Correlation Between Ionospheric Drift Motions Measured at Low Dip Latitudes by the Ion-cloud Technique and at the Equator by Incoherent Scatter+

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ABSTRACT

The Max-Planck-Institut für extraterrestrische Physik, Munich, Germany, and the National Commission on Space Research from Argentina conducted a cooperative experiment involving the release of barium and europium clouds at altitudes between 140 and 250 km. Three rockets were launched from Chamical, Argentina, (14.9° Dip Lat) in November 1972.

Electric fields of the order of 2.0 mV/m were deduced from the ion cloud drifts during evening twilight and 0.5 mV/m during morning twilight.

If projected along field lines to the magnetic equatorial plane, the drift velocities can be compared with velocities measured simultaneously with the incoherent scatter radar at Jicamarca and with earlier measurements at the magnetic equator. This comparison suggests that the times of reversal of the vertical and horizontal velocities during evening and morning hours depend on altitude in the sense that the reversals occur earlier at greater heights.

I. INTRODUCTION

The quasi-static electric field is a fundamental parameter of the physical processes in the magnetosphere and ionosphere. Electric fields are intimately related to bulk motion of the ionospheric or magnetospheric plasma, to current systems in the ionosphere and the magnetosphere and to acceleration of particles. In the last years, various techniques have been developed to measure the ambient electric field in these regions. The method of deriving the ionospheric electric field from the motion of artificially injected barium ion clouds has proved to be quite successful (Haerendel, 1970).

The experiments presented here were performed on three Argentine Rigel sounding rockets launched at low geomagnetic latitudes from Chamical, Argentina (30°21' S; 66°18' W; < 15° S Dip Lat), during evening and morning twilight on November 2, 4, and 11, 1972. The first vehicle was launched in the evening when equatorial spread F started during the recovery phase of a geomagnetic storm. The other two vehicles were launched during quiet magnetic and ionospheric conditions in the evening and morning twilights respectively. The plasma drift was measured from the drift of five artificially injected barium and europium plasma clouds.

In order to compare these ion cloud measurements with the incoherent scatter observations of E-W and vertical drifts in the F region made simultaneously at Jicamarca (1°N Dip Lat), we projected the ion cloud drift velocities to the geomagnetic equatorial plane along magnetic field lines. This projection is based on the assumption of frozen-in magnetic fields. Thus it is also possible to make a comparison with the ion cloud data from Thumba (Haerendel, 1970). A height dependence of the reversal time at the magnetic equator was deduced from these comparison.

The ion cloud experiments were under the responsibility of the Institut für extraterrestrische Physik and the Observatorio Astronómico Félix Aquilar, Universidad Nacional dè Cuyo, Argentina.

II. DESCRIPTION OF THE EXPERIMENTS

The plasma cloud experiments consisted of two europium and three barium containers mounted in three payloads. Furthermore, neutral Li clouds were generated during the rocket flight and the electron density was measured with the capacity probe of Melzner and Rabben (1970).

The optical observations of the clouds were made from three observation sites (fig. 1) including photographic and television cameras, spectrometer and photometer.

Plasma drifts were measured with the incoherent scatter radar at Jicamarca, Peru (Woodman and Hagfors, 1969; Woodman and Balsley, 1969; Woodman 1970 and 1972) simultaneously with our first and third rocket flights. In comparing our drift data with these measurements one has to realize that we derived the latter from echoes scattered at an altitude of typically 300 to 400 km, whereas the field lines intersecting the Ba^+ and Eu^+ clouds cross the equator at about 700 km. Furthermore Jicamarca differs in magnetic longitude by about 10^o or 40 minutes in local time.

During the experiments coordinated ground-based magnetometer measurements and ionograms were performed at many stations, distributed over a wide latitudinal region, from magnetic equator to Orcadas Island in order to correlate the data.

III. EXPERIMENTAL RESULTS

From the drift motion of the artificial plasma clouds (fig. 2) which are reduced from photographic observations, information about the electric field perpendicular to the magnetic field vector can be deduced. Haerendel et al. (1967) derived a relation for the electric field inside a cylindrical homogeneous barium cloud.

$$\vec{E}_{\perp} = \vec{B} \times \left[\vec{v}_{i\perp} + \frac{\lambda^{*}-1}{2} (\vec{v}_{i\perp} - \vec{v}_{n\perp}) \right] + \frac{1+\lambda^{*}}{2\varkappa_i} |B| (\vec{v}_{i\perp} - \vec{v}_{n\perp}) \quad (1)$$

where: $\vec{v}_{i\perp}$ = ion drift velocity component transverse to magnetic field B.

$\vec{v}_{n\perp}$ = neutral wind velocity transverse to magnetic field B.

$\varkappa_i$ = ω_{gi} / ν_{in} : the ratio of the gyration and ion-neutral collision frequencies.

λ^{*} = $(\sum_p^{cloud} + \sum_p^{out}) / \sum_p^{out}$: the ratio of the height integrated Pedersen conductivity along magnetic lines of force intersecting the ion cloud and outside the cloud.

In this relation (1) the coupling of the Ba-plasma to the neutral component of the atmosphere and the electric polarisation field in the cloud are taken into account.

The second term can introduce appreciable errors if due to the presence of the cloud the integrated Pedersen conductivit is changed markedly. This is especially the case when large amounts of material are released at relatively low heights ($<$ 180 km) and if the electron density in the E region is low. Then the external electric field is partly screened. In our experiments small amounts of europium (252 and 392 gr) were released in two clouds between 140 and 180 km altitude and also small amounts of barium above this level for which we estimate the correction term not to exceed 10%.

The third term on the right hand side is not important for three of the clouds produced at heights greater than 180 km, where $\mathcal{H}_i$ is sufficiently great. For the two clouds below this level a calculation of this correction term shows that the direction is more affected than the magnitude of the E-field. Thus the vertical component of the projected drift velocity can be given with an accuracy of only 15%.

The results of the three experiments are presented in table 1, where θ is the angle between geographic north and the transverse electric field vector, both in the plane normal to the magnetic field lines.

Electric fields of the order of 1.3 to 2.0 mV/m were deduced from the ion cloud drifts during evening twilight and a dependence with height was found for the second experiment with two clouds at different altitudes. We will discuss later the spatial and temporal variations. During morning twilight the electric field reaches 0.5 mV/m only.

The horizontal components of these transverse electric fields are presented in a compilation with other experiments of the Institut für extraterrestrische Physik at low latitudes (Haerendel 1970; Rieger 1971) in Figure 3. In most of the rocket flights several clouds were generated at different heights. The differences in magnitude and direction of the field obtained from one flight can be attributed to spatial variations of the field, as was observed also in the present experiments (No 63, 64 and 65). Especially when the electric field is weak (< 1 mV/m) the direction may vary appreciably.

From the mid-latitude data we deduce that after sunset the electric field is directed preferably southward in the northern hemisphere and northward in the southern hemisphere but before sunrise they have a tendency to be directed to the poles.

When projected to the ground the evening ion drift velocities (Exp. 1, 2a and 2b) had a north-eastward direction (fig. 2). Since the dip angle at Chamical is 28°, the north component of the ion drift involves a downward motion at the equator (fig. 4). For the morning experiment we found a dominant northward component at Chamical with a smaller tendency to the west, i.e. also a downward ion drift at the magnetic equator.

Figure 5 contains a comparison of horizontal and vertical drifts in the equatorial F region between 300 and 400 km altitude as measured with the incoherent backscatter facility in Jicamarca and the ion cloud drifts at 700 km for the first evening experiment. The gap in the Jicamarca data was due to the occurrence of strong spread F affecting the validity of the measurements. We see a good agreement for the eastward velocity component but not for the vertical component in which a very sudden change of this velocity component seems to occur. We have to take into account that both measurements have been made at different heights. It should be noted, however, that the magnitude of this velocity component is in agreement with the radar data two hours later.

Jicamarca drifts were not measured for the second evening experiment because of communication problems.

Figure 6 contains the same comparison for the morning experiments. The drifts during the November 10 - 11 period were rather typical with the exception of the relatively low value of vertical drift around the time of the pre-reversal enhancement at approximately 1900 hours. Also the positive vertical drift values around 2400 hours are unusual, especially for a quiet day like this one. The plasma cloud and radar data appear to be in good agreement. The fluctuation observed in the horizontal radar data between 0400 and 0500 LT are most likely due to fluctuations of the vertical component. As explained by Woodman (1972) the E-W velocities are contaminated by the first and second derivatives of the vertical drift.

Figure 7 from Woodman (1970) shows that the spread of the vertical velocity component for different days is at any time as large as the velocities themselves, even during magnetically quiet days. As seen in the lower graph of Figure 7 vertical drift values in the morning are in good agreement with radar drifts.

Furthermore our data appear to be in good agreement with an average of twelve days of drift observations randomly distributed in the period August 1970 - May 1971 at Jicamarca and the theory of Maeda (1962) (fig. 8). The ion cloud experiments on November 11, were performed close to the time of the morning reversal.

The horizontal as well as the vertical drifts (fig. 9 and 10) are known to reverse their directions near sunset and sunrise (Balsley, 1970; Woodman 1970 and 1972). There has been some debate about the actual times of occurrence (Balsley, 1972). Apart from statistical and seasonal variations, the evening reversal of the horizontal velocity in the F-region at typically 300 - 400 km height as measured by Woodman (1972) tends to occur one or two hours before sunset and substantially earlier than that of the E-layer horizontal drifts (Balsley, 1972). Barium cloud experiments at Thumba in March 1968 (fig. 11), however, appear to contradict the Jicamarca data in that, after sunset, several clouds between 150 and 250 km (Rieger, 1971) during three evenings were drifting up- and westward, which is typical for the pre-reversal phase. For these reasons an intercomparison between the plasma cloud drifts at Chamical and simultaneously measured drifts above Jicamarca is of great interest.

As seen in Figure 11 the plasma cloud data appear to be in agreement with the average horizontal drift pattern at Jicamarca and opposite to the findings at Thumba. The average vertical drifts at Jicamarca, on the other hand, agree in the evening better with the Thumba data (fig. 12), whereas the data obtained at Chamical are already typical for night time. In the morning we find reasonable agreement between the three sets of data, if we take into account that the only measurement at Thumba was very uncertain because of bad seeing conditions. It must be remembered, however, that the drifts over Chamical project to an altitude of 700 km at the equator.

In Figure 13 all the experimental data as projected into the equatorial plane have been collected. For the second evening experiment with the injection of two ion clouds at different altitudes during quiet magnetic conditions (Exp. 2a, b), it is possible to deduce a height dependence of the drift. The vertical drift component increases with height. The horizontal components are about three times larger than the vertical ones at the same levels. Experiment 1 at 700 km may be compared with radar data at 350 km height. When comparing directly the evening data (the only evening occasion where this is possible) we see a deviation in the sense that, even if we take into account the difference of 40 minutes in local time, the plasma cloud drifts are closer to the later measured night-time values than the incoherent scatter data. During the morning experiment (Nov. 11) the agreement was much better.

We suggest that this discrepancy is real and must be attributed to a height dependence of the reversals. This becomes obvious if we observe the two sets of data of Nov. 2 and Nov. 11 in the equatorial plane (fig. 13). Somewhere between 350 km and 700 km should the reversals occur in the evening experiment. In the morning, we have night condition as far as the vertical drifts are concerned, but already westward drifts, i.e. daytime conditions at the higher altitudes.

If we assume that the scales of spatial variations are of the order of hundreds of kilometers, we could try to check whether the observed field variations are imposed by the curl-freeness of $E_\perp$. Then we would expect:

$$\frac{\Delta E_z}{\Delta y} - \frac{\Delta E_y}{\Delta z} = 0$$

or, equivalently:

$$\frac{\Delta v_y}{\Delta y} + \frac{\Delta v_z}{\Delta z} = 0$$

The results are the following:

a) Evening experiment (4.11.72)

$$\frac{\Delta v_y}{\Delta y} \simeq 4.2 \times 10^{-5} \text{ sec}^{-1}$$

$$\frac{\Delta v_z}{\Delta z} \simeq -2.1 \times 10^{-4} \text{ sec}^{-1}$$

b) Morning experiment (11.11.72)

$$\frac{\Delta v_y}{\Delta y} \simeq - 1.5 \times 10^{-5} \text{ sec}^{-1}$$

$$\frac{\Delta v_z}{\Delta z} \simeq 1.2 \times 10^{-5} \text{ sec}^{-1}$$

It is satisfying that these estimates turn out to agree well with simple conclusions from Maxwells equations. This way our confidence is growing that these scattered data show a typical situation at twilight.

IV. CONCLUSIONS

Measurements of plasma drifts above 140 km at -15° magnetic latitude give information on the plasma velocities at heights above the F-layer. This way a direct comparison with incoherent scatter radar data at Jicamarca were possible during the interesting periods of the evening and morning reversals.

Although the vertical velocity profiles show normally little variation with altitude, such a dependence can be expected during reversal times.

The vertical and horizontal reversal times seem to have a height dependence in the sense that they are earlier at greater altitudes.

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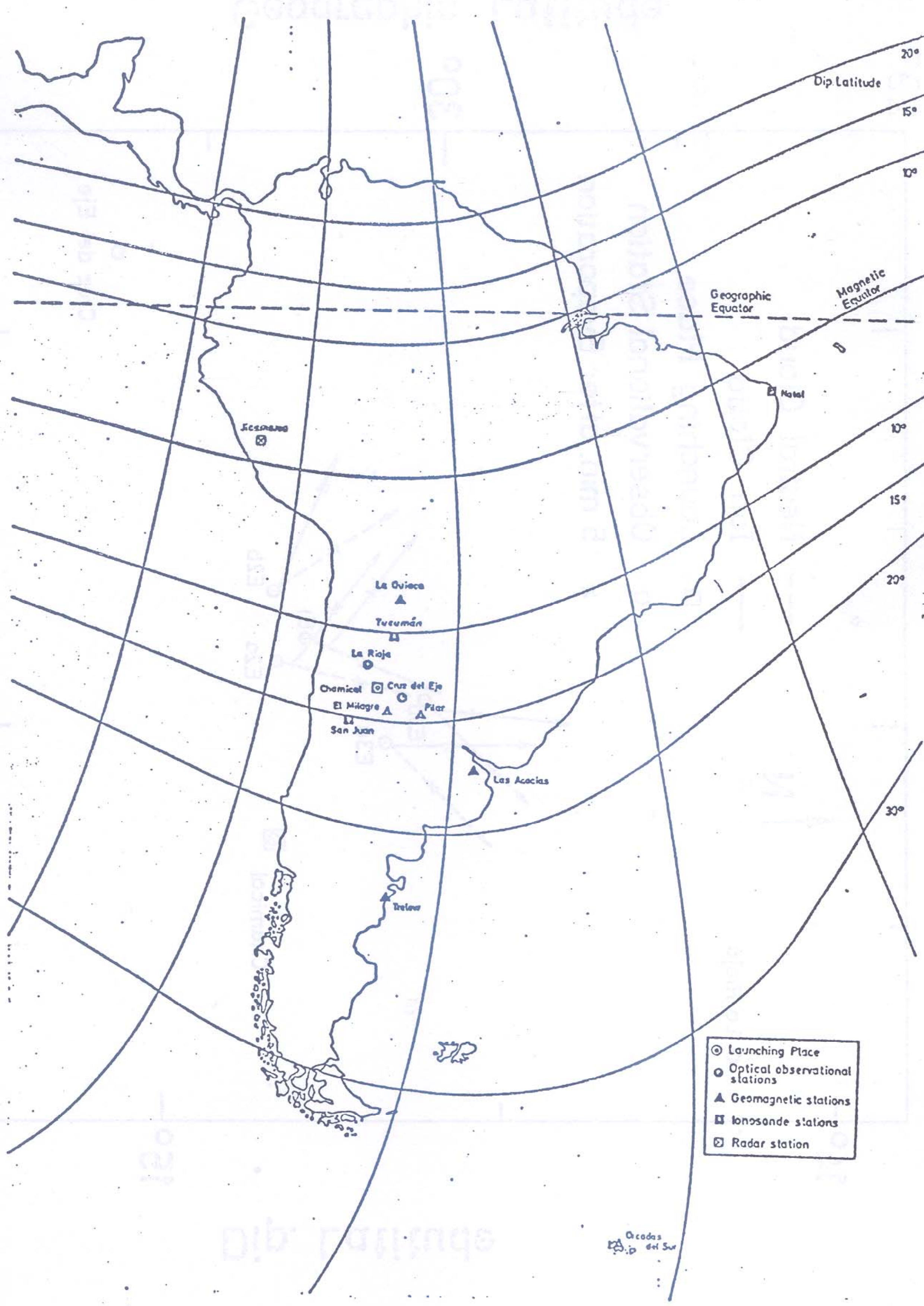
Table 1.

Exp. No.	Date 1972	Local Time	Kp	Cloud	Height of Cloud (km)	$E_\perp$ (mV/m)	Θ (degrees)
1	2.11.	19.1o	5+	Eu+Ba	141	1,27	-30
2	4.11.	19.1o	3-	Eu	160	1,46	-11
				Ba	184	1,93	-15
3	11.11.	o4.1o	1	Ba	180	0,5	-95
				Ba	225	0,5	-120



20°
Dip Latitude
15°
10°
Geographic Equator
Magnetic Equator
Natal
10°
15°
20°
La Quiaca
Tucumán
La Rioja
Chamical
Cruz del Eje
El Milagro
Pilar
San Juan
Las Acacias
30°
Trelew
Launching Place
Optical observational stations
Geomagnetic stations
Ionosonde stations
Radar station
Orcadas del Sur

Figure: 1

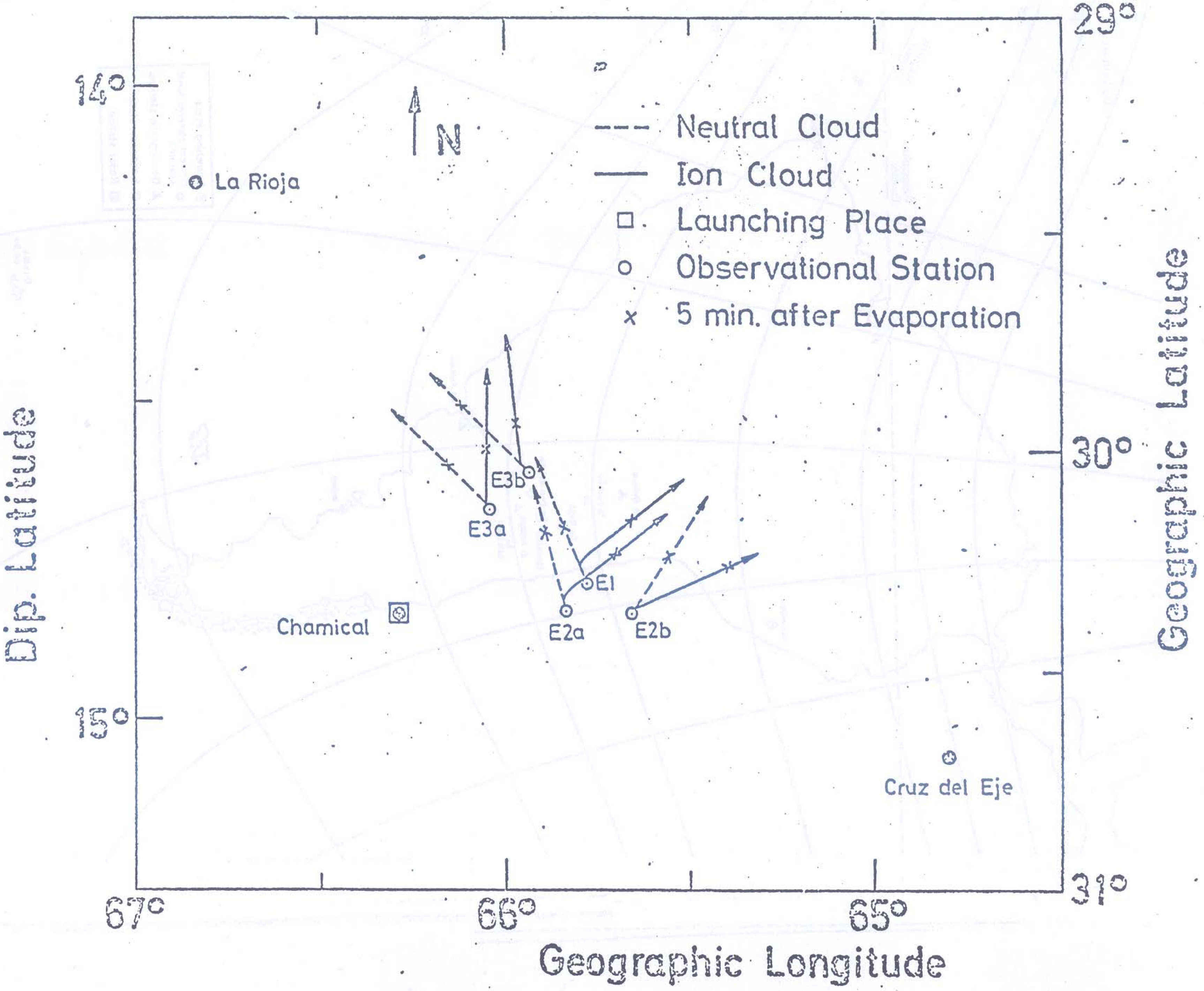


Fig. 2 Drift Path of the Neutral and Ion Clouds Projected to the Ground

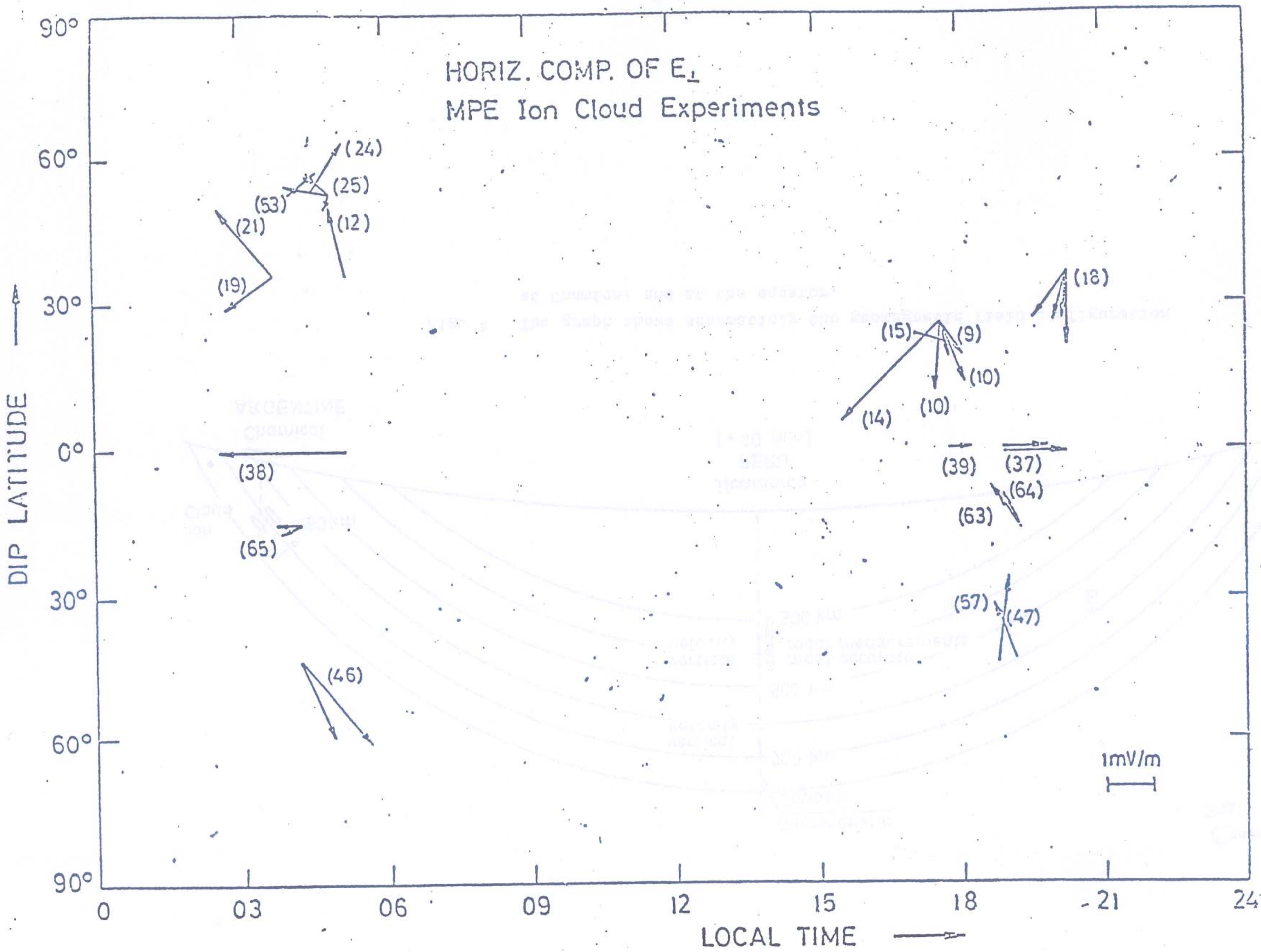


Fig. 3 Horizontal component of the transverse electric fields derived from artificial plasma cloud experiments in a dip latitude versus local time map (Haerendel, 1970; Rieger, 1971

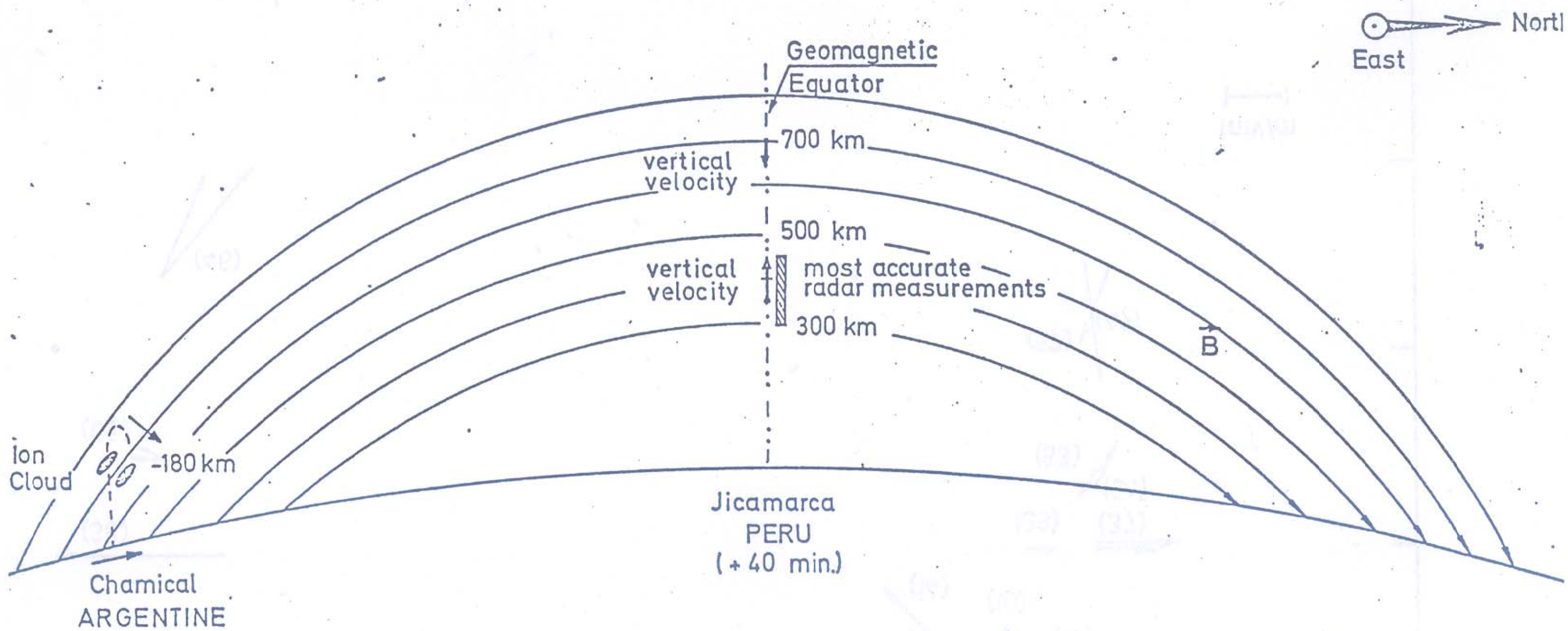


Fig. 4 The graph shows schematicly the geomagnetic field configuration at Chamical and at the equator.

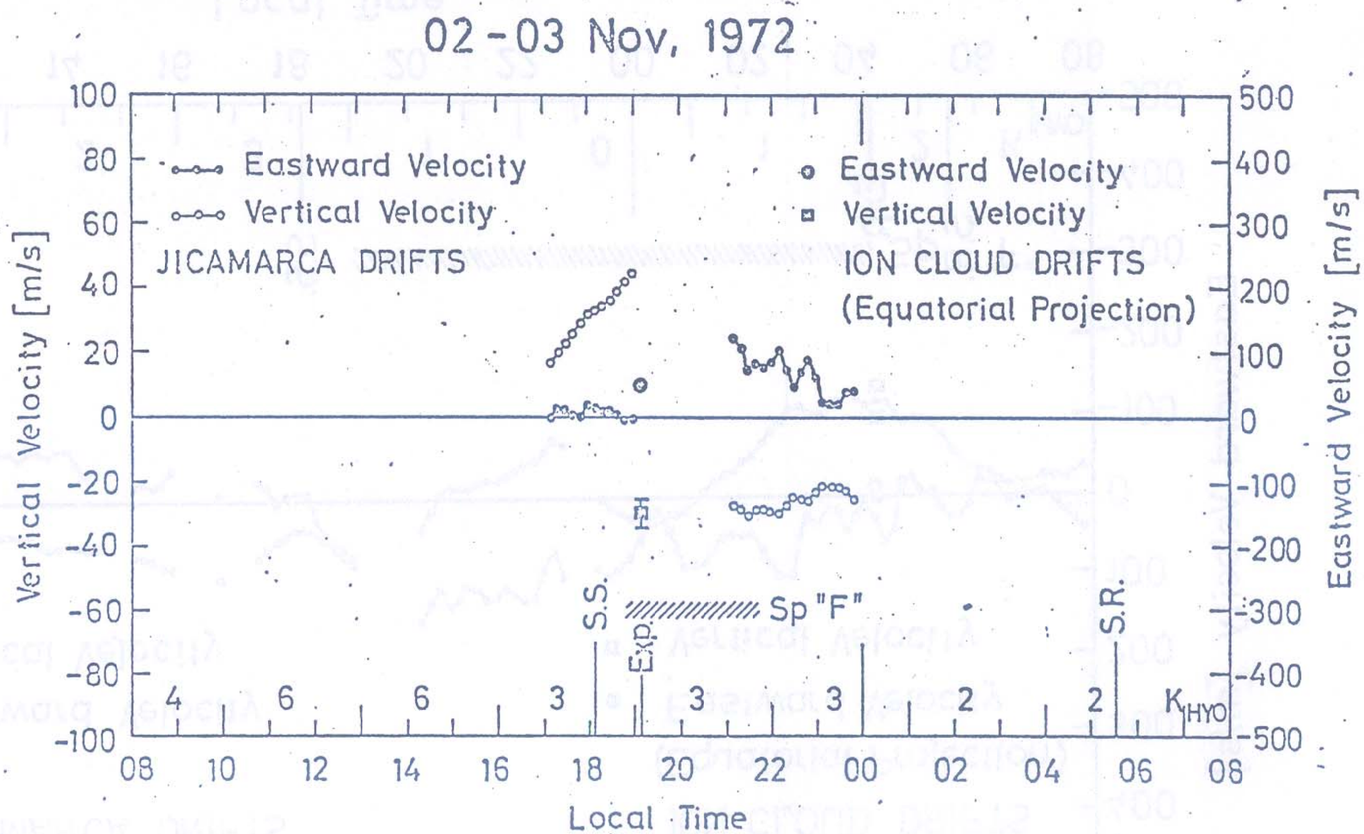


Fig. 5 Horizontal and vertical drifts in the equatorial region between 300 and 400 km altitude as measured with the incoherent backscatter facility in Jicamarca and the ion cloud drifts at 700 km for the first evening experiment. Numbers above time scale are Huancayo magnetic indices. S.S.=sunset, S.R. = sunrise.

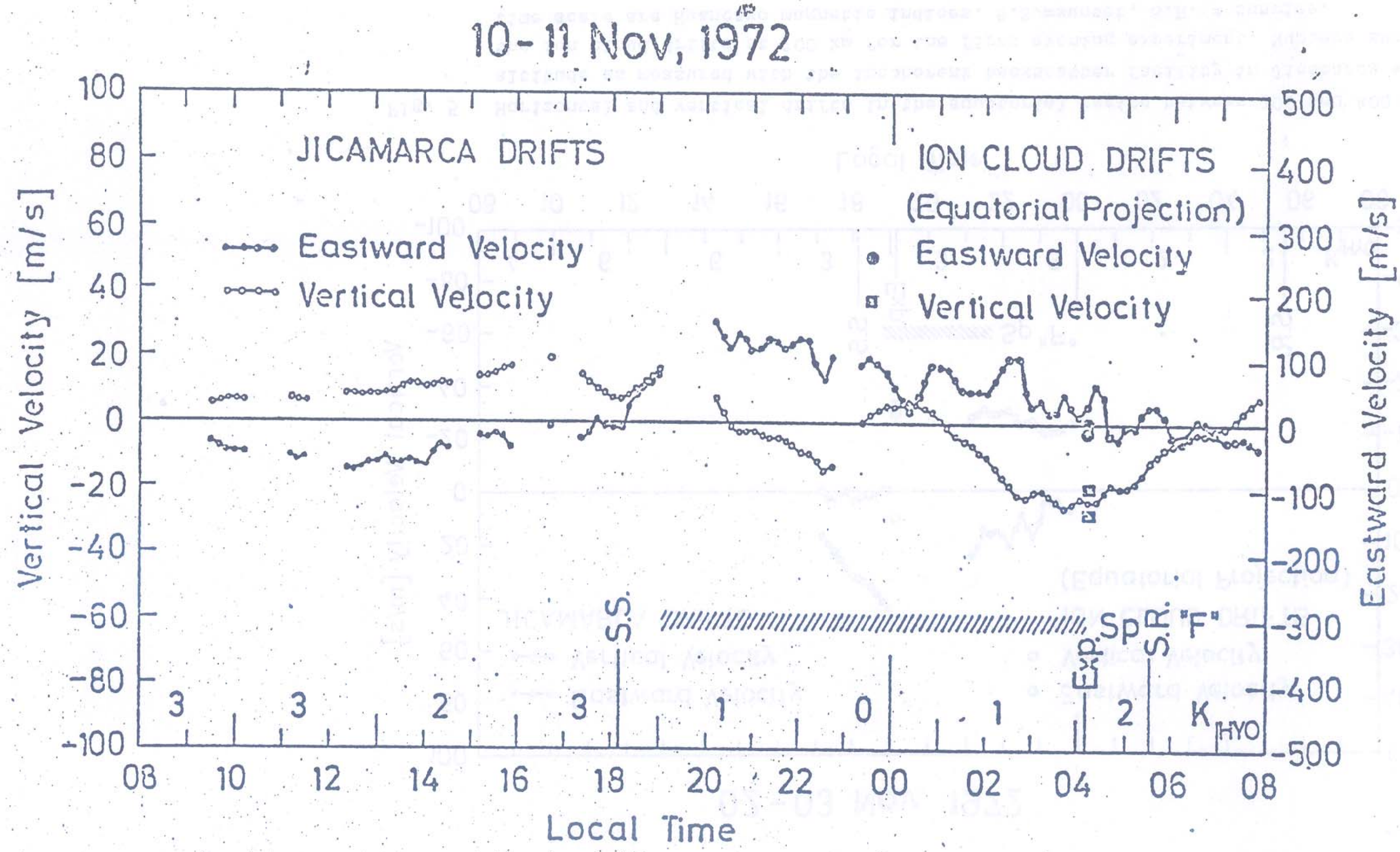


Fig. 6 Horizontal and vertical drifts in the equatorial region between 300 and 400 km altitude as measured with the incoherent backscatter facility in Jicamarca and the ion cloud drifts at 700 - 800 km for the morning experiment. Numbers above time scale are Huancayo magnetic indices. S.S. = sunset, S.R. = sunrise.

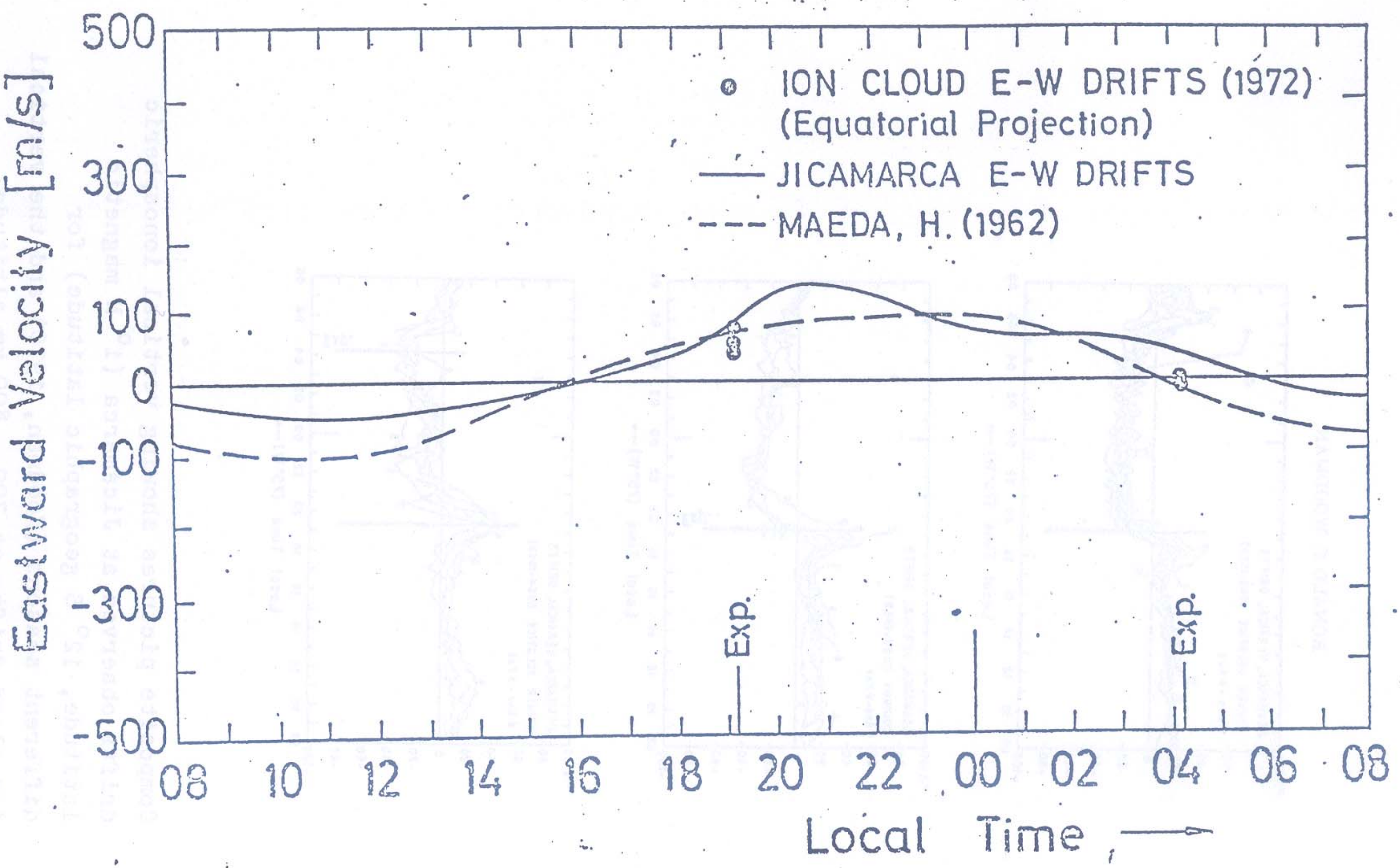


Fig. 8 A comparison between the east-west artificial plasma cloud drift velocity at the geomagnetic equator (700 - 800 km), the average curve (of 12 days) observations at Jicamarca (Woodman, 1972) and a theoretically determined drift curve by Maeda (1962).

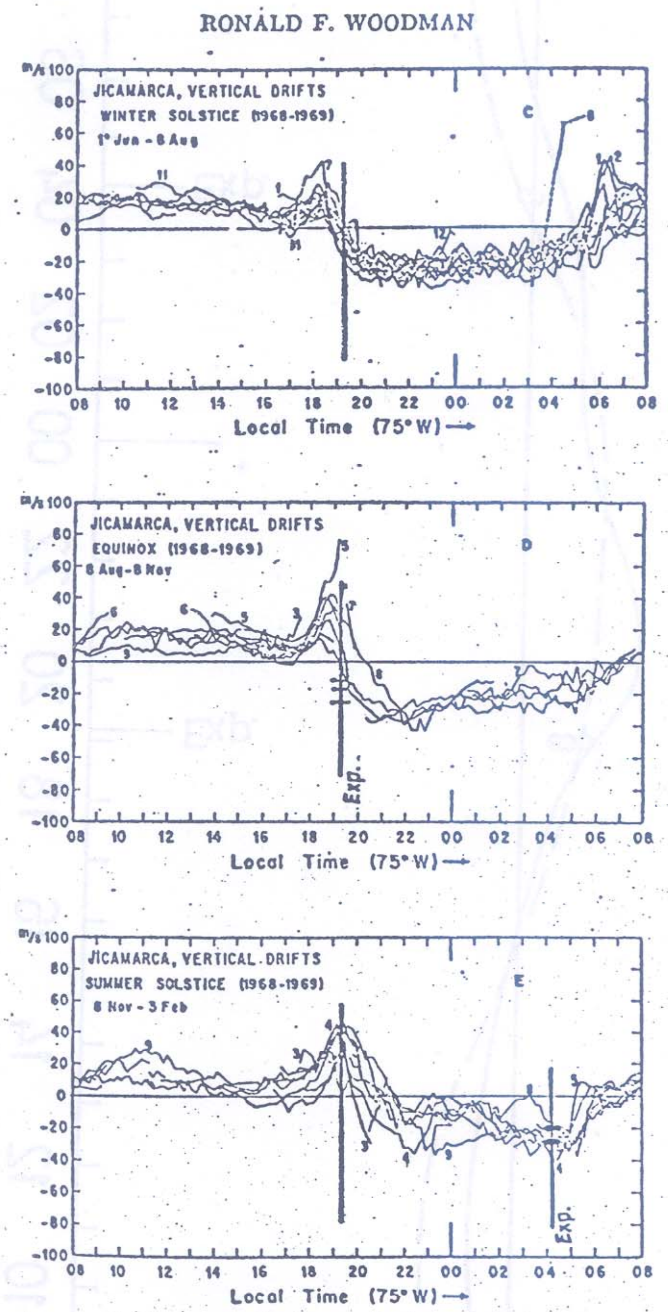


Fig. 7 Composite pictures showing vertical ionospheric drifts observed at Jicamarca (1^{o} N magnetic latitude, 12^{o} S geographic latitude) for different seasons (Woodman, 1970) and the vertical ion cloud drifts at 700 - 800 km altitude.

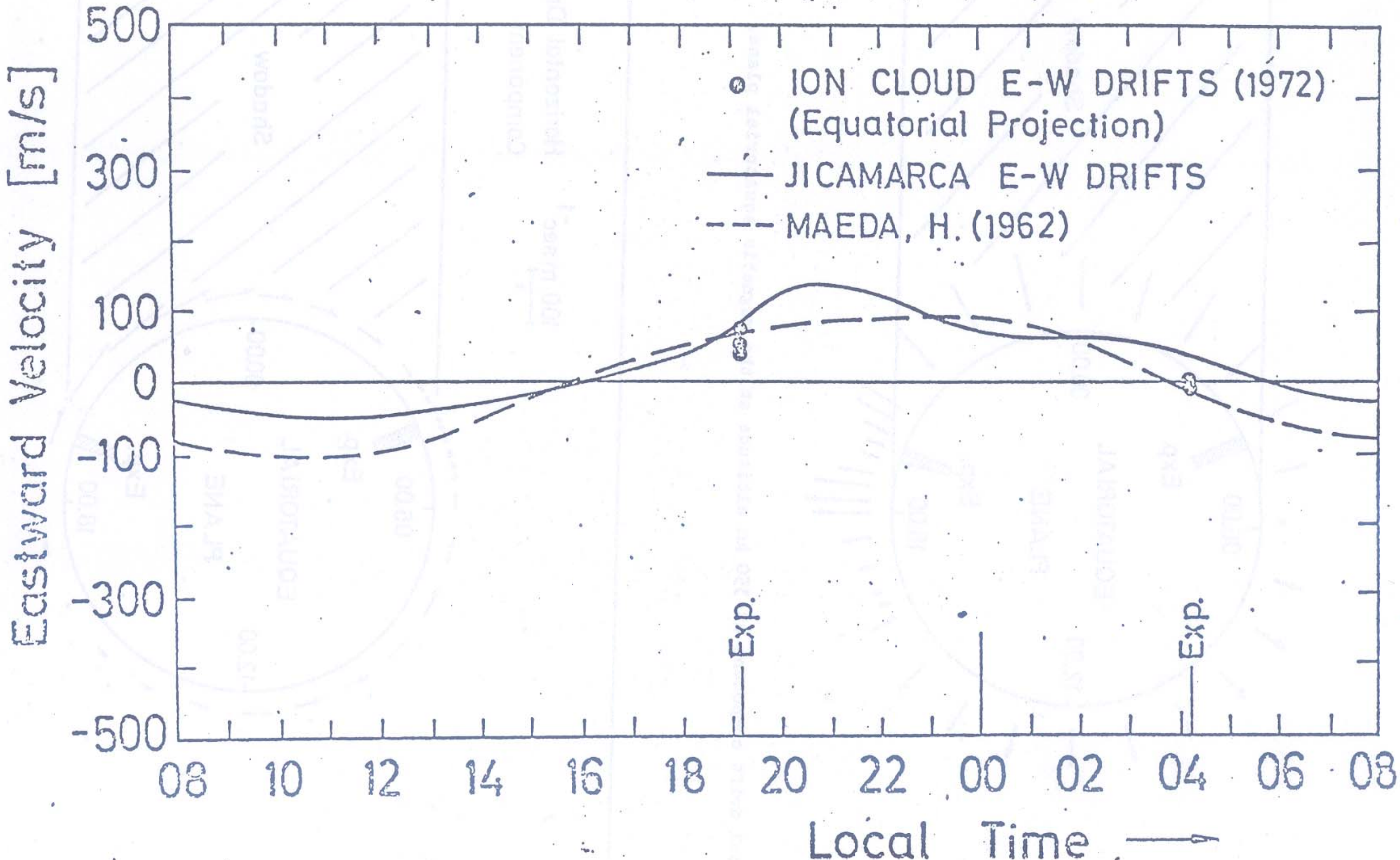


Fig. 8 A comparison between the east-west artificial plasma cloud drift velocity at the geomagnetic equator (700 - 800 km), the average curve (of 12 days) observations at Jicamarca (Woodman, 1972) and a theoretically determined drift curve by Maeda (1962).

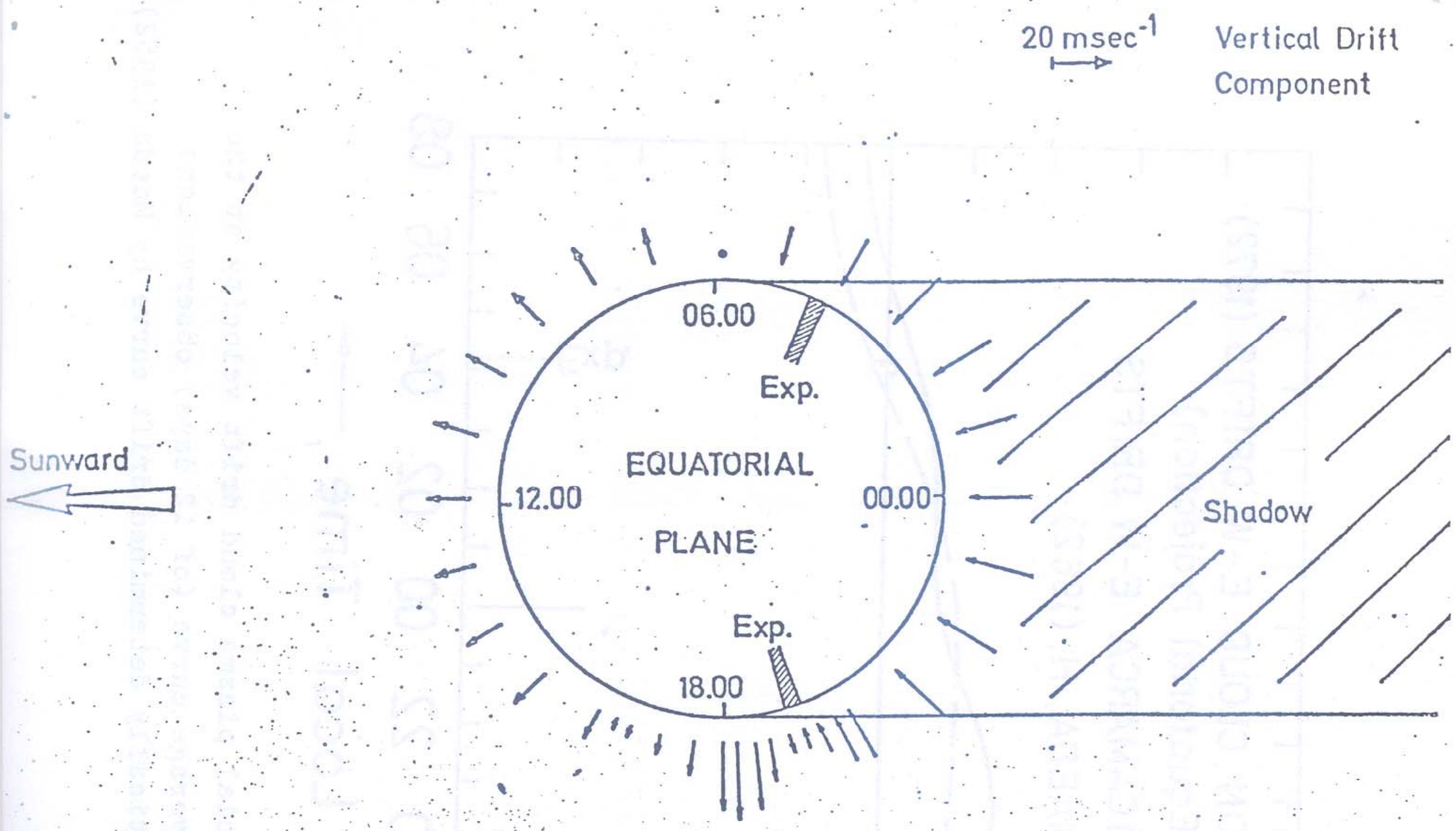


Fig. 9 Vertical drift component at 350 km altitude at the magnetic equatorial plane.

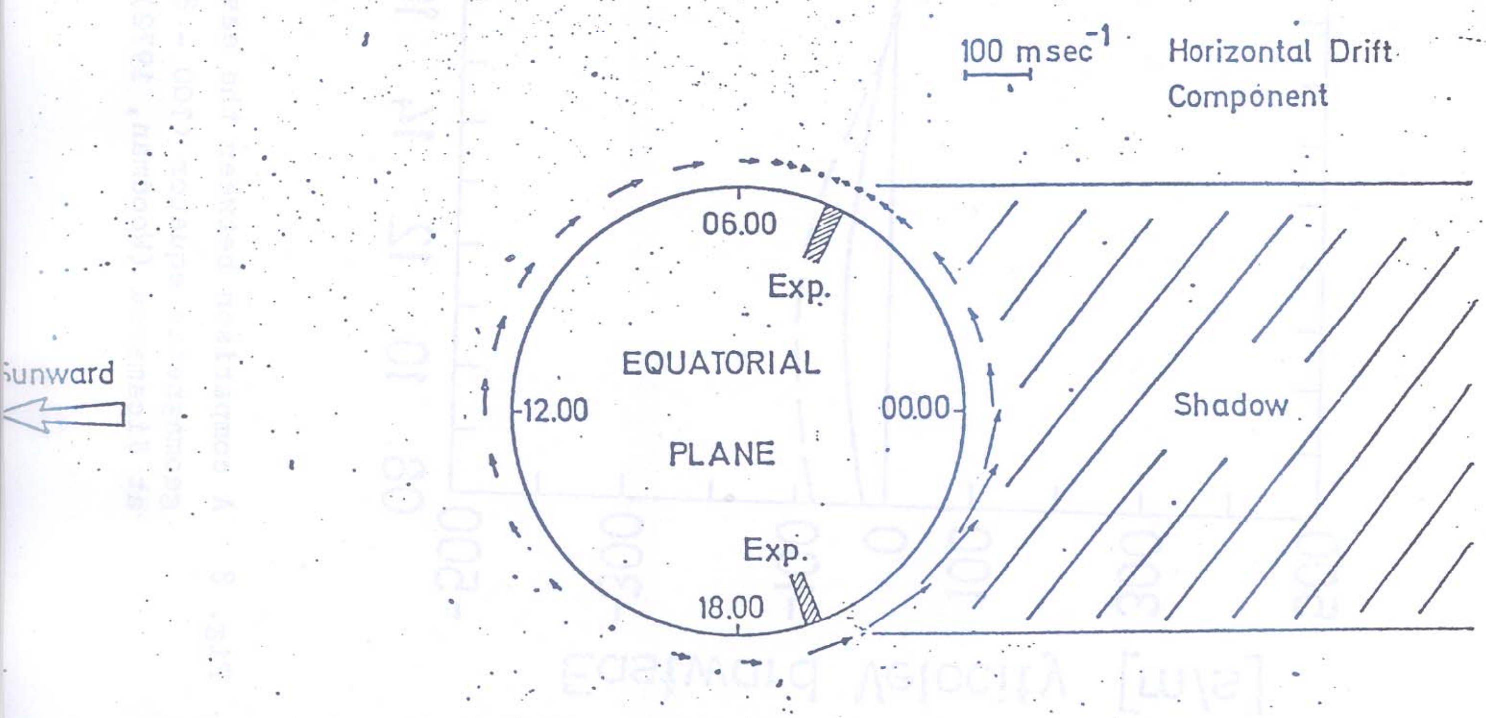


Fig. 10 Horizontal drift component at 350 km altitude at the magnetic equatorial plane.

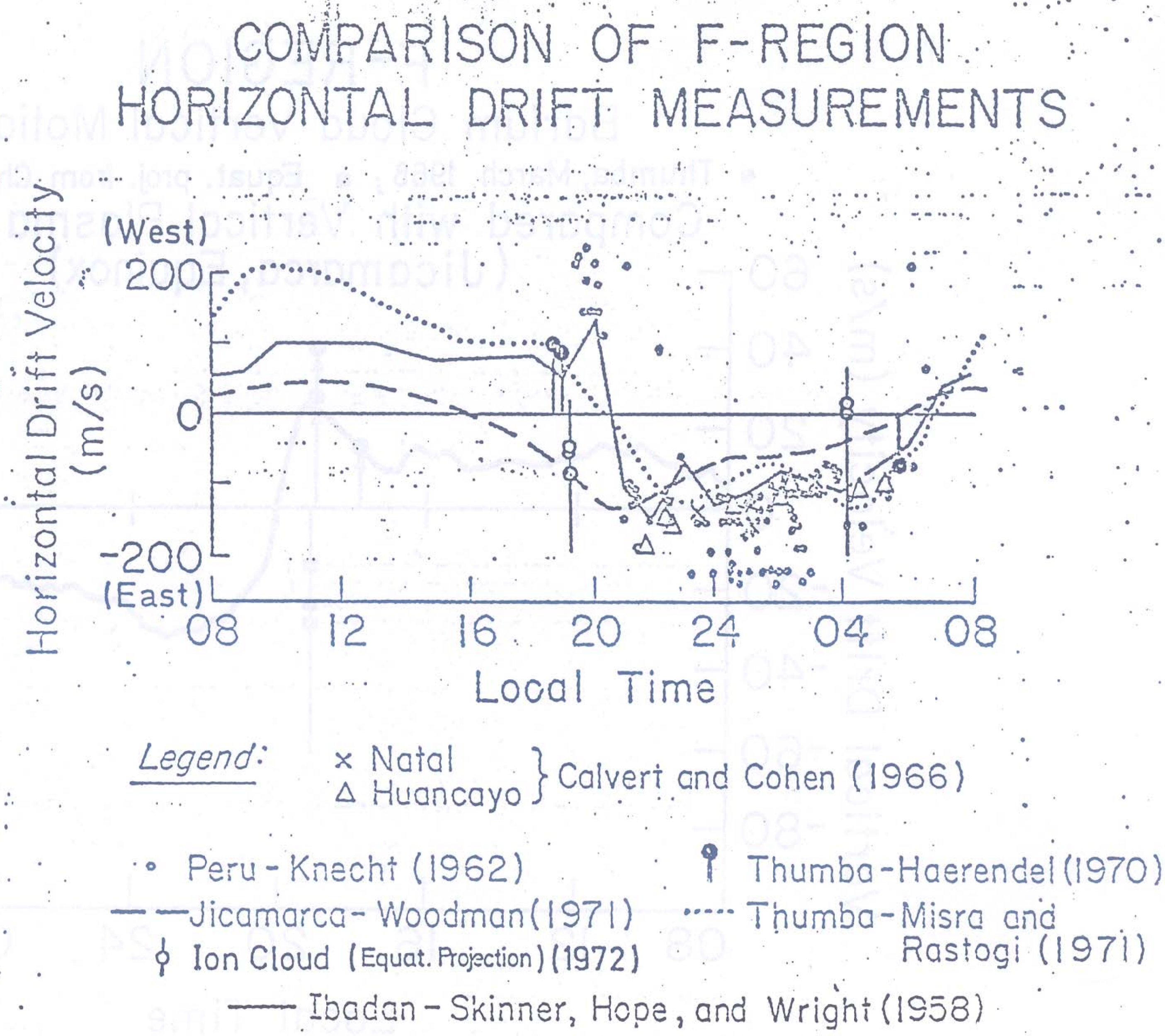


Fig. 11 Comparison between the east-west drifts obtained by the incoherent-scatter method and a variety of other techniques (Balsley, 1972).

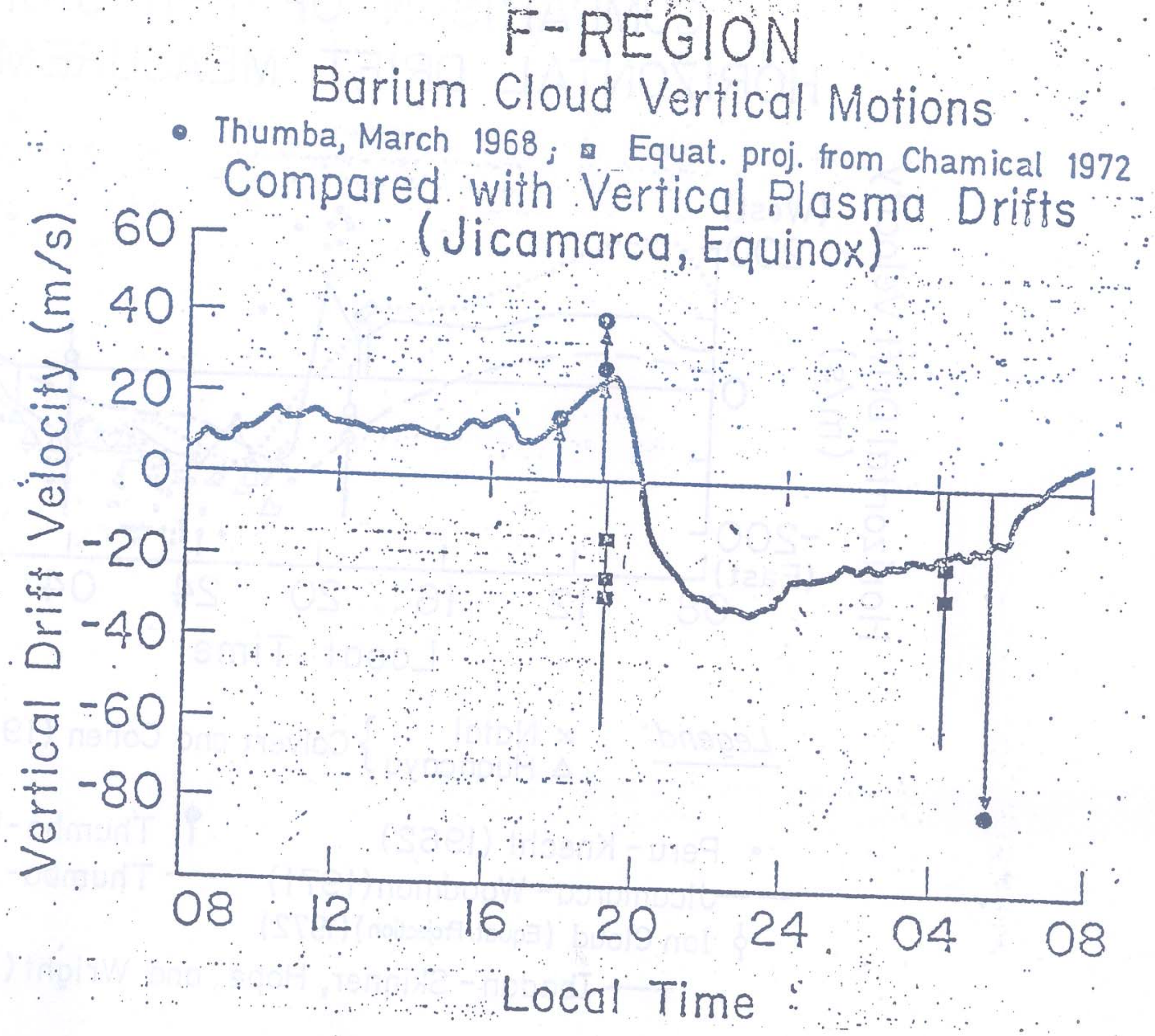


Fig. 12 A comparison between the equinoctial average of the vertical F-region drifts over Jicamarca with the vertical drift of ionized clouds over Thumba (Balsley 1972) and from Chamical.