THE EXAMPLES OF THE LARGE-SCALE ELECTRON DENSITY FEATURES REVEALED BY THE RADIO TOMOGRAPHIC METHODS IN THE DISTRIBUTIONS OF THE IONOSPHERIC PLASMA DURING THE SPACE WEATHER DISTURBANCES

E. ANDREEVA, E. TERESHCHENKO, M. NAZARENKO, I. NESTEROV,

A. PADOKHIN, YU. TUMANOVA

LOMONOSOV MOSCOW STATE UNIVERSITY, RUSSIA

POLAR GEOPHYSICAL INSTITUTE, MURMANSK, RUSSIA

OUTLINE

Radiotomography of ionosphere with low- (2D case) and high- (4D case) orbital beacon satellites

Phase-difference approach to the solution

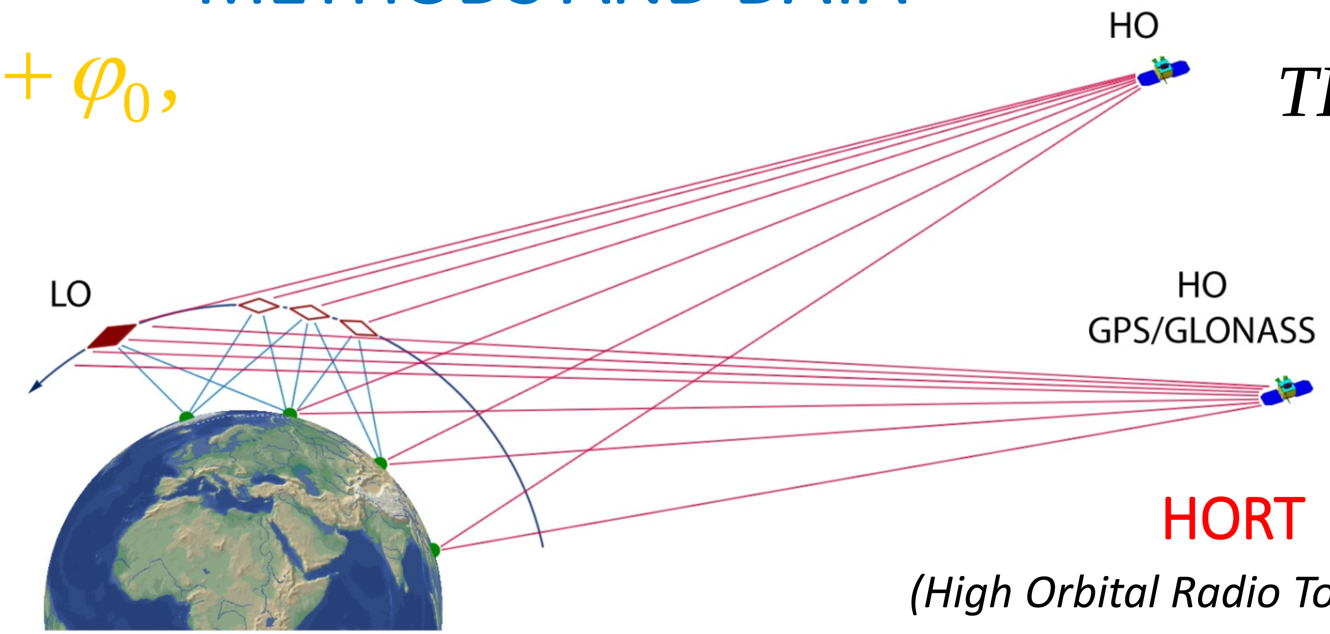
Examples of ionospheric structures under various space weather conditions

Concluding remarks

METHODS AND DATA

$$\alpha \lambda r_e \int_L N d\sigma = \Phi = \varphi + \varphi_0,$$

$$TEC = \int_l N_e(\vec{r}) dl$$



LORT

(Low Orbital Radio Tomography)

HORT

(High Orbital Radio Tomography)

"instantaneous" (~5-10 minutes)
2D RT images of the ionosphere
above the receiving chains

{ the horizontal resolution is **20-30 km**, and the vertical, **30-40 km.** The resolution can be improved up to **20-10 km** using dense receiving system and nonlinear RT}

4D RT images (3 spatial coordinates and time)

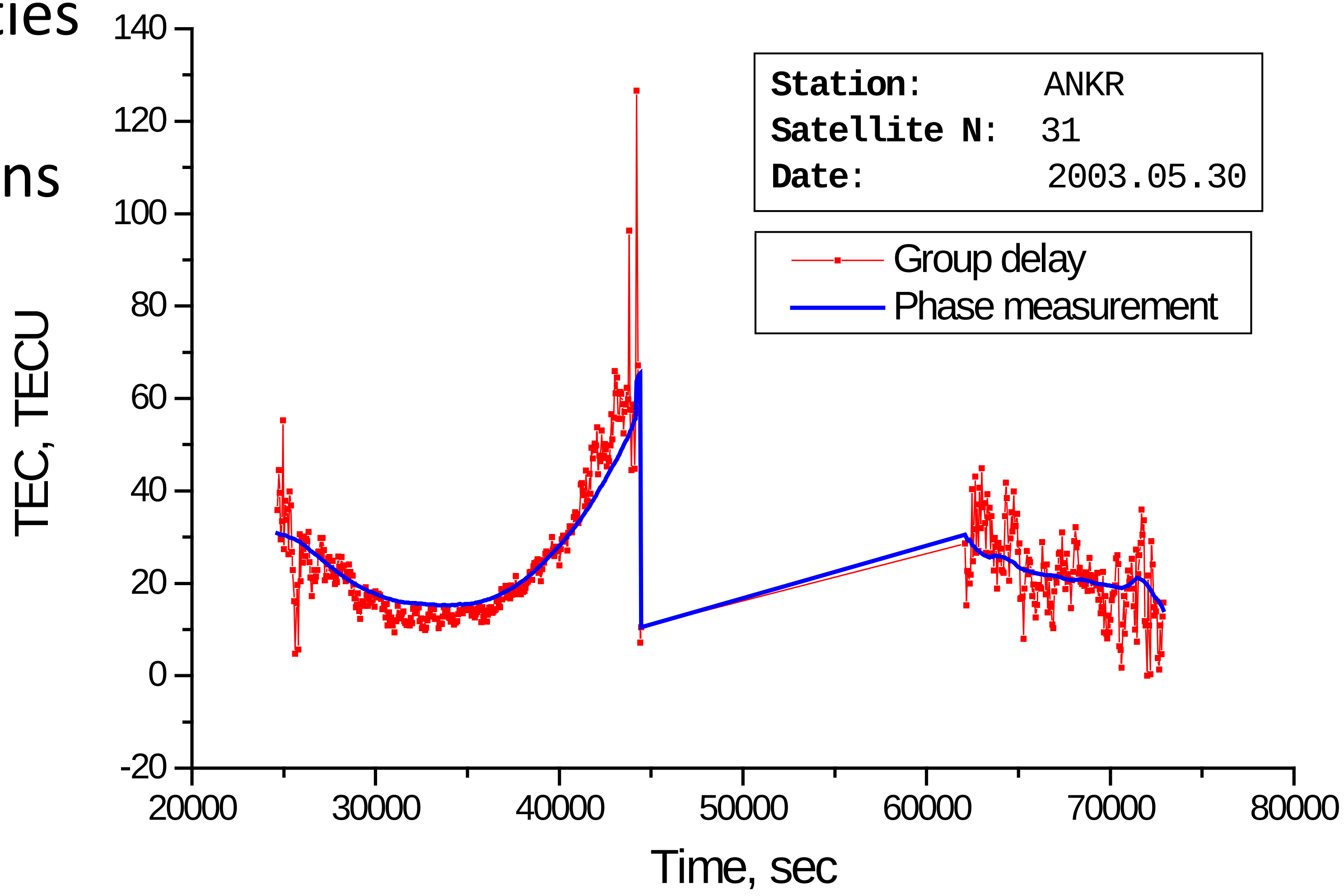
Typical resolution of HORT is about of **100-50 km** with a time step **60-20 min**.

Absolute phase or absolute TEC as an input

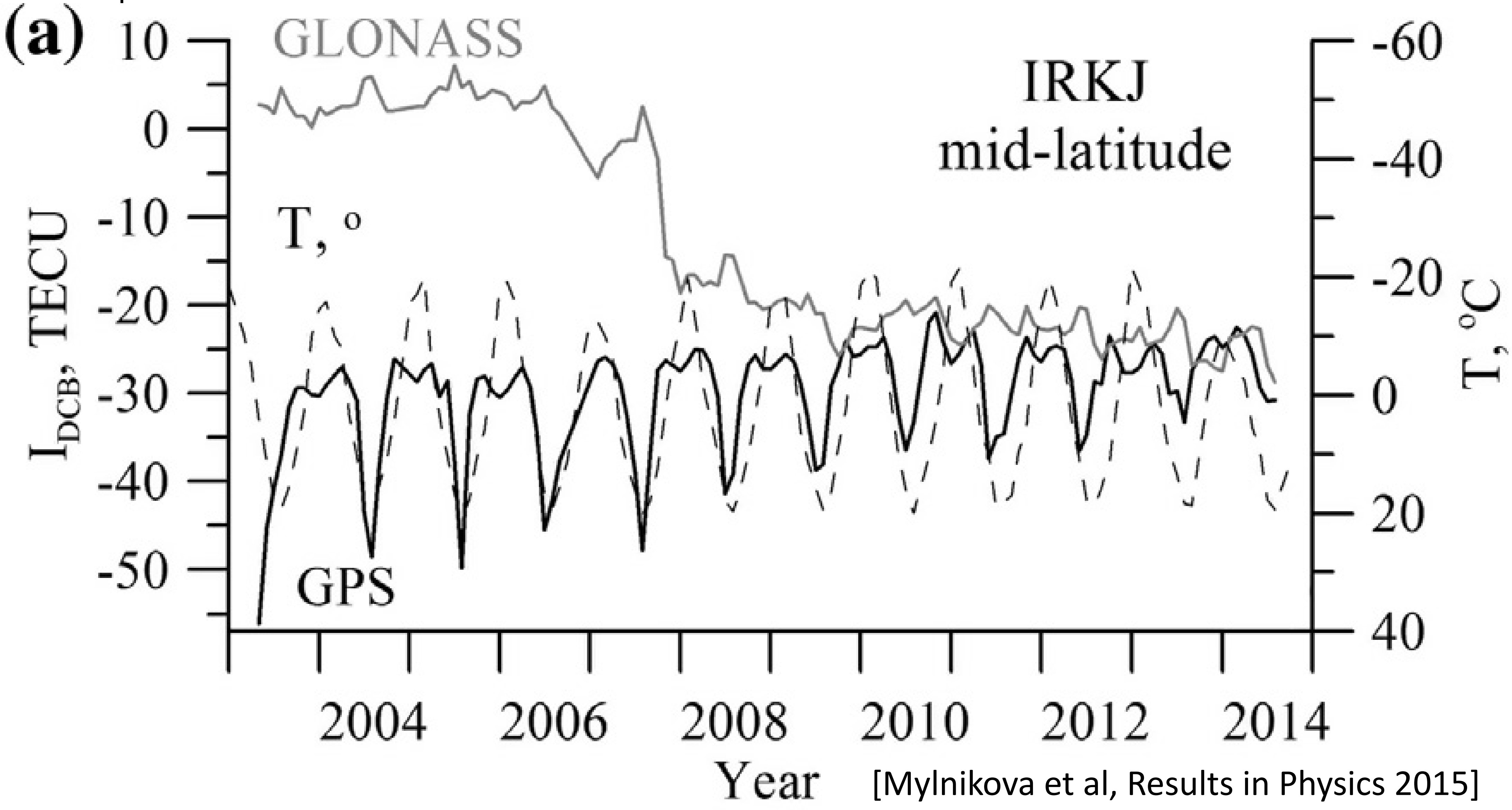
Need to resolve phase ambiguities

Code leveling + DCBs estimations

Additional source of errors



Phase-difference or TEC-difference approach



[Mylnikova et al, Results in Physics 2015]

TEC^{k-1}

$rsTEC^{k}$

No need in DCBs estimations, data from uncalibrated receivers can be used

Iterative algorithm for solving tomographic SLE

$$Af = \Psi \qquad \min \| f - f_0 \|^2_{W_n{}^2}$$

SIRT:

$$\vec{x}^{k+1} = \vec{x}^k + \sum_i \rho_i \frac{y_i - (\vec{a}_i, \vec{x}^k)}{(\vec{a}_i, \vec{a}_i)} \vec{a}_i$$

$$\min \| \vec{x} - \vec{x}_0 \|^2$$
$$A\vec{x} = \vec{y}$$

Modified SIRT:

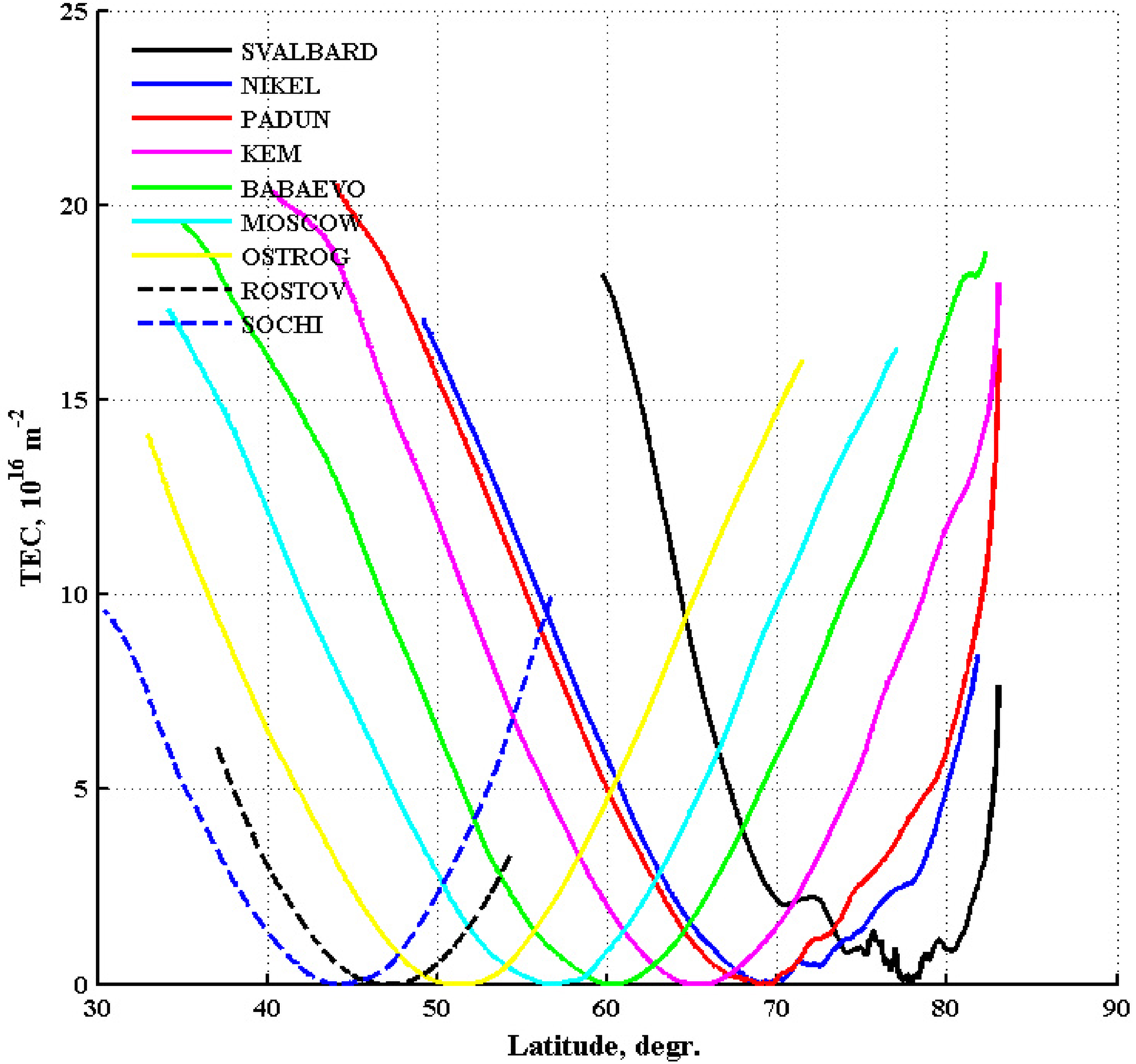
$$\vec{x}^{k+1} = \vec{x}^k + \sum_i \rho_i \frac{y_i - (\vec{a}'_i, \vec{x}^k)_L}{(\vec{a}'_i, \vec{a}'_i)_L} \vec{a}'_i$$

$$\vec{x}^{k+1} = \vec{x}^k + t\,(L^* L)^{-1} \sum_i \vec{a}_i \left(y_i - (\vec{a}_i, \vec{x}^k) \right)$$

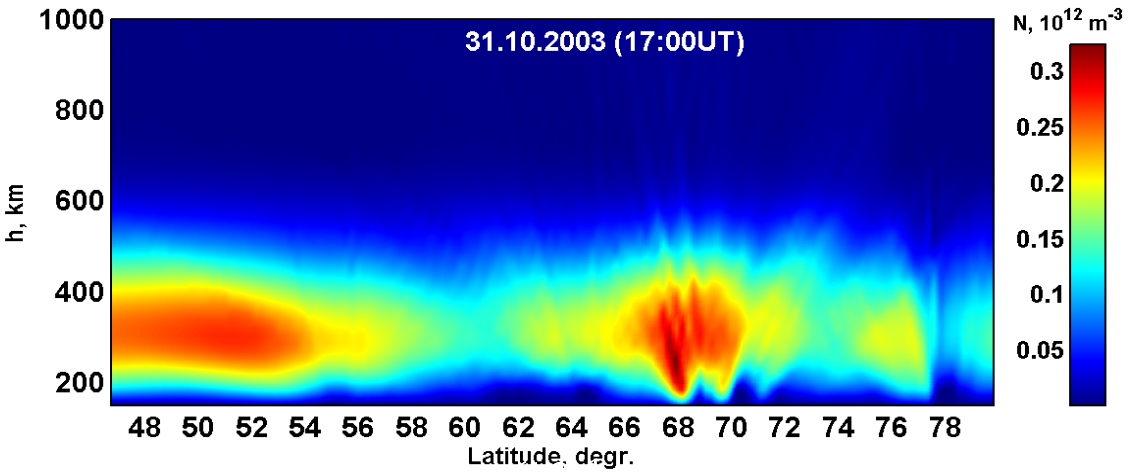
$$\min (\vec{x} - \vec{x}_0, \vec{x} - \vec{x}_0)_L$$
$$A\vec{x} = \vec{y}$$
$$\vec{a}'_i = (L^* L)^{-1} \vec{a}_i$$
$$(\vec{z}, \vec{x})_L = (L\vec{z}, L\vec{x}) = (\vec{z}, L^* L\, \vec{x})$$

see [Nesterov & Kunitsyn, ASR 2011] for details

Russian LORT system (Svalbard – Moscow - Sochi)



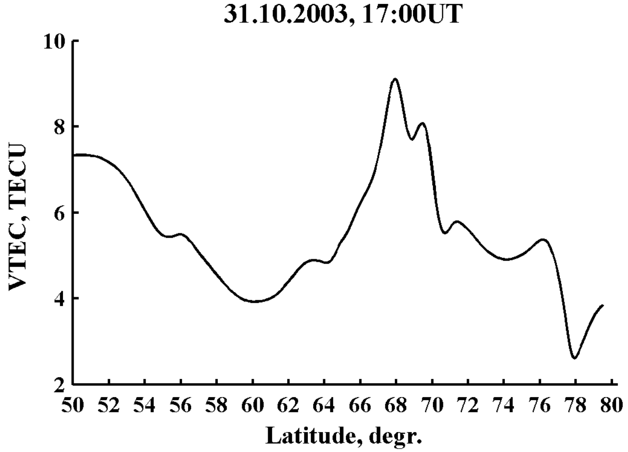
Comparison of RT-images with DMSP data (Moscow – Svalbard)



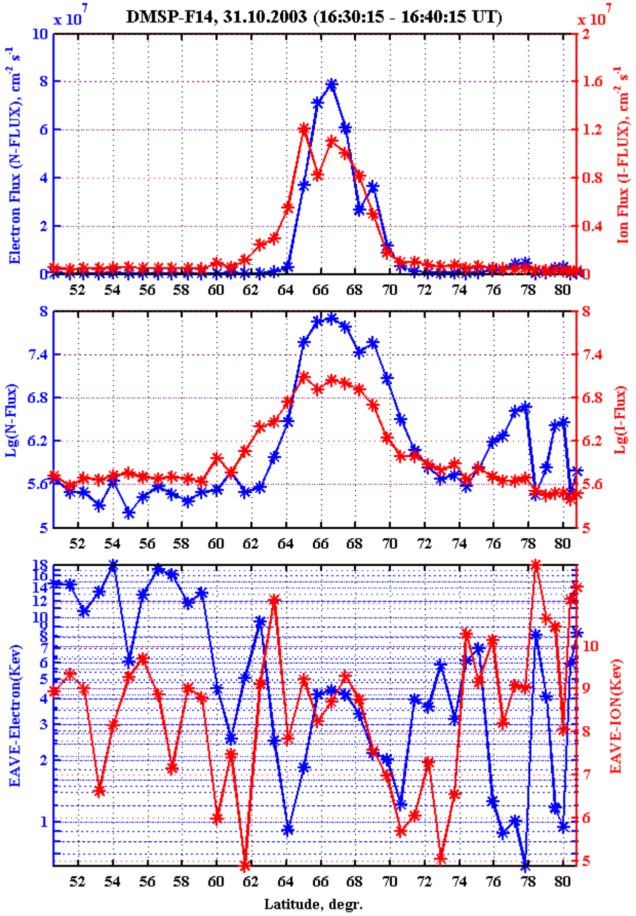
Kp = 5

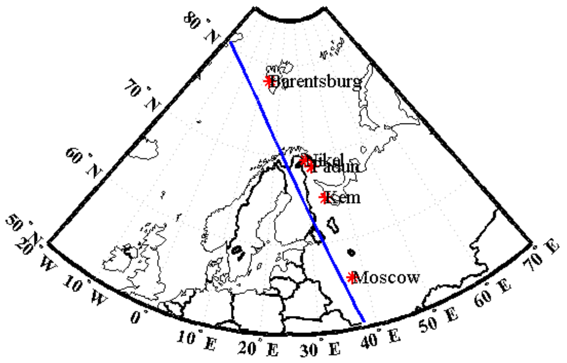
$NFLUX_{max}$=$3.3 \cdot 10^{8}$ cm^{-2} s^{-1}

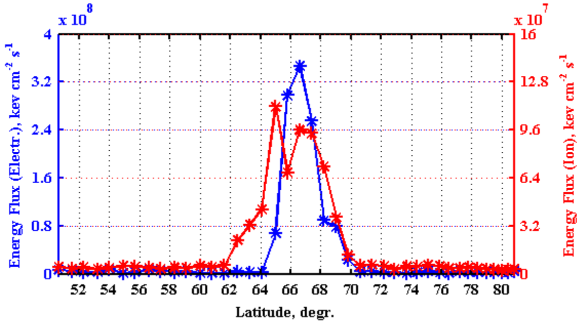
$EFLUX_{max}$= $3.5 \cdot 10^{8}$ Kev cm^{-2} s^{-1}



ΔTEC ~ 4 TECU

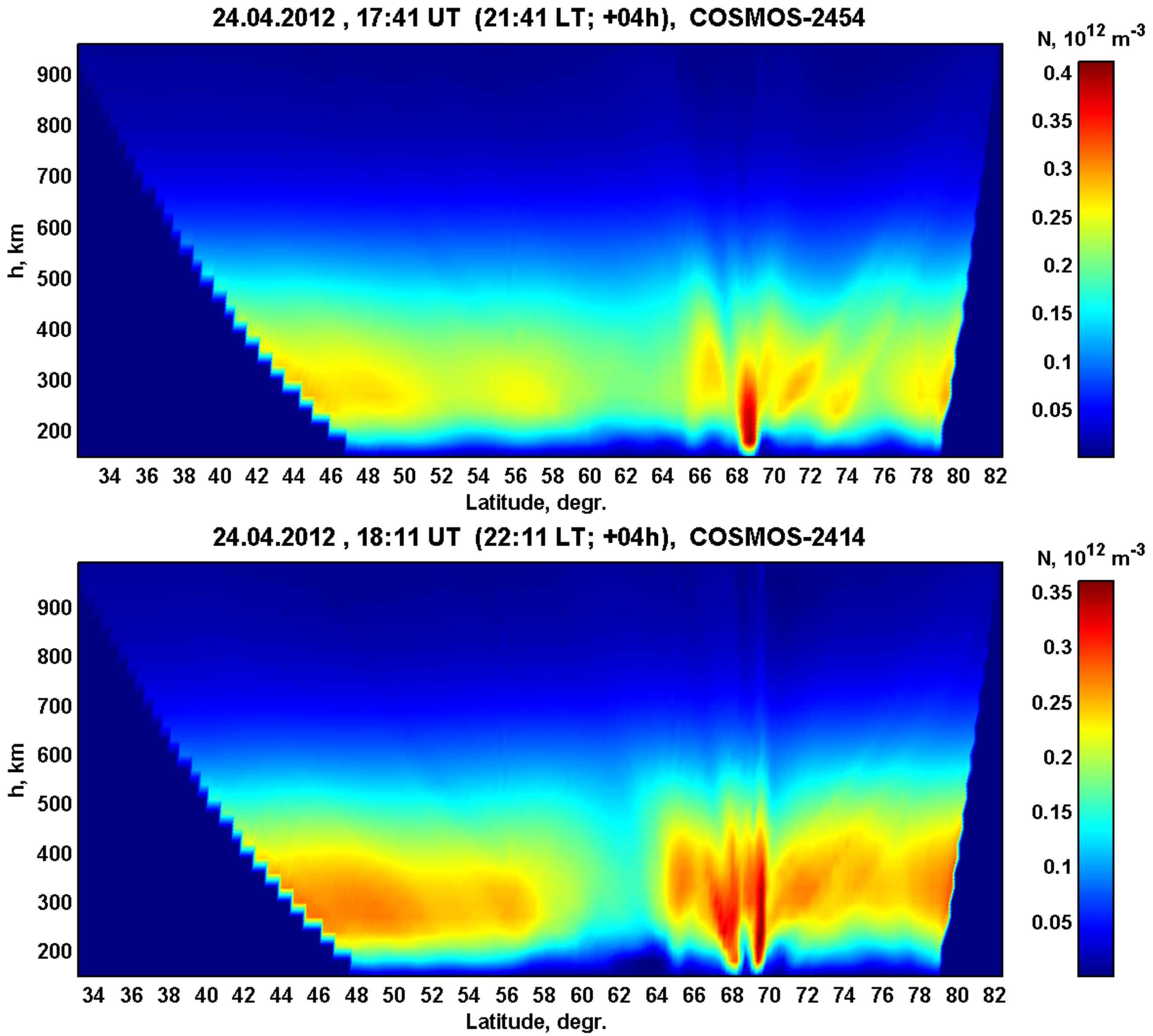






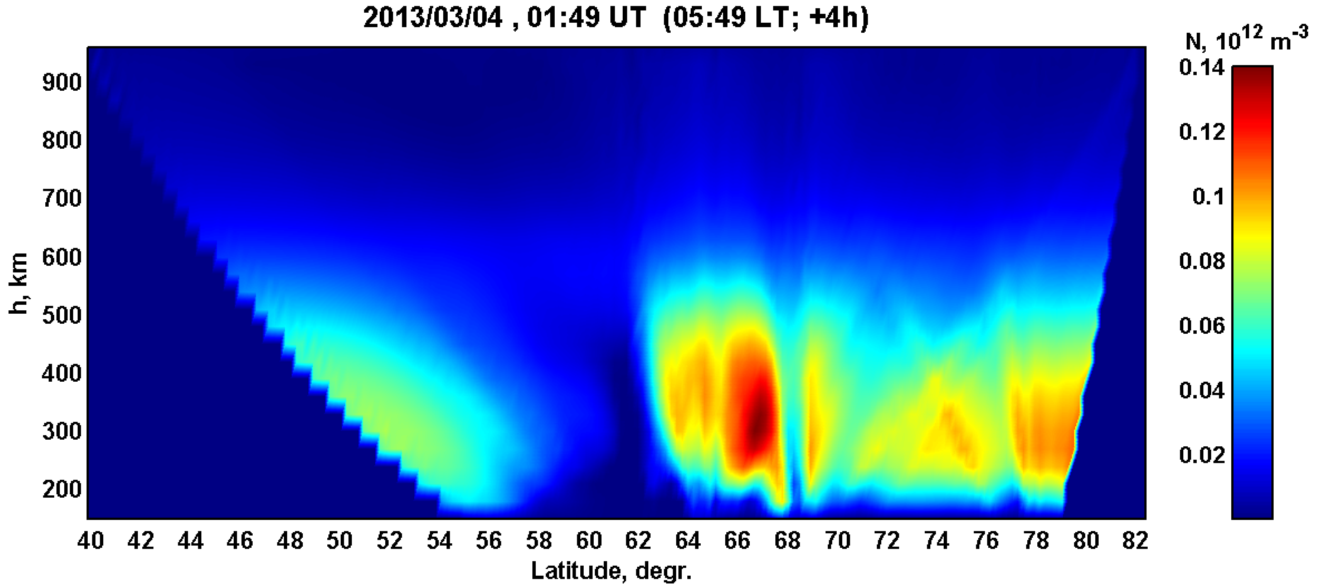
Region of Russian LORT system

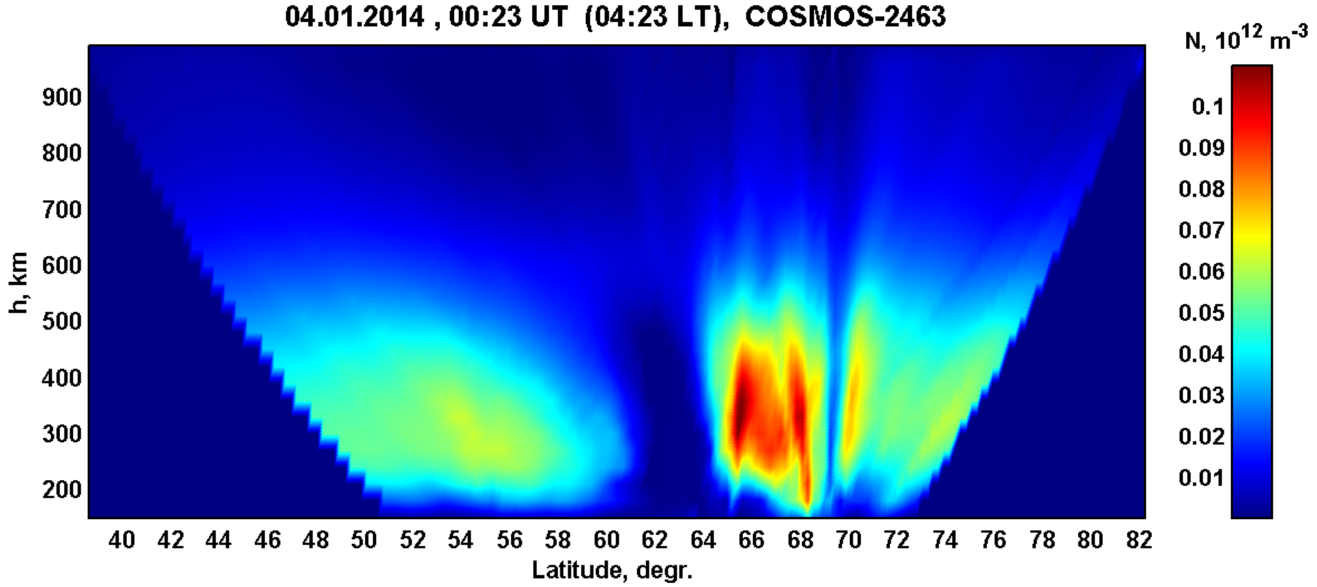
ionospheric features are probably associated with particle precipitation



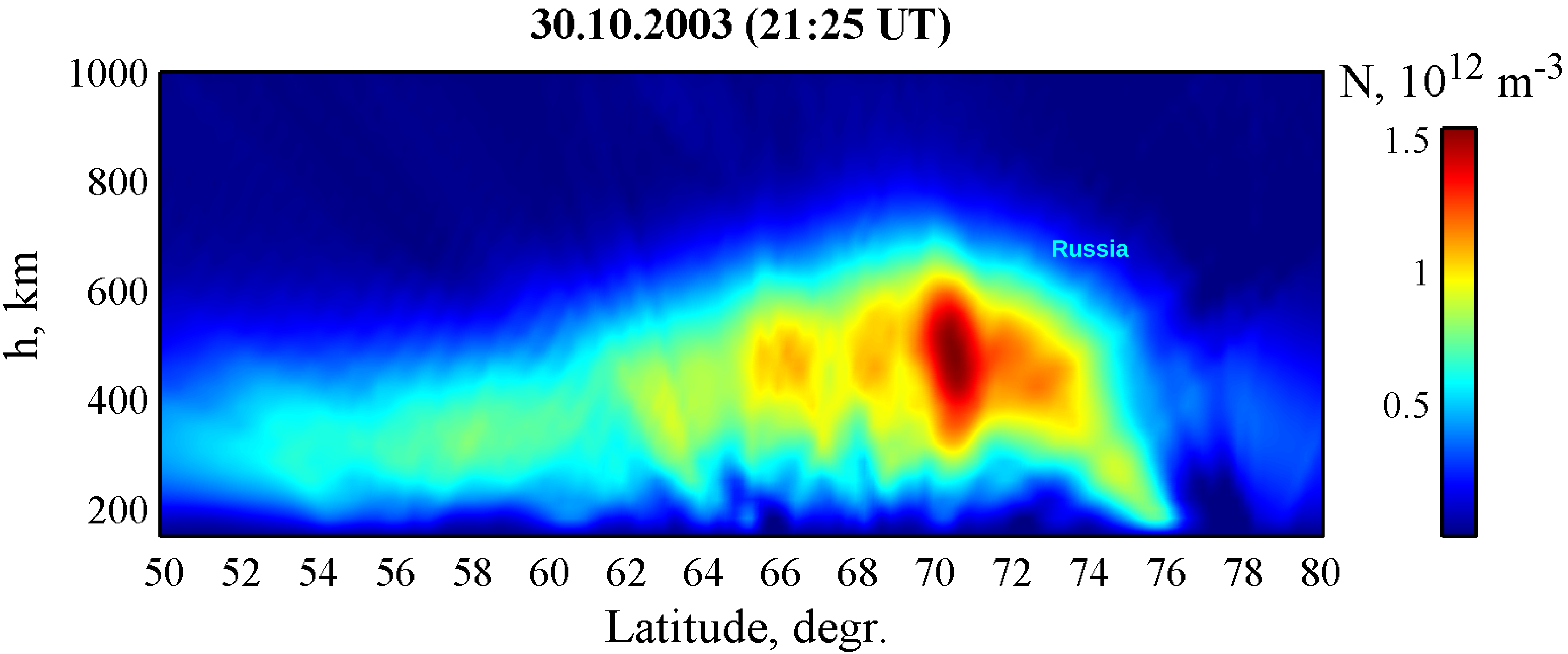
LORT images above Russian RT chain on April 24, 2012 , 17:41 and 18:11 UT

Region of Russian LORT system

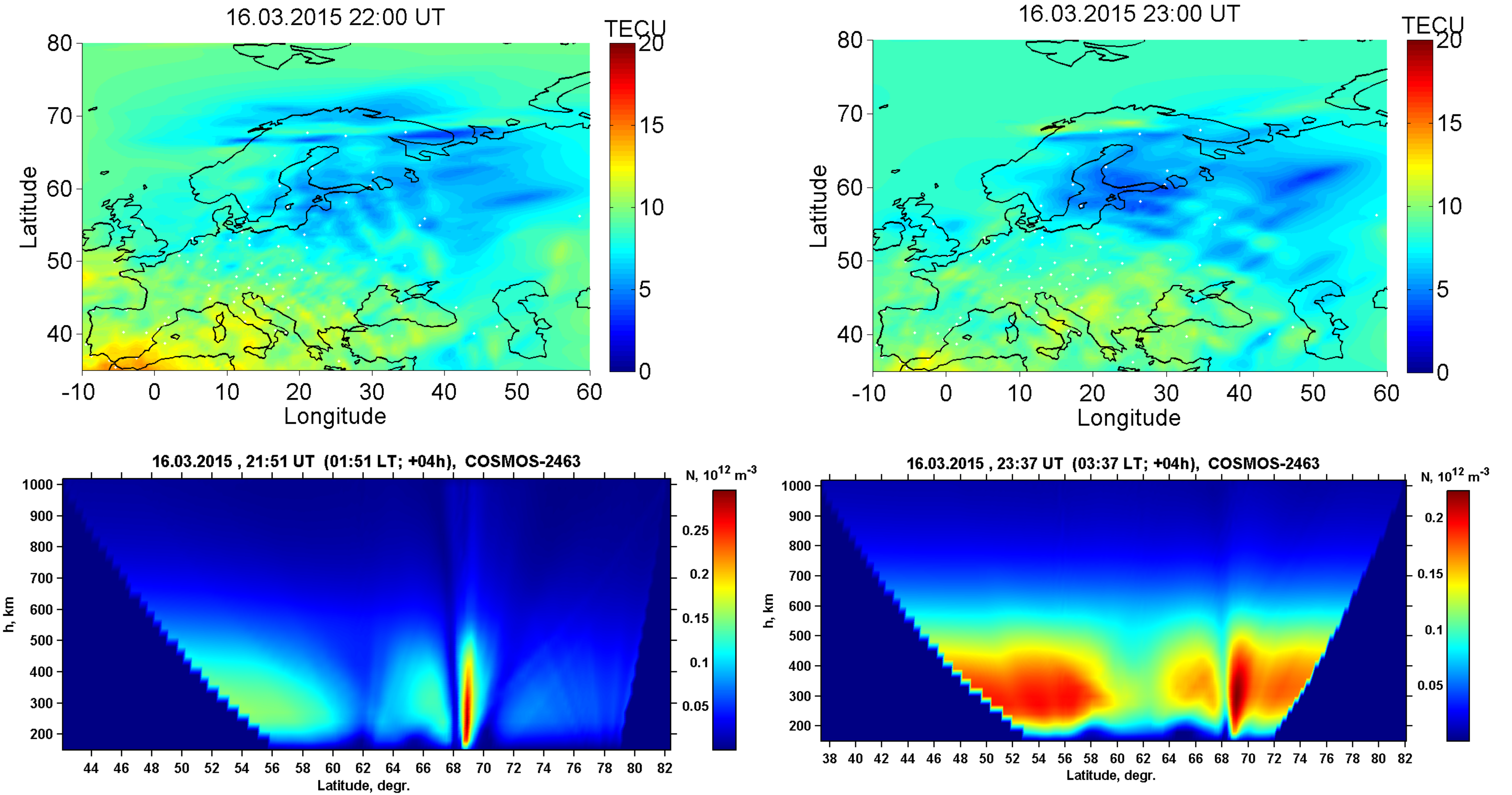




The Halloween 2003 storm

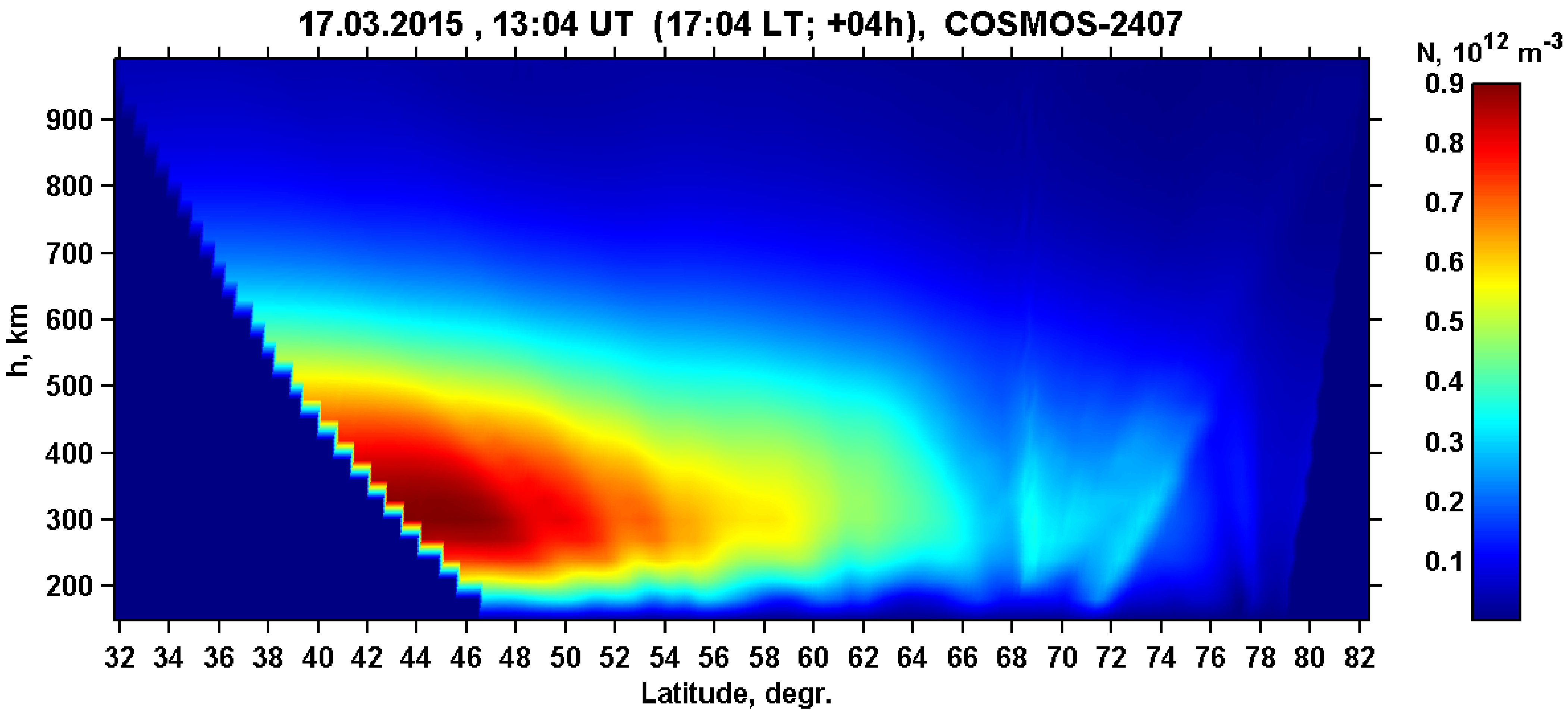


Several hours before SSC of 2015 St. Patrick's Day storm

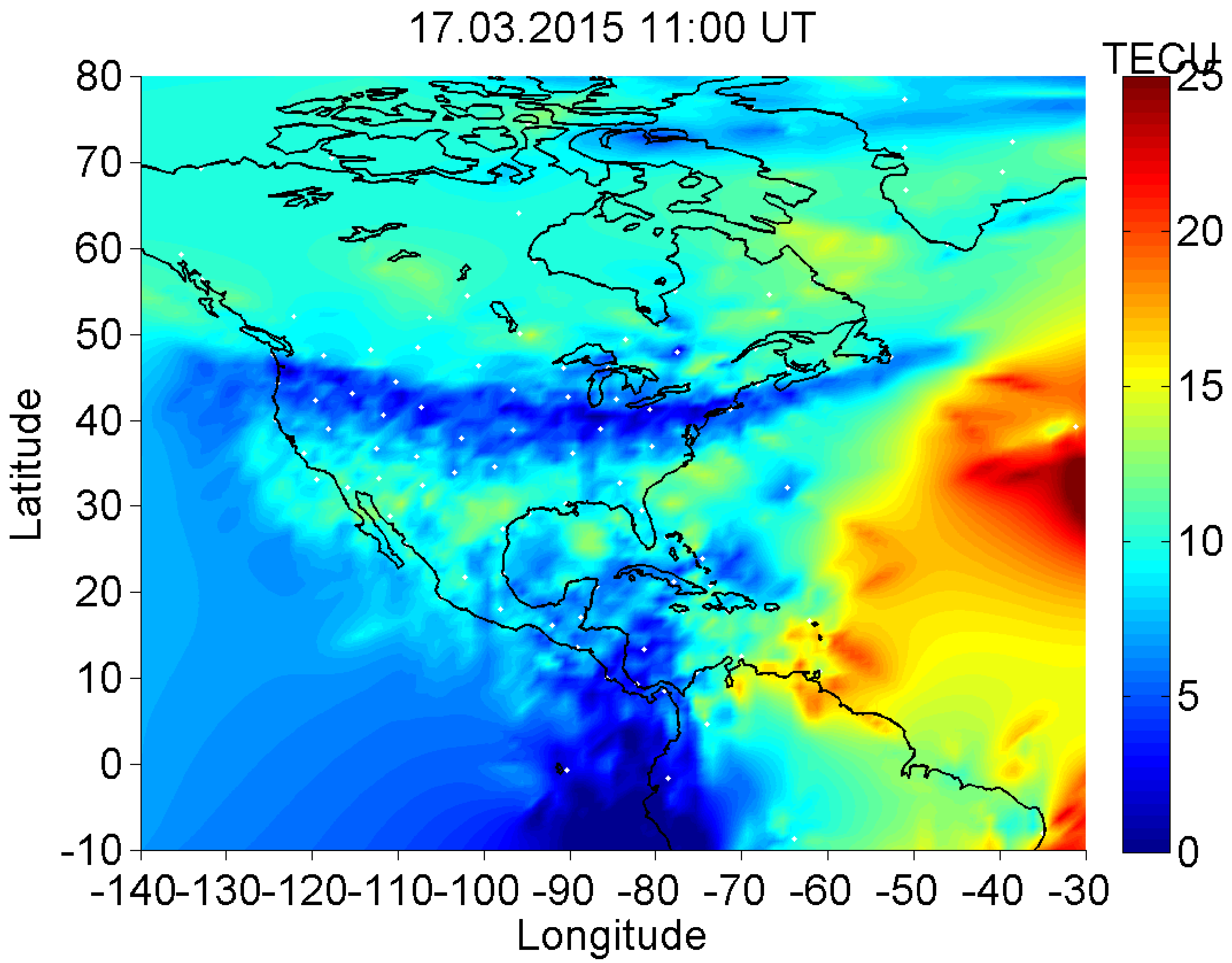


Region of Russian LORT system

2015 St. Patrick's Day storm

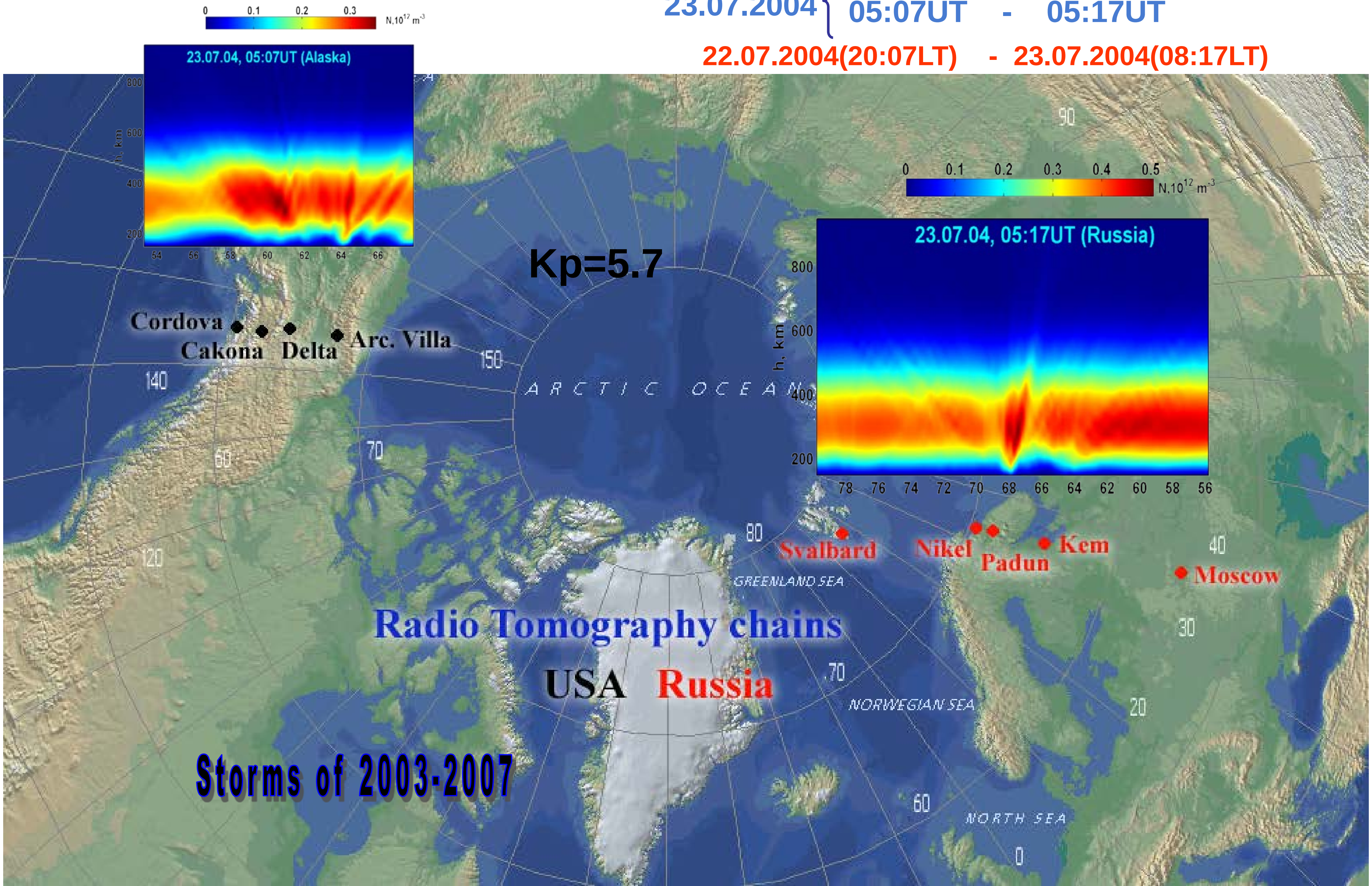


2015 St. Patrick's Day storm



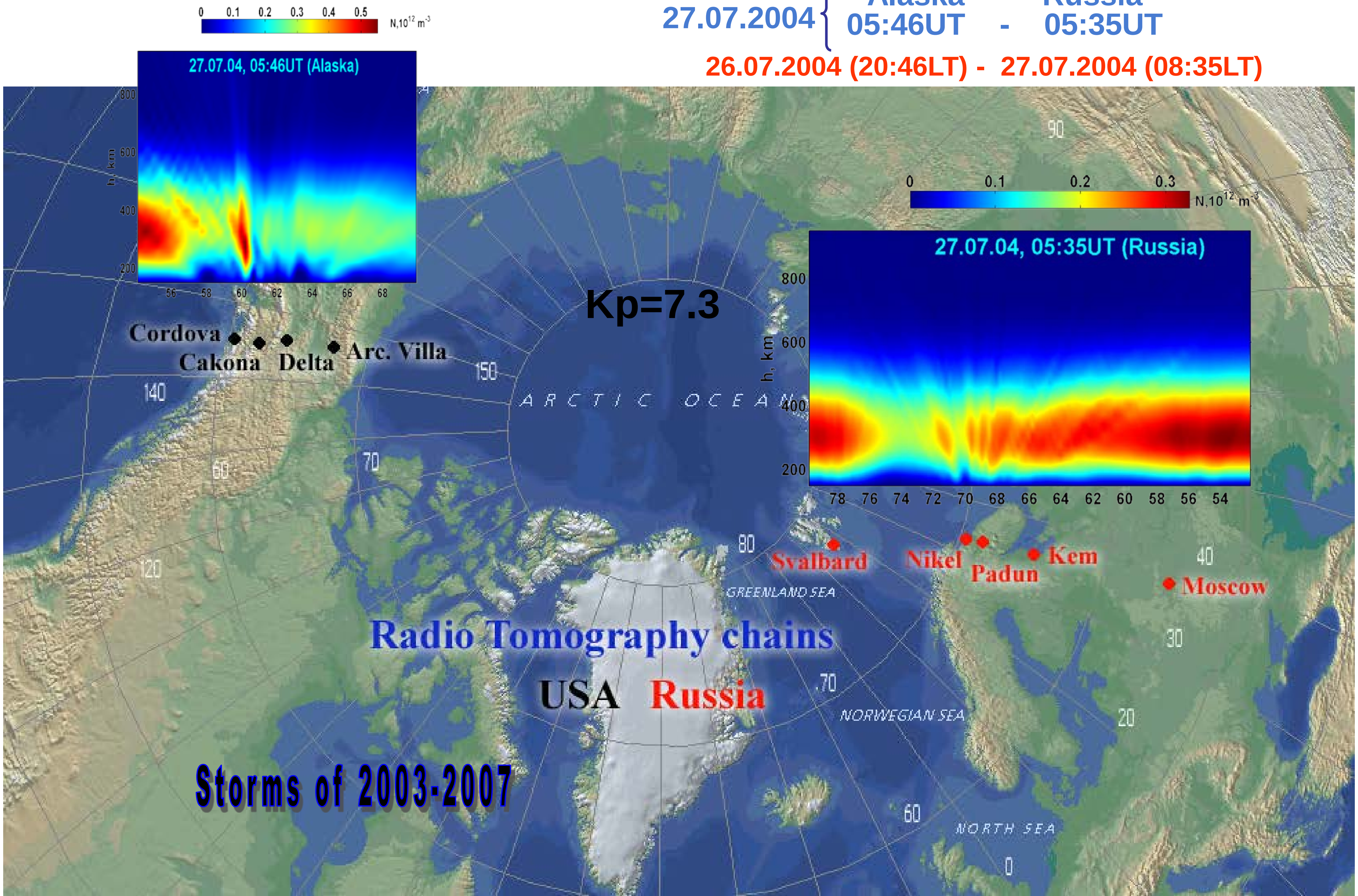
23.07.2004 { Alaska – Russia
05:07UT - 05:17UT

22.07.2004(20:07LT) - 23.07.2004(08:17LT)

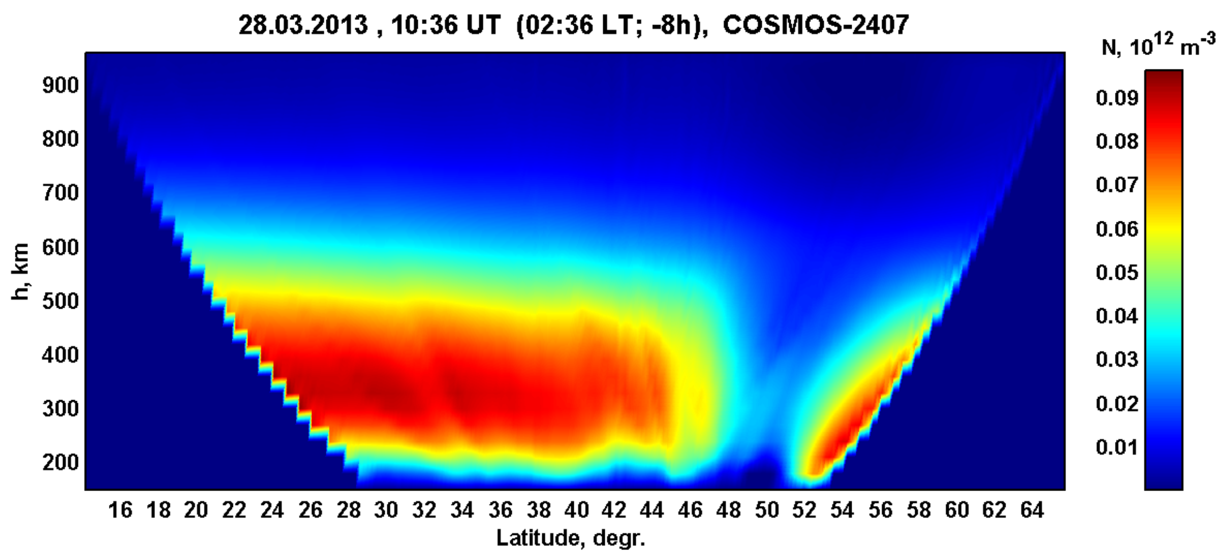


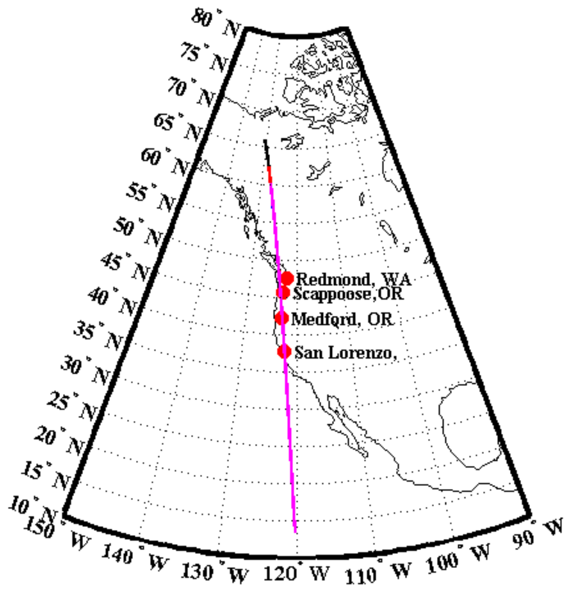
27.07.2004 { Alaska – Russia
05:46UT - 05:35UT

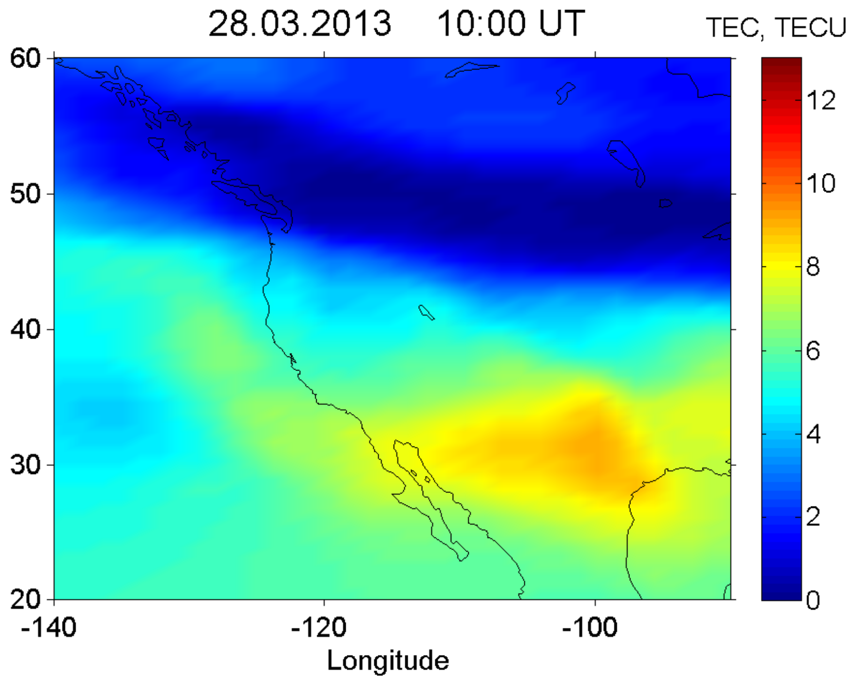
26.07.2004 (20:46LT) - 27.07.2004 (08:35LT)

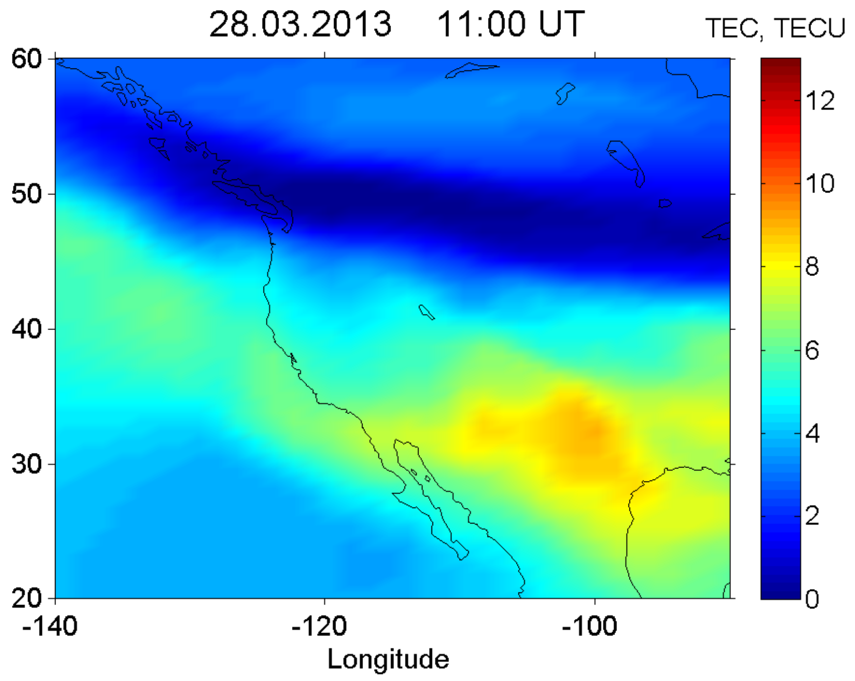


U.S. West Coast

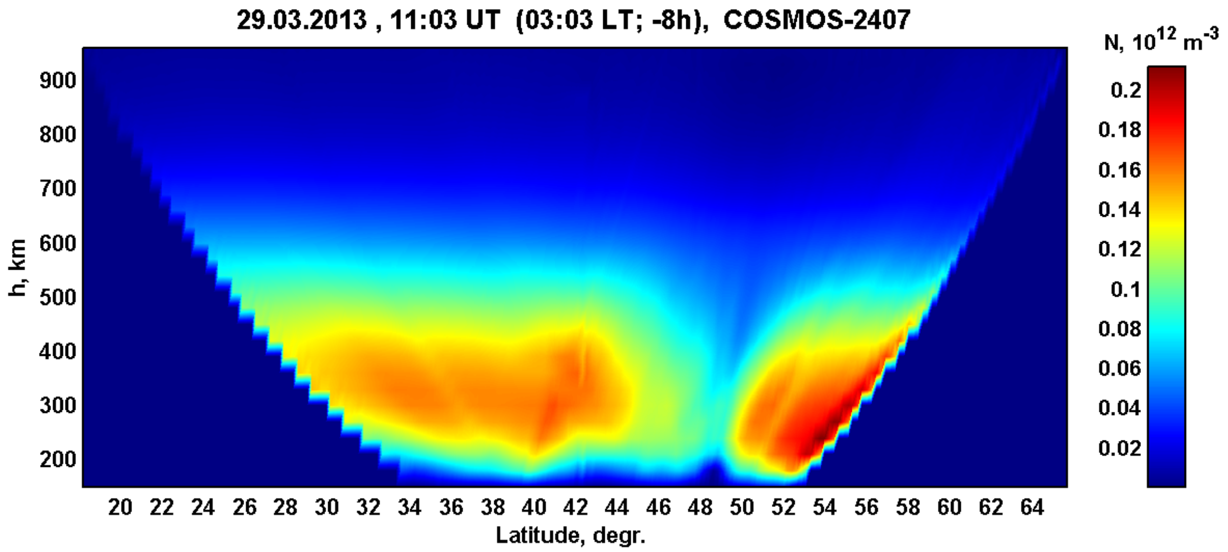


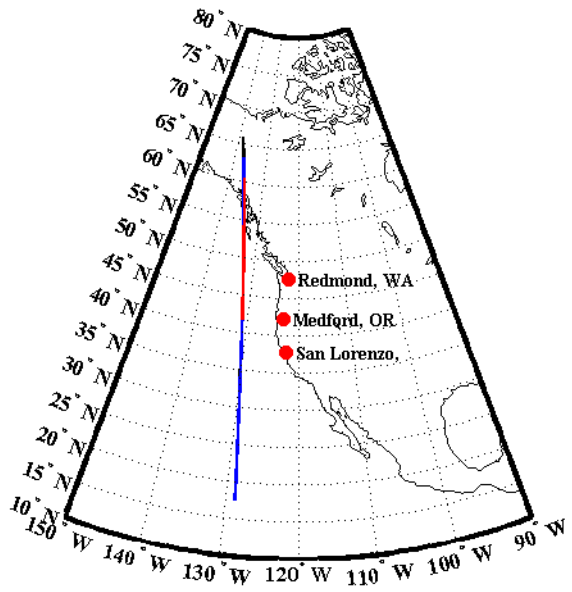


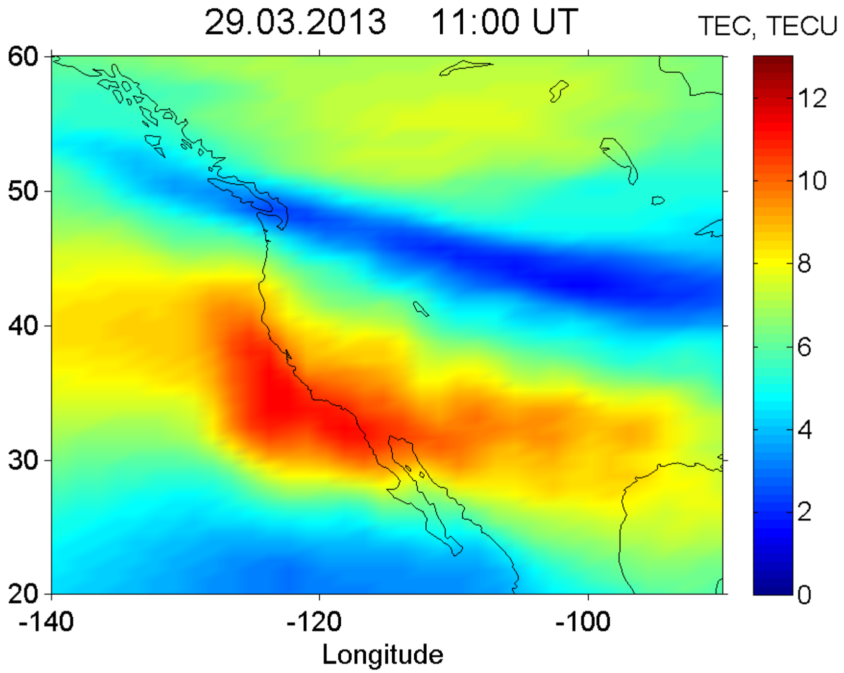


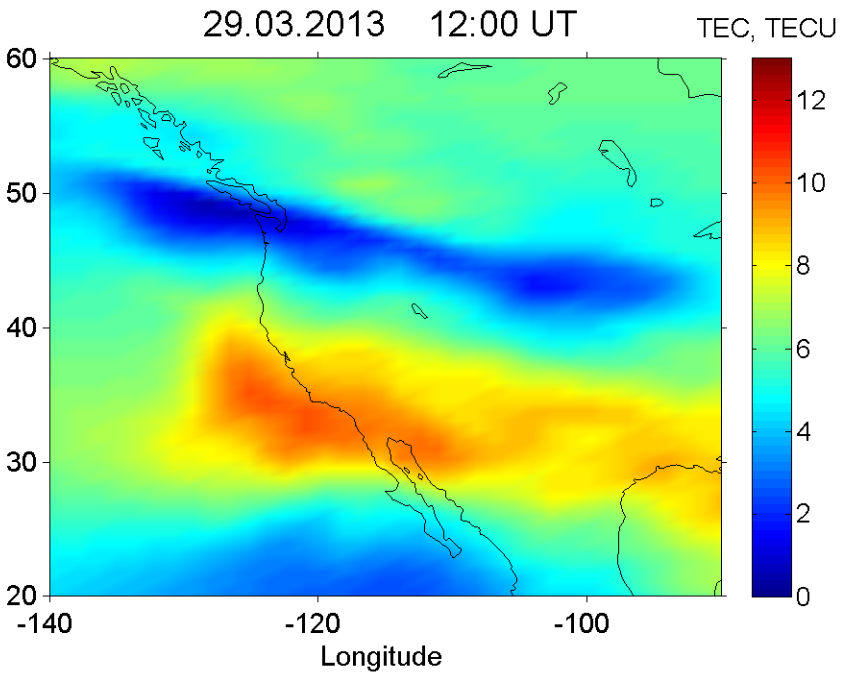


U.S. West Coast

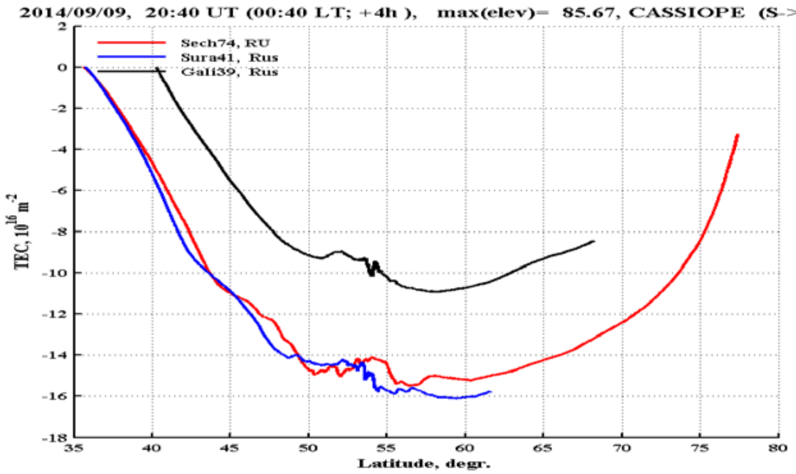


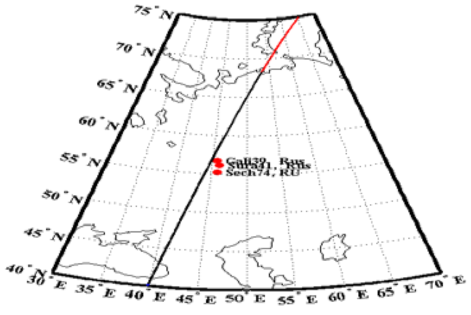


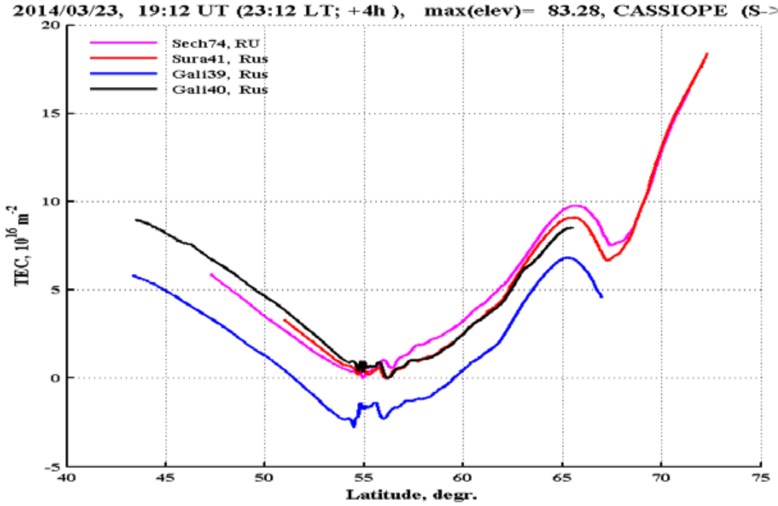


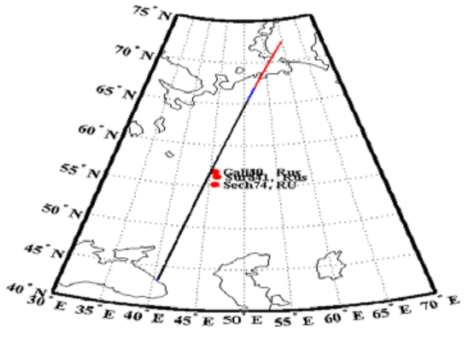


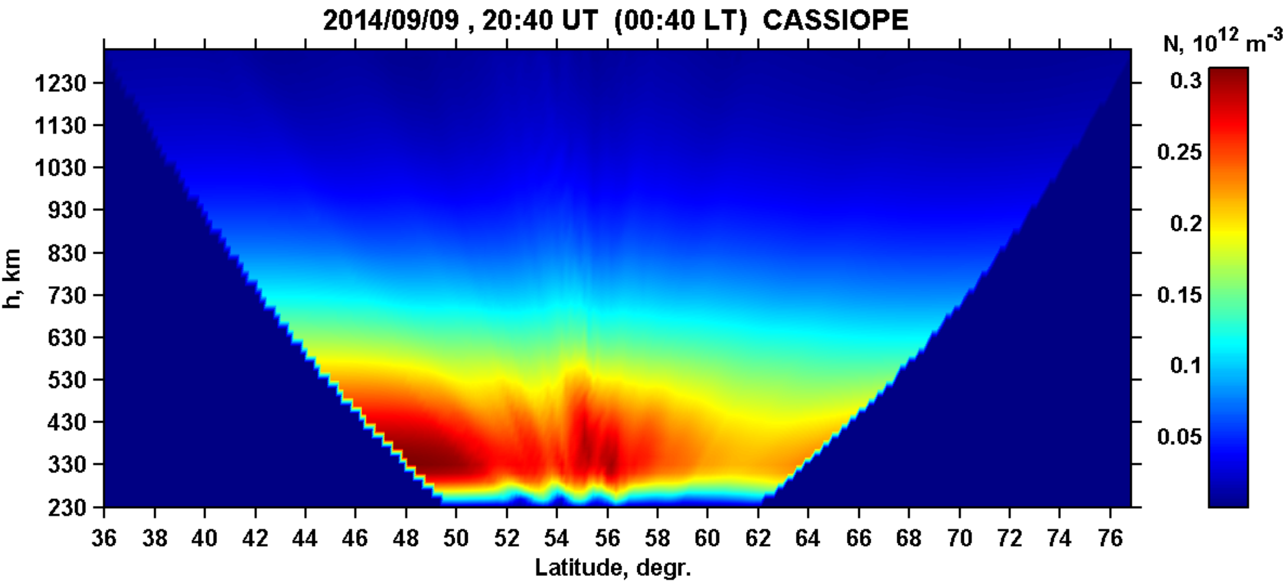
Radiotomography of artificially disturbed ionosphere

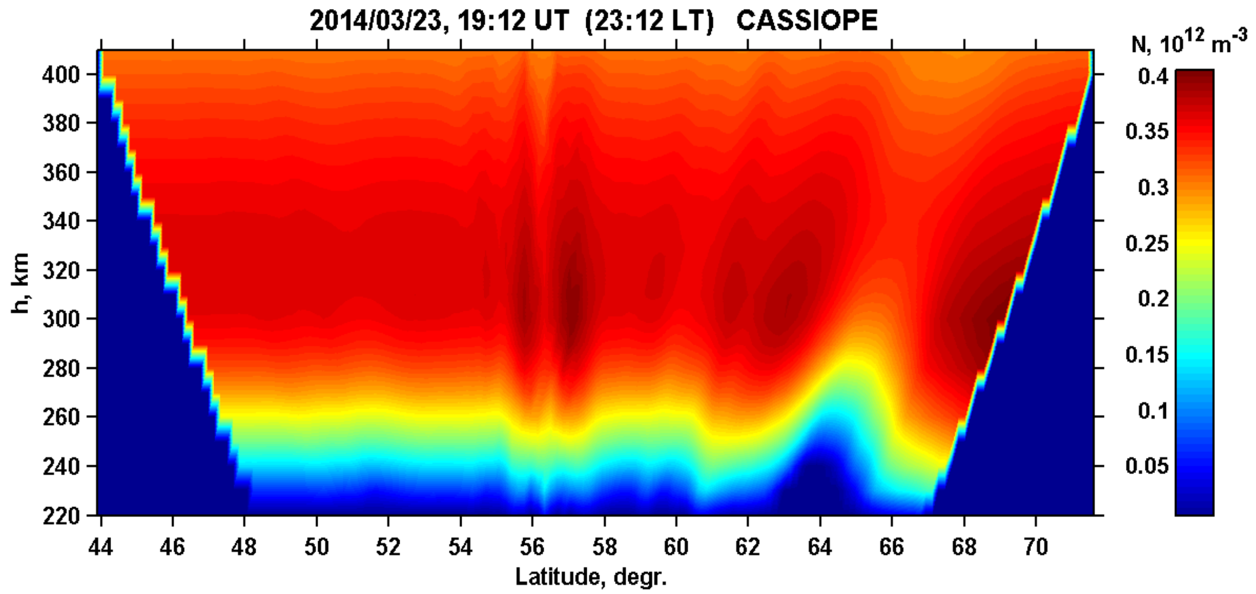




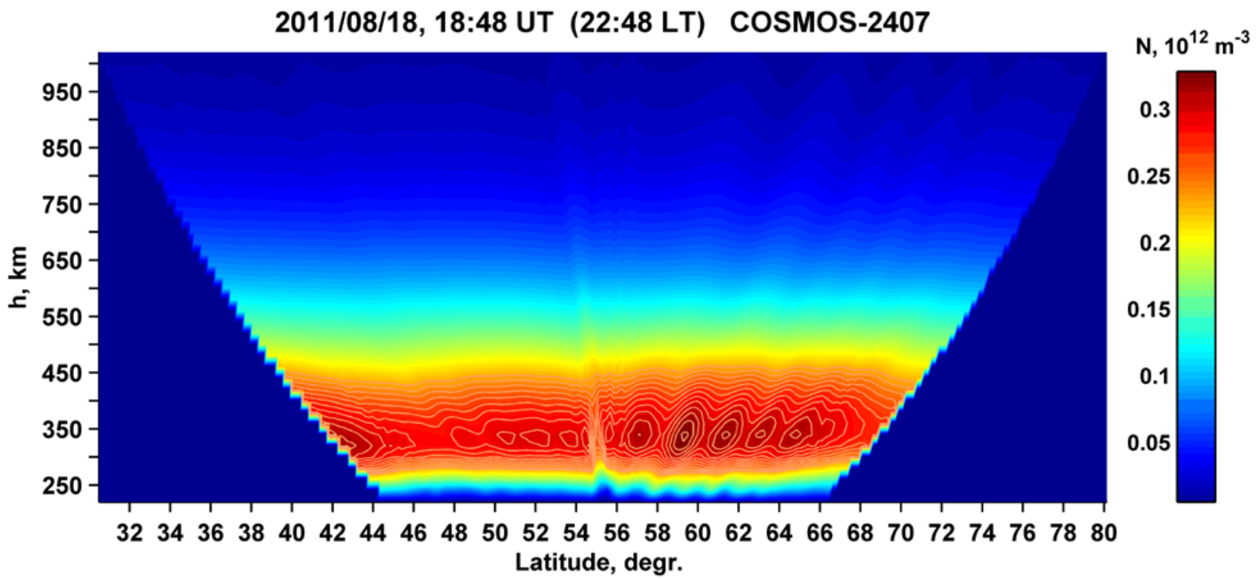


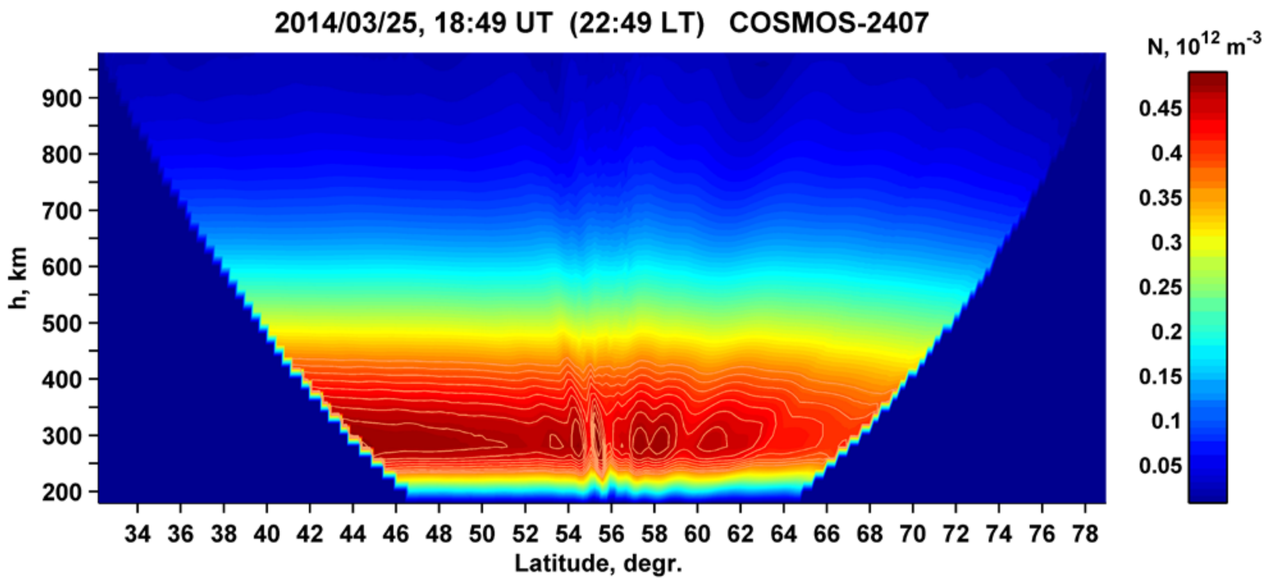


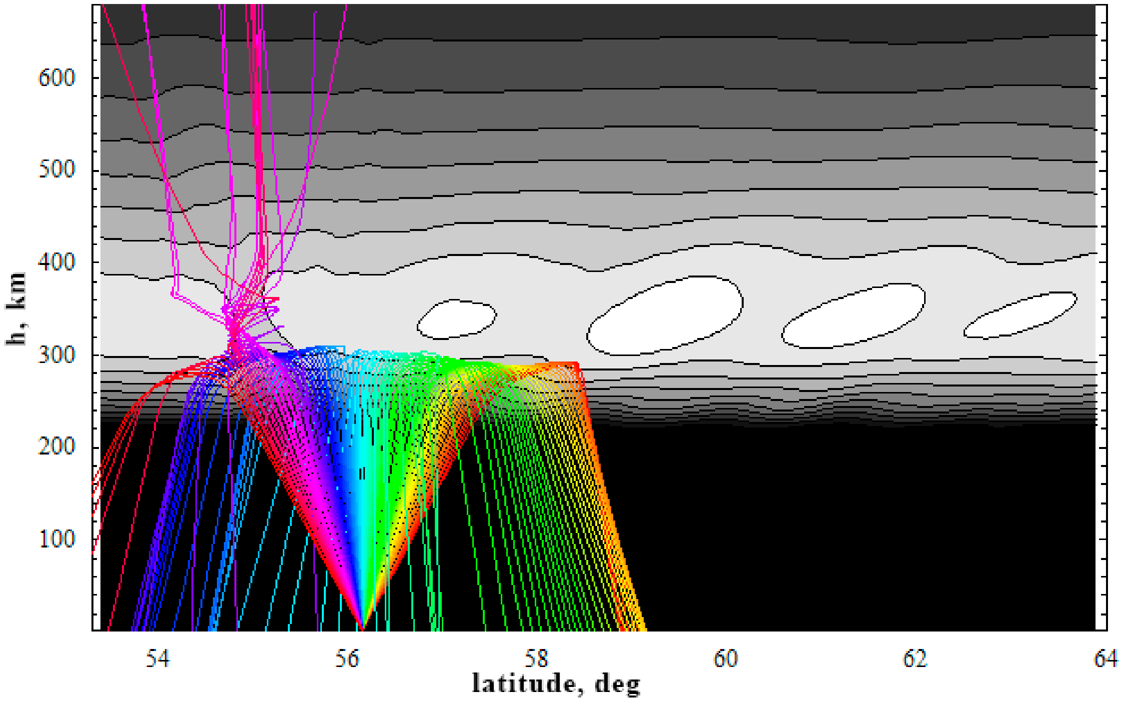


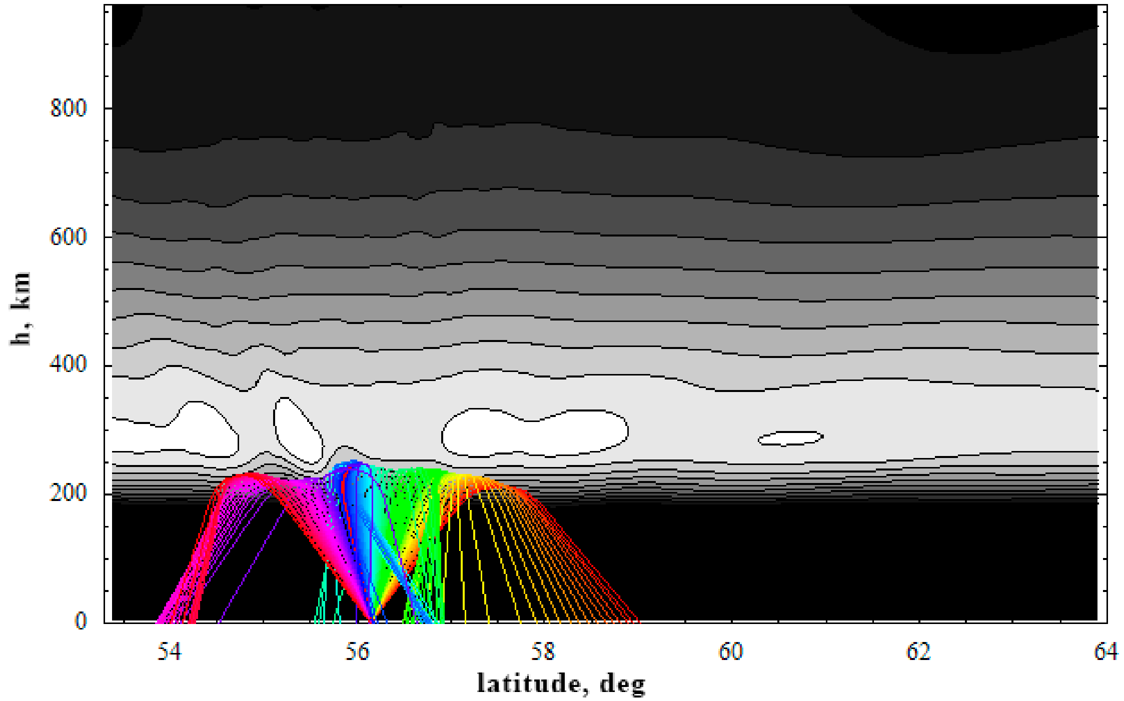


Radiotomography of artificially disturbed ionosphere [Andreeva et al. RS 2016]









CONCLUSIONS

The RT images of the ionosphere in Russian and North American regions under different space weather conditions show a great variety of structures (troughs, patches, wave-like structures etc.).

Combination of HORT and LORT methods supported by the other ground- and satellite-based observations could shed the new light on the processes controlling the distributions of ionospheric plasma at different latitudes under different space weather conditions.

New LEO beacon satellites, especially with GNSS receivers onboard could greatly benefit to the studies of fine structure of ionospheric electron density distribution during periods of helio geophysical disturbances

ACKNOWLEDGEMENTS

We are grateful to:
IGS for GNSS data
NWRA for the data from Alaska RT System
Radio-Hydro-Physics LLC for the data from West Coast US RT System
NRL and University of Calgary for providing ePOP/CER signal