

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 experiments 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 structure 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 ($46.1^{\circ}E; 56.15^{\circ}N$), $I=71^{\circ}$

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

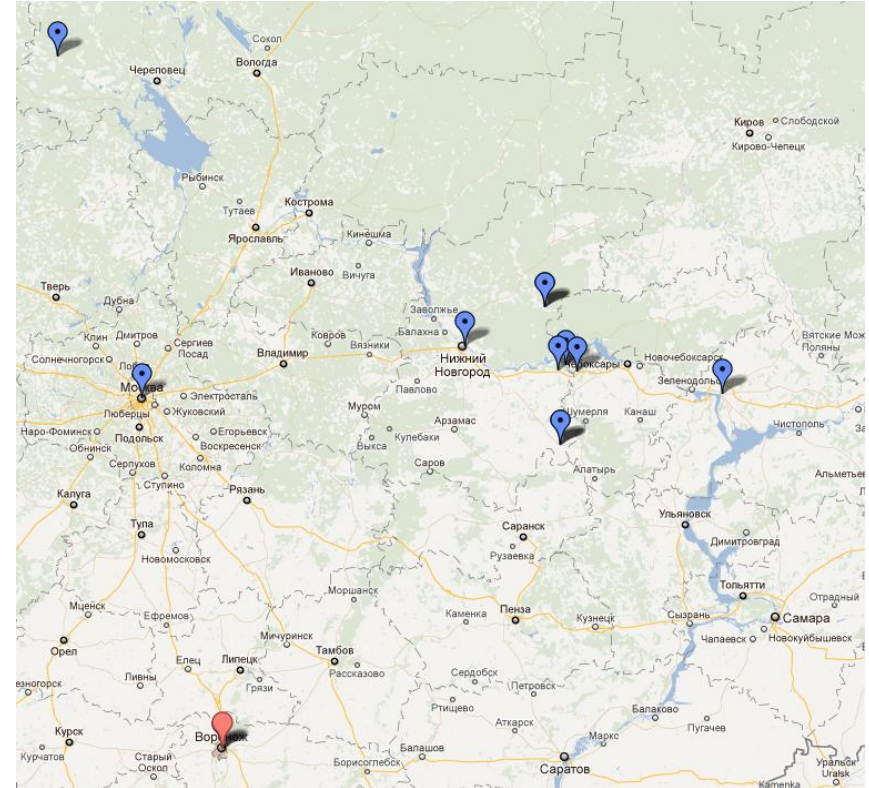
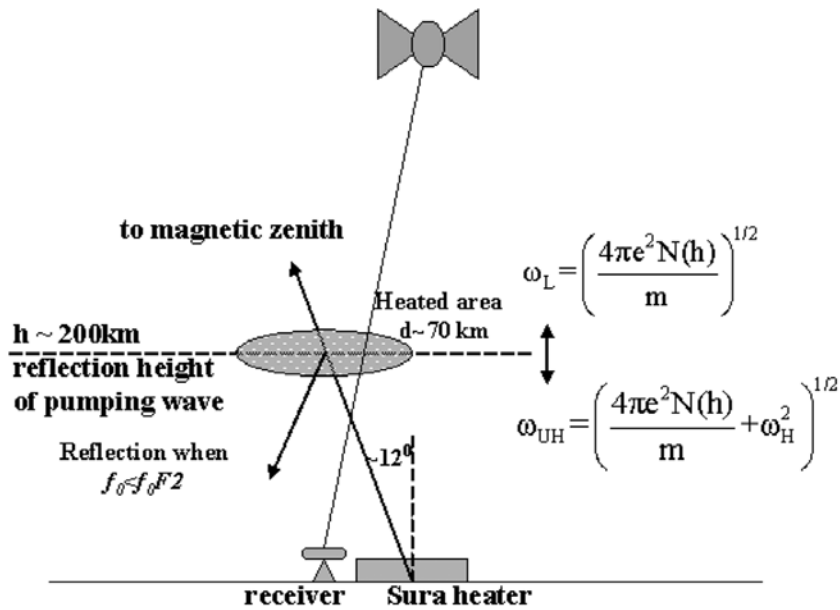
working with 150/400MHz transmissions from

*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

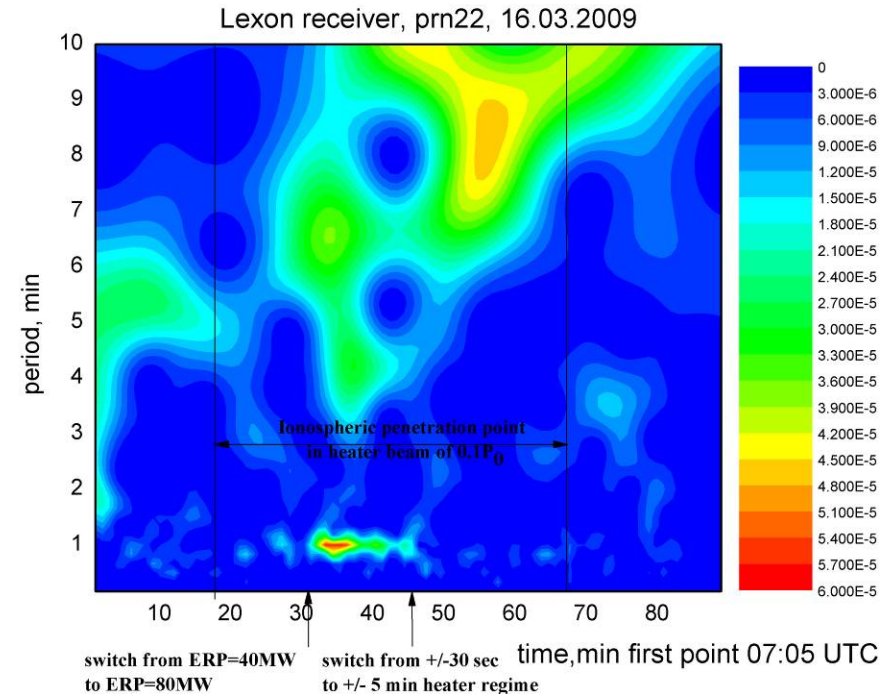
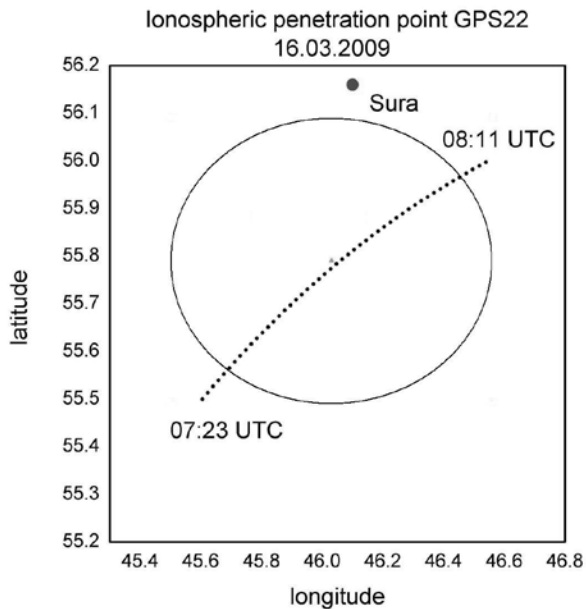
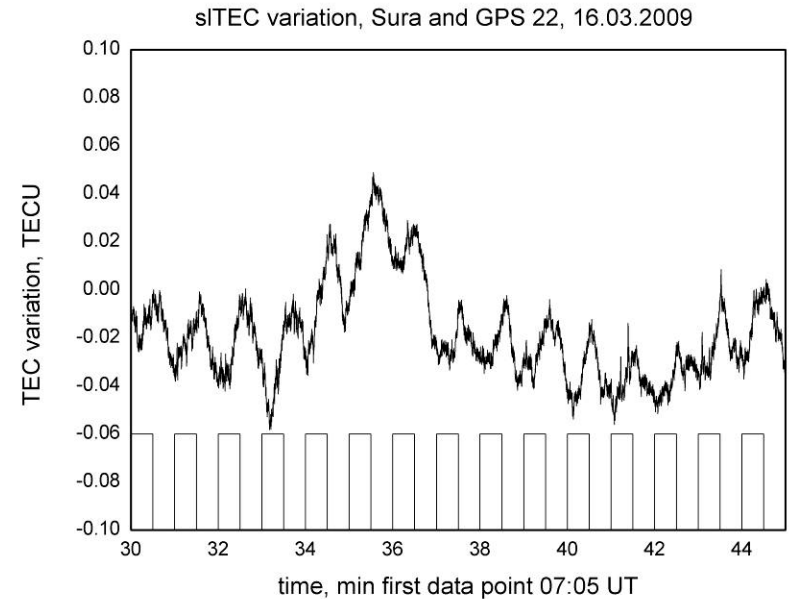
7:51-8:26UT

$f=4.3\text{MHz}$

O-mode ERP=40 Mw till 7:36

and 80 Mw later

Low geomagnetic activity ($K_p \sim 1$)



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

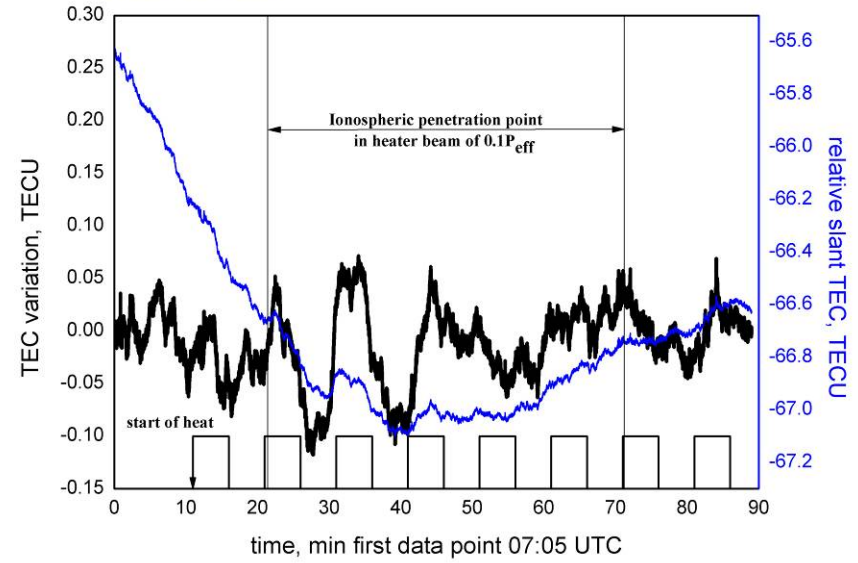
$f=4.3\text{MHz}$

O-mode ERP=80 Mw

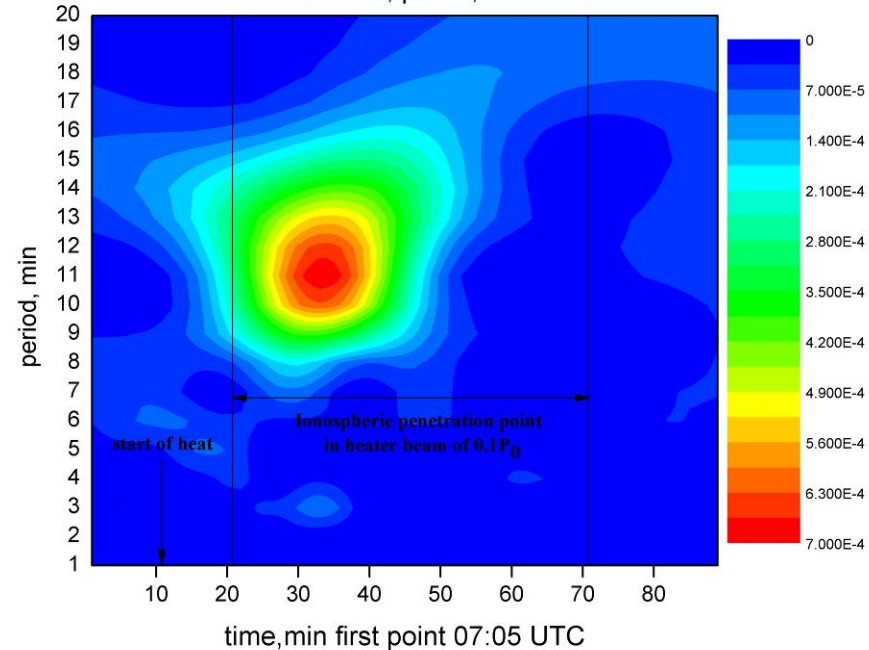
Moderate geomagnetic activity ($K_p\sim 3$)

$f_oF2 < f$ for 7:50 - 8:12 UT

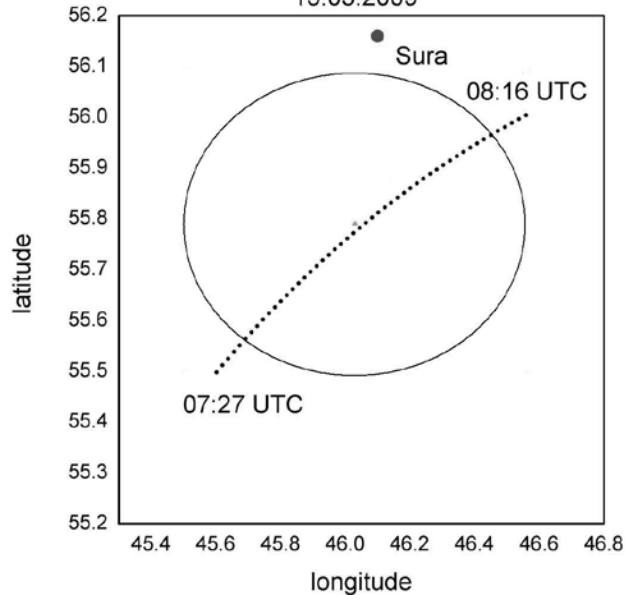
Relative slant TEC and TEC variation, Sura and GPS 22, 15.03.2009



Lexon receiver, prn22, 15.03.2009



Ionospheric penetration point GPS22
15.03.2009

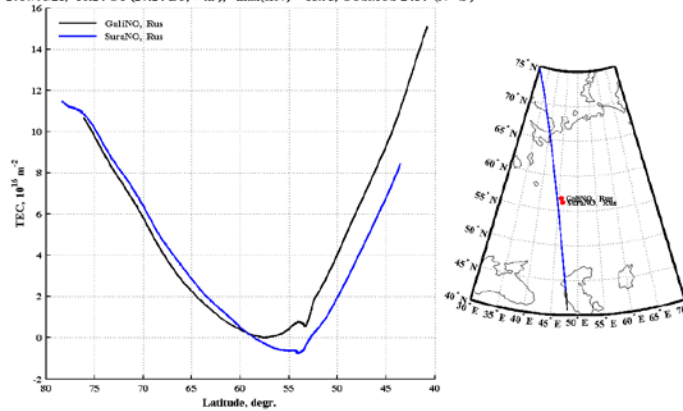


Low-orbital tomography and amplitude scintillations

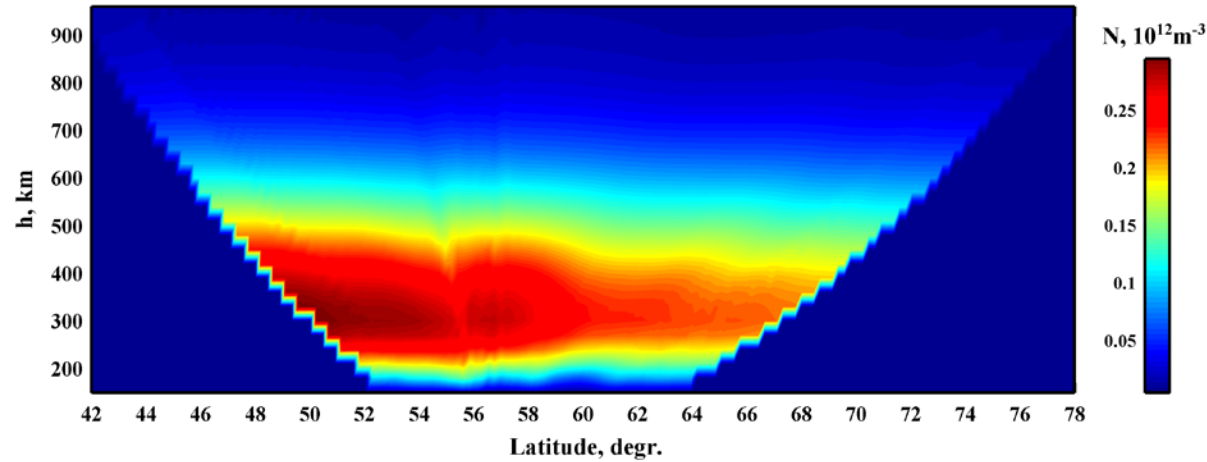
$$\phi + \phi_0 \propto \int N_e dl$$

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

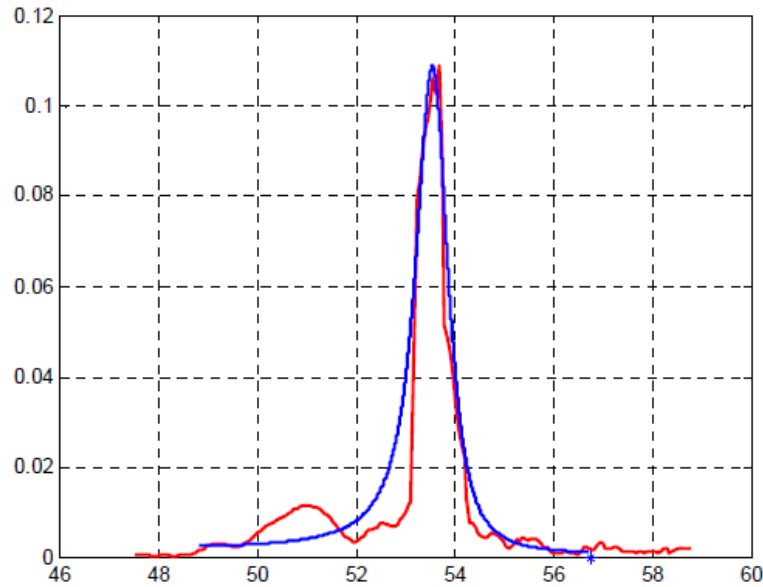
2010/08/21, 16:24 UT (20:24 LT; -4h), max(elev) = 85.95, COSMOS-2414 (N→S)



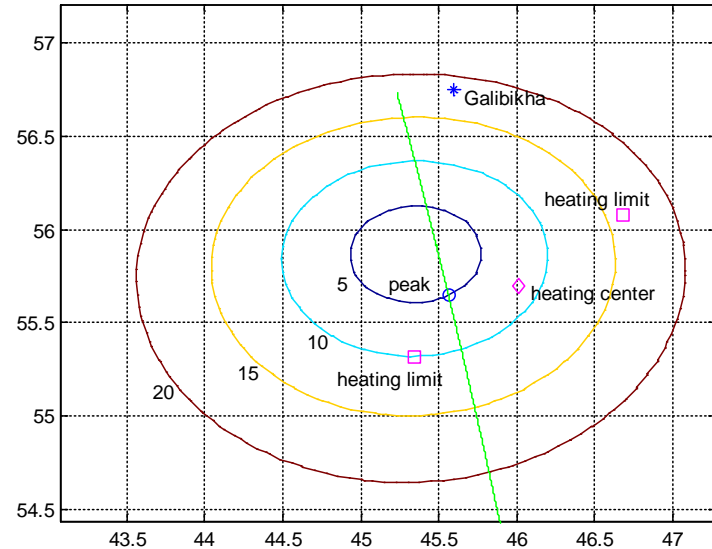
21.08.2010, 16:24 UT (20:24LT)



Galibikha 2010-08-21 16:18:07

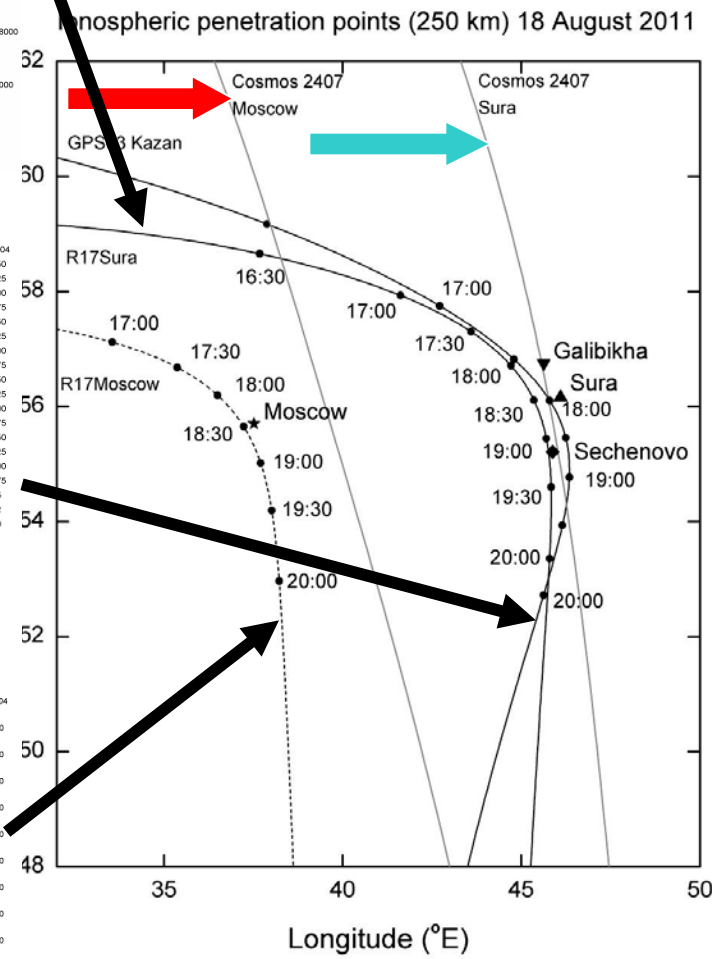
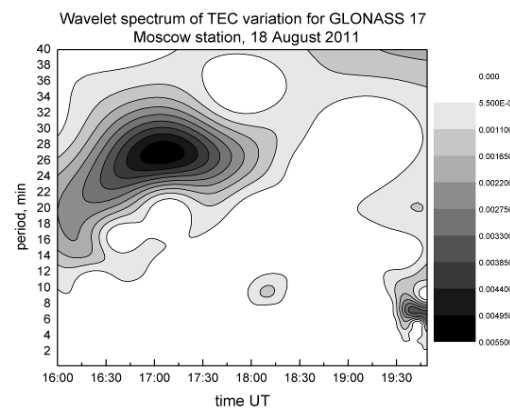
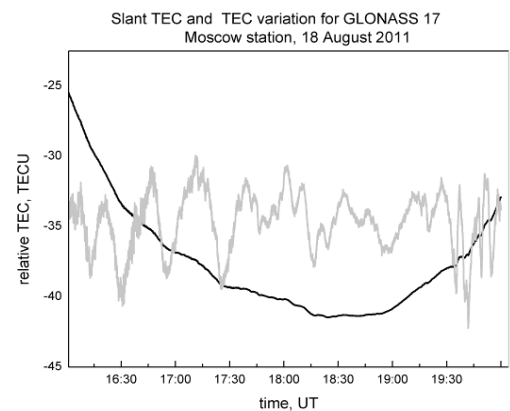
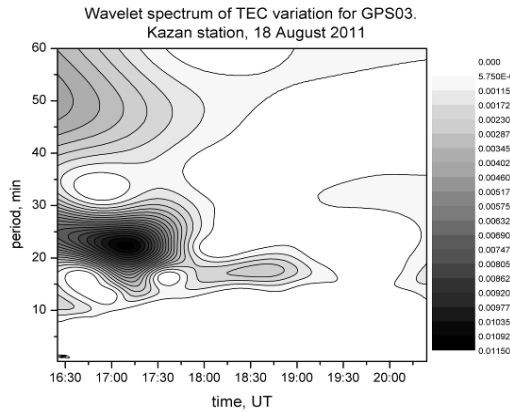
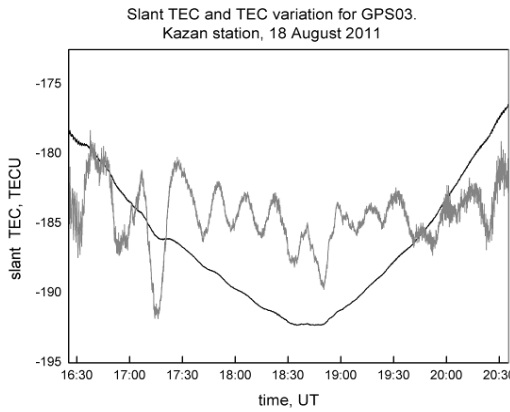
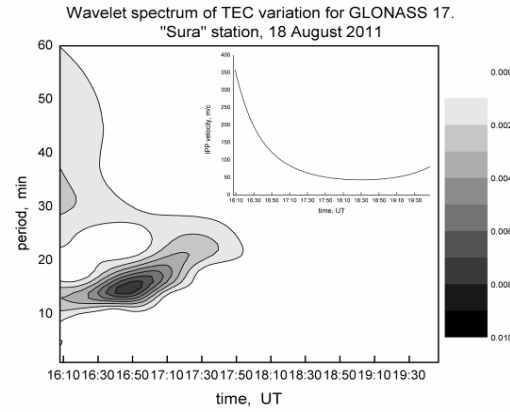
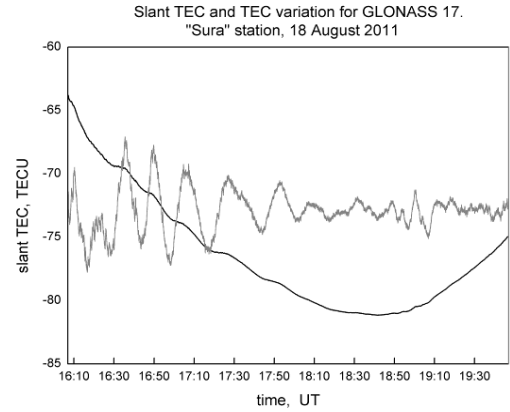


Angle between line-of-sight and magnetic field, H=300 km



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

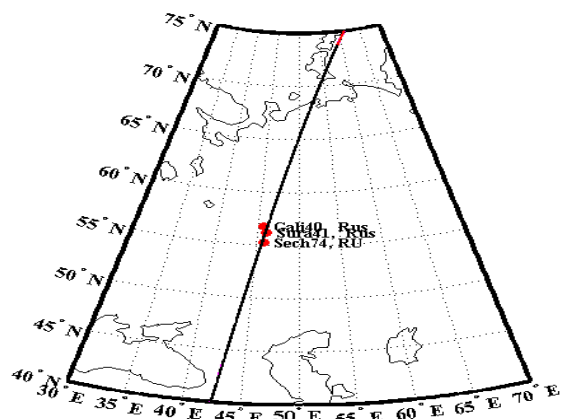
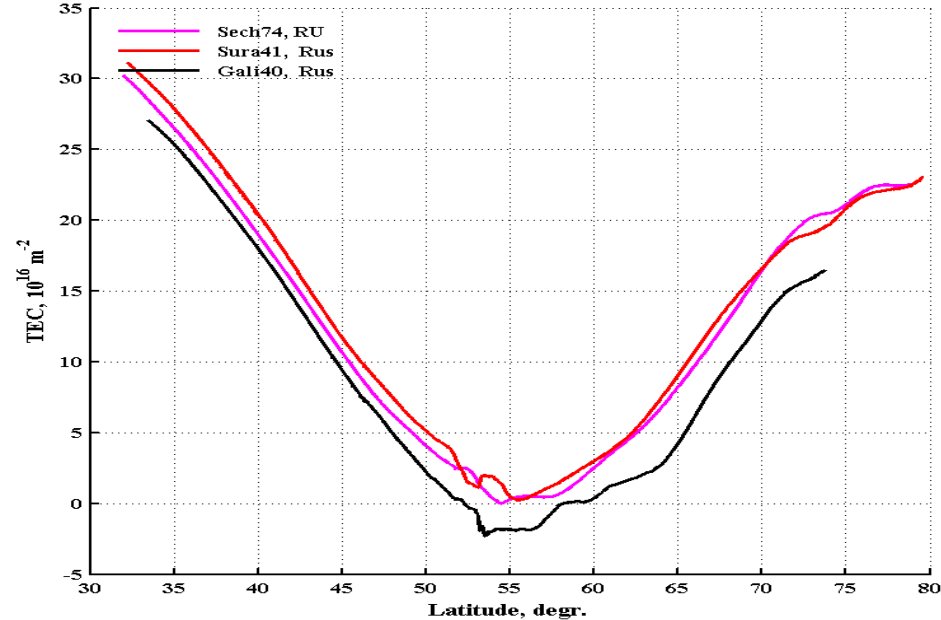


15:58 – 18:38 UT — 5455kHz (lower than f_oF2). [+10 min, -10 min], ERP ~100 MW

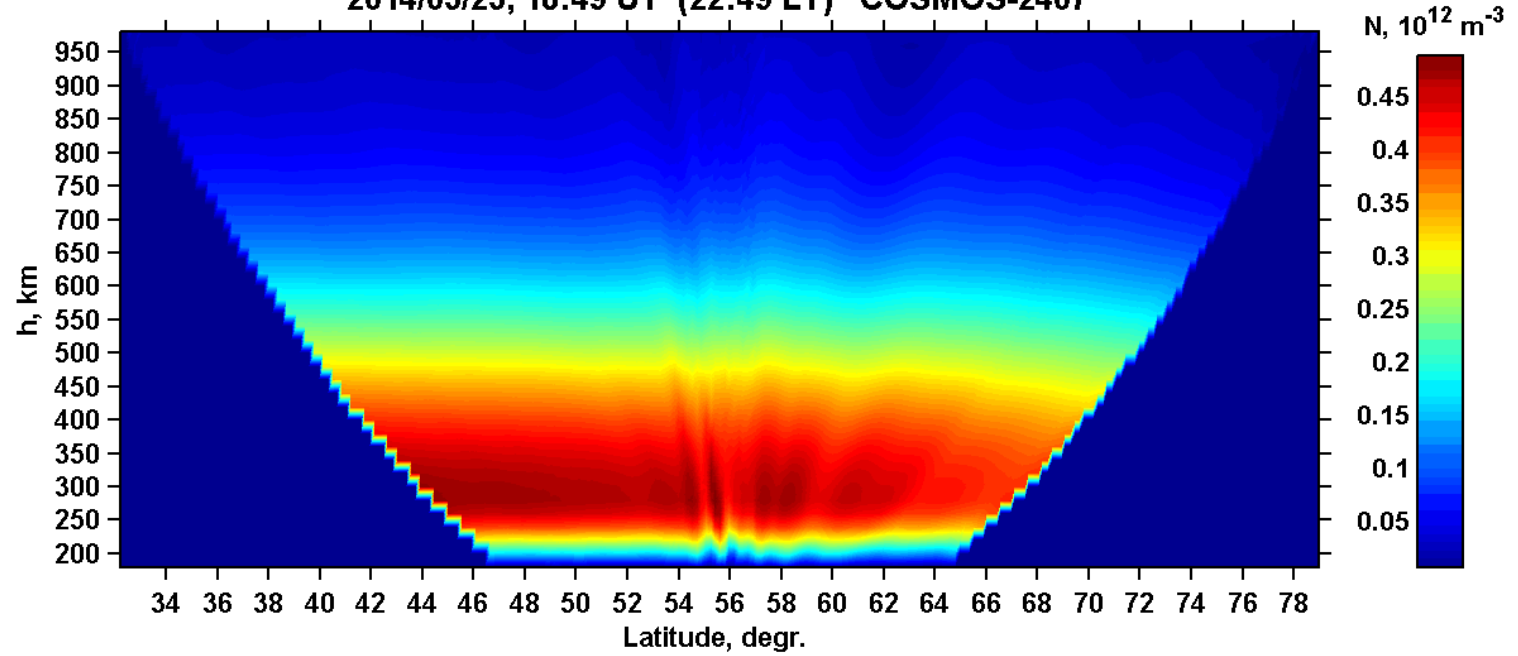
18:38 – 18:50 UT — 5455kHz CW

2014/03/25, 18:49 UT (22:49 LT; +4h), max(elev)= 88.10, COSMOS-2407 (S->N)

PARUS



2014/03/25, 18:49 UT (22:49 LT) COSMOS-2407

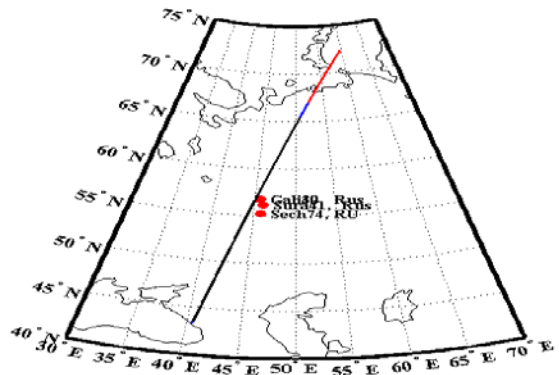
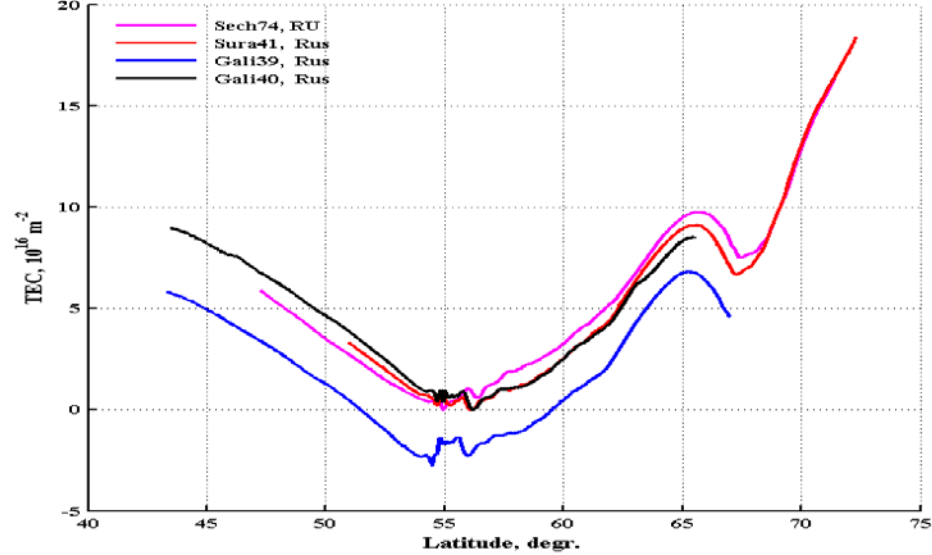


15:58 – 17:13UT – 8060kHz ± 15 min; 17:28 – 18:43UT – 4785kHz ± 15 min ERP ~ 100MW

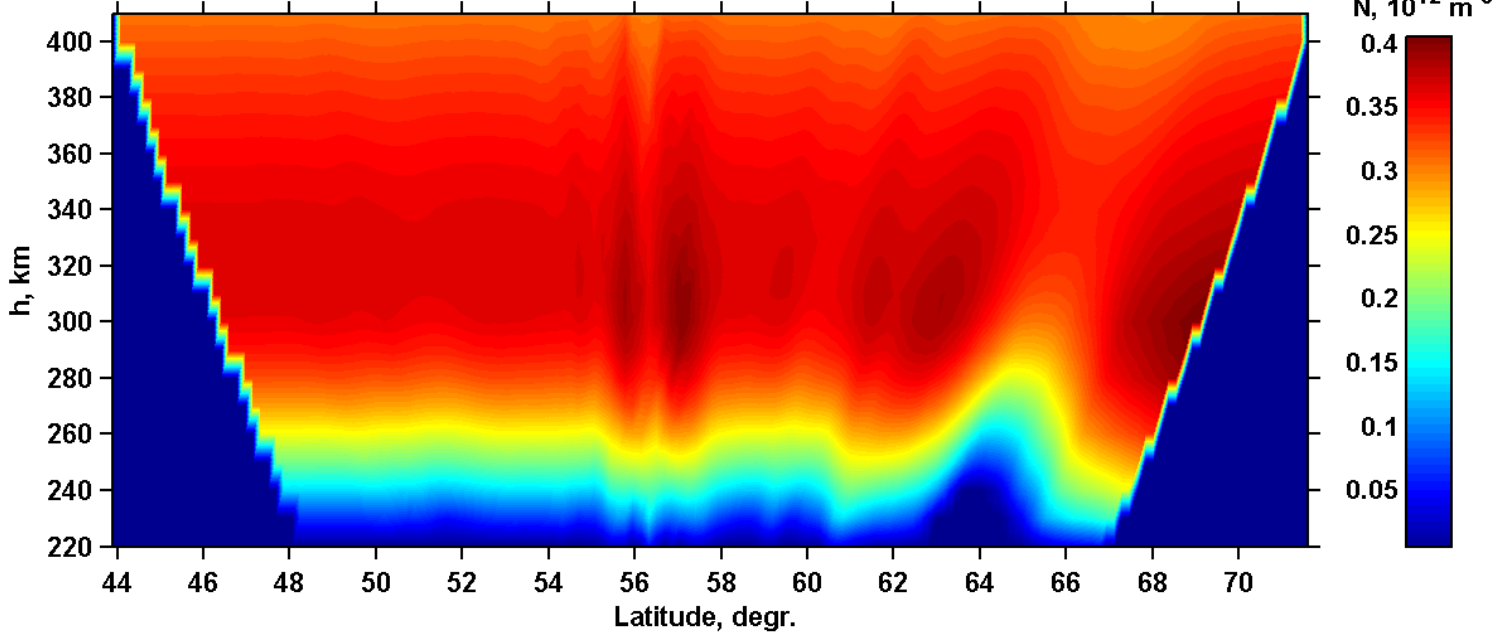
18:58 – 19:18UT – 4785kHz CW ERP ~ 100MW

2014/03/23, 19:12 UT (23:12 LT; +4h), max(elev)= 83.28, CASSIOPE (S->N)

ePOP



2014/03/23, 19:12 UT (23:12 LT) CASSIOPE

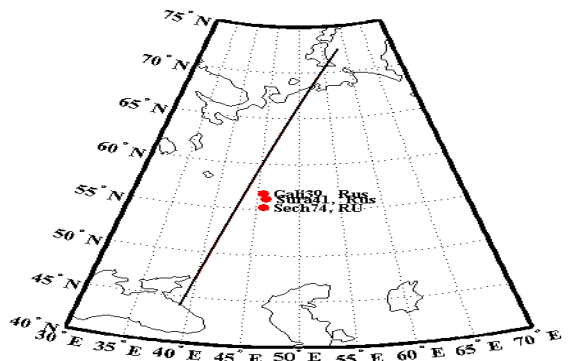
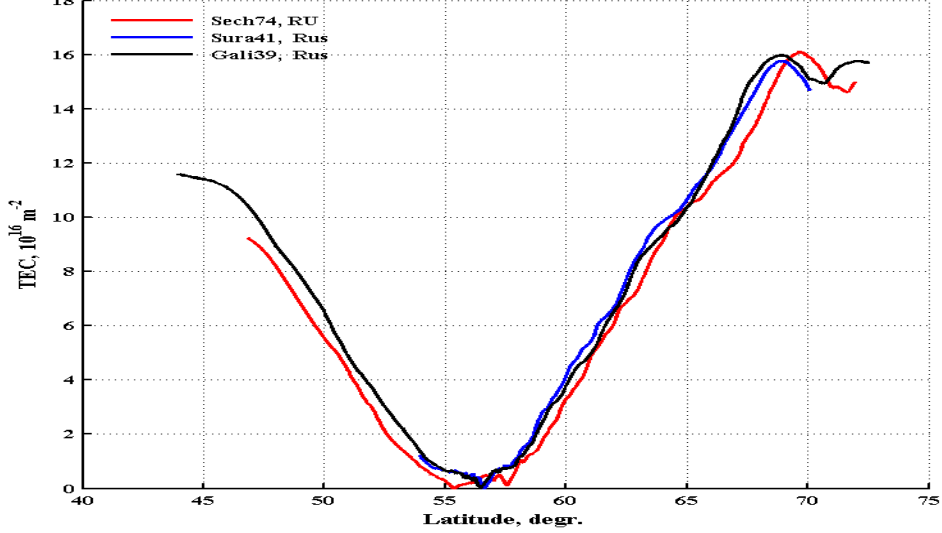


15:58 – 18:43UT – 4785kHz \pm 15 min ERP ~ 100MW

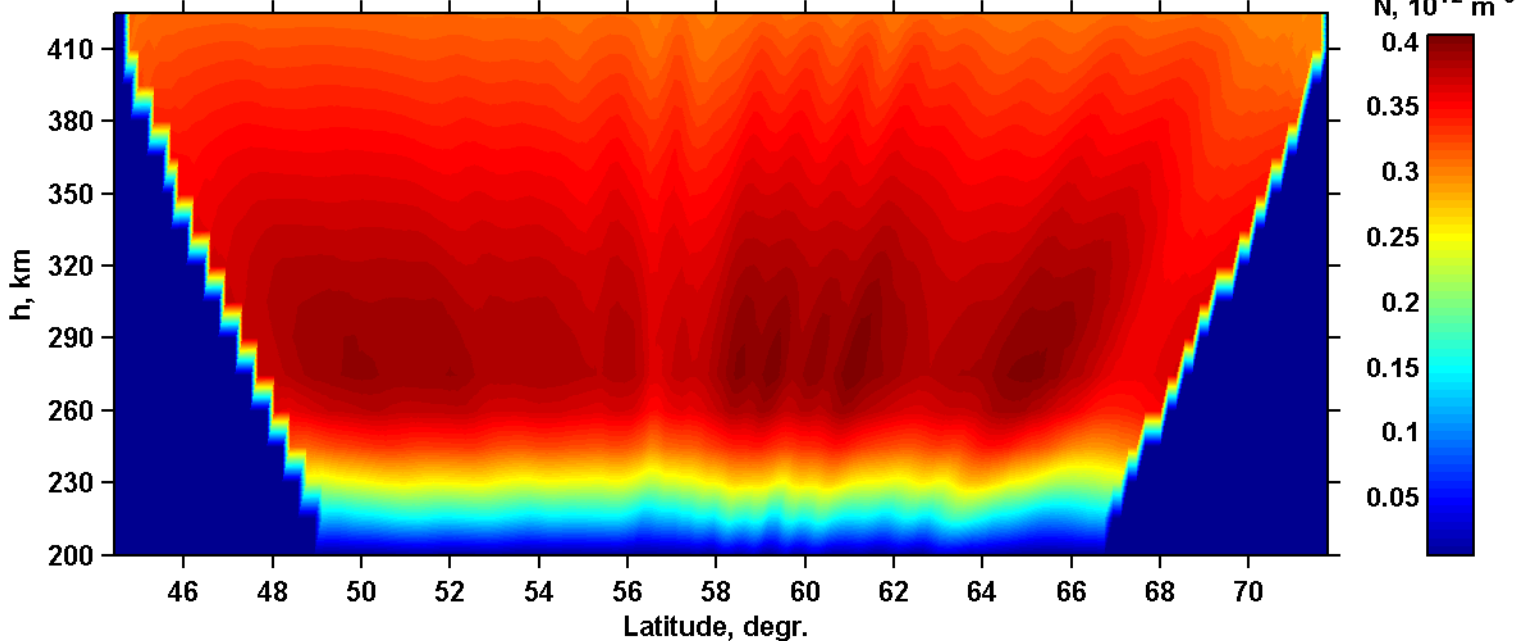
18:58 – 19:18UT – 4785kHz CW ERP ~ 100MW



2014/03/24, 19:11 UT (23:11 LT; +4h), max(elev)= 68.20, CASSIOPE (S->N)



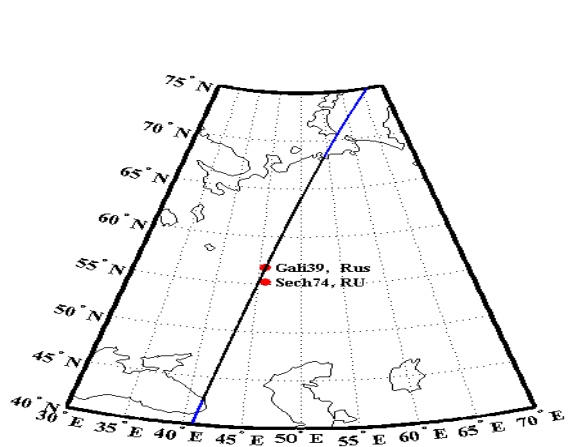
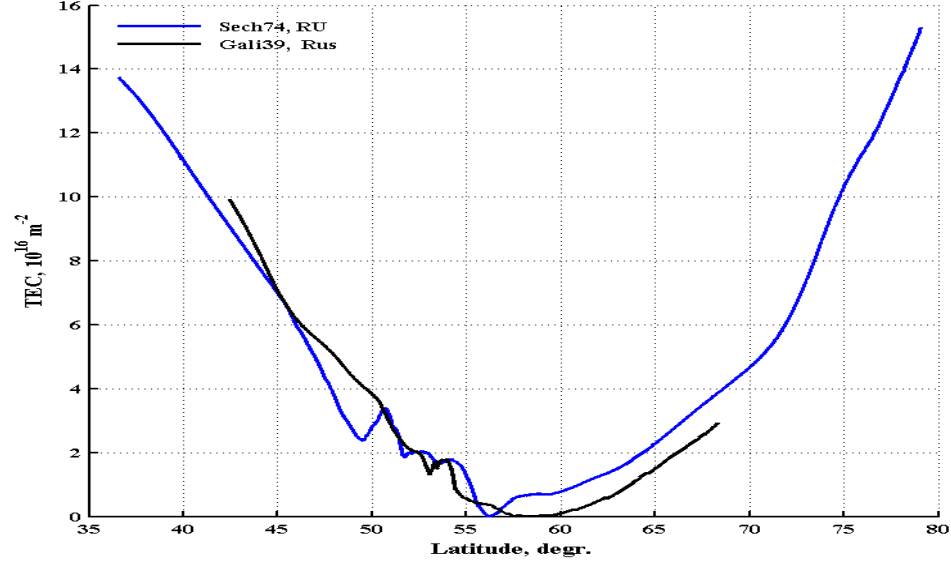
2014/03/24, 19:11 UT (23:11 LT) CASSIOPE



19:04 – 20:19 UT — 4300 kHz, [+ 15 min; – 15 min], ERP = 55 MW.

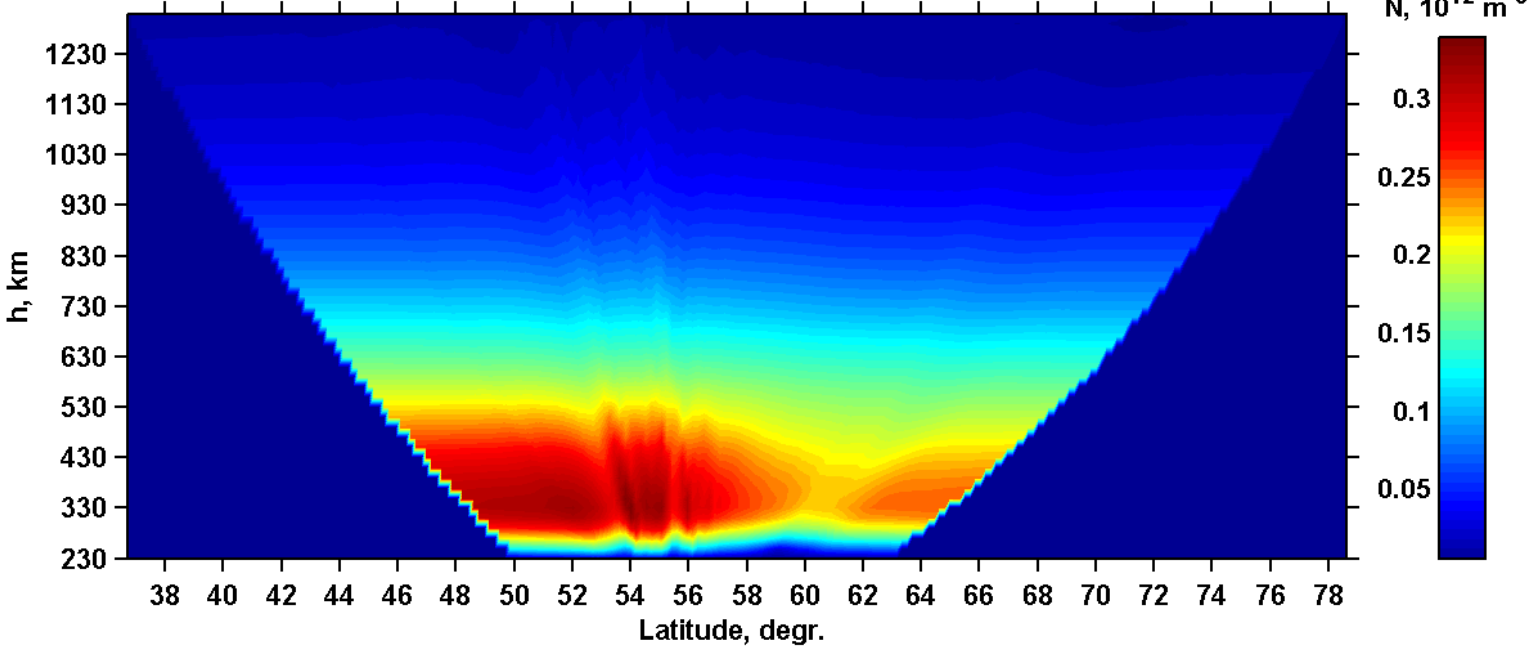
20:34 – 20:54 UT — 4300 kHz, [+ 9 s; – 1 s], ERP = 55 MW. $f_oF2 \approx 4.7$ MHz at 20:30 UT.

2014/09/08, 20:45 UT (00:45 LT; +4h), max(elev)= 86.30, CASSIOPE (S->N)



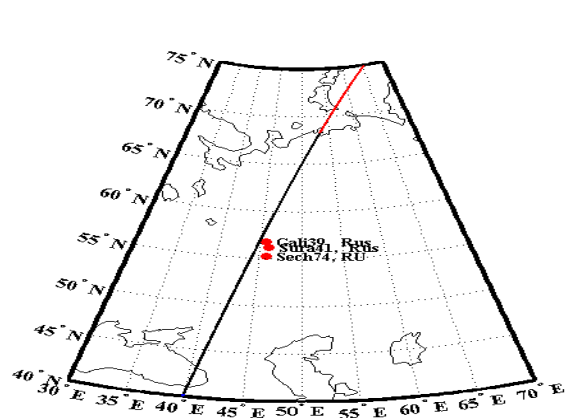
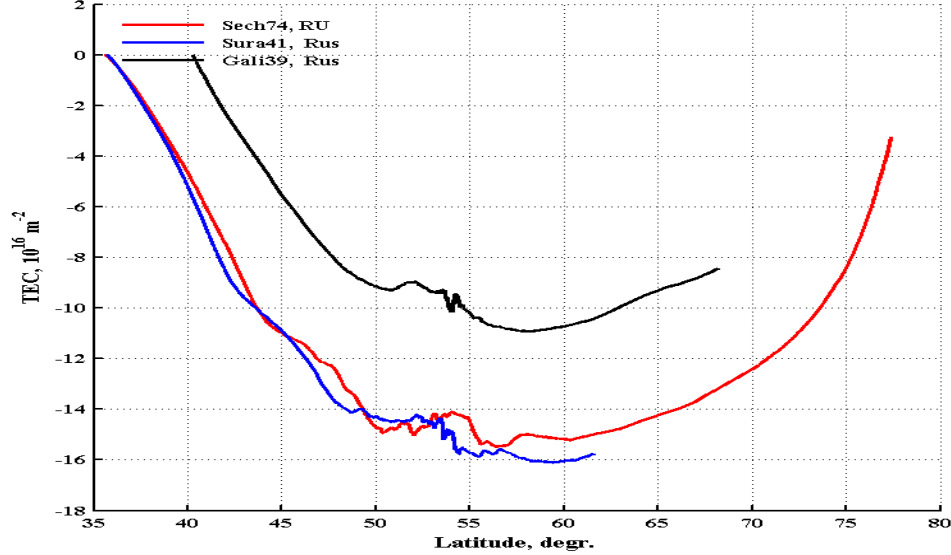
ePOP

2014/09/08, 20:45 UT (00:45 LT) CASSIOPE



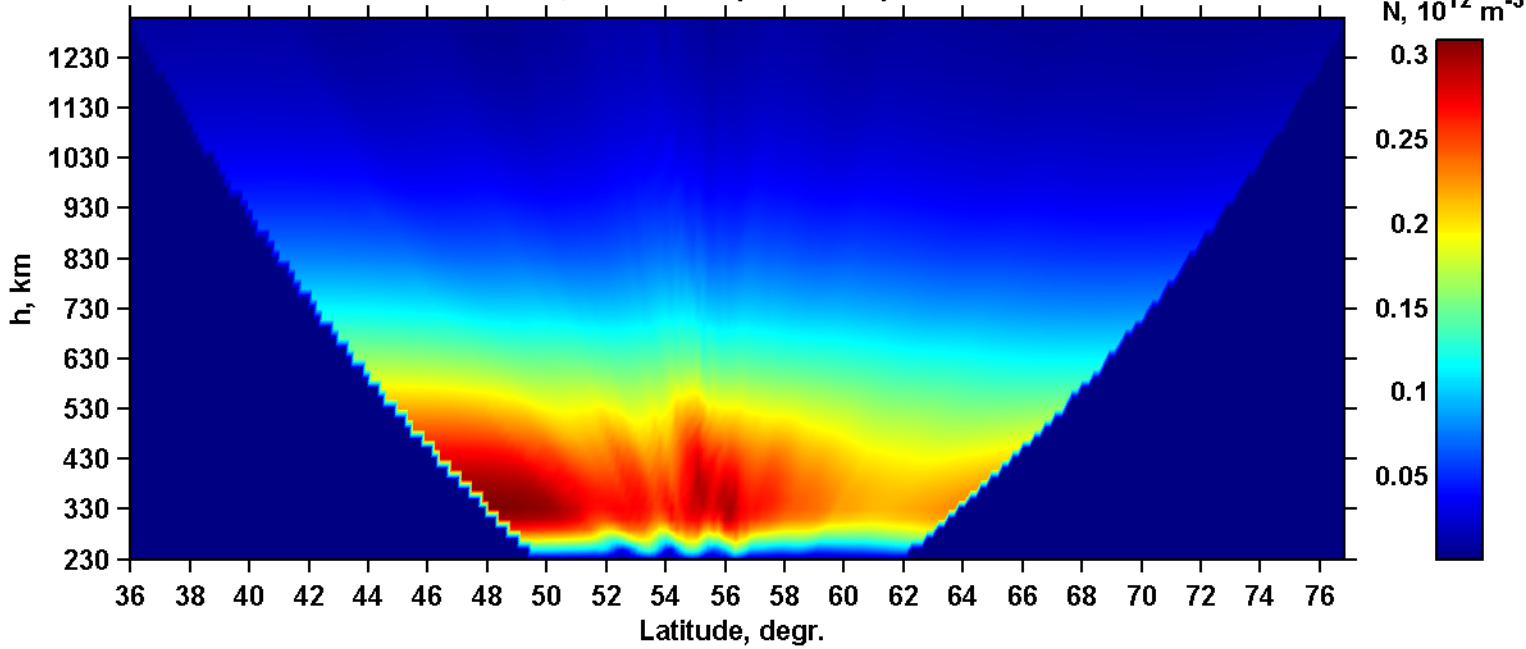
18:59 – 20:14 UT — 4300 kHz, [+ 15 min; – 15 min], ERP = 55 MW. $f_oF2 \approx 4.4$ MHz at 20:15 UT.
20:29 – 20:30 UT — 4300 kHz, CW; 20:30 – 20:49 UT -[+ 9 s; – 1 s], ERP = 55 MW

2014/09/09, 20:40 UT (00:40 LT; +4h), max(elev)= 85.67, CASSIOPE (S->N)



ePOP

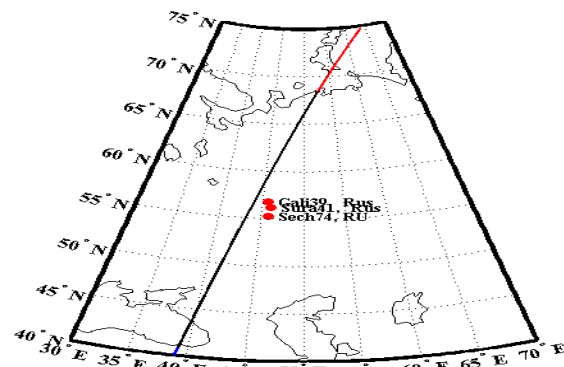
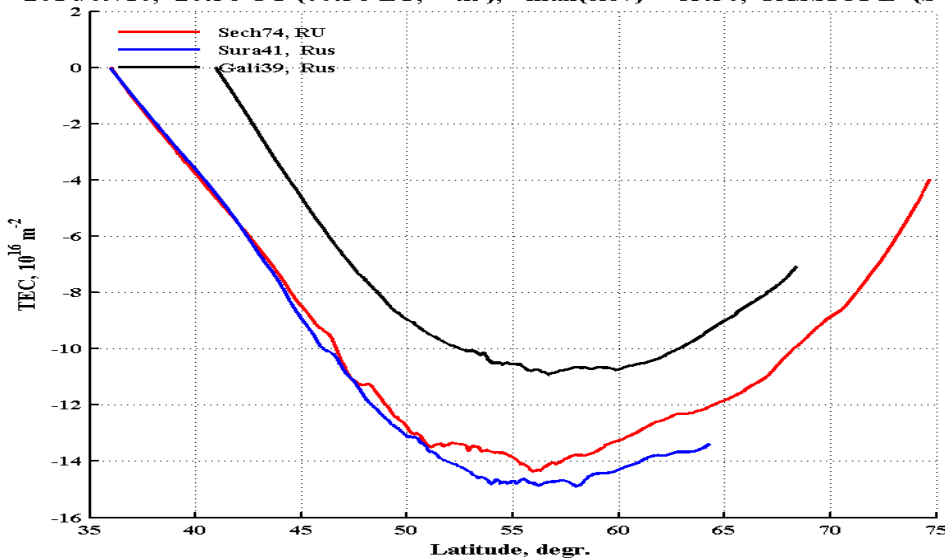
2014/09/09, 20:40 UT (00:40 LT) CASSIOPE



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

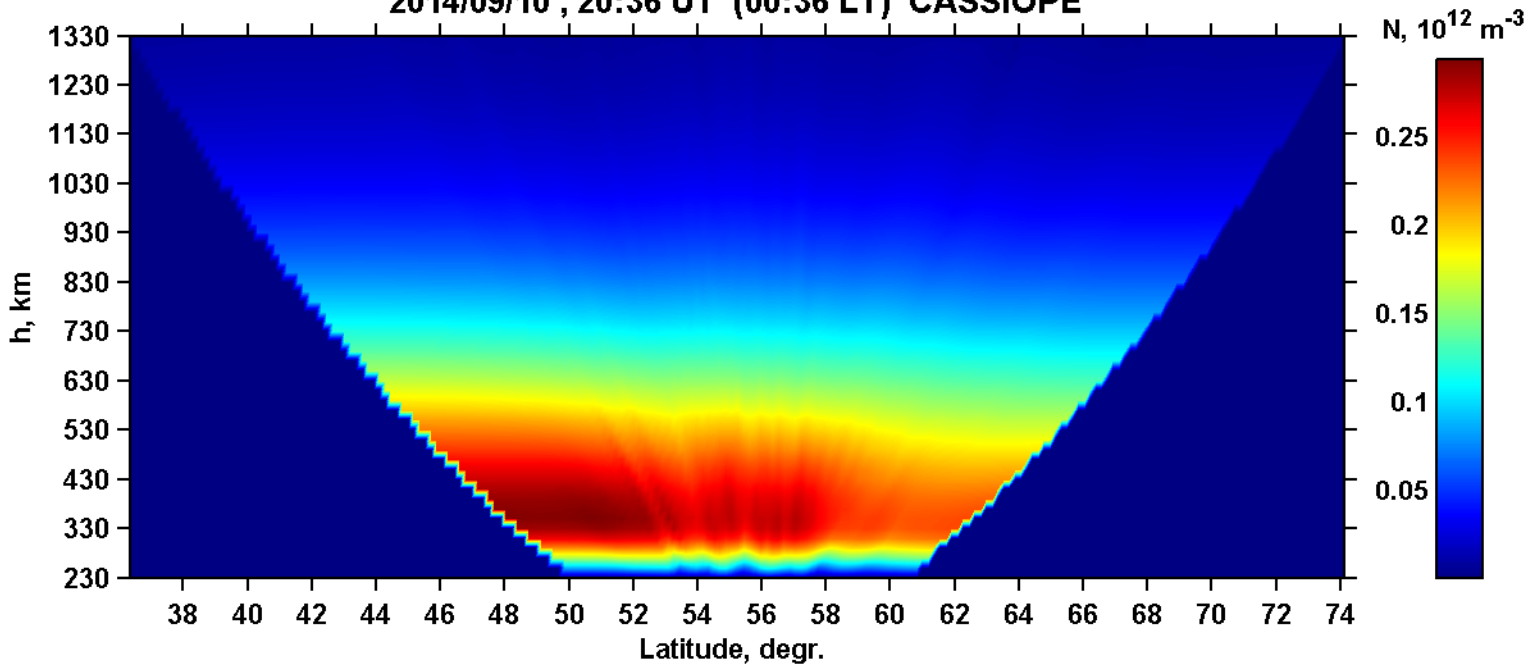
20:26 – 20:46 UT — 4300 kHz, [+ 9 s; – 1 s], ERP = 55 MW. $f_oF2 \approx 4.5$ MHz at 19:50 UT.

2014/09/10, 20:36 UT (00:36 LT; +4h), max(elev)= 83.30, CASSIOPE (S->N)

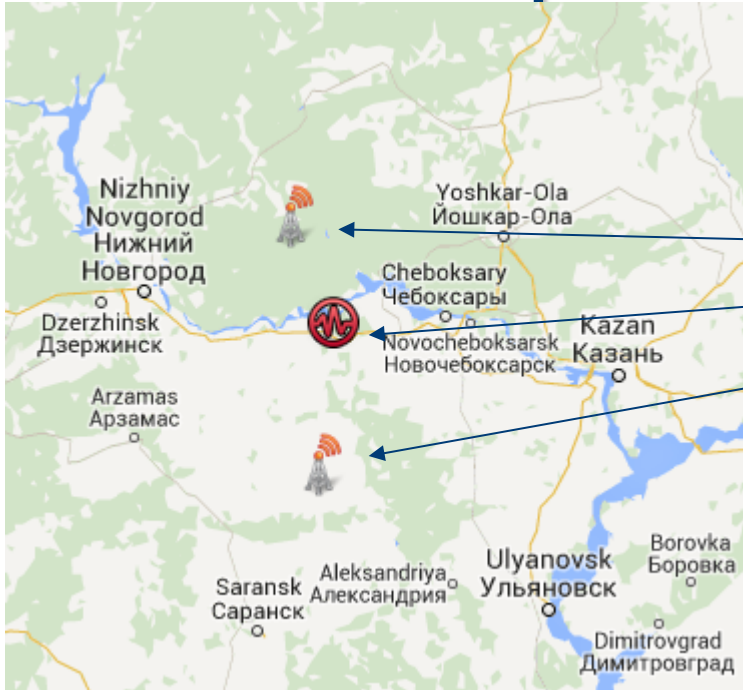


ePOP

2014/09/10, 20:36 UT (00:36 LT) CASSIOPE



ePOP-SURA tomography experiment summary

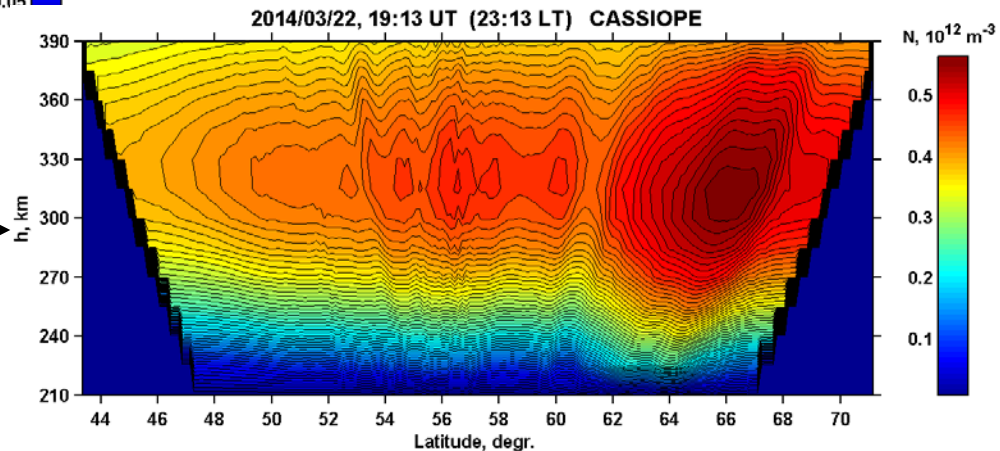
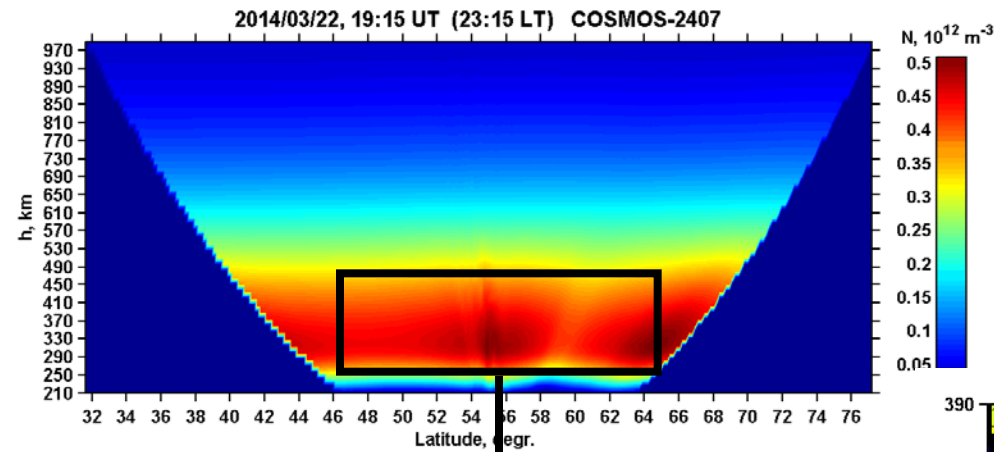
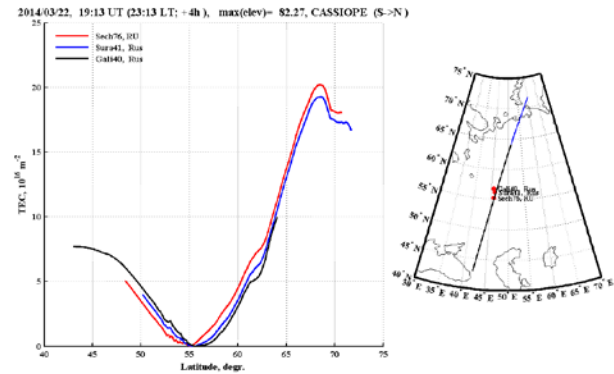
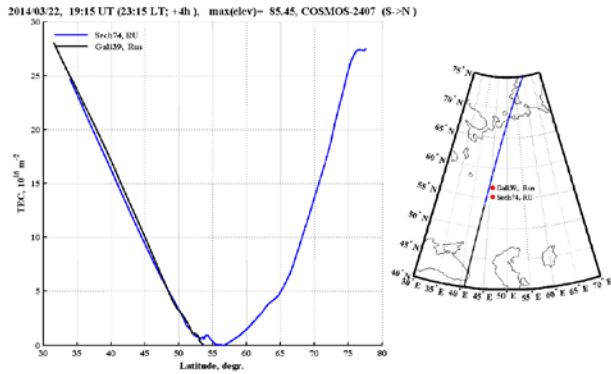


- two campaigns (March, September 2014)
- 3 receiving sites with NWRA ITS30/33S beacon receivers (150/400/1066MHz)
 - a) Galibikha(56°45'18"N, 45°36'57"E)
 - b) Sura(56°08'15"N, 46°02'40"E)
 - c) Sechenovo(55°13'28" N, 45°53'26" E)
- Sura heater (all 3 transmitters) operating O-mode, square wave modulation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

Common features to be noted on the following RT reconstructions:

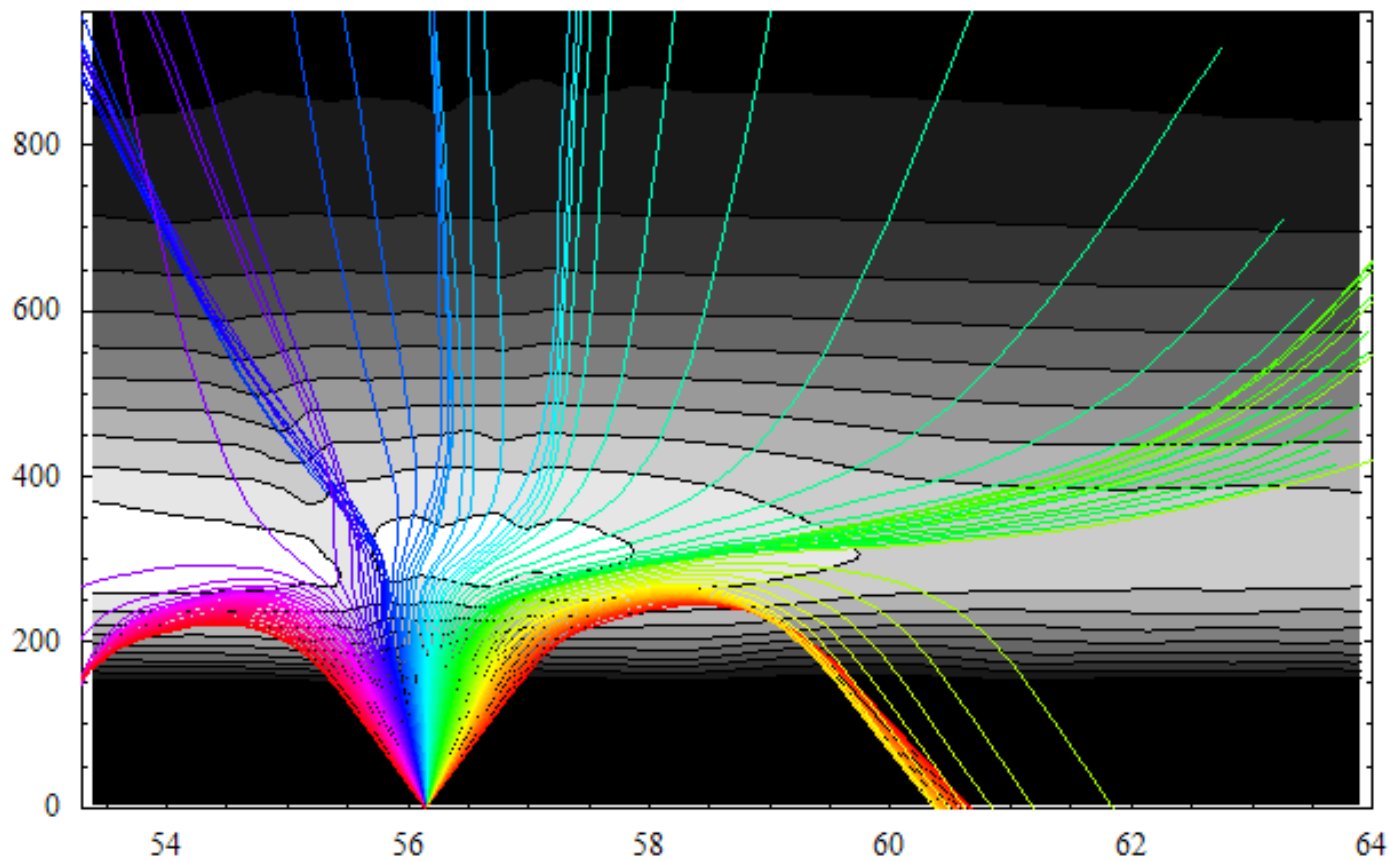
- wave-like structures, possibly artificial AGWs, diverging from the heated area
- narrow trough, corresponding to directivity pattern of Sura heater

LORT reconstructions of disturbed area using ePOP and COSMOS data



Penetration of the pumping wave up to the satellite heights

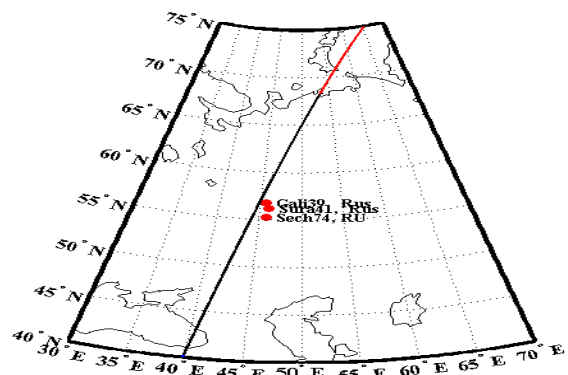
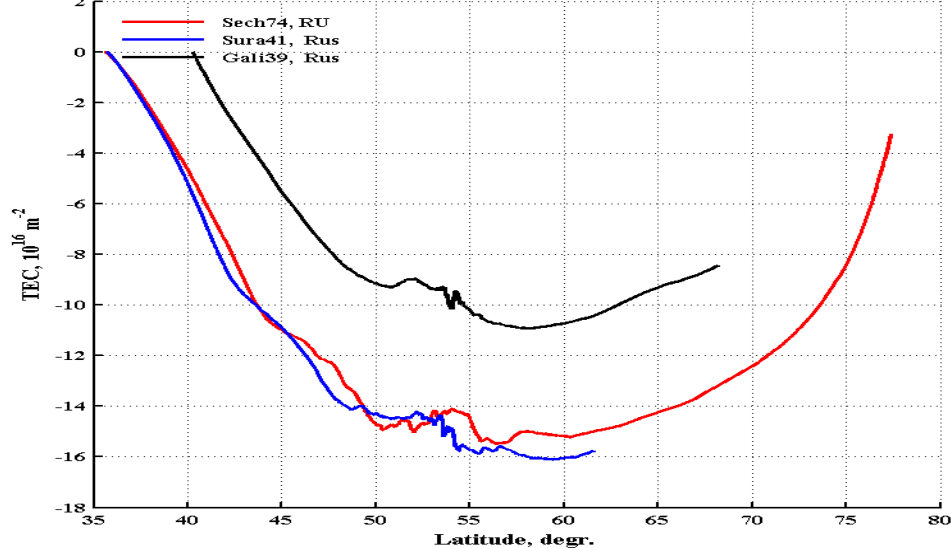
21.08.2010 16:24 UT for COSMOS 2414 pass



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

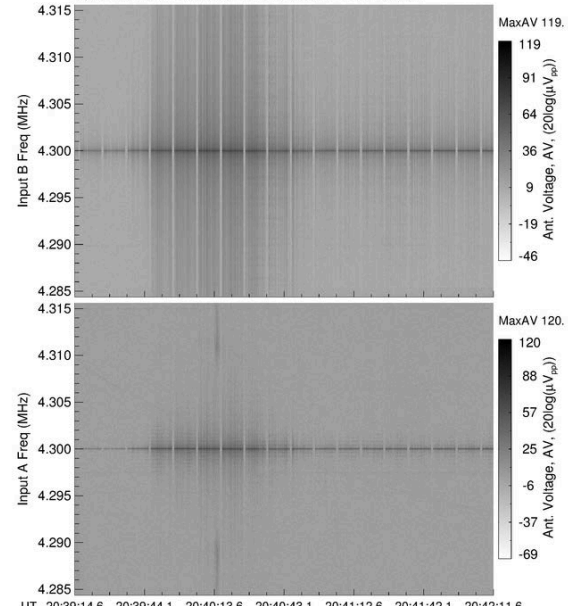
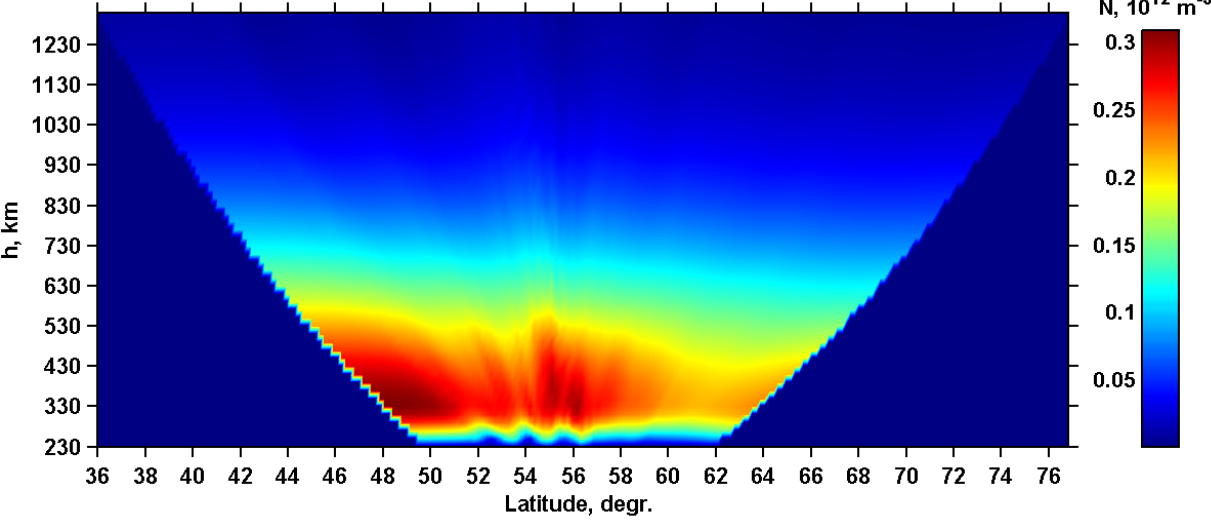
2014/09/09, 20:40 UT (00:40 LT; +4h), max(elev)= 85.67, CASSIOPE (S->N)



e-POP RRI
 September 09, 2014

Inputs: Channel 1 - I1, Channel 2 - Q1, Channel 3 - I3, Channel 4 - Q3
 Dipole Mode, GAIN1 Low, GAIN2 Low, GAIN3 Medium, GAIN4 Medium

2014/09/09, 20:40 UT (00:40 LT) CASSIOPE



UT	20:39:14.6	20:39:44.1	20:40:13.6	20:40:43.1	20:41:12.6	20:41:42.1	20:42:11.6
ALT	1240.5	1301.3	1311.3	1321.8	1331.5	1340.3	1349.8
LAT	50.6	52.2	53.7	55.2	56.6	58.0	59.5
MLAT	45.7	47.2	48.6	49.9	51.3	52.5	53.8
MLT	0.3	0.3	0.4	0.5	0.6	0.6	0.7

Produced by RRIOL v1.2
 Source session filenames: RRI_20140909_203914_203919_00000_1250.lv0 to
 _20140909_204142_204211_0000F_805E.lv0

Courtesy of Dr. Gordon James

Conclusions

- We present the evidences 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 ATTENTION