CHAPTER 3

SUPERPOSED EPOCH APPROACH

3.1 Method of Analysis

The SPE is a simple statistical analysis technique which is applied to time series. Despite being simple, the SPE is one of the powerful analysis techniques if it is used carefully. The idea was that if you average the data in some clever way in relation to an event, the event signal will remain and all other influences will tend to average out [2]. Thus, the crucial part of applying this technique is to be able to define a proper event definition.

Having defined an event, data of a specifically designated interval were extracted from the complete dataset. Then, the selected data were superposed on each other taking the zero time as the event time. By simply dividing with the total number of identified events, results of SPE were obtained. As prescribed, if the identification of an event representing a physical process succesfully made, the results would reveal dynamic component of the response, or in other words, the information containing component of the response.

3.1.1 SPE Analysis of f_0F2 Values

For the SPE analysis of the F layer critical frequencies, f_0F2, for three different event definitions relying on the magnitude of polarity reversals of IMF B_z and the polarity of IMF B_y were constructed. Since f_0F2 values experience diurnal variation, to eliminate the cyclic behaviour, the diurnal variation of the f_0F2 values for the geomagnetically quiet period ($Kp \leq 2+$) was calculated statistically. Subtracting the diurnal variation calculated from the original data yielded the filtered one to a first approximation without any diurnal variation which can be used for the SPE analysis.

Since the purpose was to investigate the influences of the Interplanetary Magnetic Field (IMF), event definitions relied on the changes of the IMF. The events were classified in accordance with the following criteria:

- Event type 1
    1. Southward polarity change
    2. $|\Delta$ IMF B_z $|/\Delta t \geq 6$ to 11 nT/h
    3. IMF B_z Polarity should be same for 3 hours before and after the event
- Event type 2
    1. Southward polarity change
    2. $|\Delta$ IMF B_z $|/\Delta t \geq 6$ to 11 nT/h
    3. IMF B_z Polarity should be same for 3 hours before and after the event
    4. Positive IMF B_y Polarity during the reversal period
- Event type 3
    1. Southward polarity change
    2. $|\Delta$ IMF B_z $|/\Delta t \geq 6$ to 11 nT/h
    3. IMF B_z Polarity should be same for 3 hours before and after the event
    4. Negative IMF B_y Polarity during the reversal period

Table 3.1: Number of Occurances of Events (1973-1993)

$\Delta B/\Delta t$ (nT/h)	Event Type 1	Event Type 2	Event Type 3
≥ 6	216	51	52
≥ 7	159	38	35
≥ 8	112	29	21
≥ 9	86	23	18
≥ 10	67	17	13
≥ 11	50	11	10

Total number of events for all event definitions were tabulated in Table.3.1. The selected data for analysis were the data extracted data from the complete dataset with ±4 days around the event time.

3.2 Results

The number of southward turnings with the change in the hourly IMF B_z values, δB_z, in one hour exceeding a given value for the years 1973 to 1993 was shown in Figure 3.2. Superimposed on the same reference frame, the number of southward turnings with IMF $B_y > 0$ and IMF $B_y < 0$ during the event time of 8 hours were also shown. From this figure, it can be seen that over 190 turnings with $\delta B_z = 2$ nT/h; 40 turnings with $\delta B_z = 6$ nT/h; 12 turnings with $\delta B_z = 11$ nT/h. In order to define and quantify the ionospheric and geomagnetic responses to these IMF changes as clearly as possible, $\delta B_z \geq 6$ nT/h and $\delta B_z \geq 11$ nT/h events were selected. This enabled to investigate the effect of varying the threshold of δB_z on the ionospheric and geomagnetic parameters. Then, the **event type 1** definition was revised to include the IMF B_y polarity. Summarizing, the **event type 2** was refered to IMF $B_y < 0$ and the **event type 3** was refered to IMF $B_y > 0$ both 4 hours before and after the southward turning of IMF B_z.

As presribed in Section 3.1, to apply the SPE Method to δf_0F2, diurnal variation of f_0F2 were calculated and subtracted from the original data, so that refined data without daily variations could be obtained. In order to calculate the diurnal variation, as prescribed in Chapter 3.1, by averaging the geomagnetically quiet hourly values of f_0F2 15 days around an event, diurnal variation of f_0F2 was obtained, and for $\delta B_z \geq 6$ nT/h case, the diurnal variation was shown in Figure 3.1.

In the Figure 3.2, 3.3, 3.4, 3.5, the probabilities and cumulative probabilities of δf_0F2 for Vertical Ionosnde Arkhangelsk, Dst and Kp were also plotted. It can be seen that, although dialy variations were excluded, the probability of having f_0F2 equal to approximately -1 was maximum. This was due to the tendency of events to mostly happen at a certain time, yielding a peak slightly translated from the zero point.

Different than the case for f_0F2, the Dst index had its maximum probability near zero. This showed that Dst index do not have a daily variation like f_0F2. For the probability of 3 hour planetary Kp index, the maximum probable value was found to be approximately 2. Since 2+ value of Kp designates as the limit between quiet and disturbed conditions, probabilities calculated confirmed the designated value.

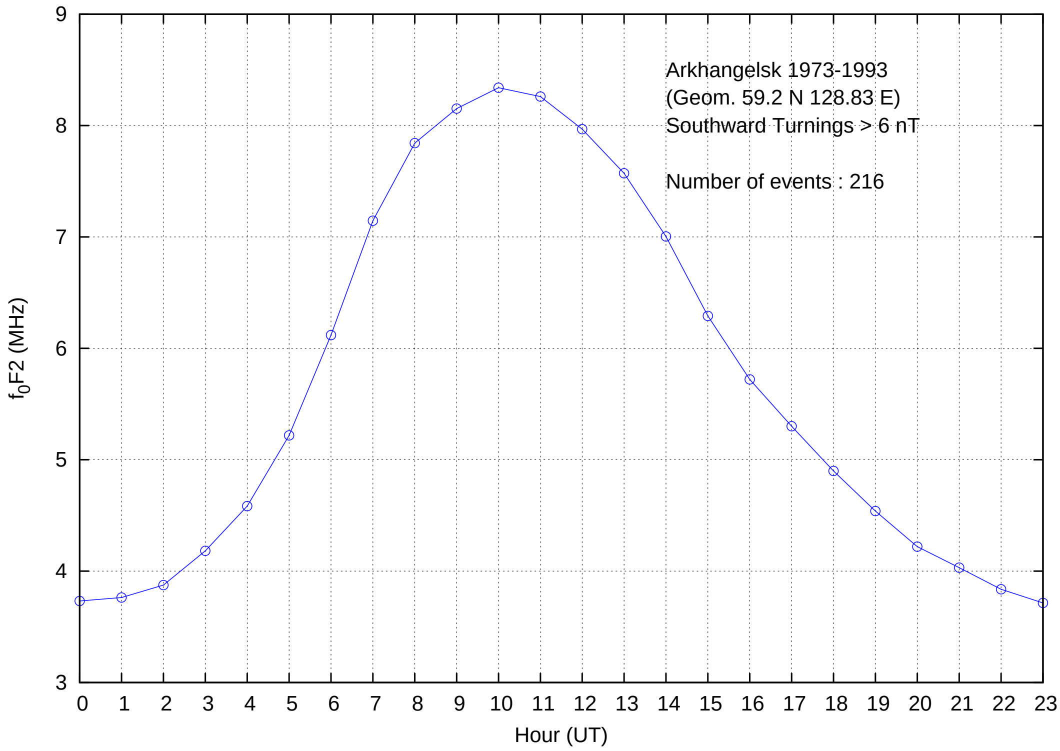

Figure 3.1: Diurnal Variation of δf_0F2 for Arkhangelsk Vertical Ionosonde

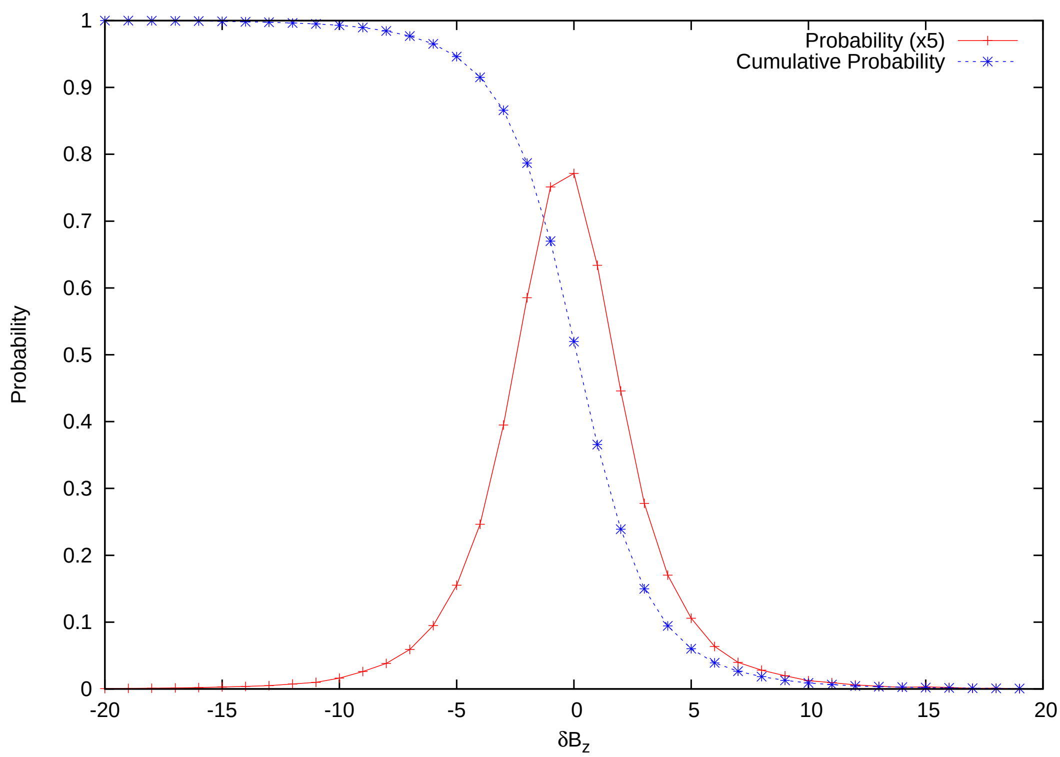

Figure 3.2: Probabilities and Cumulative Probabilities of IMF B_z

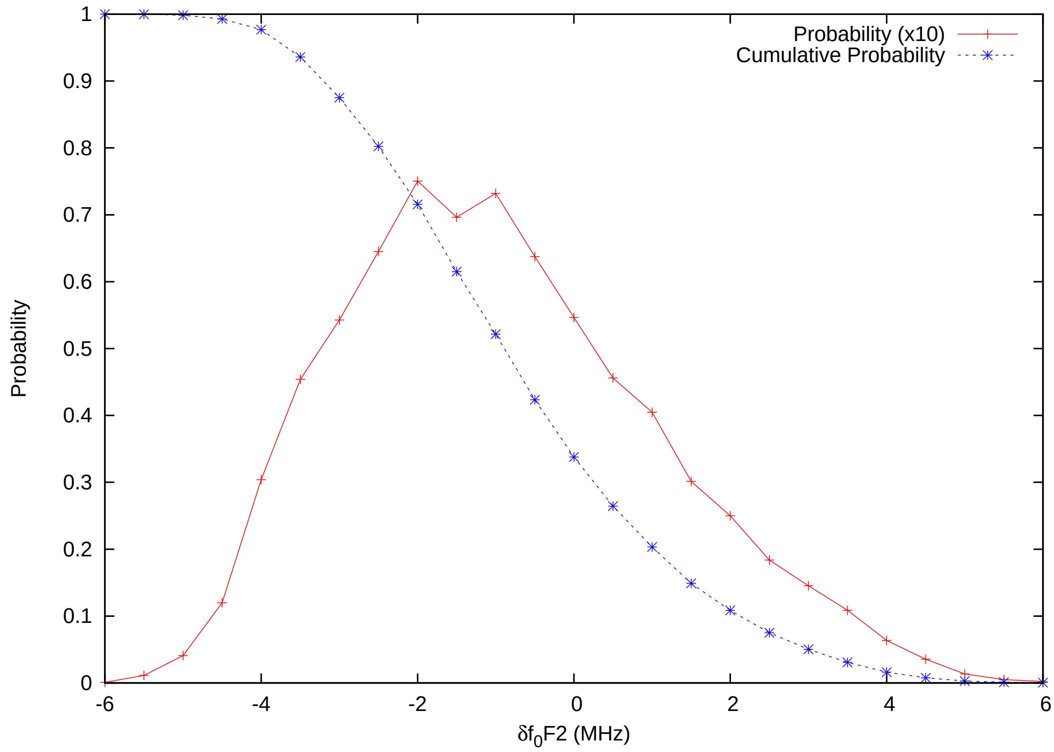

Figure 3.3: Probabilities and Cumulative Probabilities of f_0F2 values

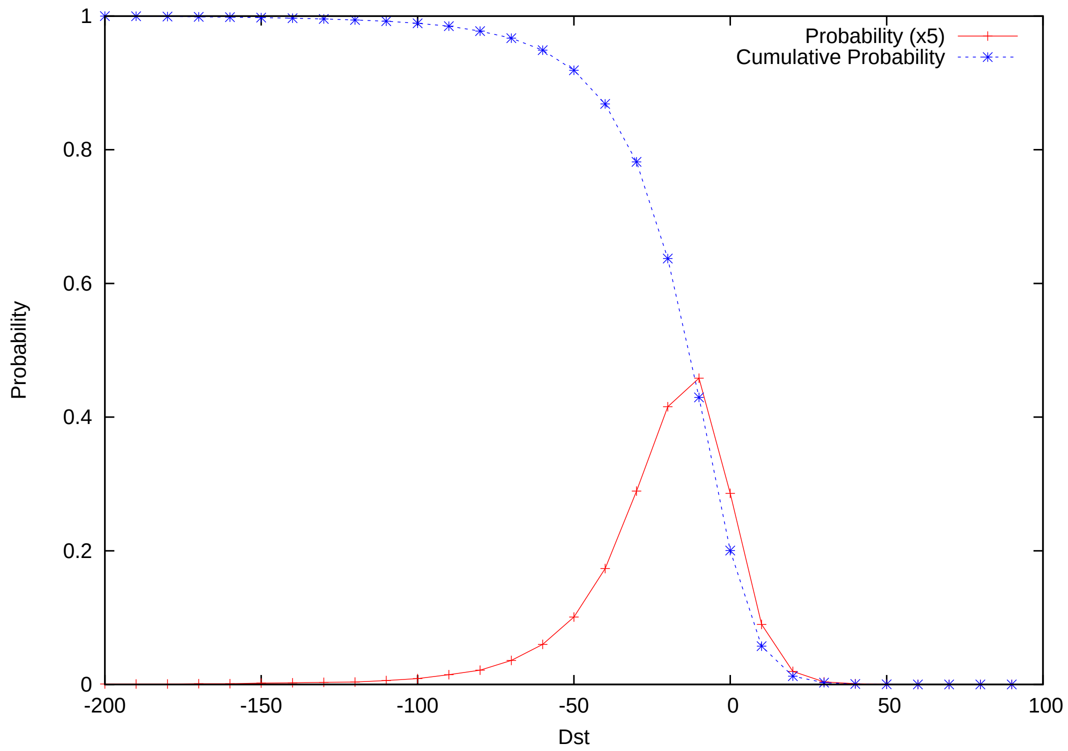

Figure 3.4: Probabilities and Cumulative Probabilities of Dst index

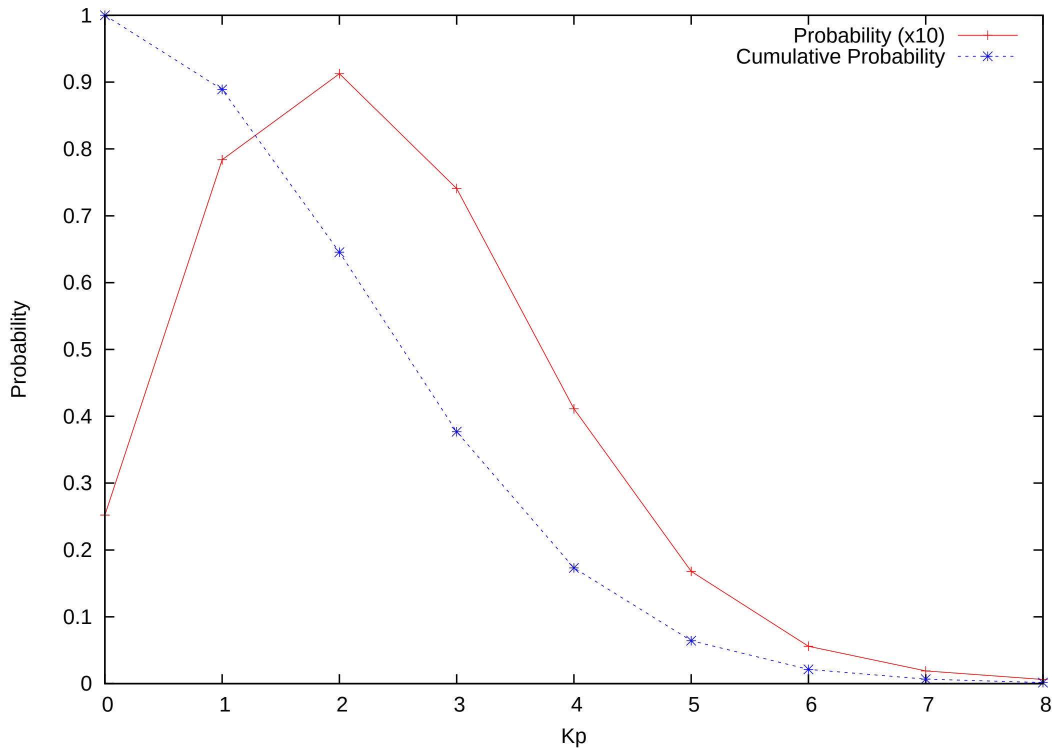

Figure 3.5: Probabilities and Cumulative Probabilities of Kp index

To be able to quantify the results, method was applied twice, which was first applied only for the IMF B_z reversal cases and the second was for the IMF B_z reversals with the IMF B_y criteria.

3.2.1 Superposed Epoch Analysis Results for IMF B_z reversals

3.2.1.1 Effects on Geomagnetic Activity

The geomagnetic response to the Interplanetary Magnetic Field variations could be traced from the geomagnetic indices. Thus, the SPE Method was applied to geomagnetic indices to reveal the response of the geomagnetic activity to IMF reversals.

Effects on Kp The effect of IMF B_z reversal on the 3 hour planetary Kp index was shown in Figure 3.6. The peak value of Kp was achieved approximately 3 hours after the zero time which was the event time.

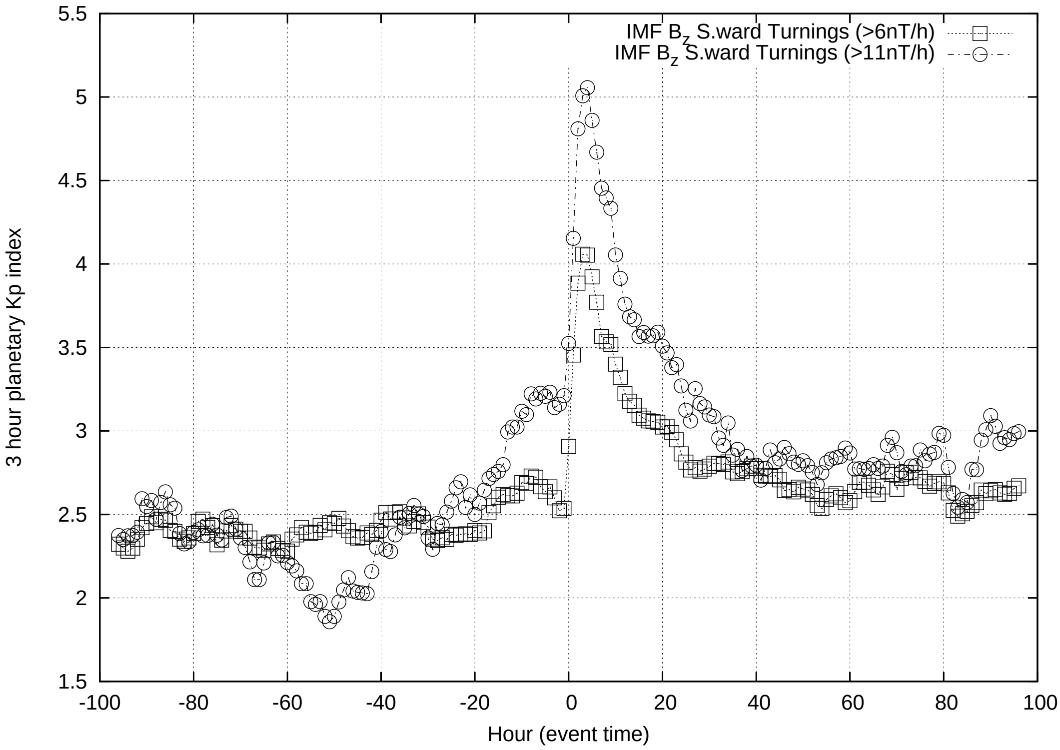

Figure 3.6: SPE Results of Kp index for southward turnings with $\delta B_z \geq 6$ nT/h and ≥ 11 nT/h

Kp index increased rapidly up to 4 and 5 for ΔIMF $B_z/\Delta t \geq 6$ nT/h and ΔIMF $B_z/\Delta t \geq 11$ nT/h, respectively. Two third of both cases were achieved ~20 hours after the zero time. These results were correlated with the ones computed by [16]

Effects on Dst The effect of IMF B_z reversal on the Dst index was shown in Figure 3.7. The peak value of Dst was achieved approximately 7 hours after the zero time which was the event time.

Dst averages about 15 nT and 19 nT before the event time in the previous 4 days and at the zero hour, Dst increases and it decreases rapidly to values as low as -40 nT and -60 nT for for $\delta B_z \geq 6$ nT/h and for $\delta B_z \geq 11$ nT/h, respectively. This represents a significant enhancement of the ring current. Two third of both cases were achieved ~20 hours after the zero time. These results were correlated with the ones computed by [16]. This was also correlated with the results obtained for the SPE results of Kp index.

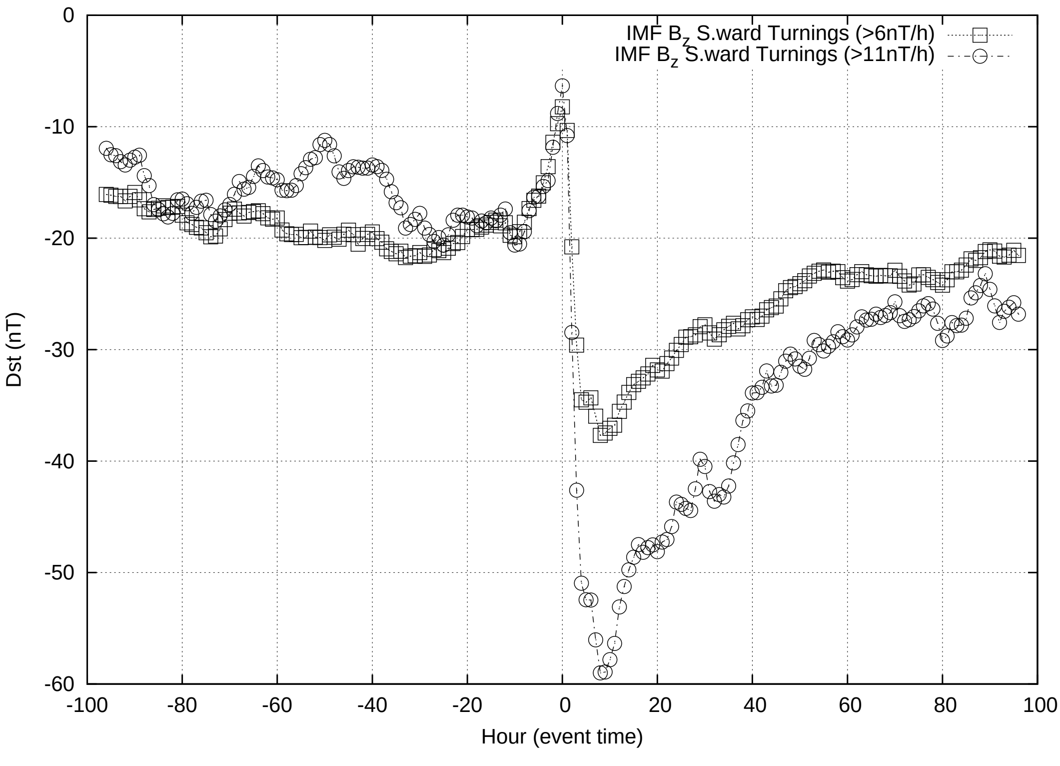

Figure 3.7: SPE Results of Dst index for southward turnings with $\delta B_z \geq 6$ nT/h and ≥ 11 nT/h

3.2.1.2 Effects on F layer Critical Frequency, f_0F2

The signal of Ionospheric variability as a response to the IMF reversals were also observed and plotted in Figures 3.8 and 3.9. Although there were small fluctuations before the event, after the zero time, event time, there was a sudden decrease in the value of δf_0F2, which was the signal of the IMF reversal signal. For both stations, Arkhangelsk and Slough, similar to geomagnetic indices, the values suddenly change and have their minimum values ~20 hours after the event, with the values -1.1 MHz and 1 MHz for Arkhangelsk and Slough, respectively.

Although there needs more detailed inspection, there should be a link between the decaying phases of f_0F2 and geomagnetic indices, since δf_0F2 achieved its minimum value at the time when the geomagnetic indices achieved their one third of their maximum values.

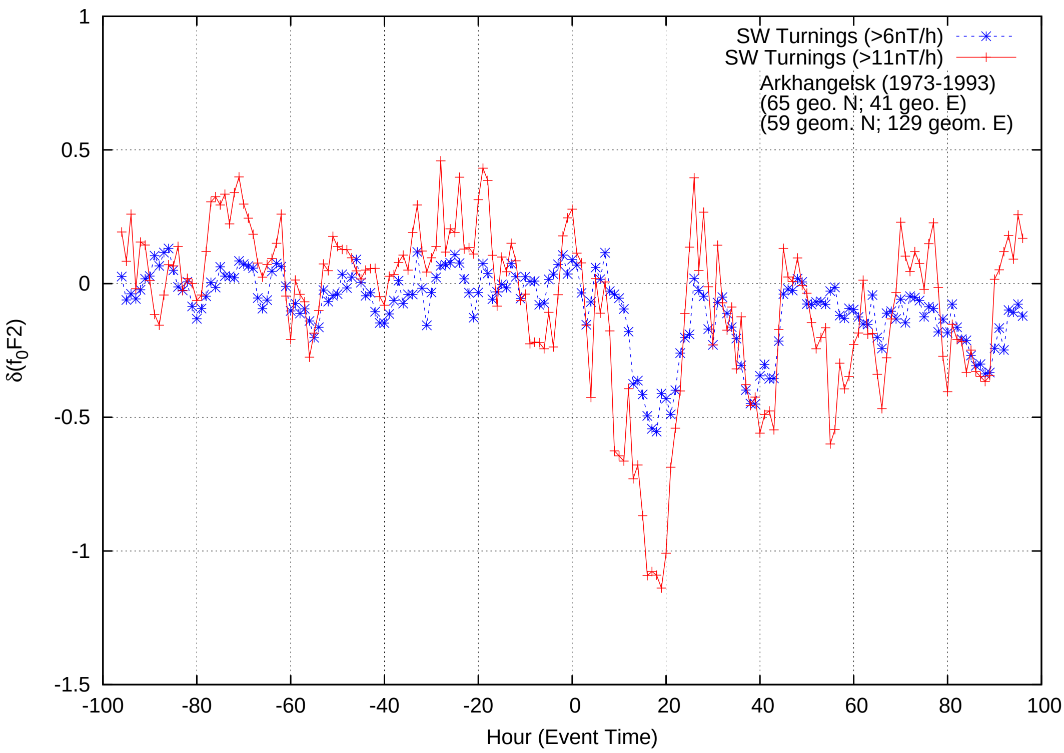

Figure 3.8: SPE Results for southward turnings with $\delta B_z \geq 6$nT/h and 11nT/h for Arkhangelsk

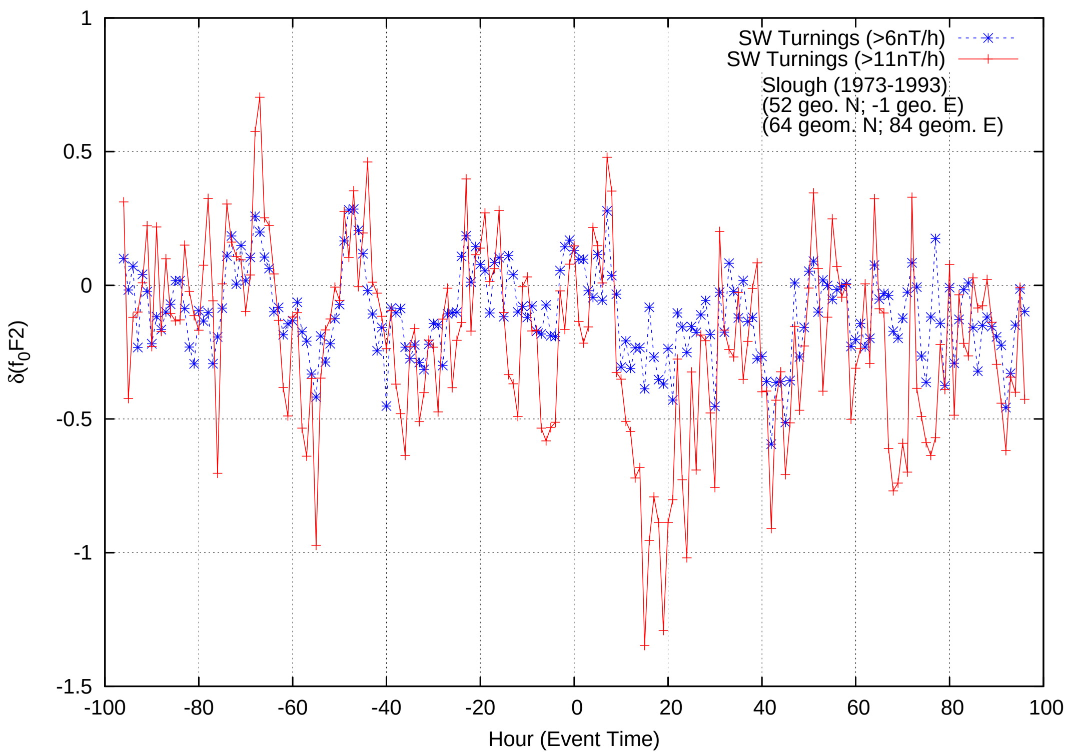

Figure 3.9: SPE Results for southward turnings with $\delta B_z \geq 6$nT/h and 11nT/h for Slough

3.2.2 Superposed Epoch Analysis Results for IMF B_z reversals during Steady IMF B_y Polarity

3.2.2.1 Effects on Geomagnetic Activity

Effects on Kp SPE Method showed that there was no significant difference for the events of $\delta B_z \geq 6$ nT/h. These results were plotted in Figure 3.10. As in the case of results obtained for the event type 1, the maximum value was 4 which was observed at 3 hours after the zero time.

However, as the magnitude of the reversal as increased to 11 nT/h, the IMF B_y signal became observable which be seen in Figure 3.11.

It was interesting to note that 3 hour planetary Kp values increases before the zero event time and remain relatively at high values for 20 hours after the zero event time when IMF $B_y > 0$ throughout the 4 day period.

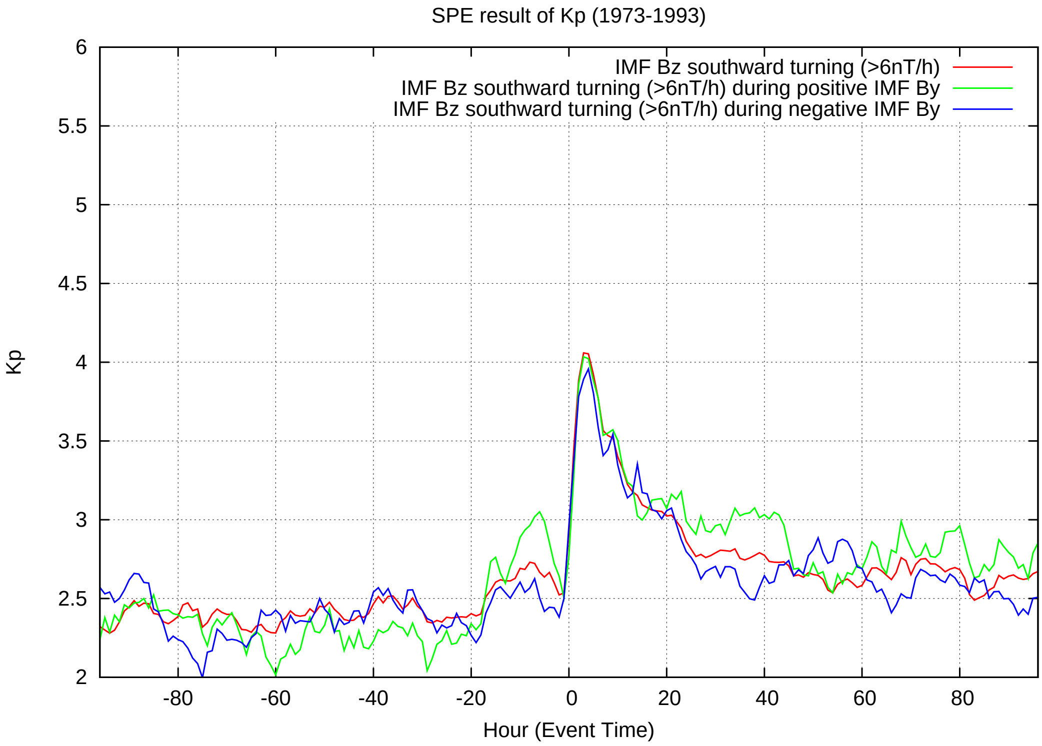

Figure 3.10: SPE Results of Kp index for southward turnings with $\delta B_z \geq 6$nT/h for three IMF B_y criteria

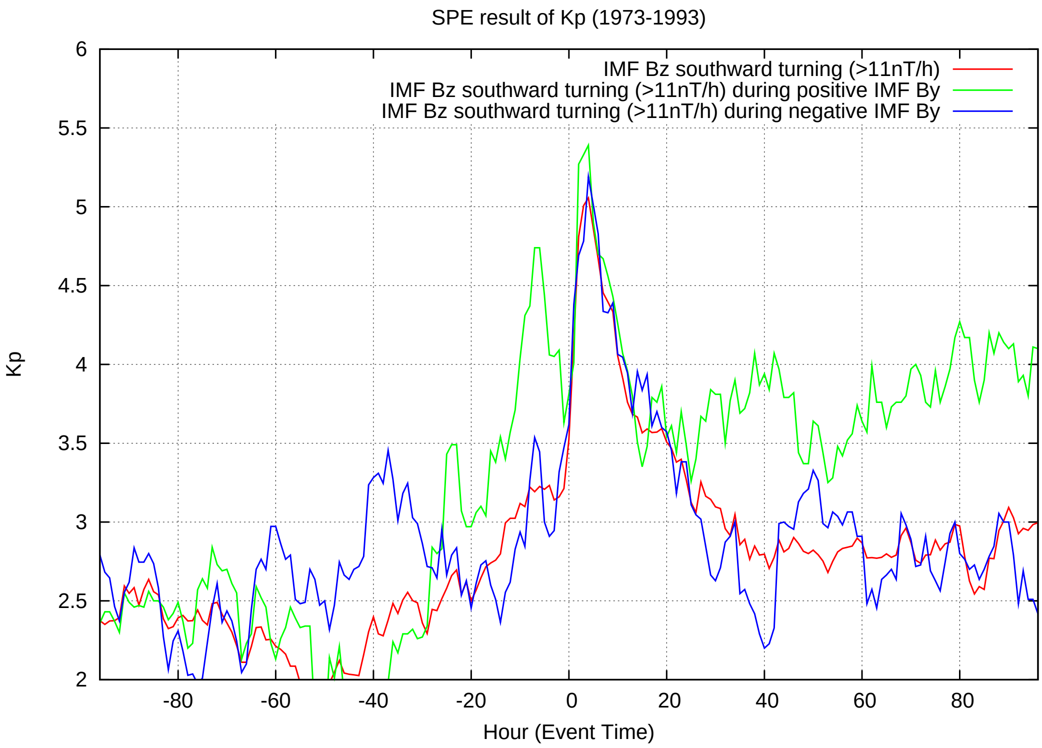

Figure 3.11: SPE Results of Kp index for southward turnings with $\delta B_z \geq 11$nT/h for three IMF B_y criteria

Effects on Dst As effects on the Kp index, there was not much significant difference between three event definitions.

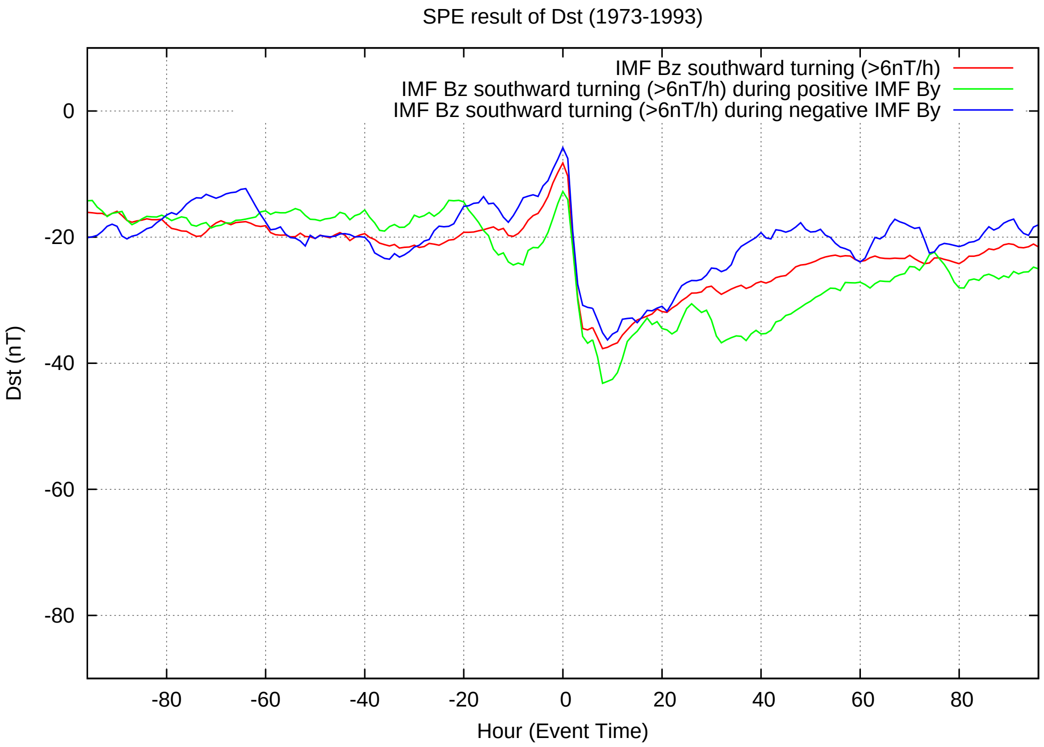

Figure 3.12: SPE Results of Dst index for southward turnings with $\delta B_z \geq 6$nT/h for three IMF B_y criteria

In the case of the Dst values, following the zero time, the Dst values remain relatively at low values for the IMF $B_y > 0$ polarity during the 4 day period after the zero event time. Moreover, it can be interpreted that the positive IMF B_y was continued more than 3 days which indicates the continuation of enhanced ring current activity.

3.2.2.2 Effects on F layer Critical Frequency, f_0F2

It was interesting to note that after the IMF B_y criteria switched on, the southward turnings of the IMF B_z, the SPE results of δf_0F2 values of event 2 and event 3 seem to exhibit a symmetrical bahaviour with respect to the δf_0F2 values of event type 1 within the first 20 hours after the zero event time. In addition to this apperance, the δf_0F2 values after the zero event time were very similar for the event type 1 and event type 2 cases.

With the limitations that f_0F2 values were not continuous indefinitely as the geomagnetic

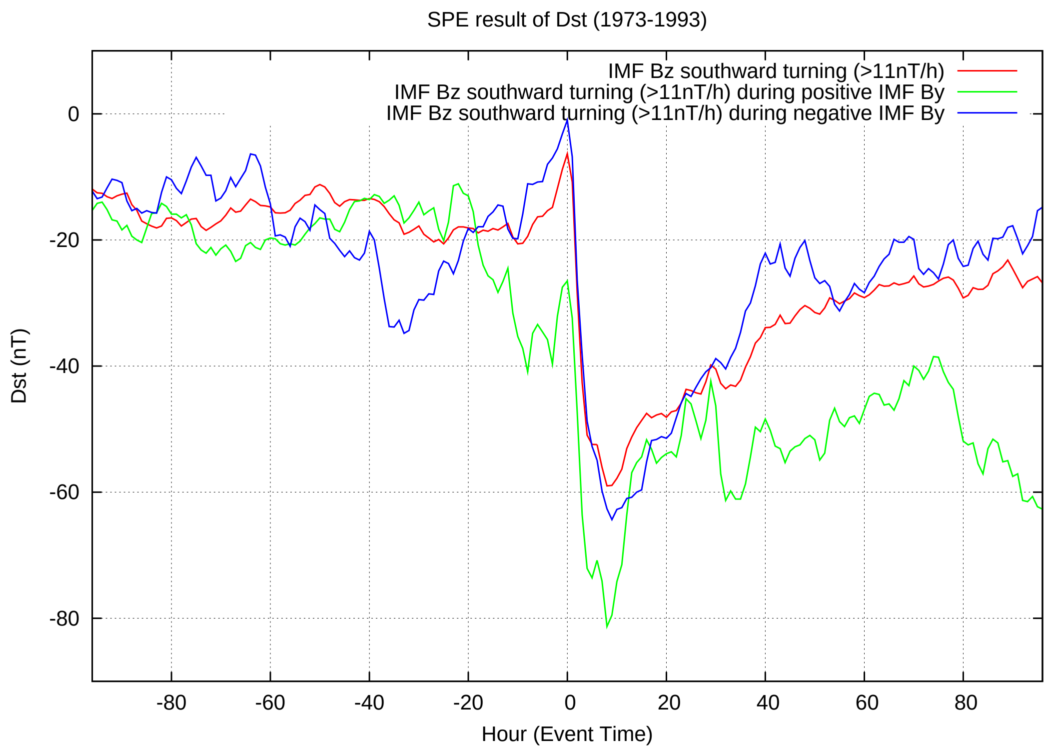

Figure 3.13: SPE Results of Dst index for southward turnings with $\delta B_z \geq 11$nT/h for three IMF B_y criteria

indices during event times, the event 2 and event 3 criteria could not be met with significant number of event cases. Thus, the analysis could not be carried out with these criteria using Superposed Epoch Method.

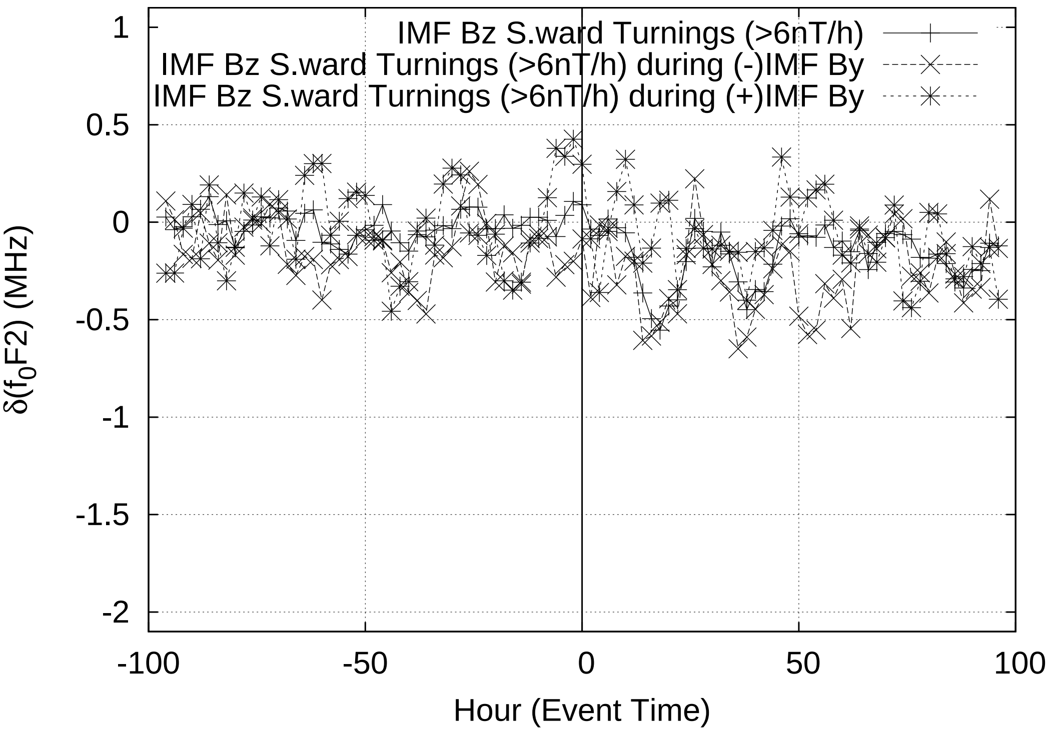

Figure 3.14: SPE Results of f_0F2 for southward turnings with $\delta B_z \geq 6$nT/h for three IMF B_y criteria