Sibsonian and non-sibsonian natural neighbour interpolation of the Total Electron Content value

Kliknij, aby edytować styl wzorca podtytułu

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Why?

- Ionosphere is strongly dispersive, especially for low-frequency radio waves
- The ionosphere may affect the observational data used to constrain theoretical models of the epoch of the reionization, solar science, space weather and cosmic magnetism
- At short baselines (less than 50km) most of the ionospheric effects may be removed by means of interferometric techniques
- LOFAR's baselines are currently up to 1500km long and may be even longer in the future

What we need to do?

- As LOFAR is incapable of removing the ionosphere effect by itself, it has to be provided with external ionosphere information

Where can we get it?

- IGS provides GIMs through seven IGS Ionosphere Analysis Centres (IAACs): CODE, ESA, JPL, UPC, NRCan, WHU, CAS
- These global ionospheric maps are computed using TEC data provided by GNSS-based ground receivers

So what's the problem?

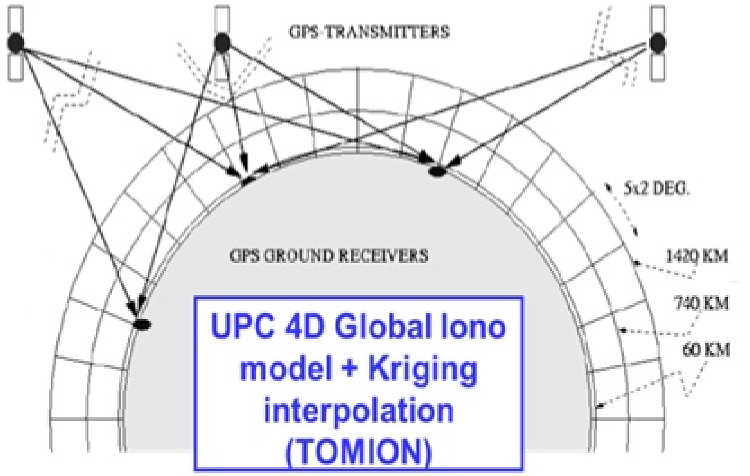
- GIM's, due to the lack of homogeneity of GNSS networks worldwide uses interpolation techniques to for filling the gaps, therefore for local areas they may be inaccurate
- Also their spatial and temporal resolution isn't that great

What we want to do?

- Local TEC maps dedicated for ILT
- 0,5° by 0,5° spatial resolution
- 15 minutes temporal resolution
- Rapid 15 min and Final 1 day IONEX files (rapid files uploaded every 15 minutes and final every 24 hours)

How?

- Getting STEC information from EUREF I
- Mapping of VTEC values with the use of del of the IONosphere) software
- Interpolation of VTEC values on 0,5° by interpolation)

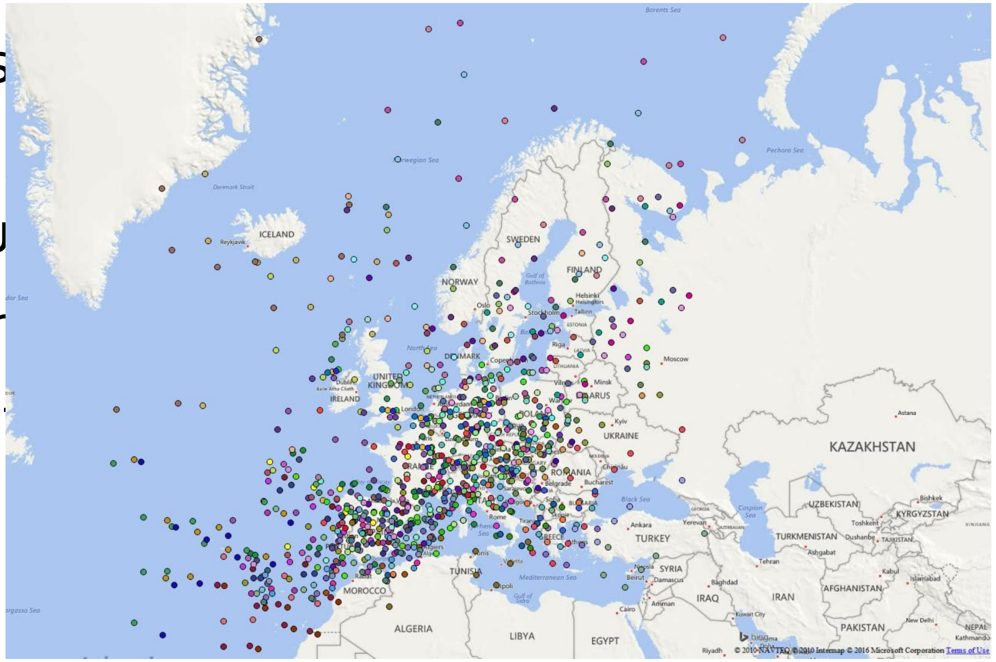


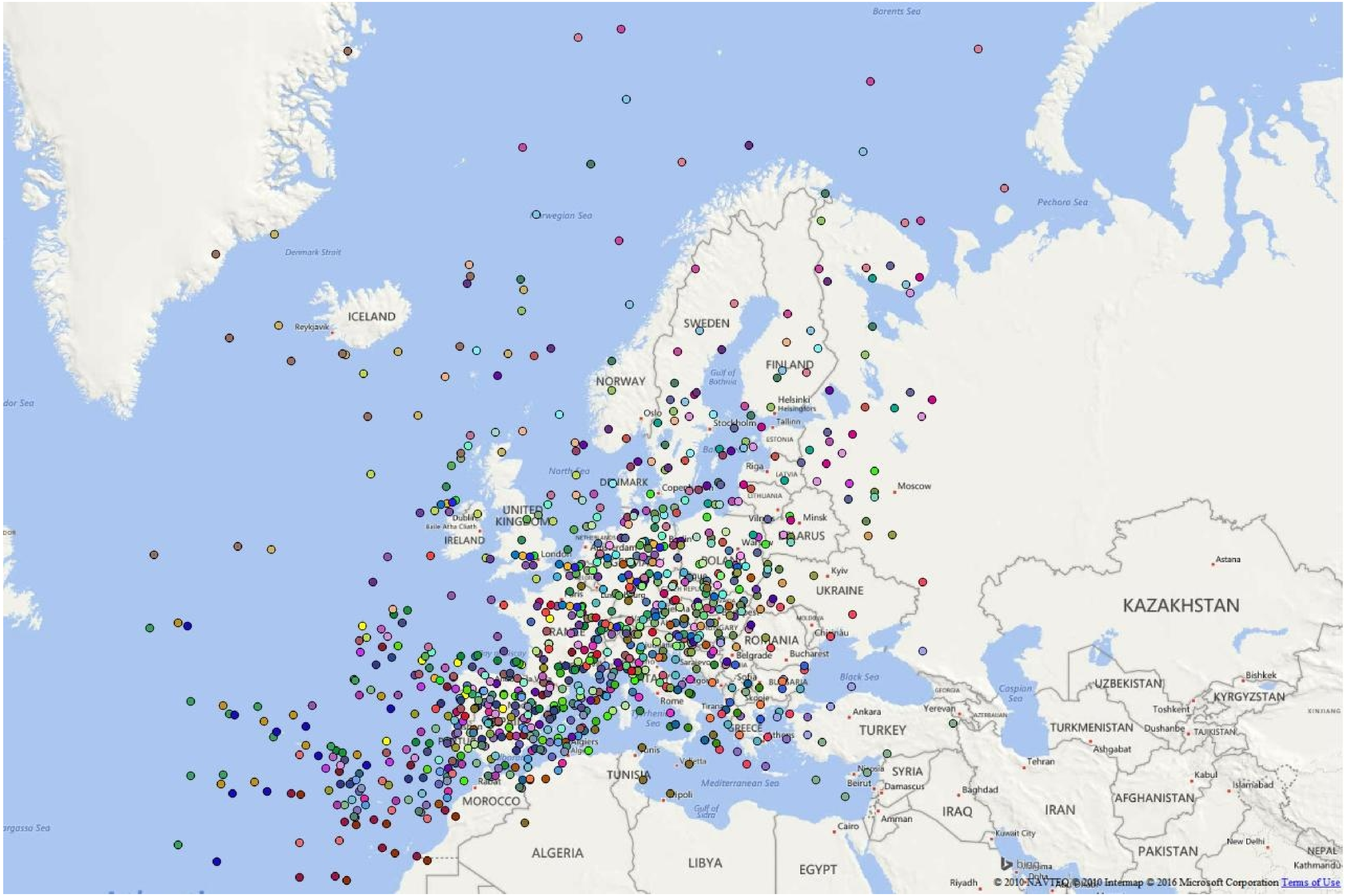
$$L_I = S + B_I \simeq \sum_{i=1}^{n} N_{e,i} \Delta l_i + B_I$$

- EPN stations with real-time processing

STEC to VTEC

- The map shows the distribution of IPPs
  the year 2015
- Data from 126 EPN stations has been u
- Each dot indicates one IPP, for which th
- For each IPP STEC can be recalculated
  dense data distribution





Barents Sea
Pechora Sea
Norwegian Sea
Denmark Strait
ICELAND
Reykjavik
SWEDEN
FINLAND
NORWAY
Oslo
Stockholm
Helsinki
Tallinn
Riga
Moscow
North Sea
DENMARK
UNITED KINGDOM
IRELAND
Dublin
London
Minsk
BELARUS
Kyiv
UKRAINE
KAZAKHSTAN
Astana
ROMANIA
Bucharest
Belgrade
Sofia
Rome
Black Sea
Ankara
TURKEY
Yerevan
Caspian Sea
UZBEKISTAN
KYRGYZSTAN
Bishkek
Toshkent
TURKMENISTAN
Dushanbe
Ashgabat
Tehran
SYRIA
Damascus
Beirut
Baghdad
IRAQ
IRAN
AFGHANISTAN
Kabul
Islamabad
PAKISTAN
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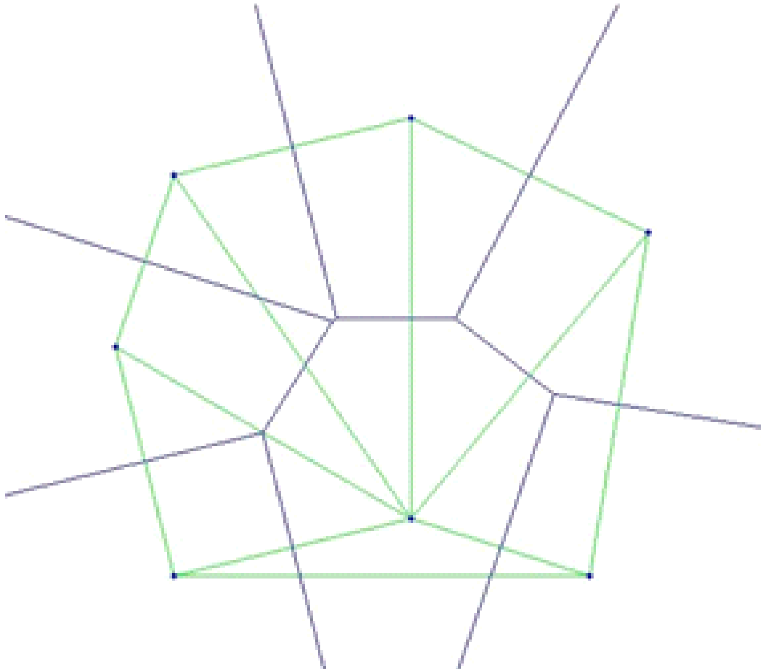
Natural interpolation



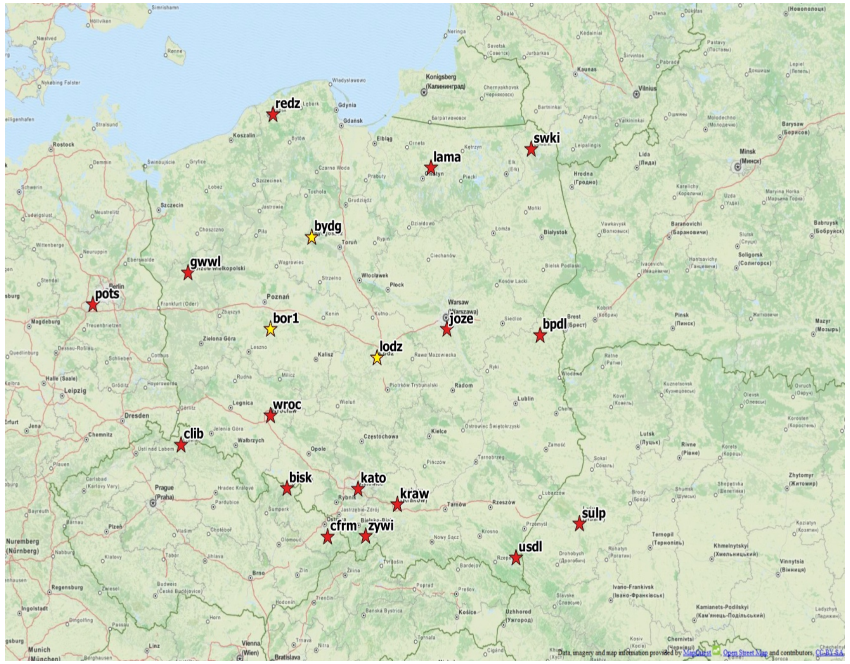
- Natural neighbour interpolation is based on the Voronoi diagram, which is strictly related to Delaunay triangulation
- Delaunay triangulation is based on circumcircles – a triangle is created when there is no point inside the circumcircle
- Each Voronoi cell marks the area closer to the point than to any other
- Voronoi edges are mid-perpendiculars of Delaunay edges
- Voronoi vertexes are the Delaunay's

Exemplary dataset

- Exemplary computations were based on the dataset consisted of TEC value observations from 19 EUREF Permanent Network (EPN) stations located within and nearby the area of Poland
- The data set provided by the UPC included Slant TEC (STEC) values for each IPP.

$$VTEC = STEC * \sqrt{1-\left(\frac{R_e}{R_e+h_{ion}}\cos\epsilon\right)^2}$$

- The STEC values were observed alongside the lines of sight between the EPN station and every satellite in view.



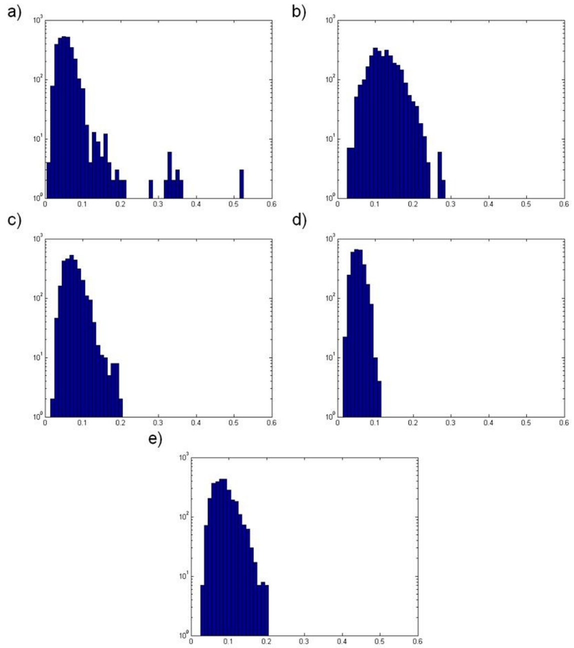
- Exemplary location of observed IPPs (black dots) for chosen EPN stations (red stars) for epoch 1440 (12:00 UT)

Exemplary dataset

- The IPPs of three stations: Borowiec (bor1), Bydgoszcz (bydg) and Lodz (lodz) were taken as unknown for the interpolation. Then their known VTEC values were used to assess the performance of the interpolation method
- Those three stations have been chosen due to their locations. Indeed they are surrounded by other stations from all sides, thus avoiding extrapolation scenarios, which are out of the scope of this work.
- Considering the fact that the dataset contains 30 seconds interval data for the whole day (24 hours observations from June 15th, 2015, during quiet geomagnetic conditions after 2013 solar activity peak), the observations of sixteen stations from the EUREF network provided 74400 interpolated points divided into 2880 one-epoch subsets

Results – root mean squares errors [TECU]

Interpolation Method	Mean	Min	1st Quartile	Median	3rd Quartile	Max
Natural	0.063	0.013	0.040	0.055	0.069	0.789
IDW	0.123	0.033	0.097	0.122	0.148	0.279
Quasi-natural	0.075	0.024	0.057	0.072	0.088	0.196
Non-sibsonian	0.054	0.017	0.042	0.053	0.064	0.113
Polynomial	0.088	0.032	0.066	0.084	0.103	0.200



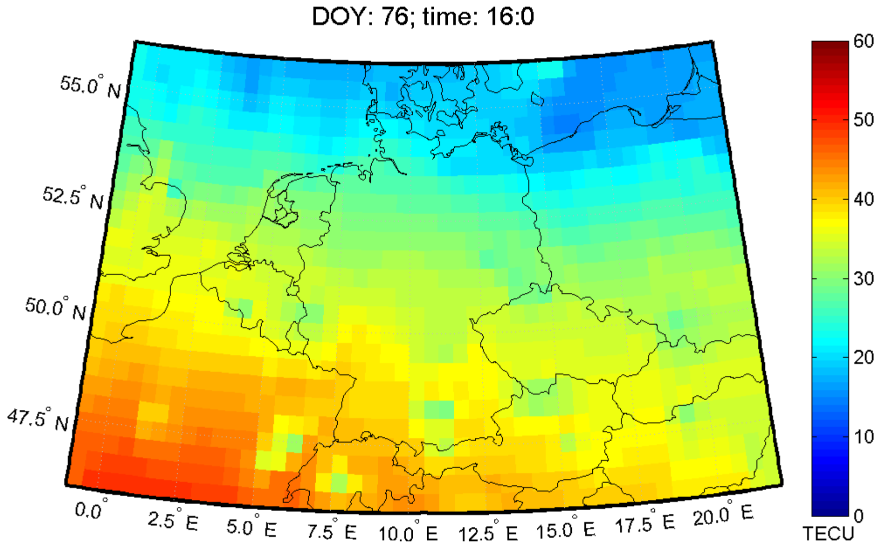
Results – computation time [s]

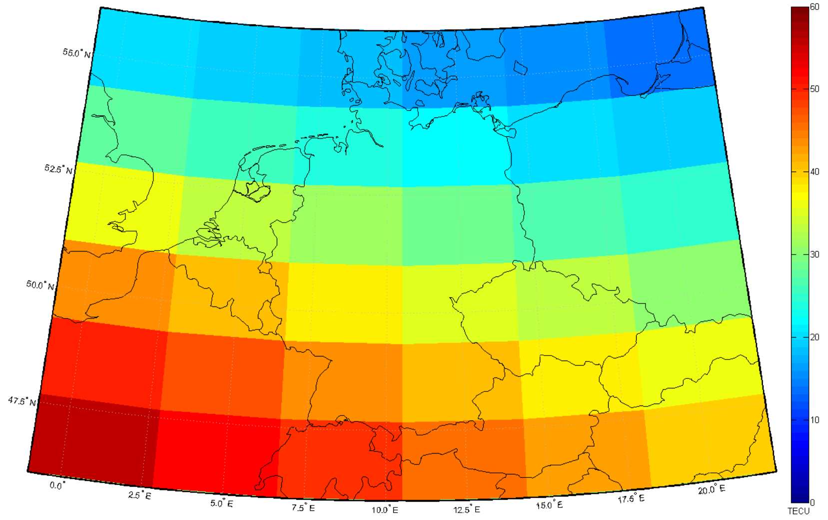
Interpolation method	Full set (74400 points)	One epoch (23 points)	One point
Natural (1st scenario)	581.2	0.1566	0.0075
Natural (2nd scenario)	2020.44	0.4773	0.0195
IDW	67.94	0.0311	0.0208
Quasi-natural	36.22	0.0174	0.0008
Non-sibsonian	585.79	0.1564	0.0076
Polynomial	96.32	0.0442	0.0192

- IONEX file generated for the area of ILT part of Europe with natural neighbour interpolation
- (header plus first rows of grid TEC data)

```
     1.0            IONOSPHERE MAPS     MIX                 IONEX VERSION / TYPE
cmpcmb v1.2    SRRC/UWM and IONO/UPC        31-may-16 12:13 PGM / RUN BY / DATE
European ionex file for ILT                                 COMMENT
Regional (european) ionosphere maps for day 076, 2015       DESCRIPTION
Created using natural neighbour interpolation               DESCRIPTION
Contact address: Andrzej Krankowski                         DESCRIPTION
                 Space Radio-Research Diagnostics Centre    DESCRIPTION
                 University of Warmia and Mazury (SRRC/UWM) DESCRIPTION
                 Prawochenskiego st. 9                      DESCRIPTION
                 10-957-Olsztyn, POLAND                     DESCRIPTION
                 e-mail:  kand@uwm.edu.pl                   DESCRIPTION
                                                            DESCRIPTION
  2015     3    17     0    15     0                        EPOCH OF FIRST MAP
  2015     3    17    23    45     0                        EPOCH OF LAST MAP
   900                                                      INTERVAL
    95                                                      # OF MAPS IN FILE
  COSZ                                                      MAPPING FUNCTION
     0.0                                                    ELEVATION CUTOFF
combined TEC calculated as weighted mean of input TEC valuesOBSERVABLES USED
   126                                                      # OF STATIONS
    32                                                      # OF SATELLITES
  6371.0                                                    BASE RADIUS
     2                                                      MAP DIMENSION
   450.0 450.0   0.0                                        HGT1 / HGT2 / DHGT
      58    46  -0.5                                        LAT1 / LAT2 / DLAT
      -1    22   0.5                                        LON1 / LON2 / DLON
    -1                                                      EXPONENT
TEC values in 0.1 tec units;  9999, if no value available   COMMENT
                                                            END OF HEADER
     1                                                      START OF TEC MAP
  2015     3    17     0    15     0                        EPOCH OF CURRENT MAP
    58.0  -1.0  22.0   0.5 450.0                            LAT/LON1/LON2/DLON/H
   72   72   72   72   72   74   72   73   72   71   71   73   74   75   77   80
   79   75   73   73   72   79   78   79   81   83   85   86   87   84   82   81
   81   81   84   90   94   95   93   92   92   92   93   95  100  105  102
    57.5  -1.0  22.0   0.5 450.0                            LAT/LON1/LON2/DLON/H
   76   76   76   77   80   82   81   79   74   72   73   74   74   74   76   84
   83   81   76   74   73   82   82   85   87   90   92   96   95   88   89   95
   96  100  102  103  101   99   95   93   92   92   94   96  100  100   98
    57.0  -1.0  22.0   0.5 450.0                            LAT/LON1/LON2/DLON/H
   77   78   79   80   83   86   87   84   81   74   75   76   77   79   83   85
   85   85   82   77   76   82   90   93   97  102  107  106  101   96   98   99
  101  106  110  108  105  102   96   93   92   92   94   96  100  102  101
    56.5  -1.0  22.0   0.5 450.0                            LAT/LON1/LON2/DLON/H
   81   81   80   78   81   87   92   85   81   78   77   78   79   82   83   83
   83   84   81   78   77   81   88   95  100  106  110  108  105  102  102  101
  104  109  111  109  108  104   97   95   94   95   96   97   98  103  104
    56.0  -1.0  22.0   0.5 450.0                            LAT/LON1/LON2/DLON/H
   82   78   76   78   80   84   90   85   82   80   80   80   80   82   83   84
   84   84   81   78   76   81   88   95  100  105  109  110  108  106  105  104
  108  110  111  111  112  107   97   98   96   96   99  101  101  100  106
```

Maps comparision



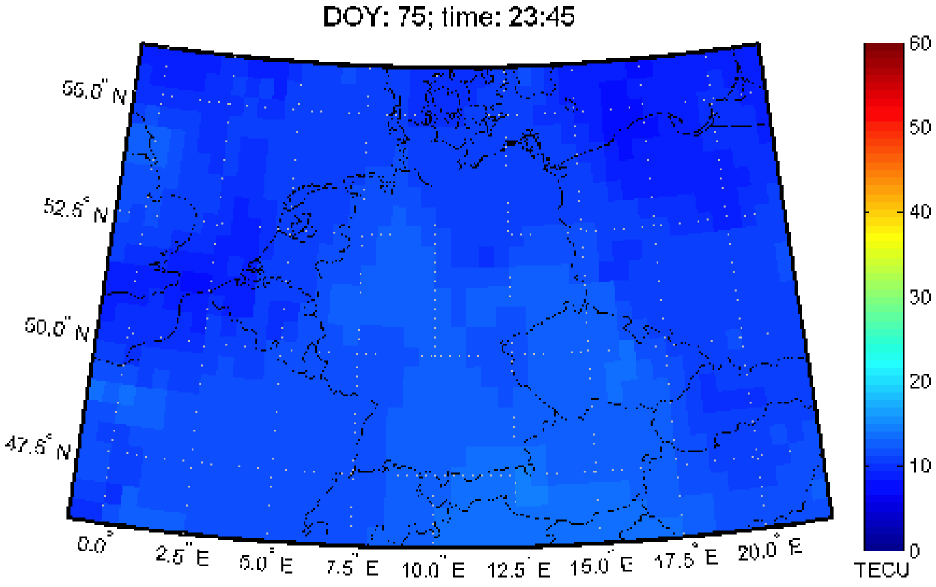


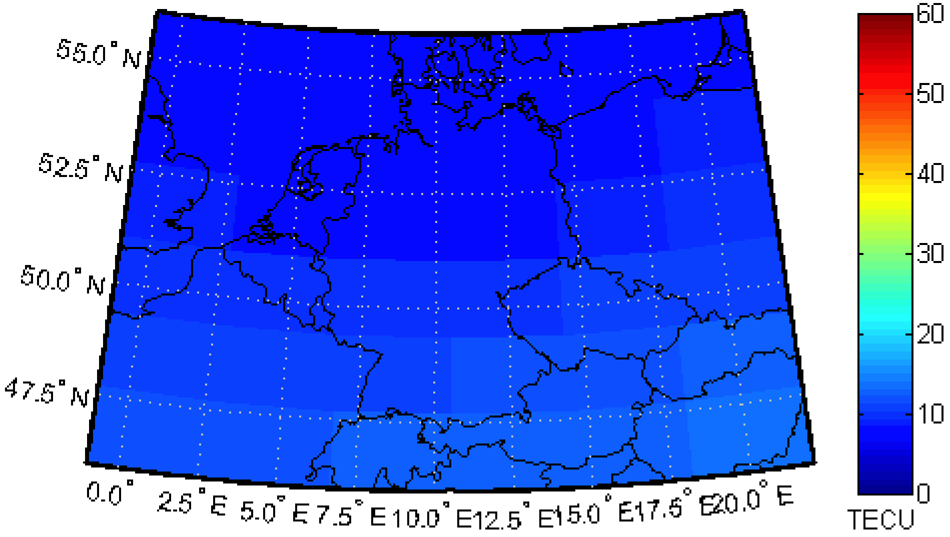
ILT IONEX regional TEC map
0.5 ° lat/lon spatial resolution
15 minutes temporal resolution

IGS IONEX regional TEC map
2.5 ° lat and 5 ° lon spatial resolution
2 hours temporal resolution

(same date, hour and color/TEC scale)

Maps comparision





ILT IONEX regional TEC map
0.5 ° lat/lon spatial resolution
15 minutes temporal resolution

IGS IONEX regional TEC map
2.5 ° lat and 5 ° lon spatial resolution
2 hours temporal resolution

Results for 76th day of year 2015 (March 17th) – the day of St. Patrick's Day geomagnetic storm

Conclusion

- Highly topology-dependent natural neighbour methods provide the best accuracy as the TEC value depends on its own topology
- However the sibsonian method in its both scenarios has to cope with many problems and point losses
- The more effective second scenario-based method requires relatively high computation time (especially when opposed to ultra-rapid quasi natural neighbour method)
- The solution to the trade-off between accuracy and computational time might be the non-sibsonian method, which is also very topology-dependent, but least sensitive to the open-cell problem.
- Another solution may be the quasi-natural method, which provides slightly worse, but still quite promising, results. This method is only partially dependent on the topology, which leads to the drop of accuracy, but on the other hand, it