Tropospheric jet stream as a source of traveling ionospheric disturbances observed by GPS

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Background

- The integrity and the reliability of real-time precise positioning applications with GPS are affected by the ionospheric variability with time and space.
- **Medium-Scale Traveling Ionospheric Disturbances (MSTIDs)** are the prevailing source of ionospheric variability over mid-latitudes.
- More precisely, the bulk of MSTIDs occur during autumn/winter daytime and are not linked to geomagnetic activity
- MSTIDs are understood as the ionospheric signature of **Atmospheric Gravity Waves (AGWs)** whose origin is either *in situ* (solar terminator) or coming from below (AGWs generated in the lower atmosphere and propagating upward).

GOAL = understand the origin of AGWs to predict MSTIDs occurrence and amplitude

1. Ionospheric irregularities detected by GPS

1. Computation of the **Total Electron Content** for each observation epoch

$$\varphi_{GF} = \varphi_{L1} - \frac{f_{L1}}{f_{L2}}\varphi_{L2} = 0,552.10^{-16}\,\mathrm{TEC} + N_{GF}$$

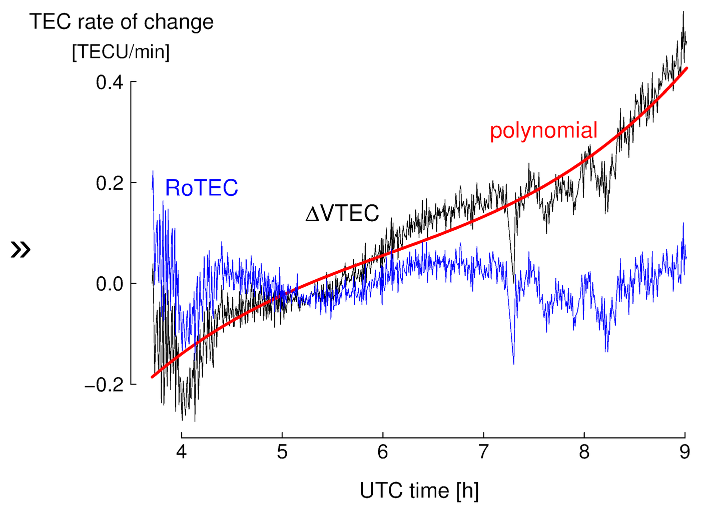
2. Computation of the verticalized **TEC Rate of change** (ΔVTEC)

$$\Delta \mathrm{VTEC}(t_k) = 1,812\,\frac{\left(\varphi_{GF}(t_k) - \varphi_{GF}(t_{k-1})\right)}{(t_k - t_{k-1})}.\cos(z_{PI}) \quad [\mathrm{TECU/min}]$$

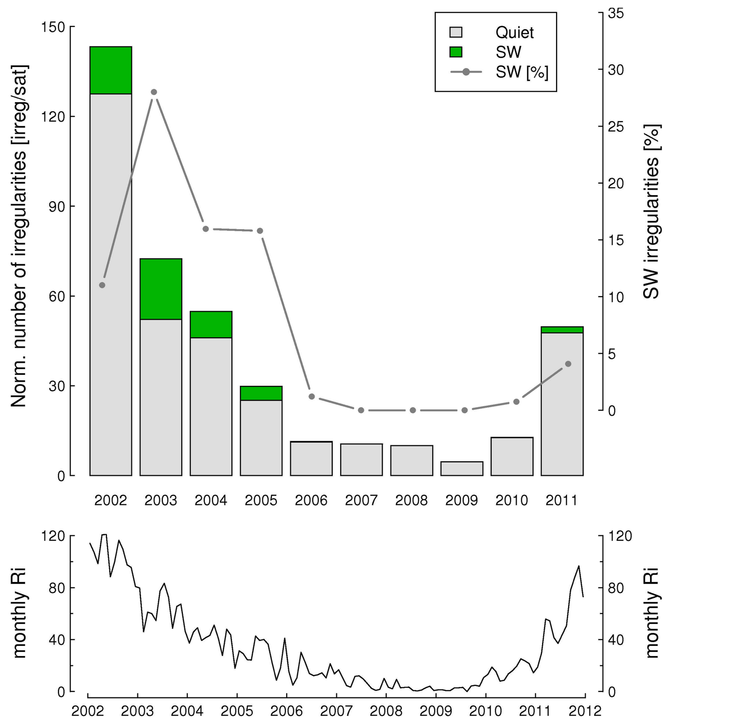
3. **Polynomial fitting** of ΔVTEC time series (satellite arc)

4. Residuals computation: « ΔVTEC – polynomial » called ***Rate of TEC* (RoTEC)**

5. Computation of 15-min **Std. Dev. σ** of RoTEC



Ionospheric irregularity if σ > 0.08 TECU/min

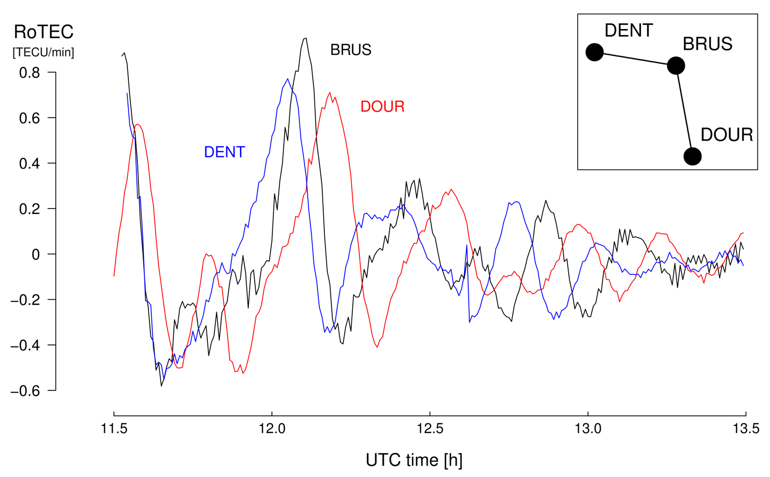


Top panel: yearly number of irregularities per satellite at BRUS as a function of solar cycle and space weather activity. Irregularities are divided into two categories: those due to disturbed space weather conditions (denoted ``SW'') and the others, not related to SW activity (denoted ``Quiet''). *Bottom panel*: corresponding time series of monthly sunspot number Ri [Wautelet *et al.* 2014]

Number of irregularities depend on solar activity, season an local time. Space Weather events (SW) represent a small fraction of observed irregularities over mid-latitudes.

Winter Daytime (WD) MSTIDs represent more than 50% of the total number of irregularities.

WD MSTIDS = ionospheric signature of AGWs



2. Tropospheric origin of AGWs

- In this paper, the phenomenon considered for AGW generation is the tropospheric jet stream at ~ 10 km altitude (non-linear interaction of unstable waves growing in the jet, see Bertin *et al.* 1973).
- Occurrence of strong jet streams during autumn and winter → would correspond to the seasonal activity peak of WD MSTIDs.
- Propagation parameters :
  - Horizontal velocity of 200 m/s [Hernandez-Pajares *et al.* 2006]
  - Vertical velocity of 50 m/s [Artru *et al.* 2005]
  - Ionospheric height at 400 km (single layer approx.)

3. Data

WEATHER

- Maps of wind speed at p=300hPa (altitude around 8-9 km) derived from the ECMWF ERA-Interim re-analysis.
- Wind speed threshold of 50 m/s (180 km/h) to extract large jetstream zones
- ECMWF maps with spatial resolution of 0.75° x 0.75° (cell size) every 6 hours.

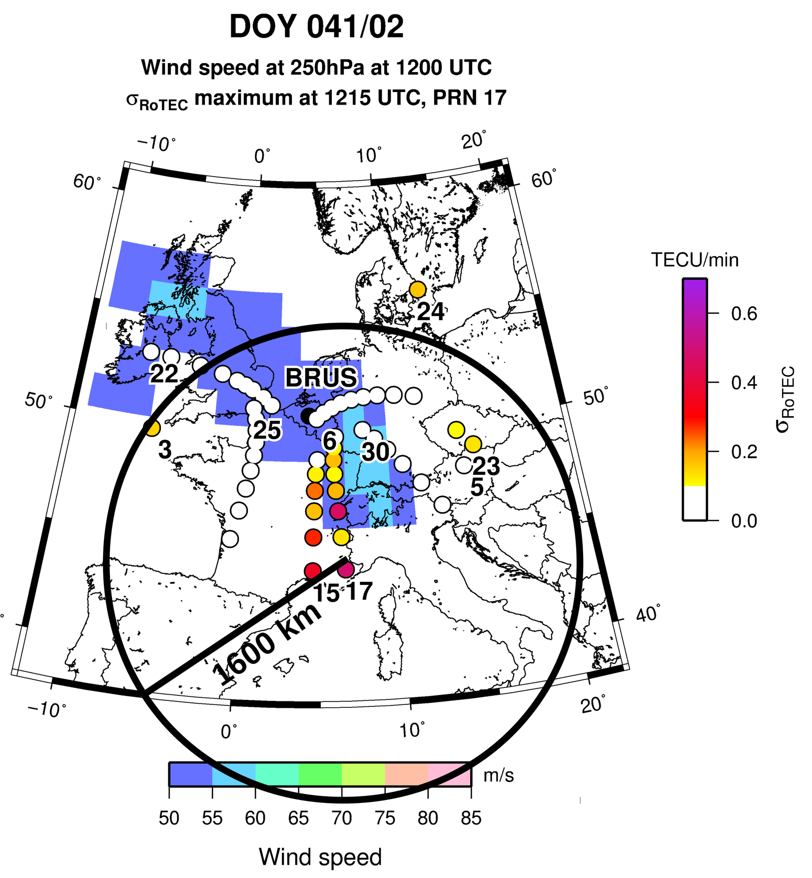
GPS

- Ionospheric variability every 15min for each satellite in view from BRUS station (Belgium)
- Selection of MSTID events during autumn/winter daytime (8 – 16 LT) → more than 4500 cases for the 10 year dataset
- Position of the satellite on the ionospheric shell : ionospheric pierce point (IPP)

4. Algorithm

- Goal = for each MSTID (*i.e.* a 15min period with enhanced variability on a given satellite), check whether a zone of strong wind is located close to the corresponding IPP. The presence of both phenomena at the same place, considering the AGW propagation, would indicate a spatial correlation between tropospheric jet stream and the presence of MSTID.
- How? Given the aforementioned propagation parameter of the AGW, the cell with high speed wind (> 50m/s) must be inside the circle centered on the IPP and having a radius of approx. 1600km, which corresponds to the horizontal distance traveled by the AGW from the troposphere up to the assumed ionospheric layer (400 km)
- Example :

In this example, let us consider the first IPP of the PRN 17, which exhibits a larger variability (purple dot).
We have superimposed the wind speed field (threshold of 50 m/s) and drawn a circle of 1600km radius centered on the IPP.
In this case, strong winds (at least 60 m/s) were blowing in the tropospheric level, making the spatial correlation between MSTID and strong jet stream positive.



5. Results

- Analysis of the approx. 4500 cases derived from our GPS dataset (table 1) shows that there is a significant spatial correlation between a strong jet stream and the presence of winter daytime MSTIDs.
- The results are not sensitive to the threshold of σ_{RoTEC} used : similar results have been found for different values of this parameter.
- This suggests that strong wind shears associated with high speed winds would generate AGWs observed as MSTIDs some 400km higher.
- However... Running the same methodology but using a more severe wind speed threshold (60 m/s) gives less significant results (table 2)

Year	% of cases (WS > 50 m/s)
2002	78
2003	78
2004	87
2005	86
2006	77
2007	90
2008	86
2009	74
2010	84
2011	71

Table 1. Percentage of cases for which a spatial correlation between strong wind speed (WS > 50 m/s) and an MSTID has been observed

Year	% of cases (WS > 60 m/s)
2002	52
2003	40
2004	51
2005	50
2006	40
2007	56
2008	61
2009	40
2010	44
2011	43

Table 2. Same as table 1, except that WS > 60 m/s

- Therefore, is the observed correlation due to a too low threshold of wind speed (*i.e.* there are too many tiles with WS > 50 m/s)?
- Similar computation should be performed with other meteorological features, such as wind speed gradients, allowing to detect regions of strong wind shears able to generate waves
- In addition, this study does not take into account the effect of background wind. This parameter should be integrated in a deeper analysis to explain potential wave reflection or to compute more accurately the horizontal distance traveled from the source up to the ionosphere

Conclusions and future work

- 10 years of GPS data in Belgium allowed to identify more than 4500 cases of winter daytime MSTID and their relationship with strong jet stream has been studied based on spatial correlation analysis using meteorological maps.
- For more than 80% of the cases in average, a zone of strong winds was blowing below the MSTID detected in the ionosphere.
- However, the presence of simultaneous and nearly colocated phenomena does not imply any causality...
- Observations of atmospheric dataset (temperature, density and pressure) from the troposphere up to the thermosphere should be included to be able to trace the travel of the AGWs.
- Moreover, future computations should use other types of meteorological data, such as wind speed gradients or divergence to better identify the source regions.

References

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