Exploring the Ionospheric Structures by Radio Tomographic Methods

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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

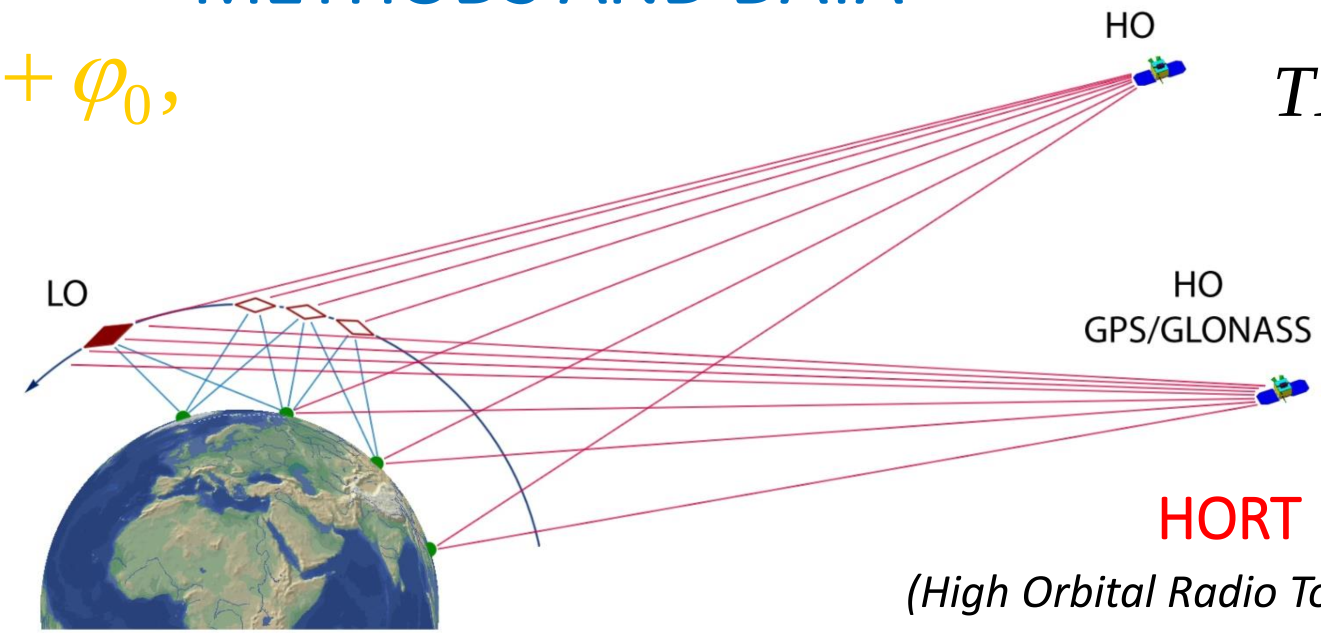
Application of RT-methods to UV ionospheric tomography

New data sources

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)

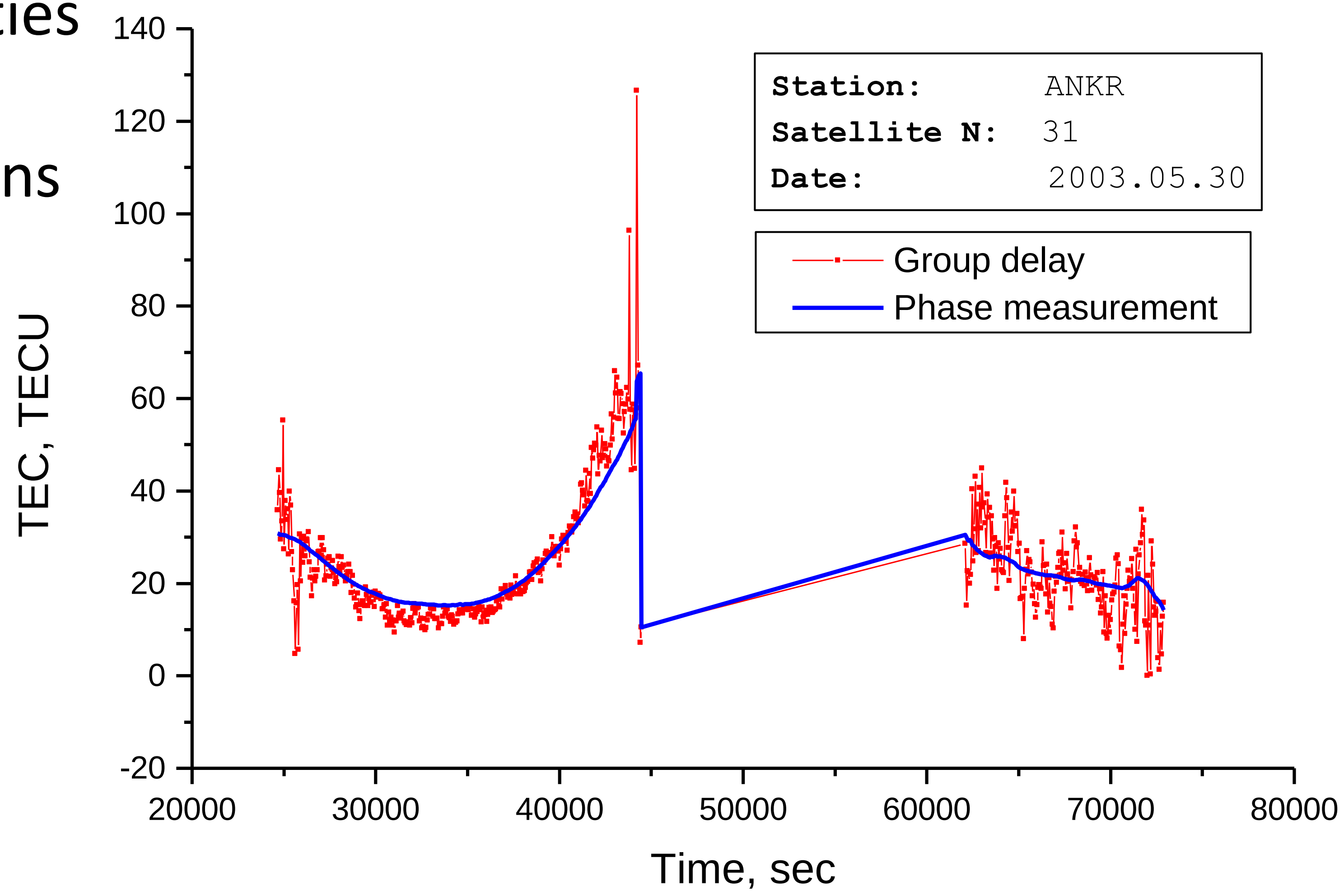
Typical resolution of HORT is about of **100-50 km** with a time step **60-20 min**.

Absolute phase or absolute TEC as an input

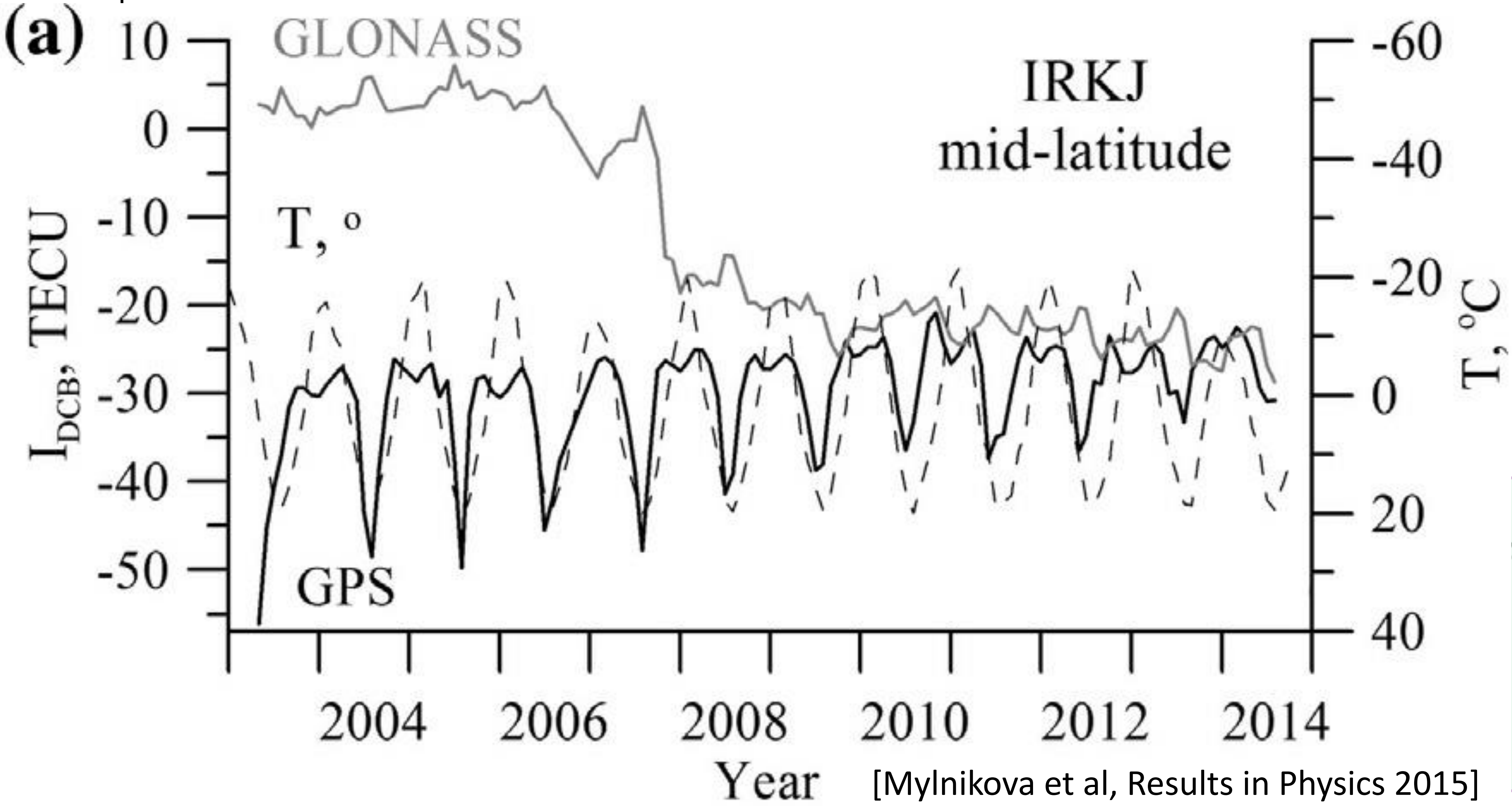
Need to resolve phase ambiguities

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:

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

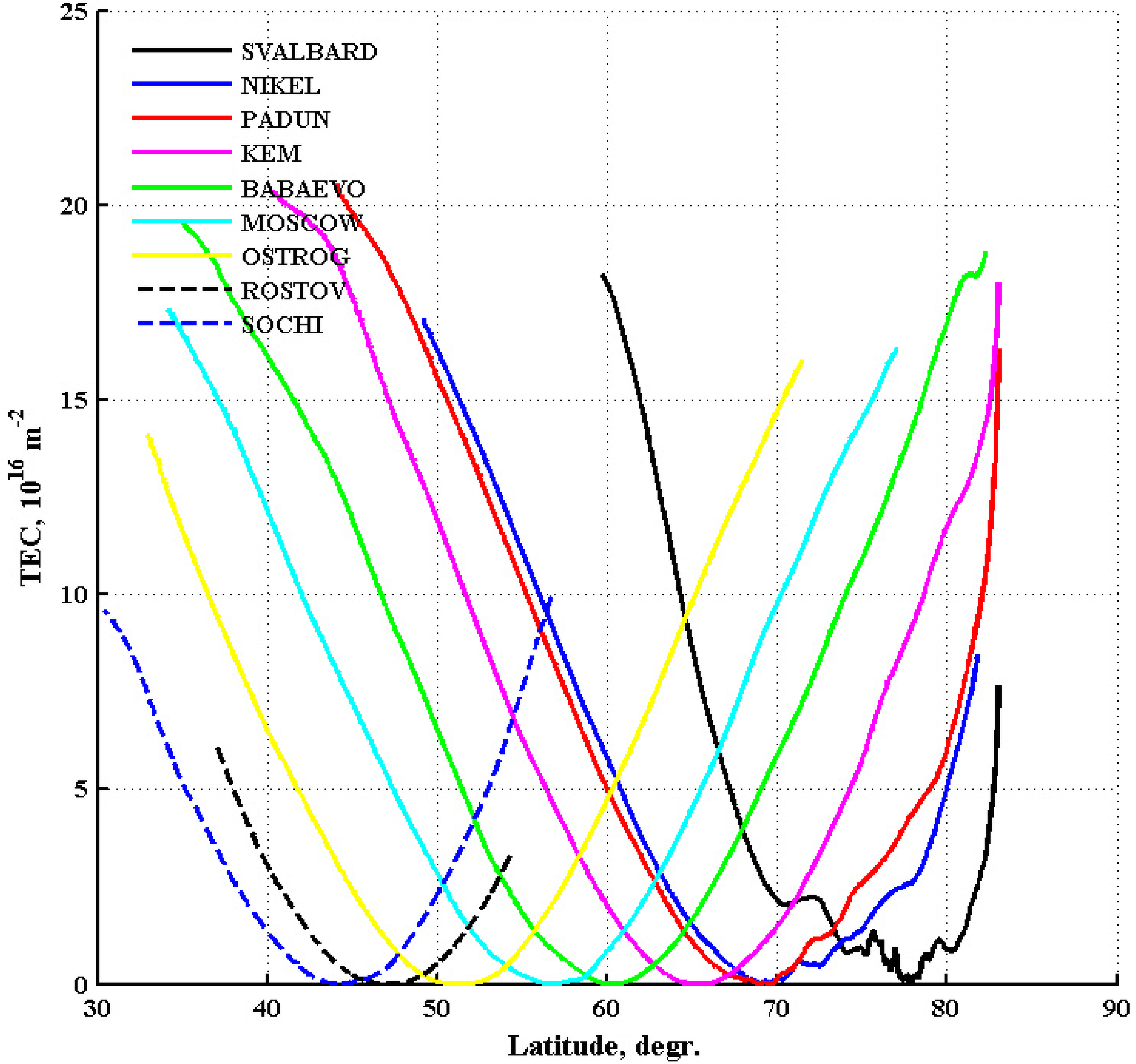
$$\min (\vec{x} - \vec{x}_0, \vec{x} - \vec{x}_0)_L$$
$$A\vec{x} = \vec{y}$$
$$\vec{a}'_i = (L^* L)^{-1} \vec{a}_i$$

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

$$(\vec{z}, \vec{x})_L = (L\vec{z}, L\vec{x}) = (\vec{z}, L^* L \vec{x})$$

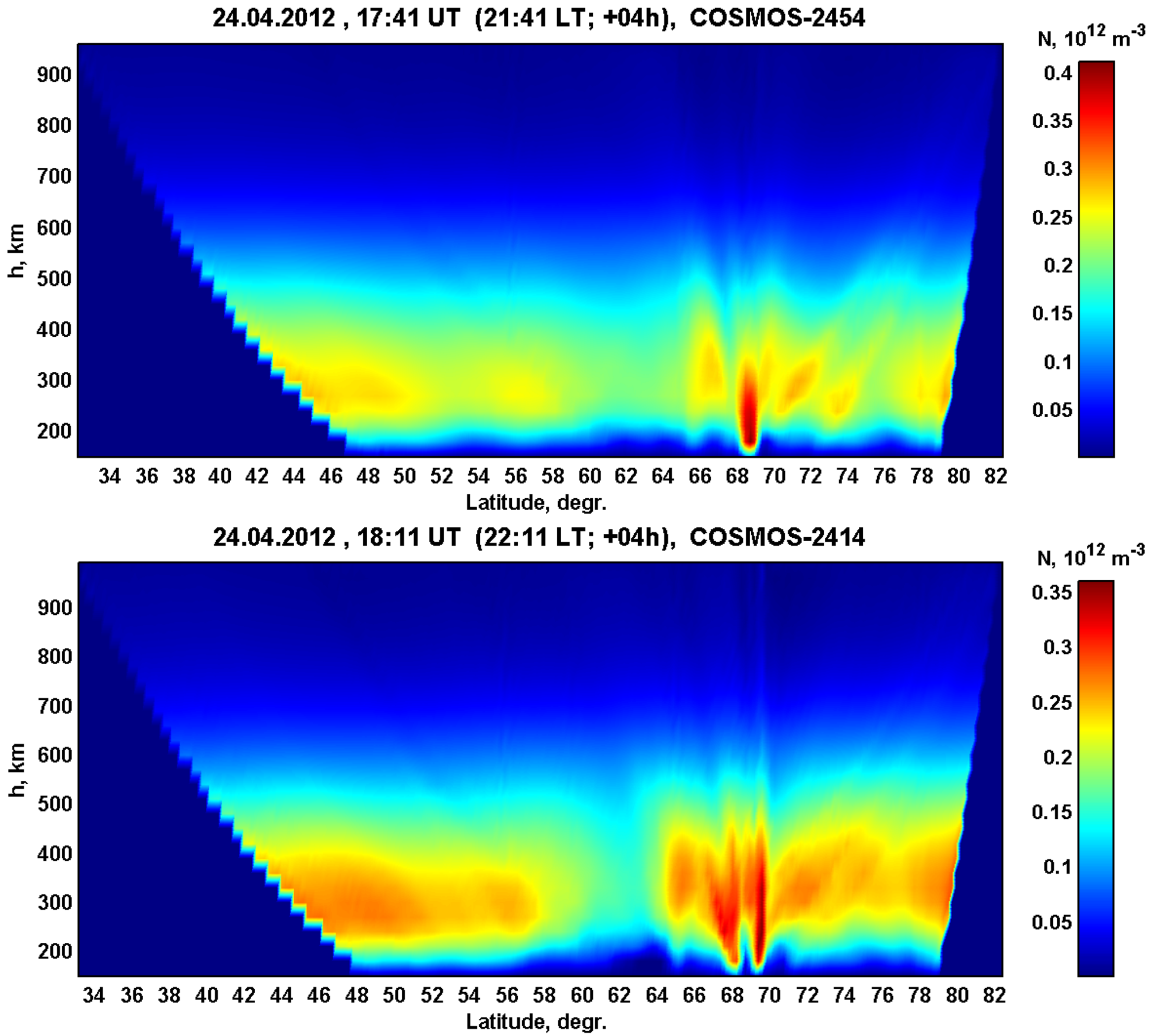
see [Nesterov & Kunitsyn, ASR 2011] for details

Russian LORT system (Svalbard – Moscow - Sochi)



Region of Russian LORT system

ionospheric features are probably associated with particle precipitation

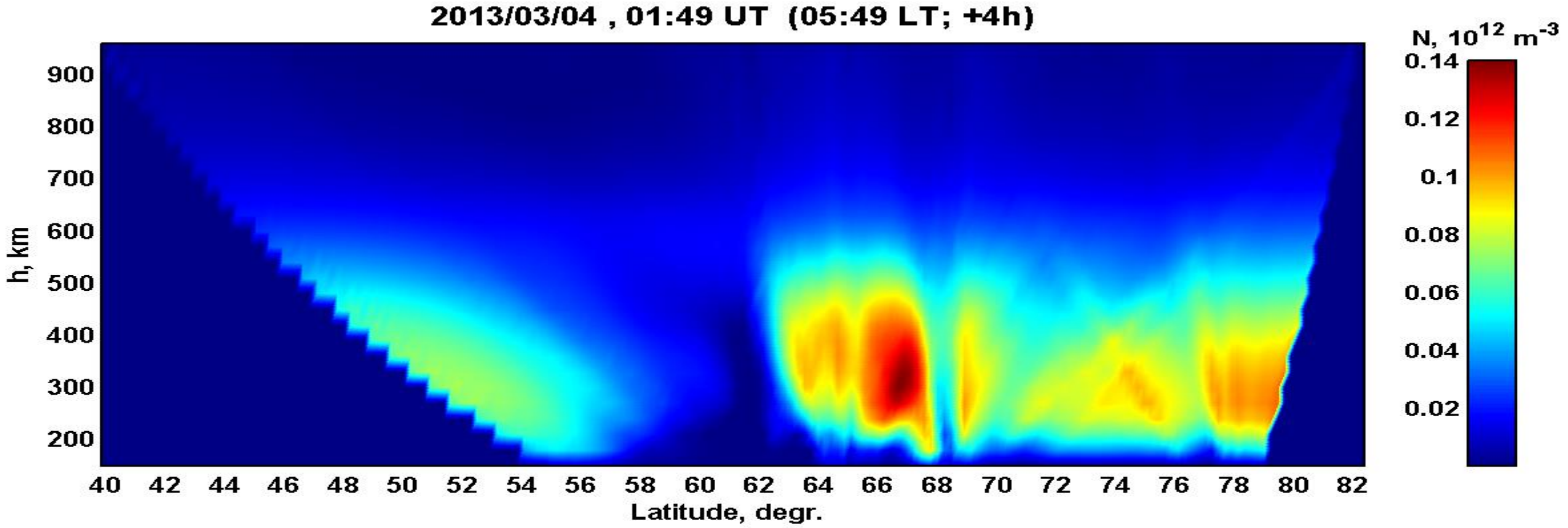


Kp=5

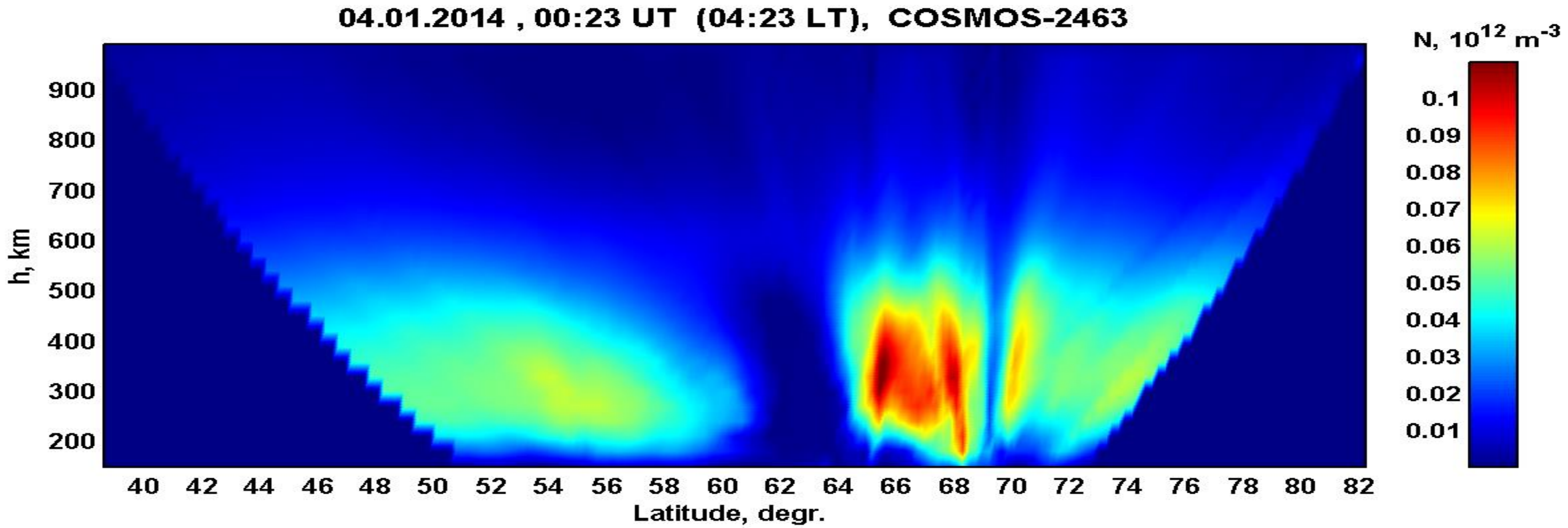
LORT images above Russian RT chain on April 24, 2012 , 17:41 and 18:11 UT

Region of Russian LORT system

Examples of ionization troughs

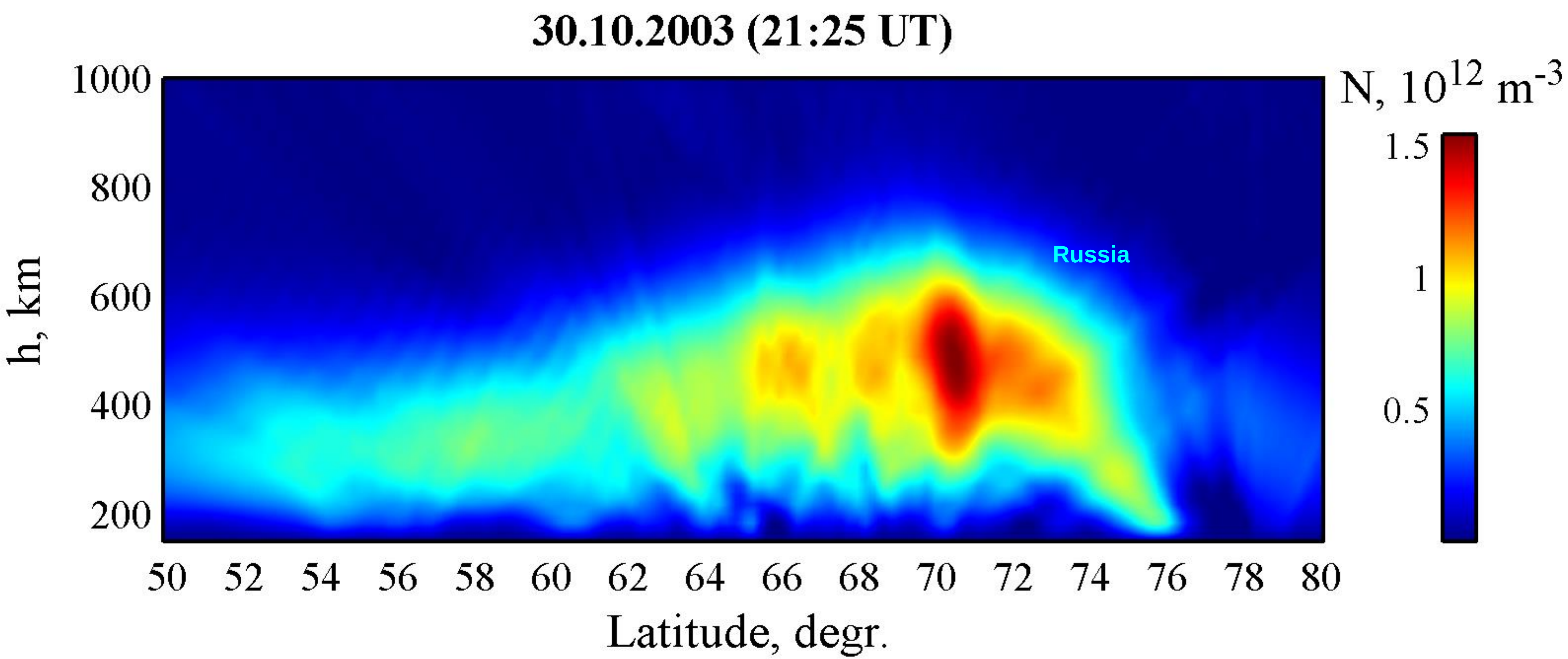


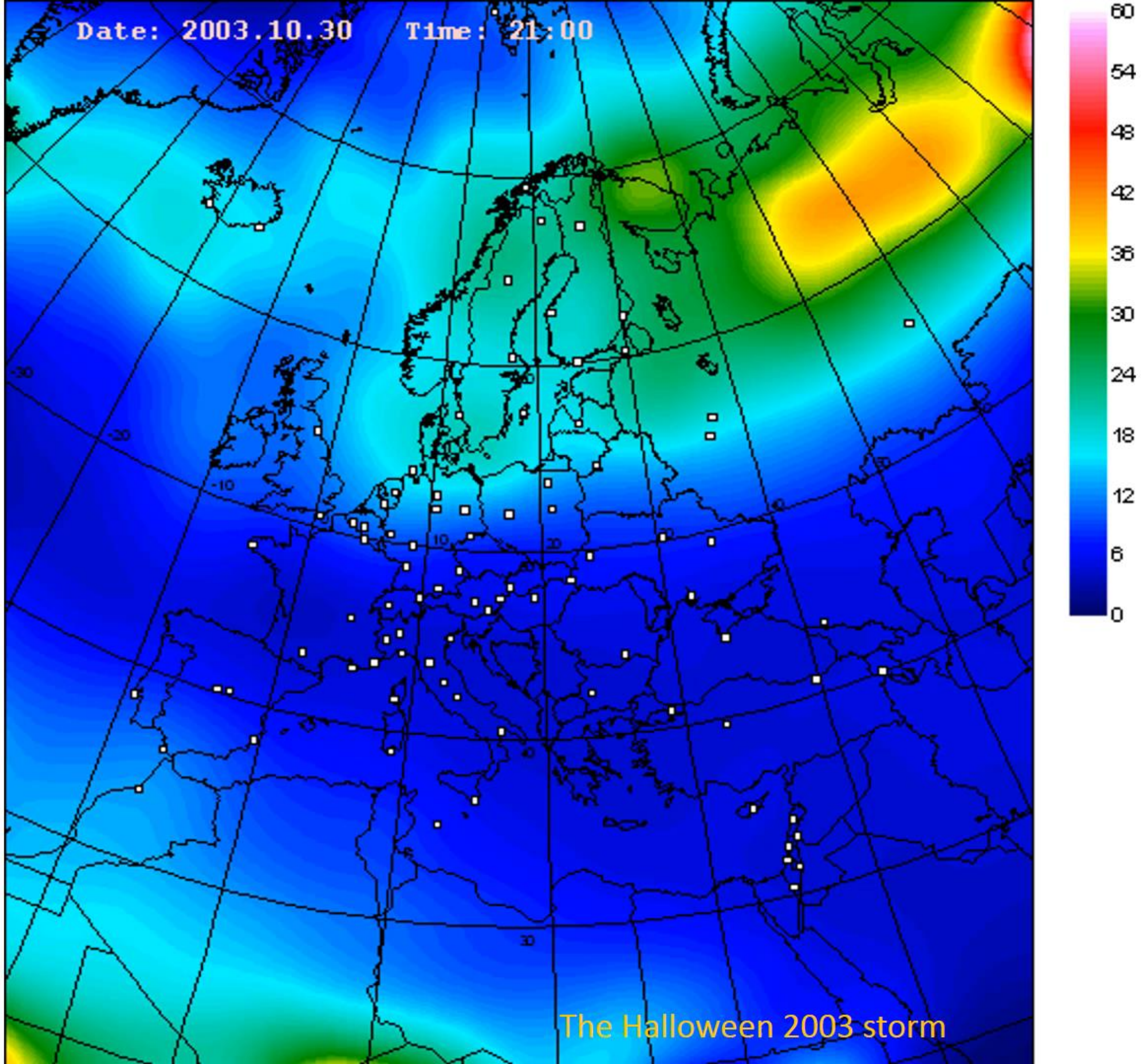
Kp=2



Kp=1.3

The Halloween 2003 storm

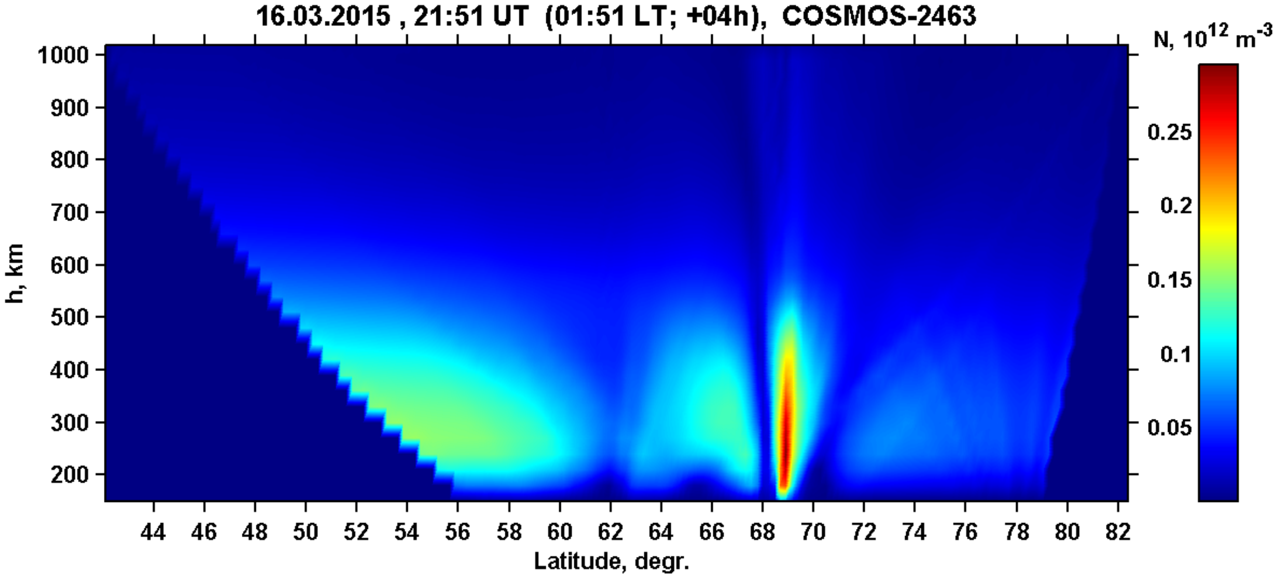


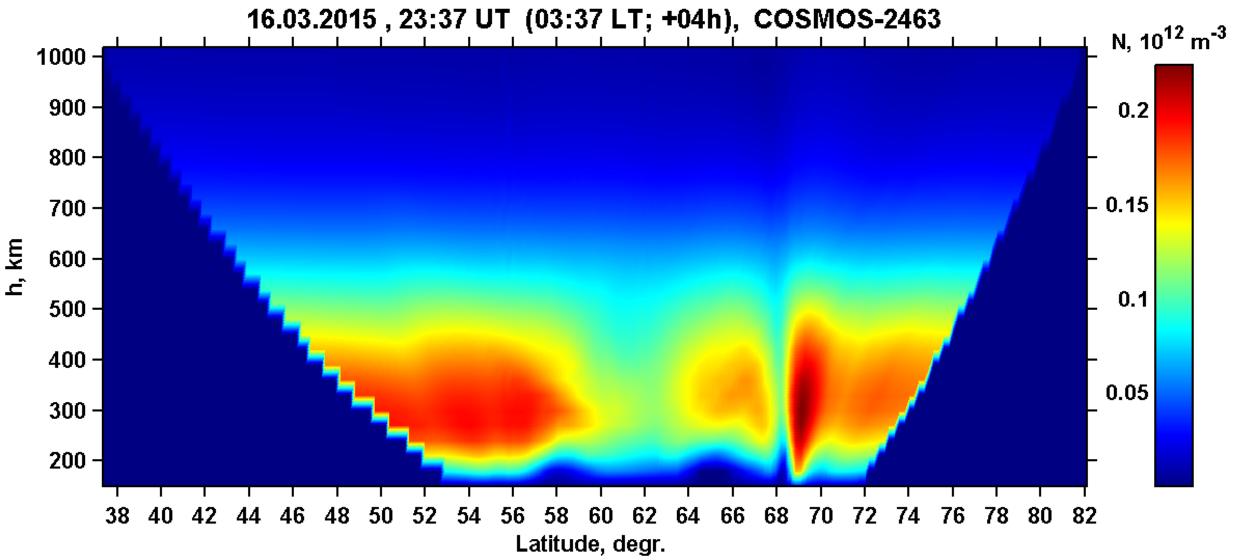


Date: 2003.10.30 Time: 21:00
60
54
48
42
36
30
24
18
12
6
0
The Halloween 2003 storm

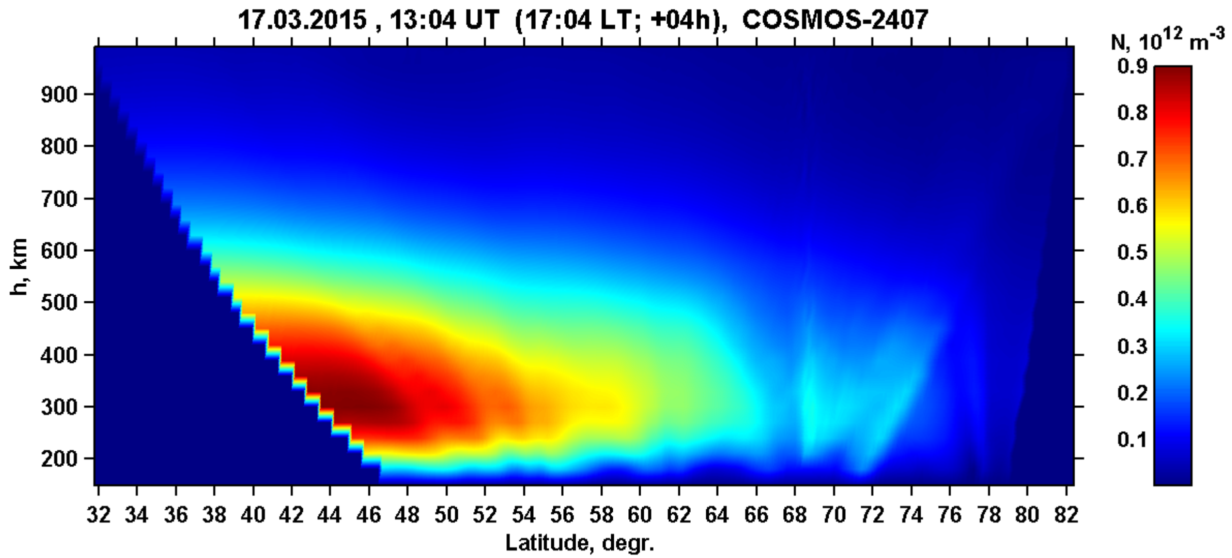
Region of Russian LORT system

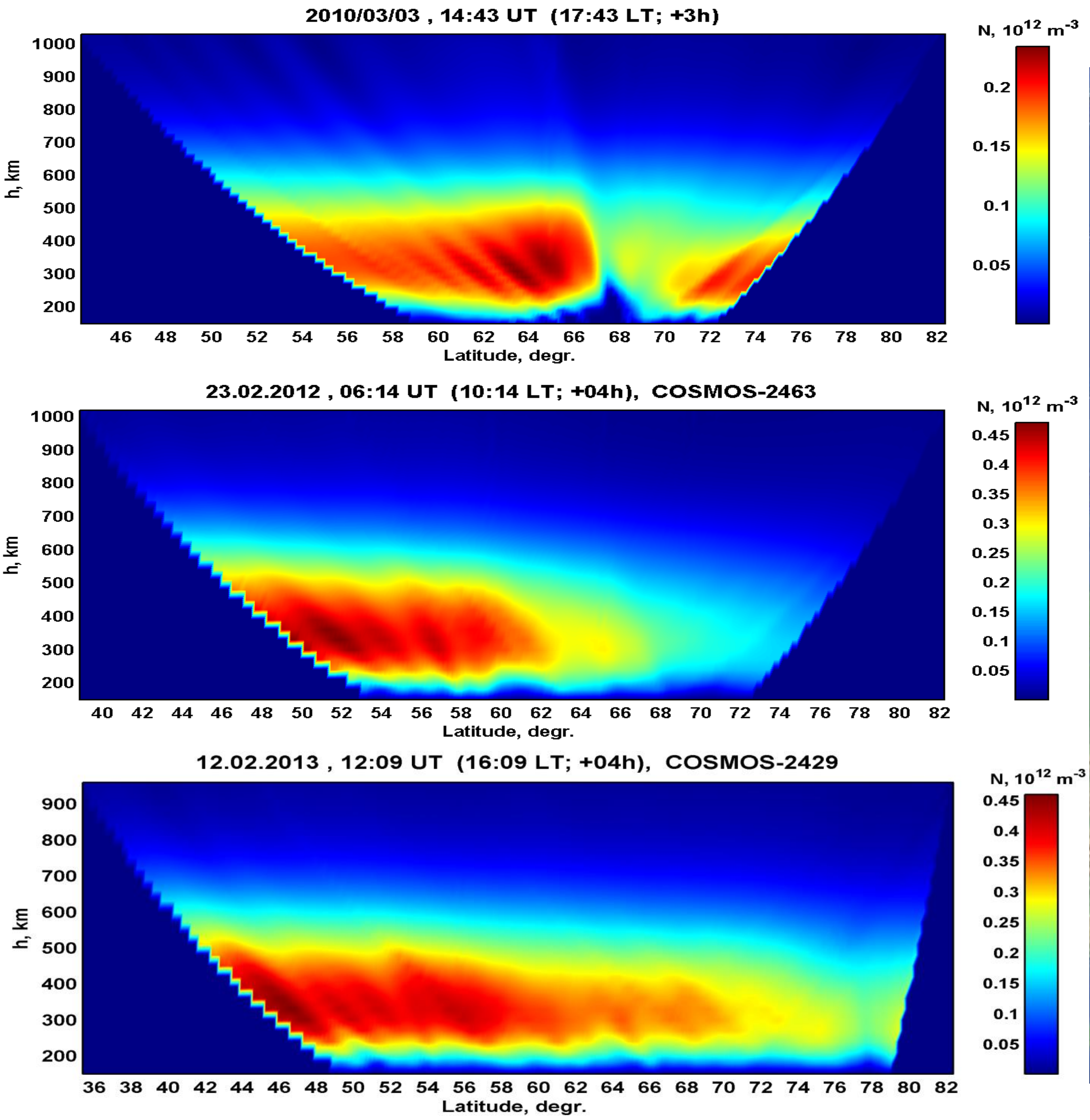
Several hours before SSC of 2015 St. Patrick's Day storm

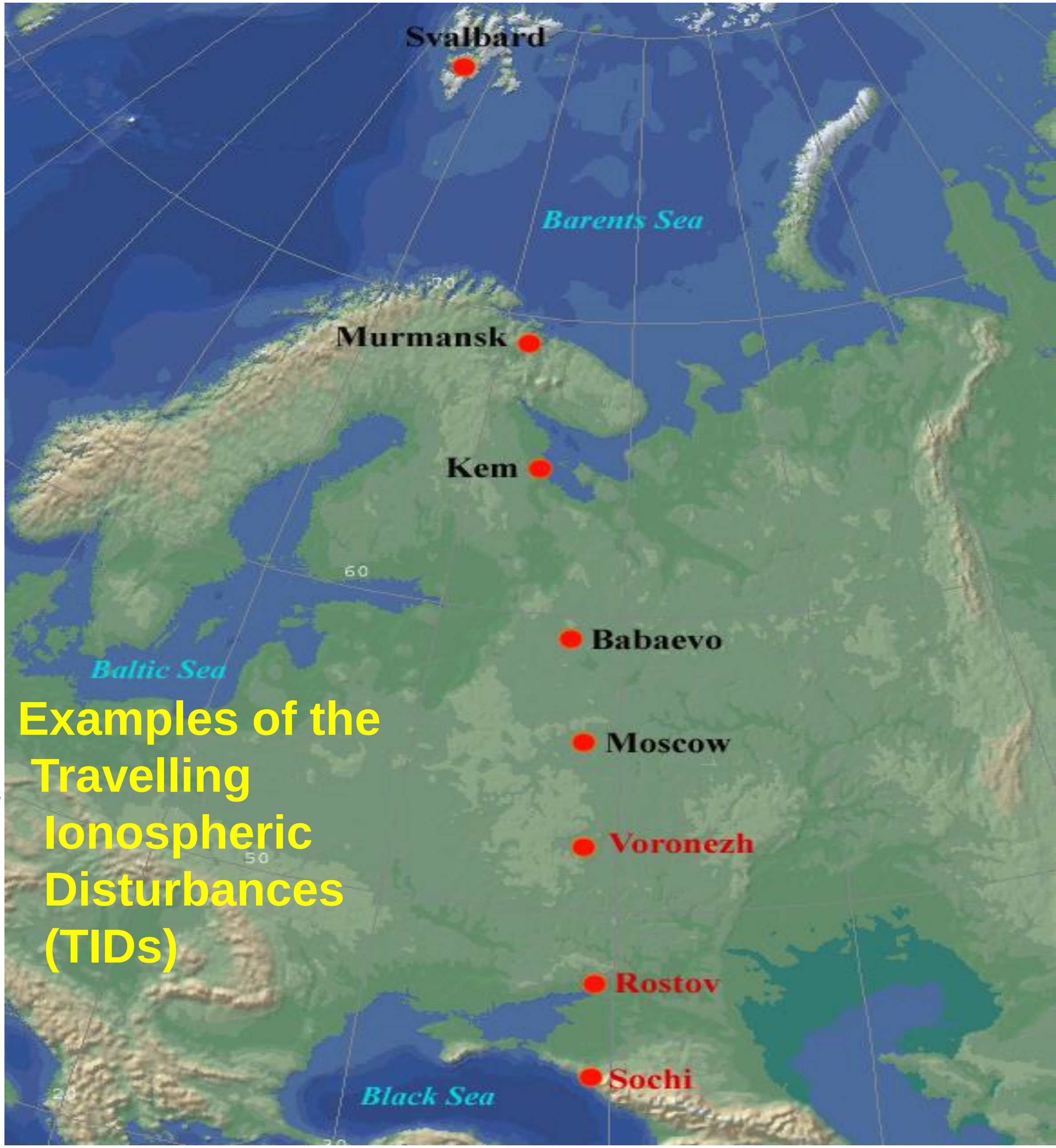




2015 St. Patrick's Day storm

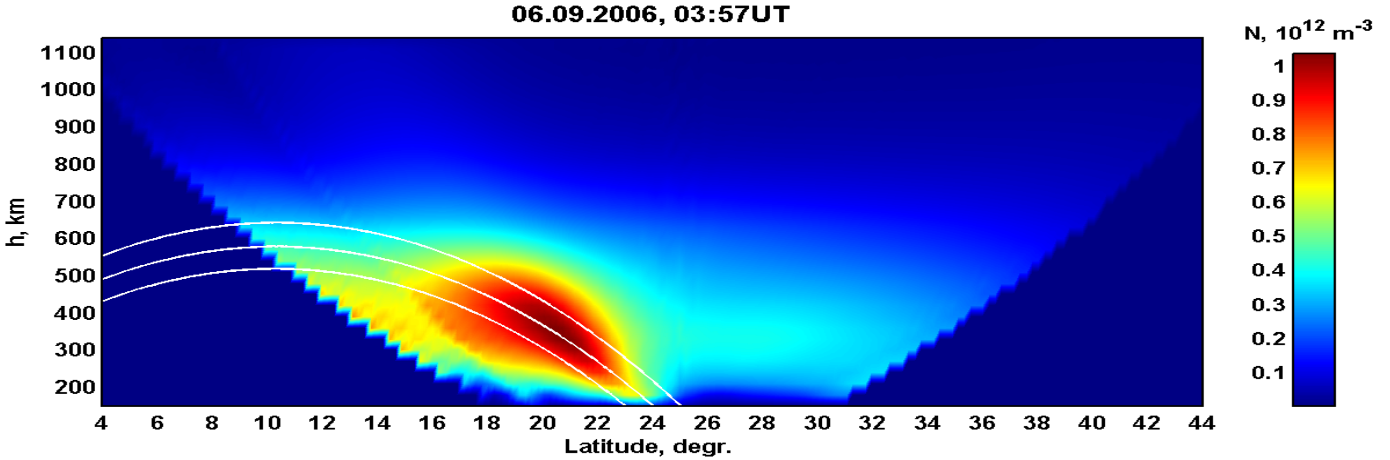


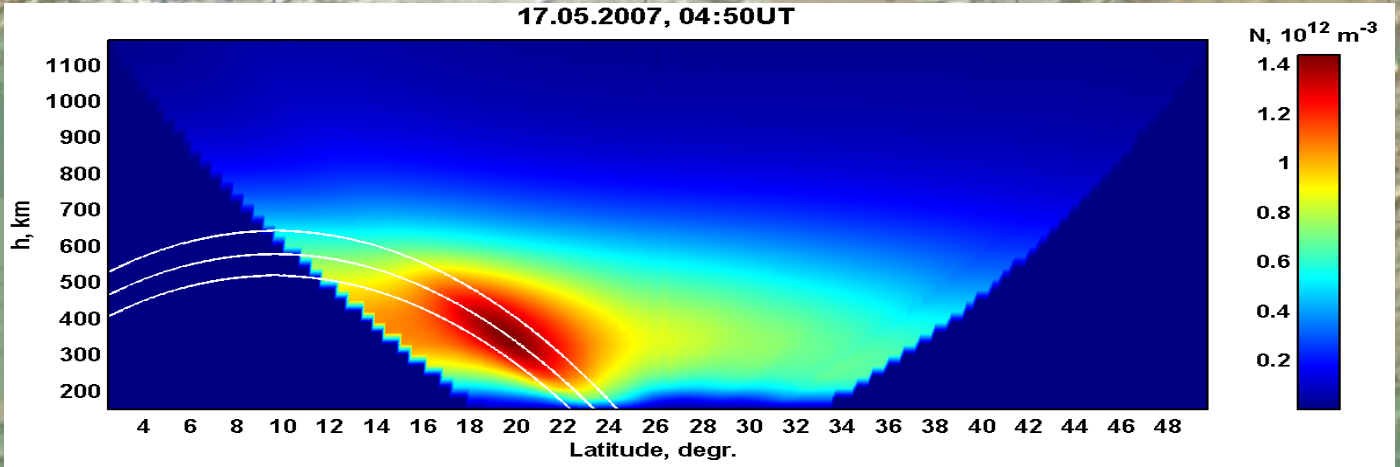

2010/03/03 , 14:43 UT (17:43 LT; +3h)
h, km
Latitude, degr.
N, 10^{12} m^{-3}
23.02.2012 , 06:14 UT (10:14 LT; +04h), COSMOS-2463
h, km
Latitude, degr.
N, 10^{12} m^{-3}
12.02.2013 , 12:09 UT (16:09 LT; +04h), COSMOS-2429
h, km
Latitude, degr.
N, 10^{12} m^{-3}

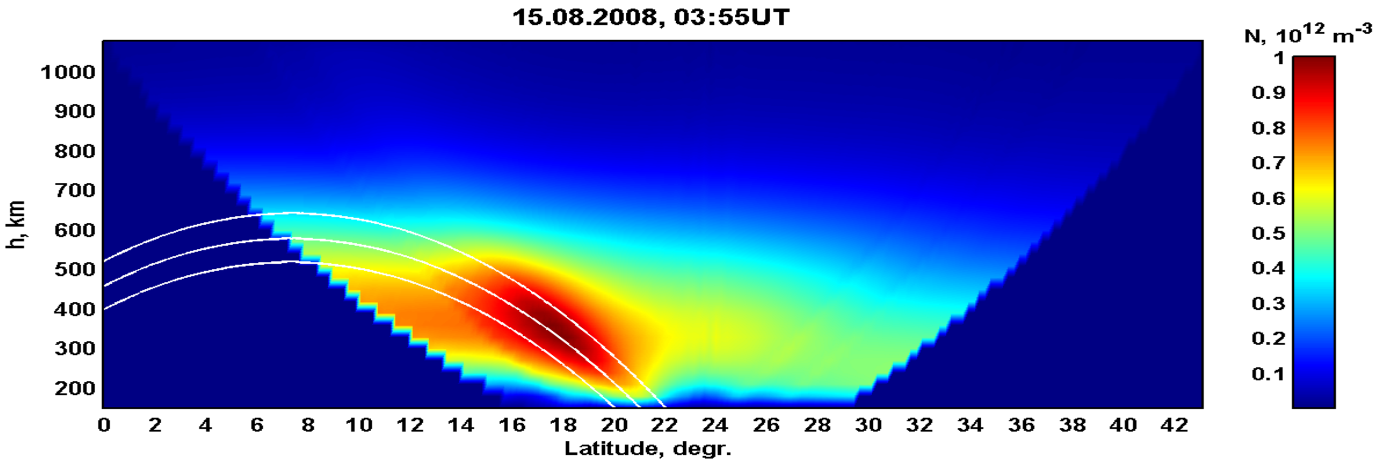

Svalbard
Barents Sea
Murmansk
Kem
Babaevo
Baltic Sea
Moscow
Voronezh
Rostov
Black Sea
Sochi
Examples of the Travelling Ionospheric Disturbances (TIDs)

Equatorial Anomaly

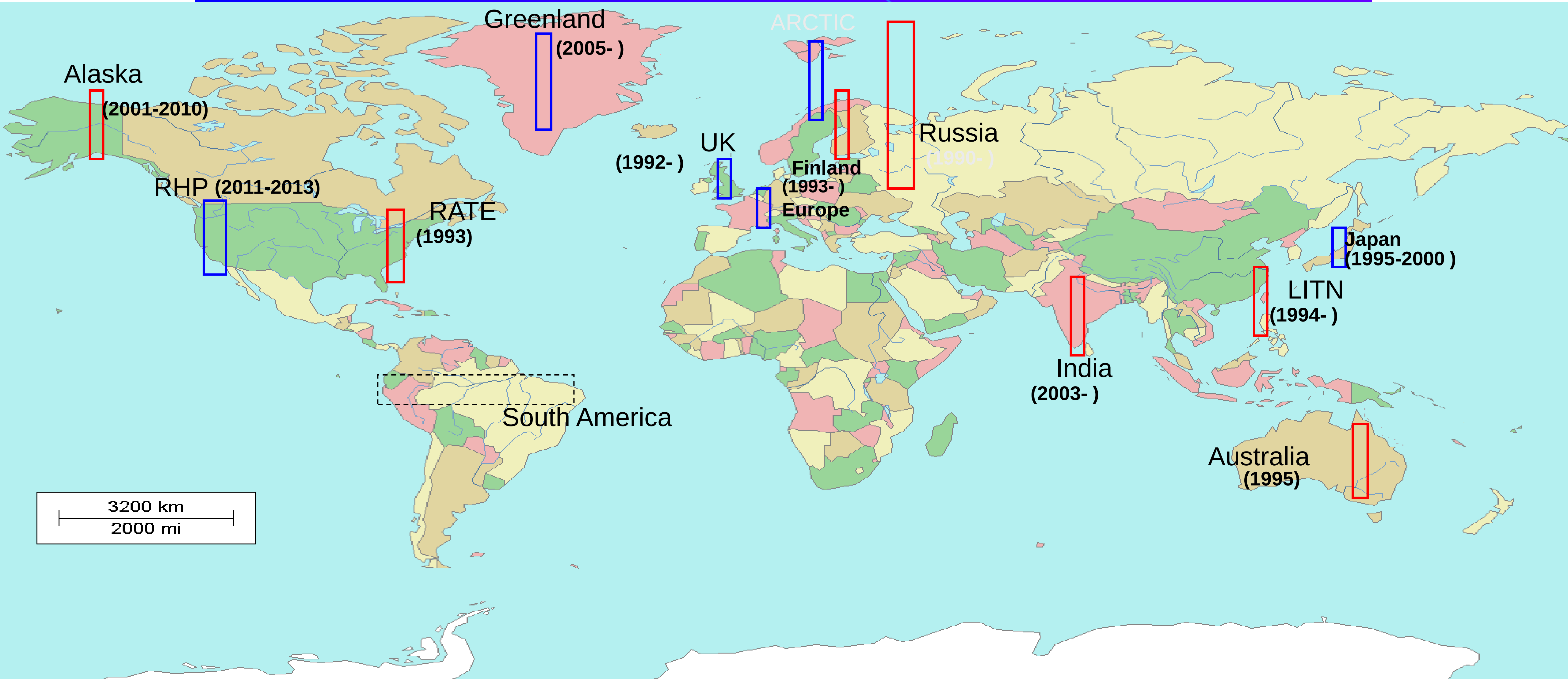
(2006…)



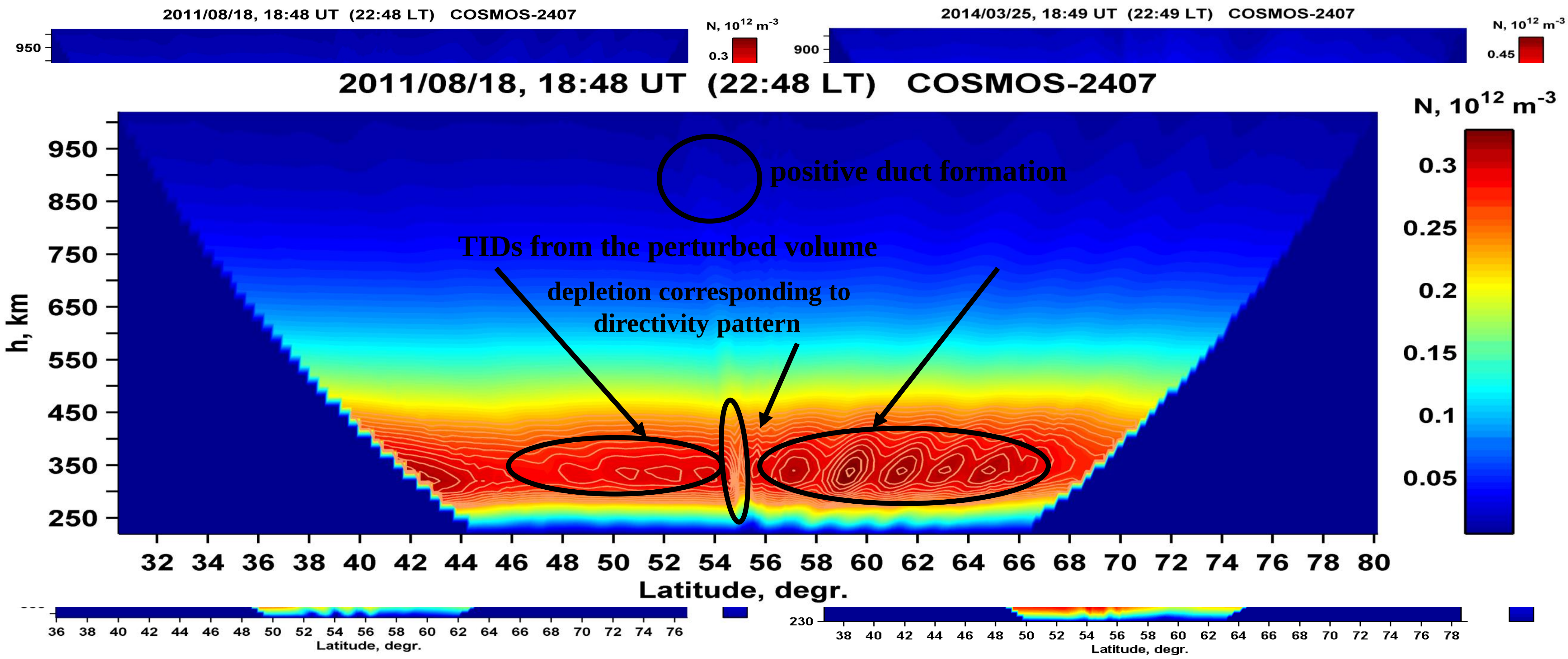




LORT Radiotomographic Systems

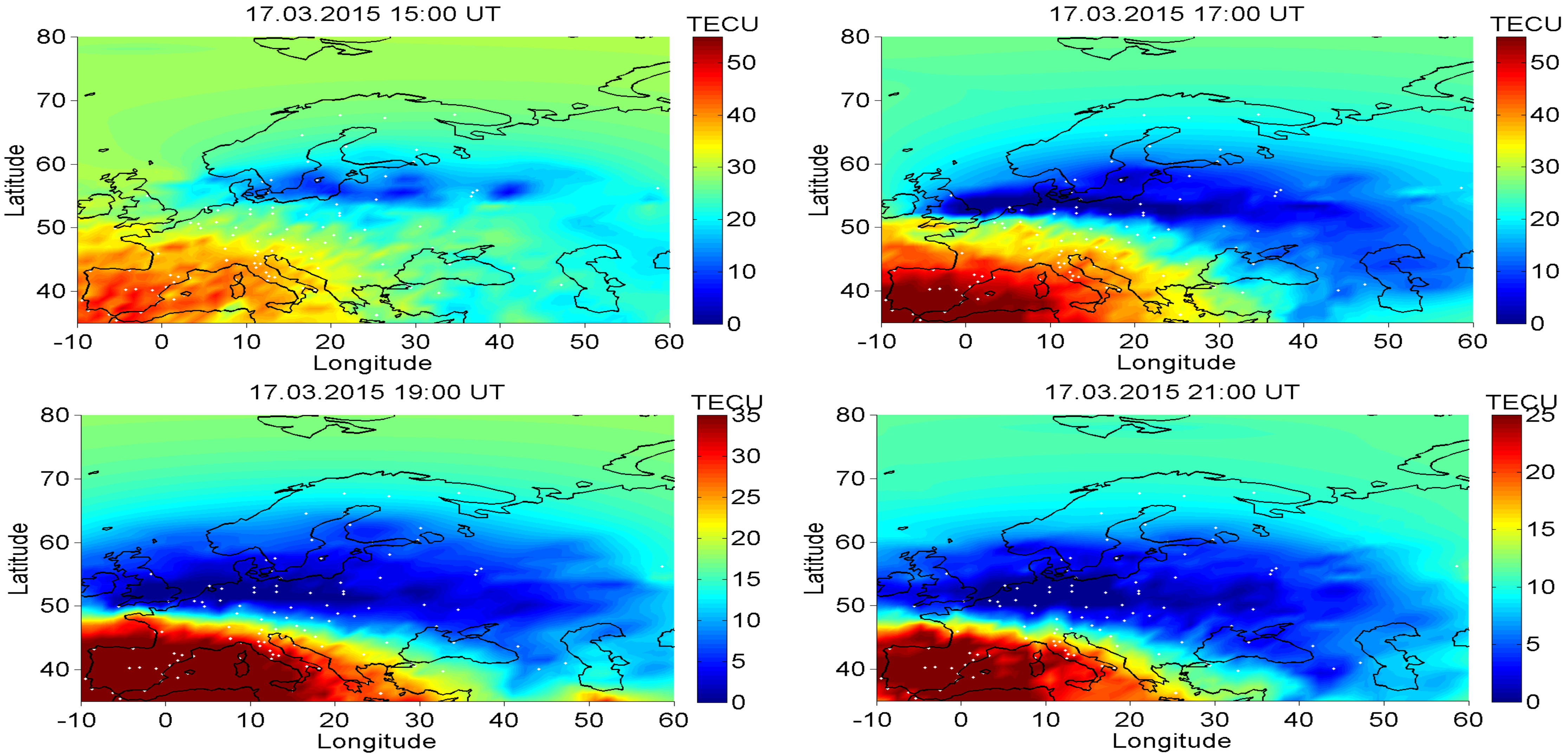


Examples of Artificial Ionospheric Disturbances above SURA Heater

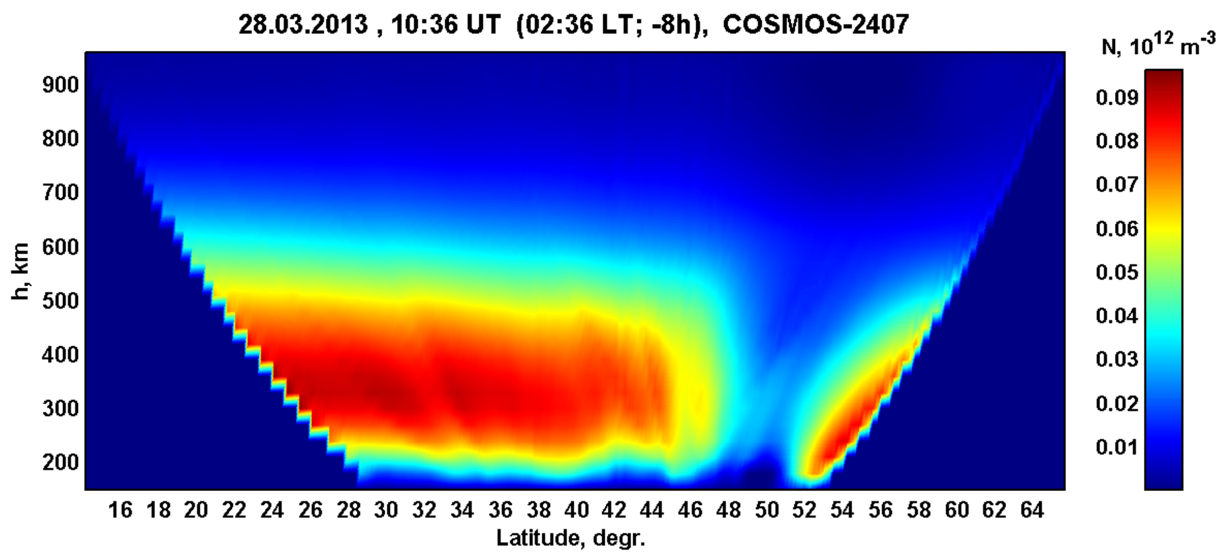


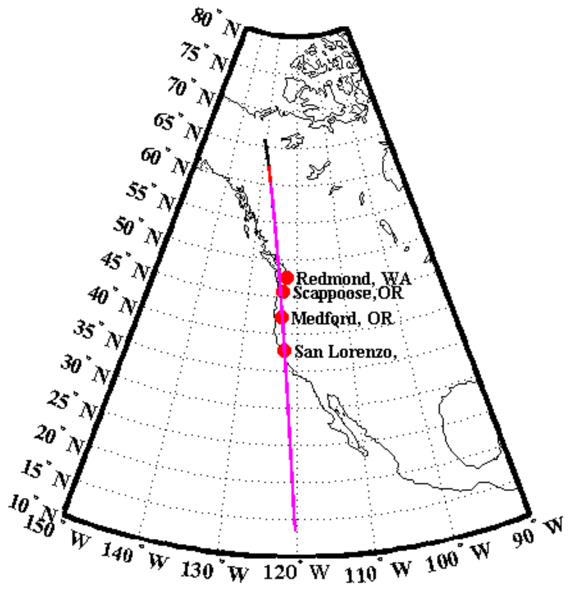
The example of evolution of the ionization trough above Europe 17.03.2015, 15:00-21:00 UT

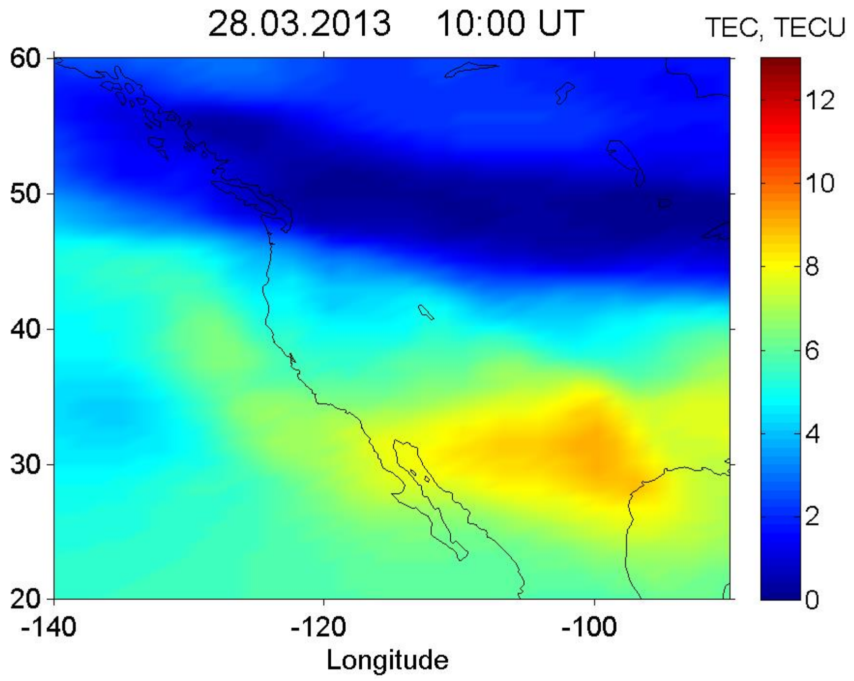
St. Patrick's Day storm **Kp = 8**

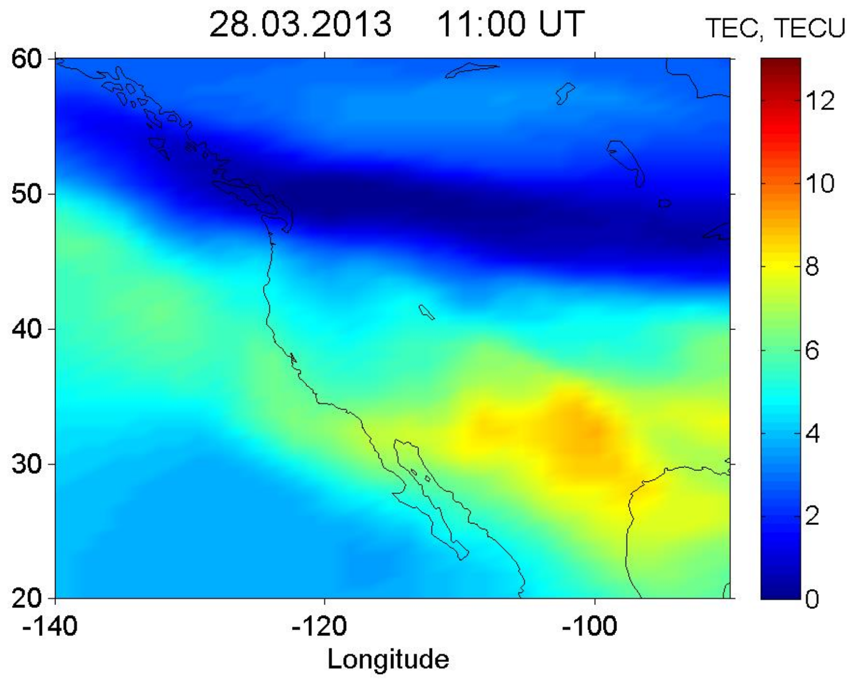


U.S. West Coast

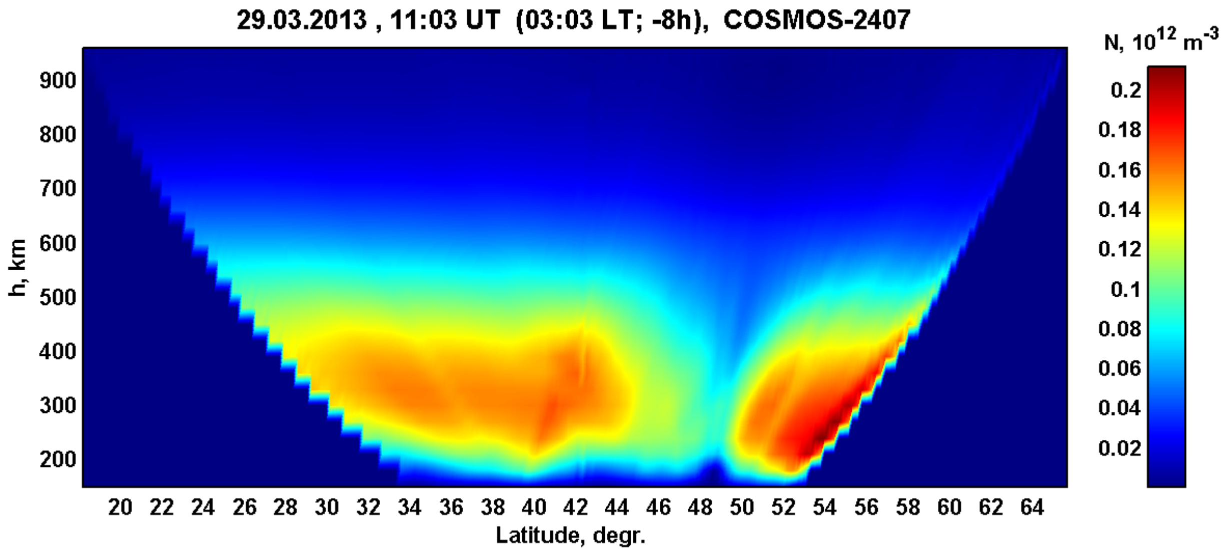


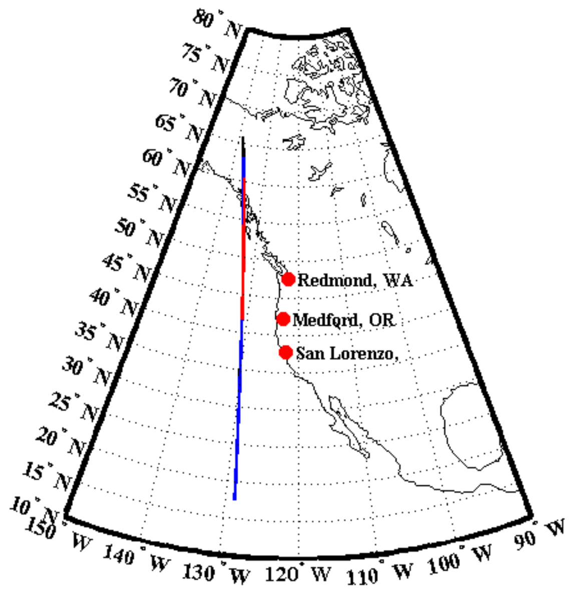


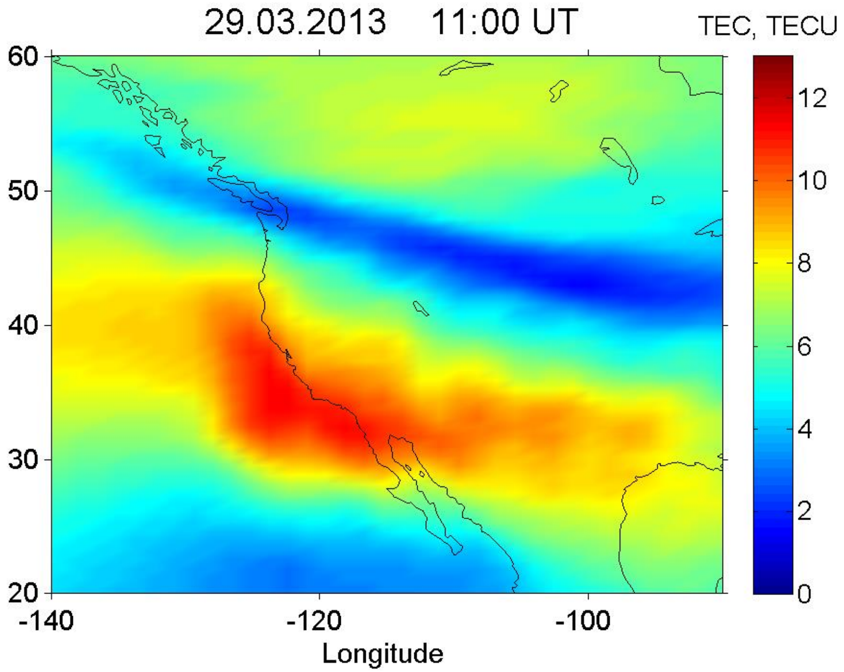


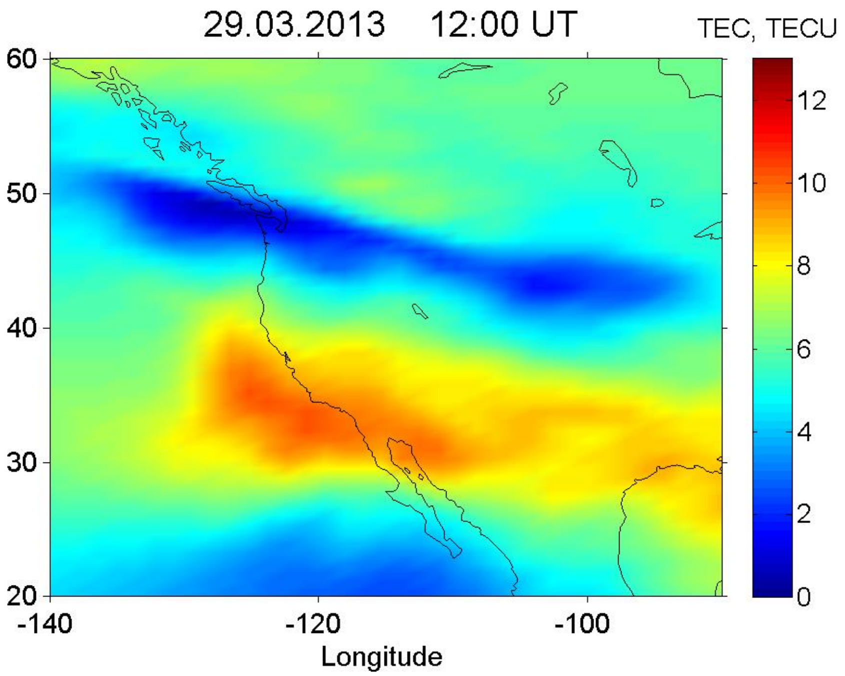


U.S. West Coast









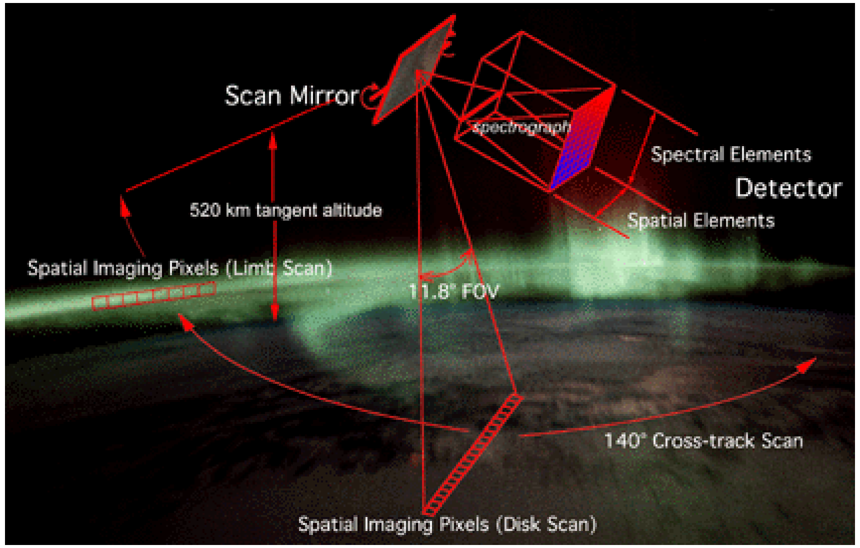
PRELIMINARY CONCLUSIONS

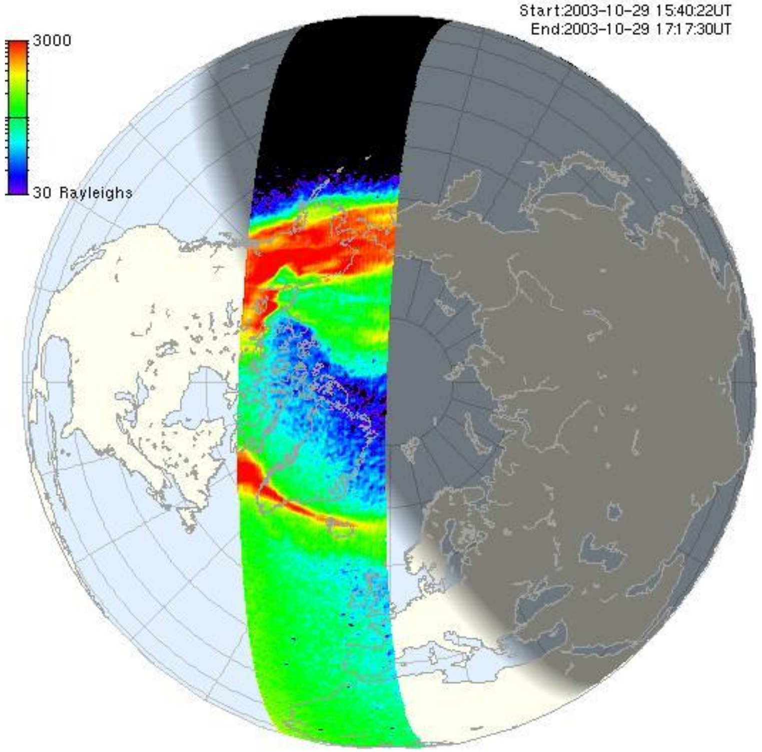
The RT images of the ionosphere in different regions under various space weather conditions show a great variety of structures (EIA, troughs, patches, wave-like structures etc.).

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

УФ-СПЕКТРОМЕТРИЯ GUVI/TIMED, SSUSI, SSULI





Источник данных http://guvi.jhuapl.edu/

<u>GUVI/ SSUSI, SSULI</u>

→ Высота орбиты 625 км/850 км

→ Измеряемы спектральные линии:

HI 121.6 нм

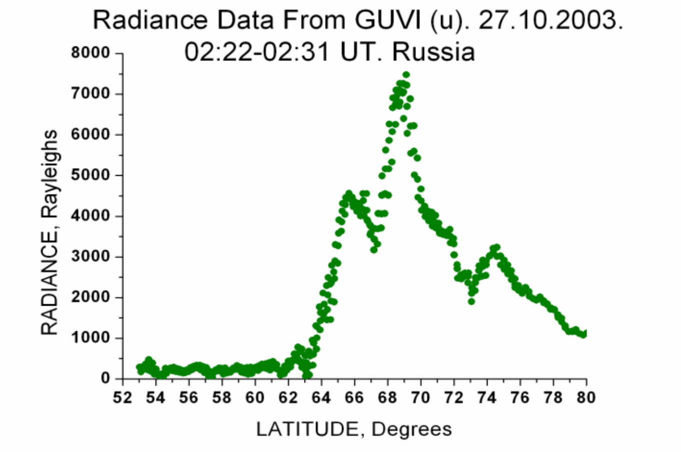
OI 130.4 нм

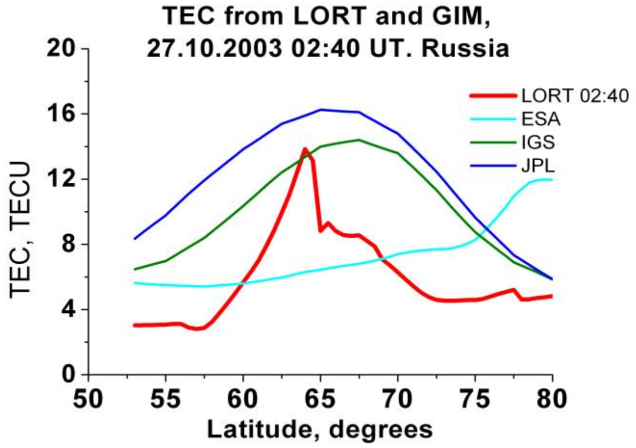
OI 135.6 нм

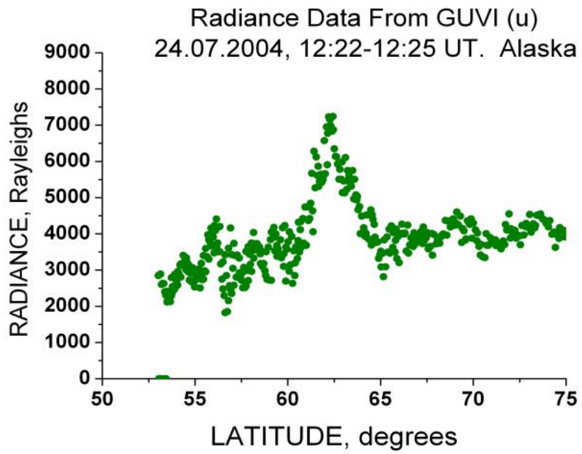
N2 Lyman-Birge-Hopfield 140-150 нм и 165-180 нм

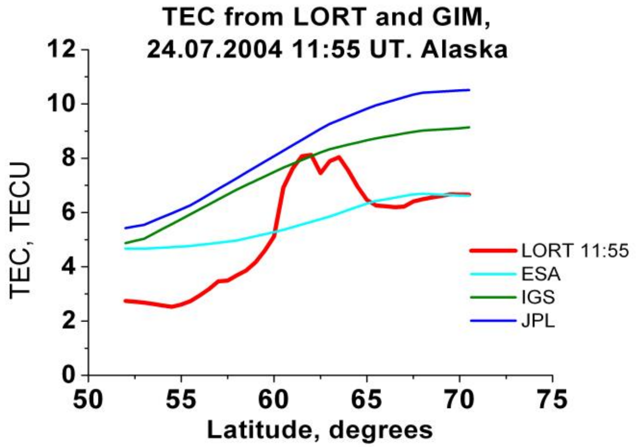
→ Данные: Средняя величина интенсивности свечения

СОПОСТАВЛЕНИЕ РЕЗУЛЬТАТОВ НОРТ С ДАННЫМИ GIM И GUVI, 2003-2004

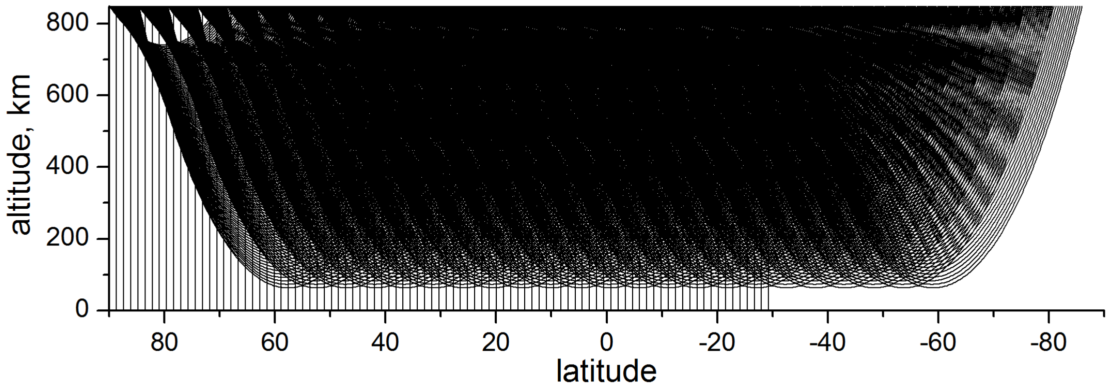


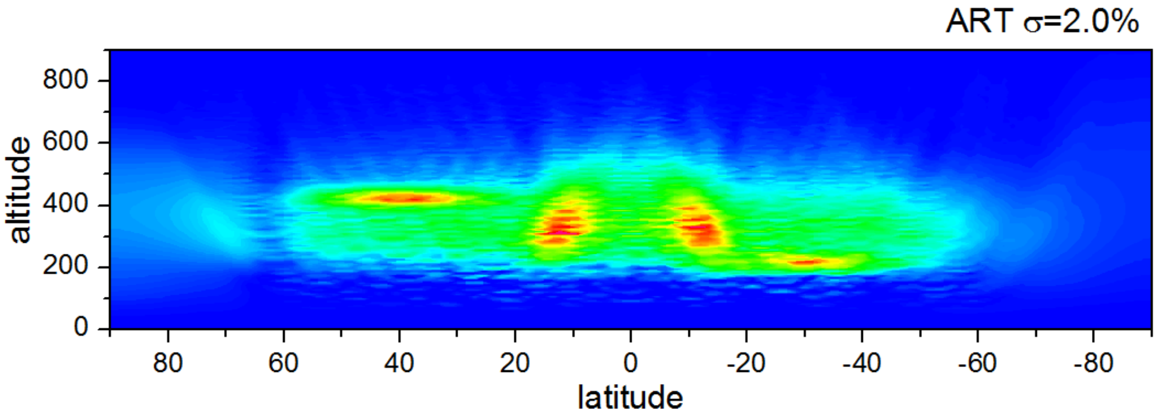


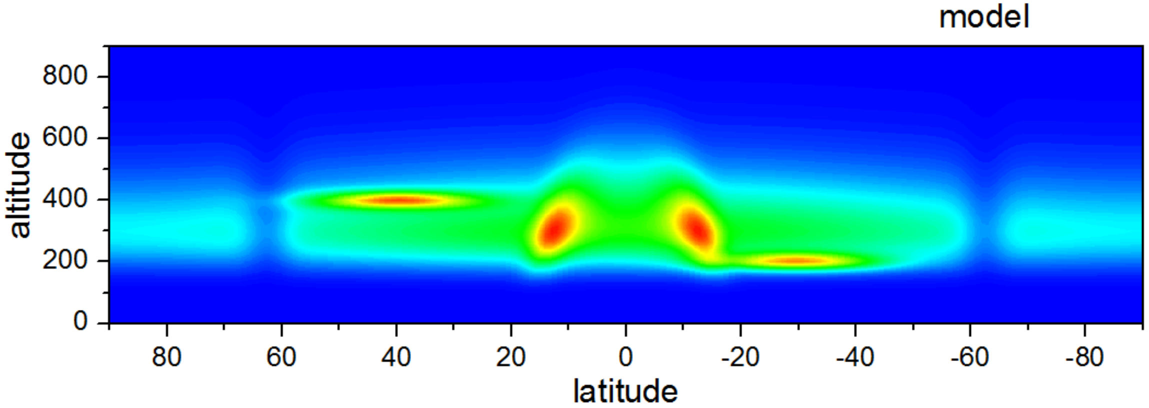


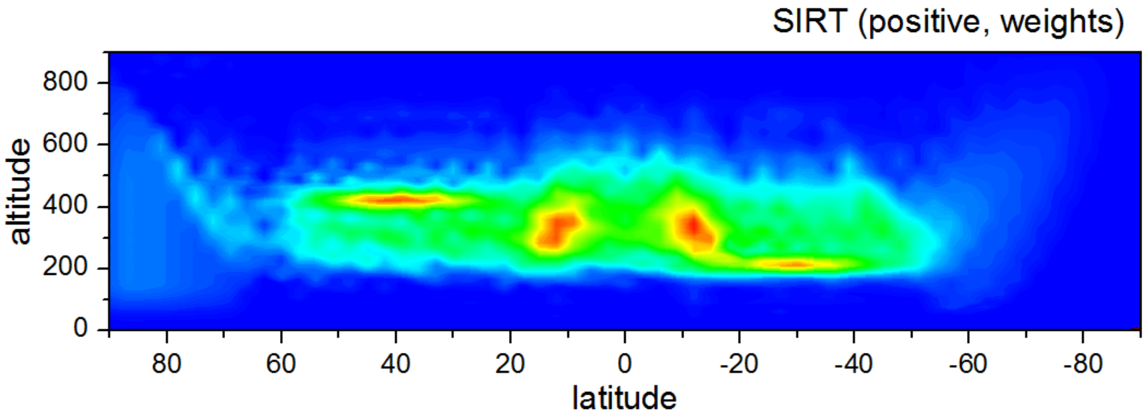


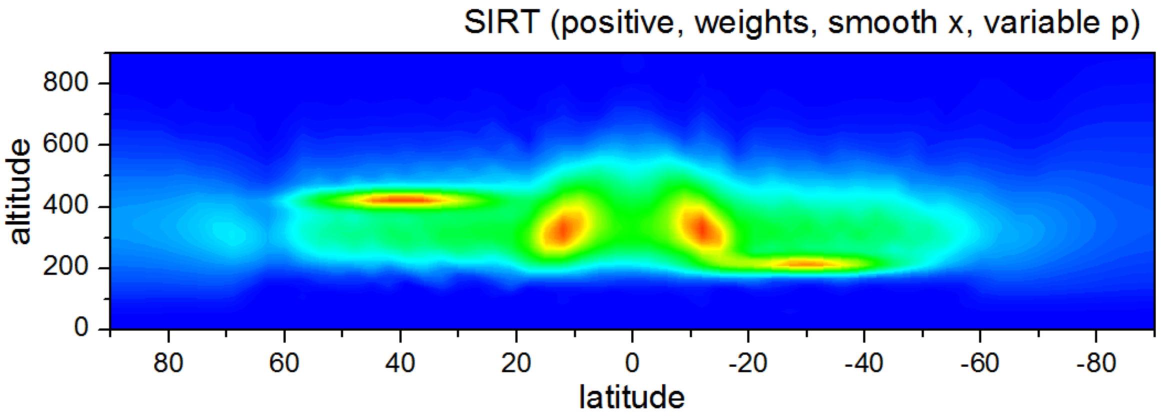
Постановка задачи УФ-томографии. Моделирование











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IGS for GNSS data
NWRA for the data from Alaska RT System
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NRL and University of Calgary for providing ePOP/CER signal
JHU for GUVI/SSUSI data