Aeromagnetic Survey of Vertical Intensity over the Sound with Apparatus of the BMZ Type

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Abstract

An attempt was made to measure the magnetic vertical intensity over a sea area and, in part, over land with an apparatus of the BMZ-type suspended in a special way in an aircraft. Some control measurements were made, and the conclusion was drawn that under certain conditions, which can easily be complied with, an accuracy of the individual measurements of about $\pm$ 20 gammas can be obtained.

It may be seen at once that magnetic measurement from an aircraft, if at all possible, implies considerable advantages, notably over sea or town areas. It is quick, and it may be made more or less independent of local anomalies, according to the height of the level chosen for making the measurements. If it is especially the vertical component Z, that is to be measured from the aircraft, not only the Z-component itself will be ascertained, but also there will be an opportunity of calculating the X and Y components (or H and D, if preferred), as was shown by D. C. SKEELS and R. J. WATSON (1949).

An attempt was made to measure Z by means of an apparatus of the BMZ type (LA COUR 1942) suspended in gimbals in an aircraft. Additional precautionary measures were taken in order to ensure as good results as possible.

Without entering further into the technique of the apparatus, which should not be regarded as quite final, the following particulars concerning the practical execution of the measurements will be given: Measurements were made on February 22 and March 28, 1950, at altitudes of 4,000 m and 500 m, respectively, along a line, 40 km in length between the fort of Trekroner near Copenhagen and the castle of Kronborg at Helsingør (see Fig. 2). At the higher altitude measurements were made on a northward as well as on a southward flight, the BMZ telescope being directed towards the magnetic north and the magnetic south respectively (cf. below the remarks on scale values). In addition to the route southward from Kronborg, on March 28 measurements were also made on five routes running at right angles to it, viz. across the Sound (see Fig. 1); namely three routes running from the west towards the east (BMZ telescope oriented towards the magnetic north) and two routes traversing the Sound from the east towards the west (the BMZ telescope turned towards the magnetic south).

Checking the accuracy of the measurements is, of course, not easy if the measurements are made over the sea, but easier if they are made over land. However, at the time of the first flight the visibility over land was hampered by a cloud-cover approaching the area from the west. A concurrent cause why most of the measurements were carried out over the sea, viz. the Sound, was the interest that must attach to a direct connection between Swedish and Danish Z-measurements on either side of the Sound.

The normal procedure in employing a BMZ apparatus is to create a zero field (LA COUR 1942); full compensation for the earth's vertical magnetic field at the position of the

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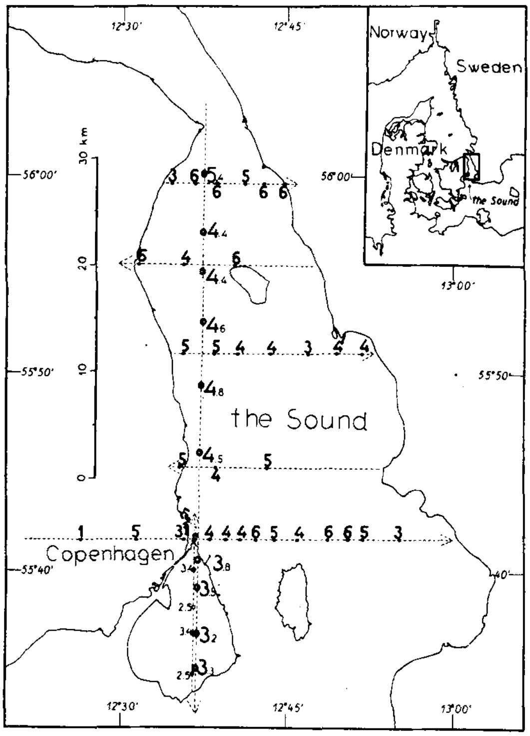

Fig. 1. The results of all observations at the height of 500 m on March 28; the figures indicate the excess in milligauss over 450 milligauss and have been reduced to 454.5 milligauss for Rude Skov (normal value about January 1, 1949). The routes flown are indicated by broken arrows. The points at which observations were made along these routes are indicated for the southward and northward routes by the small circles, while for the transverse routes they are located immediately below or immediately above the integers.

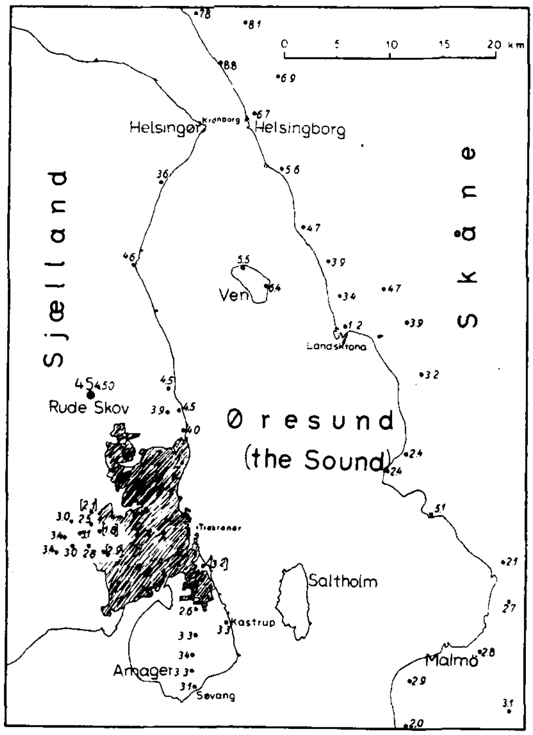

Fig. 2. Same area as shown in Fig. 1; all figures are derived from ground measurements. The true values (valid about January 1, 1949) are 450 milligauss plus the figures indicated. The accuracy of the values ranges about ± 0.1 milligauss.

balancing magnet being ensured when the reflection of the balancing magnet is seen in the same place (the neutral division) when the BMZ telescope is turned alternately towards the magnetic north and towards the magnetic south. As regards the measurements carried out from the aircraft the procedure was somewhat different. If the scale value of the position of the reflection in the telescope's field is determined and if one may assume that the neutral division does not change during the measurements, the Z-value which gives the neutral position can always be readily computed. With BMZ_{14}, which was used on February 22 at an altitude of 4,000 m, the scale value per division was 20 gammas (0.2 milligauss) for a northward orientation of the telescope and 8.5 gammas for a southward orientation. With BMZ_{15}, used on March 28 at an altitude of 500 m, the scale value was 47.5 gammas for the northward position and 6.5 gammas for the southward position.

In order that measurements of this kind should not be encumbered with systematic errors, it is further necessary that the axis of rotation of the apparatus should be absolutely vertical; this was ensured by adjustable right-angle levels in a horizontal plane and was repeatedly checked during the flights by turning the BMZ apparatus. A level, turned in the direction of the telescope, was continually read during the measurements, and from the small deviations thus observed, corrections of a few gammas were determined in calculating the results of the measurements. By clamping the balancing magnet now and again it was ensured that it was not materially shifted by vibrations.

The most serious source of error in airborne measurements employing a magnet suspended in gimbals is, no doubt, the presence of accelerations due to irregularities in the movement of the aircraft which, in addition to the gravitational acceleration, influence the suspension in gimbals. If, for instance, the aircraft turns slightly to one side all parts connected with the aircraft will be influenced by a horizontally directed centrifugal acceleration: the suspension in gimbals will adjust itself according to the resultant of all the accelerations, and instead of the true Z-component of the total magnetic intensity a component will be obtained whose direction deviates more or less from the perpendicular. At the outset it would seem probable that forward or backward accelerations during level flight are usually less than accelerations to the sides. As a consequence, as will appear from simple geometric considerations, measurement of Z during flight at right angles to the isogons (i. e. from the west towards the east, or conversely) involves greater inaccuracy than measurement of Z during flight along the isogons (i. e. from the south towards the north, or in the opposity direction). Irrespective of whether the flight takes place in one direction, or the other, it is of the greatest importance that a course once started should be maintained during any one particular series of measurements.

For the magnetic field intensity found over the Sound we can, for instance, compute that banking the airplane 1° will give rise to an error in the Z-measurement of the order of magnitude of 3 milligauss if the route is either eastward or westward, while on a northerly or southerly course the angle of bank must be eight times as great to produce the same error. Conversely, forward or backward directed accelerations give rise to greater errors on the last-mentioned routes than on the former; but, as already stated, such accelerations as a rule may be assumed to be less than accelerations to the sides.

More accurate measurements may then presumably be obtained by eliminating in one way or another the influence of these disturbing accelerations, or by continuously recording these accelerations and making corrections for their effect. The former procedure is, in fact, employed in the American airborne magnetometer (RUMBAUGH and ALLDREDGE 1949); in this way a considerable accuracy is obtained, but at the same time the possibility of measuring the individual components has disappeared.

Although the body of the aircraft used for the measurements was almost non-magnetic, being made of wood, a disturbing Z-field resulting from the engine must, of course, be expected. The magnitude of this field was found by making Z-measurements both in the aircraft while it was standing on the ground, and over the same point of the surface of the ground after the aircraft had been removed. It was found that at the location of the BMZ-apparatus in the aircraft there was an upward-directed Z-field of 298 gammas; the results of the measurements made on March 28 at the 500 m level were corrected accordingly.

Furthermore it turned out that Z-values were altered 2—3 gammas per cm of horizontal displacement of the BMZ apparatus in a longitudinal direction in the aircraft. The introduction of errors from this account was avoided on March 28; but unfortunately the location of the BMZ apparatus on February 22 (during the flights at an altitude of 4,000 m) was not as well defined, and it is probable that the values recorded for this day are too low, perhaps even 0.5 milligauss too low.

Corrections for time variations were, of course, made in the usual way, the photographic registrations in Rude Skov observatory being employed. As a fixed value for Z in Rude Skov 454.5 milligauss was chosen (cf. Fig. 2). On the whole the time-variations of Z during the flights were diminutive.

On the map in Fig. 1 all the results of measurements made at 500 m on March 28 are indicated (total duration one and a half hours). The figures give the excess in milligauss above 450 milligauss, tenths of milligauss being given for the southward flight from Kronborg to Søvang and the northward flight from Søvang to Trekroner, while only whole milligauss were recorded for the transverse flights owing to the aforementioned greater inaccuracy of the measurements on these latter flights. As already stated, all figures are reduced to the value 454.5 milligauss or 45,450 gammas for the observatory in Rude Skov, which was the normal value in Rude Skov about January 1, 1949. No corrections were made for the height above sea-level; such a correction may, however, easily be made by adding 11 gammas or about 0.1 milligauss.

At first glance Fig. 1 shows that values to the south are generally somewhat lower than those to the north. We should expect (MOLIN 1942) a decrease from the north towards the south of ca 3 milligauss per 100 km, that is, very nearly one milligauss for the distance Kronborg-Trekroner. Moreover we find in the northern part somewhat greater values to the east than to the west. The opposite is the case in the centre of the chart, and at the bottom the lowest values seem to occur on both sides, while higher values are found over the central parts of the Sound.

Although we must count upon errors of the order of 1 milligauss for the five routes across the Sound, it turns out that the values along these routes agree in all essentials with the values found by measurement on land on either side of the Sound. In Fig. 2 the positions of these observing stations are shown, and the Z-values are all converted to 454.5 milligauss for Rude Skov. The values for Sweden (including Ven) are due to K. MOLIN (1942), while for the Danish side of the Sound the measurements were made by the author, the majority at the end of 1950. In accordance with the observations made from the aircraft, comparatively high values are found at the northernmost part of the Swedish coast and at Ven, while low values occur along the southern part of the Swedish coast and the coast a little south of Helsingør. For the area of the city of Copenhagen (ruled in Fig. 2) it is very difficult to arrive at reasonably exact values owing to the many disturbing factors; but in a belt closely encircling the city Z seems to be rather low, possibly a result of the city's close proximity. Perhaps it is also an effect of the city-disturbance that values measured from the aircraft over the centre of Copenhagen are comparatively high. In Fig. 2 values which must be regarded as uncertain (e. g. owing to disturbances from the surroundings) are given in parentheses.

As already stated values measured from aircraft on southward and northward running routes must be assumed to be more certain than those obtained on transverse routes. Fortunately there is a possibility of checking those parts of the first mentioned routes that cross Amager; the northernmost portion of Amager, however, is an urban district. As regards the values obtained from the northward route, Søvang to Trekroner, it should be mentioned that the scale value for these was fairly high, viz. 47.5 gammas or ca 0.5 milligauss per division. As a result mechanical vibrations give a somewhat greater uncertainty in this case than for the southward flight, for which the scale value was 6.5 gammas.

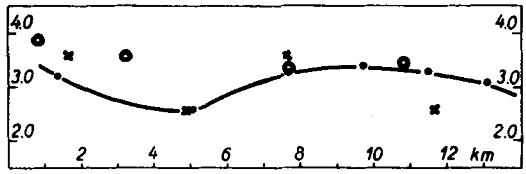

Fig. 3. Variation of the vertical magnetic intensity over Amager from the north towards the south; the unit of the abscissa is kilometers, that of the ordinate milligauss. The full dots (and accordingly the curve) are based upon ground measurements; the circles and crosses were obtained from flights at an altitude of 500 m. These latter values have been reduced to ground level.

In Fig. 3 values measured on the ground are inserted for checking, and a smooth curve is drawn through them with the abscissa indicating kilometres from the north towards the south. In this same figure the Z-values found on the southward flight are indicated by small circles, those for the northward flight by crosses. For the sake of accuracy the results of measurements from the aircraft have been reduced to the earth's surface by the addition of 11 gammas.

The fact that the northernmost three values measured from the aircraft (to the left in Fig. 3) are 40—90 gammas above the curve drawn, is no serious objection to these values; since the value obtained from measurements on land which determines this part of the curve was rather uncertain, as it was measured at a point within the town area. It is possible that here the values measured from the aircraft are the most accurate; they are somewhat higher than those measured immediately outside the urban area (cf. the remarks above). More serious is the fact that the southernmost of the values measured from the aircraft is 70 gammas below the drawn curve. This value, however, comes from the northward flight with a scale value of 47.5 gammas, and possibly the aircraft was banked a little at this particular time, for the value was read immediately after the aircraft had turned.

A precise estimate of the uncertainty of the measurements cannot, of course, be given from available data; a cautious estimate indicates the following mean errors:

1) The flight from the north towards the south on March 28 (on which the scale value was 6.5 gammas per division) yielded, from all appearances, the most accurate results; the mean error of the individual values observed is estimated as 0.2 milligauss or 20 gammas.

2) For the flight from the south towards the north on March 28 (on which the scale value was 47.5 gammas per division) when four measurement results were obtained, the mean error may evidently be put at 0.5 milligauss.

3) For the five flights across the Sound on March 28, banking of the aircraft, as already mentioned, was of prime importance in restricting the accuracy of the results obtained, and accordingly we must estimate mean errors of about 1 milligauss. From a consideration of the values obtained near the points of intersection with the aforementioned routes, it would seem, however, that these cross-Sound values are fairly good.

4) For the measurements at 4,000 m on February 22 the mean error probably ranges between 0.5—1.0 milligauss, even though the route ran along the isogons. On February 22 the suspension of the BMZ was not worked out to the same perfection as on March 28, and, as stated above, there is reason to believe that the results obtained on February 22 were encumbered with a systematic error, being as a result possibly 0.5 milligauss too low. However, as a kind of triumph for these measurements, it should perhaps be added that on the basis of them it was possible to demonstrate inaccuracies in Z-values obtained from earlier measurements on land (north of Copenhagen and on Amager); not only in the older values (Paulsen and Ryder 1913), but also in values of more recent date (Madsen 1940). The cause of the inaccuracy of the latter is perhaps that they were reduced to values valid for Potsdam, not to values valid for Rude Skov.

In Fig. 4 the results of the measurements at the 4,000 m level are plotted as a function of the distance southward from Kronborg; the flight continued a small distance beyond Trekroner. The values from the northward flight are indicated by small crosses, those from the southward flight by small circles. Further, the values from the southward flight at 500 m on March 28 are indicated by small full circles. For both days the curve of the probable variation of Z from the north towards the south is shown, the curve for an altitude of 4,000 m appearing as the broken line. The figure confirms that the uncertainty as regards these latter values is somewhat greater than the uncertainty of the values from 500 m, and that the values from 4,000 m are somewhat lower than might be expected. Assuming that Z is inversely proportional to the third power of the distance from the centre of the earth (Maple, Bowen and Singer 1950), values obtained at the 4,000 m level would be only 75 gammas lower than those for 500 m; such a change of the ordinate is indicated in Fig. 4 by the length of the two vertical lines. Of all the values for the 4,000 m level, the southernmost, amounting to 453.6 milligauss, appears to deviate the most. However, this may quite well be due, in some degree, to the fact that it was observed over the margin of the urban area of Copenhagen.

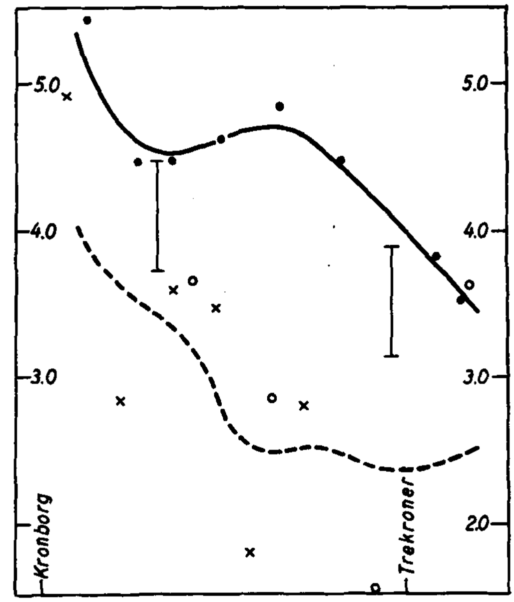

Fig. 4. The abscissa represents the southward route shown in Fig. 1, and the ordinate represents observed Z-values (with milligauss as the unit) at altitudes of 500 m (full dots) and 4,000 m (circles and crosses) respectively. The two vertical lines indicate the theoretical difference between Z-values at altitudes of 500 m and 4,000 m.

In conclusion I wish to express cordial thanks to the Danish Relief Corps, Zoneredningskorpset, which without remuneration of any kind placed an aircraft at my disposal. My thanks are also due to the Danish Meteorological Institute for placing the BMZ apparatus at my disposal, and not least to Dr J. Olsen, who has taken a great interest in the measurements, and on March 28 even participated in the observations.

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