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editing and evaluating digitally recorded geomagnetic components at canadian observatories

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Abstract. Automatic magnetic observatory systems (AMOS) incorporating a fluxgate sensor and a proton precession magnetometer are in operation at 10 Canadian observatories. Values of the field (H, D, Z, F) are recorded each minute on digital magnetic tape. Computer programs edit the data and reduce AMOS values to absolute observatory piers. Comparison of AMOS mean hourly values with similar values scaled from RUSKA magnetograms, and other tests, support the adoption of AMOS systems as primary recorders at Canadian observatories.

Résumé. Des systèmes automatisés d'observatoires magnétiques incorporant un détecteur à solénoïde à noyau saturable et un magnétomètre à protons sont en opération à 10 observatoires canadiens. Les valeurs du champ (H, D, Z, F) sont enregistrées numériquement chaque minute sur ruban magnétique. Les données sont imprimées sur programme de calculateur qui réduit les valeurs de ces systèmes à des seuils d'observation absolus. La comparaison des valeurs moyennes horaires de ces systèmes avec des valeurs semblables mises à l'échelle à partir des magnétogrammes de RUSKA, et autres essais, vient à l'appui de l'adoption de ces systèmes comme enregistreurs primaires dans les observatoires canadiens.

1. Introduction

Automatic magnetic observatory systems (AMOS) recording the geomagnetic elements in digital form have been designed and constructed by the geomagnetic laboratory of the Earth Physics Branch in order to improve the methods of geomagnetic data collection and to overcome many of the deficiencies in the present method of photographic recording (RUSKA) and manual processing. These systems are now in operation at ten Canadian observatories (Table I) of which two are new primary stations, namely Cambridge Bay, and Yellowknife. The automatic system was described in reports presented to the Madrid (IAGA, 1969) and Moscow (I.U.G.G., 1971) meetings. A detailed description of AMOS has been given by F. Andersen (1969).

The AMOS records quasi-instantaneous values of D, H, Z, and F once every minute on digital magnetic tape in a format which can be processed by a computer. The elements D, H, Z are derived from three fluxgate sensors mounted inside a square Helmholtz coil system. One pair of coils continuously nulls H and the other pair Z so that the fluxgates operate in essentially zero field. A proton precession magnetometer (PPM), with its sensor 3 metres from the fluxgates, measures F. The minute values of D, H, Z, or F for a ten-minute period together with the time (measured every ten minutes) and station identification constitute one physical record. Variations in D, H, and Z are also recorded continuously by an analogue (strip-chart) recorder. The resolution of the automatic instrument is ±1 gamma, and of the PPM ±0.1 gamma.

2. AMOS alignment

Although the instrument is designed to measure D, H, Z, it can be aligned as an X, Y, Z instrument at locations where a horizontal component is small, and less than 1000γ approximately. In the present network of automatic stations, X, Y, Z are recorded at Churchill and Baker Lake (Y < 500γ) and Resolute (X ~ 200γ).

To achieve the maximum separation between various observatory instruments, the AMOS fluxgate sensors are placed in a seldom used corner of an observatory building. This makes it difficult to use the orientation of a wall of the building as a reference in aligning the sensors in the D, H or X, Y coordinate system.

The following technique has been adopted in aligning the AMOS D, H (X, Y) sensors by assuming that the AMOS is in itself an absolute instrument. Absolute observations of the angles D and I are made with the standard observatory D and I instrument and the total field value F is observed from the AMOS proton precession magnetometer. Values for H or X and Y are then calculated and the AMOS sensor rotated in azimuth until the AMOS output coincides with the calculated absolute values of the components. This rotation is valid since the fluxgate unit is mounted on a rigid platform which can be levelled, the Z axis is perpendicular (within half-degree) to this platform and D, H (X, Y) axes are constructed orthogonally (within half-degree) to the vertical and to each other.

This alignment procedure was successful at all stations where no large gradients existed between the D and I pier and the AMOS sensors (see Section 8 on tests for misalignment).

3. Editing digital data

Frequently, unattended electronic data acquisition systems do not create on magnetic tape digital data which are compatible with the restrictions imposed by the computer's standard programming routines. Such problems as power failures, electronic device breakdowns, mechanical troubles and other unpredictable difficulties, can cause data gaps, bad coding, parity errors and irregular physical record lengths. Further, the component values themselves may not be the expected ones; for example, in the F readings, numerous spurious values are recorded because of the nature of the proton sensor itself and are hence unavoidable. Therefore, an editing program is required which will test for the various

Table I
Canadian Magnetic Observatory Network 1973

Station	Coordinates: Geographic Lat. N.	Geographic Long. E.	Geomagnetic* Lat. N.	Geomagnetic* Long. E.	Photographic Recording (RUSKA)	Low Sens. Stand-by Recorder	AMOS	TVS
Baker Lake	64.3	264.0	73.9	314.8	X Y Z	Fluxgate	X Y Z Nov. 1971	
Cambridge Bay	69.1	255.0	76.7	294.0	not installed	(Fluxgate 1973)	H D Z April 1972	June 1972
Fort Churchill	58.8	265.9	68.8	322.5	X Y Z	Fluxgate	X Y Z Sept. 1971	July 1972
Great Whale River	55.3	282.25	66.8	347.2	H D Z	Fluxgate	H D Z Nov. 1972	
Meanook	54.6	246.7	61.9	300.7	H D Z	Lacour	H D Z Nov. 1970	Aug. 1972
Mould Bay	76.2	240.6	79.1	255.4	X Y Z	Fluxgate	not installed	
Ottawa	45.4	284.45	57.0	351.5	H D Z	RUSKA Fluxgate	H D Z Sept. 1970	Aug. 1972
Resolute Bay	74.7	265.1	83.1	287.7	X Y Z	Fluxgate	(X Y Z) (1973)	
St. John's	47.6	307.3	58.7	21.4	H D Z to July 31/72	Fluxgate	H D Z Dec. 1969	Jan. 1972
Victoria	48.5	236.6	54.3	292.7	H D Z	Askania Fluxgate	H D Z Nov. 1970	Mar. 1972
Yellowknife	62.4	245.6	69.1	292.8	not installed	(Fluxgate 1974)	H D Z (1973)	

* Assuming geomagnetic pole 78.3°N, 291.0E (Finch and Leaton, 1957).

Note: Agincourt observatory ceased operation March 31, 1969.
Alert observatory ceased operation September 30, 1972.

errors in the data, recover all possible component values, correct erratic readings and store the results on magnetic tape. The essential features of this program will now be described.

As a preparatory step, the AMOS raw data tapes (200 bpi) are copied using a special purpose machine language program (IBM OS/360 Assembler) in order to generate records (at 800 bpi) consistent (in parity) with the standard input routines of higher level languages (COBOL). This program also deletes noise records and substitutes unrecognizable characters with zeros.

The data acquisition system was designed to create physical records of 336 characters containing ten consecutive sets of four geomagnetic components (D, H, Z, F) measured at each minute, and followed by time (day, hour, minute) and by identification (year, station number). The editing program logically organizes these data into 20-minute blocks or groups with a ten-minute overlap from group to group. Since the number of readings on the raw data tape must agree with the incrementation (in minutes) of the clock, extraneous values can be detected and deleted, and missing values are filled in with a string of 9's. It should be noted that the clock rarely malfunctions, since it is driven by a trickle-charged battery.

Each value of D, H, Z is now tested to lie within a certain range of control values provided by the program. The control values are the means of the previous 20-minute group of values. For the first 20-minute set of values of the data tape, these control values must be supplied via data cards during program execution. The ten-minute overlap from group to group guarantees that the means reflect the level of disturbance in the current 20-minute block being tested. The level of disturbance within any group is usually similar to that of the previous group. However, in cases when these levels from block to block are dissimilar the ten-minute overlap prevents the means from stepping erratically. Whenever large SSC's and magnetic storms occur, large jumps in the means cannot be prevented, so that the range, mentioned above, is changed (simple card inputs) to conform to the magnetic disturbance levels. If the test fails the value tested is replaced with a string of 9's.

The F values however are not tested in the above procedure to lie within a certain interval. Spurious readings of F are readily apparent from data listings.

These spurious readings occur because of radio signal pickup, power line transients and other external noise signals which occur during the measurement of the precession frequency of the PPM. However the F values can be expected to differ from $(D^2 + H^2 + Z^2)^{1/2} = F^*$ by an amount which will be a constant (to the nearest gamma) within any 20-minute grouping. The difference $\Delta F = (F-F^*)$ will generally not be zero owing to pier separation, temperature drifts in the fluxgate electronics and of course spurious readings of F. The values F* have already been tested and accepted according to the procedure outlined in the previous paragraph. On generating departures of the ΔF's about a mean $\overline{\Delta F}$ for the 20-minute group, the maximum discordant value greater than 2 times the standard deviation of the departures is a spurious reading in F and is therefore discarded. These same rules are then applied to the remaining values, and are re-applied cyclically until all spurious readings are rejected. This procedure is known as Chauvenet's criterion (Tuttle and Satterly, 1925). New values of F are simply generated with $F = F^* + \overline{\Delta F}$ for each discarded value of F where $\overline{\Delta F}$ is the mean of those ΔF's in the 20-minute group which have not been discarded. The ten-minute overlap from group to group guarantees that no more than 10 consecutive values are discarded within any 20-minute group. This is true because these 10 values have already been accepted (or generated by $F = F^* + \overline{\Delta F}$) by the application of Chauvenet's criterion to the previous 20-minute set of values. Finally, as a further check, the F values themselves are tested against the mean F of the previous 20-minute group as has been done for D, H, Z. Obviously, this is required to test those values of F when F* is missing in which case the corresponding F value is not included in the grouping of values for Chauvenet's test.

As noted above a non-zero ΔF results also from temperature drifts (see Section 5) of the fluxgate magnetometer and from the separation between the PPM and the fluxgate sensors. These effects must be removed to ensure that F−F* will be less than 1 gamma. Therefore, multiplying the D, H and Z values by F/F* reduces these values to the PPM pier and removes the temperature dependency of the fluxgate readings. The total force computed from these corrected values of D, H, Z is now equal to F to within 1 gamma.

No attempt as yet has been made to fill missing values (a string of six 9's). Gaps covering a full hour are not processed and such "missing hours" are not written on the archival tapes; these occurrences are rare. The most frequent gaps in the data occur during tape changes each month, being at best less than 10 minutes and at worst 20 minutes. Eventually these missing values should be filled by transcribing the data from strip-chart recordings.

The edited values of D, H, Z, and F are now stored temporarily on magnetic tape for further processing as discussed in next section. The above discussion provides however only an outline of the editing program. The programming logic which is required to handle data gaps (because of power failures, etc.), and those records not equal to 336 characters, and other problems, is quite extensive, but a discussion of such logic is not essential in this paper. What is important is that the procedure given above approximates that of a geomagnetician scanning simultaneous listings of D, H, Z, and F. For example, Tables IIa and IIb provide a listing of the original raw data (at St. John's) and the corresponding corrected values for a selected set of 20 values. It is easily observed in Table IIa how D, H, Z varies smoothly from minute to minute whereas F contains four erratic values which differ greatly from the remaining values. The remaining ΔF values however have a small variation from −11 to −14 gammas; Chauvenet's criterion removes this variation in ΔF's. Hence, the corrected version of F is given in Table IIb in which the ΔF's are less than 1 gamma.

Table IIa
Original Values (in gammas)

D	H	Z	F	F*	ΔF
36	17584	50826	53768.9	53781.8	− 12.9
37	17584	50825	53742.9	53780.8	− 37.9*
38	17582	50824	53766.4	53779.2	− 12.8
39	17583	50824	53767.4	53779.6	− 12.2
38	17583	50825	53767.4	53780.5	− 13.1
40	17582	50823	53765.5	53778.3	− 12.8
40	17581	50822	53762.8	53777.0	− 14.2
40	17581	50824	53766.2	53778.9	− 12.7
39	17582	50823	53643.6	53778.3	−134.7*
39	17583	50825	53768.9	53780.5	− 11.6
40	17581	50824	53766.2	53778.9	− 12.7
41	17580	50822	53765.1	53776.7	− 11.6
41	17580	50822	53764.9	53776.7	− 11.8
42	17580	50822	53676.3	53776.7	−100.4*
42	17580	50821	53764.3	53775.8	− 11.5
44	17580	50822	53763.8	53776.7	− 12.9
45	17579	50821	53332.0	53775.4	−443.4*
46	17578	50819	53761.7	53773.2	− 11.5
46	17576	50817	53758.0	53770.7	− 12.7
46	17575	50817	53757.6	53770.3	− 12.7

A 20-minute section of uncorrected values from St. John's observatory for March 29, 1970, 2008 UT to 2028 UT. $F^* = (D^2 + H^2 + Z^2)^{1/2}$ and $\Delta F = F - F^*$.

The four ΔF values marked with asterisks are erratic and we wish to remove them. The remaining values vary between −11 to −14 gammas, the mean of which represents the separation between the PPM and fluxgate sensor.

Table IIb
Corrected Values (in gammas)

D	H	Z	F	F*	ΔF
36	17580	50814	53768.9	53769.1	−0.2
37	17580	50813	53767.8	53768.2	−0.4*
38	17578	50812	53766.2	53766.6	−0.4**
39	17579	50812	53766.8	53766.9	−0.1**
38	17579	50813	53767.7	53767.9	−0.2**
40	17578	50811	53765.5	53765.7	−0.2
40	17577	50810	53764.2	53764.4	−0.2**
40	17577	50812	53766.2	53766.3	−0.1
39	17578	50811	53765.5	53765.7	−0.2*
39	17579	50813	53767.7	53767.9	−0.2**
40	17577	50812	53766.2	53766.3	−0.1
41	17576	50810	53763.9	53764.1	−0.2**
41	17576	50810	53763.9	53764.1	−0.2**
42	17576	50810	53764.0	53764.1	−0.1*
42	17576	50809	53763.1	53763.1	0.0**
44	17576	50810	53764.0	53764.1	−0.1**
45	17575	50809	53762.7	53762.8	−0.1*
46	17574	50807	53760.5	53760.6	−0.1**
46	17572	50805	53758.0	53758.0	0.0
46	17571	50805	53757.6	53757.7	−0.1

A 20-minute set of corrected values corresponding to those of Table IIa. The four spurious F values of Table IIa are here indicated by single asterisks. Here these values are replaced using $F = F^* + \overline{\Delta F}$ where $\overline{\Delta F}$ is the mean of the remaining set of ΔF's as outlined in text. Note that ten more values have been changed by (indicated by double asterisks) values up to 1.4 gammas. This represents a slight smoothing of the F values so that the variation in F more closely follows that of F*.

The effectiveness of the F/F* correction is illustrated in Figure 1 using St. John's data for January 25 and 26, 1972. The difference between the Z(AMOS) mean hourly value (MHV) and the MHV scaled from the RUSKA magnetograms is plotted for both the corrected and uncorrected values of Z(AMOS). Note that the corrected Z differences all lie within 10 gammas with no long term shifts. Although each point has an uncertainty of about 4 gammas, the two-day average of 4 gammas represents the difference in Z between the PPM and absolute piers. One should remember however that the F/F* correction reduces the Z values from the fluxgate pier to the PPM pier.

It should be noted that the F/F* ratio does not correct the data for the shifts in zero-offset of the fluxgate sensors at least in the case of the smaller components of the geomagnetic field. The ratio also cannot correct for temperature-related changes in level or azimuth of the whole fluxgate assembly. However, it does in practice significantly reduce temperature effects in the data, as the above example has illustrated.

4. Calibration of AMOS data

Additional computer programs have been drafted to plot the components D, H, Z, to make baseline corrections and to store the final, corrected magnetic observations on digital magnetic tape. A CALCOMP plotter is used to generate traces of D, H, and Z, replicating standard-run RUSKA magnetograms. From these plots, any errors in the data not detected by the procedure in previous sections are readily apparent and any sudden baseline shifts are easily observed. Selected listings of corrected D, H, Z, and F values are compared with absolute observations of the magnetic field to determine AMOS baseline values. By comparison of corrected digital magnetometer values of D, H, Z with simultaneous absolute field measurements, an AMOS D baseline is determined together with corrections necessary to reduce the AMOS H and Z values to the values of H and Z measured at the absolute piers.

5. Temperature drifts and pier separations

As is mentioned in Section 3, each component D, H, and Z was multiplied by F/F* $[F^* = (D^2 + H^2 + Z^2)^{1/2}]$ to remove temperature drifts and to correct for pier separation. Although fluxgate values are very stable over short intervals, errors may occur over intervals of several days because of temperature variations. An obvious source of such errors is the thermal expansion of the feedback coils. This temperature effect is reversible and is proportional to the magnitude of the magnetic field component. Hence, since the PPM F values are independent of temperature, the ratio given above is the required proportionality constant. A more troublesome source of error is the abrupt shifts in zero-offset of the order of 1 gamma and these are accumulative to as much as 10 gammas per month. The cause of these shifts is not well understood but it is often associated with temperature changes at the sensor.

6. AMOS baseline determinations

The procedure for reducing the AMOS values to absolute reference piers is analogous to the calculation of the baseline values of photographic magnetograms from the absolute determinations of D, I and F. F values are measured at the PPM sensor and the D and I total field values are measured at another absolute pier. In the following all fluxgate values, D, H, Z, have been reduced to the PPM pier by multiplication with the factor F/F* as discussed above.

The D (AMOS) sensor is oriented perpendicular to the direction of the average magnetic meridian and measures the magnetic intensity in gammas transverse to the meridian. A D (AMOS) baseline is obtained by calibrating the zero level of the AMOS D against the absolute measurement of D. The output of D (AMOS) in gammas is converted into minutes by using the relationship D (mins of arc) = 3438 x arc sin (D/H). The D (AMOS) baseline is then D (Absolute) −

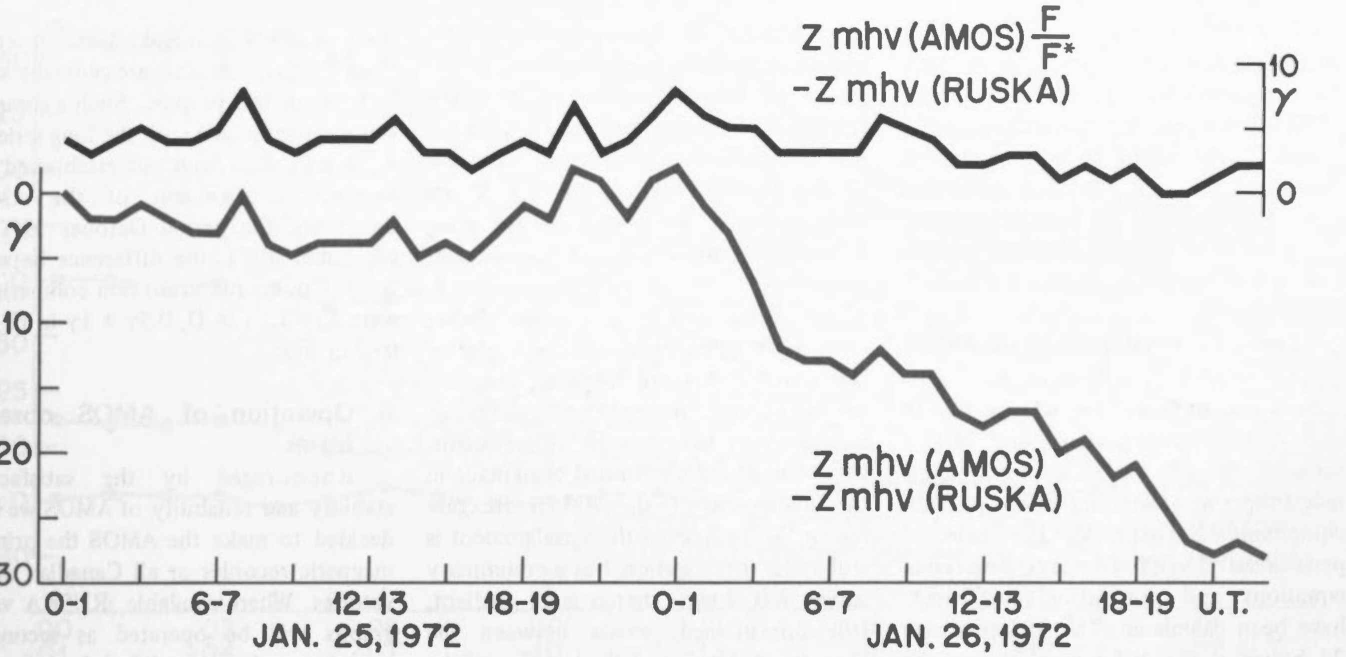

Figure 1. Z MHV (AMOS) – Z MHV (RUSKA) are the uncorrected differences; corrected differences are shown as Z MHV (AMOS) F/F* – Z MHV (RUSKA).

D (AMOS) in minutes of arc. Correctly, instead of (D/H) one should use $(D/(H^2 + D^2)^{1/2}$, where H and D are the AMOS output values. The error introduced by using H rather than $(H^2 + D^2)^{1/2}$ is less than 0.1 min unless D (AMOS) > 3.5 per cent of H. This is frequently the case at the Arctic station at Cambridge Bay (H ~ 3000γ) and will occur at all stations during intense storms. This has been one factor in the decision to express the one-minute values at all stations in the orthogonal system, X, Y, Z, since D (in minutes), $H_T = (H^2 + D^2)^{1/2}$, Z, is not an orthogonal system. The AMOS values H, D are now simply transformed into X and Y using the following rotational equations:

$$X = H_\gamma \cos D_{bl} - D_\gamma \sin D_{bl}$$

$$Y = H_\gamma \sin D_{bl} + D_\gamma \cos D_{bl}$$

where H_γ is H (AMOS) in gammas, D_γ is D (AMOS) in gammas and D_{bl} is the D (AMOS) baseline in minutes of arc as determined above.

For the case where X, Y, Z are recorded, corrections to the absolute reference field require the calculation of absolute values of X and Y from the absolute measurements of D, I, and F. In the following, the subscripts refer to the times of the absolute D, I observations:

$$H_I = F_I \cos I$$

$$H_D = H_I + \Delta H$$

where ΔH is the change in H between the times of the D and I observations. At Baker Lake and Fort Churchill, where D is about 3°, ΔH does not differ significantly from $\Delta X = X_D - X_I$. The value of ΔX is therefore obtained from the AMOS data and we have

$$X\ (\text{Absolute}) = H_D \cos D$$

$$Y\ (\text{Absolute}) = H_D \sin D.$$

The corrections to reduce the AMOS X and Y values to the absolute reference pier are given by

$$X\ (\text{Absolute}) - X\ (\text{AMOS})_D$$

and $Y\ (\text{Absolute}) - Y\ (\text{AMOS})_D$.

Similarly, Z (Absolute) = F_I sin I and the Z correction is given by

$$Z\ (\text{Absolute}) - Z\ (\text{AMOS})_I.$$

7. Comparison of AMOS data with absolute field measurements

AMOS data at all stations are regularly compared with the absolute field measurements by plotting the AMOS D baseline and the corrections required to reduce AMOS H (X, Y), Z values to the field measured at the absolute piers.

For example, a careful comparison has been made between the corrected AMOS D, H, Z values and the absolute field observations at St. John's observatory for the 12-month period March 1970 to February 1971. For H and Z the differences between the absolute observations and the corresponding AMOS values were plotted, and the straight line segments were fitted to the points. In the interval from March to December 1970, for 84 absolute (QHM) observations, the correction necessary to reduce the AMOS H to the absolute pier, as given by the best straight line fit, was 3.3 gammas with an r.m.s. deviation of 1.6 gammas. The mean adopted correction to the AMOS Z in this period was 5.1 gammas with an r.m.s. of 1.6 gammas. The typical scatter in any month in determining the AMOS D baseline was 0.6 minute or 3 gammas, comparable to the r.m.s. deviation in any one month in the absolute minus AMOS values for H and Z.

The r.m.s. deviation in the observed minus adopted H baselines for the RUSKA for the period March 1970 to December 1970 was 1.6 gammas, or the same as that found for the AMOS H. In general, it is concluded that the AMOS baseline stability is as good as the baseline stability of the RUSKA. Samples of AMOS baseline plots for St. John's are shown in Figure 2.

8. Tests for misalignment of AMOS

A detailed comparison has been carried out between the MHV's derived from AMOS minute data and MHV's scaled from the RUSKA photographic magnetograms at stations where RUSKA equipment is available. For selected periods of 5 and 10 days, regression equations and correlation coefficients have been calculated. The variation over 24 hours of the difference between the two sets of MHV has been plotted. Scale value uncertainties and misalignments between the RUSKA and AMOS systems have been observed in several cases. Any high correlation between the diurnal variation of the AMOS-RUSKA MHV differences in one element and the field of another element indicates misalignment between the AMOS and RUSKA systems. The amount of misalignment can be conveniently calculated from the monograms or formulae given by McComb (1952). For example, a strong correlation was found between the diurnal variation of the (AMOS-RUSKA) MHV in X and of Y, at Baker Lake (Figure 3), indicating a misalignment of the X component amounting to 14 degrees.

A comparison between the Baker Lake MHV given by the RUSKA and by the standby fluxgate recorder, independently aligned, showed no evidence of misalignment between the two systems, suggesting that an error had been made in the alignment of the AMOS fluxgate sensor. The cause of the misalignment is still under investigation, but a preliminary survey has shown that a large gradient, still unexplained, exists between the absolute D, I pier and the location of the AMOS fluxgate sensor. The misalignment is explained by the fact that the AMOS X sensor had been aligned to conform to the X field observed at the absolute pier.

The definitive test however for detecting any misalignment of the AMOS system is the comparison of AMOS values with simultaneous absolute measurements made for different disturbance levels of the field. Forenoon and afternoon sets of absolute measurements are generally satisfactory for this purpose. Such a comparison has been made with the long series of St. John's data, and has established the satisfactory alignment of the AMOS there: for the period October 1970 to December 1971, the difference between the forenoon and afternoon comparisons were 1γ ±1.5γ in D, 0.5γ ± 1γ in H, and 0γ ±1γ in Z.

9. Operation of AMOS observatories

Encouraged by the satisfactory stability and reliability of AMOS we have decided to make the AMOS the primary magnetic recorder at all Canadian observatories. Where available, RUSKA variographs will be operated as secondary recorders, using a modified drum capable of operating for a month without attendance. At sites where RUSKAs are not in operation an independent 3-component fluxgate recording on paper chart will provide a standby analogue recording system. RUSKA magnetograms and/or computer plots of the one minute AMOS data (replicating the RUSKA magnetograms) will be deposited regularly at WDC

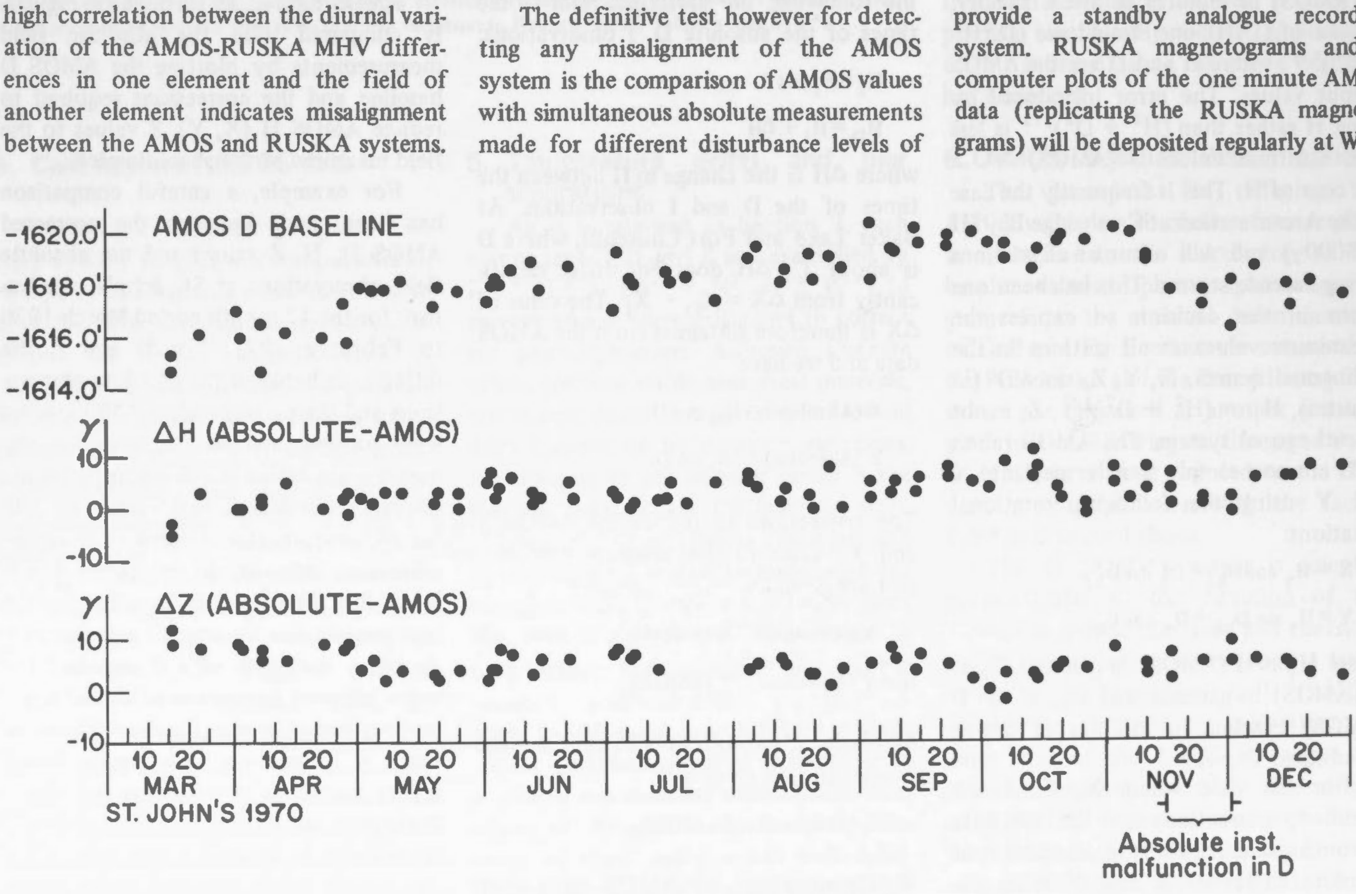

Figure 2. AMOS baseline plot, St. John's.

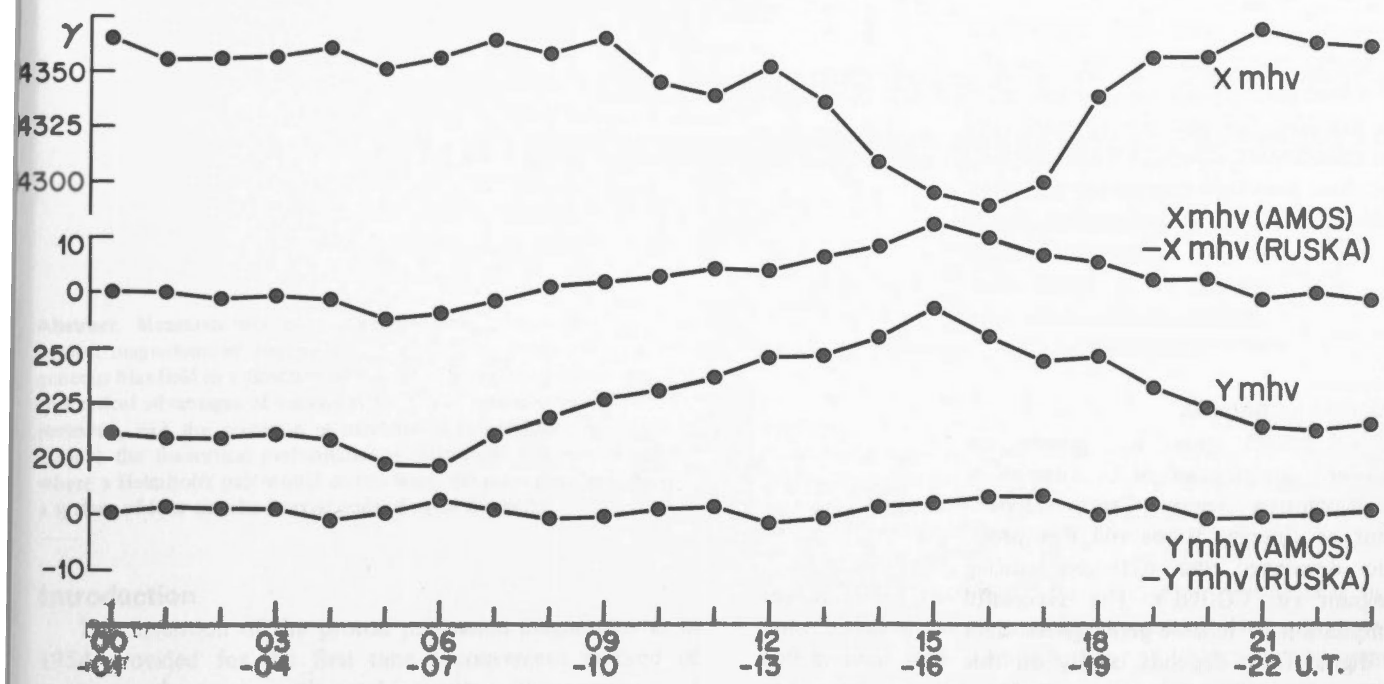

Figure 3. Example of misalignment in X component between RUSKA and AMOS recorders, Baker Lake.

A for distribution to individuals and agencies who request them. MHV tables for inclusion in observatory yearbooks will be compiled from the edited AMOS data. The scaling of MHV from photographic records will be done only for periods for which AMOS data are not available. At permanently staffed observatories additional time will be available to improve the quality and increase the number of absolute field measurements. Stations not permanently staffed, such as St. John's and Cambridge Bay, will require attendance once or twice a week for absolute observations, and instrument and building checks.

Installation and maintenance of AMOS is carried out by electronic technologists located in Ottawa, who travel as required to the AMOS sites. At sites where telephone lines are available, telephone verification systems (TVS) have been installed (Andersen, 1973). These enable the operations controller in Ottawa to check at any time the data being supplied to the tape recorder at any observatory equipped with TVS. In practice, all TVS observatories are interrogated from Ottawa for one or two minutes each day. Frequently an AMOS malfunction can be diagnosed immediately from the TVS check. Replacement modules for the equipment can then be shipped to the stations, dispensing with the necessity of a costly service trip. Use will be made of the new communication satellite Anik I for TVS checks at isolated sites where satellite facilities are available. It is evident that facilities already exist for real-time transmission of observatory data, although such an expensive service cannot be justified at this time.

10. Storage of data

The storage tape containing the final corrected values of X, Y, Z, and F are organized in blocks of records containing one hour of data on digital magnetic tape (800 bpi) as follows:

$(ID,YR,DY,UT)_0$, $(X, Y, Z, F)_1$, $(X, Y, Z, F)_2, \ldots, (X, Y, Z, F)_{60}$ where ID is 6 digit IAGA numeric station code (longitude and colatitude to the nearest degree).*

YR is 6 digit year

DY is 6 digit day ranging from 1-366

UT is a 6 digit hour ranging from 0-23

*This format will be modified to agree with that recommended by the International Association of Geomagnetism and Aeronomy for magnetic tape storage of one-minute observatory values (IAGA News No. 12, Sept. 1973).

and where the simultaneous X, Y, Z, and F values (each of 6 digits with sign) start at the first minute of the hour and end at the sixtieth minute of the same hour. Each physical record therefore has 1464 characters. The X, Y, Z values are written (as integer constants) to the nearest gamma and the F value to the nearest tenth of a gamma. Each magnetic tape volume has only one station year of data, followed (but separated with an end-of-file mark) by the hourly mean values, component ranges and summary tables.

11. Discussion and conclusion

The automatic magnetic observatory system has proven to be at least as reliable and stable as our RUSKA systems. AMOS has recorded successfully such large storms as that of August 4-5, 1972, during which the field changed by more than 1800γ/min whereas our photographic equipment failed to monitor such a disturbance. The direct recording of one-minute values on digital tape is an improvement over the manual scaling or digitizing of photographic traces. However, the more than 60 fold increase in the amount of data handled over that of

RUSKA MHV data has necessitated computer processing; the text has outlined our procedure which we feel to be the simplest. The AMOS equipment does not circumvent calibration measurements, nor does it reduce manpower and costs (which are increased significantly). AMOS does however create a large data base of reliable geomagnetic field values from which more refined studies of the geomagnetic variations can be undertaken.

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