

New Chains of Space Weather Monitoring Stations in China

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To develop an understanding of near-Earth space's response to solar activities and to eventually enhance the success of space weather predictions, it is crucial to make synergetic observations of the entire environment from the Sun to the Earth as a system. Since the beginning of the space era, direct observations by satellites have become a much needed means toward this end. However, ground-based observations also have advantages and serve as a counterpart to those made in space. For example, instruments on the ground are much less expensive and easier to repair than those on satellites. Ground-based observations provide continuous high-resolution data not subject to the limitation of the downlink data rate from satellites to ground receiving stations. Also, because some observations have been made from Earth for hundreds of years, society has long and continuous records of quantities such as geomagnetic field variations, measurements of relative ionospheric opacity, and sunspot observations. Data from spacecraft, on the other hand, go back only a few decades.

China has a total land area of about 9,600,000 square kilometers, with geomagnetic locations covering middle to low latitudes. The first geomagnetic observatory in China was constructed in Beijing in 1870 by Russians, but it ceased working in 1882. China briefly participated in the International Geophysical Year (1957–1958) and started to explore the upper atmosphere using rockets and balloons in the 1960s. Though research at government institutions and universities picked up in the late twentieth century, the ability to monitor the geospace environment and capture the evolution and characteristics of the weather in geospace above China is still insufficient today. Not only is China's large population increasingly reliant on space-based technologies, but there are also not enough locations across the country where space weather conditions are monitored. This limits Chinese scientists' understanding of the basic physical processes in geospace and their ability to make accurate predictions of adverse space weather for their country's citizens.

To acknowledge the needs of both basic science and useful space weather operations, a ground-based program to

monitor China's geospace environment is currently under way. Called the Meridian Space Weather Monitoring Project (or Chinese Meridian Project), the effort consists of a chain of 15 ground-based observatories located roughly along 120°E longitude and 30°N latitude. Each observatory is equipped with multiple instruments to measure key parameters such as the baseline and time-varying geomagnetic field, as well as the middle and upper atmosphere and ionosphere from about 20 to 1000 kilometers. Starting in 2011, the project will collect data for at least 11 years, providing the wide-range, continuous, and multiparameter data sets needed to guide model developments, which in turn will better describe and predict the characteristics and dynamics of the geospace environment.

Project Overview

The Meridian Project is funded by China's National Development and Reform Commission as part of a series of major scientific infrastructure construction projects. With a planning and construction period spanning from 2006 to 2010, its total budget is 167 million yuan (about US\$24 million). The project is a joint effort of teams at the Chinese Academy of Sciences' Center for Space Science and Applied Research (CSSAR), Institute of Geology and Geophysics, National Astronomical Observatory, and Institute of Atmospheric Physics along with teams at the Polar Research Institute of China, China Research Institute of Radiowave Propagation, Institute of Geophysics at the China Seismological Bureau, University of Science and Technology of China, Peking University, Wuhan University, and the National Centre for Space Weather Monitoring and Warning of the China Meteorological Administration.

Construction of observatories for the Meridian Project started in January 2008 and is expected to be finished by December 2010. The project's chain of observational stations begins in the north with a station in the city of Mohe. The rest run south roughly through Beijing, Wuhan, Guangzhou, and the island of Hainan (with instruments at Hikou, Fuke, and

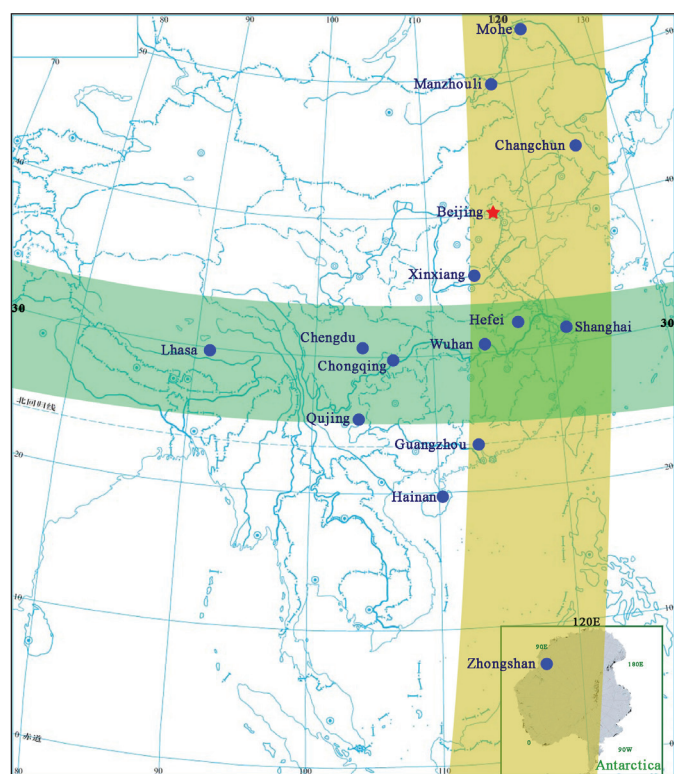


Figure 1. Distribution of observatories that form the Meridian Project (yellow band traces stations along 120°E; green band shows stations close to 30°N).

Sanya) and extend to China's Zhongshan station in Antarctica (see Figure 1). Aside from the station in Antarctica, the stations are located roughly 4°–5° of latitude, or about 500 kilometers, apart. A chain of stations is also being constructed roughly following 30°N, spanning from Lhasa to Shanghai.

Instruments at these stations include magnetometers, traditional and digital ionosondes (digisondes), incoherent scatter radars, high-frequency backscatter radars, mesosphere-stratosphere-troposphere radars, meteor radars, lidar (light detection and ranging), Fabry-Perot interferometers (FPI), and aurora spectrographs (see Figure 2). The precise locations of stations along with the types of observations that can be made at each are listed in Table 1.

Through these observations, the Meridian Project will better parameterize the geomagnetic field; the geoelectric field; the presence of cosmic rays; the density, temperature, composition, and winds of the middle to upper atmosphere; the density and temperature of electrons and ions in the ionosphere; the total electron content (TEC) over each station; irregular structures and plasma drift in the ionosphere; and the solar wind speed in interplanetary space.

The overarching framework of the Meridian Project consists of three interconnected systems necessary for successful space weather operations in China: a space environment

monitoring system, a data and communications system, and a research and forecast system. The space environment monitoring system is responsible for making measurements of the space environment from the ground using magnetometers and optical and radio instruments, and for making in situ measurements using sounding rockets. The data and communications system is in charge of collecting, transferring, processing, storing, and distributing data in quasi real time. The research and forecast system will coordinate observations, develop relevant data analysis and space weather forecasting tools, and promote international collaborations.

Measuring Magnetic Fields Along 120°E and 30°N

The driving idea behind the Meridian Project is that a chain of magnetometers can serve as an indicator of changing conditions in the ionosphere and magnetosphere at different latitudes and longitudes.

Magnetometers are currently being installed in each station along 120°E longitude and 30°N latitude to perform remote sensing of magnetospheric phenomena, to determine how irregularly shaped geomagnetic pulsations (Pi2) are suddenly produced by substorms, to determine how the energy from regular continuous geomagnetic pulsations (Pc3–Pc4) enters the magnetosphere and propagates along magnetic field lines to low latitudes, and to infer the density of the plasma sheet, among other things.

The geomagnetic field measurements to be conducted at each observatory include two types. One type is the absolute measurement; instruments in this category include proton precession magnetometers, Overhauser magnetometers, and declination/inclination (DI) fluxgate magnetometers. Proton precession magnetometers and Overhauser magnetometers measure the absolute total field information, and DI-fluxgate magnetometers provide the baselines for other components. The other type is the relative measurement, using fluxgate magnetometers and induction variometers. The relative measurements are the primary instruments for recording magnetic field variations.

Using Optical Methods to Observe the Middle and Upper Atmosphere

The Meridian Project will use active and passive optical tools to measure the density, temperature, wind field, and airglow (the very weak emission of light by the Earth's atmosphere) of the middle atmosphere, as well as the ionosphere's auroral spectrum.

A lidar chain spanning the stations from Beijing to Hainan will obtain the temperature and density profiles of the middle atmosphere from middle to low latitudes, sodium ion densities in the mesopause region (which are a good indicator of temperatures and other factors), and winds from 5 to

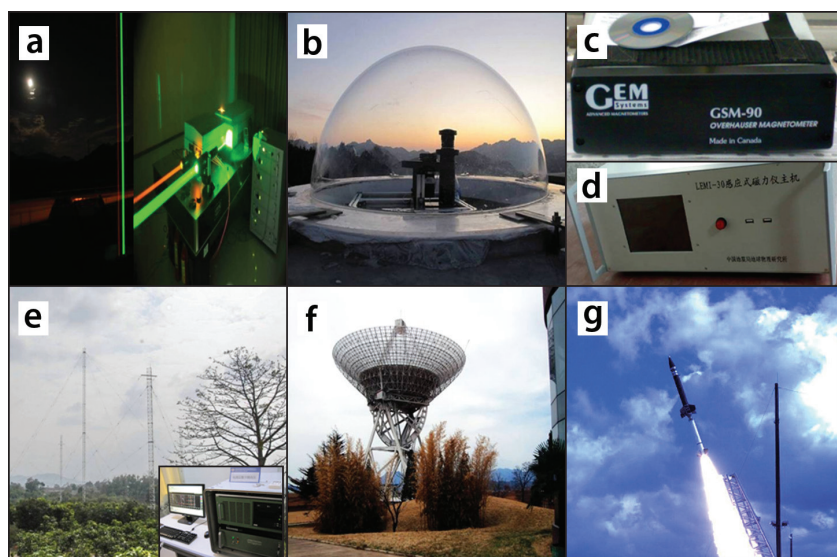


Figure 2. Examples of the observational instruments to be deployed in the Meridian Project, including (a) lidar (light detection and ranging), (b) all-sky airglow imagers, (c) Overhauser magnetometers, (d) induction magnetometers, (e) digital ionosondes (digisondes), (f) radar to monitor scintillation, and (g) sounding rockets.

40 kilometers specifically at Hefei. An all-sky airglow survey in Beijing and Hainan will observe the horizontal structure and transport features of gravity waves in the mesopause region and the thermosphere. Simultaneously, the Fabry-Perot interferometer in Beijing will observe the wind and temperature of the atmosphere in the mesopause region and the ionosphere's F_2 layer, which is important for high-frequency radio communications. A spectrometer in Zhongshan station in Antarctica will observe auroral spectra, atmospheric chemical species, and the energy spectra of energetic particles from the solar wind and the magnetosphere.

When combined, these data will help scientists infer properties of gravity waves, tides, and planetary waves and how they may couple to ionospheric and auroral processes. Furthermore, the network of stations will allow researchers to investigate the propagation of disturbances from high to low latitudes and at longitudes spanning China.

Using Radio Waves to Observe the Ionosphere

The ionosphere and upper atmosphere are parts of a coupled system that often dramatically changes in some space weather conditions. To monitor these changes, instruments at the Meridian Project's stations will beam radio waves through the atmosphere into the ionosphere. The ionospheric plasma and atmospheric medium can affect radio beam propagation, causing reflection, refraction, and scattering. This allows scientists to measure ionospheric and upper atmospheric parameters by receiving the distorted

echoes of radio signals; the magnitude of the distortion is an indicator of the quantity of free ions and particles through which the signal passed. Thus, scientists can monitor the changing density of charged particles, allowing them to better anticipate distortions to communications and navigation signals from satellites.

The most powerful instrument in the Meridian Project is an incoherent scatter radar, which will be located in Qujing, in Yunnan Province (25.6°N, 103.8°E). It will detect physical parameters of the ionosphere from 70 to 1000 kilometers, with a peak transmission power of 2 megawatts. Additionally, two mesosphere-stratosphere-troposphere radars, one in Beijing and one in Wuhan, will make wind observations in the mesosphere, troposphere, and stratosphere with a wave frequency of about 50 megahertz. Continuous wind measurement in the mesopause region will also be made by a meteor radar at Wuhan. In addition, a high-frequency coherent scatter radar in Zhongshan station near the Amery

Ice Shelf in East Antarctica will detect the motion of the ionospheric structure within an azimuth angle of 52° and a height of 3000 kilometers by receiving scatter echo from ionospheric irregularities.

A digisonde chain with instruments in Mohe, Beijing, Wuhan, Hainan, and Zhongshan will observe the electron profile within the altitudes that radio waves are reflected by the ionosphere's F layer as well as monitor ionospheric plasma drift. In addition, real-time ionospheric TEC and scintillation monitors will also be deployed along the same chain (except in Zhongshan). Also, a high-frequency Doppler drift monitor chain will record the propagation of ionospheric disturbances at multiple scales through the use of a long-baseline system, including an array of three high-frequency Doppler antennas in Beijing and a monitor in Wuhan.

Measurements With Sounding Rockets

Sounding rockets are the only means to make in situ measurements of the temperature, density, wind field, and ionospheric electric field in the range of 20–200 kilometers. This region is beyond the capability of balloons and is too low for a satellite to maintain longtime operation, making rockets the best platform for collecting observations.

The sounding rocket launching base will be in Hainan, a low-latitude location. The scientific payloads include an atmospheric detecting package for measuring temperature, wind field, and density; a Langmuir probe for measuring the electron temperature, electron density, and electrical poten-

tial of plasma; and a gas analyzer for detecting microconstituents in the atmosphere.

A Central Data Center

The Meridian Project is a multistation and multi-instrument geospace environment monitoring network. Thus, a central data center is vital to collecting raw data in real time, turning the raw data into scientific data in accordance with international standards, archiving the data in a central data portal, and making them available to different users according to the data policy of the Meridian Project.

In principle, ordinary scientific data will be publicly available; the high-resolution data may be limited to the participating Chinese institutes and universities involved for a certain period of time. Further, specific high-resolution data sets may be exchanged with international users on a case-by-case basis.

The central data center will be in Beijing at China's Center for Space Science and Applied Research (see Figure 3).

Toward Space Weather Modeling and Predictions

The Meridian Project gives Chinese researchers a unique opportunity to contribute new capability for space weather predictions, both nationally and internationally. The synergies between the Meridian Project and satellite missions worldwide are essential for understanding geospace responses to interplanetary disturbances.

Located in Beijing, the Meridian Project's Science Operation Center will be responsible for making short-, middle-, and long-term observational plans for the Meridian Project. CSSAR and Wuhan University will place more emphasis on middle to upper atmospheric modeling, while the Chinese Academy of Sciences' Institute of Geology and Geophysics and the China Research Institute of Radiowave Propagation have been developing both empirical and physics-based ionospheric models. The Polar Research Institute of China will focus on modeling magnetosphere-ionosphere coupling. In addition, the State Key Laboratory of Space Weather at CSSAR and the University of Science and Technology of China are developing independent three-dimensional solar coronal–interplanetary magnetohydrodynamic models and global magnetospheric magnetohydrodynamic models.

Table 1. Meridian Project Station Locations, Along With the Types of Observations and Instruments Deployed at Each

Station	Latitude	Longitude	Instruments
Mohe	53.5°N	122.4°E	magnetometer, digisonde, TEC ^a monitor/ionospheric scintillation monitor
Manzhouli	49.6°N	117.4°E	magnetometer, ionosonde
Changchun	44.0°N	125.2°E	magnetometer, ionosonde
Beijing	40.3°N	116.2°E	magnetometer, digisonde, lidar, ^b all-sky imager, Fabry-Perot interferometer, mesosphere-stratosphere-thermosphere radar, interplanetary scintillation monitor, cosmic ray monitor, TEC monitor/ionospheric scintillation monitor, high-frequency Doppler frequency shift monitor
Xinxiang	34.6°N	113.6°E	magnetometer, ionosonde, TEC monitor/ionospheric scintillation monitor
Hefei	33.4°N	116.5°E	lidar
Wuhan	30.5°N	114.6°E	magnetometer, digisonde, lidar, mesosphere-stratosphere-thermosphere radar, meteor radar, TEC monitor/ionospheric scintillation monitor, high-frequency Doppler frequency shift monitor
Guangzhou	23.1°N	113.3°E	magnetometer, ionosonde, cosmic ray monitor, TEC monitor/ionospheric scintillation monitor
Hainan	19.0°N	109.8°E	magnetometer, digisonde, TEC monitor/ionospheric scintillation monitor, lidar, all-sky imager, very high frequency radar, sounding rockets, meteor radar
Zhongshan	69.4°S	76.4°E	magnetometer, digisonde, high-frequency coherent scatter radar, aurora spectrometer
Shanghai	31.1°N	121.2°E	magnetometer, TEC monitor
Chongqing	29.5°N	106.5°E	magnetometer, ionosonde
Chengdu	31.0°N	103.7°E	magnetometer, ionosonde
Qijing	25.6°N	103.8°E	incoherent scatter radar
Lhasa	29.6°N	91.0°E	magnetometer, ionosonde

^aTotal electron content.

^bLight detection and ranging.

The Meridian Project will help supply data for China's space weather integrated model (SWIM), an effort similar to the United States' Center for Integrated Space Weather Modeling (CISM) and Center for Space Environment Modeling (CSEM). Through SWIM, data from the Meridian Project will be combined with data from China's National Astronomical Observatory, which predicts solar activity. The better space weather models that will result from SWIM will be translated into operational frameworks through the Laboratory for Space

Environment Research and Forecast at CSSAR, which provides space weather forecasts for Chinese manned flight missions and Chinese lunar missions. Operational frameworks will also be facilitated through the National Centre for Space Weather Monitoring and Warning at the China Meteorological Administration, which provides space weather services to the general public, and Chinese weather satellites.

Toward International Collaborations

The Meridian Project is just one arm of a larger effort that Chinese scientists are proposing for the international community. This effort, called the International Space Weather Meridian Circle Program (ISWMCP), would connect 120°E and 60°W chains of ground-based monitors all over the world (mainly in Australia, Brazil, Canada, Russia, and the United States), which will enhance the ability of scientists to monitor the space environment worldwide.

The main purpose of ISWMCP would be to coordinate observations and share data among stations along the meridian to obtain the most scientific benefit for the global space weather community. No great circle-wide effort has been attempted before. ISWMCP is in its early stages—several discussions with other countries about how to proceed with this effort are currently under way.

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Figure 3. The Meridian Project's (a) central data center and (b) science operation center, located in Beijing at the Center for Space Science and Applied Research (CSSAR).