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***R**esearch in* ***A**stronomy and* ***A**strophysics*

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 weather station, spectrometer for precipitable water vapor (PWV) and S-DIMM and carried out observation on weather elements, precipitable water vapor and daytime seeing condition 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 Fried parameter of daytime seeing observation at Saishiteng Mountain is 3.42 cm. Its solar direct radiation data shows that solar average observable time is 446 minutes per day and premium time is 401 minutes per day in August 2019.

Key words: site testing— seeing

1 REQUIREMENT FOR AIMS CANDIDATE SITES

The Infrared System for the Accurate Measurement of Solar Magnetic Field (AIMS), is a 1 meter telescope which is dedicated to measure the solar magnetic field at middle infra-red waveband by using a Fourier Transform Spectrometer with high spectral resolution. In order to maximized 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 μm, AIMS requires 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 need to be measured in order to obtain good daytime image quality which is closely related to AIMS performance. In the nighttime, the seeing condition was usually measured using Differential Image Motion Monitor (DIMM) such as investigation in Euroupean Southern Observatory at Chile (Sarazin & Roddier 1990), while the daytime seeing condition could be measured by using Solar Differential Image Motion Monitor (S-DIMM) such as in Fuxianhu 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 consider the well finished stations with good accommodation and infrastructure conditions due to limited construction period. As a result Ali in Tibet, Nanshan station in Xinjiang, Delingha station in Qinghai and Daocheng in Sichuan were selected as first four primary candidate sites. Nanshan

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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 live condition is tough. The site test survey of Daocheng in daytime has been done more than one year (Song et al. 2018). The weather station was installed at Nanshan, Ali and Delingha station and a precipitable water vapor spectrometer was deployed in Delingha Station. In phase II (2018-2020), we focus site testing observation on Saishiteng Mountain (38°36'24"N, 93°53'45"E, with altitude of 4200 m) located in the north edge of Qiadam basin, Qinghai province (Figure 1). It is 50 kilometer east of Lenghu town which is the only inhabited town with an altitude of 2750 m, with arid climate all around. In November, 2018, a S-DIMM was deployed and the daytime seeing condition was carried out more than one year. An observing tower with a height of 10 meters was built on the Saishiteng mountain (Figure 2) in November, 2018. In the following sections, we introduce the weather element result in Section 2, show the 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 includes five weather elements: temperature, relative humidity, wind speed and direction and solar direct radiation. All the weather elements were recorded in the time interval of 1 minute. The wind speed is an important weather element which is related to seeing condition. Figure 3 is monthly variation of wind speed in Mt. Saishiteng with median value of 3.2 m/s, and the highest speed of 26.34 m/s. The wind speed in Ali station is the highest with median value of 4.7 m/s and highest speed of 31.2 m/s (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 m/s and the median value in Nanshan station is 2.4 m/s.

Figure 5 shows the monthly variation of temperature in Mt. Saishiteng during July 27, 2019-June 5, 2020 with median value of -6.5 Celsius, 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 the Table 2. The monthly variation of relative humidity in Mt. Satshiteng is shown in Figure 6 with median value of 40.3% and average value of 45%.

The total solar irradiance (TSI) is the intensity of solar radiance outside the Earth atmosphere with a constant of around 1361 W/m^2 (Kopp 2021). Due to the absorption of atmosphere, the intensity of solar direct radiance is usually lower than 1200 W/m^2 on the surface of the Earth. On a clear day, the maximum of solar irradiance indicates the absorption (or extinction) of local atmosphere. On a cloudy day, the solar direct radiation reflects the thickness of cloud through the path from 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 our experience, a solar telescope can observe the Sun continually when solar direct radiation is more than 500 W/m^2 and observe the Sun intermittently when solar irradiance ranges between 300-500 W/m^2 due to cloud or fog. It is hard to observe the Sun normally when solar direct radiation is below 300 W/m^2. In this paper, we define solar premium time and observable time as the solar direct radiation is more than 500 W/m^2 and 300 W/m^2 respectively.

The solar direct radiation meter which is used in AIMS site testing contains a thermoelectric pile which measures the solar irradiance within field of view of 5° in spectral range of 300-3000 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 right ascension in a speed of 15°/hour, while it need to be adjusted manually along declination. Later we find its performance is poor if no one dedicate to adjust the tube pointing to the Sun once the Sun's declination varies or electricity outage occurs occasionally. Figure 7 are the monthly solar irradiance distribution in June 2017 at Delingha station with an average premium time of 296 minutes (5.95 hours) and an observable time of 360 minutes (6

Table 1: Annual wind speed (m/s) statistics of Ali. Nanshan, Delingha station 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

hours) per day. The blue and red horizontal lines indicate low limitation of solar radiance 300 W/m^2 and 500 W/m^2 for observable hour and premium hour respectively. In Mt. Saishiteng, we deployed a fully automatic solar tracking system which can follow the Sun in an accuracy less than 1 ° during the Sun appears above horizon (Figure 8 top). 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 hour) per day and and observable time is 446 minutes (7.4 hour) 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 of solar irradiance is 1103 W/m^2 and the maximum of solar irradiance at Ali reached 1173 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 maybe that we set some part of abnormal irradiance data which appear 1999 W/m^2 to zero.

3 PRECIPITABLE WATER VAPOR

The precipitable water vapor (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 residual intensity of the absorption line of H_2O molecule centered at 935 nm. When the tube of spectrometer is pointing to the Sun, precipitable water vapor is calculated from intensities at 935 nm and 889nm from the function below.

$$R = 0.59^{\sqrt{W}} \tag{1}$$

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

, The PWV measurementsat Nanshan station and Ali station were obtained in only a few days which is not statistically significant. The observations of precipitable water vapor was carried out every 30 minutes in clear day between May 2017 to June 2018 at Delinagha station. Its monthly variation of PWV is shown in Figure 10 with 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 pointing to the Sun while W_0 indicates the corrected value of W to local zenith —that is W_0=W/a, where a is the air mass. Figure 11 shows monthly variation of precipitable water vapor during the period from Nov. 2018 to June 2020 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 show that in the early morning, the W value is high due to great optical thickness and the W reached 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 meter high tower whose pier stood alone separately to 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 was opened as sub-apertures and was covered by a Baade film with 10^{-5} transmission. The diameter of two

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

Table 3: Monthly statistics of premium time, observable time, solar maximum irradiance, altitude and month of observation of Ali, Nanshan, Delingha station and Mt. Saishiteng.

site	premium (hour)	observable time (hour)	maximum irradiance (W/m^2)	altitude (m)	month of observation
Ali	-	-	1173	5100	July 2017
Nanshan	1.95*	2.8*	995	2000	June 2017
Delingha	4.95	6	1036	3100	June 2017
Mt. Saishiteng	6.7	7.4	1103	4200	August 2019

*maximum irradiance refers to maximum solar irradiance among all data at one site.

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	ZWO ASI 174MM
size	11.3*7.1 mm
pixels number	1936×1216
field of view	13’×8.1’
one pixel	0.44”

sub-apertures is 5 cm and their separation is 22 cm. Two prisms with separate angle 10 arc seconds were mounted in the each sub-apertures. A 1/40 neutral filter was installed before the focal plane. The CMOS camera is ZWO ASI 174MM with a sensor of 1936×1216 pixels. Each pixel correspondents to 0.44 arc seconds (see Table 4).

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

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

$$\sigma^2 = 2\lambda^2 {r_0}^{-\frac{5}{3}}[0.179D^{-\frac{1}{3}} - 0.0968d^{-\frac{1}{3}}] \tag{2}$$

or in a simple form (Tokovinin 2002)

$$\sigma^2 = K(\frac{\lambda}{r_0})^{\frac{5}{3}}(\frac{\lambda}{D})^{\frac{1}{3}} \tag{3}$$

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

$$k = 0.364(1 - 0.532b^{-\frac{1}{3}} - 0.024b^{-\frac{7}{3}}) \tag{4}$$

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 in every 30 minutes through remote control in each clear day from November 7, 2018 to June 5, 2020 except the days when site testing instruments was in either outage or off-line. Figure 15 is the hourly variation of Fried parameter on May 23, 2019. 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 cumulative frequency of 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 17a) and wind direction (Figure 17b) during seeing measurement. It shows an almost isotropic distribution of Fried parameter r_o indicating little correlation to the direction of wind, nor the wind speed.

5 DISCUSSION

For AIMS observation at middle infrared waveband, the PWV is the essential parameter among the all site testing parameters. The Delingha station and Mt. Saishiteng are both located in west part of Qinghai Province with a distance about 400 kilometers, 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 Baiying river's bed. Anyway, our method measuring PWV is not accurate than the method by using a commercial Low Humidity 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 European Southern Observatory at Paranel, Chile is 2.5 mm (Kerber et al. 2012).

The average observable time per day in August 2019 is 7.4 hours at Mt. Saishiteng, which means that there are about 2701 observable hours in a year. The highest solar radiance of 1103 W/m^2 indicates the transparency of sky is high at Mt. Saishiteng. Both the living and working condition is tougher in Ali station with altitude of 5100 m above the sea level and the highest solar radiance of 1173 W/m^2. At Delingha station, the average observable time per day is 6 hours in June 2017.

For a 1 meter telescope observing the Sun at infra-red band around 12.3 μm, 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 diameter of 4 meters (Özişik & Ak 2004). The median value of Fried parameter r_0 in Daocheng, Sichuan is 7.2 cm (Song et al. 2018).

Fig. 1: Mt. Saishiteng is located at north edge of Qiadam Basin, China (N 38°36'45", E 93°53'45").

During initial phase in 2018, the equipments for site testing were carried up to Mt. Saishiteng by a helicopter and we must climb to Mt. Saishiteng on foot in order to install and adjust the telescope. Up to now, an asphalt road, internet and electricity grid have reached to Mt. Saishiteng. Considering the site testing results and other conditions for accommodation and logistics of all candidate sites comprehensively, the Mt. Saishiteng is selected as the home of AIMS. The actual site of AIMS's dome was selected at a new hill top with altitude of 4090 meters above sea level (38°34'26"N, 93°53'45"E) which is about 900 m south to the original one due to the possible block of sunshine from a eastern ridge during sunrise in the summer time. By the end of 2021, the construction of AIMS dome has completed and Figure 18 is a wide angle view of the AIMS dome on Mt. Saishiteng taken on August 8, 2022.

Acknowledgements I would like thank to staffs of Delingha station in Qinghai, Purple Mountain Observatory, Ali station, National Astronomical Observatories and Nanshan station, Xinjiang Astronomical Observatory for their help and effort during site testing observation. I would also like to thank Tengfei Song, Yunnan Astronomical Observatory, for preparing optical wedge of S-DIMM. This work is sponsored by the National Natural Science Foundation of China (NSFC) under the grant numbers of 11427901 and No. 12273059, and National Key R&D Program of China under grant number of 2021YFA1600500.

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Fig. 2: The AIMS site testing tower for monitoring daytime seeing condition (left) with a height of 10 meters.

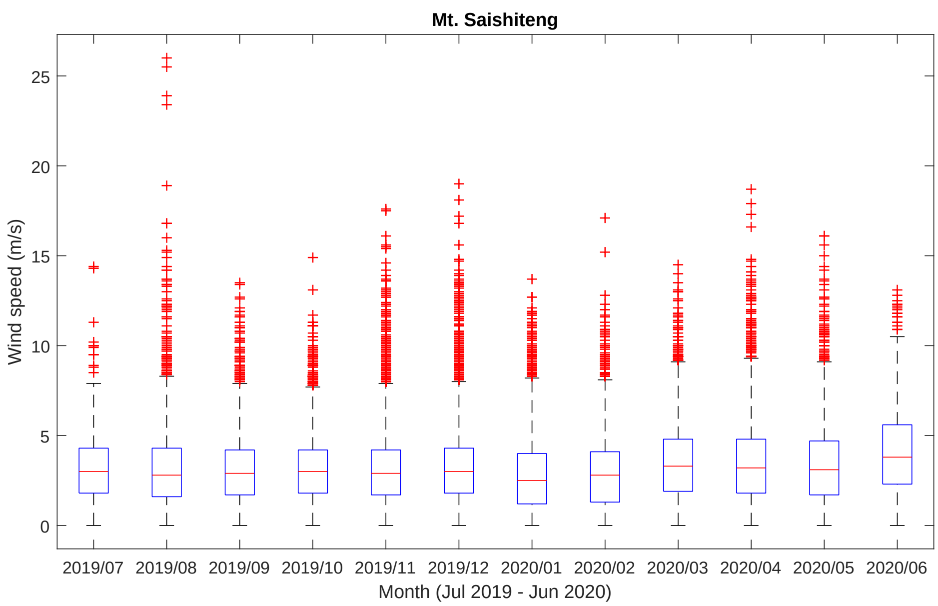

Fig. 3: Monthly variation of wind speed at Mt. Saishiteng. The upper tip, upper top of a box, mid-bar in a box, bottom of a box and lower tip represent 95%, 75%, 50%, 25% and 5% of the measured data for each month respectively. Plus signs represent the outlier data which are beyond box.

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Sarazin, M., & Roddier, F. 1990, A&A, 227, 294 1, 5
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Tokovinin, A. 2002, PASP, 114, 1156 5

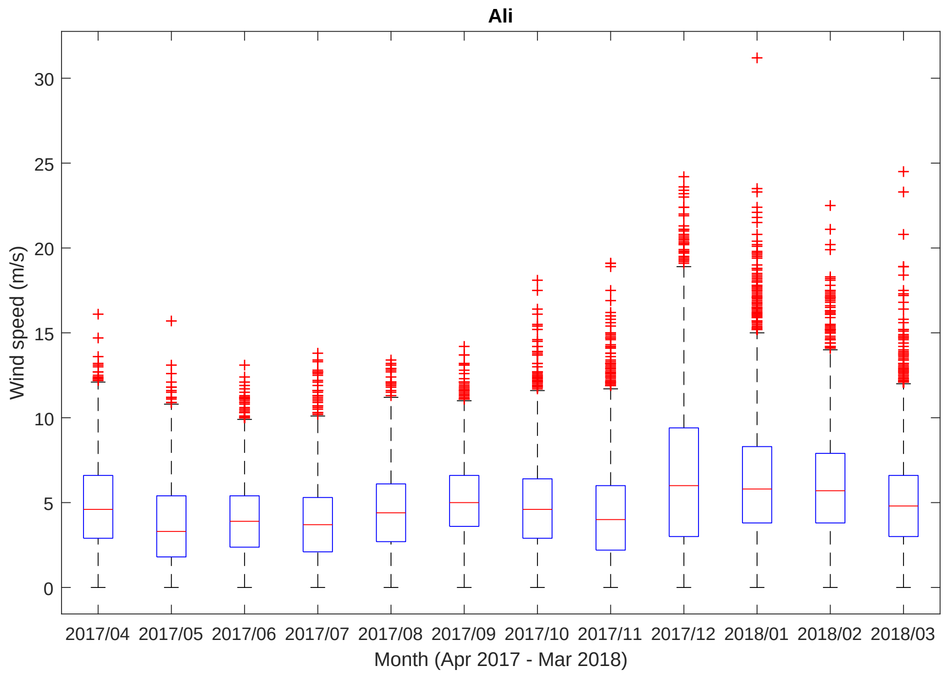

Fig. 4: Monthly variation of wind speed at Ali station.

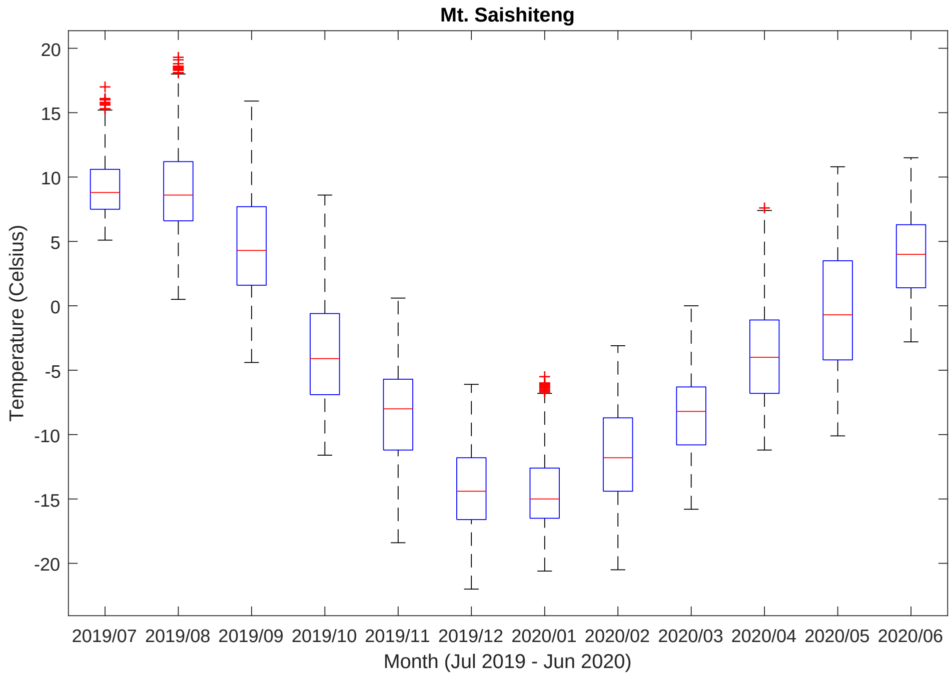

Fig. 5: Monthly variation of temperature at Mt. Saishiteng. The median temperature is -6.5 $^{\circ}C$, the highest temperature is 19.2 $^{\circ}C$ and the lowest temperature is -22 $^{\circ}C$

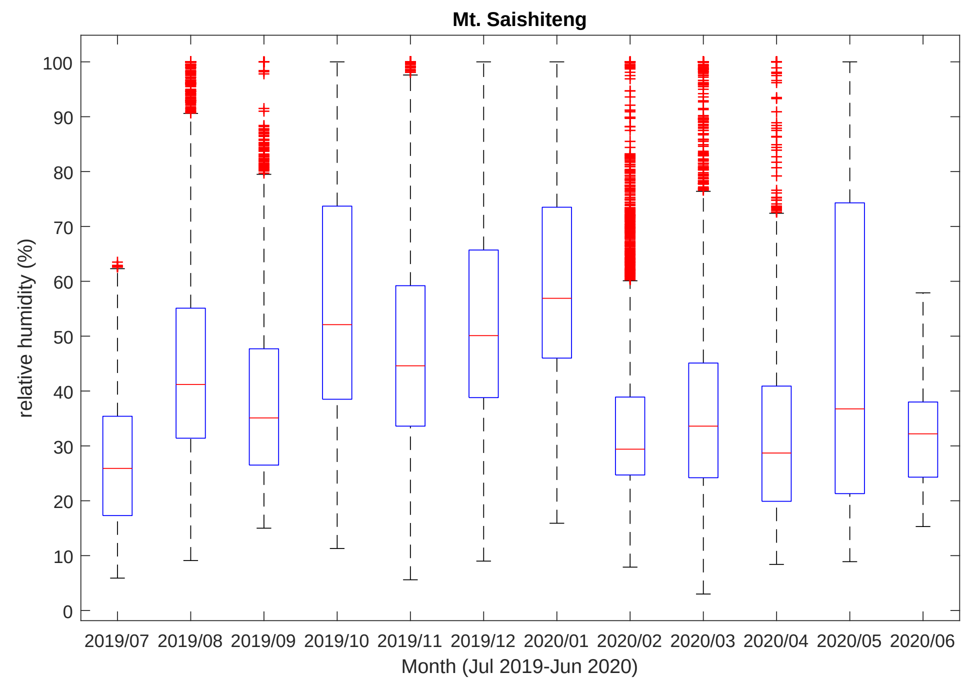

Fig. 6: Monthly variation of relative humidity at Mt. Saishiteng.

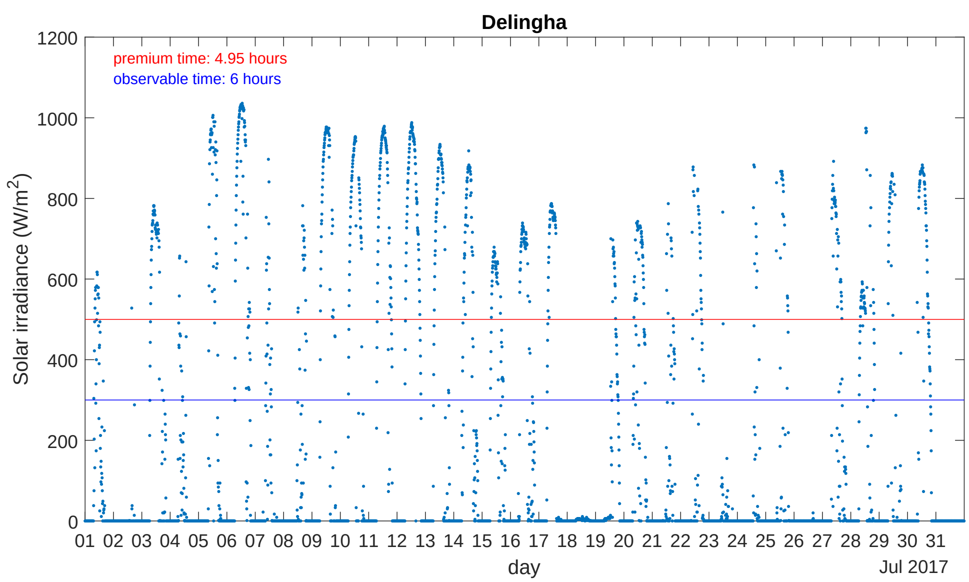

Fig. 7: The solar radiance variation in July, 2017 at Delingha station. Red and blue horizontal lines indicate solar radiation of 500 and 300 W/m^2 respectively. In each day, its average premium time is 296 minutes (5.95 hours) and observable time is 360 minutes (6 hours).

Fig. 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° and tracking accuracy of solar tracker is less than 1 °. S-DIMM and precipitable water vapor spectrometer were mounted together on an ATR equatorial mounting at Mt. Saishiteng (bottom).

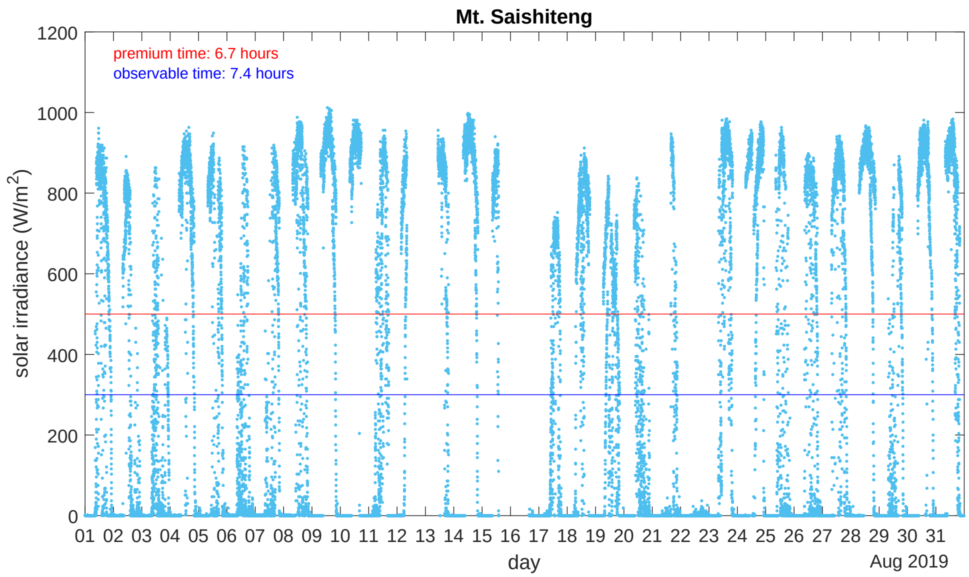

Fig. 9: The solar irradiance variation in August, 2019 at Mt. Saishiteng. Red and blue horizontal lines indicate solar radiation of 500 and 300 W/m^2 respectively. In each day, its average premium time is 401 minutes (6.7 hours) and observable time 446 minutes (7.4 hours).

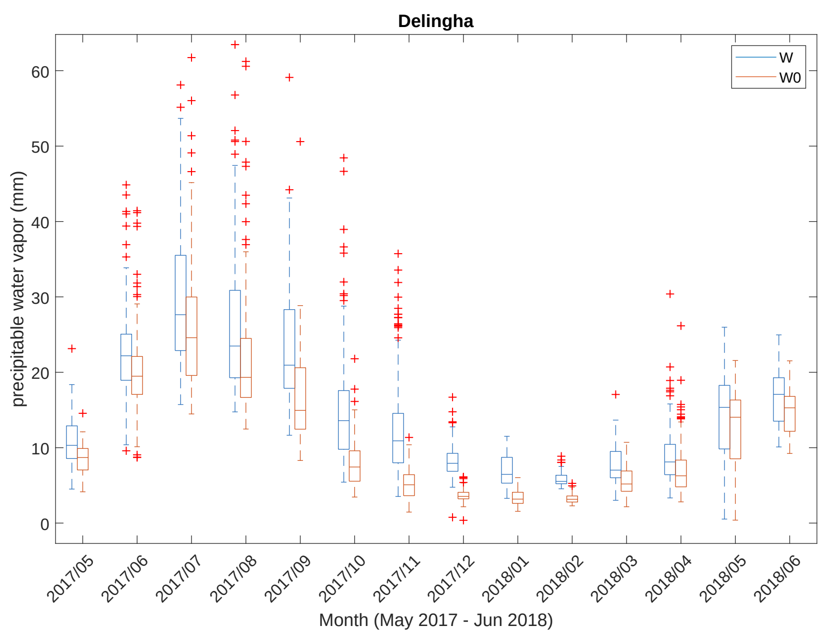

Fig. 10: Monthly variation of precipitable water vapor in Delingha in Qinghai province. W (blue) represent observational PWV and W_0 (orange) represent PWV corrected to the zenith.

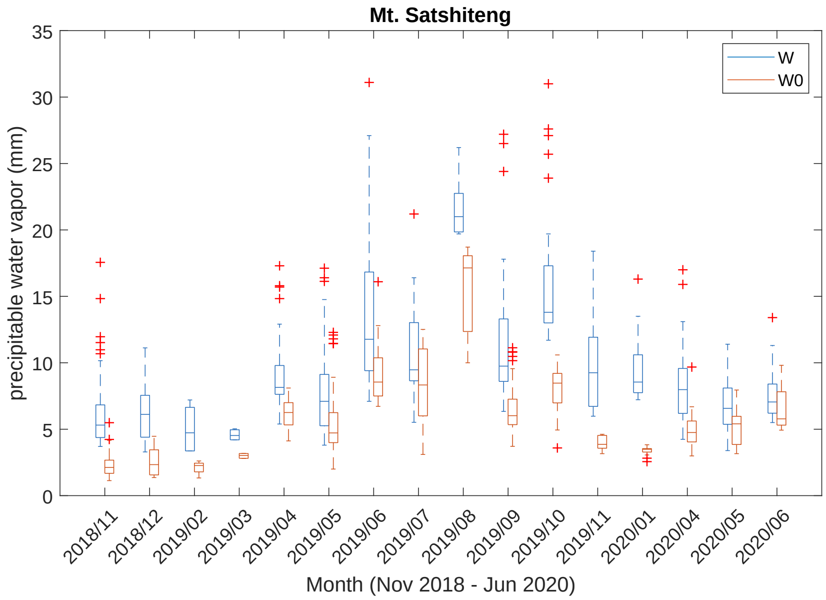

Fig. 11: Monthly variation of precipitable water vapor W (blue) at Mt. Saishiteng during Nov. 18, 2018-July 06, 2020. W_0 (orange) indicates the value W with correction to the zenith (precipitable water vapor divided by air mass). The upper tip, upper top of a box, mid-bar in a box, bottom of a box and lower tip represent 95%, 75%, 50%, 25% and 5% of the measured data for each month respectively.

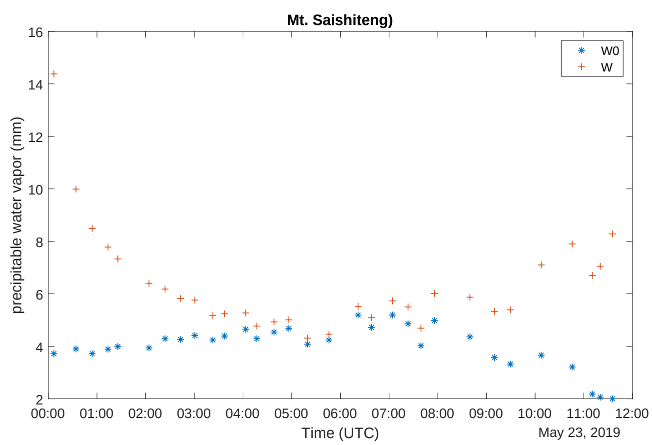

Fig. 12: Hourly variation within a day of PWV on May 23, 2019 at Mt. Saishiteng.

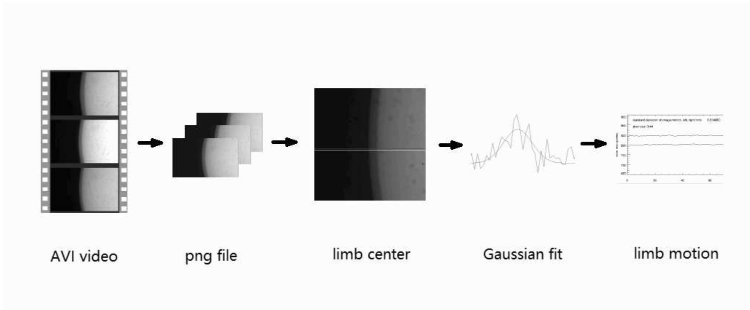

Fig. 13: Process of seeing data observation and reduction of S-DIMM at Mt. Saishiteng.

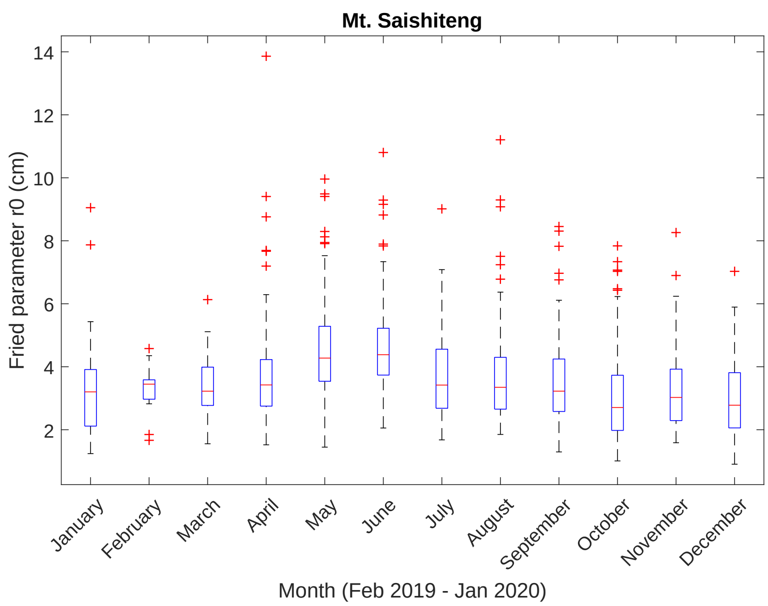

Fig. 14: Monthly variation of daytime seeing r_0 at Mt. Saishiteng. The upper tip, upper top of a box, mid-bar in a box, bottom of a box and lower tip represent 95%, 75%, 50%, 25% and 5% of the measured data for each month respectively.

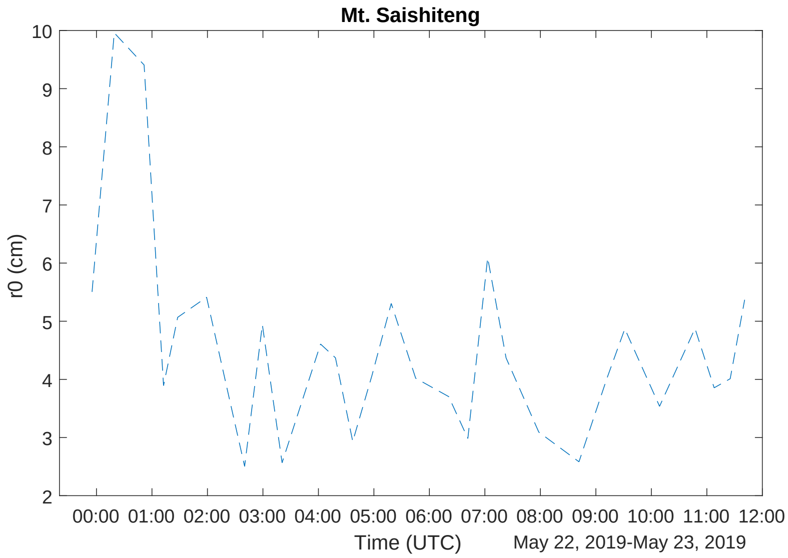

Fig. 15: Hourly variation of daytime seeing condition r_0 at Mt. Saishiteng on May 23, 2019.

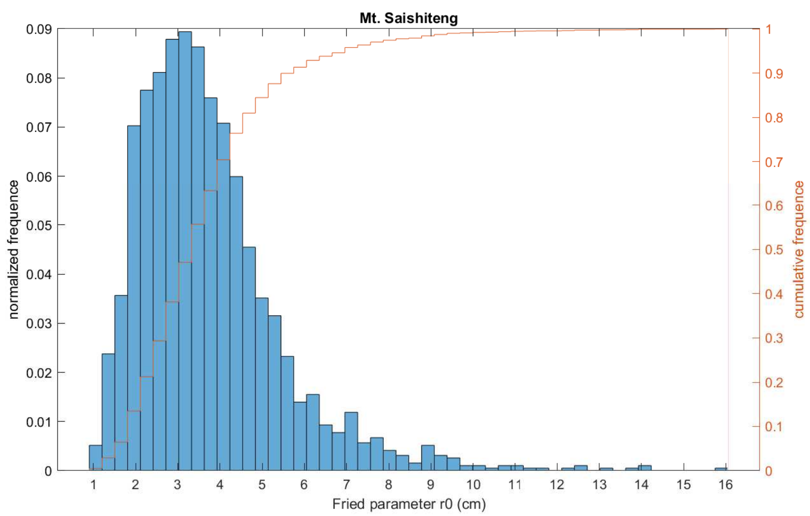

Fig. 16: Daytime Fried parameter r_0 distributions (blue) and cumulative distribution functions (orange) at Mt. Saishiteng. It peaks at 3.2 cm, 90% is than 5.6 cm, 70% is less than 4.3 cm and 30% is less than 2.7 cm.

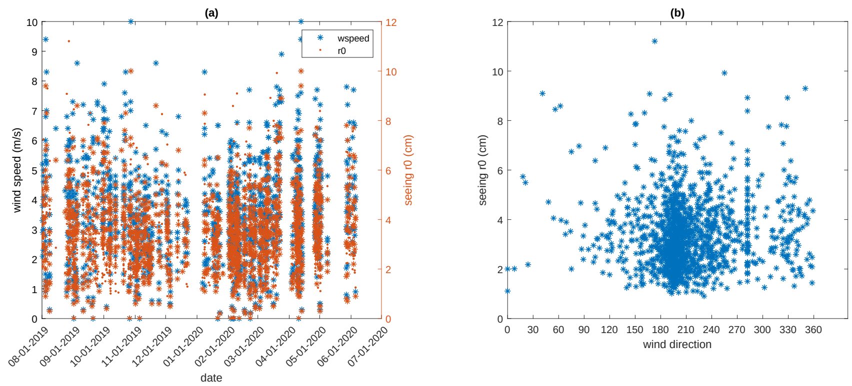

Fig. 17: Comparison of daytime Fried parameter r_0 (orange) distribution with wind speed in blue color (a), and wind direction (b). 0 degree indicates the north direction.

Fig. 18: A wide angle view of AIMS dome on Saishiteng Mountain.