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SEASONAL AND UNIVERSAL TIME VARIATIONS OF THE AU, AL AND DST INDICES

BYUNG-HO AHN[1] AND GA-HEE MOON[2]
[1]Department of Earth Science
E-mail: bhahn@knu.ac.kr
[2]Department of Astronomy and Atmospheric Sciences
Kyungpook National University, Daegu, 702-701, Korea

ABSTRACT

Various attempts have been made to explain the pronounced seasonal and universal time (UT) variations of geomagnetic indices. As one of such attempts, we analyze the hourly-averaged auroral electroject indices obtained during the past 20 years. The AU and AL indices maximize during summer and equinoctial months, respectively. By normalizing the contribution of the solar conductivity enhancement to the AU index, or to the eastward electroject, it is found that the AU also follows the same semiannual variation pattern of the AL index, suggesting that the electric field is the main modulator of the semiannual magnetic variation. The fact that the variation pattern of the yearly-mean AU index follows the mirror image of the AL index provides another indication that the electric field is the main modulator of magnetic disturbance. The pronounced UT variations of the auroral electrojet indices are also noted. To determine the magnetic activity dependence, the probability of recording a given activity level of AU and AL during each UT is examined. The UT variation of the AL index, thus obtained, shows a maximum at around 1200-1800 UT and a minimum around 0000-0800 UT particularly during winter. It is closely associated with the rotation of the geomagnetic pole around the rotational axis, which results in the change of the solar-originated ionospheric conductivity distribution over the polar region. On the other hand the UT variation is prominent during disturbed periods, indicating that the latitudinal mismatch between the AE stations and the auroral electrojet belt is responsible for it. Although not as prominent as the AL index, the probability distribution of the AU also shows two UT peaks. We confirm that the Dst index shows more prominent seasonal variation than the AE indices. However, the UT variation of the Dst index is only noticeable during the main phase of a magnetic storm. It is a combined result of the uneven distribution of the Dst stations and frequent developments of the partial ring current and substorm wedge current preferentially during the main phase.

Key words : Geomagnetic activity index : AU - AL - AE - Dst

I. INTRODUCTION

The semiannual variation of geomagnetic activity has long been recognized (e.g., Cortie 1912; Chapman & Bartels 1940), with higher activity during equinox than solstice. To explain the phenomenon, three different mechanisms have been proposed - the axial hypothesis (Cortie 1912; Bohlin 1977), the equinoctial hypothesis (Bartels 1925; McIntosh 1959; Svalgaard 1977), and the Russell-McPherron effect (Russell & McPherron 1973). From the analysis of the *am* index, Cliver et al. (2000) suggested that the semiannual variation of the index seemed to be more closely associated with the equinoctial effect than with the Russell-McPherron effect. The theoretical explanation of the seasonal/diurnal variation of various geomagnetic indices is currently under debate (e.g., Cliver et al. 2002; Svalgaard 2002). Besides clarifying the cause, several attempts have been made to evaluate the size of the seasonal/diurnal variation for the purpose of space weather research. Recently Hajkowicz (1998) studied extensively the UT and solar cycle variation of the AE index. Ahn et al. (2000a) also examined the UT variation of the auroral electrojet indices. On the other hand, Takalo & Mursula (2001) and Ahn et al. (2002) showed that the seasonal/diurnal variation is also apparent in the |Dst| index, minimizing around 1200UT due to the unfavorable distribution of the Dst stations.

The purpose of this study is to provide the community with an idea about the size of the seasonal/diurnal variation of geomagnetic activity and to examine its implication to the space weather study. In particular, by examining the UT variation of geomagnetic indices, it is attempted to evaluate the effect of the unfavorable distribution of geomagnetic stations on the reliability of geomagnetic indices. For this purpose we analyze auroral electrojet (AE) indices and Dst index. According to Kamide & Kokubun (1996), and Ahn et al. (1999), however, the physical process governing the eastward and westward auroral electrojets are significantly different. Thus it would be physically more meaningful to examine AU and AL, representing respectively the

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Corresponding Author: B.-H. Ahn

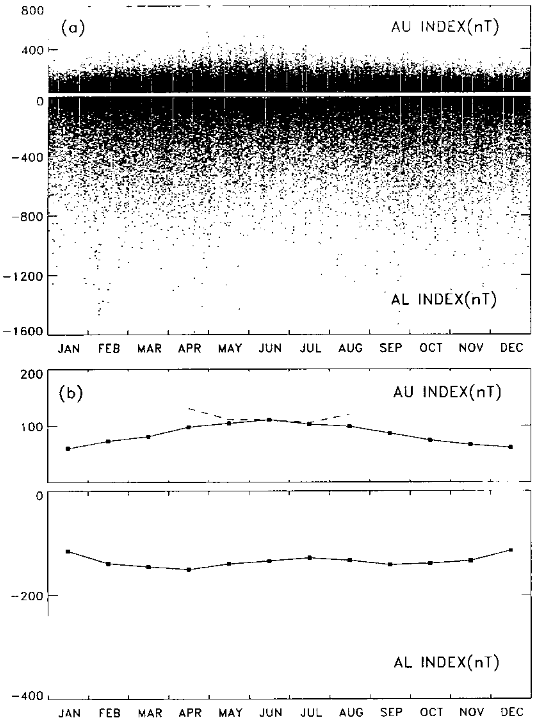

Fig. 1.— The seasonal variation of the AU and AL indices based on (a) the entire database, (b) the monthly-mean value. The dashed line represents the theoretical AU index, adopted partly from Ahn et al. (2000b).

eastward and westward electrojets, separately rather than the composite one, AE index. We utilized an extensive database of the hourly-averaged auroral electrojet indices obtained during 1966-1987, and the Dst index for the past 35 years from 1964 to 1998.

II. SEASONAL VARIATION OF THE AURORAL ELECTROJET INDICES

Fig.1 shows the seasonal variation of AU and AL indices for the past 20 years (Ahn et al. 2000b). One can clearly note that the AU shows a maximum during summer while the AL index tends to be intensified during equinoctial season. The average AU index of the entire period was 84.6 nT while the maximum and minimum appearing in June and January were 110.4 nT and 59.8 nT, respectively, corresponding to 30.5% higher and 29.3% lower than the yearly-mean value. On the other hand, the |AL| index shows two maxima in April and September and two minima in January and July. The average |AL| index of the entire period was 135.1 nT while the maximum in April was 11.8% higher and the minimum in January was 14.1% lower than the yearly-mean value. Although both AU and AL indices show seasonal variation, the mechanism governing the variations does not seem to be the same. The variation of the AU index is closely associated with the seasonal ionospheric conductivity change, maximizing in summer and minimizing in winter.

To clarify the reason why the two indices show different seasonal behavior, the effect of the seasonal change of ionospheric conductivity is examined. As is well known, the ionospheric conductivity results largely from the two sources, the solar EUV radiation and auroral particle precipitation. According to Allen & Kroehl (1975), the maximum contribution to the AU and AL index comes from the magnetic disturbance recorded at the AE stations located at 1730 and 0330 MLT (magnetic local time) sectors, respectively. They further suggested that the AE station contributing significantly to the AU index is from around the latitude of Barrow, 69.4° in the apex latitude (Richmond 1995). On the other hand, from the Chatanika radar measurements of ionospheric conductivity and electric field, Ahn et al. (1999) showed that the ionospheric conductivity during daytime particularly from noon to 1800 MLT sector is mostly controlled by the solar EUV radiation. Allowing that the auroral electrojet is largely Hall current flowing in the east-west direction, one can approximate it as the combined result of the Hall conductivity and north-south electric field. Since the solar-originated Hall conductivity can be estimated empirically, it is possible to infer the contribution of the north-south electric field to the AU index. In other word, one may convert the observed AU index into a theoretical one by assuming that the same Hall conductivity prevails the entire year.

Adopting the solar zenith angle at Barrow on the 15th of each month, the corresponding solar Hall conductivity is calculated. For this purpose we employed the empirical formula by Robinson & Vondrak (1984), which uses the solar zenith angle and the 10.7cm solar radio flux as input. Unfortunately such a formula is only applicable when the sun is above the horizon at 1730 MLT sector. Thus the theoretical AU index was calculated for five months from April to August and shown as the dotted line in Fig.1(b). Interestingly it shows a similar trend as the AL index, becoming higher during equinoctial season. Since Ahn et al. (2000b) showed that the ionospheric conductivity in the night hemisphere does not show any noticeable seasonal dependence, it is concluded that the electric field variation is the main modulator of the semiannual variation of AU and AL indices.

Fig.2 shows the annual variation of the AU and AL index during the past 20 years with the data of two years, 1976 and 1977, missing. It is interesting to note in Fig.2(b) that the annual variation of the AL index follows the mirror image of the AU index. Ahn et al. (2000b) reported that the annual *aa* index also shows the quite similar variation pattern of the AU and AL indices. It is a strong indication that the same modulator, i.e., the electric field, controls various semiannual geomagnetic activity.

It is worth examining the seasonal variation of AL index during disturbed periods separately. Since the

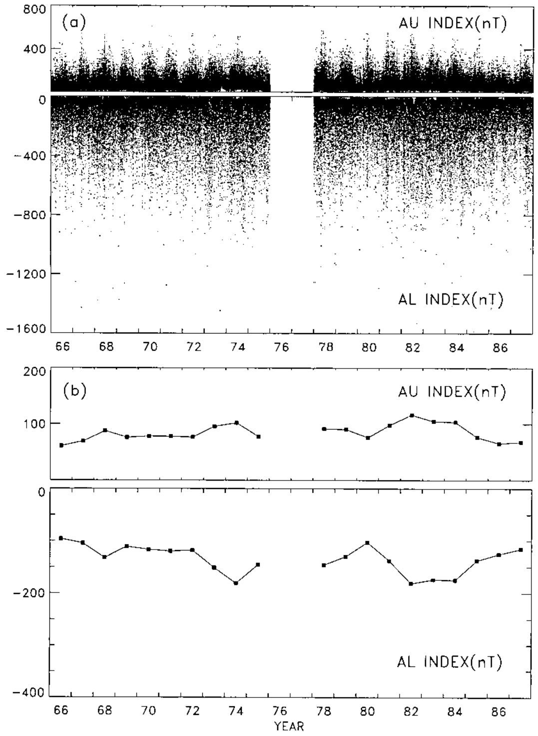

Fig. 2.— The distribution of the AU and AL indices over the past 20 years based on (a) the entire database, (b) the yearly-mean value, adopted partly from Ahn et al. (2000b).

average value of the AL index during the past 20 years was -135 nT, the occasions with AL<-135 nT are considered as disturbed periods. The AL index satisfying this criterion during the past 20 years was -295.9 nT; see the solid line in Fig.3(a). No significant difference between the two curves - one for all data and the other for disturbed ones - however, is noted. We also examined how the number of hours observing the occasions with AL<-135 nT changes with season. If the probability of observing such occasions is the same regardless of season, each month recorded approximately the same number of hours, 5092, during the past 20 years. Although the probability distribution shows a similar pattern with the ones in Fig.3(a), the amplitude of the variation in Fig.3(b) exceeds those of Fig.3(a). It suggests that the disturbed periods during equinoctial season are not only associated with the intrinsic increase of magnetic activity itself but also with more frequent occurrence of disturbed conditions. The average fluctuation of monthly AL from the yearly-mean value during the disturbed periods was 4.7%, while the fluctuation of the number of hours from the average, 5092 hours, was 7.9%. It is an indication that a favorable condition, which increases the solar wind-magnetospheric coupling efficiency, tends to be established more frequently during equinox.

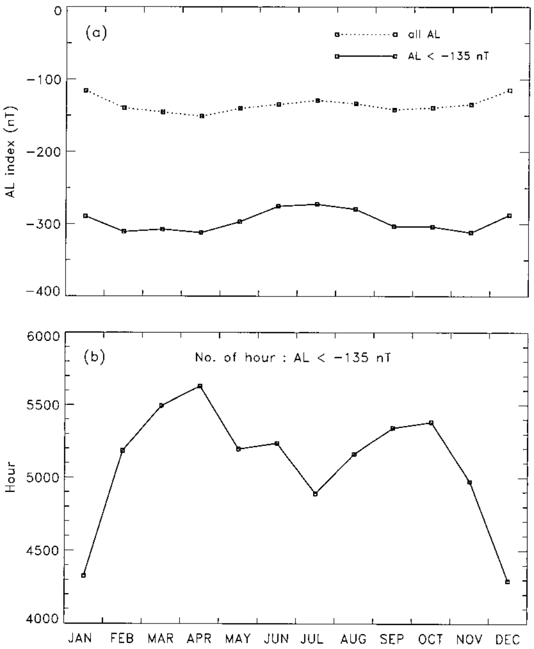

Fig. 3.— The seasonal variations of the AL index based on (a) the entire database and the data satisfying AL<-135 nT. (b) The distribution of the occurrence frequency during disturbed periods with AL<-135 nT.

III. UNIVERSAL TIME VARIATION OF THE AURORAL ELECTROJET INDICES

It is an interesting topic to examine the UT variation of the auroral electrojet indices, because it provides us with an idea on whether the current AE station network is ideal in monitoring the auroral electrojets. Fig.4(a) shows the UT variation of the AU index during three seasons. As pointed out previously, it is the solar EUV radiation that makes the AU index higher (lower) during summer (winter). Gizler et al. (1976) has reported that the AU index is extremely low during winter. In spite of a significant UT variation the AU index during summer is generally higher than those of the other seasons, indicating that the current AE network is relatively ideal in monitoring the eastward electrojet. Summing up, the AU index during June exceeds 30.5% from its yearly-mean value, while the largest UT variation recorded at 1500 UT during summer deviates 15.3% from its summer mean value. Thus we can conclude that as far as the AU index is concerned, the seasonal variation is more prominent than the UT variation.

Fig.4(b) shows the UT variation of the AL index during the three seasons. Unlikely the AU index, the AL index shows a significant UT variation particularly during winter. To understand such a trend, it would be helpful to recall that the geomagnetic pole is separated from the geographic axis by approximately 11°. At around 0500 UT the geomagnetic pole is located

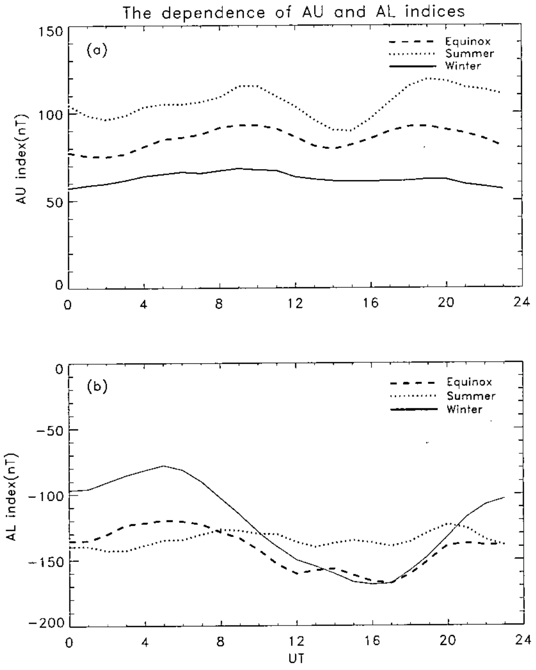

Fig. 4.— The universal time variations of (a) the AU index and (b) the AL index during the three seasons.

away from the day-night terminator towards night side, thus leaving most of the AE stations in the dark hemisphere, which in turn results in a lower ionospheric conductivity. This is the reason why the |AL| index is so low at around 0500 UT during winter. On the other hand, at around 1600 UT the situation becomes reversed. During the other seasons, particularly summer in the northern hemisphere, however, most of the AE stations are in the sun-lit hemisphere regardless of UT, thus with no significant conductivity difference being expected among the stations. That is the reason why no apparent UT variation is noted during summer. The percentile difference indicates that the AL index during April exceeds 11.8% from its yearly-mean value, while the largest UT variation recorded at 1700 UT during winter deviates 38.6% from its winter mean value. Thus it is concluded that the UT variation is more important than the seasonal one in the AL index.

We have seen that the seasonal or UT variation makes the AU or AL index deviate from the mean value at most by a 100 nT level. In the space weather point of view, however, the effect associated with such a level of variation is insignificant during severely disturbed periods. Thus it is desirable to evaluate it during severely disturbed periods. For this purpose, as shown in Fig.5, we examined the variations at every 200 nT level for the AL index. Note that the vertical axes are expressed in terms of the occurrence frequency in percentile value rather than the magnitude of the AL index itself. If there is absolutely no seasonal or UT variation, the probability of observing a given level of AL during a UT hour would be the same, 4.17%. Actually, for the lowest activity level from 0 to -200 nT, no significant variation is noticeable with the probability being about 4% regardless of season or UT. But one can clearly see that they become more apparent as magnetic activity increases. In particular, it is winter when the seasonal variation is most significant; see the bottom panel of Fig.5. The probability observing the AL index of the activity level, -600~-800 nT, during 1200-1800 interval, is higher than that of 0000-0600 interval by a factor of four. In other words, the probability of recording the highly disturbed AL index during early UT hours is very low during winter. Although such a tendency has been explained in terms of seasonal conductivity change as shown in Fig.4(b), the difference by a factor of four is too large to attribute simply to the conductivity change alone.

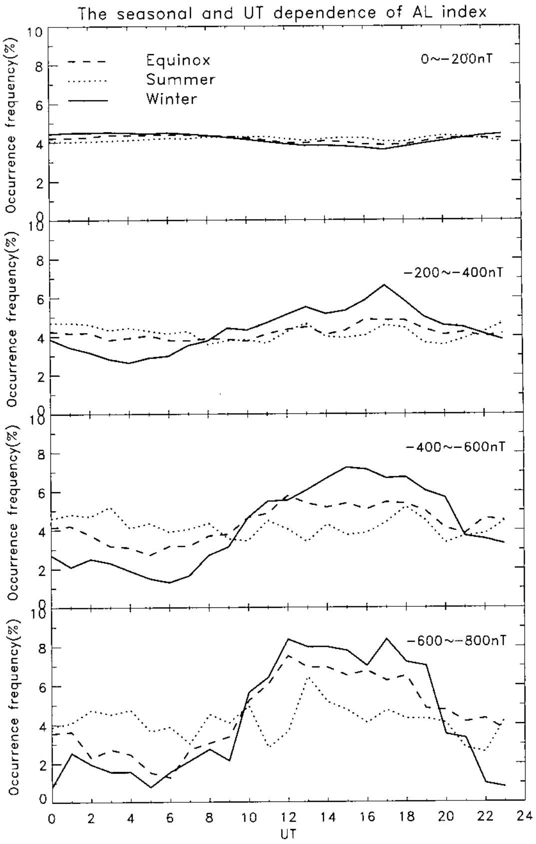

Fig. 5.— The distributions of the occurrence frequency during different magnetic activity levels, every 200 nT, and different seasons.

Ahn et al. (2000a) examined the local time distribution of the AE stations during 0000-0600 UT interval and noted that the main contributing AE stations around 0330 MLT(Allen & Kroehl, 1975) were Leirvogur(65.6 °) and Narssarssuaq(67.6 °) During 1200-1800 UT interval, however, three stations, Barrow (69.4 °), College(64.6 °), and Cape Wellen(62.2 °), come

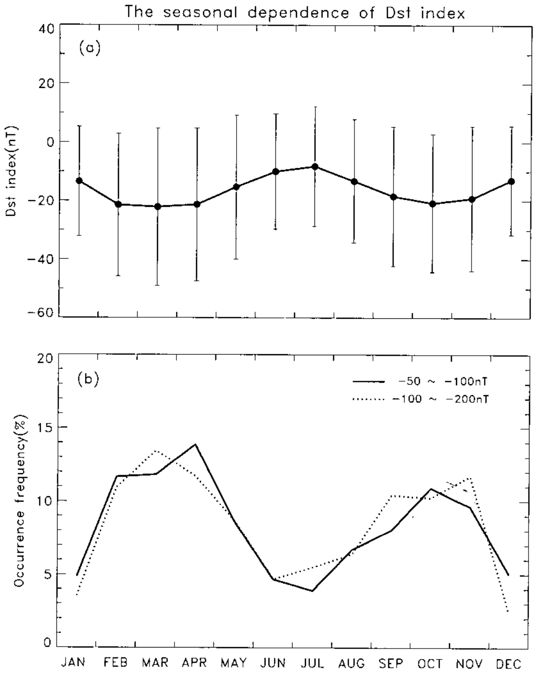

Fig. 6.— The seasonal variation of the Dst index using (a) the entire database of 35 years. (b) The seasonal distribution of the occurrence frequency of the Dst index for two different activity levels, -50~-100 nT and -100~-200 nT.

to around 0330 MLT sector. Considering that the westward electrojet easily tends to expand equatorward during disturbed periods even beyond Leirvogur, the three stations during the late UT hours covering as low as 62.2 ° are more ideal in detecting the westward electrojet properly than the two stations during the early UT hours. This is another reason why the UT variation of the AL index during disturbed periods is so prominent. We also examined the seasonal and UT variations of the AU index during different magnetic activity levels. Although not shown here, the AU index shows a noticeable UT variation too, maximizing at around the intervals of 0600-1000 and 1400-1800 UT. But no clear seasonal dependence is noted. Admitting that the eastward electrojet generally flows through a higher latitudinal region than the westward electrojet, the current AE network with the average apex latitude being 67.1 ° is more favorable in monitoring the former than the latter. This is the reason why the AU shows less prominent variation than the AL index does.

IV. SEASONAL AND UT VARIATION OF THE DST INDEX

The seasonal variation of the Dst index is clearly seen in Fig.6(a), maximizing during equinoctial season. The average fluctuation of the Dst from the yearly-mean value during the past 35 years was about 28%, far exceeding that of the AL index, 7.6%. Admitting that the four Dst stations are located at the mid latitude region - thus far away from the auroral region and consequently less affected by seasonal conductivity change - the prominent seasonal variation of the Dst index seems to reflect the enhancement of the coupling efficiency between the solar wind and magnetosphere during equinoctial season. As was done with the AL index, the seasonal variation of the Dst index is examined for two activity levels, -50~100 nT and -100~200 nT, corresponding to moderate and big storm periods, respectively. If there were no seasonal variation, the probability of observing a given level of Dst would be the same, about 8.4% per month. Fig.6(b) shows, however, that the probability distribution follows exactly the same seasonal variation pattern of the Dst index in Fig.6(a). The amplitude of the average fluctuation from the mean value is as large as 38.1%. But it does not seem to show any dependence on storm size.

Ahn et al. (2002) studied the UT variation of the Dst index by dividing a storm into two intervals, the main and the recovery phases, and found that the |Dst| index shows a prominent UT dependence during the main phase, increasing around 0400-0800 UT and decreasing around 1000-1400 UT. However, it is almost unnoticeable during the recovery phase. Ahn et al. argued that such large deviations have to do with the uneven distribution of the Dst stations in longitudinal direction and frequent developments of the partial ring current and substorm wedge current during the main phase. To monitor the ring current intensity properly, the ideal spacing between adjacent Dst stations should be 90 ° because the current Dst network consists of four stations. In reality, however, it is not the case. For example, Honolulu and Kakioka are located as close as 61.7 °. Considering the fact that the Dst index is the average magnetic disturbance obtained from the four stations, a UT variation would be inevitable whenever the ring current is not uniform azimuthally and the two closely-spaced stations happen to be at the same local time sector with any inhomogeneity of the current system. If the partial ring current, which flows in the same direction as the ring current, develops during 0400-0800 UT interval, it is the time when the two stations would come to the same local time sector with it, thus recording the intensified ring current. That is the reason why the |Dst| increases during this UT time interval. On the other hand, the substorm wedge current used to develop in the midnight sector and flows the opposite direction with the ring current. Thus if it develops during 1000-1400 UT interval, the two stations come to the midnight sector and naturally register a reduced |Dst| index.

V. SUMMARY AND DISCUSSION

We examined the seasonal and universal time variation of the AU, AL and Dst indices. For this purpose we utilized hourly-averaged AU and AL indices of the past 20 years and the Dst index obtained during the last 35 years. Generally the geomagnetic indices except the

AU show a semiannual variation, maximizing during equinoctial season and minimizing during solstitial season. The seasonal variation of the AU index, however, maximizes during summer and is largely controlled by the seasonal ionospheric conductivity change. This is so prominent that the semiannual variation, which is clearly seen from the other indices, is dwarfed by the effect associated with the solar zenith angle variation. By normalizing the ionospheric conductivity contribution to the eastward electrojet, however, it is found that the AU also tends to show a semiannual variation, maximizing during equinoctial season. On the other hand, the annual variation patterns of the AL index during the past 20 years follows the mirror image of the AU index. It is interesting to note that in spite of the fact that the sources of the ionospheric conductivity of the eastward and westward electrojets are considerably different, i.e., being closely associated with the solar EUV radiation and auroral particle precipitation, respectively, the two indices show the same seasonal variation pattern. It strongly suggests that the main modulator of the seasonal variation of the auroral electrojets is not the ionospheric conductivity but the electric field. It is also worth mentioning that the semiannual variation of the AL index is not only due to the magnitude increase but also due to the increased frequency of disturbed conditions during equinoctial season. It is a clear indication that the efficiency of the coupling between the solar wind and magnetosphere increases during equinoctial season.

The auroral electrojet indices show a pronounced UT variation. Particularly, the |AL| index is the case during winter, minimizing around 0500 UT and maximizing around 1600 UT. It is the consequence of the rotation of the geomagnetic pole around the geographic axis, which in turn changes the area of the sunlit part over the polar region. For example, at around 1600 UT more AE stations are in or near the sunlit hemisphere, thus being under enhanced ionospheric conductivity region. The probability distribution of recording a given level of the AL shows a maximum around 1200-1800 UT and a minimum around 0000-0800 UT particularly during disturbed periods, indicating that the latitudinal mismatch between the AE stations and the auroral electrojet belt also seems to be responsible for it. Therefore, during disturbed periods the variability of the AU and AL indices are closely associated with the unfavorable AE network and the ionospheric conductivity variation, which results from the change of the relative position of the geomagnetic pole to the geographic pole. And this variability seems to far exceed the effect due to the seasonal dipole tilt change with respect to the solar wind.

The Dst index shows a prominent seasonal variation too, maximizing during equinoctial season with the amplitude of the variation far exceeding that of the AU or AL index in terms of percentile value. As noted from the auroral electrojet indices, the enhancement of Dst index during equinox seems to be the combined result of the magnitude increase of the |Dst| index itself and more frequent occurrence of disturbed conditions during equinox. Allowing that the Dst stations are located in the mid latitude region and monitoring the ring current flowing in the equatorial plane of the magnetosphere, the effect associated with the seasonal ionospheric conductivity change would be minimal. Thus the seasonal change of the dipole tilt with respect to the solar wind seems to play a major role in the Dst variation. The Dst index also shows UT variation, noticeable only during the main phase of a magnetic storm. Ahn et al. (2002) argued that it is the combined result of the uneven distribution of the Dst stations and frequent developments of partial ring current and substorm wedge current preferentially during the main phase.

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