Ground based measurements of ionospheric turbulence manifestations induced by the VLF transmitter

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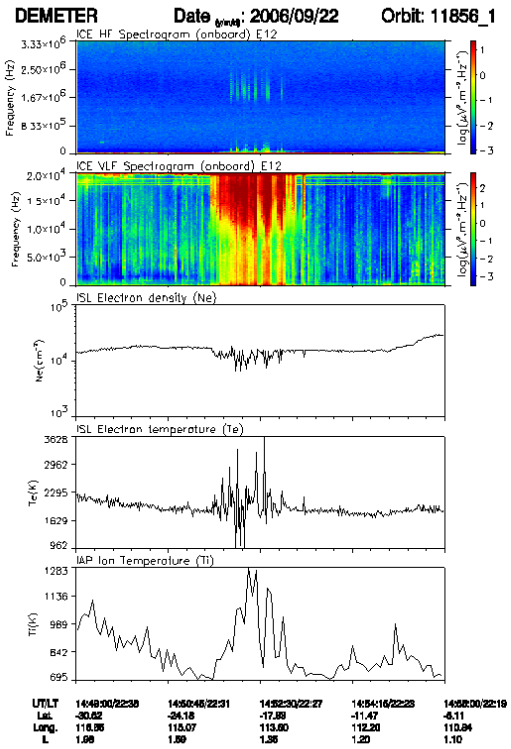
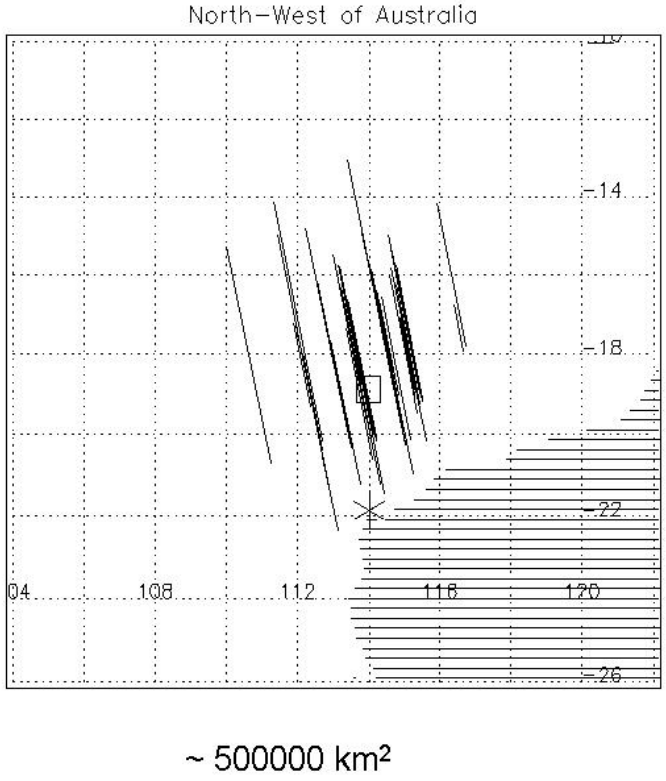
- Recently Parrot et al. reported the results of the DEMETER satellite observations of strong plasma density and temperature perturbations simultaneously with different events in VLF/ELF electrostatic emissions when the satellite orbit crossed the region about 500 km in the diameter above the ground-based VLF transmitters at the height about 700 km.
- Some heuristic presupposition led us to believe that such manifestations of turbulence in the upper ionosphere can be detected by ground methods. That is why we have conducted a focused experiment in September 2014.

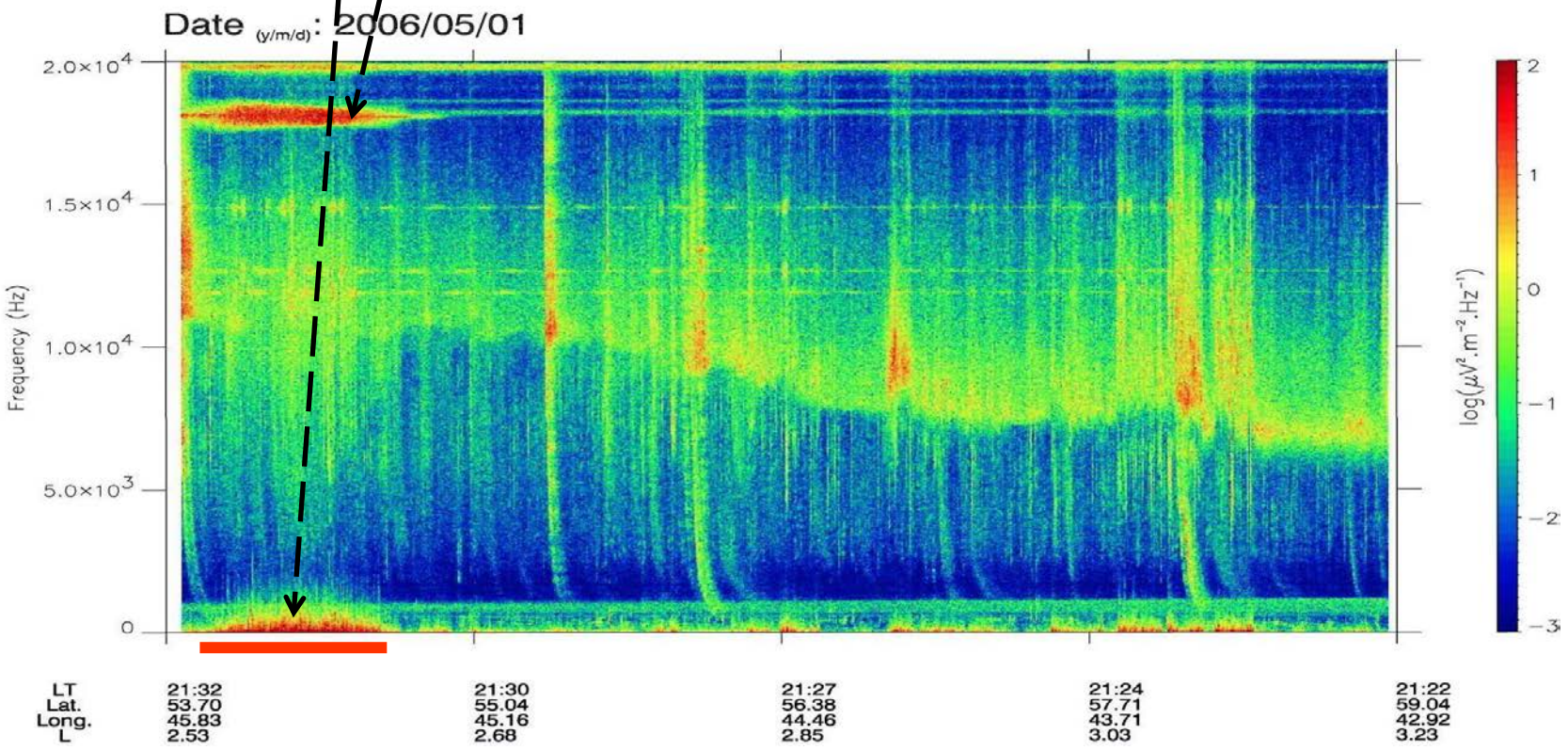
DEMETER satellite results





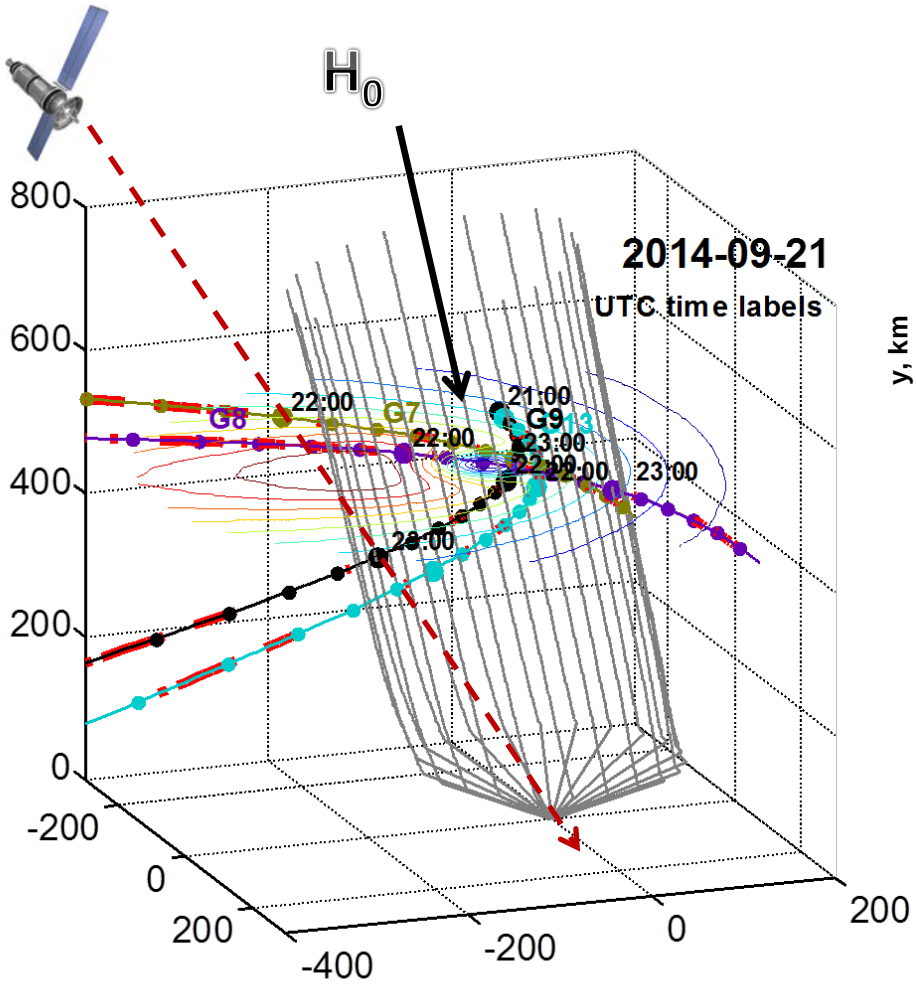
Parrot, A,, et al., (2007), First in-situ observations of strong ionospheric perturbations generated by a powerful VLF ground-based transmitter. Geophys. Res. Lett., 34, L11111, doi:10.1029/2007GL029368.

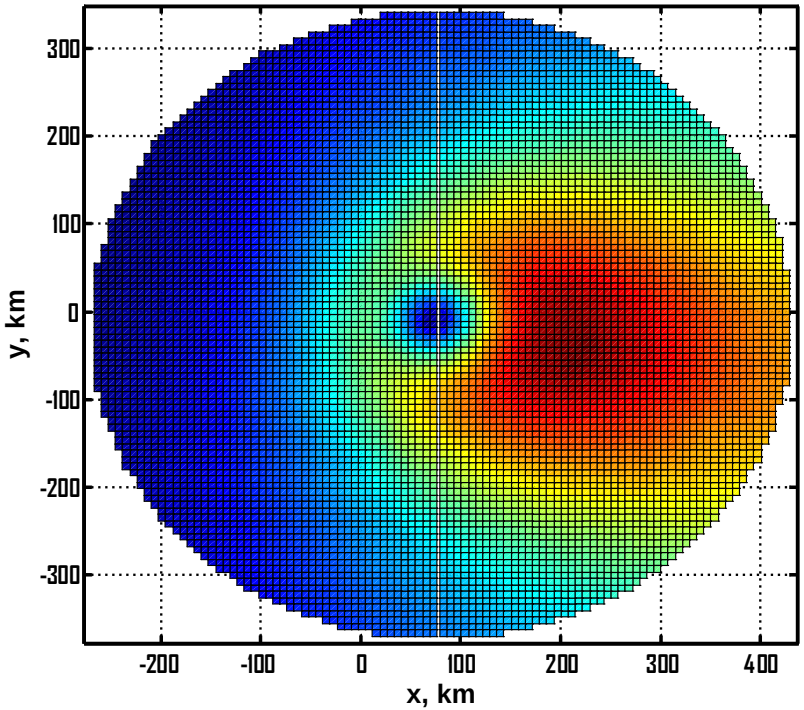
An example with Russian VLF transmitter near N. Novgorod (DEMETER)



Rapoport, et al., RQE, *2007* , *v. 50, # 8, pp. 645-656*

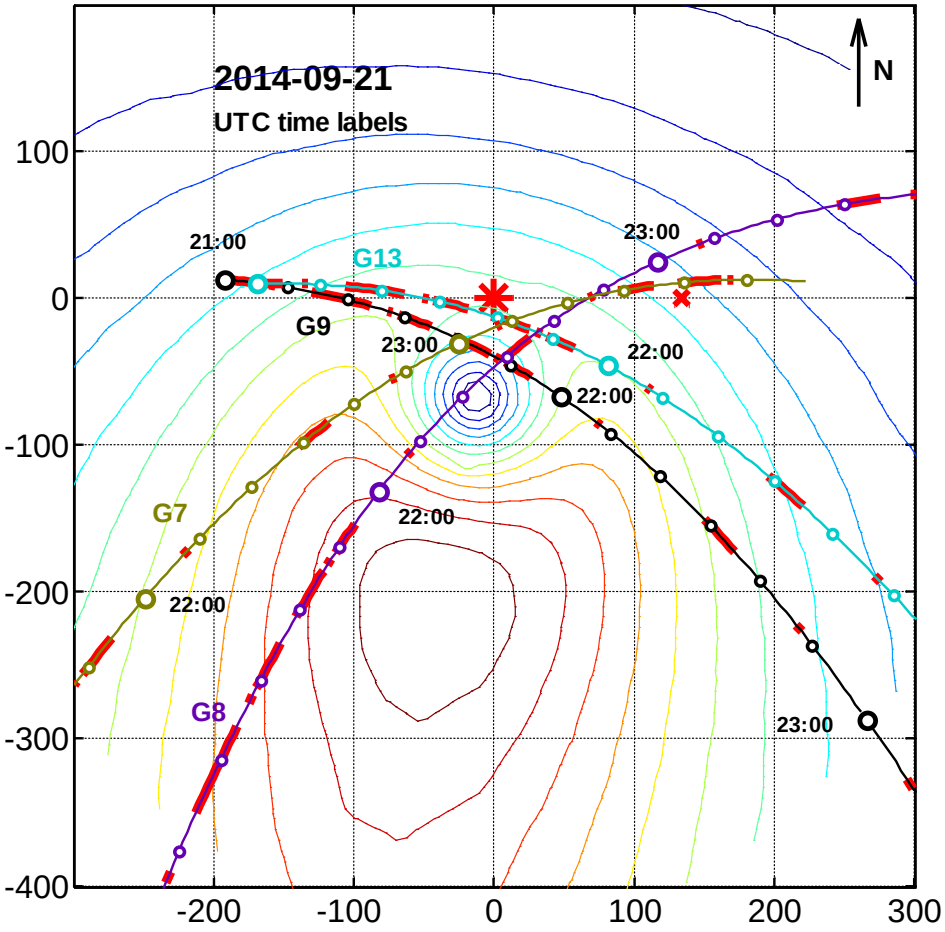
Geometry of the experiment





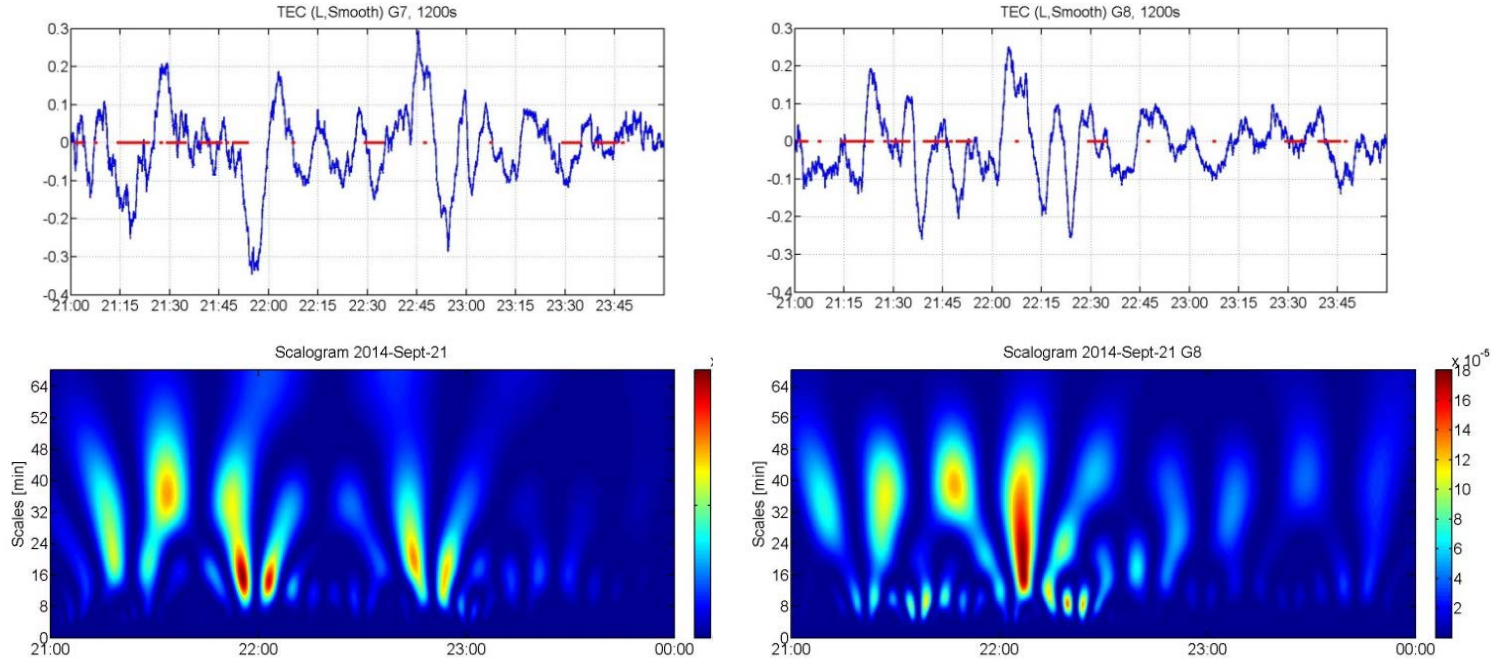
VLF field amplitude distribution at the altitude of 500 km above the Earth's surface

Earth projection of intersection traces of radio beams from GPS satellites and the ionosphere at 500 km altitude for the 2014-September-21 (GPS satellites G7, G8, G9 and G13).

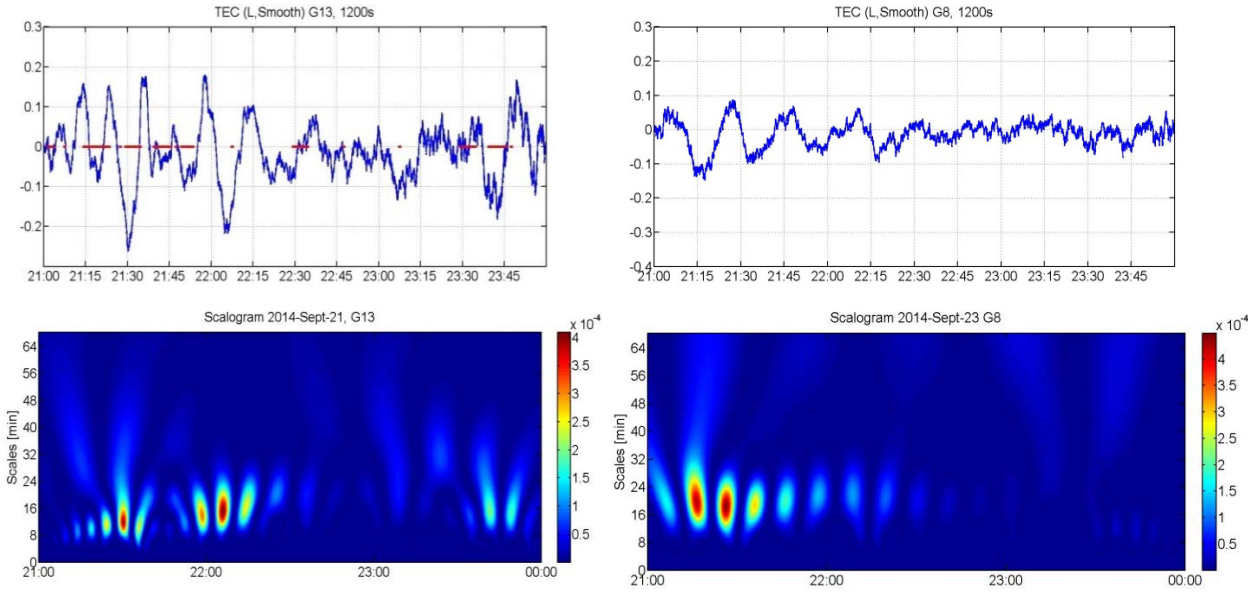


Thickening (in red) of the trajectories corresponding to the intervals of the transmitter operation, the circles on the trajectories indicate the hour and ten minute time marks. Isolines are made match the intensity of the VLF field with a minimum to the south-west from the transmitter at a distance of about 70 km and a maximum at a distance of about 240 km in the same direction

RESALTS OF THE EXPERIMENTS

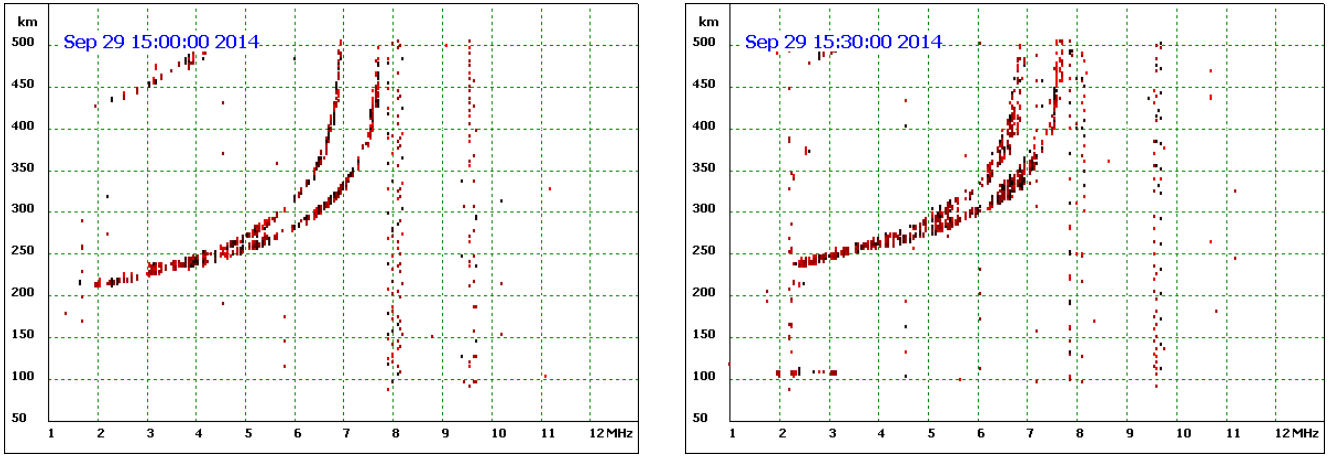


TEC variations for G7 and G8 satellites (upper panel) and their scalograms (lower panel) for 2014-September-09 from 21:00 to 24:00 UT. Red lines on the upper panel denotes the time of VLF transmitter operation.



TEC variations and scalogram for peripheral satellite G13 for 2014-September-21 (left panel) and the same for satellite G8 for 2014-September-23 (right panel) from 21:00 to 24:00 UT when the VLF transmitter was out of operation. Red lines on the upper panel denote the time of VLF transmitter operation

The ionograms from CADI Ionosonde shown that VLF transmitter operation during 30 minutes led to the appearance of F-spread

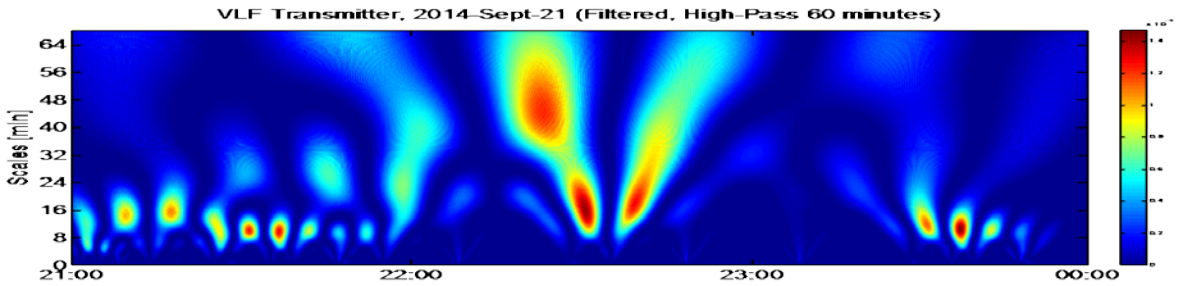


The Ionograms from CADI Ionosonde on 2014 September 29. Left panel - 15:00 UT (corresponds to the start of VLF transmitter operation) and right panel - 15:30 UT (transmitter was switched off).

CONCLUSIONS

- **All TEC variation records obtained in our 2014 September experiment are characterized by increase of small-scale fluctuations as the GPS satellite approaches the center of the VLF radiation maximum domain in the topside ionosphere.**
- **TEC variations for G7 and G8 satellites were maximal during the passage of the impact area and reduced when withdrawn from it. At the same time the amplitude of TEC variation was only half for the peripheral G13 satellite.**
- **Quite a different TEC variations curve was observed for the controlling day when the transmitter was out of operation with TEC variation amplitude three times smaller compared to September 21.**
- **The most intense TEC variations and scalogram structure with 8-10 minute periods were observed for the G8 satellite of which the track was closest to the center of the impact area for time term 21:30-22:00. Similar structures for TEC scalograms were observed for others satellites on 2014-September-21.**

- **The scalogram structure for the time consequence of VLF transmitter operation with the same period of 8-10 minutes also was observed at the same time. Such coincidence is evidence of causality between two time series – transmitter timetable and TEC variations.**



The scalogram for the VLF transmitter operation time consequence of on 2014-September-21,

- **VLF transmitter operation during 30 minutes in the evening led to the appearance of F-scattering in the ionosphere. F-spread was observed consistently during VLF transmitter operation at night. Pause in the transmitter operation up to 15 minutes did not affect the degree of F-scattering.**

Thank you very much for attention