RADIO SCIENCE Journal of Research NBS/USNC–URSI
Vol. 69D, No. 8, August 1965

# Experimental Results on the Dynamics of the *F* Region[1]

W. Becker, R. Rüster, and J. Klostermeyer

Max-Planck-Institut für Aeronomie, Institut für Ionosphären-Physik, Lindau/Harz, Germany

(Received February 3, 1965)

The first part of this paper deals with the response of the nighttime ionosphere to variations of the earth's magnetic field, especially to variations of its horizontal component. It is shown both theoretically and experimentally that the whole *F* region is set in motion by such variations of the earth's magnetic field and that these motions may be of an oscillatory or a nonoscillatory character. Amplitudes in real height of 75 and 200 km respectively are reported. The second part of this paper deals with other kinds of ultra-low-frequency oscillatory movement of the *F* region during magnetically quiet winter nights of which some last for at least 10 hr. A 3-station network of identical ionosondes allows interpretation of them as traveling waves propagating mostly southward and only occasionally northward. Their phase velocities cover the range 15 to 35 km/min and the respective periods of duration lie between 2.8 and 1.5 hr. Missing ionograms of the field stations prevented phase velocity calculations for a 0.7 hr wave. The amplitudes of all the waves covered the range between 10 and 15 km. Traveling waves of longer and shorter wavelengths may be possible but could not be detected because of experimental reasons. It is believed that these traveling waves represent internal gravity waves as suggested by Hines [1960].

## 1. Introduction

It is well known that ultra-low-frequency electromagnetic fields cause oscillatory movements and consequently heating effects in the ionosphere [Dessler, 1959; Akasofu, 1960; and Paetzold, 1963]. But the amount of respective experimental results is still very poor. It is the purpose of this paper, therefore, to talk only on experimental results of which some could be explained by us quantitatively as the response of the *F* region to ultra-low-frequency electromagnetic fields. The origin of the others is not yet known. No contribution on heating effects in the *F* region caused by hydromagnetic waves will be given as Becker [1963] already has presented his respective results at Skeikampen more than a year ago.

## 2. Experimental Results

### 2.1. Data of Observation

The starting experimental data of our investigations are electron density profiles deduced from ionograms taken at Tsumeb (South-Africa), Lindau, and two other field stations of ours: Gedern and Ostenland, 100 and 150 km apart from Lindau in the south and in the west respectively. Our network was operated by K.-H. Geisweid, W. Barke, K. Oberländer, and W. Jahn. Their assistance is highly appreciated. The results themselves only refer to nighttime intervals of observations. The reason for this data selection is former theoretical and experimental investigations; they showed that the nighttime *F* layer approximates a Chapman layer distribution [Becker, 1959]. Thus we could immediately found our dynamical studies on the height variation of normalized layer levels; that is to say levels representing constant ratios: plasma frequency $f_0$ over critical frequency $fc_0F2$. The method used for the calculation of the electron density profiles is a somewhat sophisticated digital computer method; it was developed by one of us about $2\frac{1}{2}$-years ago [Becker, 1964; Becker and Stubbe, 1963].

### 2.2. Movements of the *F* Region During Magnetic Disturbances

It is well known that magnetic disturbances are closely linked with electric field variations in the dynamo region, and D. F. Martyn has shown long ago [Martyn, 1955] that these electric fields are communicated into the *F* region. Becker [1961] could show that the response of the ionosphere to such field variations lasting for about 4 hr at an intensity of 60 $\gamma$ may cause a total rise of the *F* layer of some 200 km above midlatitude stations (fig. 1). The amplitude depends of course on the intensity and the duration of the magnetic disturbance.

Theory has shown that the response of the *F* region will also result in detectable oscillatory movements if the electrical field disturbances are of an extremely low frequency. Indeed one of us could experimentally verify this prediction [Rüster, 1964].

[1]Paper presented at the ULF Symposium in Boulder, Colo. 17–20 August 1964.

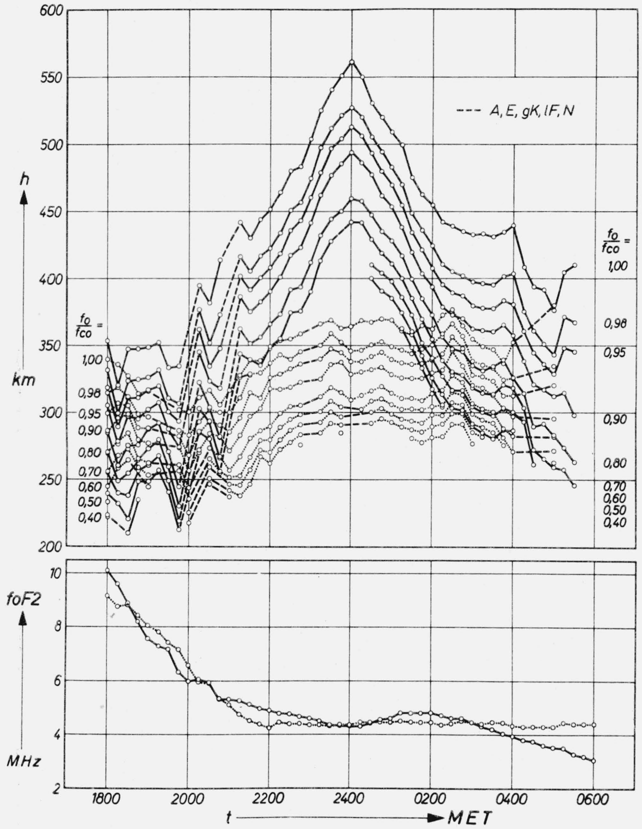


FIGURE 1. *Real height* h, *and ordinary critical frequency variation of the* F-*region during a magnetically quiet (November 30/December 1, 1958, . . . .) and a disturbed night (December 2/3, 1958,—) --- means interpolation.* $f_0$=*plasma frequency;* $fc_0=f_0F2$=*ordinary critical frequency.*

MET = 15° EST.

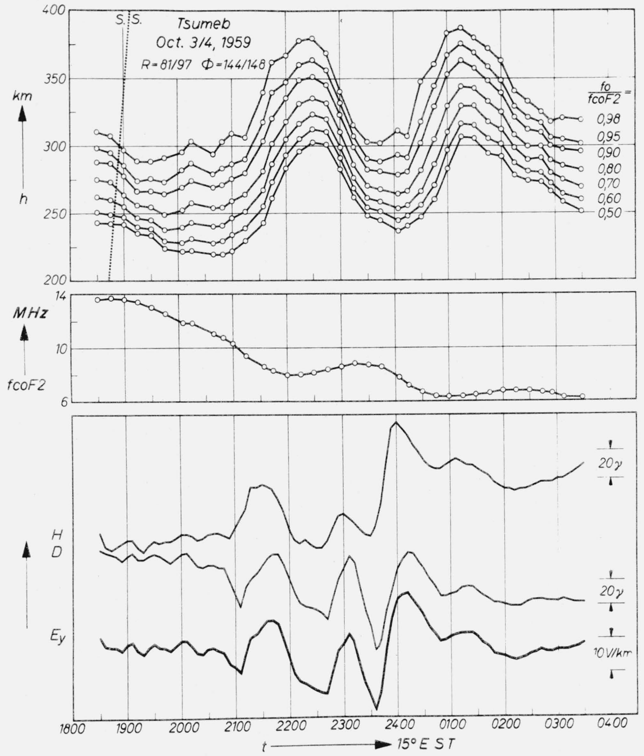


FIGURE 2. *Real height* h, *and ordinary critical frequency* $fc_0F2$, *and intensity variation of the horizontal field components of the earth's magnetic field* (H, D) *during the night October 3/4, 1959.*

$R$ = sunspot number, $\Phi$ = 10.7 cm solar radio noist intensity [$10^{-22}$ W/m²sec/c] as observed at Ottawa by Nat. Res. Council Canada. S.S. = sunset. $Ey$ = approximate electric field strength in the ionosphere corresponding to the $H$, $D$ — variation.

It is most striking in figure 2 that the oscillatory movements of the layer manifests itself also in the variation of the critical frequency. That is to say, $fc_0F2$ decreases when the $F$ layer moves upwards and increases when it is pressed against the lower ionosphere by the horizontal electric field. As far as the spatial scale of these ionospheric movements is concerned, one can say that it is of the same order of size as the respective magnetic disturbance and as the latter is worldwide the above movements are worldwide too.

## 2.3. Movements of the Ionosphere During Magnetically Quiet Nights

The final part of our experimental investigations is concerned with movements of the $F$ region during magnetically quiet nights. The data analysis was carried out by J. Klostermeyer. Sequences of ionograms taken by our own 3-station network at 5 and 15 min intervals were used.

Figure 3 shows the real height variations of a series of normalized $F$-layer levels above the 3-stations Lindau, Ostenland, and Gedern during the night November 20/21, 1960. The corresponding variation of the critical frequencies is shown below. Figure 3 shows that at least during the second part of the night $fc_0F2$ was practically constant, which means that our layer-levels representing constant ratios $f_0/fc_0F2$ practically represent isoionic contours too. This fact may help those people who are more familiar with such a kind of representation. The data represented by figure 3 were also analyzed statistically. First running mean values over an interval of 165 min were calculated in order to get the mean variation. This is shown by figure 4.

In order to get the movements themselves somewhat smoothed out, running mean values of the differences: observed heights minus respective running mean values with amplitude corrections according to Stumpf [1937] over a period of 75 min, were calculated. Sinusoidal height-variations with an average amplitude of 15 km and an approximate 150-min period of variation are the result of this analysis (fig. 5).

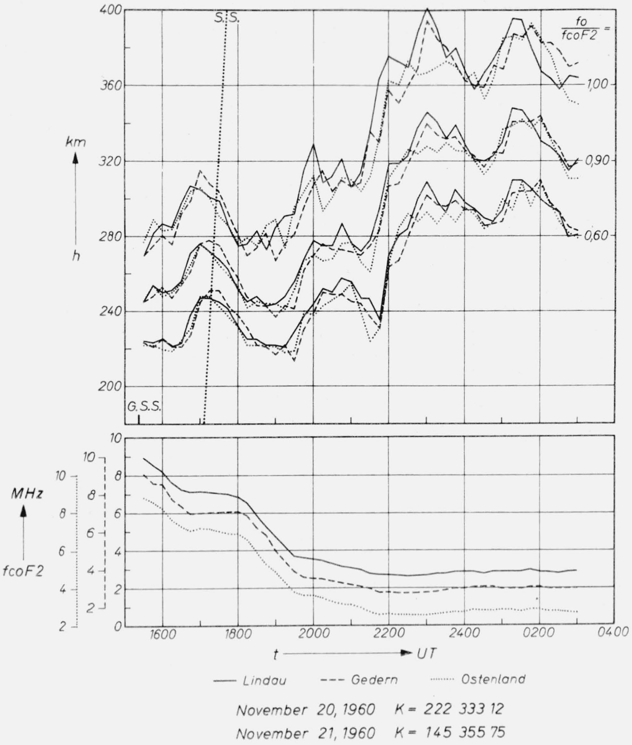


FIGURE 3. *Real height* h, *and ordinary critical frequency* $fc_0F2$ *variation of the* F *region above Lindau, Gedern, and Ostenland.*
S.S. = sunset. All the 3 hr geomagnetic *K* indices are given for November 20 and 21.

Finally it was possible to calculate the speed and the direction of the traveling waves by using these data and the basis-length of the 3 station network. Figure 6 shows that the direction of speed at all the layer levels generally points south to the equator and the apparent horizontal phase velocity has its maximum value 22 km/min or 370 m/sec approximately at about those layer heights where the direction of speed points directly southward. The corresponding wavelengths vary between 3700 and 1800 km. Besides the preceding example other investigations were carried out too. A comparison of the profiles for Freiburg (south of Lindau) and Lindau showed that the above traveling waves propagate over a 500 km path without an important change of amplitude.

Figure 7 finally shows the phase delay time $\tau$ of the $f_0/fc_0 = 0.6$ level against the peak versus $T$, the period of the respective wave. One can recognize a second order increase of $\tau$ with $T$. Finally we are going to investigate the nighttime rise of the $F$ layer at about 20 to 21 hr local time and its descent at about 4 hr above medium latitude stations [Becker, 1961]. We could find that this effect does not show any seasonal but local influence (fig. 8). The rate of change of the peak height amounts to about 25 km/hr in winter and 15 km/hr in summer, and the total variations amount to 80 and 40 km respectively. It is believed that this effect is closely linked with the variation of the daily ionospheric current system or rather its horizontal electrical field. We are going to check it quantitatively.

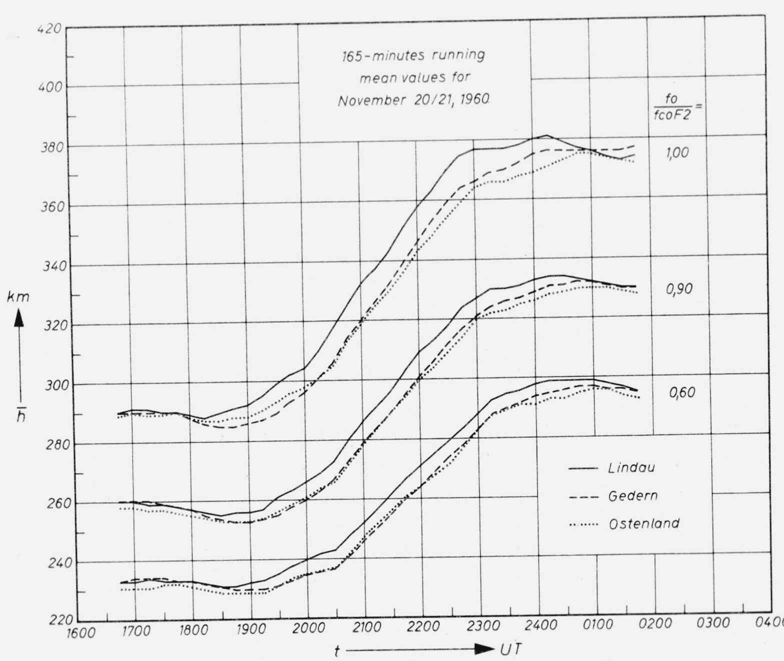


FIGURE 4. *165-min running mean values of the real height data given by figure 3.*

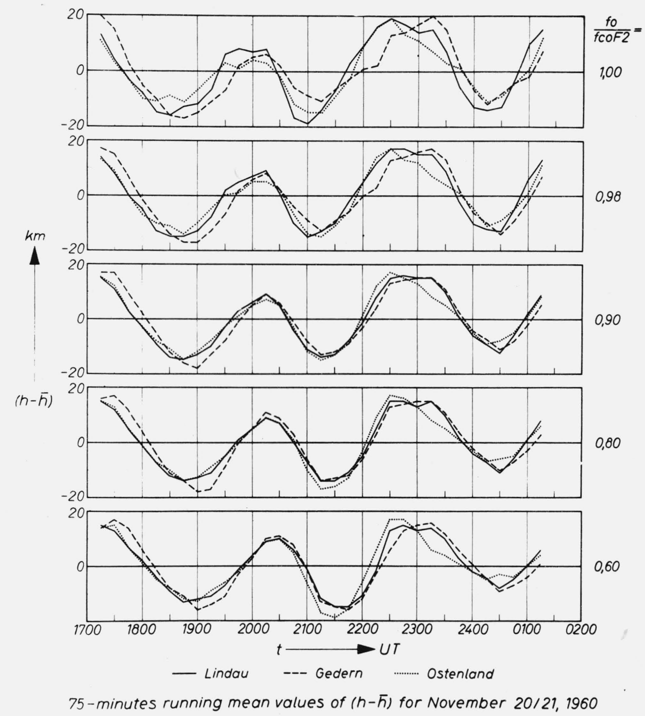


FIGURE 5. *75-min running mean values of the differences: observed real height data given by figure 3 minus 165 min running mean values shown by figure 4.*

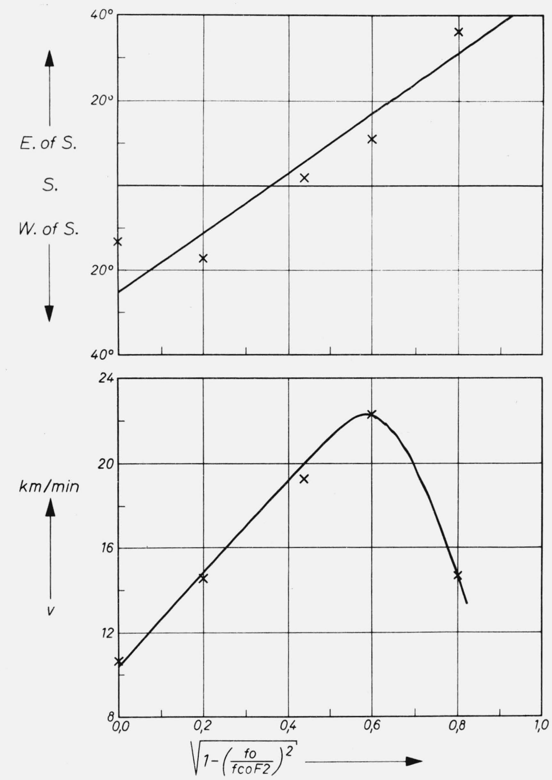


FIGURE 6. *Mean direction and speed v of propagation of the traveling wave observed on November 20/21, 1960 at different layer levels* $f_0/fc_0F2$; $f_0$ = *plasma frequency;* $fc_0F2$ = *ordinary critical frequency.*

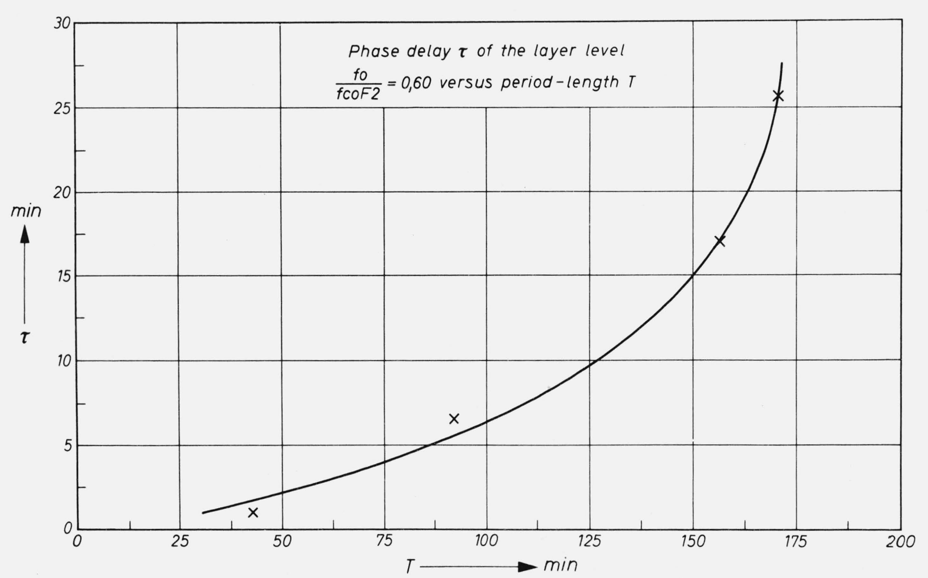


FIGURE 7. *Observed phase delays τ between the layer levels* $\frac{f_0}{fc_0F2}$ = *1.0 and 0.60 versus period length* T.

The respective traveling waves from left to right were observed during the nights December 8/9, 1961; October 18/19, 1961; December 8/9, 1961 and November 20/21, 1960. $f_0$ = plasma frequency; $fc_0F2$ = ordinary critical frequency of the *F* layer.

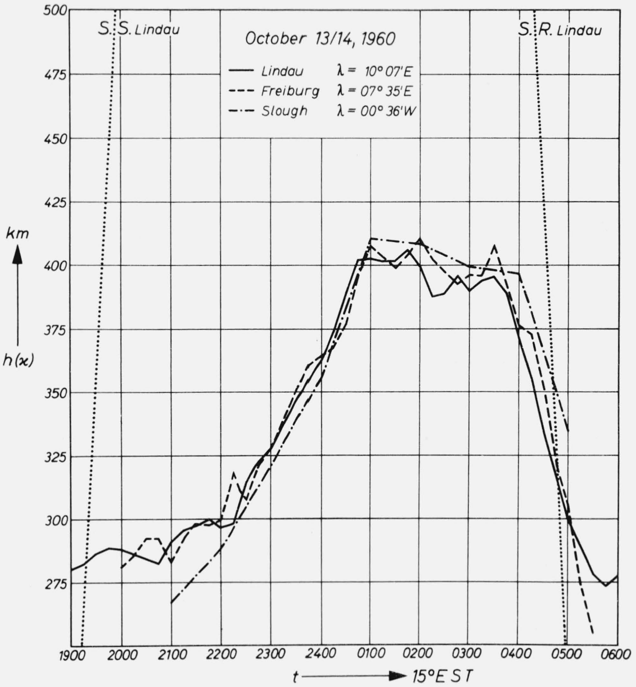


FIGURE 8. *Rise and descent of the* F *layer well after and before sunrise S.R. and sunset S.S. above Lindau, Freiburg, and Slough,* h(χ)*=real height of the layer level* $\chi = f_0/fc_0F2 = 0.95$, $f_0$*=plasma frequency;* $fc_0F2$*=ordinary critical frequency.*

## 3. Interpretation

Trying to interpret the upper oscillatory movements during magnetically quiet nights, we must state first, that we do not believe that these waves are the only ones possible in the ionosphere and that only one wave can exist at the same time. For example, one sequence of ionograms allowed to detect at the same time 40 and 150 min waves. Possibly there are also traveling waves in the ionosphere of shorter and longer wavelengths. We could not detect the former ones because the sounding intervals were too long (5 min and more) and the height resolution was not good enough. It may be very hard to detect longer waves during any night because of the relatively short length of a night. Bigger effects do certainly occur too; we did not take them into account because then a real height analysis is doubtful. It is believed that the so-called traveling disturbances mentioned in literature (see for instance the summary paper [Heisler, 1963]) comprise all kinds of traveling disturbances in the *F* region, that is to say also the above mentioned traveling waves and the nighttime height variation effect mentioned above.

Therefore, a comparison of the respective results with the present ones is very difficult. The Australian results mostly represent group velocities and such for daytime hours. Only Heisler and Whitehead [1961] tried to deduce phase velocities from ionograms taken by one station at noon. For that purpose they had to make a series of assumptions. Besides that they did not take account of ionization density variations and variations of the earth's magnetic field; they restricted themselves to an interval of observation of about 1 hr only. Finally, they could not check whether the direction of propagation of this disturbance agreed with that of the traveling disturbance they referred to, which was observed at the same time together with two far distant stations. Heisler and Whitehead got 300 km/hr as an average phase velocity in the *F* region at noon. Klostermeyer got for a similar wave period a phase speed of about 1200 km/hr for the nighttime *F* region. Agreement was found in the height dependency of the phase delay. As the characteristics of the above mentioned traveling waves can be interpreted very well by Hines' theory on internal gravity waves [Hines, 1960] the authors regard them as such waves.

## 4. References

Akasofu, S. I. (1960), On the ionospheric heating by hydromagnetic waves connected with geomagnetic micropulsations, J. Atmospheric Terrest. Phys. **18**, 160–173.

Becker, W. (1959), Die allgemeinen Verfahren der Station Lindau/Harz zur Bestimmung der wahren Verteilung der Elektronendichte in der Ionosphäre, Arch. Elektr. Ubertragung **13**, 373–382.

Becker, W. (1961), Vertikale Bewegungsvorgänge in der nächtlichen Ionosphäre, Arch. Elektr. Ubertragung **15**, 569–577.

Becker, W. (1963), Real height analysis of an ionospheric storm, Electron density distribution in ionosphere and exosphere, Proc. NATO Advanced Study Institute Skeikampen, Norway, 152–159, ed. E. Thrane (North-Holland Publishing Co., Amsterdam).

Becker, W. (1964), Das elektronische Verfahren der Station Lindau/Harz zur Berechnung von Elektronendichteprofilen der Ionosphäre aus Ionogrammen, ed. Fernmeldetechnisches Zentralamt Darmstadt, Kleinheubacher Berichte **9**, 45–51.

Becker, W. and P. Stubbe (1963), Temperature variation in the *F*-region during the last sunspot cycle, Proc. International Conference on The Ionosphere, held at Imperial College London 1962, The Institute of Physics and the Physical Society, London, 35–42.

Dessler, A. J. (1959), Upper atmosphere density variations due to hydromagnetic heating, Nature **184**, 261–262.

Heisler, L. H. (1963), Observation of movement of perturbations in the *F*-region, J. Atmospheric Terrest. Phys. **25**, 71–86.

Heisler, L. H., and J. D. Whitehead (1961), The phase speed of a traveling disturbance in the *F*-region of the ionosphere and its comparison with group velocity, Australian J. Phys. **14**, 481–488.

Hines, C. O. (1960), Internal atmospheric gravity waves at ionospheric heights, Can. J. Phys. **38**, 1441–1481.

Martyn, D. F. (1955), Theory of height and ionization density changes at the maximum of a Chapman-like region, taking account of ion production, decay, diffusion and tidal drift, Rep. of the Physical Society Conference on The Physics of the Ionosphere, The Physical Society, 254–259.

Paetzold, H. K. (1963), Solar activity effects in the upper atmosphere deduced from satellite observations, Space Research III, Proc. 3rd International Space Science Symposium, ed. W. Priester, 28–52 (North-Holland Publishing Co., Amsterdam).

Rüster, R. (1964), Die Änderung des Elektronendichteprofiles in Tsumeb während erdmagnetischer Bai-Störungen, ed. Fernmeldetechnisches Zentralamt Darmstadt, Kleinheubacher Berichte, 101–110.

Stumpf, K. (1937), Grundlagen und Methoden der Periodenforschung, Springer Verlag, Berlin, 263–268.

(Paper 69D8–541)