Ionospheric research for space weather service support

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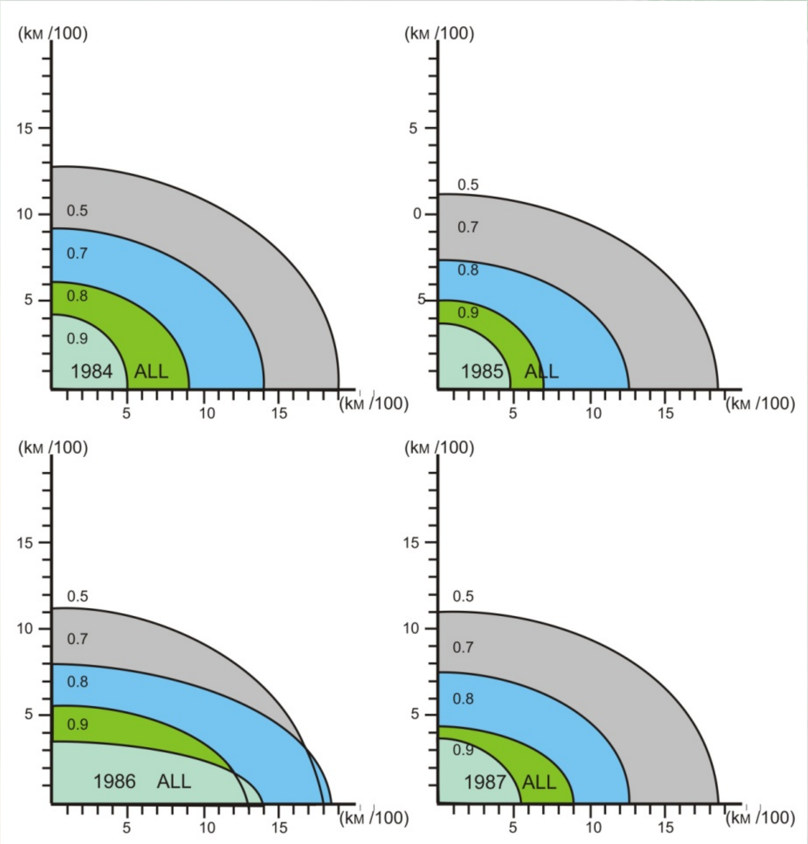
The joint research Project on the ‘Ionospheric Weather’ of SRC PAS and IZMIRAN is aimed to provide on-line the ionospheric parameters characterizing the space weather in the ionosphere. It is devoted to science, techniques and to more application oriented areas of ionospheric investigation in order to support space weather services. The studies based on data mining philosophy increasing the knowledge of ionospheric physical properties, modelling capabilities and gain applications of various procedures in ionospheric monitoring and forecasting were concerned.

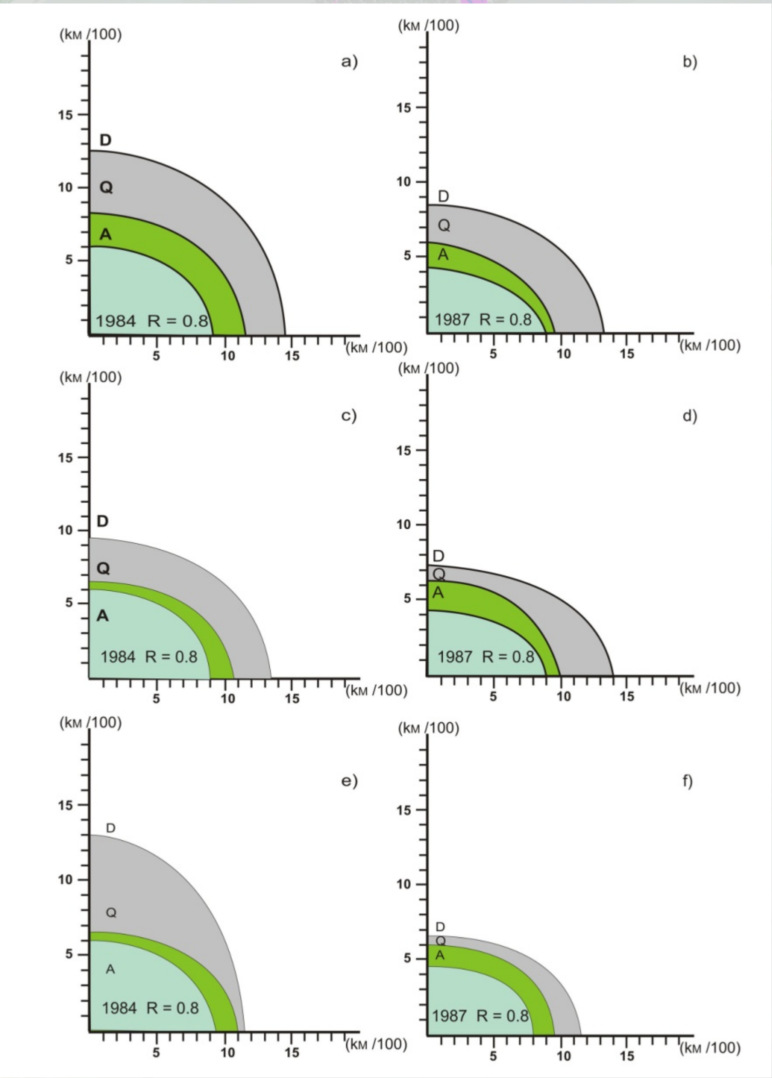
History of the project:

- 1997 - IDCE (Ionospheric Dispatch Centre in Europe) w Centrum Badań Kosmicznych PAN (ionospheric characteristic maps and its distribution, catalogue of ionospheric disturbances, catalogue for quiet and disturbed days): http://www.cbk.waw.pl/rwc;
- 2006 - „Ionospheric weather" in IZMIR AN : http://www.izmiran.ru/services/iweather;
- 2008 - classification method of W index and criteria determination of Wp storms according to W maps based on TEC maps;
- 2008 - catalogue of ionospheric storms from 1988 up to day;
- 2010 - regional maps of W index;
- 2013 - global TEC maps;
- 2014 - Ionospheric characteristics and indices maps (delay, TEC, Rate of TEC, W, ETA)

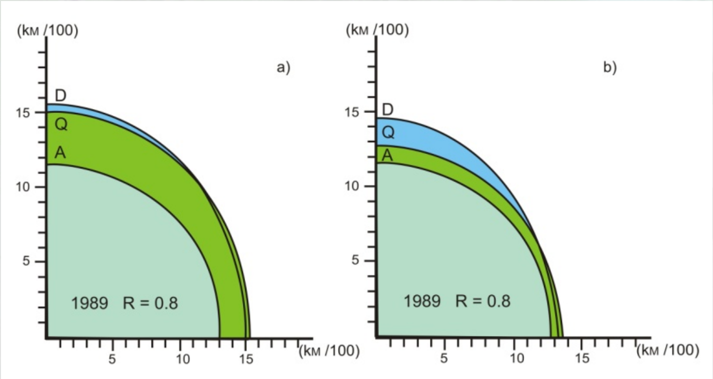
Ionosonde data for correlation distances



The differences between measured daily-hourly foF2 values and medians were determined for each station to eliminate the daily trend and the cross-correlation was calculated for the resulting differences for each pair of the stations to determine which ionospheric changes at one location are linearly related to changes at another. The overall 0.9-correlation distance was found to be around 500 km E-W and slightly less N-S. This anisotropy is systematically growing for decreasing correlation distances and becomes the greatest for 0.5, however in this last case it does not exceed 1300 km N-S and 2000 km E-W. Considerably stronger correlation can be seen under quiet and disturbed conditions.

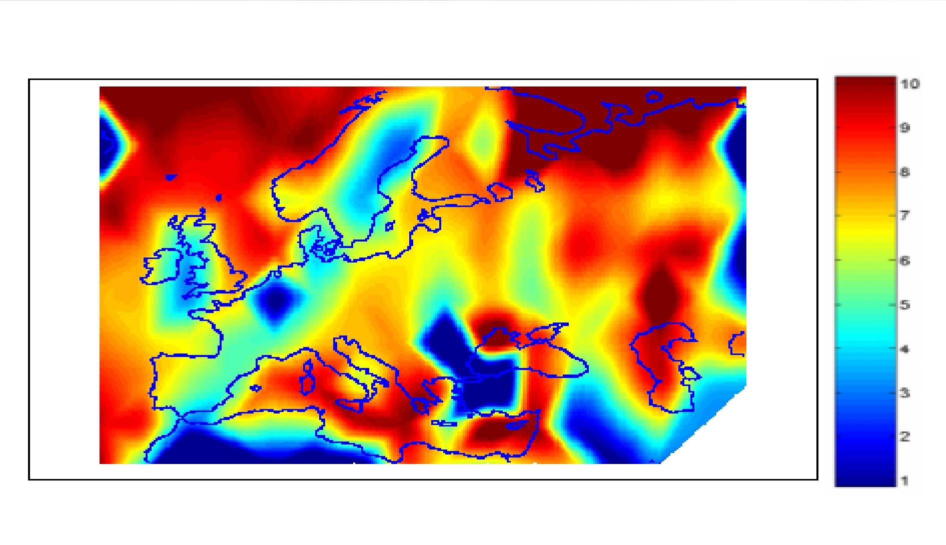


Correlation coefficient R=0.8 for quiet and disturbed conditions defined by ionospheric and magnetic catalogues for 1984 and 1987.



Tropospheric elements

The tropospheric delay algorithm has been implemented the same way as in EGNOS but it uses own tropospheric data

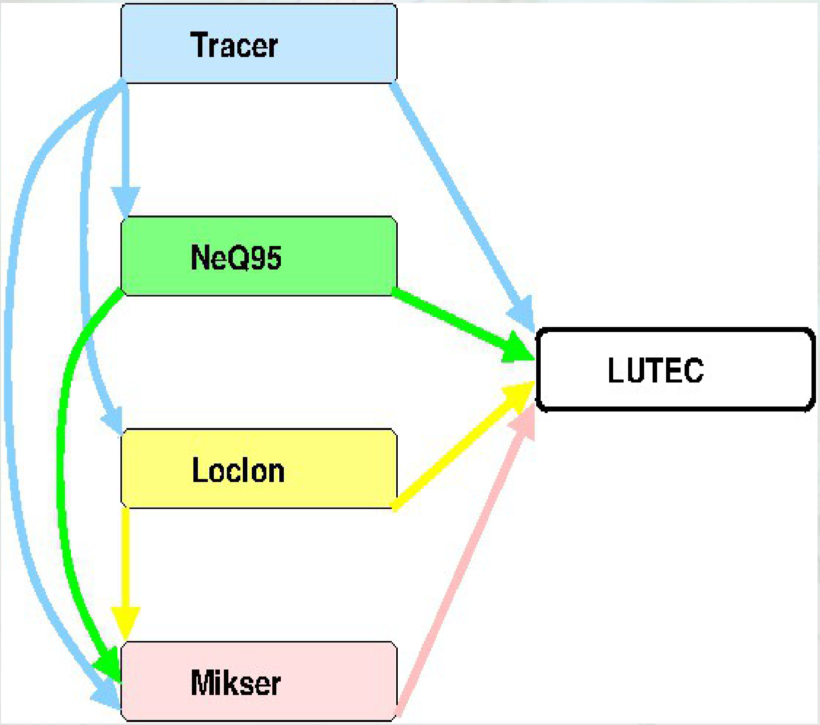


Sample map of the hypothetical vertical tropospheric delay error [cm] defined as difference between regional corrections and EGNOS correction.

Algorithms implantation - operation

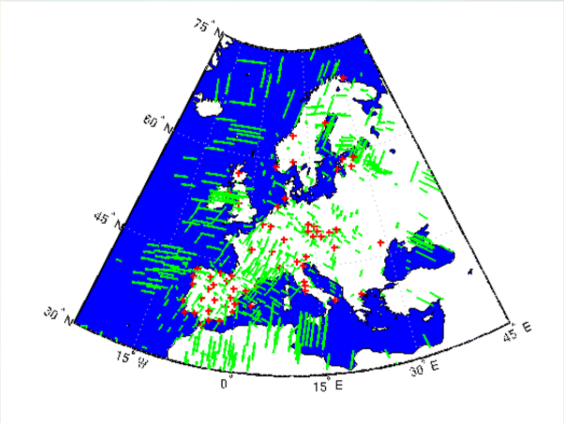
An example of LUTEC Software, was developed in standalone application, uses GPS and Ionosonde data.

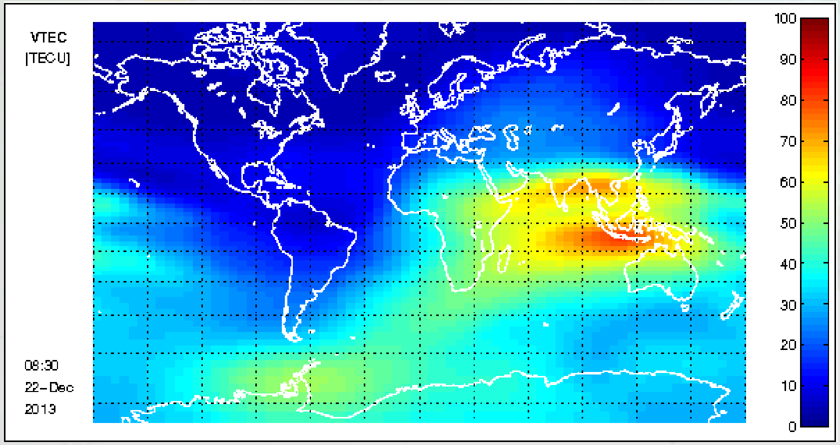
LUTEC Software architecture:
· Tracer: the module providing the necessary routines for transformation of coordinates, some generally used functions and numerical schemes.
· NeQ95: the module providing electron density; Here the model based on NeQuick2 and NeQuick 2.1 is used, but it can be easily changed by another one.
· LocalIono: module entering and using the local ionosonde parameters.
· Mikser: module providing the final value of the electron density, using the model and the ionosonde data. It is independent on the specific form of the model.
· LUTEC: main program.



Ionospheric elements

In the first phase using the ionosonde data and the NeQuick model the height of maximum concentration used to calculation of pierce point was determined. Then, using the GNSS satellite ephemeris and ionosphere model was determined the point of intersection of the radiation beam with the ionosphere. These parameter and the values of slant TEC are used to fit the b-spline model depended on latitude, longitude and local time.



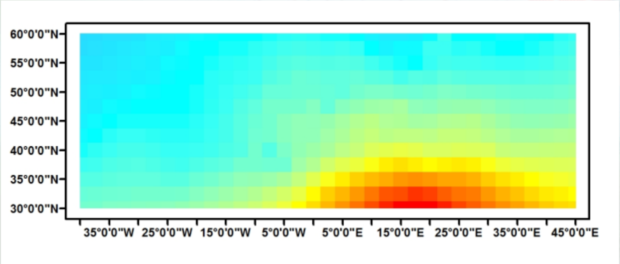


Examples of pierce points position for 15 minutes, and sample vTEC map. Model of ionosphere on the height of 350km.

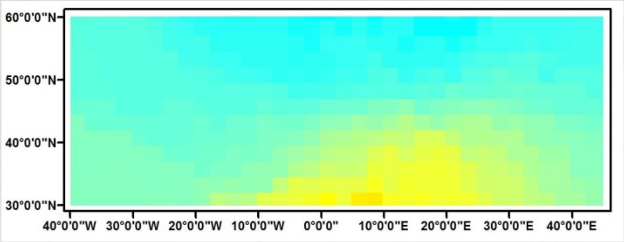
Ionospheric elements

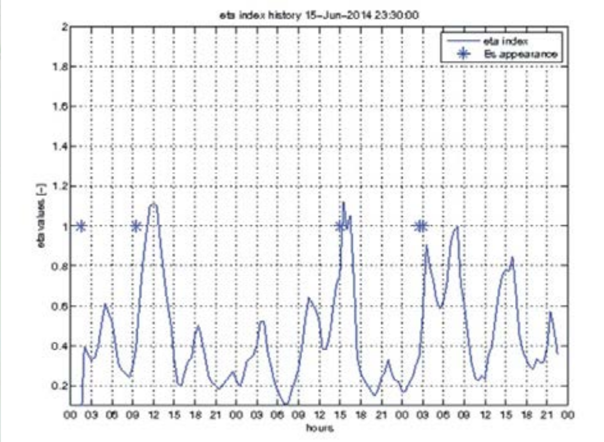
Parallel regional TEC instantaneous and forecast maps are constructed by means of kriging with single station modelled semivariograms and autocovariance method.

TEC maps 2012-09-30 **12:00:00 UT**



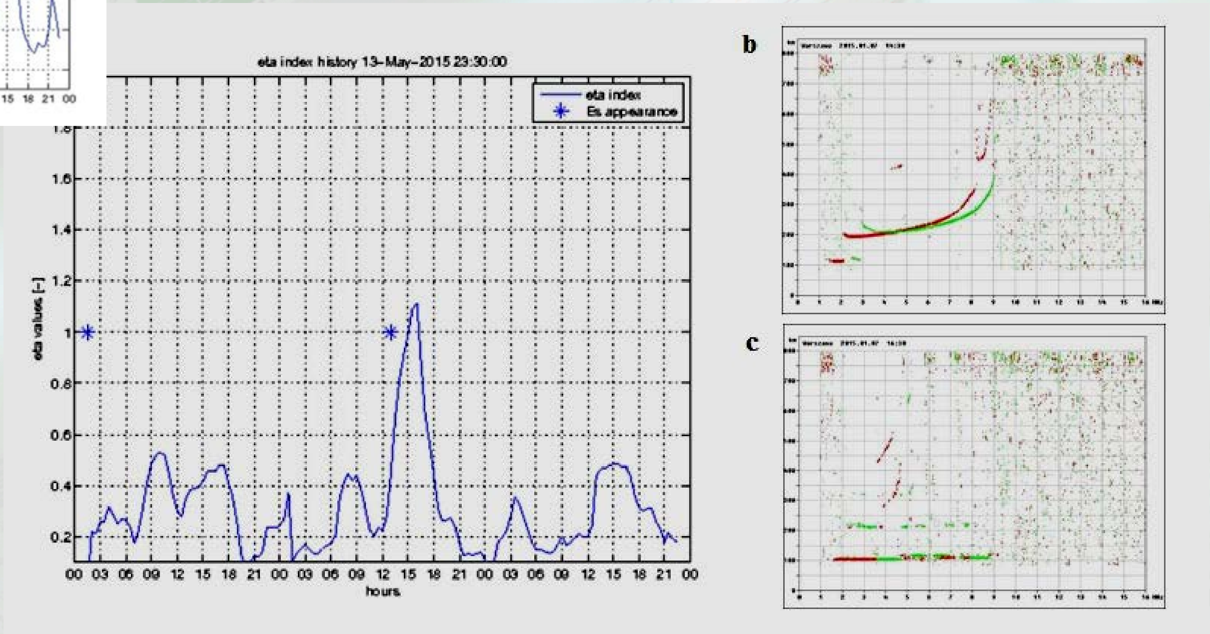
One hour ahead TEC forecast 2012-09-30 13:00:00UT



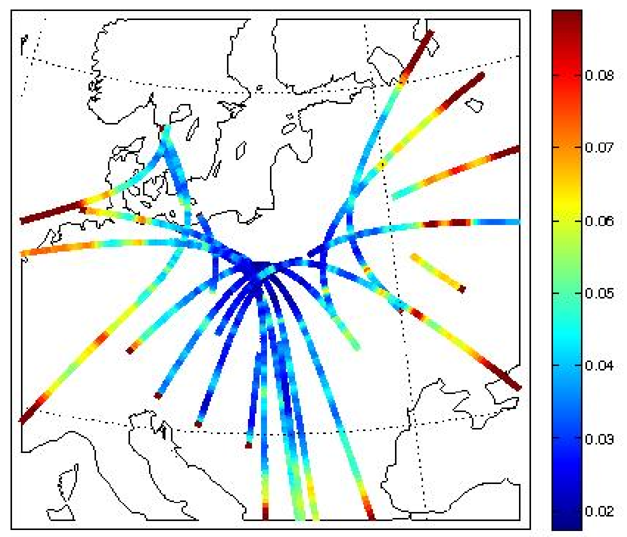


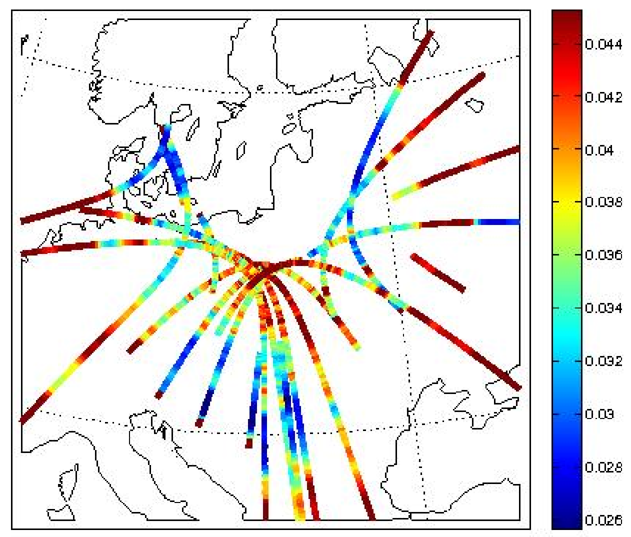
Sporadic E layer

dots 2 h ahead Es forecast



Index η during 11-13 May 2015 in Belsk magnetic observatory [51,8°N, 21,8°E] and Warsaw ionograms. Asterix – unusual increase of η index.



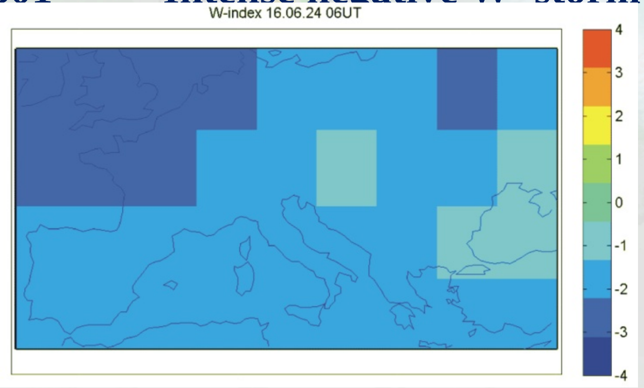


Values of S4 index for Warsaw GPS stations 24.06.2016 (last 6 hour)

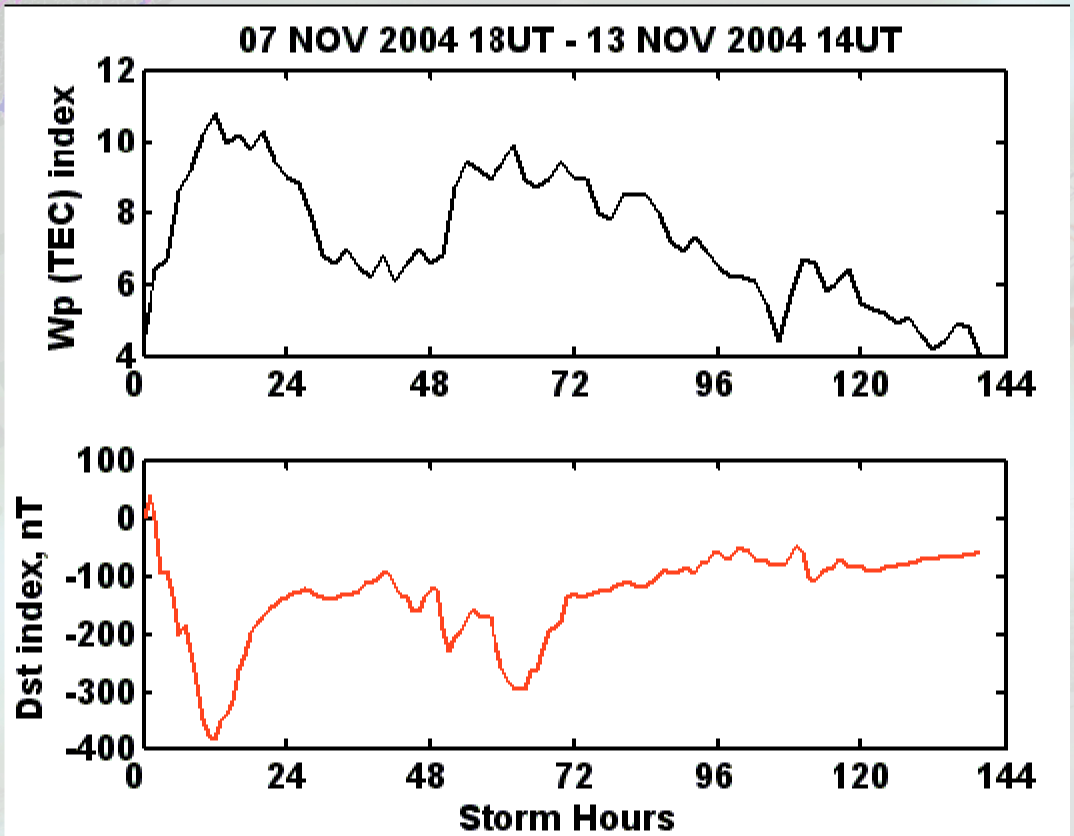
Values of phase variance for Warsaw GPS stations 24.06.2016 (last 6 hour)

W-index	DTEC	Ionospheric state
4	DTEC > 0.301	Intense positive W+ storm
3	0.155 < DTEC ≤ 0.301	Moderate W+ storm or substorm
2	0.046 < DTEC ≤ 0.155	Moderate W+ disturbance
1	0.0 < DTEC ≤ 0.046	Quiet W+ state
0	DTEC = 0.0	Reference Quiet state
-1	-0.046 ≤ DTEC < 0.0	Quiet W- state
-2	-0.155 ≤ DTEC < -0.046	Moderate W- disturbance
-3	-0.301 ≤ DTEC < -0.155	Moderate W- storm or substorm
-4	DTEC < -0.301	Intense negative W- storm

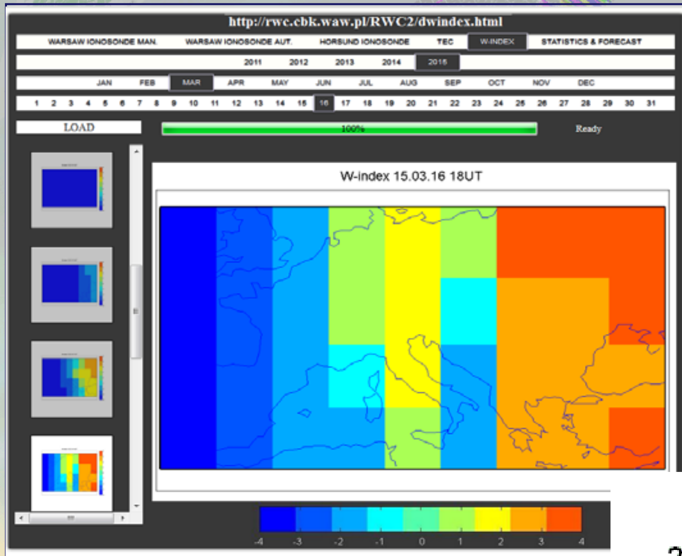
$DTEC = \log(TEC/TECmed)$



Statistical characteristics for the area of the maximum risk of the positive and negative storm appearance has been analyzed for 1999-2014 years.

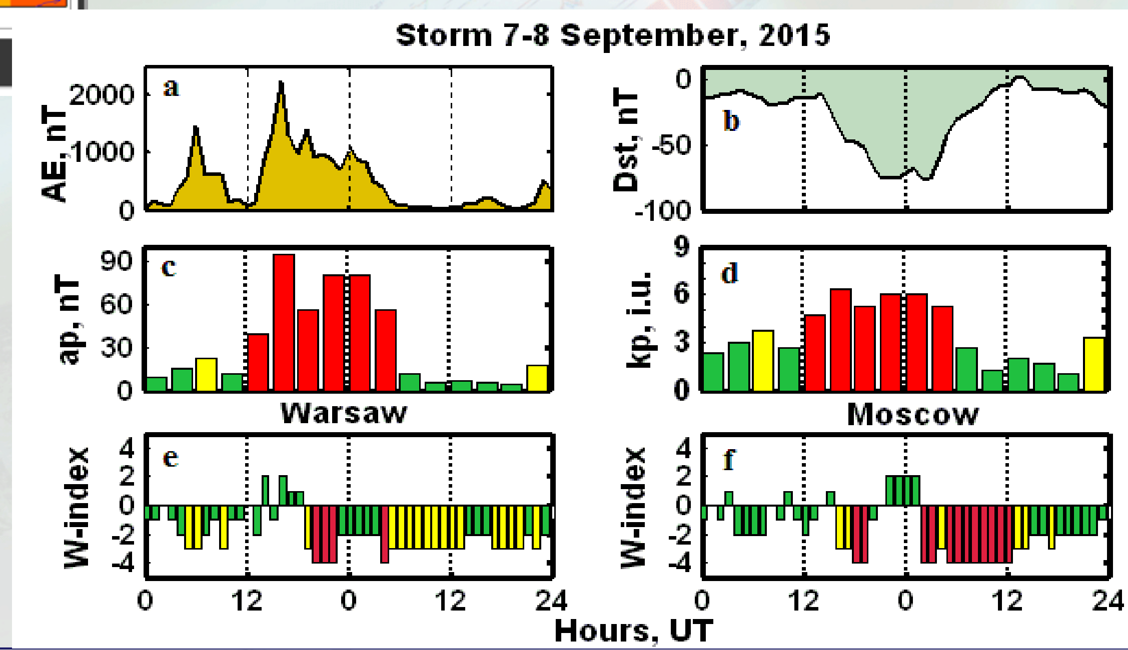


Coherent ionospheric Wp index and magnetospheric Dst index during space weather super-storm on 7 to 13 November 2004.



Local W index in Warsaw and Moscow, together with AE, Dst, ap and Kp indices.

W index for European area in IDCE based on EGNOS data at 16 March 2015 at 18UT (one day before St. Patric day)

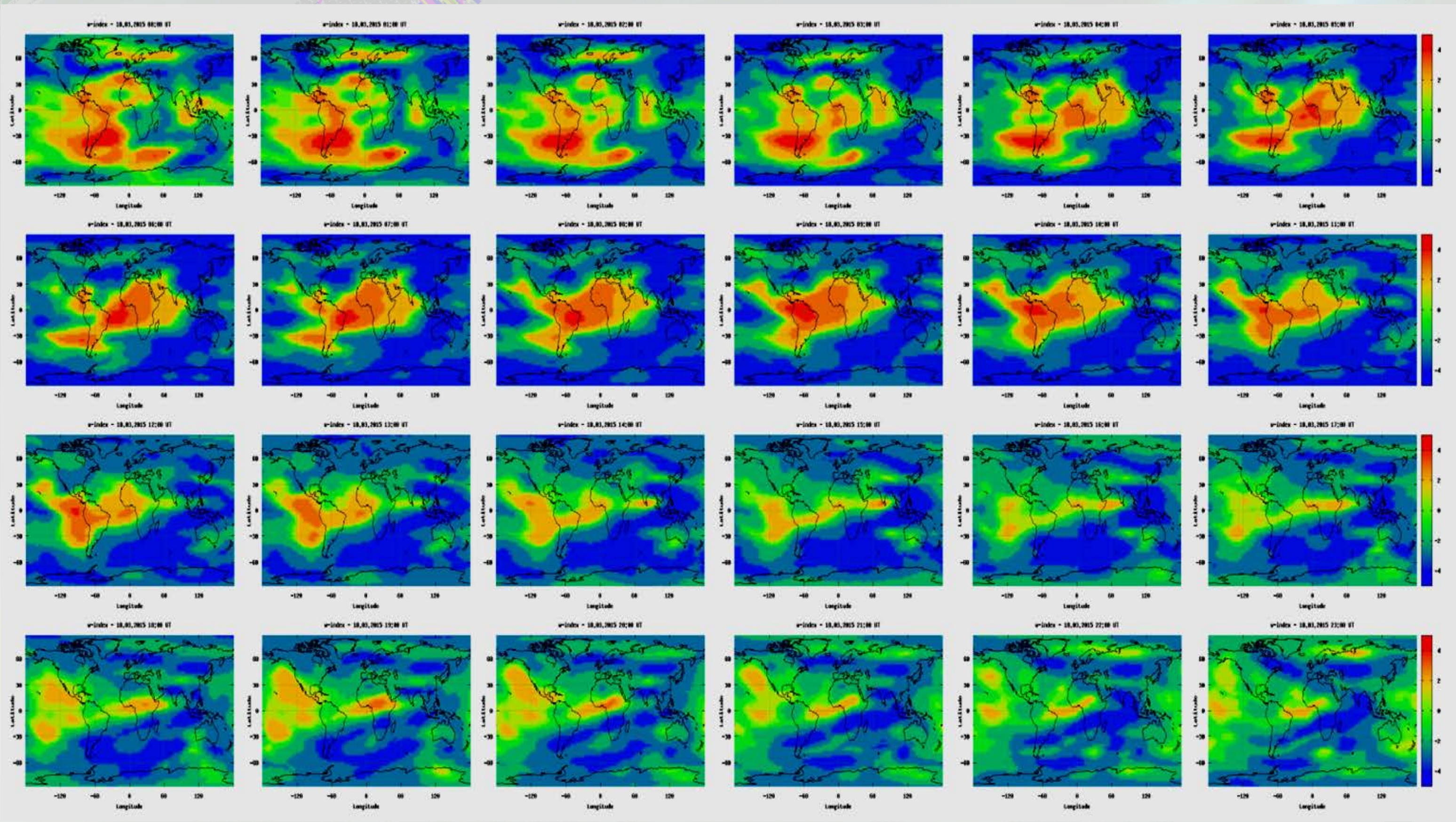


Ionospheric-plasmaspheric storms based on Wp index

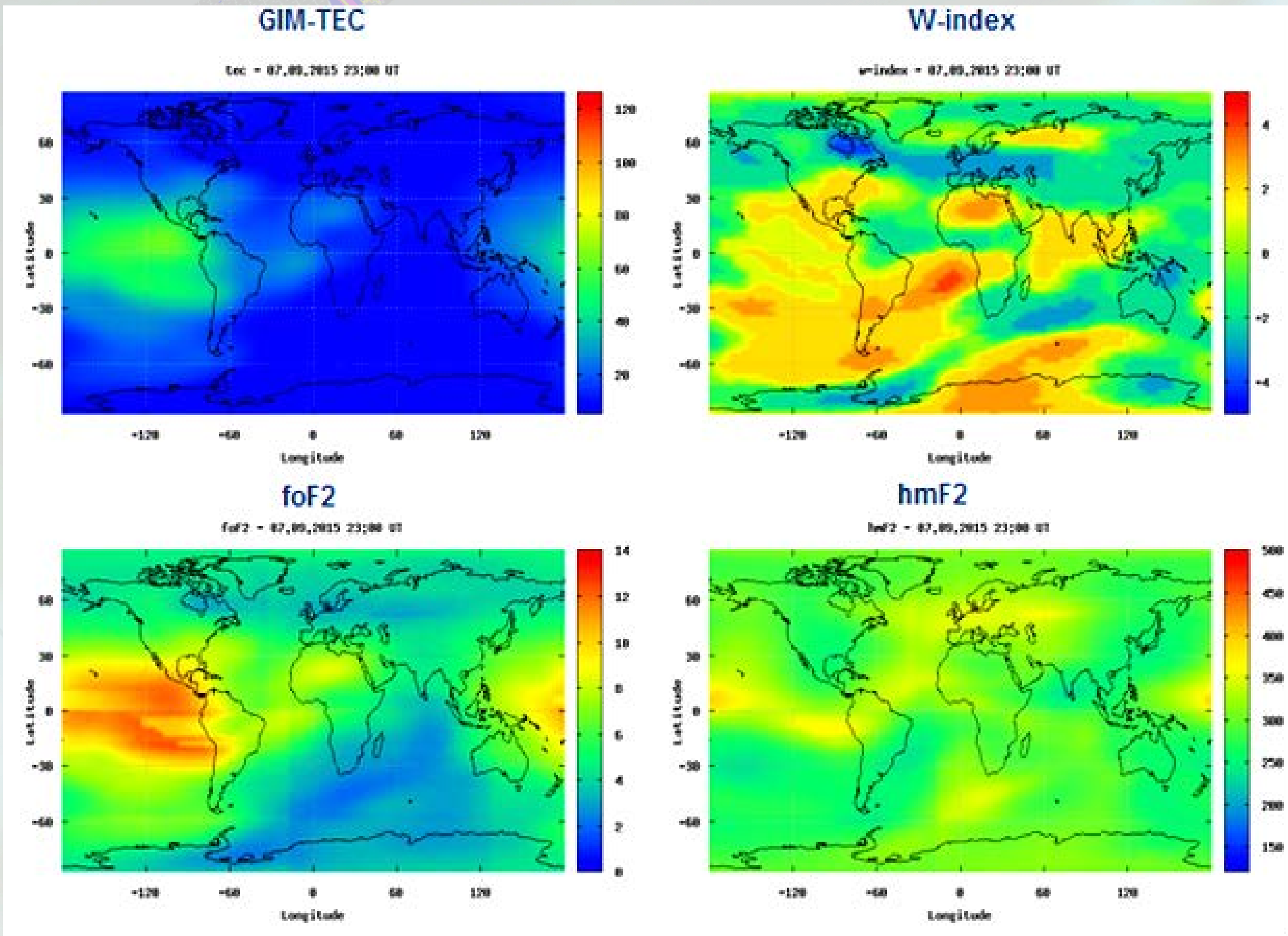
The examples of some storms

Start	UT	Peak	UT	Wp_{max}	End	UT	Hrs	$\langle Wp \rangle$	Power
2000.04.06	19	2000.04.06	23	9.0	2000.04.08	11	41	6.3	369.0
2000.07.15	15	2000.07.16	01	10.0	2000.07.17	11	45	6.7	450.0
2001.05.19	21	2001.05.20	21	9.0	2001.05.21	01	29	6.9	261.0
2001.11.05	21	2001.11.06	07	9.4	2001.11.08	01	53	5.9	498.2
2003.10.28	18	2003.10.29	22	9.4	2003.11.02	00	103	6.4	968.2
2003.11.19	12	2003.11.20	22	9.3	2003.11.23	14	99	5.5	920.7
2004.11.07	17	2004.11.08	06	9.9	2004.11.13	16	144	6.4	1425.6
2015.03.17	08	2015.03.18	07	9.5	2015.03.21	00	89	6.1	845.5

The power of the storm is defined as the peak value multiplied by the storm duration, in hours.

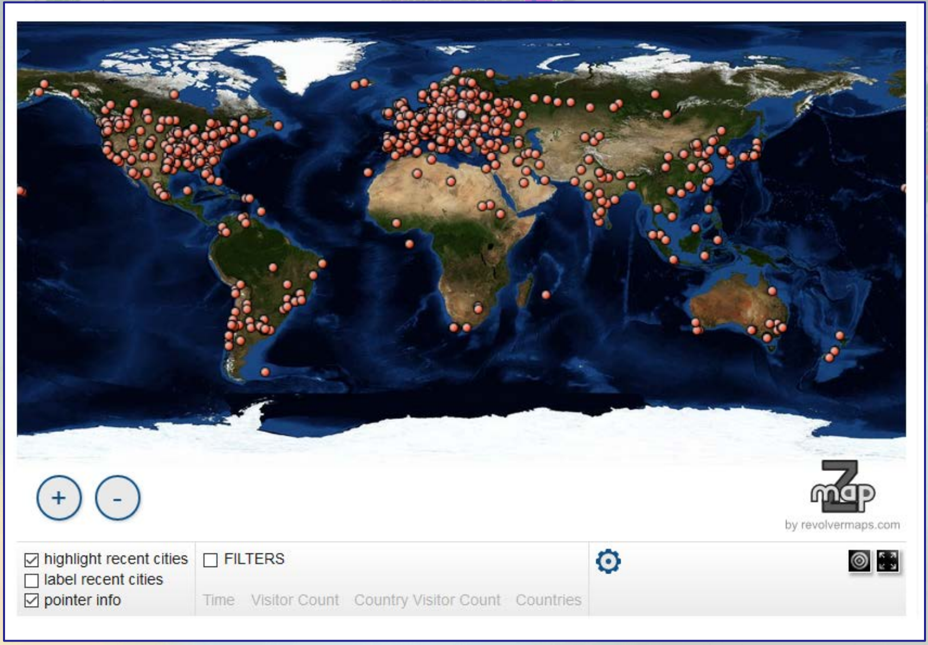


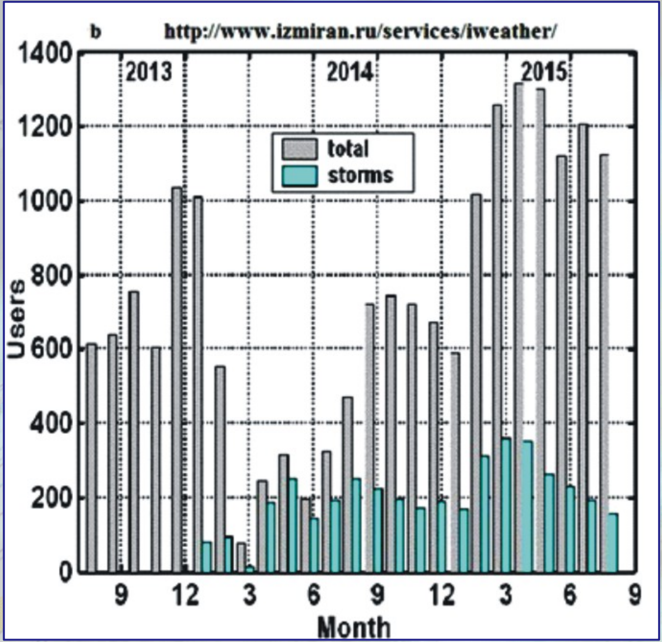
W index dynamics seen at global maps with 1 hour resolution during St. Patric storm 18 March 2015.



Maps for TEC, foF2, hmF2 and W for 07.09.2015 23 UT.

Visits





27 000 users from 91 countries since 2010 in SRC

Users per month from August 2015 until August 2015 in IZMIRAN

http://www.cbk.waw.pl/rwc

http://www.izmiran.ru/services/iweather