First climatology results of equatorial vertical drifts derived from new medium power ISR observations at Jicamarca

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1. INTRODUCTION AND MOTIVATION

Introduction

- The vertical component of equatorial F-region drifts is an important manifestation of the ionospheric electrodynamics at low latitudes. For instance, the equatorial vertical plasma drifts are known to contribute to the generation of equatorial plasma bubbles (EPBs).
- The Jicamarca Radio Observatory (JRO) has provided equatorial drift measurements through its high-power incoherent scatter radar (ISR) system.

Motivation

- Two solid-state transmitters with a combined peak power of ~200 kW were installed at Jicamarca in 2022.
- Previous Jicamarca radar experiments relying on MW transmitters [1] limited the traditional ISR operations (i.e., < 40 days per year).
- The new transmitters enable a new ISR mode, referred to as medium power ISR (MP ISR), and semi-routine observations (i.e., > 200 days per year).

➢ **Here, we present and discuss results of a fundamental and important examination of the first year of MP ISR vertical drift measurements.**

2. RELEVANCE

- We seek a better understanding of the short-term (day-to-day) variability of the ionospheric drifts. However, measurements of drifts made with the Jicamarca ISR generally do not exceed a total of ~20 days per year with only 4-5 days of consecutive measurements.
- The limitation in the traditional Jicamarca ISR measurements might also impact our ability to determine seasonal and solar flux effects. This is because ISR observations have been non-uniformly distributed over a somewhat wide range of days and solar fluxes. Additionally, it takes decades for enough measurements to be collected before they can be used in seasonal studies, for instance.

➢ **The new MP ISR measurements expand the observational capabilities of the JRO. They will allow a better understanding of the short- and long-term variability of equatorial ionospheric drifts.**

3. RESEARCH QUESTIONS (RQs)

- **RQ1.** Can MP ISR measurements reproduce the expected diurnal and seasonal behavior of vertical drifts?
- **RQ2.** To what extent do the MP ISR measurements agree with predictions by empirical models of the vertical drifts?

4. MEASUREMENTS

- **Figure 1** includes pictures of the Jicamarca Radio Observatory (left) and the new kW transmitters (right).
- To obtain line-of-sight drift measurements with ISR, two radar beams are pointed near-perpendicular to the geomagnetic field to produce narrow spectra [2].
- The doppler shifts from fitting the narrow spectra become the drift value reported by Jicamarca.

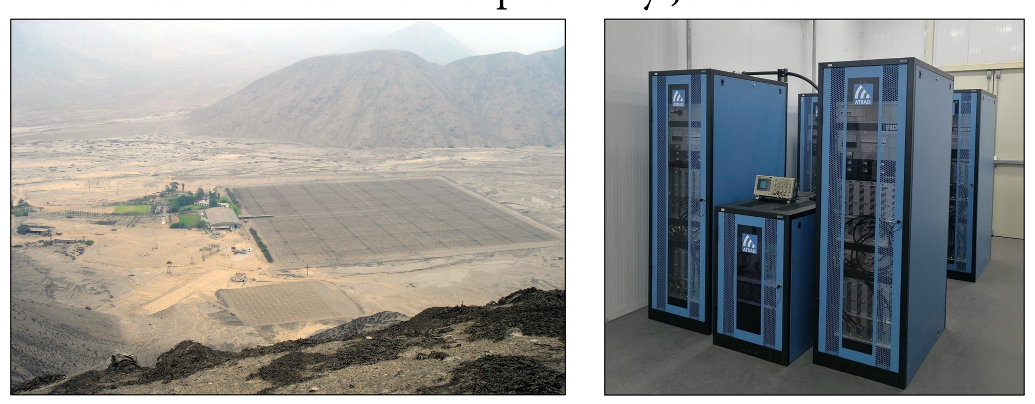

Figure 1. (Left) The Jicamarca Radio Observatory. (Right) The two new 96 kW solid-state transmitters (Reproduced from [3]).

5. ANALYSIS

- **Figure 2** shows MP ISR (a) echoes and (b) vertical plasma drift estimates from observations on 4 February 2024.
- Strong coherent echoes associated with equatorial spread F (ESF) are seen after sunset and before local midnight (i.e., post-sunset).
- Please note that vertical drift estimates were not provided at times and heights with strong coherent echoes.

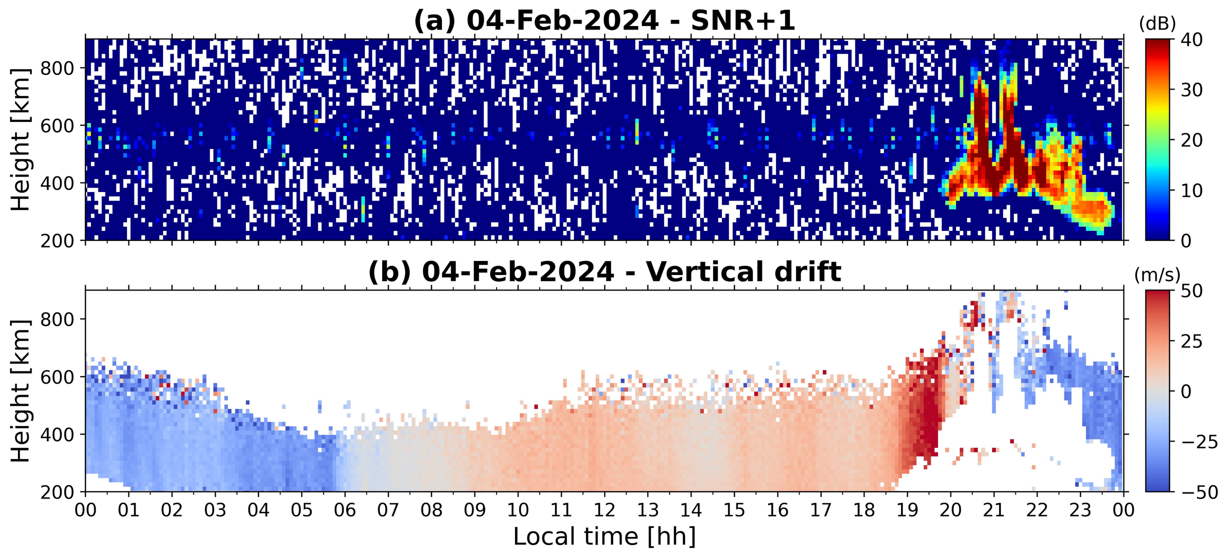

Figure 2. (a) Range-Time-Intensity map of MP ISR coherent echoes and (b) vertical plasma drift estimates for 4 February 2024.

- In a similar methodology to Smith et al. [4], we computed height-averaged (200-400 km) drift values that are representative of F-region heights.
- **Figure 3** shows (a) a zoomed-in view of drift measurements at F-region heights for 4 Feb. 2024 and (b) a 15-minute height-averaged drift curve obtained for our analyses.

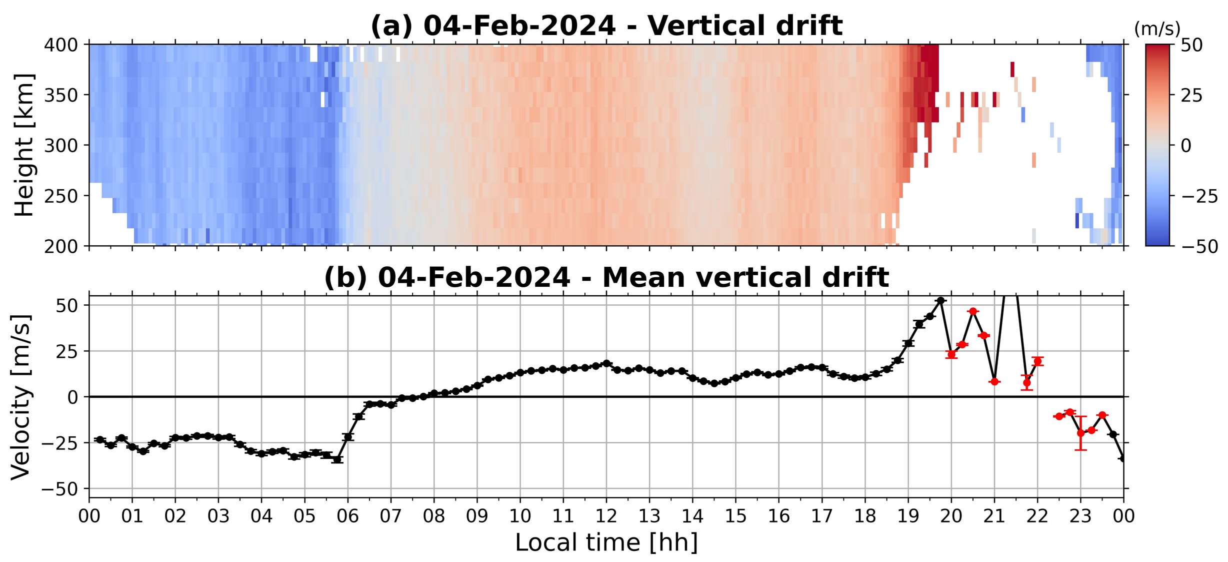

Figure 3. (a) Vertical plasma drifts at ionospheric F-region heights and (b) corresponding mean drift values for MP ISR observations on 4 Feb. 2024. 15-minute weighted averages (i.e., inverse-variance weighted means) were computed to obtain values. Values plotted in red indicate 15-minute bins with < 15 available F-region drift measurements due to ESF.

- **Figure 4** illustrates the availability of (a) MP ISR and (b) Jicamarca ISR observations between 1 Oct. 2023 and 31 Oct. 2024.
- We performed our analysis on all 300 MP ISR observations.

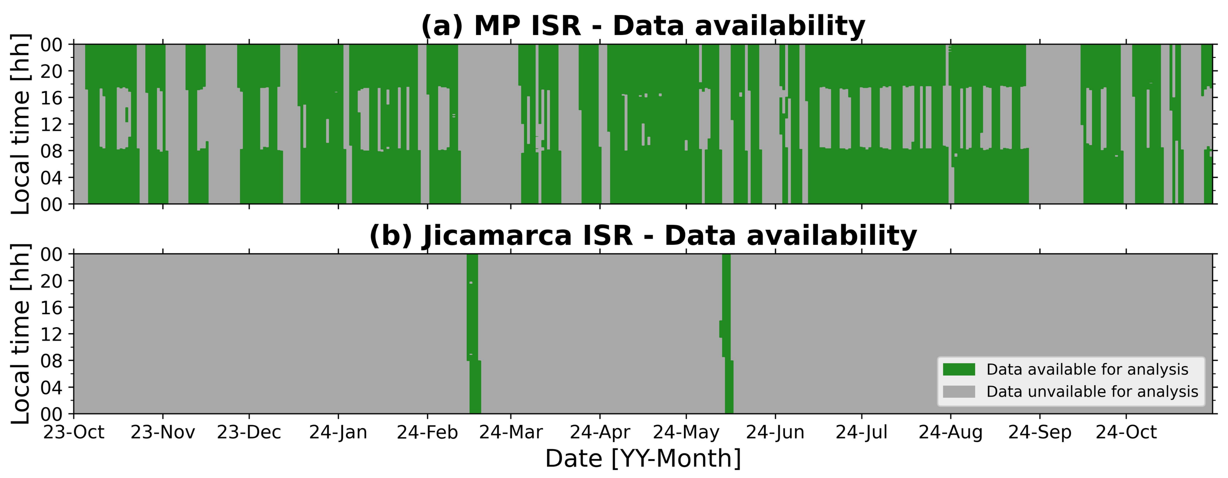

Figure 4. Availability of drift observations for (a) MP ISR and (b) the Jicamarca radar during the first year of operation in a standard mode.

6. RESULTS AND DISCUSSION

- We discuss the results of our analysis in **Sections 6.1 and 6.2.**
- Mean drifts obtained using > 15 vertical drift measurements made during geomagnetic quiet time (Kp < 4 at the time of measurement and for ~ 9 hours prior) are included in our results.
- Mean drifts were sorted by season. Seasons were defined as ± 45 days centered around the 21 of March, June, September, and December. Equinoxes were combined to increase the availability of observations during that season.

6.1. MP ISR CLIMATOLOGY

- Here, we present the first quiet-time climatology results for the MP ISR vertical plasma drift measurements.
- **Figure 5** shows scatter plots of mean vertical drift daily curves derived from the observations made between 1 Oct. 2023 and 31 Oct 2024.

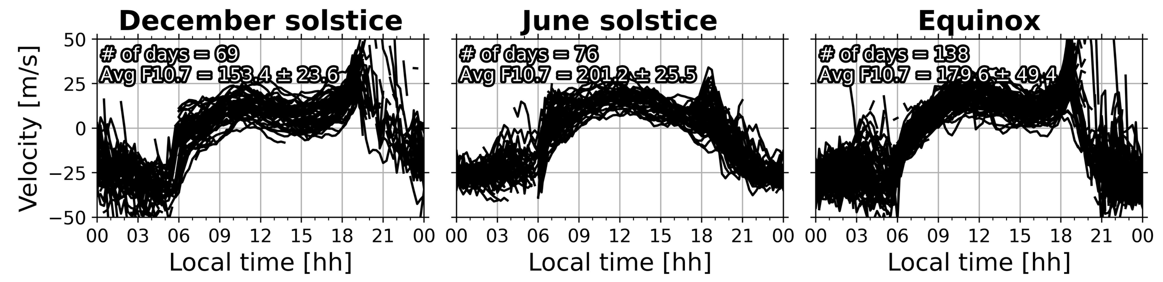

Figure 5. Daily mean vertical plasma drift curves from MP ISR observations sorted by season. Panels are annotated with the number of observations in each season and the average daily F10.7 solar flux index in solar flux units, as well as the F10.7 standard deviation.

- The results in Figure 5 illustrate the day-to-day variability of vertical drifts for different seasons.
- The results also show the overall diurnal behavior of the drifts in all seasons, with positive (upward) drifts during the day and negative (downward) drifts at night.
- To aid our analyses and interpretation of results, **Figure 6** shows average curves (climatology) for each season.

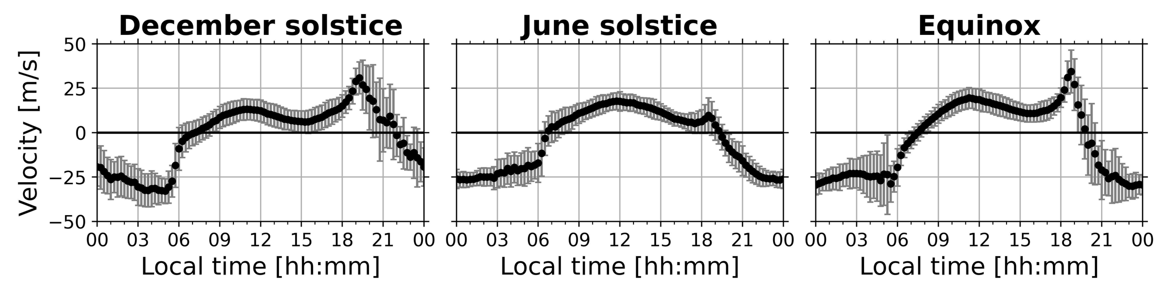

Figure 6. Quiet time climatology of MP ISR vertical plasma drifts. Error bars quantify the standard deviation of mean drift values used in averaging.

- The results in Figure 6 show, more clearly now, the typical diurnal and seasonal variation of the drifts.
- Figure 6 shows the well-known pre-reversal enhancement (PRE) of the vertical drifts that is commonly observed between 18 and 20 LT, particularly during December solstice and Equinox. Figure 6 also shows that the PRE peak is less pronounced during June solstice, which explains the reduced occurrence of post-sunset ESF compared to other seasons [4].

➢ **The results in Figures 5 and 6 show that one year alone of MP ISR measurements already captures well the overall behavior of the vertical drifts, including the diurnal and seasonal variations (RQ1).**

6.2. COMPARISON WITH EMPIRICAL MODELS

- Here, we present a comparison between our MP ISR climatological vertical plasma drifts and drifts from two empirical models.
- **Figure 7** shows our MP ISR drifts and the drifts predicted by the SF99 [5] climatological model and drifts predicted by the height-dependent SR20 [6] machine learning-based empirical model.

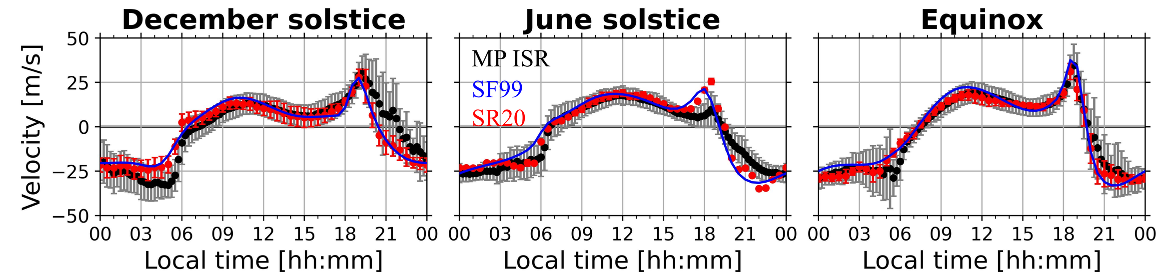

Figure 7. Quiet time drifts reproduced from MP ISR (black) analyses, SF99 model (blue), and SR20 model (red). Inputs to the SF99 model are local time and F10.7. Inputs to the SR20 model are local time, F10.7, and height (350 km).

➢ **The results in Figure 7 show that the first year of MP ISR measurements can reproduce well the behavior and magnitudes predicted by empirical models created using longer term (i.e., tens of years) measurements made by the traditional Jicamarca ISR mode (RQ2, 1st finding).**

- While Figure 7 shows that the mean MP ISR drifts capture the overall mean behavior of the drifts predicted by empirical models, a few peculiarities can be observed. Here, we focus on the behavior noticed between 04:00-07:00 LT.
- To assist our analyses, **Figure 8** shows the drift acceleration (computed as $\Delta v/\Delta t$ between consecutive drift values) in the late-night and near dawn for the MP ISR climatology and the empirical models.
- For all seasons, the MP ISR climatological drifts have the largest acceleration values. SF99 greatly underestimates the climatological acceleration values.

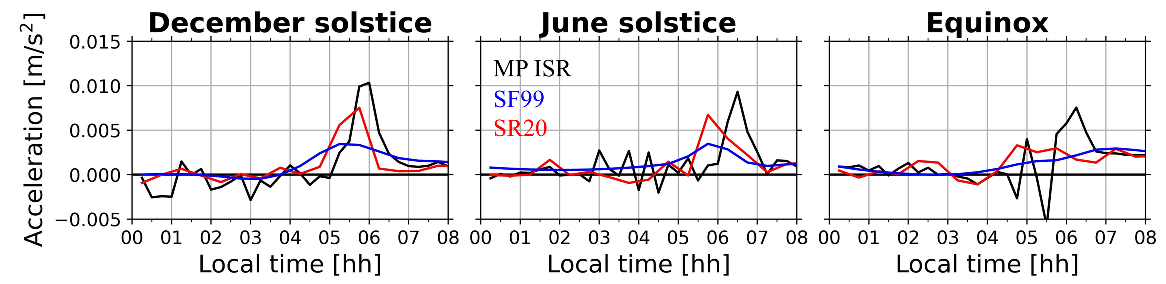

Figure 8. Late-night and dawn quiet time drift acceleration values from MP ISR climatology (black), SF99 (blue), and SR20 (red) at 350 km.

➢ **The MP ISR results in Figure 8 reinforce the SR20 predictions of a rapider negative-to-positive drift change near dawn than those predicted by SF99 (RQ2, 2nd finding).**

7. MAIN FINDINGS

- We addressed the task of examining the new drift measurements made by the MP ISR mode that is now available at Jicamarca. More specifically, we investigated how the new drifts measured over 1 year match expectations based on previous studies and observations made by the traditional Jicamarca ISR.
- We found that the MP ISR measurements capture well the expected diurnal behavior of quiet time vertical drifts, including the seasonal variations in the PRE **(RQ1).** These findings are illustrated in Figures 5 and 6.
- Furthermore, we found that 1 year alone of MP ISR measurements was able to reproduce most of the features predicted by climatological models developed with long-term (i.e., tens of years) traditional Jicamarca ISR drift measurements **(RQ2, 1st finding).** A noticeable peculiarity can be seen around dawn. The MP ISR results reinforce SR20 results showing a rapider negative-to-positive drift change than those predicted by SF99 **(RQ2, 2nd finding).** These findings are illustrated in Figures 7 and 8.

ACKNOWLEDGEMENTS AND REFERENCES

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[1] Kudeki, E., Bhattacharyya, S., and Woodman, R. F. (1999), A new approach in incoherent scatter F region E × B drift measurements at Jicamarca, JGR Space Phys, 104, 28145-28162.
[2] Milla, M. A. and Kudeki, E. (2011), Incoherent Scatter Spectral Theories—Part I: A General Framework and Results for Small Magnetic Aspect Angles, IEEE Tran Geo Rem Sens, 49, 315-328.
[3] Kuyeng, K., Condor, P., Manay, E., Scipión, D., and Milla, M., Preliminary results of new operation mode JULIA Medium Power at JRO, in 2023 CEDAR workshop (June 25-30).
[4] Smith, J. et al. (2016), Coherent and incoherent scatter radar study of the climatology and day-to-day variability of mean F region vertical drifts and equatorial spread F, JGR Space Phys, 121, 1466-1482.
[5] Scherliess, L. and Fejer, B. G. (1999), Radar and satellite global equatorial F region vertical drift model, JGR Space Phys, 104, 6829-6842.
[6] Shidler, S. A. and Rodrigues, F. S. (2020), Modeling equatorial ionospheric vertical plasma drifts using machine learning, Eart Pl Space, 72(102).