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The auroral occurrence over Zhongshan Station, Antarctica

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Abstract The auroral data observed by all sky TV camera during 1995 and 1997 at Zhongshan Station of Antarctica are used to analyze the statistic characteristics of the aurora over Zhongshan Station. Around postnoon (1200 - 1600 UT) and midnight (2000 - 0100 UT), the aurora appears more frequently and stronger than those in evening (1600 - 2000 UT). The corona type auroras mainly occur at poleward and overhead of Zhongshan Station during postnoon and around midnight. The band type auroras mainly appear during postnoon, while during evening and around midnight only appear at equatorward. The active surges mostly appear around midnight, while the transpolar arcs mainly occur after midnight. Except for the transpolar arcs, the occurrences of the other three type auroras are related with Kp index. Usually Zhongshan Station enters the auroral oval at postnoon, the exact time depends on Kp index.

Key words aurora, auroral occurrence, Kp index, Antarctica, Zhongshan Station.

1 Introduction

Zhongshan Station is located at 69°22′24″S, 76°22′40″E, where aurora observation started in 1995. The magnetic coordinate of this station is 77.2°S, 120.5°E, invariant latitude is about 75°S, L=13.9, and corrected magnetic latitude is also about 75°S (Liu *et al.* 1997). The local time at Zhongshan Station is 5 h plus the universal time, and the magnetic local time is about 2 h plus the universal time. The midnight sun lasts at Zhongshan Station for 54 d, while the number of days with "Polar night" is approximately 58 d. Zhongshan Station is situated under the ionospheric projection of the magnetospheric cusp region at noon, and in the polar cap region at midnight, twice passing through the auroral oval during a day (Liu and Lü 1998). Particularly the dayside aurora is observable there during mid-winter. Therefore Zhongshan Station is a unique ground base for studying important problems related to auroral physics (Hu 1999), especially for postnoon aurora (Makita *et al.* 1998).

Statistic analysis has been made with the auroral data taking from the all sky TV camera at Zhongshan Station for the years of 1995 and 1997. The number of effective

observing day is 149 altogether. Four types of aurora are mainly observed. They are corona aurora, band aurora, active surge and transpolar aurora arc. Typical all sky pictures of the aurora are shown in Fig. 1, and Fig. 1(a) - (d) refer to corona, band, active surge and transpolar arc respectively. The time range is limited in 1200 - 0200 UT with an interval of half an hour in the statistic analysis. The space range is divided into three parts: overhead (zenith angles between 30° south and 30° north), poleward side (zenith angles between 30° and 70° south) and equatorward side (zenith angles between 30° and 70° north). In this paper, four geomagnetic situations are considered, they are all cases, $Kp \leqslant 1$, $1 < Kp \leqslant 2$, and $Kp > 2$.

2 Statistic results

Fig. 2 - 5 present the auroral occurrence over Zhongshan Station for all cases, for

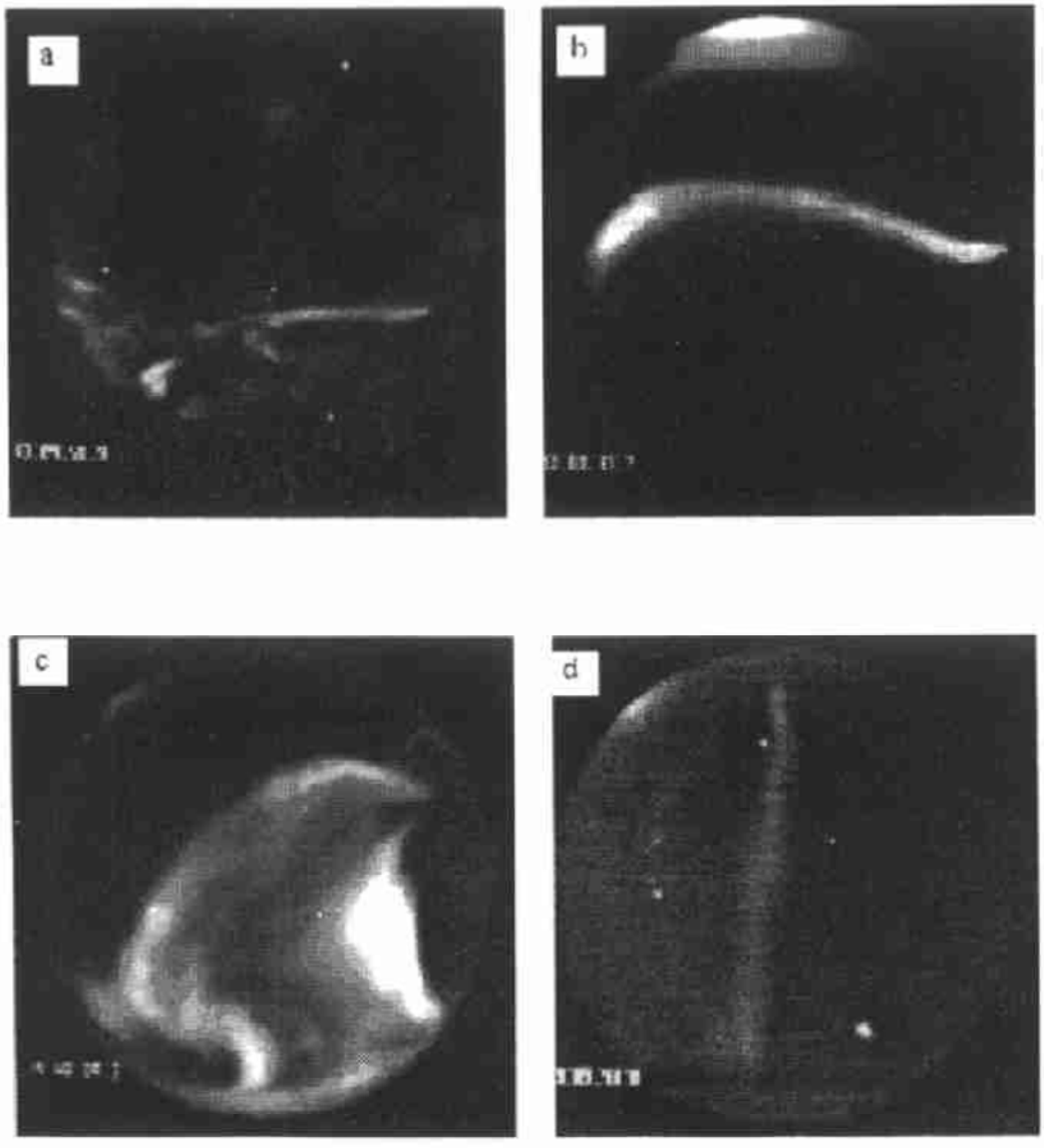

Fig. 1. Four kinds of typical aurora observed at Zhongshan Station, Antarctica. (a)corona; (b)band; (c)active surge; (d)transpolar arc.

$Kp \leqslant 1$, $1 < Kp \leqslant 2$, and $Kp > 2$ respectively. Each figure has (a), (b), (c), (d) four plates, demonstrating auroral occurrence over all sky view field, occurrences of various kinds aurora at poleward, at overhead and at equatorward of Zhongshan Station respectively. In each plate, abscissa refers to universal time in hour; ordinate refers to auroral occurrence. The capital S, W, and N represent auroral intensity strong, weak and no aurora respectively. While capital T, A, B, and C represent transpolar arc, active surge, band and corona respectively.

2.1 For all cases

As shown in Fig. 2(a), during the whole dark period, the aurora is possible to be observed at Zhongshan Station. During 1200 - 1600 UT (local magnetic postnoon) and during 2000 - 0100 UT (around local magnetic midnight), the aurora occurs most frequently. Particularly, during 1300 - 1400 UT period and at midnight, the occurrences are about 90% and 80% respectively. During 1600 - 2000 UT period the aurora occurs less, with an occurrence of 65%.

Fig. 2(a) also shows that the diurnal variation of the intensified aurora occurrence has two peaks. One peak locates in postnoon sector (1200 - 1400 UT), another at midnight (2000 - 0000 UT). It is shown that there are often gaps between dayside aurora and nightside aurora. The first peak is related to passing through aurora oval in postnoon and the second one is owing to the poleward expansion during auroral substorms around midnight.

Fig. 2(b) describes the occurrence for different type of aurora at poleward of Zhongshan Station. It shows that, at poleward of Zhongshan Station, the aurora occurs more frequently in postnoon sector (1200 - 1600 UT) than in midnight sector. At 1230 UT, the aurora occurrence reaches 60%, while at midnight it is only about 45%. In evening sector (1600 - 1900 UT), the auroral occurrence is 20%. In postnoon sector, the band and the corona occur more frequently than the other two. The corona often occurs near magnetic noon, while the band appears most frequently during 1330 - 1400 UT, reaching 45%. In the same period, the active surge occurs very few, and the transpolar arc is hardly seen. In evening sector, the corona appears few, the transpolar arc appears sometimes, with the band occurrence decreasing, while occurrence of the active surge increasing. In midnight sector, the active surge is dominant, reaching 30%. In addition, the band, the corona and the transpolar arc appear sometimes.

Fig. 2(c) gives the auroral occurrence overhead of Zhongshan Station, which demonstrates that the aurora overhead occurs more frequently than those at poleward of Zhongshan Station, and the occurrence overhead has a similar diurnal variation with that at poleward. The main differences lie in the facts that the corona still often appears in late postnoon, and the band always appears more frequently, especially after midnight. The peak of the postnoon band delays to 1500 UT. The occurrence of midnight active surge increases apparently, reaching 35% at 2200 UT.

Fig. 2(d) shows that the auroral occurrence at equatorward of Zhongshan Station is quite different from poleward and overhead situations. Comparing with the aurora occurring poleward and overhead of Zhongshan Station, the equatorward aurora appears with a different diurnal variation. Before midnight (2200 UT), the equatorward auroral

occurrence increases with time, while after midnight it decreases. The corona appears less in postnoon sector apparently. Although in postnoon sector the band occurrence increases slowly and reaches its peak at 1500 UT, its change is not so dramatic. While the transpolar arc appears less, and the equatorward active surge occurrence is similar with the overhead.

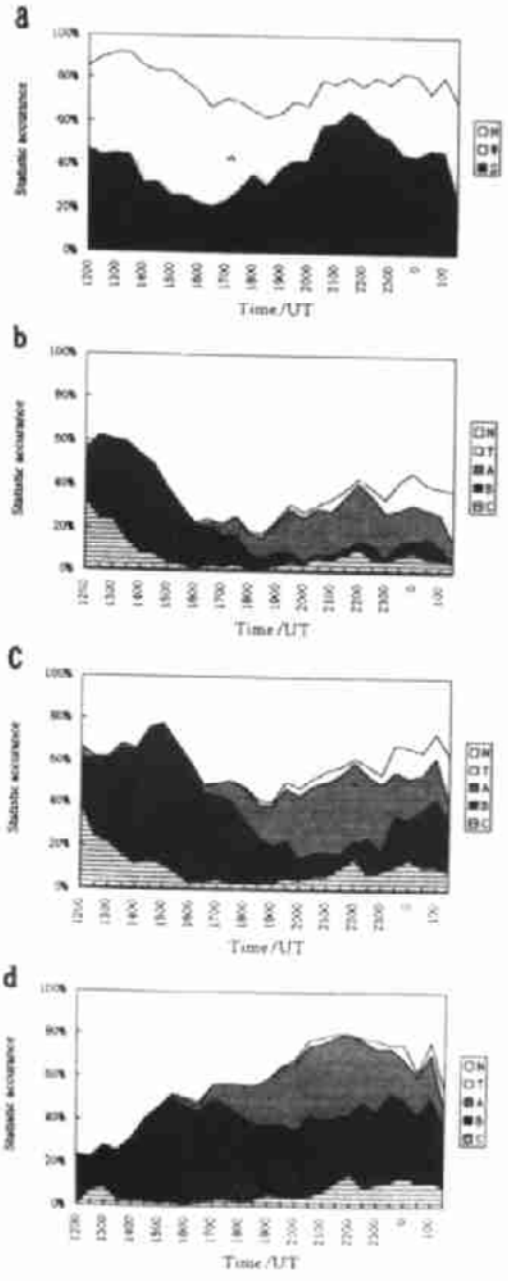

Fig. 2. Aurora statistic appearance over Zhongshan Station, Antarctica. (a) appearance in all sky scale; (b) appearance at the polarward; (c) appearance over the zenith; (d) appearance to the equatorward. (S: auroral intensity strong; W: weak; N: no; while T: transpolar arc; A: active surge; B: band; C: corona.)

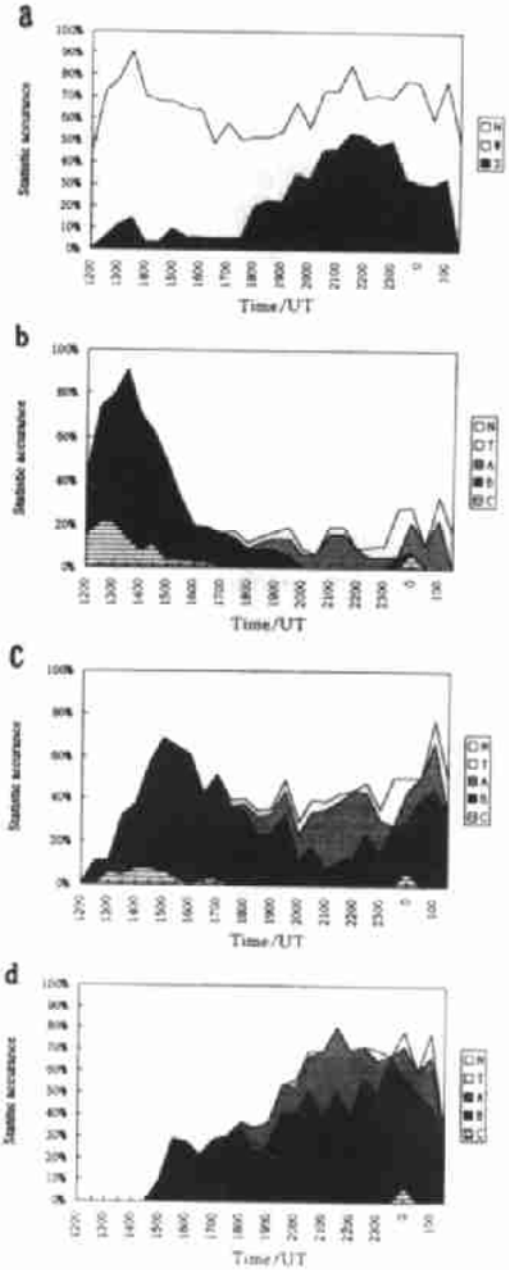

Fig. 3. Aurora statistic appearance over Zhongshan Station of Antarctica as $Kp \leqslant 1$. (a) appearance in all sky scale; (b) appearance at the polarward; (c) appearance over the zenith; (d) appearance at the equatorward.

2.2 For $Kp \leqslant 1$

As shown in Fig. 3(a), the auroral occurrence for $Kp \leqslant 1$ has a similar diurnal variation with that for all cases. In postnoon sector the aurora occurs most frequently, reaching 90% at 1330 UT. While the postnoon intensified aurora occurs few, only about 10%. In evening sector, the aurora occurs less than in postnoon, with 50% possibility. In midnight sector, the aurora appears frequently, reaching 80% at 2200 UT, and the intensified aurora also occurs apparently more than in postnoon, the peak occurrence reaches 55%.

Fig. 3(b) shows that, for $Kp \leqslant 1$ situation, the aurora at poleward of Zhongshan Station in postnoon sector is apparent more than that in evening sector. In postnoon sector, the auroral occurrence reaches 90% at 1330 UT, including 80% band and 10% corona. Such band occurrence is also the peak value for whole period. While the corona occurrence decreases with time in the postnoon. On the contrary, in evening sector, the corona appears few, and the band occurs less and less, while the active surge and the transpolar arc occurring possibilities increase. In midnight sector the auroral occurrence is similar to that in evening sector, with a value of 20%, but dominated by the active surge and the transpolar arc.

As illustrated by Fig. 3(c), for $Kp \leqslant 1$ situation, in postnoon sector the band is dominant at overhead of Zhongshan Station, while the corona is minority. At 1200 UT the aurora hardly could be observed at overhead of Zhongshan Station. From then on, the aurora appears more and more frequently, and reaches its peak occurrence of 70% at 1500 UT. The aurora occurring in evening sector is also less than the one in postnoon. In evening sector, the corona seldom appears. The transpolar arc mainly appears in the evening, and more frequently after local magnetic midnight. After midnight, the band occurrence also increases, while the active surge occurs more frequently in midnight sector.

Fig. 3(d) shows the occurring possibilities of four kind auroras at equatorward of Zhongshan Station for $Kp \leqslant 1$. It demonstrates that the aurora could not be observed during 1200 - 1500 UT period, and that the band can only be seen (30%) during 1500 - 1700 UT. Although the active surge occurrence increases to 30% at midnight, the band is still the majority in night sector. The transpolar arc appears sometimes in night sector, while the corona hardly can be observed during the whole period.

2.3 For $1 < Kp \leqslant 2$

Fig. 4(a) gives auroral occurrences in all sky field of Zhongshan Station for $1 < Kp \leqslant 2$. It shows that although the aurora appearing frequency and intensity in night sector for $1 < Kp \leqslant 2$ are similar to the ones for $Kp \leqslant 1$, in postnoon and evening sectors the auroral appearances are apparent different. The main differences lie in that the aurora appears more frequently for $1 < Kp \leqslant 2$, and the intensified auroral occurrence is apparent higher. During 1300 - 1330 UT, the aurora can be observed almost every day, the intensified aurora also occurs frequently (60%). In evening sector the aurora and intensified aurora appear less than those in postnoon and midnight sectors.

Fig. 4(b) shows the occurrences of four special types aurora appearing poleward of

Zhongshan Station for $1 < Kp \leqslant 2$. It demonstrates that the aurora occurs most frequently in postnoon sector, less in midnight sector, least in evening sector. In postnoon sector, the band and the corona are majorities, while the active surge is the minority. During 1200 - 1300 UT the aurora appears most frequently, reaching 70%. Among this the occurrence of corona reaches 40%. In evening sector, the active surge with an increasing tendency and the band with a decreasing tendency are dominant. In midnight sector, active surge is dominant, the other three appear less. After midnight, the active surge occurrence decreases, while the band and the transpolar arc increase.

As shown in Fig. 4(c), although the aurora occurrence at overhead of Zhongshan Station has similar characteristics with the poleward one, the former is higher than the latter during the whole period. Another apparent difference is that the postnoon peak moves form 1200 - 1230 UT to 1430 - 1530 UT.

From Fig. 4(d) it can be seen that the aurora occurrence for $1 < Kp \leqslant 2$ at equatorward of Zhongshan Station is quite different from the overhead and poleward. The occurrence increases slowly until reaching 80% at half an hour before midnight, and then decreases gradually. In postnoon sector, the band is dominant; the corona and the active surge are seldom appears, while the transpolar arc is hardly observed. In evening sector, the aurora occurrence increases instead of decreases, the band and the active surge are dominant, and the active surge with an increase tendency. In midnight sector, the active surge and the band are majorities, while the corona and the transpolar arc are minorities.

2.4 For $Kp > 2$

Fig. 5(a) illustrates that the aurora occurrence over Zhongshan Station for $Kp > 2$ has a similar characteristics to the one for $1 < Kp \leqslant 2$. The apparent differences lie in that the former is higher than the latter during whole period, and that the postnoon peak shifts from 1300 - 1330 UT to 1200 - 1300 UT.

Fig. 5(b) demonstrates that the aurora occurrence at poleward of Zhongshan Station for $Kp > 2$ has different characteristics in different time period. In postnoon sector, the auroral appearing frequency is apparent lower than that for $1 < Kp \leqslant 2$, especially for the band. In evening sector, the auroral occurrence looks like M shape curve, which is more frequently than that for $1 < Kp \leqslant 2$. At meanwhile, the corona appears sometimes. In midnight sector, the aurora occurs apparent more frequently than that for $1 < Kp \leqslant 2$, especially for the corona and the active surge.

Fig. 5(c) shows that the aurora appearance at overhead of Zhongshan Station for $Kp > 2$ is similar to that for $1 < Kp \leqslant 2$. The main differences lie in that the auroral occurrence in postnoon sector is greater than the one for $1 < Kp \leqslant 2$, especially for the corona, and that the postnoon peak moves up. In evening sector, the corona appears sometimes. In midnight sector, the aurora appearing possibility increases apparently, especially for the corona and the active surge.

Fig. 5(d) demonstrates that, except for the active surge, the auroral appearance for $Kp > 2$ at equatorward of Zhongshan Station is apparent different from the poleward and the overhead. The postnoon aurora occurs less than that in evening or at midnight, dominated by the band and the corona. In evening and midnight sectors, any type aurora

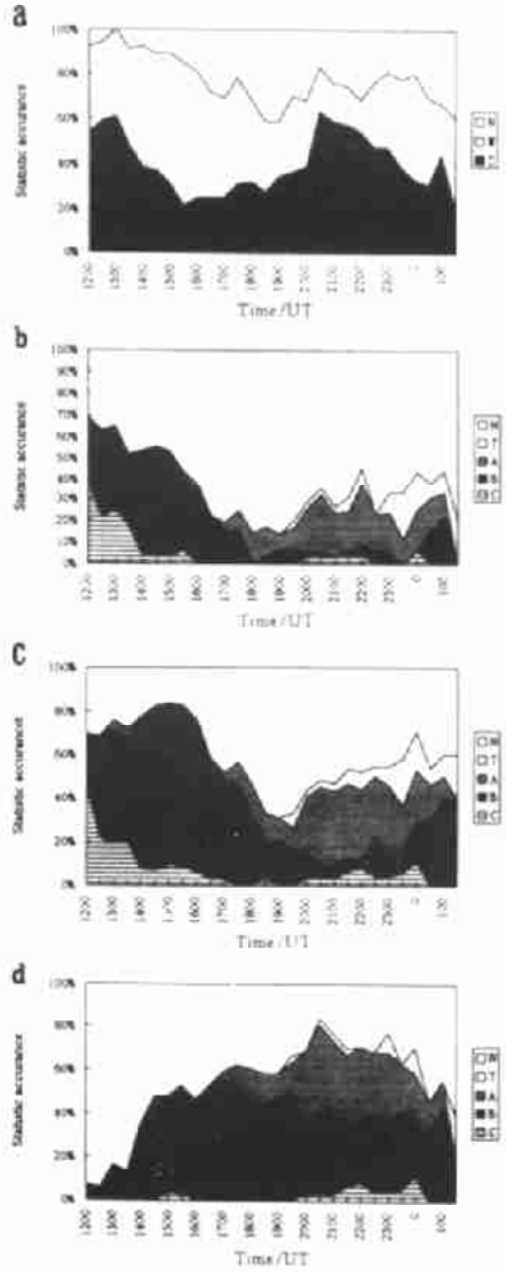

Fig. 4. Aurora statistic appearance over Zhongshan Station of Antarctica as $1 < Kp \leqslant 2$. (a) appearance in all sky scale; (b) appearance to the polarward; (c) appearance over the zenith; (d) appearance to the equatorward.

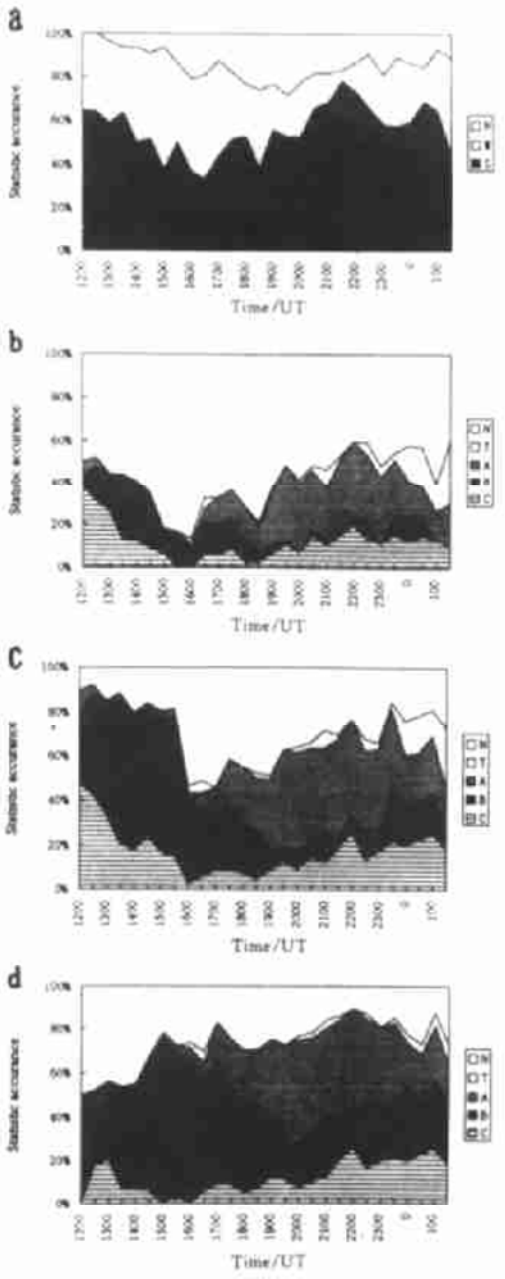

Fig. 5. Aurora statistic appearance over Zhongshan Station of Antarctica as $Kp > 2$. (a) appearance in all sky scale; (b) appearance to the polarward; (c) appearance over the zenith; (d) appearance to the equatorward.

may occur; however, the band is more frequent for the former sector, while the active surge is dominant for the latter sector.

3 Summary and discussion

In summary, the statistic results can be described as follows:

(1) The diurnal variation of auroral occurrence (for both weak and strong one)

has two peaks, which is similar to the result that Cao (1986) obtained from the aurora observation at Davis Station, a station about 100 km apart from Zhongshan Station. One peak locates in postnoon sector (1200 - 1600 UT), and the other in midnight sector (2000 - 0100 UT). It is shown that there are often gaps between dayside aurora and nightside aurora. The first peak is related to passing through aurora oval in postnoon and the second one is owing to the poleward expansion during auroral substorms around midnight. The gap between dayside and nightside suggests that along auroral oval exist two auroral centers.

(2) The occurrence for different type of aurora is similar with results we got in case studies (Hu *et al.* 1999a; 1999b). The corona aurora mainly occurs in postnoon and midnight sectors. The band aurora mainly occurs in postnoon sector, equatorward side of evening and equatorward of midnight. But the active surge mainly occurs in midnight and the transpolar arc in midnight too.

(3) The relative ratios occurrence (absolute occurrence in brackets) in different time sectors are listed in Table 1, which shows the percentages of each type of aurora in different time sectors and different space ranges. It can be seen from the table that in postnoon the band aurora is dominant (75%), the corona aurora is the second (22%), there is no transpolar aurora arc observed. In evening sector the occurrence of band aurora is the first (65%), the active surge is the second (25%), and the transpolar arc is the lowest (3%). In midnight sector the active surge is dominant (52%) although the band aurora and transpolar arc sometimes occur.

Table 1. Percentages of occurrences for each type of aurora(%)

	Postnoon (1200 - 1600 UT)			Evening (1600 - 2000 UT)			Midnight (2000 - 0100) UT		
Auroral type	Poleward	Zenith	Equatorward	Poleward	Zenith	Equatorward	Poleward	Zenith	Equatorward
Corona	25(12)	22(16)	8(3)	9(2)	7(4)	5(3)	19(7)	16(9)	12(9)
Band	74(37)	75(52)	90(32)	48(11)	65(32)	71(40)	9(3)	22(13)	45(34)
Active surge	1(0)	2(2)	2(1)	37(9)	25(12)	23(13)	57(21)	52(30)	40(30)
Transpolar arc	0(0)	0(0)	0(0)	6(1)	3(1)	1(0)	15(6)	10(6)	3(2)
No aurora	(50)	(31)	(64)	(77)	(51)	(44)	(61)	(42)	(24)

(4) Location of Zhongshan Station relative to the auroral oval is verified. The auroral occurrence in poleward side, overhead and equatorward side as shown in Fig. 2 (b), (c) and (d) are compared. It can be seen that before 1230 UT the occurrence in poleward side is the largest and the occurrence in equatorward side is the smallest, indicating that Zhongshan Station is located in low latitude edge of the dayside auroral oval. In afternoon sector the occurrence in poleward become smaller and smaller, the occurrence in overhead increase first then decrease and the occurrence in equatorward become larger and larger as time goes on, indicating that Zhongshan Station passes through auroral oval in the afternoon. Zhongshan Station is under the auroral oval at about 1500 UT, then goes into the inner side of the auroral oval. In evening and midnight sector the occurrence of aurora in poleward is the smallest and the occurrence in equatorward is the largest, indicating that Zhongshan Station is located in polar cap or in the polar edge of the aurora oval at that time.

(5) Auroral occurrence depends on geomagnetic activity level. Comparing statistic results for different Kp conditions, it shows that the auroral occurrence over Zhongshan

Station is closely related with Kp, the transpolar arc is the only exception. When Kp is small, the corona only occurs in postnoon sector at poleward and overhead of Zhongshan Station infrequently. As Kp increases, the corona may appear in all time sectors, and its occurrence increases, especially in postnoon and midnight sectors. The smaller Kp, the more band occurs at poleward of Zhongshan Station in postnoon sector, the less band appears at equatorward in postnoon and evening sectors, the more band occurs at equatorward in midnight sector. The larger Kp, the more active surge occurs in evening and midnight sectors. The aurora intensity also related with Kp. As Kp increases from $Kp \leqslant 1$ to $Kp > 2$, the intensified auroral occurrence increases from 10% to 60%.

(6) Location of Zhongshan Station relative to auroral oval depends on geomagnetic activity level. Comparing different statistic results for different Kp, it can be seen that the position where Zhongshan Station passing through the oval in the postnoon is apparent related to Kp. As $Kp \leqslant 1$, before 1330 UT the aurora occurrence at poleward is apparent higher than the overhead, at meanwhile in equatorward side no aurora occurs, which suggests that Zhongshan Station locates at equatorward of the auroral oval. As $1 < Kp \leqslant 2$, at about 1200 UT, the auroral occurrence at poleward is almost equal with the overhead, and the aurora appears less at equatorward, and from then on, the aurora occurring at poleward decreases, while the one appearing overhead and equatorward increases. Which shows that at that time Zhongshan Station locates at equatorward side of auroral oval. As $Kp > 2$, at 1200 UT, the auroral occurrence overhead is higher than the equatorward and the poleward, which demonstrates that Zhongshan Station is just under the oval at that time. The reason why relative position of Zhongshan Station depends on Kp lies in the fact that as Kp increasing the auroral oval expands from lower latitude to higher latitude. In midnight sector, as Kp increasing, the auroral occurrence over Zhongshan Station increases, indicating that the auroral oval spreads to higher latitude.

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