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Special Collection:
Introduction to Representative Equipment and Preliminary Observation Results of Chinese Meridian Project

China's Ground-Based Space Environment Monitoring Network—Chinese Meridian Project (CMP)

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Key Points:

- Chinese Meridian Project (CMP) has achieved end-to-end tracking and monitoring capabilities for solar storms from the solar atmosphere to near Earth space
- The CMP has deployed network monitoring capabilities covering various space layers of the solar-terrestrial space
- Special arrangements have been made to focus on the fine structures for key regions

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Abstract Monitoring and investigation of the solar-terrestrial space environment is a huge challenge for humans in space age. To this end, China has established the Ground-based Space Environment Monitoring Network, namely Chinese Meridian Project (CMP). The project comprises three major systems: the Space Environment Monitoring System, Data and Communication System, and Scientific Application System. The Space Environment Monitoring System adopts a well-designed monitoring architecture, known as "One Chain, Three Networks, and Four Focuses," to achieve stereoscopic and comprehensive monitoring of the entire solar-terrestrial space. The "One-Chain" component utilizes optical, radio, interplanetary scintillation, cosmic ray instruments to cover the causal chain of space weather disturbances from the solar surface to near-Earth space. For the ionosphere, middle and upper atmosphere, and magnetic field, instruments are deployed along longitudes of 120° and 100°E, and latitudes of 30° and 40°N, forming the "Three Networks." Furthermore, more powerful monitoring facilities or large-scale instruments have been deployed in four key regions: the high-latitude polar region, mid-latitude region in northern China, low-latitude region at Hainan Island, and the Tibet region. These four regions are crucial for disturbances propagation and evolution, or possess unique geographical and topographical characteristics. The Data and Communication System and Scientific Application System are designed for data collecting, processing, storage, mining, and providing user service based on data acquired by the Space Environment Monitoring System. The data obtained by CMP will be shared with the global scientific community, facilitating enhanced collaboration on space weather and space physics research.

Plain Language Summary Space weather seriously affects human space activities and some ground facilities. Therefore, monitoring and researching the space environment has important scientific significance and application value. In order to gain a comprehensive understanding of the space environment from the sun to the Earth, China is building a large-scale ground-based space environment monitoring system, known as the Chinese Meridian Project (CMP). This monitoring system covers the entire chain from the Sun's surface and interstellar space to the Earth's magnetosphere, ionosphere, and mid and upper atmosphere. The monitoring system adopts optical, radio, geomagnetic, and other means to achieve a networked monitoring system. Meanwhile, for some key regions, advanced large-scale instruments are used for three-dimensional, comprehensive and high spatiotemporal resolution detection. The construction of CMP is divided into two phases. The Phase I is from 2008 to 2012. The Phase II started construction in 2019 and will be put into operation this year. We are convening a special collection in Space Weather journal to introduce its representative equipment and preliminary observation results. This article is one of this special collection. It serves as the overall introduction to the CMP, which will enhance understanding of the project and promote collaborative exchanges.

1. Introduction

The solar-terrestrial space refers to the vast area from above the Earth's troposphere up to the solar atmosphere, including the middle and upper atmospheres, ionosphere, magnetosphere, interplanetary space, and the solar atmosphere. It represents the fourth environment closely related to modern human activities, in addition to the ocean, atmosphere, and land environments. The Sun's intense radiation, solar wind, and high-energy particles have significant impacts on the solar-terrestrial space environment. Geological disasters such as earthquakes, tsunamis, and strong events in the lower atmosphere, such as typhoons, also affect the near-space environment of the Earth. Consequently, the solar-terrestrial space environment is a complex system of multiple layers coupled with each other, serving as a natural laboratory that is challenging to replicate on the ground and an important testbed for nurturing scientific discoveries.

The solar-terrestrial space environment has a dual nature. On one hand, it provides valuable resources for humanity, including microgravity, space activities, navigation and communication, and remote sensing applications. On the other hand, disastrous space weather events could cause serious harm to human high-tech systems, leading to disturbances to satellite operations, communication, navigation, and power systems, and affecting the normal operation of space-based and ground-based national high-tech infrastructure, as well as possibly endangering human health and life.

Understanding the characteristics of the solar terrestrial space environment, revealing the causal chain process of its variation, and improving the accuracy of space weather forecasting are crucial for monitoring and studying the solar terrestrial space environment. This is also an important prerequisite for human space exploration and utilization. Effectively monitoring, studying, and predicting the complex processes in the solar terrestrial space environment presents a significant challenge for modern society.

Ground-based space environment monitoring is an irreplaceable and important observation approach, offering the advantage of continuous monitoring of critical areas and parameters. This approach has been highly valued in international space weather research due to its “5C” advantages (continuous, convenient, controllable, credible, and cost-effective). Presently, ground-based monitoring is trending toward networked development, with research groups worldwide establishing various ground monitoring networks, such as SuperDARN, MAGDAS, and INTERMAGNET. It also forms a vital component of the satellite-ground joint space environment comprehensive monitoring system.

To achieve monitoring and research on the complex solar terrestrial space environment, including the coupling of the solar atmosphere, interplanetary space, magnetosphere, ionosphere, and middle and upper atmosphere, and to form a comprehensive ground-based monitoring capability for the solar terrestrial space environment, Chinese scientists proposed the construction of the Ground-based Space Environment Monitoring Network in China. This initiative was approved and funded by the Chinese funding agency as a national major science and technology infrastructure project, known as the Chinese Meridian Project (CMP).

The CMP has three major scientific goals:

- Exploring the propagation and evolution of space weather events and their impact on the space environment, with nationwide coverage and high temporal and spatial resolution from the solar atmosphere to near Earth space.
- Revealing the characteristics of change and differences in the space environment over different regions of China, including special regions such as the Tibetan Plateau, the north and south of China, and evaluating relationship between the regional characteristics of China's territorial space environment and the global space environment.
- Studying the coupling mechanism between different spatial layers and physical processes during space weather events, and the coupling process of the solid Earth, lower atmosphere, and near-Earth space environment under special geological and geographical conditions in China.

The construction of CMP is divided into two phases. The construction period of the first phase, CMP-Phase I, was from 2008 to 2012 (Wang, 2010). After 2012, the CMP-Phase I was put into operation. From 2012 to present, the CMP-Phase I has been running for more than one solar cycle. Significant progress in the regional characteristics of the space environment, the propagation of space weather disturbances, and the coupling of matter and energy between different layers have been made by using data from the CMP-Phase I (Wang et al., 2023). The second phase, CMP-Phase II, began in 2019 and has been completed, forming a comprehensive solar-terrestrial space environment monitoring network covering the Chinese Mainland and the polar regions. In addition to conventional instruments, the CMP-Phase II also constructed a batch of advanced large-scale monitoring instruments. This network extends the detection altitude from near-Earth space to the solar atmosphere, providing a stereoscopic monitoring capability for the entire solar-terrestrial space, and is expected to make breakthroughs in research on the solar-terrestrial space environment, space weather forecasting, and applications.

The CMP will share data with scientists worldwide through our data center website (http://www.meridianproject.ac.cn), and introducing this “Chinese Meridian Project Special Collection” to enhance understanding of the

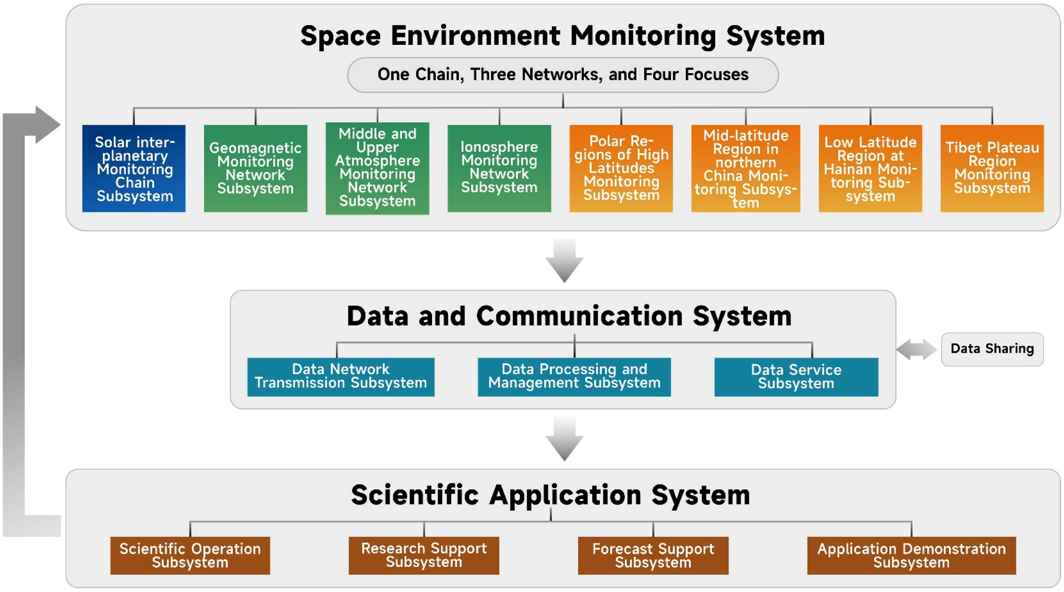

Figure 1. System framework diagram of the Chinese Meridian Project.

project and promote collaborative exchanges. This collection includes an overall introduction to the project and detailed articles on important advanced large-scale monitoring instruments. This article serves as the overall introduction to the CMP, with subsequent sessions presenting the composition and architecture of the project, its major systems, and finally the summary.

2. Composition and Overall Architecture

The CMP is composed of three major systems: the Space Environment Monitoring System, Data and Communication System, and Scientific Application System. These three systems work together to achieve comprehensive monitoring of the space environment, data collection and sharing, scientific research, and space weather forecasting.

The Space Environment Monitoring System includes monitoring instruments distributed across China mainland, as well as in the Antarctic and Arctic regions, to conduct comprehensive monitoring of the space environment.

The Data and Communication System consists of data transmission network facilities and centralized data centers, which handle data transmission, storage, processing, and distribution services.

The Scientific Application System is responsible for analyzing data extracting information from the monitoring system. It provides high-level data products for various research and applications, supports space environment models, and facilitates space weather forecasting. Additionally, the Scientific Application System is responsible for the operation and management of the CMP.

The integration of these three major systems forms the complete CMP framework, enabling centralized operation and rapid response. It establishes a comprehensive information mining and user service system from observation to data. The composition and overall architecture of the CMP is given in Figure 1.

3. Space Environment Monitoring System

The CMP is a ground-based space environment monitoring network consisting of nearly 300 monitoring instruments distributed across the Chinese Mainland and the polar regions. These instruments are installed at 31 observation stations, strategically located approximately along longitude 120°E, longitude 100°E, latitude 30°N, and latitude 40°N, effectively covering the territory of China. To ensure optimal observation conditions, each station may have multiple near-by sites for installing different instruments. For example, geomagnetic and radio instruments are often placed at separate sites to prevent interference. In total, nearly 100 observation sites have

Figure 2. Layout of the observation sites of Chinese Meridian Project.

been established, with adjacent sites typically spaced less than 500 km apart, or less than 100 km in densely populated areas, enabling the monitoring of small to medium scale physical processes, shown in Figure 2.

Given the extensive range of the solar-terrestrial space and the diverse parameters that need to be monitored, the CMP employs a wide variety of monitoring instruments. These instruments utilize geomagnetic (electrical) measuring, radio remote sensing, optical remote sensing, and other methods to continuously monitor various physical parameters, including solar magnetic field, solar monochromatic radiation, solar wind speed, atmospheric density, atmospheric temperature, electron density and temperature, ion density and temperature, electric field, magnetic field, neutral wind field, plasma drift speed etc.

To achieve comprehensive and three-dimensional detection of the entire solar terrestrial space, the CMP adopts a monitoring architecture consisting of eight subsystems, namely "One Chain, Three Networks, and Four Focuses" (shown in Figure 1). The so-called "One Chain" is formed by optical, radio, interplanetary scintillation (IPS), and cosmic ray instruments, covering the entire space chain from the solar surface to interplanetary space, and further

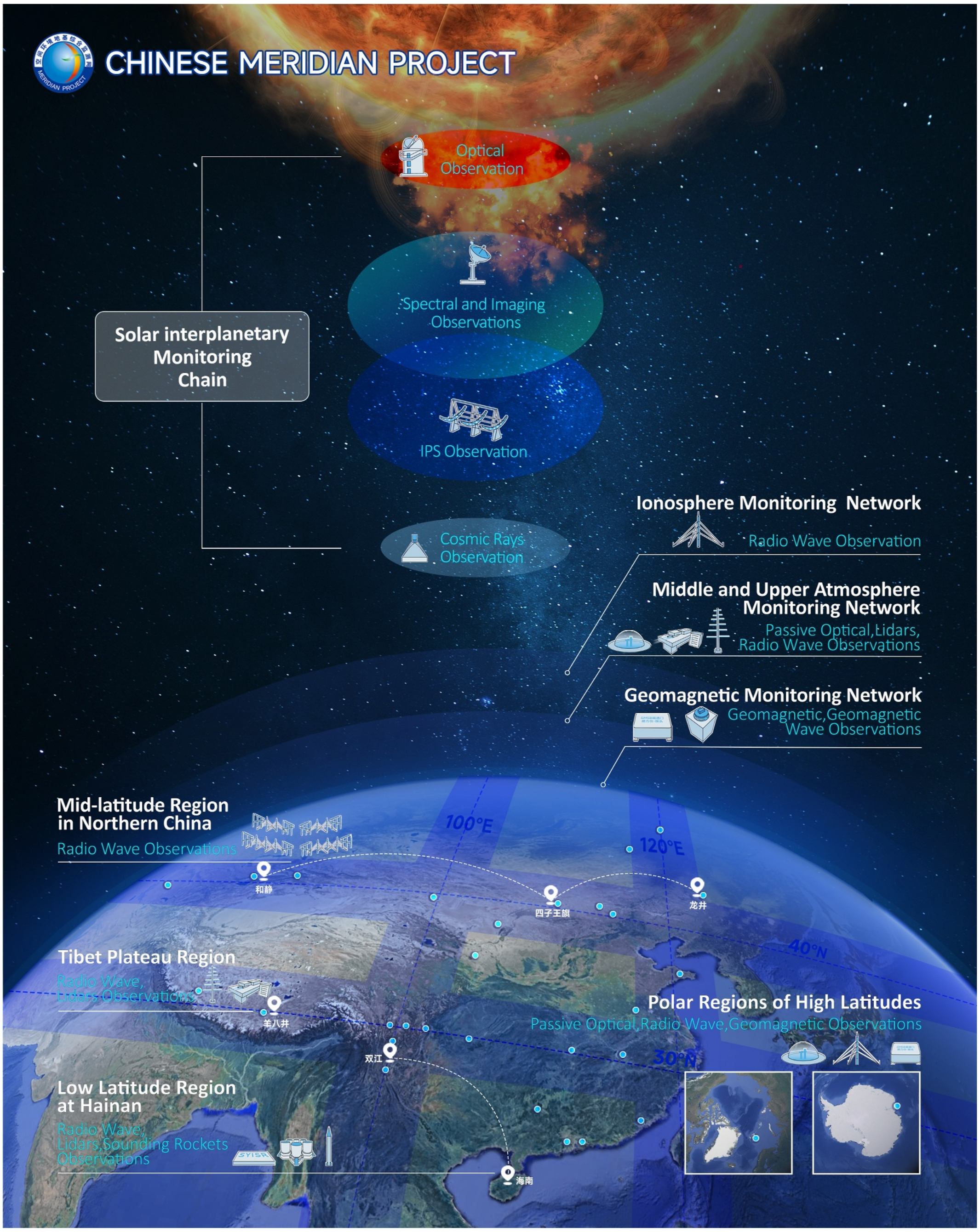

Figure 3. Schematic diagram of Chinese Meridian Project's space environment monitoring system.

to the geospace. The “Three Networks” conduct grid-like monitoring for the ionosphere, middle and upper atmosphere, and geomagnetic field over the territory of China. Additionally, four key areas with special regional characteristics or serving as key nodes for the propagation of space weather disturbances have been identified, and large-scale instruments or most powerful monitoring facilities have been established in these areas to carry out detailed detection. These key regions include the high latitude polar regions, the mid-latitude region in northern China, the low latitude region at Hainan, and the Tibet Plateau region.

The space environment monitoring system of the CMP is depicted in Figure 3, illustrating the comprehensive and intricate architecture of the monitoring network. Each component of this monitoring architecture will be further elaborated in the subsequent paragraphs.

3.1. One Chain-Solar Interplanetary Monitoring Chain Subsystem

The sun serves as the primary source of disturbances in the solar terrestrial space environment. Solar activities, such as sunspots, flares, and eruptions in the solar photosphere and chromosphere, exert significant influence on the space between the sun and the Earth. The highly structured corona encompasses various physical processes, including coronal heating, solar wind formation and acceleration, prominences, coronal mass ejections (CMEs), shock waves, current sheets, and fluctuations in various scales. Material and energy released by solar eruptions propagate and dissipate in the vast interplanetary space, involving complex processes such as solar wind high-speed flows and solar wind turbulences. Monitoring the solar atmosphere and interplanetary space is crucial for understanding the mechanisms of solar eruptions and the transmission laws of matter and energy, as well as improving space weather forecasting performance.

In the solar-interplanetary space, significant differences exist in the frequency of electromagnetic radiation across various regions. Electromagnetic radiation primarily occurs in the visible and near-infrared bands in the photosphere and chromosphere. Optical imaging and spectral line detection enable the direct acquisition of burst information near the solar surface. In contrast, electromagnetic radiation in the solar corona and interplanetary space mainly occurs in the radio wave band. Ground-based radio detection, due to the Earth's ionosphere shielding effect, operates within the frequency range of approximately 30 MHz to 20 GHz, with its radiation source region corresponding to the region within 10 $R_\odot$ (solar radius) above the photosphere's surface. Electromagnetic radiation from interplanetary spaces farther from the sun is blocked by the ionosphere, rendering it undetectable using ground-based radio instruments. However, high-frequency radio signals from distant cosmic radio sources experience fluctuations in phase and amplitude due to solar wind disturbances when passing through interplanetary space, a phenomenon known as interplanetary scintillation (IPS). By receiving IPS signals, it becomes feasible to derive solar wind characteristics, such as bulk speed and density, from a heliocentric distance of about $20R_\odot$ to the outer edge of the Earth's magnetosphere. Additionally, continuous monitoring of cosmic rays provides disturbance information on solar wind can be obtained. For example, the emergence of CME often coincides with a decline in cosmic ray recordings known as the Forbush Decrease.

To account for the differences in various space regions, the CMP's solar interplanetary monitoring chain employs various detection methods, including optics, radio, IPS, and cosmic rays, to cover the space region from the solar atmosphere to the vicinity of the Earth's magnetosphere. This comprehensive approach forms a full chain with tracking and monitoring capability for solar eruption activities from the solar surface to near-Earth space. The main monitoring instruments in this chain include:

- Solar Disk Chromosphere Telescope: This instrument utilizes the Hα spectral line (656.3 nm) for continuous and rapid imaging of the solar chromosphere, capturing a complete image in just 1 s.
- Solar Magnetism and Activity Telescope: Featuring two independent channels, one for chromosphere Hα (656.3 nm) imaging with a time resolution of 1 s, and another (532.4 nm) utilizing the Zeeman effect to measure the magnetic field intensity of the solar photosphere, with a time resolution of 15 min.
- Solar Full-disk Multi-layer Magnetograph: This instrument consists of two independent optical channels, each alternately observing with two working wavelengths, resulting in a total of 4 working wavelengths, namely 656.3, 854.2, 532.4, and 486.1 nm. It can obtain the solar magnetic field (vector magnetic field of photosphere, longitudinal magnetic field of chromosphere), velocity field, and monochromatic images of the sun. The time resolution of velocity field and magnetic field is 15 min.
- Spectral Imaging Corona Graph: This instrument observes the solar corona within 2 $R_\odot$, capturing information on the radiation intensity, Doppler velocity, and spectral line broadening of the corona's emission. The working spectral line wavelength of the device is 637.4 nm, with extending capability.
- Radioheliographs: Multiple solar radio imaging instruments operating in different frequencies perform imaging observations across a wide band of 30 MHz-15 GHz. The multitude can sweep all frequency points within 1 s, providing a frequency resolution of 1 MHz. These instruments include a Meter-Decameter Wave Radioheliograph (30–400 MHz), a Circular Array Solar Radio Telescope (150–450 MHz), and a Centimeter-Decimeter Wave Radioheliograph (400 MHz-15 GHz).
- Solar spectrum monitoring instruments: These instruments include a Metric Wave Solar Radio Spectrometer (90–300 MHz), a Decimetric Wave Solar Radio Spectrometer (400 MHz-2 GHz), and a Centimetric Wave Solar Radio Spectrometer(2–15 GHz), offering spectrum monitoring ability across a super wide band from 90 MHz up to 15 GHz.

Table 1
Instrument Configuration of the Solar Interplanetary Monitoring Chain Subsystem

Space region	Parameters measured	Instruments
Photosphere	Magnetic field, velocity field and monochromatic image	Solar Magnetism and Activity Telescope, Solar Full-disk Multi-layer Magnetograph
Chromosphere	Magnetic field, velocity field and monochromatic image	Solar Disk Chromosphere Telescope, Solar Magnetism and Activity Telescope, Solar Full-disk Multi-layer Magnetograph
Corona	E corona radiation intensity, velocity field	Spectral Imaging CoronaGraph
Corona and interplanetary (0–10$R_\odot$)	Solar radio flux, radio image	Spectrometers and radioheliographs in multiple frequency bands
Interplanetary(20–215 $R_\odot$)	Solar wind velocity, density, and structures	IPS telescope, Moun telescope and neutron counter

- IPS array: This array comprises three IPS telescopes located at vertexes of a triangle with border length of about 200 km. This multi-site architecture reduces dependence on models when calculating solar wind speed, density, and other parameters. The operating frequencies of the instrument include 327, 654, and 1.4 GHz, and the observation range extends from the heliocentric distance 20 $R_\odot$ to the vicinity of the Earth's magnetosphere.
- Cosmic ray monitoring instruments: These instruments include 2 muon telescopes and one neutron counter, deployed in mid-latitude and low-latitude areas to monitor different types of cosmic ray secondary particles.

In total, there are 17 instruments in the Solar Interplanetary Monitoring Chain Subsystem, distributed across four far-flung regions in the east, west, south and north of China to reduce the impact of weather on optical observations and extend the observation time of the sun. This comprehensive monitoring approach provides valuable data for understanding solar eruptions, with the sun observation time per day exceeding 10 hr in summer. The instruments of the Solar Interplanetary Monitoring Chain Subsystem are listed in Table 1.

3.2. Three Networks

The CMP has deployed a comprehensive network of instruments to monitor the near-Earth space environment, including the geomagnetic field, the ionosphere, and the middle and upper atmosphere. These instruments are approximately located along the meridians (120° east longitude, 100° east longitude) and latitude lines (30° north latitude, 40° north latitude), providing extensive coverage across China's territory in a grid pattern. The observation stations are denser near the 120° east longitude meridian line, with a minimum station interval of about 100 km. This layout enables thorough monitoring of the rich longitude and latitude variations and regional characteristics of the near-Earth space environment over China.

3.2.1. Geomagnetic Monitoring Network Subsystem

The geomagnetic field includes both internal and external components. The internal field, including the remnant magnetism of the lithosphere, is generated by the dynamo mechanism within the solid earth and exhibits relatively stable, long-term changes. On the other hand, the external source field originates from current systems in space, such as ring current, ionospheric current, field-align current, and is characterized by various fluctuation phenomena, including ULF waves from the magnetosphere, VLF waves and whistle waves generated by sky electricity. These fluctuations make the external source field rapidly changing and rich in information closely related to space plasma and various physical processes.

The CMP Geomagnetic Monitoring Network Subsystem has deployed 109 geomagnetic (and electrical) instruments to detect long-term changes, rapid changes, and fluctuations in the geomagnetic field and near-surface electric fields. The network conducts the following types of observation:

- Absolute geomagnetic observation: The fluxgate theodolite and the Overhauser magnetometer are used to measure the direction and total intensity of the geomagnetic field, respectively. These instruments accurately measure the three components of the geomagnetic field vector and obtain the baseline value of the geomagnetic field. The CMP has developed an automated fluxgate theodolite for this purpose, conducting

Table 2
Instrument Configuration of the Geomagnetic Monitoring Network Subsystem

Instrument	Number	Capabilities
Fluxgate Theodolite	13	Precision: 0.1’ Candence: 2 times per week for manual instrument, and 1 hr for the auto model
Overhauser magnetometer/Proton magnetometer	20	Precision: 0.01 nT Time resolution: 1 s
Fluxgate magnetometer	30	Frequency band: DC-0.3 Hz Precision: 0.01 nT Time resolution: 1 s
Search coil magnetometer	25	Frequency band: 1 mHz ~30 Hz Dynamic range: ±200 nT Sensor noise:10^{-2} nT/$\sqrt{\text{Hz}}$ @0.01 Hz 10^{-4} nT/$\sqrt{\text{Hz}}$ @1 Hz Sample rate: 64 Hz/32 Hz/16 Hz
Wideband magnetic field wave monitor	5	Frequency band: 0.1 mHz-50 kHz Dynamic range: ±65,000 nT(0.1 mHz–2 Hz) ±1,000 nT(0.2 Hz–2 kHz) ±100 pT(0.2–50 kHz)
Low frequency magnetic field wave receiver	4	Frequency band: DC-20 kHz Dynamic range: ±100 nT(1–100 Hz) ±100 pT(100 Hz–20 kHz)
Geoelectric field monitor	5	Resolution: 10 μV Number of channels: 6 Time resolution: 1 min
Atmospheric electric field monitor	9	Precision: 0.1 V/m(for small range),2.5 V/m(for large range) Time resolution: 1 s

baseline observations every hour under unmanned conditions. The Overhauser magnetometer measures once per second with an accuracy of 0.1 nT.

- Relative geomagnetic observation: Fluxgate magnetometers continuously monitor the variation of the geomagnetic field, with a time resolution of 1 s and a measurement accuracy of 0.1 nT. Due to their long-term drift characteristic, the fluxgate magnetometers use absolute geomagnetic observations for baseline calibration.
- Geomagnetic wave observation: Along the 120° meridian east and 40° latitude north, the Geomagnetic Monitoring Network has built 7 geomagnetic wave observation stations to measure geomagnetic waves and their propagation processes. The monitoring instruments include a broadband magnetic field wave monitor, an ultra-low frequency magnetic field wave monitor, and a low-frequency magnetic field wave receiver. Their combined frequency range covers 0.001 Hz-100 kHz and provides observational information on ULF, ELF, and VLF waves.
- Electric field observation: Relevant monitoring instruments include atmospheric electric field detector and geoelectric field detector. The former measures the atmospheric electric field in the vertical direction near the ground, while the latter measures the horizontal electric field in the shallow layer of the Earth's surface.

The detailed instrument configuration of the Geomagnetic Monitoring Network Subsystem is shown in Table 2.

3.2.2. Middle and Upper Atmosphere Monitoring Network Subsystem

The middle and upper atmosphere, including the stratosphere, mesosphere, and thermosphere, is a crucial region for the transition of the Earth's atmosphere into space. It is influenced by factors such as solar radiation and particle deposition, as well as material and energy from the lower atmosphere, resulting in complex photochemical, thermodynamic, and dynamic processes with varying scales and significant regional characteristics. At the same time, the upper part of this region coincides with the ionosphere, and the interaction between neutral and ionized components has a very important impact on the space environment. The networked monitoring of density, temperature, composition, and wind field in the middle and upper atmosphere is of great significance.

The Middle and Upper Atmosphere Monitoring Network Subsystem comprises various radio radars, airglow monitoring instruments, and LiDARs.

The Meteor radar is an atmospheric wind field detection instrument that explores meteor trails and obtains horizontal wind fields in the altitude range of 70–110 km, with the advantage of easily deployed and all-weather and full-diurnal-cycle operation. The CMP has built an all-sky meteor radar monitoring network consisting of 12 observation stations, providing a three-dimensional horizontal wind field monitoring capability.

At most meteor radar observation stations, airglow instruments, including Dual Channel Optical Interferometers and Dual Channel All-sky Airglow Imagers, have been constructed. The Dual Channel Optical Interferometer uses 557 and 630 nm spectral lines to detect the wind fields at the top of the middle layer (about 96 km) and in the thermosphere (about 250 km), respectively. The data it collected can be used in conjunction with meteor radar wind field measurements and for cross comparison analysis. The Dual Channel All-sky Airglow Imager also works on these two spectral lines, and the joint observation range of multiple stations covers almost the whole region of mainland China, forming a complete double-layer airglow observation network.

The development of LiDARs for the CMP has evolved from broadband to narrowband, from dual wavelength (589 and 532 nm) to multi wavelength, and from low altitude to high altitude. From the very beginning of the CMP-Phase I, four broadband LiDARs were deployed. They utilize Rayleigh scattering of atmospheric molecules and fluorescence scattering of metal layers to detect atmospheric density, temperature, and metal atom density. While in CMP-Phase II, the atmospheric wind field can be obtained by using narrowband LiDARs. Meanwhile, due to the improved optical filtering efficiency in a narrowband LiDAR, it has the ability to work continuously day and night, enhancing the continuity of observation data. This is very important for the study of certain phenomena, such as the diurnal variation characteristics of atmospheric tides. The detection altitude of metal layer LiDARs is usually in the range of 80–105 km, depending on the actual development height of the metal layer. In some occasions, the metal layer may develop in the thermosphere, leading to a detection altitude far exceeding 105 km.

To explore the lower atmosphere and its coupling with the middle and upper atmosphere, the Middle and Upper Atmosphere Monitoring Network Subsystem has also constructed radio wave instruments and LiDARs with detection range extending to the troposphere, including Mesosphere-Stratosphere-Troposphere (MST) radar, Middle and Low Atmosphere Temperature Lidar, and Middle and Low Atmosphere Constituent Lidar. The detection of wind fields by MST radar can cover certain altitude ranges in the mesosphere, stratosphere, and troposphere. The temperature lidar adopts the principle of pure rotational Raman spectroscopy to measure atmospheric temperature at an altitude range of 0.3–35 km, with an accuracy of up to 1°C. The constituent lidar utilizes the polarization effect of aerosol particles on incident light to measure parameters such as depolarization ratio.

The instruments of the Middle and Upper Atmosphere Monitoring Network Subsystem are listed in Table 3. Due to the diverse types of LiDARs used in the CMP, the specific names of the instrument may vary from those listed in the table.

3.2.3. Ionosphere Monitoring Network Subsystem

The ionosphere, a partially ionized atmospheric region, is influenced by solar and geomagnetic activities, as well as the neutral atmosphere, exhibiting complex spatial and temporal variations and significant regional characteristics. In China, the geomagnetic declination changes from negative to positive moving from east to west, and the geomagnetic latitude varies from mid to low, encompassing the Equatorial Ionospheric Anomaly (EIA). Notably, there is a significant longitudinal variation in the ionosphere over China, with the peak concentration differing by 50% from east to west in the mid-latitude region. The peak electron concentration in the EIA zone surpasses that on both the north and south sides, and the intensity and position of EIA exhibit significant daily

Table 3
Instrument Configuration of the Middle and Upper Atmosphere Monitoring Network Subsystem

Instrument		Number	Parameters measured	Altitude range
Radio wave radars	Meteor Radar	12	Horizontal wind	70–110 km
	MST Radar	3	Horizontal wind	3.5–10 km, 10–25 km, and 60–90 km
Passive optical	Dual Channel All-sky Airglow Imager	12	Gravity activities, ionospheric traveling disturbances, and plasma bubbles	Mesopause (87 km), and ionospheric F2 layer (250 km)
	Dual Channel Interferometer	12	Horizontal wind	Mesopause (96 km), and ionospheric F2 layer (250 km)
Lidars	Multi-metal Particle Lidar	1	Density of Na, Ca, Fe, K, Ni, and Ca+	80–110 km (dependent on altitude of metal layers)
	Wind and Temperature Lidar	3	Wind and temperature	30–70 km, 80–110 km
	Broad Band Lidar	4	Temperature and Na density in sodium layer	80–110 km (dependent on altitude of sodium layer)
	Middle and Low Atmosphere Temperature Lidar	2	Temperature	0.3–35 km
	Middle and Low Atmosphere Constituent Lidar	1	Aerosol depolarization ratio	0.5–15 km

variations. Furthermore, local terrain and meteorological activities are closely linked to ionospheric disturbances. These intricate and ever-changing features necessitate a comprehensive ionospheric monitoring network.

The CMP has established an Ionospheric Monitoring Network Subsystem using various conventional instruments, including 17 ionospheric digisondes, 41 GNSS Ionospheric TEC and Scintillation Monitors, and 16 Ionospheric High-Frequency Doppler Shift Monitors. The instruments of the Ionosphere Monitoring Network Subsystem are listed in Table 4.

The Ionospheric Digisonde can detect criticalparameters such as critical frequency, virtual height, peak density, and peak height of each layer in the ionosphere, and invert the electron concentration profile below the ionization peak (foF2) height. Totally 17 digital ionosodes were deployed across China's mainland and the Antarctic region, with emphasis on 120°E meridian line where more stations were setup resulting in a smaller station spacing.

The GNSS Ionospheric TEC and Scintillation Monitors can measure the total electron content (TEC) for the entire ionosphere height range and obtain information on ionospheric amplitude scintillation and phase scintillation. Its full-height coverage capability complements the Digisonde measurement below the peak of the F2 layer. This type of instrument has been deployed at all 31 comprehensive stations of the CMP, receiving signals from multiple navigation systems such as GPS, BD, GALILEO, GLONASS, QZSS, and IRNSS, and simultaneously detecting at over 1000 pierce points.

Table 4
Instrument Configuration of the Ionosphere Monitoring Network Subsystem

Instrument	Number	Capabilities
Ionospheric digisonde	17	Altitude rage: 80–1,000 km (fitting results for above hmF2) Height resolution: 2.5 km Frequency range: 1–30 MHz Frequency step: 50 kHz Candence: 15 min/5 min/2 min (15 min for routine observation)
GNSS ionospheric TEC and scintillation monitor	41	Supported systems: GPS, BeiDou, GALILEO, GLONASS, QZSS, IRNSS Relative precision: 0.02TECU Absolute precision: 3TECU
Ionospheric high-frequency doppler shift monitor	16	Doppler shift range: ±2 Hz Resolution: 0.1 Hz

The Ionospheric High-Frequency Doppler Shift Monitors measures Doppler shift on a fixed frequency point to derive information on the movement of the ionosphere. In CMP-Phase I, instruments were established in Beijing (116.3°E, 40.0°N) and Shenzhen (114.0°E, 22.6°N) to receive signals (10 MHz, 109.0°E, 34.1°N) from the China Time Service Center and carry out ionospheric Doppler frequency shift detection. To monitor the propagation characteristics of ionospheric disturbances in the meridian direction, four high-frequency Doppler frequency shift monitoring arrays have been constructed near 120° east longitude in the second phase of the CMP. These arrays, deployed in Mohe (120.0°E, 53.0°N), Beijing (116.3°E, 40.0°N), Wuhan (114.4°E, 30.5°N), and Shenzhen (114.0°E, 22.6°N), each have one transmitter and three receivers spatially separated by tens of kilometers, enabling the measurement of the three-dimensional velocity vector of the overall ionospheric motion. Unlike the first phase, the newly constructed high-frequency Doppler frequency shift monitoring arrays independently adopt a working frequency of 5 MHz. This frequency is usually lower than the critical frequency of the ionospheric F2 layer and thus can achieve a better observation quality.

3.3. Four Focuses

In order to monitor the space environment in four key regions more extensively, that is, the polar regions of high latitudes, mid-latitude region in northern China, low latitude region at Hainan, and the Earth's "third pole" Tibet Plateau region, powerful monitoring facilities or large-scale instruments have been deployed at the stations in these regions.

3.3.1. Polar Regions of High Latitudes Monitoring Subsystem

The polar regions of the Earth serve as a natural gateway for the solar wind to enter the magnetosphere due to the unique configuration of the Earth's magnetic field. These regions are crucial for magnetosphere-ionosphere coupling and are ideal for research in space weather and space physics. Furthermore, disturbances in polar regions can propagate along the meridian toward low-latitude regions, significantly impacting the space environment of mid to low latitude regions.

The CMP utilizes existing scientific stations established by China in the polar regions, or with the assistance of international cooperation, to deploy instruments for comprehensive monitoring the space environment of the polar regions. This includes monitoring the ionosphere, middle and upper atmosphere, auroras, and geomagnetic field wave. Key stations include Zhongshan Station in Antarctica (76.4°E, 69.4°S), Great Wall Station (59.0°E, 62.2°S), and Longyearbyen Station in Arctic (16.0°E, 78.2°N). Longyearbyen Station and Zhongshan Station are roughly located at magnetic conjugation positions, enabling them to work in conjunction with stations within China to form a complete meridian monitoring system. The significant latitude difference between the Great Wall Station and Zhongshan Station allows for exploration of the low latitude edges of the polar cap region and the auroral oval. Table 5 shows the instrument configuration of Polar Regions of High Latitudes Monitoring Subsystem.

The ionospheric digisondes, GNSS Ionospheric TEC and Scintillation Monitor, and Search Coil Magnetometer share the same models or have similar specifications to those used in the Ionosphere Monitoring Network Subsystem or the Geomagnetic Monitoring Network Subsystem. In addition, the Whistler Wave Monitor can collaborate with the Geomagnetic Monitoring Network Subsystem to perform a broader range of geomagnetic wave observation. Furthermore, the High Frequency Radar has joined the international SuperDARN network and holds significance as a key member of it.

3.3.2. Mid-Latitude Region in Northern China Monitoring Subsystem

China is situated in the mid to low latitude regions, and disturbances generated in polar regions travel through the northern region before propagating into China. Monitoring the entire path of space weather disturbance propagation from polar regions to mid and low latitudes is crucial for understanding the law of disturbance propagation and studying the north-south coupling mechanism of the space environment. This knowledge is essential for space weather predicting and warning.

To link domestic monitoring with polar region monitoring, the second phase of the CMP have built high frequency radar arrays at three observation stations located in the northern region of China: Longjing (129.4°E, 42.8°N), Siziwang (111.6°E, 41.8°N), and Hejing (83.7°E, 42.9°N). These radar arrays conduct large-scale

Table 5
Instrument Configuration of Polar Regions of High Latitudes Monitoring Subsystem

Observation site	Instrument	Capabilities
Longyearbyen station in Antarctic	All-sky Aurora Imager	Wavelength: 557.7 and 630.0 nm (filter manually replaced) Filter band (FWHM): 2 nm Pixels of sensor: 1024 × 1024 Candence: 10 s(normal), 5 s(fast)
	Dual Wavelength Interferometer	Wavelength: 557.7 and 630.0 nm Wind precision: 5 m/s Time resolution: 2.5 min (wavelength fixed)
Great wall station in Arctic	Ionospheric Digisonde	The same as the Ionosphere Monitoring Network
	GNSS ionospheric TEC and scintillation monitor	
	Whistler wave monitor	Frequency band: 300 Hz - 10 kHz Sensitivity: 0.1 pT/$\sqrt{}$Hz Sample rate: 50 kHz
	Fluxgate magnetometer	Frequency band: DC-30 Hz Precision: 0.1 nT Time resolution: 1 s
	Search coil magnetometer	The same as the Geomagnetic Monitoring Network
ZhongShan station in Arctic	Aurora spectrometer	Spectrum range: 420–730 nm Spectral resolution: 1.5 nm@550 nm Angle resolution: 0.04°–0.1°
	High frequency radar	Frequency: 8–20 MHz(fixed) Beam number: 7 Effective range: 3,000 km Detecting period: 2 min
	Ionospheric digisonde	The same as the ionosphere monitoring network

scanning detection of the ionosphere. Each observation station is equipped with two High Frequency Radars, one facing northeast and the other facing northwest. The combination of the two radars forms a fan-shaped scanning region with an angle of approximately 158°. As a result, the combination of detection region of the three stations is about 10,000 km in the east-west direction and over 3,500 km in the north-south direction. This setup allows for obtaining complete 2-dimensional velocities of the ionospheric irregularities in areas where the detection ranges of the three observation stations overlap.

The mid-latitude high frequency radar array of the CMP, along with the high-latitude and mid-latitude observation networks of SuperDARN, forms a comprehensive mid and high latitude ionospheric monitoring network.

3.3.3. Low Latitude Region at Hainan Monitoring Subsystem

The low latitude regions play a crucial and unique role in the global space environment. The ionosphere in these areas exhibits a bi-peak structure with high electron density and strong latitude and altitude gradients, making it susceptible to plasma instability and nonlinear effects. Additionally, the region experiences frequent atmospheric activities such as typhoons, leading to active and complex coupling between the neutral atmosphere and the ionosphere. During solar storms, the low latitude region may also undergo unique ionosphere-magnetosphere coupling effects. During a super strong magnetic storm, the ionosphere can rapidly expand outward to heights exceeding 1500 km due to the action of a super fountain, potentially resulting in strong matter and energy coupling with the inner magnetosphere. Establishing a comprehensive observation system for the low latitude ionosphere is of great significance for analyzing and understanding the atmosphere-ionosphere-magnetosphere coupling and multi-scale variation processes.

Hainan Island in southern China, located between geomagnetic latitudes of 8–10°N, serves as an ideal area for observing and studying the Earth's low latitude space environment. The CMP has established multiple large-scale radio wave and optical monitoring instruments in the area to comprehensively detect the fine spatial structure of the middle and upper atmosphere, ionosphere, and inner magnetosphere around Hainan Island and over the South China Sea, spanning altitudes from 80 km to thousands of kilometers.

The CMP has deployed various instruments in the region, including Very High Frequency (VHF) radars in Danzhou City of Hainan Province, and Shuangjiang City of Yunnan Province, to detect the distribution and movement of ionospheric irregularities. A Low Latitude High Frequency Radar was built in DongFang City of Hainan Province, exploring the horizontal characteristics of magnetic field lines in the low latitude region, to detect ionospheric irregularities in the east and west directions. An incoherent scattering radar (ISR) was constructed in Qujing City of Yunnan Province, during the first phase of the CMP, and a phased array incoherent scattering radar system (SYISR) are built in the second phase, with transmitters and receivers located in Sanya City, Danzhou City, and Wenchang City of Hainan Province. An Array Type Large-Aperture LiDAR built in Danzhou City of Hainan Province integrates multiple optical telescopes to detect metastable helium atom fluorescence resonance echo signals excited by lasers in the altitude range of 200–1,000 km, and it also has the ability to detect atmospheric density, temperature, and sodium atom density within an altitude range of 30–105 km.

In addition to fixed ground-based instruments, the CMP also conduct rocket sounding in the Hainan region. Sounding rockets were launched during the first phase of the CMP for ionospheric and atmospheric detection, and the second phase of the project plans to launch one ionospheric rocket and one thermosphere rocket. The in-situ measurements obtained by sounding rockets, combined with ground-based measurements, provide valuable data for joint analysis and cross calibration. The instruments of the Low Latitude Region at Hainan Monitoring Subsystem are listed in Table 6.

3.3.4. Tibet Plateau Region Monitoring Subsystem

The Tibet Plateau, often referred to as the “third pole” of the Earth, possesses a unique geographical environment and complex atmospheric disturbances, which play a crucial and distinctive role in understanding the vertical coupling relationship between the lithosphere, lower atmosphere, middle and upper atmosphere, and ionosphere. This region is particularly notable for the prominent impact from bottom to top. For instance, the upward propagation of gravity waves triggered by mountainous terrain causes disturbances in the middle and upper atmosphere and ionosphere, while the strong convective system on the plateau transports matter and energy to the stratosphere, even higher (Li et al., 2016; Smith et al., 2009).

In order to comprehensively observe the middle and upper atmosphere of the “third pole” and achieve continuous monitoring of atmospheric temperature, wind field, density, metal layer, and other parameters from the surface to the lower thermosphere, the CMP has constructed multiple monitoring instruments at the Yangbajing Station (90.5°E, 30.1°N, 4,290 m) located on the Tibet Plateau. These instruments include an MST radar, an Atmosphere Wind Temperature Lidar, and a Millimeter-Wave and Infrared Imager. Table 7 shows the instrument configuration of the Tibet Plateau Region Monitoring Subsystem. These instruments are crucial for observing and analyzing the complex atmospheric dynamics and disturbances in the region, providing valuable insights into the vertical coupling relationships between different layers of the atmosphere and the ionosphere.

3.4. Large-Scale Advanced Monitoring Instruments

In addition to deploying a large number of conventional monitoring instruments, the space environment monitoring system also implements multiple large monitoring instruments in key areas and locations. Especially in CMP-Phase II, several large-scale instruments with superior performance will play vital roles in the research of key areas and physical processes, making significant contributions to the breakthrough of fundamental scientific problems in space physics and space weather. The following are brief lists of these instruments, with more detailed explanations provided in corresponding articles in the “Chinese Meridian Project Special Collection.”

For solar-interplanetary space, the large-scale advanced instruments mainly include the Solar Full-disk Multilayer Magnetograph, Spectral Imaging CoronaGraph, Circular Array Solar Radio Telescope, and IPS Telescope. More details are listed in Table 8.

Table 6
Instrument Configuration of Low Latitude Region at Hainan Monitoring Subsystem

Instrument	Number	Capacities
VHF radar	2	Frequency: 47 MHz Effective range: 80–200 km (E region) 180–900 km (F region) Range solution: ≤0.5 km (E region) ≤2 km (F region) Observation cycle: 2 min
Low latitude high frequency radar	1	Frequency: 8–22 MHz Effective range: >2,000 km (eastward and westward respectively) Range resolution: 10–50 km Observation cycle: 2 min
Incoherent scatting radar	2	Hainan (multi-static): Frequency: 440 MHz Gain: 46 dB Noise temperature: 110 K Qujing (mono-static): Frequency: 500 MHz Gain: 39 dB Noise temperature: 130 K
Array-type large aperture lidar	1	Wavelength: 1083 , 589, 532 nm Altitude range: 200–1,000 km, 80–105 km, 30–80 km respectively for the three wavelengths
Sounding rocket	4	The Ionospheric sounding rocket reaches altitude of 320 km, measuring electric field, electron density, mass spectrum of atmosphere, and density of atmosphere, etc. The thermosphere sounding rocket reaches altitude of 180 km, measuring electric field, electron density, density of atmosphere, and wind, etc.

For ionosphere monitoring, large-scale advanced instruments include multi-static incoherent scattering radar and multiple types of high frequency radar. More details are listed in Table 9.

For atmosphere monitoring, large-scale advanced instruments include MST radars and many Lidars of various kinds. Table 10 shows the details of the large-scale advanced instruments for monitoring the atmosphere.

4. Data and Communication System

The Data and Communication System includes Data Network Transmission Subsystem, Data Processing and Management Subsystem, and Data Service Subsystem, with core functions of data collection, processing, storage, and user services (please see Figure 1). To ensure security, the system has established a VPN network that connects all monitoring instruments to the data center. In order to provide essential data products to different users, the system classifies the data files accordingly. Most data files are designed to be collected in real-time through network transmission to the data center, while others are scheduled for manual transportation to the data center. The majority of monitoring data can be transmitted to the data center and made publicly available within 15 min.

Upon completion of data collection, the Data and Communication System conducts quality inspection on the data files and stores qualified files in a file pool. Simultaneously, the system records various information about the data files in a database to support subsequent data management and sharing. For frequently accessed data, recordings are extracted from files and directly saved in the database. The storage capacity of the CMP Data Center is 10.6 PB, comprising 1 PB of online storage and 9.6 PB of hierarchical storage (tape library). With the accumulation of

Table 7
Instrument Configuration of the Tibet Plateau Region Monitoring Subsystem

Instrument	Capacities
MST radar	Frequency: 50 MHz Peak power: 1.8 MW Detecting range: 3.5–10 km, 10–25 km and 60–90 km Range resolution: 150 m(3.5–10 km), 600 m (10–25 km), and 1,200 m (60–90 km)
Atmosphere wind and temperature lidar	Wavelength: 589 nm, 532 nm Temperature detecting altitude: 15–105 km (nocturnal), 30–50 km and 80–110 km (daytime) Wind detecting altitude: 15–60 km and 85–105 km (nocturnal), 15–40 km and 80–110 km (daytime)
Millimeter-wave and infrared imager	Frequency: 35 GHz ± 500 MHz (Ka band) 94 GHz ± 500 MHz (W band) 9.6–11.5 μm (Infrared band) Detecting range: 0.3–30 km

data, the system's storage capacity can be expanded to 32 PB to fulfill the objective of permanently storing the monitoring data.

Space environment monitoring data can be utilized for scientific research or to support space weather applications. The user services of the Data and Communication System are divided into public user services and application user services. The former provides services to domestic and international registered users through Internet, while the latter actively disseminates monitoring data to specific application users via dedicated network connections. Public users can access the CMP website(http://www.meridianproject.ac.cn) to download data or utilize the interface provided by the Data Communication System for online data processing.

5. Scientific Application System

Efficiently managing the numerous monitoring instruments of the CMP, promoting scientific research using CMP monitoring data, and better connecting with the needs of space weather users are the main tasks of the CMP Scientific Application System. The system includes the Scientific Operation Subsystem, Research Support Subsystem, Forecast Support Subsystem, and Application Demonstration Subsystem (please see Figure 1).

To achieve smooth and collaborative operation of the CMP monitoring instruments, the Scientific Operation Subsystem is in charge of monitoring the status of each instrument and making appropriate detection plans. This subsystem facilitates information communication between various monitoring instruments and the CMP operation headquarter located in Huairou, Beijing, enabling all distributed monitoring instruments to operate efficiently and collaboratively as an integrated facility. The main users of this subsystem are the management

Table 8
Large-Scale Advanced Instruments for Monitoring Solar-Interplanetary

Instrument	Location	Main function
Solar full-disk multi-layer magnetograph	Ganyu (119°E, 35°N)	Observe magnetic field of photosphere and chromosphere, velocity and monochromatic images at multiple spectrum lines.
Spectral imaging coronagraph	Yulong (100°E, 26°N)	E corona radiation intensity at Fe X line (637.4 nm) and radial velocity.
Circular array solar radio telescope	Daocheng (100°E, 29°N)	Obtain solar radio images and spectrum from 30 to 450 MHz, corresponding to heliocentric radius within 5 $R_\odot$.
IPS telescope array	Mingantu (115.3°E, 42.2°N) Yihegaolei (115.1°E, 44.7°N) Wurigentala (113.1°E, 43.5°N)	Three telescopes, spacing for about 200 km, work in conjunction to obtain solar wind velocity and density.

Table 9
Large-Scale Advanced Instruments for Monitoring the Ionosphere

Instrument	Location	Main function
Multi-static incoherent scattering radar	Sanya (109.6°E, 18.4°N) Danzhou (109.1°E, 19.5°N) Wenchang (110.8°E, 19.6°N)	Detect parameters like 3-D drift velocity and electron density up to altitude of 1,000 km
Mid-latitude high frequency radar	Longjing (129.4°E, 42.8°N) Siziwang (111.9°E, 41.8°N) Hejing (83.7°E, 42.6°N)	Detect ionospheric drift velocity in areas from north of China to polar region
Low latitude high frequency radar	Dongfang (108.8°E, 19.2°N)	Observing ionospheric irregularities and background ionosphere over a wide longitude region of more than 4,000 km

personnel of the CMP. They can access the subsystem through both mobile phones and PCs to obtain the information such as the status and detection plan of each instrument, significantly improving their working efficiency.

The Research Support Subsystem mines and processes monitoring data obtained by monitoring instruments to support scientific investigations. This supporting role is mainly achieved through space weather models, space weather event recognition, and production of space weather indices. The subsystem has integrated 14 space weather models, including the CME full chain propagation and evolution model, interplanetary shock model, three-dimensional structure model of magnetopause, ionospheric model, and middle and upper atmosphere model. It can intelligently identify space weather events such as CME, metal layer enhancement, and ionospheric travel disturbance conceived in monitoring data and generate various spatial weather indices, such as Kp and Dst index.

The Forecast Support Subsystem is to promote connections to the forecast service groups or organizations, providing advanced forecast data products. These data products include information on solar activity, solar wind density and velocity, atmospheric density on satellite orbit, and TEC maps, which are important inputs for conducting space weather forecasting. In addition, the Application Demonstration Subsystem of the Scientific Application System aims to explore new applications for space environment monitoring data, providing service for several application domains such as satellite and ground data comparison, and GNSS atmospheric effect mitigation.

Both the Data and Communication System and the Scientific Application System are located in Information and Operation Control Center Building in HuaiRou, Beijing (shown in Figure 4).

Table 10
Large-Scale Advanced Instruments for Monitoring the Atmosphere

Instrument	Location	Main function
MST radar	Yangbajain (90.5°E, 30.1°N) Qinzhou (108.7°E, 22.1°N)	Measure wind field and the refractive index structure parameter (Cn^2) for mesosphere, stratosphere, and troposphere
Array large aperture lidar	Danzhou (109.1°E, 19.5°N)	Detect atmosphere density in altitude range of 200–1,000 km.
Middle-upper atmosphere wind-temperature -metal-constituents lidar	Mohe (120.0°E, 53.0°N)	Detect density of Na, Fe, K, Ni, Ca and Ca^+
Middle-upper atmosphere wind-temperature lidar	Yuzhong (104.1°E, 36.0°N) Urumqi (87.2°E, 43.5°N)	Detect wind field in thermosphere
Atmosphere wind-temperature lidar	Yangbajain (90.5°E, 30.1°N)	Detect wind field in height range from troposphere to thermosphere
Middle and low atmosphere temperature lidar	Wuhan (114.4°E, 30.5°N) Boluo (114.5°E, 23.5°N)	Detect temperature in middle to low atmosphere
Middle and low atmosphere constituent lidar	Boluo (114.5°E, 23.5°N)	Detect aerosol depolarization ratio in middle to low atmosphere

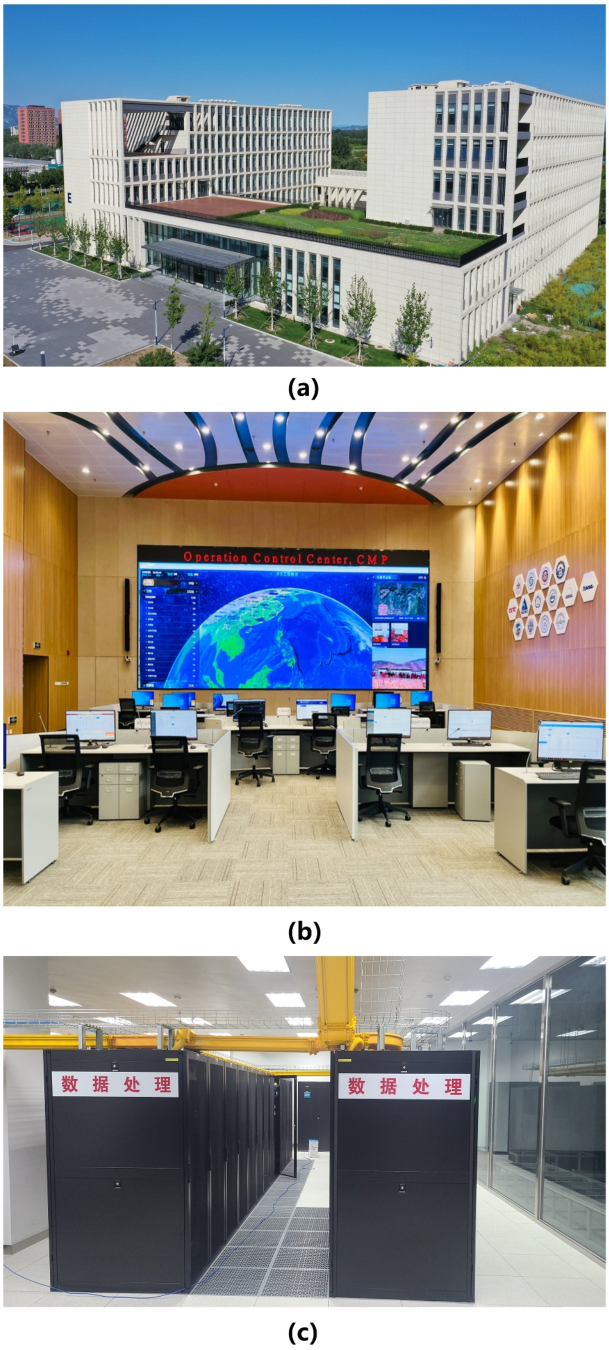

Figure 4. (a) The Information and Operation Control Center Building, (b) The Operation Control Center hall, and (c) The Data and Computing Center Facility.

6. Discussion and Summary

Ground-based space environment monitoring is crucial for advancing the understanding and utilization of the outer space, as well as addressing the challenges posed by severe space weather events. The CMP develops a comprehensive and stereoscopic monitoring network for the solar-terrestrial space environment, which boasts several outstanding capabilities and advantages:

- End-to-end tracking and monitoring capabilities from the solar atmosphere to near-Earth space

The Space Environment Monitoring System of the CMP employs a solar-interplanetary monitoring chain, utilizing various detection methods such as solar optics, multi-band solar radio, interplanetary scintillation, and cosmic rays. This comprehensive approach enables the tracking and monitoring of solar eruption activities from the solar surface to near-Earth space, facilitating in-depth research on the occurrence, evolution, propagation, and impact of solar activity events, and enhancing the accuracy of space weather forecasting.

- Network monitoring capabilities covering various space layers of the solar-terrestrial space

The vast solar-terrestrial space encompasses the middle and upper atmospheres, ionosphere, magnetosphere, interplanetary space, and solar atmosphere, each with complex physical processes and numerous distinct physical parameters. The CMP has deployed various types of monitoring instrument to detect different physical properties of eachlayer, achieving a stereoscopic comprehensive detection capability covering all space layers of the solar-terrestrial space through a monitoring architecture of "One chain, Three networks, and Four focuses".

- Fine scale monitoring for key regions

Approximately 300 monitoring instruments are strategically distributed near the meridians of 120° and 100°E, as well as the latitude lines of 30° and 40°N, enabling networked detection capability for the propagation and evolution of disturbances. Specifically, along the meridian of 120°E longitude, the layout of observation stations is denser, which can monitor the propagation process of various disturbances in the geomagnetic, ionospheric, and middle and upper atmosphere along the meridian with higher spatial resolution. At the same time, The CMP focuses on monitoring four key regions: high latitude in the polar regions, mid latitude in the north of China, low latitude at Hainan Island, and the Tibetan Plateau, using various monitoring instruments to detect the fine processes of space environmental changes in these special areas.

- Utilization of advanced large-scale monitoring instruments

The CMP has constructed a batch of large-scale advanced monitoring instruments, such as the solar radio telescope, interplanetary scintillation telescope, incoherent scatter radar, high frequency radar, MST radar, and large-aperture Helium Lidar. These instruments, combined with other networked monitoring devices, play an essential role to key space environment parameters in higher altitudes with finer resolutions.

Successful construction and operation of CMP will add great capabilities to the global undertaking of ground-based space environment monitoring. First and the most important, it contributes to form a much fuller coverage of the globe by filling the huge gap over China's territory leaving by some important international programs, such as IGS, SuperDARN, GIRO, INTERMAGNET. This is crucial for studying near-Earth space characteristics of various scales, from global to regional. Consequently, studies on relationships between different parts of the globe and global transportation processes can be better carried out. For example, also most prominent, the multitude of wind measuring instruments of CMP, such as meteor radars, MST radars, airglow interferometers, lidars, will operate collectively with their counterparts all over the world in an effort to address topics such as tidal, planetary waves, gravity waves and interhemispheric coupling. In addition, international cooperation between CMP and observation facilities in other countries can form a crucial "sun never set" capability for ground-based space weather research and forecasting.

In summary, the CMP represents the largest geographical span, most complete space coverage, and most comprehensive ground-based space environment monitoring capability in the world. The monitoring data of CMP is processed and stored by a centralized data center, and is publicly accessible worldwide.

Based on the CMP, Chinese scientists are actively promoting the International Meridian Circle Program (IMCP). With broad international participation, the IMCP aims to collaborate with monitoring facilities near the 120°E and 60°W meridian circle to establish a global ground-based comprehensive space environment monitoring network. It will have the full latitude and day-and-night monitoring capability for the space environment, in order to conduct in-depth research on the motion laws of Earth's space matter and energy under the dual drive of solar and Earth activities, the global propagation and evolution of space weather events from the Sun to the Earth,etc. Currently, the IMCP headquarters building has settled in Beijing. China and Brazil have collaboratively established China-Brazil Joint Laboratory for Space Weather. Based on the Meridian Project, the IMCP has launched multiple in-depth joint explorations with the SuperDARN, China-Brazil Joint Laboratory for Space Weather, and ground-based monitoring facilities in Southeast Asia and polar regions (see Liu et al., 2021 for details).

Data Availability Statement

No data were used in preparing this manuscript.

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