On the magnitude and variability of height gradients in the equatorial F-region vertical plasma drifts

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ABSTRACT: Previous radar studies have shown significant height gradients in the equatorial F-region vertical ExB plasma drifts. These studies, however, were limited to few observation days and particular solar flux conditions. The increased number of measurements of low-latitude ExB drifts at topside heights, including those to be made by upcoming satellite missions (ICON and COSMIC-2) motivated us to carry out a comprehensive evaluation of height gradients in the equatorial vertical drifts. To properly evaluate the height gradients in the vertical drifts, we analyzed long-term (1986-2017) quiet-time measurements of plasma drift profiles made by the incoherent scatter radar (ISR) of the Jicamarca Radio Observatory (JRO).

In this study, we quantified the mean behavior and variability of the height gradients as a function of local time and two distinct solar flux conditions (mean $F_{10.7}$ around 80 and 150 SFU). As a result, we identified the occurrence of a significant positive mean gradient in the vertical drifts around sunrise, which we associated with decelerating zonal drifts. We also point out difficulties caused by the height gradients when relating drifts measured by satellites and equatorial spread F.

1. RELEVANCE AND MAIN OBJECTIVES

In the F-region ionosphere, the zonal (U_i) and vertical (W_i) components of the ExB plasma drifts, for a curl-free electric field, are related by [Murphy and Heelis 1986]:

$$\frac{\partial W_i}{\partial r} = \frac{2W_i}{r} - \frac{1}{r}\frac{\partial U_i}{\partial \phi} \qquad \text{Equation (1)}$$

Where r and ϕ correspond to height and longitude, respectively. Previous radar studies have confirmed the existence of the height gradients of the vertical drifts but were limited to either few observation days [e.g. Murphy and Heelis 1986; Pingree and Fejer 1987] or focused on the height variation in the evening sector [e.g. Nayar and Sreehari 2004; Fejer et al., 2014]. This study addressed the height variability of the low-latitude F-region vertical plasma drifts as a function of local time and as a function of solar flux conditions using a larger data set than previously available. Additionally, the investigation is motivated, by an increase in the number of satellite observations of low latitude plasma drifts including those to be made by the upcoming ICON and COSMIC-2 missions [Yue et al., 2014; Immel et al., 2018]. The satellite observations would benefit form a specification of the magnitude and variability of height gradients in the vertical drifts. In summary, the main question addressed in this study is:

- What is the magnitude and variability of the height gradients of the equatorial F-region vertical plasma drifts?

2. METHODOLOGY

To address the science question above, we processed vertical plasma drift measurements made by the Jicamarca ISR between 1986 to 2017 .

2.1 Data Processing

- Only geomagnetic quiet data was processed (Kp at the time of the measurement and three previous 3-hour Kp values don't exceed 3).
- We removed measurements occurring during both minor and major sudden stratospheric warming (SSW) events which occur primarily in Jan. and Feb.
- ISR measurements with SNR values greater than 1 dB were associated with equatorial spread-F (ESF) and were removed.
- During our analysis, we found sudden changes in drift measurements from one range gate to the next were associated with ESF. Therefore, measurements that produce absolute differences greater than 5m/s from one height to the next (15km) were removed from our analysis.
- Measurements were binned by low (mean $F_{10.7}$ = 80 SFU) and high (mean $F_{10.7}$ = 150 SFU) solar flux conditions. Hereby referred to as LSF and HSF.

2.2 Data Analysis

- We consider a linear model of the vertical drifts (W_i) given by:

$$\widehat{W}_i(h) = \beta_0 + \beta_1 h \qquad \text{Equation (2)}$$

Where h (in km) is the altitude and β_0 (in m/s) and β_1 (in m/s/km) are the coefficients of the linear model determined by a weighted least-squares procedure. The height gradients $(\partial W_i/\partial r)$ are estimated by β_1.

- For each fit, we computed the root-mean-square error (RMSE) of the data. Linear fits with a RMSE greater than 1.65 m/s were rejected.
- To better quantify the range and variability of the gradients in the drifts, we subdivided the data into sets for daytime (0700-1800LT), nighttime (1800-0700LT) and near the PRE (1800-1900LT). For each set of measurements, we constructed cumulative distributions functions (CDFs).

EXAMPLE PROFILES

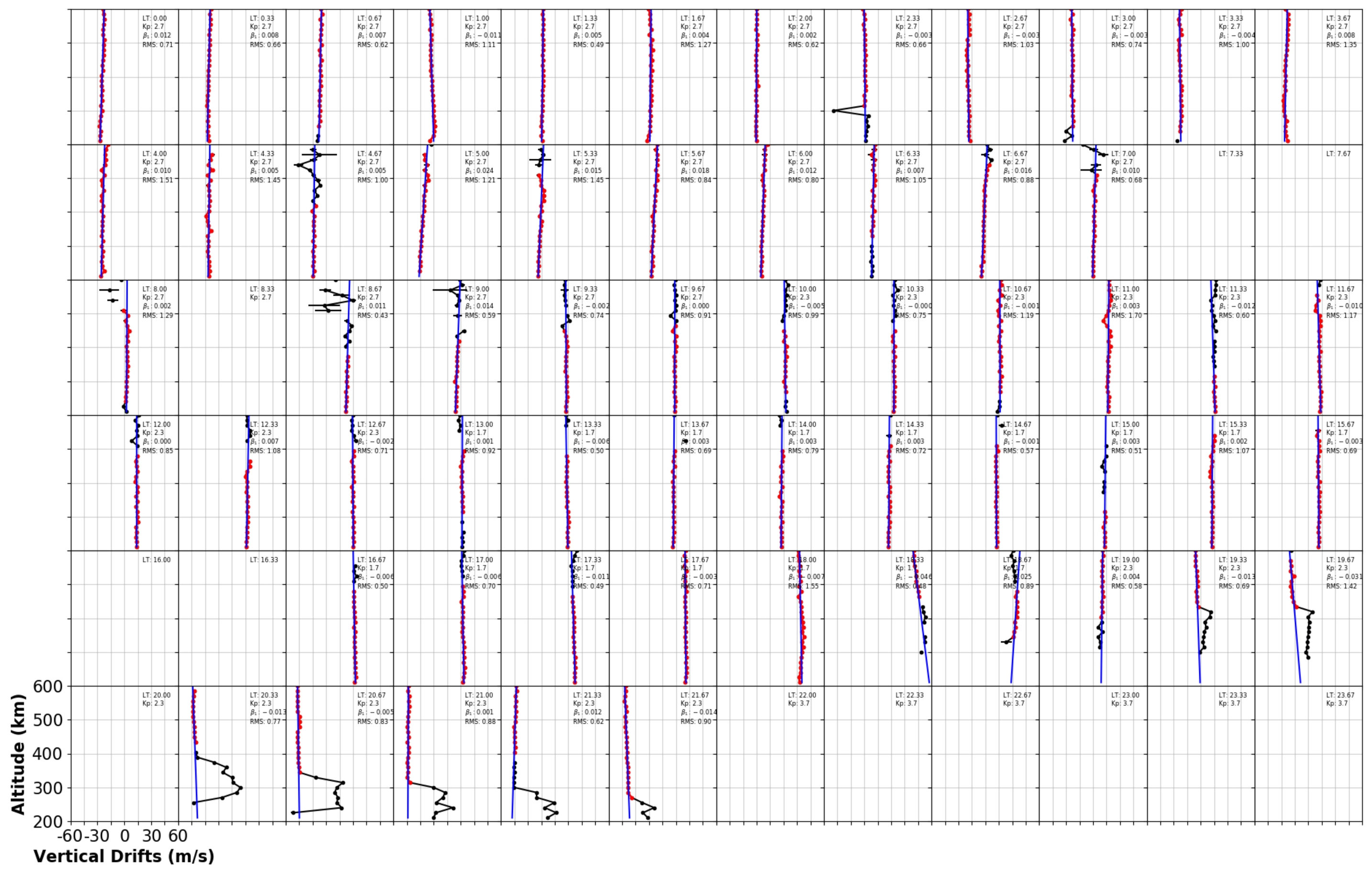

Figure 1: Examples of measured vertical drift profiles (black markers) measured by the Jicamarca ISR for different local times on April 13, 2000. We also show the results of linear fits (blue line) to data that meets our quality control and selection criteria (red markers).

3. RESULTS AND DISCUSSION

3.1 Local Time Behavior of the Height Gradients of the Vertical Plasma Drifts

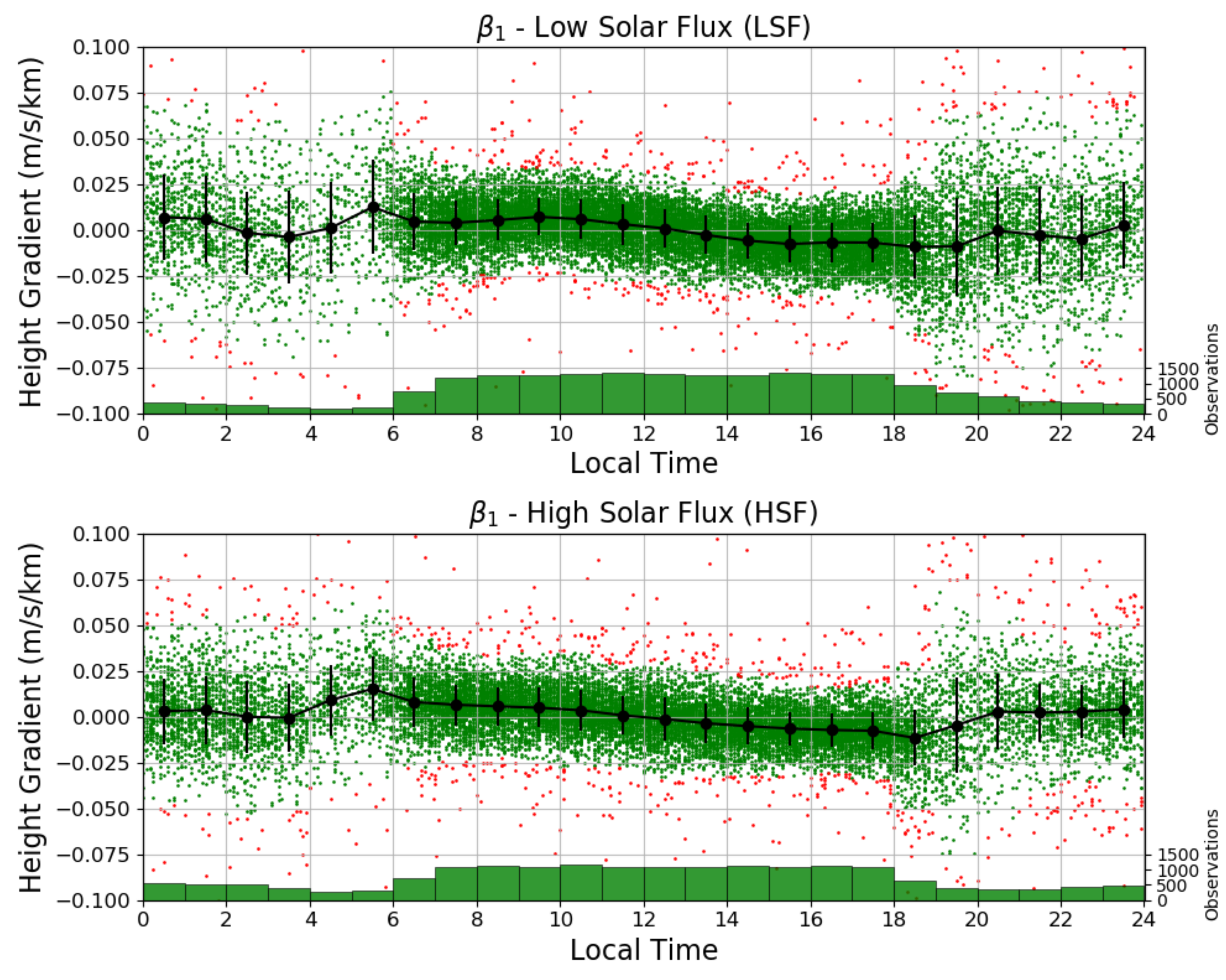

Figure 2: Local time variation of the quiet-time height gradients (green markers) estimated from the vertical drift profiles for low (top) and high (bottom) solar flux conditions. The black curve and error bars represent hourly averages and standard deviation computed for every 1-hour wide data bin. The vertical bars at the bottom of the plot represent the number of observations in each bin. The red markers represent outlier measurements in each bin using the 1.5*IQR rule.

ASSESSMENT

- In general, height gradients are positive in the morning and negative in the afternoon.
- The mean gradients are small (< |0.01| m/s/km or < |1.00| m/s per 100 km), except near dawn and in the evening sector.
- Our results confirm the existence of the enhanced negative gradient near 1830LT for both solar flux conditions. This feature is associated with the rapid eastward acceleration of the zonal plasma drifts near this time that is known to occur [e.g. Pingree and Fejer, 1987; Fejer et al., 2014; Shidler et al., 2019].
- Additionally, we also identified an enhanced positive gradient in the dawn sector. We associated this behavior in the vertical drifts with a strong negative longitudinal gradient in the zonal plasma drifts that is expected to occur around that time.
- Finally, the variability of the height gradients are slightly higher during LSF compared to HSF.

3.2 Quantifying the Variability of the Height Gradients of the Vertical Plasma Drifts

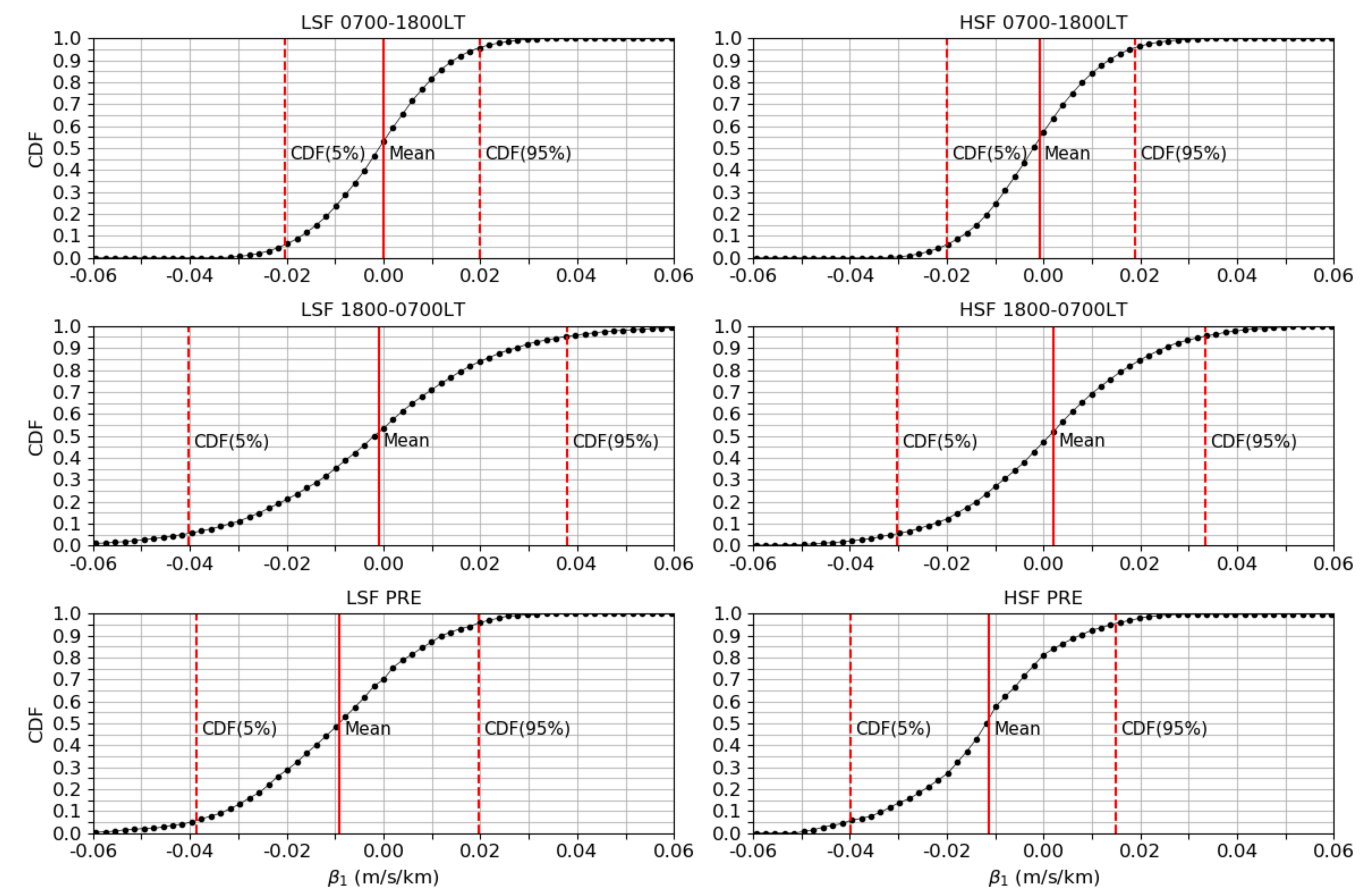

Figure 3: Cumulative distribution functions of drift gradients (β_1) for daytime (0700-1800LT), nighttime (1800-0700LT) and PRE (1800-1900LT) during low (mean $F_{10.7}$ = 80 SFU) and high (mean $F_{10.7}$ = 150 SFU) solar flux conditions

ASSESSMENT

- During daytime hours, 10% of the drift profiles have gradients with magnitudes greater than 0.02 m/s/km for both LSF and HSF.
- During nighttime, 10% of the drift profiles have gradients with magnitudes greater than ~0.04 (~0.03) m/s/km during LSF (HSF).
- During the PRE period, 5% of the profiles have negative gradients with magnitudes greater than ~0.04 m/s/km for both solar flux conditions. This will result in a difference of 12m/s between vertical drifts in the bottomside (200km) and topside (500km) F-region ionosphere.

4. CONCLUDING REMARKS

- In this study, we used long-term (32 years) measurements made by the Jicamarca ISR to determine the magnitude and variability of the height variation of the equatorial F-region vertical ExB plasma drifts as a function of local time and solar flux conditions.
- We found that the mean height gradient in the vertical plasma drifts is relatively weak, typically < |1.00| m/s per 100 km, for most local times except a few hours around sunrise and sunset.
- We identified an increased positive mean height gradient around sunrise, which seems to be a counterpart to the negative height gradients observed in the past. We associate the gradients around sunrise to decelerating zonal plasma drifts (second term on the RHS of equation 1) which are expected to occur around that time.
- Finally, our results indicate that significant height gradients in vertical drifts can exist in the evening sector causing difficulties when relating drifts measured by sensors on satellites to bottomside F-region stability conditions and to equatorial spread F.

REFERENCES

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