Postprint: Research on Real-time Correction Methods for Laser Ranging Prediction of Non-cooperative Targets

Authors: Zhang Xunfang^{1,2}, Zhao Xue^{1,2}, Li Rongwang^{1,3}, Li Zhulian^{1,3}

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Abstract

Laser ranging predictions for non-cooperative targets are generally based on extrapolation from Two-Line Element (TLE) sets, which often exhibit significant deviations that substantially impact the success rate of laser ranging. By combining orbital theory of space targets with analysis of actual measurement data, it is found that prediction deviations primarily arise from discrepancies between the mean anomaly of the space target on its operational orbit as extrapolated through the prediction model and the actual mean anomaly. Based on the miss distance of the non-cooperative target in the telescope tracking field of view, relevant algorithms can be employed to determine an optimal time element deviation to correct the mean anomaly of the space target. Following such correction, the apparent position deviation of the space target is improved, and the range deviation can be reduced from hundreds of meters to tens of meters, thereby enhancing the accuracy of the expected echo arrival time and enabling higher-precision range gating for single-photon detectors, which improves the success rate of ranging.

Full Text

Preamble

Geng Lihong[1], Tan Chengming[1], Dun Jinping[2], Zhang Hong[3], Jia Yanhui , Yan Yihua[1], Chen Zhijun[1], Ma Suli[1], , Liu Donghao[1], Du Jing[1], Su Cang[1]

[1]CAS Key Laboratory of Solar Activity (National Astronomical Observatories), Chinese Academy of Sciences, Beijing 100101
[2]Key Laboratory of Space Weather, National Center for Space Weather, China Meteorological Administration, Beijing 100081

[3]The 16th Research Institute of China Electronics Technology Group Corporation, Hefei, Anhui 230043
The 54th Research Institute of China Electronics Technology Group Corporation, Shijiazhuang, Hebei 050081
China University of Petroleum, Qingdao, Shandong 266580

Abstract

Long-term monitoring of solar radio flux using ground-based telescopes represents a crucial method for space weather forecasting, enabling prediction of various disturbances on Earth triggered by solar activity. Two newly constructed three-band solar radio telescopes—located in Mingantu and Tashkurghan—will serve China's space weather monitoring and forecasting efforts. This paper introduces their system architecture, design characteristics, and a dual-noise-source calibration method. The system stability exceeds 1% over 10-hour periods, with sensitivity better than 1 solar flux unit (s.f.u.). Preliminary results from the Mingantu Solar Radio Telescope' s 2017 trial observations are presented.

Keywords: solar radio flux; telescope; F10.7 index; calibration; space weather

1. Solar Radio Flux and Space Weather

Changes in the state of geospace caused by solar activity and other natural phenomena are referred to as "space weather," with solar activity being the primary driver. Severe space weather variations can lead to space weather disasters. Increasing evidence demonstrates that a single space weather disaster can simultaneously impact multiple technological systems—including communications, navigation, aviation, aerospace, exploration, and energy—resulting in substantial consequences. Numerous issues require urgent research and comprehensive planning, such as establishing space weather observation systems, responding to space weather disasters, evaluating the impacts of severe space weather events, and providing reliable forecasts to mitigate these effects.

Space weather disaster monitoring must trace the entire causal chain from the Sun through interplanetary space, the magnetosphere, and the ionosphere to the upper and middle atmosphere. Solar activity forecasting constitutes the most important aspect of space weather prediction, encompassing solar flares, coronal mass ejections, proton events, solar radio flux, and high-speed solar wind. The total solar radio flux at a specific wavelength reflects the level of solar activity in a particular layer of the solar corona. Solar radio flux exhibits correlations with relative sunspot number, flare eruptions, X-ray bursts, and high-energy electron and proton events, with the 2840 MHz band (wavelength 10.7 cm) showing the most significant relationship. The 10.7 cm solar radio flux (F10.7), measured in "solar flux units" (s.f.u.), typically ranges from 50-500 for quiet Sun conditions. Since the 1960s, F10.7 has served as a solar activity index and remains a primary parameter for solar activity forecasting.

Research on quiet Sun radio emission, combined with optical data, enables the establishment of more precise models of the solar atmosphere (chromosphere and corona). The slowly varying solar radio flux density demonstrates strong statistical correlations with sunspot and plage areas. The height and size of slowly varying radio sources generally increase with wavelength, and the flux density also varies with wavelength. Observations reveal that the spectral peak of slowly varying radio emission occurs in the 5-20 cm band, with the specific location shifting as solar activity increases (such as with enhanced magnetic fields in sunspots). Simultaneous observations of slowly varying solar radio emission at multiple wavelengths can monitor the physical state of different layers of the solar atmosphere above active regions (such as electron density and temperature). Typically, solar eruptions coincide with the appearance of numerous sunspots. F10.7 maintains a good linear relationship with sunspot number. Solar storms occur during periods of high solar radio flux, with the flux increasing abruptly 1-2 days before a solar storm eruption, accompanied by significant changes in the radio energy spectrum characteristics.

Solar ultraviolet radiation affects the density of Earth' s upper atmosphere, which in turn produces drag effects on spacecraft and influences satellite orbits. Specifically, atmospheric drag correlates closely with solar ultraviolet flux, with most drag models currently using F10.7 to represent solar ultraviolet flux. Earth' s upper atmosphere also exhibits pronounced long-term variations following an 11-year cycle, significantly impacting the orbits and lifetimes of long-duration spacecraft. In summary, solar radio flux serves as the most useful indicator of solar activity and solar ultraviolet radiation bursts, characterizing the overall level of solar activity.

2. The Three-Band Solar Radio Telescopes MST and TST

Numerous single-antenna, single-frequency or multi-frequency solar radio flux observation systems continue operating internationally, including Canada' s Ottawa/Penticton 2800 MHz system, which has conducted routine observations since February 1947. Its daily solar flux density represents an internationally recognized solar activity index with absolute accuracy better than 5% and relative stability exceeding 2% over decades. The Nobeyama Radio Observatory in Japan operates seven single-frequency polarimeters at 1.0, 2.0, 3.75, 9.4, 17, 35, and 80 GHz, serving as an internationally recognized standard for solar radio flux spectra. The U.S. Air Force Radio Solar Telescope Network (RSTN) consists of four stations—LEAR (without 35 GHz), PALE, SGMR, and SVTO —providing 24-hour continuous observations at nine frequencies: 0.245, 0.41, 0.606, 1.415, 2.695, 4.995, 8.8, 15.4, and 35 GHz. The Institute of Applied Physics at the University of Bern conducts observations at eight frequencies: 3.2, 5.2, 8.4, 11.8, 19.6, 35.0, 50.0, and 92.5 GHz. Additionally, the National Astronomical Observatories operates a 2840 MHz system that has conducted routine observations since the 1970s.

However, China has historically relied on foreign monitoring data for F10.7 indices in space weather forecasting, resulting in time-lagged information and limited data availability—typically only one data point per day. The Tashkurghan Three-Band Solar Radio Telescope represents part of the China Meteorological Administration’ s National Center for Space Weather Monitoring and Warning’ s overall plan for a ground-based solar observation system dedicated to space weather forecasting operations, with the National Astronomical Observatories of the Chinese Academy of Sciences responsible for overall implementation to develop China’ s comprehensive, seamless space weather detection capabilities.

Considering maintenance requirements, climate conditions, and solar observation constraints, two three-band solar radio telescopes operating at 2801 MHz, 4542 MHz, and 9084 MHz (wavelengths 10.7 cm, 6.6 cm, and 3.3 cm) have been constructed at the Mingantu Observatory Base of the National Astronomical Observatories in Inner Mongolia and in Tashkurghan, Xinjiang. The telescopes, designated MST (Mingantu Three-Band Solar Telescope) and TST (Tashkurghan Three-Band Solar Telescope), are located at 42.22°N, 115.24°E, 1356 m altitude and 37.78°N, 75.23°E, 3091 m altitude, respectively [Figure 1: see original paper]. Spanning approximately 5000 km across China with a time difference of about 2 hours and 40 minutes, the two telescopes provide extended solar observation time coverage. Their results can mutually validate and complement each other, and after calibration, data are transmitted promptly to the National Space Weather Warning Center of the China Meteorological Administration to provide timely and reliable first-hand information for solar activity forecasting and real-time solar storm alerts.

TST is situated within the Tashkurghan Meteorological Bureau near the city center, where the electromagnetic environment poses significant challenges for three-band solar radio observations. With the advancement of China’s “Belt and Road” initiative, Tashkurghan has become an important node for the “China-Pakistan Economic Corridor” within China’ s borders, and rapid development of mobile communication networks is expected. Additionally, its borders with Pakistan, Afghanistan, and Tajikistan to the southeast, southwest, and northwest respectively further deteriorate TST’ s electromagnetic environment, necessitating consideration of relocation. The Mingantu Observatory Base of the National Astronomical Observatories has implemented various radio environmental protection measures and is located more than 20 km from the relatively densely populated Mingantu town, resulting in a far superior electromagnetic environment for MST compared to TST.

The Mingantu Spectral Radioheliograph (MUSER), located at the Mingantu Observatory Base, represents a new generation of solar-dedicated imaging equipment based on aperture synthesis principles, featuring high temporal, spatial, and spectral resolution simultaneously. Accepted in July 2016, MUSER stands as one of the most powerful instruments internationally for observing the dynamic nature of solar activity, probing the coronal atmosphere, and advancing solar physics research. MUSER comprises low- and high-frequency arrays, with MUSER-II operating in the 2.0-15.0 GHz band, consisting of 60 2-meter parabolic antennas arranged in a three-arm spiral array. Its conventional observation mode employs full-band frequency sweeping (intermediate frequency bandwidth 400 MHz) with a temporal resolution of 206.25 ms, compared to MST' s 1 ms resolution. During MUSER-II' s high-spatial-resolution imaging observations of phenomena such as flare eruptions, MST' s simultaneous three-frequency, dual-polarization observations at the same site facilitate mutual verification of observational data and may provide more detailed evolutionary processes at high temporal resolution across three layers of the solar atmosphere at the corresponding three frequencies.

3.1 System Components and Performance

MST and TST feature automatic data acquisition, analysis and processing, generation and transmission of formatted data products compliant with meteorological operational specifications, as well as system calibration and self-checking capabilities. The systems demonstrate high reliability and stability, enabling continuous long-term operation under all-weather conditions and adaptation to harsh climatic environments. The system block diagram is shown in Figure 2 [Figure 2: see original paper]. The systems employ GPS timing and UPS backup power supply. A 3-meter equatorial-mounted parabolic antenna provides efficiency exceeding 40%.

A broadband 90° hybrid coupler converts linearly polarized signals received by the Eleven feed into left- and right-hand circularly polarized signals, operating at 2801 MHz, 4542 MHz, and 9084 MHz with time resolutions of 1 s, 100 ms, and 1 ms. The instantaneous dynamic range exceeds 30 dB. The half-power beam widths for the three bands are 150' , 92' , and 46' , respectively, covering the full solar disk. Pointing accuracy exceeds 1/15 of the operating wavelength, with pointing updated once per second under computer control during solar tracking.

The harsh climate conditions at both sites necessitate system performance stability and noise reduction through the use of dual low-noise amplifiers. Temperature-sensitive outdoor RF front-end components are housed in a high-precision constant-temperature box near the feed, following the MUSER analog outdoor front-end method. Low-loss coaxial cables transmit RF signals with gain fluctuations less than 1% per 10 hours. The outdoor RF front-end operates in environments from -30°C to +60°C, with temperature control ranging from 10°C to 40°C (settable according to ambient temperature) and tested temperature control accuracy better than ±0.05°C. Figure 3 [Figure 3: see original paper] shows the configuration diagram and photograph of the constant-temperature outdoor front-end box.

The sensitivity formula for a single-antenna system is:

$$\Delta S_{\min} = \frac{2kT_s}{A_e \eta \sqrt{\tau \Delta f}} \cdot \frac{R_{\min}}{R_{\min} - 1}$$

where R_{min} is the minimum usable signal-to-noise ratio (typically $R_{\mathrm{min}} = 5$); Boltzmann constant $k = 1.38 \times 10^{-23}$ J/K; receiving antenna geometric area $A = \pi D^2/4$ with $D = 3$ m; integration time $\tau = 100$ ms; integration bandwidth $\Delta f = 10$ MHz; and antenna efficiency $\eta = 0.4$.

The system noise temperature is approximately:

$$T_s \approx (T_a + T_{\mathrm{sun}}) \cdot b + T_0 \cdot (1 - b) + T_{\mathrm{rec}}$$

where $T_a + T_{\mathrm{sun}}$ represents antenna noise (pointing to cold sky) and quiet Sun radiation power; b is the transmission coefficient from antenna output to receiver input; with $T_a \approx 100$ K, $T_{\mathrm{sun}} \approx 500$ K at 2801 MHz, $b \approx 0.5$, and $T_0 = 290$ K. The dual-channel limiting low-noise amplifiers exhibit measured noise figures less than 2.5 dB within the operating band. The receiver system noise figure is less than 3.0 dB, with receiver system noise temperature $T_{\mathrm{rec}} < 290$ K, yielding $T_s \approx 735$ K. Consequently, the system sensitivity $\Delta S_{\mathrm{min}} \approx 0.36$ s.f.u. Both MST and TST achieve relative sensitivity better than 1% and possess the capability to detect small bursts of several s.f.u.

3.2 User-Friendly Interface

MST and TST employ aesthetically pleasing and user-friendly interfaces that are convenient and easy to operate, as shown in Figure 4 [Figure 4: see original paper]. The main interface displays the system architecture, allowing users to set time resolution and select data storage disks. Additional buttons provide access to system configuration and status display, antenna control and status display, and real-time power display interfaces. The interface is concise, clear at a glance, and easy to operate. In automatic observation mode, the system automatically starts and stops observations according to schedule, places the antenna in a stowed position after stopping, and enables monitoring of system status and real-time power. The antenna control interface allows setting the antenna to point in specific directions, selecting rotation direction and speed in both right ascension and declination axes, and enabling automatic target tracking according to specified orbits. The real-time power display interface allows zooming in and out on both axes, selecting any of the three bands for display, and choosing between real-time data display or playback of daily data.

3.3 Calibration

Calibration establishes the relationship between receiver values and signal strength. Only through calibration do observational data acquire physical meaning and become comparable with results from other instruments. As a "variable star," the Sun requires daily calibration at each band as an essential component of solar radio telescope observation procedures. Solar radio telescope calibration methods include absolute calibration, relative calibration, and non-linear calibration, with relative calibration being most commonly employed

—using known standard sources to calibrate raw data. Calibration parameters are functions of frequency, temperature, and zenith angle Z when atmospheric absorption is considered.

(1) Absolute Calibration

For an antenna with relatively wide beam patterns, the flux density of a point source can be expressed as:

$$S(\nu) = \frac{2k_B T_A(\nu)}{A_e(\nu)} = \frac{2k_B \Delta T_A}{\eta D_0 \lambda^2/4\pi}$$

where $S(\nu)$ is the flux of the point source at frequency ν; k_B is the Boltzmann constant; D_0 is the antenna directivity coefficient; K is the antenna pattern correction factor; τ_0 is the atmospheric absorption factor; z is the zenith angle, and $e^{\tau_0 \sec(z)}$ is the atmospheric correction factor (typically approximated as 1). The antenna gain $G = \eta D_0$, and ΔT_A is the antenna temperature increment from the celestial body (Sun). Since the Sun' s ΔT_A varies daily, stable and reliable measurement of ΔT_A constitutes a prerequisite for absolute calibration. Obtaining the Sun' s absolute flux density requires experimental measurement of antenna gain and standard noise source values, followed by conversion of antenna temperature increments to radio flux using the above formula. Absolute calibration renders radio telescope observations independent of other telescopes, creating a self-contained system.

(2) Relative Calibration

MST and TST initially adopted the calibration method systematically developed by Tanaka et al. in the 1970s, utilizing noise sources with known noise temperatures, matched loads, and sky background to determine net solar radio flux values. Signals from the Sun' s right- and left-hand circular polarizations output from the circularly polarized feed pass through low-noise amplifiers and then connect to two inputs of a four-way microwave switch. The switch's remaining two inputs were initially designed as a noise source with 15 dB excess noise ratio and a 50-ohm matched load. High backend noise in the receiver system elevates the noise floor, such that when the microwave switch connects to the 50-ohm load, the terminal reading reflects the receiver system noise equivalent to before the microwave switch. This issue is resolved using dual noise sources with different excess noise ratios, replacing R_n, R_t and T_n, T_t with R_{n1}, R_{n2} and T_{n1}, T_{n2}, as shown in Figure 5 [Figure 5: see original paper].

Subtracting readings from the right-hand quiet Sun and sky background yields the net right-hand quiet solar radio flux after sky background radiation removal:

$$\Delta T_{A,R}^{\text{sun}} - \Delta T_{A,R}^{\text{sky}} = \frac{S_{\text{sun},R}(\nu)}{G_R(\nu) A_{e,R}(\nu)} - \frac{S_{\text{sky},R}(\nu)}{G_R(\nu) A_{e,R}(\nu)}$$

The effective antenna area $A_e(\nu)$ differs for right-hand circular polarization $A_{e,R}(\nu)$ and left-hand circular polarization $A_{e,L}(\nu)$. The system gains G_L and G_R incorporate the left- and right-hand gain characteristics from the low-noise amplifier front-end to the microwave switch, while T_r represents the receiver system gain from the microwave switch to the digital terminal.

From the four equations above, we obtain:

$$C_R(\nu) = \frac{R_{n2}(\nu) - R_{n1}(\nu)}{T_{n2}(\nu) - T_{n1}(\nu)} \cdot \frac{S_{\mathrm{sun},R}(\nu) - S_{\mathrm{sky},R}(\nu)}{R_{\mathrm{sun},R}(\nu) - R_{\mathrm{sky},R}(\nu)}$$

and equation (1) becomes:

$$S_{\mathrm{sun},R}(\nu) - S_{\mathrm{sky},R}(\nu) = C_R(\nu) \cdot \frac{R_{\mathrm{sun},R}(\nu) - R_{\mathrm{sky},R}(\nu)}{R_{n2}(\nu) - R_{n1}(\nu)} \cdot (T_{n2}(\nu) - T_{n1}(\nu))$$

Similarly, the net left-hand solar radio flux after sky background removal is:

$$S_{\mathrm{sun},L}(\nu) - S_{\mathrm{sky},L}(\nu) = C_L(\nu) \cdot \frac{R_{\mathrm{sun},L}(\nu) - R_{\mathrm{sky},L}(\nu)}{R_{n2}(\nu) - R_{n1}(\nu)} \cdot (T_{n2}(\nu) - T_{n1}(\nu))$$

Both right-hand sides of equations (2) and (3) contain only recorded known values. Under ideal conditions, observations of a quiet Sun without sunspots should yield zero circular polarization, as the full-disk quiet Sun exhibits no circular polarization. However, actual quiet Sun observations produce unequal left- and right-hand circular polarization outputs.

The non-circular-polarization characteristic of the quiet Sun can calibrate the telescope' s polarization reception properties. The actual quiet Sun left- and right-hand radio flux should each represent half of the total solar radio flux $S_\Theta(\nu)$ at that frequency band:

$$S_{\mathrm{sun},R}(\nu) = S_{\mathrm{sun},L}(\nu) = \frac{1}{2} S_\Theta(\nu)$$

where $S_\Theta(\nu)$ adopts the standard international solar radio flux spectrum values for the observation day. However, standard $S_\Theta(\nu)$ values cannot generally be obtained in real-time daily.

Substituting known $S_\Theta(\nu)$ values over a period into equations (2) and (3) yields normal distributions of $C_R(\nu)$ and $C_L(\nu)$ during that period. Their mean values serve as calibration coefficients $C_R^*(\nu)$ and $C_L^*(\nu)$ for the right- and left-hand circular polarization channels:

$$C_R^*(\nu) = \frac{R_{n2}(\nu) - R_{n1}(\nu)}{T_{n2}(\nu) - T_{n1}(\nu)} \cdot \frac{S_{\text{sun},R}(\nu) - S_{\text{sky},R}(\nu)}{R_{\text{sun},R}(\nu) - R_{\text{sky},R}(\nu)}$$

$$C_L^*(\nu) = \frac{R_{n2}(\nu) - R_{n1}(\nu)}{T_{n2}(\nu) - T_{n1}(\nu)} \cdot \frac{S_{\text{sun},L}(\nu) - S_{\text{sky},L}(\nu)}{R_{\text{sun},L}(\nu) - R_{\text{sky},L}(\nu)}$$

Within the receiver' s linear range, net solar radio burst flux left- and right-hand components can be calibrated:

$$S_{\text{burst},R}(\nu) = C_R^*(\nu) \cdot \frac{R_{\text{burst},R}(\nu) - R_{\text{sky},R}(\nu)}{R_{n2}(\nu) - R_{n1}(\nu)} \cdot (T_{n2}(\nu) - T_{n1}(\nu))$$

$$S_{\text{burst},L}(\nu) = C_L^*(\nu) \cdot \frac{R_{\text{burst},L}(\nu) - R_{\text{sky},L}(\nu)}{R_{n2}(\nu) - R_{n1}(\nu)} \cdot (T_{n2}(\nu) - T_{n1}(\nu))$$

Environmental and atmospheric parameter changes cause short-term fluctuations and annual variations in calibration coefficients. Calibration accuracy degrades during solar maximum years. MST and TST' s three bands span the centimeter-decimeter range, with atmospheric absorption affecting each band differently. Calibration requires receivers with excellent linearity and stability. Obtaining precise and reliable calibration coefficients demands statistical analysis of long-term observational data.

Trial observations for MST and TST began in late 2016. Figure 6 and Table 1 present comparisons between MST observations on December 15, 2016, and similar solar radio telescopes at Shidao and Nobeyama, Japan, demonstrating MST system stability better than 1% over 10 hours. During solar bursts, intense radio signals cause significantly increased standard deviations in observational results. Even during quiet periods without sunspots, telescopes receive electromagnetic signals from various celestial bodies or sky backgrounds. Therefore, assessing system stability through solar observations requires analysis of long-term monitoring data. Additionally, reducing environmental impacts represents an important guarantee for achieving long-term stability. Future work will conduct extended stability testing and further analyze factors affecting system stability.

System stability typically refers to receiver stability. The Allan test represents the ultimate method for measuring stability but requires extensive measurement time. This paper assesses receiver stability through measurement of long-term gain fluctuations and signal-to-noise ratio, as shown in Figure 7 [Figure 7: see original paper], demonstrating minimal gain fluctuations over 16 hours of receiver operation with signal-to-noise ratio greater than 20 dB, indicating receiver stability better than 1%.

Figure 8 [Figure 8: see original paper] compares MST S-band solar radio flux data (red dots) from January-October 2017 with Canadian Penticton data (green line, without Earth-Sun distance correction). By October 31, 2017, MST had effectively observed the Sun on 148 days. MST data were processed by integrating millisecond-level data to seconds, subtracting daily backgrounds from noon 1 PM observations (avoiding bursts when present) for both polarizations and three bands, then multiplying by corresponding correction coefficients. Further debugging of MST antenna, receiver, and software in early March 2017 enabled automated observations. Changes in system state before and after debugging may explain larger deviations between MST and Canadian data in January and February. Seasonal variations in system state also cause deviations, representing a factor that future system calibration must address. In September 2017, solar active region AR2673 triggered a series of solar eruption events, including the most brilliant X9.3-class flare ever recorded at 20:02 Beijing time on September 6. Figure 9 [Figure 9: see original paper] presents MST observations during September 1-12, while Figure 10 [Figure 10: see original paper] shows enlarged details of MST X-band observations on September 6, 2017.

5. Conclusion

Two three-band solar radio telescopes have been constructed at the Mingantu Observatory Base of the National Astronomical Observatories in Inner Mongolia and in Tashkurghan, Xinjiang. Plagued by electromagnetic interference, TST is currently under consideration for relocation. MST has already obtained solar flux data and observed several solar bursts, demonstrating that high stability (better than 1%/10 hours), high sensitivity (better than 1 s.f.u.), large dynamic range (30 dB), and adjustable time resolution design enable the telescopes to function for both solar radio burst observations and flux monitoring, though observational results require further verification. This paper presents the first design and implementation of a dual-noise-source calibration method. Based on 2017 trial observations, MST underwent further debugging by the end of 2017, resulting in more stable and reliable system operation. More effective observational data are expected in 2018, enabling deeper calibration work and further analysis and testing of factors affecting stability.

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Two New 3-Bands Solar Radio Polarimeters and Spaceweather

Geng Lihong[1], Tan Chengming[1], Dun Jinping[2], Zhang Hong[3], Jia Yanhui , Yan Yihua[1], Chen Zhijun[1], Ma Suli[1], , Liu Donghao[1], Du Jing[1], Su Cang[1]

[1]CAS Key Laboratory of Solar Activity (National Astronomical Observatories), CAS, Beijing 100101, Email: genglh@nao.cas.cn; [2]Key Laboratory of Space

Weather, National Center for Space Weather, China Meteorological Administration, Beijing 100081, China; [3]The 16th Research Institute of China Electronics Technology Group Corporation, Hefei, China; The 54th Research Institute of China Electronics Technology Group Corporation, Shijiazhuang, 050081, China; China University of Petroleum, Qingdao, 266580, China

Abstract: It is an important method of space weather predictor to monitor the solar flux continuously in long-term with the ground-based solar radio telescopes. Solar flux is one of the most useful observable indexes for predicting kinds of turbulence occurred on the earth excited by the sun activities and solar ultraviolet radiation. It represents the solar total activity level, especially the 10.7cm solar flux, which has long been used as solar activity index since 1960s. With the financial support of NSMC (National Satellite Meteorological Center) and NAOC (National Astronomical Observatories), two new 3-bands radio telescopes used to monitor the solar flux on three wavelengths (10.7cm, 6.6cm and 3.3cm) have been set up in 2016 December in Mingantu Observatory of NAOC in inner Mongolia province and in Tashkurghan in Xinjiang province. The two telescopes, named MST and TST separately, each consisting of a 3-m size diameter parabolic antenna, 2-10 GHz wide band two-polarization feed, a constant temperature front-end box, will give more time coverage to observe the sun with the distance between the two sites is about 5000km and 2.67 hours zone away. Constant temperature of the front-box helps to keep the system stability, especially in Mingantu and Tashkurghan the weather changes severely from hour to hour. After calibrated, data sets of fits format will be uploaded automatically everyday through the internet to the data reduction center of NSMC, used as space weather monitoring data. Double noise sources methods is first adopted in system calibration. The system stability is better than 1% in over 10 hours, system sensitivity is better than 1 s.f.u., with $\Delta f = 10$MHz and $\Delta t = 0.1$s. The electromagnetic environment of MAT is much better than that of TST. In 2017, MST has gotten some preliminary results. In 2018, more efficient data can be expected, and further work will be done in system calibration and system stability testing and analyzing.

Key words: solar radio flux; telescope; F10.7 index; calibration; spaceweather