Comparison of ionosonde and incoherent scatter drift measurements at the magnetic equator

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[1] It has been proposed that ionosondes can be used to measure vectorial nighttime ionospheric drifts at *F* region altitudes. These measurements have been validated at mid and high magnetic latitudes on campaign basis. Here we report concurrent *F*-region drift measurements made at Jicamarca (11.95°S, 76.87°W), under the magnetic equator, using the main Incoherent scatter radar (ISR) and a digisonde portable ionosonde (DPS). As far as the vertical drift measurements, we show a fair agreement between the two techniques at periods when convection dominates other factors (e.g., around pre-reversal enhancement). At other times, production and recombination dominate, and DPS vertical drifts are not reliable. For the horizontal drift component, we limited our measurements to the zonal component. We find poor agreement, being worse at times when the *E* region electron density is high (e.g., during the day). The amplitude of DPS zonal velocities are significantly larger than ISR zonal drifts. During the day, we find that the DPS zonal drifts are in better agreement with the drift velocity of the long wavelength equatorial electrojet (EEJ) instabilities. This is to be expected since, the diffraction pattern on the ground – to which any reflection HF drift technique will be sensitive to – is mainly, if not solely, dependent on the electron density structure at EEJ heights, where the electron irregularity density is sufficiently high to diffract the phase front of the *F* region reflected wave. **Citation:** Woodman, R. F., J. L. Chau, and R. R. Ilma (2006), Comparison of ionosonde and incoherent scatter drift measurements at the magnetic equator, *Geophys. Res. Lett.*, *33*, L01103, doi:10.1029/2005GL023692.

1. Introduction

[2] It has been proposed that digisondes (DPS) can be used to measure vectorial ionospheric drift measurements at the altitudes of reflection. Relative success has been reported at midlatitudes [*Bullet*, 1994] and high-latitudes [*Scali et al.*, 1995]. Based on few days of comparisons, nighttime ionosonde observations of both vertical [*Gonzales et al.*, 1982] and zonal [*Bullet*, 1994] velocities at midlatitudes, have been reported to be in good agreement with incoherent scatter radar (ISR) estimates (at times when production and recombination are not important).

[3] Given the need of more spatial coverage and also continuous observations to improve the understanding of the climatology and weather of the low latitude electrodynamics [e.g., *Fejer*, 1997], one might be tempted to generalize mid and high latitude findings at low latitudes. But, the physical situation is different at latitudes close to the magnetic equator, particularly due to the presence of strong equatorial electrojet (EEJ) irregularities. In addition, at high altitudes there is a connection between *F*- and *E*-region altitudes along the magnetic field lines that does not exist at the magnetic equator.

[4] Since the late 1960's the Jicamarca incoherent scatter radar (ISR) has measured with very good accuracy both vertical and zonal **E** × **B** drifts [e.g., *Woodman and Hagfors*, 1969; *Woodman*, 1972; *Kudeki et al.*, 1999]. However, these observations are limited to: (a) few days (on average less than 20) a year, and (b) the Jicamarca longitude sector. Given the poor time and spatial coverage of ISR drift measurements, alternative means have been investigated using coherent scatter techniques with low power systems [e.g., *Balsley*, 1969; *Hysell and Burcham*, 2000; *Chau and Woodman*, 2004].

[5] Digisondes appear to be another means of getting ionospheric drifts, during day and night. At equatorial latitudes, comparison and validation studies have not been yet conducted on these DPS drift measurements. Here we compare those measurements with concurrent ISR **E** × **B** drifts. As expected from results obtained at Arecibo [*Gonzales et al.*, 1982] and from theoretical work [*Bittencourt and Abdu*, 1981], we find that DPS vertical velocities at low latitudes are not reliable during the day due to the recombination and production effects. Furthermore, daytime DPS zonal velocities are affected by the strong EEJ irregularities. Nevertheless, DPS drifts might be useful if they are accompanied with proper modelling and understanding of the scattering processes.

2. Experimental Setup

[6] The ionosonde measurements have been obtained with digital portable sounder version 4.0 (DPS). Such instrument provides ionosonde drift vectors via a program called Digisonde Drift Analysis (DDA). Briefly, the DPS vertical drift is obtained from the line-of-sight Doppler velocity. Similar results are obtained if the velocities are obtained from the changes of true height as a function of time [e.g., *Bertoni*, 2004]. The zonal and meridional components are obtained from solving a linear set of equations composed of different line-of-sight velocities and their respective angles of arrival. The angular locations are obtained using an interferometric configuration of four antennas. The measurements reported here have been obtained every 15 minutes with typical errors between 1 and 10 m s^{-1} (5–30 m s^{-1}) for the vertical (zonal) components. More details are given by *Bullet* [1994].

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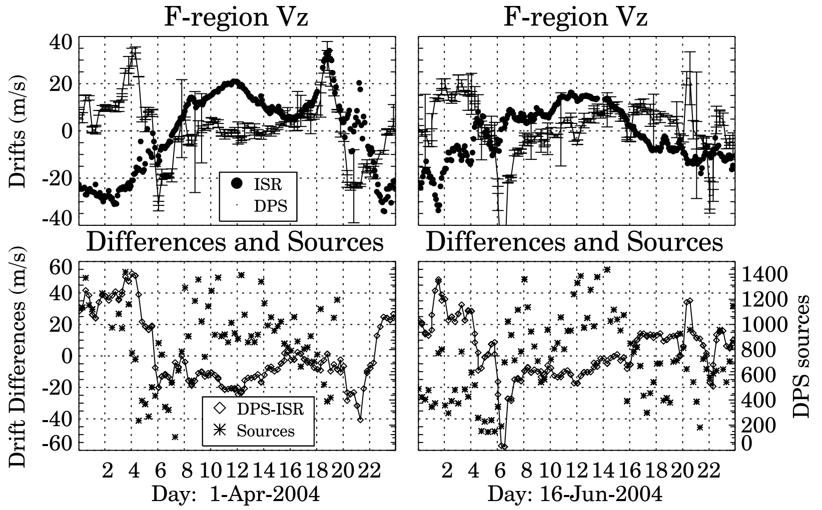

Figure 1. Measured mean F-region vertical velocities at Jicamarca with the ISR (●) and the ionosonde (DPS) (with error bars), for April 1, 2004 (left) and June 16, 2004 (right). The lower panels show the velocity difference DPS-ISR (✧). In addition, the number of sources used by the DPS are shown (∗) with values indicated by the right axis.

[7] The ISR drifts at Jicamarca are obtained from pulse-to-pulse experiments using antennas pointing perpendicular to the magnetic field (**B**) few degrees to the East and West [e.g., *Woodman*, 1972; *Kudeki et al.*, 1999]. Combining the radial velocities of both beams, one obtains measurements of F-region vertical and zonal **E** × **B** drifts, with excellent accuracy (~1 m s^{-1} and ~8 m s^{-1}, respectively). Typical measurements are obtained every 15 km and 5 minutes. Details of the current experimental setup and processing technique are given by *Kudeki et al.* [1999].

[8] As we mentioned in the Introduction, we are also comparing the ionosonde zonal drifts to the 3-m EEJ zonal electron drift. These measurements are obtained using a small COCO array pointing 45° off zenith West of Jicamarca with ~30° beam width. The EEJ zonal drift is obtained from the type-2 Doppler velocity every 30 seconds [e.g., *Balsley*, 1969].

3. Experimental Results

[9] The experimental setup described in the previous section have been run for 10 days during the World day campaigns scheduled in March–April 2004 and June 2004. In Figure 1 we present the observations of two days: April 1, 2004, when ESF irregularities occurred, and June 16, 2004 when no ESF echoes were observed. The mean ISR F-region vertical drifts (V_z) have been obtained from averaging observations around the F-peak. The DPS values are shown with their error bars as calculated by the DDA technique [e.g., *Bullet*, 1994]. In the case of the ISR values, the errors are usually smaller than the size of the dots in the plot. In the lower panels, we use the ISR measurements as a reference and show the velocity difference DPS-ISR. In addition, as requested by one of the reviewers, we show the number of echo sources used by the DPS.

[10] Compared to ISR vertical **E** × **B** drifts, the DPS vertical velocities are only fair around a large pre-reversal enhancement (PRE) on April 1, 2004. On the other hand, on June 16, 2004 when PRE was small, the discrepancy is significant, not only in magnitude (few 10 m s^{-1} and much larger than the DPS errors) but also in direction. At other times, the agreement is poor. For example note the close-to-zero DPS vertical velocities during the day, producing discrepancies of 10–20 m s^{-1}. These discrepancies are much larger than ISR V_z errors of ~1 m s^{-1} and comparable to the vertical velocities we want to measure.

[11] In Figure 2 we show the observations of zonal drifts (V_x) measured with the ISR and the DPS. In addition, we are showing the zonal drift of 3-m EEJ irregularities. Compared to ISR zonal **E** × **B** drifts, the DPS zonal velocities present the same sign (direction) most of the time, but consistently larger amplitudes (>100 m s^{-1}). Note that, during the day, these velocities are smaller than the 3-m EEJ zonal velocities, but close to the expected phase velocity of the EEJ primary kilometer-scale waves, i.e., 100–200 m s^{-1} [*Kudeki et al.*, 1982]. At night, after PRE and before sunrise, the agreement in direction is good, but the amplitudes are larger than the ISR zonal drifts.

[12] Note that the number of sources used by the DPS are in general good enough (more than 800). In both cases, vertical and zonal estimates, the DPS velocity errors are much less than the differences with respect to the ISR drifts.

4. Discussion

[13] The significant differences of the DPS vertical drifts with respect to the ISR vertical drifts occur mainly at times when the production and recombination are important. It should be recalled that the vertical velocities obtained by an ionosonde, either by the use of the Doppler or the $h'F$ derivative, is determined by the apparent vertical velocity of the reflection height. This is determined not only by the vertical drift but also by the changes in shape produced by production and recombination effects. An example illustrates the point: If a significant drift of 15 m s^{-1} constant for a long time exists (e.g., around noontime), the $N_e(h)$ profile will reach an equilibrium situation, its shape will be constant, $h'F$ will be constant and so will be its derivative. The ionosonde technique will give us zero vertical drift when the ISR will give us the real 15 m s^{-1}. Similar results

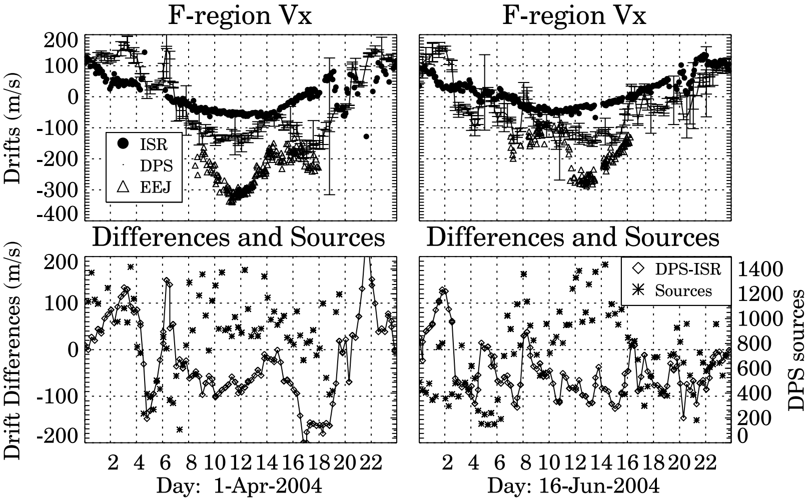

Figure 2. Measured mean *F*-region zonal drifts at Jicamarca with the ISR (●) and the ionosonde (DPS) (with error bars), for April 1, 2004 (left) and June 16, 2004 (right). In addition, we are showing zonal drifts of EEJ irregularities (△). The lower panels show the velocity difference DPS-ISR (◇). The number of sources used by the DPS are shown (∗) with values indicated by the right axis.

and arguments were given by *Gonzales et al.* [1982]. It is clear that fair agreement is obtained only at times when either recombination or production are not the dominant effects. For example, during large PRE when convection dominates.

[14] In the case of zonal drifts, the ionosonde technique determines the velocity of the diffraction pattern on the ground. This in turn, is determined by either the structure of the reflecting layer at *F*-region height, or by the structure in the refraction screens across the propagation path of the incident and reflected rays, or by both, if both structures are important.

[15] At the equator, the *F* region at the reflection point is very smooth during the day, but the *E* region has sufficient density and has large density fluctuations as a consequence of the existence of the EEJ instabilities. It is expected then, that the refraction pattern on the ground will reflect the *E* region structure and its velocity (corrected by the geometry).

[16] There are different scale sizes in the EEJ irregularities [*Kudeki et al.*, 1982]. The diffraction pattern, due to Fresnel filtering [e.g., *Ratcliffe*, 1956], will favor the larger structures, i.e., the kilometer-scale ($\sim$2 km) primary waves which exist there, over the smaller structures which have been used to determine the drifts. According to *Kudeki et al.* [1982], the former drifts at 100–200 m s^{-1} during the day. From Figure 2 and from many years of observations [*Woodman*, 1972; *Fejer et al.*, 1985], the *F* region drifts at $\sim$50 m s^{-1} during the day, at significantly smaller velocities than the DPS zonal drifts. It is not surprising then, that the daytime DPS zonal drifts, conforms with the expected velocities of the large primary unstable waves in the *E* region and not with the concurrent measured ISR *F* region drifts. At night the EEJ effects are expected to be less than during the day given the smaller densities, however, as shown in Figure 2 there are periods when the DPS zonal drifts are more than 50 m s^{-1} larger in amplitude than the ISR zonal drifts.

[17] An independent support of our claim was presented by *Woodman et al.* [1995]. They were able to measure directly the kilometer scale EEJ waves by studying the radio star 50 MHz scintillations of Hydra ($\sim$9h17.80′RA, $\sim -12°5'$Dec) with two spatially separated antennas. Moreover, by cross-correlating the information they obtained zonal velocity of $\sim$132 m s^{-1} which is similar to the usual DPS zonal drifts.

[18] Although our work is based on digisonde measurements, we claim that our findings can be generalized to other HF reflection techniques, independent of the ionosonde instrument or processing algorithm. For example, concurrent ionosonde measurements of *E* and *F* region zonal drifts at Huancayo in the early 1980's during the CONDOR campaign, showed that both regions moved at the same velocity, close to what we expect from kilometer-scale EEJ waves (W. Wright, personal communication, 2005). We expect to corroborate this statement in the near future by comparing concurrent ISR drifts with other types of HF reflection techniques at Jicamarca (G. Crowley, personal communication, 2005).

[19] Our studies have been limited to the comparison of vertical and zonal drifts, since Jicamarca is not able to measure the meridional component. *Miller et al.* [1986] show that using an ionospheric model and ionosonde measurements, reasonable meridional winds can be inferred at mid latitudes. However, we expect the DPS meridional component also to be affected by the strong EEJ irregularities, but we are not in position to quantify such effects.

5. Conclusions

[20] Although nighttime vertical and horizontal drifts deduced from Doppler and diffraction pattern velocities of the *F*-region HF reflected waves have shown to be a good proxy of the vertical and horizontal drift velocities at high latitudes, this is not the case at equatorial latitudes. We have shown that those measurements generally do not agree with IS measurements at latitudes close to the magnetic equator, except during very special conditions. As an exception, ionosonde vertical drifts are in fair agreement with ISR drifts when convection dominates

production and recombination, e.g., during periods of large pre-reversal enhancements. On the other hand, ionosonde zonal drifts can be used when the *F*-region height is structured and the *E*-region density is low or stable.

[21] *F*-region ionosonde vertical drifts could be improved if a proper theoretical model is used to take into account the effects of production and recombination. Such an effort has been started by different groups [e.g., *Bertoni*, 2004; M. J. Nicolls et al., Observations and modeling of post-midnight uplifts near the magnetic equator, submitted to *Annales Geophysicae*, 2006]. In addition, the ionosonde zonal drift which we show represents the zonal drift of kilometer scale EEJ irregularities, could be used to determine the daytime zonal electron drift velocities, and in turn the *F*-region zonal electric field, i.e., its vertical drift [e.g., *Balsley*, 1969; *Hysell and Burcham*, 2000].

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