

Footprints of Space Weather Coupling and the ROTH R System

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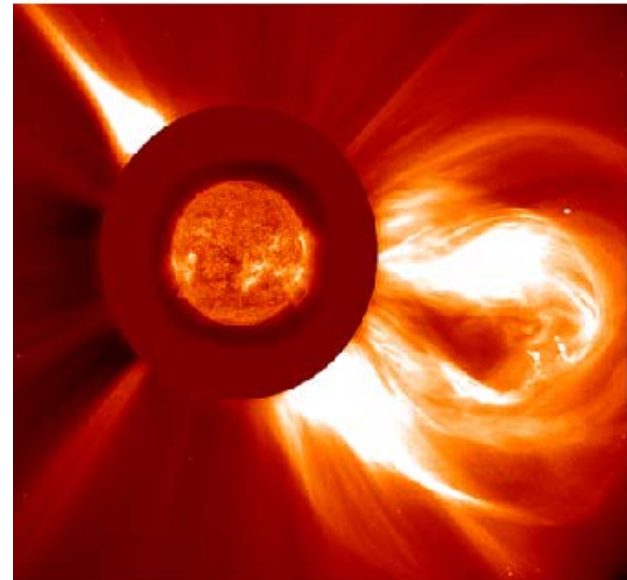
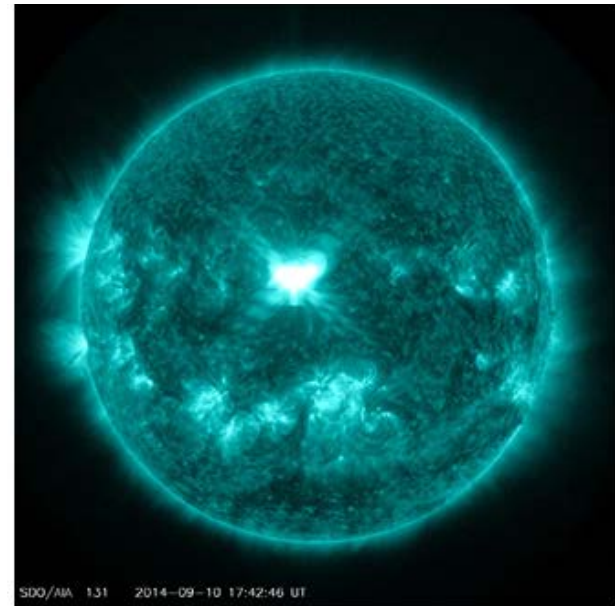
W R Systems Ltd

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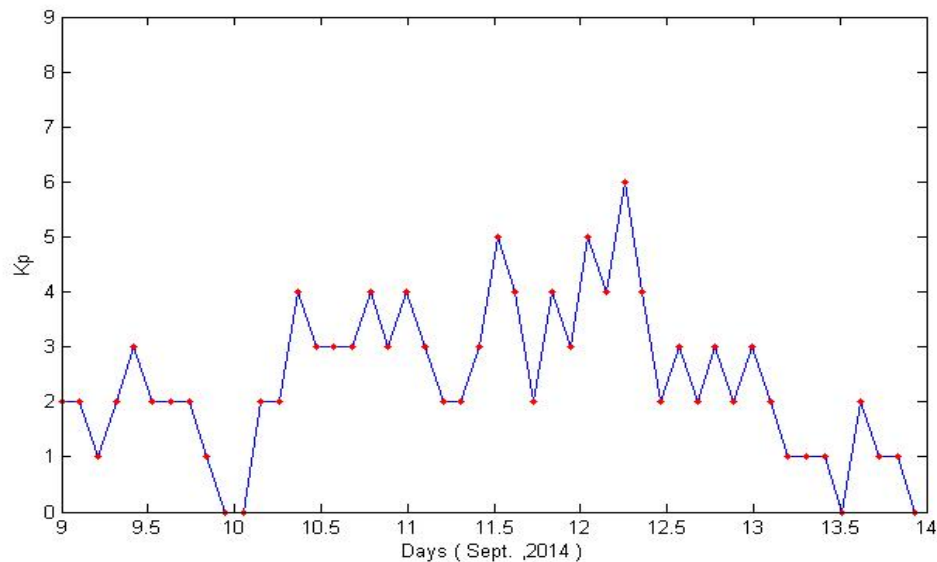
Scope of paper

- Study Effects of Space Weather specifically Solar Flares and Coronal Mass Ejection (CME) on HF Communications as related to Re-locatable Over The Horizon Radar(ROTHR)
- A Solar Flare is an explosion that occurs on the Sun when energy stored in twisted magnetic fields (usually above sunspots) is suddenly released
- Solar flares produce a burst of radiation across the electromagnetic spectrum, from radio waves to x-rays and gamma rays.
- Solar flares are classified into three categories (X-, M-, and C-class flares) based on x-ray brightness in the 1 – 8 Å wavelength band.
- X-class flares have not only the largest energy (peak power $> 10^{-4} \text{ W m}^{-2}$), but the effect also lasts longer and can trigger earth-wide radio blackouts
- Solar flares are occasionally accompanied by solar bursts. Solar bursts, which have energy at L band frequencies, also affect GPS availability/performance
- M-class flares are medium-sized and can cause brief radio blackouts, and effects are typically limited to Polar Regions. C-class flares have relatively unnoticeable effects on radio signals.

- Solar Flares Effects are observed all over earth (dayside) simultaneously.
- Solar Flare is localized phenomena. Possible cause include magnetic reconnection
- Coronal Mass Ejection (CME) is a massive burst of gas and magnetic field from Sun
- Most ejections originate from active regions on the Sun's surface, such as groupings of sunspots associated with frequent flares.
- When the ejection is directed towards Earth and reaches it as an interplanetary CME (ICME)
- The shock waves of the traveling mass of solar energetic particles can cause a geomagnetic storm
- Solar energetic particles cause strong aurorae in large regions around Earth's magnetic poles
- CME effects occur first at high latitudes and then propagate to lower latitudes (e.g., TID's)



- Solar Flare occurred on 10th September, 2014.
- Pair of CMEs hit Earth's magnetic field in quick succession on Sept. 11th and 12th, 2014 .
- During CME's Aurora observed from mainland USA
- Magnetic field before and after CME



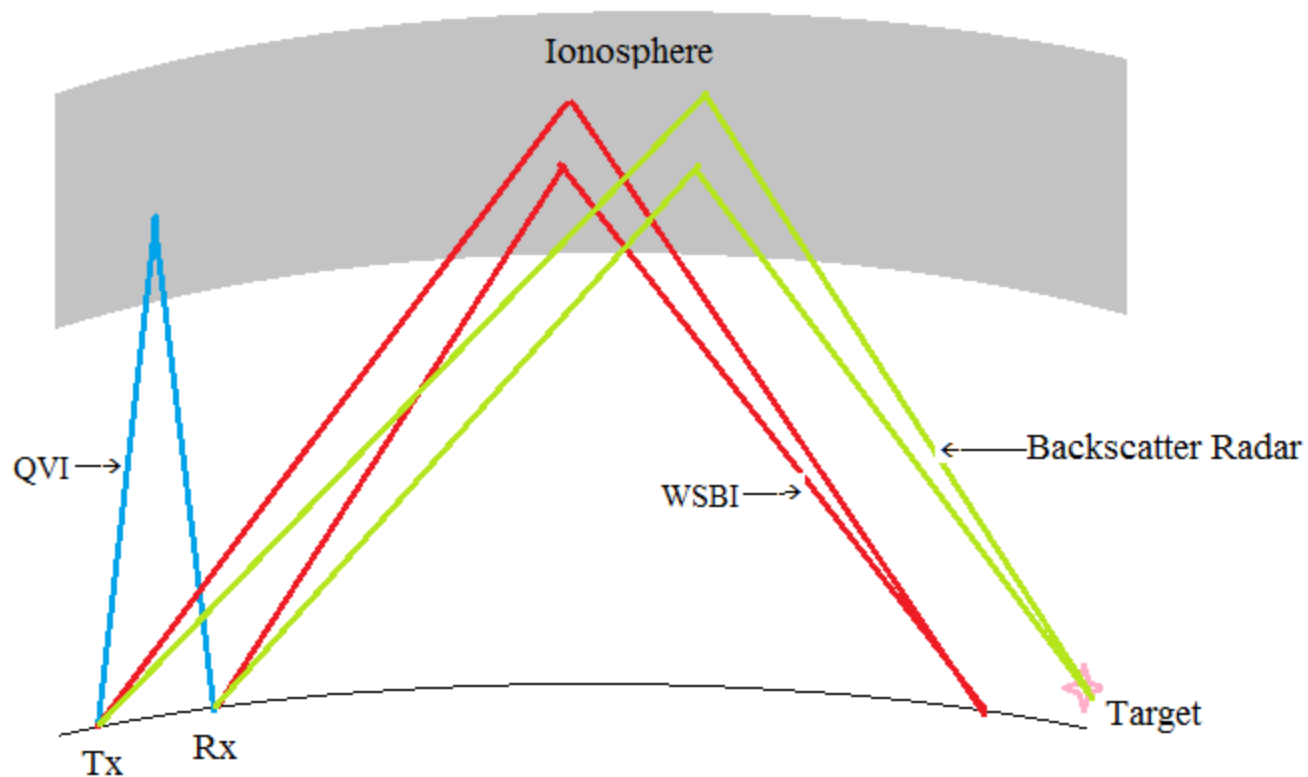
Relocatable Over the Horizon Radar (ROTHR)

Consists of two independent components

Monitor and assess the environment (Ionosphere)

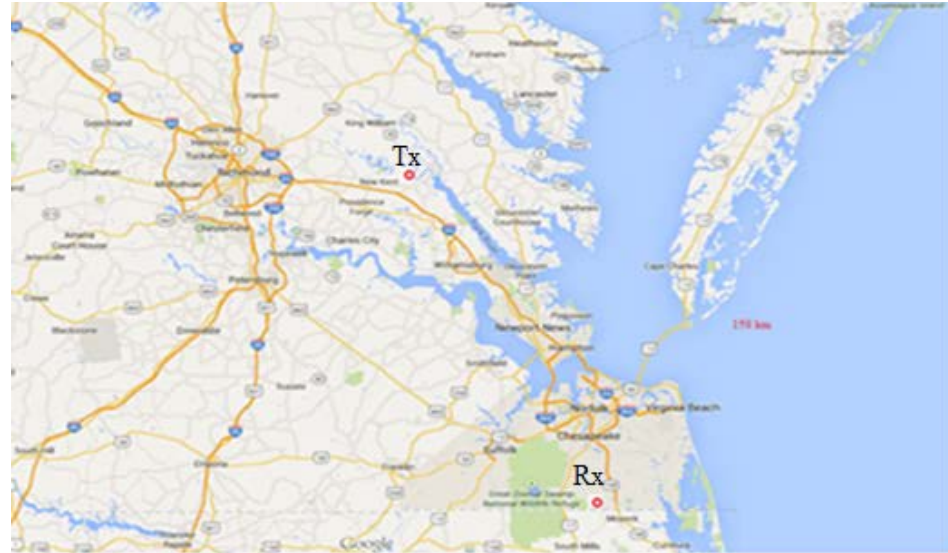
Environment monitored by QVI and WSBI

Backscatter radar to detect & track targets

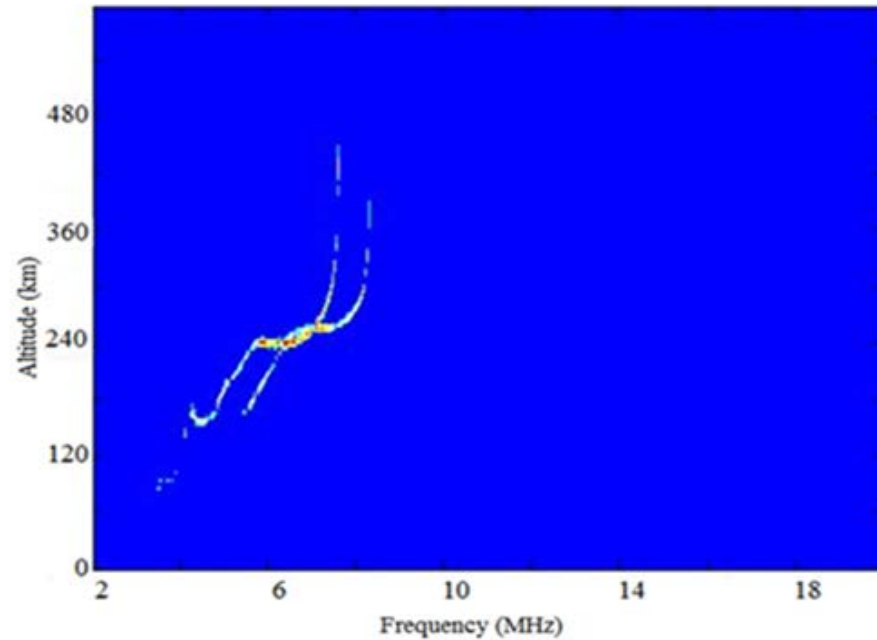


Virginia ROTHF

Transmitter and Receiver
separated by 158 kilometers



Typical Quasi Vertical
Ionogram (QVI) looks like
vertical ionogram



Wide Sweep Backscatter Ionogram (WSBI)

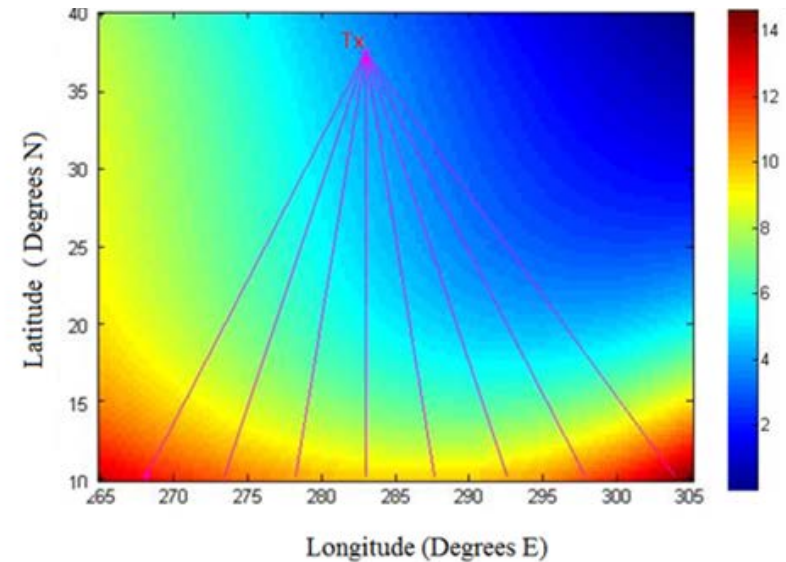
foF2 contours in Virginia ROTH region of operation (9-9-2014, 1900 UT)

HF beams launched in 8 azimuths separated by 8° . Backscatter Ionograms, known as WSBI, are measured in range vs frequency format from each azimuth

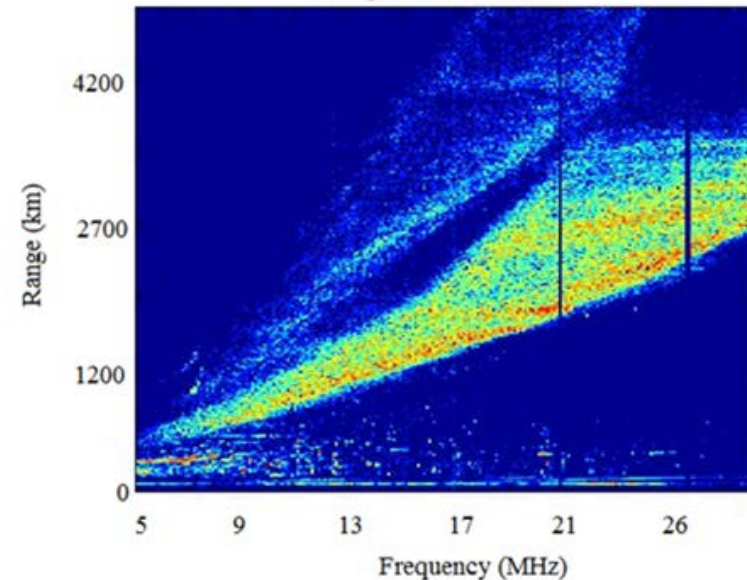
HF frequency operation range for ROTH is 5 – 28 MHz

Leading edge is prominent feature of WSBI.

We have ingested leading in to RIBG ionospheric model for real time updates

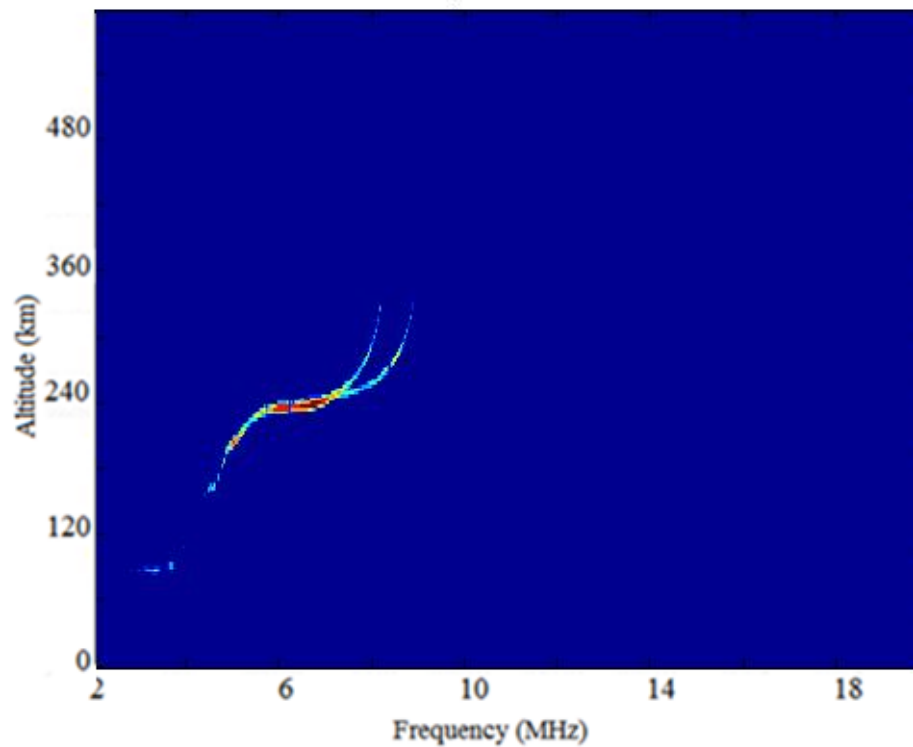


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Solar Flare Effects on QVI

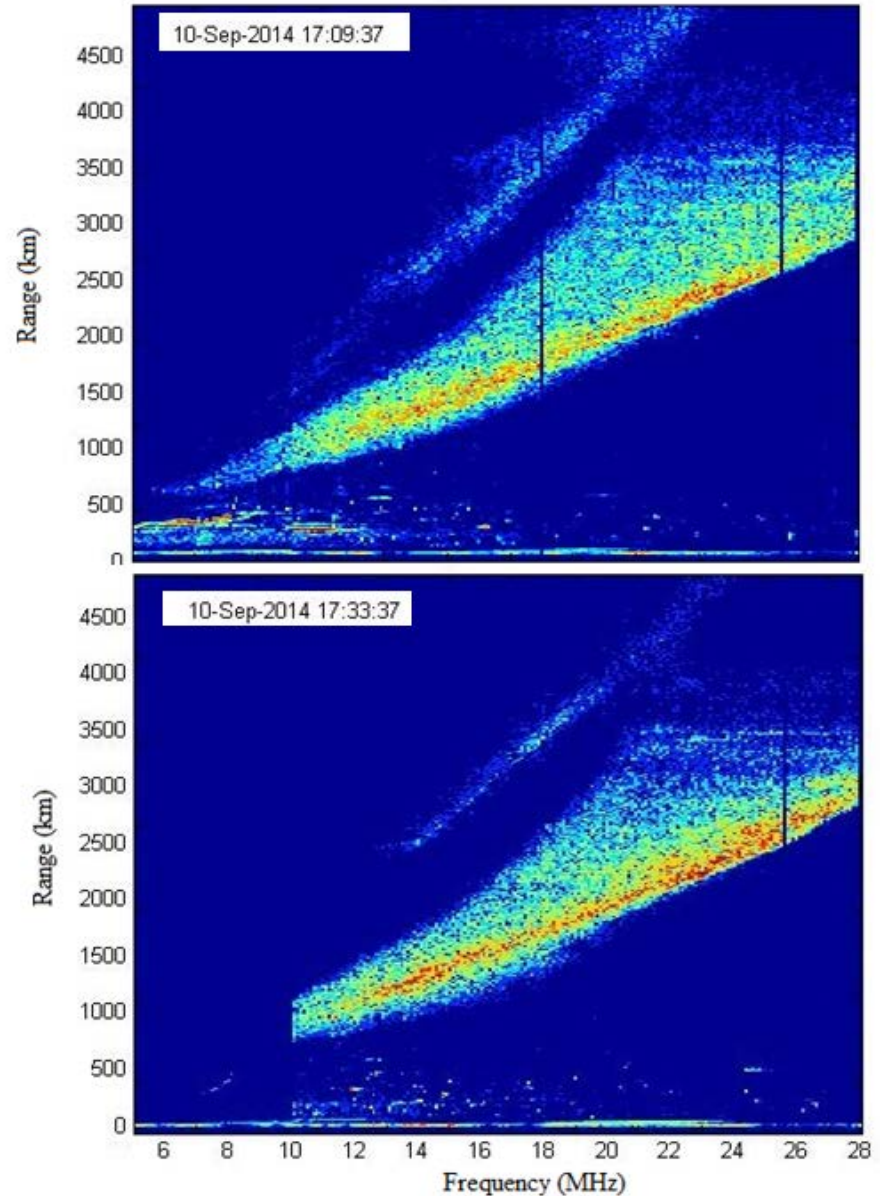
- QVI and WSBI measured every 12 minutes
- QVI just before Solar Flare
- No QVI's after Solar Flare for about two hours



Solar Flares and WSBI

WSBI Before and at Solar Flare

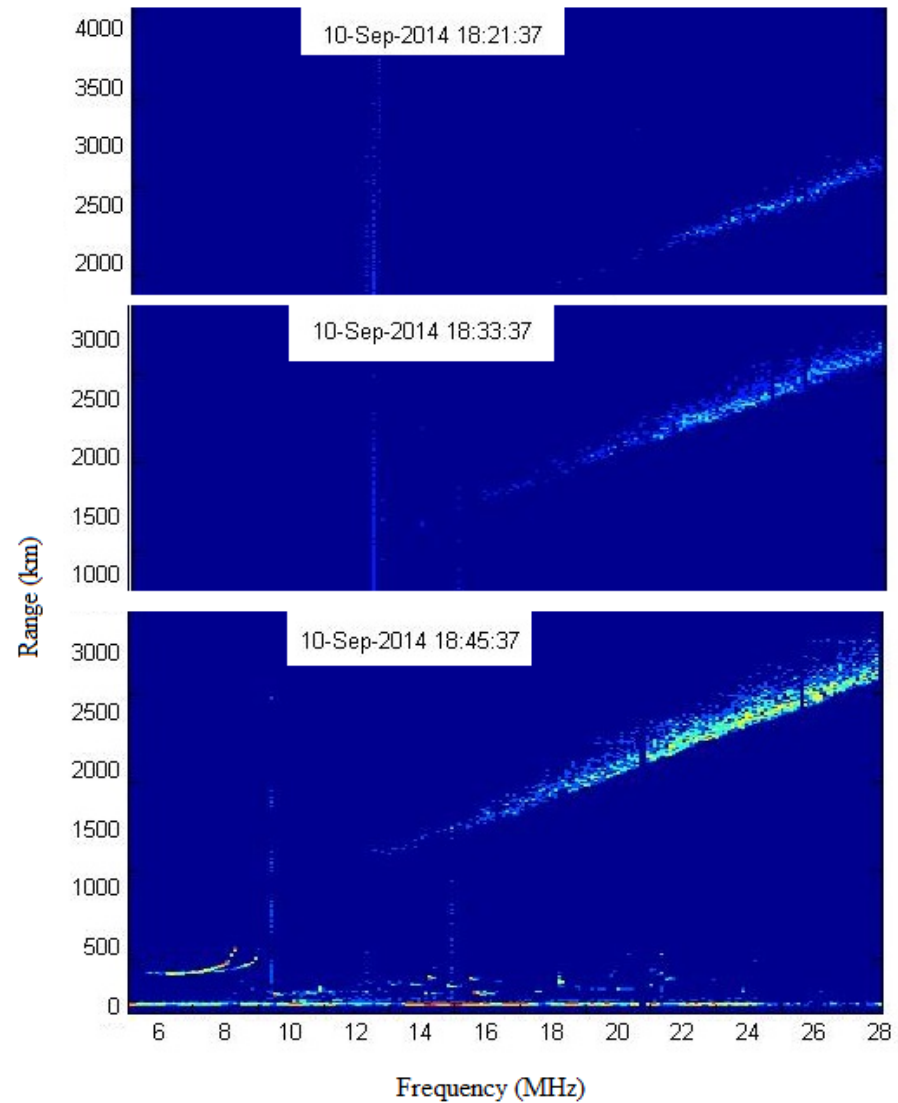
The effect starts at lower frequencies



Recovery of WSBI

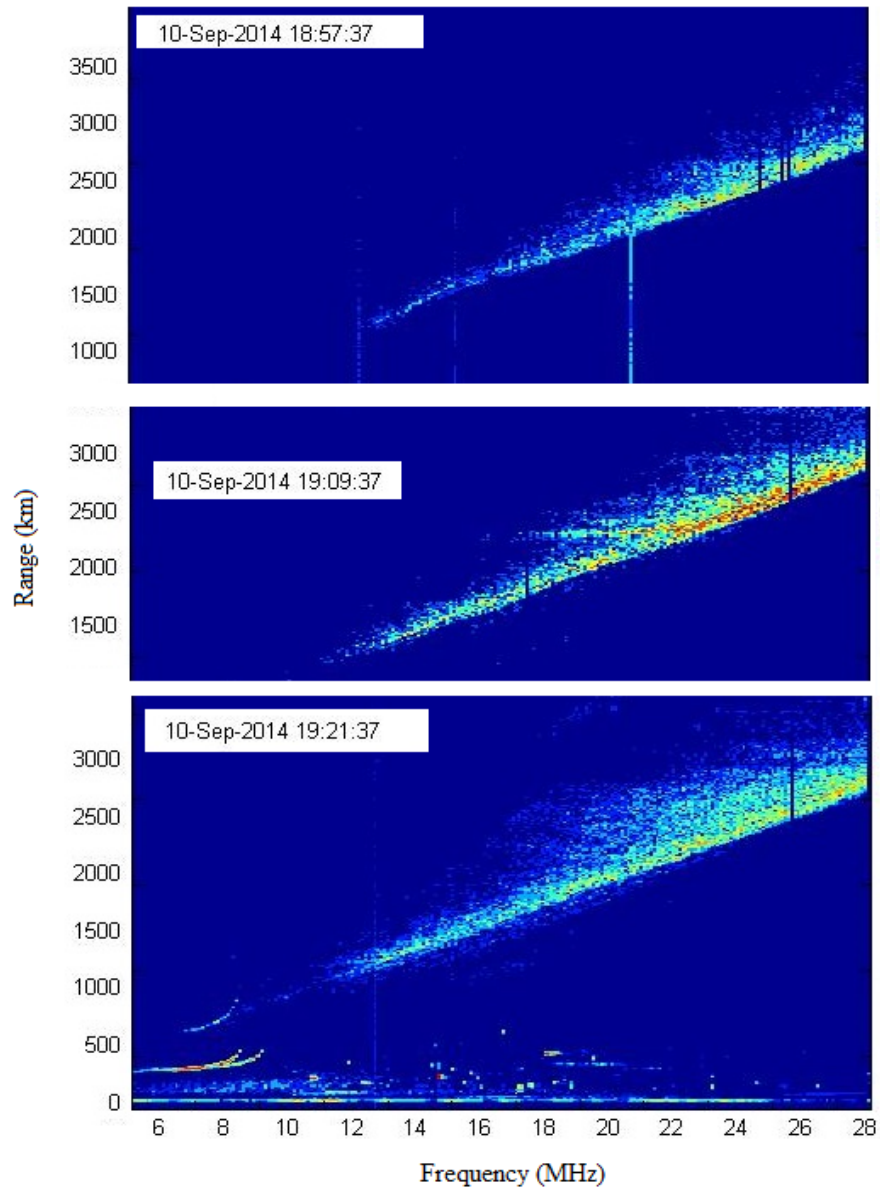
Recovery starts at Higher
Frequencies First

48 Minutes from the onset
of Solar Flare



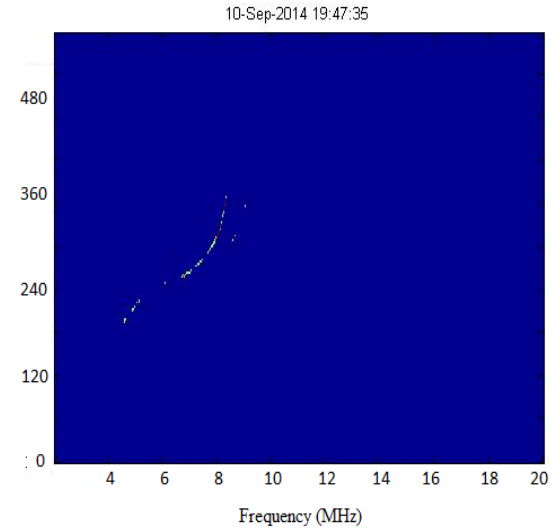
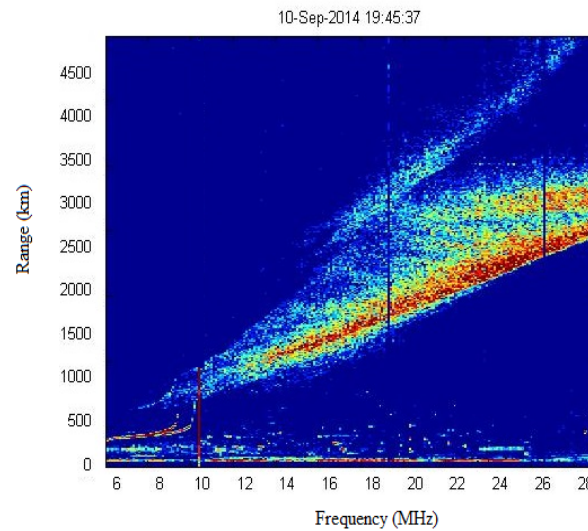
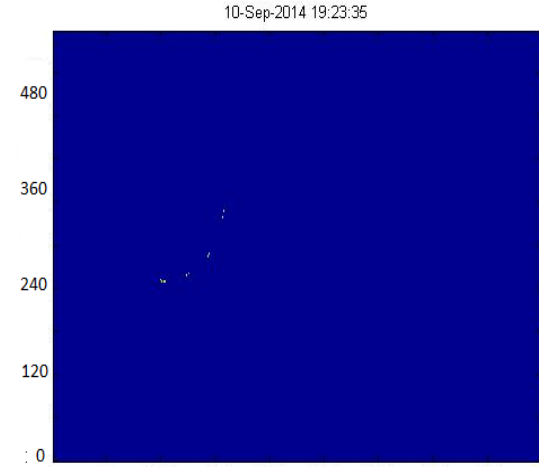
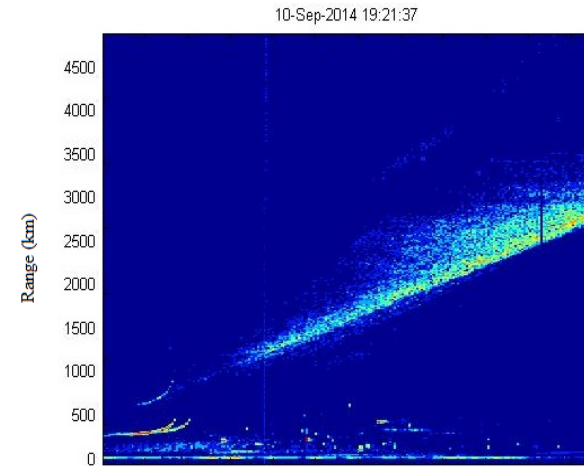
Recovery of WSBI

Recovery continues
from higher to lower
frequencies



Recovery of WSBI and QVI

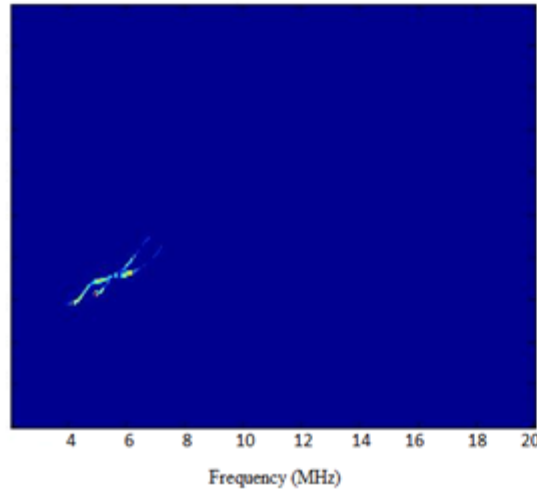
Recovery after about two hours of both WSBI and QVI



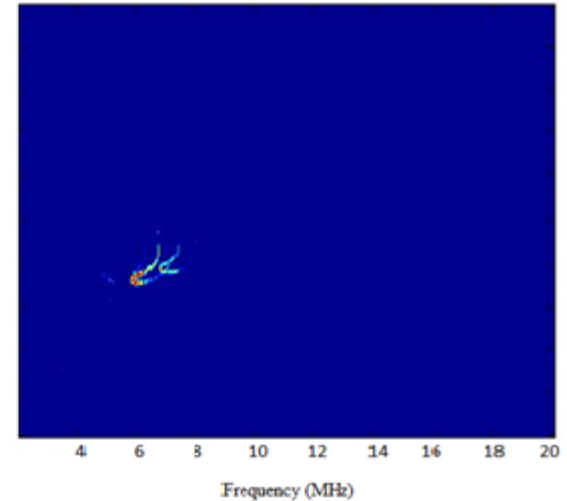
CME Effects

- The solar charged particle effects are first observed at high latitudes (aurora, scintillations)
- Transferred to lower latitudes either in the form TID's
- CORS network of consist of hundreds of GPS receivers which can track and determine characteristics of TID's
- Some QVI and WSBI observations during CME

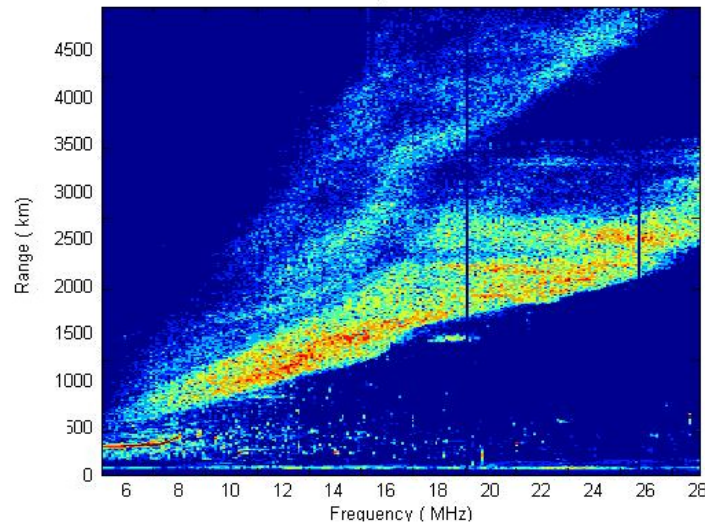
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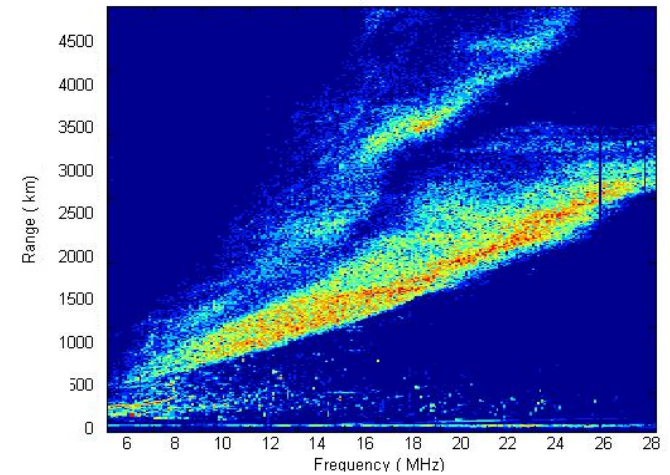
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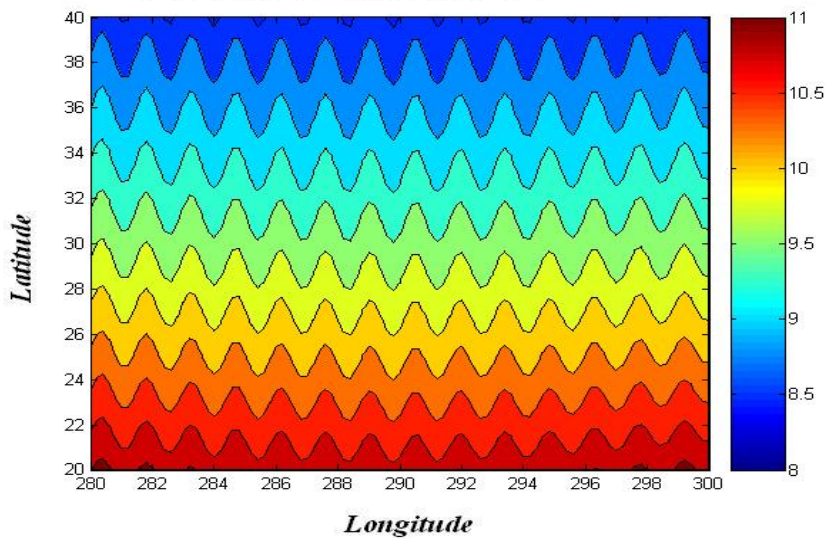
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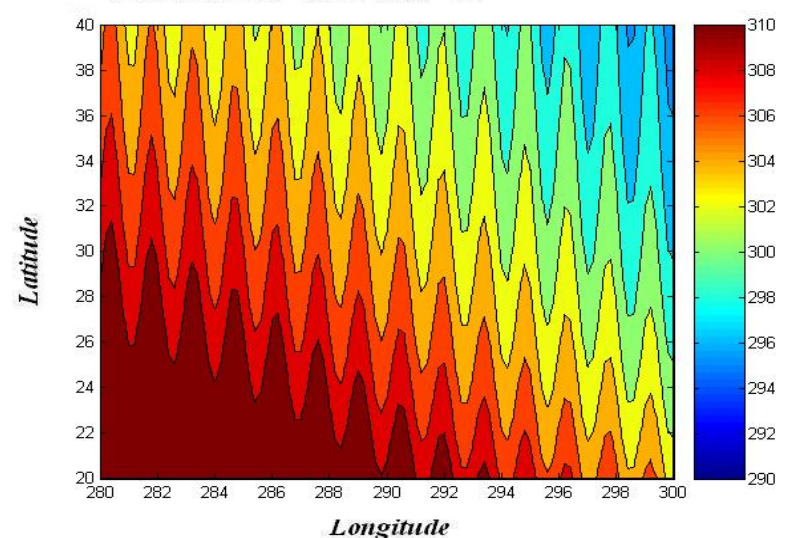
TID Simulator

- The RIBG model (raytrace through the combined models of ionospheric conductivity and electron density (ICED), Bent, and Gallagher models) is utilized to model ionosphere.
- RIBG can ingest TEC (from GPS receivers) and Ionosonde data to determine driving parameter (e.g., effective sunspot number) to recreate the observed ionospheric conditions (Singh and Reilly)
- Technique has been expanded to ingest WSBI data (leading edge measurements)
- Developed simulator that produces ionosphere populated with TID's which are function of scale size, time period, speed, and direction
- Example of ionosphere populated with medium scale (150 km) TID's in east-west directions.

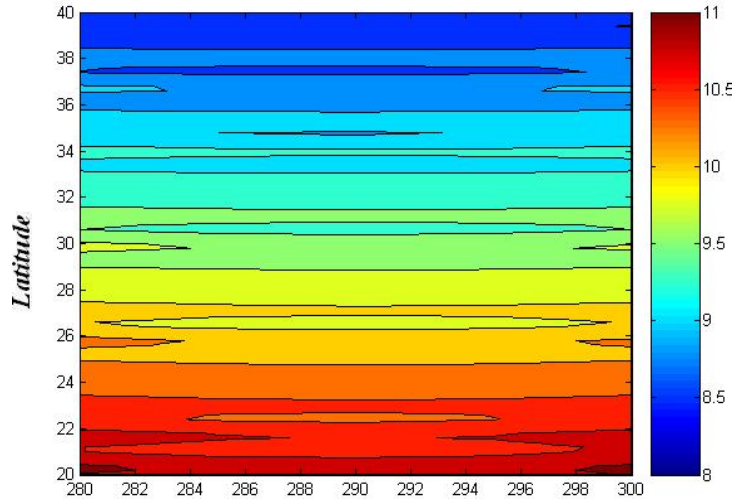
9-26-2013 UT = 1900 SSN =80 foF2 with EW TID



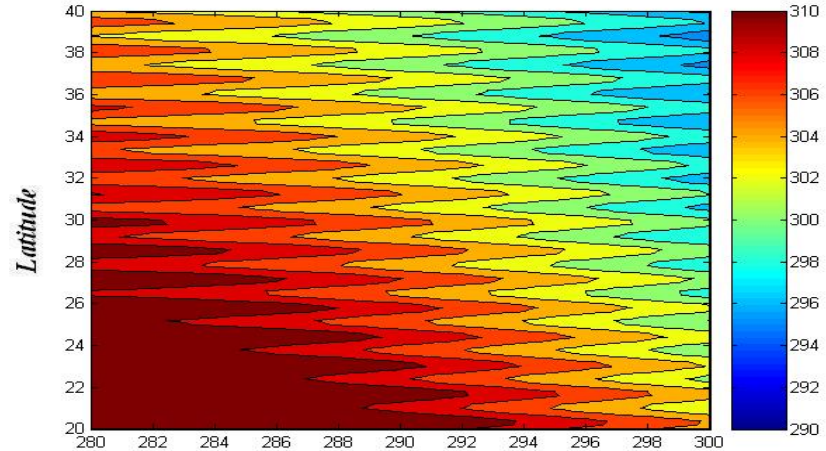
9-26-2013 UT = 1900 SSN =80 hmF2 with EW TID



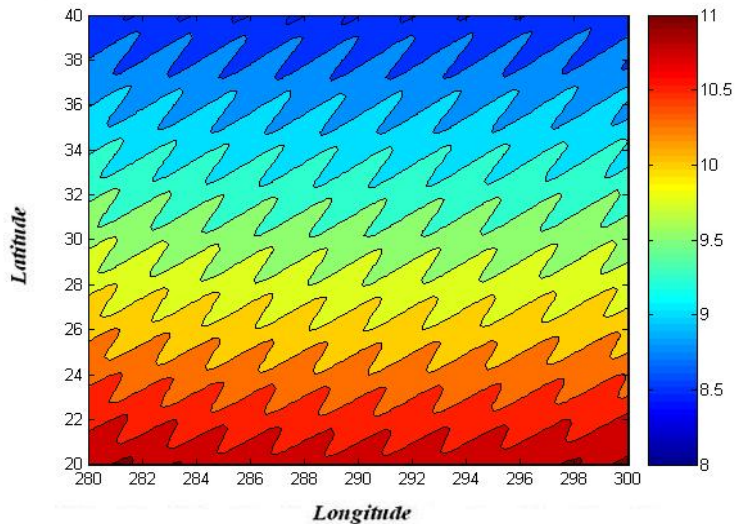
9-26-2013 UT = 1900 SSN = 80 foF2 with NS TID



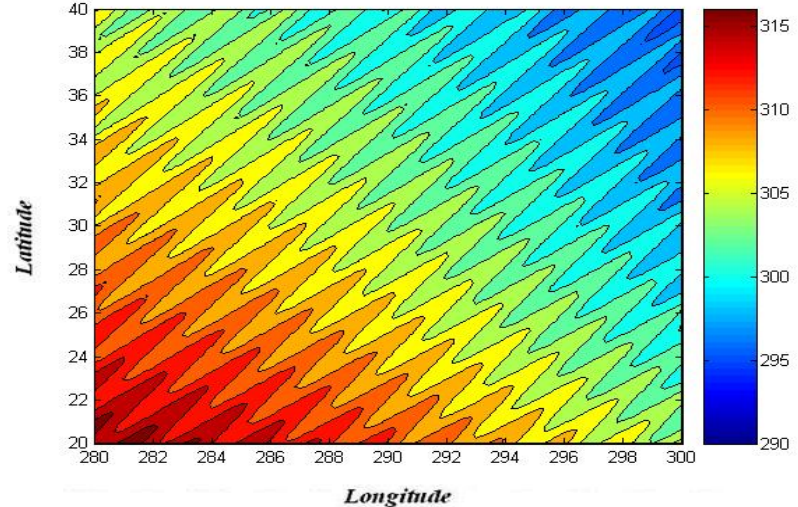
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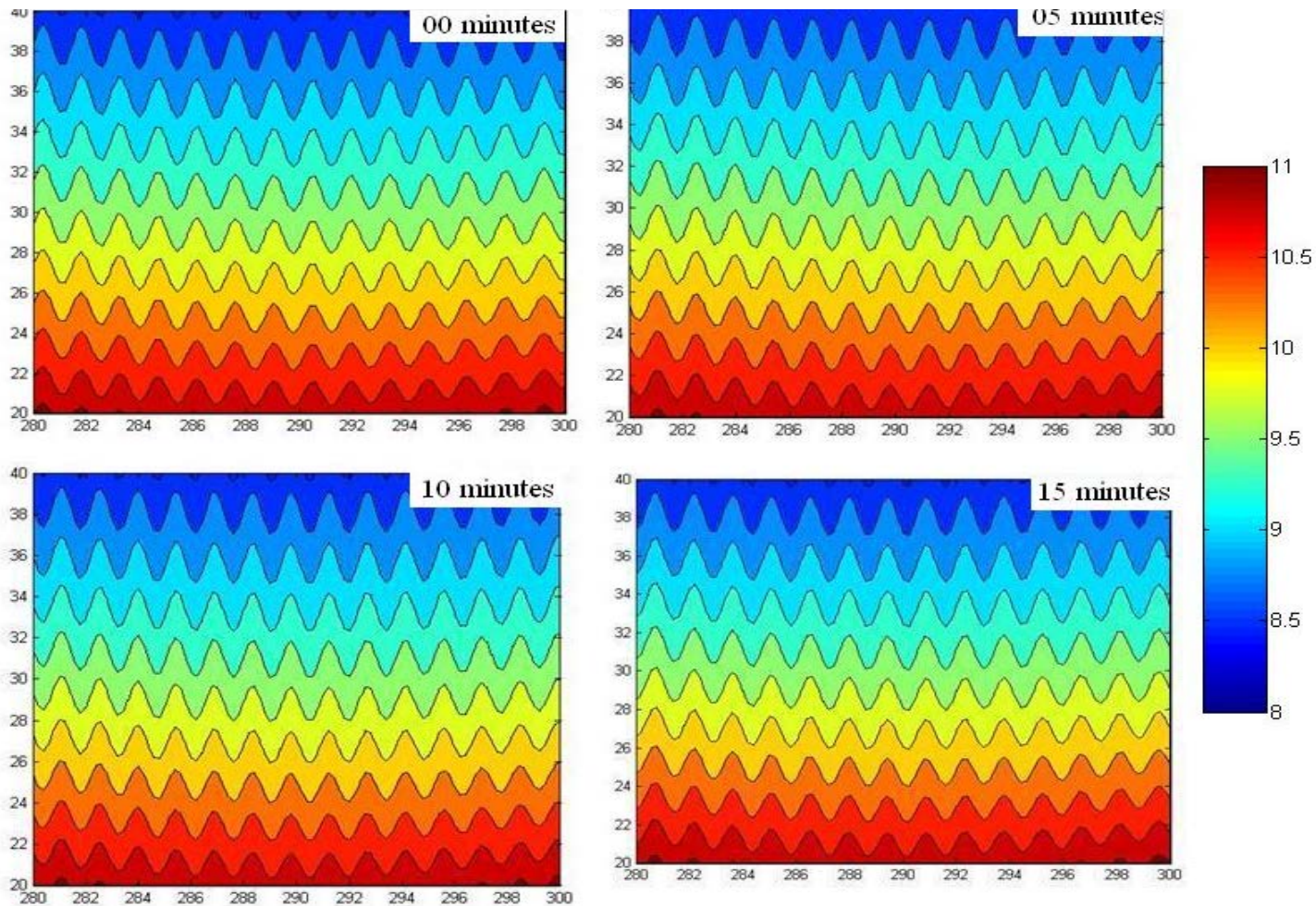
foF2 for 9-26-2013 SSN = 80 UT = 1900 TID @ 315 Azimuth



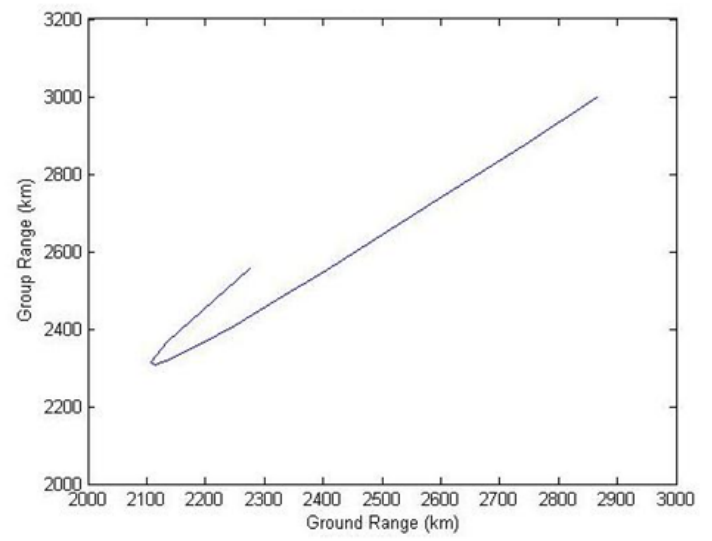
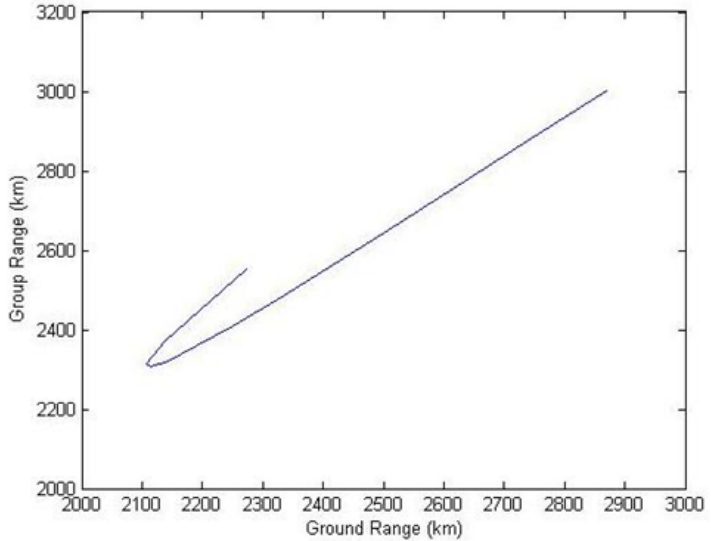
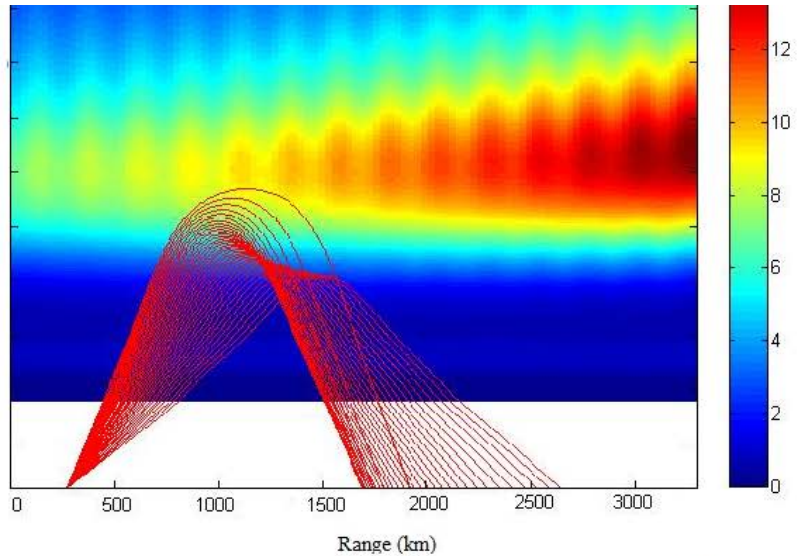
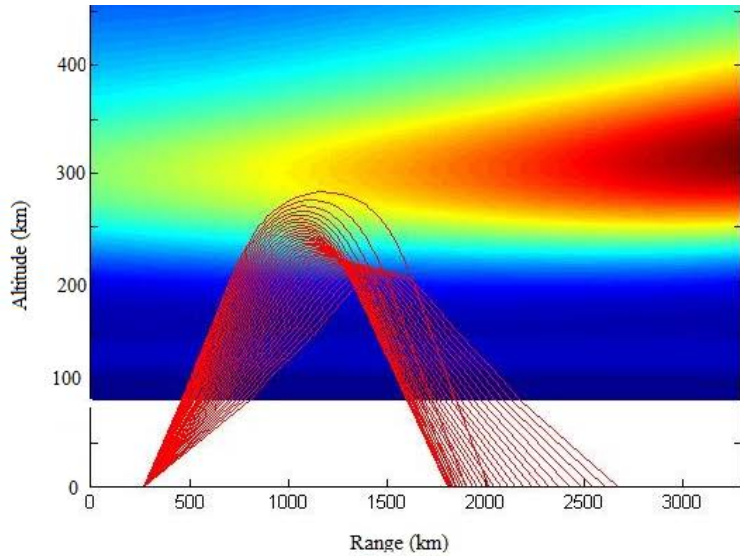
hmF2 for 9-26-2013 SSN = 80 UT = 1900 TID @ 315 Azimuth



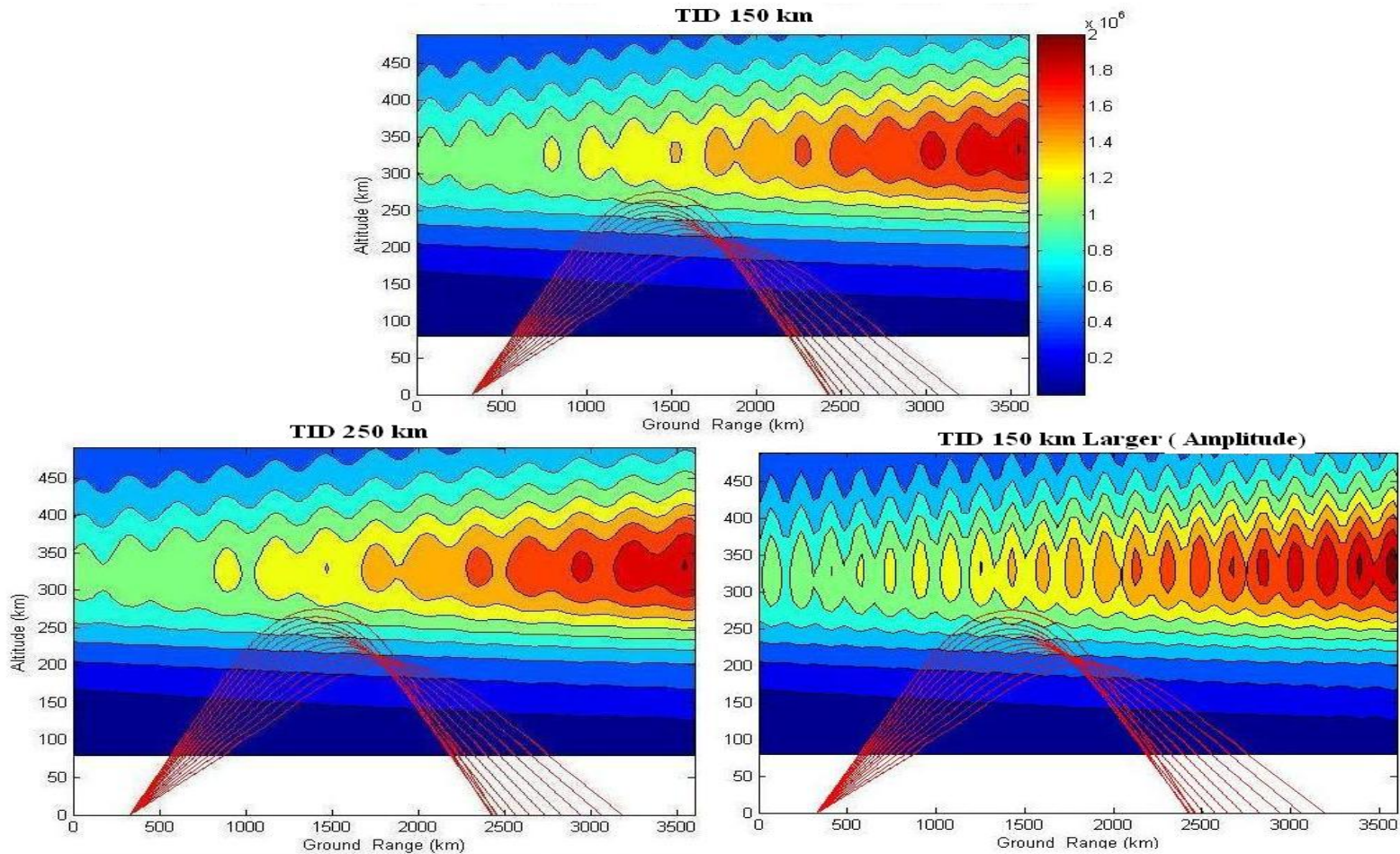
foF2 ,hmF2 in the presence of TID's in NS and @ 135 Azimuth directions



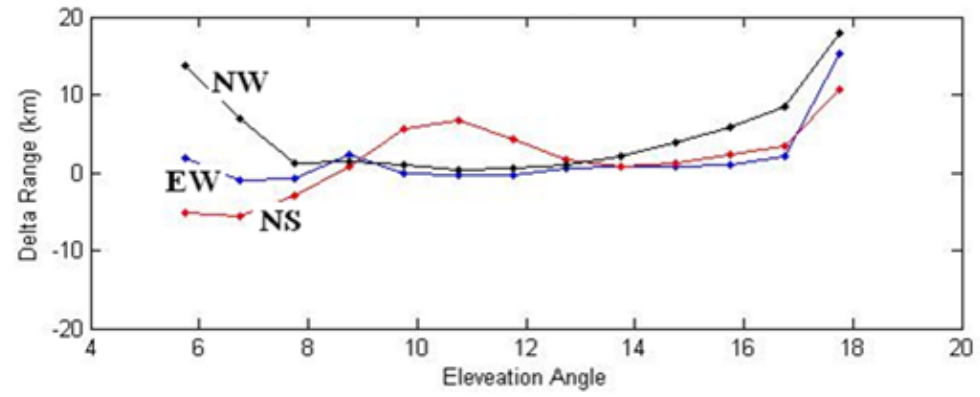
foF2 at various stages of TID cycle (0, 5, 10 ,15 minutes) for TID of 20 minute period for EW TID



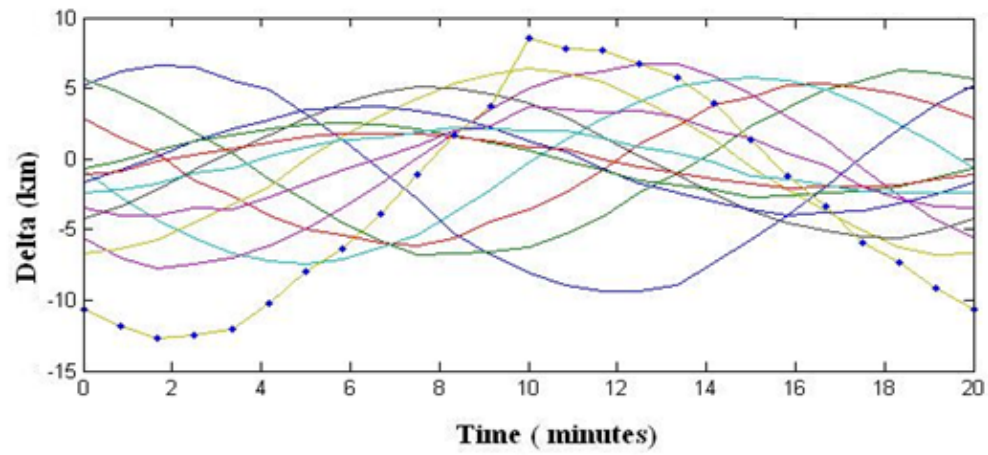
Raytrace thru ionosphere with and without the presence of TID's (@16 MHz)



The raytrace thru the ionosphere in the presence of TID's with scale sizes of 150, 250, and larger amplitude for elevation angles of 7.75 to 17.75°.



Delta Group Range due to TID's as function of elevation angle



Delta Group range at different phases of TID's

Summary

- During Solar Flares, HF propagation is virtually non existent
- There is no QVI or WSBI for some time
- HF propagation recovers at higher frequencies first.
- During CME, HF propagation is modified
- Expanded the technique to ingest WSBI data to update RIBG model
- Developed TID simulator which can produce TID's as function of scale size, time-period, and velocity
- There is a shift in group /ground range due to TID's. The shift can/will be correlated to shift in CR