



# The AIMS Site Survey

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## Abstract

This paper reports site survey results for the Infrared System for the Accurate Measurement of Solar Magnetic Field, especially in Saishiteng Mountain, Qinghai, China. Since 2017, we have installed a weather station, spectrometers for precipitable water vapor, and Solar Differential Image Motion Monitor, and have carried out observations on weather elements, precipitable water vapor, and daytime seeing conditions for more than one year in almost all candidates. At Mt. Saishiteng, the median value of daytime precipitable water vapor is 5.25 mm and its median value in winter season is 2.1 mm. The median value of the Fried parameter of daytime seeing observation at Saishiteng Mountain is 3.42 cm. Its solar direct radiation data show that solar average observable time is 446 minutes per day and premium time is 401 minutes per day in 2019 August.

*Key words:* site testing – atmospheric effects – methods: analytical

## 1. Requirement for AIMS Candidate Sites

The Infrared System for the Accurate Measurement of Solar Magnetic Field (AIMS), is a 1 m telescope that is dedicated to measuring the solar magnetic field at the middle infra-red wave band by using a Fourier Transform Spectrometer with high spectral resolution. In order to maximize the performance of AIMS observation, a couple of astronomical environmental factors are considered in site test investigation. First, the Sun is observed at Mg I 12.3  $\mu\text{m}$ , AIMS requires a very low level of perceptible vapor water since atmospheric water vapor content has a strong impact on the transparency of the atmosphere in the infrared and submillimeter domains (Kerber et al. 2012). Second, the daytime seeing condition needs to be measured in order to obtain good daytime image quality which is closely related to AIMS performance. In the night time, the seeing condition was usually measured using Differential Image Motion Monitor (DIMM) such as investigation in European Southern Observatory in Chile (Sarazin & Roddier 1990), while the daytime seeing condition could be measured by using Solar Differential Image Motion Monitor (S-DIMM) such as in Fuxian Lake, China (Liu & Beckers 2001) and in TUG, Turkey (Özişik & Ak 2004). Third, AIMS requires as much solar observable time as possible.

The site testing investigation for AIMS started in 2016 with two phases. In phase I (2016–2018), we mainly considered the well-finished stations with good accommodation and infrastructure conditions due to a limited construction period. As a result, Ali in Tibet, Nanshan station in Xinjiang, Delingha station in Qinghai, and Daocheng in

Sichuan were selected as the first four primary candidate sites. Nanshan and Delingha are well-built stations with good accommodation. The altitude of Ali station is 5100 m above sea level and its logistic is poor and living conditions are tough. The site test survey of Daocheng in the daytime has been done for more than one year (Song et al. 2018). The weather station was installed at Nanshan, Ali, and Delingha stations and a precipitable water vapor spectrometer was deployed at Delingha Station. In phase II (2018–2020), we focus site testing observations on Saishiteng Mountain ( $38^{\circ} 36'24''\text{N}$ ,  $93^{\circ}53'45''\text{E}$ , with an altitude of 4200 m) located in the north edge of Qiadam basin, Qinghai province (Figure 1). It is 50 km east of Lenghu town which is the only inhabited town with an altitude of 2750 m, with an arid climate all around. In 2018 November, an S-DIMM was deployed and the daytime seeing condition was carried out for more than one year. An observing tower with a height of 10 m was built on the Saishiteng mountain (Figure 2) in 2018 November. In the following sections, we introduce the weather element result in Section 2, show the precipitable water vapor (PWV) result in Section 3, describe the S-DIMM configuration and processing method, display daytime seeing result in Section 4, and discuss the site testing result in Section 5.

## 2. Weather Elements

In Nanshan, Ali, Delingha, and Mt. Saishiteng sites, we have carried out meteorological data observation which include five weather elements: temperature, relative humidity, wind speed and direction, and solar direct radiation. All the weather



**Figure 1.** Mt. Saishiteng is located at the north edge of Qaidam Basin, China ( $38^{\circ}36'45''\text{N}$ ,  $93^{\circ}53'45''\text{E}$ ).



**Figure 2.** The AIMS site testing tower for monitoring daytime seeing conditions (left) with a height of 10 m.

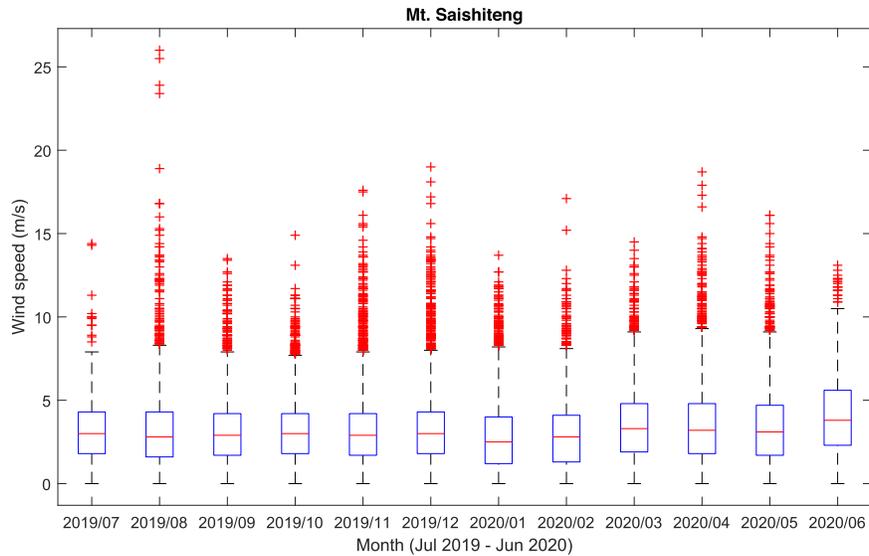
elements were recorded in the time interval of 1 minute. The wind speed is an important weather element that is related to seeing conditions. Figure 3 is the monthly variation of wind speed in Mt. Saishiteng with a median value of  $3.2 \text{ m s}^{-1}$ , and the highest speed of  $26.34 \text{ m s}^{-1}$ . The wind speed in Ali station is the highest with a median value of  $4.7 \text{ m s}^{-1}$  and the highest speed of  $31.2 \text{ m s}^{-1}$  (Figure 4). Table 1 summarizes the wind speed statistics of the four sites, among them, Delingha station has recorded the lowest median value of  $1 \text{ m s}^{-1}$  and the median value in Nanshan station is  $2.4 \text{ m s}^{-1}$ .

Figure 5 shows the monthly variation of temperature in Mt. Saishiteng during 2019 July 27–2020 June 5 with a median value of  $-6.5$  Celsius, an average value of  $-5.0$  Celsius, the highest temperature of  $19.2$  Celsius and the lowest temperature

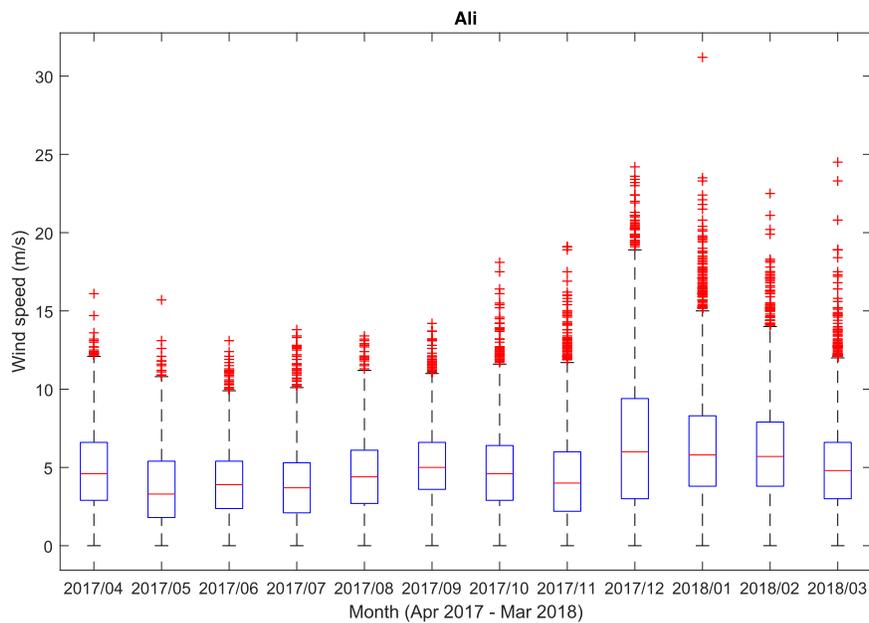
of  $-22$  Celsius. Its monthly average temperature is shown in Table 2. The monthly variation of relative humidity in Mt. Saishiteng is shown in Figure 6 with a median value of 40.3% and an average value of 45%.

The total solar irradiance (TSI) is the intensity of solar radiance outside the Earth's atmosphere with a constant of around  $1361 \text{ W m}^{-2}$  (Kopp 2021). Due to the absorption of the atmosphere, the intensity of solar direct radiance is usually lower than  $1200 \text{ W m}^{-2}$  on the surface of the Earth. On a clear day, the maximum solar irradiance indicates the absorption (or extinction) of the local atmosphere. On a cloudy day, the solar direct radiation reflects the thickness of the cloud through the path from the observer to the Sun regardless cloud covering the sky outside the Sun. Therefore, we can determine if the Sun can be observed and how long it can be observed from the solar direct radiation data. According to our experience, a solar telescope can observe the Sun continually when solar direct radiation is more than  $500 \text{ W m}^{-2}$  and observe the Sun intermittently when solar irradiance ranges between  $300$  and  $500 \text{ W m}^{-2}$  due to cloud or fog. It is hard to observe the Sun normally when solar direct radiation is below  $300 \text{ W m}^{-2}$ . In this paper, we define solar premium time and observable time as the solar direct radiation is more than  $500$  and  $300 \text{ W m}^{-2}$  respectively.

The solar direct radiation meter which is used in AIMS site testing contains a thermoelectric pile that measures the solar irradiance within a field of view of  $5^{\circ}$  in a spectral range of  $300\text{--}3000 \text{ nm}$ . In the early phase, a semi-automatic tracking system was used to follow the Sun at Nanshan, Ali, and Delingha stations. It follows the Sun automatically along R.A. in a speed of  $15^{\circ}/\text{hr}$ , while it needs to be adjusted manually



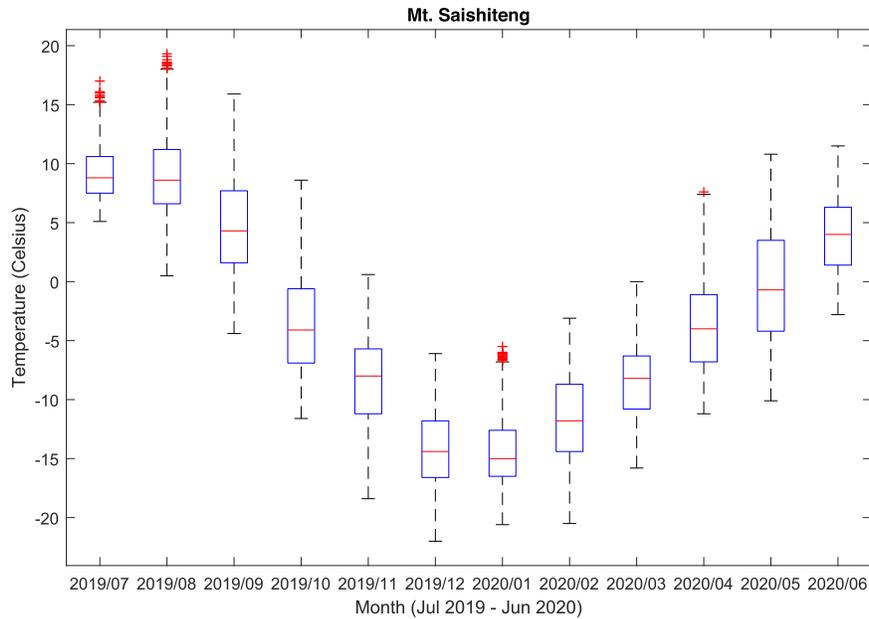
**Figure 3.** Monthly variation of wind speed at Mt. Saishiteng. The upper tip, upper top of a box, mid-bar in a box, bottom of a box, and lower tip represent 95%, 75%, 50%, 25%, and 5% of the measured data for each month respectively. Plus signs represent the outlier data which are beyond box.



**Figure 4.** Monthly variation of wind speed at Ali station.

along decl. Later we find its performance is poor if no one is dedicated to adjusting the tube pointing to the Sun once the Sun's decl. varies or electricity outage occurs occasionally. Figure 7 shows the monthly solar irradiance distribution in 2017 June at Delingha station with an average premium time of 296 minutes (5.95 hr) and an observable time of 360 minutes

(6 hr) per day. The blue and red horizontal lines indicate low limitation of solar radiance  $300$  and  $500 \text{ W m}^{-2}$  for an observable hour and a premium hour respectively. In Mt. Saishiteng, we deployed a fully automatic solar tracking system which can follow the Sun with an accuracy of less than  $1^\circ$  during the Sun appears above the horizon (Figure 8 top).



**Figure 5.** Monthly variation of temperature at Mt. Saishiteng. The median temperature is  $-6.5\text{ }^{\circ}\text{C}$ , the highest temperature is  $19.2\text{ }^{\circ}\text{C}$  and the lowest temperature is  $-22\text{ }^{\circ}\text{C}$ .

**Table 1**

Annual Wind Speed ( $\text{m s}^{-1}$ ) Statistics of Ali, Nanshan, Delingha stations and Mt. Saishiteng

Site	Average	Median	High	Observation Period
Ali	5.02	4.7	31.2	April 2017-April 2018
Nanshan	2.05	2.24	11.6	April 2017-May 2018
Delingha	1.63	1	14.7	April 2017-May 2018
Mt. Saishiteng	3.5	3.2	26.3	July 2019-June 2020

Figure 9 shows the monthly solar irradiance variation at Mt. Saishiteng in August, 2019. It indicates that the average premium time is 401 minutes (6.7 hr) per day and the observable time is 446 minutes (7.4 hr) per day. Table 3 lists the monthly statistics of solar premium time and observable time, maximum irradiance, altitude, and date of four sites. We can see that the higher the altitude, the higher the maximum irradiance. At Mt. Saishiteng, the maximum solar irradiance is  $1103\text{ W m}^{-2}$  and the maximum solar irradiance at Ali reached  $1173\text{ W m}^{-2}$ . It is easy to understand that the atmosphere transparency of Ali is the highest since its altitude is the highest (5100 m) among the all sites. One reason why the observable hour in Nanshan station is too low may be that we set some part of abnormal irradiance data which appears as  $1999\text{ W m}^{-2}$  to zero.

**Table 2**

Monthly Average Temperature at Mt. Saishiteng

Month	Average	Median	High	Low
August	8.9	8.6	19.3	0.5
September	4.6	4.3	15.9	-4.4
October	3.4	4.1	8.6	-11.6
November	-8.5	-8.0	0.6	-18.4
January	-14.5	-15.0	-5.5	-20.6
February	-1.6	-11.8	-3.1	-20.5
March	-8.4	-8.2	0	-15.8
April	-3.8	-4	7.6	-11.2
May	-0.3	-0.7	10.8	-10.1

### 3. Precipitable Water Vapor

The PWV can be measured by several methods such as radiosonde balloons, radiometers from both ground and satellites, Sun photometers, lunar photometers, GPS receivers, Fourier transform infrared spectrometers, and others (Qian et al. 2019). In the AIMS site testing survey, the precipitable water vapor was measured by a spectrometer which measures the residual intensity of the absorption line of the  $\text{H}_2\text{O}$  molecule centered at 935 nm. When the tube of the spectrometer is pointing to the Sun, precipitable water vapor is calculated from intensities at 935 and 889 nm from the function below.

$$R = 0.59\sqrt{W} \quad (1)$$

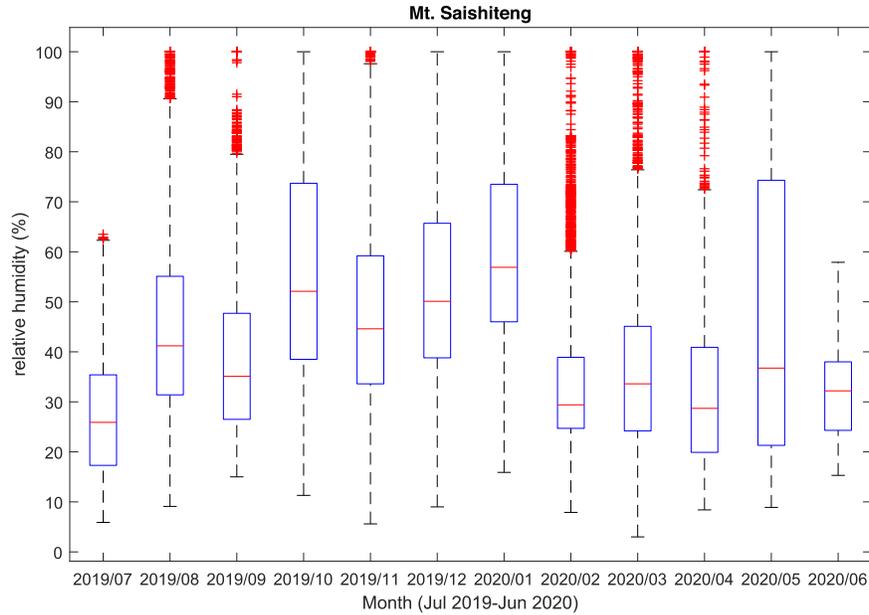


Figure 6. Monthly variation of relative humidity at Mt. Saishiteng.

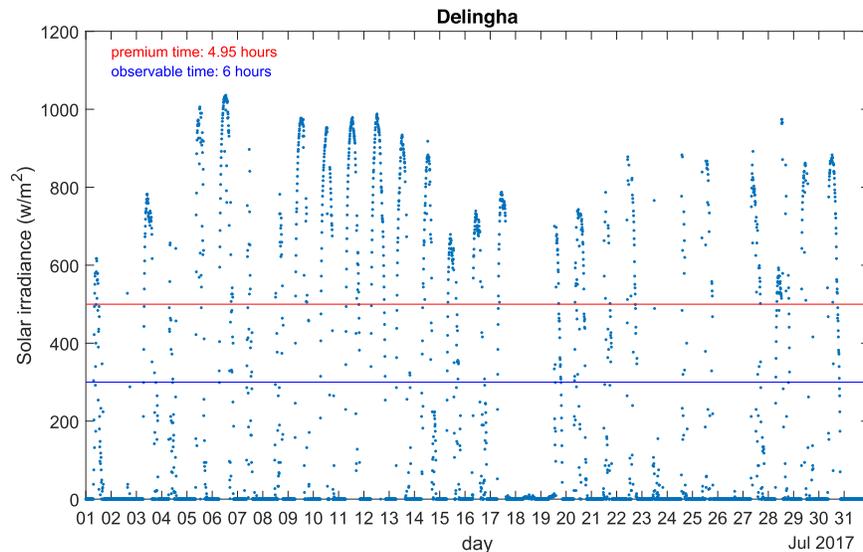


Figure 7. The solar radiance variation in 2017 July at Delingha station. Red and blue horizontal lines indicate solar radiation of 500 and 300  $W m^{-2}$  respectively. In each day, its average premium time is 296 minutes (5.95 hr) and its observable time is 360 minutes (6 hr).

where  $R$  is the residual intensity; It is the ratio between the intensity at 935 and 889 nm.  $W$  is PWV.

The PWV measurements at Nanshan station and Ali station were obtained in only a few days which is not statistically significant. The observations of precipitable water vapor were carried out every 30 minutes on a clear day between 2017 May and 2018 June at Delingha station. Its

monthly variation of PWV is shown in Figure 10 with a median value  $W$  of 11.5 cm and  $W_0$  of 7.0 cm.  $W$  indicates the actual value of PWV measured when the spectrometer points to the Sun while  $W_0$  indicates the corrected value of  $W$  to the local zenith—that is  $W_0 = W/a$ , where  $a$  is the air mass. Figure 11 shows the monthly variation of precipitable water vapor during the period from 2018 November to 2020



**Figure 8.** The solar direct radiation meter was mounted on a fully automatic Solar tracker in Mt. Saishiteng (top). The field of view of solar radiation meter is  $5^\circ$  and tracking accuracy of solar tracker is less than  $1^\circ$ . S-DIMM and precipitable water vapor spectrometer were mounted together on an ATR equatorial mounting at Mt. Saishiteng (bottom).

June at Mt. Saishiteng. Its median value of  $W$  and  $W_0$  are 8.07 mm and 5.25 mm respectively. In the winter season, Mt. Saishiteng's PWV is low with a median value of  $W_0$  2.1 mm. In Figure 12, the hourly variation within a day of PWV shows that in the early morning, the  $W$  value is high due to great optical thickness and the  $W$  reaches its lowest value after the Sun passes the local meridian.

#### 4. Daytime Seeing Observation

In Saishiteng Mountain, the S-DIMM is installed on a 10 m high tower whose pier stands alone separately from the platform (Figure 2). It consists of a Celestron C11 XLT telescope with a clear aperture 280 mm and a F/10 focal ratio (Figure 8 bottom). On the cover of C11 telescope, two holes were opened as sub-apertures and were covered by a Baade film with  $10^{-5}$  transmission. The diameter of two sub-apertures is 5 cm and their separation is 22 cm. Two prisms with separate angles  $10''$  were mounted in each sub-aperture. A 1/40 neutral

filter was installed before the focal plane. The CMOS camera is ZWO ASI 174MM with a sensor of  $1936 \times 1216$  pixels. Each pixel corresponds to  $0''.44$  (see Table 4).

When measuring the seeing condition, the solar images were recorded on an AVI video with an exposure time of 14 ms, then 100 png files were extracted from the AVI video. At first, an intensity distribution along a horizontal direction crossing the solar eastern or western limb is drawn and then the profile of the intensity gradient of the solar eastern or western limb along the horizontal direction is a Gaussian curve. The positions of the two limbs were determined at the center by using Gaussian fit (Figure 13). The variation  $\sigma$  of the distance between two solar limbs is calculated from the differences in the position of two solar limbs.

Then the Fried parameter  $r_0$  can be calculated from variation  $\sigma^2$  (Sarazin & Roddier 1990):

$$\sigma^2 = 2\lambda^2 r_0^{-5/3} [0.179D^{-1/3} - 0.0968d^{-1/3}] \quad (2)$$

or in a simple form (Tokovinin 2002)

$$\sigma^2 = K \left( \frac{\lambda}{r_0} \right)^{5/3} \left( \frac{\lambda}{D} \right)^{1/3} \quad (3)$$

where  $D$  is the diameter of sub-aperture, and  $K$  is the coefficient:

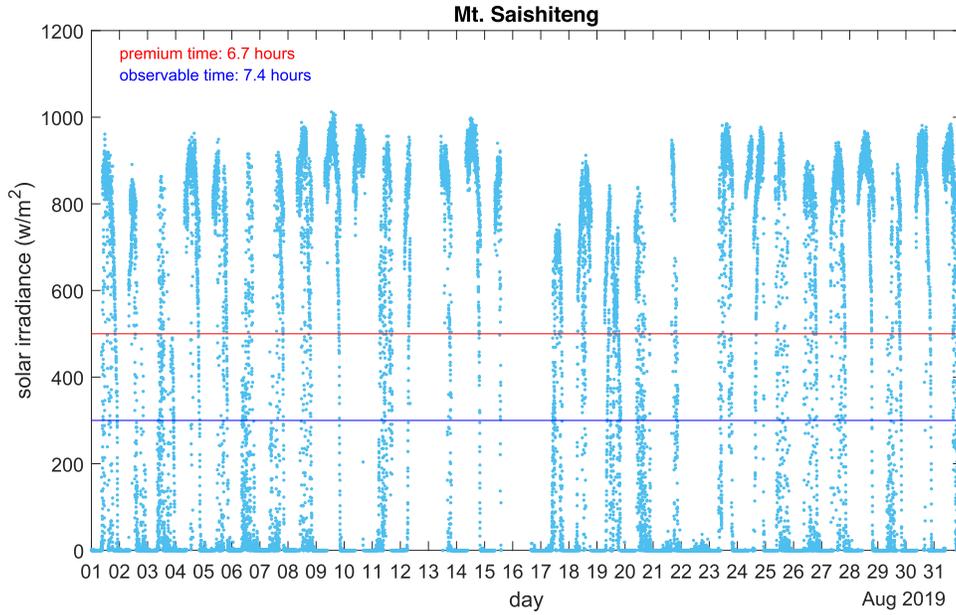
$$k = 0.364(1 - 0.532b^{-1/3} - 0.024b^{-2/3}) \quad (4)$$

where  $b = d/D$ ,  $d$  is apertures separation.

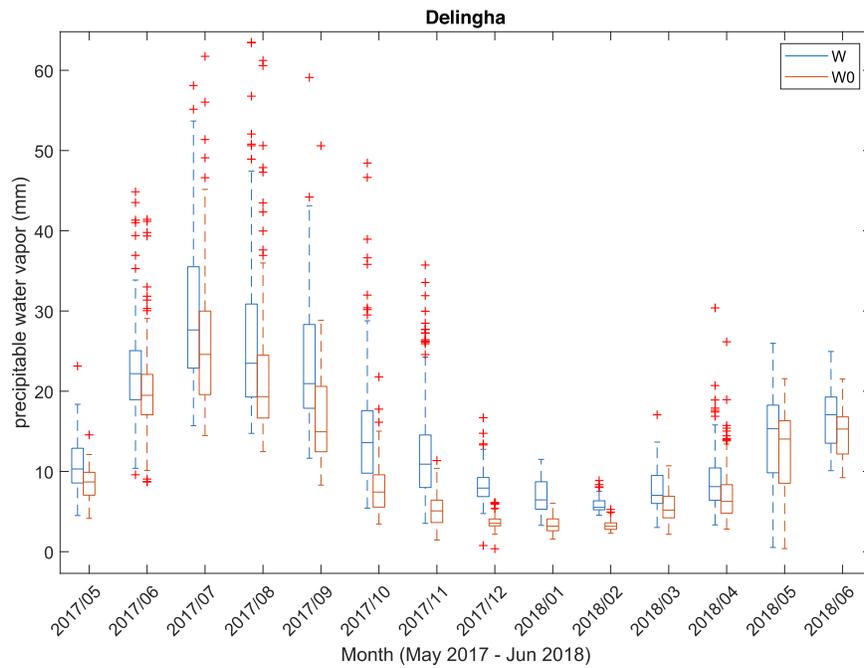
Figure 14 shows the monthly variation of Fried parameter  $r_0$  at Mt. Saishiteng with a median value of 3.4 cm. The total 1935 seeing data was taken every 30 minutes through remote control on each clear day from 2018 November 7 to 2020 June 5 except the days when site testing instruments were in either outage or off-line. Figure 15 is the hourly variation of the Fried parameter on 2019 May 23. It shows that very good seeing condition appears in the early morning which indicates that the atmosphere is not disturbed severely by the sunshine. Figure 16 shows the distribution histogram with the cumulative frequency of the daytime Fried parameter and indicates that it peaks at 3.2 cm, 90% is less than 5.6 cm, 70% is less than 4.3 cm and 30% is less than 2.7 cm. In order to explore the relationship between seeing condition  $r_0$  and wind direction and speed, we plot a distribution of Mt. Saishiteng's seeing condition with wind speed (Figure 17(a)) and wind direction (Figure 17(b)) during seeing measurement. It shows an almost isotropic distribution of the Fried parameter  $r_0$ , indicating little correlation to the direction of wind, nor the wind speed.

#### 5. Discussion

For AIMS observation at the middle infrared wave band, the PWV is the essential parameter among all site testing



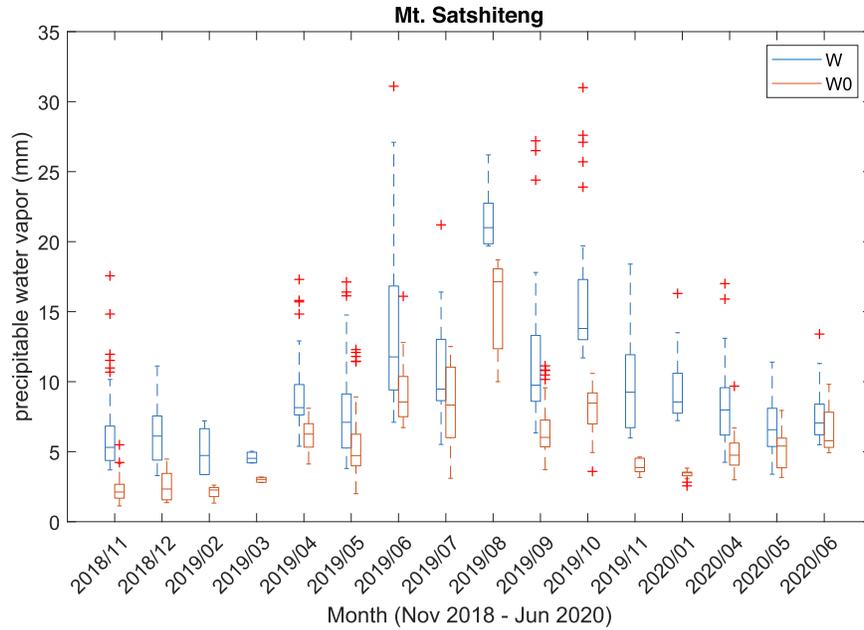
**Figure 9.** The solar irradiance variation in 2019 August at Mt. Saishiteng. Red and blue horizontal lines indicate solar radiation of  $500$  and  $300 \text{ W m}^{-2}$  respectively. In each day, its average premium time is 401 minutes (6.7 hr) and observable time 446 minutes (7.4 hr).



**Figure 10.** Monthly variation of precipitable water vapor in Delingha in Qinghai province. W (blue) represent observational PWV and  $W_0$  (orange) represent PWV corrected to the zenith.

parameters. The Delingha station and Mt. Saishiteng are both located in the western part of Qinghai Province with a distance of about 400 km, but the the PWV in Delingha is higher than that in Mt. Saishiteng. One reason behind this is

because of their different altitudes (about 1000 m). Another possible reason is that Delingha is located near the Bayin River's bed. Our method for measuring PWV is not as accurate as the method using a commercial Low Humidity



**Figure 11.** Monthly variation of precipitable water vapor  $W$  (blue) at Mt. Saishiteng during 2018 November 18–2020 July 6.  $W_0$  (orange) indicates the value  $W$  with correction to the zenith (precipitable water vapor divided by air mass). The upper tip, upper top of a box, mid-bar in a box, bottom of a box and lower tip represent 95%, 75%, 50%, 25%, and 5% of the measured data for each month respectively.

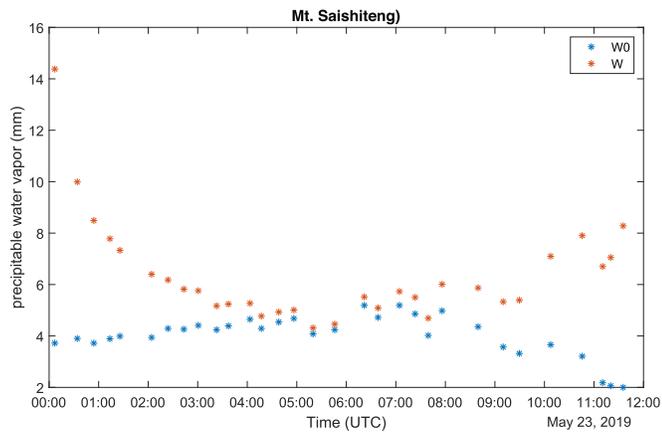
**Table 3**

Monthly Statistics of Premium Time, Observable Time, Solar Maximum Irradiance, Altitude and Month of Observation of Ali, Nanshan, Delingha Stations and Mt. Saishiteng

Site	Premium (hour)	Observable Time (hour)	Maximum Irradiance ( $W m^{-2}$ )	Altitude (m)	Date
Ali	...	...	1173	5100	July 2017
Nanshan	1.95 <sup>a</sup>	2.8 <sup>a</sup>	995	2000	June 2017
Delingha	4.95	6	1036	3100	June 2017
Mt. Saishiteng	6.7	7.4	1103	4200	August 2019

**Note.**

<sup>a</sup> maximum irradiance refers to maximum solar irradiance among all data at one site.

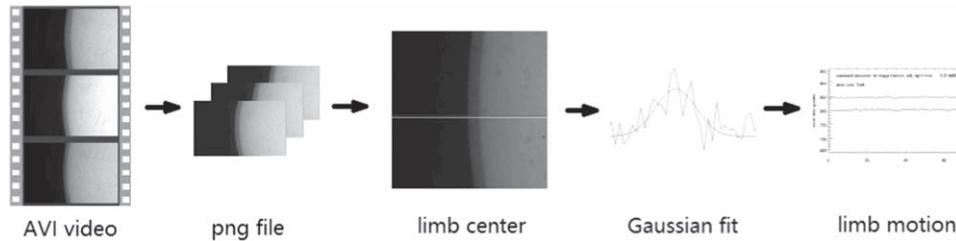


**Figure 12.** Hourly variation within a day of PWV on 2019 May 23 at Mt. Saishiteng.

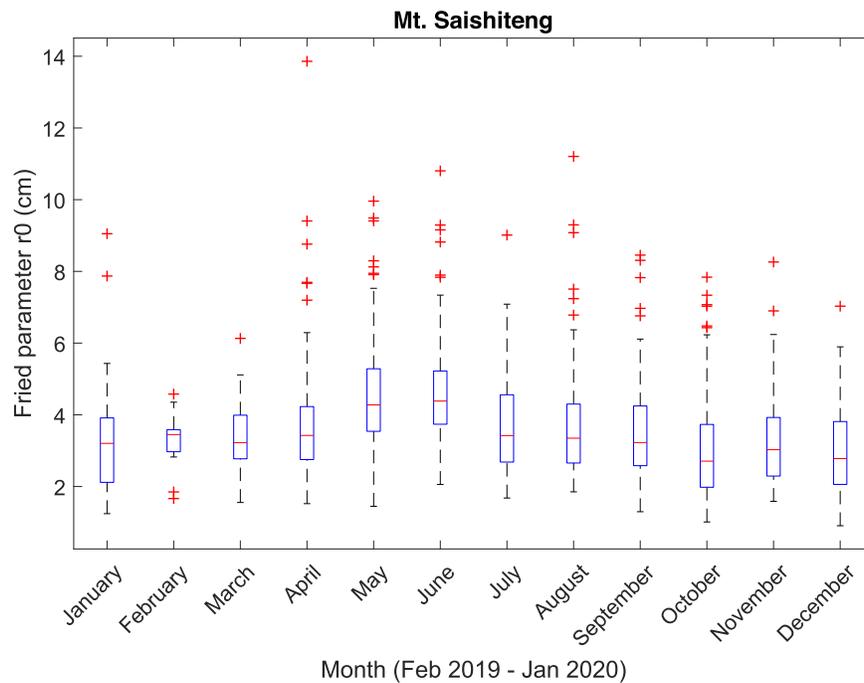
**Table 4**

Parameters and Technical Specifications of Mt. Saishiteng S-DIMM

Telescope and Mount	
model	Celestron CGX 1100
diameter	280
focal length	2800
mount	ASTROOM ATR Aries
Hartmann Mask	
sub-aperture diameter	50
sub-aperture separation	220
deviation angle	10'
solar filter	BAADER Film
sensor	
CMOS model	
size	ZWO ASI 174MM
pixels number	11.3*7.1 mm
field of view	1936 × 1216
one pixel	13' × 8'1
	0''44



**Figure 13.** Process of seeing data observation and reduction of S-DIMM at Mt. Saishiteng.



**Figure 14.** Monthly variation of daytime seeing  $r_0$  at Mt. Saishiteng. The upper tip, upper top of a box, mid-bar in a box, bottom of a box and lower tip represent 95%, 75%, 50%, 25%, and 5% of the measured data for each month respectively.

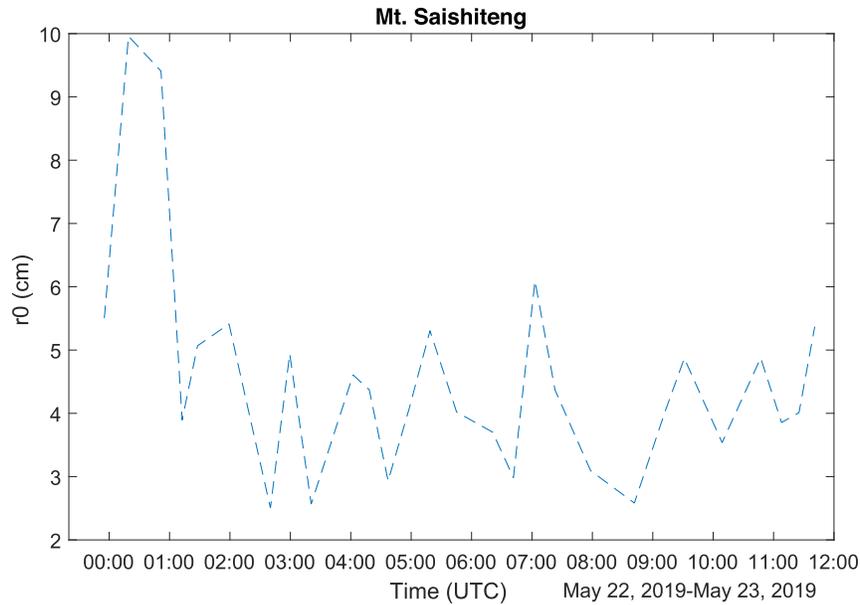
And Temperature Profiling Radiometer (LHATPRO). For example, the median value of PWV is about 0.52 mm at Muztagh-ata in Xinjiang and 2.1 mm at Daocheng in Sichuan (Feng et al. 2020). The median value of PWV in the European Southern Observatory at Paranel, Chile is 2.5 mm (Kerber et al. 2012).

The average observable time per day in 2019 August is 7.4 hr at Mt. Saishiteng, meaning there are about 2701 observable hours in a year. The highest solar radiance of  $1103 \text{ W m}^{-2}$  indicates the transparency of the sky is high at Mt. Saishiteng. Both the living and working condition is tougher in Ali station with an altitude of 5100 m above sea level and the highest solar radiance of  $1173 \text{ W m}^{-2}$ . At

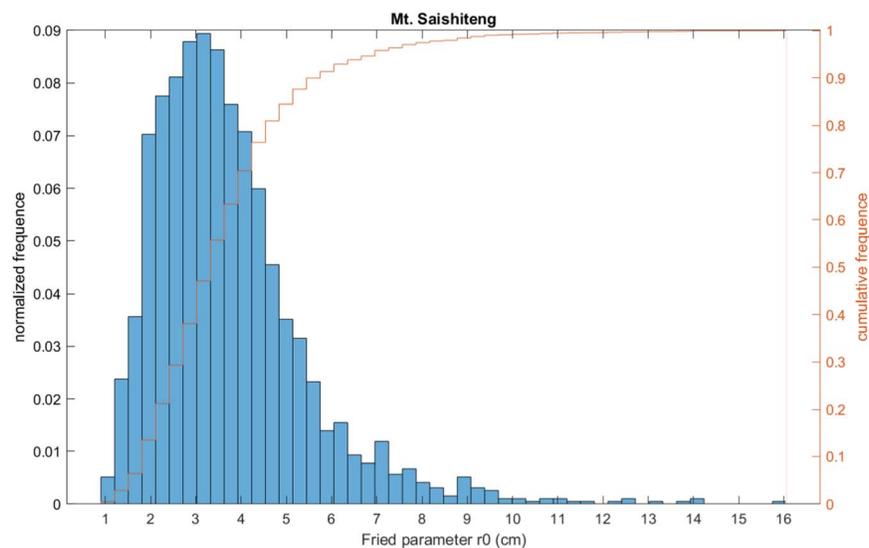
Delingha station, the average observable time per day was 6 hr in 2017 June.

For a 1 m telescope observing the Sun at an infra-red band around  $12.3 \mu\text{m}$ , the median value of Fried parameter  $r_0$  3.4 cm at Mt. Saishiteng is enough and comparable to that in Haleakala, Hawaii for Daniel K. Inoue Solar Telescope (DKIST) with a diameter of 4 m (Özişik & Ak 2004). The median value of Fried parameter  $r_0$  in Daocheng, Sichuan is 7.2 cm (Song et al. 2018).

During the initial phase in 2018, the equipment for site testing was carried up to Mt. Saishiteng by helicopter and we had to climb to Mt. Saishiteng on foot in order to install and adjust the telescope. Up to now, an asphalt road,



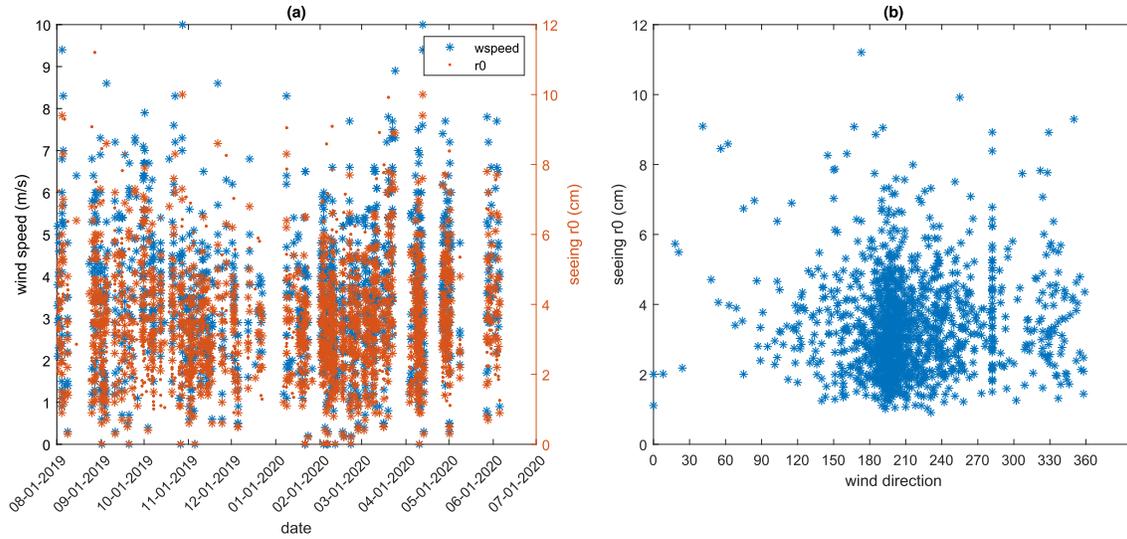
**Figure 15.** Hourly variation of daytime seeing condition  $r_0$  at Mt. Saishiteng on 2019 May 23.



**Figure 16.** Daytime Fried parameter  $r_0$  distributions (blue) and cumulative distribution functions (orange) at Mt. Saishiteng. It peaks at 3.2 cm, 90% is than 5.6 cm, 70% is less than 4.3 cm and 30% is less than 2.7 cm.

internet, and electricity grid have reached Mt. Saishiteng. Considering the site testing results and other conditions for accommodation and logistics of all candidate sites comprehensively, Mt. Saishiteng is selected as the home of AIMS. The actual site of AIMS's dome was selected at a new hilltop with an altitude of 4090 m above sea level ( $38^{\circ}34'26''N$ ,  $93^{\circ}$

$53'45''E$ ) which is about 900 m south of the original one due to the possible block of sunshine from an eastern ridge during sunrise in the summer time. By the end of 2021, the construction of the AIMS dome has completed and Figure 18 is a wide-angle view of the AIMS dome on Mt. Saishiteng taken on 2022 August 8.



**Figure 17.** Comparison of daytime Fried parameter  $r_0$  (orange) distribution with wind speed in blue color (a), and wind direction (b).  $0^\circ$  indicates the north direction.



**Figure 18.** A wide angle view of AIMS dome on Saishiteng Mountain.

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