A New Type of Magnetic Activity Forecast

by

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Abstract

A new type of geomagnetic activity forecast provides daily estimates of a range parameter for each of the three major magnetic zones over Canada (sub-auroral, auroral, and polar cap). The parameter used is the mean of the twenty-four one-hour ranges in one of the components of the magnetic field. Forecasts are made up to 27 days in advance, based primarily on the recurrent features in the magnetic field and in solar activity, resulting from the solar rotation.

Overall accuracy, measured by a figure of merit defined in the paper, exceeds 70%, during the latter part of 1984 and early 1985, a period of generally low magnetic activity. A comparison between data obtained during this period and data from the last peak in magnetic activity (1982) demonstrates the contrasts in activity, on a solar cycle basis, seasonally, and latitudinally.

Introduction

In recent years, forecasting of geomagnetic activity has been in increasing demand by a variety of user groups, from the exploration industry to communications agencies and power utilities to scientific researchers. A number of agencies around the world now provide some kind of forecast of magnetic activity. The Earth Physics Branch in Ottawa has provided such a forecast service since 1974. At first, only medium-term forecasts based on the 27-day solar rotation were issued. Since 1976, in addition, short-term forecasts up to 3 days have been issued. The format of these forecasts has been straightforward and brief, in an attempt to summarize the complexity of the magnetic field at high latitudes. The forecast has given a single activity level for each day for the whole of Canada (Hruska, 1979).

However, it has long been recognized that the level of activity during a given time interval can vary greatly with geomagnetic latitude (e.g. Whitham et al., 1960). To reflect the latitudinal dependence in the geomagnetic activity in the forecasts, Hruska (1983) recommended the use of a three-zone forecast format for the dominant magnetic zones in Canada and adjacent regions. Implementation of this new, multi-zone concept has become possible as a result of recent developments in the Canadian Magnetic Observatory Network (Coles et al., 1984). At present this format is restricted to the medium-term, 27-day forecasts.

Magnetic Data

In Canada, the geomagnetic field is continually monitored by the Canadian Magnetic Observatory Network, comprising 12 standard observatories and one variation station (Figure 1). The instrumentation is digital, using the AMOS III system (Trigg and Nandi, 1985). Eleven of the stations are interrogated daily by telephone, using an automatic dial-up system driven by a minicomputer in Ottawa. The data that are routinely available to the minicomputer through this telephone link are hourly ranges and mean hourly values, although more detail can be obtained for limited time periods if required. The two most northern stations, Mould Bay (MBC) and Alert (ALE), cannot yet be accessed in such a direct manner, and the summary data are not available as promptly.

The observatory distribution broadly reflects major zones of distinct magnetic character - subauroral (STJ, OTT, VIC, GLN, MEA), auroral (PBQ, FCC, YKC) with auroral/cleft (BLC, CBB), and polar cap (RES, MBC, ALE). The station at Meanook (MEA), being close to the southern edge of the auroral zone, shows some characteristics of both auroral and subauroral zones.

Detailed magnetic character over Canada

A suitable form for displaying magnetic data for forecasting purposes is to group them in 27-day intervals according to the Bartels rotation numbers. This affords ready comparison with other indices, such as Kp and C9, that are published routinely in a similar manner, and of course aids in the recognition of recurring features attributable to the sun's rotation. In the following figures, hourly ranges in the north horizontal component X are used as examples. Whitham et al. (1960) discussed the relative merits of various measures of magnetic activity at high latitudes and concluded by selecting the hourly range in a component for their studies.

Figure 2 concentrates, as an example, on an auroral zone station, Fort Churchill (FCC), and shows four 27-day intervals in 1984/85. There are several features (both active and quiet) recurring at approximately 27-day intervals. By taking note of these, and also of their changes in amplitude from one rotation to the next, a basis for forecasting the activity in the next rotation interval can be developed. The changes in amplitude of features from one rotation to the next reflect either growing or decaying active regions on the sun, or they may be related to seasonal changes in the state of the magnetosphere and ionosphere.

Figure 3 shows range data for the interval December 23, 1984 to January 18, 1985, corresponding to Bartels rotation 2069, for several observatories in Canada. The station plots, similar in form to those in Figure 2, are arranged in approximately the relative geographic positions of the observatories (see Figure 1). The greatly increased levels of activity at all times in the auroral zone (Yellowknife, Churchill) are readily apparent. The polar cap station (Resolute Bay) exhibits a character that is different in intensity and in detail from that of the auroral zone. Plots of this kind are produced routinely and are used not only for actual forecasting, but also in hindsight in research on the forecasting process.

There are often major similarities among stations in a particular zone. Although all stations in the Canadian network contribute data, particularly for research into longitudinal variations in activity levels and into more sophisticated forms of forecast, current procedure emphasizes the data from four representative stations, namely RES (polar cap), FCC (auroral), MEA (auroral/subauroral), and OTT (subauroral). Station MEA behaves as a subauroral station during quiet intervals, but during more active periods as the auroral oval expands and its southern limit moves southward, MEA has a distinct auroral-zone character. Therefore, MEA tends to intensify the contrasts between disturbed and quiet intervals(Figure 3).

An example of the variation in the daily mean of the hourly ranges in the X component over Canada is shown in Figure 4.

Three-zone forecasts of magnetic activity

We have shown above that there are three major magnetic zones over Canada that have magnetic activities with distinctly different characters. We have developed a three-zone forecast, in which we forecast the average of the 24 one-hour ranges in each day for each of the three zones (polar cap, auroral, subauroral)(Hruska and Coles, 1985). For example, we might forecast that the mean range for the polar cap for a particular day will lie within the limits 40 to 80 nanotesla.

An example of the three-zone forecast is shown in Figure 4, for the same interval as shown in Figure 3. The forecast in each zone is shown by stippling. The means subsequently determined from actual observations are shown as solid circles.

Discrepancies may result largely from solar activity not present on previous rotations or from errors in the estimation of the recurrence rate or strength of individual magnetic events. These medium-term, 27-day forecasts rely primarily on recurrence patterns (of both active and quiet periods), and to a lesser extent, on different seasonal variations at different latitudes and on the position in the 11 year solar cycle (Loomer and Jansen van Beek, 1969). Seasonal peaks in activity occur at different times of the year in the different zones (Whitham et al., 1960).

Figure 5 displays in a graphic form both the contrasts in activity levels between zones and also the seasonal variations in the three zones. The equinoxes are the most active times for the auroral and subauroral zones. Particularly notable is the contrast between summer and winter for the polar cap, the summer being considerably more active. In Figure 5, the bins are the same as the ones used for the forecasts. Figure 6 shows, in similar fashion, data for 1982, at the time of the most recent maximum of magnetic activity associated with the 11-year solar cycle. Note the generally increased levels of activity, compared to those in Figure 5, and note also the more irregular patterns.

Forecasting accuracy

A problem common to all forecasting is how to measure a forecast's accuracy. Many types of forecast now use a probabilistic form of expression. For example, one might hear that there is a 30% chance of rain tomorrow; if it actually rains, one gets wet, if not, fine. But, was the forecast right or wrong - how accurate was it? What should one's response to such a forecast be?

The magnetic activity forecasts described here use a more direct approach, forecasting an actual quantity. For purposes of assessing the accuracy of these forecasts, we have devised a quantitative measure which considers, over an extended period (say 27 days), the ratio between the mean difference ("forecast bin" minus "observed bin") and the mean "observed bin", i.e.:

$$A = 100 (1 - sum(mod(for-obs))/sum(obs))$$

This gives a score of 100% for fully correct forecasts for the period. Using this algorithm, figures of merit A for the forecasts over seven solar rotations in 1984-85 have been calculated for each zone. For the polar cap, A is 76%; for the auroral zone, A is 77%; for the subauroral zone, A is 68%. For some rotations, A is as high as 89%. During the recent months, the level of activity in the sub-auroral zone has been relatively difficult to forecast. Few clearly identifiable events with which to establish recurrences have been found in the record.

Variations in activity levels during 24 hour periods

These 27-day forecasts currently only provide an estimator of each day's mean activity level. The plots in Figures 2 and 3, for example, demonstrate that there are often significant diurnal variations in the level of the activity. These are related to the rotation of the earth within the magnetosphere-ionosphere system. An extension of the current forecasts might well be to forecast the amplitude of the diurnal variation in activity.

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FIGURE CAPTIONS

Fig. 1. The Canadian Magnetic Observatory Network.

Fig. 2. Plot of hourly ranges in nanotesla for the X(north) component of the magnetic field measured at Fort Churchill magnetic observatory during the winter of 1984-85. (In two instances, days 85002 and 85049, data were not available.)

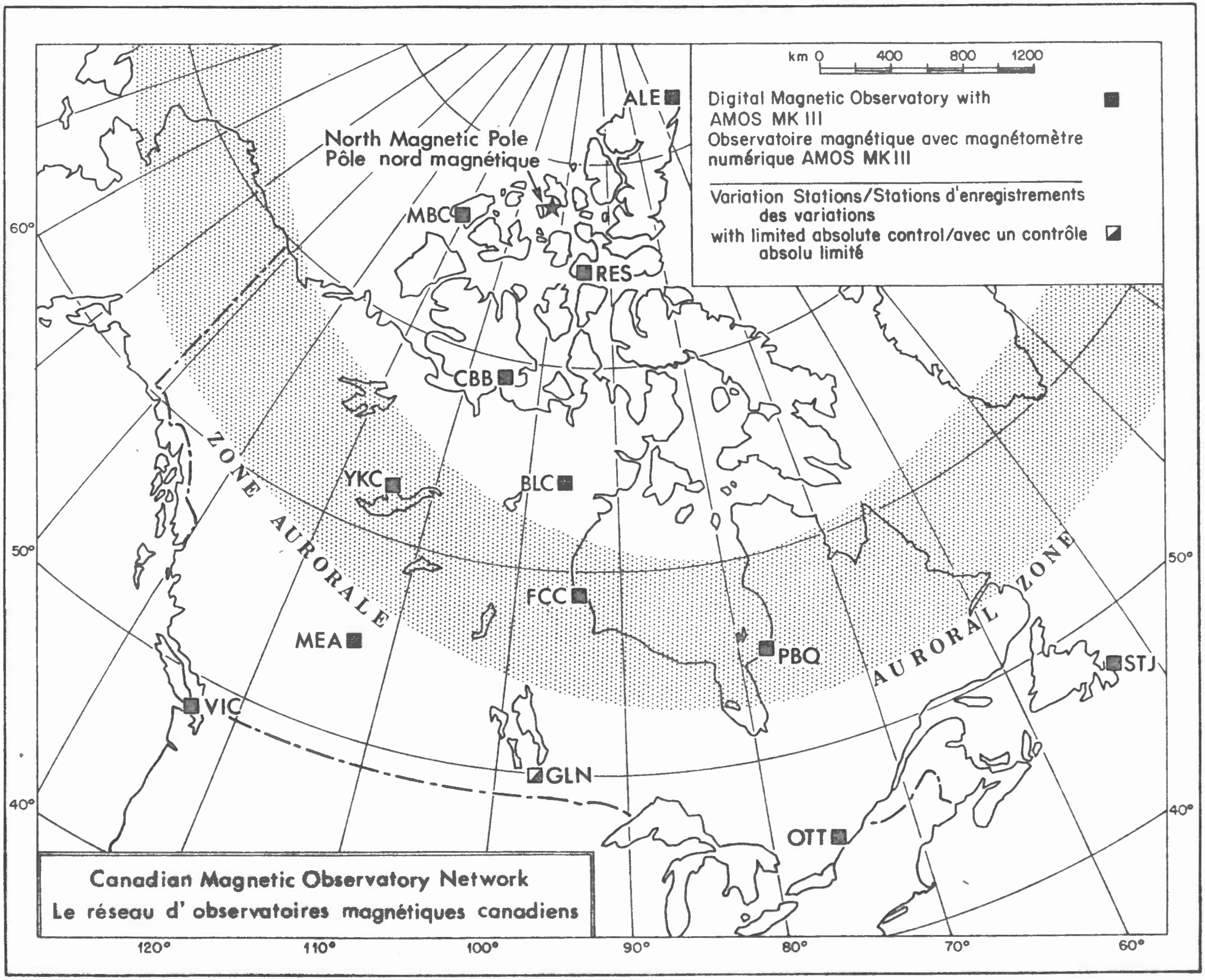
Fig. 3. Plots of simultaneous hourly range data from several Canadian observatories, showing the typical differences in activity levels across Canada.

Fig. 4. An example of a 3-zone magnetic activity forecast, with the subsequently observed data superimposed. This period (Bartels rotation 2069) is the same one used in Figure 3, and also shown in Figure 2.

Fig. 5. Summary bar-graphs of activity levels in the sub-auroral, auroral and polar cap regions. The bin sizes for each region are those used for the forecasts (Figure 4). Each bar-graph summarizes the activity for one Bartels rotation period of 27 days. In this form of presentation, the bar-graphs are linked to aid in the visualizing of trends. The graphs cover the winter of 1984-85, a period of relatively low magnetic activity.

Fig. 6. Summary bar-graphs of activity levels, similar in form to those of Figure 5, for 1982, a period at the most

recent peak in magnetic activity associated with the solar 11-year cycle.



Canadian Magnetic Observatory Network
Le réseau d' observatoires magnétiques canadiens

EMR CANADA   EARTH PHYSICS BRANCH

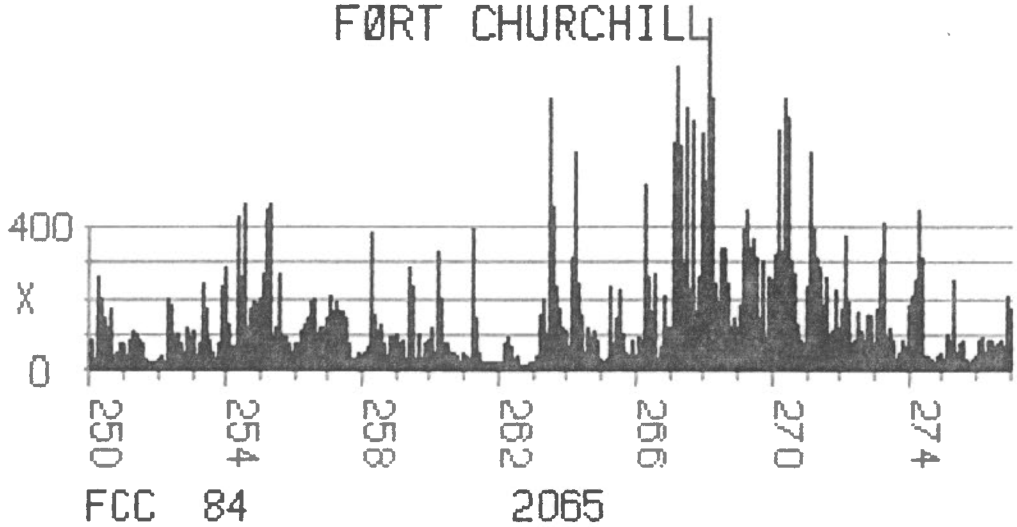
GEØMAGNETIC ACTIVITY RECURRENCE PLØTS

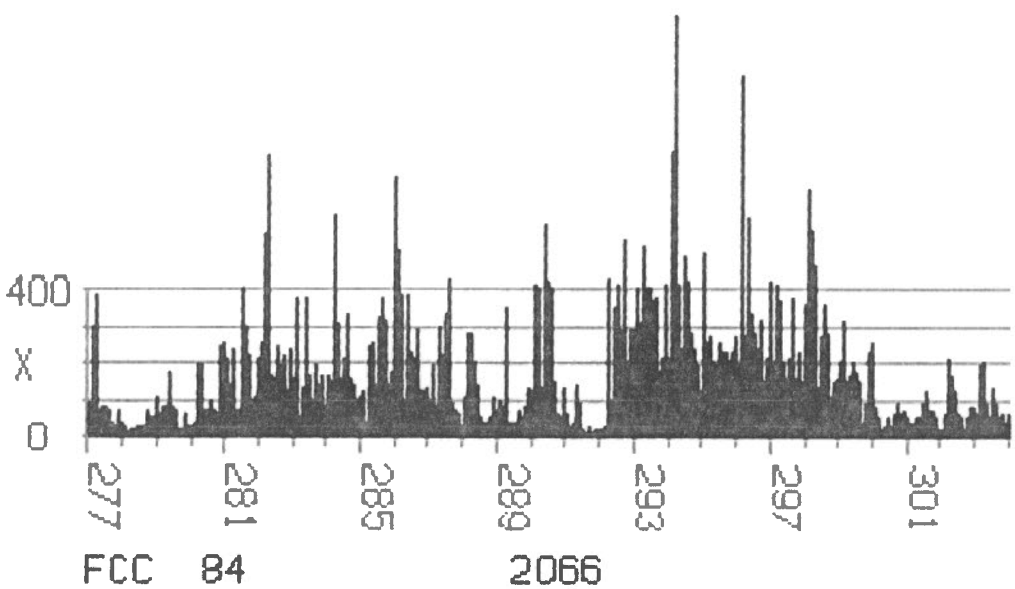
CANADIAN MAGNETIC ØBSERVATØRY (AMØS III) NETWØRK

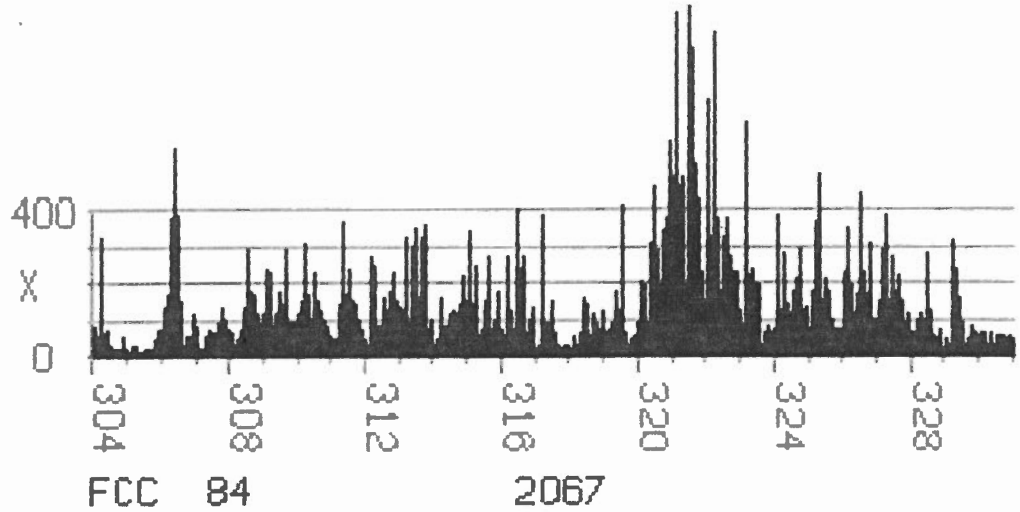
27-DAY BARTELS SØLAR RØTATIØN PERIØDS

HØURLY RANGES (NT) FØR CØMPØNENT X

FØRT CHURCHILL



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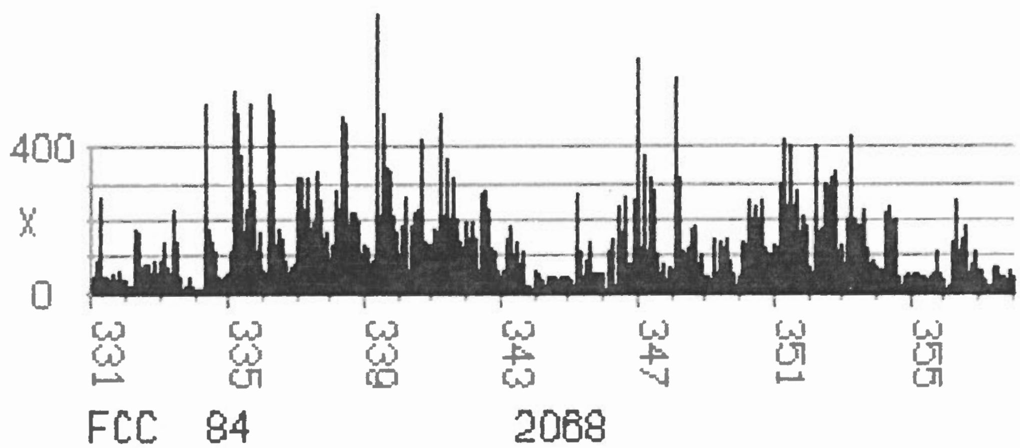
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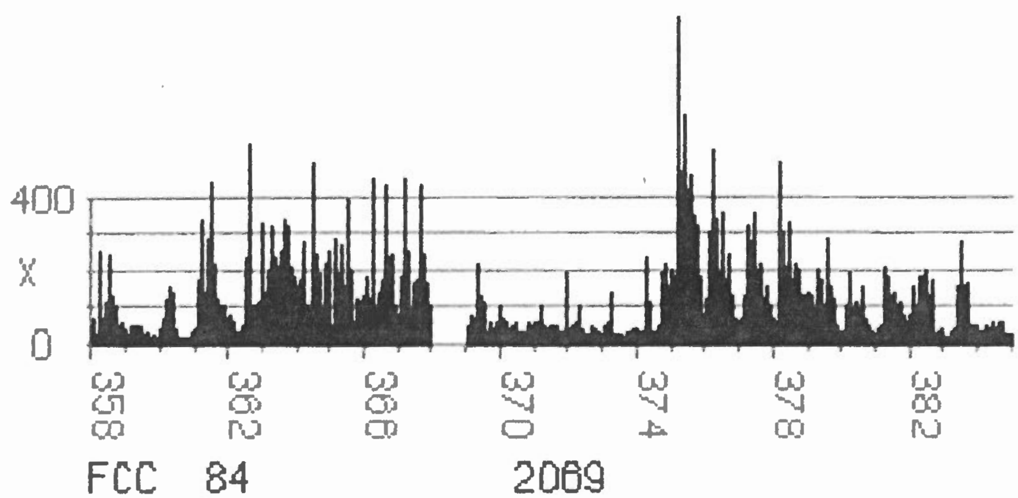
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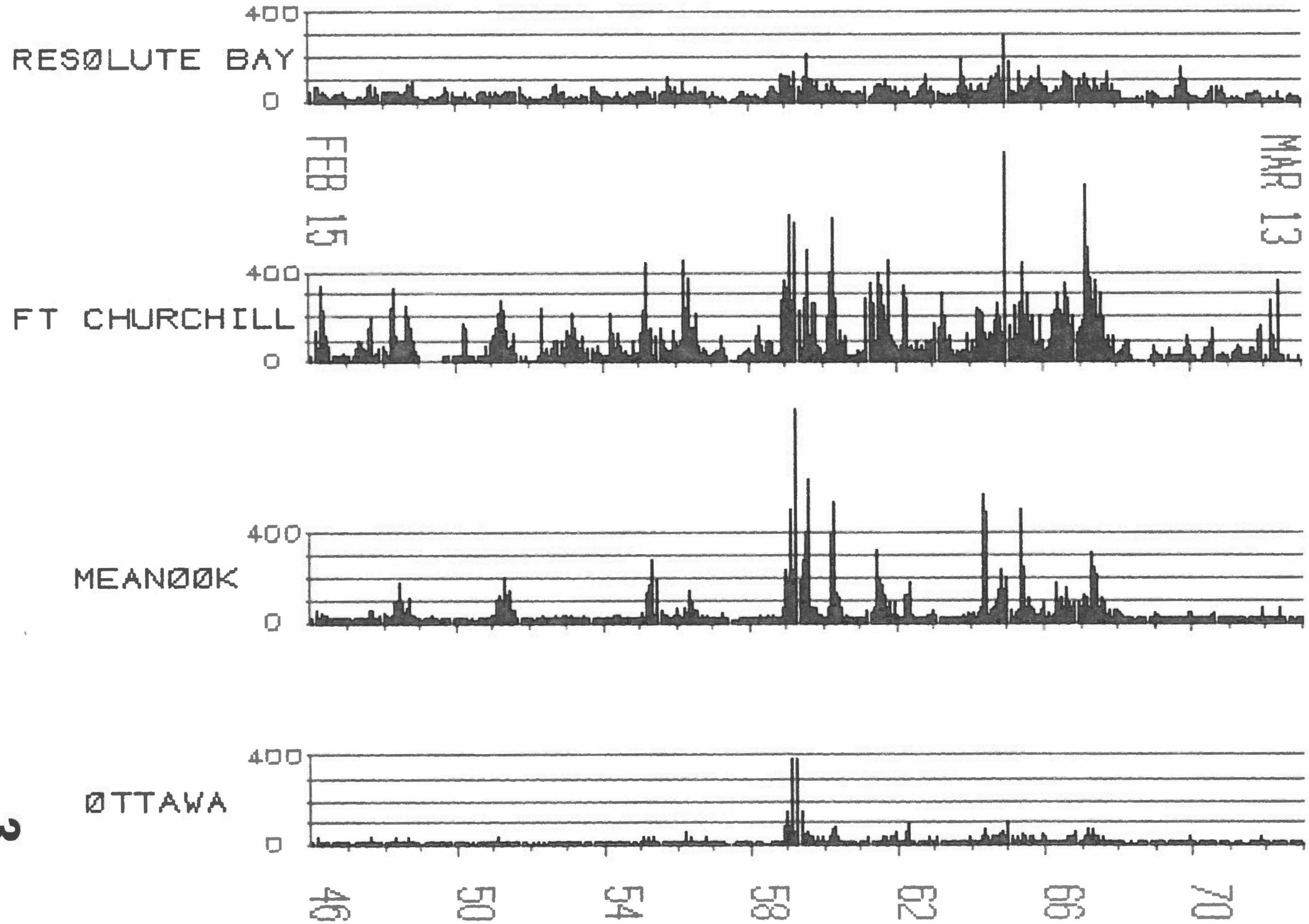
EMR CANADA EARTH PHYSICS BRANCH
GEOMAGNETIC ACTIVITY RECURRENCE PLOTS
CANADIAN MAGNETIC OBSERVATORY (AMOS III) NETWORK
27-DAY BARTELS SOLAR ROTATION PERIOD 2071
HOURLY RANGES (NT) FOR COMPONENT X
1985



MAGNETIC ACTIVITY FORECAST

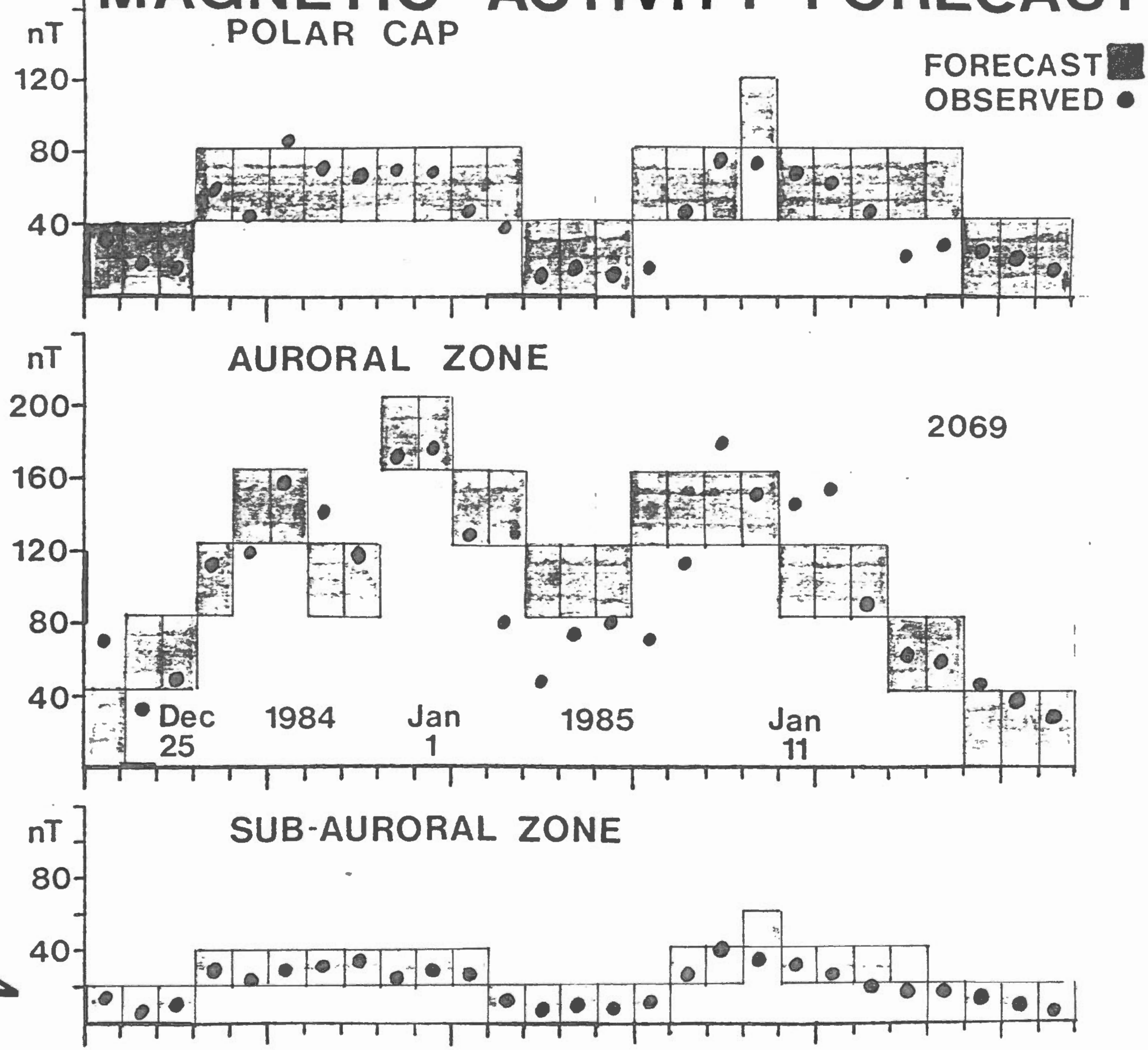
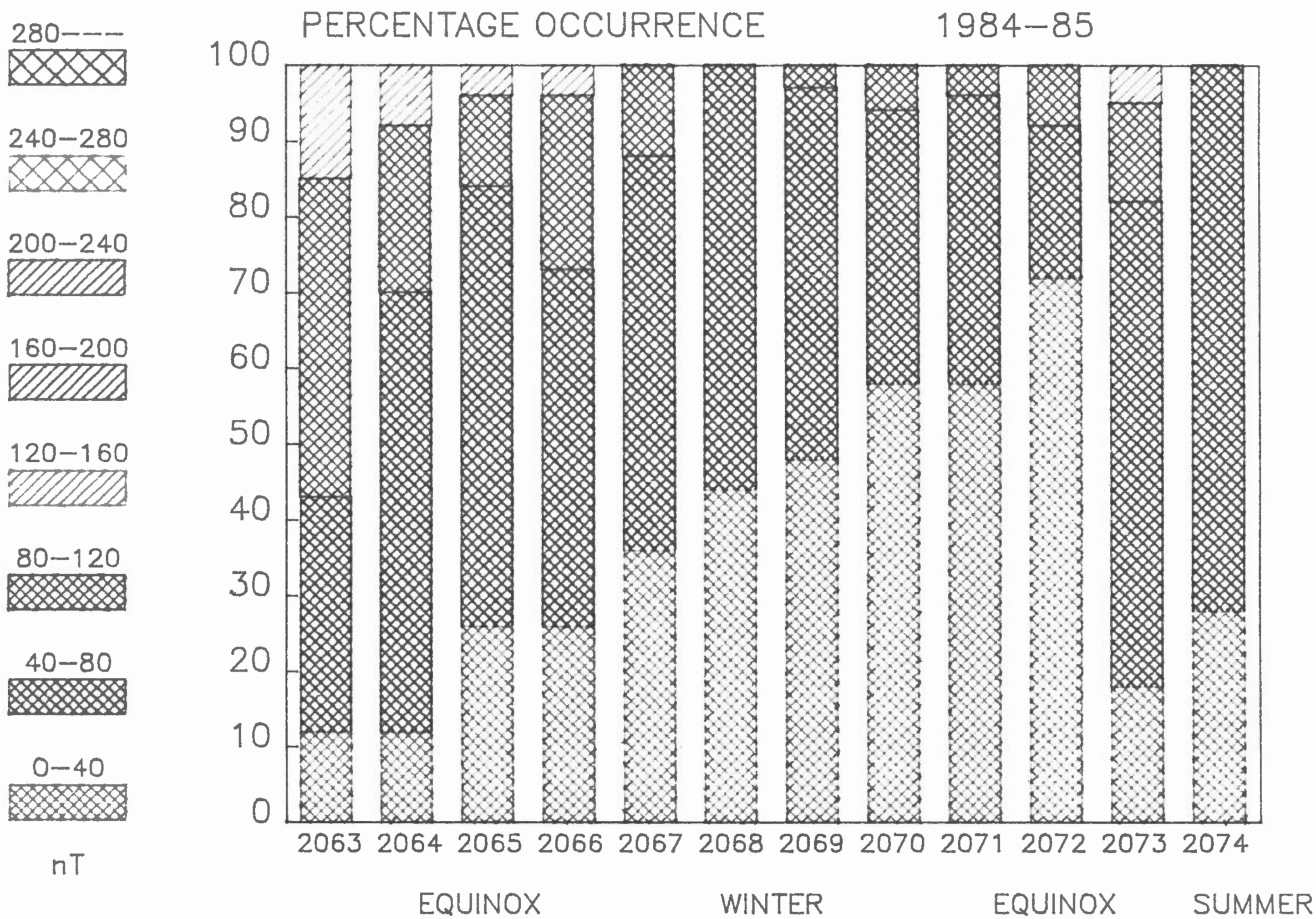


Fig. 4

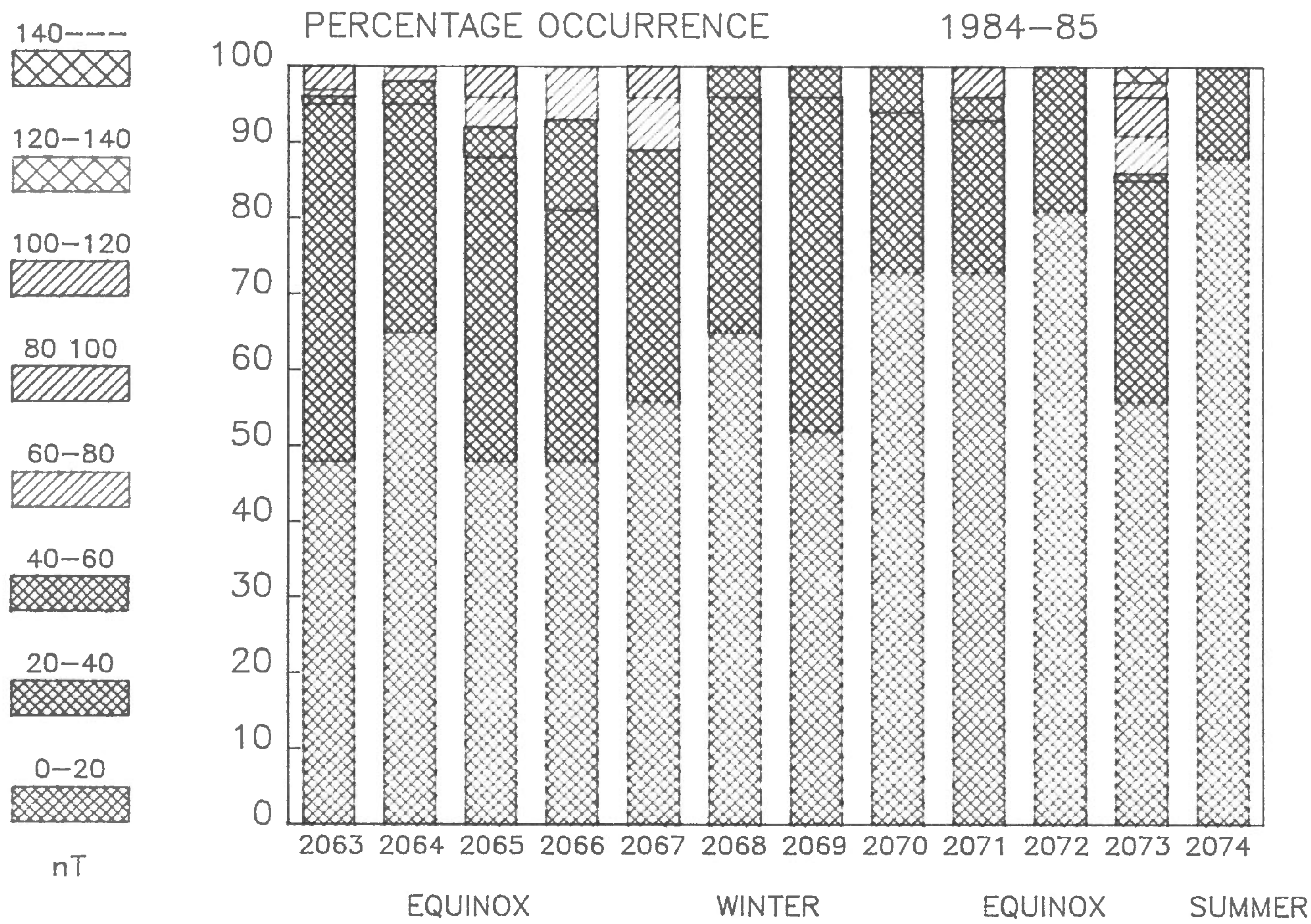
LOW ACTIVITY PORTION OF 11 YEAR CYCLE

POLAR CAP

MEAN HOURLY RANGES

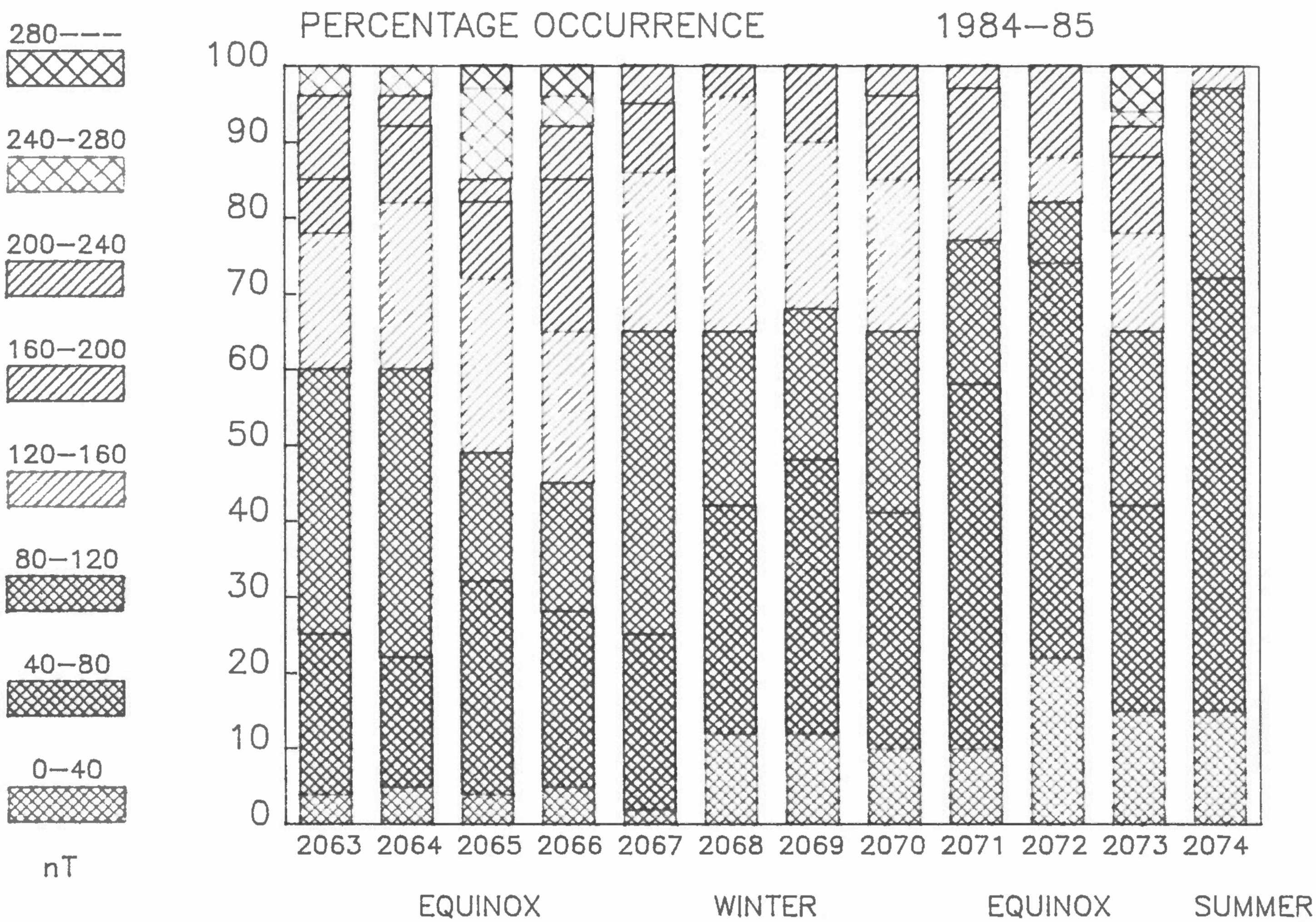


SUB-AURORAL
MEAN HOURLY RANGES



AURORAL

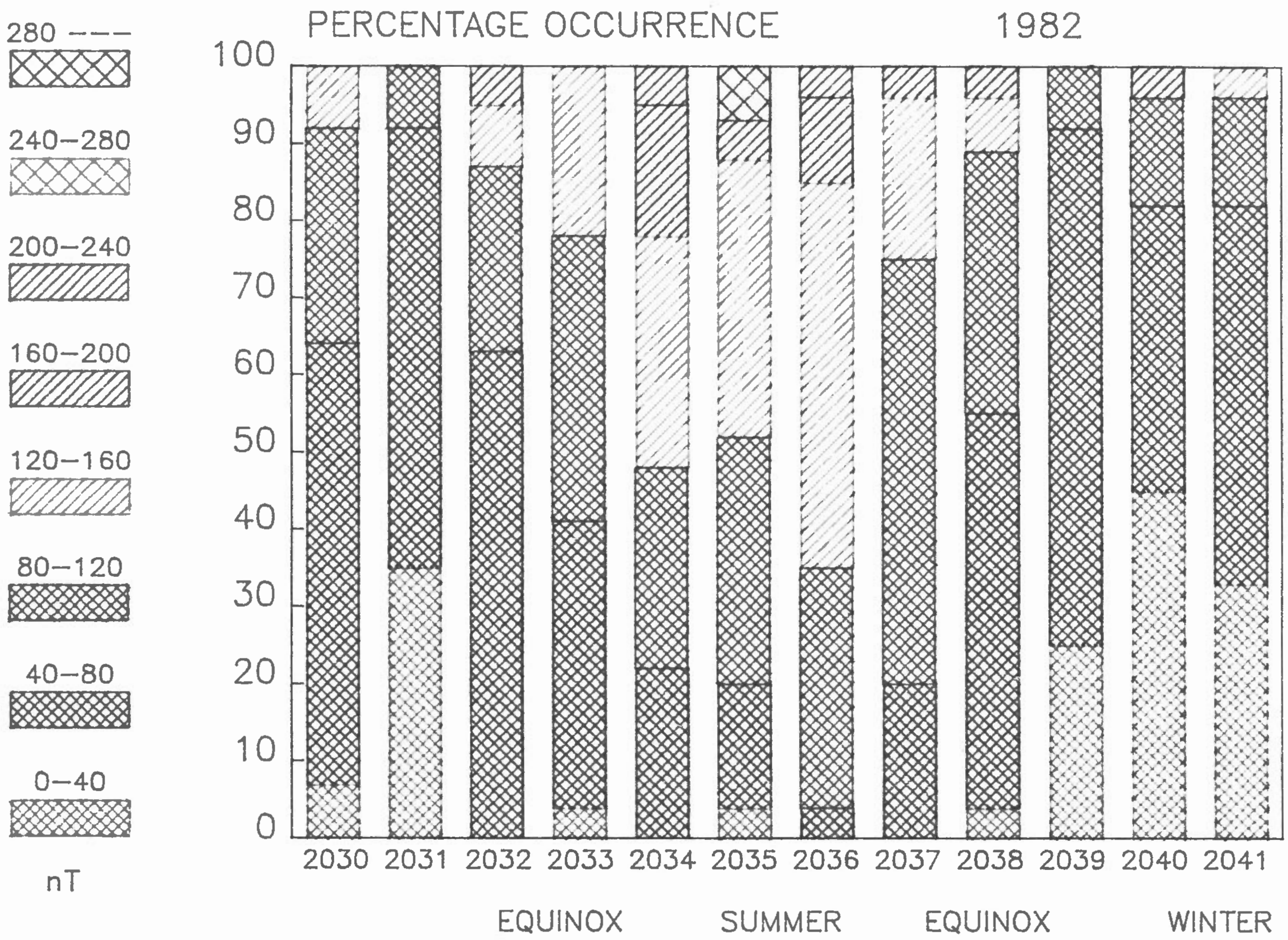
MEAN HOURLY RANGES



MAXIMUM ACTIVITY PORTION — 11 YEAR CYCLE

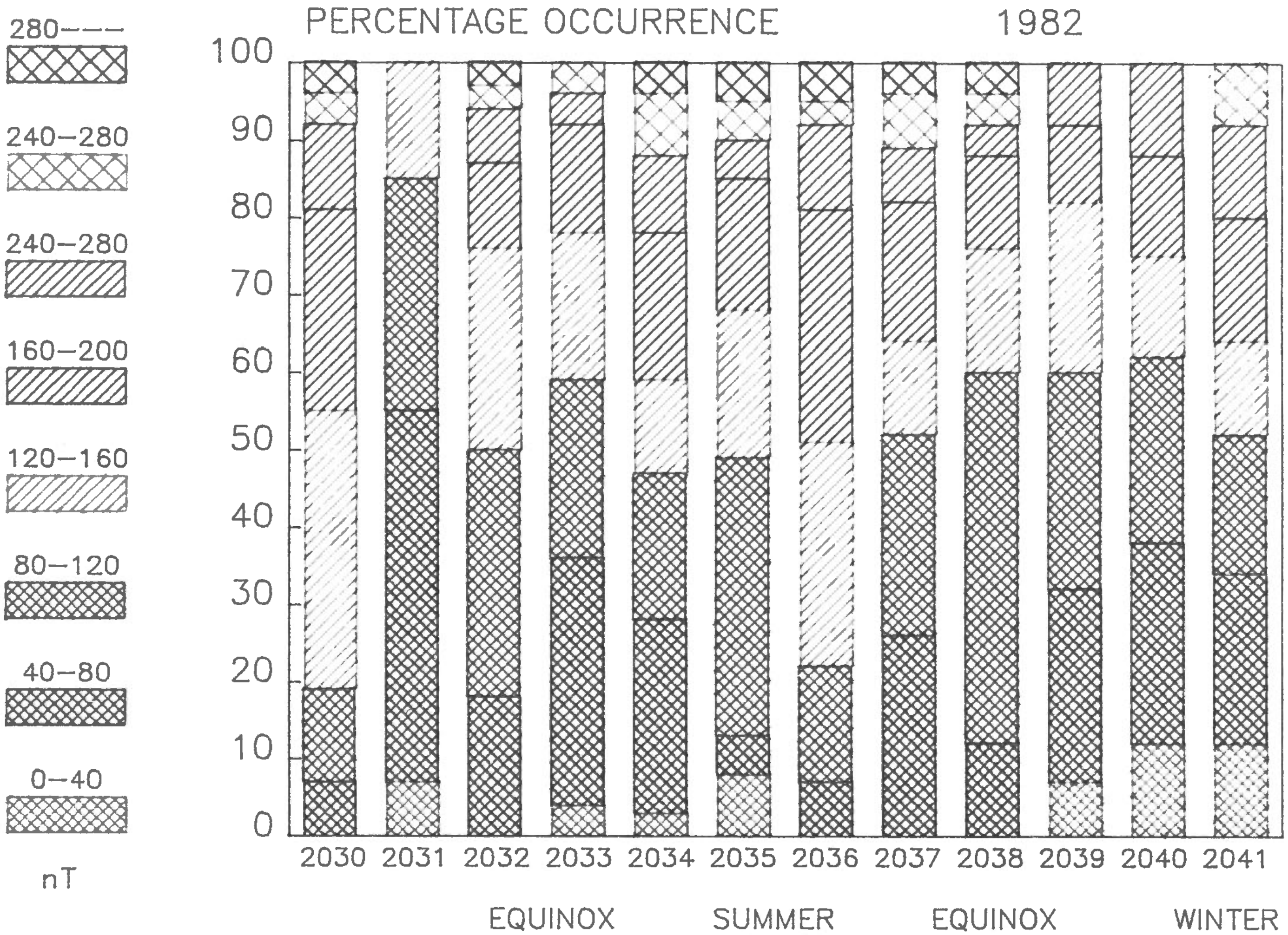
POLAR CAP

MEAN HOURLY RANGES



AURORAL

MEAN HOURLY RANGES



SUB—AURORAL
MEAN HOURLY RANGES