RUSSIAN FEDERAL SERVICE FOR HYDROMETEOROLOGY AND ENVIRONMENTAL MONITORING (ROSGYDROMET)

Federal state budget institute

“Institute of applied geophysics named academician E.K. Fedorov” (FIAG)

The experience of working as a provider of information on space weather in Russian Federation

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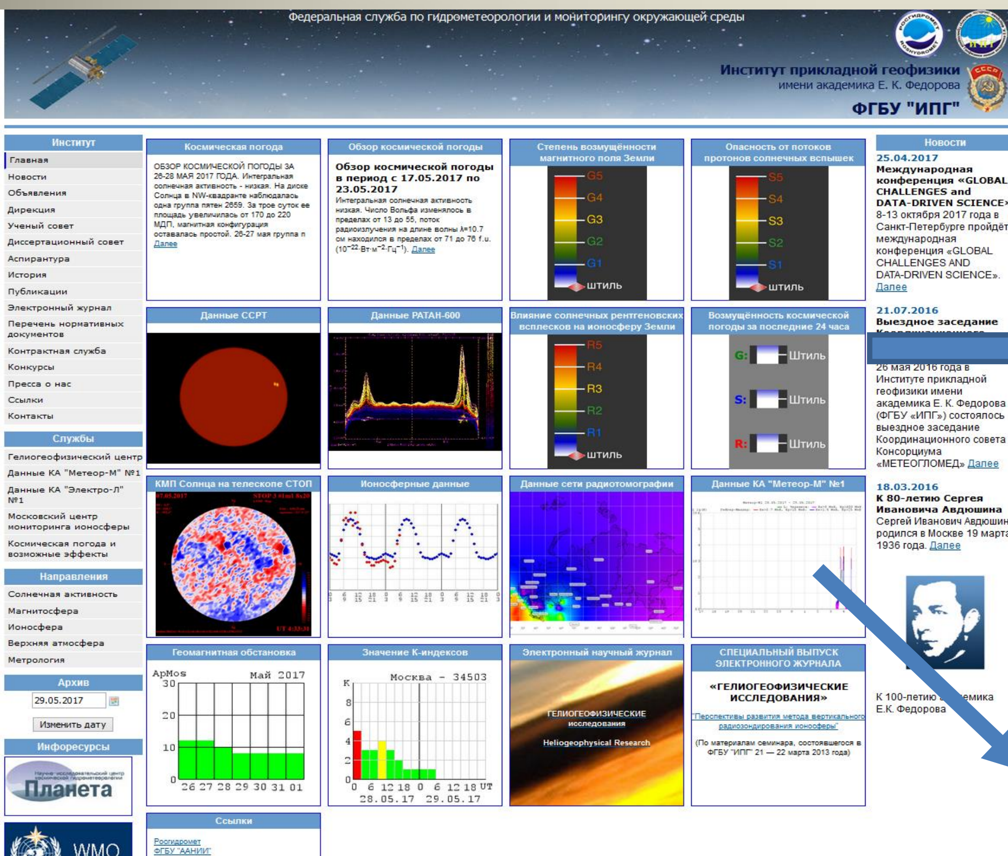
International Committee on Global Navigation Satellite Systems (ICG): Providers' Forum – 6 June 2017

1. History and Status

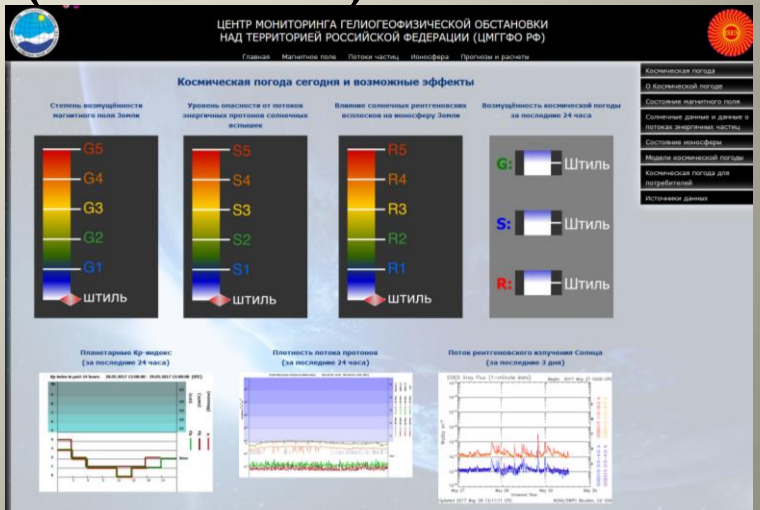
Fedorov Institute of Applied Geophysics (FIAG) is a pioneer in the investigations of space weather in Soviet Union and Russian Federation.

Now FIAG is the official provider information on Space Weather in Russian Federation.

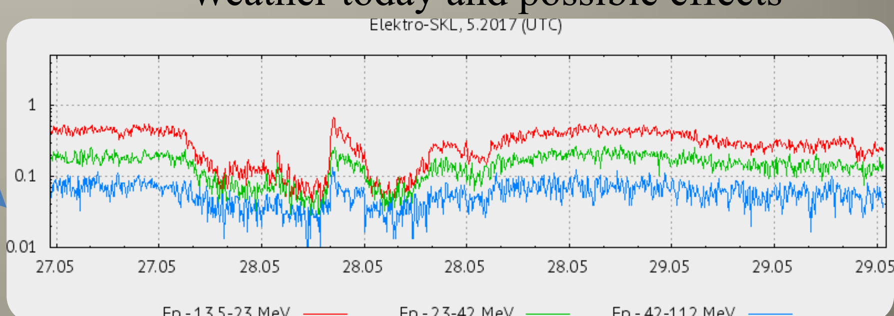
FIAG provides this information more than 100 Russian customers and is one of the centers of Space Weather in the World taking part in the international change in the frames of **Interprogramme Coordination Team on Space Weather (ICTSW-WMO)**



Official site of FIAG: http://ipg.geospace.ru http://space-weather.ru



One of the windows of the site: "Space Weather today and possible effects"



Data from satellite "Electro"

2. Data opportunities

Groundbased observations:

- Network of ionosounds
- Network of magtetometers
- Network of riometers
- Network of solar telescopes
- Radiotomography network
- Radio telescope

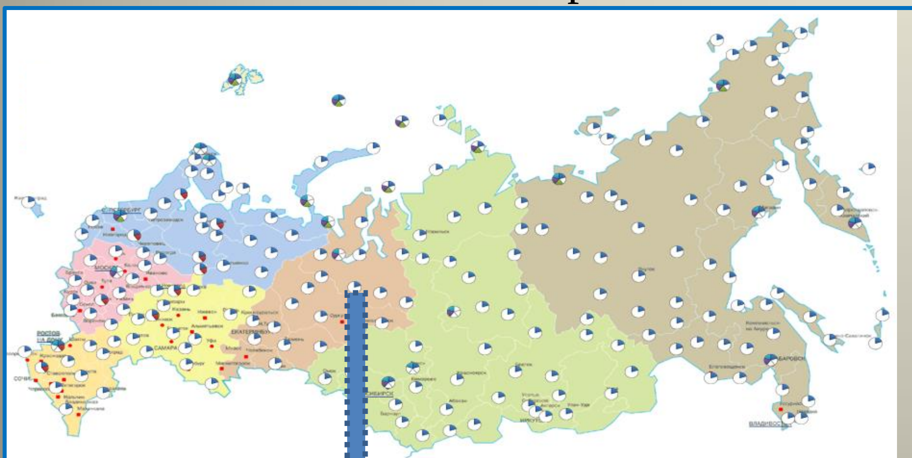
Spacebased observations:

- Satellites “Meteor”
- Satellites “Electro”

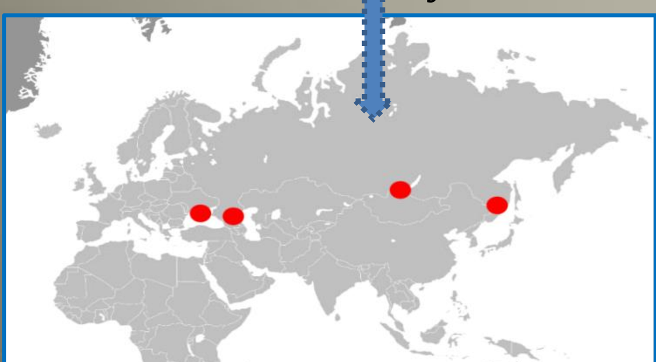
Perspective:

- Constellation “Ionosphere” – 4 sats

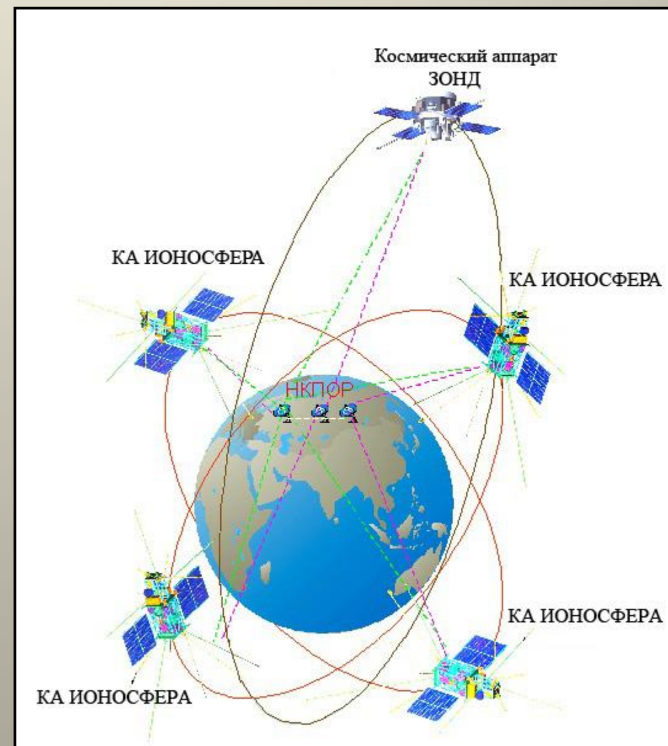
International sources of information: satellites, ionosounds, et.al



Points of observations of the ground based networks on territory of Russian Federation

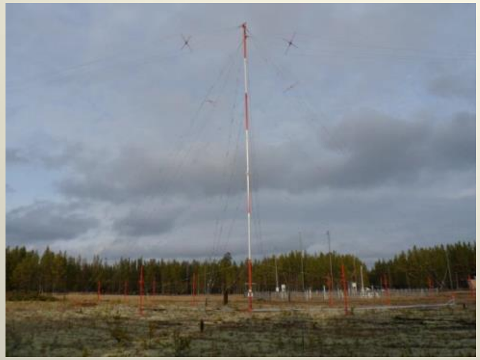


Solar telescopes



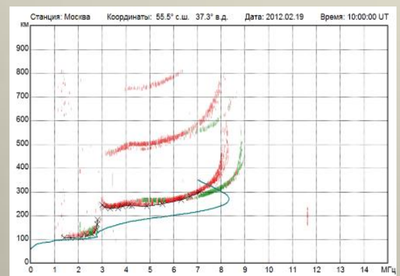
Perspective constellation for monitoring the ionosphere

3. Examples of instruments used for monitoring

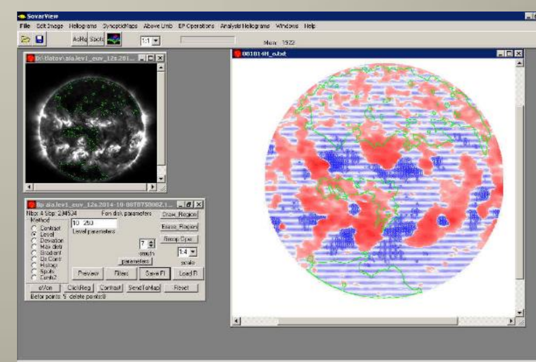


Ionosound antennas

Ionosounds Parus and Cadi



Ionogram with automatic processing



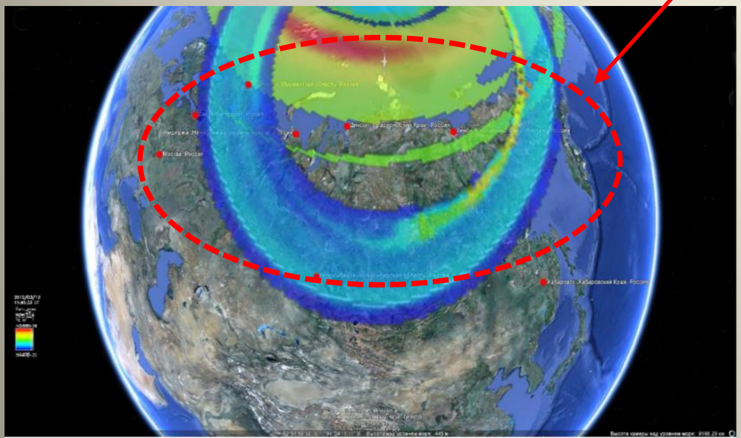
Siberia Solar telescope and its information

Satellite Sounder for ultraviolet radiation, λ near 121,6 nm

Satellite Sounder for x-rays radiation, 0.05<λ<0.4 nm

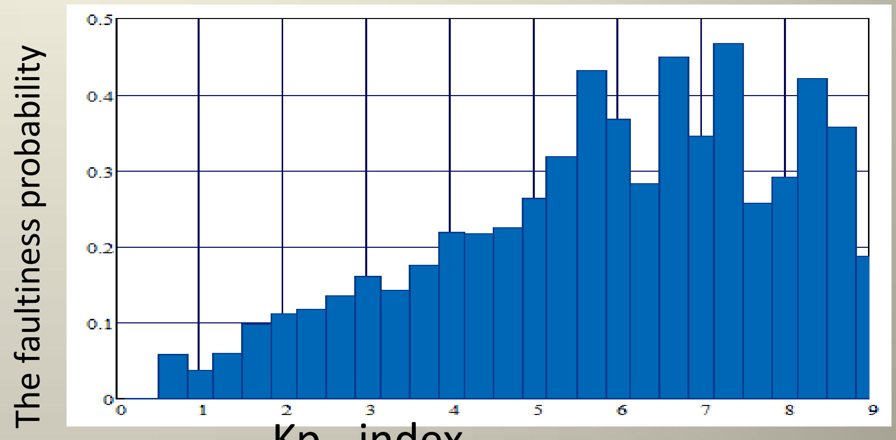
4. Effects of Space Weather

Zones of the dangerous geophysical phenomena –most part of Russian Federation is in this zone

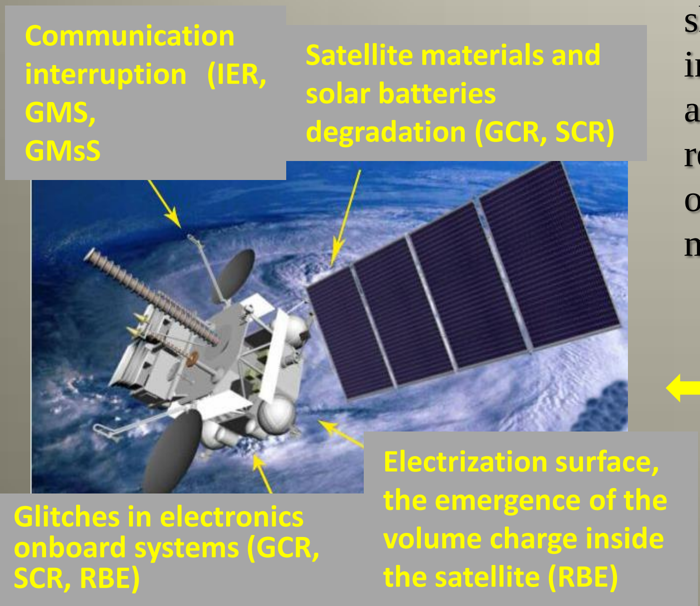


There is a lot of effects of Space Weather:

- on ground infrastructure (electrical lines, pipes, et.al.)
- on satellites



The total number of faults in spaceborne systems of the satellites and violation of sharing by control and destination information during high geophysical activity increases in 2-2.5 time. This fact dramatically reduces the time to the target application of the satellites. More than 50 % (and on some systems up to 90%) of reduces the time of the target applications occur because of external influences of near Earth space on on-board equipment of satellites. During these periods motion prediction errors of the satellites increase



Main factors of action:

- **Galactic cosmic rays (GCR);**
- **Solar cosmic rays (SCR);**
- **Ionizing electromagnetic radiation (IER);**
- **Radiation belts of the Earth (RBE);**
- **Geomagnetic storms (GMS);**
- **Geomagnetic substorms(GMsS)**

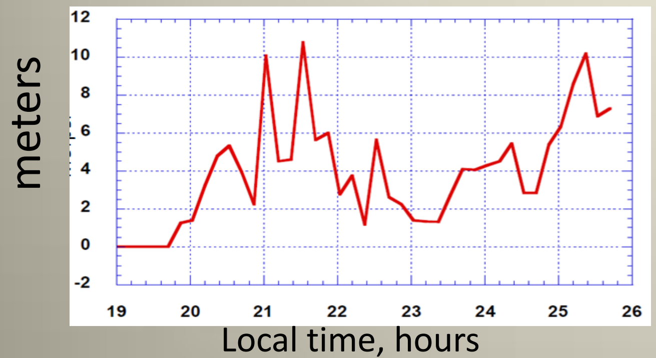
5.Negative effects on signals of Global Navigation Satellite System (GNSS)

Negative effects depend on phenomena on the Sun but independently GNSS signals deteriorate due to the effects of the ionosphere

For practice, it is important to consider two kinds of effects on GNSS signals:

a) rapid and extensive changes of the ionospheric delay

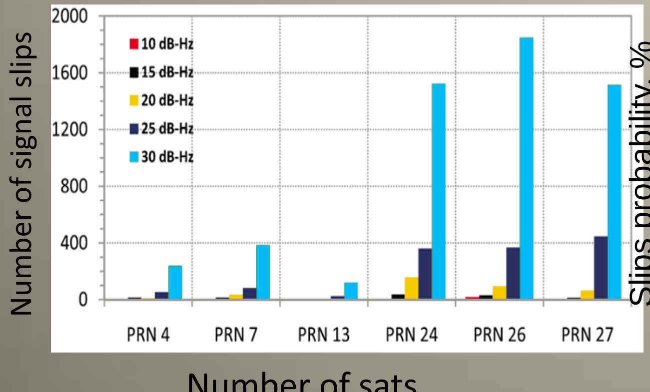
Changes in ionospheric delays cause error of range definition, which should be taken into account in the design of systems that use GNSS signals



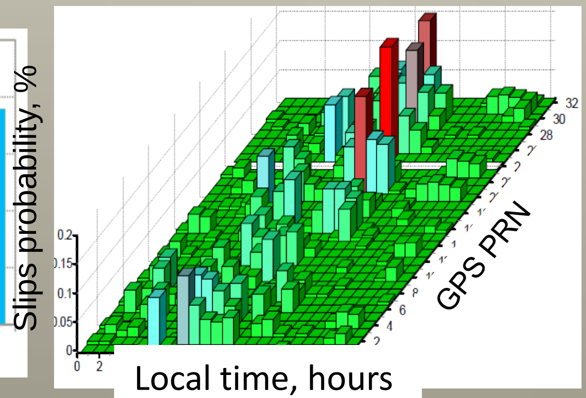
Example of positioning error during rapid and extensive changes of the ionospheric delay

b) ionospheric scintillation (fast amplitude and phase fluctuations).

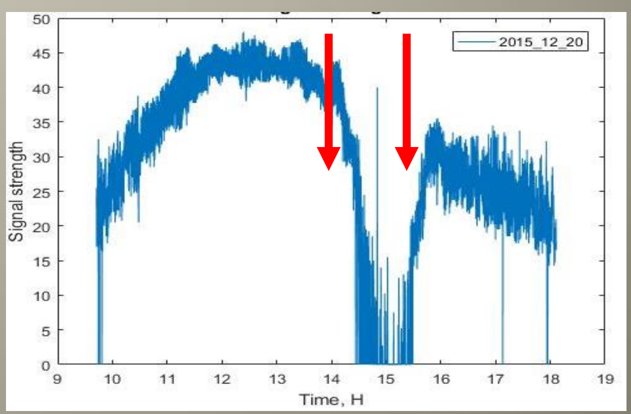
Strong ionospheric scintillation may cause temporary loss of one or more satellite signals



Example of signal slips during one night in time of geomagnetic storm



Example of signal slips probability during one night in time of geomagnetic storm



Example of loss of signal during one hour geomagnetic storm (red arrows)

The dynamics of the parameter TEC, which is important for research applications, is even more pronounced in its dependence on geomagnetic conditions.

The slip probabilities in determining the TEC are considerably (in **100–200** times) higher than the purely instrumental ones and grow likewise during geomagnetic and heliomagnetic disturbances of different nature. Depending on the storm class, the probability of jumps in the time derivative of TEC at a rate of more than 1 TECU/min increases more than **6–15** times; for jumps at a rate of more than 2 TECU/min, the slip probability increases **4–10** times when the storm class goes from 3 to 4 and from 4 to 5 (for example, in *).

6. The monitoring and prediction of the ionosphere state is a very important one

So, FIAG designed and created the **System of Ionosphere Monitoring**

It consists of:

Data

Ground based Roshydromet's ionosounds (25)

Ground based Russian and foreign ionosounds of different owners

Ground based Roshydromet's Radiotomographic systems (140)

Planning spacebased Roshydromet's ionosounds (4)

Telecommunication system

Models

Empirical

Assimilative

Prognostic

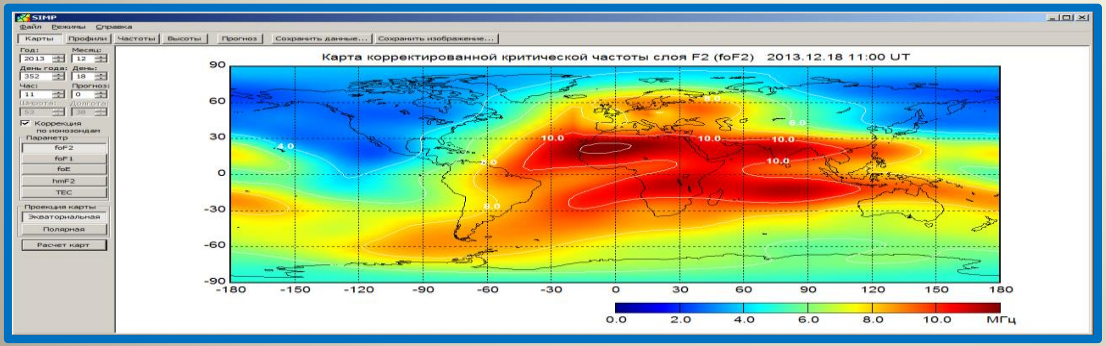
Visualization tools

Means of delivering information to consumers

V. I. Zakharov*a*, *b*, Yu. V. Yasyukevich*b*, and M. A. Titov*a*c, Effect of Magnetic Storms and Substorms on GPS Slips at High Latitudes *ISSN 0010-9525, Cosmic Research, 2016, Vol. 54, No. 1, pp. 20–30. © Pleiades Publishing, Ltd., 2016*

7. Components of the FIAG System of Ionosphere Monitoring

7.1 Assimilative and prognostic model: “System of ionosphere monitoring and prediction” – SIMP-2

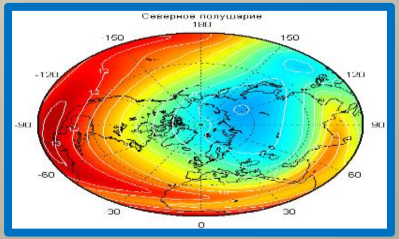


The system SIMP-2 is designed for monitoring and short-term forecast (1-24 hours) of the ionosphere global state

Example of foF2 distribution for 18 december 2016 at 11.00 UT.
On European region the model assimilated data of European ionosphere stations

The SIMP-2 contains the **principal new global models of E, F1 and F2 regions** of the ionosphere, which parameters changes during events of the space weather. This model describes the **disturbed ionosphere** as well as in the auroral region with more higher accuracy than IRI.

Example of foF2 prediction



Example of foF2 distribution for auroral region

Output parameters of SIMP-2:

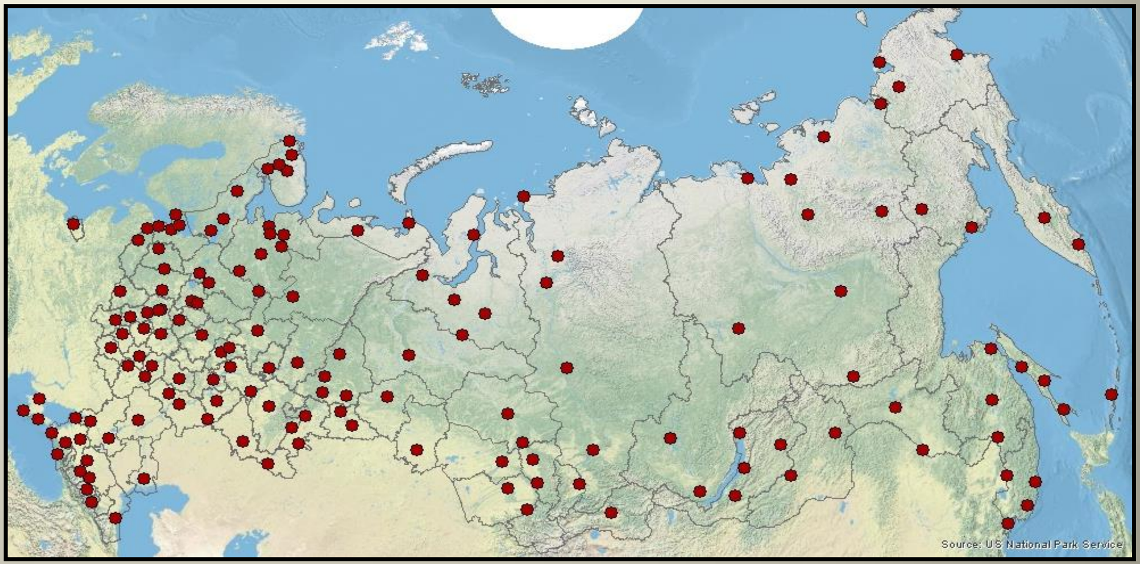
1. Maps of foF2, foF1, foE, hmF2 and TEC distribution for any time and for any from 24 predicted hours
2. Daily variations of foF2, foF1, foE, hmF2 и TEC for given point with coordinates (latitude, longtitude) and given moments in time
3. Profile of electron density Ne(h) in the height range of (80-1000) км for given point with coordinates (latitude, longtitude) and given moments in time

7.2 Multi-functional radio tomography network

It consists of 153 hardware-software systems which have multi-systems multi-frequency GNSS receivers

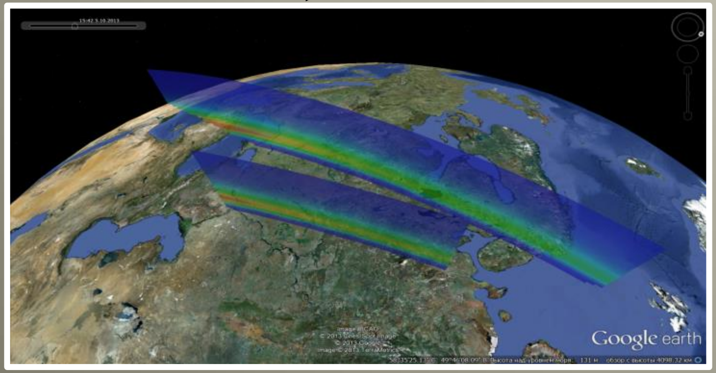
a) Map of low-orbital radiotomography (LORT) segment

Segment a) has 13 receivers of GNSS «Cosmos», “Transit” et.al.

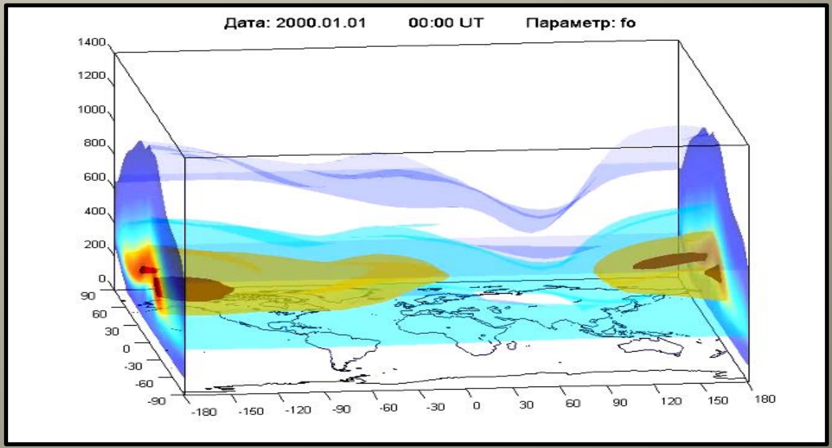


b) Map of high-orbital radiotomography (HORT) segment

Segment b) has 140 receivers of GNSS GLONAS, GPS, GALILEO, SBAS, QZSS



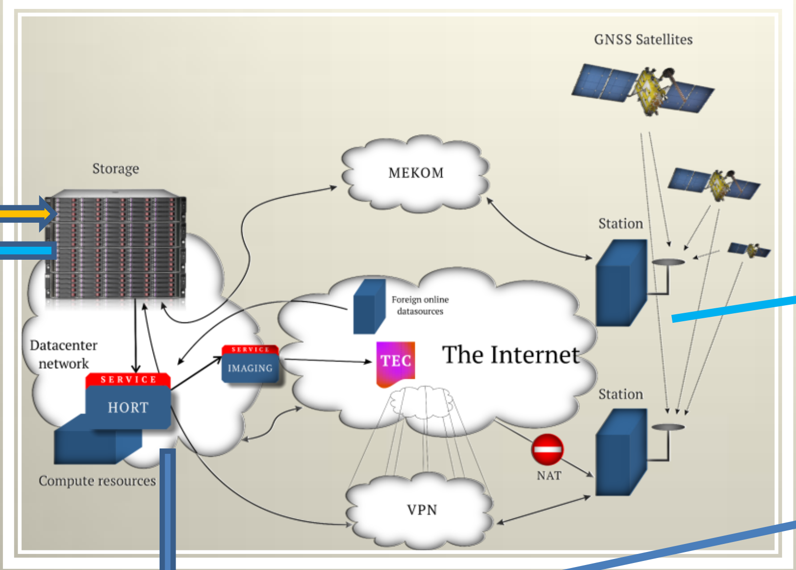
2D distribution of electron density with use of segment LORT



3D distribution of electron density with use of segment HORT

7.2. Multi-functional radiotomography network – subsystem of the FIAG System of Ionosphere Monitoring

SIMP-2



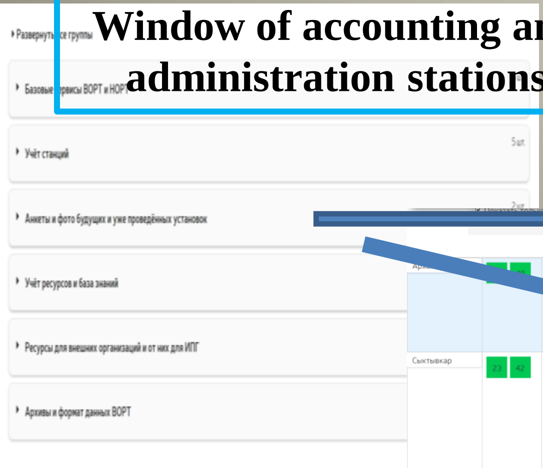
Features of work

1. Network stations - Automatic Compact hardware-software systems with low power consumption ≈ 20 Vt
2. Advanced software of data transmission, remote control, processing
3. Wide-area coverage of the territory of the country

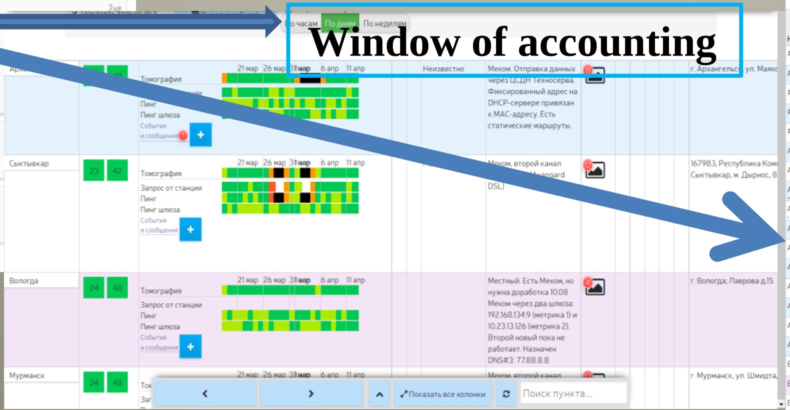
4. Used some different methods for reconstruction of the ionosphere state:
- phase-difference tomography algorithms
- single-position radio-sounding
- GPS-detector

Radiotomography server

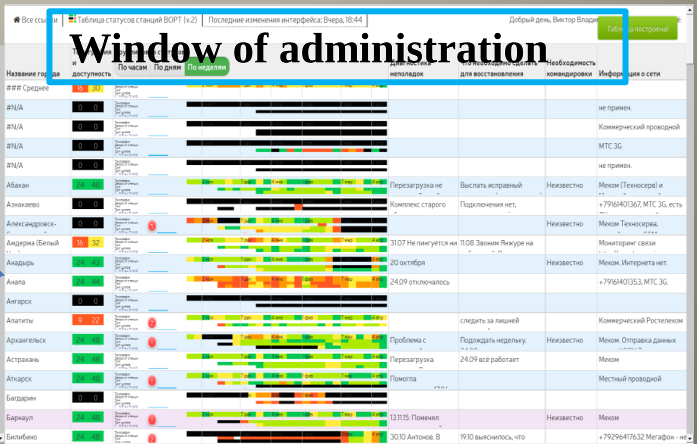
Window of accounting and administration stations



Window of accounting



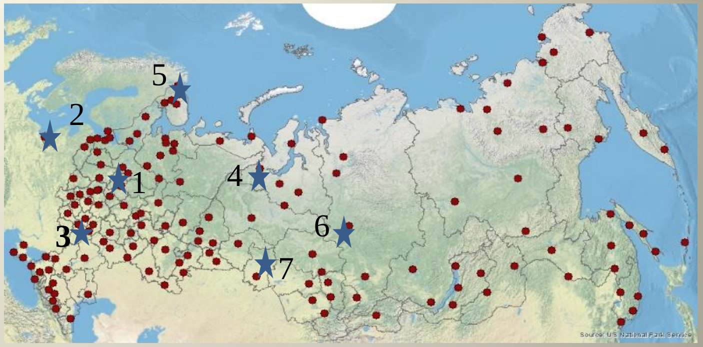
Window of administration



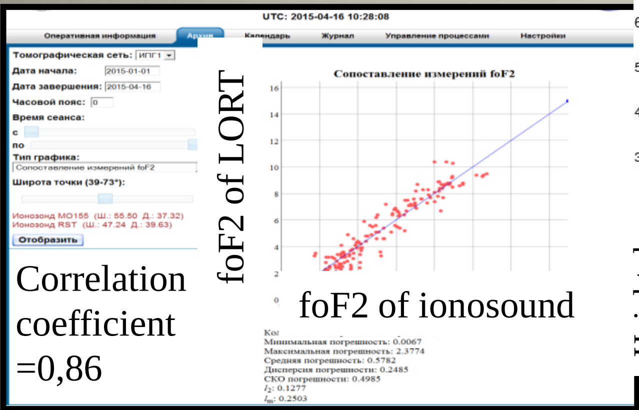
7.2. Validation and verification of the radio tomography results

❑ *Comparison of the critical frequencies f0F2, measured by HORT and ground-based ionosounds*

Point of observations	Correlation coefficient	Average difference, MHz	RMS deviation of the difference, MHz	Number of measurements
1-Troitsk	0,9	0,15	0,79	8200
2-Kaliningrad	0,87	0,1	0,75	7600
3-Rostov-na-Donu	0,9	0,03	0,64	5860
4-Salehard	0,85	-0,21	0,54	4100
5- Murmansk	0,82	0,25	0,9	3700
6- Podkamennaya Tunguska	0,813	0,29	0,63	3600
7 Tomsk	0,88	0,27	0,66	3 300

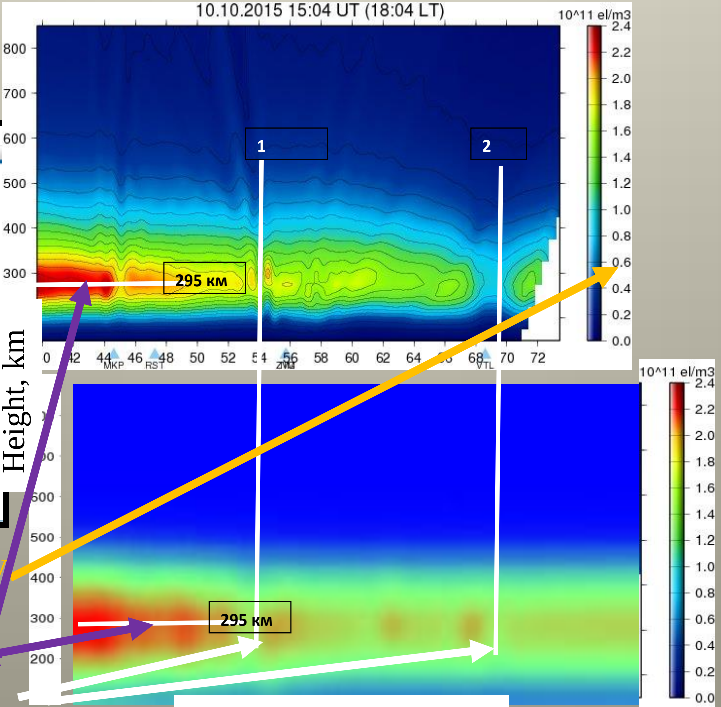


❑ *Comparison of the critical frequencies f0F2, measured by LORT and ground-based ionosounds*

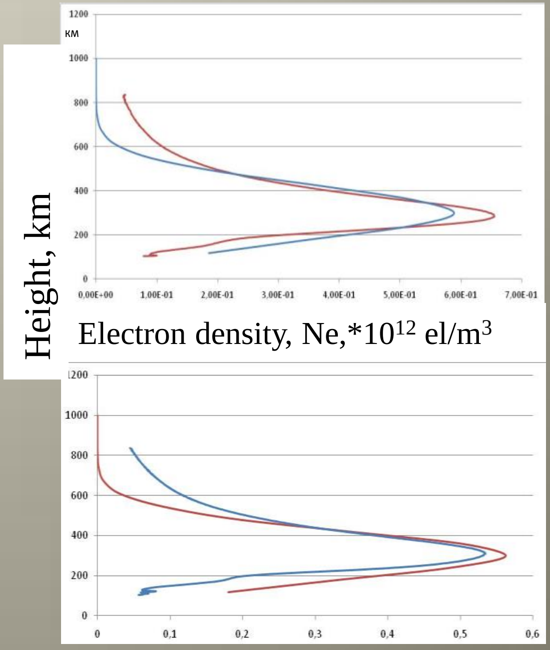


Correlation coefficient =0,86

❑ *Comparison of 2D distributions of LORT and HORT*



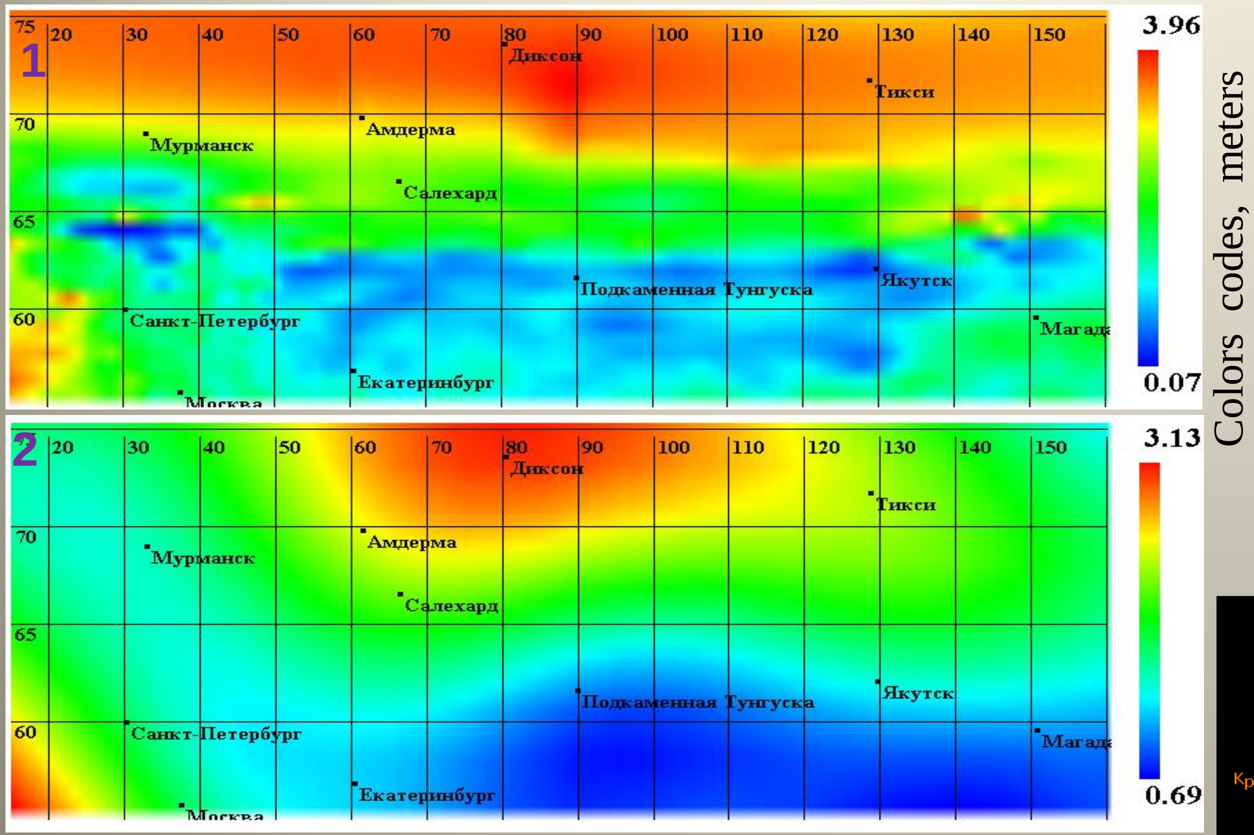
❑ Comparison of the 1D profiles of HORT and COSMIC

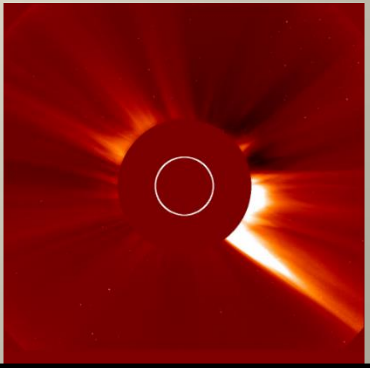


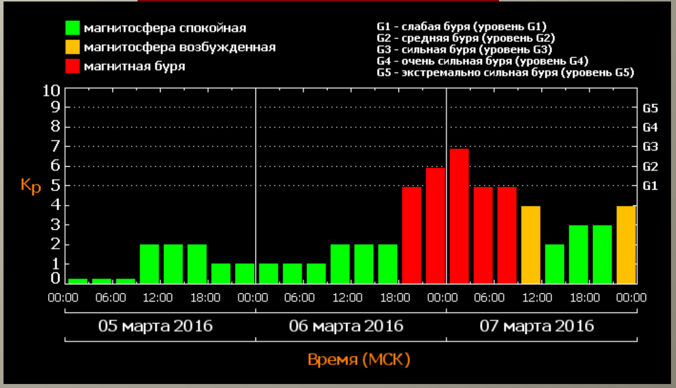
Top: 46^0 N.L., 56^0 E.L.;
Bottom: 60^0 N.L., 41^0 E.L.

- Absolute values of electron density are very close each other
- Height of F2-layer max is very close
- Very similar the geophysical features

❑ Comparison of ionospheric corrections for L1 for single-frequency GNSS receivers for geomagnetic storm G3: Russia, 6 March 2016 17:00:00 UTC





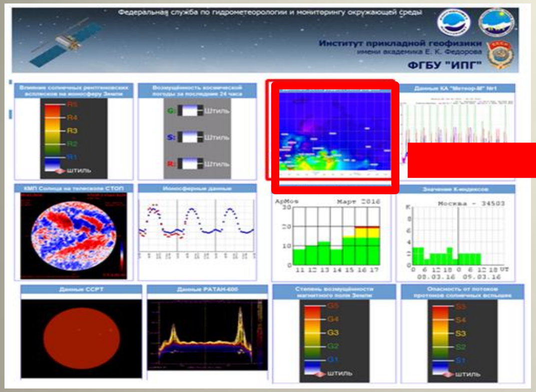


1 – FIAG radio tomography

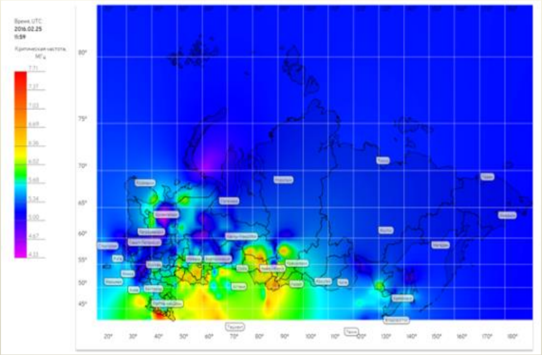
2 - IGS (CODE GIM)

Geophysical situation:
Top: “Solar Wind” picture, March 2016 23:48 in optics, device LASCOC2 of satellite SOHO
Bottom: 3-hour Kp index

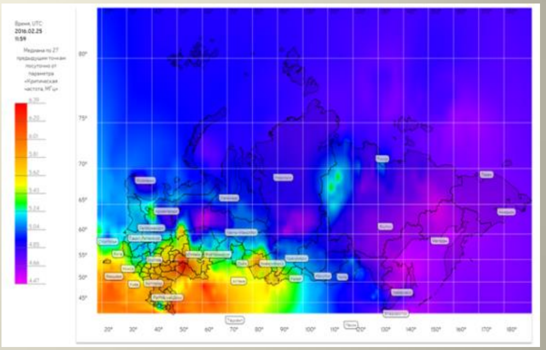
8. Specialized ionospheric information products of radio tomography



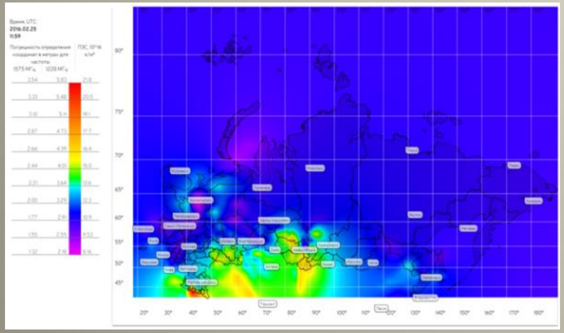
Website of FIAG



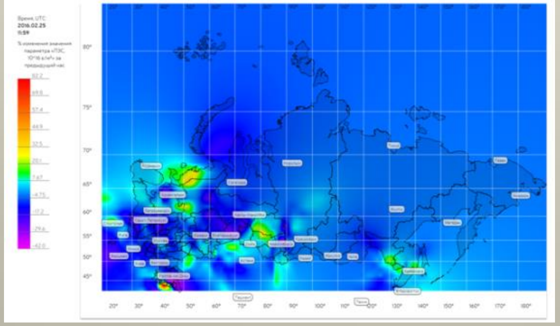
a) Map of critical frequency f0F2



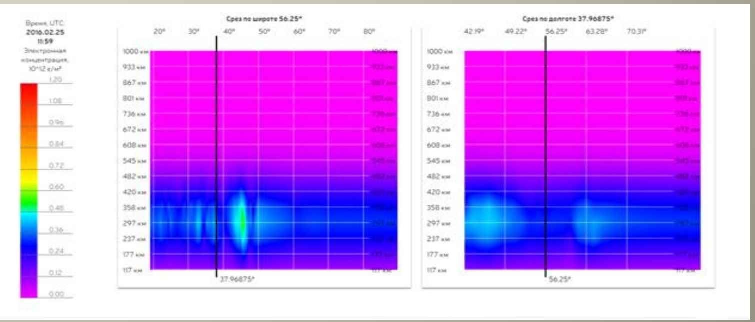
b) Map of 27-days median for critical frequency f0F2



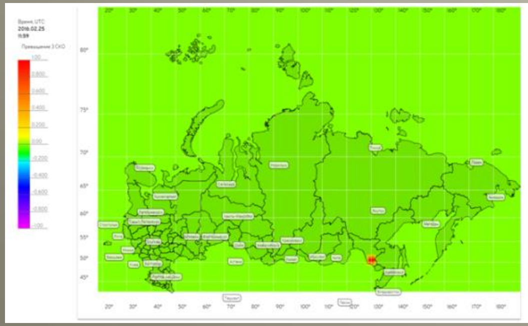
c) Map of TEC



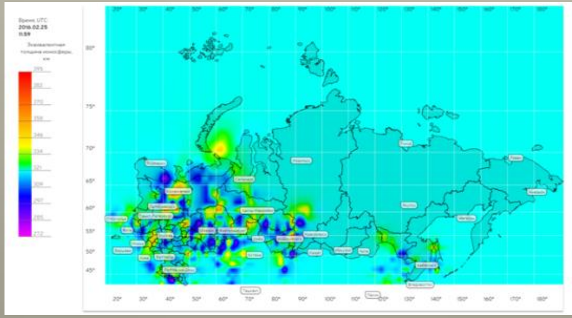
d) Map of 1- hour TEC changing



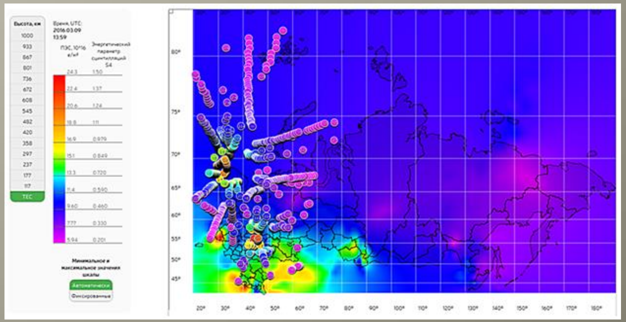
e) Latitude (longtitude)-height sections



f) Map of strong ionospheric perturbations: f0F2>3*RMSD from median



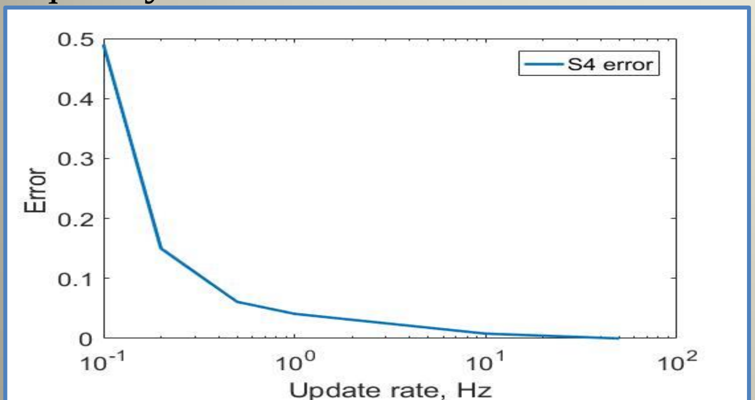
g) Map of equivalent slab thickness of the ionosphere

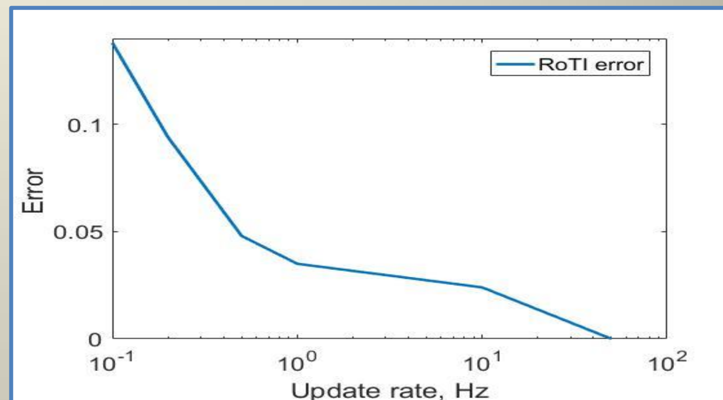


h) Map of scintillation index and RoTi

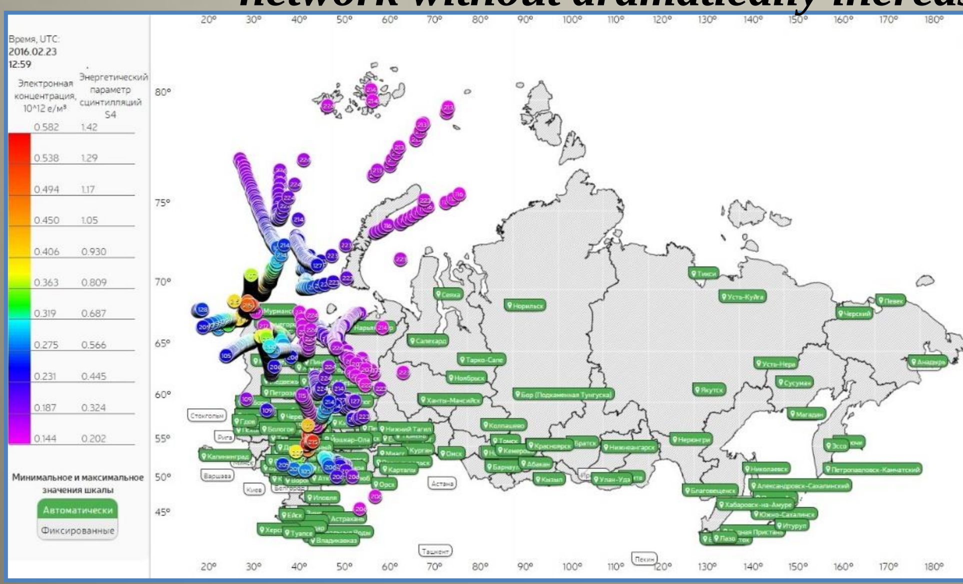
FIAG radio tomography network allows to do monitoring the scintillations (index S4, σ_φ) and rapid TEC change (index RoTI)

FIAG investigated the possibilities of developed hardware-software systems in radio tomography network to carry out calculations of **S4**, $\boldsymbol{\sigma_\varphi}$ and **RoTI.** It was shown that these parameters may be obtained with use of update rate of 1 Hz with error not more than 5% in comparing with frequency of 50 Hz.





It is important result because one can get information from all stations of radio tomography network without dramatically increasing information traffic



Example of a map of scintillation index S4 for two points: Murmansk and Nizhniy Novgorod equipped with receivers of 50 Hz update rate

Thank you for attention