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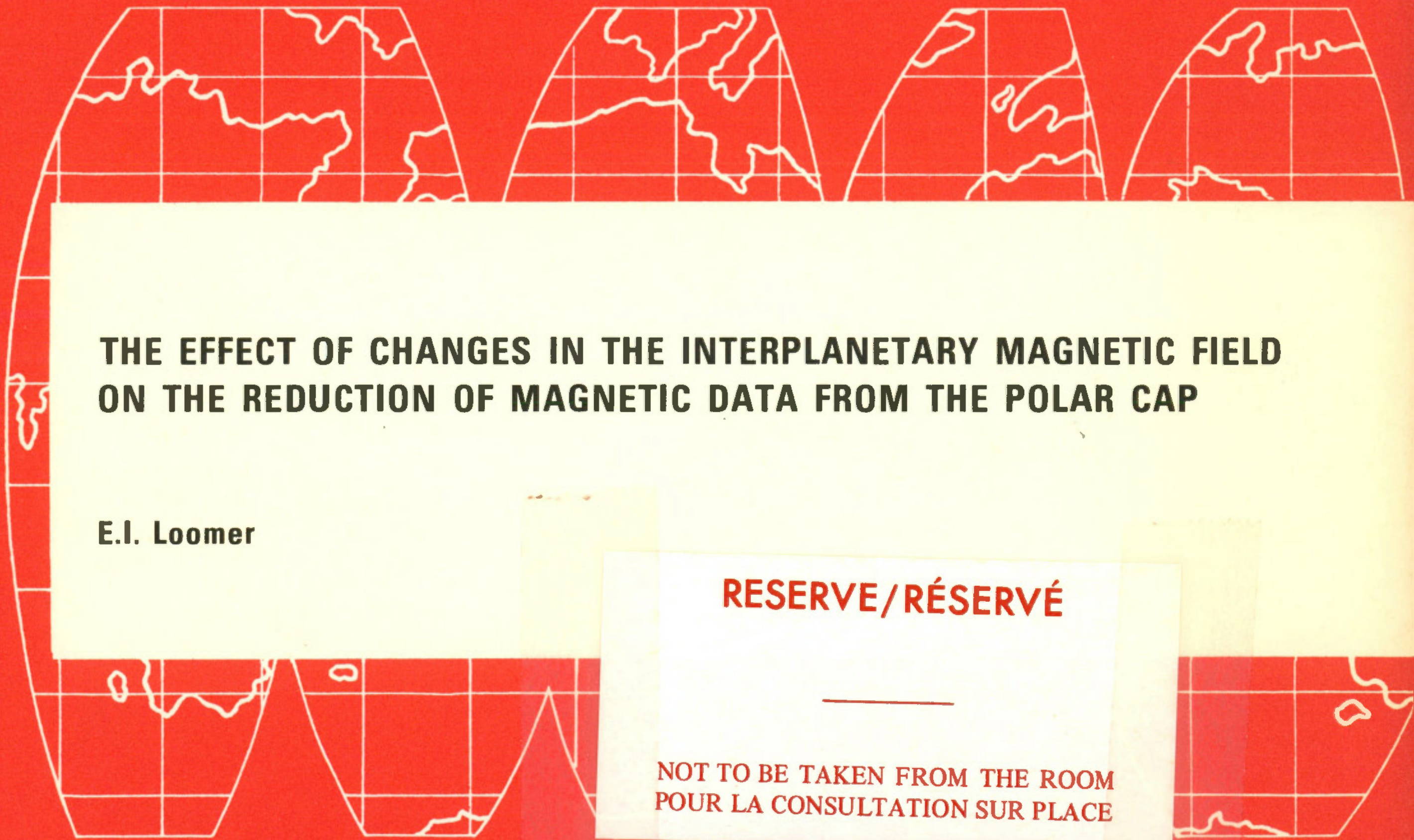

THE EFFECT OF CHANGES IN THE INTERPLANETARY MAGNETIC FIELD ON THE REDUCTION OF MAGNETIC DATA FROM THE POLAR CAP

E.I. Loomer

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CONTENTS

Abstract

Data from the high-latitude Canadian magnetic observatories at Resolute Bay, Mould Bay and Cambridge Bay have been analyzed to determine the effect of changes in interplanetary magnetic field (IMF) sector polarity on magnetic field variations in the polar cap. Several implications of these effects for the reduction of observatory and survey data from the polar cap are discussed.

The diurnal variation of the field in the polar cap and the distribution of magnetic disturbance are shown to differ systematically between positive and negative sector days and between the two six-month intervals January to June and July to December. It is suggested that these differences result from the annual variation in the tilting of the sun relative to the earth's magnetic field.

A consistent change in the form of the annual variation in X and Y at Resolute Bay and Mould Bay with a change in the IMF sector polarity has been observed.

Résumé

Les données des observatoires magnétiques canadiennes des hautes latitudes à Resolute Bay, Mould Bay et Cambridge Bay furent analysées pour déterminer l'effet de changement de polarité de secteur dans le champ magnétique interplanétaire (IMF) sur la réduction de données magnétiques du cap polaire. Plusieurs implications de ces effets pour la réduction des données des observatoires et des relevées au cap polaire sont discutés.

Une différence systématique est indiquée pour la variation diurne du champ au cap polaire et la distribution des perturbations magnétiques entre les jours de secteur positif et les jours de secteur négatif et entre les deux intervals de janvier à juin et de juillet à décembre. Il est proposé que ces différences sont du à la variation annuelle de l'inclinaison solaire relatif au champ magnétique terrestre.

Un changement régulier a été observé entre la forme de variation annuelle de X et Y à Resolute Bay et Mould Bay et un changement de polarité de secteur du IMF.

THE EFFECT OF CHANGES IN THE INTERPLANETARY MAGNETIC FIELD ON THE REDUCTION OF MAGNETIC DATA FROM THE POLAR CAP

E.I. Loomer

Introduction

The dominant zones of magnetic field behaviour in Canada are the auroral oval and the polar cap, with boundaries defined by physical features in the magnetosphere. Figure 1, showing a noon-midnight meridional section of a model of the magnetosphere, illustrates the compression of the earth's magnetic field by the solar wind[1]. In this compression, the earth's field lines at polar cap latitudes are swept back into the tail of the magnetosphere. As a result of this anti-solar convection of field lines, a field-free cleft or cusp is formed around the noon meridian into which the solar wind penetrates on the sun-ward side of the polar cap. In this penetration interplanetary magnetic field (IMF) lines are connected to the field lines in the polar cap. On the earth's surface the high latitude boundary of the day-side cusp is, on the average, the 79° invariant latitude (INVL) line. The polar cap, characterized by open field lines, is conveniently defined as the region contained within the poleward boundary of the day-side cusp.

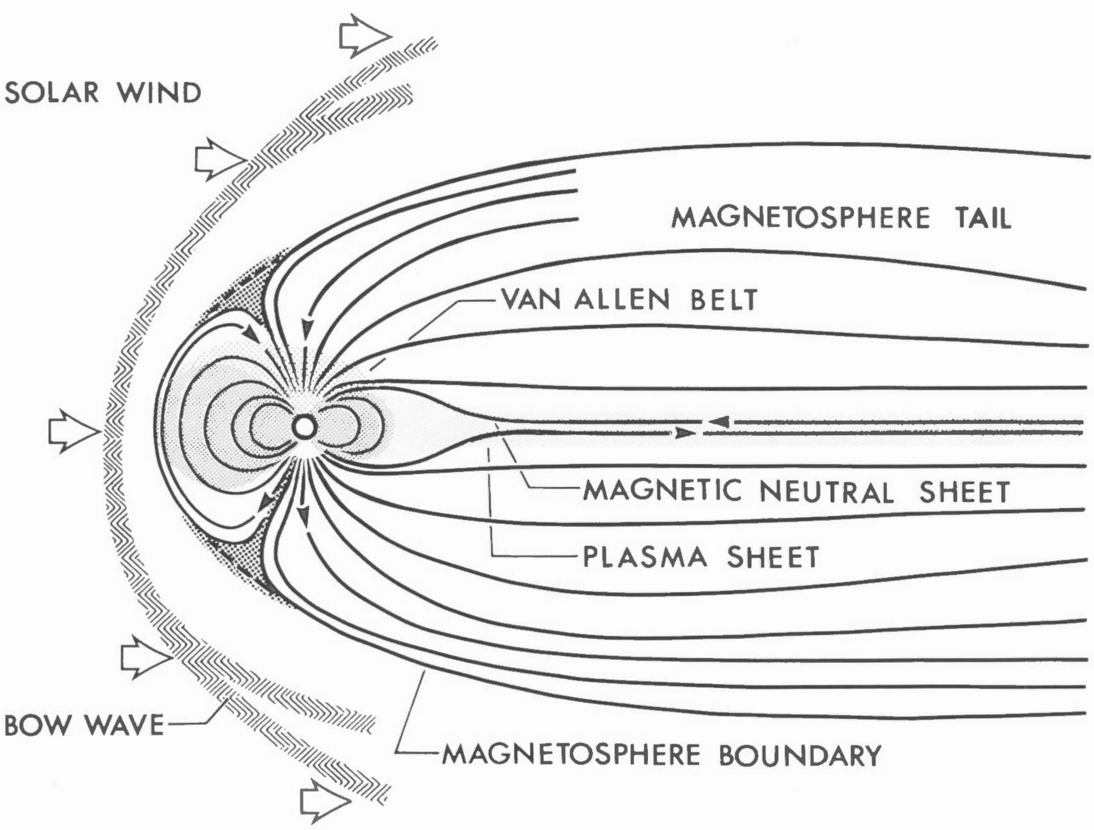

Figure 1. Model of magnetosphere.

In an early study of magnetic disturbance in the polar cap, it was found that a persistent 24-hour wave did not exist in the Z diurnal variation at Resolute Bay[2]. It was later shown that the polarity of the IMF had a systematic influence on high latitude geomagnetic variations,[3,4,5,6] and that the magnetic signature which most clearly characterizes the polar cap regime is the enhancement or depression of the vertical component in the hours around local noon. This effect is attributed to the penetration of interplanetary fields into the polar ionosphere. Described very briefly, the IMF consists of small magnetic fields of solar origin frozen into the solar wind or plasma flowing from the sun. The IMF lines are stretched out into Archimedes' spirals owing to the radial flow of the plasma from the sun and the rotation of the sun. The Archimedes' angle is about 45^o at the position of the earth. The IMF vector along the Archimedes' spiral has a radial component away from the sun or towards the sun, and an azimuthal component. Interplanetary space may be divided into alternating spiral sectors in each of which the radial component is directed either towards or away from the sun. This so-called sector structure[7] is repeated every 27 days with only slight distortion. The existence of an azimuthal component, which is directed westward in the toward sector and eastward in the away sector, leads to an asymmetry in the polar electric field and convection pattern[8]. This asymmetry gives rise to significant differences in the daily magnetic variation observed at polar cap stations between away and toward days.

An annual variation in the predominant polarity (toward or away from the sun) of the interplanetary magnetic field has been discussed by several authors.[9,10] An annual variation in the IMF effect observed at the earth would result from the annual variation in the tilting of the sun relative to the earth's magnetic field. During the six-month interval Dec 7 to Jun 7 the southern polar region of the sun is tipped towards the earth, and the predominant polarity of the IMF should be the same as that of the southern polar region of the sun, and vice versa for the interval Jun 7 to Dec 7. If this is the case, since the polarity of the sun's polar regions changes with a 22 year cycle, such a cycle should also be observed in the distribution of the predominant IMF polarity at the earth.

As all the landmass in the polar cap of the northern hemisphere is contained within the Canadian archipelago and northern Greenland, the Canadian polar cap observatories at Resolute Bay (RES) and Mould Bay (MBC) are essential in assessing IMF effects on magnetic data recorded at the surface of the earth. Cambridge Bay (CBB), normally in the polar cleft region, and Baker Lake (BLC), a typical transition station with both polar cap and auroral oval characteristics, are useful in interpreting certain aspects of the IMF effect. However, the boundaries of the auroral oval and polar cap are not fixed but may vary through several degrees with season and with the level of magnetic activity. There are occasional invasions of one zone by the other; e.g., Mould Bay, generally a polar cap station, does on occasion register sub-storms of very great intensity characteristic of an auroral oval station. On the other hand, magnetic field changes in the afternoon hours typical of the IMF effect in the polar cap were observed at Churchill during the unusually intense storm of August 4, 1972.[11] A map showing the location of the Canadian observatories is reproduced as Figure 2.

Methods generally used to reduce observatory and survey data from the polar cap and cleft regions should be re-examined in view of our present knowledge of the IMF effects in this area. In particular, the magnitude of these effects on quiet day levels, and on the diurnal and annual variation of the magnetic field could be expected to require some changes in conventional methods of data handling.

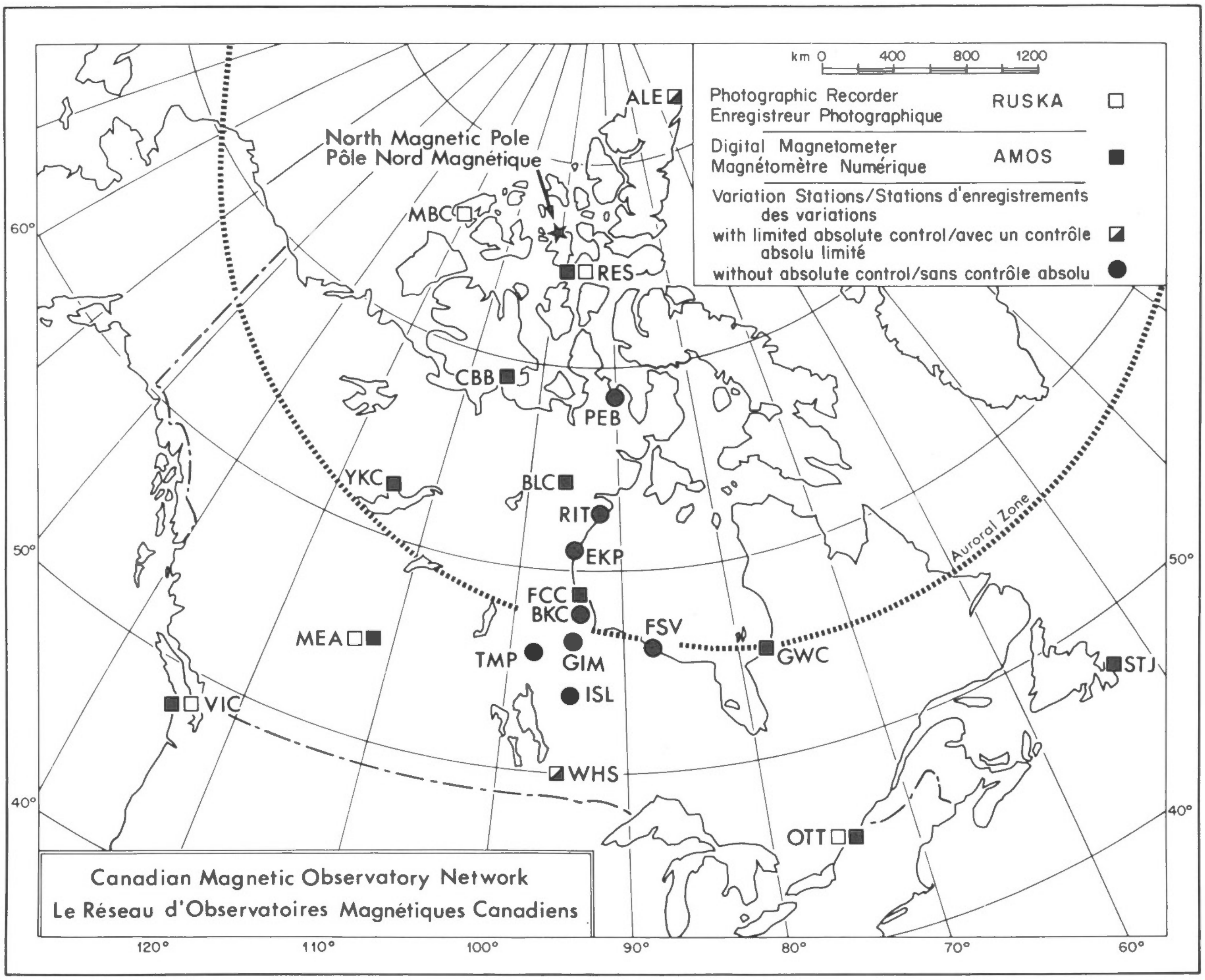

Figure 2. Map showing Canadian observatory network.

Variation of the IMF effect 1963-1973

As of June 1973 information on IMF sector polarity inferred from mean hourly values of the vertical component Z at Resolute Bay and Thule in the arctic and Vostok in the antarctic is published monthly by IZMIRAN, Moscow. By convention the IMF polarity is positive in a sector where the predominant direction of the field is away from the sun and a polar cap observatory records a depression in Z around local noon. Similarly the IMF polarity is negative in a sector where the predominant direction is towards the sun, and a polar cap observatory records an enhancement in Z around local noon. Effects opposite in sign to Z are observed in the horizontal components. At stations on or near the boundary of the polar cap, the effect is predominantly in H(X).[3]

For the 11-year solar cycle prior to 1973 a selection of away and toward days was made from the Z mean hourly value tables for Resolute Bay. Days were selected with means differing from the monthly mean by 20 nT or more. The 20 nT limit was adopted to ensure that the days chosen have a well-defined polarity, and that days on which polarities were mixed or for some other reason uncertain would be excluded. In effect the days for this period have been divided into three classes: +Δ Z days showing a positive change in Z around noon; -Δ Z days showing a negative change in Z around noon; and days which do not satisfy the selection criterion. Over the 11-year period investigated, 15% of the days in the winter, 50% in the equinoxes, and about 70% in the summer were classified as +Δ Z or -Δ Z days.

The total departure of the Z daily means from the monthly mean for the days selected at Resolute Bay has been chosen to define the IMF effect in the northern polar cap. Sums for +Δ Z days and -Δ Z days (1963-1973) have been plotted (Figure 3(a)) about a common zero line to illustrate the high degree of symmetry in the IMF effect between the two classes of days. A similar plot (Figure 3(b)) has been made for the years 1973.5 to 1977, based on the IZMIRAN classification. A pronounced seasonal variation is evident: the average amplitude of the days selected for the summer months is about twice that found for the winter. A marked decrease in winter is expected owing to the decrease in the conductivity of the polar ionosphere in winter. In addition, the change in the direction of the magnetic axis relative to the solar wind may reduce the possibility of the precipitation of particles in winter.

A closer comparison of the curves in Figure 3(a) reveals some interesting asymmetries. The IMF effect is more pronounced (by 25 - 35%) in the Jan to Jun months than in the latter half of the year for both +ΔZ and -ΔZ days. Also the effect observed on +Δ Z days is generally somewhat larger (by about 10%) than the effect observed on the -Δ Z days. A further asymmetry is evident for August 1972: the very large disturbance on August 4 of that year has led to a second maximum in the Σ + Δ Z curve.

An 11-year cycle is suggested by the small amplitude of the IMF effect in 1965, and the much larger amplitude observed in 1969 and 1970, the years of maximum activity in the solar cycle (Figure 4). 1973 was considerably more active magnetically than either of these years, but much more data is of course required before the precise nature of the 11-year variation of the IMF effect can be defined.

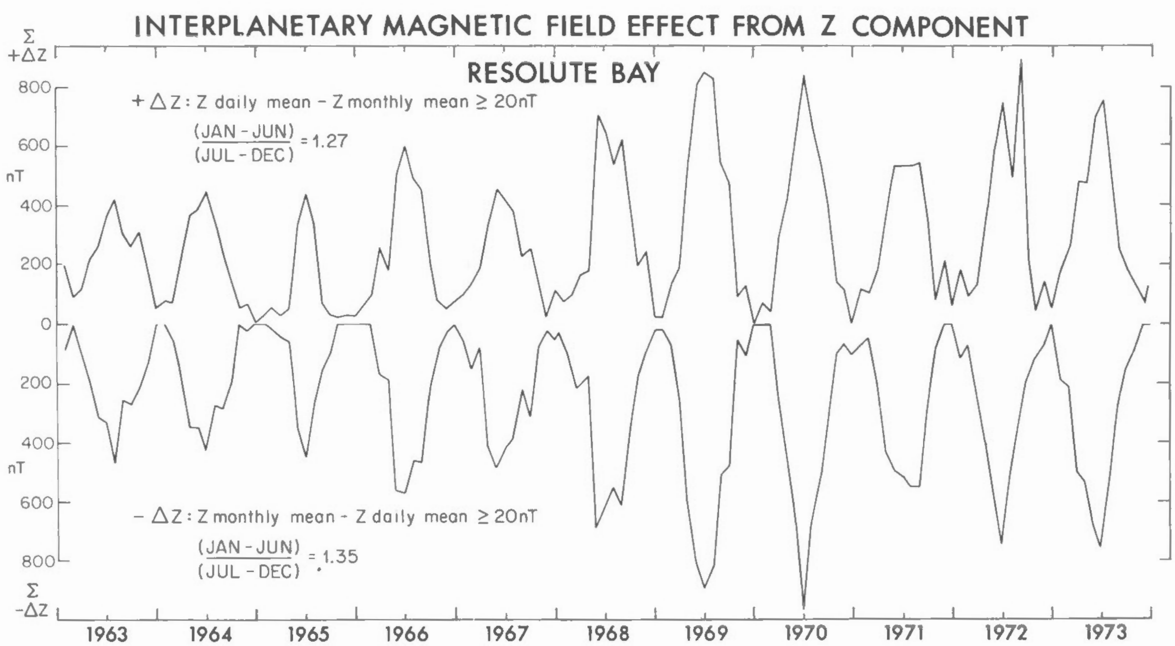

Figure 3(a). Positive and negative sector days determined from Z mean hourly values at Resolute Bay 1963 to 1973.

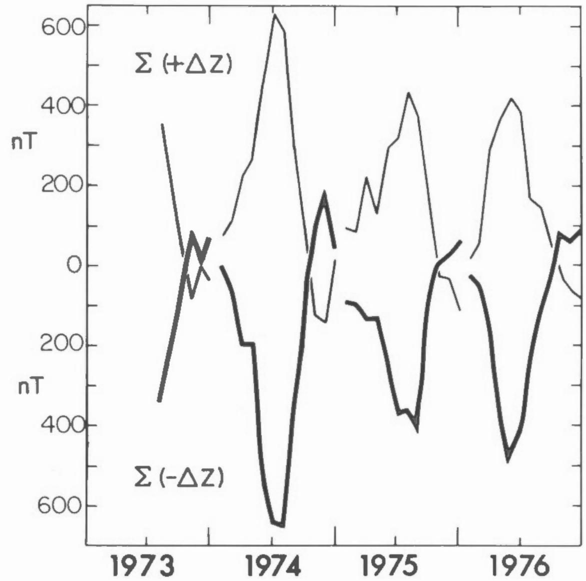

Figure 3(b). Positive and negative sector days determined from IZMIRAN listings (1973.5 - 1977).

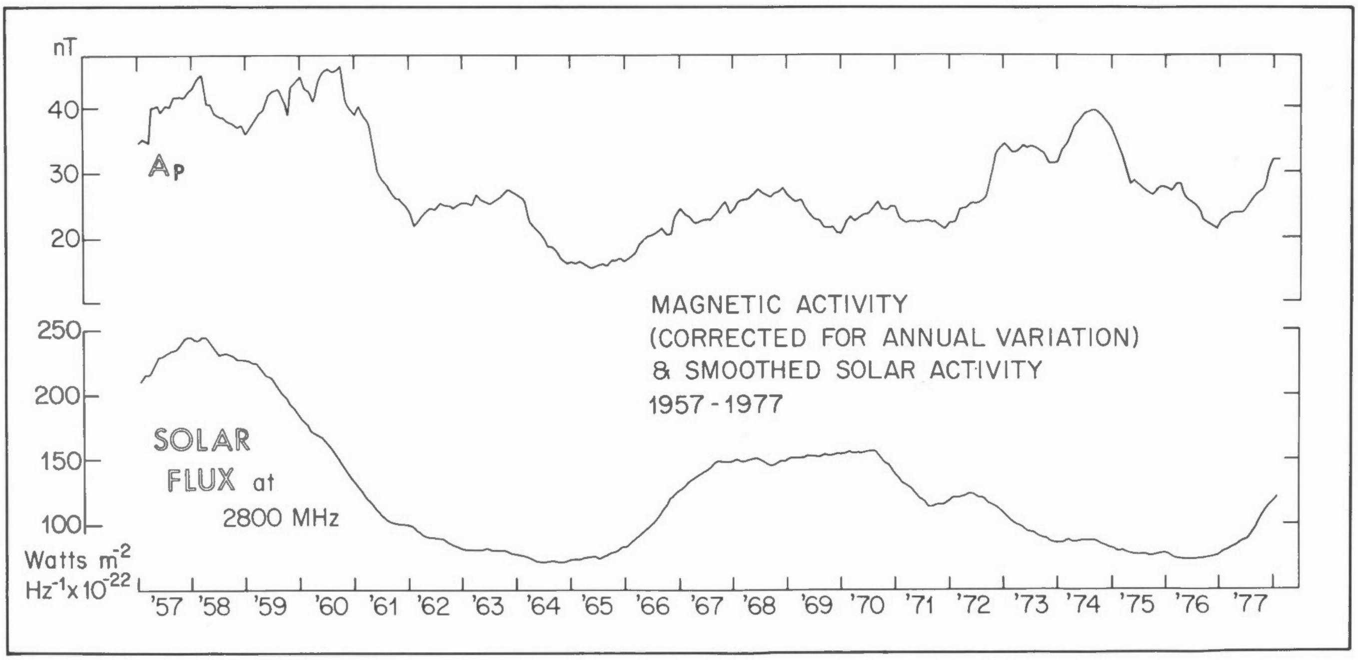

Figure 4. Eleven-year solar and magnetic activity cycle.

Magnetic Disturbance and Sector Polarity

The distribution of the international quiet and disturbed days between the $+\Delta Z$ and the $-\Delta Z$ days selected on the basis of RES daily means had suggested a significant association in winter between the $+\Delta Z$ days and magnetic disturbance. However, the IMF effect is not readily identified in the winter months on the RES records, and the number of days selected in the winter was relatively small: four times as many days on the average were selected in summer as in winter. Moreover, owing to the small amplitude of the IMF effect in the northern hemisphere in winter, and the poleward contraction of the auroral oval, daily means in Z are strongly influenced by magnetic activity in the oval, and the identification of sector polarities by Z daily means is not always certain. If the IZMIRAN listings, available since 1973.5, are used, no significant association of magnetic disturbance in winter with $+\Delta Z$ days is found. However, if the data are analyzed in the two periods (Jan to Jun) and (Jul to Dec) rather than by season a strong association is observed between the international disturbed (ID) and quiet (IQ) days and sector polarity. As shown in Table 1 this association reverses between (Jan - Jun) and (Jul - Dec). This is consistent with the observation reported by several authors[12,13,14] that a spring maximum of activity is predominant when the direction of the IMF is towards the sun, and a fall maximum when the direction is away from the sun.

TABLE 1

Summary of Association of I_D and I_Q Days with Sector Polarity (inferred)

		% of I_Q Days clearly identified as	
		$+\Delta Z$ days	$-\Delta Z$ days
1973.5 - 1978.5	Jan-Jun	20	54
	Jul-Dec	52	31
	Winter	39	42
	Equinox	39	47
	Summer	30	49
		% of I_D Days clearly identified as	
		$+\Delta Z$ days	$-\Delta Z$ days
1973.5 - 1978.5	Jan-Jun	57	27
	Jul-Dec	15	70
	Winter	35	50
	Equinox	38	44
	Summer	34	51

Effect of IMF changes on the Quiet-day Mean in the Polar Cap

In contrast with conditions in the auroral oval, the field-changes from day to day are remarkably uniform throughout the polar cap. To illustrate this, daily mean values in X and Y at RES, MBC and CBB were plotted for selected days for the summer months of 1972 and 1973; the results for 1973 are shown in Figures 5 and 6, together with the daily means for RES Z. Daily means were used in order to eliminate differences in the diurnal variation at the three stations. The days selected were relatively quiet. No day was used which showed any effect of the midnight activity originating in the auroral oval. As ring current effects in the horizontal component at these latitudes is very small, it can therefore be assumed that the field changes shown result from IMF effects. The IMF effect on the horizontal components of the field should be opposite to the effect in Z. This is clearly the case, as a comparison with RES Z shows. It is evident that RES and MBC correlate very highly. The correlation between these stations and CBB is not as high. This is to be expected owing to the position of CBB at the edge of the polar cap. In particular, August 4 and 5 do not show the expected change at CBB in X and Y.

The magnitude of the effect on the quiet day level is most impressive. For example for these stations, the change between the daily mean values in X for two successive international quiet days, August 17 and 18, is 30 to 40 nT; from June 9 to 10 the change is over 80 nT.

Regression equations were calculated in X and Y between RES and MBC data, and between CBB and MBC data, for relatively quiet days in the summer months; for international quiet days and for the midnight level on relatively quiet days. Using daily means for the 43 relatively quiet days in the summer, the correlation between RES and MBC was 0.967 in X and 0.827 in Y. The standard error in estimating RES values from MBC values was 6 nT in X and 10 nT in Y. The standard error in estimating MBC values from CBB was about 14 nT in both X and Y. The best correlation was found using daily means on relatively quiet days. Standard errors of estimate of similar magnitude have been recently reported by Dawson and Newitt.[15]

Effect of IMF on Diurnal Variation in the Polar Cap

Diurnal variation curves in X, Y, Z were drawn for RES, CBB and MBC (1974 - 1976) for the two classes of day ($+\Delta Z$ and $-\Delta Z$) for winter, equinox and summer, and for the periods (Jan-Jun) and (Jul-Dec). Only the days for which a definite sector polarity was assigned in the IZMIRAN listings were selected for this analysis. The curves for 1976, which are typical for this period, are shown in Figure 7.

The diurnal variation curves are similar at RES and MBC. The curves are more confused and difficult to interpret in the winter, when the IMF effect is very small or missing in the northern polar cap. The expected day-time effect in all elements and the pronounced phase shift in Z in summer and equinox is observed at both RES and MBC. At all three stations both X and Y curves show a distinct separation in level of field for these two classes of days in summer. The field separation is relatively small in all elements around local midnight.

The effect in Z is especially large at RES in the summer, where the maximum difference between mean hourly values on $+\Delta Z$ and $-\Delta Z$ days is around 200 nT at local noon (223 nT at 19 - 20 UT in 1974). Corresponding differences in X and Y were -82 nT (19 - 20 UT) and -65 nT (15 - 16 UT) respectively. At CBB the major effect is in X, where the maximum difference between mean hourly values in summer on $+\Delta Z$ and $-\Delta Z$ days was -152 nT at 17 - 18 UT in 1975.

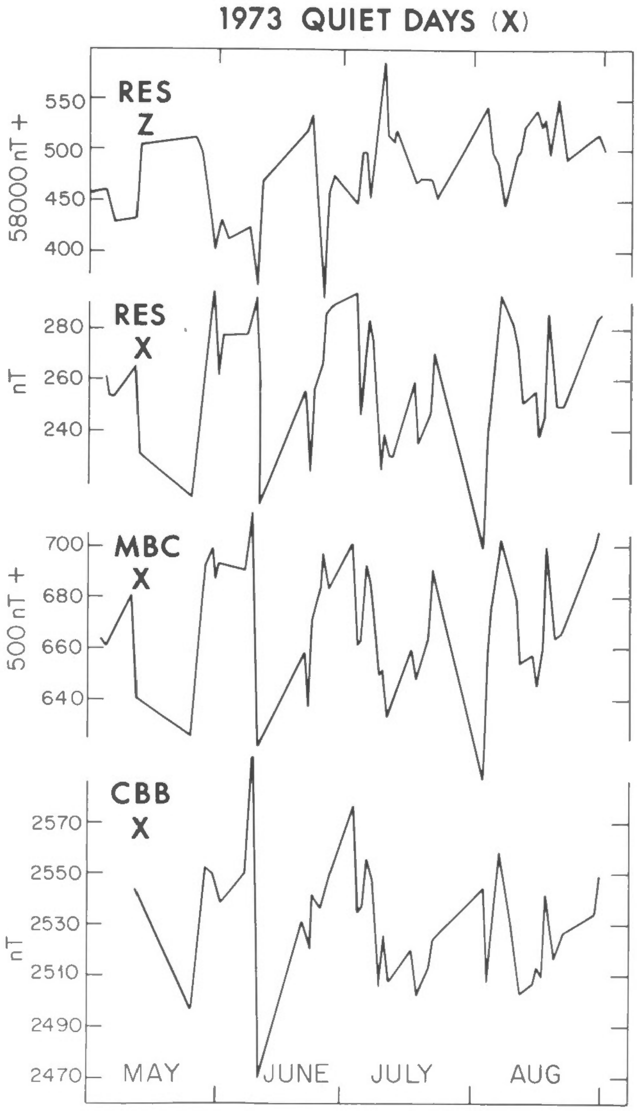

Figure 5. IMF effect on quiet-day levels in X, 1973.

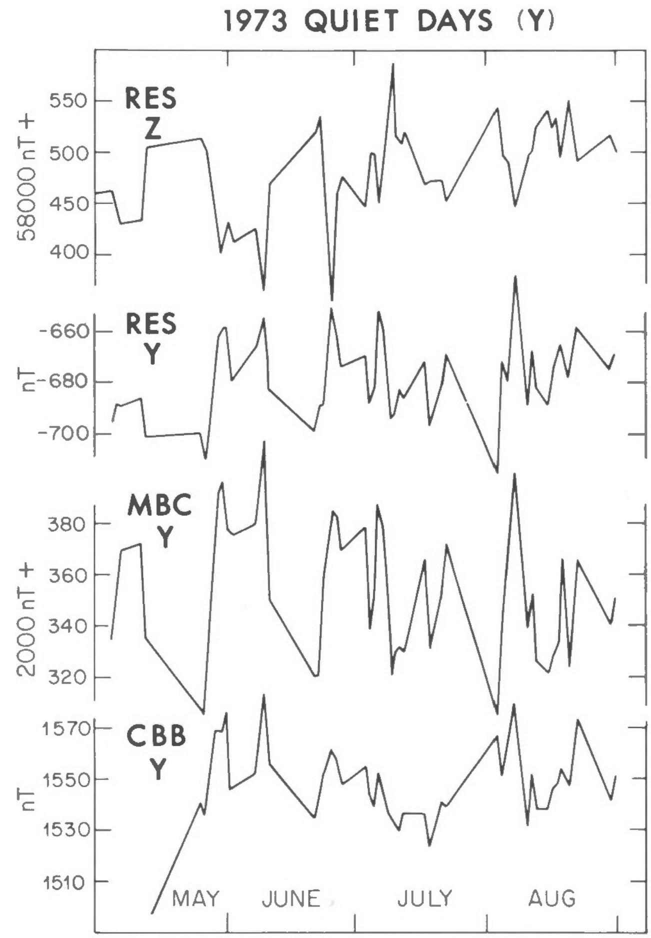

Figure 6. IMF effect on quiet-day levels in Y, 1973.

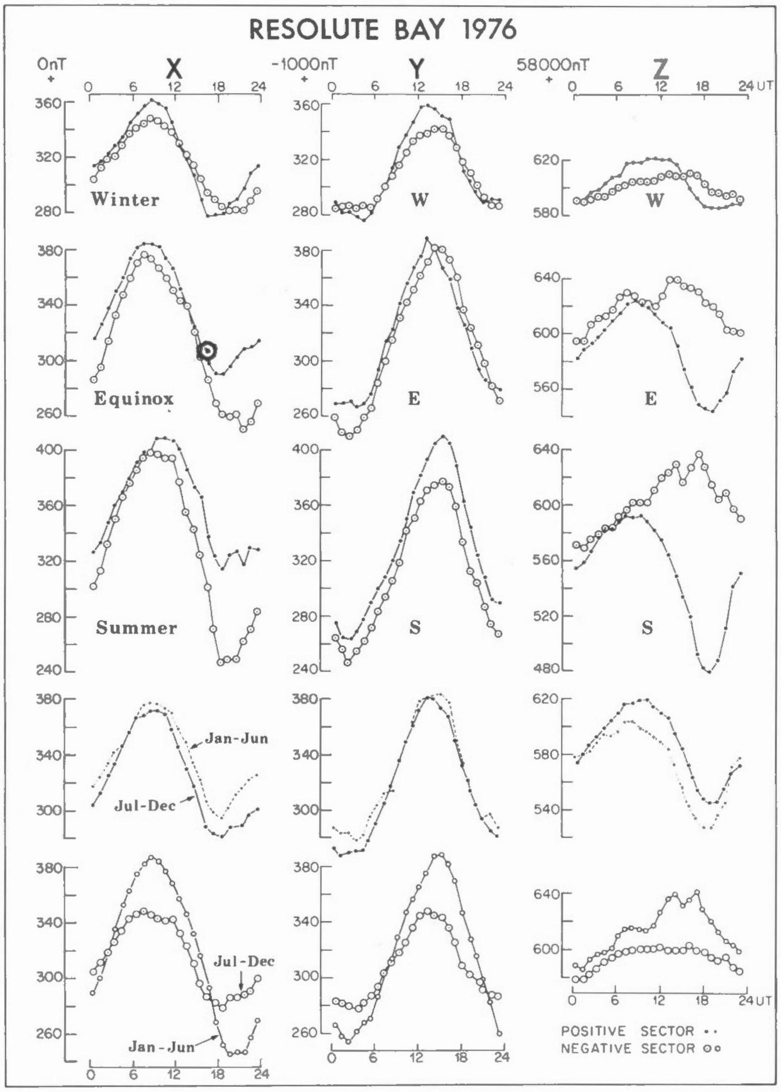

Figure 7(a). Diurnal variation curves for Resolute Bay, 1976.

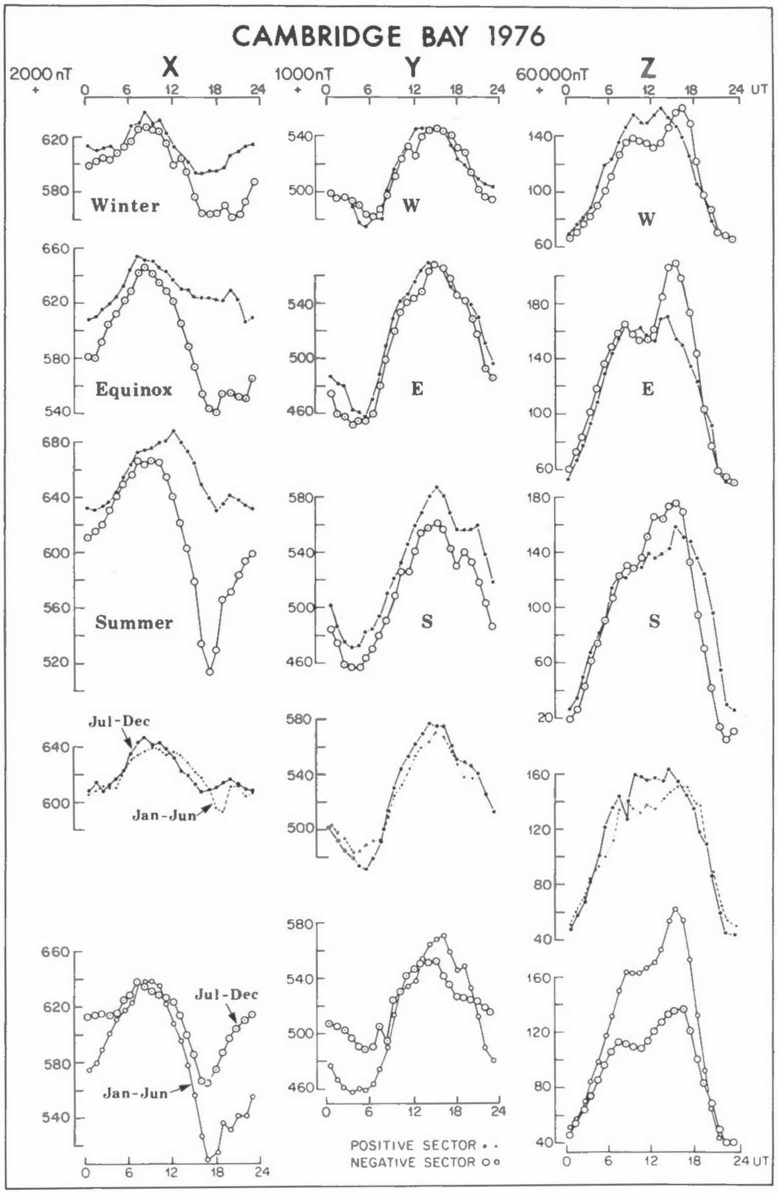

Figure 7(b). Diurnal variation curves for Cambridge Bay, 1976.

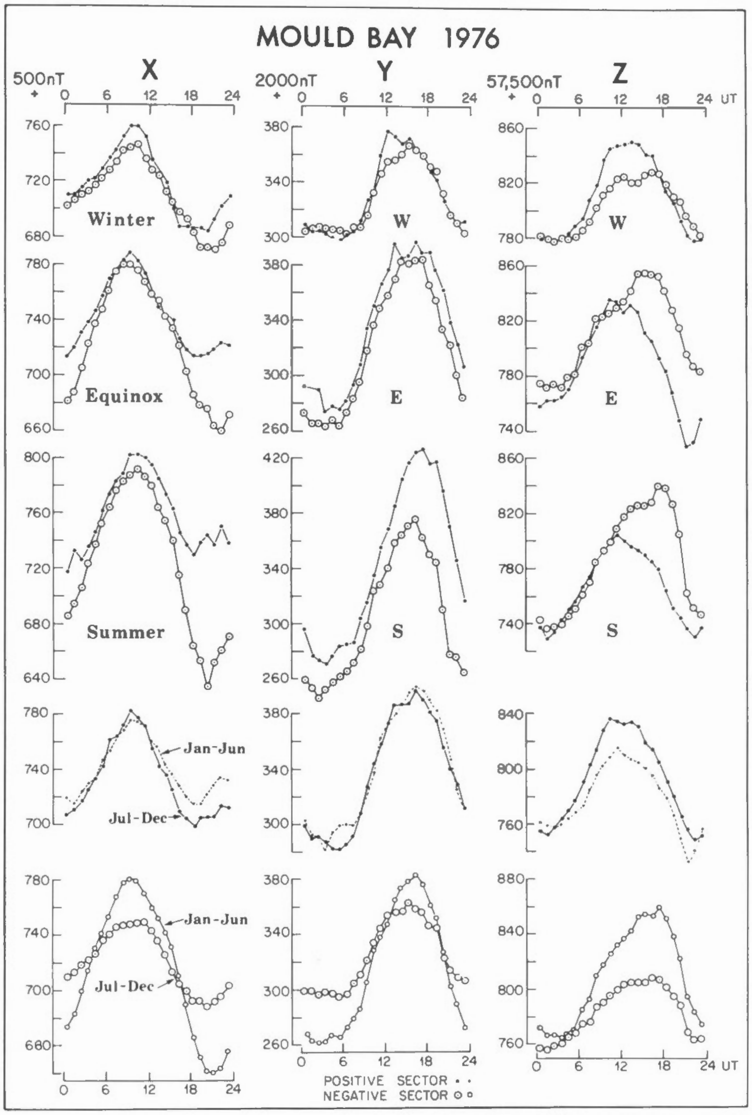

Figure 7(c). Diurnal variation curves for Mould Bay, 1976.

At both RES and CBB the range of the average diurnal variation in summer is always greater than in winter. However, this contrast is more pronounced for negative sector (+ΔZ) days, and is especially strong in the case of X. A summary follows of the ratio of summer to winter ranges of diurnal variation.

		Ratio of summer to winter ranges of diurnal variation		
		X	Y	Z
+ve sector (-ΔZ) days	RES(1974,75,76)	1.14±0.03	1.86±0.24	2.96±0.24
-ve sector (+ΔZ) days	"	2.11±0.13	2.03±0.16	3.53±0.40
+ve sector (-ΔZ) days	CBB(1975, 76)	1.30±0.02	1.62±0.03	1.34±0.10
-ve sector (+ΔZ) days	"	2.16±0.20	1.72±0.04	1.94±0.17

The ratio of the range of the diurnal variations for (Jan-Jun) to the range for (Jul-Dec) is given below for +ΔZ and -ΔZ days for RES (1974, 1975, 1976) and CBB (1975, 1976).

	+ΔZ days		-ΔZ days	
	RES	CBB	RES	CBB
X	1.65	1.54	0.85	1.21
Y	1.67	1.70	0.83	0.84
Z	1.57	1.52	0.80	0.90

The change in character of the diurnal variation between +ΔZ and -ΔZ days is particularly evident between November and February, as shown in the sequence of curves for months November 1974 to February 1975 and November 1975 to February 1976 in Figure 8.

Effect of IMF on Mean Field Levels

The difference in field level between the two types of day is summarized in the following. RES values are the means for 1974, 1975 and 1976; CBB values are the means for 1975 and 1976.

	W nT	E nT	S nT	Jan-Jun nT	Jul-Dec nT
X(+ΔZ days) minus X(-ΔZ days)					
RES	-3	-14	-37	-17	-16
CBB	-11	-30	-46	-34	-16
Y(+ΔZ days) minus Y(-ΔZ days)					
RES	-4	-6	-24	-10	-13
CBB	-4	-8	-20	-14	-8

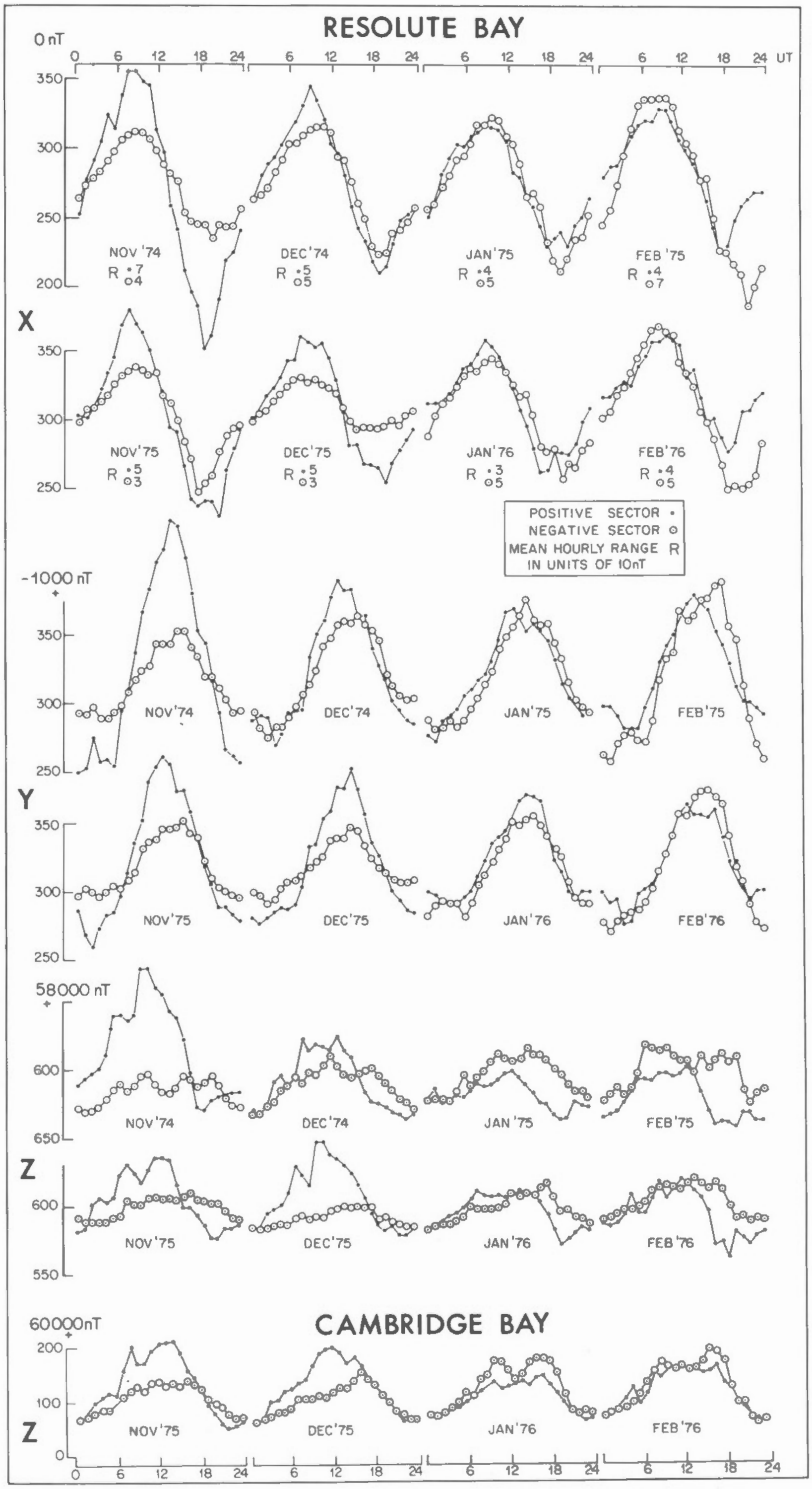

Figure 8. Diurnal variation curves November to February for Resolute in X,Y,Z for 1974 to 1976, and for Cambridge Bay in Z for 1975, 1976.

Z($+\Delta Z$ days) minus Z($-\Delta Z$ days)					
RES	-2	+24	+66	+41	+18
CBB	-6	+2	-6	+12	-18

A consistent difference in the level of the field (corrected for the effect of secular change) is evident at RES between the two classes of days in all intervals considered, except for Z in the winter months, when the IMF effect is known to be small. As expected, the mean field level at RES on $+\Delta Z$ days is smaller in X and Y and larger in Z than on $-\Delta Z$ days, this effect being most pronounced in the summer. At CBB the effect is predominantly in X, as expected for a station on or near the boundary of the polar cap.

For RES Z this difference is significantly more pronounced in Jan-Jun (41 nT ± 6) than in Jul-Dec (18 nT ± 7). A correspondingly large asymmetry is also observed in X and Z at CBB: differences in Z were + 12 nT ± 4 (Jan-Jun) and -18 nT ± 4 (Jul-Dec); differences in X were -34 nT ± 2 (Jan-Jun) and -16 nT ± -4 (Jul-Dec).

It is evident from the diurnal variation curves that the effect of a change in direction of the IMF is not confined to hours around local noon, although this is clearly the time of the dominant effect in Z at RES and in X at CBB. The X and Y fields are generally depressed in all seasons on $+\Delta Z$ days from midnight into the forenoon hours. For all elements the difference in field is relatively small (less than 10 nT) in the hours near local midnight.

Effect of IMF on Annual Variation

12-monthly running means of the mean hourly values from 1963 to 1973 for all days, international quiet days and $+\Delta Z$ days and $-\Delta Z$ days have been used to examine the annual (1 cycle/year) variation of the magnetic field at Resolute Bay and Mould Bay (Figures 9, 10). $+\Delta Z$ and $-\Delta Z$ days were selected on the basis of RES daily means in Z using the method described previously. The annual variation plot for RES (Fig. 9) was extended to 1975 using the IZMIRAN classification. In addition, annual variation curves for MBC X were derived using the mean hourly values at local midnight (07 - 08 UT) only for 1963 to 1973, for the two classes of days $+\Delta Z$ and $-\Delta Z$ (see Figure 11). Owing to the small number of days on which a significant IMF effect can be discerned in winter, dotted lines have been used in Figure 11 to connect values shown for the winter months.

The annual variation derived for all days was found to be fairly regular in X with average amplitude for the years 1964 to 1972 inclusive of about 20 nT at both stations. The amplitude of the all-day annual variation for these years in Z was 34 nT. It was considerably smaller and less regular in Y.

The annual variation averaged over the 9 years for the international quiet days was generally similar to that for all days, except that the Y amplitude at MBC and the Z amplitude at RES were considerably larger on the international quiet days.

The annual variation curves derived for the $+\Delta Z$ and $-\Delta Z$ days differed in some important respects. The form of the variation on $-\Delta Z$ days is generally similar to that derived for all days and for international quiet days, but a significant phase shift is evident in the X and Y variation curves for the $+\Delta Z$ days.

The curves for $-\Delta Z$ days in X were remarkably similar at RES and MLB, with a well-defined maximum in summer. The Y curves for $-\Delta Z$ days were similar to those for X at both stations, but with reduced amplitude and a broader maximum at RES. In general the broadening of the maximum in Y at RES reflects the

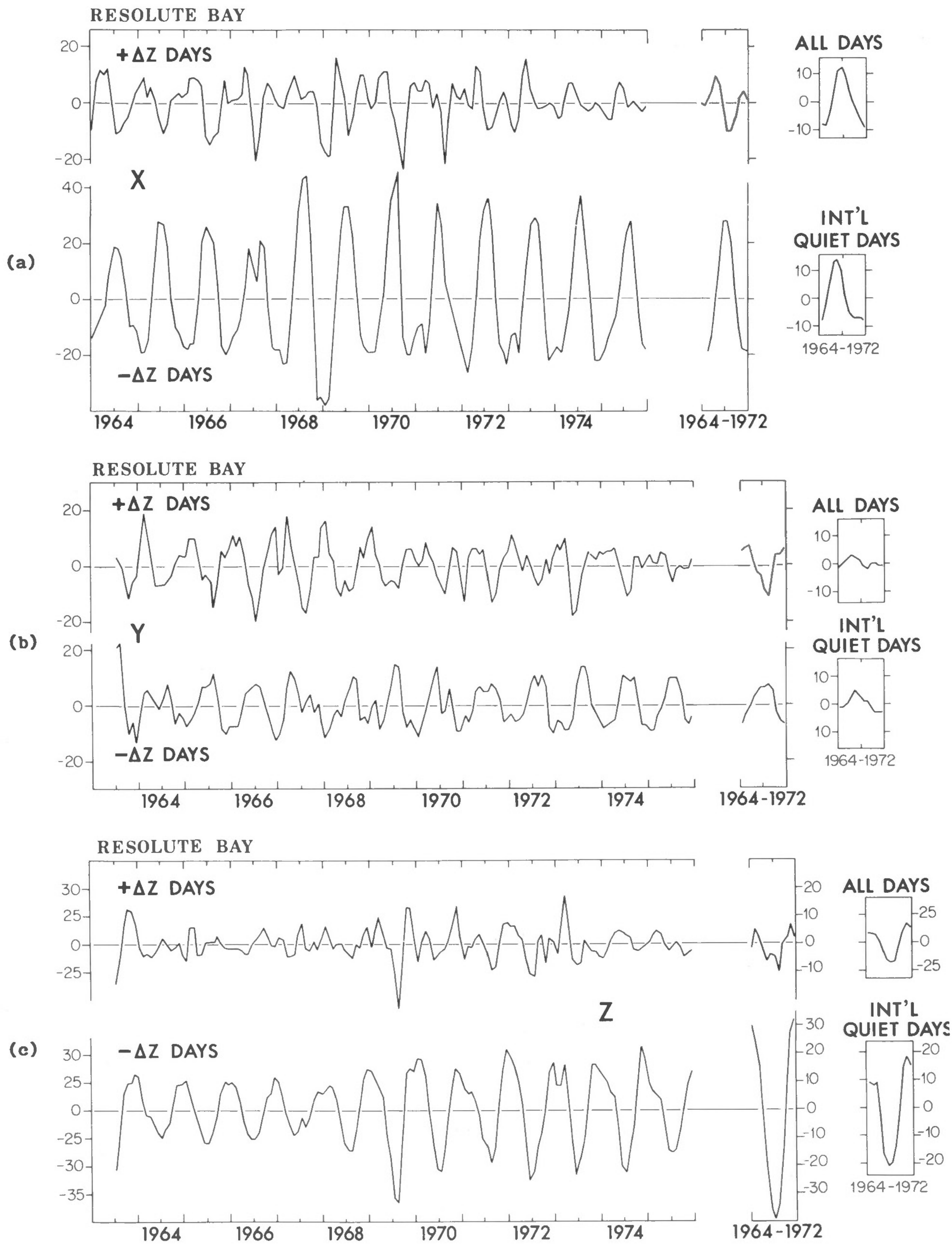

Figure 9. Annual variation derived from 12-monthly running means for Resolute Bay for (a) X; (b) Y; (c) Z.

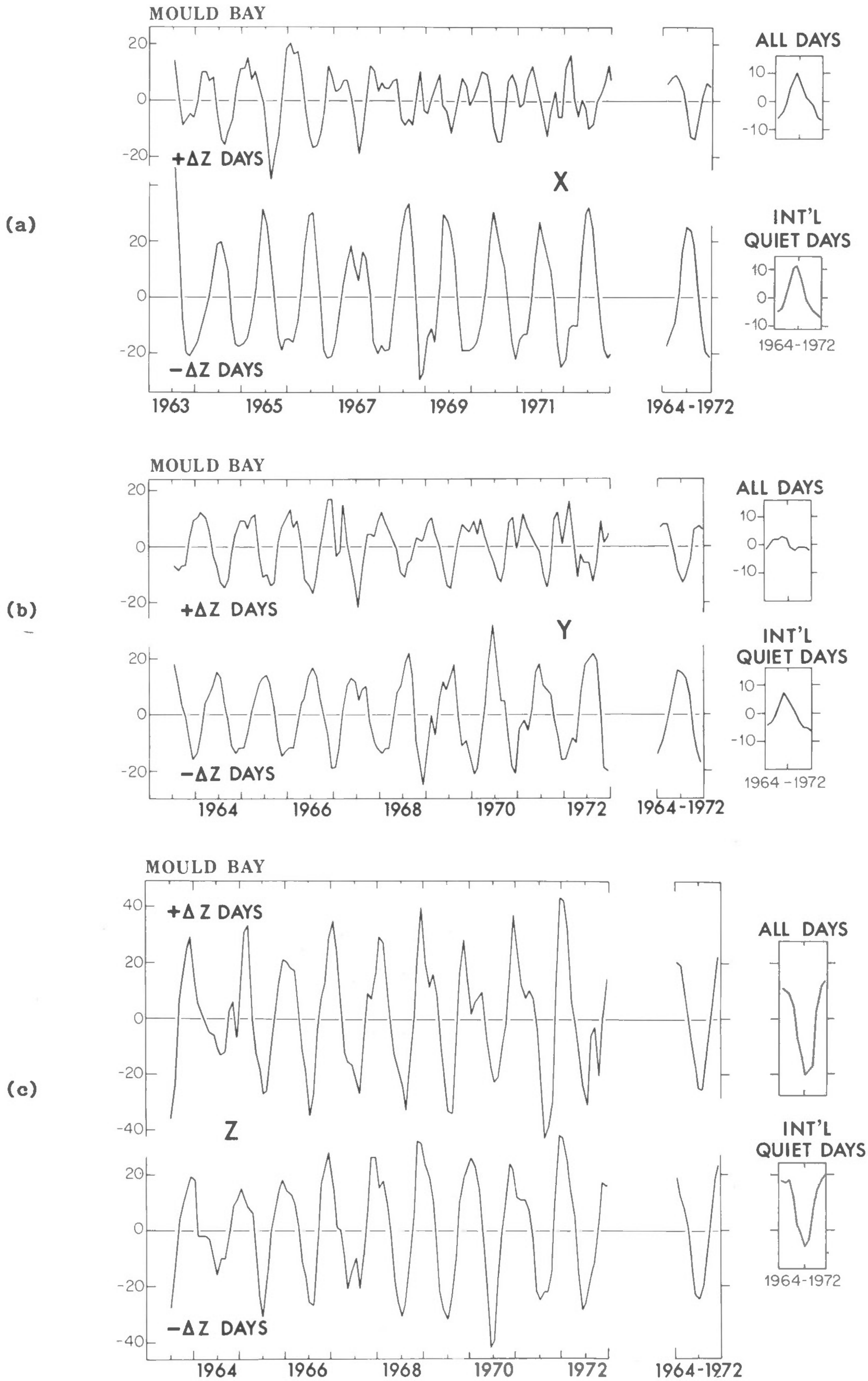

Figure 10. Annual variation derived from 12-monthly running means for Mould Bay for (a) X; (b) Y; (c) Z.

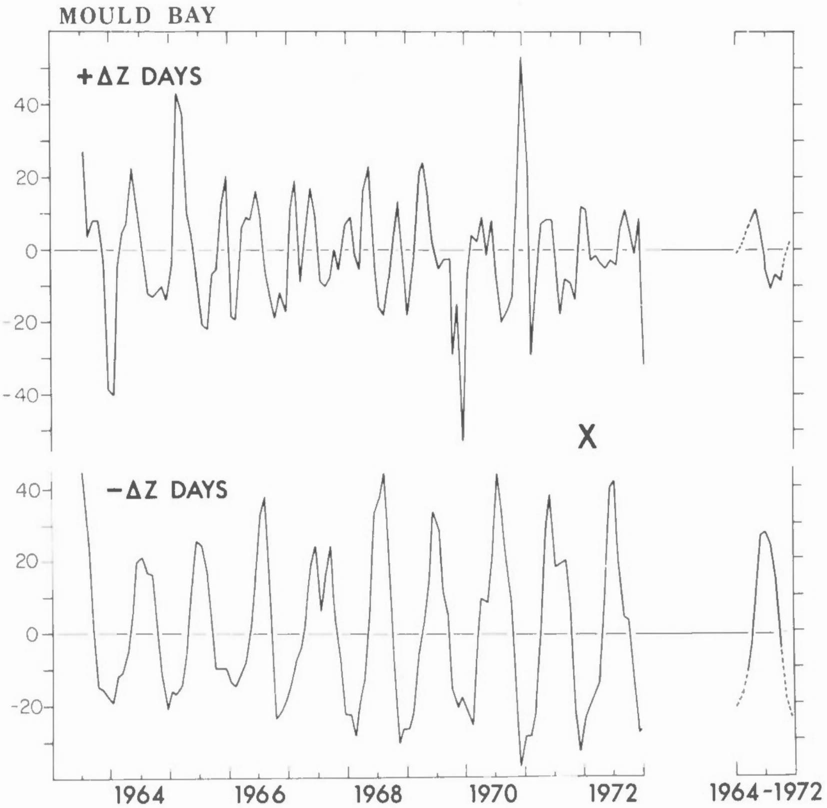

Figure 11. Annual variation for Mould Bay derived from 12-monthly running means of the 07 - 08 UT mean hourly value.

highly irregular variation in individual years. The annual variation curves for +ΔZ days are similar in both X and Y at RES and MBC, with a sharp minimum in the summer months. This minimum is about 1 to 2 months later on the average than the summer maximum observed on the -ΔZ days. The variation on +ΔZ days is not as well defined as that on -ΔZ days. Equinoctial maxima are evident in both X and Y at both stations on the +ΔZ days, the spring maximum in X at RES being particularly pronounced.

The annual variation derived for X for the +ΔZ days at MBC using only the local midnight mean hourly value shows the sharp summer minimum observed on the curves derived from the daily means, but the amplitude of the autumn maximum is greatly reduced and the spring maximum occurs 1 to 2 months later. The curve for -ΔZ days is essentially the same as that derived from all-day means.

The form of the all-day annual variation curves for X and Y is seen to be closely approximated by the average of the -ΔZ day and +ΔZ day curves.

At the latitude of BLC the annual variations for the +ΔZ and -ΔZ days are similar. This is illustrated for the case of X in Figure 12.

The Z annual variation curves for both +ΔZ and -ΔZ days show a sharp summer minimum in all intervals at both MBC and RES, except for 1964 - 1967 in +ΔZ at RES. In general, the Z curves for +ΔZ days for RES are considerably less regular and have smaller amplitudes than is the case for MBC. The phase reversal between -ΔZ and +ΔZ days, so evident for X and Y, is not present in Z. As was the case for the X and Y curves the minimum in Z for +ΔZ days occurs about 1 month later than for the -ΔZ days, and the variation is generally larger and more regular on -ΔZ days.

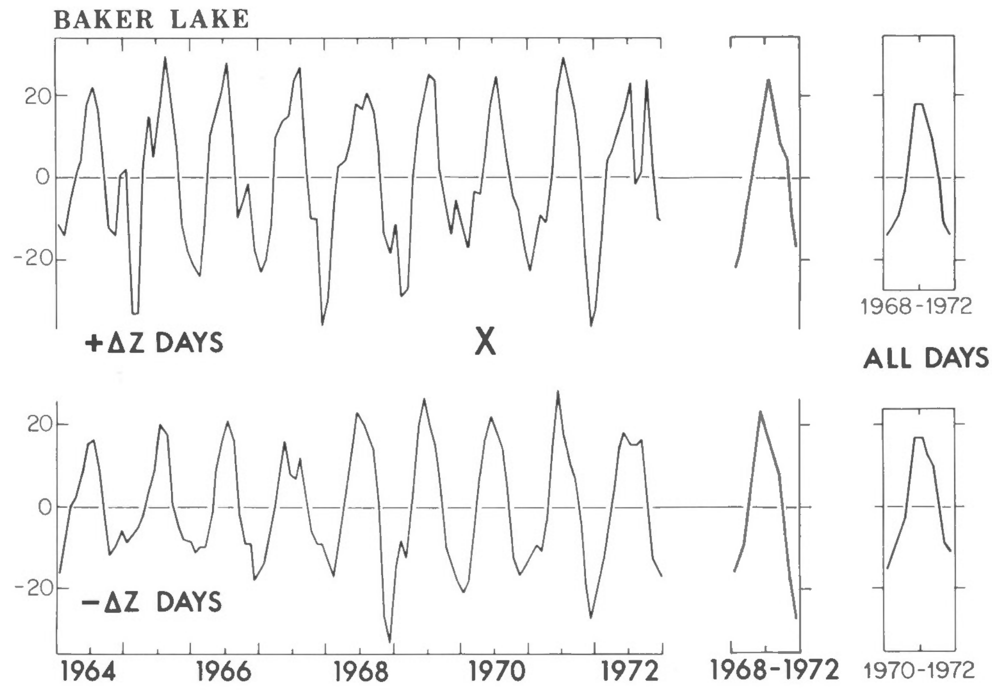

Figure 12. Annual variation in X from 12-monthly running means for Baker Lake.

Amplitudes of the annual variation for the four classes of days (all-day, international quiet, +ΔZ and −ΔZ) for the period 1964 to 1972 are listed in Table II. Average amplitudes for +ΔZ and −ΔZ days are also shown for the periods 1964 to 1967 and 1968 to 1972.

Effect of IMF on Annual Mean Values

The difference between the annual means derived from all days, +ΔZ days and −ΔZ days are given in Table III. The close correspondence between the modulus of the 'all-day' minus (+ΔZ) day and the 'all day' minus (−ΔZ) day differences in X and Y indicates that the annual mean for all days is very nearly the average of the +ΔZ and −ΔZ day annual means. However, in Z, the all-day means are biased somewhat towards the −ΔZ day level, especially at MBC.

To the accuracy that can be expected from this method, the rate of secular change is the same regardless of the class of day used, as is clearly shown in the table which lists the difference between annual means for successive years for each class of day (Table IV).

Discussion

The IMF sector polarities used in this analysis have been inferred from the Z daily means of RES (1963 to 1973) or from the lists prepared by IZMIRAN based on the mean hourly values of arctic and antarctic observatories (1973.5 to the present). In general the inferred values are in good agreement with satellite observations of the IMF[3]: a comparison between polarities inferred from the RES records and satellite data for 1969 gave agreement in 73% of cases for positive sector days and in 94% of cases for negative sector days.

Two results from this analysis require further study: the change in character of the diurnal variation with change in IMF sector polarity, particularly between November and February; and the change in form of the annual variation in X and Y at RES and MBC with change in IMF sector polarity.

TABLE II

Amplitude of Annual Variation 1964-1972

	X_{nT}				Y_{nT}				Z_{nT}			
Resolute Bay	All Days	I.Q. Days	(+ΔZ) Days	(-ΔZ) Days	All Days	I.Q. Days	(+ΔZ) Days	(-ΔZ) Days	All Days	I.Q. Days	(+ΔZ) Days	(-ΔZ) Days
1964	21	25	23	32	10	10	25	14	20	31	17	54
1965	16	18	20	47	7	16	25	22	19	22	30	57
1966	17	36	24	46	15	19	34	20	24	62	23	55
1967	22	31	34	40	20	24	35	23	16	32	30	48
1968	48	52	24	80	10	15	27	22	45	55	29	74
1969	27	25	35	71	14	17	22	23	103	79	90	123
1970	34	40	35	66	11	19	18	25	70	61	28	101
1971	23	31	30	53	7	12	20	14	46	52	43	101
1972	23	37	23	62	7	11	18	21	72	80	46	110
1964-1972	21	22	20	47	5	8	18	14	34	39	17	71
1964-1967			23	39			24	16			18	50
1968-1972			21	59			13	16			33	92
Mould Bay												
1964	17	28	27	38	16	28	27	30	20	18	26	31
1965	28	35	46	50	13	12	27	29	26	27	60	49
1966	18	39	34	51	10	27	34	36	41	42	64	55
1967	16	26	31	39	17	16	36	27	29	28	62	47
1968	22	31	19	62	14	26	19	47	52	39	72	63
1969	21	24	21	48	9	27	25	39	44	29	62	58
1970	20	14	25	52	16	24	23	53	44	28	60	56
1971	19	23	25	52	21	16	27	34	41	28	82	59
1972	25	37	26	53	14	22	29	42	49	45	73	54
1964-1972	17	18	23	46	5	14	21	33	34	27	48	48
1964-1967			28	40			27	28			44	42
1968-1972			16	50			21	37			56	54

TABLE III

Differences (in nT) between Annual Means Derived From Different Classes of Days

	X			Y			Z		
	All Days minus +ΔZ Days	All Days minus -ΔZ Days	+ΔZ Days minus -ΔZ Days	All Days minus +ΔZ Days	All Days minus -ΔZ Days	+ΔZ Days minus -ΔZ Days	All Days minus +ΔZ Days	All Days minus -ΔZ Days	+ΔZ Days minus -ΔZ Days
RES									
1963	11	- 8	-19	6	- 7	-13	-34	27	61
1964	9	- 8	-17	5	- 6	-11	-29	23	52
1965	9	- 9	-18	3	- 7	-10	-32	24	56
1966	14	-12	-26	4	- 6	-10	-36	30	66
1967	8	-11	-19	5	- 7	-12	-40	37	77
1968	7	-10	-17	4	- 5	- 9	-37	38	75
1969	9	-11	-20	3	-10	-13	-41	40	81
1970	13	-12	-25	5	- 4	- 9	-38	34	72
1971	7	-12	-19	4	- 6	-10	-37	34	71
1972	10	-12	-22	6	- 6	-12	-40	38	78
1973	10	-11	-21	6	- 8	-14	-41	36	77
Average	9.7	-10.5	-20.3	4.6	-6.5	-11.2	-36.8	32.8	69.6
MBC									
1963	16	-13	-29	15	-12	-27	-25	14	39
1964	14	-11	-25	14	-13	-27	-20	11	31
1965	15	-15	-30	13	-12	-25	-22	8	30
1966	18	-16	-34	14	-16	-30	-25	13	38
1967	13	-16	-29	19	-18	-37	-25	19	44
1968	14	-14	-28	17	-19	-36	-25	21	46
1969	11	-11	-22	17	-21	-38	-24	18	42
1970	15	-13	-28	21	-14	-35	-28	18	46
1971	11	-14	-25	16	-18	-34	-27	17	44
1972	13	-14	-27	21	-17	-38	-22	20	42
1973	15	-13	-28	18	-17	-35	-29	21	50
Average	14.1	-13.6	-27.7	16.8	-16.1	-32.9	-24.7	16.4	41.1

TABLE IV

Secular Variation in nT/Year

	X			Y			Z		
	All Days	(+ΔZ) Days	(−ΔZ) Days	All Days	(+ΔZ) Days	(−ΔZ) Days	All Days	(+ΔZ) Days	(−ΔZ) Days
RES									
1963-64	+ 9	+11	+ 9	+15	+16	+14	+24	+19	+28
1964-65	+15	+15	+16	+ 9	+11	+10	+26	+29	+25
1965-66	+ 9	+ 4	+12	+11	+10	+10	+38	+42	+32
1966-67	+12	+18	+11	+14	+13	+15	+42	+46	+35
1967-68	+13	+14	+12	+15	+16	+13	+41	+38	+40
1968-69	+13	+11	+14	+19	+20	+24	+29	+33	+27
1969-70	+14	+10	+15	+17	+15	+11	+50	+47	+56
1970-71	+ 6	+ 8	+ 6	+18	+19	+20	+47	+46	+47
1971-72	+23	+20	+23	+11	+ 9	+11	+27	+30	+23
1972-73	+28	+28	+27	+ 4	+ 4	+ 6	+64	+65	+66
Average									
(10 yrs.)	+14.2	+13.9	+14.5	+13.3	+13.3	+13.4	+38.8	+39.5	+37.9
r.m.s. deviation	6.6	6.8	6.3	4.6	4.9	5.3	12.7	12.7	14.3
MBC									
1963-64	+14	+16	+12	+ 4	+ 5	+ 5	+ 8	+ 3	+11
1964-65	+19	+18	+23	+ 8	+ 9	+ 7	+12	+14	+15
1965-66	+19	+16	+20	+13	+12	+17	+31	+34	+26
1966-67	+14	+19	+14	+14	+ 9	+16	+28	+28	+22
1967-68	+11	+10	+ 9	+11	+13	+12	+34	+34	+32
1968-69	+14	+17	+11	+18	+18	+20	+28	+27	+31
1969-70	+23	+19	+25	+30	+26	+23	+39	+43	+39
1970-71	+10	+14	+11	+16	+21	+20	+25	+24	+26
1971-72	+16	+14	+16	+11	+ 6	+10	+34	+29	+31
1972-73	+20	+18	+19	+10	+13	+10	+32	+39	+31
Average									
(10 yrs.)	+16.0	+16.1	+16.0	+13.5	+13.2	+14.0	+27.1	+27.5	+26.4
r.m.s. deviation	4.2	2.8	5.5	7.0	6.7	6.1	9.9	11.8	8.4

Diurnal variation and sector polarity

To summarize the effects of changes in the IMF on the diurnal variation in the polar cap and cleft, significant differences in the character of the diurnal variation have been noted between the two classes of days, $+\Delta Z$ and $-\Delta Z$. This difference was found to be greatest in the summer months in Z at RES and in X at CBB as was expected. However, significant differences have also been observed on $+\Delta Z$ and $-\Delta Z$ days between the periods (Jan-Jun) and (Jul-Dec). These differences have been listed in the foregoing as changes in level of the field and in the range of the diurnal variation. The results suggest that the IMF effect is stronger on $+\Delta Z$ days and in the (Jan-Jun) months. A similar result was noted in the section "Variation of the IMF Effect 1963 - 1973" (see Figure 3a) in which the effect was more pronounced in (Jan-June) for both classes of day by 25 to 35%, and somewhat larger, by about 10% on $+\Delta Z$ days.

The association between international quiet and disturbed days, and sector polarity was found to reverse between (Jan-Jun) and (Jul-Dec). The preponderance of disturbed days in the negative sector ($+\Delta Z$) for (Jan-Jun) could explain the relatively larger range of diurnal variation observed in this interval for these days. Conversely, the relatively larger range in the diurnal variation curves in (Jul-Dec) on $-\Delta Z$ days could be explained by the association of disturbed days with the positive sector in these months. These conclusions are supported by the magnetic activity indices R (hourly ranges) at RES and CBB which are distributed in a similar pattern. For $-\Delta Z$ days, the ratio (R(X) Jan-Jun)/(R(X) Jul-Dec) is 0.9, and for $+\Delta Z$ days the ratio is 1.2 at RES. The corresponding values at CBB are 0.9 and 2.0. However, the differences in range and phase of the diurnal variation for the international quiet and disturbed days as compared with positive and negative sector days, indicate that these two sets of days, although related, are probably registering the effect of different physical processes: 'quiet' and 'disturbed' days being determined by events in the auroral oval, while the positive and negative sector days refer to IMF changes in the polar cap.

The association of disturbance with sector polarity, reversing between (Jan-Jun) and (Jul-Dec) may also explain the change in character of the diurnal variation between November and February (see R indices given in Figure 8). The association between equinoctial maxima of geomagnetic activity in Am and AE indices and the IMF sector polarity has been reported by several authors. The distribution of international disturbed days (1973.5-1978.5) in the positive and negative sectors shows weak equinoctial maxima according to the predicted pattern (Table I). More striking, as summarized below, the distribution from (Jul-Dec) in negative sectors is similar to that from (Jan-Jun) in positive sectors, and the distribution in positive sectors from (Jul-Dec) is similar to that in negative sectors from (Jan-Jun). A change clearly occurs between May-Jun and Jul-Aug in each of the years considered, and also between Nov-Dec and Jan-Feb.

Number of International Disturbed Days

Negative Sector	Jul -Aug	Sep -Oct	Nov -Dec		Jan -Feb	Mar -Apr	May -Jun	Jul -Aug
1973	1	2	2	1974	7	6	5	2
1974	2	1	3	1975	4	5	6	3
1975	3	0	1	1976	8	9	6	1
1976	1	0	1	1977	5	7	2	3
1977	3	1	1	1978	3	7	5	1
	10	4	8		27	34	24	10

Positive Sector

1973	6	7	7	1974	3	1	3	7
1974	7	7	7	1975	3	5	4	7
1975	7	9	7	1976	2	0	4	6
1976	6	9	7	1977	3	2	4	6
1977	6	4	9	1978	2	0	4	6
	32	36	37		13	8	19	32

The change in character with sector polarity of the diurnal variation for all elements from November through to February illustrated in Figure 8 strongly suggests that a basic change occurs in the IMF sector structure between November and February. No corresponding change is observed in the diurnal variation characteristics between May-Jun and Jul-Aug. The ratio 'r' of the range of the diurnal variation on positive ($-\Delta Z$) sector days to that on negative ($+\Delta Z$) sector days for November to February at RES is as follows:

r	Nov 74	Dec 74	Jan 75	Feb 75	Nov 75	Dec 75	Jan 76	Feb 76
X	2.61	1.44	0.78	0.69	1.55	3.45	1.09	0.71
Y	2.86	1.26	0.82	0.73	2.46	1.96	1.11	0.85
Z	3.68	1.40	0.87	1.05	2.64	3.78	1.21	1.87

Furthermore if the IMF effect defined as Σ (Z daily mean minus Z monthly mean) is calculated for 1973.5 to 1977 using the sector polarities given in the IZMIRAN listing, a discontinuity is again evident from Nov-Dec to Jan-Feb. (Figure 3(b)).

It is possible that all these observed discontinuities between Nov and Feb and between Jun and Jul, as well as the differences previously discussed in the magnitude of the IMF effect between (Jan-Jun) and (Jul-Dec) for different IMF sector polarities are a result of the annual variation in the tilting of the sun relative to the earth's magnetic field. If so, the different character of the field observed Jan-Feb compared with that of Nov-Dec would reflect the difference between the magnetic fields emanating from the northern and southern hemispheres of the sun.

Annual Variation and Sector Polarity

Malin and Isikara have recently published a comprehensive paper on the annual variation of the geomagnetic field using data from 69 observatories for the years 1957 to 1961. In their work, the annual term is derived from filtered monthly means. Only data near local midnight were used, to avoid contamination from Sq. They concluded that for stations lower than $\pm 60^{\circ}$ dip-latitude the annual variation in the geomagnetic field results from an annual variation in the latitude of the ring current. For high latitude stations (dip-latitude higher than $\pm 60^{\circ}$) the annual variation was shown to be consistent with a north-south oscillation of the mean position of the auroral electrojets during the year.

In their study, no polar cap stations were included. The most northerly stations were Godhavn (INVL 77.5^{o}) and Baker Lake (INVL 75^{o}). At Baker Lake (BLC) the annual variation in H derived by Malin et al. had amplitudes of 29 nT, 47 nT and 57 nT for the three years (1957.5 to 1960.5). For the years 1970 to 1972, which are similarly located within the solar cycle, the amplitude of the diurnal variation in X using 12-monthly running means was 33 nT for all days (Figure 12), or 36 nT if multiplied by the factor, 1.11 used by Malin et al. to compensate for the effect of smoothing. Minimum was Dec-Jan and maximum was May-Jul. Considering the decrease in activity in 1970 to 1972 relative to 1957-1960, it is evident that the two methods give comparable results for BLC.

If the years 1968-1972 are used, range and phase at BLC are unchanged for 'all days'. However, when calculated for days selected according to sector polarity, the amplitude of the annual term in X is observed to increase significantly (by about 50%), being somewhat larger and slightly more regular for $-\Delta Z$ days (51 nT) that for $+\Delta Z$ days (46 nT). Maximum occurs Jun-Jul for $+\Delta Z$ days and May-Jun for $-\Delta Z$ days.

Within the polar cap at MBC and RES the annual term for X is similar to that at BLC for $-\Delta Z$ days in both amplitude and phase. However, for $+\Delta Z$ days both X and Y at RES and MBC have a sharp minimum in the summer months. The Z annual variation for both $+\Delta Z$ and $-\Delta Z$ days is similar at RES, MBC and BLC, but less regular and with smaller amplitude at RES on $+\Delta Z$ days.

It is evident that the annual term on $-\Delta Z$ days in the polar cap is identical with the so-called 'polar' variation identified by Malin et al. for stations between $\pm$ 60^{o} dip-latitude and the polar cap. The explanation for the reversal of phase with change in sector polarity in the horizontal components at RES and MBC is not known. To ensure that this reversal is not merely a modulation of the diurnal amplitude, as discussed by Malin et al., the annual term for the X component at MBC, which exhibits the sector effect most strongly, was calculated using only the midnight (07-08 UT) mean hourly value. These curves are shown for $+\Delta Z$ and $-\Delta Z$ days in Figure 11. It is clear that they are basically similar to the curves derived from the all-day means.

In general the X and Y curves for RES and MBC for $+\Delta Z$ days have equinoctial maxima with the spring maximum being dominant. It is perhaps relevant to an explanation for the annual variation observed on $+\Delta Z$ days that the spring maximum of activity is predominant in both the Am and AE indices when the IMF is directed towards the sun, i.e., on $+\Delta Z$ days.

Conclusions

The diurnal and annual variation of field at stations in the polar cap and cleft are affected by changes in sector polarity.

1. Both the diurnal variation and the distribution of disturbance are systematically different on the average for $+\Delta Z$ and $-\Delta Z$ days, and between periods (Jan-Jun) and (Jul-Dec) for different sector polarities. A preponderance of disturbed days in (Jan-Jun) in the negative sector and in (Jul-Dec) in the positive sector has been observed. Moreover a discontinuity from December to January and from June to July in the distribution of the international disturbed days in both positive and negative sectors, and a change in the character of the diurnal variation with sector polarity between Nov-Dec and Jan-Feb is clearly seen for all elements. It is suggested that these discontinuities result from the annual variation in the tilting of the sun relative to the earth's magnetic field.

In general, results show that for the period considered the IMF effect is stronger on $+\Delta Z$ days and in the (Jan-Jun) months. As expected the effect is strongest in the summer, being largest in Z at RES and MBC and in X at CBB.

2. A change in form is observed in the annual variation in X and Y at RES and MBC with change in IMF sector polarity. For -ΔZ days the annual terms in X and Y show a sharp summer maximum at RES and MBC; for +ΔZ days a summer minimum is observed and a strong spring maximum with somewhat smaller values in the autumn months. The annual variation is generally smaller and less regular on +ΔZ days. No phase reversal is evident at BLC, south of the polar cap, where the annual term shows a sharp summer maximum for both classes of day. The annual term in Z is similar in form at all three stations for both +ΔZ and -ΔZ days. Although the Z term, and the annual variation in X and Y on -ΔZ days, may be explained as suggested by Malin et al. by a north-south oscillation of the mean position of the auroral electrojets during the year, the explanation for the phase reversal in X and Y in the polar cap with change in sector polarity is not known. It is similar to the variation of magnetic activity on +ΔZ days, in that a spring maximum is predominant.

The analysis leads to several conclusions with important practical implications for the reduction of magnetic observatory and survey data from the polar cap and cleft region.

1. The magnitude of the effect of polarity changes in the IMF on the diurnal variation and the quiet-day level of field emphasizes the importance of classifying days at polar cap observatories according to sector polarity. This is seen to be more meaningful in many ways than the conventional classification into quiet and disturbed days. It is especially important to use days having the same sector sign when extrapolating baselines or when estimating means for those days or months in which data are missing.

2. The systematic difference in field for different sector polarities between the periods (Jan - Jun) and (Jul - Dec) emphasizes the inadequacy of calculating means according to the Lloyd's seasons (winter, summer and equinox).

3. It has been shown that the difference in field between +ΔZ and -ΔZ days is minimum or reasonably small around local midnight. It is evident that the quiet midnight level rather than the quiet-day mean is to be preferred in calculating sub-storm perturbations at polar cap stations, and in reducing survey data to a quiet level.

As discussed in the 1974 Annual Report for Magnetic Observatories, the uniformity of the average field changes in the polar cap provides a valuable control on the quality of data in that intercomparisons between the polar cap observatories are valuable in confirming the absolute levels of field during intervals when instrumentation at an observatory is inoperative or defective, or when measurements are considered to be unreliable.

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