Quantifying the day-to-day variability in the bottomside ionosphere using Bistatic HF observations

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Abstract

The purpose of this investigation is to quantify the day-to-day variability of the bottomside ionosphere to better understand the contribution that traveling ionospheric disturbances have on day-to-day variability. To quantify day-to-day variations we use nearly continuously collected bistatic HF data from Coastal Ocean Dynamics Applications Radars (CODARs). The frequency modulated continuous wave (FMCW) waveforms of these radars can be used to extract group delay measurements from which the virtual height of an ionospheric layer can also be estimated. The cadence of observations is approximately 2 minutes for this investigation. We show results from several CODAR transmitters located along the Eastern coast of the United States, all ranging in transmission frequencies from 4 - 13 MHz collected from September to December of 2020-2023. The receiver was located near Clemson University. Here we present results showing the dominant frequencies of the virtual height oscillations as a function of day of month found using the Lomb-Scargle Periodogram. We compare the day-to-day observations of the dominant frequencies with standard metrics of geomagnetic indices and standard seasonal variation to determine if a correlation exists.

Methods

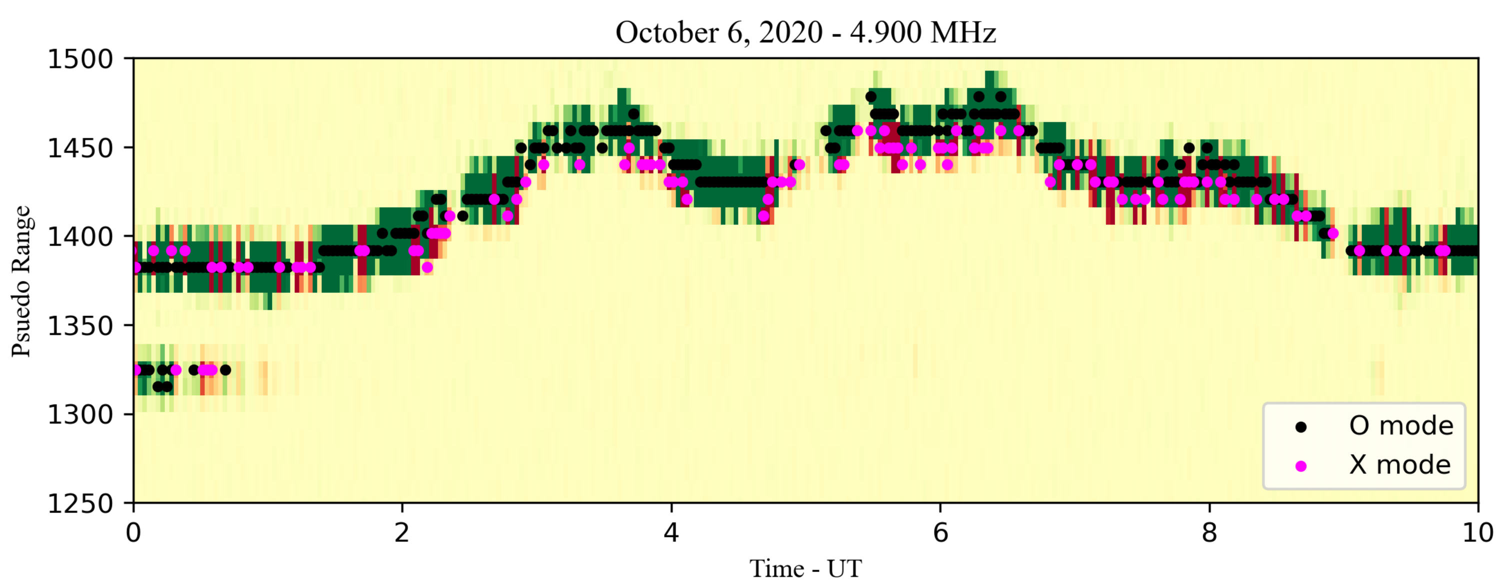

Fig 1. Here we show an example of a signal collected from a CODAR transmitter located in Western Florida. The red and green lines show the pseudo range of the collected signal after initial processing as described in Kaeppler et al 2020. The black and pink circles show the extracted pseudo range, color coded by propagation mode.

- For each night (1 – 9 UT) a peak finding algorithm, as shown in the figure above (black and pink circles), was used to extract the group range (propagation delay time: cΔt) of the collected signals. This was done for both O and X mode propagation.
- Using the group range an estimated virtual height can be calculated based on the technique described in Davies 1989.
- This was done for the months of September, October, and November in 2020-2022. These months were chosen based on data quality.
- The periodic variations in virtual height were then extracted using a Lomb Scargle Periodogram (a technique for categorizing periods in unevenly spaced data), which can be seen in Figure 3.
- The most dominant periods were then plotted as a function of day of month for each of the three months listed above to see the day-to-day variation.

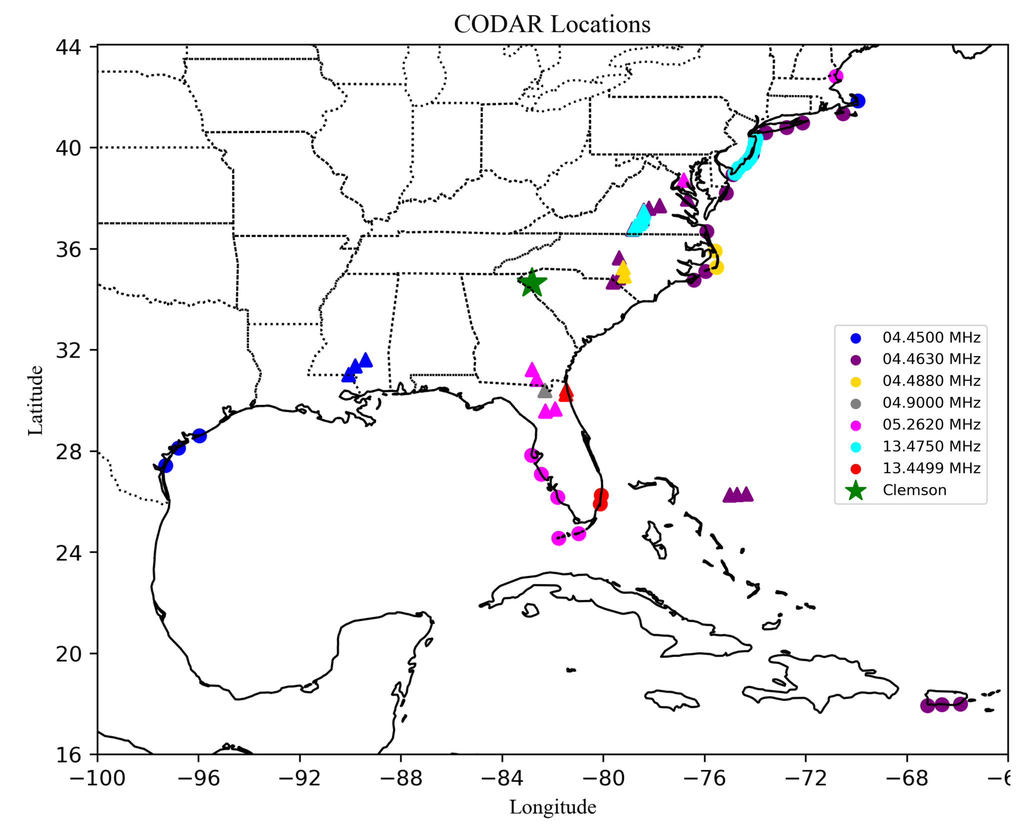

Fig 2. Here we show a map of all collected CODAR transmitters, color coded by transmission frequency. The circles represent the transmitter locations, and the triangles represent the assumed ionospheric reflection point for mirror like propagation. The green star labeled 'Clemson' is the location of the receiver used for all frequencies.

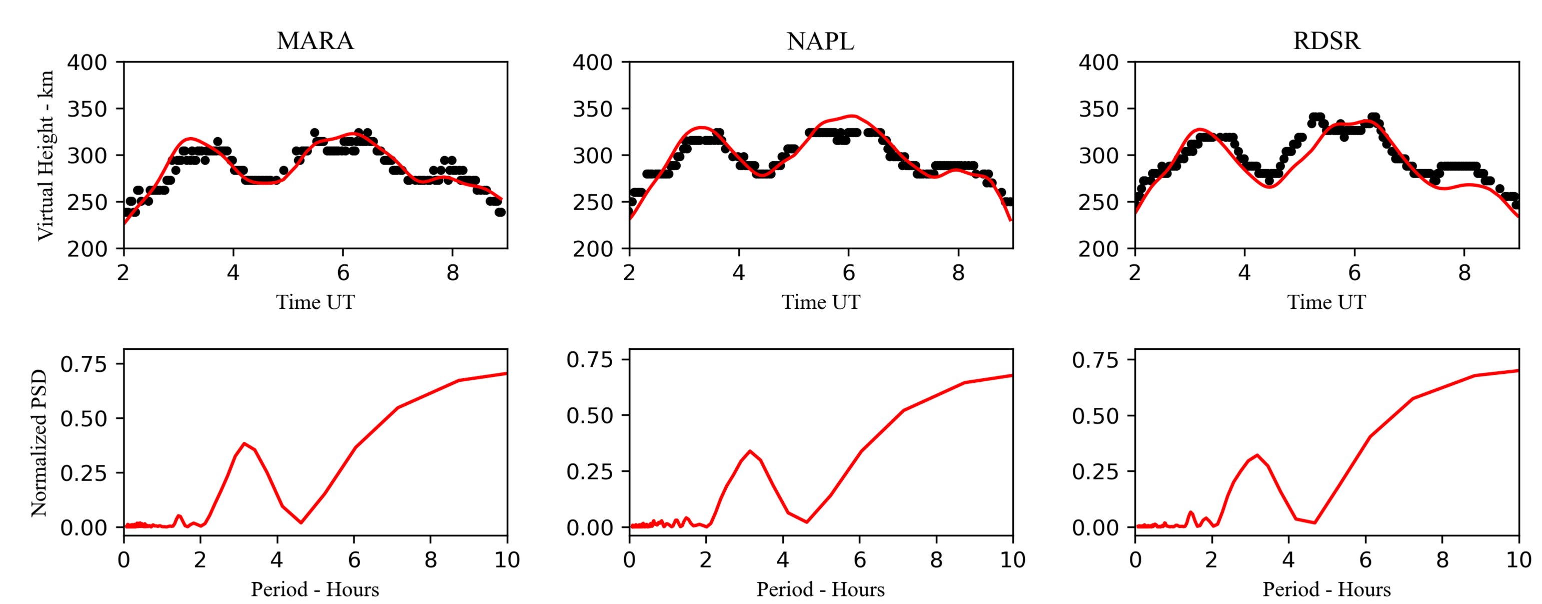

Fig 3. Here we show an example output of the calculated virtual height and periodogram of the trace in Figure 1. The top panel is showing the estimated virtual height (black circles) from three separate transmitters [MARA, NAPL, and RDSR] located along the western coast of Florida. With a transmission frequency of 4.900 MHz. The red line in the top panel is the reconstructed waveform based on the most prominent periods extracted from the periodogram in the bottom panel, i.e. the waveform was recreated using periods of approximately 3 and 8 hours.

Results

- Based on initial observations it can been seen that the most dominant periods day-to-day range from 2 to 4 hours. One possible cause of these periods could be Traveling Ionospheric Disturbances (TIDs). However, different transmitter locations and data sources must be considered to further support these claims.
- After initial inspection of the variation in Kp index, in general it does not appear to have much correlation with variations in virtual height of the corresponding days.

- **Future Work**: a similar study is planned using all other transmitters shown in Figure 2. Along with a more detailed case study on the day shown in Figure 3.

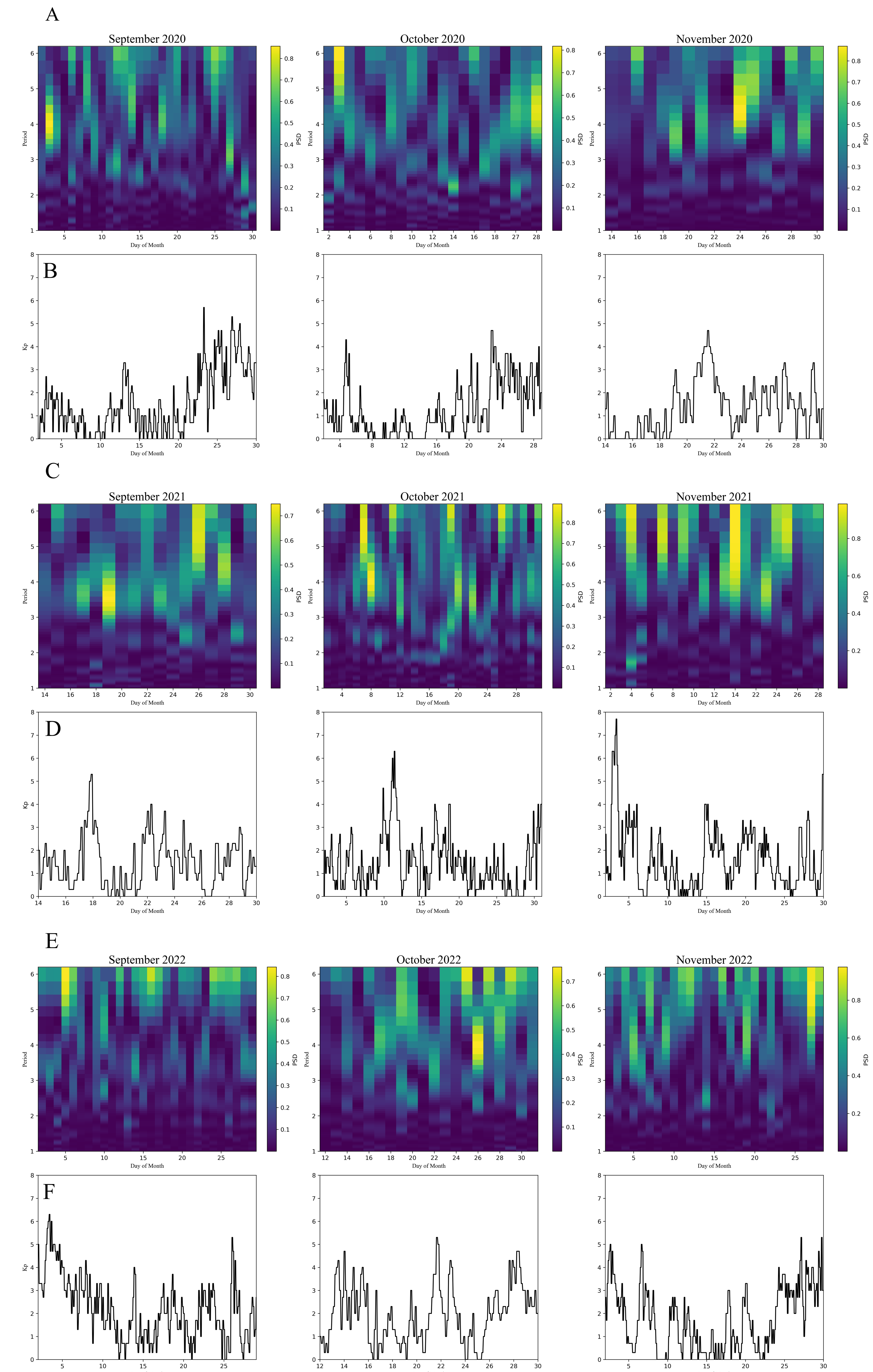

Fig 4. For figures A,C, and D we show dominant periods of oscillation as a function of day of month. For all three years the MARA transmitter was used to maintain consistency. Note, only statistically significant peaks were considered. Figures B, D, and F are showing the hourly averaged Kp index for each respective day of the month.

References
[1] Kaeppler et al 2020
[2] VanderPlas 2018
[3] Davis 1989