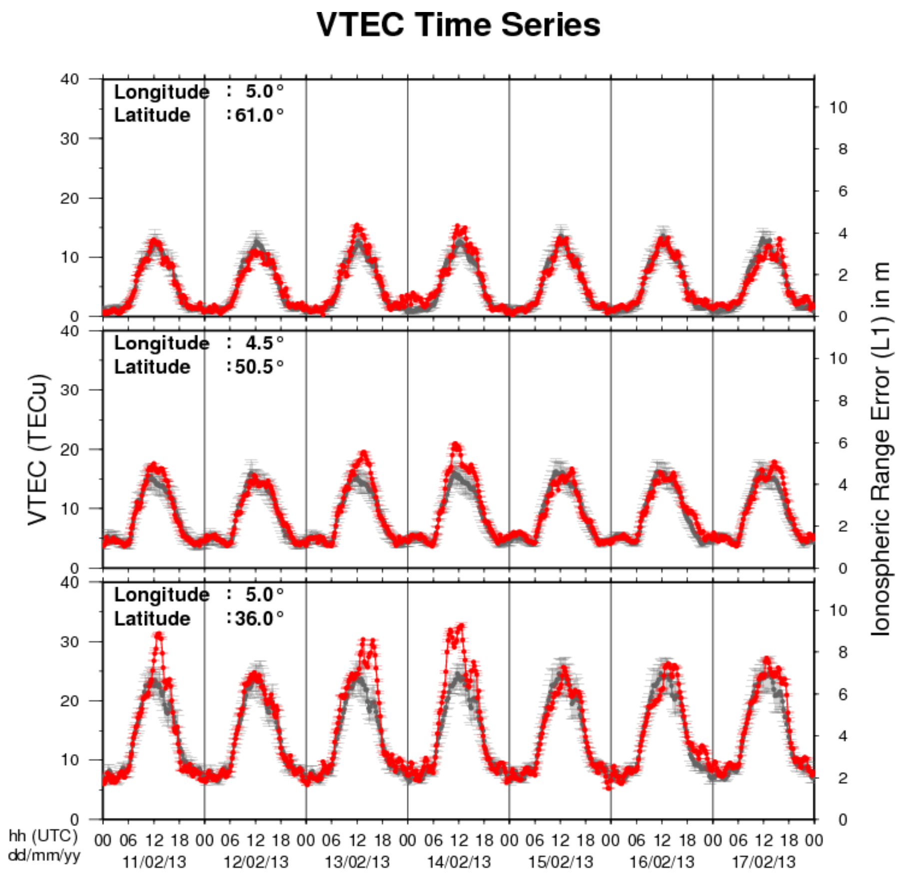

Figure 1: VTEC time series at 3 locations in Europe from 11 February 2013 till 17 February 2012.

Figure 1 shows the time evolution of the Vertical Total Electron Content (VTEC) (in red) during the second week of February 2013 at three locations:

a) in the northern part of Europe (N61° , 5°E)
b) above Brussels (N50.5° , 4.5°E)
c) in the southern part of Europe (N36° , 5°E)

This figure also shows (in grey) the normal ionospheric behavior expected based on the median VTEC from the 15 previous days.

The VTEC is expressed in TECu (with 1 TECu = 10^{16} electrons per square meter) and is directly related to the signal propagation delay due to the ionosphere (in Figure 1: for delay on GPS L1 frequency).

The Sun's radiation ionizes the Earth's upper atmosphere, the ionosphere, located from about 60 km to 1000 km above the Earth’s surface. The ionization process in the ionosphere produces ions and free electrons. These electrons perturb the propagation of the GNSS signals (Global Navigation Satellite System) by inducing a so-called ionospheric delay.

For example, an ionosphere containing 10 TECu along the signal path between one satellite and the receiver induces an error of 1.6 m on the observed distance satellite-receiver when using the GPS L1 frequency (1575.42 MHz). However, a receiver needs signals from at least 4 satellites to determine its position. Hence, if no ionospheric corrections were taken into account, the GNSS receiver positioning error could reach up to 50 m, depending on ionospheric conditions.

For **single frequency** GNSS users, the ionospheric delay is corrected using models such as Klobuchar for GPS and Nequick for Galileo which allow the removal of 40% to 70% of the ionospheric delay.

For **dual frequency** GNSS receivers, almost all (99%) of the ionospheric delay can be removed using the two different frequencies. The small remaining error is mainly dependent on the geomagnetic field effects. Nevertheless, these small error sources of the ionospheric delay should be taken into account during high ionospheric activity.

For example, during the Halloween geomagnetic storms of 28-30 October 2003 (Figure 2), the precision of kinematic GPS station (dual frequency receivers) positioning was degraded significantly with errors up to 25 cm, while during quiet ionospheric activity this error hardly reaches 3 cm. Such errors play an important role in many applications requiring cm level of precision (e.g. mining surveys, guidance of mobile robots or engine …).

Space weather centres monitor the ionosphere to better understand its impact on GNSS signals, and provide corrections to the users.

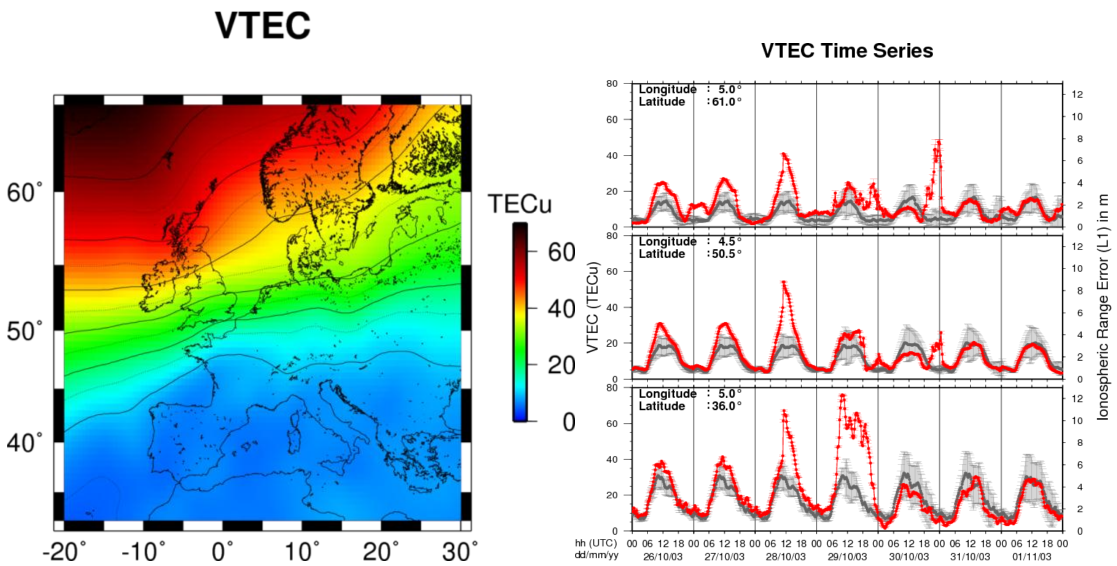

Figure 2: Left: VTEC map during the Halloween geomagnetic storm (from 23:30 to 23:45 on 30 October 2003). The graph shows the impact of the storms on the ionosphere. Right: VTEC time series at 3 locations in Europe during the geomagnetic storm of 30 October 2003.