribution of FY-2 infrared difference dust index (FY-2/IDDI)).

3.3 The difference between FY-2F/CTA products and Manual observed TCC under various cloud cover levels of Xinjiang

310   Referring to the definition of cloud cover levels in weather forecast and the classification of cloud cover level by Han et al. (2015), taking the ground-based manual TCC observation as the standard, the amount of TCC ranges from 0-10 % is defined as clear sky, 20 %-30 % as partly cloudy, 40 % -70 % as cloudy and 80 %-100 % as overcast. Figure 10 shows the precision, consistency and error of FY-2F/CTA under different cloud cover levels of Xinjiang. It can be seen that, in general, the PR of FY-2/CTA in Xinjiang region is directly proportional to the amount of TCC, with 97.2 %, 92.0 %, 85.9 % and 31.8 % for

315   overcast > cloudy > partly cloudy > clear sky respectively, that is, the higher the amount of TCC, the better the PR of FY-2F/CTA identification overall. Under different cloud cover levels, the MR is high and FR is low (except clear sky). The FR decreases with the increase of the TCC, and it is the highest in clear sky, up to 64.9 %, it is zero in all other weather conditions. The MR is the lowest under partly cloudy and the highest under cloudy, that is, partly cloudy > cloudy > clear sky > overcast, which are 14.1 %, 8.0 %, 3.3 % and 2.9 % respectively. The CR is inversely proportional to the amount of

320   TCC, that is, partly cloud > clear sky > overcast > cloudy, the CR are 82.2 %, 76.6 %, 34.1 % and 30.3 % respectively, that is to say, the higher the amount of TCC, the lower the CR of FY-2F/CTA identification overall. Under different cloud cover levels, WR is high and SR is low. The SR decreases with the increase of the amount of TCC, that means, clear sky > partly cloudy >cloudy > overcast , the SR are 23.4 %, 11.0 %, 3.9 % and 0.4 % respectively. On the contrary, the WR increases with the increase of the amount of TCC, that is, cloudy day > overcast > partly cloudy > clear sky, the WR are 65.8 %,

325   65.5 %, 6.7 % and 0.01 % respectively. The EIs are also proportional to the amount of TCC. Under clear sky condition, the precision of FY-2/CTA increases from the centre to the north and south, that is, the PR and CR are the highest, and the EIs are the lowest in SX. Under partly cloudy, cloudy, overcast conditions, the precision of FY-2/CTA decreases from the centre to the south, that is, the PR and CR are the highest, and the EIs is the lowest in Tianshan. In Xinjiang region, the CR of FY-2F/CTA under clear sky and partly cloudy conditions is higher than the average value of 63 % in china (Li et al., 2018),

330   and of about 60 % in North China and Huanghuai region (Han et al., 2015).

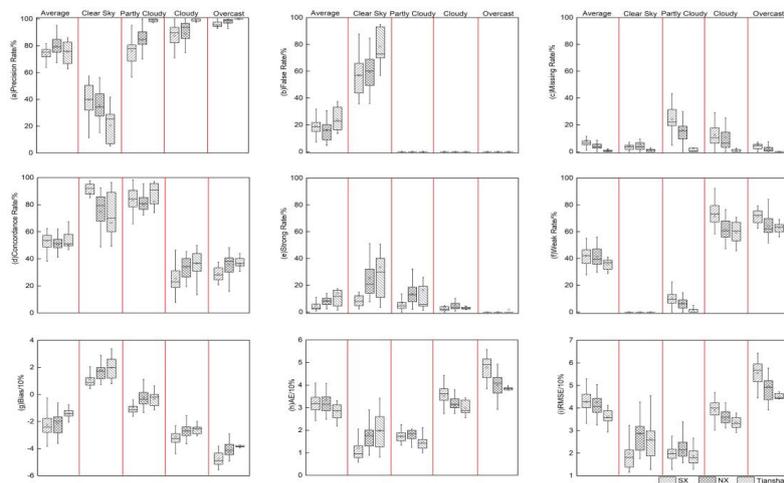



Figure 10. The precision, consistency and error comparison box plot of FY-2F/CTA

under different TCC levels in Xinjiang.

4 Conclusions

Using satellite data to retrieve TCC makes up for the deficiency of traditional ground-based manual TCC observations, and provides valuable basic data for many studies. However, Errors are unavoidable in the calculation process of the TCC from radiometric values of satellite, it is limited by the accuracy of many algorithms such as calibration, positioning and cloud detection, as well as the effects of underlying surface type, surface temperature and weather conditions. In this paper, Xinjiang was taken as the test area, nine evaluation indexes (PR, FR, MR, CR, SR, WR, Bias, AE and RMSE) of FY-2F/CTA are calculated and analysed under complex underlying surface type, various temperature and altitude, dust effects and different cloud cover levels, and the precision, consistency and EIs of FY-2F/CTA are tested and evaluated, and the following main conclusions are reached.

(1) The PR of FY-2F/CTA in Xinjiang region shows a trend of gradually decreasing from north to south, and it demonstrats a high FR (the highest in Tianshan) and a low MR (the highest in SX). There is little difference in the CR among three sub-regions of Xinjiang, showing a high SR and a low WR, which means that the amount of TCC inverted from FY-2 satellite data are generally lower than that observed by ground observation stations. The EIs increase from central to the north and south of Xinjiang, that means the EIs are the lowest in Tianshan, and the highest in SX.

(2) The PR and CR of FY-2F/CTA in the vegetation underlying surface are better than those of non-vegetation. That is, FY-2F/CTA have the best identification effect on the forest and plowland underlying surface, and the worst effect on the snow and ice underlying surface. The MR of vegetation is high (grassland is the highest), and the FR of non-vegetation area

is highe (ice and snow is the highest). The WR is higher than the SR in all kinds of surface underlying, but there is little

difference between them in snow and ice underlying surface.

(3) With the increases of temperature, the PR and CR of FY-2F/CTA increase, while the EIs decrease. Under various

355 temperature conditions, FY-2F/CTA have always been exhibiting high MR, low FR (on the contrary in January), high WR

and low SR.

(4) With the increase of altitude, the AR and CR of FY-2F/CTA decrease, but the PR increases significantly when the altitude

is higher than 2000 m.

(5) Dust reduces the CR of FY-2F/CTA, increases the SR, but it has little effect on the identification of cloud and non-cloud.

360 (6) Under different cloud cover levels, the PR and EIs of FY-2F/CTA are proportional to the amount of TCC, while the CR is

inversely proportional to it. It presents a high MR and a low FR (except clear sky), and a high SR and a low WR. That means,

under clear sky conditions, the PR and CR are the highest, and the EIs are the lowest in the SX; Under partly cloudy, cloudy

and overcast conditions, the PR and CR are the highest, and the EIs are the lowest in Tianshan.

Although the FY-2F/CTA data set released by the national satellite center has some systematic errors with the ground-based

365 manual TCC observations, it should be appropriate corrected by considering the complex underlying surface conditions, the

influence of dust and different cloud cover levels, which could provide better data guarantee for the research. And the data

sequence length, accuracy and spatial-temporal resolution can meet the needs of most climate research we need.

Appendix A: Abbreviations

370 TCC   Total cloud cover

TCCPs   Total cloud cover products

FY-2F   FengYun-2F

FY-2F/CTA   Cloud total amount products of FengYun-2F stationary satellite

PR   Precision rate

375 FR   False rate

MR   Missing rate

CR   Consistency rate

WR   Weak rate

SR   Strong rate

380 EIs   Error indexes

AE   Absolute error

RMSE   Root mean square error

NX   Northern Xinjiang

Tianshan   Tianshan Mountains

385 SX   Southern Xinjiang

Data availability. Data published in this main paper's figures and tables are available via the Texas Data Repository

(https://doi.org/10.6084/m9.figshare.22015592, Comparing FY-2F/CTA products to ground-based manual total cloud cover

observations in Xinjiang under complex underlying surfaces and different Weather Conditions, DataSET, 2023). Underlying
390   research data are also available by request to Li, S. (rainlishuai@163.com).

Author contributions. Li, S., Zhang, H., Chen, Y. H., Wang, Z. L.,Li, X. Y., Li, Y., and Xue, Y. Y. designed the study. Li, Y.,
and Xue, Y. Y. carried out the data collection. Li, S. , Wang, Z. L. and Li, X. Y. carried out the data processing and analysis.
Li, S., Zhang, H., and Chen, Y. H., assisted with the interpretation of results. All co-authors contributed to writing and
395   reviewing the paper.

Competing interests. The contact author has declared that none of the authors has any competing interests.

Disclaimer. Publisher's note: Copernicus Publications remains neutral with regard to jurisdictional claims in published maps
400   and institutional affiliations.

Acknowledgements. We are thankful to the National Satellite Meteorological Center for FY-2F/CTA data support.

Financial support. This work was financially supported by the National Natural Science Foundation of China(grant no.
405   42275039) and the National Key R&D Program of China (grant no. 2017YFA0603502).

References

Betts, A. K., Desjardins, R., Worth, D., and Beckage, B.: Climate coupling between temperature, humidity, precipitation, and
    cloud cover over the Canadian Prairies, J. Geophys. Res.: Atmos., 119(23), 13305–13306,
410   https://doi.org/10.1002/2014JD022511, 2014.

Boers, R., Acarreta, J. A., and Gras, J. L.: Satellite monitoring of the first indirect aerosol effect: Retrieval of the droplet
    concentration of water clouds, J. Geophys. Res., 111, D22208, https://doi.org/10.1029/2005JD006838, 2006.

Bony, S., Colman, R., Kattsov, V. M., Allan, R. P., Bretherton, C. S., Dufresne, J. L., Hall, A., Hallegatte, S., Holland, M. M.,
    Ingram, W., Randall, D. A., Soden, B. J., Tselioudis, G., and Webb, M. J.: How well do we understand and evaluate
415   climate change feedback processes?, J. Clim., 19, 3445–3482, https://doi.org/10.1175/JCLI3819.1, 2006.

Bony, S., Stevens, B., Frierson, D. M. W., Jakob, C., Kageyama, M., Pincus, R., Shepherd, T. G., Sherwood, S. C., Siebesma,
    A. P., Sobel, A. H., Watanabe, M., and Webb, M. J.: Clouds, circulation and climate sensitivity, Nat. Geosci., 8, 261–268,
    https://doi.org/10.1038/NGEO2398, 2015.

Boucher, O., Randall, D., Artaxo, P., Bretherton, C., Feingold, G., Forster, P., Kerminen, V. M., Kondo, Y., Liao, H.,
420   Lohmann, U., Rasch, P., Satheesh, S. K., Sherwood, S., Stevens, B., and Zhang, X. Y.: Clouds and aerosols, In: Stocker,
    T. F., Qin, D., Plattner, G. K., Tignor, M., Allen, S. K., Doschung, J., Nauels, A., Xia, Y., Bex, V., Midgley, P. M., eds,
    Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of
    the Intergovernmental Panel on Climate Change, Cambridge, Cambridge University Press, 571–657, 2013.

Ceppi, P., Brient, F., Zelinka, M. D., and Hartmann, D. L.: Cloud feedback mechanisms and their representation in global

425   climate models, WIREs Clim. Change, 8, e465, https://doi.org/10.1002/wcc.465, 2017.

Chen, T., Rossow, W. B., and Zhang, Y. C.: Radiative effects of cloud type variations, J. Clim., 13, 264–286,

         https://doi.org/10.1175/1520-0442(2000)013<0264:reoctv>2.0.co;2, 2000.

Chepfer, H., Noel, V., Winker, D., and Chiriaco, M.: Where and when will we observe cloud changes due to climate

         warming?, Geophys. Res. Lett., 41, 8387–8395, https://doi.org/10.1002/2014GL061792, 2014.

430   Danso, D. K., Anquetin, S., Diedhiou, A., Lavaysse, C., Kobea, A., and Touré N. D. E.: Spatio-temporal variability of cloud

         cover types in West Africa with satellite-based and reanalysis data, Q. J. Roy. Meteor. Soc.,145(725), 3715–3731,

         https://doi.org/10.1002/qj.3651, 2019.

Ding, S. G., Shi, G. Y., and Zhao, C. S.: Analyzing global trends of different cloud types and the their potential impacts on

         climate by using the ISCCP D2 dataset, Chinese Sci. Bulle., 49(11), 1105–1111, https://doi.org/10.1360/03wd0614,

435   2004.

Errrico, R. M.,Ohring, G., Bauer, P., Ferrier, B., Mahfouf, J. F., Turk, J., and Weng, F. Z.: A simulation of satellite cloud and

         precipitation observations in numerical weather prediction models: Introduction to the JAS special collection, J. Atmos.

         Sci., 64(11), 3737–3741, https://doi.org/10.1175/2007JAS2622.1, 2007.

Feng, J. D., Wu, Z. T., Peng, K. J., Chen, Y. H., Wu, J. J., Wei, W. S.,Cui, C. X., and Gao, Y.: Variations in the heights of

440   different clouds over three major mountains in Xinjiang based on CloudSat observation, J. Glaciol. Geocryol., 36(2),

         310–317, https://doi.org/10.7522/j.issn.1000-0240.2014.0038, 2014.

Free, M., Sun, B., and Yoo, H. L.: Comparison between total cloud cover in four reanalysis products and cloud measured by

         visual observations at US weather stations. J. Clim., 29(6), 2015–2021, https://doi.org/10.1175/JCLI-D-15-0637.1,

         2016.

445   Guo, Z., Zhou, T. J., Wang, M. H., and Qian, Y.: Impact of cloud radiative heating on East Asian summer monsoon

         circulation, Environ, Res. Lett., 10, 074014, https://doi.org/10.1088/1748-9326/10/7/074014, 2015.

Han, Y. Q., and Cong, C. H.: Analysis and validation of FY-2E total cloud amount productions in north China and Huanghuai

         area, J. Meteor. Environ., 31(5), 153–158, https://doi.org/10.3969/j.issn.1673-503X.2015.05.022, 2015.

Harrison, E. F., Minnis, P., Barkstrom, B. R., Ramanathan, V., Cess, R. D., and Gibson, G. G.: Seasonal variation of cloud

450   radiative forcing derived from the Earth radiation budget experiment, J. Geophys. Res., 95(D11), 18687–18703,

         https://doi.org/10.1029/JD095iD11p18687, 1990.

Haynes, J. M., Vonder Haar, T. H., L'Ecuyer, T., and Henderson, D.: Radiative heating characteristics of Earth's cloudy

         atmosphere from vertically resolved active sensors, Geophys. Res. Lett., 40, 624–630,

         https://doi.org/10.1007/s00382-015-2542-0, 2013.

455   Kadiayi A.,:Temporal and spatial variation of surface temperature and influencing factors analysis in Xinjiang from 2001 to

2019, Master's thesis, Xinjiang Normal University, Urumqi, China, 58 pp, 2021.

Kang, Z. W., Zhang, Z.Y., Liu, L., Wang, T. X., Tian, H., Chen, H. J., and Zhang, X. Y.: Spatio-temporal variation characteristics of land surface temperature in Xinjiang based on MODIS, GEOGRAPHICAL Res., 41 (4), 997–1017, https://doi.org/10.11821/dlyj020210232, 2022.

460 Kiran, V. R., Rajeevan, M., Gadhavi, H., Rao, S. V. B., and Jayaraman, A.: Role of vertical structure of cloud microphysical properties on cloud radiative forcing over the Asian monsoon region, Clim. Dyn., 45, 3331–3345, https://doi.org/10.1007/s00382-015-2542-0, 2015.

Kotarba, A. Z.: A comparison of MODIS-derived cloud amount with visual surface observations, Atmos. Res., 92 (4), 522–530, https://doi.org/10.1016/j.atmosres.2009.02.001, 2009.

465 Li, J. D., Wang, W. C., Dong, X. Q., and Mao, J. Y.: Cloud-radiation-precipitation associations over the Asian monsoon region: An observational analysis, Clim. Dyn., 49: 3237–3255, https://doi.org/10.1007/s00382-016-3509-5, 2017.

Li, J. D., Wang, W. C., Mao, J. Y., Wang, Z. Q., Zeng, G., and Chen, G. X.: Persistent spring shortwave cloud radiative effect and the associated circulations over southeastern China, J. Clim., 32, 3069–3087, https://doi.org/10.1175/JCLI-D-18-0385.1, 2019.

470 Li, S., Hou, X. G., Cui, Y., Liang, F. C., and Xu, Z. D.:Research on cloud characteristics in Xinjiang region based on FY-2F satellite data , Plateau Meteor., 38(3), 617–624. https://doi.org/10.7522/j.issn.1000-0534.2018.00101, 2019.

Li, Y., Guo, J. X., Cao, Y.C., Zhou, C., Chen, Y. Z.: Compare and analyze FY-2G cloud products to ground-based manual observed cloud amount, Plateau Meteor. (in Chinese), 37(2), 514–523, https://doi.org/10.7522/j.issn.1000-0534.2017.00027, 2018.

475 Liu, J., Yang, X. F., and Cui, P.: Validation of total cloud amount in 2007 derived by NOAA/AVHRR, Plateau Meteor. (in Chinese), 35(4), 1027–1038, https://doi.org/10.7522/j.issn.1000-0534.2015.00029, 2016.

Liu, J., Cui, P., and Xiao, M.: The bias analysis of FY-2G cloud fraction in summer and winter, J. Appl. Meteor. Sci. (in Chinese), 28(2), 177–188, https://doi.org/10.11898/1001-7313.20170205, 2017.

Liu, R. X., Chen, H. B., Zheng, Z. J., Liu, N. Q., Shi, C. X., and Liu, Y. J.:Analysis and validation of total cloud amount data

480 in China[J]. J. Appl. Meteor. Sci. (in Chinese), 20(5), 571–578, https://doi.org/10.3969/j.issn.1001-7313.2009.05.008, 2009.

Loeb, N. G., Doelling, D. R., Wang, H. L., Su, W. Y., Nguyen, C., Corbett, J. G., Liang, L. S., Mitrescu, C., Rose, F. G., and Kato, S.: Clouds and the Earth's Radiant Energy System (CERES) Energy Balanced and Filled (EBAF) Top-of-Atmosphere (TOA) Edition-4.0 data product, J. Climate, 31, 895–918,

485 https://doi.org/10.1175/JCLI-D-17-0208.1, 2018.

Pavolonis, M. J., and Key, J. R.: Antarctic cloud radiative forcing at the surface estimated from the AVHRR Polar Pathfinder and ISCCP D1 datasets, 1985–93, J. Appl. Meteor., 42(6), 827–840,

https://doi.org/10.1175/1520-0450(2003)042<0827:ACRFAT>2.0.CO;2, 2003.

Ronald, M. E., George, O., Peter, B., Brad, F., Jean-François, M.,Joe, T., and Weng, F. Z.: Assimilation of satellite cloud and
precipitation observations in numerical weather prediction models: Introduction to the J A S special collection, J. Atmos.
Sci, 64(11), 3737–3741, https://doi.org/10.1175/2007JAS2622.1, 2007.

Slingo, A., and Slingo, J. M.: The response of a general circulation model to cloud longwave radiative forcing. I:
Introduction and initial experiments, Q. J. R. Meteor. Soc., 114, 1027–1062, https://doi.org/10.1002/qj.49711448209,
1988.

Sun, B.: Cloudiness over the contiguous United States: Contemporary changes observed using ground-based and ISCCP D2
data, Geophys. Res. Lett., 30(2), 1053, https://doi.org/10.1029/2002GL015887, 2003.

Sun, B., Free, M., Yoo, H. L., Foster, M. J., Heidinger, A., and Karlsson, K. G.: Variability and trends in US cloud cover:
ISCCP, PATMOS-x, and CLARA-A1 compared to homogeneity-adjusted weather observations, J. Clim., 28(11),
4373–4389, https://doi.org/10.1175/JCLI-D-14-00805.1., 2015.

Wang, M. Y., and Wang, B. M.: Total cloud amount difference between ISCCP product and ground observation over China, J.
Appl. Meteor. Sci. (in Chinese), 20(4), 411–418, https://doi.org/10.3969/j.issn.1001-7313.2009.04.004, 2009.

Wang, Y., and Zhao, C.: Can MODIS cloud fraction fully represent the diurnal and seasonal variations at DOE ARM SGP
and Manus sites? J. Geophys. Res.: Atmos., 122(1), 329–343, https://doi.org/10.1002/2016JD025954, 2017.

Werkmeister, A., Lockhoff, M., Schrempf, M., Tohsing, K., Liley, B., and Seckmeyer, G.: Comparing satellite to
ground-based automated and manual cloud coverage observations-a case study, Atmos. Meas. Tech., 8(5), 2001–2015,
https://doi.org/10.5194/amt-8-2001-2015, 2015.

Wu, W., Liu, Y., Jensen, M. P., Toto, T., Foster, M. J., and Long, C. N.: A comparison of multiscale variations of decade-long
cloud fractions from six different platforms over the Southern Great Plains in the United States, J. Geophys. Res.:
Atmos. (in Chinese), 119(6), 3438–3459, https://doi.org/10.1002/2013JD019813, 2014.

Xi, L., Shi, C. X., Zhao, B. F., Zhu, C., and Zhu, X. L.: Validation and evaluation of cloud amount by geostationary satellite
from 1995 to 2010, Meteor. Sci. Technol., 41(1), 8–14, https://doi.org/10.3969/j.issn.1671-6345.2013.01.002, 2013.

Yang, Y., Zhao, C., and Fan, H.: Spatiotemporal distributions of cloud properties over China based on Himawari-8 advanced
Himawari imager data, Atmos. Res., 240, 104927, https://doi.org/10.1016/j.atmosres.2020.104927, 2020.

Yao, J. Q., Zhao, Y., Chen, Y. N., Yu, X. J., and Zhang, R. B.: Multi-scale assessments of droughts: A case study in Xinjiang,
China, Sci. Total Environ., 630, 444–452, https://doi.org/10.1016/j.scitotenv.2018.02.200, 2018.

Yousef, L. A., Temimi, M., Molini, A., Weston, M., Wehbe, Y. and Mandous, A. A.: Cloud Cover over the Arabian Peninsula
from Global Remote Sensing and Reanalysis Products, Atmos. Res., 238, 104866,
https://doi.org/10.1016/j.atmosres.2020.104866, 2020.

Zelinka, M. D., Randall, D. A., Webb, M. J., and Klein, S. A.: Clearing clouds of uncertainty, Nat. Clim. Change, 7, 674–678,

520   https://doi.org/10.1038/nclimate3402, 2017.

Zhang, H., Wang, F., Wang, F., Li, J., Chen, X., Wang, Z., Li, J., Zhou, X., Wang, Q., Wang, H., You, T., Xie, B., Chen, Q., and Duan, Y.: Advances in cloud radiative feedbacks in global climate change (in Chinese), Scientia Sinica Terrae, 52(3), 400–417, https://doi.org/10.1360/SSTe-2021-0052, 2022.

Zhou, C. L., Yang, X. H., Zhong, X. J., Yang, F., and Chou, H. M.: Dust weather in hinterland of the Taklamakan desert, Arid

525   Zone Res., 34(2), 324–329, https://doi.org/10.13866/j.azr.2017.02.11, 2017.

Zhou, S., Yang, J., Wang, W. C., Zhao, C., Gong, D., and Shi, P.: An observational study of the effects of aerosols on diurnal variation of heavy rainfall and associated clouds over Beijing-Tianjin-Hebei, Atmos. Chem. Phys., 20,5211–29, https://doi.org/10.5194/acp-20-5211-2020, 2020.