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Chinese Antarctic Magnetometer Chain at the Cusp Latitude

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Abstract A Chinese Antarctic Magnetometer (CAM) chain from Zhongshan Station (ZHS) to Dome-A (DMA) has been established since February 2009. A regular magnetometer is operated at ZHS, and four low power magnetometers are operated along the interior route from ZHS to DMA in the cusp latitude, extending over a distance of 1260 km. These stations fill an important void in the Antarctic magnetometer network. Furthermore, the CAM chain is magnetically conjugated with the Arctic region reaching from the Svalbard archipelago to Daneborg, on the east coast of Greenland. Conjugate measurements using the Arctic and Antarctic magnetometers provide excellent opportunities to investigate phenomena related to the coupling of the solar wind to the magnetosphere and ionosphere, such as magnetic impulse events, flux transfer events, traveling convection vortices and ultra-low frequency waves.

Keywords **Magnetometers, magnetic perturbation, cusp latitude, conjugate**

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1 Introduction

The Earth's magnetic field is crucial for protecting human, animal and plant life from direct radiation caused by charged particles originating from the Sun and interstellar space. The geomagnetic field shields the Earth's surface from such radiation, and could be considered the third essential condition for the evolution of human life, aside from water and atmosphere.

The geomagnetic field is also the most fundamental parameter in space weather and magnetospheric physics, perhaps equivalent to temperature in meteorology. In fact, the geomagnetic field forms the domain of the magnetosphere. In the inner magnetosphere, it confines the motion of charged particles; in the outer magnetosphere, these particles distort the geomagnetic field, compressing it on the sunward side of the planet and drawing it out into a long tail on the night side. The geomagnetic field varies with time and location. The main field generated by the inner core of the Earth slowly changes in strength and polarity, while components external to the Earth are produced by variable currents that flow in space and through the surface of the ground. Developing our understanding of the dynamic geomagnetic field is an important goal for forecasting of space weather.

A general way to monitor the geomagnetic field is to establish observatory networks by deploying magnetometers along the latitude and the longitude, such as the IMAGE Chain[1] along the Scandinavia Peninsula, the Greenland Chain[2] along the Greenland coast, and the Canadian Magnetometer Network[3] located in the north of Canada. Several magnetometer chains have also been built in distant reaches of Antarctica, such as the magnetometer chain from Dome-C to Harley Station established by the British Antarctic Survey, and the chain from Dome-F to Showa Station built

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by the National Institute of Polar Research, Japan. Recently, the United States' Virginia Polytechnic Institute and State University established a magnetometer chain along the 40°W meridian, orthogonal to the Cusp chain discussed here[4].

A composite observational system for upper atmospheric science has been established at Zhongshan Station, Antarctica through continuous efforts over the last twenty years. Observations from Zhongshan have produced advances in scientific research for space physics in the cusp region. However, observations from a single site have limited benefit for investigation of the vast and complex magnetospheric system. Thus, the observations have been extended to Dome-A (DMA). DMA(80.4S 77.5E GEO; 77.8S 54.5E CGM) is located in the interior of Antarctica, at a distance of about 1260 km inland from ZHS (76.4S 69.4E GEO; 74.6S 96.6E CGM). At DMA, Kunlun Station (KLN) has been established since 2009, although it is a summer station at the current stage. Building an observational chain by deploying magnetometer along the route from ZHS to DMA is an obvious way to significantly enhance our capability to monitor the space environment.

2 Locations

It is well-known that ZHS is located at the ionospheric projection of the magnetospheric cusp region, where there is most active coupling and interaction between the solar wind, the magnetosphere, the ionosphere and even the neutral atmospheric system. That is the reasons that a comprehensive observational system on space physics has been built at ZHS. DMA is also located in the vicinity of the magnetospheric cusp. The cusp is formed when the geomagnetic field reconnects with the interplanetary magnetic field (IMF), in which mass and energy can be transported into the magnetosphere and energetic particles may precipitate into the ionosphere[5]. The location of the cusp region is rather dynamic, variable with the solar wind dynamic pressure and the IMF orientation, and even with the magnetic condition within the magnetosphere. A magnetometer chain from ZHS to DMA will provide a lot of opportunities to see typical physical phenomena occurring in space.

The Chinese Antarctic Magnetometer (CAM) chain comprises five sites, ZHS, ZK1, ZK2, ZK3 and DMA (Figure 1), roughly distributed at intervals of 300 km. Owing to the topography and the traverse route, ZK1 and ZK2 are located at a distance of 260 km and 520 km from ZHS, respectively, where as ZK3 is 900 km from ZHS. The five sites are lined roughly westward in the corrected geomagnetic coordinate system (CGM), covering about 3 h in magnetic local time (MLT), which would favor investigation of propagation of ULF waves and any perturbation motions in the East–West direction. Information about these sites, including the latitude and the longitude in the geographic (GEO) and the corrected geomagnetic (CGM) system, is listed in Table 1.

ZHS is geomagnetically conjugated with Svalbard Island, where Ny Alesund (NAL) village and Longyearbyen (LYR) town are located. The Chinese Yellow River Station (YRS) is located in the NAL region (Figure 2). The conjugated region of DMA is located in the middle of Greenland, while that of ZK2 is located near DNB on the east coast of Greenland. So, the CAM chain will form a cross with the magnetometer chain along the Greenland east coast, which will help tracing magnetic disturbance in two dimensions. As a major station, ZHS is conjugated with YRS, where a composite observational system on upper atmosphere has also been built. This will greatly benefit conjugate studies for space physical phenomena. Table 2 lists the coordinate parameters for some ground sites in the Arctic region.

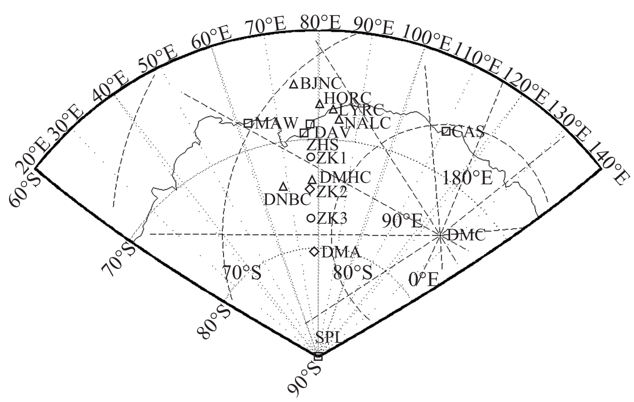

Figure 1 Location of the Chinese Antarctic Magnetometer (CAM) chain. The CAM chain comprises five sites, i.e., ZHS, ZK1, ZK2, ZK3 and DMA, extending 1260 km along the southern cusp latitude. The stations in the Arctic and their geomagnetic conjugates are plotted together. DMHC denotes the conjugated site of DMH, and the other codes are defined similarly. The geographical system originates at South Pole (SPL) and the corrected geomagnetic system originates at Dome-C (DMC).

Table 1 CAM Chain Station Coordinates

Sites	S/km	H/m	Geo. Lat.	Geo. Lon.	CGM. Lat.	CGM. Lon.	L	MLT noon
ZHS	0	20	-69.37	76.38	-74.37	96.88	14.54	10.21
ZK1	260	2290	-71.60	77.71	-76.15	90.95	-	10.57
ZK2	600	2714	-74.58	77.02	-77.13	79.55	-	11.31
ZK3	900	2983	-77.26	76.96	-77.73	68.28	-	12.08
DMA	1228	4093	-80.37	77.54	-77.92	54.36	-	13.07

Notes: S denotes the distance in km from the interior sites to ZHS Station; H denotes the height in m above sea level. The remaining six columns respectively denote the latitude and the longitude in geographical system (GEO), and in the corrected geomagnetic system (CGM), the distances from Earth's center to the magnetic shell in equatorial plane with a unit in the Earth's radius, and the magnetic local noon in universal time. The last four parameters are derived from the 2009 NASA-GSFC model.

Table 2 IMAGE Chain Station Coordinates

Station	Geographical		Corr. Geomagnetic (CGM)		L value	MLT noon (UT)
	Lat.	Long./(°E)	Lat.	Long./(°E)		
NAL (Ny Alesund)	78.92	11.95	76.38	110.07	-	0900
LYR (Longyearbyen)	78.20	15.82	75.44	111.09	-	0857
HOR (Horsund)	77.00	15.60	74.31	108.66	13.9	0905
BJN (Bear Island)	74.50	19.20	71.62	107.34	10.21	0908
SOR (Sørøya)	70.54	22.22	67.50	105.69	6.94	0924
OUJ (Oulujärvi)	64.52	27.23	61.15	105.93	4.36	0921
NUR (Nurmijärvi)	60.50	24.65	57.02	102.03	3.43	0928
TAR (Tartu)	58.26	26.46	54.61	102.80	3.03	0925

Note: The corrected geomagnetic coordinates, the L value and the magnetic local noon are derived from the 2009 NASA-GSFC model.

The CAM chain can perform conjunction observations with other magnetometer chains or sites, such as the magnetometers at Davis and Mawson, those surrounding the South Pole, and those from Halley to Dome-C. These locations form an Antarctic magnetometer network, distributed over a vast area: across the open-closed boundary of the geomagnetic field lines and extending deeply into the polar cap, where open magnetic field lines dominate. Used in together, these magnetometers could provide excellent tracking of typical space physical phenomena including flux transfer events (FTEs), traveling convection vortices (TCVs), magnetic impulse events (MIEs), and ULF waves.

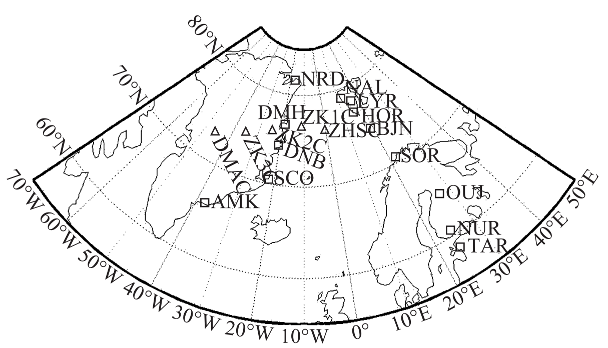

Figure 2 Chinese Antarctic Magnetometer (CAM) chain conjugated regions in the Arctic. The CAM chain comprises five sites, i.e., ZHS, ZK1, ZK2, ZK3 and DMA, conjugated with ZHSC, ZK1C, ZK2C, ZK3C and DMAC, respectively. Plotted together are several magnetometer sites in the Arctic region, such as NAL from the IMAGE chain and DMH from the East Coast chain of Greenland Island. The coordinate labels are in geographical (GEO) system.

3 Magnetometers

A regular fluxgate magnetometer has been deployed at ZHS since January 2013. It consists of a sensor, an electronic unit and a controlling personal computer (Figure 3). The sensor can detect the magnetic field vector in three dimensions, and is placed outdoors, 30 m away from the building, where the electronic unit and the personal computer are placed. The electronic unit receives signals from the sensor via a multi-core signal cable, and sends data to the personal computer via a RS-232 line, and can also record the magnetic field data on a magnetic Flash-card. The computer can store the data on its hard disk and transmit them via the internet, and can be remotely operated via the internet. The magnetometer can sample data in frequencies of 1, 5 and 25 Hz, with an amplitude resolution of 0.01 nT. The manufactory is Research Centre Geomagnet, Ukraine. Magnetometers of the same type have been deployed in both YRS and Longyearbyen (LYR) in Svalbard Island since August 2013 and 2014 respectively.

Four low-power fluxgate magnetometers (LPMs) have been deployed in the interior Antarctic, at ZK1, ZK2 ZK3 and DMA. Kunlun Station at DMA, established in 2009, is a summer station without regular power supply or regular visitors because of the extremely harsh climate,with an average temperature of −58°C and lows close to −80°C, as well as 4 months of polar night. The LPM is composed of a data-recording box, a set of storage batteries, a set of solar cell panels and a sensor (Figure 4). The data-recording box and the solar cell panels are supported by aluminum alloy poles and

Figure 3 A regular fluxgate magnetometer running at Zhongshan Station, which consists of an electronic unit, a sensor and a GPS antenna. A signal cable connects the sensor and the electronic unit. Additionally, a personal computer is used to monitor observation and register data, which is connected to the electronic unit via a RS-232 serial port.

lifted above the snow surface, while the storage batteries and sensors are buried under the snow. The LPM installation was completed by the 25th Chinese National Antarctic Research Expedition (CHINARE) between January–February 2009.

The most critical issue for magnetometer use is a stable power supply. Storage batteries and solar cells are used to provide electric power for the LPMs during night and daytime, respectively. The solar cells provide direct electric power and the batteries can be recharged when sunlight is available. The LPMs register the magnetic field vector data at 1 Hz with an amplitude resolution 1 nT, consuming power at a rate of 0.5 W. The magnetic data are recorded on a 2 GB flash card, which allows two years of LPM operation without any maintenance. After two years, the Flash-Disk needs to be replaced. The data-recording box can be brought back for examination when necessary.

The LPM are manufactured by the British Antarctic Survey, using the same pattern as those deployed along the longitudinal line from Halley Station to Dome-C.

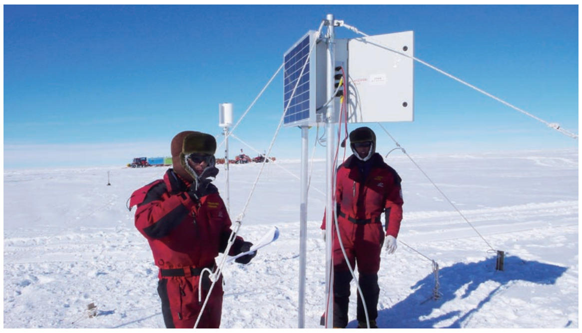

Figure 4 A low power magnetometer (LPM) running in inner land of Antarctica, which consists in a sensor, a data recording box, a set of storage battery, a solar panel and a wind generator. The sensor and the storage battery are buried under the ice/snow, while the data recording box, solar panel and the wind generator are supported by aluminum poles above the ground.

4 Scientific Aim

Owing to its geomagnetic location roughly along the cusp latitude, the CAM chain contributes to and supports scientific research on the upper atmosphere at high latitude.

The cusp is a convergence of the geomagnetic field lines in the magnetosphere over a vast area. Physical phenomena occurring in the distant magnetotail, the mangnetopause and even in the opposite hemisphere can be observed near the cusp region because the relevant disturbances can propagate along the magnetic field lines. One typical phenomenon is ULF waves. ULF waves (0.001—5 Hz) can be excited by physical processes such as interaction between the input solar wind stream and its reflection from the bow-shock[6], the Kelvin-Helmholtz instability between the solar wind stream and the magnetosphere at the magnetopause[7], the electromagnetic cyclotron instability in the minimum magnetic field regions in the outer magnetosphere[8], and field line flapping in the magnetotail[9]. These physical processes could generate ULF waves in different frequency bands and may be recorded near the cusp on the ground. Data gathered using the CAM chain could be used to derive the wave propagation direction and hence help identify the source of the waves. This will help gain further insight into these processes as they appear in space.

As mentioned in Section 2, the conjugate point of ZHS is located near Svalbard Island; that of DMA is in the middle of Greenland, and that of ZK2 is near DNB. This configuration would greatly benefit our ability to trace the movement of the footprint of geomagnetic field lines. Thus, the conjunction observations between the satellite and the ground in both hemispheres would significantly help investigate the generation and propagation mechanism of ULF waves, as well as other physical processes[10-11].

Flux transfer events result from episodic and/or patchy magnetic reconnection between the Earth's magnetosphere and the Sun's magnetic field near the magnetopause on the dayside. A temporary flux tube is then formed through which high-energy particles such as solar wind can flow into the magnetosphere[12]. This is the main way that the solar wind couples to the Earth's magnetosphere. Extensive work has been done on FTEs but many issues remain unresolved, including the factors that control the reconnection rate[13-14]. The CAM chain along the cusp latitude could potentially improve tracing of FTE movement.

Traveling convection vortices events area twin-vortex structure associating with an upward/downward field-aligned current pair. Once formed, the TCV will propagate tailward from the local noon at speeds of several km/s. However, they become weaker as they propagate and only last for about 10–20 min. The generation of the associated field-aligned current pairs and the movement of the TCV structure are controlled by complicated physical processes in the outer magnetosphere. These could possibly include the kink instability[15], boundary waves, plasma density gradient or magnetic field gradient[16], and perhaps even field line resonance [17]. The observations from the CAM chain will help clarify TCV issues.

5 Observations

The CAM chain has been gathering valuable geomagnetic field data since it was built in February 2009. With a sampling frequency at 1 Hz, it can be used to study ULF waves in the Pc3-5 and Pc1-2 band, and other phenomena associated with magnetic perturbation including FTE and TCV.

As an example, Figure 5 shows an MIE that occurred over 1420–1440 UT on 2 December 2009. The data have been converted into the CGM coordinate system; on the right side is the latitude in CGM for the respective site on the left. This was a global magnetic perturbation event, with a significant bipolar structure recorded on the ground from high latitude to middle and even low latitude in both hemispheres. The magnitude of the perturbation maximizes at the cusp latitude (DMA, ZK1, NAL and LYR), near the magnetopause boundary, decreasing from high to low latitude. Additonally, the perturbation has larger amplitude in the southern than in the northern hemisphere at the same latitude, which suggests that the perturbation may have first appeared in the southern hemisphere. We notice that DMA and ZK1 are located at a sector in west of NAL and LYR and the signal arrived at DMA and ZK1 much earlier than at NAL and LYR. This suggests that the magnetic perturbation may have come from the dusk flank of the magnetosphere, and further supports the suggestions that the southern magnetosphere maybe have been the first disturbed.

A detailed analysis for this MIE event, involving further ground station and satellite observations, will be given in a companion paper.

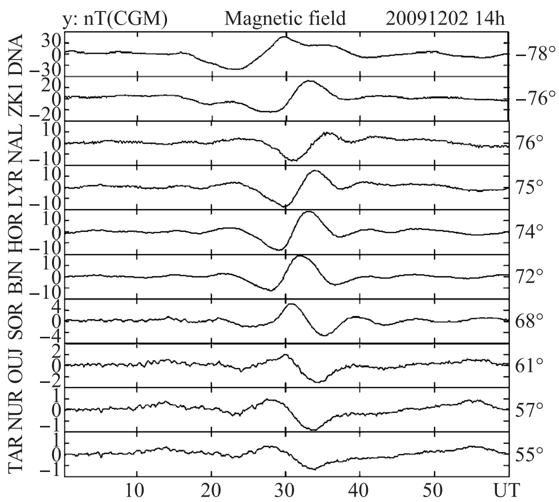

Figure 5 A magnetic impulse event (MIE) occurred over 1420-1440 UT on 2 September 2009 and recorded by CAM chain and the IMAGE chain. A significant bi-pulse structure appeared on the sites in both hemispheres. The top two panels show the results from DMA and ZK1, in the CAM chain in Antarctica, while the remained eight panels show the records from the IMAGE chain in the Arctic. The magnetic data are recorded in CGM system and the latitude in CGM for the magnetometer sites are shown in right.

6 Summary

The CAM chain between ZHS and DMA has been active since 2009. The chain consists of five instrumented sites, ZHS, ZK1, ZK2, ZK3 and DMA, which are located at the southern cusp latitude and extend magnetically westward for about 3 local magnetic hours. A regular fluxgate magnetometer is deployed at ZHS, and four LPMs are installed at the four interior sites. The LPMs operate automatically using a power supply comprising chemical batteries and solar panels; the solar panels can recharge the batteries when solar light is available. Sampling at 1 Hz, the LPMs can register magnetic data on a flash card with 2 GB of storage, allowing for two years' worth of data. The observations from the CAM chain can be used to study phenomena such as MIEs, FTEs, TCVs and ULF waves on the basis of geomagnetic perturbations. The CAM chain magnetometers fill a void in magnetic observations in Antarctica, and in combination with other existing Antarctic magnetic facilities, can significantly enhance the field of view for monitoring space physical phenomena. Additionally, as the magnetometers have conjugate points in the Svalbard region and east coast of Greenland in the Arctic, they can thus contribute to inter-hemisphere study of the space environment.

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