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THE EFFECT OF CHANGING MAGNETIC DECLINATION ON THE COMPASS

L.R. Newitt

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THE EFFECT OF CHANGING MAGNETIC DECLINATION ON THE COMPASS

INTRODUCTION

The magnetic compass has been used for navigation for hundreds of years. At one time, it was the only reliable means of navigation on days when the sun and stars were not visible. Nowadays, sophisticated equipment is available that enables users to determine their bearing accurately and to pinpoint their location to within a few metres. However, such equipment has not made the compass obsolete. It is still the only practical tool for navigation for most small craft and for those on foot. Even airplanes and ships equipped with more sophisticated equipment carry a compass as a backup.

Compasses come in a variety of shapes and sizes depending on their intended use. The type of compass used on a ship or aircraft is a complex piece of equipment capable of compensating for both the motion of the craft and its metallic structure. At the other extreme are small pocket compasses of low precision intended for casual use. One of the most popular varieties is the orienteering compass (Fig. 1a), widely used by backpackers, canoeists and other outdoor enthusiasts.

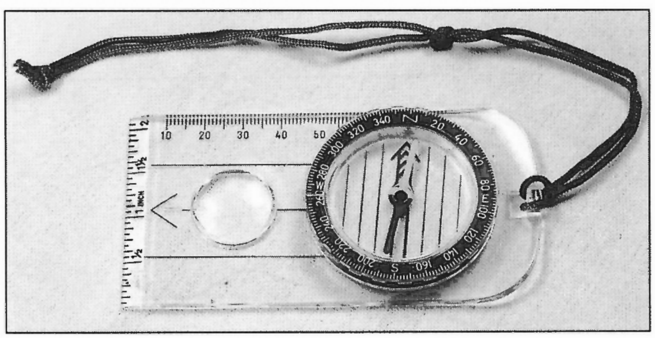


Figure 1a. A typical orienteering compass consisting of a baseplate, a capsule with a rotating dial marked from 0° to 360°, and a magnetized needle.

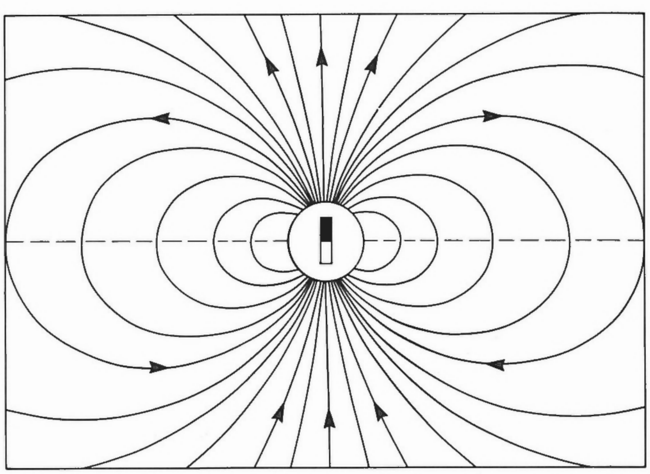


Figure 1b. The magnetic field that would be produced around a simple bar magnet located in the centre of the earth.

Regardless of their intended purpose or the complexity of their construction, most compasses operate on the same basic principle. A small, elongated, permanently magnetized needle is placed on a pivot so that it may rotate freely in the horizontal plane. The earth possesses a **magnetic field** shaped approximately like the field around a simple bar magnet (Fig. 1b). The earth's magnetic field exerts a force on the compass needle, causing it to rotate until it comes to rest in the same direction as the field. Over much of the earth, this direction is roughly north, hence the compass's early importance for navigation.

This simple process is complicated by the fact that the magnetic field is constantly changing in both strength and direction. This causes the orientation of a compass needle to change in a corresponding manner. Thus there is a fundamental uncertainty in compass navigation that may or may not be important, depending on its application by the user. This report describes some aspects of the magnetic field that can have an effect on compass navigation, and how to compensate for those effects and still ascertain a correct bearing.

MAGNETIC DECLINATION AND SECULAR VARIATION

Many people do not realize that a compass does not normally point true north, but at some angle east or west of true north. The direction in which the compass needle points is referred to as **magnetic north**, and the angle between magnetic north and the true north direction is called **magnetic declination**. You will often hear the terms "variation", "magnetic variation", or "compass variation" used in place of magnetic declination, especially by mariners. Figure 2 is a simplified chart showing lines of equal magnetic declination over Canada.

The magnetic declination does not remain constant. Due to complex fluid motion in the outer core of the earth (the molten metallic region that lies from 2800 km to 5000 km below the earth's surface), the magnetic field undergoes a continual slow change referred to as **secular variation** or secular change. As a result, the magnetic declination is continually changing. Examples of how the magnetic declination has changed with time at various locations in Canada are given in Figure 3. As a result of the secular variation, declination values shown on old topographic, marine and aeronautical charts need to be updated if they are to be used without large errors. Unfortunately, the annual change corrections given on most of these maps cannot be applied reliably if the maps are more than a few years old since the secular variation also changes in time in an unpredictable manner. If accurate declination values are needed, and if

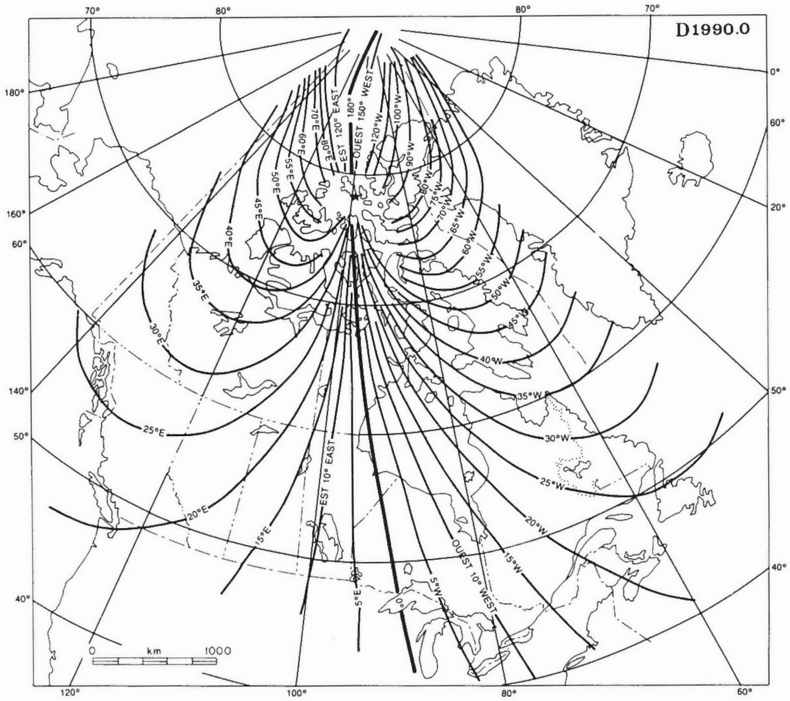
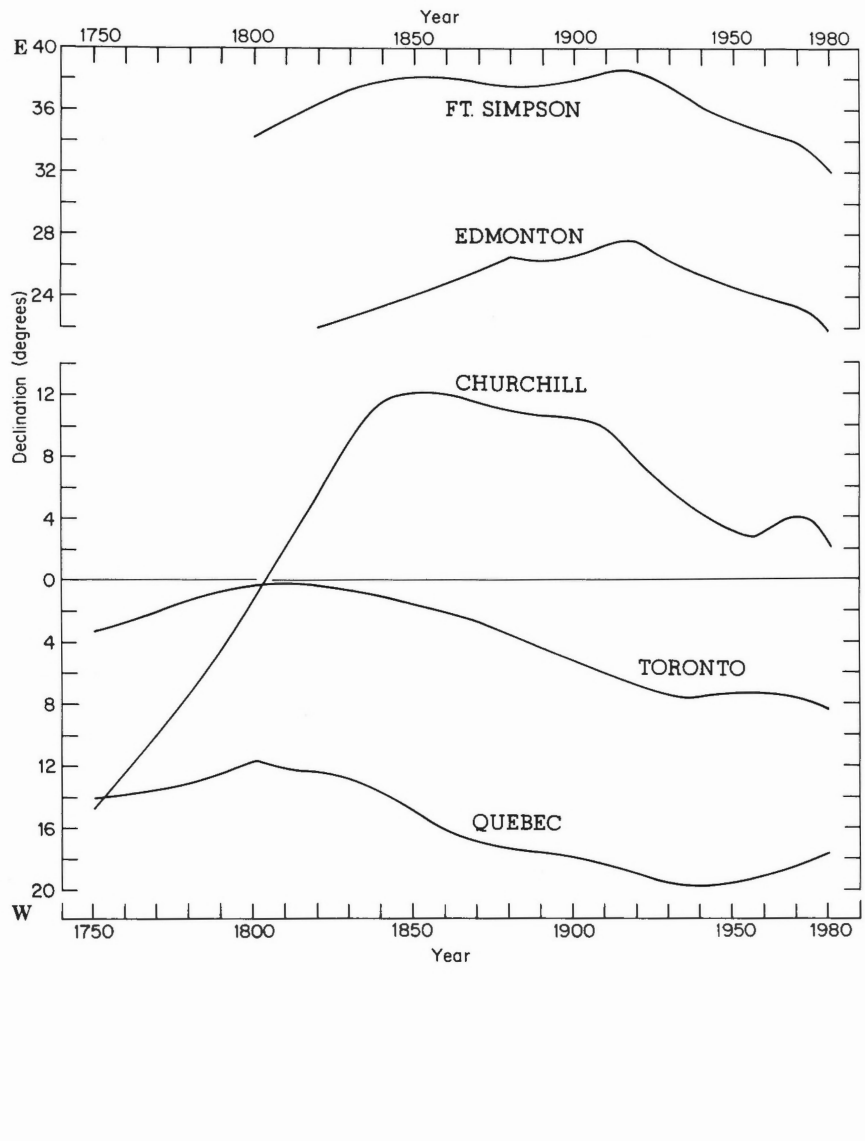


Figure 2. Chart showing lines of equal magnetic declination in Canada for the year 1990.

Figure 3. Secular variation of the magnetic declination at selected locations in Canada.



recent editions of the charts are not available, up-to-date declination values may be obtained from the Geological Survey of Canada, Geophysics Division, 1 Observatory Crescent, Ottawa, Canada, K1A 0Y3.

MAGNETIC DECLINATION AND SOLAR ACTIVITY

The magnetic field also undergoes changes that are much more rapid than the secular variation and are a result of solar activity. The processes by which the continual stream of particles emanating from the sun interacts with the earth's magnetic field and upper atmosphere are very complex but they result in continual fluctuations in the magnetic field with resultant changes in magnetic declination.

Scientists have numerous classifications for rapid fluctuations of the magnetic field which take into account such factors as the size and speed of the fluctuations and the physical processes responsible for them. However, the average compass user needs to be aware of only a few of these.

Even on days when solar activity is very low the magnetic field will undergo a smooth, cyclical change called the **daily variation.** Figure 4 shows the typical daily variation in magnetic declination for Ottawa Magnetic Observatory. Ottawa is in the subauroral zone, one of three zones that are characterized by distinctly different types of magnetic activity (Fig. 5). Note, in Figure 4, that the magnetic declination is most easterly in the morning and most westerly in the afternoon. Typically, in southern Canada, the maximum change in magnetic declination over the course of a day is several minutes of arc.

A number of times each year, the earth is affected by large disturbances of the magnetic field referred to as **magnetic storms.** The onset of a magnetic storm occurs almost instantaneously everywhere on the earth, and the storm may last for more than 48 hours. The magnetic field changes that occur during a storm differ from one location on earth to another, and from one storm to another. Changes in magnetic declination may at times be large enough to be detectable with a standard compass, especially at high latitudes. An observer may actually see a compass needle swing back and forth as the declination changes. Figure 6 shows changes in declination during a major magnetic storm.

In addition to worldwide magnetic storms, intense disturbances of much shorter duration occur quite frequently in the auroral zone (see Fig. 5 for location). Although they normally last for no more than a few hours and occur primarily at night, these disturbances can be quite intense (Fig. 7).

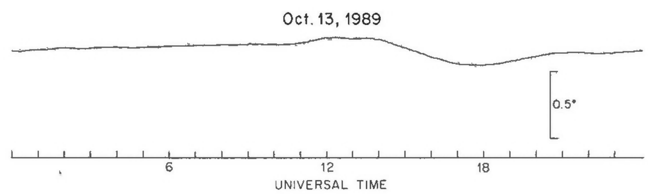


Figure 4. Typical quiet day variation of the magnetic declination recorded at Ottawa, October 13, 1989. Easterly changes are toward the top of the diagram; westerly changes are toward the bottom of the diagram. The vertical scale indicates the size of changes in the magnetic declination, in degrees of arc. Thus, between the peak and the trough of the curve, a change of 0.17° (10' of arc) has occurred. The horizontal scale gives the time of day, in Universal Time.

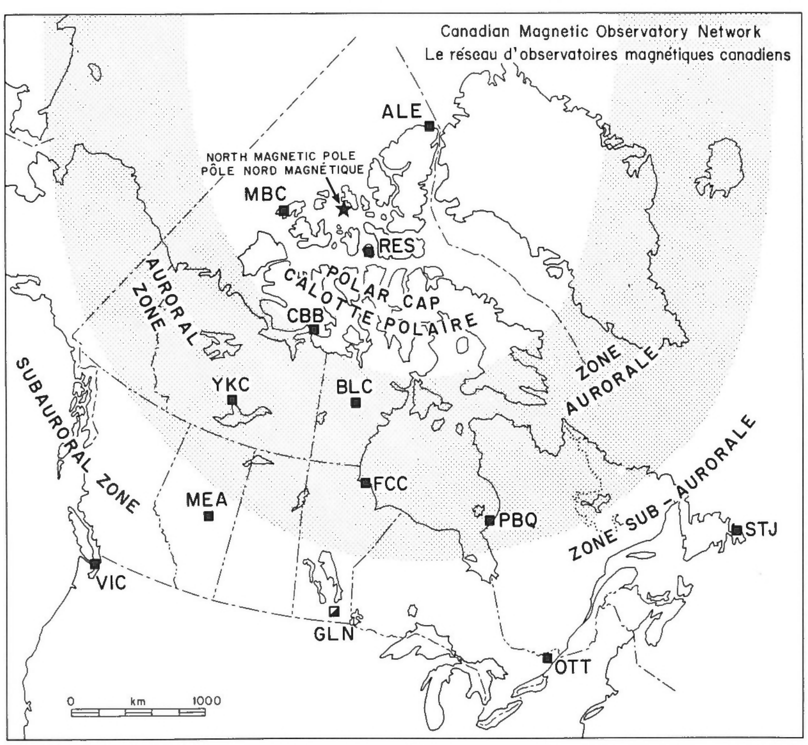


Figure 5. Location of the magnetic observatories in Canada. The five observatories used in this study are Victoria (VIC), Meanook (MEA), Yellowknife (YKC), Cambridge Bay (CBB), and Resolute Bay (RES). Also shown on the map are the location of the auroral zone and the north magnetic pole.

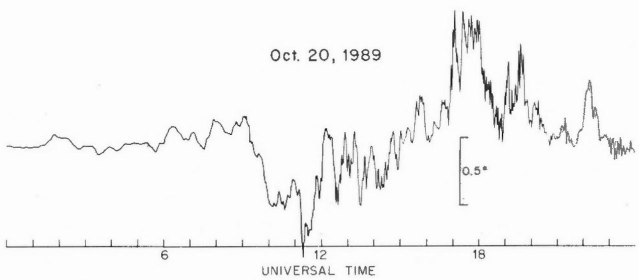


Figure 6. Variation of the magnetic declination during a typical magnetic storm, recorded at Ottawa, October 20, 1989.

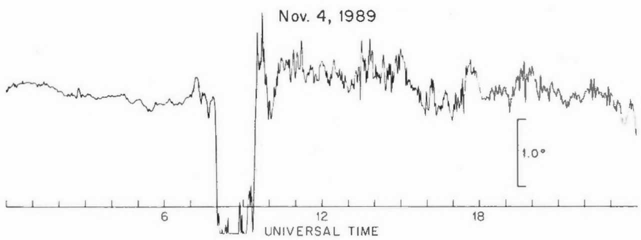


Figure 7. Variation of the magnetic declination during a typical magnetic substorm, recorded at Fort Churchill, November 4, 1989. Note change in scale from Figure 4.

Regardless of their cause, rapid fluctuations in the magnetic declination become larger as one approaches the **north magnetic pole**. This is because the **horizontal force** of the magnetic field becomes smaller as one approaches the pole. It is this horizontal force that causes the compass needle to align itself in the magnetic field direction. If this force is small, changes in the magnetic field will have a relatively greater effect on the declination than would be the case farther south where the horizontal force is large.

If the horizontal force is too small, an ordinary compass will become useless because the frictional forces in the compass will exceed the horizontal force of the magnetic field. As a general rule, standard pivot compasses become unreliable when the horizontal force of the magnetic field drops below 6000 nT, and useless when the horizontal force is less than 3000 nT. These regions are shown in Figure 8. In some aircraft, fluxgate magnetometers are used in place of mechanical compasses since they are immune to the effects of friction.

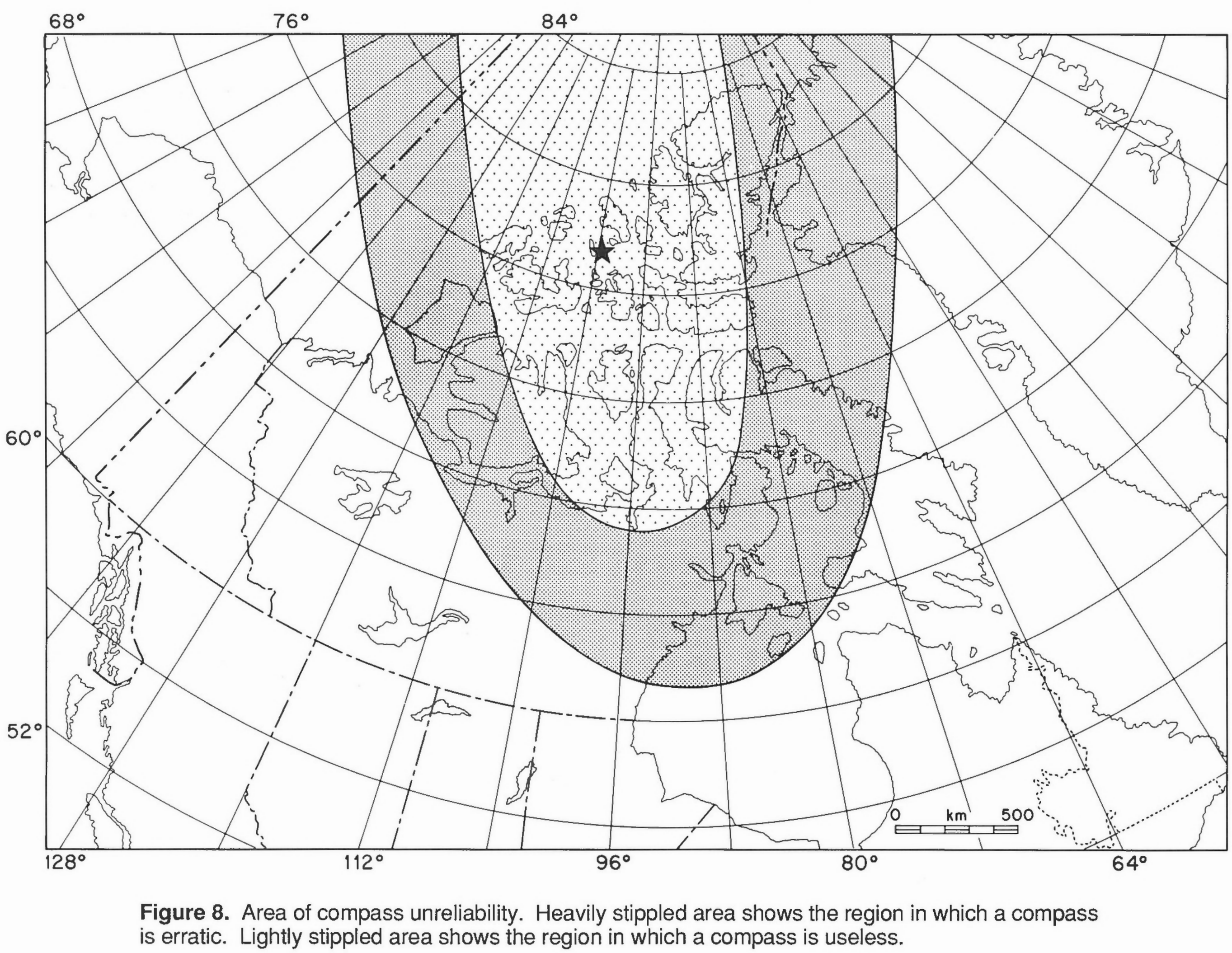


Figure 8. Area of compass unreliability. Heavily stippled area shows the region in which a compass is erratic. Lightly stippled area shows the region in which a compass is useless.

FREQUENCY OF LARGE DECLINATION CHANGES

How often does the magnetic declination depart from its normal value to such an extent that the departure might be of consequence to navigation? This will depend on where you are in the country. It will also depend on what size error can be tolerated for a given application. A standard compass, such as an orienteering compass or one that would be found in a small boat, has a precision of about 2 degrees. Some military compasses and those used by surveyors, on the other hand, have a much higher precision, on the order of 5 minutes of arc. Thus users of these high precision compasses should be concerned about much smaller changes in the magnetic declination than should users of standard compasses.

To show the magnitudes of fluctuations in magnetic declination in a variety of locations and conditions, data from five of the magnetic observatories shown in Figure 5 (VIC, MEA, YKC, CBB, RES) were examined. Data from two complete years, 1976 and 1981 were reviewed, and the difference between maximum and minimum values of magnetic declination on each day (the daily range) and the amount by which the maximum and minimum values of declination differed from the normal value on each day (referred to as the positive and negative departures) were calculated. This information is summarized in Table 1.

The table shows that the daily range is generally larger in 1981 than in 1976. This is a result of the approximately 11 year cycle that both solar and magnetic activity undergo. At the time of writing of this report, the current cycle of magnetic activity has almost reached its peak.

Table 1. Average daily range of magnetic declination during a quiet year (1976) and a disturbed year (1981).

	1976			1981		
Station	Range	+ve	-ve	Range	+ve	-ve
Victoria	0°15′	0°08′	0°07′	0°20′	0°11′	0°08′
Meanook	0°39′	0°22′	0°17′	0°55′	0°28′	0°22′
Yellowknife	2°11′	1°09′	1°02′	2°01′	1°01′	1°00′
Cambridge	4°39′	2°31′	2°08′	5°26′	3°17′	2°09′
Resolute	18°39′	8°14′	10°25′	22°28′	10°32′	11°56′

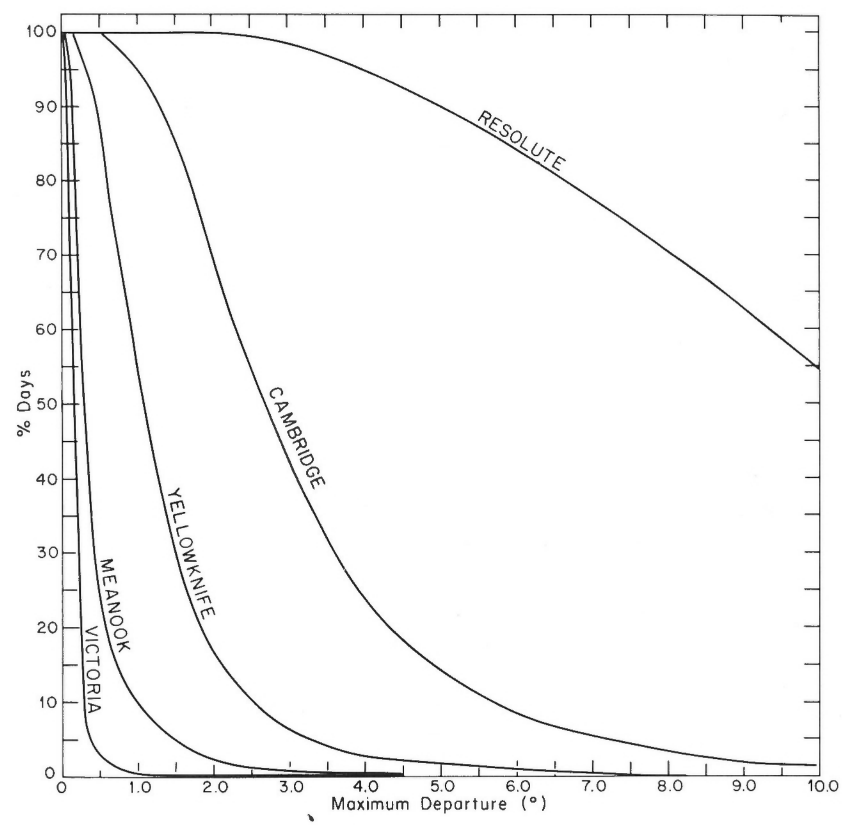


Figure 9. The diagram gives, for each of the five observatories, the percentage of days on which the departure of the magnetic declination from its normal value is greater than the amount indicated along the horizontal axis.

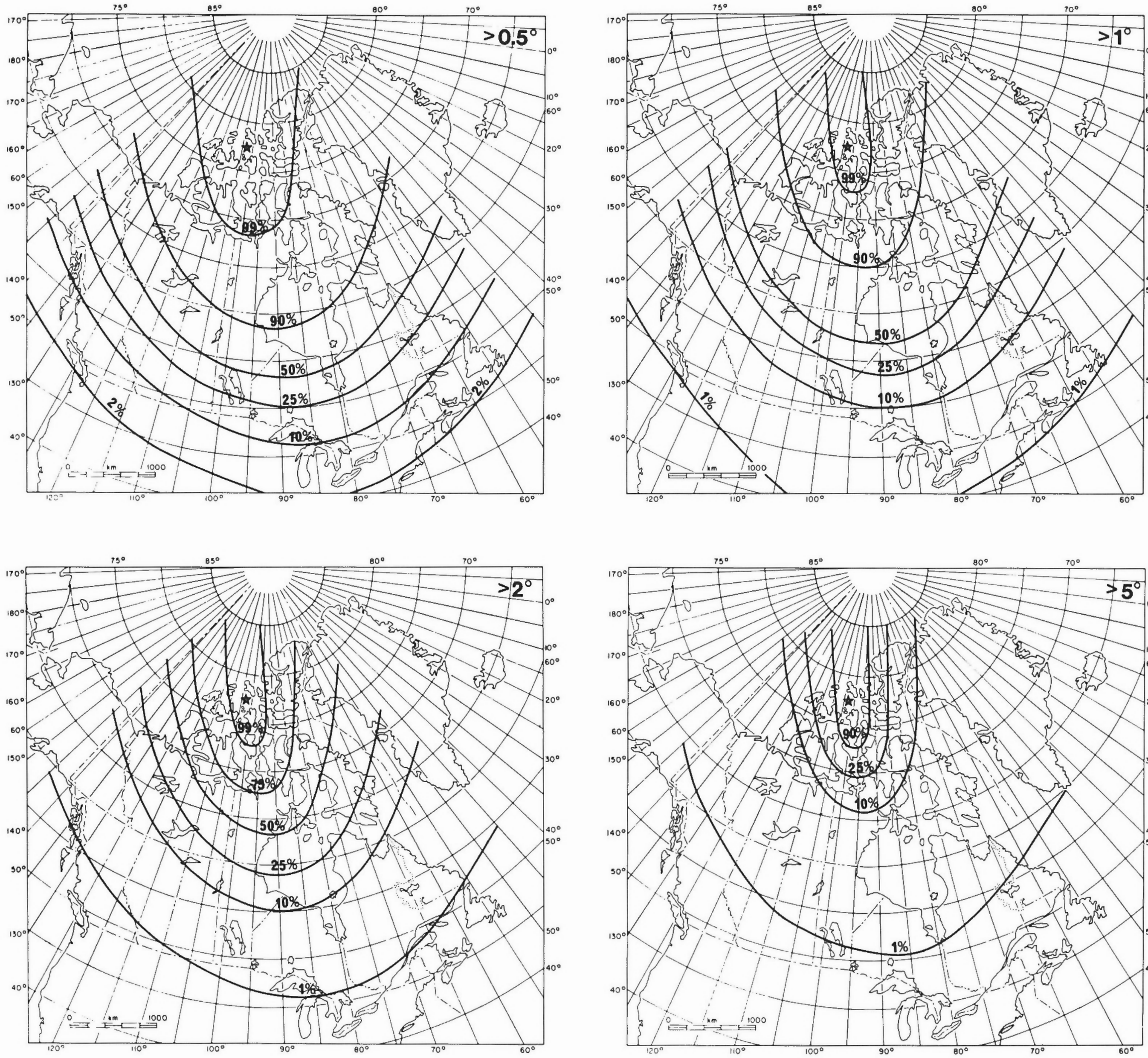


Figure 10. Probability that an observer will experience a fluctuation in magnetic declination anywhere in Canada in excess of (a) 0.5°, (b) 1.0°, (c) 2.0°, (d) 5.0°.

There is also a large increase in range in magnetic declination as one proceeds north, a result of the decreasing horizontal strength of the magnetic field. However, Table 1 indicates (looking at the positive and negative departures) that on the average, the magnetic declination should not depart from its normal value by an amount large enough to cause problems for the average compass user anywhere in southern Canada. Users of precision compasses must be concerned about fluctuations much smaller than 2 degrees. The average departures of over 20 minutes that occur at Meanook, near Edmonton, are thus a potential problem. In the Arctic regions, average departures are large enough to be of concern to most users. In those regions, users of mechanical compasses have the additional problem of compass unreliability due to frictional forces.

Even though the average departure of magnetic declination is typically small in southern Canada there are, nevertheless, occasions during magnetic storms when fluctuations in declination are large. Using the data from both 1976 and 1981, a diagram has been compiled (Fig. 9) showing the percentage of days on which the maximum difference between the actual declination and the normal value exceeded a given amount, at each of the five observatories. At Victoria, there was only one day in that two year period (0.137% of days) on which the departure in declination was greater than 2 degrees. However, at the latitude of Yellowknife, in the auroral zone, departures of more than 2 degrees occurred on 17% of days. Smaller departures, which can nevertheless affect users of precision compasses, naturally occurred much more frequently. Figure 9 shows that even at low latitude stations such as Victoria, departures in excess of 0.3 degrees (18 minutes) occur on approximately 15% of days. At the latitude of Yellowknife, such departures were almost a daily occurrence.

The information contained in Table 1 and Figure 9 is more conveniently summarized for the user in Figure 10. This figure shows the probability of the magnetic declination departing from the normal value by more than a certain amount. For example, Figure 10a shows that at Winnipeg, declination departures of more than 0.5 degrees (30 minutes) occur on almost 25% of days. However, Figure 10c shows that departures in excess of 2 degrees occur on only 2% to 3% of days at Winnipeg.

CONCLUSION

In much of southern Canada changes in magnetic declination large enough (2 degrees) to be of concern to the average compass user are relatively rare, occurring only once every couple of years on the average. However, in and north of the auroral zone, the frequency of large departures increases rapidly, and can be a major source of error for compass navigation.

For users of high precision compasses, changes in magnetic declination must be of continual concern since changes in declination in excess of 0.5 degrees occur frequently even in much of southern Canada.