# Characteristics of Es and F layer observed by CODAR SeaSonde HF radar

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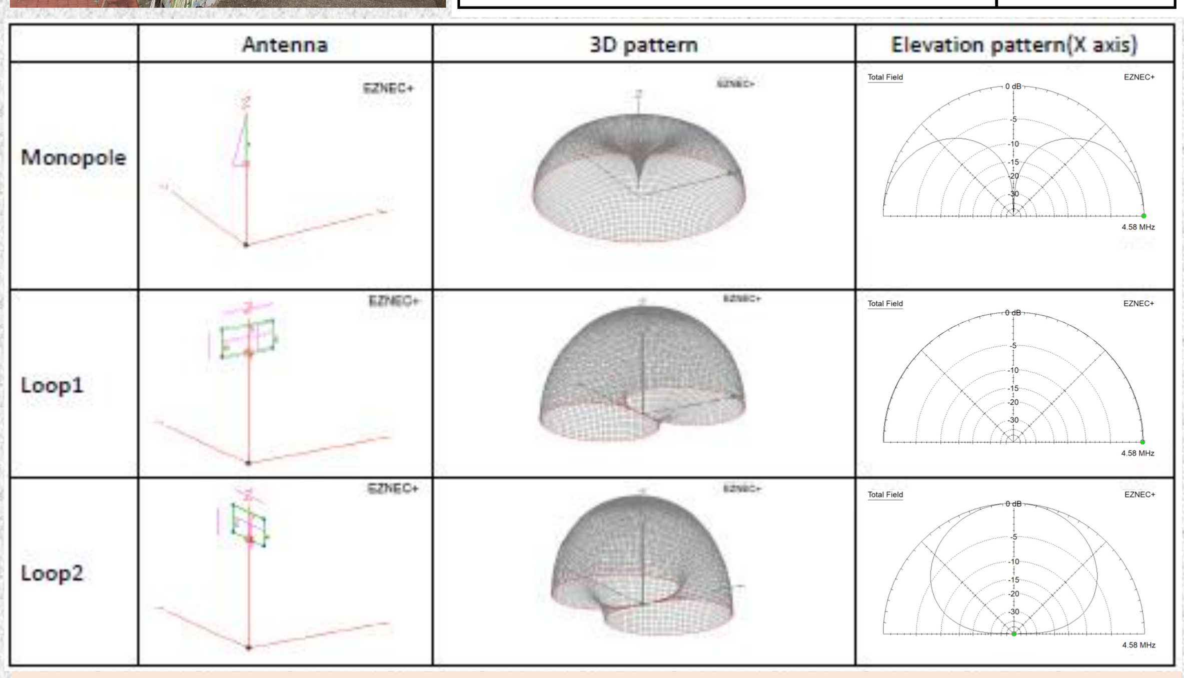
## Abstract

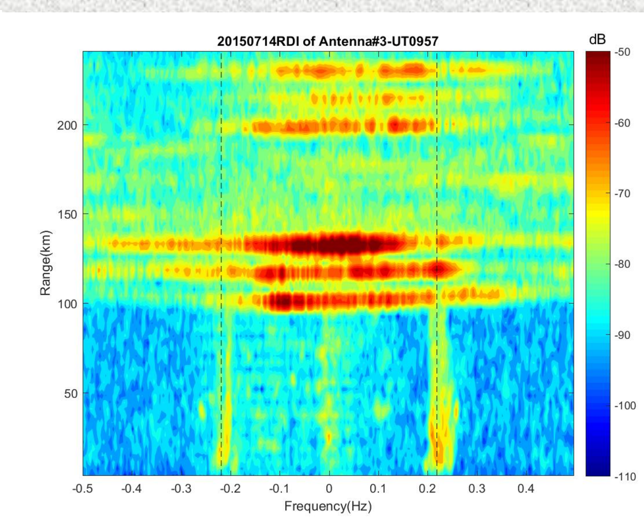
CODAR SeaSonde radar is designed exclusively for ocean remote sensing. However, the HF radar wave reflected from Ionospheric Es and F layers at high elevation angle, which are transmitted by a monopole antenna equipped at a CODAR SeaSonde, may severely interfere the sea echoes in a range approximately from 100km to 400km. In order to realize the characteristics of the ionospheric interference on the Doppler spectra of the CODAR radar echoes over Taiwan area, we develop an algorithm to distinguish and separate the ionospheric interferences from the normal sea echoes in the Doppler spectral domain. The data employed in this study were taken from the CODAR radar located at DATAN (121.0329667N, 25.0327500) for 2016. We find that the patterns of the range-local time distributions of the CODAR radar-detected Es layer echoes are in general agreement with those of the Es layer 3-meter field-aligned irregularity echoes observed by the Chung-Li VHF radar. In addition, the occurrences of the ionospheric interferences recorded by the CODAR radar are also highly correlated to the presences of the Es traces in ionograms observed by the ionosonde locate at Chung-Li City (121.247827E, 24.905056N). These features seem to suggest that the use of the ionosonde data combined with coherent VHF radar adjacent to the CODAR radar can provide useful information on the range and time of the ionospheric interferences occurred in the CODAR radar-detected sea echoes. By carefully removing the ionospheric interference, the data quality of the CODAR radar estimated ocean current and wave parameters can be significantly improved.

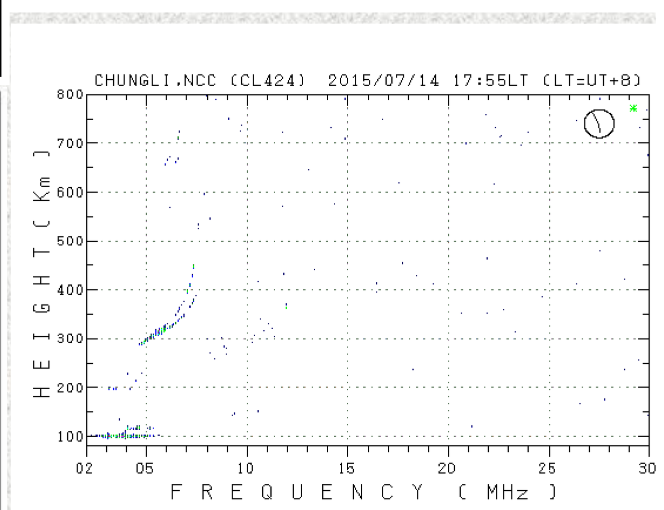
## Introduction & Method

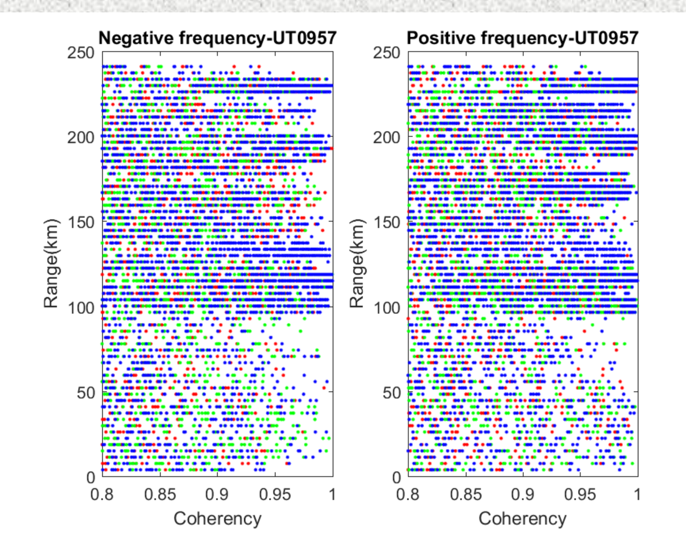
| Waveform | FMCW |
|---|---|
| Operating frequency(MHz) | 4.58 |
| Bandwidth(kHz) | -40.439 |
| Sweeps | 1024 |
| Sweep time(sec) | 1 |
| Blanking time(us) | 1945.6 |
| Blanking delay(us) | 8.6 |
| Range resolution(km) | 3.71 |
| Radial velocity resolution(m/s) | 0.03 |
| Effective depth(m) | 2.61 |
| Bragg wave length(m) | 32.75 |
| First-order Bragg frequency(Hz) | 0.218 |

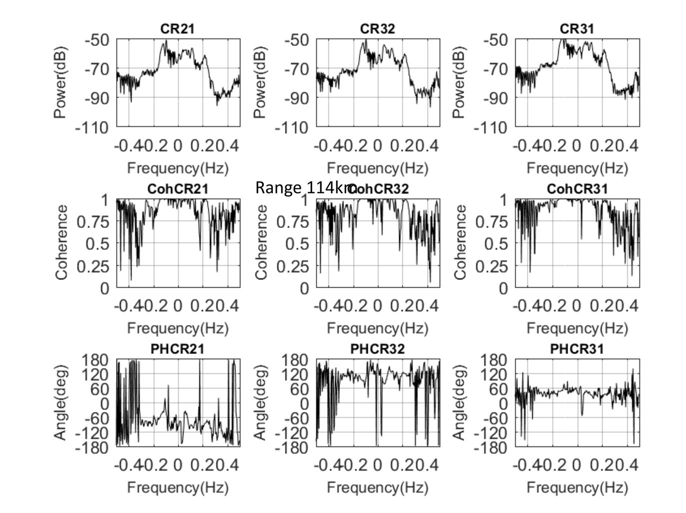



CODAR SeaSonde radar transmits frequency modulation continuous wave (FMCW) to observe sea surface. The compact antenna array contains a monopole antenna and two cross loop antennas that radiate patterns as shown in above figure. The acquisition time of a data file is about 17 minutes. For a long range type, the operating frequency is 4.58 MHz that corresponds to Bragg scale of 32.75 meters and Doppler frequency of sea echo is 0.218 Hz.

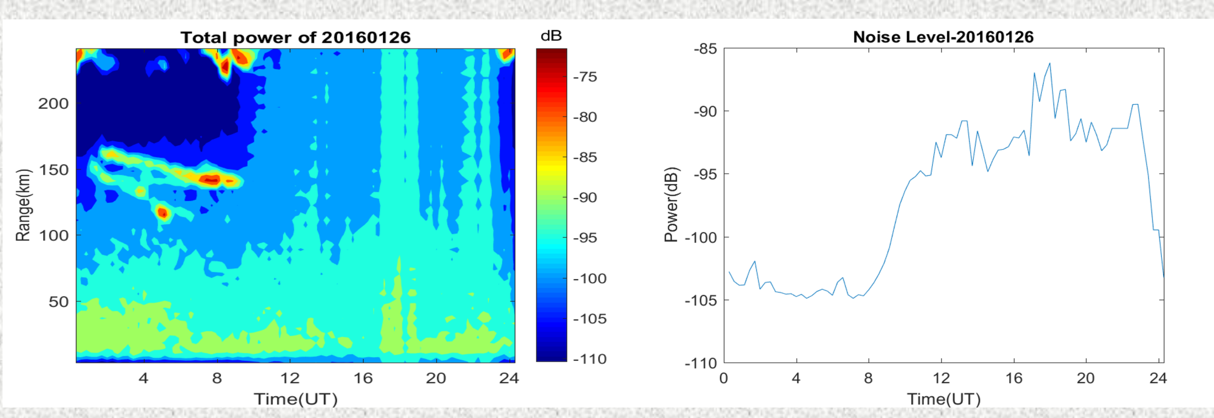



We can see from the figures that if there are traces in the ionogram, the corresponding ionospheric interference may present in sea echo Doppler spectrum in a range beyond 100 km. Notice that the coherences are high and the phases are stable in the cross spectral domain of ionospheric echoes. From the plot of coherence greater than 0.8, the dense property of CohCR21(red), CohCR32(green), and CohCR31(blue) can be seen in ionospheric echo region. Therefore, it is easy to specify the occurrence ranges of E layer and F layer echoes from the range-coherence plot.




HF radar echo power has large difference between daytime and nighttime which caused by the ionospheric absorption mainly in D region. Statistics show that noise level has approximately 15dB difference between day and night. In order to deal with this phenomenon, the recorded powers of the sea echoes are normalized by the noise level to achieve signal-noise-ratio (SNR).

## Results

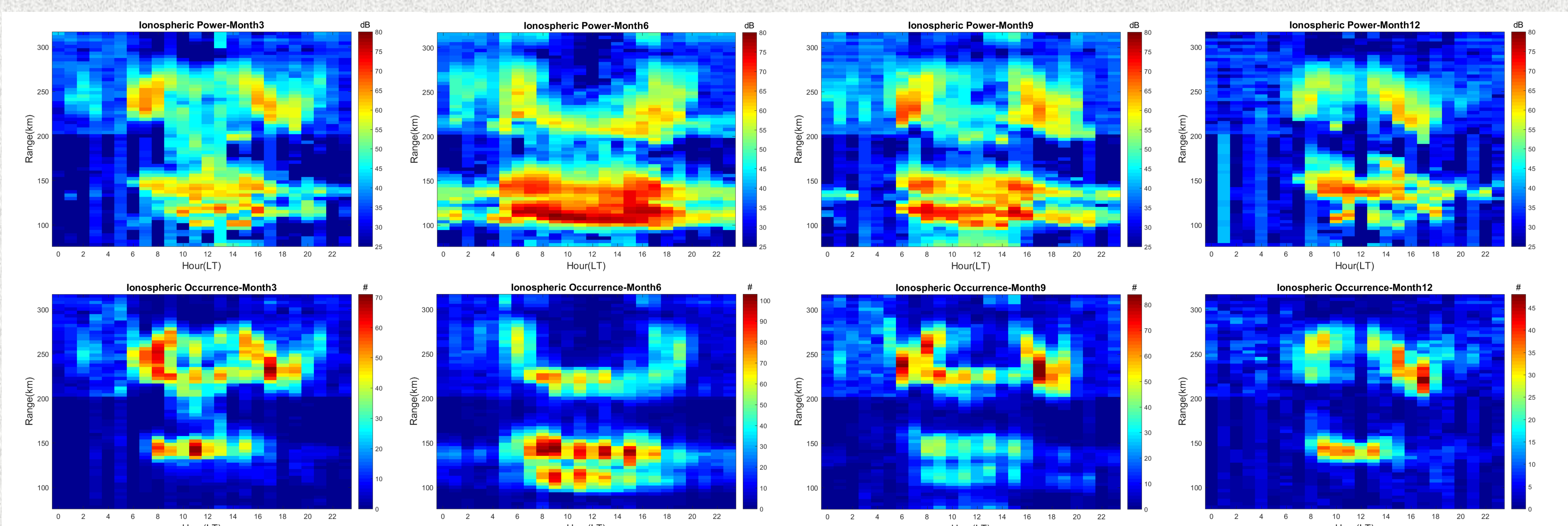
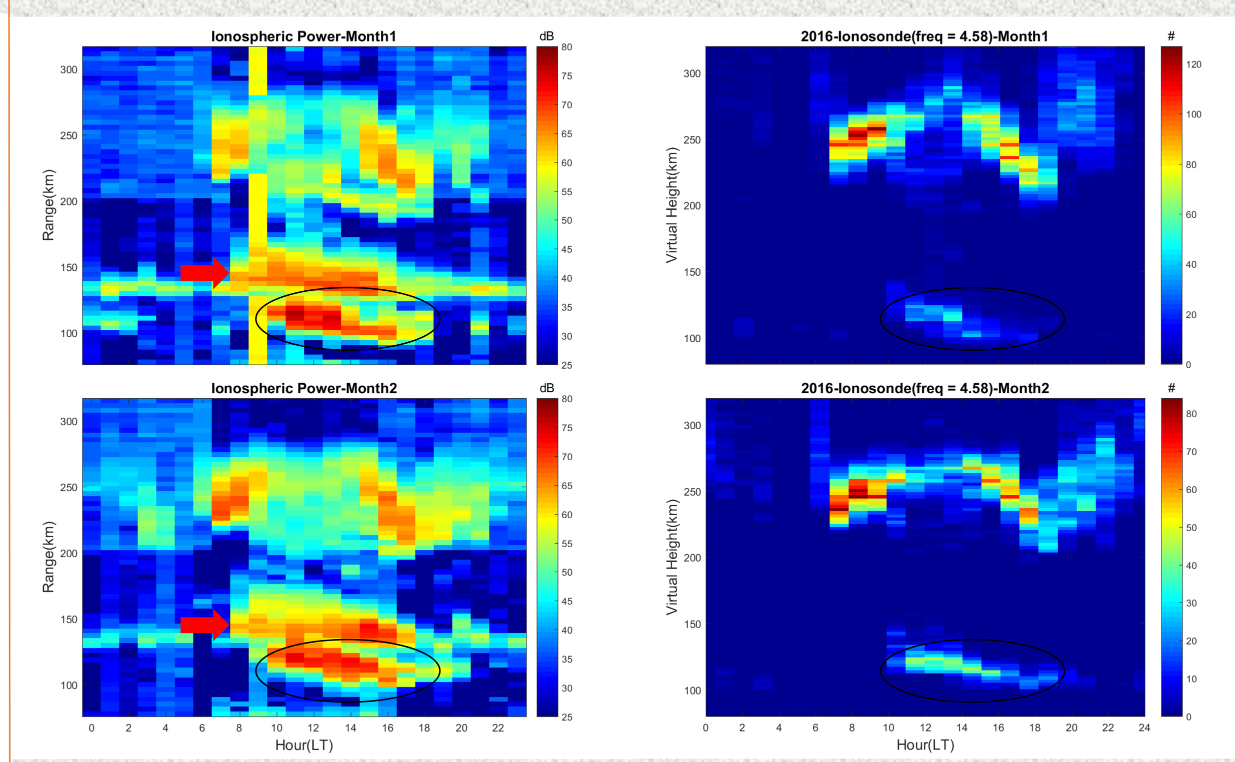
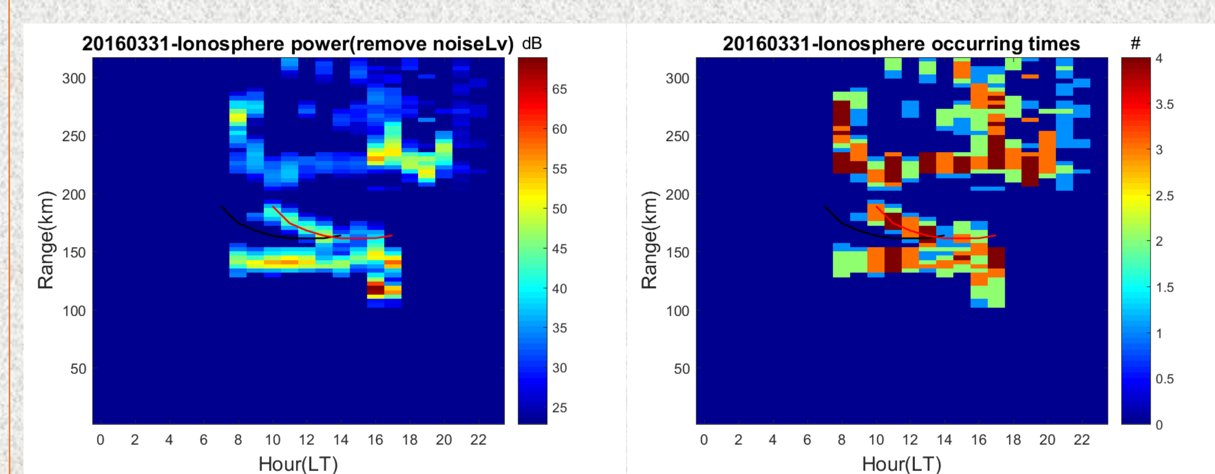



Figure shows equinoxes and solstices results. Upper row indicates signal to noise ratio of monthly statistic and lower raw is the accumulation of occurrence. Generally speaking, the greater number of occurrence corresponds to larger signal to noise ratio. However, it has some difference between them which caused by other interferences meeting the threshold of coherence of cross spectrum. Overall, the signal to noise ratio result has more spatial details for analysis.

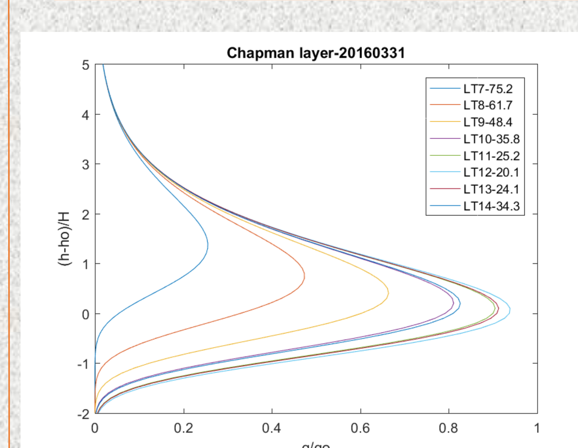
## Discussion

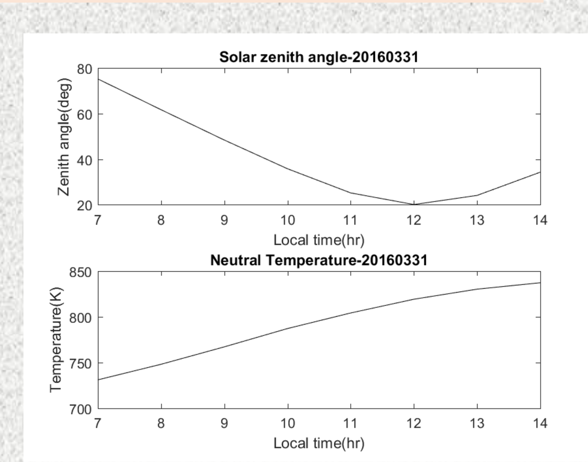



We compare observations between CODAR seasoned radar and Ionosonde. It is clear to see that they have similar patterns both in E region and F region excepting for the echo from 150 km. This extra echo may come from reflection of extraordinary wave. The reason is that the linear polarized wave will split into two circular polarized waves which have different reflection heights when it comes into ionosphere . The semi-diurnal tide is responsible for descending feature of the ionospheric echoes in E region during local time 10 to 18. The range variation of F layer echoes is caused by diurnal thermal bulge that neutral wind flows across isobar from high pressure to low pressure and pushing plasma upward or downward along magnetic field line.




Occasionally, ionospheric echoes from F1 layer descending in range over time can be seen in CODAR Doppler spectrum. Because F1 layer is characterized by a β-Chapman layer, it is expected that solar zenith angle plays a crucial role in determining its height variation over time. We use IRI model to obtain solar zenith angle and neutral temperature on March 31, 2016 to calculate the normalized height of F1 peak density and scale height. The slope of spatial variation with time is consistent with CODAR observation. Red line is three hours delay from simulating result(black line).




$$q(\chi, h) = q_0 e^{[1-Z-sec\chi e^{-Z}]} \qquad Z = \frac{h-h_0}{H} \qquad H = \frac{KT}{mg}$$

## Summary

- CODAR seasonde HF radar receives echoes not only from sea surface but also from ionosphere due to omnidirectional radiation pattern.
- The coherence of cross spectrum helps to identify contaminating region from ionosphere.
- E layer descending feature can be seen both on the observation of CODAR and ionosonde which caused by semi-diurnal tide.
- Diurnal bulge can describe F region temporal and spatial variation from statistic results.
- F1 layer descending slope meets chapman layer height variation from the changing of zenith angle and scale height.