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A comparative study on the ionospheric current systems in the Antarctic and Arctic regions*

Xu Wenyao (徐文耀)
Institute of Geophysics, Academia Sinica, Beijing 100101, China

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Abstract The current systems representing the solar and lunar daily variations (S and L) of the geomagnetic field have been calculated on the basis of the date obtained from the global network of geomagnetic observatories. The characteristics of these current systems in the Antarctic and Arctic regions have been analysed comparatively. The results show that: (1) There are certain differences in the current systems of these two regions, that implies definite differences in the ionospheric dynamo process, responsible for both S and L, and the field-aligned current, responsible for S. The differences of the magnetic field structure in these two polar regions may be the basic reason of the above-mentioned differences. (2) There are remarkable differences in the internal current systems of these two polar regions, that is attributed to both the inducing field (current) and the underground conductivity. In general, the conductivity of the Antarctic region is higher than that of the Arctic region.

Key words polar region, geomagnetic field, current system, conductivity.

1 Introduction

The differences between the Antarctic and Arctic regions are clearly exhibited in their geographic and geophysic characteristics: Antarctica is a continent circled by seas and oceans, while the Arctic region is an ocean bounded by continents. The latitudinal distance between the magnetic and the geographic poles is 24° in Antarctica, instead of 15° in the Arctic region. The structure of the main magnetic field is also different in these two regions, as shown in Fig. 1 (Johnson, 1965).

Solar daily variation S and luner daily variation L in the earth magnetic fields are created by the ionospheric dynamo current systems driven by tidal winds and their induced current systems within the earth (Chapman and Batels, 1940). The dynamo processes in the ionosphere depend upon three factors: the earth magnetic field, tidal winds and the ionospheric conductivities. The conducitvities are closely related with the magnetic field. It is expected that the significant differences of the magnetic field in the Antarctic and Arctic regions should lead to different current systems in the polar regions. Besides, the magnetic field lines from the polar regions extend to far magnetotail instead

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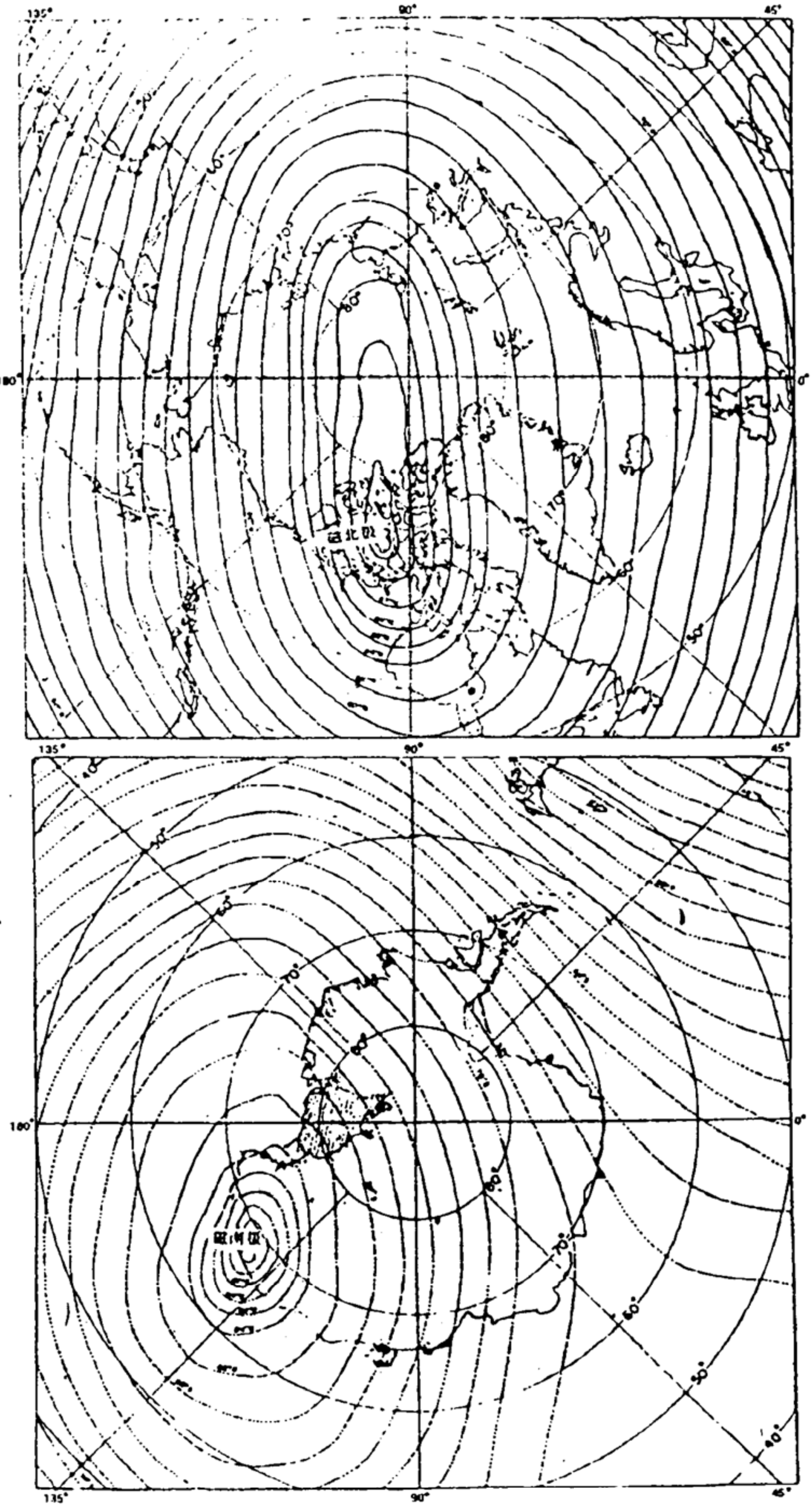

Fig. 1. Isoclinals in the polar regions for 1960.

of connecting with each other as at mid-low latitudes. In this case, the dynamo-induced static electric fields are hardly neutralized by field-aligned coupling, consequently, the differences between both polar regions can be maintained.

The field-aligned currents in the auroral zones contribute largely to the magnetic solar variation in the polar regions. Different magnetic configurations in the polar regions will affect the field-aligned current distributions, that may be one of the reasons causing differences of S current systems.

In this paper, comparative study method is used to analyse the spatial and temporal characteristics of S and L current systems in both polar regions. The obtained results will help us to understand the differences of geophysical fields and their physical mechanisms.

2 Characteristics of the external currents S^{pe} in the polar regions

The magnetic data at 100 stations during IGY / IGC are used in this paper (Gupta and Chapman, 1968). External equivalent ionosphreic current system S^e and induced current system S^i within the earth are calculated for different seasons and yearly average. The height of the ionosphere is assumed to be 120km. It should be pointed out that the data on all days through the year are used, thus obtained solar daily variations (denoted by S) include the contributions from magnetic disturbances. At mid and low latitudes, the S variation is almost equivalent to S_q, but at high latitudes they have some differences.

In order to get an overall concept of S^e current system, the yearly average S^e current system and S^{pe} current system after removing the mid-low latitude part of S^e are shown in Fig2, in which the top panels are for northern hemisphere, the bottom for southern hemisphere, and the geomagnetic latitude-local time coordinate system is used.

The global current S^e is the summation of two parts:

$$S^e = S^{oe} + S^{pe}$$

Where S^{oe} represents the current system at mid and low latitudes, decreasing smoothly to the geomagnetic pole. S^{pe} represents the polar region currents. The basic characteristic of S^{oe} is that there is one mid-low latitude current vortex on each hemisphere. The center of the vortex is located at 30° latitude and near noon. The principal features of S^{pe} in the Arctic region are two oppositely convecting current vortexes with clockwise direction at morning side and counterclockwise direction at afternoon side. In the Antarctic region the current directions are opposite to those in the Arctic region. In one word, the polar cap currents flow toward the sun. These currents can be simply described by the total polar cap current between two foci of the current vortexes and its dirrection.

Fig. 2 shows clearly the importance of S^{pe} in the global current system and the differences of S^{pe} in the Antarctic and Arctic regions:

(1) The total polar cap current is about 260 kA (or 215 kA) in the Arctic (or Antarctic) regions.

(2) The polar cap currents in northern hemisphere flow toward the sun, while in southern hemisphere only the central part of the polar cap currents directs to the sun,

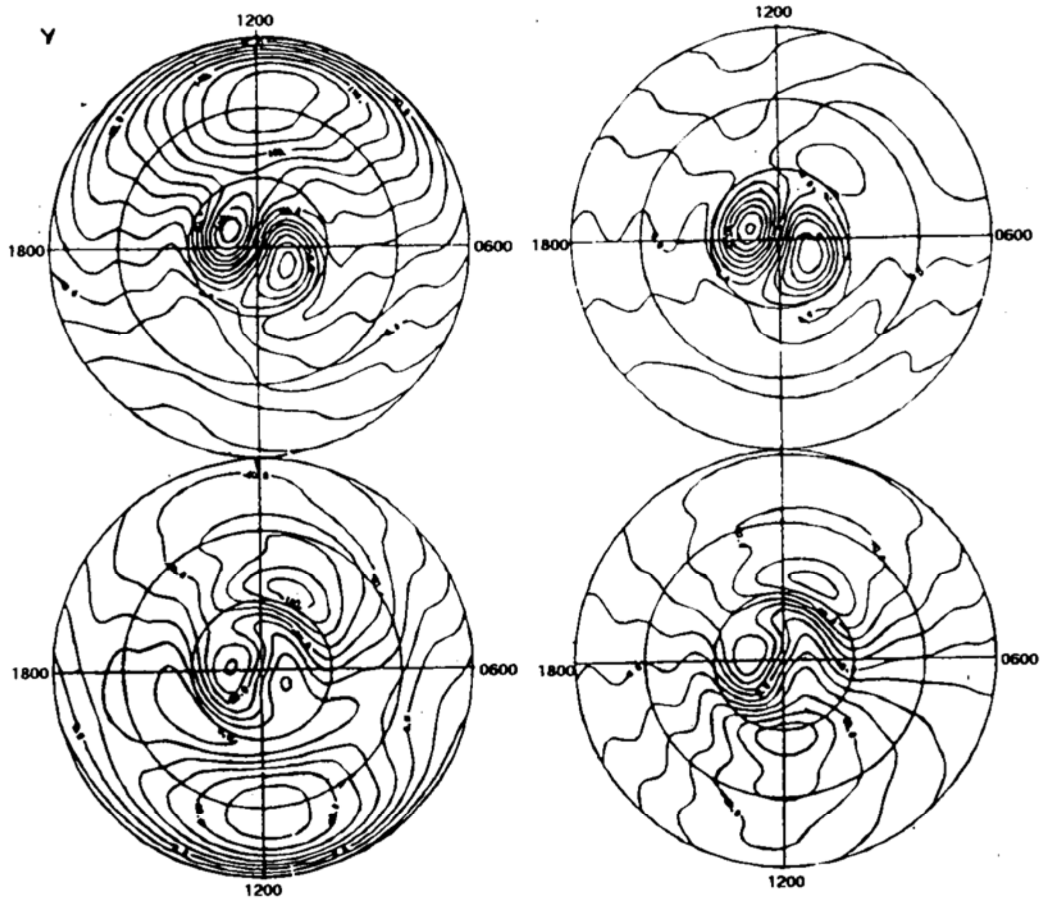

Fig. 2. Global current systems S^{q} (a) and polar region current systems S^{pc} (b). Top panels are for northern hemisphere, bottom for southern hemisphere. Three circles represent 0°, 30° and 60° geomagnetic latitudes, contour interval is 20 kA.

other part of the currents changes gradually in the direction.

(3) The two-vortex construction of the polar region currents is regular in the Arctic region with the vortex centers near the dawn-dusk meridian. However, a remarkable distortion of the current pattern appears in the Antarctic region. Especially, the morning vortex center shifts to near midnight and −60° latitude.

The S^{pc} current systems in both hemispheres for different seasons are illustrated in Fig. 3 for comparison. From local winter to local summer S^{pc} currents in northern hemisphere become stronger and stronger , the direction of the polar cap currents turns from toward forenoon to toward noon. In southern hemisphere the intensity of S^{pc} currents show the same seasonal variation as in northern hemisphere, but the current direction varies in opposite way. The characteristic values of the currents are listed in Table 1.

3 Characteristics of the external currents L^{pc} in the polar regions

The ionospheric L current system is produced by dynamo process of lunar tide. As the S currents, the L current system can be divided to two parts: the mid-low latitude currents L^{o} and the polar region currents L^{p}. The semidiurnal component is most import-

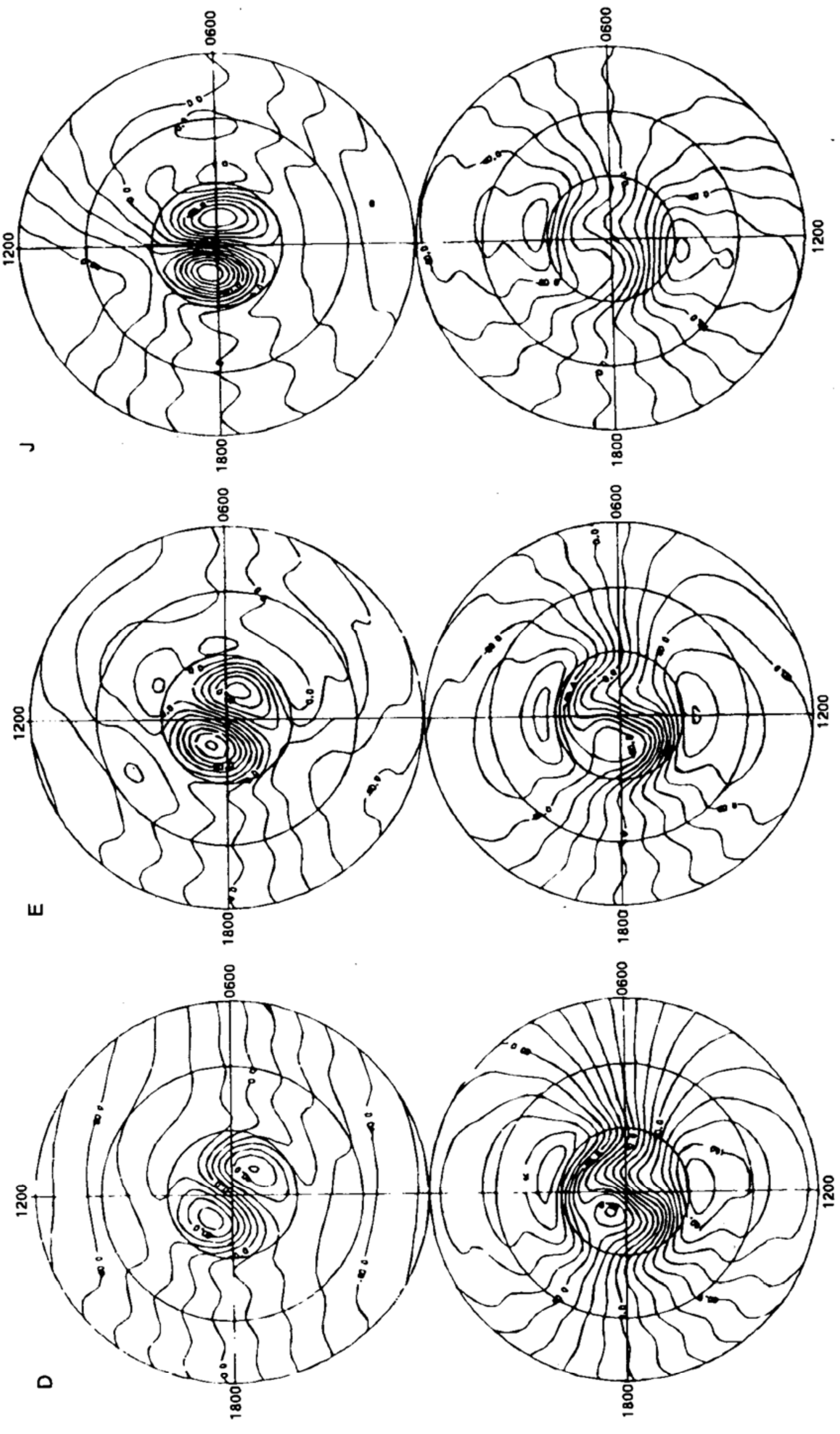

Fig. 3. S^{p} current systems for different seasons.

Table 1. Characteristics of S^r current systems in southern and northern hemispheres

Season	S^{vc}						S^{pc}			
	N-hemisphere			S-hemisphere			N-hemisphere		S-hemisphere	
	Total current kA	Vortex focus		Total current kA	Vortex focus		Polar cap current		Polar cap current	
		Geom. Lati.	LT		Geom. Lati.	LT	Total current kA	Direction	Total current kA	Direction
D	138	30	12.1	205	−33	12.8	213	To 9.5^h	190	To 15.0^h
E	211	32	11.0	270	−32	12.0	252	10.5	225	13.5
J	229	30	10.2	254	−32	11.0	318	11.9	298	14.0
Y	182	30	11.0	210	−32	12.0	260	11.0	215	14.0

ant for L variation (Matsushita and Xu, 1982a), therefore, the following discussion is confined to this component. The external current system L^{pc} of semidiurnal compoment for yearly average is shown in Fig. 4. It can be seen from the figure that the principal structure of L^{pc} current system is four oppositely convecting current vortexes near the auroral zone. The total current of each vortex is 2.6 kA (or 1.2 kA) in northern (or southern) hemisphere. In the polar cap there are other four current vortexes with intensity of 0.5 kA (or 1.4 kA) for northern (or southern) hemisphere.

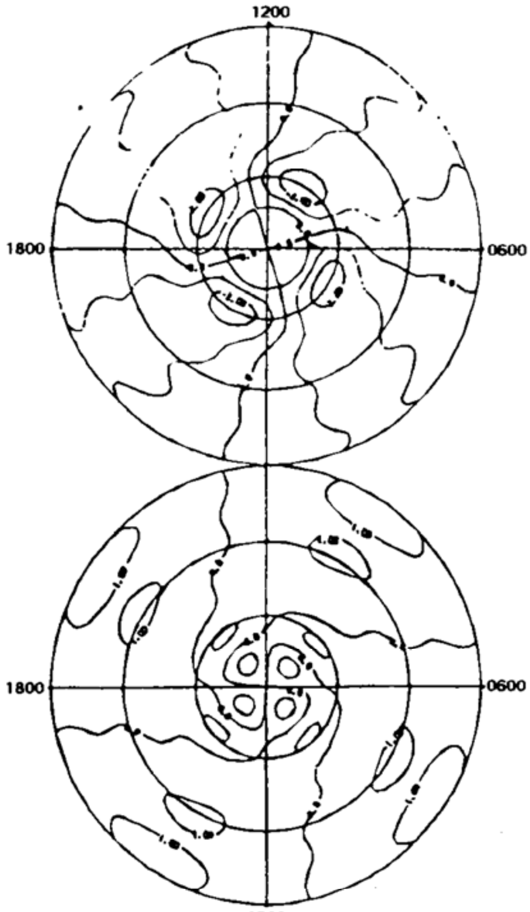

Fig. 4. Yearly average L^{pc} current system, contour interval is 2 kA.

Seasonal variations of L^{pe} are illustrated in Fig. 5. In northern hemisphere the intensity of the auroral vortex is 3.6 kA at 55° latitude in winter. In equinoctial months the vortexes move to 60° latitude with intensity of 3.8 kA. In summer the vortexes completely enter into the polar cap with current centers at 75° latitude and intensity of 4.0 kA. As for southern hemisphere the seasonal variations are much more complicated.

4 Internal currents S^{pi} and L^{pi}

The induced currents in the earth produced by the ionospheric currents depend upon the structure and intensity of the inducing field, as well as the magnitude and distribution of the conductivity in the earth. Consequently, the studies on S^{pi} and L^{pi} current systems should help us to understand the earth's conductivity structure (Campbell, 1987).

The yearly average induced current systems of S^{pi} and L^{pi} are depicted in Fig. 6. The S^{pi} currents induced by S^{pe} show remarkable differences in northern and southern hemispheres: the S^{pi} currents in northern hemisphere are much smaller than those in southern hemisphere. The L^{pi} currents have similar characteristics. Since the ratios S^{pi}/S^{pe} and L^{pi}/L^{pe} reflect approximatly the earth's conductivities, Fig. 6 would lead to the following conclusion: conductivity in the Antarctic region is larger than that in the Arctic region. The principal harmonics of S and L with periods 6—24 hours can penetrate to depth of a few hundreds kilometers, therefore the above-mentioned data reflect the conductivities in the crust and the upper mantle (Rikitake, 1966).

5 Conclusion and discussion

Comparative analyses of S and L current systems in the Arctic and Antarctic regions show that:

(1) There are certain differences in the external current systems of the two polar regions, that suggests differences between the polar regions in the ionospheric dynamo process (for S and L) and field-aligned currents (for S). The differences of the magnetic field in the polar regions may be basic factor causing the above-mentioned differences.

(2) There exist remarkable differences in the internal currents of the two polar regions, which is attributed to both differences of the external inducing field (or external currents) and differences of the earth conductivity. The results show that the conductivity in the Antarctic region is higher than that in the Arctic region.

The ionospheric current systems in the polar regions obtained by using geomagnetic data in this paper can be combined with satellite and radar data and used to study important space phenomena, such as ionospheric electric field, plasma movement, field-aligned currents and ionosphere-magnetosphere coupling. It should be pointed out that:

(1) As is well known, polar region currents are closely correlated with solar wind, interplanetary magnetic field (IMF) and magnetospheric processes. Matsushita and Xu (1982b) indicated that S^{pe} current is mainly caused by field-aligned currents, although the dynamo process in the polar regions also play an important role. On the contrary, the

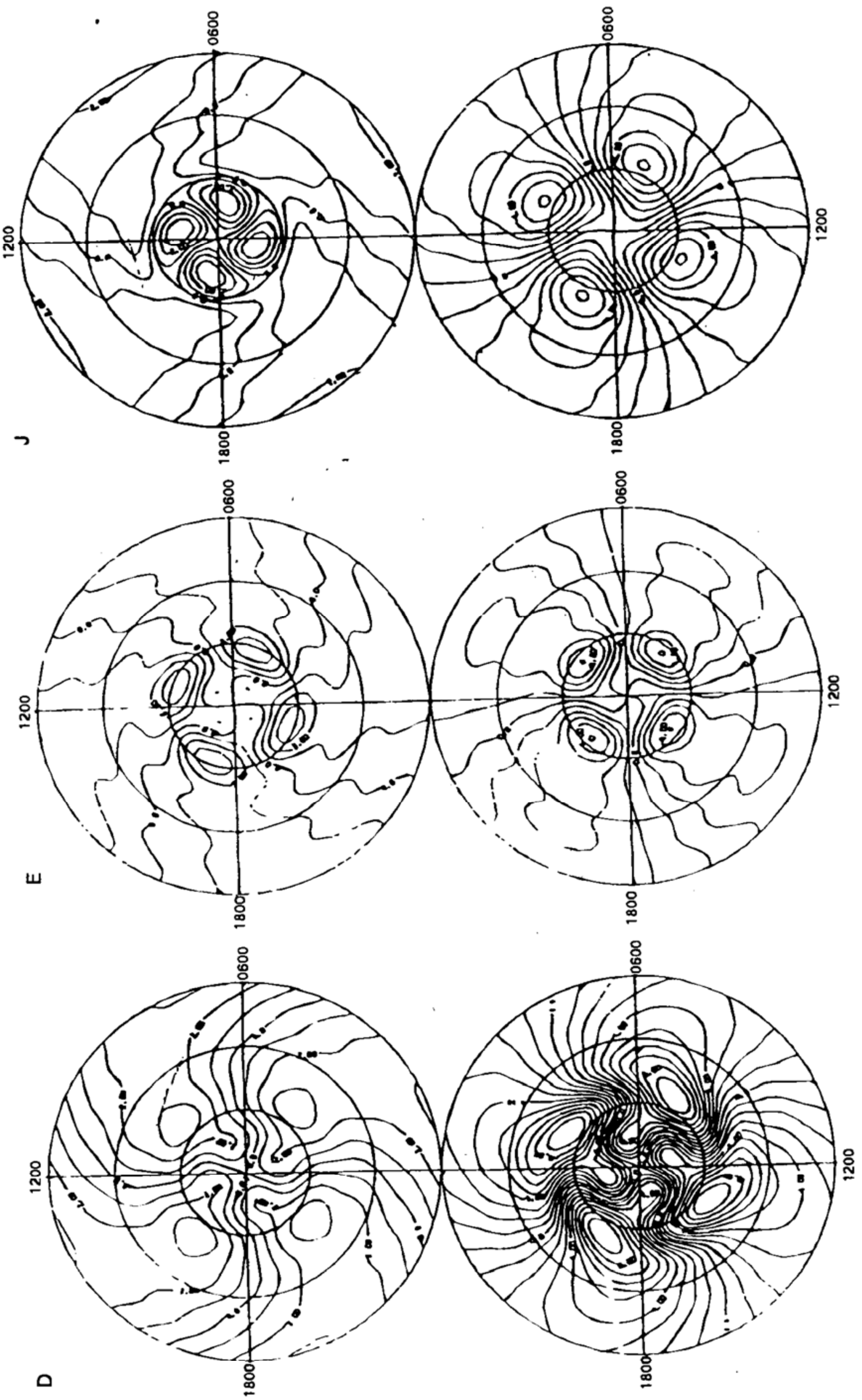

Fig. 5. Seasonal variation of L^{w} current system.

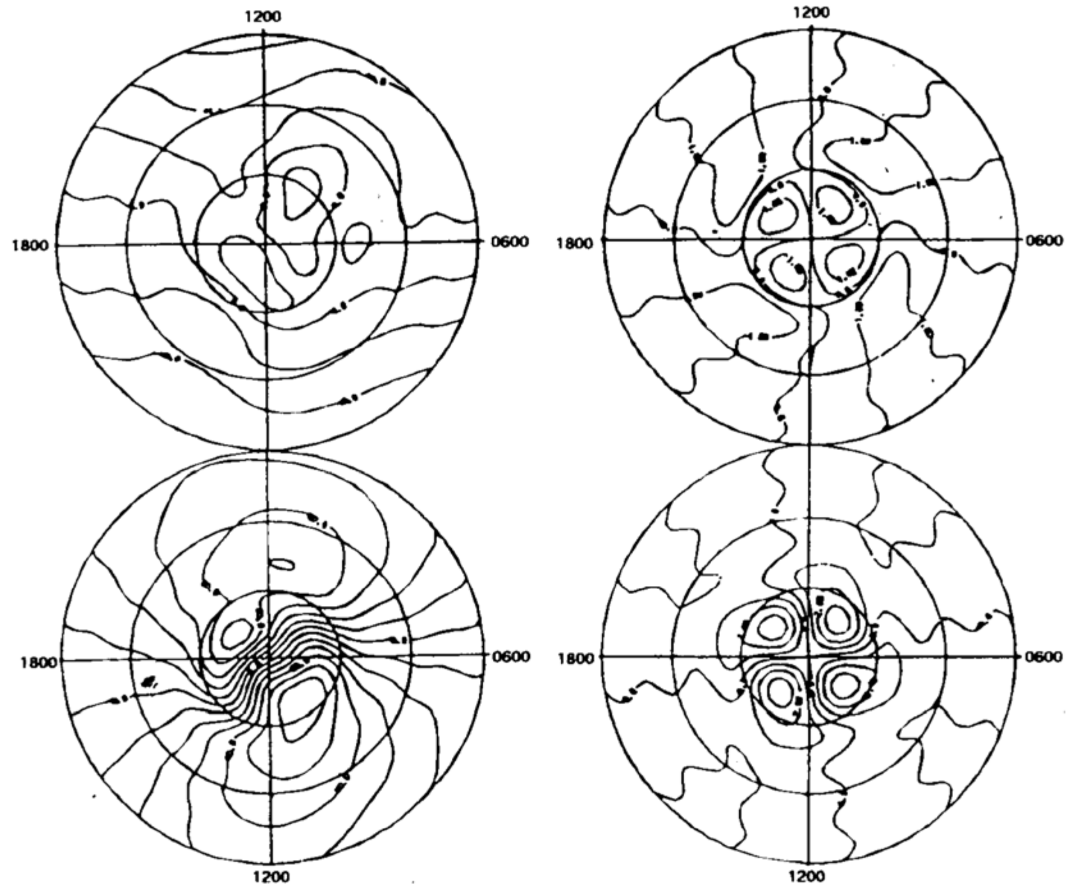

Fig. 6. Yearly average current systems S^{p} (left) and L^{p} (right).

L^{p} currents are entirely created by dynamo process. The basic morphology of S^{p} depends on the basic state of the magnetospheric convection, while L^{p} on the global dynamo process. The two-vortex construction of S^{p} and four-vortex pattern of L^{p}, as their basic features, always remain (Friis-Christensen, 1984), even during storms and substorms (Kamide and Matsushita, 1979). Solar wind state, IMF and magnetospheric process affect their intensity , location and extent. The present results obtained on the basis of yearly avarage data show the basic state of the magnetospheric convection and ionospheric dynamo process.

(2) Sparsity of the stations in the polar regions (only 7 in Antarctica) limits detailed studies of current systems. Fortunately, the observations of satellites, rockets and radars support the results obtained in this paper (Foster, 1984; Xu, 1989).

(3) The differences of the current systems in the two polar regions reflect their differences in electromagnetic environment, ionosphere-magnetosphere coupling and conductivity in the crust and upper mantle. Further quantitative results are hardly obtained because of station sparsity and data limitation. Anyhow, the obtained results are useful to understanding polar region state and processes.

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