Regional Ionosphere Maps over Austria using the Kriging Interpolation Technique

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Abstract

The ionosphere is a portion of the upper atmosphere and has the characteristics of getting easily ionized by solar radiation. Variations of the solar activity change the conditions of the Sun-Earth environment and can dramatically disturb the ionospheric mean conditions. These ionospheric disturbances will significantly increase in the forthcoming years due to reaching the solar maximum at around 2013. The ionosphere plays an important role in high-technological systems for navigation, telecommunication and space missions because the microwave signals travelling through it experience a delay that depends on the number of free electrons along the ray path. Space geodetic techniques observing at two frequencies, such as the Global Positioning System (GPS) allow the observation and modeling of the ionosphere, which is a key point in correcting electromagnetic measurements for ionospheric disturbances. The kriging interpolation method is an estimation and interpolation method applied in geostatistics, which uses known sample values and a variogram to determine the unknown values at different locations. At each location kriging produces an estimate and a confidence bound on the estimate. This study aims at developing regional maps of Vertical Total Electron Content (VTEC) over the Austrian GNSS network using the kriging interpolation method. To validate the developed maps, comparisons with CODE global maps have been performed leading to the conclusion that Kriging is a valid method for the realization of TEC maps over Austria.

Methodology

In order to create a TEC map over Austria, following steps have been followed:

1. VTEC Determination
2. Creation of empirical variogram
3. Fitting of theoretical variogram
4. Kriging interpolation and creation of TEC map

VTEC Determination

For the TEC representation, a single layer model (SLM) ionospheric approximation was used. SLM assumes that all the free electrons are contained in a shell of infinitesimal thickness at altitude h (450 Km). A mapping function to relate the STEC and the vertical TEC at the Ionospheric Pierce Point (IPP) is used. The VTEC values have been calculated using the approximation of first order refractive index. The ionospheric delay has been computed using the geometry-free linear combination (L4) (Differential Code Biases, DCB, were in this case estimated).

In this work the maps have been created for the 5th of June 2011 for the reference times 2:00 to 22:00 UTC every 2 hours using the observations from stations AMST, GRAZ, LEOB, MATT, SALZ, WTRZ and ZIMM (fig. 1) 15 min. before and after the reference epoch.

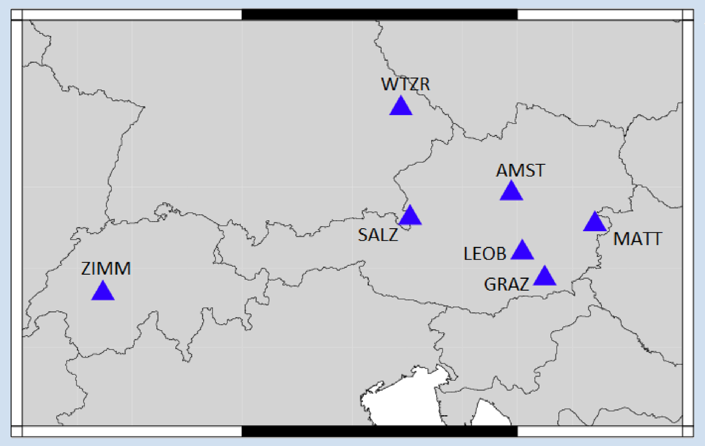

Fig. 1 GNSS Network

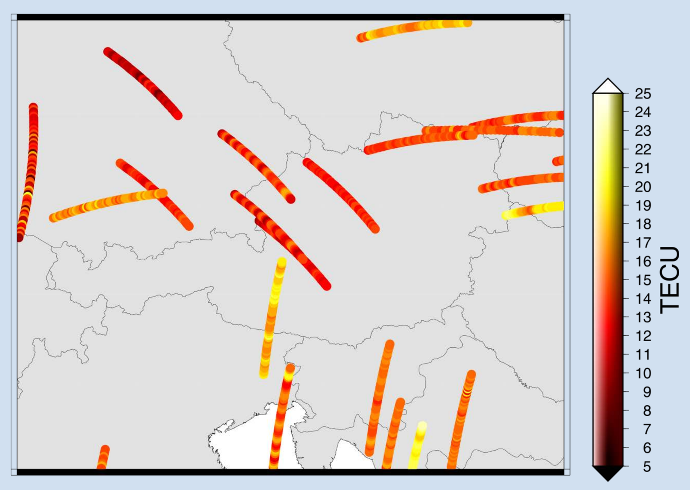

Fig. 2 IPP and their VTEC value (8:00 UTC)

Creation of Empirical Variogram

One optimal interpolation algorithm for GNSS data is the kriging technique, which is based on the assumption of an error decorrelation function with distance and direction. It is an estimation and interpolation method applied in geostatistics, which uses known sample values and a variogram to determine the unknown values at different locations.

The variogram describes the correlations between different measured values that form a sample. From empirical data, the variogram for a certain distance or distance class can be calculated with:

$$\hat{\gamma} = \frac{1}{2n(h)} \sum_{i=1}^{n(h)} (z(x_i + h) - z(x_i))^2$$

n(h) -> amount of measurements that create the distance class
z -> measurements inside of the distance class

The data in this case is non-aligned and irregularly spaced. Moreover, in order to detect possible anisotropies (the ionosphere is not having the same behaviour in every direction since typically it is correlated over appreciably greater distances E-W than N-S (Edwards et al., 1975)) variograms in different directions α (N, E, NE and NW) have been calculated. Each data value z has been associated with every other value located within the arc defined by α ± δ(α) (in this work δ(α)=22.5 deg). Within this angle class, the data can be grouped into distance classes (in this case 100 km).

Fitting of Theoretical Variogram

The variogram calculated with formula mentioned above changes considerably if the distance class or the amount of data in the sample is changed. Moreover, the variogram has to fulfill some requirements (for instance, isotropy, negative definition …). There are some already existing models that fulfill these requirements. It is possible to obtain the theoretical variogram by fitting the empirical one in one of these models.

Kriging Interpolation and Creation of TEC Map

In this case a grid over Austria (latitude/longitude resolution of 1.25/2.5°) has been created and the VTEC have been calculated for every intersection point following the simple kriging method.

Since for some reference epochs the amount of IPP and their respective VTEC values are quite small as well as being unevenly distributed, no clear signs of anisotropy have been observed in the experimental variograms, therefore, it has not been considered in this work.

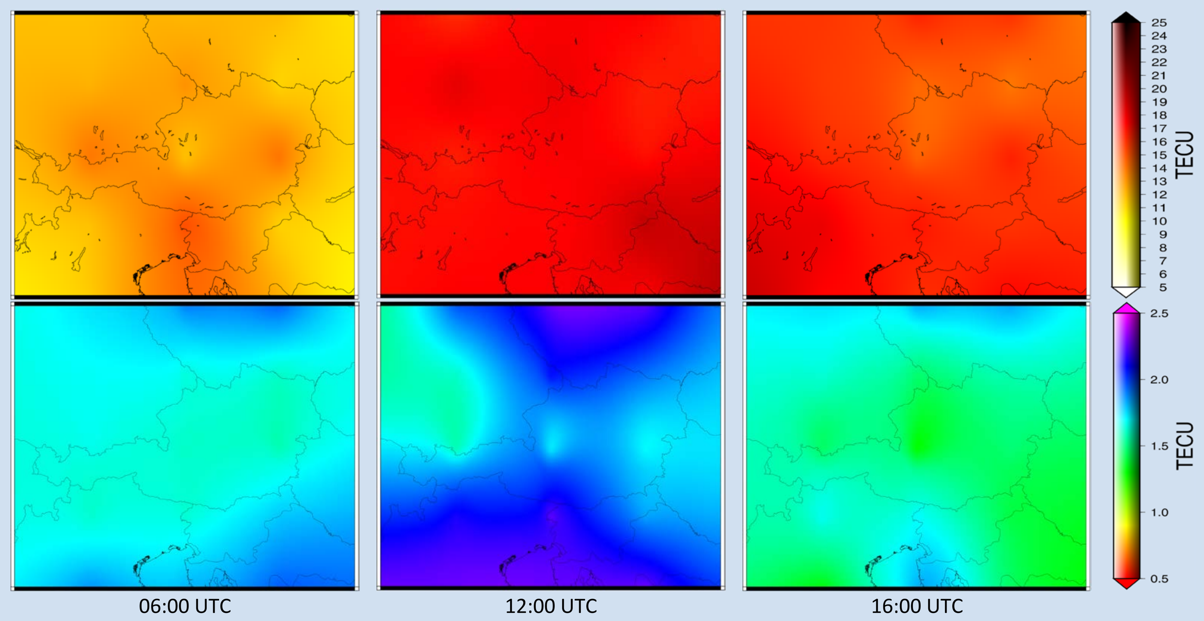

Fig. 3 Some examples of kriging TEC maps (top) and their standard deviations (bottom)

Comparison with CODE – TEC Maps

Figure 4 shows the differences between CODE TEC maps and their corresponding maps generated within this work. It can be seen that CODE maps generally present higher VTEC values. CODE maps also show a smoother behaviour since they are global maps, whereas maps made by kriging show small structures that are due, in most cases, to the heterogeneous distribution of IPPs. The anisotropic behaviour of the ionosphere can be seen in the CODE maps.

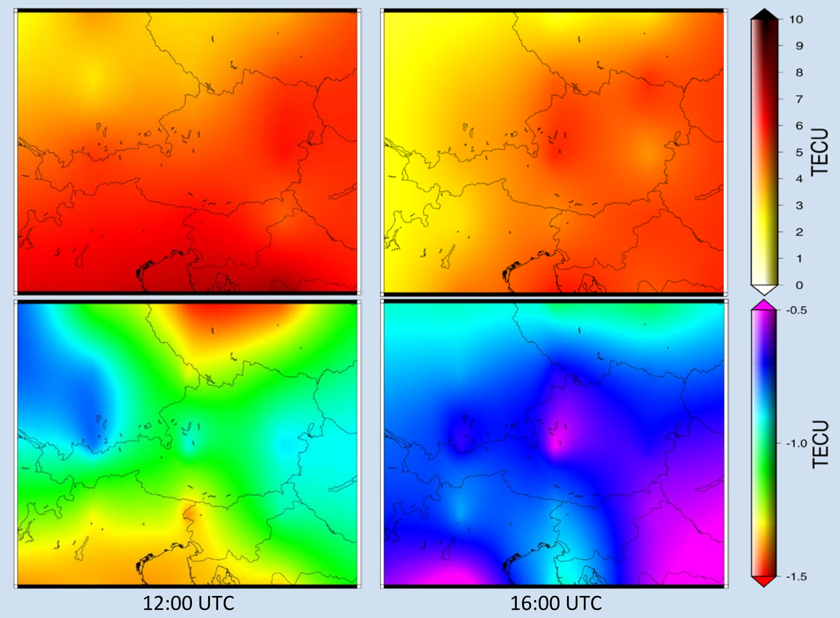

Fig. 4 Difference between CODE TEC map and maps generated with the kriging method (top) and difference between CODE RMS and kriging standard deviation (bottom)

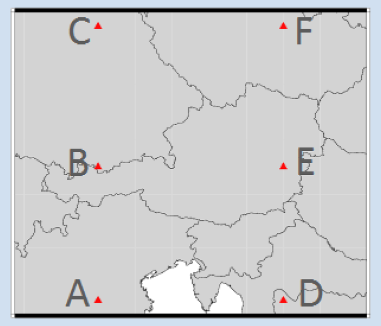

Fig. 5 Grid points for which the TEC values have been calculated

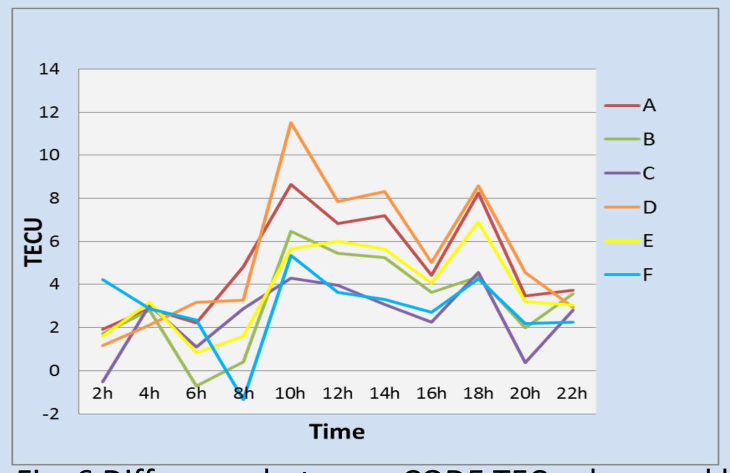

Figure 6 shows the difference between CODE TEC values and kriging TEC values for six different grid points (fig. 5) at different times during the day. Here it can be seen that the difference between the CODE maps and the kriging maps are bigger on the afternoon than on the morning. The scatter of the differences in the various grid points also presents this behaviour

Fig. 6 Difference between CODE TEC values and kriging TEC values for the grid points shown in fig. 5

Conclusions

Kriging has proved to be a valid method for the representation of TEC maps over Austria. However, the results obtained in this work can be improved if more observations from different stations would be available, so that the number of IPPs increases and their distribution gets more homogeneous.

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