

High Performance Ionospheric Sounding

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Abstract

The application of digital receivers, digital signal processing and other advanced electronics and antenna technologies have become sufficiently mature and cost effective to be implemented into High Frequency radars for ionospheric sounding. When these technologies are used to improve the performance of the HF radar, new observational modes with greater resolution, sensitivity and precision are possible, which allow for discovery, research and renewed investigation of the ionosphere. This paper presents unique data from high performance ionosondes.

1 Introduction

Advances in digital technology at the turn of the century, such as low cost analog to digital converters and digital downconverter receivers, enabled the practical use of these technologies in ionosondes and High Frequency (HF) radars while still meeting the cost requirements of the users of these instruments[1,2]. These technologies, along with improvements in active receive antennas, high power solid state transmitters and transmitting antenna design, were combined into a new generation of high performance HF radar based on the NOAA Dynasonde[1]. This radar is also known as the Vertical Incidence Pulsed Ionospheric Radar (VIPIR). There are now eight of these instruments installed and several more in the planning stages. By using the improved technology to increase the overall capability of the instrument, there are more radar resources available to the experimenter to be applied to the observational objectives. Examples in this paper show the application of these radar resources to new modes of ionospheric sounding.

2 Impulse Response and Precision Range

Digital receivers and downconverters have precise impulse and frequency responses which are stable over time and between receivers. The impulse response of a raised cosine to the 4th power is the usual waveform[1], although the programmable digital downconverters allow for great flexibility in this choice. The narrow frequency response of the waveform, in both the receiver and the linear high power transmitter, allows for closely matched filtering and low cross-channel interference in both reception and transmission. The very predictable impulse response allows the experimenter to assign geophysical origin to small deviations of the data from this response.

The radar performance of the VIPIR typically affords 30dB to 40dB of single-pulse signal to noise ratio (SNR) on frequencies without interfering transmitters. Figure 1 shows that by fitting the theoretical impulse response of the receiver to the received samples, the precise range of a resolved reflection can be determined to within a few percent of the waveform width or about 150m, even for echoes where the ionosphere is not perfectly smooth and the echo shows some deviation from the ideal impulse response. Differential phase with frequency Dynasonde techniques [3] can also be used to obtain similar precisions, but these require more transmitted pulses and hence a longer observation time.

3 Rapid Scan Ionograms

The high single-pulse SNR allows echo characteristics to be obtained rapidly without a need for the complexities of pulse compression or the time of coherent integration. The result is shorter observation

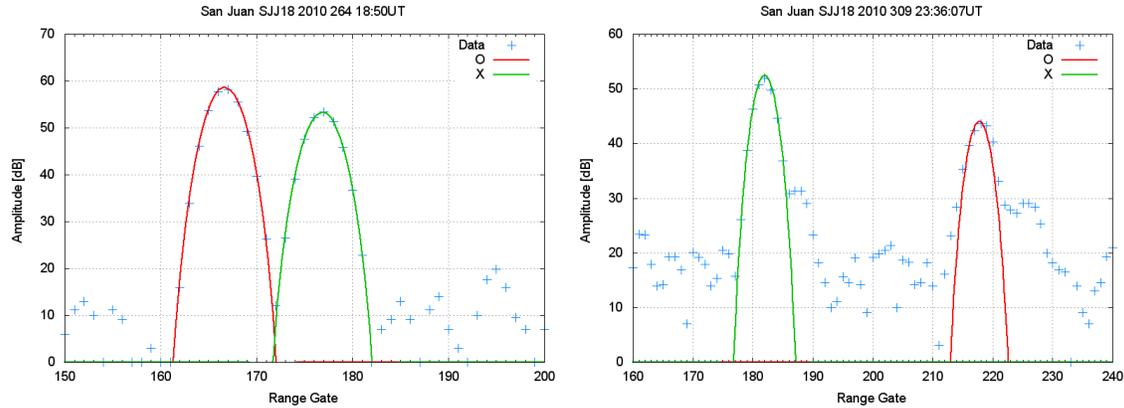


Figure 1: Received power from Puerto Rico indicating the receiver impulse response from a single receiver and linearly polarized antenna due to ionospheric reflections. The data are the blue + symbols. Lines represent impulse response models with range and amplitude values fit to the data. O mode and X mode echoes are distinguished from the associated ionogram and the relative phase shift of orthogonally polarized linear antennas (not shown).

times. Using only 4 pulses per transmitted frequency, an ionogram with a logarithmic frequency progression of 0.5% from 1 to 25 MHz can be produced in about 30 seconds. The low harmonics of the solid state transmitter and narrow emission band of the waveform make it practical to repeat these ionograms every minute on a long term basis without any practical interference to nearby spectrum users. A few station-years of one minute data have been taken at Boulder, CO and Wallops Island VA. Sequences of ionograms, such as in Figure 2, reveal the presence of ionosphere dynamics on the time scale of about a minute, even under quiet mid-latitude conditions.

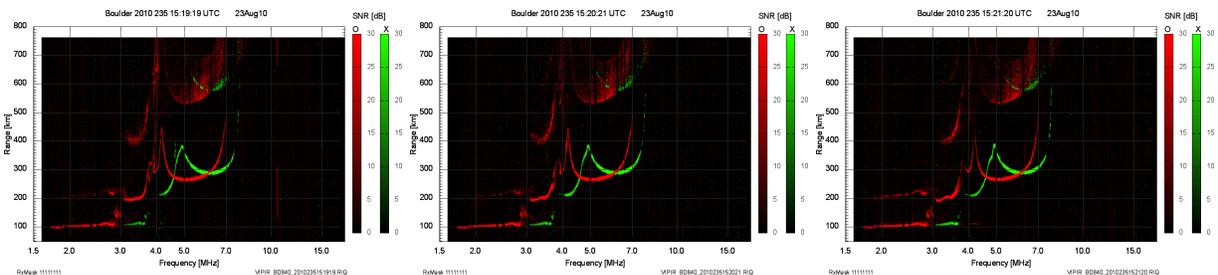


Figure 2: Ionograms from Boulder plotted as signal to noise ratio for separate O and X mode reflections. The duration of each sweep was 20 seconds and the measurements are taken 1 minute apart. Note the rapid variation in the F1 trace.

4 Shuffle Mode

The ability of the radar to transmit pulses with an arbitrary frequency pattern, at pulse rates subject to the 2% duty cycle limitation of the transmitter, allows for “shuffling” or interleaving two or more separate measurements on a pulse-by-pulse basis. In fact, since relatively long pulse repetition intervals (PRI) are needed to prevent range aliasing of multiple earth-ionosphere reflections, more efficient use of the transmitter duty cycle can be made by interleaving modes where the frequency changes by more than the receiver passband on alternating pulses. Figure 3 shows a sweep frequency ionogram and a fixed frequency measurement made simultaneously. The combined sweep and fixed frequency observations were repeated every 30 seconds. Such a mode reveals short time scale variations of reflections in the post-sunset E layer, which is barely visible in the sweep frequency data, and also shows short time scale variation in the lower F layer.

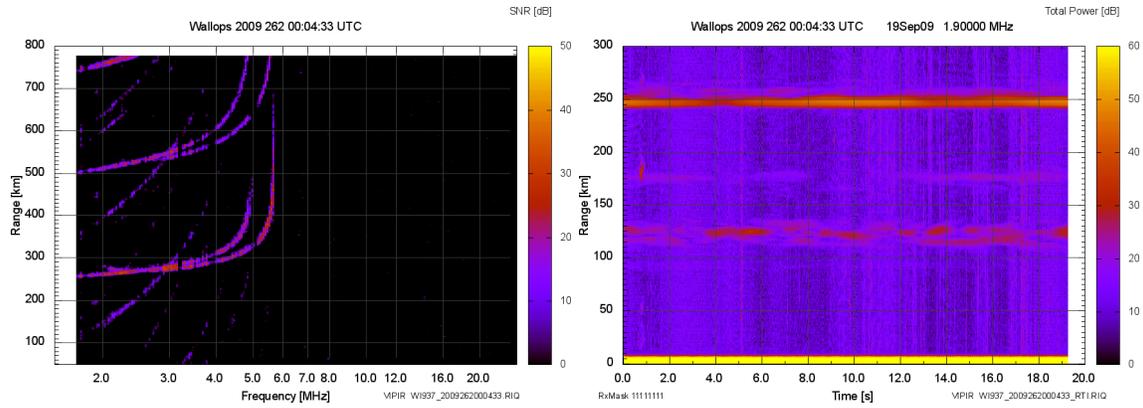


Figure 3: Shuffle mode data from Wallops Island showing an ionogram sweep (left) plotted in SNR and fixed frequency data at 1.9 MHz (right) plotted as total power vs range and time. The fixed frequency data show the variations in the E and F region reflection strengths over 20 seconds.

5 Meteor Trails

The plasma trails of ablating meteors are frequency evident in both the fixed frequency and ionogram mode data. The fixed frequency data isolate the rapid time variability of these echoes from the combined time and frequency changes in the ionogram mode, making interpretation of the data similar to other meteor radars. Figure 4 provides an example of meteor trails.

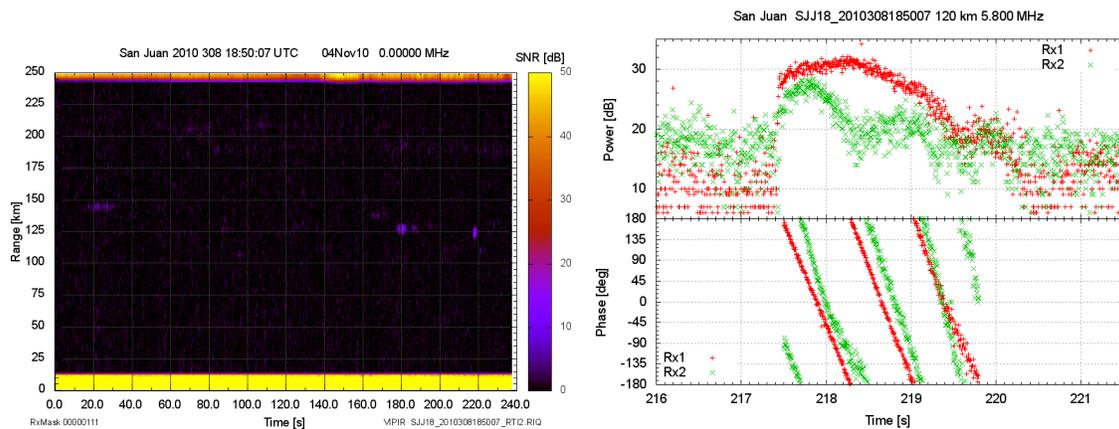


Figure 4: Meteor trails seen from Puerto Rico operating at a fixed frequency of 5.8 MHz. The left panel shows a Range-Time-Intensity plot of three meteor trails. The right panel selects the 3rd trail and shows the amplitude and phase of the received signals on two orthogonal antennas.

6 Data Summaries

Raw ionograms from a radar with eight receivers taking 16-bit inphase and quadrature samples every 10 microseconds make raw data files on the order of 30MB per ionogram. With compression, routine one-minute ionograms occupy 1TB per station-month. Even with animations, looking at 1440 ionograms per day is a daunting task. One way to manage this is to statistically remove the radar range from the data set and produce a daily plot of received amplitude versus frequency and time of day. Figure 5 is an example of such a plot. This graph reveals a wealth of information about the ionosphere, the instrument, the HF propagation environment and local sources of interference.

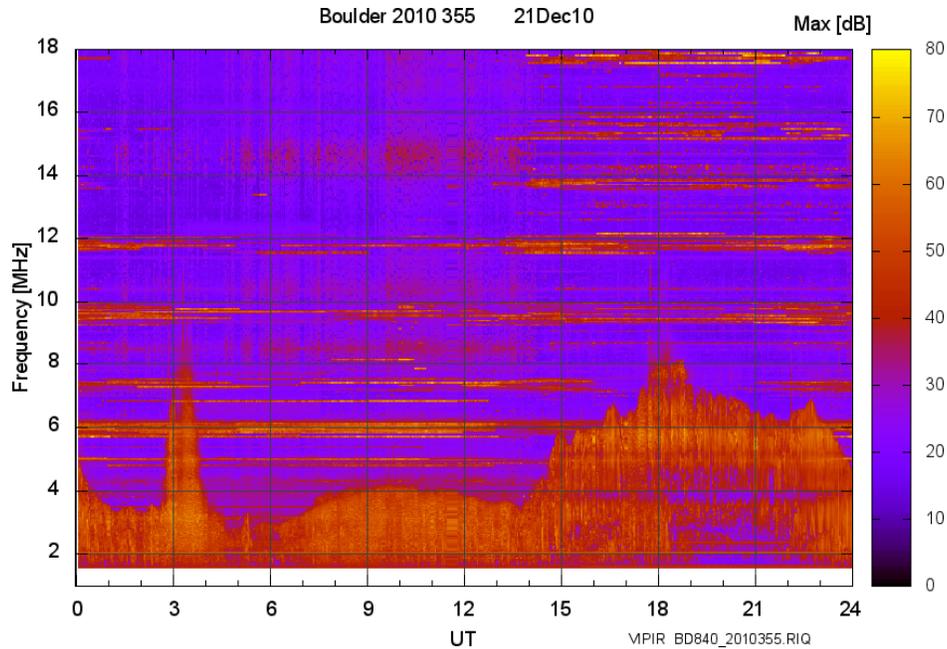


Figure 5: Maximum receiver output as a function of frequency and time of day for Boulder, CO on 21 December 2010. The maximum frequency reflected by the ionosphere is shown. The frequency schedule of HF broadcasters between day and night is apparent. Deviative absorption in the E-layer cusp is visible. System antenna patterns show up as horizontal features.

7 Conclusion

Advances in radar technology and engineering are able to produce more capable ionosonde and HF radar instruments at modest costs. These more capable instruments are being operated in new modes at 3 locations in the US. These new modes have revealed new details of the ionosphere. New data displays are being implemented to manage the increased data volume.

8 Acknowledgments

These instruments would not be possible without the craftsmanship of Dick Grubb and Robert Livingston. Instrument operations in the US are made possible in part by the NASA sounding rockets program, USGS Geomagnetism program and NOAA Space Weather program. This work is performed in cooperation with the US National Geophysical Data Center in Boulder, Colorado, USA.

9 References

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