INVESTIGATION OF THE ACCURACY OBTAINED WITH THE DECCA SYSTEM FOR SURVEY IN THE SOUTHERN BALTIC

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In order to establish the accuracy of the Decca System, purchased by the Royal Swedish Hydrographic Office for surveying purposes, a series of tests was made in the summer of 1948. Since the Decca System has already been described in detail the following will only include some brief technical data about the Swedish network.

Technical equipment.

The Hydrographic Office's Decca equipment consists of mobile units intended exclusively for surveying. The required range being comparatively small, the power output of the transmitting stations is only 600 watts and the antenna height is only 30 metres. With this set-up, adequate field strength is obtained to well over 200 nautical miles, which is actually more than is required for any kind of survey in Sweden.

In addition to the Master station two Slave stations are required to complete the red and green hyperbolic lattices. Further a monitor station was set up for checking the stability of the network. The stations are located as in fig 1. The various locations had been chosen to get the best possible intersection within the actual survey area. For this reason the stations were not placed along the coast but instead 10 km. inland. Later this proved to be a considerable disadvantage owing to the greatly differing speeds of propagation over land and water.

Decca's special survey receivers (fig. 2) were used aboard the survey ships as well as at the monitoring station. These survey receivers operate with greater accuracy than the regular Decca receivers, permitting a reading of 1/1,000th of a lane. For the positons of the stations, reciprocal distances, frequencies, etc..., see chart below.

STATION	RED SLAVE	MASTER	GREEN SLAVE
Position	57° 22' 39"9 N. 16° 28' 44"9	58° 04' 51"1 N. 16° 30' 07"5 E.	58° 50' 09"9 N. 17 14' 23"1 E.
Frequency	118,021 c/s	88,516 c/s	132,774 c/s
Comparison frequency	354,065 c/s		265,548 c/s
Distances in km...	78.312		94.490
Total number of lanes at c = 299.350 km./s.—	185.252		167.640

Examination of the Stability of the Hyperbolic Lattice.

As soon as the stations had been adjusted a series of continuous observations under varying conditions was started at the monitor station as well as on board a moored ship in order to ascertain the stability of the hyperbolic pattern. Due to the light summer nights and long summer days no after-dark surveying is done in Sweden, so no experiment with night-effect was carried out.

Inasmuch as good co-ordination was effected between the monitor station and the ship, the variations which were discovered were due to phase variations at the slave stations, which were not corrected by the automatic phase control system. The interrelation between the phase variations and rain was particularly noticeable when sudden weather changes took place. See fig. 3. It seems likely, that due to existing uncontrollable elements outside the automatic phase control (antenna and ground net) a phase shift takes place. This phase shift is probably caused by the weather and must be corrected by hand. The required corrections are made at the slave stations after a message has been transmitted to them from the monitor station.

Originally, messages concerning desired phase adjustments were sent over the Swedish telephone network. However, since the period of waiting for the call to come through was sometimes too long, a simplified system of radio communication was introduced instead. This proved to be extremely efficient. If, for example, an increase of 3/100 lane was desired, 3 long signals (— — —) were sent from the monitor station. On the other hand, if a reduction was desired, 3 short signals (. . .) were sent. Correction of the phase to the monitor value was in this way performed in less than a minute's time and an accuracy of ± .03 lane was easily obtained.

At the present time, the hydrographic service is constructing a device for fully automatic phase correction operating from the monitor station, built as follows. The adjustable phase regulator at the monitor receiver is turned from its normal value to make the deccometer show exactly 0, 25, 50 or 75 hundredths of a lane on the hyperbola net at correct position. The current in either of the phase discriminators will then pass through zero when the phase position is correct. If a difference in phase exists, either a positive or negative current at the discriminator is obtained, which actuates a polarized relay to produce either of two audio modulating notes on the communication transmitter with pitch different for increase and for decrease. Red and green meters give different notes. In the output circuits of special radio receivers at the slave stations are selective filters, tuned to the above-mentioned modulating notes, which actuate relays for the operation of small motors that turn the phase control knobs for either an increase or a decrease of phase in accordance with whatever note has been transmitted from the monitor station. As soon as the current at the discriminator output becomes zero, i.e. when no phase shift exists any longer, the motor, which has been actuated, automatically stops. With this method it is estimated that a stability of .01 of a lane can be maintained without difficulty.

In addition to greater stability, this method for automatic phase control will bring about several other advantages. Surveying can, for instance, be started immediately after the stations have been turned on without waiting for the apparatus to reach constant temperature, because deviations in phase will be corrected all the time. This means a saving of approximately one hour for each station. The positions of the master and the slave stations can be chosen irrespective of the vicinity of electric wires which, at least in Sweden, with its widespread telephone and power line network, will facilitate considerably the siting of the stations.

Contrary to what the Decca Company has indicated in its instructions, however, the site of the monitor station must be chosen with care so as to eliminate any local sources of error. A good ground net should be laid out and the ground should have good electric conductivity. The distance to insulated wires should be at least 200 metres. The monitor station should also be compared with measurements from a moored ship for some time before the beginning of every survey season so as to be sure that there are no local variations. The monitor station should, if possible, be near the area which is the object of the survey.

One solution of the monitor problem which has many advantages is to use a smaller ship, for example, a small houseboat which, every season, is moved to a suitable small harbour within the survey area in question.

Accuracy control in the Decca System and calculation of radio propagation speeds.

Before commencing operation of the Decca stations, the Hydrographic Office had computed the hyperbolic pattern for certain parts of the survey area. Using the results of English and Dutch experiments, and taking into consideration the high attenuation characteristics of the terrain where the Decca-chain is located in Sweden, 299,350 km/s had been selected as a suitable average land-and-water figure for the phase velocity of radio propagation. When making the calculation a new system evolved by the Hydrographic Office was used.

A detailed account of this system, which is considerably simpler and quicker than the earlier methods used in England and Denmark, and no less accurate in the final result, is given by the State Geodetic Surveyor, Mr. S. Hilding, in a separate article.

In order to find out how this computed hyperbolic pattern agreed with the Decca readings on board ship, a special survey expedition was made for a 14-day period with the survey-vessel "Gustav af Klint". In order to estimate the speed of radio propagation across land, the trip was extended to include certain parts of the archipelago, where otherwise the Decca system is of no interest in surveying. Also, the base line extensions were crossed whenever possible. Survey points can be seen in figure 4. In order to eliminate any errors due to variations in the phase position of the stations, the monitor readings were taken and, on board, the Decca position was read at even minutes by synchronised chronometers. Thus, a correction due to possible errors in phase position could be easily applied. The slave stations were phased to give best possible agreement between the computed lattice and the actual readings at sea near the coast in the vicinity of the monitor station.

The ship's position was determined by horizontal angles to three triangulation points whose positions were known from earlier triangulation to an accuracy of better than $\pm$ 0.3 m. At every observation station the speed of the ship was reduced as much as possible and at least five consecutive observations were made at one minute intervals. The Decca readings on board ship and at the monitor station were made to 1/1,000 lane. By drawing a curve through the recorded observations, as shown in figure 5, a graphic mean is obtained of the results and the comparatively complicated computation of the Decca co-ordinates is carried out for only one group of these values. The accepted speed of 299,350 km/s was used in these calculations.

The base line extension values were measured both from the ship and from an aircraft flying at an approximate altitude of 200 metres. Several crossings at different distances from the station were made according to figure 6; typical curves for such crossings can be seen in figures 7 and 8. The differences between observed and computed Decca readings can be seen for each survey position in figure 4.

In the area N.-E. of the master station the agreement between observed and computed lattices is rather good, principally due to the initial phase adjustment on the slave stations. For the rest the computed co-ordinates do not agree with those read off. This applies particularly to the survey points near the red slave station where the master signal had to traverse a long stretch of land. On the base line extension the error amounts to not less than 1/2 lane.

From the above, it seemed likely that the main reason for the unsatisfactory agreement was that the true speed of radio-propagation over land differed from that estimated.

If the speed is estimated with the data measured on the base line extension, quite different results are obtained from those used for computing the hyperbolic lattice. With a distance between the red slave station and master station of 78.312 km., an observed phase difference between the base line extensions of 186.01 lanes, and a comparison frequency of 354,065 c/s the propagation speed

$$c = 2 \cdot \frac{78{,}312 \times 354{,}065}{186.01} = 298{,}140 \text{ km/s is obtained.}$$

For the green lattice the corresponding figure is somewhat higher — c = 298,590 — probably due to the fact that part of the path between the stations lies over water.

The reason for these abnormally low figures is probably due to the low conductivity of the terrain between the stations. This has also been experienced during field strength measurements on broadcasting stations when the conductivity has been as low as $.5.10^{-14}$. On the other hand, the very hilly terrain could also make the distance travelled by the radio waves considerably longer than the geodetically measured distance between the stations, causing a lower apparent propagation velocity.

As there is no good reason for assuming that the speed of propagation across the water of the Baltic, with a salt content of about 1/2 % in the survey area in question, should differ very considerably from the speed measured in other areas of c = 299,750 km/s, the difference between the speeds over land and over sea is so large that it is hardly possible to use an average between these when computing the hyperbolic pattern.

A simple examination of the conditions that arise when having to take into account different speeds over land and sea (see appendix 1) shows, however, that the lattice can be computed using the water speed and that a correction for the distance over land can be made afterwards. This correction is

$$\Delta \phi = k. \Delta l$$

where Δ l is the difference between the distances over land traversed by the slave signal and the master signal. Thus if the distance over land to the point under survey is the same for each station, the delay due to the slower land speed will be the same in each case and no correction is required. As long as the type of ground is the same, the value of k is constant for a given comparison frequency. If the propagation speed is known, k can be calculated from the expression :

$$k = \frac{\Delta c.f}{c^2}$$

where Δ c is the difference between the speed over water and land and f is the comparison frequency.

In order to find out if the speed over land is sufficiently constant to give a definite value to the correction constant k, the differences between the computed Decca co-ordinates and those observed on the control surveys were drawn as functions of the difference between the land distances crossed from the master and slave stations. This difference of distance has been plotted with a positive sign when the distance to the slave is greater than to the master, and with a negative sign in the opposite case. If the value of k is fixed, that is, the speed over land the same for varying directions, all survey points will lie on an inclined straight line where the inclination gives the value of k according to the expression.

$$k = \frac{\Delta \phi}{\Delta l}$$

The best approximation to a straight line was obtained when, instead of the earlier speed of 299,350 a recalculation to 299,650 was made which can therefore be taken as a likely mean speed for transmission over water. The diagrams for the red and green lattice for the speed of 299,650 km/s can be seen from figures 9 and 10. For the red lattice a mean value of k = .0092 and for the green lattice k = .0058 lane/km.

For the red lattice this means a correction of 0,92 hundredths of a lane for each km. difference of distance passed over land from the stations in question. This difference must therefore be established quite accurately which is often a great problem in Sweden, where the coast is not a straight line, but deeply indented and screened by a deep archipelago. To simply add together the varying distances of mainland and island would probably not give a correct result, as islands or peninsular extensions smaller than the wave length used would probably not give a corresponding reduction in the speed of transmission. The relatively great dispersion in the diagram especially of the red values is probably due to this. The reason for the high errors in the area north of the master station (top right in figure 9), is probably due to the fact that over the agricultural land here the velocity of propagation is greater.

When computing the speed of propagation from mean values of the constant k,

$$\Delta\ c = k.\ \frac{c^2}{f} = 2{,}370\ \text{km/s}$$

is obtained for the red lattice which corresponds to the speed over land

$$c_1 = 299{,}650 - 2{,}370 = 297{,}280\ \text{km/s}.$$

The corresponding value for the green lattice is

$$c_1 = 299{,}650 - 1.880 = 297{,}770\ \text{km/s}.$$

And as far as is known these are the lowest values of the phase velocity of radio waves measured until now.

For the sake of simplicity it has been assumed in the above calculation that the speed of transmission is the same for both master and slave stations. Over water this supposition may be correct but over land where the speed differs very much from the theoretical value, it is not improbable that the speed can vary with frequency. The readings measured along the baseline extensions also indicate that this is the case. If the speeds for the slave and master station frequencies are the same, the readings along a base line extension would be fixed. As can be seen from figure 6, rather variable readings are obtained, especially from the green lattice southwards, where, at a distance of about 220 km. over land, the difference amounts to 0.46 lanes. Over the less attenuating terrain northward, a variation was measured on the opposite green base line extension of 0.23 lanes at a distance of about 170 km. For the red lattice 0.23 lanes difference was obtained northward at 90 km. Southward no surveys were made as the red base line there goes over water.

No attempt has been made to estimate from the above data the different speeds of propagation from the master and slaves. For surveying purposes it is probable that the different speeds of different frequencies will be of no importance, as the correction for the traversed land distances could not be calculated with greater accuracy, owing to the variation of ground characteristics in the path of the signal. From the purely scientific view, however, a determination of speed for the different frequencies is of very great importance, and therefore if practicable, more of the necessary surveys will be made as soon as possible.

From the above analysis, it can be seen that when Decca stations are used for survey in areas having poor conductivity characteristics, the stations should be located as near the coast as possible, to minimize the land path of the transmissions. To avoid moving the Swedish stations from their present sites immediately, an attempt was made to correct the hyperbolic pattern by means of correction factors for the stretches over land according to the expression

$$\Delta \varphi = K. \Delta l.$$

with values for k equal to .92 hundredths and .58 hundredths of a lane per km. for green and red respectively. The difference between the computations corrected by the above factor and the observed readings can be seen in figure 11. Within the survey area in question the average error for the red lattice is within 3.5 hundredths of a lane and for the green lattice within 3.0 hundredths. For the survey to be made with the stations at their present location this accuracy is acceptable and therefore the stations will remain in position until the area has been completely surveyed. In future the stations will be located as near to the coast as possible in order to avoid a correction for low propagation speed over land.

Before the actual survey is started, however, a detailed control will take place along the coasts of the survey area concerned each summer. Using the speeds determined above over land and water, and the data from the control, a fictitious coast line will be constructed "as it looks to radio waves". After this, the required correction will be estimated with due consideration for the low velocity over land and the land stretches will be measured from this fictitious coastline. Examination shows that the average error can thereby be kept to within 2 hundredths of a lane.

In order to incorporate this correction into the lattice computations a method, which is chiefly graphic, has been evolved by the Hydrographic Office. From comparisons made it gives just as high an amount of accuracy as the purely mathematical method, at least for scales less than 1 : 30,000. As the construction of the hyperbolae can be done in a fraction of the time required for the normal mathematical method, even if corrections are not made, the Hydrographic Office will use this method only, for its future computations. A more detailed account of the apparatus used can be found in appendix 2.

The values of propagation velocity of low frequency radio over land obtained in Sweden from the Decca System are of great interest, not only for the system's use in survey but also for navigation at sea and in the air.

When siting Decca navigational stations in countries with the same type of topography as that of Sweden, great consideration should be given to the problem of speed variation over land and water. In such countries theoretically constructed lattices should not be relied upon. In the more important waters at least the lattice should be checked and the charts should be printed with a corrected lattice.

The transmissions from the Danish navigational chain are not expected to have discrepancies of the same magnitude as the Swedish survey chain has on the East Coast of Sweden, but a detailed check will still be made to detect disturbances due to local conditions, before charts of the West Coasts of Sweden are issued with an overprinted Danish lattice.

Along ordinary air routes detailed navigation is not necessary and a deviation of some hundredths of a lane can be tolerated. Precision, however, should be as great as possible in the vicinity of airfields where observations and corrections should be made to increase the reliability of the map or chart.

In high-precision air mapping of unknown territories the Decca system seems inefficient with regard to territories of high attenuation as is very often the case in non-cultivated areas, because in these areas it is impossible to control the propagation speed by previously triangulated points ; the Shoran system seems therefore better suited for this purpose. Because the earth does not influence the ultra short waves used in this system, the speed of propagation can be precomputed with great precision.

In spite of the difficulties experienced in Sweden because of low propagation speeds over land the Swedish Hydrographic Office consider Decca at the present time to be the most suitable system of hydrographic survey when out of sight of land.

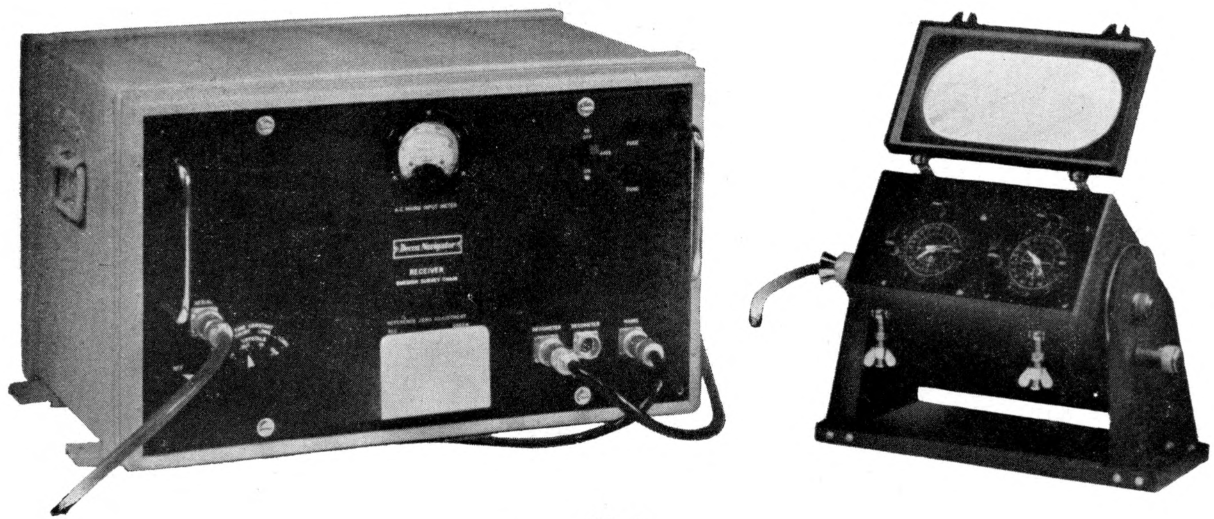

FIG. 2
Photo showing the special Decca survey receiver.

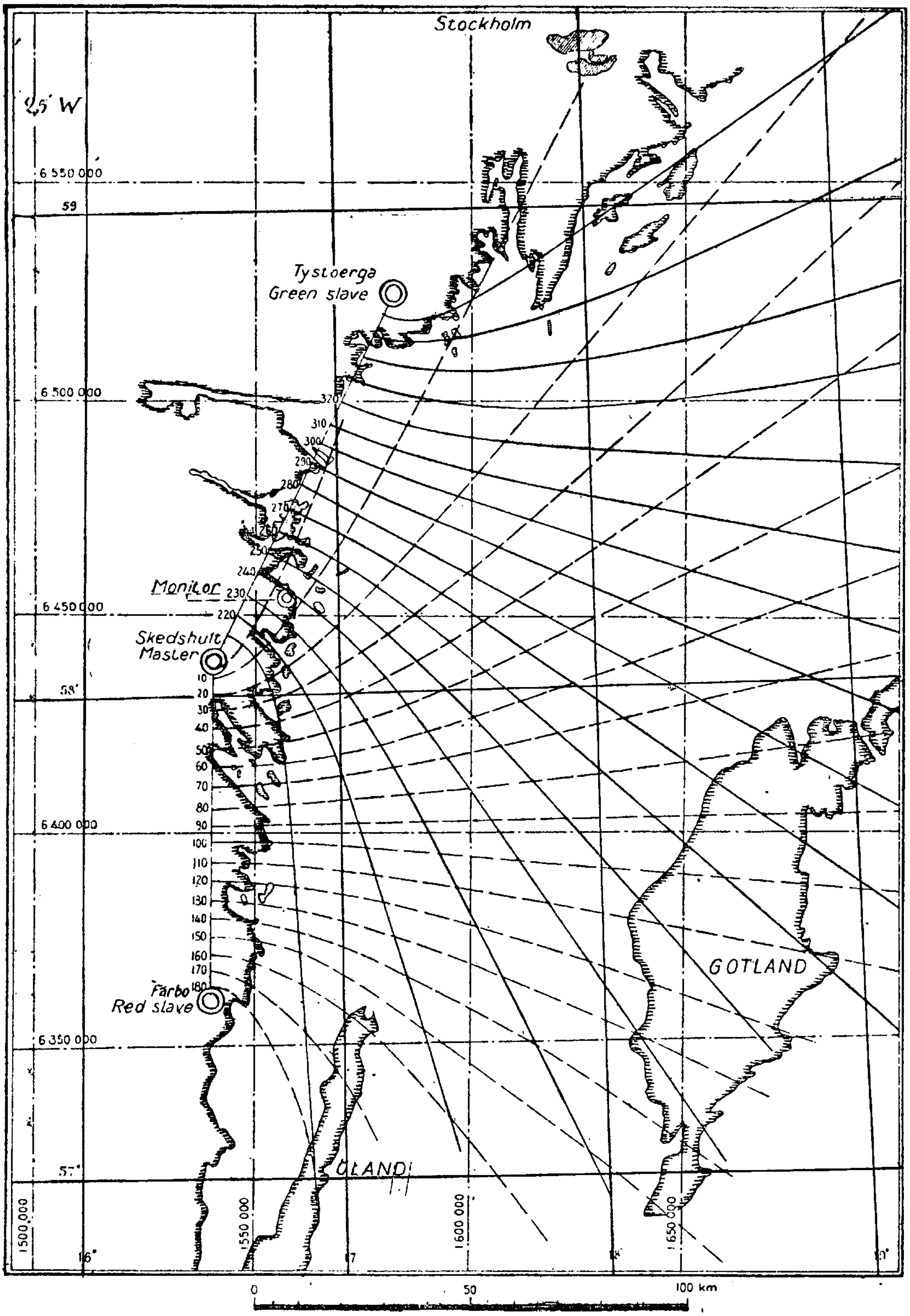

FIG. 1
Chart showing the position of master,—slave—and monitor stations in the Swedish Survey Chain used in the Southern Baltic.

FIG. 4
Chart showing positions where the computed lattice has been checked with the triangulation grid. Upper figures in the circles correspond to the red, lower figures to the green pattern.

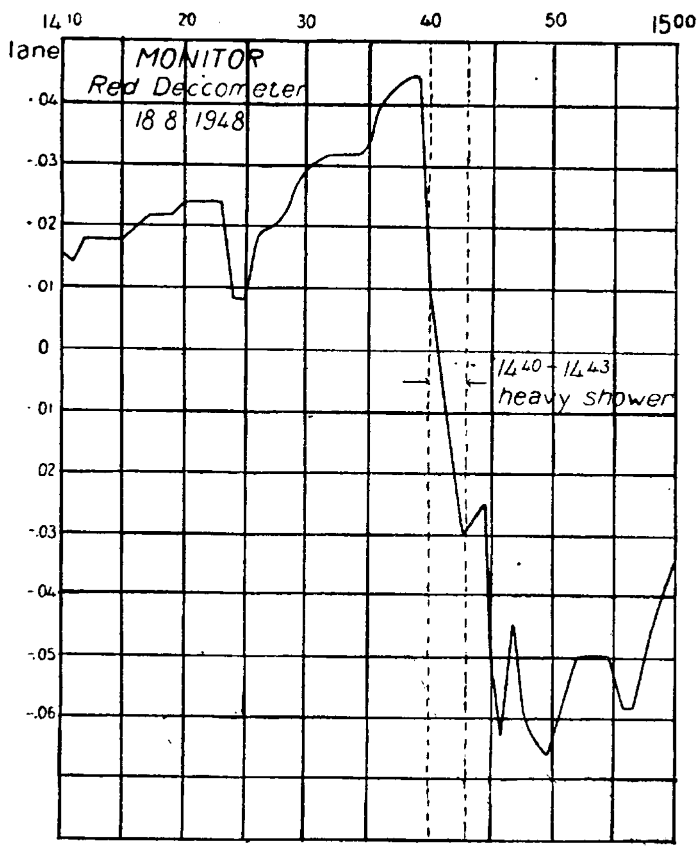

FIG. 3
Curve showing Deccometer readings during a rapid change of weather conditions.

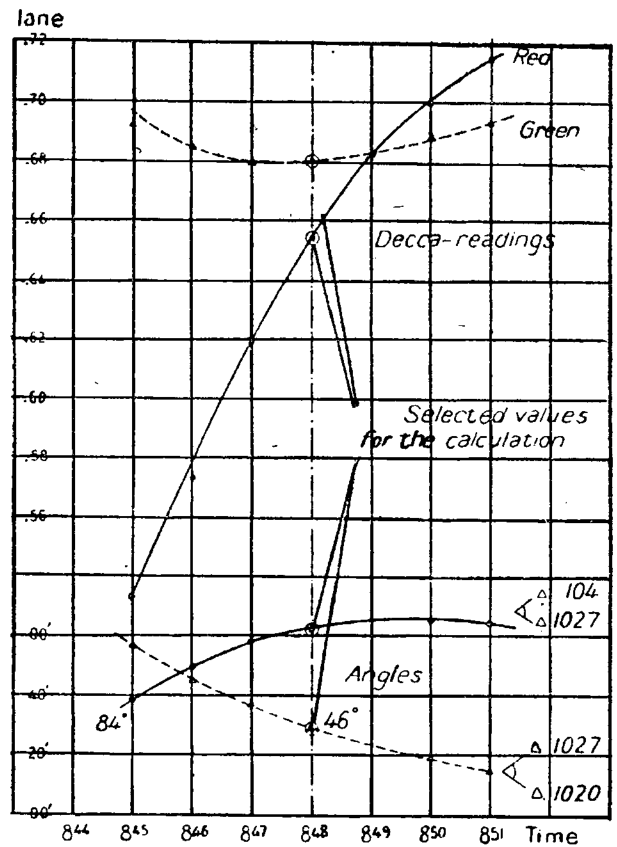

FIG. 5
Variations of measured values for a series of observations of angles and Decca co-ordinates.

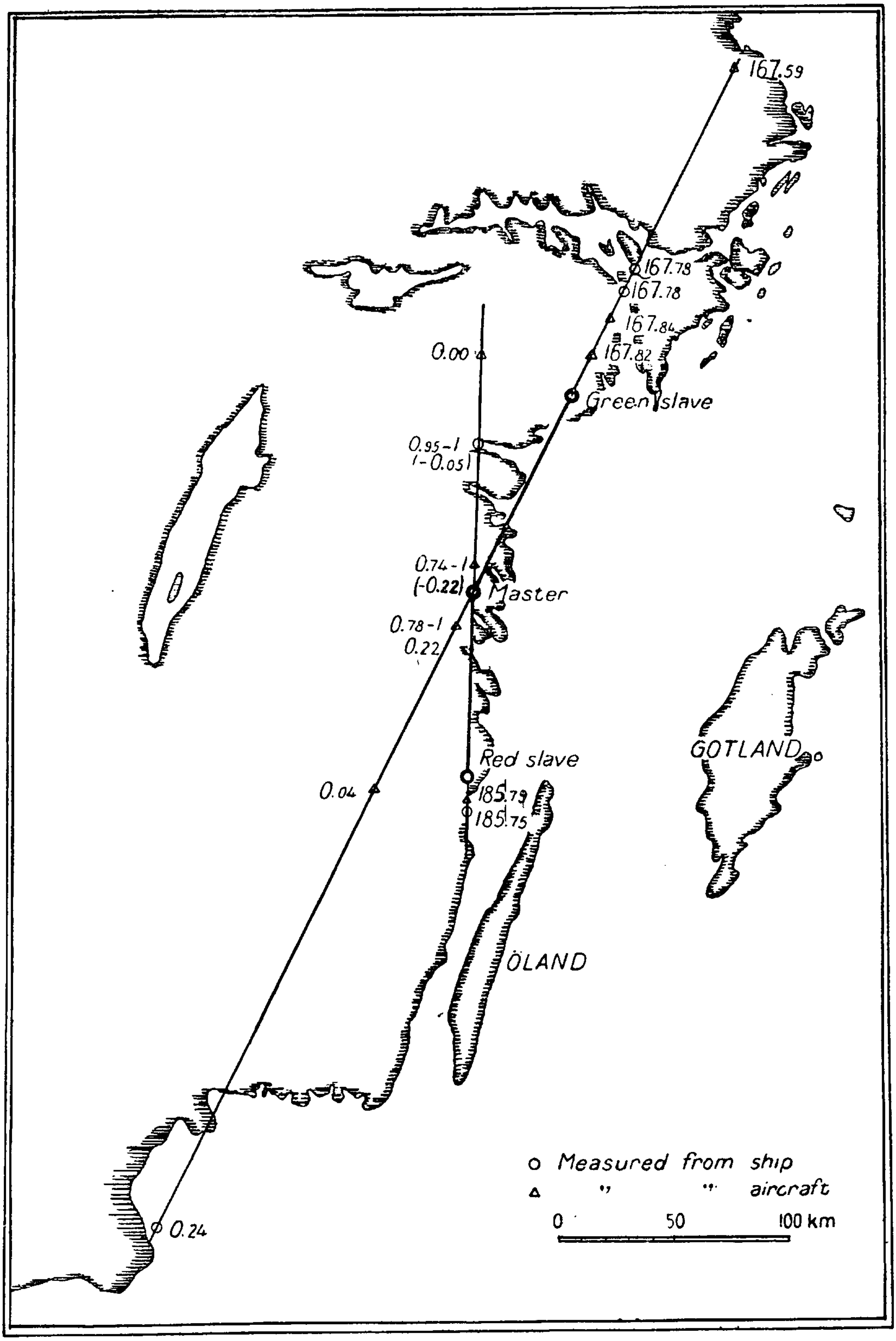

FIG. 6
Chart showing measurements on the base line extensions from ship and from aircraft.

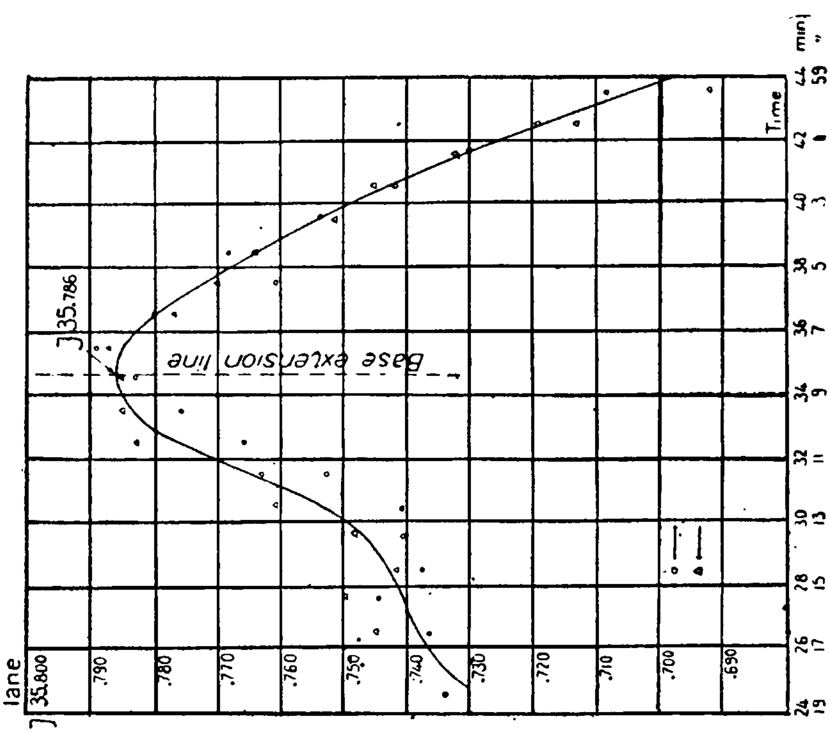

FIG. 7
Diagram showing a base line extension passage by ship.

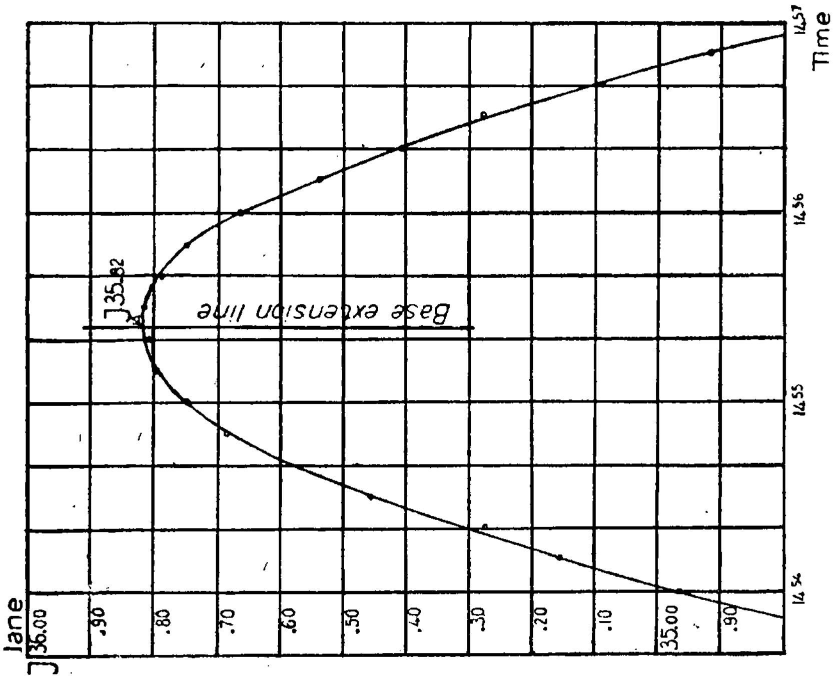

FIG. 8
Diagram showing a base line extension passage by aircraft.

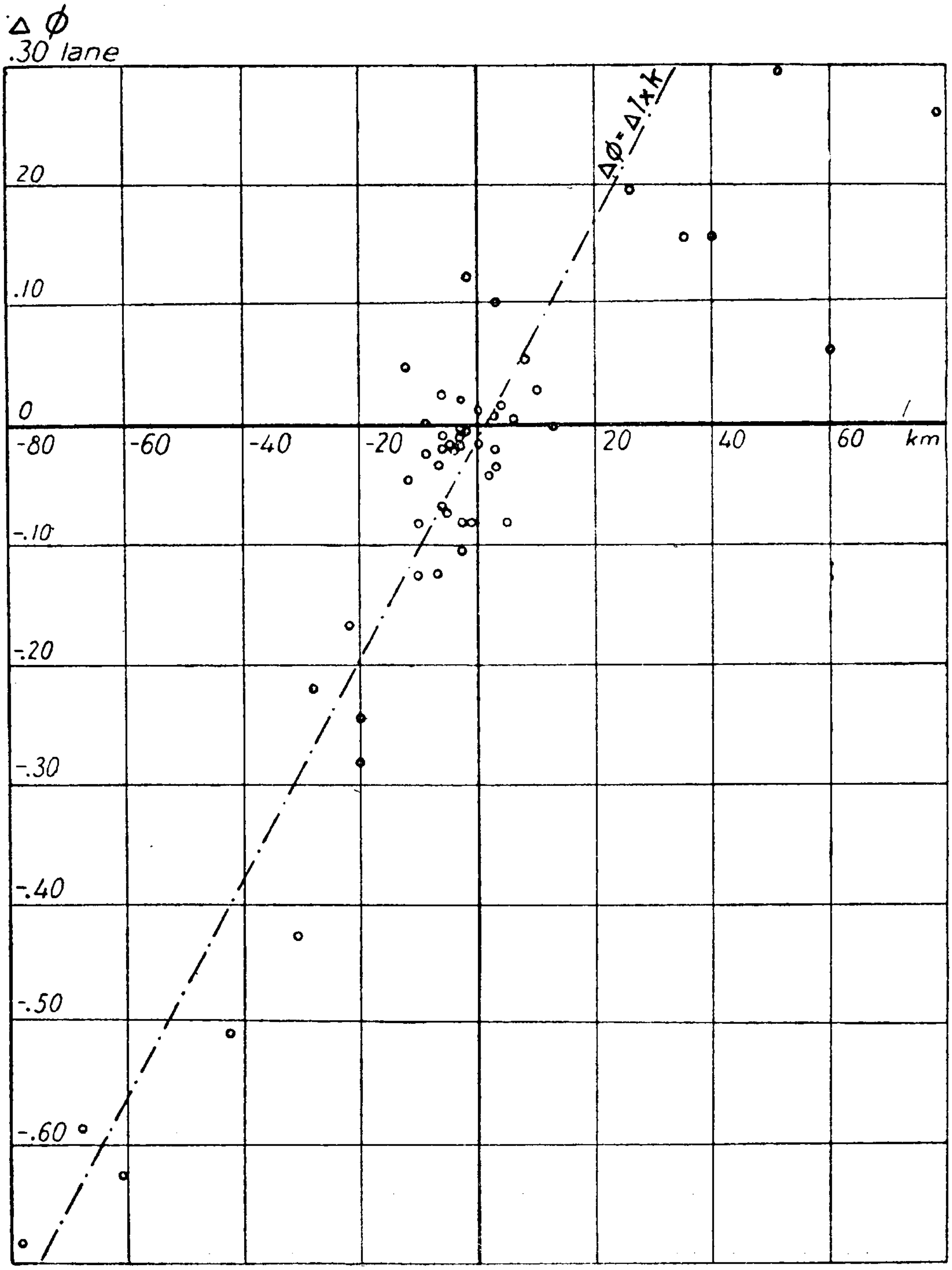

FIG. 9

Diagram showing errors as a function of difference of land paths to master—and slave stations at c = 299,650 km/s for the red lattice.

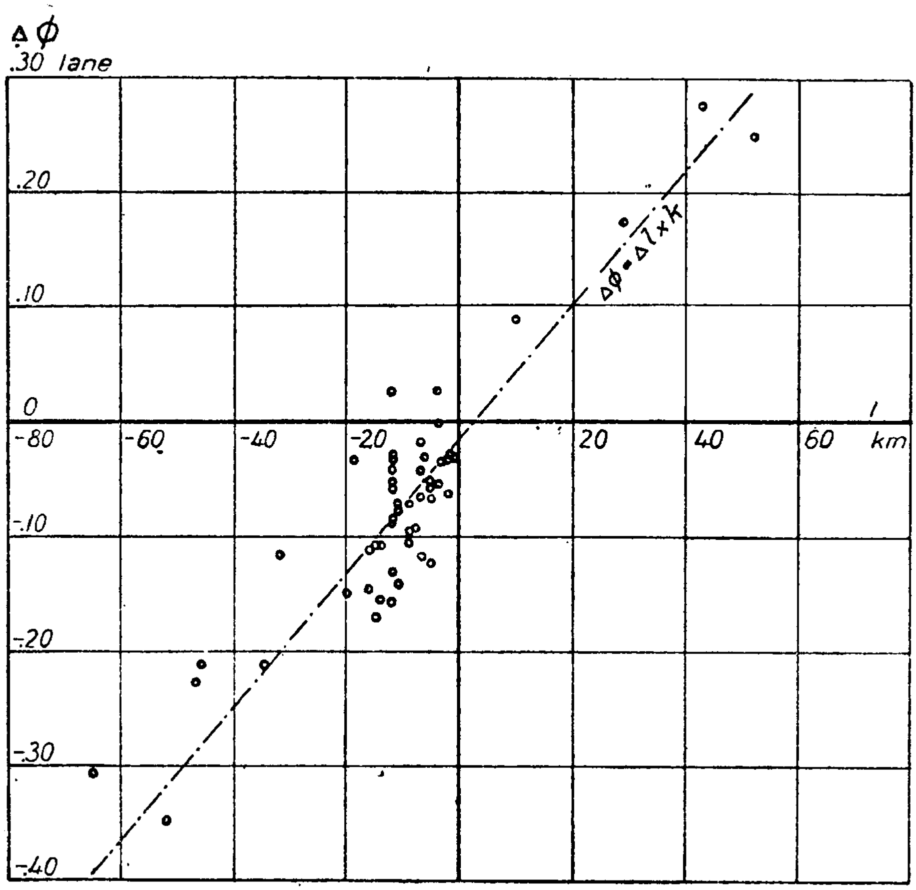

FIG. 10

Diagram showing errors as a function of difference of land paths to master—and slave stations at c = 299,650 km/s for the green lattice.

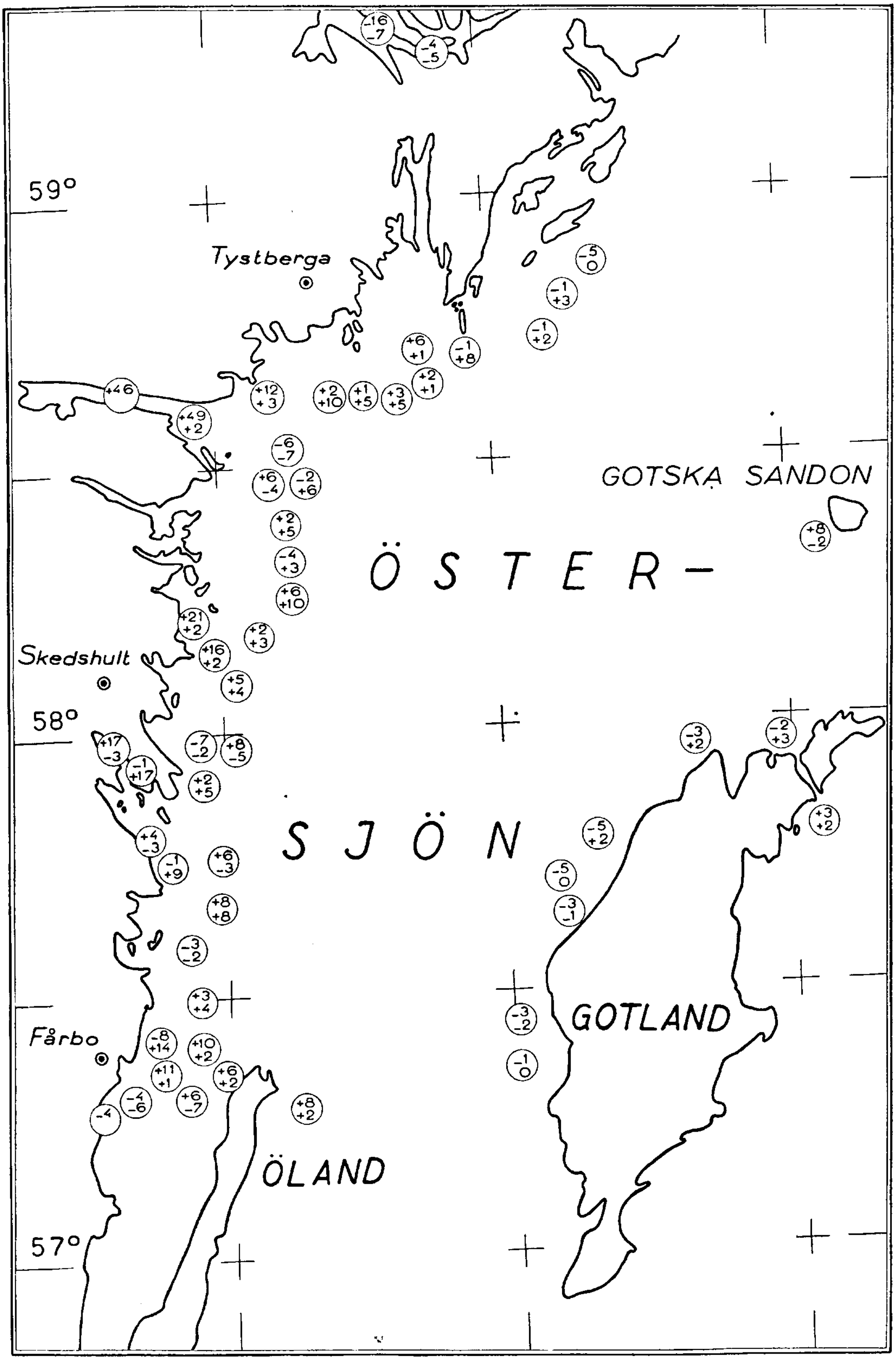

FIG. 11

Chart showing residual errors, when the lattice is corrected for the reduced propagation speed over land. Upper figures correspond to the red, lower figures to the green pattern.

APPENDIX I

If the phase velocity of the radio waves over water is c_w and over land $= c_l$, then the corresponding comparison wave-lengths are

$$\lambda_l = \frac{c_l}{f} \text{ and } \lambda_w = \frac{c_w}{f}$$

since the frequency f is constant.

If the phases at the slave A and the master B are ϕ_A and ϕ_B, the phase in the point P for the wave travelling from the slave is

$$\phi_{PA} = \phi_A + \frac{l_A}{\lambda_l} + \frac{w_A}{\lambda_w} = \phi_A + \frac{l_A . f}{c_l} + \frac{w_A . f}{c_w}$$

and for the wave from the master ϕ_{PB}

$$\phi_{PB} = \phi_B + \frac{l_B}{\lambda_l} + \frac{w_B}{\lambda_w} = \phi_B + \frac{l_B . f}{c_l} + \frac{w_B . f}{c_w}$$

The phase difference in P is thus

$$\phi_P = \phi_{PA} - \phi_{PB} = \phi_A - \phi_B + f\left(\frac{l_A - l_B}{c_l} + \frac{w_A - w_B}{c_w}\right)$$

If the hyperbolic pattern is calculated with a constant speed of velocity $c_l = c_w$ the corresponding phase difference is

$$\phi'_P = \phi_A - \phi_B + f\left(\frac{l_A - l_B}{c_w} + \frac{w_A - w_B}{c_w}\right)$$

The error due to the different speed of propagation $\Delta\phi$ is therefore

$$\Delta\phi = \phi_P - \phi'_P = f\left(\frac{l_A - l_B}{c_l} + \frac{w_A - w_B}{c_w} - \frac{l_A - l_B}{c_w} - \frac{w_A - w_B}{c_w}\right) = f\left(\frac{l_A - l_B}{c_l} - \frac{l_A - l_B}{c_w}\right).$$