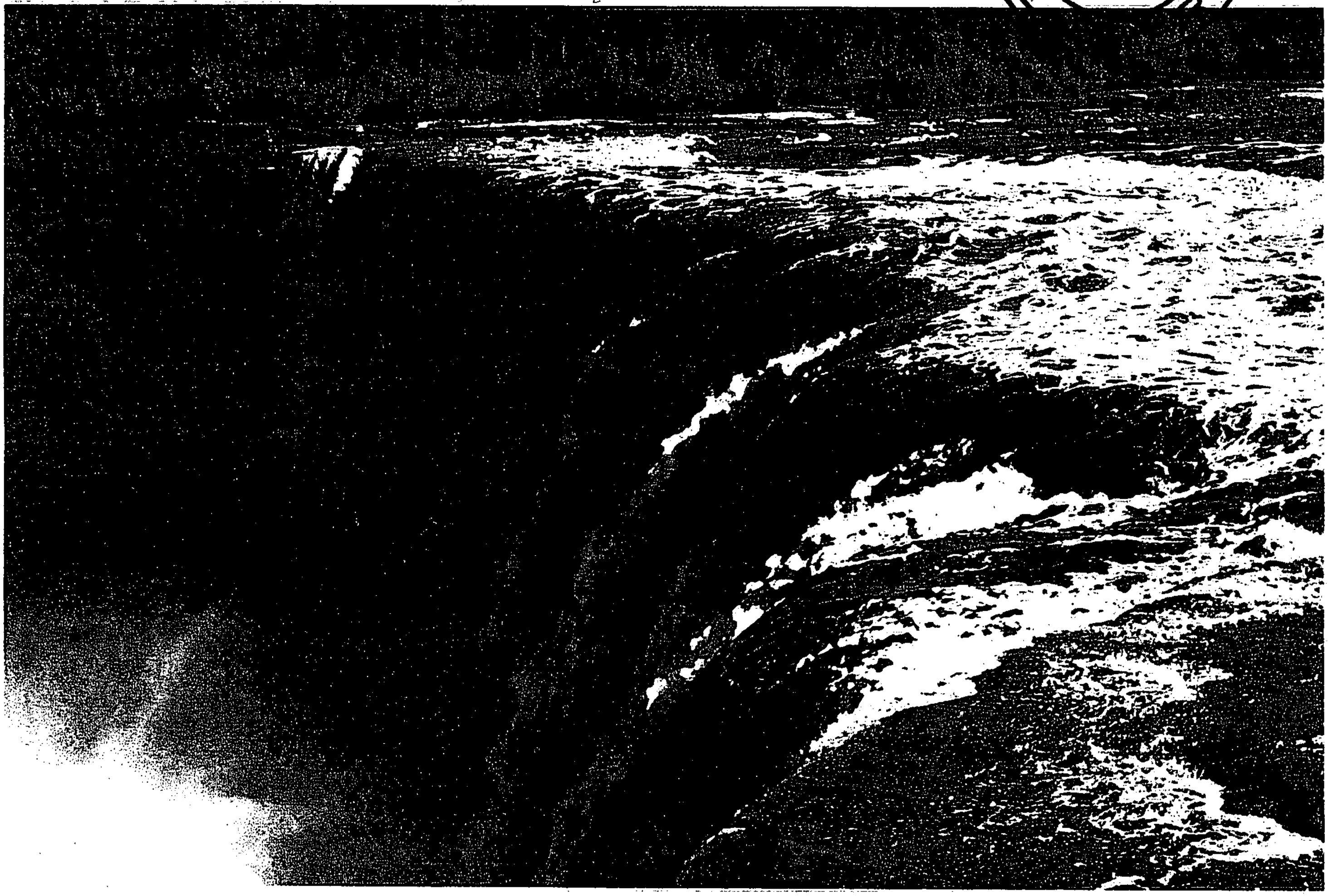
Practical Methods of Aiming Antennas at Geostationary Satellites



Technical Bulletin No. 104

Fisheries and Environment Canada
Pêches et Environnement Canada

Practical Methods of Aiming Antennas at Geostationary Satellites

I.A. Reid

TECHNICAL BULLETIN NO. 104
(Résumé en français)

INLAND WATERS DIRECTORATE,
WATER RESOURCES BRANCH,
OTTAWA, CANADA, 1978.

Cat. No. En36-503/104

ISBN 0-662-10330-0

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Abstract

The procedure for aligning Data Collection Platform (DCP) antennas in the Geostationary Operational Environmental Satellite (GOES) System is presented. A method is given for determining (a) the angle of elevation and (b) the azimuth or bearing, to which an antenna must be set to bring it in line with a satellite. Two detailed methods, one using a compass and the other a watch, are presented for setting an antenna on the predetermined bearing.

Résumé

Le présent rapport décrit la procédure de visée utilisée pour orienter les antennes de la plate-forme d'entrée des données dans le réseau du Satellite géostationnaire opérationnel de l'environnement (GOES). Il traite d'une méthode qui sert à déterminer: (a) le pointage en hauteur et (b) le pointage en direction (azimutal), pour viser l'antenne sur le satellite. Enfin, deux méthodes détaillées, l'une utilisant une boussole, l'autre une montre, sont fournies pour orienter une antenne dans la direction prédéterminée.

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INTRODUCTION

The Geostationary Operational Environmental Satellite (GOES) System, operated since 1975 by the National Environmental Satellite Service (NESS) of the United States Department of Commerce, is essentially a data relay network which uses equatorial orbiting satellites to retransmit data from data-gathering devices on the ground; the data are retransmitted by the satellites to a central receiving station, processed and made available by land line to users. The data-gathering devices at which data are collected and transmitted to the satellites are known as Data Collection Platforms (DCP's).

Figure 1 is a diagram showing the principal components of the GOES System.

Many different data parameters can be sensed and relayed by the satellites. The more important of these from the hydrometric and hydrometeorological point-of-view are water level and water velocity, presence or absence of river ice cover, water content of snow, precipitation, air temperature, wind speed and direction, relative humidity and atmospheric pressure; water quality parameters such as water temperature, pH, dissolved oxygen, conductivity and turbidity are also sensed and relayed to the receiving station.

The system has demonstrated its effectiveness as a means of gathering and disseminating environmental data of all kinds on a continuous operational basis and with minimum delay; for Inland Waters Directorate the system has enormous potential.

Major users of data may, with the permission of NESS, establish their own receive stations which permit them to receive retransmitted data directly from the satellite. One such station, serving Canadian needs, is operated by the Canada Centre for Remote Sensing, Department of Energy, Mines and Resources at Prince Albert, Saskatchewan.

GOES SATELLITES

The satellites used in the GOES system are geostationary satellites, i.e., their orbital path and speed match the speed of the earth's rotation so that the positions of the satellites relative to any point on the earth's surface are constant. With respect to the earth, they are stationary.

There are three satellites in the system stationed above the equator at an altitude of about 35 800 km; two of them are stationed at longitudes of 75° west and 135° west respectively, and a third, a standby satellite, at 105° west longitude, midway between the two operational satellites. Each satellite can receive and retransmit data from over 10 000 Data Collection Platforms.

DATA COLLECTION PLATFORMS

A DCP is a small transmitter connected to one or more sensors, which transmits data to the satellite. A radio transmitter and directional antenna are integral parts of the equipment and the unit is powered by solar-charged batteries. Installation of a DCP and components is a relatively simple operation and experience to date has shown that there are few maintenance problems.

DCP ANTENNA ALIGNMENT FOR TRANSMISSIONS TO SATELLITE

The GOES System of data collection is extremely sophisticated, not only in concept but in the technology which supports it. Each component, from the sensor that records a parameter to the satellite that receives and relays the information to the processing and distributing centre, is a highly developed product of modern research. But the proper functioning of the system depends also to no less a degree upon a single, much less sophisticated operation. This operation is the alignment of the DCP's transmitting antenna in such a way that the radio transmission can be picked up by the satellite. If the alignment is not accurate, the transmission will be beamed past the satellite and the encoded information will be lost. It is obvious then that accuracy in aligning the DCP antenna is essential if the system is to fulfill its design function.

This report describes one method of determining (a) the angle of elevation and (b) the azimuth or bearing, to which the antenna must be set to bring it in line with

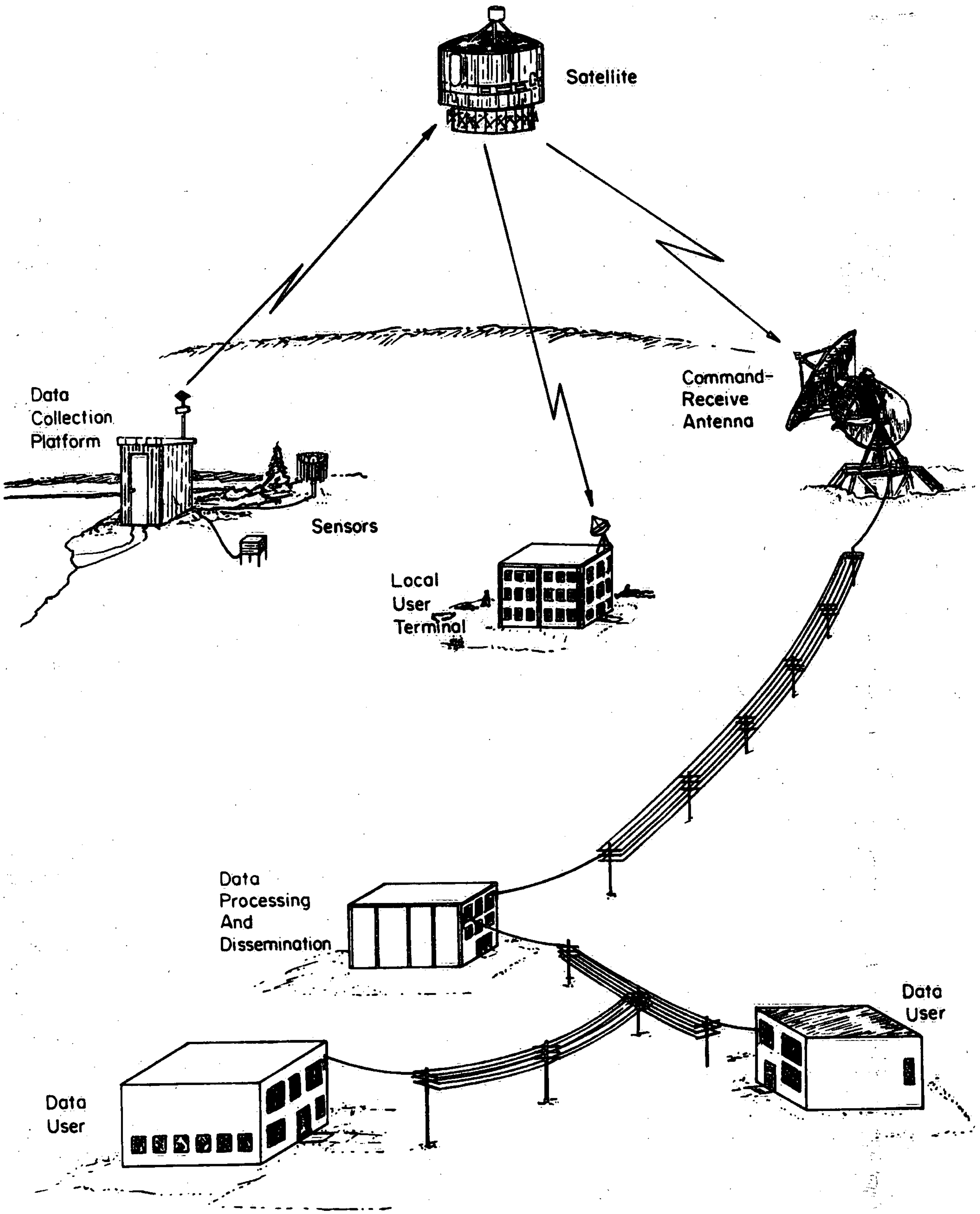


Figure 1. GOES data collection system (from Halliday, 1975).

the satellite, and two methods, one using a compass and the other an ordinary watch, of setting the antenna on the predetermined bearing.

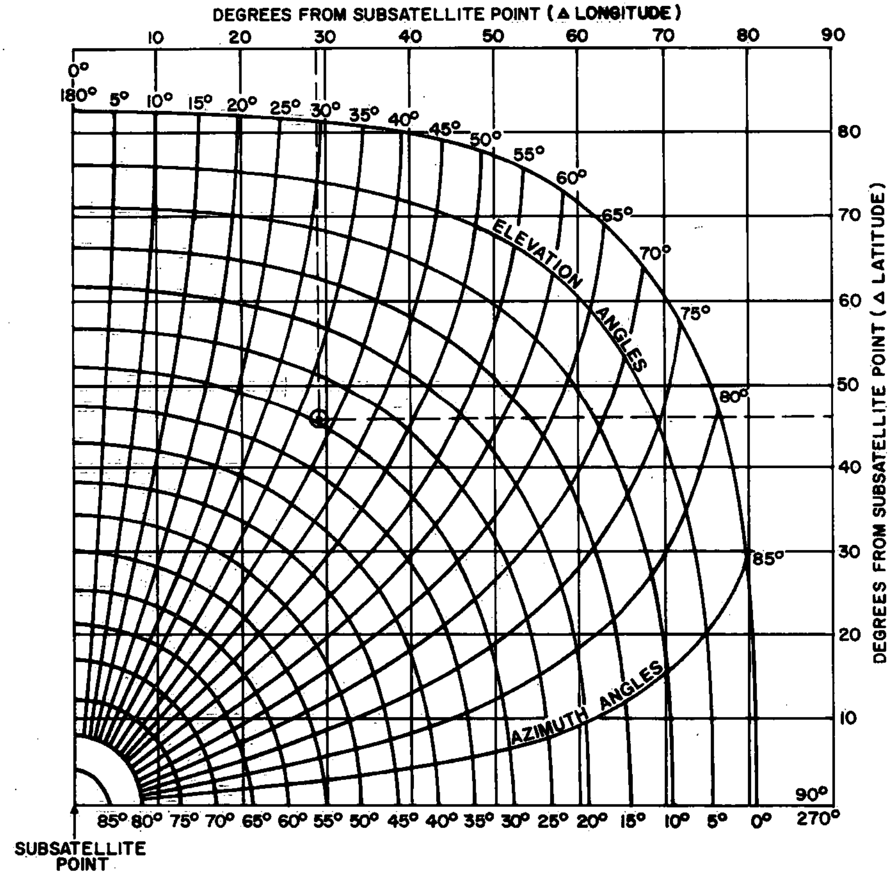
ANGLE OF ELEVATION AND AZIMUTH

The information required for determining angle of elevation and azimuth is

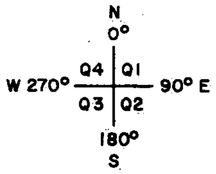
(a) latitude and longitude of the DCP,
(b) latitude and longitude of the satellite, and
(c) orbital altitude of the satellite.

Figure 2 is a plot showing the angle of elevation and azimuth for aligning a DCP antenna to any geostationary (synchronous) satellite positioned directly over the equator. The angle of elevation and azimuth are read against the appropriate combination of latitude difference (△ latitude) and longitude difference (△ longitude) between the position of the DCP and the position of the satellite. Figure 2 is plotted to take into account the satellite's orbital altitude. The reference point for the quadrant, marked on Figure 2 as "subsatellite point," is a point on the equator directly below the satellite.

To determine the angle of elevation and azimuth, the difference in latitude and longitude between the position of the satellite and the position of the DCP must first be established. The latitude and longitude of the DCP are already known to the user. The latitude of the satellite, which is stationed directly above the equator, is 0°. The longitude to be used for the satellite aiming point is calculated according to which satellite is being used. There are, as previously mentioned, three satellites: the East satellite at 75° west longitude, the West satellite at 135° west longitude, and a standby satellite midway between at 105° west longitude. The entire range of frequencies used by the system is apportioned between the two operational satellites; the frequency (Channel 13) allocated for Canadian operations is handled by the East satellite. Should the East satellite cease to function, the load would be taken up by the standby satellite. For this reason, NESS, which operates the GOES System, recommends that antenna alignment be carried out by aiming the antenna at a point midway between the East satellite and the standby satellite, i.e., at a point directly above the equator with a longitude of 90° west. In the case of DCP transmitting frequencies assigned to the West satellite, the antenna aiming point would be at longitude 120° west.



QUADRANT ANGLES
(GROUND STATION AT CENTRE)



AZIMUTH ANGLE CONVERSION
(QI ANGLES ARE SHOWN ON CHART)

QI	Q2	Q3	Q4
0	180	180	0
5	175	185	355
10	170	190	350
15	165	195	345
20	160	200	340
25	155	205	335
30	150	210	330
35	145	215	325
40	140	220	320
45	135	225	315
50	130	230	310
55	125	235	305
60	120	240	300
65	115	245	295
70	110	250	290
75	105	255	285
80	100	260	280
85	95	265	275
90	90	270	270

Figure 2. Azimuth and elevation angles for antenna alignment with equatorial synchronous satellites.

In the following example, the longitude of the satellite aiming point is 90° west. This example illustrates the calculation for determining △ latitude and △ longitude:

DCP (Water Survey of Canada DCP No. 15) position:
46°38′ north latitude
60°57′ west longitude

Satellite aiming point position: 0° latitude
90° west longitude

△ latitude = 46°38′ - 0°00′ = 46°38′
△ longitude = 90°00′ - 60°57′ = 29°03′

Using these two values, the angle of elevation is read directly from the plot as 30°.

The azimuth, in the context of this exercise, is taken to mean the *true* bearing of the satellite from the DCP, measured from *true* north. The azimuth angle for the foregoing example, read off the plot, is 38°. It should, however, be pointed out that the plot in Figure 2 provides azimuth angles for quadrant Q1 only, that is from due north to due east, or 0° to 90°. Azimuth angles for quadrants Q2, Q3 and Q4 must be adjusted to determine the azimuth or bearing from *true* north. The intersect in the Quadrant Angle diagram (Fig. 2) is at the DCP position. In the example cited above, the satellite aiming point is south and west of the DCP; this places the satellite aiming point in quadrant Q3. In the Azimuth Angle Conversion table (Fig. 2) the equivalent Q1, azimuth of 38°, is 218° for Q3 (38° +180°).

The *true* azimuth or bearing of the satellite aiming point from the Data Collection Platform, therefore, is 218°, measured from true north, and the angle of elevation is 30°.

AIMING THE DCP TRANSMITTING ANTENNA

The angle of elevation and the azimuth angle determined above are essentially the only two pieces of information required to aim the DCP antenna at the satellite with sufficient accuracy to ensure that the information is received by the satellite for relay to the data processing station.

SETTING THE ANGLE OF ELEVATION

It is a relatively simple matter to set the antenna to the required angle of elevation. The newer antennas used with the GOES System are mounted on a frame graduated in degrees; all that is necessary is to ensure that the antenna support is vertical. If the antenna frame is not graduated, an Abney level can be used to set the antenna to the required angle of elevation (Fig. 3).

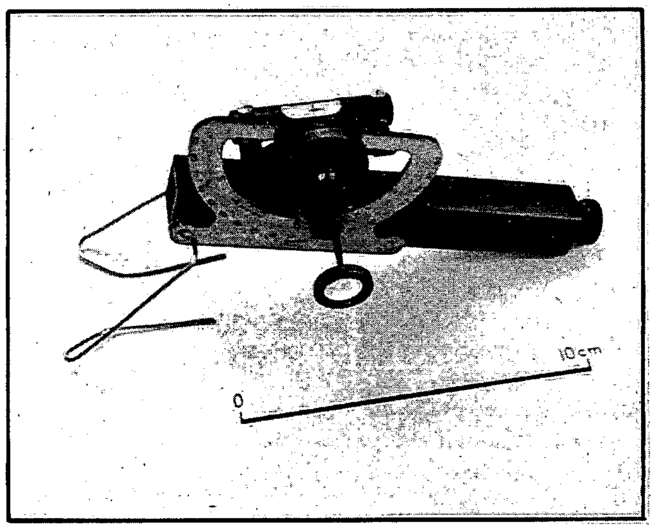


Figure 3. Abney level.

SETTING THE AZIMUTH

Setting the antenna to the proper azimuth is not quite as straightforward a procedure as setting the angle of elevation. Two methods are described here; one uses a compass and the other, an ordinary watch.

Compass Method

In the example used earlier, the bearing of 218° between satellite aiming point and DCP is a true bearing, i.e., it is referenced to true north. A compass, on the other hand, indicates compass north; true north and compass north are rarely the same.

The true north pole is a geographic point marking the north end of the earth's axis of rotation; the compass needle, however, points to the magnetic north pole, which is on the northeastern tip of Bathurst Island in the Canadian arctic. The magnetic north pole changes position slightly from year to year. Obviously, if the compass method is to be used, the true azimuth derived from Figure 2 must be corrected before a compass can be used to apply the azimuth to the antenna setting.

In calculating the amount of the correction, the two distinct elements that make up the difference between true and compass bearings must be taken into account; these are (a) *deviation* and (b) magnetic *declination,* known also as magnetic variation. A *compass* bearing corrected for deviation gives a *magnetic* bearing; a magnetic bearing corrected for declination gives a *true* bearing.

Deviation is the angle through which a compass needle is deflected by the presence of ore bodies or metallic objects in the immediate vicinity. To eliminate or minimize deviation, vehicles, moveable metallic equipment and metal tools, including pocket knives, should be removed from the DCP site. If compass readings taken within a radius of 50 m show any significant inconsistency after metallic equipment has been removed from the site, it can be assumed that the compass needle is being affected by some local influence such as an ore body. In these circumstances the compass method of aligning the antenna should not be used. If there is no significant inconsistency in the readings, it can be assumed that there are no local influences affecting the needle; deviation therefore can be ignored and compass bearings considered to be magnetic bearings.

Declination is the angle between the magnetic bearing indicated on the compass, and the true bearing (Fig. 4). Figure 5 is an isogonic chart showing declination for all areas of Canada at intervals of 5°. Values for points situated between the isogonal lines can be estimated by interpolation; alternatively these values may be obtained from an isogonic chart showing the same information at 1° intervals, available from the Department of Energy, Mines and Resources, Ottawa.

It can be seen on Figure 5 that a line of zero declination, known as an agonic line, extends south from the north magnetic pole along the western edge of Hudson Bay and the western edge of Lake Michigan. East of the agonic line, declinations are westerly, and west of the agonic line, declinations are easterly. To apply the declinations derived from Figure 5, therefore, the following rules should be applied:

(1) If the DCP is situated *east* of the agonic line, the declination is *westerly* and should be *added* to the *true* azimuth to obtain the *magnetic* (or compass) bearing.

(2) If the DCP is situated *west* of the agonic line, the declination is *easterly* and should be *subtracted* from the *true* azimuth to obtain the *magnetic* (or compass) bearing.

In the example previously cited, the true azimuth was found to be 218°. The DCP in this example, DCP No. 15 in Figure 5, is situated on Cape Breton Island at 46°38′ north latitude and 60°57′ west longitude. The declination at this position, as interpolated from Figure 5, is 24°W. This declination is added to the true azimuth of 218° to obtain a magnetic or compass azimuth of 242° [see rule (1) above].

In the case of DCP No. 15, the antenna would be set to an angle of elevation of 30°, and aligned with the satellite aiming point by rotating the antenna to a compass bearing of 242°.

On most good compasses, the north point of the needle is clearly marked. If it is not clearly marked, the south point can usually be identified by the presence of some form of counterweight between the pivot and the south-pointing tip. This counterweight often takes the form of a piece of wire wound around the south portion of the needle, and is used to hold the needle horizontal against the down pull exerted on the north portion of the needle by the north magnetic pole.

Watch Method

If a compass is not readily available or if the DCP is situated in a highly mineralized area where local magnetic attraction causes significant deviation of the compass needle, the DCP antenna can be aligned with the satellite aiming point by means of an ordinary dial-faced watch, using the position of the sun at any time between sunrise and sunset. The watch should be accurate to within 2 min and should be set to *standard* time for the particular time zone.

For geographical reference purposes, the earth's surface is divided in a north-south direction by lines of latitude referenced to the equator (the line of zero latitude), and in an east-west direction by lines of longitude, or meridians of longitude, referenced to the Principal Meridian which passes from the north geographic pole to the south geographic pole through Greenwich Observatory near London, England. The Principal Meridian is the line of zero longitude.

The earth rotates on its axis through one complete revolution, or 360°, once in every 24 h. Each time zone of 1 h, therefore, represents 15° of longitude on the earth's surface (Fig. 6). Greenwich Mean Time, the standard time reference, is the time in a 15° band of longitude extending from 7 1/2° west of the Principal Meridian to 7 1/2° east of the Principal Meridian. As the earth rotates in a counterclockwise direction, viewed from above the north geographic pole, times west of the Principal Meridian are calculated by *subtracting* at the rate of 1 h from Greenwich Mean Time for every 15° of longitude. Times east are calculated by adding to Greenwich Mean Time. The mid-line of longitude for each time zone is known as the standard

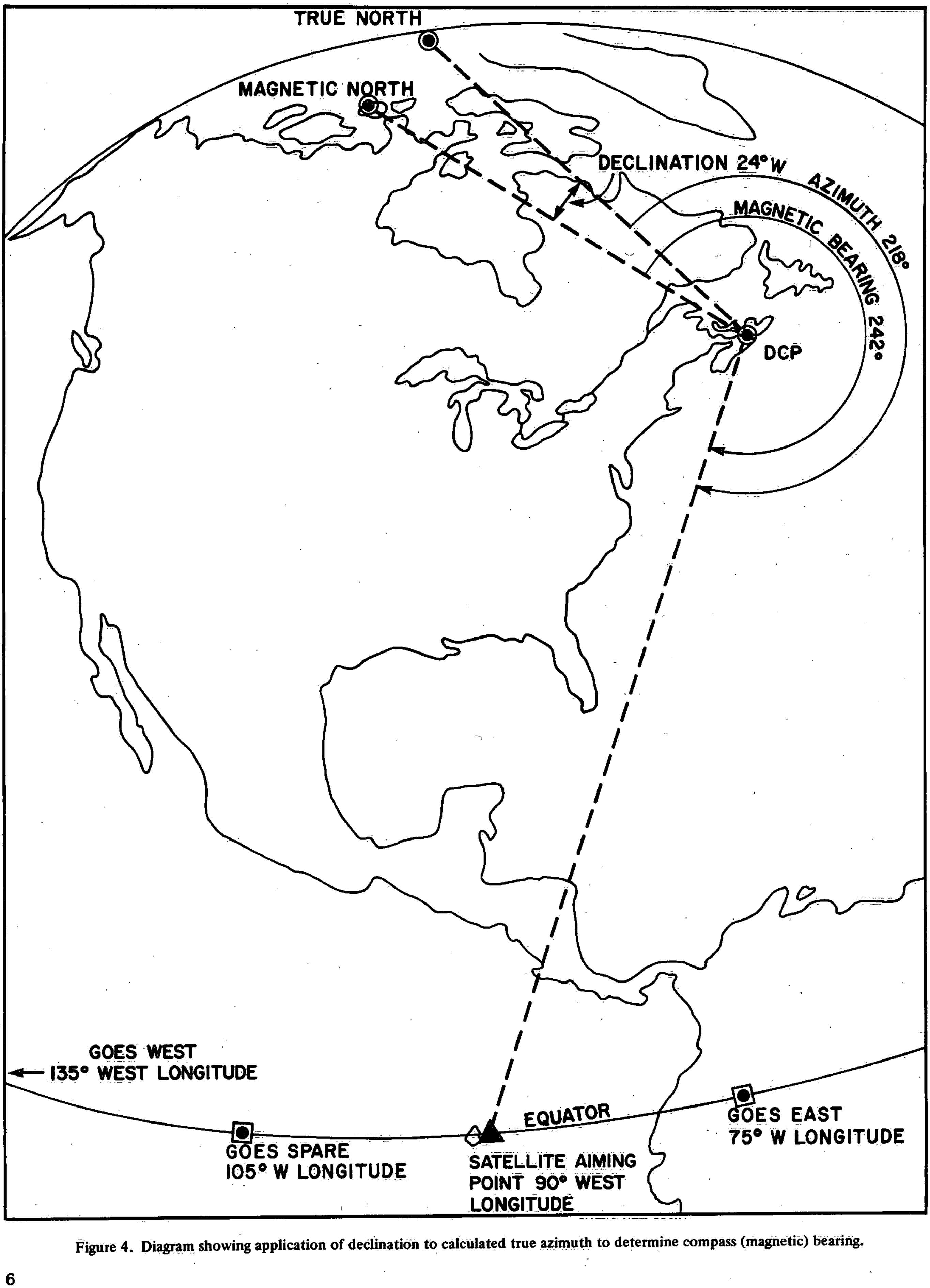


Figure 4. Diagram showing application of declination to calculated true azimuth to determine compass (magnetic) bearing.

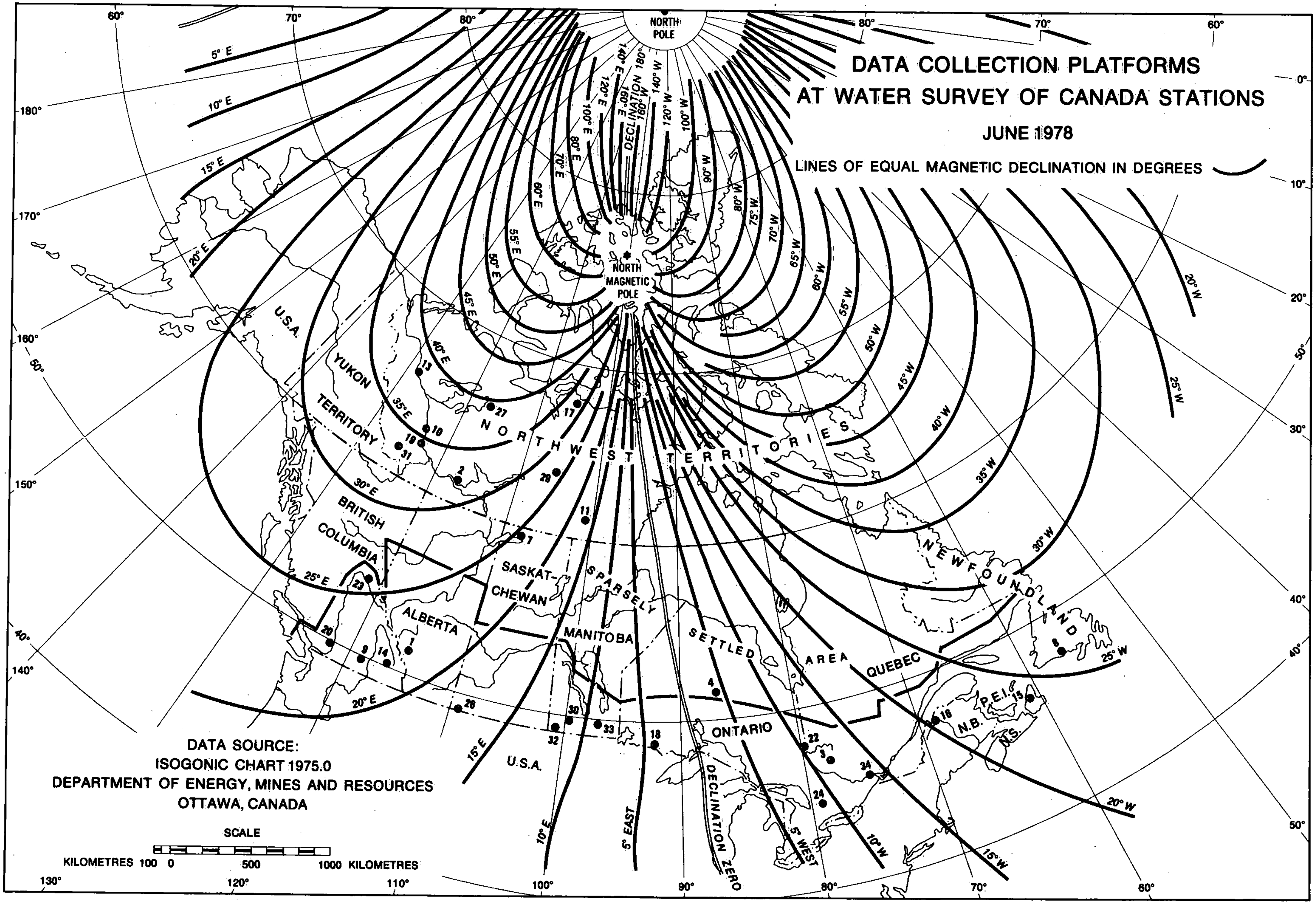


Figure 5. Isogonic chart indicating declination for different parts of Canada and location of data collection platforms in June 1978.

meridian for that zone, and for practical purposes the sun is assumed to be directly above the standard meridian in each time zone at 12 o'clock noon.

Determining True North for Watch Dial

The following examples cover the range of combinations of DCP positions and times of day.

(a) *DCP situated on standard meridian, time at noon*—Lay the watch flat on a horizontal surface; hold a straight pin, toothpick or similar object in a vertical position on the rim of the watch dial directly opposite the hour hand (12 o'clock position), and rotate the watch until the shadow cast by the pin falls exactly along the hour hand; the projection of the pin's shadow to the other side of the dial indicates true north (Fig. 7a). To align the DCP antenna for station No. 20 (lat. 49°57′ north, long. 121°52′ west) for example, consider the watch dial as a compass with each hour division equivalent to 30° ($\frac{360°}{12}$). The azimuth for station No. 20, determined from Figure 2, is 141° (true). This azimuth, or its equivalent 4 2/3 h, is set off on the dial in a clockwise direction from north and the DCP antenna pointed in the direction indicated.

(b) *DCP not situated on the standard meridian, time at or near noon*—For example, to determine north at the site of station No. 33, situated in the Central Time zone at 49°52′ north latitude and 97°24′ west longitude, the same general procedure is followed, but the distance of the DCP from the standard meridian must be taken into account. The standard meridian for the Central Time zone is at 90° west longitude. The earth rotates from west to east at a rate of 1° in every 4 min. The sun is directly above the standard meridian at noon; it will therefore be directly above the 97th meridian at 12:28. At 12:28, repeat the procedure

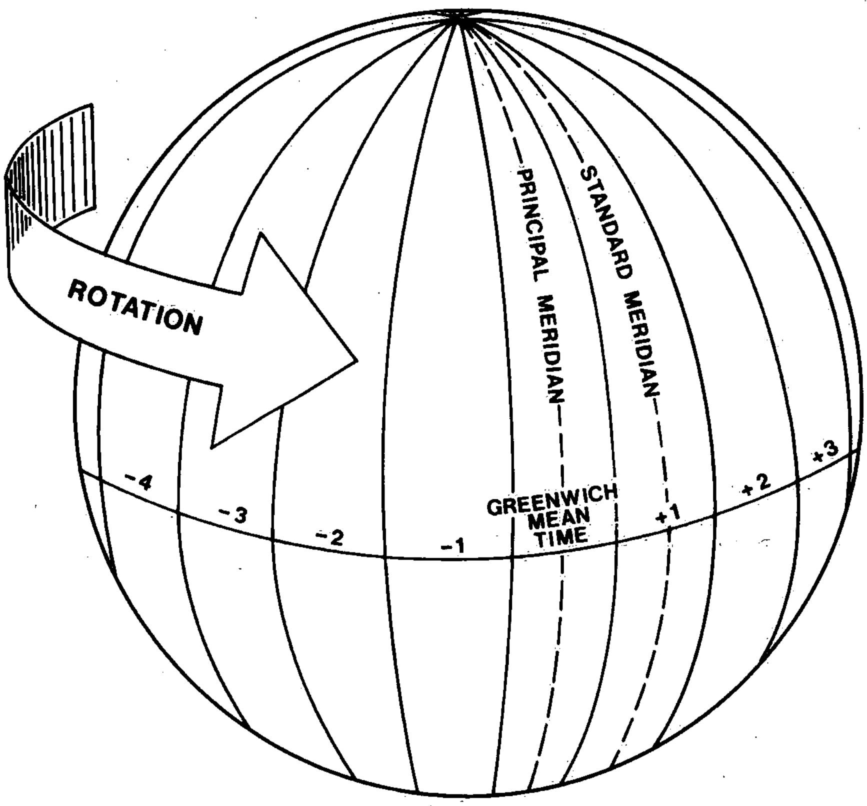


Figure 6. Time zone diagram. The Principal Meridian runs through Greenwich Observatory in England. Adjustment to Greenwich Mean Time to obtain local standard time is shown in hours along the equator; adjustment changes at the rate of 1 h for every 15° of longitude. The extension of the Principal Meridian on the other side of the globe is known as the International Date Line. Along this line the adjustment jumps from +12 h to -12 h. Travellers crossing the International Date Line westbound lose one whole day; travellers crossing eastbound gain one whole day.

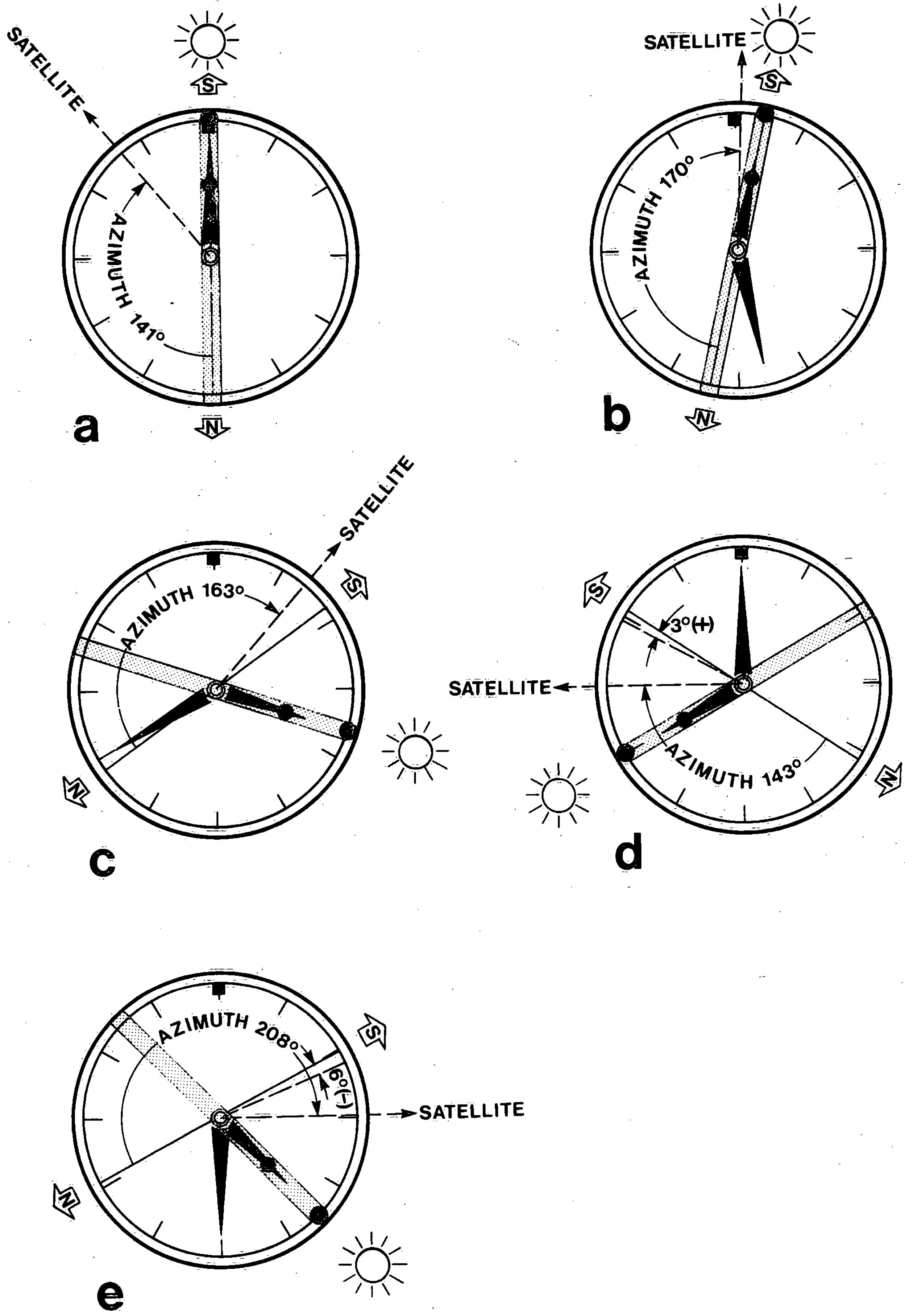


Figure 7. Determining true north by means of a watch dial and the position of the sun. (a) DCP on standard meridian, time at noon; (b) DCP not on standard meridian, time at or near noon; (c) DCP on standard meridian, any time of day; (d) DCP west of standard meridian, any time of day; (e) DCP east of standard meridian, any time of day.

described in (a) above, but place the pin on the rim of the watch dial directly opposite the hour hand and rotate the watch until the shadow of the pin falls along the hour hand. The projection of the shadow to the opposite side of the dial indicates north (Fig. 7b). The azimuth for station No. 33 is 170° (true). Setting this off from the north point (clockwise), the direction of the satellite aiming point is slightly clockwise from the 12 o'clock noon point on the watch dial as shown on Figure 7b. If the DCP was situated *east* of the standard meridian for the time zone, the procedure for determining north would be carried out between 11:30 and noon, depending upon the longitude of the DCP.

(c) *DCP situated on standard meridian, any time of day*—Using station No. 29 (lat. 63°36′ north, long. 105°09′ west) as an example, and assuming a time of 15:40, to determine true north, set the pin on the rim of the dial directly opposite the hour hand and rotate the watch until the shadow falls along the hour hand (Fig. 7c). *South* is midway between the position of the hour hand and the 12 o'clock position (measured *clockwise* from the hour hand for times between sunrise and noon and *counterclockwise* for times between noon and sunset). As the time in the example is 15:40, south is midway between the hour hand position and the 12 o'clock position, measured *counterclockwise* from the hour hand. The azimuth for station No. 29 is 163° (or the equivalent 5 h 26 min on the watch dial, measured from *north*).

(d) *DCP west of standard meridian, any time of day*—Using station No. 19 (lat. 62°29′ north, long. 123°26′ west) as an example, and assuming the time to be 8:00, follow the procedure for (c) above, bisecting the angle between the hour hand position (8 o'clock) and the 12 o'clock position. The midpoint (clockwise from 8:00) would indicate due south if the DCP was on the standard meridian for the Pacific Time zone (120° west longitude). In this example, however, the DCP is 3°26′ west of the standard meridian, and a correction equal to the difference in longitude between the standard meridian and the DCP position, in this case 3°26′ or 3 1/2°, should be applied. As the DCP is *west* of the standard meridian, the correction is *positive* and should be applied in a *clockwise* direction from the mid-line (Fig. 7d). The azimuth for station No. 19 is 143°. This is laid off from north (corrected), which is the extension on the opposite side of the dial from south (corrected).

(e) *DCP east of standard meridian, any time of day*—Using station No. 16 (lat. 47°12′ north, long. 68°57′ west) as an example, and assuming the time to be 16:30, follow the procedure for (c) and (d) above, bisecting the angle between the 16:30 position of the hour hand and the 12 o'clock position (counterclockwise) from 16:30. The midpoint would indicate south if the DCP position was on the standard meridian for the Eastern Time zone (75° west longitude). In this example, however, the DCP is 6°03′ east of the standard meridian, and a correction equal to the difference in longitude between the standard meridian and the DCP position should be applied. As the DCP is east of the standard meridian, the correction is *negative* and should be applied in a counterclockwise direction from the midpoint (Fig. 7e). The azimuth for station No. 16 is 208°; this is laid off from north (corrected).

ACKNOWLEDGMENTS

The author gratefully acknowledges the comments of Dr. K.C. Arnold, research scientist with the Glaciology Division, Department of Fisheries and the Environment, Ottawa.

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