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Progress of International Meridian Circle Program*

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Abstract In 2024, the Chinese Meridian Project (CMP) completed its construction, deploying 282 instruments across 31 stations. This achievement not only provides a robust foundation but also serves as a reference template for the International Meridian Circle Program (IMCP). The IMCP aims to integrate and establish a comprehensive network of ground-based monitoring stations designed to track the propagation of space weather events from the Sun to Earth. Additionally, it monitors various disturbances generated within the Earth system that impact geospace. Over the past two years, significant progress has been made on the IMCP. In particular, the second phase of construction for the China-Brazil Joint Laboratory for Space Weather has been completed, and the North Pole and Southeast Asia networks are under active construction. The 2024 IMCP joint observation campaign was successfully conducted. To facilitate these developments, the scientific program committee of IMCP was established, following the success of 2023 IMCP workshop and the space weather school, which was co-hosted with the Asia-Pacific Space Cooperation Organization (APSCO) and sponsored by Chinese Academy of Sciences (CAS) and Scientific Committee on Solar-Terrestrial Physics (SCOSTEP). Preparations are now underway for the 2024 workshop in collaboration with the National Institute for Space Research (INPE) in Brazil.

Key words Chinese Meridian Project (CMP), International Meridian Circle Program (IMCP), China-Brazil Joint Laboratory for Space Weather, North Pole and Southeast Asia networks

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1 Introduction

The International Meridian Circle Program is proposed to bring together over ten countries along the 120°E and 60°W meridians to create an integrated global monitoring network. Equipped with more than 1000 instruments,

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the IMCP aims to study Earth as a connected system encompassing space, atmosphere, and surface. Its goal is to understand how solar wind disturbances affect our mother planet and how disturbances originating from the Earth's surface and atmosphere might also impact our space environment. This international effort addresses critical questions, such as how solar energy and matter outputs interact with Earth's magnetic field and atmosphere, and how space weather is in turn, impacted by global change and environmental hazards. The IMCP leverages a wide range of international collaborations to address these global scientific challenges through real-time monitoring, data sharing, and joint research activities[1–4].

Over the past two years, significant progress has been made on the IMCP. The Chinese Meridian Project completed its construction, the second phase of the China-Brazil Joint Laboratory for Space Weather (CBJLSW) was successfully concluded, and ongoing advancements are being made in the North Pole and Southeast Asia networks. The 2024 IMCP joint observation campaign was successfully conducted, making a significant milestone. The IMCP scientific committee was established, a successful workshop was held in 2023, and an IMCP space weather school was co-hosted with the APSCO. Preparations are currently underway for a 2024 workshop in collaboration with the INPE in Brazil.

2 Chinese Meridian Project

Construction of the second phase of the Chinese Meridian Project began in 2019 and successfully passed the engineering acceptance evaluation in June 2024. This expanded network has created a robust ground-based monitoring system that spans across China and the Earth's polar regions. It comprises a range of conventional instruments such as optical, radio, and geomagnetic equipment, as well as several large and advanced devices including a radio heliograph, an interplanetary scintillation telescope, a Mesosphere-Stratosphere-Troposphere (MST) radar, a mid-latitude high-frequency radar, a new generation tristatic incoherent scatter radar with electronic beam steering, a low-latitude high-frequency radar, an array-type large-aperture helium lidar, and a large-aperture metal-layer lidar.

Once fully operational, the CMP will provide data from its diverse array of instruments to a wide spectrum of user communities. This will enhance our ability to monitor and understand the complex interactions between solar activities and terrestrial processes, contributing to the global scientific effort to mitigate the effects of space weather and understand Earth's dynamic system[5,6].

3 China-Brazil Joint Laboratory for Space Weather

The China-Brazil Joint Laboratory for Space Weather (CBJLSW) is set to complete its second phase of construction by the end of 2024. Sixteen sets of space environment monitoring equipment have been deployed across South America's low-latitude region, including geomagnetic, radio, and optical instruments (see Figure 1). Headquartered in Brazil, CBJLSW aims to expand its network to encompass Peru and Chile.

As a model project for the IMCP, the construction of the CBJLSW has systematically explored and continues to refine collaborative efforts in areas such as responsibility allocation, investment, personnel exchange and training, and data/result sharing. This focus maximizes return on investment and fosters sustainable development, ultimately establishing an efficient framework for joint observation and collaborative research.

4 North Polar Ionospheric Monitoring Network

Funded by a key international cooperation grant from the National Natural Science Foundation (NSFC), a collaborative effort is underway to establish the north polar ionospheric monitoring network (see Figure 2). This joint project brings together researchers from the University of New Brunswick (Canada), the University of Oslo (Norway), NSSC and Shandong University of China.

The first phase involves installing GNSS TEC and scintillation receivers and all-sky airglow imagers at three observation stations: Resolute Bay, Pond Inlet, and Iqaluit. This will facilitate comprehensive monitoring of the ionosphere in the North Polar region. Upon completion, real-time data sharing will be established with the

Fig. 1 Monitoring network of the CBJLSW

Canadian High Arctic Ionospheric Network (CHAIN) and Norway monitoring network.

5 Ionospheric Incoherent Scatter Radar Network in Northern Europe

China Research Institute of Radiowave Propagation (CRIRP) formally joined the European Incoherent Scattering Scientific Association (EISCAT) in 2006 approved by Ministry of Science and Technology of China (MOST). CRIRP has broadly contributed to the scientific production of EISCAT by performing a large number of experiments, observation, data analysis and model research activities on ionospheric irregularities, ionospheric radio propagation, space plasma and ionospheric incoherent scatter measurement methods. At present, the next generation European Incoherent Scatter radar system (EISCAT 3D) is being tested and will be put into operation at the end of 2024. EISCAT 3D consists of one core site in Skibotn, Norway and two reception sites in Kaiseniemi, Finland and Karesuvanto, Sweden. The key capabilities of EISCAT 3D include volumetric imaging, aperture synthesis imaging, multistatic imaging, and continuous monitoring, making it the leading radar equipment for the study of the geospace environment. EISCAT thinks highly of the IMCP and signed the memorandum of understanding with CRIRP about the cooperation between IMCP and EISCAT 3D in 2018.

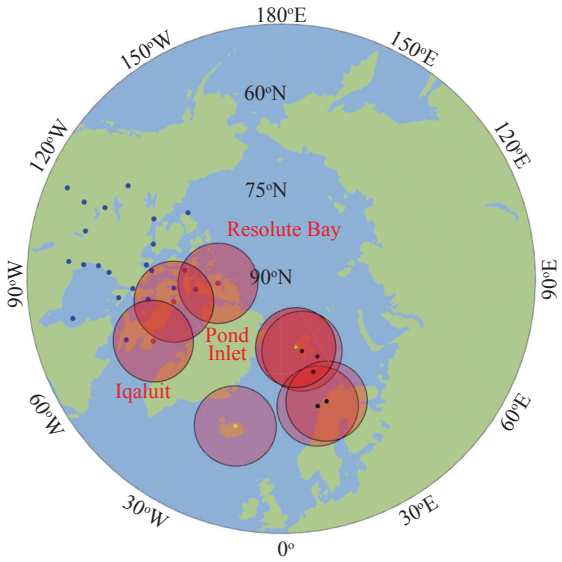

Fig. 2 North polar ionospheric monitoring network

6 Southeast Asia Region Monitoring Network

Significant progress has been made on the southern extension of the East Asia/Southeast Asia Ionospheric Irregularity and Scintillation Observation Network (IONISE) and the China-Southeast Asia Upper Atmosphere Double-Layer Airglow Observation Network.

Agreements have been signed with the National Astronomical Research Institute of Thailand (NARIT), the Vientiane Meteorology and Hydrology Department in Laos, and Telkom University in Indonesia. In collaboration with these partners, new instruments have been deployed at stations in Songkhla and Chiang Mai (Thailand), Pontianak, West Sumatra, Bandung (Indonesia), Vientiane, Pakse, and Attapeu (Laos). These instruments include all-sky airglow imagers, GNSS-TEC and scintillation monitors, PDI agile digital ionosondes, and wideband vector magnetometers.

7 IMCP Joint Observation Campaign

Leveraging capabilities from the CMP, the international Incoherent Scatter Radar network, CBJLSW, and other ground-based networks, we organize one to two IMCP Joint Observation Campaigns each year.

During the strong magnetic storm between November to December 2023, a call for joint observations was issued on 30 November, recognizing the potential impact. Observation participants responded swiftly, enabling the collection of highly valuable, synchronized multi-element observational data throughout the storm.

Ground-based facilities participating in these observations employed diverse detection methods, including radio waves, optical sensors and geomagnetic field measurements. This comprehensive approach, drawing on data from over 80 key stations, yielded a rich dataset encompassing the ionosphere and the middle-to-upper atmosphere. This data will be instrumental in providing researchers with a detailed picture of the space environment during such magnetic storm events. Scientific analysis of this campaign has resulted in presentations and publications[7,8].

8 IMCP Headquarters and Activities

Marking a significant milestone, the IMCP Headquarters Building was officially inaugurated and opened for the IMCP community in September 2023. This new facility now houses key organizations, including the Chinese office of the CBJLSW, the Sino-Russian Space Weather Joint Center, and the Regional Warning Center (China).

In 2023, IMCP successfully hosted its annual workshop from 14 to 17 September and co-hosted, with APSCO, a space weather school from 17 to 21 September (see Figure 3). The workshop attracted the participation of 106 international scientific experts, and 41 students from 14 countries attended courses taught by 25 esteemed lecturers from five countries. In May 2024, the

Fig. 3 2023 IMCP workshop in front of IMCP headquarters building

SuperDARN/IMCP school was successfully held at the Siziwang Observatory of Space Weather. These educational and training activities further demonstrate IMCP's commitment to knowledge sharing and capacity building within the space weather community.

On 23–27 September 2024, a new annual IMCP workshop will be organized under the theme "Monitoring Geospace Disturbances from the Ground: Scientific Challenges, Observational Networks, and International Collaboration". It will be held in São Paulo State, Brazil, hosted by NSSC together with INPE, and sponsored by SCOSTEP, NSFC and other organizations.

9 Future Directions of IMCP

Space weather is a global phenomenon that requires international cooperation and participation. We have already collaborated with scientists from multiple countries to establish the IMCP framework. Moving forward, in addition to constructing and enhancing the 120°E–60°W Meridian circle, we also plan to expand the IMCP network along the 30°E–150°W Meridian circle in cooperation with the International Space Weather Initiative (ISWI). We envision a future where thousands of IMCP instruments observing together will form a three-dimensional information grid spanning five continents, providing real-time information about near Earth's space environment and contributing to safeguarding our planet against natural and anthropogenic hazards. We may also benefit from space weather monitoring systems commonly developed to shield our society.

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Author Biography

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