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Recent Development and Preliminary Results of Chinese Meridian Project*

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Abstract The Meridian Project is a ground-based network program to monitor solar-terrestrial space environment, which consists of a chain of 15 ground-based observatories located roughly along 120°E longitude and 30°N latitude. The Meridian project started in 2008, and its construction was completed by 2011. The integration and test phase of the Meridian Project conducted in 2011 demonstrated its observation capabilities as expected. The project will be in full operation in 2012. This report gives an overview of the recent development and preliminary results of the Meridian Project since 2010.

Key words Meridian Project, Space weather, Ground-based

Classified index P 353

0 Recent Development

The three systems of the Meridian Project, namely the space environment monitoring system, data and communication system and research and forecast system, entered joint operational test phase in 2011. It carried out geomagnetic (geoelectronic) monitoring along 120°E meridian and 30°N latitude line, ionosphere and upper atmosphere monitoring in middle and low latitudes, and provided space weather forecast, nowcast or warning for major national space activities. The operational units which had been tested and inspected individually, including 95 monitoring instruments of the space environment monitoring system, the science operation center of the research and forecast system, research and modeling subsystem, the forecast and service platform, forecast protection platform, data center of the data and communication system, and all the eight data-node stations, were all put into the joint operation.

At present, the monitoring instruments of the space environment monitoring system are in operation. Based on the geomagnetic field, geomagnetic pulsations, and geoelectronic field observation by the south and north geomagnetic (geoelectronic) monitoring chains, the geomagnetic (geoelectronic) monitoring subsystem has collected comprehensive, continuous, reliable space physical and geophysical field observation data, providing basic information for studying various physical phenomena in the Earth's space environment. The 8 monitoring instruments of the atmospheric optical monitoring subsystem have already collected the data of density, temperature, wind field, aurora spectrum and air-glow *etc.* of the

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middle and upper atmosphere in different latitude stably, providing observations for understanding the photochemical and dynamical processes in the middle and upper atmosphere, studying the coupling of the thermosphere, ionosphere and middle atmosphere, and exploring the Sun-Earth system coupling mechanism. Using 33 monitoring instruments including the radio radar monitoring chain, the ionosphere altimeter monitoring chain, space environment disturbance real-time continuous monitoring chain and incoherent scatter radar *etc.*, the radio monitoring subsystem has achieved joint monitoring of the middle and upper atmosphere, ionosphere, magnetosphere, as well as the interplanetary structures and disturbances.

The first sounding rocket of the Meridian Project was successfully launched on May 7, 2011, and made the measurements of key parameters up to 200 km including the atmospheric micro-constitutes, atmospheric electric field, electron density and temperature, and ion density, *etc.* Further sounding rocket missions are under development for the in-situ measurements of ionospheric key parameters.

The data and communication system are all in operation, and the data transmission, storage, preprocessing, management, distribution, and service have been provided for a long time.

The research and forecast system is all in operation, and the science operation center has achieved scientific control and effective supervision for all the operational stations and node stations. The research and modeling subsystem has begun to utilize the monitoring data gradually. The forecasting platform has been in business operation, and supplied the space environment forecasting and services successfully for the major national space launch missions.

1 Preliminary Results

1.1 Responses of the Geospace Environment to Solar Storms

With the approaching of the maximum of the 24th solar cycle peak year (2012—2014), magnetic storm activities increased significantly, and the Meridian Project has repeatedly observed the responses of the space environment to solar storms over China.

On August 6, 2011 (UT), the most intense geomagnetic storm since 2007 event occurred. Kp and Dst index reached 8 nT and -115 nT respectively, and a continuous solar proton event began on August 5. The Meridian Project was in joint operation, which geomagnetic monitoring subsystem, optical monitoring subsystem and radio monitoring subsystem clearly observed the influences of solar activities on Earth's space environment.

Based on the solar wind conditions during this solar storm, the Meridian Project's space weather physical forecast model obtained the location and shape of the magnetopause and bow shock (see Figure 1), the distribution of the ionosphere potential (see Figure 2), to reflect the influence of the solar activity on the Earth's large-scale structure. The results show that the subsolar point of the magnetopause was compressed to $6.4\,R_{\rm e}$, the magnetopause just shifted inside the geosynchronous orbit, and the geosynchronous satellites were under the threat of high-energy particles from the solar wind. The transpolar potential drop was about 400 kV, implying strong currents over high-latitude regions, and the geomagnetic disturbances caused by the currents might have impacts on ground-based instruments.

1.2 Strong Ionosphere Disturbances Caused by $3\cdot11$ Japan Earthquake

8.9 Earthquake occurred in Japan at 13:46 (Beijing Time) on March 11, 2011. The Meridian Project real-time ionospheric monitoring chain, consisting of HF Doppler Drift Monitors in Peking University station, Changping station and Shenzhen station, observed a special strong disturbance of the Earth's ionosphere 10 minutes later, which was shown as an infrasound wave packet with multiple frequencies (see Figure 3). Three hours after the earthquake, the three stations observed another ionospheric infrasound distur-

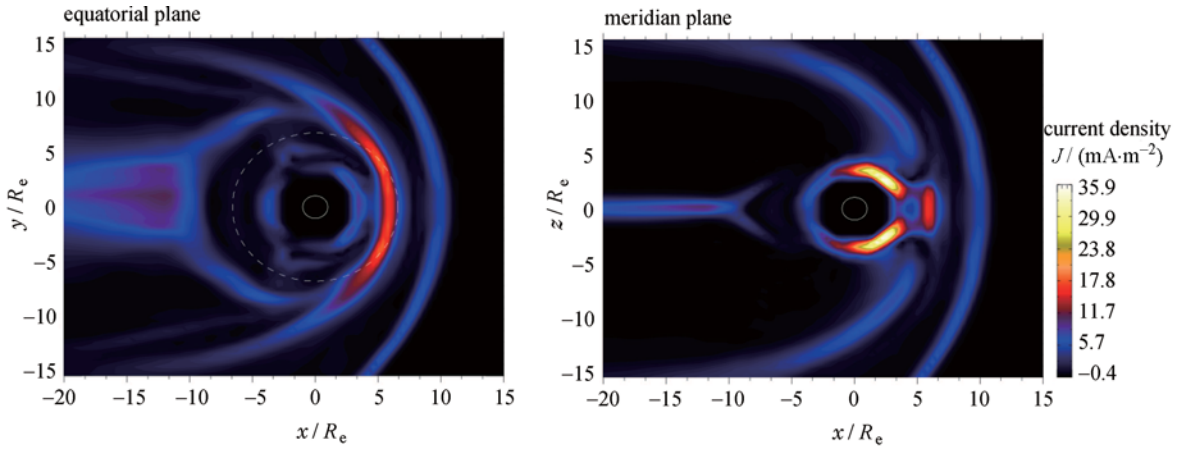


Fig. 1 Location and shape of magnetopause and bow shock (dashed line is the synchronous orbit)

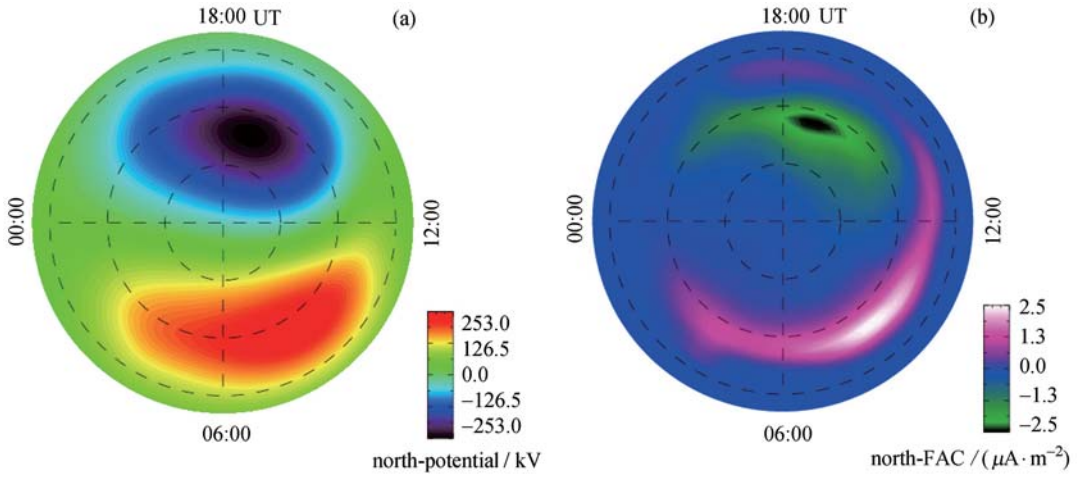


Fig. 2 Potential distribution (a) and Field-Aligned Current (FAC) distribution (b) of northern hemisphere polar cap

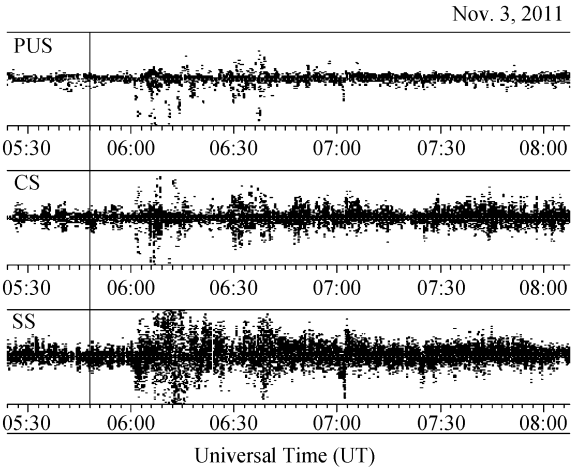


Fig. 3 HF Doppler drift monitoring data (red line: 05:46 UT, the earthquake time). Wave packet delay observed by Peking University Station (PUS), Changping Station (CS) and Shenzhen Station (SS)

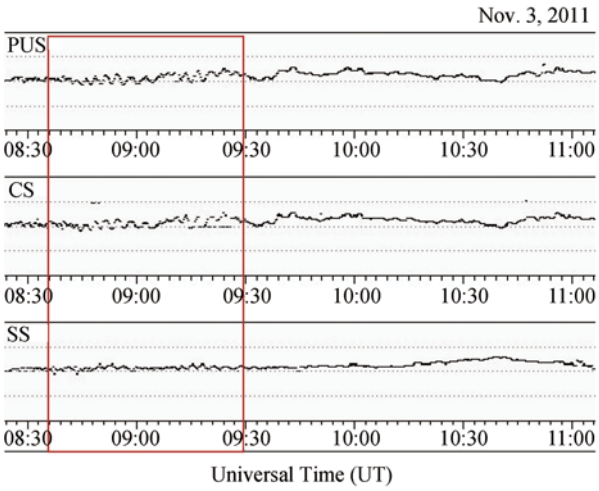


Fig. 4 Disturbances with a period of 3 minutes observed by Peking University Station (PUS), Changping Station (CS) and Shenzhen Station (SS) 3 hours after the earthquake

bance at a single frequency (period of about 3∼5 minutes), which lasted about one hour (see Figure 4).

Preliminary analysis indicates that the observed ionospheric infrasound disturbance is related directly to the transmission of the atmospheric wave caused by the tsunami after the earthquake. In particular, the relationship between right and left sound waves of 3-minute period in the ionosphere and tsunami, rarely has been reported in China and abroad, while it is a strong evidence for the lithosphere-atmosphere-ionosphere coupling.

1.3 Simultaneous Measurements of Gaseous, Liquid and Solid State of Atmospheric Water

The Meridian Project lidar at Wuhan University is the first full-water-spectrum Raman lidar in China, which has strong detection capability at about 8 km in height and 0.23 nm in spectral resolution. The development of the full-water-spectrum Raman lidar shows that lidar exploration of cloud in China ranks among the advanced countries.

The Meridian Project lidar at Wuhan University can measure the echo signals generated by gaseous, liquid and solid state water simultaneously, and then obtain the relative content, height distribution and time evolution of the three different phase water in the atmosphere. It is important to reveal the cloud microphysical processes, establish the atmospheric radiative transmission model, and make accurate weather forecast and weather/climate analysis.

It was snowy on January 18, 2011 in Wuhan. Lidar at Wuhan station observed the Raman spectrum characteristics of the cloud water and water vapor and the cloud height characteristics before the snow. Figure 5 shows the measurements of lidar at Wuhan station on January 16 and 17, 2011. It is shown that the liquid water content in the cloud on January 17 enhanced significantly comparing with that on January 16.

1.4 Statistical Characteristics of Gravity Wave Activities in Northern China

An All-Sky Airglow Imager (ASAI), which was an instrument of the optical-atmospheric monitoring subsystem of the Meridian Project, was installed at Xinglong in northern China to study the morphology of Atmospheric Gravity Waves (AGWs) in the Mesosphere and Lower Thermosphere (MLT) region. Using one year of OH airglow imager data from December 2009 to November 2010 collected by ASAI, the characteristics of short-period AGWs are investigated and a yearlong AGW climatology in northern

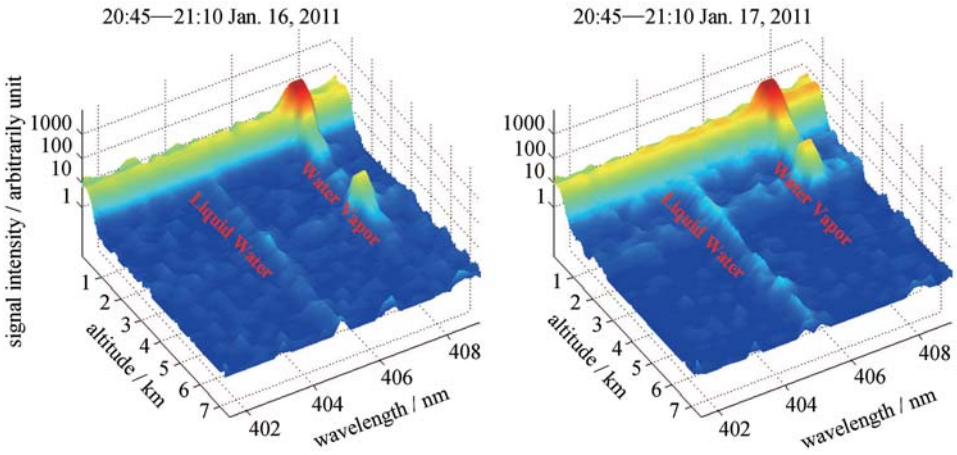


Fig. 5 Original echo signal height maps of the Meridian Project lidar at Wuhan University

China is first ever reported.

AGW occurrence frequency in summer and winter is higher than that in equinoctial months. Observed bands mainly have horizontal wavelengths from 10 to 35 km, observed periods from 4 to 14 min and observed horizontal phase speeds in the range of 30 to 60 $m \cdot s^{-1}$ (see Figure 6). Most of the bands propagate in the meridional direction. The propagation directions of the bands show a strong southwestward preference in winter, while almost all bands propagate northeastward in summer (see Figure 7). Although the wind filtering in the middle atmosphere may control AGW propagations in the zonal direction, the non-uniform distribution of wave sources in the lower atmosphere may contribute to the anisotropy in the meridional direction in different seasons.

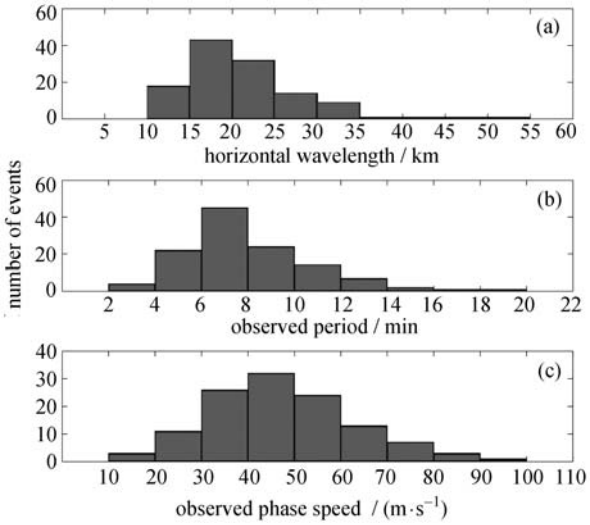


Fig. 6 Histograms of band parameters. (a) Horizontal wavelength, (b) observed wave period, (c) observed horizontal phase speed

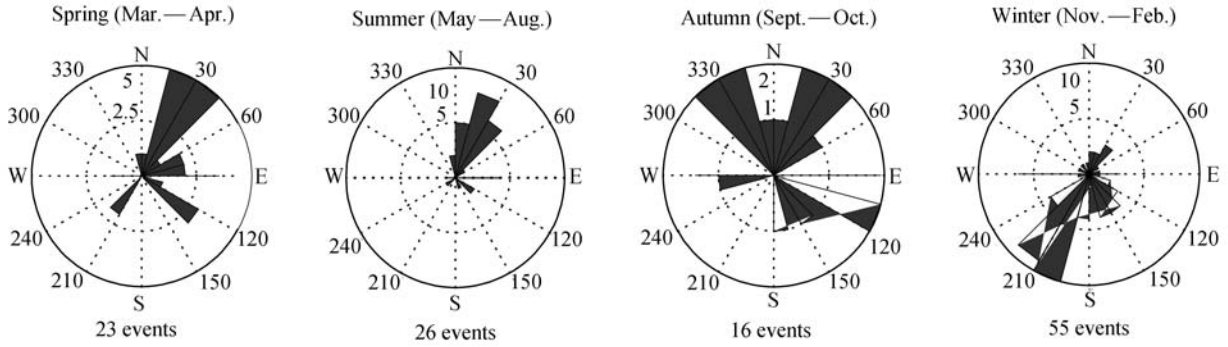


Fig. 7 Seasonal variations of the propagation directions of bands

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