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The Chinese ground-based instrumentation in support of the combined Cluster/Double Star satellite measurements

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Abstract. Ground-based observations can be used to provide substantial support for Cluster/Double Star measurements and greatly enhance the mission's scientific return. There are six Chinese ground stations involved in coordinated cluster/Double Star and ground-based instrument observations. Among them, the Chinese Zhongshan Station in Antarctica and the Yellow River Station on Svalbard are closely magnetic conjugate and are situated under the ionospheric projection of the magnetospheric cusp regions, which, combined with satellite data, provide a perfect configuration to conduct conjugate studies of cusp phenomena. In this paper we present the ground-based instrumentation at these stations, discuss the restriction which is applyed to the optical sites and present an overview of the occurrences for conjunctions of these instruments with the spacecraft. Samples of data products are given to illustrate the potential use of these instrumentations in coordination with Cluster/Double Star measurements.

Keywords. Ionosphere (Instruments and techniques; Particle precipitation) Magnetospheric physics (Auroral phenomena)

1 Introduction

The Chinese scientific satellite mission Double Star Project (DSP), complementing the four Cluster spacecraft, gives an unprecedented opportunity to study the structure and dynamics of the magnetosphere. In addition, ground-based observations can be used to provide important support for Cluster/Double Star data and greatly enhance the mission's scientific return. The European Space Agency (ESA) has established a working group to coordinate the ground-based observations with the Cluster. Opgenoorth and Lockwood (1997) have discussed ways to support the multipoint in-situ satellite measurements and presented a number of potentially useful configurations between the satellites and any one ground-based observatory. A number of papers have been published since Cluster launched to show how the combined spacecraft and ground-based observation could help to shed light on outstanding questions in magnetospheric physics (Opgenoorth et al., 2001; Lockwood et al., 2001a, b; Moen et al., 2001).

There are solar-terrestrial physics observations in China, Antarctica and on Svalbard (Liu Ruiyuan et al., 1998; Wu et al., 2000). In this paper we present the Chinese ground-based instrumentations in support of the combined Cluster/Double Star satellite measurements, discuss what constraints apply to the optical sites and how frequent the conjunctions are of these stations with the spacecraft. Some examples of data products are shown to illustrate the potential use of these instrumentations in coordination with Cluster and Double Star measurements.

2 Ground-based instrumentation

There are six Chinese ground stations involved in coordinated Cluster/Double Star and ground-based instrument observations. Among them, three geomagnetic stations, Mohe, Beijing and Sanya, are located in middle and low latitudes on the China mainland, the Great Wall and the Zhongshan station (ZHS) in Antarctica and the Yellow River Station on Svalbard. In Table 1 the geographic coordinates are listed, as well as the instruments at these stations.

The Antarctic Zhongshan Station was established in February 1989. Figure 1 shows the location of Zhongshan with respect to the Antarctic magnetometer stations. The

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Table 1. Chinese ground stations and instrumentation in support of the combined Cluster/Double Star satellite measurements.

Station	Geographic location	Instruments
Yellow River	78.9°N 11.9°E	Three-Wavelengths CCD All-sky Auroral Imager (630.0nm, 557.7 nm, 427.8 nm) Imaging riometer (8×8)
Mohe	53.5°N 122.4°E	CTM-DI Magnetometer Proton precession magnetometers Quartz-3E Variometer
Beijing	40.4°N 116.2°E	Standard Vector Proton Precession Magnetometer (Model: CHS) Declination and Inclination Magnetometer (Type DIM-100) CZM2 proton precession Magnetometer Induction Magnetometer Quartz-3E Variometer
Sanya	18.4°N 109.6°E	Proton precession magnetometers Quartz-3E Variometer
Great Wall	62.2°S 58.9°W	Ionosonde Ionospheric scintillation measurement Fluxgate magnetometer Induction magnetometer Quartz-3E Variometer VLF receiver
Zhongshan	69.4°S 76.4°E	Panchromatic all-sky TV camera Monochromatic all-sky CCD imager (630.0 nm, 557.7 nm) Multi-channel scanning photometer (630.0 nm, 557.7 nm, 427.8 nm) Imaging riometer (8×8) DPS-4 Ionosonde Fluxgate magnetometer Induction magnetometer Proton precession magnetometers Quartz-3E Variometer VLF receiver Ionospheric scintillation measurement

corrected geomagnetic latitude of Zhongshan is about 74.5° and the equivalent L value is about 14. Zhongshan Station is situated under the ionospheric projection of the magnetospheric cusp region at noon, and the polar cap region at night, twice passing through the auroral oval during a day. Therefore, Zhongshan station is a well-located ground base for studying important problems related to solar-terrestrial physics (Zhang et al., 1999; Yang et al., 2000; Sato et al., 2001).

Figure 2 shows the map of the Arctic and Antarctic in altitude adjusted corrected geomagnetic (AACGM) coordinates (Baker and Wing, 1989), looking down on the geomagnetic North Pole at 10:00 UT. The boundaries of the auroral oval (Q=3) are shown as solid lines in the figure. It is shown that the magnetic conjugate point of Zhongshan Station is near Svalbard. The Chinese Yellow River Station was set up in November 2003 at Ny-Ålesund (NAL) of Svalbard. Table 2 gives the geographic and geomagnetic coordinates of Zhongshan Station in Antarctica and the stations in Svalbard (Auroral Station at Longyearbyen and Yellow River Station at Ny-Ålesund). It is noticed that Svalbard is under the common field of view of CUTLASS-Finland and CUTLASS-Iceland radars, and Zhongshan Station of Antarctica is under the common field of view of the Syowa Easter and Kerguelen Island radars. Both Zhongshan Station and Yellow River Station are closely magnetic conjugate and are situated under the ionospheric projection of the magnetic cusp region at noon, which, combined with the satellite, would provide an ideal configuration to do conjugate studies of cusp phenomena, looking at its similarities and differences.

At Yellow River Station there are three sets of CCD all-sky auroral imagers, working at 630.0 nm, 557.7 nm and 427.8 nm wavelengths, respectively. The sampling rate is 6 s for each set, allowing for the studying of the Pc3 pulsations. At Zhongshan Station there are optical instruments: a panchromatic all-sky TV camera, a monochromatic all-sky CCD imager (630.0-nm or 557.7-nm filter), a multi-channel scanning photometer (630.0 nm, 557.7 nm, 427.8 nm).

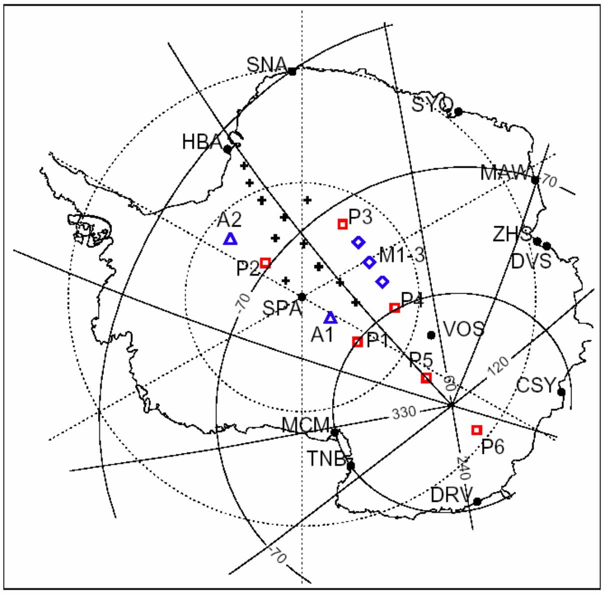

Fig. 1. Location of Zhongshan Station in Antarctic with geographic (geomagnetic) coordinates given by the dotted (solid) lines. Manned stations are shown by a three-letter international station name code. U.S. AGO/PENGUIN sites are shown by P#. British low-power magnetometers are shown by crosses. Proposed U.S. autonomous low power magnetometer (M1, M2, M3) sites are shown as blue diamonds and two proposed multi-instrument ARRO sites are marked as A1 and A2.

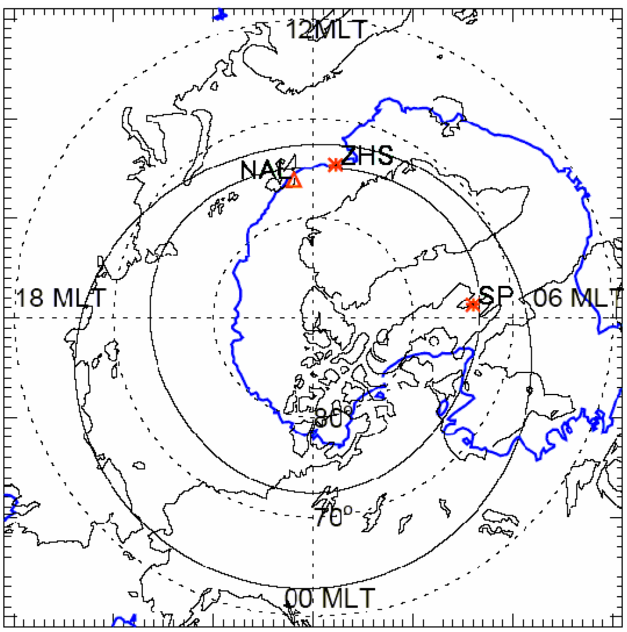

Fig. 2. The map of the Arctic and Antarctic in altitude-adjusted, corrected geomagnetic (AACGM) coordinates, looking down on the geomagnetic north pole at 10:00 UT. The boundaries of the auroral oval (Q=3) are shown as solid lines in the figure.

Table 2. Coordinates of the observational sites.

Site	Geographic Lat.	Geographic Long.	Corr. Geomagnetic Lat.	Corr. Geomagnetic Long.	MLTMN /UT	L
Zhongshan	–69.37	76.38	–74.55	96.48	22:13	14.0
Ny-Ålesund	78.92	11.95	76.19	111.25	20:52	16.0
Longyearbyen	78.20	15.82	75.25	112.08	20:48	15.4

Figure 3 shows the Keogram derived from the all-sky TV camera at Zhongshan Station during 01:00–01:30 UT on 17 July 2004 when the Double Star TC-1 spacecraft is in conjunction with it. The MLT is around 03:00. In the figure the poleward moving of the aurora bulge is clearly shown during a substorm at 01:10 UT. Figure 4 shows the Keograms derived from 3 sets of CCD all-sky imagers at Yellow River Station in Ny-Ålesund during 10:00–11:00 UT on 2 January 2004 when the Double Star TC-1 spacecraft is in conjunction with it. The MLT is around 13:30.

The intensity of the luminance of the all-sky imagers at Yellow River Station was calibrated in the laboratory. The multi-channel scanning photometer at Zhongshan Station was also calibrated with standard lamps during observation. Therefore, the precipitation information (the characteristic energy and the energy flux of the electronic precipitation) can be derived from multi-wavelength optical measurements (Rees and Luckey, 1974; Rees, 1988).

The sunlight limits dayside auroral observations at Zhongshan in Antarctica and Yellow River Station on Svalbard to special seasons. The ground-based optical instruments are usually observational when the solar elevation angle is under –12°. Figures 5a, b show the Sun diagram over Ny-Ålesund and Zhongshan Station, respectively. In the figures the ordinate is local time and the abscissa is month. It is shown that Ny-Ålesund is capable of observing cusp aurora and dayside magnetospheric boundary phenomena for about 40 days around December. On the other hand, Zhongshan Station is suitable to observe post-noon aurora and related phenomena in the southern winter because the magnetic noon is 3 h after local noon. The Zhongshan–Ny-Ålesund pair would provide more of a chance to do coordinated observation with spacecraft, particularly for optical instruments when one site is in the midnight Sun and the other sites in the polar night.

The imaging riometer enables observation of the complex dynamics of auroral and polar radio-wave absorption events, and could provide detailed characteristics of spatial and temporal structures of small-scale disturbance events, velocity vectors for drifting features and frequency spectra for modulated events (Detrick and Rosenberg, 1990; Stauning, 1996). The observation of the imaging riometer has been used to study the ionospheric impacts on space weather events (Stauning, 1998; Liu et al., 2001) as well. In 1997 an 8×8 beam imaging riometer was installed at Zhongshan Station under the cooperation between the Polar Research Institute

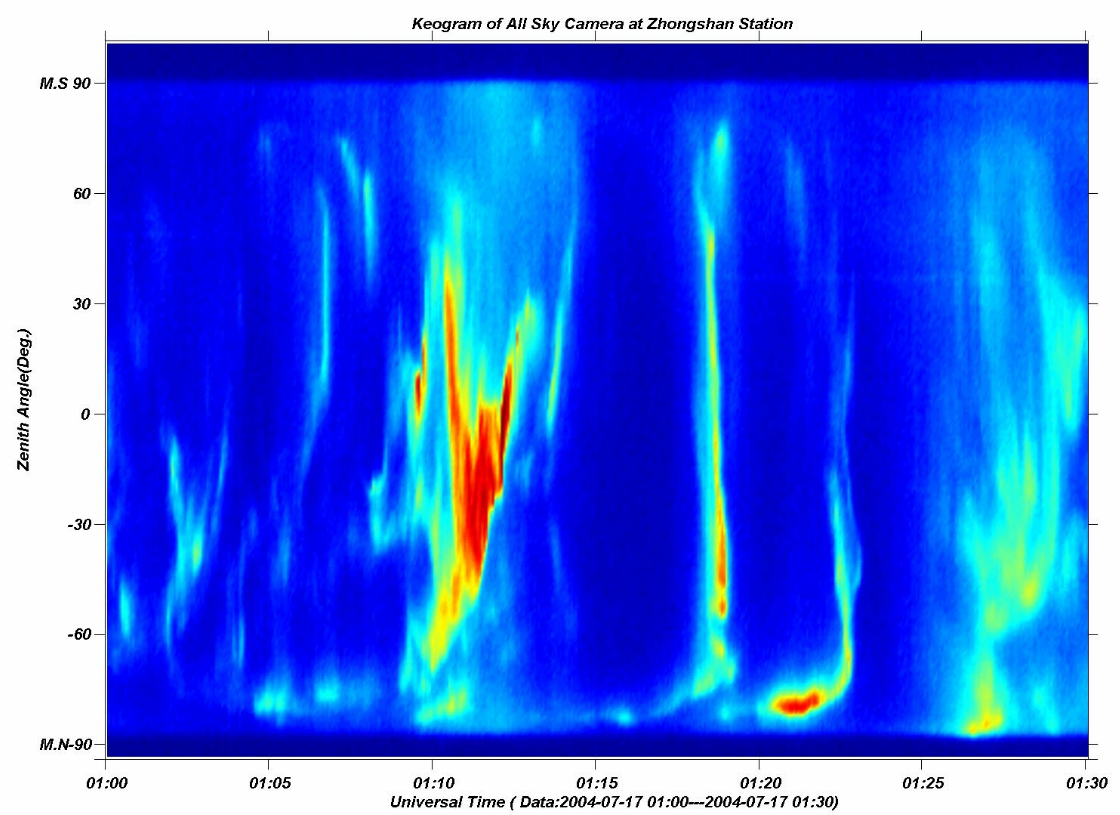

Fig. 3. The Keogram derived from the all-sky TV camera at Zhongshan Station during 01:00–01:30 UT on 17 July 2004.

of China and the National Institute of Polar Research, Japan (Liu et al., 1999; Yamagishi et al., 2000). There is an 8×8 beam imaging riometer at Ny-Ålesund, which originally belonged to the Solar-Terrestrial Environment Laboratory of Nagoya University. The Polar Research Institute of China took over in August 2004. Figures 6a, b show the 64 antenna beam patterns at Zhongshan Station and at Ny-Ålesund, respectively (Nishino et al., 2000). Figure 7 is a line plot of absorption intensities for different imaging riometer channels at Zhongshan Station between 10:00 and 11:00 UT on 10 September 2002. The Cluster CL-1 spacecraft is in conjunction with it during the southern cusp crossing around 10:20 UT. The absorption has been normalized with respect to the quiet day levels so that the undisturbed trace would be horizontal lines. The beams have been arranged in sequence from east (lower trace) to west (upper trace). We concentrate on the central beam N4E4 in Fig. 7. It is shown that the absorption started at 10:13 UT and lasted until 10:30 UT. The time of the absorption peak is different for different beams. Assuming that the absorption occurred at an altitude of 90 km, an eastward velocity of 150 m/s is derived from time lags between the sequent traces in the figure.

The measurement instruments at the above six stations are in operation for regular observation and long-term monitoring. This makes it easy to do coordinated studies with satellite observation.

3 Occurrences of the conjunctions between Cluster/Double Star spacecraft and the ground stations

For the planning and the selection intervals of coordinated studies it is necessary to predict/calculate conjunctions between the spacecraft and the ground station. In a statistical assessment the satellite orbit was projected into the Northern/Southern Hemispheres along magnetic field lines. We assume that the conjunction happens when the geographic latitude difference (absolute value) is less than 5° and the geographic longitude difference (absolute value) is less than 15° between the satellite footprint and the ground station. This means the time deference is less than 1 h and the distance (in north–south direction) less than 500 km. The Tsyganenko 96 model was adopted in the calculation of magnetic field lines (Tsyganenko and Stern, 1996). In the model the input parameters P_{sw}, D_{st}, IMF B_y and IMF B_z are taken as 2.0 nPa, 0 nT, 0 nT, 0 nT, respectively.

We have calculated all the conjunctions between the Double Star TC-1 spacecraft and ZHS/NAL from 2 January 2004 to 31 July 2005, between the Double Star TC-2 spacecraft and ZHS/NAL from 16 June 2004 to 31 July 2005, and between the Cluster CL1 spacecraft and ZHS/NAL from 15 August 2000 to 31 July 2005. Statistical results are shown in Table 3, in which the times that each spacecraft (TC-1, TC-2 and CL-1) is in conjunction with ZHS/NAL are listed

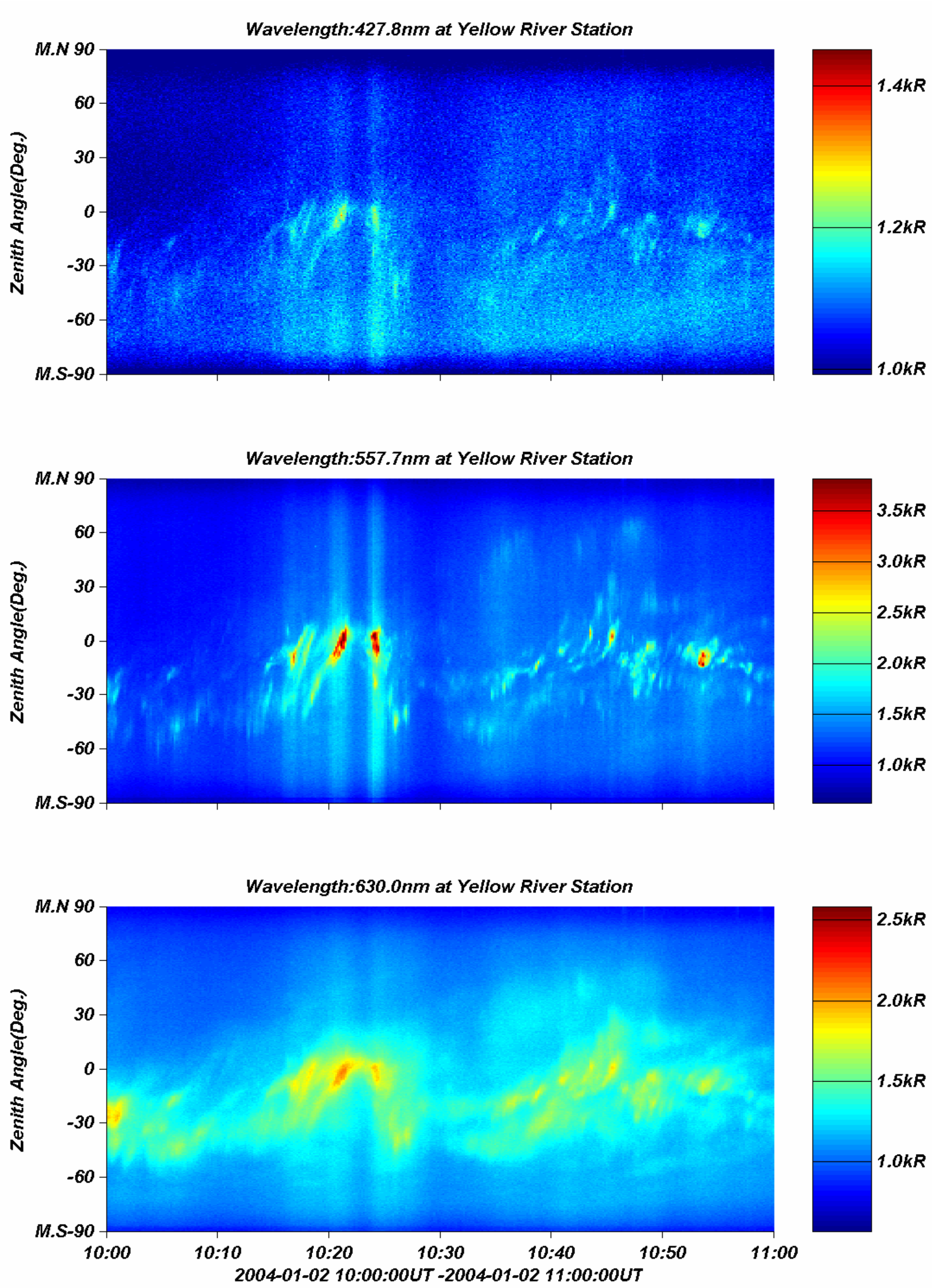

Fig. 4. The Keograms derived from 3 sets of CCD all-sky imagers at Yellow River Station in Ny-Ålesund during 10:00–11:00UT on 2 January 2004.

according to magnetic local time. The occurrence of the conjunctions is shown between the ground-based instruments and the spacecraft. For example, the TC-2 spacecraft has a short orbital period (about two cycles a day around the Earth), having more of a chance to be in conjunction with ground stations. An example of the detailed results is shown in Table 4, in which the times of the conjunctions between the TC-1 spacecraft and ZHS are listed according to different magnetic local times and different months. Although the total number of conjunctions is not small, for a special configuration the number of conjunctions is limited and usually concentrated in a few months. For example, the magnetic noon

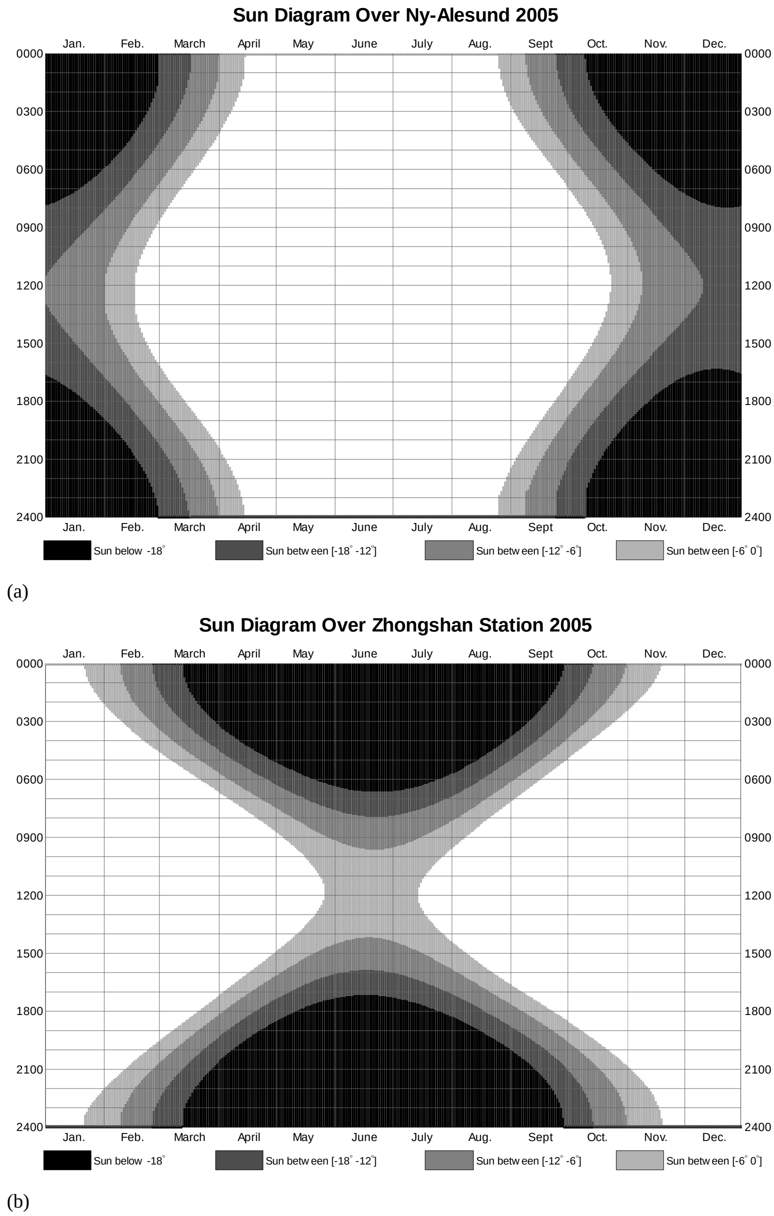

Fig. 5. The Sun diagram over **(a)** Ny-Ålesund and **(b)** Zhongshan Station.

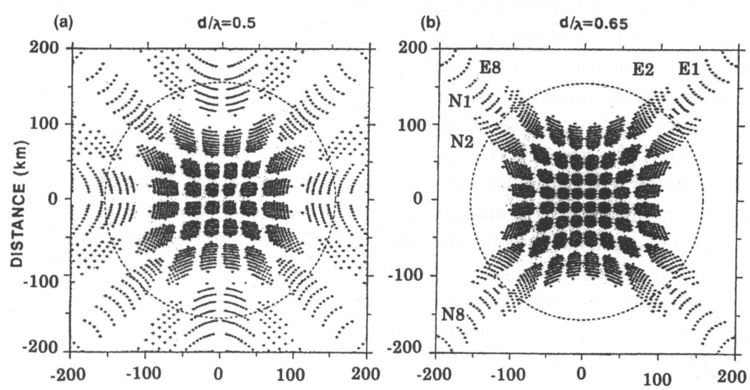

Fig. 6. The projection of a half-power width of the 64 antenna beams onto an ionospheric absorption altitude of 90 km. The patterns are shown for **(a)** 0.5 wavelength spacing at Zhongshan station and **(b)** 0.65 wavelength spacing at Ny-Ålesund station.

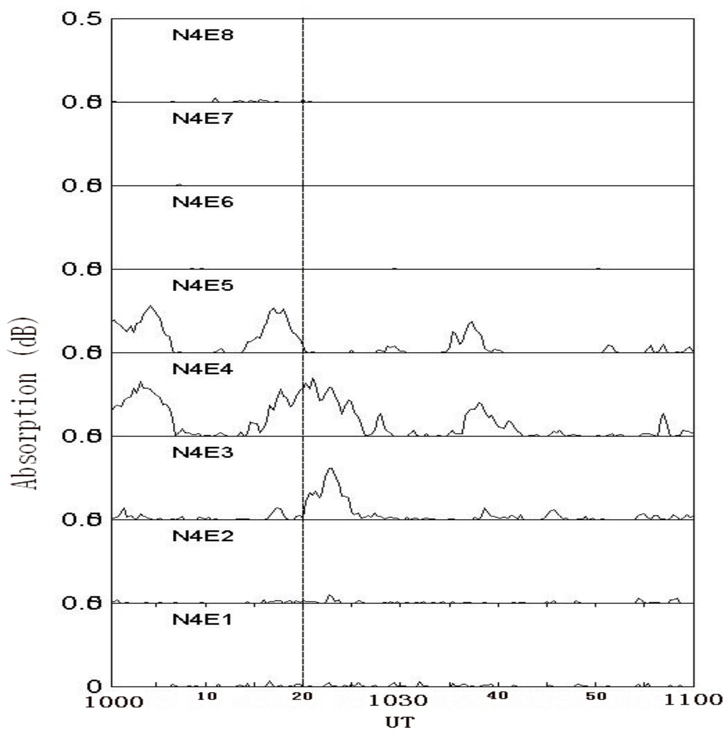

Fig. 7. Absorption intensities for different imaging riometer channels at Zhongshan Station between 10:00 and 11:00 UT on 10 September 2002.

Table 3. The times that each spacecraft (TC-1, TC-2 and CL-1) is in conjunction with ZHS/NAL, listed according to magnetic local time.

	MLT	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Times	N_1	3	4	9	18	24	22	28	25	29	32	36	29	21	18	21	16	15	14	12	7	9	8	8	5
	N_2	7	14	22	25	49	41	36	26	26	33	39	32	30	26	21	22	28	28	39	31	40	14	17	4
	N_C	41	62	51	50	48	52	53	62	58	66	65	55	29	37	45	43	42	46	55	61	51	54	47	43
	N_1*	0	0	0	0	2	9	18	20	22	21	23	19	8	4	13	13	8	9	6	8	2	0	0	0
	N_2*	5	4	8	13	18	31	26	18	23	21	18	16	19	17	15	14	20	22	24	16	26	17	20	9
	N_C*	24	22	35	35	43	44	36	42	43	35	43	34	23	17	29	32	40	32	37	42	46	33	28	26

Notes: N_1 (N_1*): Times that DS TC-1 is in conjunction with ZHS (NAL) from 2 Jan 2004 to 31 July 2005.
N_2 (N_2*): Times that DS TC-2 is in conjunction with ZHS (NAL) from 16 June 2004 to 31 July 2005.
N_C (N_c*): Times that Cluster CL-1 is in conjunction with ZHS (NAL) from 15 Aug 2000 to 31 July 2005.

(12:00 MLT) conjunction (suitable for coordinated studies of cusp phenomena) frequently happens in spring and does not happen in the later half year; the total number of 12:00 MLT conjunctions is 42 times in one year.

From the prediction of the conjunctions between the spacecraft and the ground station, we can select intervals of a special configuration for coordinated studies. For example, all TC-1, TC-2 and CL-1 spacecraft will make a magnetic noon conjunction with ZHS/NAL around 11:00 UT on 25 February 2005. Figures 8a, b show the footprints of the spacecraft orbit in the Northern and Southern Hemispheres on that day.

4 Summary and concluding remarks

Ground-based observations can be used to provide important support for Cluster/Double Star data and greatly enhance the mission's scientific return. There are six Chinese ground stations involved in coordinated observations with Cluster/Double Star spacecraft. The location and instrumentation of these stations are presented in the paper. Among them, Zhongshan Station in Antarctica and Yellow River Station on Svalbard are magnetic conjugated and situated under the ionospheric projection of magnetic cusp regions, which, combined with satellite measurements, provide a perfect configuration to study cusp phenomena.

Table 4. The times of conjunctions between TC-1 spacecraft and ZHS, listed according to different magnetic local times and different months.

	MLT	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Month	1	0	0	0	0	0	0	0	0	0	0	0	0	4	6	10	8	6	3	1	0	0	0	0	0
	2	0	0	0	0	0	0	0	0	0	1	3	4	9	12	15	11	7	3	1	0	0	0	0	0
	3	0	0	0	0	0	0	0	1	3	5	8	11	11	10	7	3	1	0	0	0	0	0	0	0
	4	0	0	0	0	0	0	1	3	9	13	17	17	10	5	2	0	0	0	0	0	0	0	0	0
	5	0	0	0	0	0	1	5	8	17	20	22	17	6	1	0	0	0	0	0	0	0	0	0	0
	6	0	0	0	2	6	15	17	15	19	18	16	8	2	0	0	0	0	0	0	0	0	0	0	0
	7	0	2	6	16	24	21	23	16	9	7	6	1	0	0	0	0	0	0	0	0	0	0	0	0
	8	2	4	9	16	18	7	10	7	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	9	3	2	3	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3	5
	10	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	5	6	8	5
	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	7	6	9	7	5	0
	12	0	0	0	0	0	0	0	0	0	0	0	0	0	1	4	5	8	11	11	6	4	2	0	0

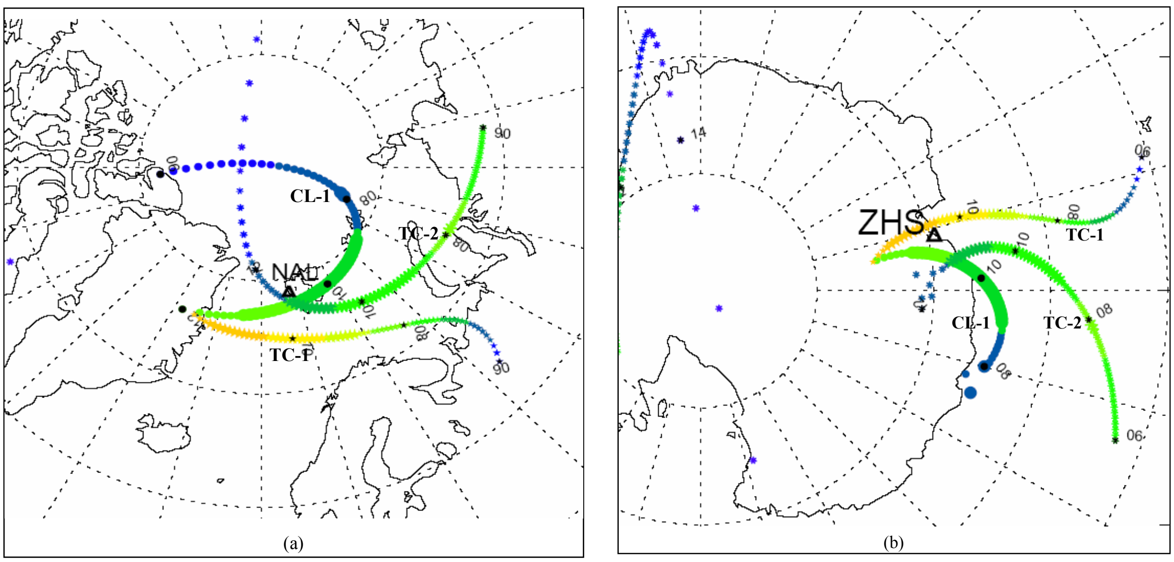

Fig. 8. Locations of the footprints of TC-1, TC-2 and CL-1 spacecraft in **(a)** the Northern Hemisphere and **(b)** the Southern Hemisphere, respectively, during 06:00–18:00UT on 25 February 2005.

The restrictions applying to the optical sites are discussed. Ny-Ålesund is very suitable to observe cusp aurora while Zhongshan Station is suitable to observe post-noon aurora. The Zhongshan-Ny-Ålesund pair would provide more of a chance to do coordinated observations with spacecraft. Samples of data production are given to illustrate the potential use of these instrumentations in coordination with Cluster/Double Star measurements.

Statistical results show that, although the total number of conjunctions between Cluster/Double Star and ground stations is not small, for a special configuration the number of conjunctions is limited and concentrated in a few months. It is expected that the Double Star complemented to the Cluster spacecraft will provide a good opportunity for coordinated satellite and ground-based observations and further studies of the magnetosphere-ionosphere coupling system.

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