Seasonal and solar flux variations in the occurrence of equatorial *F*-region UHF radar echoes observed by AMISR-14 at the Jicamarca Radio Observatory

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Abstract: Coherent backscatter radar observations made at the Jicamarca Radio Observatory (JRO) have contributed significantly to our understanding of equatorial spread F (ESF). These observations, however, have been made predominantly at VHF (50 MHz). The deployment of the 14-panel version of the Advanced Modular Incoherent Scatter Radar (AMISR-14) at Jicamarca provided an opportunity for radar observations of ESF at UHF (445 MHz) [1]. Here, we present a summary of semi-routine observations carried out between August 2021 and October 2022. The observations were made with a 10-beam *F*-region mode that was used to scan the *F*-region in the magnetic equatorial plane. **Analyses of a total of 234 observation days allowed us to determine the behavior of the UHF echoes during geomagnetic quiet periods as a function of time and height, as well as season. The results confirm that the occurrence of UHF *F*-region echoes is controlled by the occurrence of ESF. Additionally, the multi-beam observations allowed us to confirm the absence of strong local (< a few 100s of km) zonal variations in the climatology of echoes.** We also compared the UHF observations made by AMISR-14 with collocated VHF measurements made by the Jicamarca Unattended Long-term studies of the Ionosphere and Atmosphere (JULIA) system. **The overall behavior in UHF echo occurrence is similar to that observed in VHF.** Differences in the absolute occurrence rates are due to differences in radar parameters.

1. RELEVANCE

This study is relevant to the development and application of advanced radar systems for fundamental and applied investigations of the geospace environment. The study is also relevant to space weather research at low latitudes. More specifically, it addresses investigations related to low-latitude ionospheric *F*-region irregularities.

2. SCIENCE QUESTIONS (SQ)

- ❑ **SQ1:** How do equatorial *F*-region UHF echoes vary with local time and height for different seasons and solar flux conditions?
- ❑ **SQ2:** To what extent do the 2D observations by AMISR-14 show any local (within a few 100s of km) variations in UHF echo climatology?
- ❑ **SQ3:** How does the AMISR-14 (UHF) echo climatology compare with the JULIA (VHF) echo climatology?

3. METHODS

- ❑ Following the approach used by [2], we analyzed Range-Time-Intensity (RTI) maps for each beam of 234 AMISR-14 *F*-region mode observation days and produced an *F*-region echo detection map for each RTI map. **Figure 1** shows an example of this analysis for 5 February 2022.
- ❑ **Echo detection:** Detection maps were determined based on the number of echoes (50) above a threshold signal-to-noise ratio (SNR) (-8 dB) within local time (5 minute) versus height (15 km) bins. Only geomagnetically quiet observation days (Kp during observations and previous twelve hours had to be lower than 4) were used to obtain echo occurrence rates. A total of 175 quiet observation days were available for our analysis.
- ❑ **Occurrence rates:** The occurrence rates were computed as the fraction of the number of echo detections in each local time versus height bin over the total number of observation days in the relevant season. Observations were grouped into Mar./Sep. equinoxes and Jun./Dec. solstices. The results are summarized in **Figure 3.**

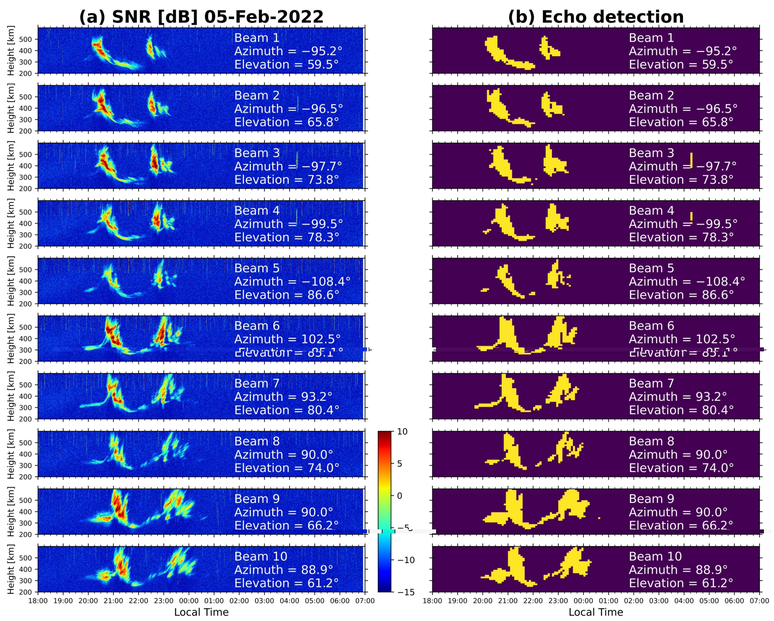

Figure 1. Beams from west (top) to east (bottom) are shown with the beam number, azimuth angle, and elevation angle indicated in each panel. (a) RTI maps of the observations made by the 10-beam AMISR-14 *F*-region mode. (b) Maps indicating the occurrence (yellow) or absence (purple) of echoes.

4. RESULTS AND DISCUSSION

- ❑ **Figure 2** shows RTI maps for observations made on 6 March 2022. It shows that, given the spatio-temporal dynamics of *F*-region irregularities, echoes observed by the westmost beam can differ substantially from echoes observed by the eastmost beam. On a given day, echoes are not evenly distributed.
- ❑ **Figure 3** shows the expected seasonal variation in the *F*-region echo occurrence rates, with the lowest rates during June solstice [3] **(SQ1).** It also shows a lack of zonal variability in the occurrence rates for local zonal distances (~ 400 km in zonal distance at 350 km in height) observed by AMISR-14 **(SQ2).**
- ❑ **Figure 4** shows beam 6 (close to vertical) occurrence rates and changes associated with solar flux effects. The rates reach higher altitudes for 2022 September Equinox than 2021 September Equinox [4] **(SQ1).** See the highlighted rows in **Table 1** for the average solar flux index (F10.7) for both seasons.

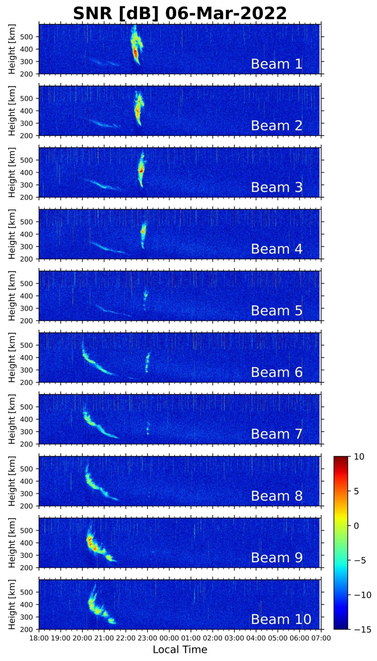

Figure 2. Example of AMISR-14 RTI maps for observations made on 6 March 2022.

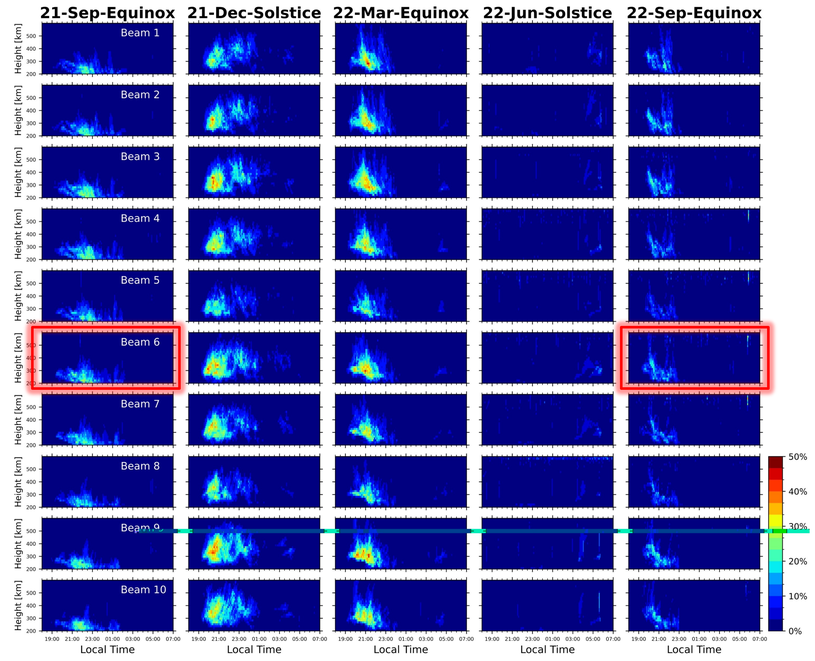

Figure 3. Occurrence rates of *F*-region echoes observed by AMISR-14 for different seasons (columns, labelled YY-Month-Season) and for different beams (rows). The red boxes highlight panels reproduced in Figure 4.

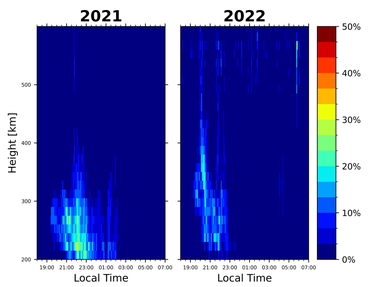

Figure 4 (above). Occurrence rates (beam 6) during 2021 and 2022 September equinoxes.
Table 1 (below). Average daily F10.7 (SFU) per season. The red boxes highlight values for Sep. equinoxes in Figure 4.

Season	Average F10.7
21-Sep-Equinox	86.6
21-Dec-Solstice	96.7
22-Mar-Equinox	119.1
22-Jun-Solstice	128.2
22-Sep-Equinox	131.1

- ❑ **Figure 5** shows RTI maps for JULIA and AMISR-14 from observations made on 26 November 2021.
- ❑ We analyzed 179 JULIA observation days between August 2021 and July 2022, generating detection maps based on the number of echoes (20) above a threshold SNR (-20 dB) within local time versus height bins of the same resolution as our analyses with AMISR-14 RTI maps. Only geomagnetically quiet observation days, determined as described in Section 3, were used to obtain JULIA occurrence rates, leaving 143 quiet days for our analysis.
- ❑ The results in **Figure 6** show that, overall, the behavior of occurrence rates derived from each instrument matches well **(SQ3).**

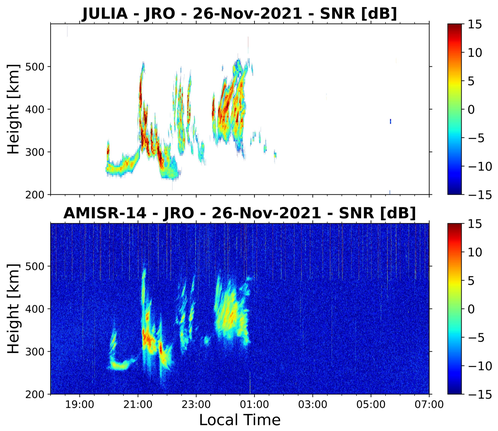

Figure 5. RTI maps for same-day JULIA (top) and AMISR-14 (beam 6, bottom) observations made on 26 November 2021.

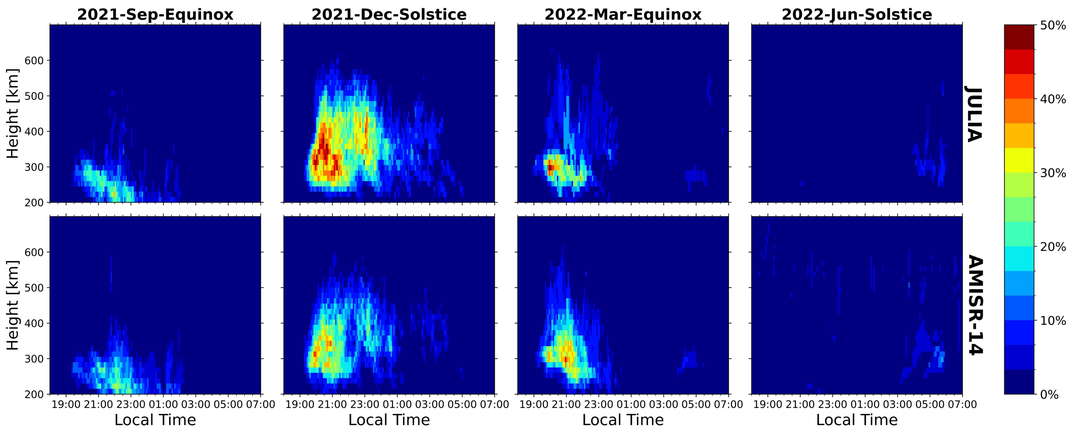

Figure 6. Dual-instrumented occurrence rates of *F*-region echoes grouped by season (columns, labelled YYYY-Month-Season). The instrument used to obtain the results is indicated to the right of each row. Occurrence rates for AMISR-14 are derived from beam 6 observations.

5. MAIN FINDINGS AND FUTURE WORK

- ❑ Results from the AMISR-14 10-beam *F*-region mode show that the occurrence rates of UHF echoes observed by AMISR-14 as a function of local time, height, season, and solar flux conditions follow the climatology of ESF in the Peruvian sector.
- ❑ Results from AMISR-14 show that *F*-region echo climatology does not show any significant variations over local zonal distances near Jicamarca.
- ❑ The overall occurrence of UHF echoes as a function of local time, height, and season is very similar to that derived from collocated VHF observations. Small, but noticeable, differences exist and can be attributed to differences in radar parameters and/or to differences in irregularity scale sizes (one order of magnitude: JULIA and AMISR-14 observe Bragg scattering caused by ~ 3 m and ~ 0.34 m irregularities, respectively).
- ❑ Specific experiments and analyses will be carried out in the future to better understand differences in the dual-frequency (VHF-UHF) observations.

REFERENCES

[1] Rodrigues FS, et al. 2015. *Geophys Res Lett* **42(13).**
[2] Zhan W, Rodrigues FS, Milla MA. 2018. *Geophys Res Lett* **45(15).**
[3] Fejer BG, Scherliess L, De Paula ER. 1999. *Journal of Geophys Res: Space Phys* **104(A9).**
[4] Smith JM, et al. 2016. *Journal of Geophys Res: Space Phys* **121(2).**

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