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INDEX

A THEORETICAL COMPARISON BETWEEN APPARENT AND REAL VERTICAL IONIZATION DRIFT VELOCITIES IN THE EQUATORIAL F-REGION

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ABSTRACT

A theoretical analysis of the time-dependent distribution of ionization in the low-latitude ionosphere is performed using a realistic dynamic computer model of the equatorial F-region, with special interest in the vertical motions of the electron density profile at the magnetic equator. The time-dependence of the F2-peak height, at the magnetic equator, is governed primarily by the electromagnetic $\tilde{E} \times \tilde{B}$ plasma drift velocity. It is shown that, for special time periods during sunset and evening hours, when the height of the F-layer is above a threshold of 300km, the apparent vertical displacement velocity of the F-layer, inferred from ionosonde measurements, is the same as the vertical $\tilde{E} \times \tilde{B}$ plasma drift velocity, as determined from incoherent backscatter radar measurements in the F-region.

A THEORETICAL COMPARISON BETWEEN APPARENT AND REAL VERTICAL IONIZATION DRIFT VELOCITIES IN THE EQUATORIAL F-REGION

J.A. Bittencourt and M.A. Abdu

1. INTRODUCTION

Electric fields play an important role in the dynamics of the equatorial ionospheric F-region. The distribution of ionization in the low-latitude F-region, which manifests itself in the form of the so-called ionospheric equatorial anomaly or Appleton anomaly, is strongly dependent on the electromagnetic $\underset{\sim}{E} \times \underset{\sim}{B}$ plasma drift. This plasma drift, due to an east-west electric field, whose main source is the E-region dynamo driven by tidal winds, transports the ionization perpendicularly to the magnetic field lines. This transport process, coupled with plasma diffusion along the magnetic field lines, caused by gravity and pressure gradients, gives rise to the well known "fountain effect".

The effects of variations of the $\underset{\sim}{E} \times \underset{\sim}{B}$ drift velocity on the crest-to-trough ratio and the latitudinal location of the crests, in the equatorial anomaly, have been studied by many investigators (e. g., Hanson and Moffett, 1966; Sterling et al., 1969; Anderson, 1973a,b; Bittencourt and Tinsley, 1976), who find that these parameters increase with increasing upward drift velocity. At the magnetic equator, the trough in electron density, and the height of the F2-peak (h_mF2) are greatly affected by the electromagnetic drift velocity.

Measurements of vertical plasma drifts above about 300km in the F-region, at the magnetic equator, made by Woodman (1970), have shown, typically, upward velocities of 20 to 25 m/s during the day and downward velocities of about the same magnitude at night, with a prereversal peak in the upward velocity centered around 18 LT, the enhanced upward velocities at the peak being of the order of 40 m/s. It was also found that the spread in velocities for different days, at any given time, may be as large as the velocities themselves, even for magnetically quiet days. The vertical drifts were also found to be nearly constant as a function of height. The prereversal enhancement is a common feature during solar cycle maximum years, but it is either much reduced or completely absent during solar minimum years (Fejer et al., 1979).

The very pronounced upward movement, which is normally observed around sunset, causes the F2-peak to rise sometimes above 500 km or higher, leaving a region of very low electron densities at lower heights (Hanson and Sanatani, 1973). This evening rise of the equatorial F-layer is certainly due to an enhanced eastward electric field, whose origin is believed to be the F-region dynamo, driven by thermospheric winds (Rishbeth, 1971a,b; Heelis et al., 1974). Also, it is the prereversal enhancement in upward drift velocity, around sunset, that generates the conditions necessary for the onset of equatorial spread-F, scintillations and equatorial bubbles.

This paper theoretically analyzes the relative temporal behavior of the apparent vertical velocities and the real $\underset{\sim}{E} \times \underset{\sim}{B}$ vertical drift velocities of the F-layer, at the magnetic equator, using a realistic dynamic computer model of the tropical ionospheric F-region. It is found that, during the local time periods when the layer is sufficiently high, as in the hours near sunset and evening hours, the apparent vertical displacement velocity of the F-layer, defined here as the time rate of change of the layer height, as determined from its vertical motion, coincides with the real $\underset{\sim}{E} \times \underset{\sim}{B}$ vertical drift velocity which is put into the model calculations to simulate the ionospheric equatorial anomaly. Below a certain threshold height, which is found to be at about 300 km, the apparent vertical velocity starts to depart significantly from the real $\underset{\sim}{E} \times \underset{\sim}{B}$ drift velocity, owing to the importance of recombination processes at these lower heights. Therefore, we find that, during time periods near sunset and evening hours, when the F-layer height is above this threshold, the apparent velocity associated with the vertical motion of the F-layer, as determined, for example, with an ionosonde, is an effective measurement of the real vertical $\underset{\sim}{E} \times \underset{\sim}{B}$ plasma drift velocity in the F-region.

2. THEORETICAL MODEL AND RESULTS

The dynamic computer model of the tropical ionospheric F-region, used here, is the same as that previously described by Bittencourt and Tinsley (1976) (see, also, Bittencourt and Sahai, 1978; 1979), and only a very brief description will be given here.

In summary, it solves the coupled nonlinear system of time-dependent continuity equations for the ions O^+, O_2^+, NO^+, N_2^+ and N^+, in the low-latitude ionospheric F-region, taking into account production and loss of ionization, considering photoionization of the atmospheric species by the solar XUV radiation and several chemical and ionic reactions, as well as transport processes, including ambipolar diffusion, $\underset{\sim}{E} \times \underset{\sim}{B}$ plasma drifts and thermospheric neutral winds. The Earth's magnetic field is taken to be a tilted, centered, magnetic dipole, and the equations are solved along a given magnetic field line, in a frame of reference moving with the $\underset{\sim}{E} \times \underset{\sim}{B}$ plasma drift velocity. Several magnetic field lines, at different equatorial heights, are treated simultaneously in a given meridional plane, in order to obtain time-dependent vertical profiles for each ion species in the -20^0 to $+20^0$ magnetic latitude range. For the neutral atmospheric species and temperature, the Jacchia (1971) model atmosphere was used, and the calculations were performed for conditions of medium solar activity, with a minimum nightime exospheric temperature of 1000K.

Three hypothetical vertical drift models, giving the vertical drift velocity as a function of local time, at the magnetic equator, have been used as input in this investigation. These models have been chosen based on the observations of Woodman (1970) in Jicamarca, and are shown in Figure 1 by the solid lines. For each one of these vertical drift models, the distribution of ionization in the low-latitude F-region was calculated as a function of local time, with particular interest in the time-dependent vertical profile of electron density at the magnetic equator. Since the transport of ionization by thermospheric neutral winds is essentially along the magnetic field lines, which are horizontal at the magnetic equator, the neutral wind is expected to have no significant effect on vertical motions of h_mF2 at the magnetic equator. Therefore, the vertical plasma motions at the magnetic equator are associated primarily with the $\underset{\sim}{E} \times \underset{\sim}{B}$ plasma drift velocity.

The time-dependent vertical motions of the F-layer electron density profile, at the magnetic equator, determined from the computer model, have been used to calculate the F-layer apparent vertical displacement velocity, $V_D^{(a)}$, taken to be the time rate of change of the F-layer bottomside height. For calculation purposes, this height was specifically chosen as the height where the electron density is one order of magnitude smaller than that at the F2-peak, although any height in between could be equally adequate, provided the shape of the electron density profile is stable, which is considered to be the case.

In Figure 1 we have shown, at the magnetic equator, as a function of local time, the height of the bottomside of the F2-layer (dashed lines), together with the apparent vertical displacement velocity, $V_D^{(a)}$ (dots), determined as indicated, and the real $\underset{\sim}{E} \times \underset{\sim}{B}$ vertical drift, $V_D^{(r)}$ (solid lines), which was put into the model calculations.

3. DISCUSSION

It is clear from the results of the three models shown in Figure 1 that, when the F-layer is sufficiently high, as during the sunset and evening hours, the apparent vertical displacement velocity of the bottomside, $V_D^{(a)}$, coincides with the real vertical drift velocity, $V_D^{(r)}$. This is not so, however, after the downward drift has lowered the bottomside below a certain threshold height, where recombination starts to become important. At these lower heights in the F-region, the recombination processes are effective enough to reduce the apparent downward drift to very small or even zero velocities.

Even at 200 km, in the F-region, the charged particle collision frequency is still much smaller than the gyrofrequency, for both electrons and ions, so that they gyrate several times about the field lines before they are affected by collisions. This means that the electric field which exists at these lower heights, in the F-region, still generates a vertical $\underset{\sim}{E} \times \underset{\sim}{B}$ drift motion of electrons and ions. However, at these lower heights, the recombination processes become very important, reducing significantly the apparent vertical motions of the F-layer.

It is to be noted, from the results shown in Figure 1, that the maximum in the height of the bottomside of the F-layer depends on the magnitude of the upward drift velocity as well as on the time of reversal. The greater height achieved in the third model shown in Figure 1, as compared to the second model, is due to a later time of reversal of the vertical drift velocity, in spite of smaller upward drift velocities.

An estimate of the threshold height can be obtained from the results of the dynamic computer model. For this purpose, we have plotted, in Figure 2, the height of the bottomside of the F2-layer as a function of the ratio of apparent vertical velocities to real $\underset{\sim}{E} \times \underset{\sim}{B}$ drift velocities, $V_D^{(a)}/V_D^{(r)}$, taken from the results of Figure 1. Thus, it is seen that this ratio departs significantly from one only for heights below about 300 km, due to the recombination processes. The scattering in the points is due to numerical errors in the calculation of $V_D^{(a)}$, resulting from the relatively large steps used in Δt.

A very simple calculation can also be performed to estimate this height threshold, as follows. Since the recombination rate decreases exponentially with height, whereas the importance of transport processes increases with height, there exists a height level above which transport dominates over recombination. This height level can be obtained by determining the height at which the time constant for vertical transport, τ_D, becomes equal to the time constant for recombination, τ_R. The time constant for vertical transport, by the $\underset{\sim}{E} \times \underset{\sim}{B}$ drift process, can be taken to be approximately equal to the time required for vertical transport through one plasma scale height, $H(O^+)$, at the plasma drift velocity, $V_D^{(r)}$. Hence,

$$\tau_D = H(O^+)/V_D^{(r)} \tag{1}$$

On the other hand, the time constant for recombination, considering the following reactions

$$O^+ + O_2 \xrightarrow{K_1} O_2^+ + O \tag{2}$$

$$O^+ + N_2 \xrightarrow{K_2} NO^+ + N \tag{3}$$

is given by

$$\tau_R = \left[K_1 \, n(O_2) + K_2 \, n(N_2) \right]^{-1} \tag{4}$$

where $n(O_2)$ and $n(N_2)$ denote the number densities of O_2 and N_2, respectively, and the reaction rate coefficients are given by (McFarland et al., 1973).

$$K_1 = 2 \times 10^{-11}(300/T)^{0.4} \ \mathrm{cm^3 s^{-1}} \tag{5}$$

$$K_2 = 1.2 \times 10^{-12} \; (300/T) \quad cm^3 s^{-1}; \; T \leq 750K \tag{6}$$

$$K_2 = 8 \times 10^{-14} \; (T/300)^2 \quad cm^3 s^{-1}; \; T > 750K \tag{7}$$

where T is the temperature in degrees Kelvin. Therefore, equating τ_R to τ_D, we obtain

$$V_D^{(r)}/H(O+) = K_1 \; N(O_2)_o \; \exp\left[-(z_t - z_o)/H(O_2)\right] + $$

$$+ \; K_2 \; n(N_2)_o \; \exp\left[-(z_t - z_o)/H(N_2)\right] \tag{8}$$

where the index "o" refers to the base level z_o, and z_t is the height level above which transport by the electromagnetic drift dominates over recombination. Plugging in numerical quantities taken from the Jacchia (1971) model, we find z_t to be about 280km, which is in agreement with the threshold height inferred by inspection from Figure 2, which is based on the results of the dynamic model.

The measurements of vertical drift velocities made by Woodman (1970), at Jicamarca, indicate that the increase in the upward drift velocity which occurs just after sunset, is a regular feature characteristic of solar maximum years. During this local time period, when the layer is at higher altitudes, the electromagnetic plasma drift velocities can, therefore, be inferred from the vertical motions of the bottomside isodensity contours of the F-layer. This result is useful to determine vertical drift velocities from ionosonde measurements, at the magnetic equator, particularly during near sunset and evening hours, when the F-layer is at relatively high altitudes.

4. SUMMARY AND CONCLUSIONS

The time-dependent distribution of ionization in the low-latitude ionospheric F-region has been analyzed, based on a realistic dynamic computer model of the tropical F-region, with particular interest in the vertical motions of the electron density profile at the magnetic equator. It has been shown that the apparent vertical displacement velocity of the F-layer, as determined from the time rate of change of a given height below or near the F2-peak, in the calculated vertical profile at the magnetic equator, is exactly the same as the real $\underset{\sim}{E} \times \underset{\sim}{B}$ plasma drift velocity that was put into the model calculatations, provided this height is above a certain threshold, which is found to be at about 300 km. Below this height level, the recombination processes significantly affect the apparent vertical displacement velocity of the layer. Therefore, during time periods when the layer is sufficiently high, as in the hours near sunset and during the evening hours, the vertical motions of the F-layer, as determined, for example, with an ionosonde at the magnetic equator, can be considered as an effective measurement of the $\underset{\sim}{E} \times \underset{\sim}{B}$ plasma drift velocity. This technique can be applied to equatorial stations in different longitude sectors to derive a comprehensive picture of the longitude variation in vertical drifts between about 18 and 23 LT. An experimental verification of the results presented here can be made through a direct comparison of simultaneous $\underset{\sim}{E} \times \underset{\sim}{B}$ vertical drift measurements made with an incoherent backscatter radar, as with the Jicamarca radar for example, and apparent vertical displacement velocities of the F-layer as determined from ionosonde measurements performed, for example, with the ionosonde at Huancayo.

5. ACKNOWLEDGEMENTS

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FIGURE CAPTIONS

Fig. 1 - The vertical $\underset{\sim}{E} \times \underset{\sim}{B}$ plasma drift velocity (solid lines), the apparent vertical displacement velocity of the bottomside of the F-layer (dots), and the height of the bottomside (dashed lines), at the magnetic equator, as a function of local time, for three different models.

Fig. 2 - Height of the bottomside of the F-layer as a function of the ratio of the apparent vertical displacement velocity to the real vertical drift velocity, $V_D^{(a)}/V_D^{(r)}$.

REFERENCES

Anderson, D.N., A theoretical study of the ionospheric F-region equatorial anomaly - I. Theory, *Planet. Space Sci.*, 21, 409-419, 1973a.

Anderson, D.N., A theoretical study of the ionospheric F-region equatorial anomaly - II. Results in the American and Asian sectors, *Planet. Space Sci.*, 21, 421-442, 1973b.

Bittencourt, J.A. and B.A. Tinsley, Tropical F-region winds from OI 1356 Å and [OI] 6300 Å emissions - 1. Theory, *J. Geophys. Res.*, 81, 3781-3785, 1976.

Bittencourt, J.A., and Y. Sahai, F-region neutral winds from ionosonde measurements of hmF2 at low latitude magnetic conjugate regions, *J. Atm. Terr. Phys.*, 40, 669-676, 1978.

Bittencourt, J.A., and Y. Sahai, Behavior of the [OI] 6300 Å emission at the magnetic equator and its relation to the vertical $\mathbf{E} \times \mathbf{B}$ plasma drift velocity, *J. Atm. Terr. Phys.*, 41, 1233-1239, 1979.

Fejer, B.G., D.T. Farley, R.F. Woodman and C. Calderon, Dependence of equatorial F-region vertical drifts on season and solar cycle, *J. Geophys. Res.*, 84, 5792-5796, 1979.

Hanson, W.B., and R.J. Moffett, Ionization transport effects in the equatorial F-region, *J. Geophys. Res.*, 71, 5559-5572, 1966.

Hanson, W.B., and S. Sanatani, Large N_i gradients below the equatorial F peak, *J. Geophys. Res.*, 78, 1167-1173, 1973.

Heelis, R.A., P.C. Kendall, R.J. Moffett, D.W. Windle, and H. Rishbeth, Electrical coupling of the E- and F-regions and its effect on F-region drifts and winds, *Planet. Space Sci.*, 22, 743-756, 1974.

Jacchia, L.G., Revised static models of the thermosphère and exosphere with empirical temperature profiles, *Smiths. Astrophys. Obs. Sp. Rep.* 332, 1971.

McFarland, M., D.L. Albritton, F.C. Fehsenfeld, E.E. Ferguson, and A.L. Schmeltekopf, Flow-drift technique for ion mobility and ion-molecule reaction rate constant measurements, 2, Positive ion reaction of N^+, O^+, and N_2^+ with O_2 and O^+ with N_2 from thermal to ~ 2eV, *J. Chem. Phys.*, 59, 6620, 1973.

Rishbeth, H., The F-layer dynamo, *Planet. Space Sci.*, 19, 263-267, 1971a.

Rishbeth, H., Polarization fields produced by winds in the equatorial F-region, *Planet. Space Sci.*, 19, 357-369, 1971b.

Sterling, D.L., W.B. Hanson, R.J. Moffett, and R.G. Baxter, Influence of electromagnetic drifts and neutral air winds on some features of the F2-region, *Radio Sci.*, 4, 1205-1023, 1969.

Woodman, R.F., Vertical drift velocities and east-west electric fields at the magnetic equator, *J. Geophys. Res.*, 75, 6249-6259, 1970.

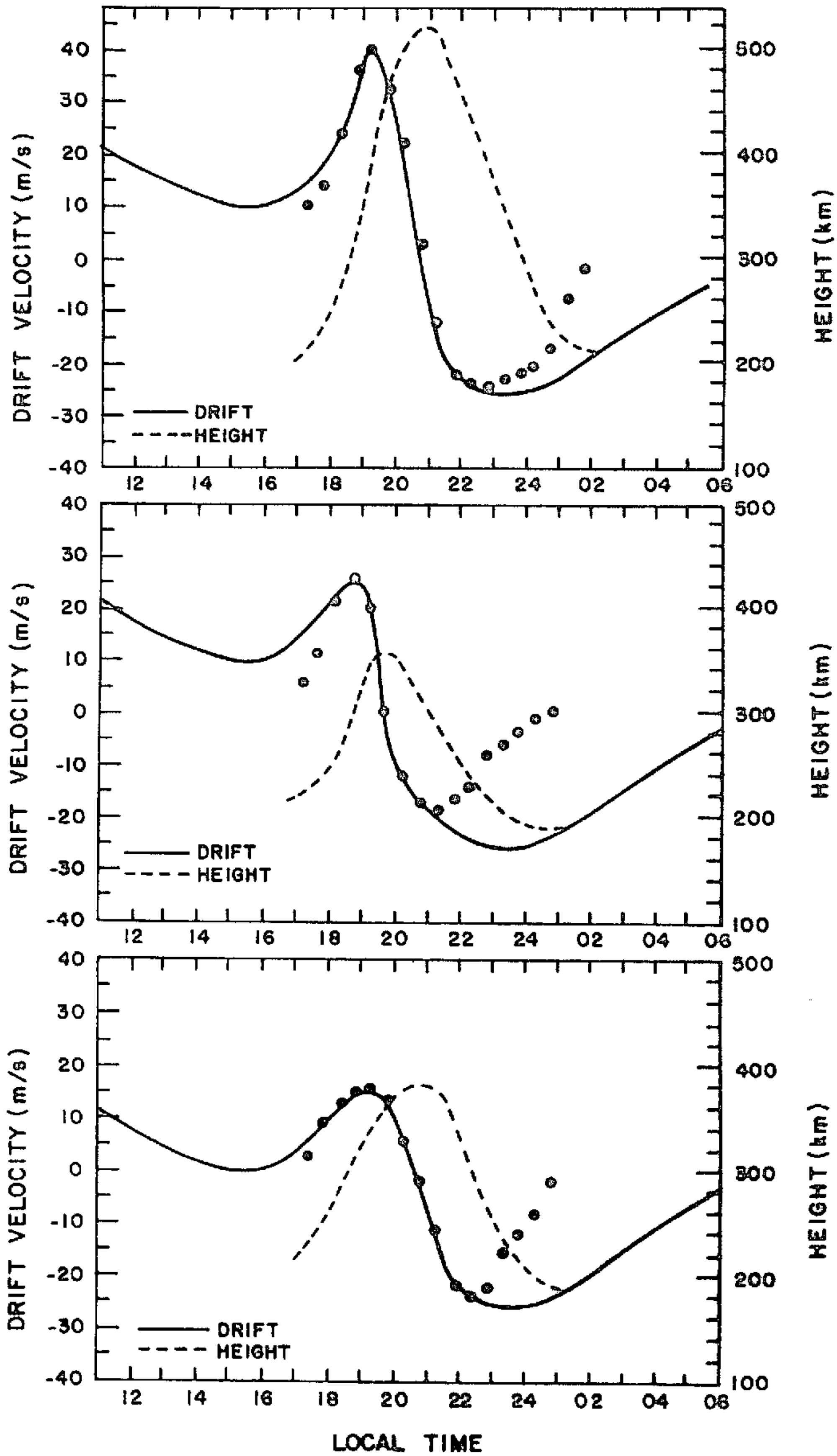
DRIFT VELOCITY (m/s)
HEIGHT (km)
DRIFT
HEIGHT
LOCAL TIME
40
30
20
10
0
-10
-20
-30
-40
500
400
300
200
100
12
14
16
18
20
22
24
02
04
06

Fig. 1

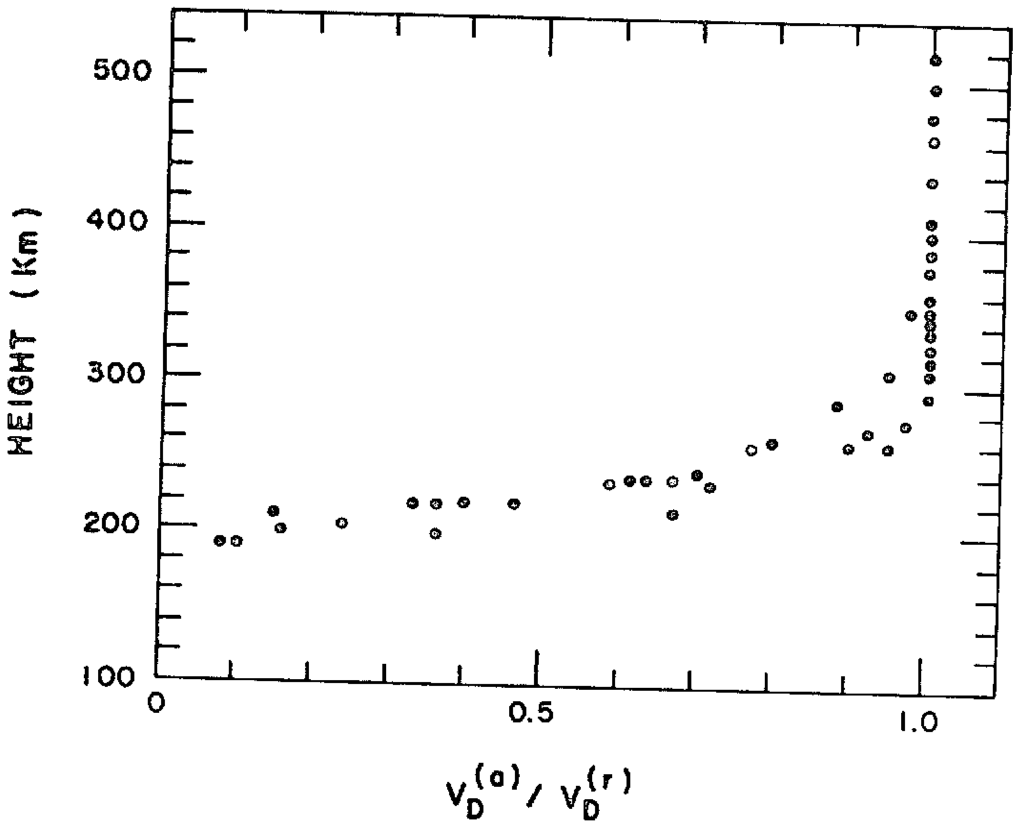

Fig. 2