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INDIRECT PHASE HEIGHT MEASUREMENTS IN CENTRAL AND EASTERN EUROPE FOR MONITORING D REGION PLASMA

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Low-frequency propagation experiments for the investigation of the lower part of the ionospheric D region were at first used by BRACEWELL et al. (1951) at Cambridge in the early fifties. Among these was the method of indirect phase height measurements which has been further developed by LAUTER (1958) at Kuhlungsborn for continuous monitoring of the lower ionosphere. It is based upon field strength measurements of commercial radio transmitters in the frequency range between 50 and 200 kHz at distances from 500 to 1500 km. The field strength records show characteristic diurnal variations with maxima and minima, produced by interference between the ground wave and the ionospherically reflected sky wave, the phase difference between which varies in correspondence to the diurnal variation of the reflection height. The upper part of Figure 1 gives two examples of field strength records on radio frequencies of 164 kHz and 155 kHz at distances of 1023 km and 1359 km, respectively. The variations during forenoon and afternoon are quasi-symmetrical with respect to the real noon at the propagation path midpoint.

From investigations in the LF-range (SMITH, 1973) it is known that the dominant part of downcoming sky wave is the extraordinary component. On the basis of the magneto-ionic reflection condition we can calculate the electron density necessary for reflection of the extraordinary component at a given frequency and angle of incidence. For frequencies ranging from 50 to 200 kHz, these calculated reflection electron densities are between 250 and 550 el cm . The diurnal height variation of the level where electron density has this given value governs the interference pattern. The height difference corresponding to two successive interference extrema ranges from 2 to 5 km, depending on frequency and propagation path length. The coordination of the individual field strength extrema to corresponding reflection heights is in principle ambiguous, but if two or more simultaneous indirect phase height measurements are available this ambiguity can be removed so that a definite absolute height can be ascribed to each extremum. This coordination can also be achieved by comparison with rocket-measured electron density profiles obtained in the same location.

In the following a very simple approach of interpretation is attempted on the basis of geometric-optic consideration. The lower part of Figure 1 shows an example of height determination from measurements on two frequencies. The times of field strength extrema are referred to the respective solar zenith angles, χ, at the propagation path midpoint and coordinated to the corresponding geometric heights. The diurnal variation of the reflection height ranges between 75 and 85 km. The relation between the reflection heights and the logarithm of the Chapman function of χ is linear, forming during forenoon and afternoon two straight lines with different slopes. The difference between the forenoon and afternoon branches corresponds to a distinct time difference of about 10

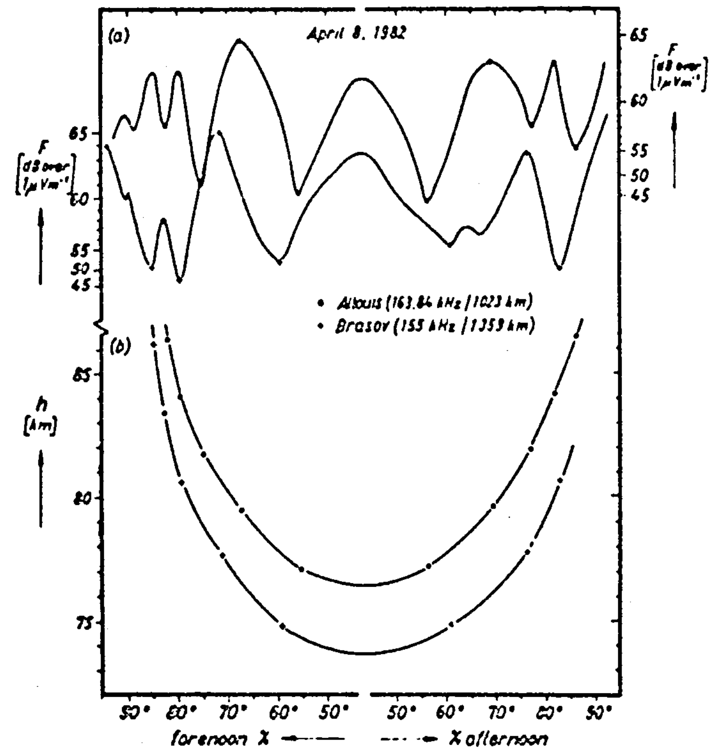

Figure 1. (a) Field strength records of LF signals on long-distance transmission paths at Kuehlungsborn. (b) Diurnal variation of apparent reflection height by coordinating each field strength extremum to its triangulation height.

minutes.

During daytime the normal electron density in the D-region between 70 and 85 km is mainly produced by nitric oxide ionization due to solar Lyman-α-radiation. Molecular oxygen is considered as the main absorber for solar Lyman-α-radiation. On the basis of this concept it can be shown that the height of a level of constant electron density in the D region indeed varies linearly with ln Ch χ, just as does the reflection height in our indirect phase height measurements. The time lag between the forenoon and afternoon values is due to recombination processes in the ionospheric plasma whereas the average of the forenoon and afternoon values approximately represents equilibrium conditions in the D-region. In this case the slope will represent the mean scale height of the neutral atmosphere.

In order to check the validity of this kind of interpretation, field strength measurements on two LF-measuring paths were installed in the Soviet Union, with their path midpoints situated very near to the rocket sounding station Volgograd.

A series of electron density profiles measured at Volgograd by rockets up to a height of 85 km at different solar zenith angles well confirms the assumption that the reflection height is connected with a fixed value of electron density. Figure 2 shows the height of this reflection electron density obtained by rockets in comparison with the reflection height determined at the same solar zenith angle from indirect phase height measurements. The slope of the regression line does not show the expected 45° angle. The variation of the reflection height in dependence on χ is larger than the corresponding change of the fixed electron density level. This result can be explained by variable additional phase changes of the downcoming signal due to variations of electron density below the reflection height. Thus, one has to be aware that the accuracy of phase height determination is somewhat reduced by this effect.

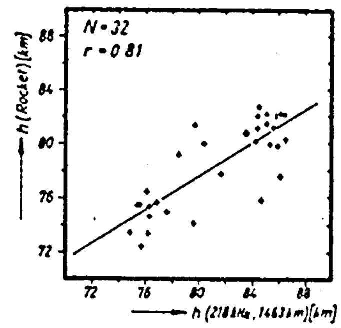

Figure 2. LF reflection height (218 kHz/1463 km) in comparison with corresponding heights derived from rocket-measured electron-density profiles.

An impressive demonstration of the effectiveness of indirect phase height measurements is the appearance of solar flare effects in the records. The strongest observed effects seem to decrease the reflection height by as much as 15 km. But some part of this amount may be also due to a flare-induced additional phase change below the reflection level.

It can be shown that the reflection height depends on the variation of the optical depth for the ionizing solar Lyman-α-radiation; that means it depends on air pressure. It has turned out that an appropriate characteristic for describing the day-to-day variations is the inverse Chapman-function, $Ch^{-1}\chi$, of the solar zenith angle value at which the diurnal course of the reflection height crosses a given height level. This quantity is mainly connected with the pressure variation, as confirmed by comparison with the seasonal variation of air pressure measured by rockets.

In Figure 3 the correlation is presented of daily pressure values obtained by rockets at a height of 70 km with corresponding values of $Ch^{-1}\chi$ during the winter of 1974/75. They are given as deviations from the mean seasonal variation. The result shows a weak but significant correlation. This winter had particularly large variations of air pressure. A similar investigation for other winters did not show such a significant correlation. Thus, it must be assumed that other quantities also influence the $Ch^{-1}\chi$-values in the same order of magnitude.

A comparison of the slope of the mean daily variation of reflection height with corresponding temperatures measured by rockets is difficult. The slope

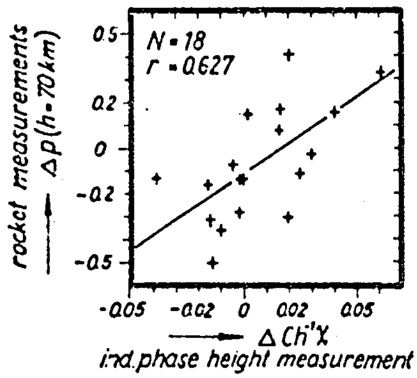

Figure 3. Pressure deviation from seasonal variation in 70 km height in comparison with corresponding $Ch^{-1}\chi$ values near 78 km height from December 1974 to March 1975.

results from the whole diurnal variation of the reflection height; that means that there is inevitably an averaging over a height range up to 10 km where the vertical temperature profile may considerably vary and likewise an averaging over many hours where also considerable temperature changes may occur. On the other hand, it must be assumed that additional phase changes caused by variations of electron density also influence the slope. Thus, one cannot expect a good correlation between scale heights derived from the slope of the diurnal phase height variation and instantaneous local temperatures measured by rocket. The seasonal variation, however, of the slope is very similar to the seasonal variation of temperature in the altitude around 80 km.

In Figure 4 different data for the winter of 1974/75 are presented in the following manner: The upper curve gives daily values of ionospheric absorption at constant solar zenith angle $\chi = 78.5°$. The two curves below show daily values of $Ch^{-1}\chi$. They rise when the isobaric surface near 80 km is rising and vice versa. Curve (b) gives $Ch^{-1}\chi$ values from Eastern Europe and curve (c) from Central Europe. The distance between the path's midpoints is about 2400 km. Both curves show very similar variations, a hint to large-scale pressure variations in this region. The lowest curve of the figure gives some pressure values at 70 km height measured by rockets in Volgograd. The pressure data show similar large variations as those of the $Ch^{-1}\chi$ values, which confirm the close connection between both of them, as also seen in the figure before. The variation of ionospheric absorption precisely follows inversely the changes of the $Ch^{-1}\chi$ curves, i.e. large ionospheric absorption is connected with low pressure and vice versa. The high variability in this winter is mainly caused by large-scale changes of pressure.

The results of comparison between indirect phase height measurements and simultaneous rocket soundings in the D-region can be summarized as follows:

- The reflection height approximately varies with the height of a fixed electron density; that means that a continuous patrol of one point of the electron density profile is possible by these measurements.

- The interdiurnal variation of the value of the inverse Chapman function, $Ch^{-1}(\chi)$, at the moment of crossing a given reflection height contains

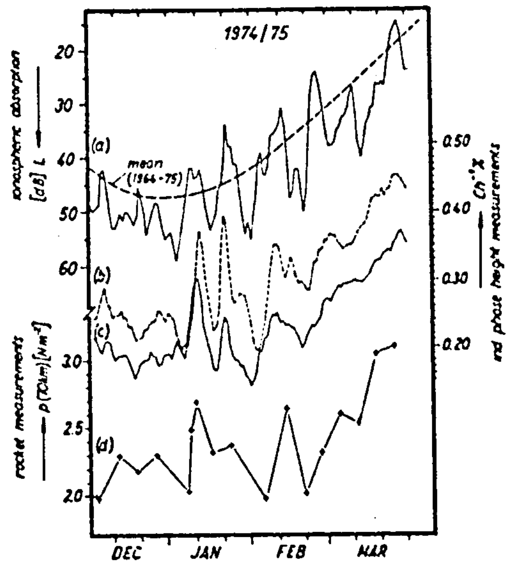

Figure 4. (a) HF-absorption measurements (cos χ − 0.2) in Central Europe; (b), (c) Ionospheric D-region parameter $Ch^{-1}\chi$ from LF indirect phase height measurements in Eastern Europe and Central Europe near the 80-km level; (d) Rocket data of pressure at 70 km height in Eastern Europe in winter 1974/75.

information about day-to-day changes of atmospheric characteristics, mainly air pressure.

- Thus, indirect phase height measurements are a useful completion to rocket measurements, because they allow continuous monitoring of the D-region also between the rocket soundings and, therefore, support the valuation of the rocket results according to the respective background.

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