GNSS observational bias in the frame of ionospheric studies

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European Space Weather Week 11

17-21 November 2014, Liège, Belgium

Abstract

Using moving satellites to monitor the Total Electron Content (TEC) and its variations in time and space induces some observational biases. Indeed, there is a relative movement between the moving observer (the satellite), the moving structure (the ionospheric disturbance) and the receiver station.

As a consequence, one-way measurements are affected by the relative movement between the Ionospheric Pierce Points (IPPs) and the ionospheric disturbance. The consequence resulting from this relative motion, which is elevation-dependent, is that apparent TID wavelength and period are distorted with respect to their true value.

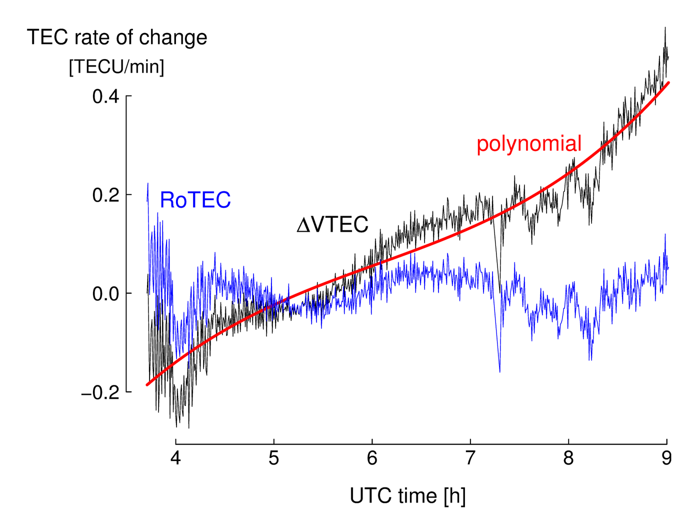
In this context, the aim of this paper is to identify geometrical conditions leading to distortions in the observation of TIDs with GNSS, which are the most common source of ionospheric disturbances over mid-latitudes.

Based on simulation of several GNSS constellations (GPS, GLONASS, Galileo, Beidou) but also of measurements related to geostationary and inclined geosynchronous satellites, it is proposed to study the reconstruction of a simulated TID observed from a single GNSS station on Earth.

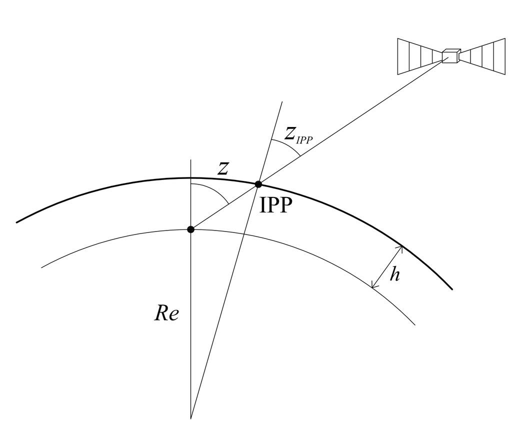
1. Ionospheric irregularities observed by GNSS

- Methodology

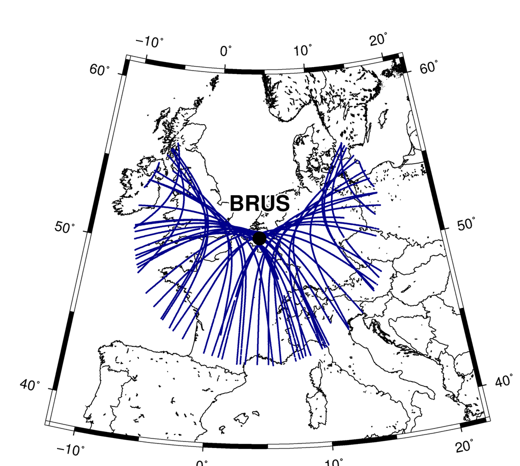
1. Computation of the Vertical **Total Electron Content** and its time derivative (ΔVTEC) for each observation epoch, using dual-frequency GNSS data
2. **Polynomial fitting** of ΔVTEC time series (satellite arc)
3. Residuals computation: « ΔVTEC – polynomial » called ***Rate of TEC* (RoTEC)**
4. Computation of 15-min **Std. Dev. σ** of RoTEC



- Use of **thin single layer model** to approximate the ionosphere

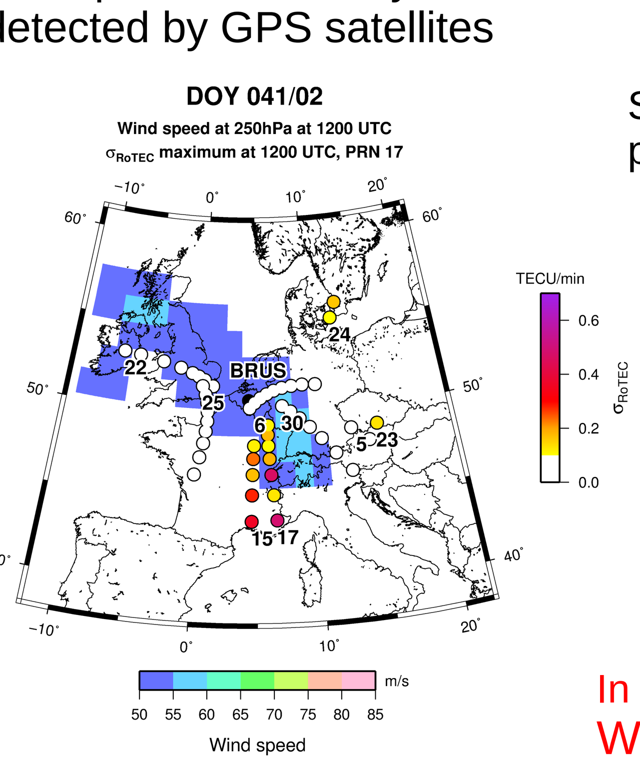


Ionospheric shell height : 400 km
IPP = Ionospheric Pierce Point

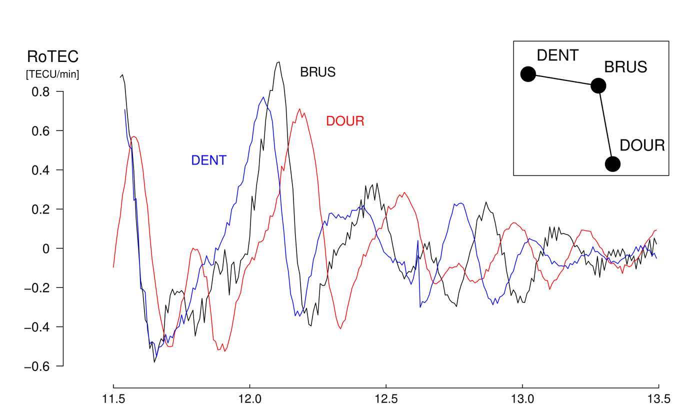


IPP map (24 hours GPS data)
Cut-off : 20°

- Example of winter daytime Medium-Scale Traveling Ionospheric Disturbance (MSTID) detected by GPS satellites



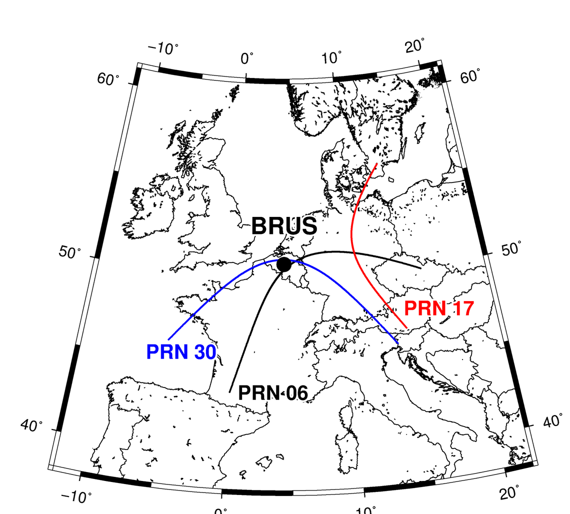
Satellites 15 and 17 detect the same TID, propagating equatorwards

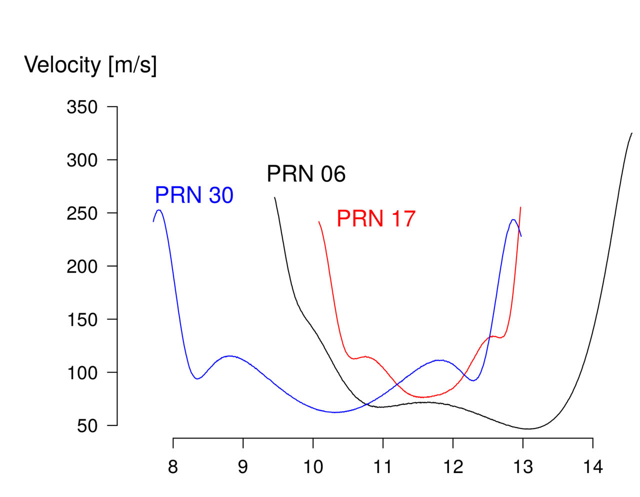


In the same area, sat 30 does not detect any TID !
WHY ??

2. Observational bias: "Doppler-like" effect

- IPP velocity for GPS satellites depends on satellite elevation (ratio 1:7) : 50 to 350 m/s
- Relative motion between TID and IPP results in distortions of apparent TID period in TEC time series, with respect to its true value





➡ Simulation of several configurations:
- TID travels parallel to the satellite
- TID travels anti-parallel to the satellite
- TID travels perpendicular to the satellite (relative velocity is null → no effect)

➡ Simulation of several GNSS constellations

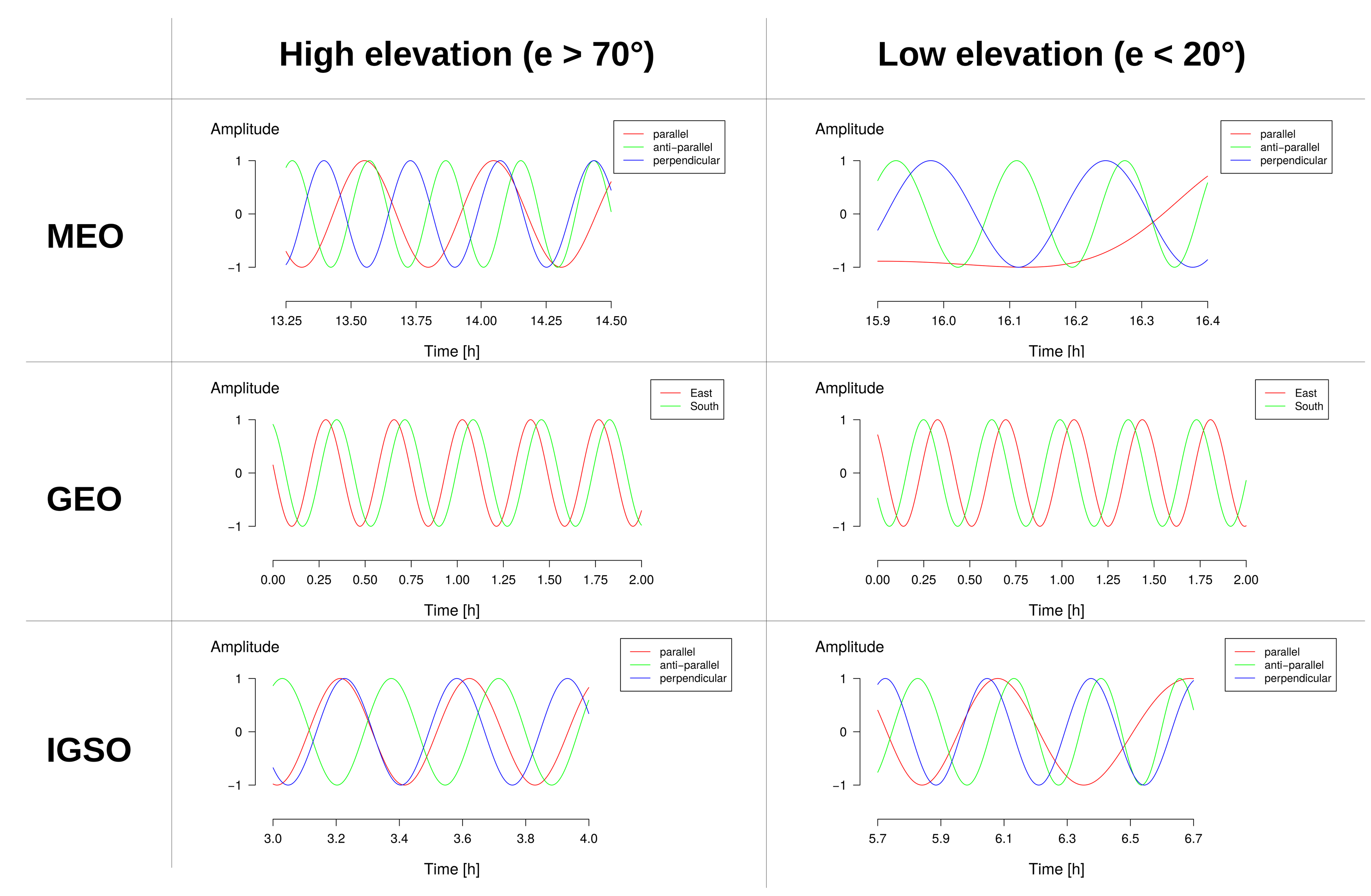
➡ Simulation of two types of TIDs : small-scale (SSTID) and medium-scale (MSTID)

3. Several GNSS simulated

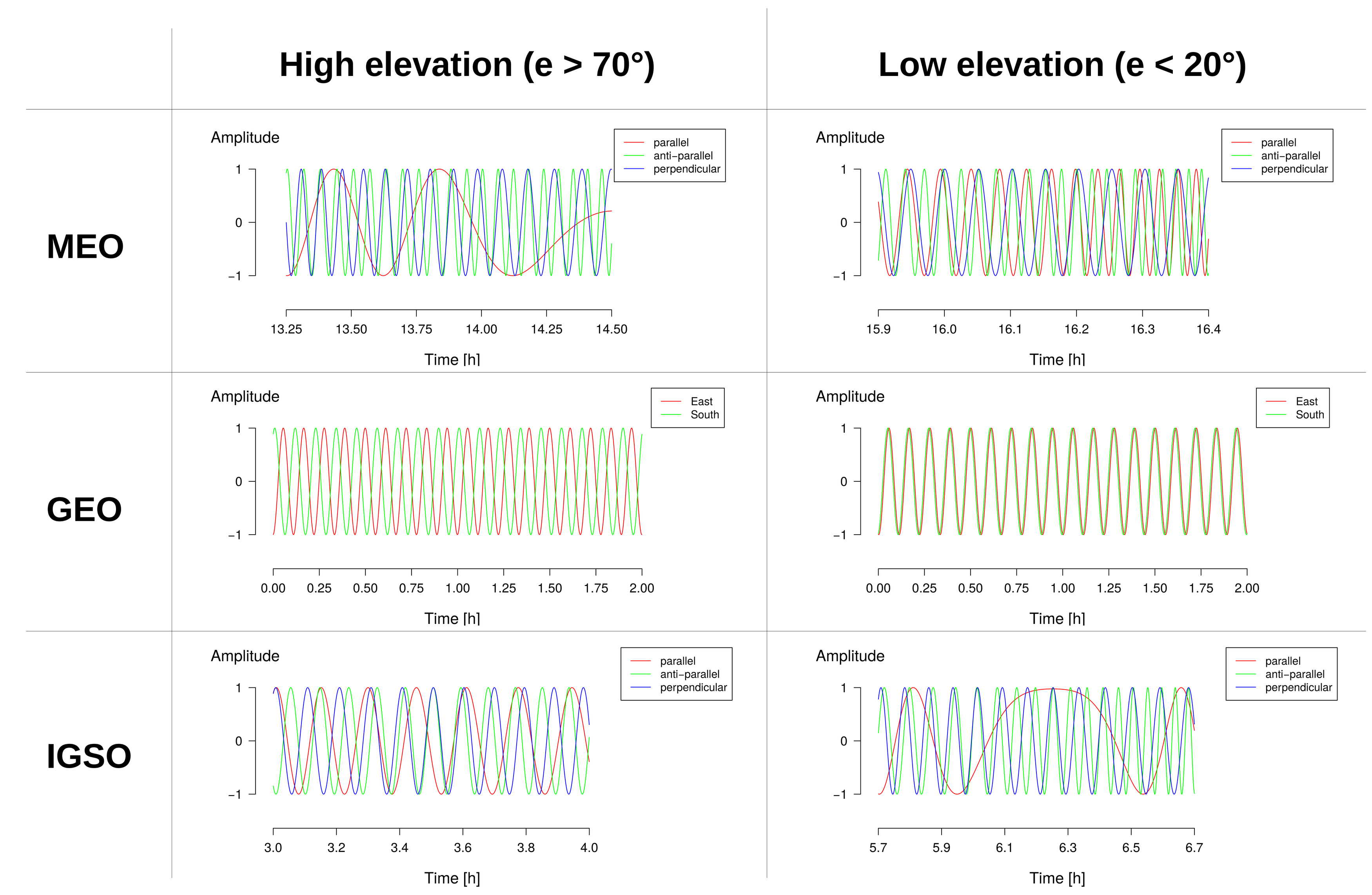
	MEO (medium earth orbit)	GEO (geostationary)	IGSO (inclined geosynchronous)
Name	GPS, GLONASS, Galileo, Beidou	EGNOS, WAAS, Beidou	Beidou
Inclination	55 – 65 °	0°	55°
Period	11h15 – 14h05	1 sidereal day	1 sidereal day
Altitude [km]	19100 – 23222	35786	35786
IPP velocity [m/s]	50 – 350	0	15 - 300

4. Medium and Small-Scale TID simulations : results

- **MSTID** : wavelength = 200 km ; speed = 150 m/s → period = 22.2 min



- **SSTID** : wavelength = 20 km ; speed = 50 m/s → period = 6.7 min



Analysis and conclusions

- The apparent TID period observed in TEC time series can be seriously stretched or shortened with respect to its true value. Some observational conditions do not allow to detect TIDs at all (*i.e.* MSTID not seen with GPS at low elevation, if IPPs and the TID have the same direction)
- Geostationary satellites offer an unbiased view of the TIDs, as their position in the user's sky is fixed. The related period corresponds to the true period of the TID.
- For MSTID study, IGSO satellites allow a better reconstruction of the period compared to MEO ones, thanks to their smaller IPP velocity, even at low elevation.
- Concerning SSTID study, high elevation does not constitute the best observational conditions for MEO satellites, since IPP velocity is the order of magnitude of that of SSTIDs (about 50 m/s).