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Progress of International Meridian Circle Program*

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Abstract Based on the Chinese Meridian Project (CMP), the International Meridian Circle Program (IMCP) aims to coordinate the deployment of a comprehensive ground-based monitoring network along the 120°E–60°W Great Meridian Circle to track the propagation and evolution of space weather events from the Sun to the Earth, as well as the imprints of other major natural and anthropic hazards on the ionosphere, the middle and upper atmosphere. Currently, we have completed the IMCP headquarters building in Beijing and established the China-Brazil Joint Laboratory for Space Weather in cooperation with Brazil. Meanwhile, the Chinese Meridian Project Phase II and different components of the IMCP observation system are under construction.

Key words Chinese Meridian Project (CMP), Global ground monitoring, Space weather, International Meridian Circle Program (IMCP)

Classified index P35

1 Concept, Objectives and Implementation

The International Meridian Circle Program (IMCP) is a major international program led by the Chinese Academy of Sciences to deploy, integrate and operate a global network of monitoring instruments, primarily along the 120°E–60°W great meridian circle. This globally distributed network, coordinated with satellite observations, will provide a comprehensive three-dimensional representation of key geospace parameters across all latitudes over each diurnal cycle, making it possible to investigate the imprints of energy inputs from the Sun into the Earth on the Ionosphere, Middle and Upper Atmosphere (IMUA), and to quantitatively assess the threats to the human society due to the different types of natural and anthropic hazards.

Based on the deployment of a globally distributed ground-based monitoring and research network observing the IMUA, the IMCP is to study Earth's geospace and its different coupled layers as a whole system. In this way, IMCP aims to reveal several key scientific questions[1,2]: How do interplanetary disturbances (upstream disturbances) influence the solar-terrestrial environment? How do they disturb the atmospheric system at different altitudes and latitudes, and how do the responses in different atmospheric regions couple with each other? At the same time, how do disturbances generated internally in the Earth system (bottom disturbances, *e.g.*, long-term variations of the geomagnetic field and the

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climate, earthquakes, severe weather events) propagate to the IMUA? What characteristic imprints do they leave on it?

One of the major parts of the IMCP observing system is the Chinese Meridian Project, a ground-based space environment monitoring facility funded by the National Development and Reform Commission of China with 1.5 billion yuan whose construction started in 2008. In 2012, the first phase of the Chinese Meridian project started operation. By 2021, more than 8 TB of monitoring data with 64 kinds of space environment parameters have been collected. After the completion of the second phase of the Chinese Meridian Project in 2024, it will form a two-cross enhanced and more powerful space weather monitoring network over China[3].

The IMCP will also rely on a space-based satellite — the CAS-ESA Solar wind Magnetosphere Ionosphere Link Explorer (SMILE, scheduled to be launched in 2024)[4]. The cooperation of these two projects makes it possible to link the solar wind-magnetosphere interaction (driving source, observed by SMILE) to the ionospheric responses (observed by the ground-based IMCP), to follow the whole process of energy transfer from the interplanetary space to the geospace and to monitor the global responses of the terrestrial environment to solar energy inputs.

2 Major Achievements

We describe below several major achievements in IMCP development during the reporting period.

2.1 Western Hemisphere-Brazil

As the first step of the international cooperation of IMCP, the China-Brazil Joint Laboratory for Space Weather (CBJLSW) has passed the acceptance of the first-phase construction and started its second-phase construction.

Since Brazil is in the low-latitude region of the southern hemisphere and at 60° west longitude, joint detection and analysis of events by CBJLSW and CMP teams make it possible to investigate day-night and inter-hemispheric contrasts in the response of the terrestrial environment to interplanetary disturbances.

So far, the CBJLSW has built a data center in South America with a storage capacity of up to 200 TB, as well as a Potassium-Sodium dual-wavelength Lidar, Digisonde, GPS-TEC ionospheric scintillator, and Magnetometer. In the second phase, a total of 16 sets of space environment monitoring equipment, including geomagnetic, radio, and optical, will be further deployed to detect geomagnetism and geoelectricity parameters, the density, temperature, and wind field of middle and upper atmospheric, ionospheric electron density and concentration, as well as solar wind events over South America, see Fig.1. CBJLSW supports space science research in South America, revealing the characteristics of the atmosphere and ionosphere in the western hemispheres in low latitudes, and their relationship with global space weather processes.

At the same time, Both China and Brazil attach great importance to talent training and joint research, jointly training 27 postdoctoral fellows and publishing 64 scientific papers such as the JGR journal. The construction of the CBJLSW has been incorporated in the cooperation agreement between China and Brazil and listed as a key cooperation project in 2015 and 2018.

2.2 Eastern Hemisphere-Southeast Asia

Southeast Asia is at low geomagnetic latitudes, south of the CMP network along about 120°E. This region is characterized by strong convective weather and a special magnetic field configuration. Joint monitoring of space weather events by CMP and Southeast Asia networks makes it possible to track their propagation along this meridian.

At present, we cooperate with the National Astronomical Research Institute of Thailand, Telkom University (Indonesia), the Hydrographic Bureau of Laos, to build three observation networks: Ionospheric Observation Network for Irregularity and Scintillation in East/Southeast Asia (IONISE), China-Southeast Asia Upper Atmosphere Double Airglow Observation Network, and APSCO Geomagnetic Observation Network.

2.3 Ionospheric Observation Network for Irregularity and Scintillation in East/Southeast Asia (IONISE)

IONISE[5] mainly includes three crossed chains of GNSS TEC/scintillation receivers, which can track Beidou geostationary satellite signals along 110°E, 23°N, and 40°N respectively, multi-static portable digital ionosondes (which can be operated to obtain Doppler ionograms with a time interval less than 1 min for vertical and

Fig. 1 CBJLSW stations

oblique observations), and VHF radars equipped with beam steering and providing multi-baseline imaging observations (see Fig.2).

The scientific objectives of IONISE are: (i) to trace the occurrence and movements of ionospheric irregularities producing GNSS loss-of-lock and scintillations, (ii) to capture ionospheric disturbances of various scales produced by natural sources *e.g.*, low atmosphere activity, geomagnetic activity, and earthquakes, and (iii) to reveal extremely large gradients of background ionosphere over southern China and adjacent regions.

2.4 China-Southeast Asia Upper Atmosphere Double Airglow Observation Network

The double-layer airglow observation network of the middle and upper atmosphere is deployed mainly along the 100°E meridian in Southeast Asia, starting from the equator to northward, and consists of 15 OH (87 km) airglow observation stations and 12 OI red-line (250 km) airglow observation stations (see Fig.3).

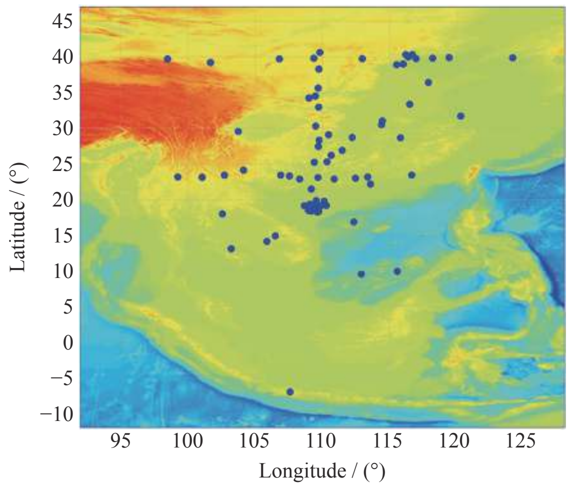

Fig. 2 IONISE stations

The network provides an advantage for studying the propagation and evolution of atmospheric waves ranging from several kilometers to thousands of kilometers

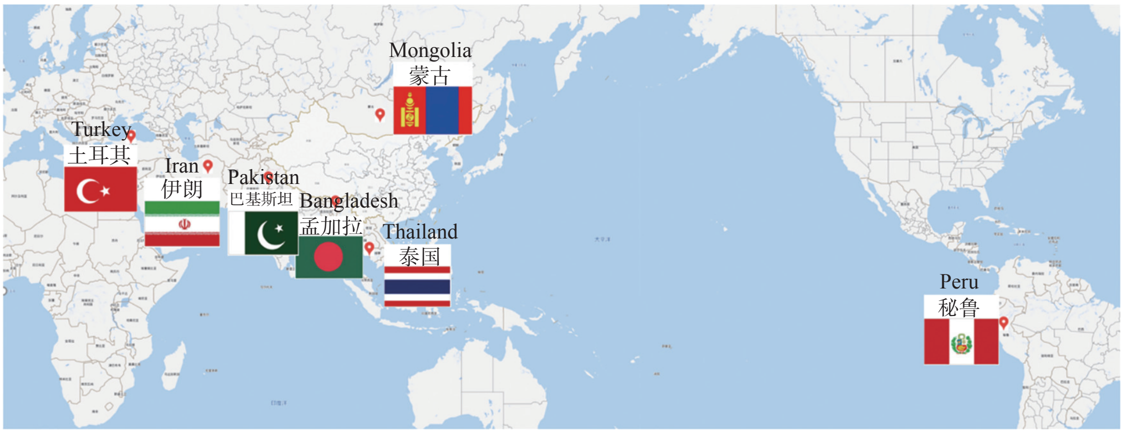

Fig. 4 APSCO geomagnetic observation network

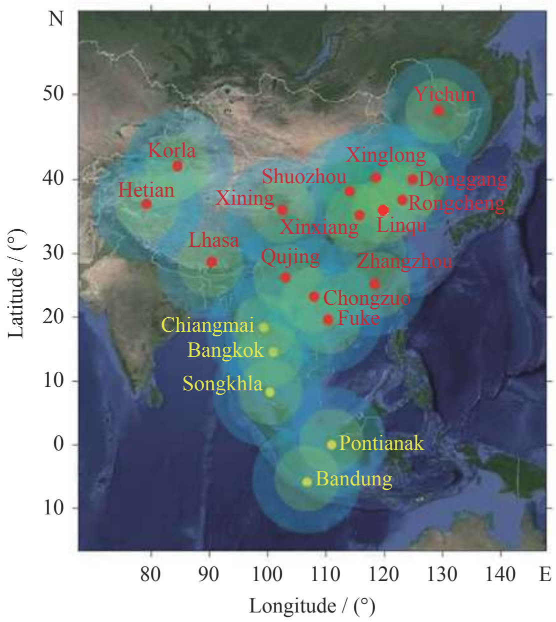

Fig. 3 China-Southeast Asia double-layer airglow observation network of the middle and upper atmosphere

in the horizontal and vertical directions, as well as coupling processes of atmospheric waves between different regions of the atmosphere.

2.5 APSCO Geomagnetic Observation Network

The APSCO Geomagnetic Observation Network, mainly based on the APSCO seismic observation project, is to build several geomagnetic stations in seven APSCO member countries, namely Thailand, Bangladesh, Pakistan, Iran, Turkey, Mongolia, and Peru. Such a network can provide the geomagnetic data for comparative study with the magnetic field at the Sun-synchronous orbit by China Seismo-Electromagnetic Satellite (see Fig.4).

3 Conclusions and Perspectives

In the coming years, we will continue to focus on the 120°E–60°W meridian circle, its broad coverage of land facilitates and deployment of the instrument networks. In addition, we will also discuss and plan with additional international partners a secondary circle, *i.e.*, the 30°E–150°W meridian circle, to capture the significant longitudinal variations of hazard sources induced by land-ocean contrasts and by the geographic longitudinal asymmetries of the geomagnetic field.

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