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Influence of the disturbed solar wind on atmospheric processes in Antarctica and El-Nino Southern Oscillation (ENSO)

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Abstract. The dramatic deviations of atmospheric winds from the regular pattern (anomalous winds) at two Antarctic coast stations located in the Western Pacific, Leningradskaya and Russkaya, and at the near-pole station Vostok have been examined in relation to strong disturbances in the interplanetary magnetic field (IMF), on the one hand, and ENSO variations, on the other hand. The Southern Oscillation Index (SOI) has been used to characterize the phase and intensity of the ENSO activity. Taking into account that the negative SOI values tend to appear and develop strictly during March-August, the winds in the winter Antarctica were only analyzed. The anomalous winds at three stations turned out to be observed 1-2 months ahead of the event. On the other hand, the statistically significant relationships between anomalous winds and the southward IMF take place. To check a possible link between the El-Nino events and Space Weather the behavior of SOI for 1987-2001 has been compared with variation of the AE index. It is shown, that El-Nino events follow the magnetic activity increase with delay time of 2-3 months.

Key words. Solar wind, interplanetary electric field, Antarctica, atmosphere processes, anomalous winds, El-Nino Southern Oscillation.

1. Introduction

The existent models of the atmosphere changeability do not take into consideration the changes of solar activity. Indeed, the total energy, contributed in the Earths atmosphere by the solar wind and fluxes of the solar and galactic cosmic rays, is extremely insignificant in comparison with the total solar irradiance. But, as distinct from the total solar irradiance, the energy of solar wind and cosmic rays can increase tens and hundreds times in periods of high solar activity.

That is way, the attempts to ascertain the cause-effect relation between the solar activity variations and weather and climate changeability have a long story (Wilcox, 1975; Herman and Goldberg 1978). The galactic cosmic rays altered by solar wind are traditionally regarded as the most plausible agent of the solar activity influence on the Earths atmosphere. However, the hypothesis about determining influence of the galactic cosmic rays on the total cloudness (Svensmark and Friis-Christensen 1997) or low-cloud properties (Marsh and Svensmark 2003) was rejected by subsequent, more detail researches (Farrar, 2000; Palle and Butler 2002; Laut 2003). Meanwhile, evidence for

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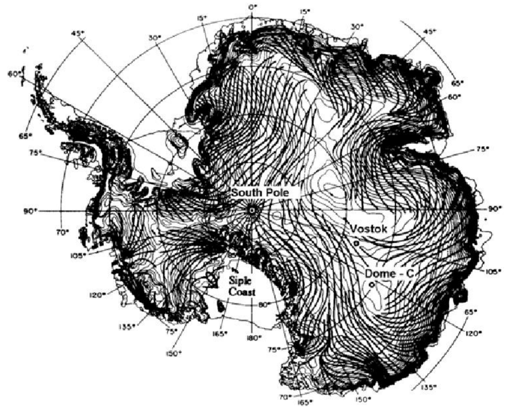

Fig. 1. Pattern of near-surface drainage winds in the Antarctic (Parish and Bromwich 1987). Thin lines present isohypses, thick lines show direction of the drainage winds. Location of the station is marked by black dots.

crucial influence of the solar wind variations on the atmospheric temperature have been obtained in course of studies carried out in AARI. These studies basing on meteorological observations fulfilled in the Central Antarctica demonstrate a peculiarity of the atmospheric phenomena in the winter Antarctica and their likely exclusive role in changeability of the global atmospheric processes.

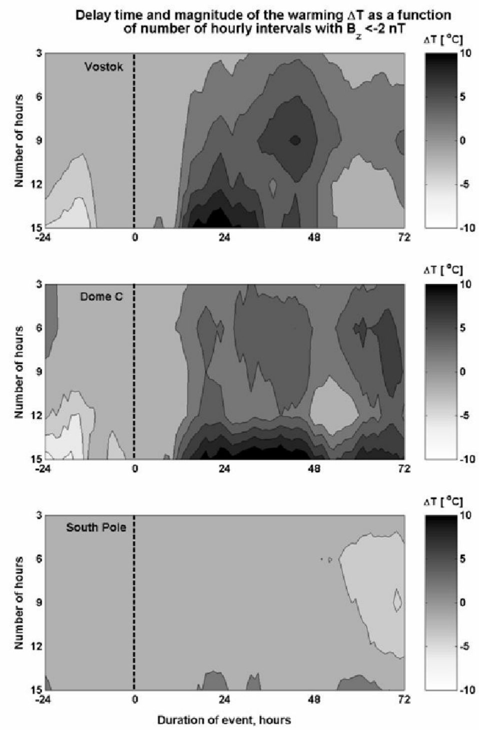

Fig. 2. Character of temperature changes DT at stations Vostok, Dome C, and South Pole as a function of number of the hourly interval with $BZ < -2nT$.

2. Katabatic wind system as a specific feature of atmospheric circulation in Antarctica

Katabatic wind regime is powerful drainage stream of the near-surface air masses flowing radially from the Antarctic ridge to coastline (Figure 1, taken from Parish and Bromwich (1987)). This drainage is determined by the negative air buoyancy supported by severe radiation cooling of the atmosphere on the ice sheet surface. As a result, the large-scale system of vertical (meridional) circulation is formed in the winter Antarctic, since the mass continuity requires the permanent substitution of the air masses in the near-surface layer. The system includes drainage of the air masses along the slope of Antarctic ice sheet, ascending flow near the cost line, return movement in the lower and middle troposphere, and descending flow in the near-pole region (Parish and Bromwich 1991). The spatial structure of katabatic winds is one of the most stable atmospheric phenomena on the Earth (Schwerdtfeger 1984). The circumpolar vortex typical of Antarctica is tied to the intensity of the katabatic wind regime (Parish 1991). Superposition of the constant radiation cooling of air situated at the ice sheet and adiabatic warming of air masses, which income from above, supports the atmosphere on the Antarctic ridge in state of the thermal quasi-equilibrium.

3. Sudden warmings in the Central Antarctic and their relation to disturbances in the solar wind

Sometimes strong warmings (up to 20C) happen in some hours in the central Antarctica

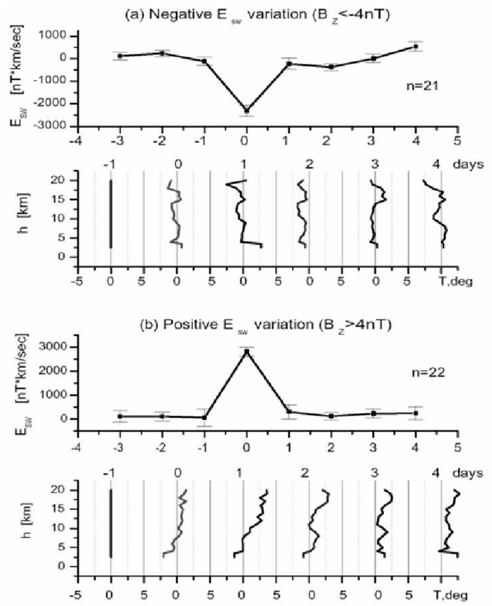

Fig. 3. Profiles of the averaged temperature deviations above Vostok station for negative (a) and positive (b) variations of the interplanetary electric field ESW.

during the winter seasons. These exclusive events were studied (Troshichev et al. 2003; Troshichev and Janzhura 2004) on the basis of three sets of meteorological data: (1) daily meteorological observations (temperature, pressure and winds) on the ground level at Vostok station (h =3.45 km) for 1978-1992, (2) hourly temperature values derived from the 10-min observations provided by the automatic stations (AWS) at Dome C, South Pole and Vostok for 2000-2001, and (3) daily aerological measurements of temperature, pressure and winds above Vostok station h = 3.5 - 20 km) for 1978-1992. It was found that warmings came after large increase of the negative (southward BZS) component of the interplanetary magnetic field. BZS component is the most geoeffective parameter, after the solar wind speed V. Increase of BZS indicates the growth of the interplanetary electric field (ESW $\approx -VxBZ$) coupling with the Earths magnetosphere. Figure 2 shows the statistical response of the ground hourly temperature DT at stations Vostok, Dome C and South Pole to variations in ESW in 2000-2001 as a function of the southward IMF duration (Troshichev and Janzhura 2004). The abscissa axis presents duration of event, the ordinate axis is for number of the successive hourly intervals with negative $BZ < -2nT$. The time of the maximum deviation in ESW was determined as a key (zero) date.

The temperature variation (DT) was calculated as difference between values of T for the key moment and for preceding and succeeding hours. One can see that increase in the ground temperature is determined by power of the negative BZ action: the longer BZS field exposure (and the higher electric field intensity) the more is the temperature deviation and shorter is time delay between the key moment and the temperature change: at stations Vostok and Dome C the 15-hours exposure affects the effective warming (up to DT= +20) after >>12 hours at level of statistical significance 0.99. However, the warming at station South Pole may be observed only under condition of the powerful interplanetary electric field, and this link is statistically insignificant. So diverse effects in the ground temperature at stations Vostok and Dome C, on the one hand, and South Pole, on the other hand, are evidently explained by their different disposition relative to the katabatic wind system. Indeed, stations Vostok and Dome C are located on the Antarctic ridge, which is area of the descending tropospheric air mass flow, whereas South Pole is located in area of the developed drainage stream.

As results (Troshichev et al. 2003) show, dependence of DT on BZ and DT on ESW is well approximated by the linear low, the correlation between temperature and interplanetary electric field being much more perfect. It is meaningful that response of temperature to the ESW influence is quite opposite in the lower and upper troposphere. Figure 3 shows the profiles of the averaged daily temperature deviations above Vostok station for negative and positive variations of ESW, the temperature profile for the −1 st day, preceding to the zero day (i.e. day of the maximum ESW deviation), being taken as a level of reference for all succeeding days. The average warming at

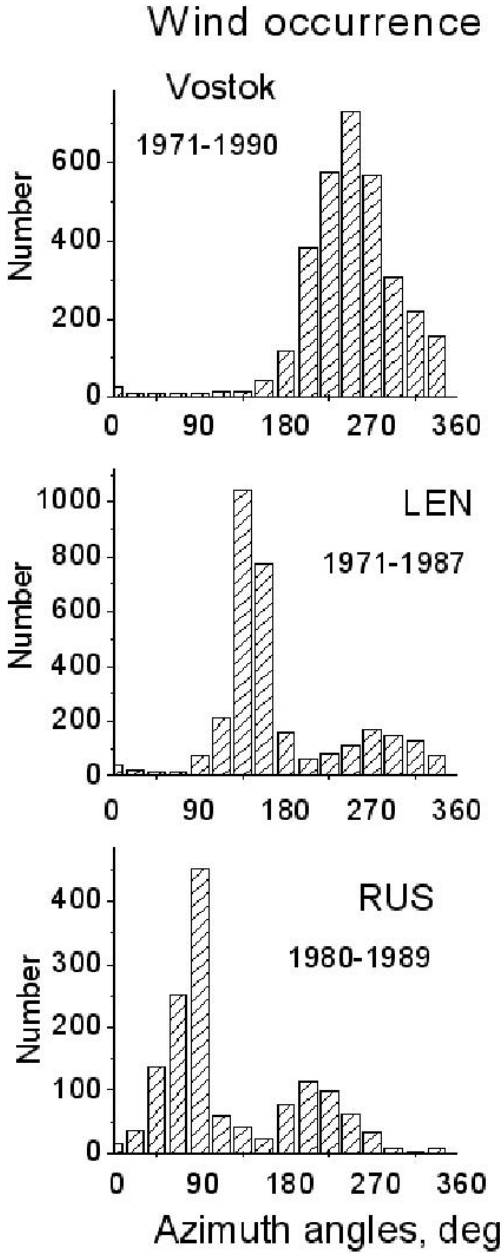

Fig. 4. Diagrams of the wind occurrence at different azimuths for stations Vostok (VOS), Leningradskaya (LEN) and Russkaya (RUS).

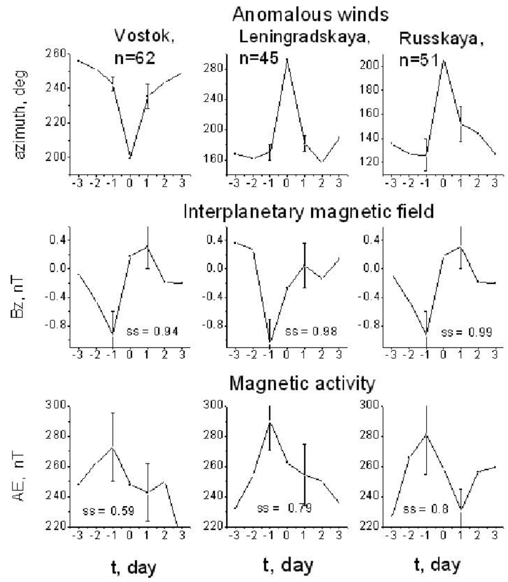

Fig. 5. The anomalous winds at stations Vostok, Leningradskaya and Russkaya in their relation to behavior of IMF BZ and AE index for winter seasons of 1981, 1982, 1985-1987.

the ground level (h = 3.45 - 3.5 km) responds, within 1−2 days, to the negative leap in DESW, but at altitudes more 10 km the cooling is observed (upper panels). The opposite behaviour is typical of the positive leap in ESW: the atmosphere gets cool at the ground level, and gets warm at h > 10 km (lower panels). Such regularity would observe if a cloud layer appears at altitudes 5-10 km under influence of the negative ESW variations, and disappear under influence of the positive ESW variations. A cloud layer would efficiently backscatter the long wavelength radiation going from the ice sheet, but it will not affect the adiabatic warming process.

As a result of the radiative cooling reduction, the atmosphere would be heat below the cloud layer and would be cool above the layer. Conclusion was maid in (Troshichev and Janzhura 2004) that superposition of the constant radiation cooling of air situated at the ice sheet and adiabatic warming of air masses, which income from above, supports the atmosphere on the Antarctic ridge in state of the thermal quasi-equilibrium. The interplanetary electric field affects this equilibrium through the global electric circuit affecting the cloud layer at altitude about 5-10 km. It was sug-

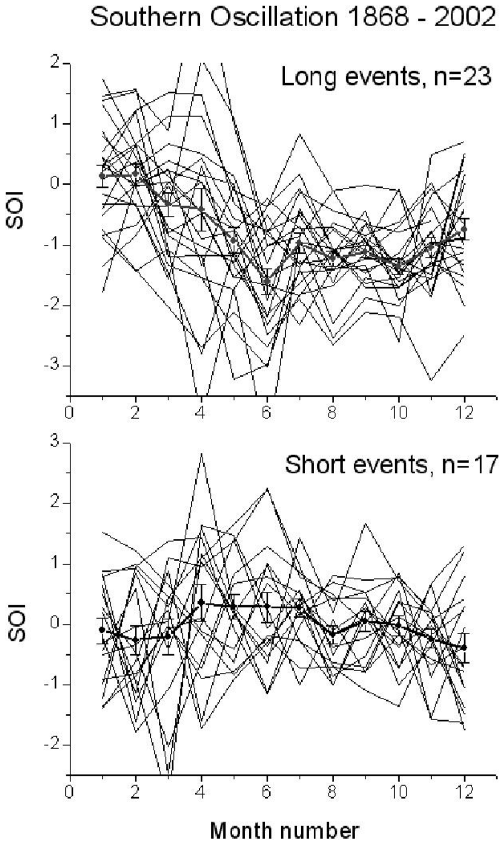

Fig. 6. Behavior of SOI index in course of large negative long-lived and short-lived SOI deviations during 1868-2002.

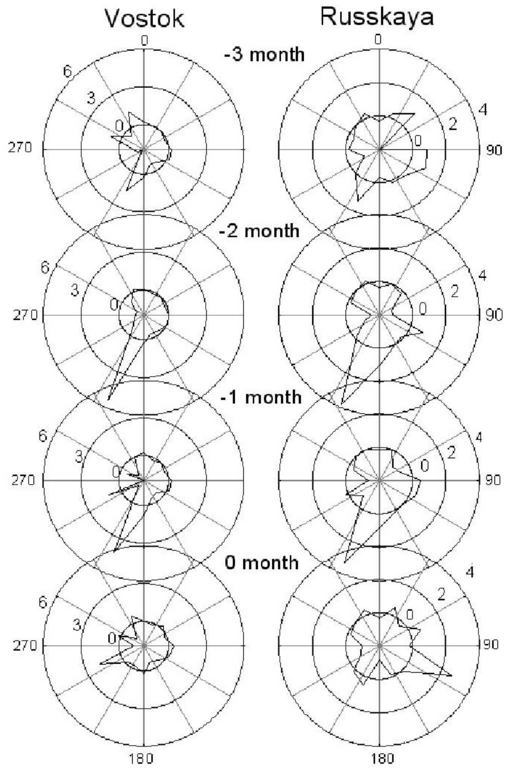

Fig. 7. Differential wind roses, characterizing the changes in wind occurrence in course of El-Nino events for stations Vostok (a), and Russkaya (b).

gested that sudden warming in the Central Antarctic would violate the structure of wind over the entire continent.

4. Anomalous winds and their relation to disturbances in the solar wind

As known, El-Nino events originate in the Western Pacific. Two Russian coast stations were operated in this sector: Leningradskaya in 1971-1990 and Russkaya in 1980-1989. The data from the near-pole station Vostok were taken, correspondingly, for period from 1971 to 1990. Figure 4 presents the diagrams of the wind occurrence at different azimuths for stations Vostok (VOS), Leningradskaya (LEN) and Russkaya (RUS) for the specified years. One can see that two azimuths are typical of winds at stations LEN and RUS: the main occurrence, characterizing the circumpolar circle, is observed at 135 degrees (LEN) and 90 degrees (RUS), and the secondary occurrence is seen around 290 degrees and 200 degrees, appropriately. We shall name these secondary winds, possessing, besides, the high speed, as the anomalous winds.

The anomalous (by their extreme speed) winds at Vostok are aligned around 250. To check a possible link between the disturbances in the Antarctic wind system and changes in the IMF BZ we examined the anomalous wind occurrence at three stations in their relation to the IMF BZ. The winter seasons of 1981, 1982, 1985-1987 have been chosen for analysis, since these years are remarkable by the

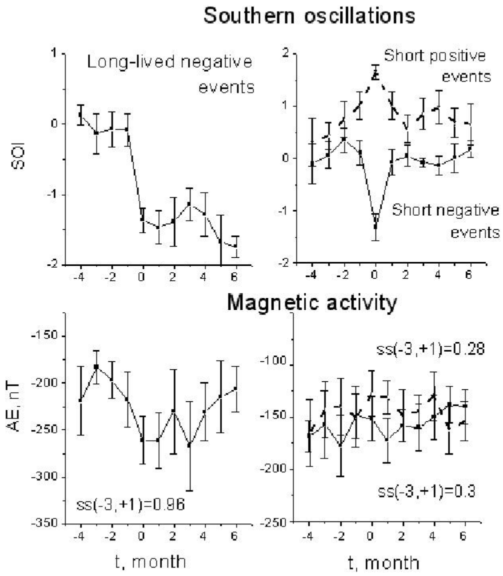

Fig. 8. Relationship between changes in monthly values of SOI and AE indices for long-lived negative deviation of SOI (a), and short-lived negative and positive deviation of SOI (b).

best coverage of simultaneous daily IMF and ground wind data over period under examination. The superposed epoch method is used in the analysis, the day of maximal deviation of the ground wind from the regular direction being taken as a zero day. The mean course of anomalous winds before and after the zero day has been calculated as average of all events with anomalous winds for indicated years. The corresponding mean variation of the IMF BZ has been calculated in the same manner. All days with anomalous winds have been taken into account for each station. Results presented in Figure 5 show that increase of the southward IMF BZ is foregoing by 1 day to the anomalous wind at stations Vostok and Russkaya. The same result has been obtained for the cost station Leningradskaya. The Students t-test has been applied to determine if there is significant difference between the mean BZ values before (-1st day) and after (+1st day) the key date with anomalous wind. Statistical significance (ss) of results turned out to be 0.94 (Vostok), 0.98 (LEN), and 0.99 (RUS). Therefore, the anomalous winds are related, with high level of statistical significance, to negative deviations of the IMF BZ component. It is common knowledge that the southward IMF favors to the magnetospheric activity, the extreme disturbances in the solar wind being followed with confidence by strong magnetic substorms. So, we can wait that the anomalous winds above Antarctica would be associated with high magnetic activity as well. The AE index is commonly used as a characteristic of magnetic activity in the high latitudes and we applied the AE index in our analysis even though it is based exclusively on data from the northern hemisphere. As Figure 5c shows, the magnetic activity actually reached the pronounced maximum one day before development of the anomalous winds at the stations, but statistical significance of these changes is not too high (ss=0.79 for LEN, and ss=0.80 for RUS).

5. Anomalous winds and their relation to SOI

Southern Oscillation (SO) is determined (Philander and Rasmussen 1985) as a negative correlation between the sea level pressure fluctuations in the Southeast Pacific high and the North Australian-Indonesian low. A coupled system linking an anomalous warming of surface water in the eastern Pacific (El Nino) to an atmospheric branch SO, was named ENSO. During the years between warm events the opposite regularity often occurs and a cold phase of ENSO, the La Nina, exists (Van Loon and Shea 1985). Nature of the ENSO action is unknown. Stable links between Southern Oscillation and atmospheric processes in Antarctica was revealed in many studies (Trenberth 1980; Mo et al. 1987; Van Loon and Shea 1985, 1987; Parish and Bromwich 1987; Smith and Stearns 1993; Bromwich et al. 1993). The conclusion was made, that propagation of the katabatic winds from Antarctica is a phenomenon that is accompanied by changes that involve the entire southern hemisphere (Bromwich et al. 1993). To characterize the phase and intensity of the ENSO activity the Southern Oscillation Index (SOI) is used. SOI presents difference between the monthly pressure anomalies at Tahiti

(Central Pacific) and Darwin (North Australia) (Van Loon and Shea 1987). The SOI is a nondimensional index, which is negative when ENSO is in a warm phase (El Nio events) and positive when ENSO is in a cold phase (La Nina events). One of the most intriguing feature of El Nino events is the seasonal regularity in their occurrence: formation of ENSO occurs mainly during the southern autumn-winter season (Van Loon and Shea 1987). In our study we examined all large negative SOI deviations during 1868-2002 and separated them in two groups in accordance with their duration: the short-lived deviations, lasting less than 3 months (17 events), and long-lived deviations, lasting more 6 months (23 events). It turned out that long negative deviations (Figure 6), which correspond to real El-Nino events, start usually between March and June (thin lines), and their mean early variation (thick line) reaches the minimum in June and tends to restore in November/December. The short deviations of SOI can begin in any time of year and their mean monthly values are close to zero. Taking into account this peculiarity we shall analyze relation of El-Nino events to atmospheric processes in the winter Antarctic. To demonstrate the possible relation of the anomalous winds to SOI we have examined the mean angular distribution of the monthly winds (the wind roses) at each station for months preceding and succeeding the El-Nino beginning. Only El-Nino events with sharp onset (decrease of SOI value more than 1 during the month) have been included in the examination. Using the wind rose for the 4^{th} month, preceding the El-Nino onset, as a level of reference for all succeeding months, we constructed differential wind roses, characterizing the changes in the wind azimuths before and in course of the El-Nino event. Results of the analysis are presented in Figure 7 for stations Vostok and Russkaya as the differential wind roses in -3d, -2d, -1st, and zero (El-Nino onset) months. The evident excess of winds above the level of reference was observed 1-2 months ahead of the El-Nino at angles 195-210 for Vostok, 185-215 for Russkaya, and 270-300 for Leningradskaya (not shown). They correspond to secondary maximum in the wind distribution for LEN and RUS in Figure 4. It is meaningful that anomalous winds are typical of months preceding the El-Nino onset, not of succeeding months. The direction of anomalous winds is eastward (directly opposite to circumpolar flow) at LEN and strictly northward at RUS. At all three stations the wind roses for -3d and zero months are similar, suggesting that the wind system above Antarctica restores to initial state after the violation.

6. Relation of SOI to magnetic activity

Availability of statistically significant relationships between SOI and anomalous winds above the Antarctica, on the one hand, and anomalous winds and disturbed solar wind, on the other hand, makes it possible to suggest that linkage between development of SOI and the disturbed solar wind is available. Unfortunately, the monthly IMF data are very incomplete for years preceding 1998, and we had to examine the relation of SOI to AE index instead of IMF. Only sharp changes of SOI have been included in this examination, when the monthly value of SOI (negative or positive) was changed by 1 or more. The month of this sharp change has been taken as a zero date in the superposition analysis. Figure 8 shows behavior of SOI index for three types of changes in the southern oscillation: (a) sharp declination of SOI with subsequent keeping of negative value during many months (basically, it is real El-Nino events with sudden onset) observed in 1969, 1972, 1982, 1986, 1991, 1994, (b) sharp short-lived declination of SOI (1959, 1961, 1979, 1980, 1984, 1985), and (c) short-lived increase of SOI (1962, 1964, 1970, 1975). The low panel in Figure 8 presents the proper changes in AE index. The significant changes of the AE index in relation to the SOI changes (s.s. = 0.96) have been found only for El-Nino events. One can see, that in case of long negative SOI deviations the mean magnetic activity starts to increase 2-3 months before the beginning of El-Nino, reaches maximum just in month of the beginning, and continue to be high during the next some months. On the contrary, in cases of short-term positive or negative deviations of SOI, the magnetic activity does not show the noticeable changes before and after the SOI impulses. These results make it possible to conclude, that changes, negative or positive, in the southern oscillation occur irrespective of the solar wind influence, but development of the veritable El-Nino events, happening during southern winter, is likely influenced by the intense and lasting disturbances in the interplanetary electric field and correlate with corresponding magnetic activity.

7. Discussion and conclusion

A dynamic link between Antarctica and the large-scale circulation of the southern hemisphere was suggested by Trenberth (1980). He found influence of the topography of Antarctica on a blocking ridge common to the New Zealand area and its associated cut-off low over the Tasman Sea. As a result, Trenberth (1980) proposed that Antarctic processes may be related to changes in the Australian end of the Southern Oscillation system. The case study of Mo et al. (1987) showed that the amplitude and longevity of the New Zealand block is strongly influenced by cold air releases from the Antarctic continent. Smith and Stearns (1993) examined the monthly anomalies of surface pressure and temperature patterns in Antarctica in their relation to the Southern Oscillation index. They concluded that the atmospheric processes observed in Western-Pacific sector of Antarctica in periods before SOI minimum may be responsible for maintaining the New Zealand block and may influence the western branch of the ENSO. Our results, displaying appearance of the anomalous winds at the cost stations one-two months before El-Nino events, strongly support the idea argued by Trenberth (1980), Mo et al. (1987) and Smith and Stearns (1993). The data presented lead to the following conclusions:

1. The atmospheric parameters in zone of the Central Antarctic Ridge are dramatically influenced by the disturbed solar wind.
2. The warming at the ground level is observed when the interplanetary electric field of dawn-dusk direction is enhanced (DBZ <0). The atmospheric parameters at altitudes > 10 km respond to changes in ESW in opposite manner than at the ground level.
3. The dramatic warming in the Central Polar Region leads to reconstruction of the wind system above the Antarctic and can affect the atmospheric processes in the Southern Pacific.
4. Development of El-Nino events is likely influenced by the intense disturbances in the Interplanetary electric field.

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