RADIOTOMOGRAPHIC IMAGING OF THE ARTIFICIALLY DISTURBED MIDLATITUDE IONOSPHERE WITH CASSIOPE AND PARUS SATELLITES

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Motivation

- **Since first theoretical works [Grigor'ev, 1975 etc] the topic of artificial AGWs generation in the HF heating experemts was of great interest. Recent works report on the generation of AGW/TIDs in experiments at HAARP [Mishin et al., 2012; Pradipta et al, 2015, etc] and SURA [Burmaka et al., 2009; Chernogor et al., 2011] heaters. Still there is lack of the information of the spatial struture of such disturbances.**

- **Radiotomography technique is successfully applied during the past decades and provided information on many ionospheric structures such as the ionization troughs, equatorial anomaly, travelling ionospheric disturbances, equatorial plasma depletions, etc [Kunitsyn and Tereshchenko, 2003; Pryse, 2003; Bust and Mitchell, 2008]**

- **The aim of this work is to report the experimental results on the influence of the electron density perturbations caused by HF heating in the nightside midlatitude ionosphere on Parus/Transit and ePOP signals and present reconstructed parameters of heating-induced perturbations with the focus on artificial AGW/TIDs generation**

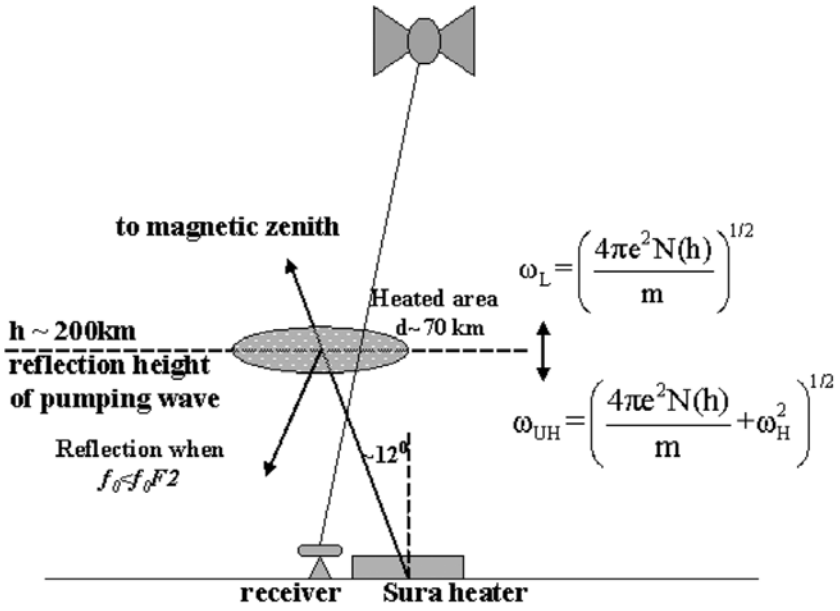
Experimental equipment

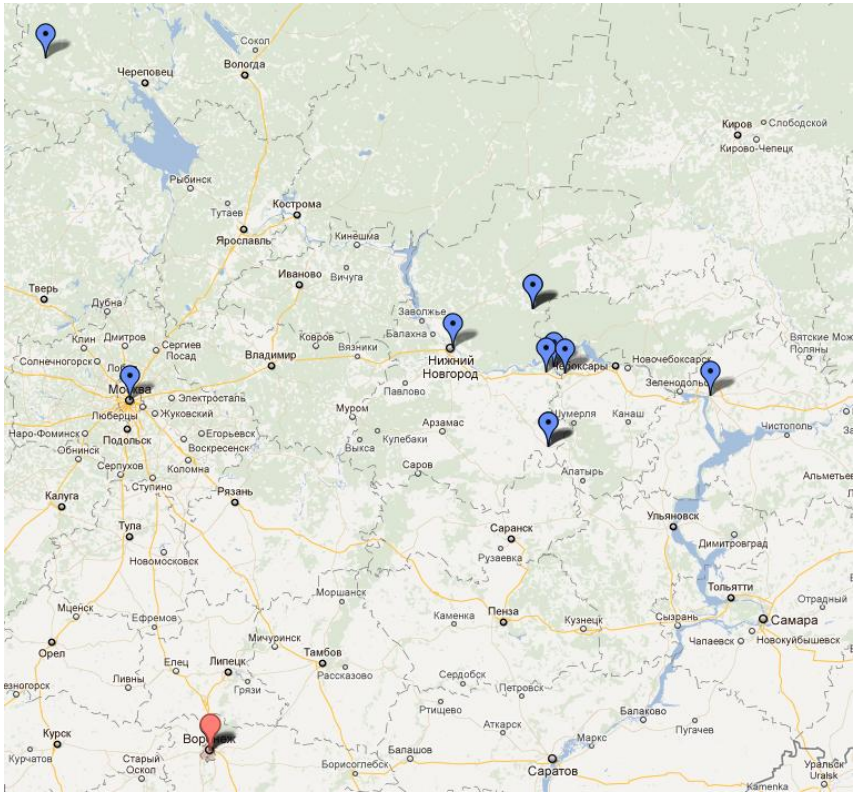
Sura Heater *(46.1^{0}E;56.15^{0}N), I=71^0*
3x250kW transmitters
12x12 dipoles antenna array
4.3-9.5MHz pumping frequency range
(O & X modes) ERP=80-280MW

GNSS Receivers
Multiconstellation (GPS/GLONASS/
GALLILEO/COMPASS/SBAS/QZSS)
JAVAD SIGMA or DELTA receivers
with up to 100 Hz sampling of L1/L2/L5...

Beacon Receivers NWRA ITS30/33S, ADK4M
working with 150/400MHz transmissions from
PARUS *(Russian LEO navigation system)*
satellites – COSMOS 2407, 2463..
and 150/400/1066MHz transmissions from
ePOP/CER *instrument onboard* ***CASSIOPE***

Description of the Experiment





Results from Sura Heater Heating on 16 March 2009

[Frolov et al. 2010, Kunitsyn et al. 2011]

30 sec. heating 30 sec. pause regime

6:15-7:51UT

5 min. heating 5 min. pause regime

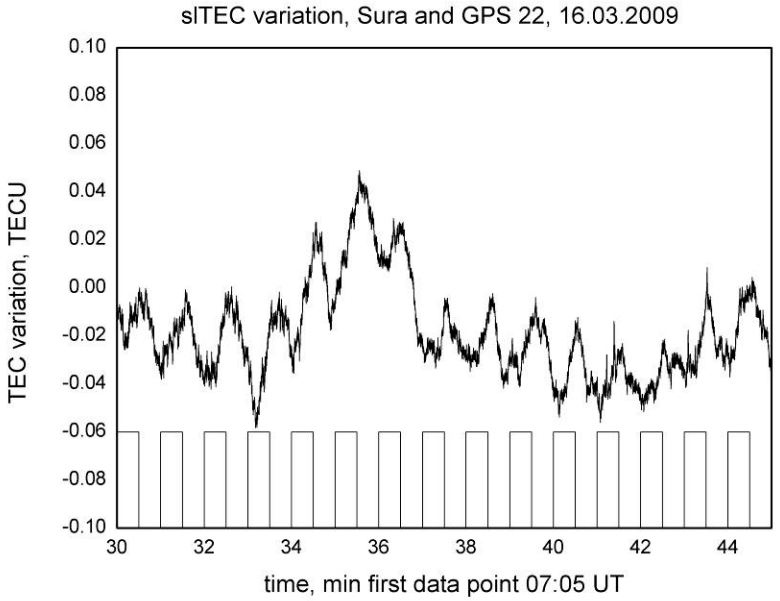
7:51-8:26UT

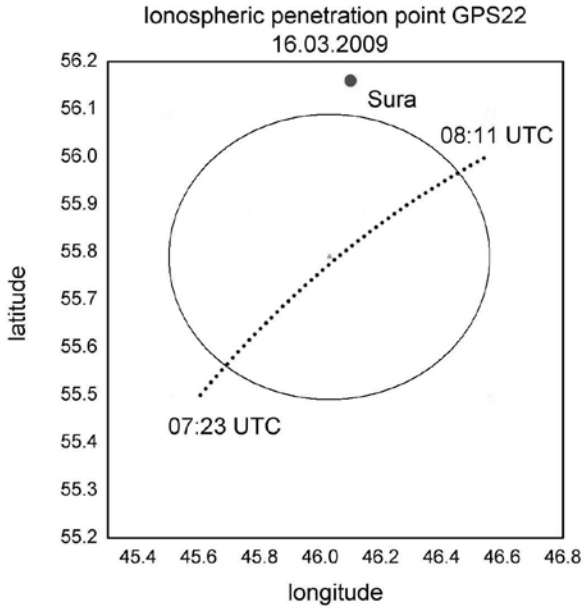
f=4.3MHz

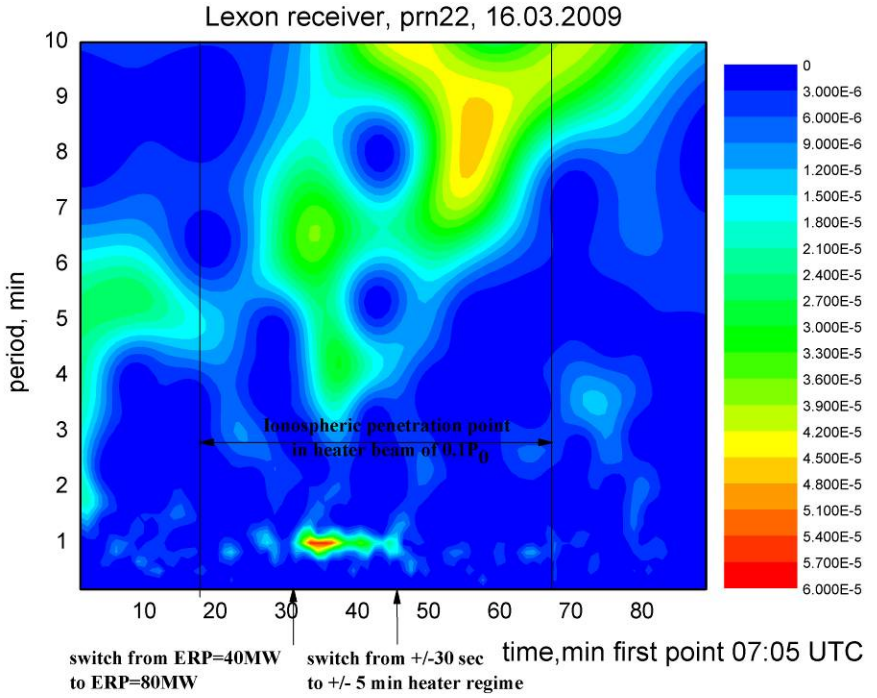
O-mode ERP=40 Mw till 7:36

and 80 Mw later

Low geomagnetic activity (Kp~1)







Results from Sura Heater Heating on 15 March 2009

[Frolov et al. 2010, Kunitsyn et al. 2011]

5 min. heating 5 min. pause regime

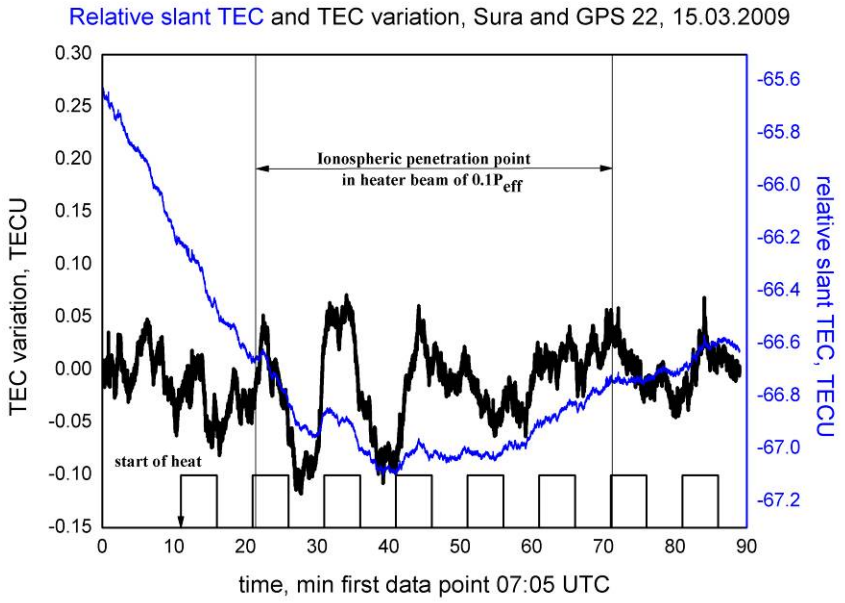
7:16-8:41UT

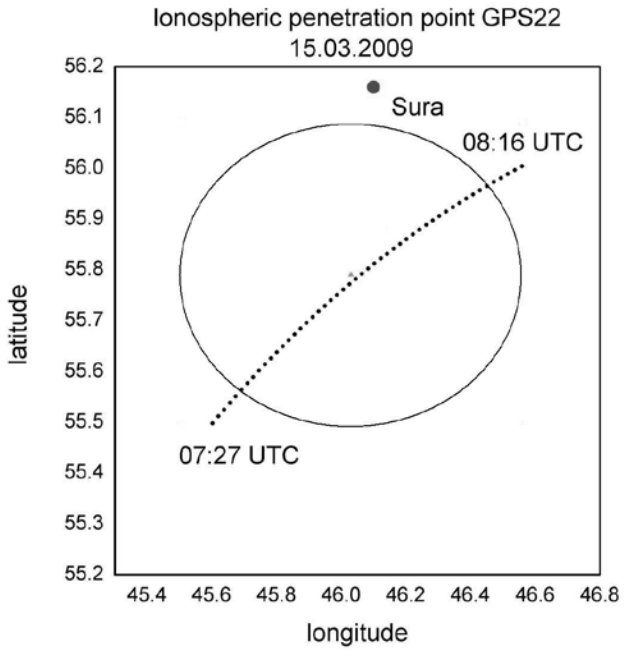
f=4.3MHz

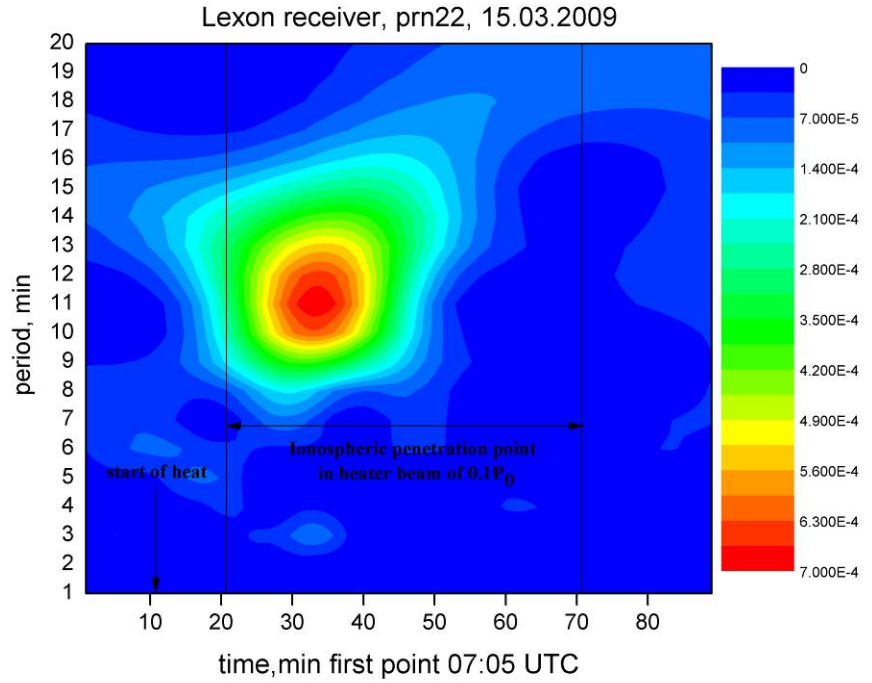
O-mode ERP=80 Mw

Moderate geomagnetic activity (Kp~3)

$f_0F2<f$ for 7:50 - 8:12 UT



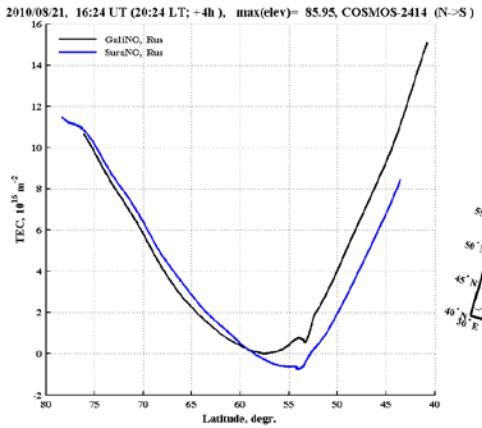


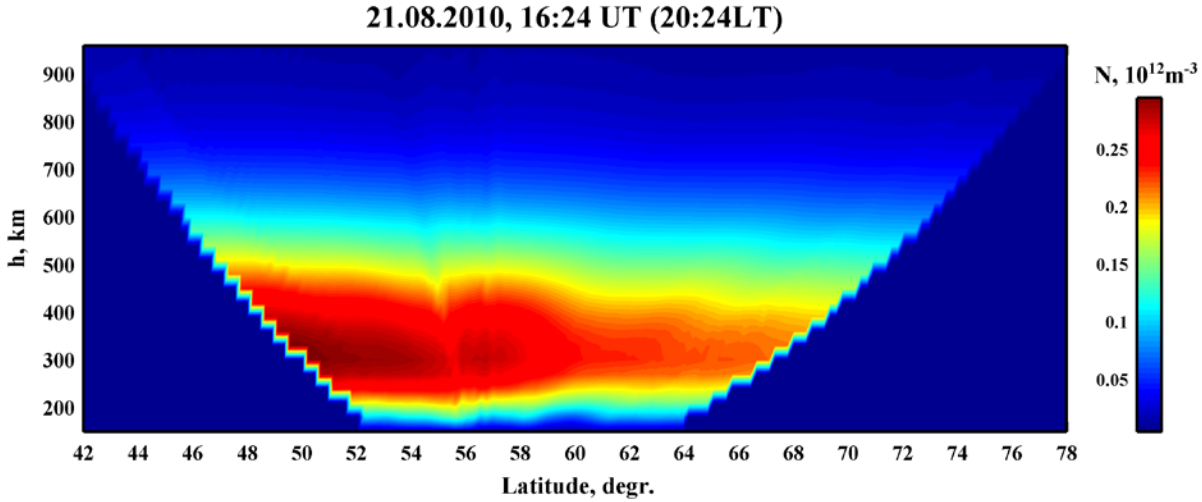


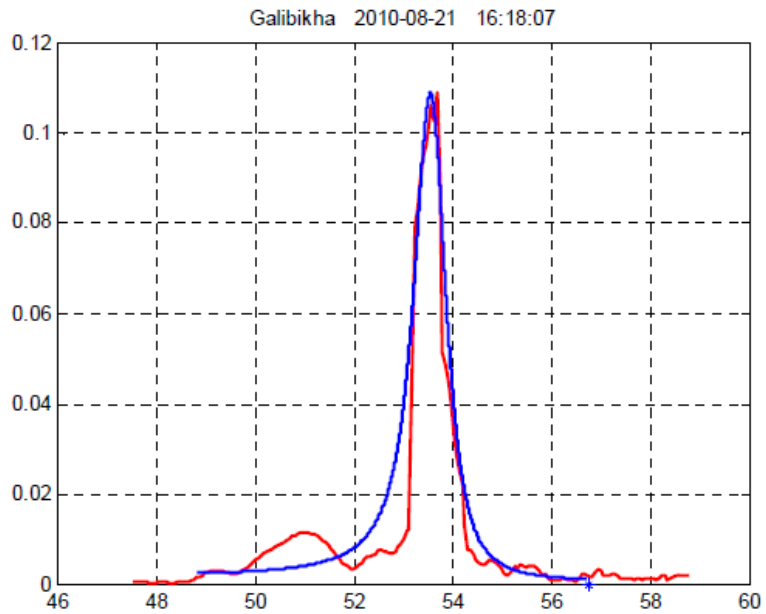
Low-orbital tomography and amplitude scintillations

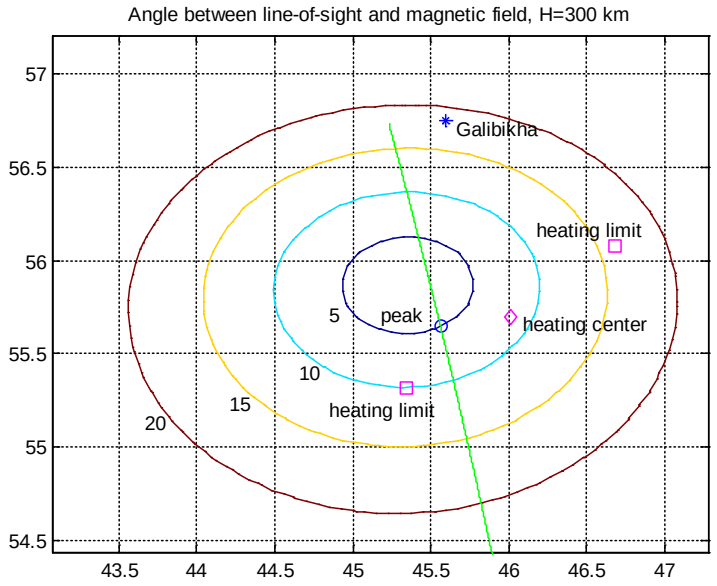
$$\phi + \varphi_0 \propto \int N_e dl$$

$$\sigma_\chi^2 \propto \int \sigma_N^2(z) f\left[R_F(z), \alpha, \beta, \Psi, p, \Theta(z)\right] dz$$

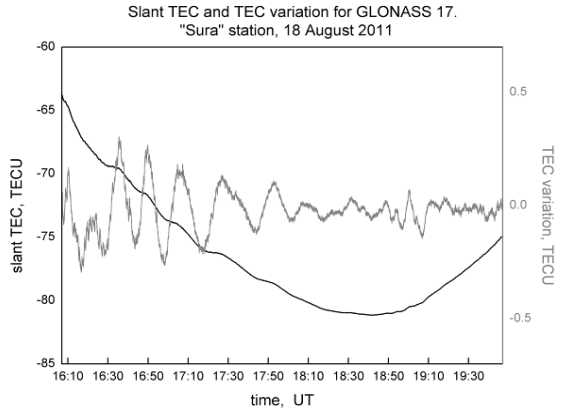


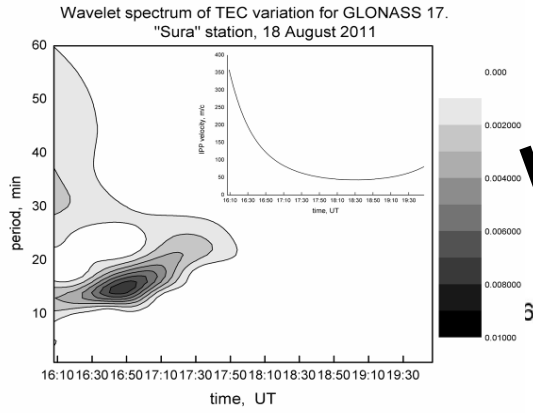


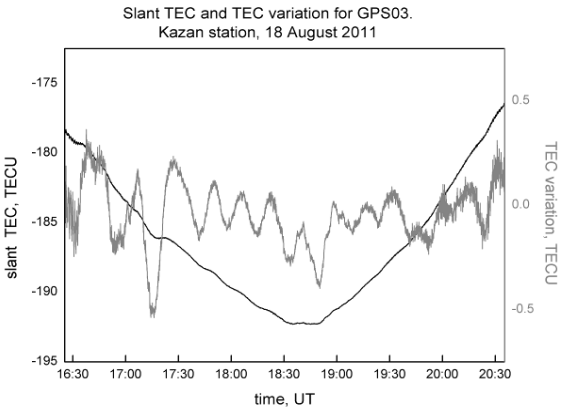


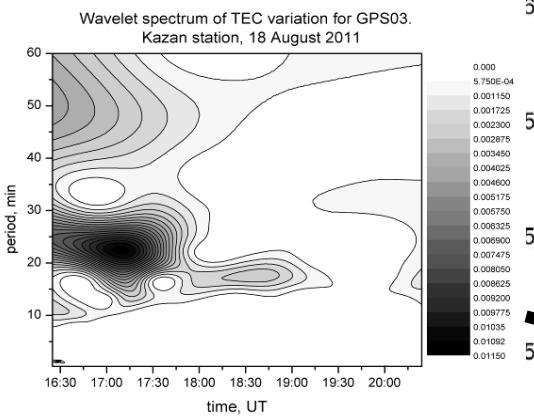


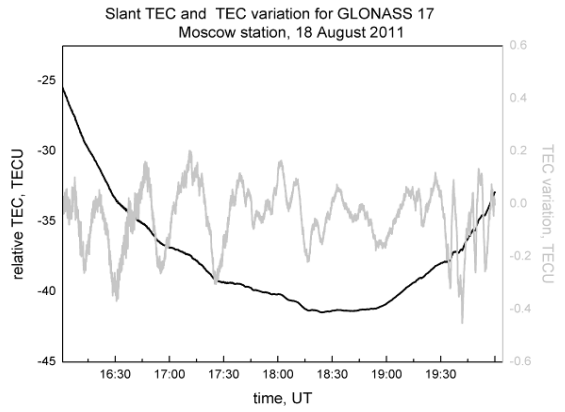
Coordinated GNSS and LORT observations of the wavelike disturbances induced by HF-heating. August,18 2011 [Kunitsyn et al., 2012].

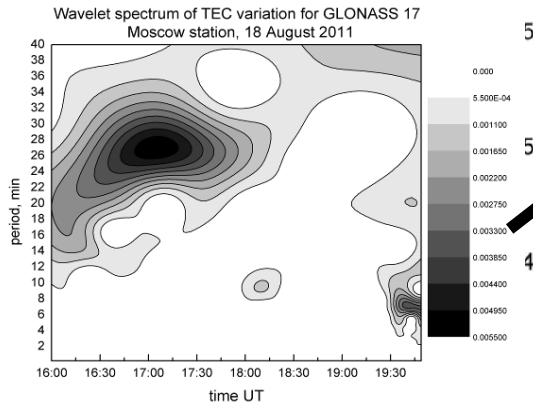




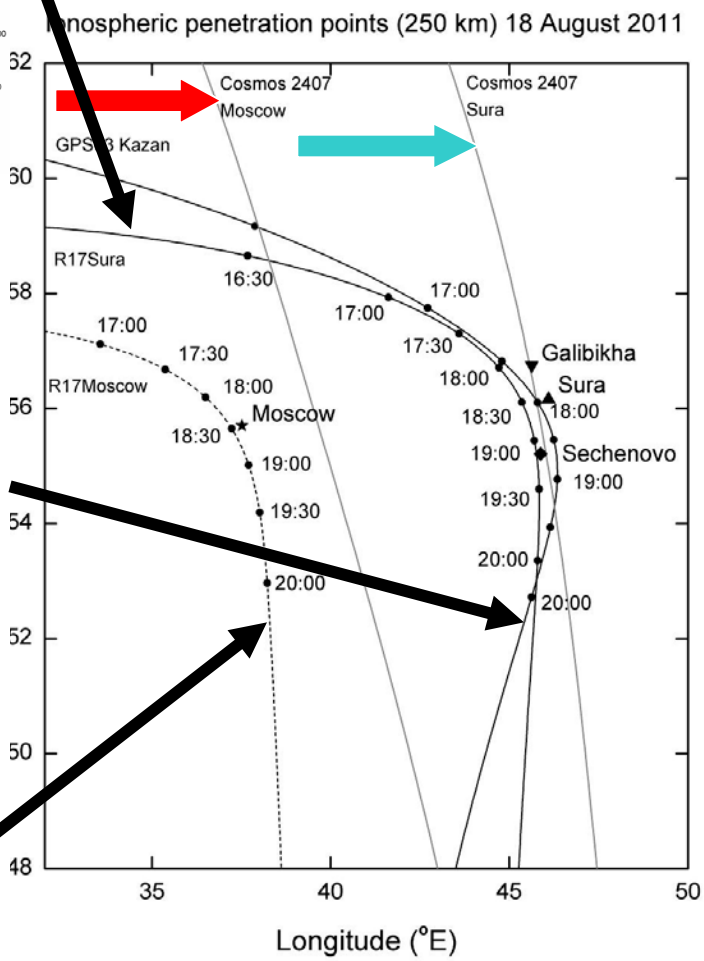








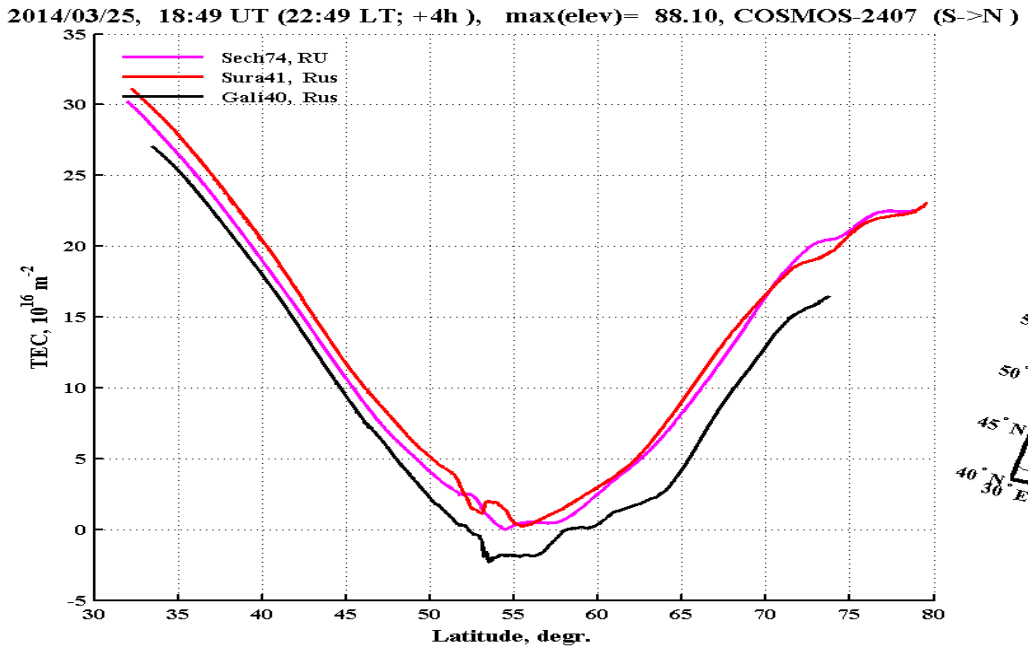
14:16 -16:56 UT, 4785kHz
17:01 -18:51 UT, 4785kHz
±10 min with ERP = 100MW
f_oF2 = 5.7 MHz

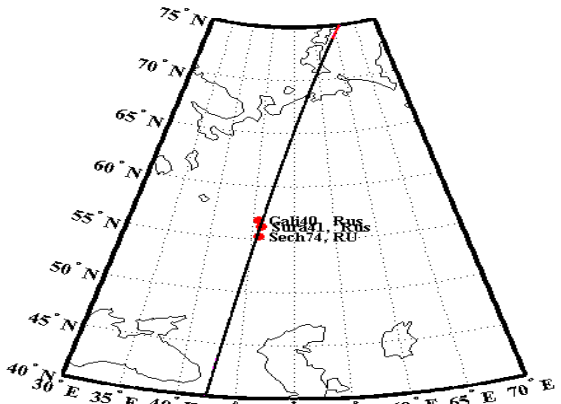


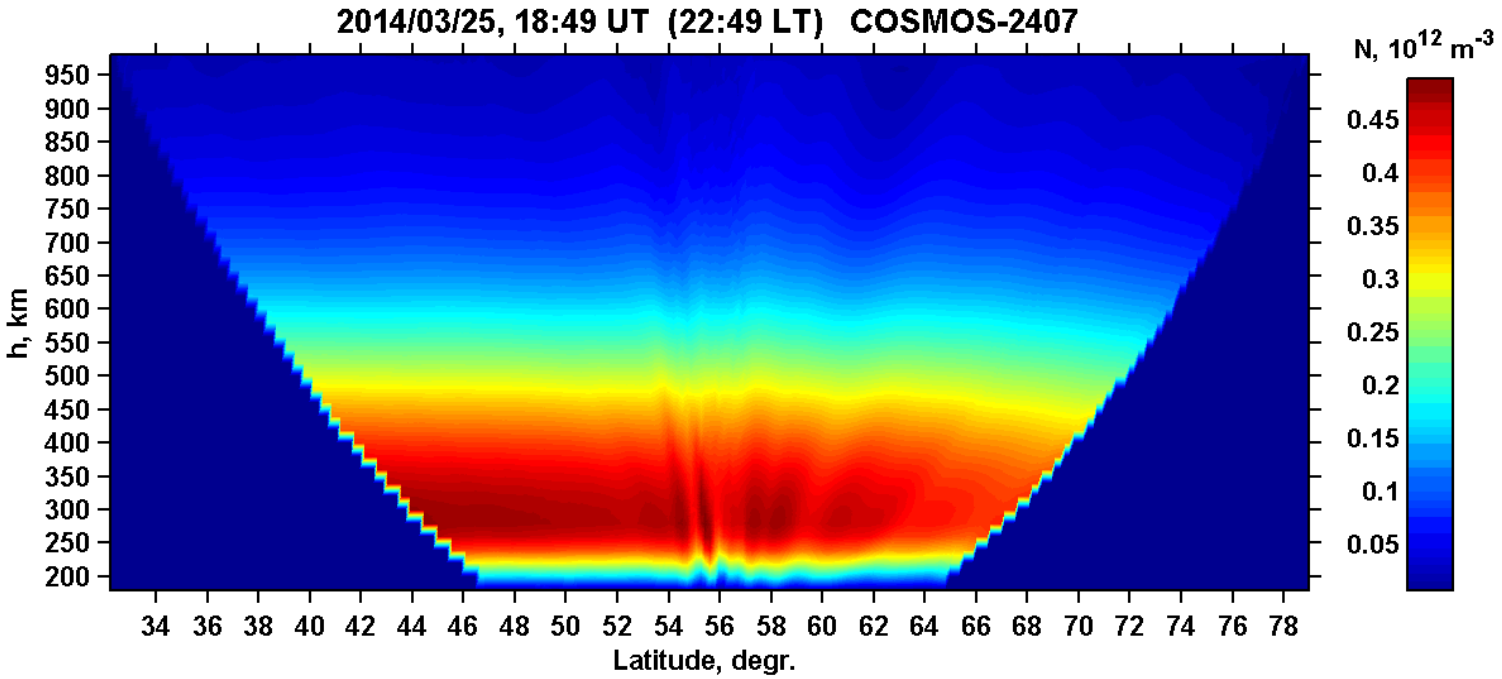
15:58 –18:38 UT — 5455kHz (lower than f_OF2). [+10 min, -10 min], ERP ~100 MW

18:38 – 18:50 UT — 5455kHz CW

PARUS

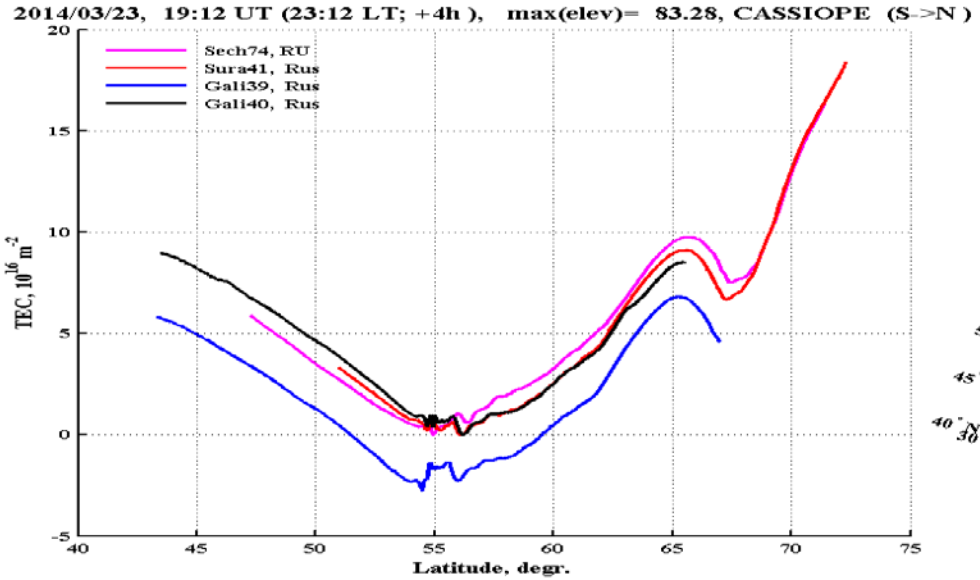




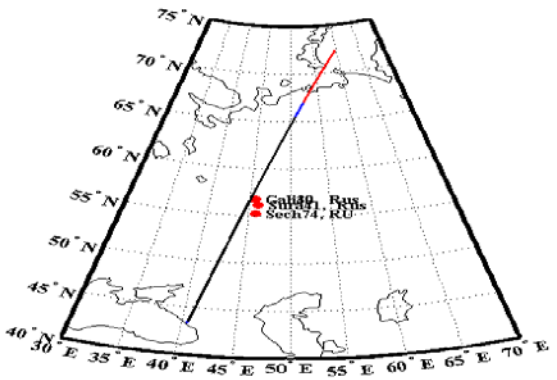


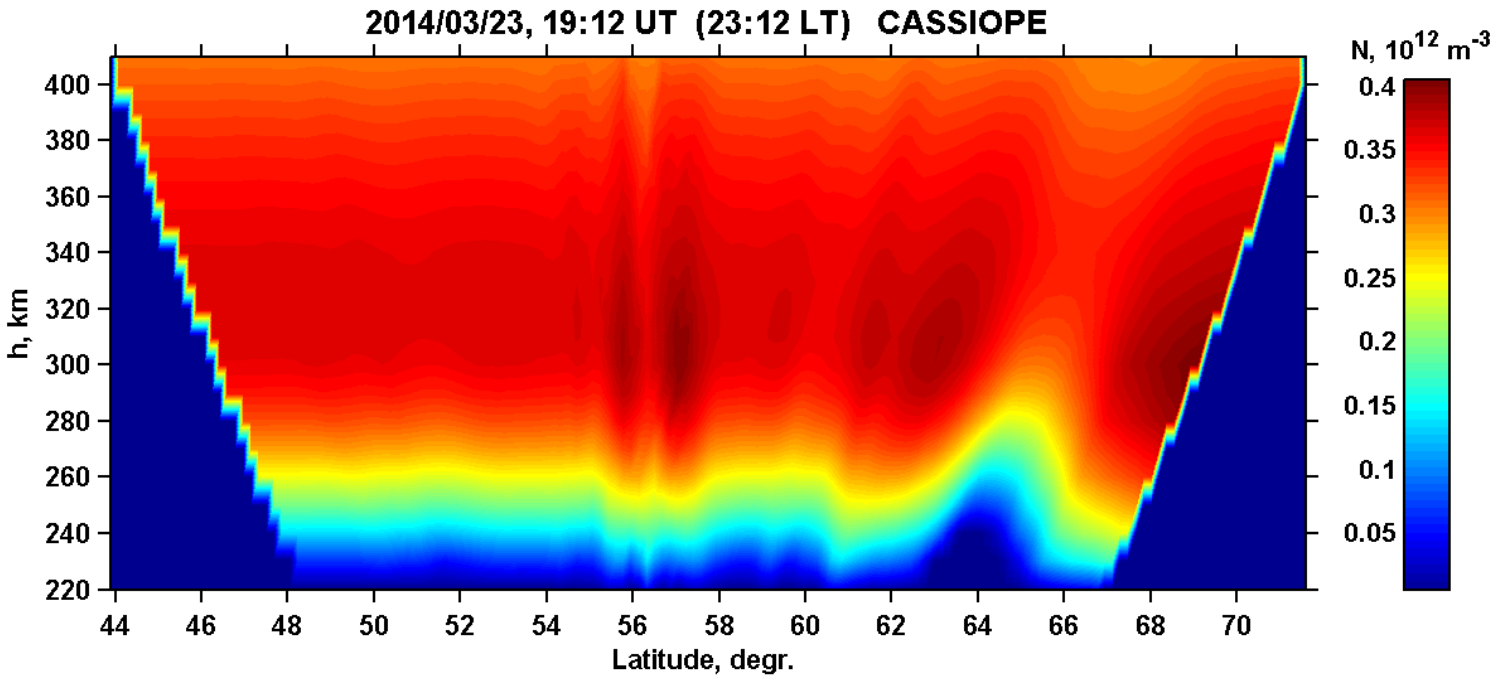
15:58 – 17:13UT – 8060kHz ±15 min; 17:28 – 18:43UT – 4785kHz ±15 min ERP ~ 100MW

18:58 – 19:18UT – 4785kHz CW ERP ~ 100MW



ePOP

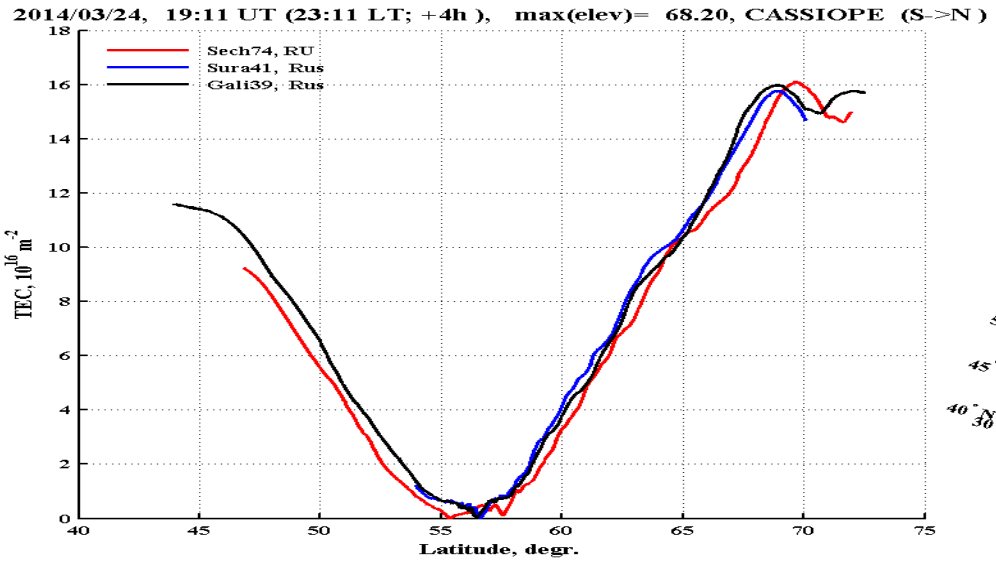


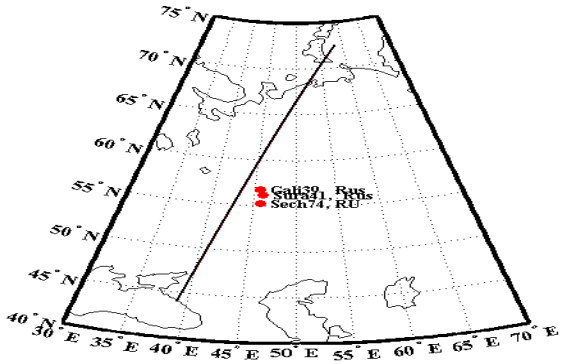


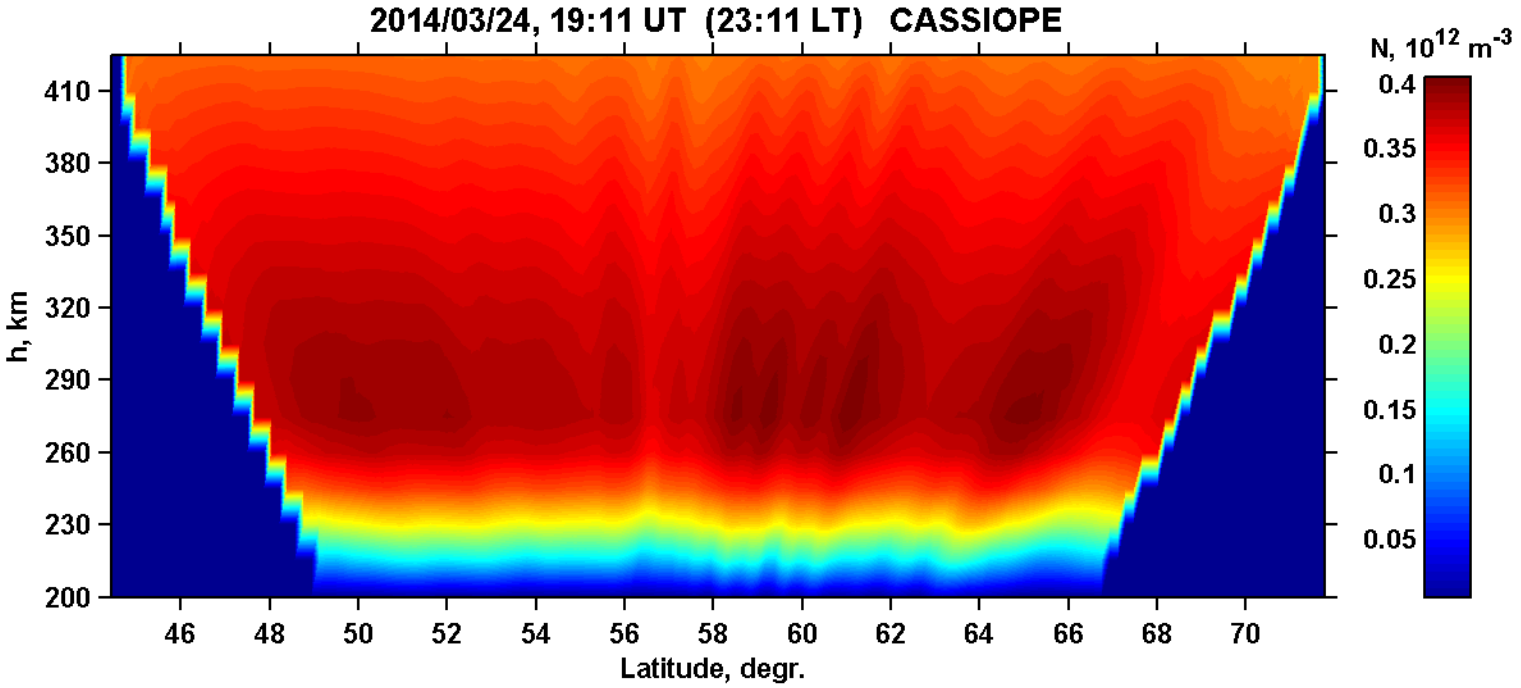
15:58 – 18:43UT – 4785kHz ±15 min ERP ~ 100MW

18:58 – 19:18UT – 4785kHz CW ERP ~ 100MW

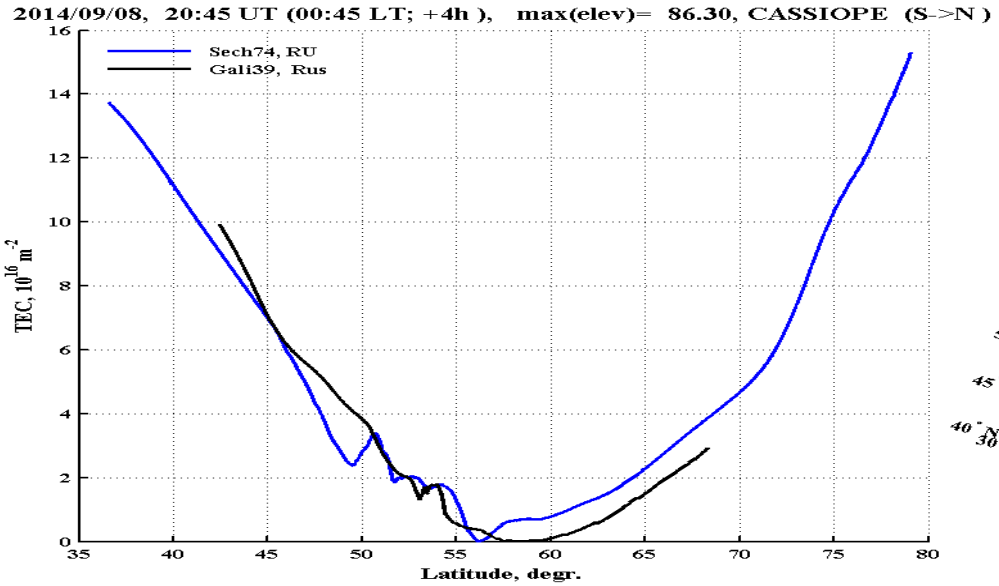
ePOP

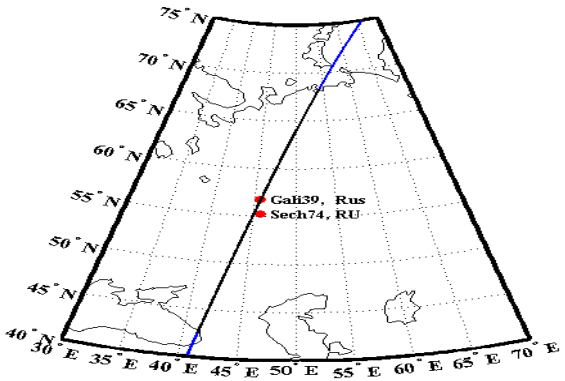






19:04 – 20:19 UT — 4300 kHz, [+ 15 min; – 15 min], *ERP* = 55 MW.
20:34 – 20:54 UT — 4300 kHz, [+ 9 s; – 1 s], *ERP* = 55 MW. f_OF2 ≈ 4.7 MHz at 20:30 UT.





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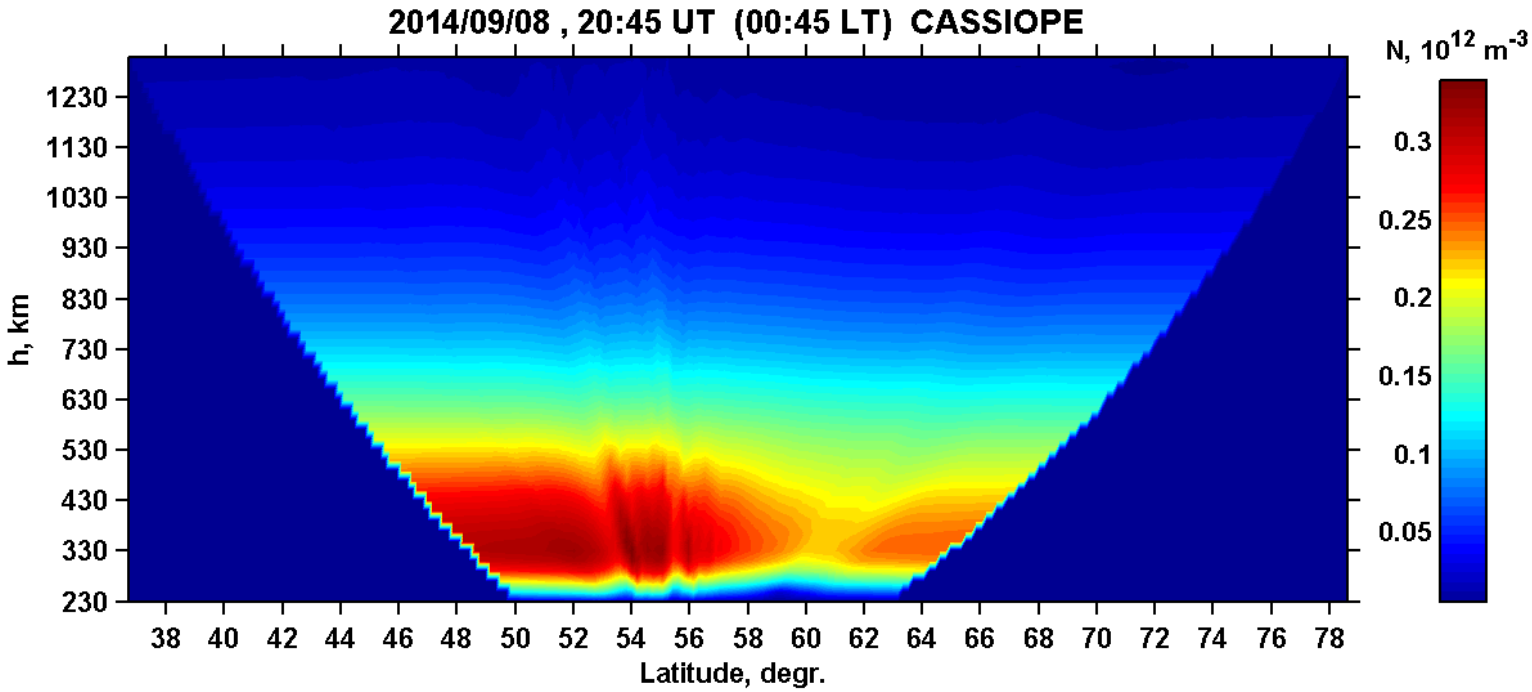
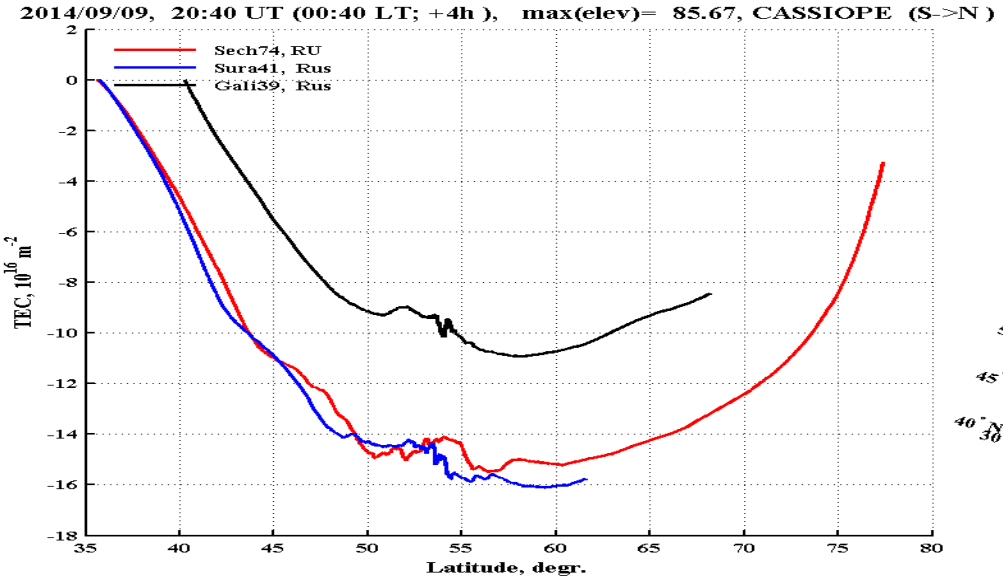
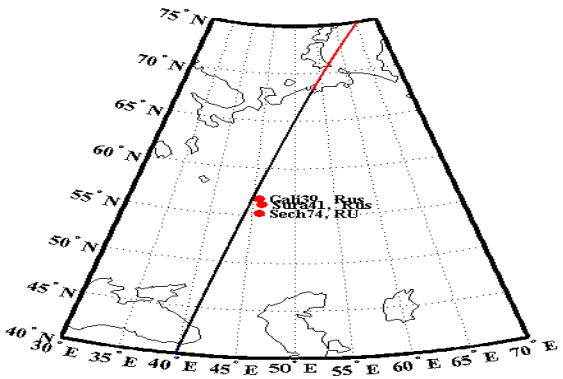


18:59 – 20:14 UT — 4300 kHz, [+ 15 min; – 15 min], *ERP* = 55 MW. $f_OF2 \approx 4.4$ MHz at 20:15 UT.
20:29 – 20:30 UT — 4300 kHz, CW; 20:30 – 20:49 UT -[+ 9 s; – 1 s], *ERP* = 55 MW





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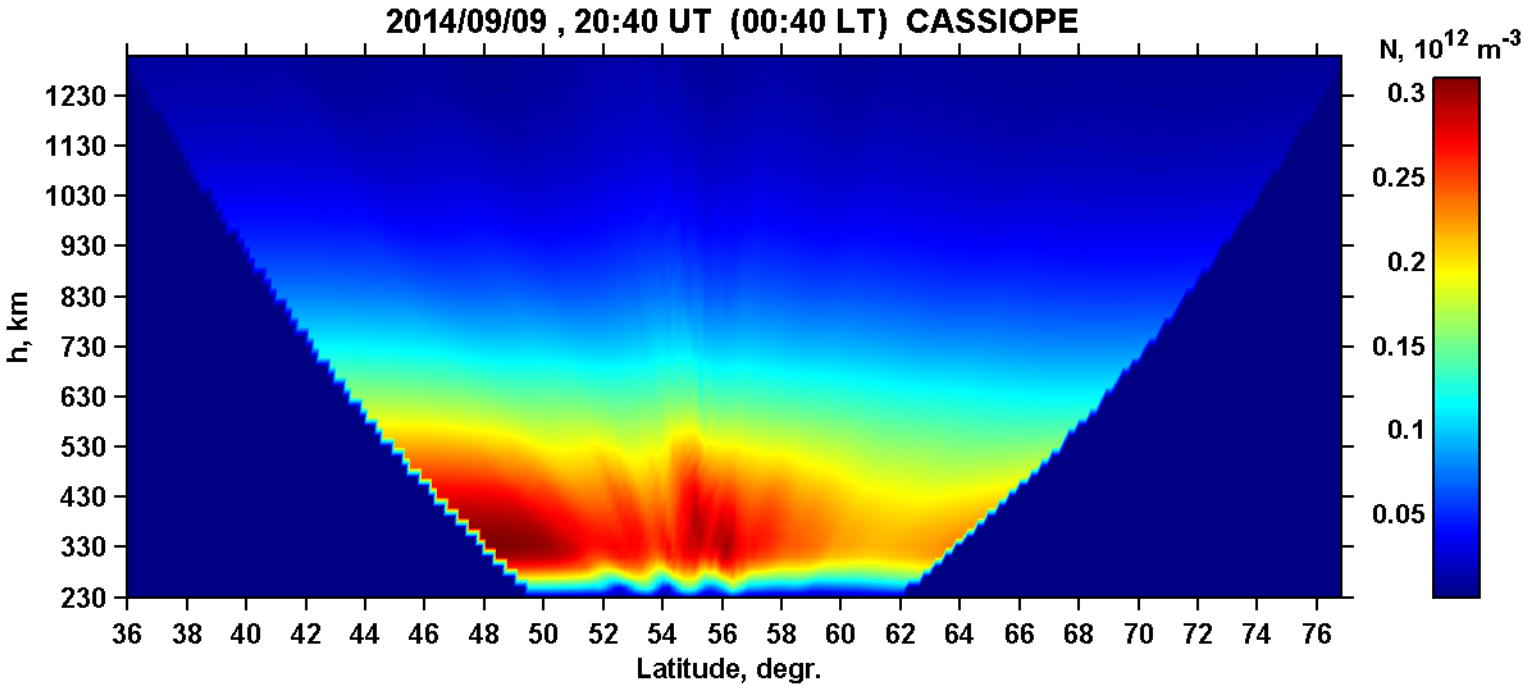
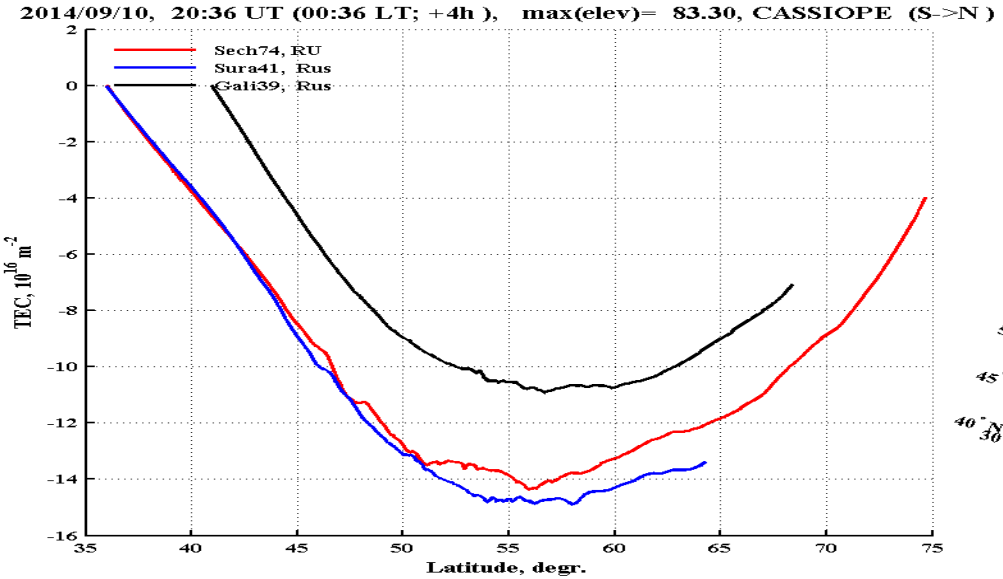
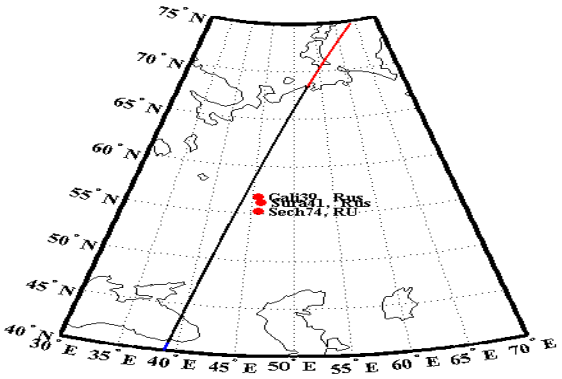


18:56 – 20:26 UT — 4300 kHz, [+ 10 min; – 10 min], *ERP* = 55 MW.

20:26 – 20:46 UT — 4300 kHz, [+ 9 s; – 1 s], *ERP* = 55 MW. $f_0F2 \approx 4.5$ MHz at 19:50 UT.





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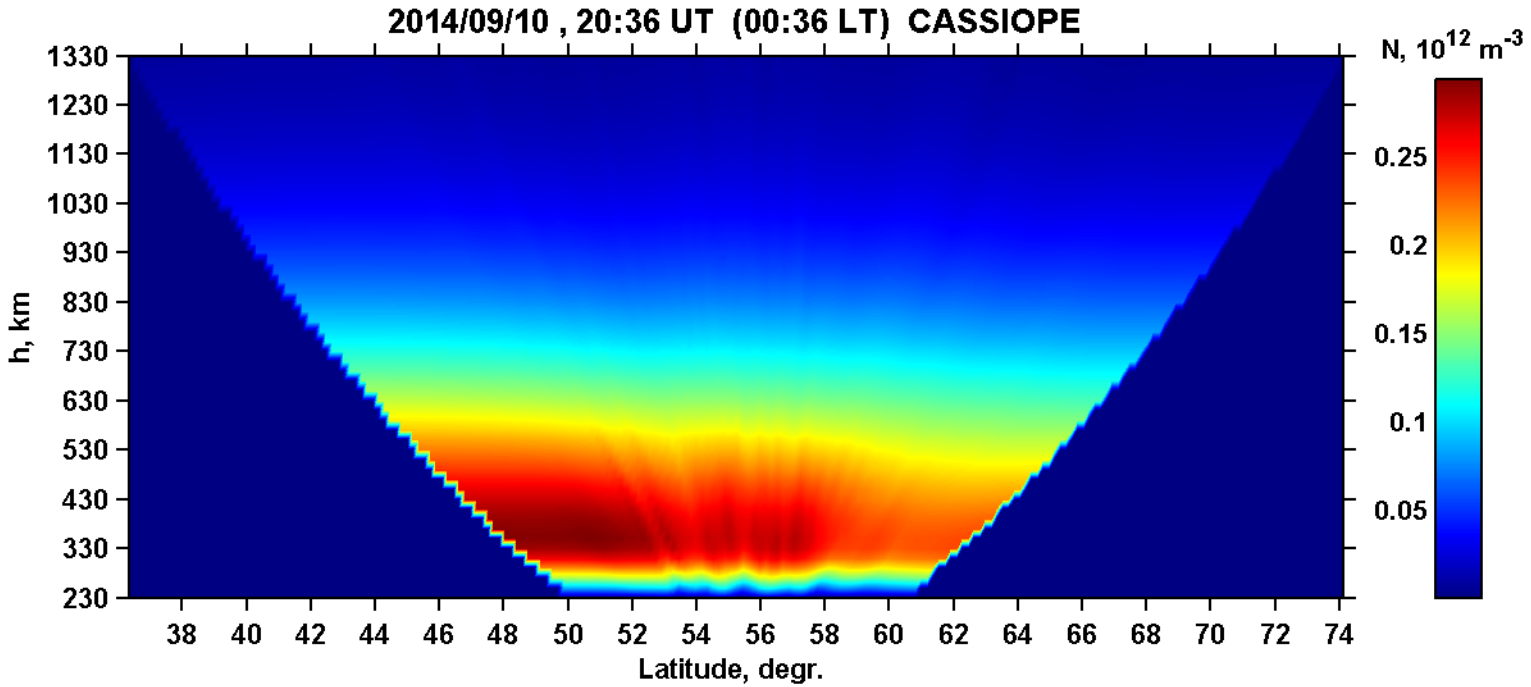
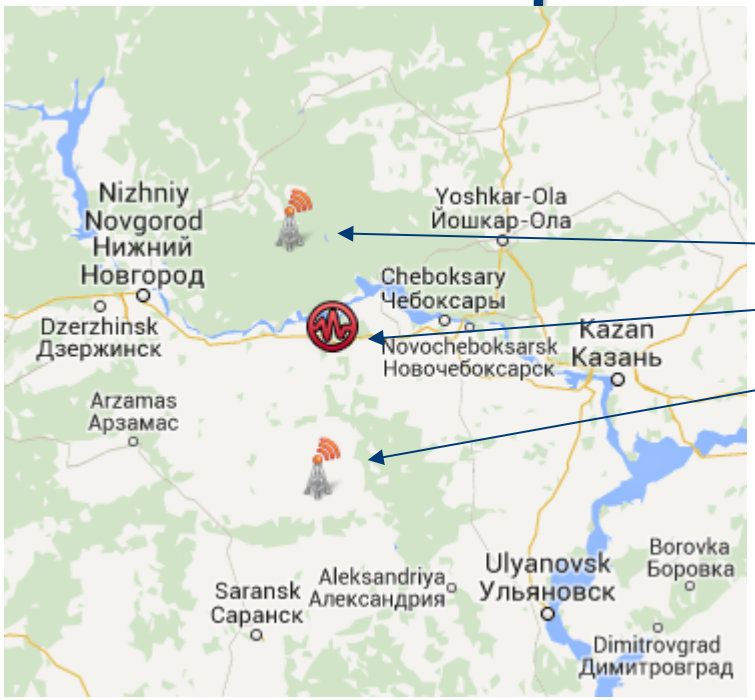


ePOP-SURA tomography experiment summary

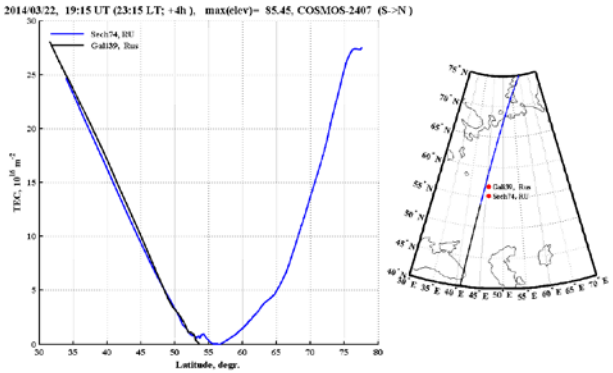


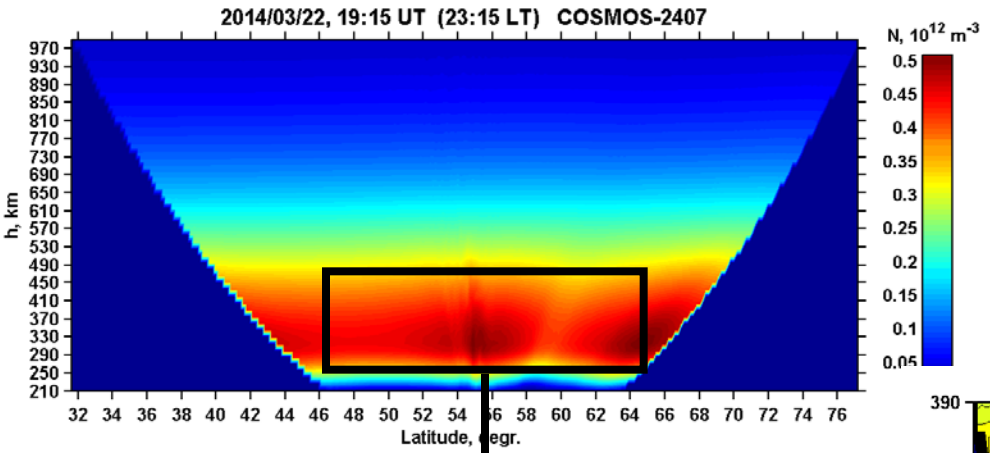
- two campaigns (March, September 2014)
- 3 receiving sites with NWRA ITS30/33S beacon receivers (150/400/1066MHz)
  - a) Galibikha(56°45′18″N, 45°36′57″E)
  - b) Sura(56°08′15″N, 46°02′40″E)
  - c) Sechenovo(55°13′28″ N, 45°53′26″ E)
- Sura heater (all 3 transmitters) operating O-mode, square wave modulation of ERP at a frequency of the order of the Brunt-Vaisala frequency, $f_H \leq f_O F2$, nighttime conditions

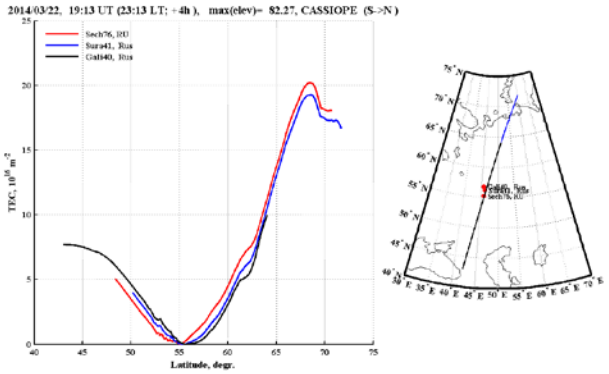
Common features to benoted on the following RT reconstructions:

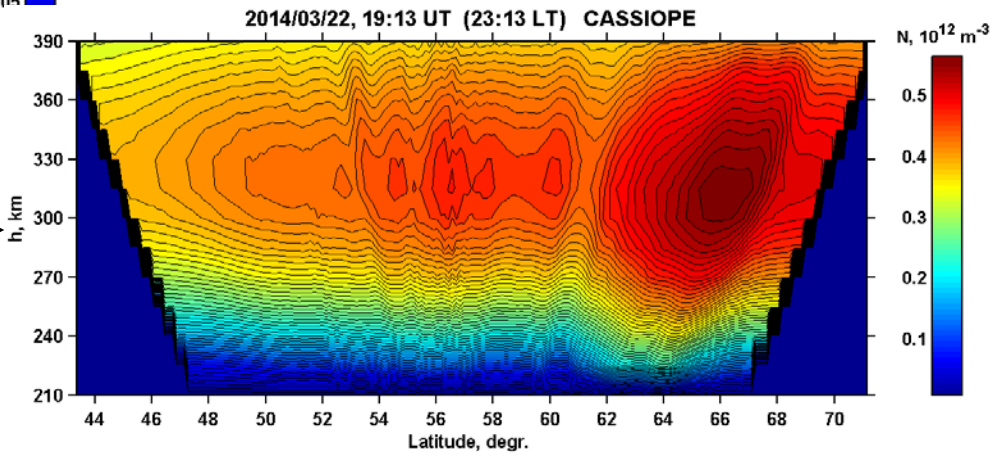
- wave-like structures, possibly artificial AGWs, diverging from the heated area
- narrow trough, corresponding to directivity pattern of Sura heater

LORT reconstructions of disturbed area using ePOP and COSMOS data



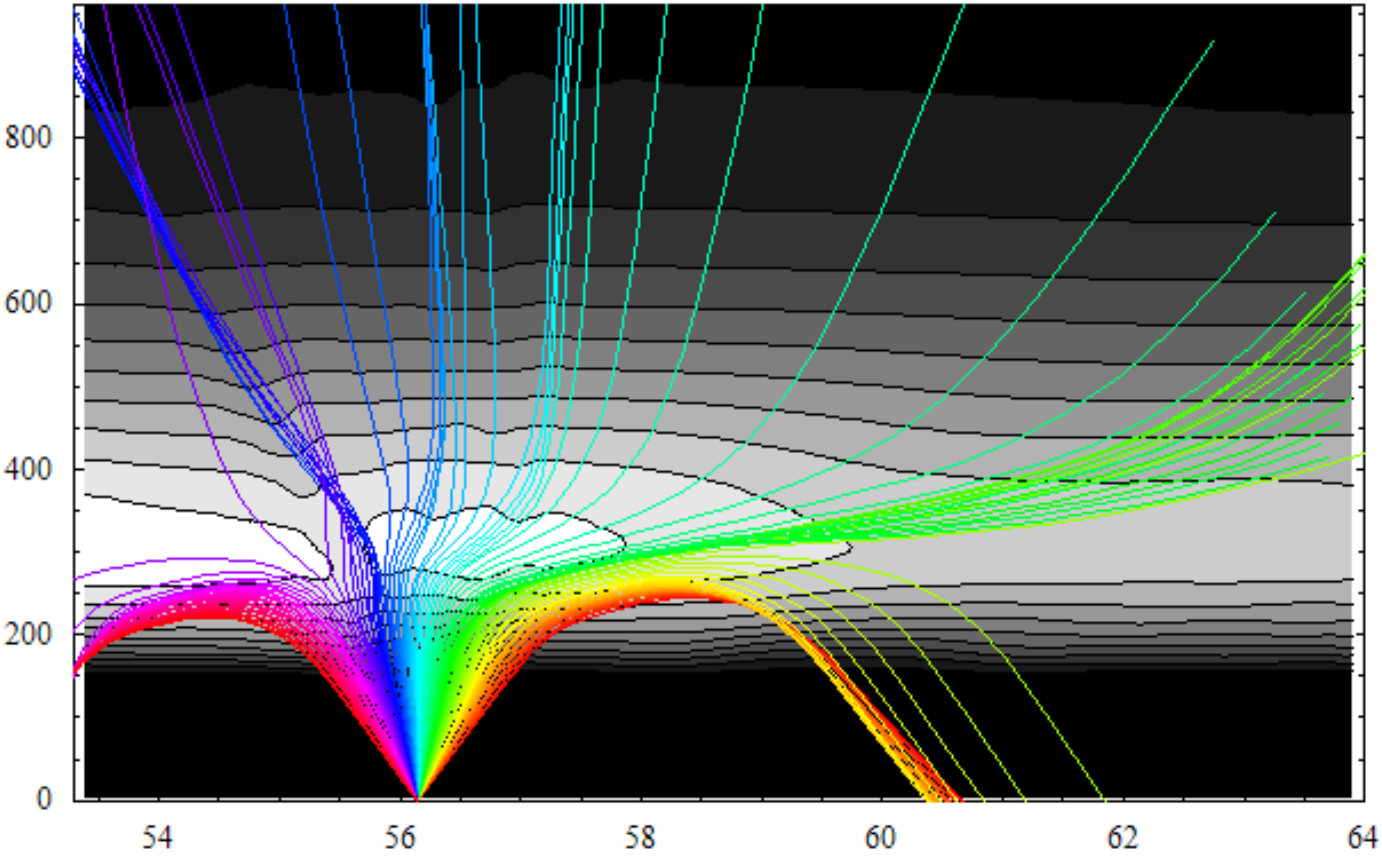






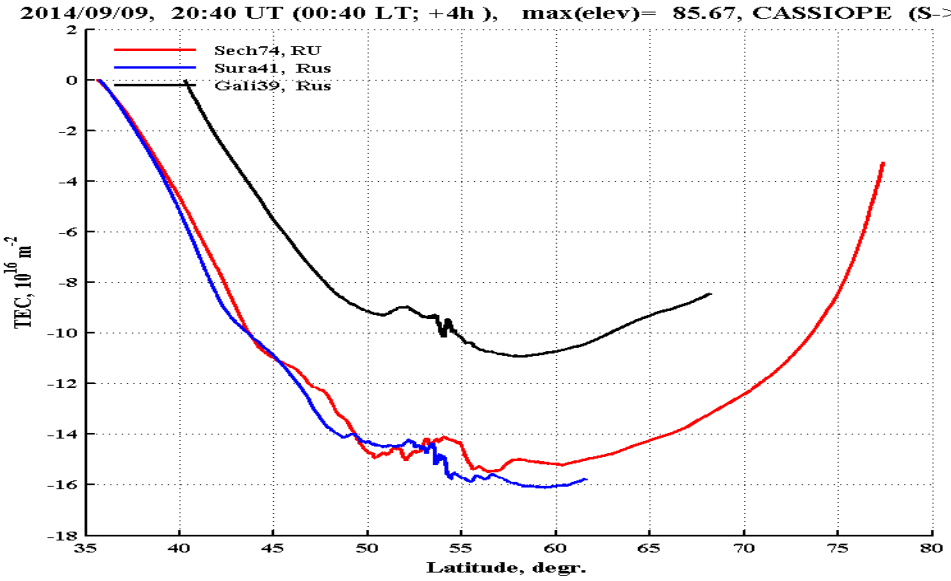
Penetration of the pumping wave up to the satellite heights

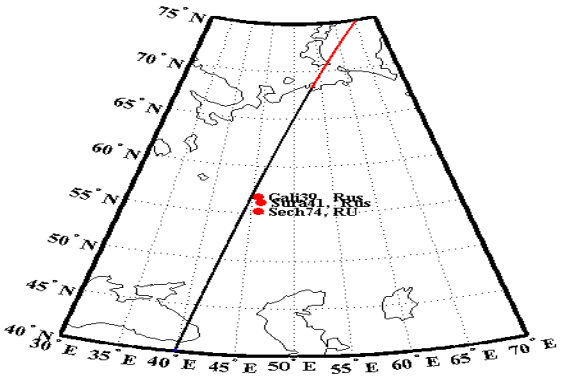
21.08.2010 16:24 UT for COSOMOS 2414 pass

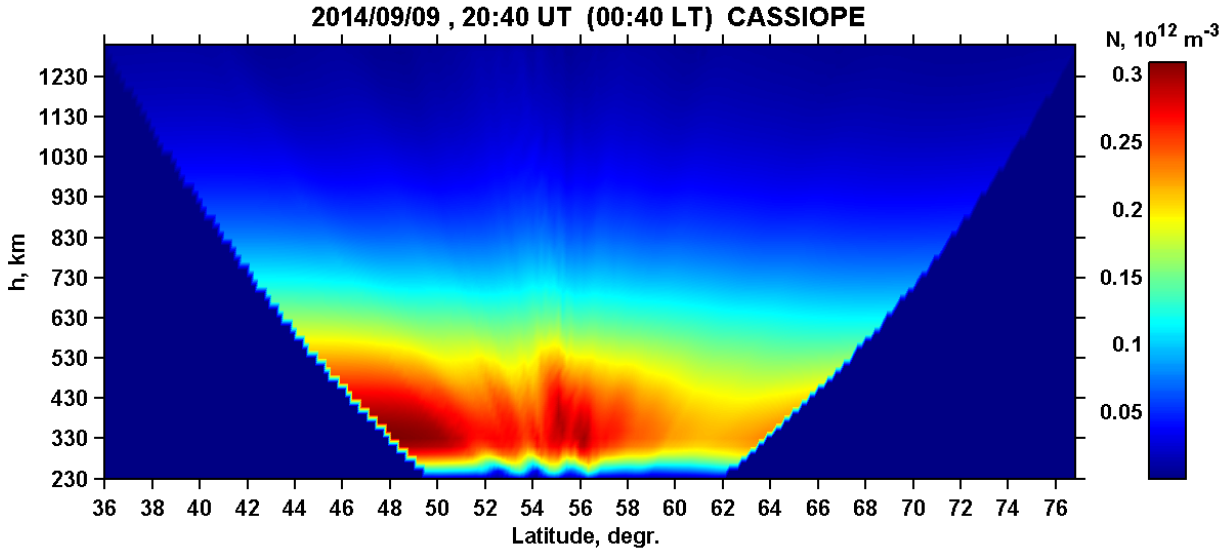


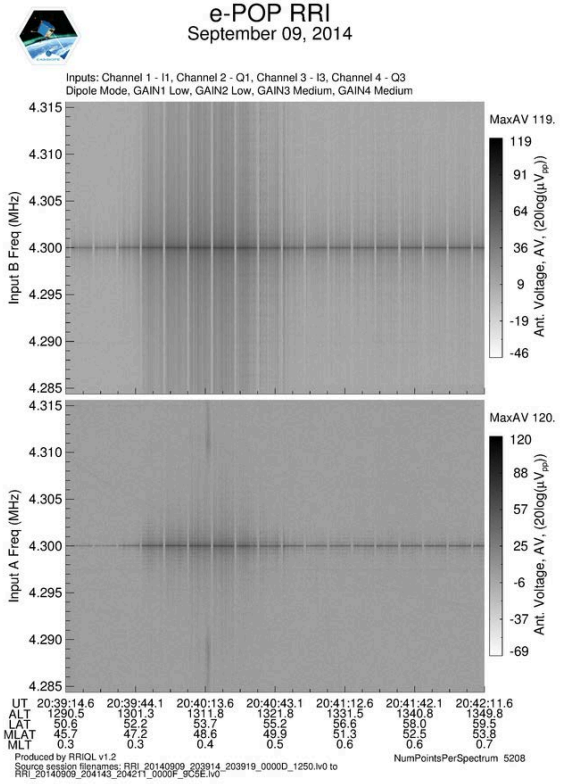
Courtesy of Prof. A. Krukovsky

18:59 – 20:14 UT — 4300 kHz, [+ 15 min; – 15 min], *ERP* = 55 MW. f0F2 ≈ 4.4 MHz at 20:15 UT.
20:29 – 20:30 UT — 4300 kHz, CW; 20:30 – 20:49 UT -[+ 9 s; – 1 s], *ERP* = 55 MW









Courtesy of Dr. Gordon James

Conclusions.

- We present the evedences for the generation of artificial AGW/TIDs in ionospheric heating experiments at Sura heater when the ERP is modulated with a square wave at a frequency lower than the Brunt-Vaisala frequency of the neutral atmosphere at the reflection height of the pump wave.
- A comprehensive model of HF-induced thermospheric perturbations has not yet been developed. More observational, theoretical and modeling efforts are required to understand the underlying generation processes. ePOP/CASSIOPE instruments can contribute highly to this work.

THANK YOU FOR YOUR ATTENETION