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High time resolution TEC and ionosonde observations at Dourbes, Belgium, during the March 2015 solar eclipse

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ABSTRACT

A total solar eclipse occurred on 20 March 2015 over the North Atlantic. As a result, a partial solar eclipse was visible over Belgium, with a maximal eclipse of 81.5% happening at 9:34UT. An eclipse will of course have an effect on the ionosphere and therefore also on the delay of the GNSS signals. Effects of previous solar eclipses on the ionosphere in general and GNSS signals in particular have been studied before [1–3]. However, we present here for the first time a comparison of GNSS-based TEC measurements during an eclipse, not only with measurements of the key ionospheric E- and F-layers' characteristics, but also with high time resolution observations of the ionospheric plasma drift and tilt.

In some respects the conditions during an eclipse are similar to those around sunrise and sunset. However, there are also some important differences. The first difference is that, over a single location, the eclipse happens relatively quickly. The onset of the eclipse, as observed from Belgium, happened at 8:27UT, while it ended at 10:47UT. Thus, both the decreasing and increasing phases in solar irradiation take about one hour in total. This means that the ionosphere does not have enough time to reach equilibrium, typical for night-time conditions, but remains out of equilibrium for the entire period of the eclipse.

The second important difference between the effects of a solar eclipse and the normal sunset/sunrise behavior is that the former is very localised. The region of eclipse totality is rather small, and even the region where a partial eclipse is visible is also relatively small. Therefore, again, the ionosphere during a solar eclipse is out of equilibrium. While the region of the ionosphere that is in the Moon's shadow experiences a decrease in ionisation as well as cooling, the surrounding areas remain in a normal day-time condition, causing the formation of strong gradients. As a consequence, transport process will be of major importance with plasma flowing towards the eclipsed region.

One significant effect of the non-equilibrium condition of the ionosphere is that, while the peak level density can be depleted to values normally associated with night-time conditions, the shape of the electron density profile during eclipse is not the same as the profile during night. In the bottom-side of the ionosphere, the E-layer is still present (albeit reduced) during eclipse but not during night. In the topside ionosphere, the non-equilibrium conditions during eclipse pose major difficulties when modelling the (vertical) plasma distribution, for which no adequate measurement are available for data-assimilation , so models have to rely on theoretical/empirical profilers [4]. One way to characterise this change in the profile shape is to use the ionospheric slab thickness, defined as the ratio of TEC to peak electron density. Figure 1 shows the deviations of the slab thickness from the monthly median around the day of the eclipse. At the moment of maximal eclipse, there is a relative increase of 100%, but due to the after-effects of a major geomagnetic storm that started a couple of days earlier, on 17 March 2015, this effect is superimposed on even larger deviations from the median.

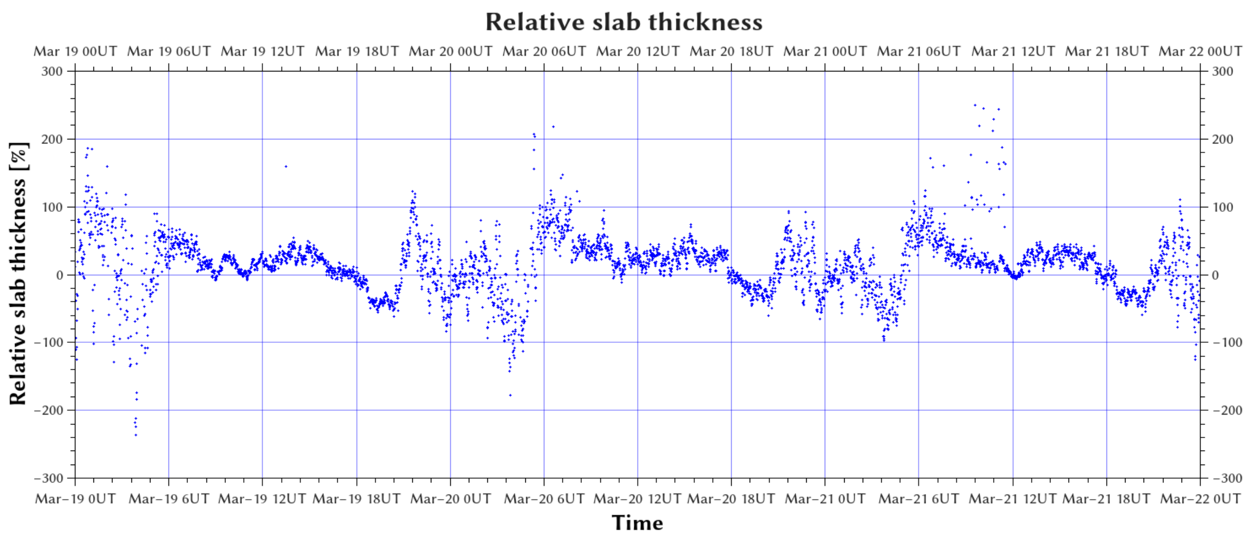

Figure 1: Three days—March 19 to March 21, 2015—of relative slab thickness, calculated from the DourbesDigisonde and GNSS receiver observations. The effect of the solar eclipse during the morning of March 20 ispartially obfuscated by the influence of a major geomagnetic storm on March 17, which causes deviations from themedian in the slab thickness for a long period afterwards (mostly the nigh-time deviations are the result of thisstorm). Note also that these data have not been manually corrected, resulting in some outliers; e.g. during themorning of March 21.

In addition to the general non-equilibrium state of the ionosphere, it can also be expected that a solar eclipse will cause some traveling ionospheric disturbances (TIDs). These smaller scale disturbances are not immediately visible, neither in the TEC data nor in the ionograms if viewed separately. Nevertheless, considering the fact that TIDs are possible source of scintillations in the GNSS signals, it is important to track TIDs during eclipses.

With the Digisonde-4D installed in Dourbes (50.1°N, 4.6°E), direct measurements of ionospheric tilts and plasma drifts (SkyMaps) can be made in addition to the traditional vertical soundings. For the observation of the 2015 solar eclipse, a special campaign was run, during which both an ionogram and a SkyMap measurement were obtained every thiry seconds. In Figure 2, high time

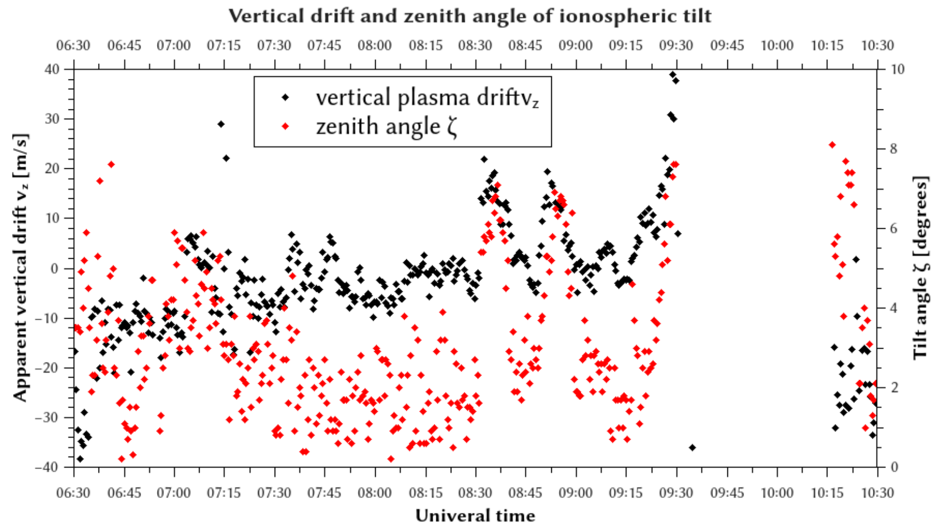

Figure 2: Apparent vertical drift and ionospheric tilt measured by the Dourbes Digisondeon March 20, 2015. Two minor disturbances can be seen before the larger one at themoment of the solar eclipse.

resolution observations of the vertical plasma drift and the zenith angle of the ionospheric tilt, determined by the Dourbes Digisonde, are shown. These drift and tilt data show signs of TIDs, which can also be seen in the profilograms derived from vertical soundings.

References:

[1] Afraimovich, E.L., Palamartchouk, K.S., Perevalova, N.P., Chernukhov, V.V, Lukhnev, A.V., Zalutsky, V.T. (1998), Ionospheric effects of the solar eclipse of March 9, 1997, as deduced from GPS data, Geophysical Research Letters, Volume 25, Issue 4, Pages 465–468, doi:10.1029/98GL00186.

[2] Altadill, D., Sole, J.G., Apostolov, E.M. (2001), Vertical structure of a gravity wave like oscillation in the ionosphere generated by the solar eclipse of August 11, 1999, Journal of Geophysical Research, Volume 106, Pages 21419–21428, doi:10.1029/2001JA900069.

[3] Jakowski, N., Stankov, S.M., Wilken, V., Borries, C., Altadill, D., Chum, J., Buresova, D., Sauli, P., Hruska, F., Cander, Lj.R. (2008), Ionospheric behavior over Europe during the solar eclipse of 3 October 2005, Journal of Atmospheric and Solar-Terrestrial Physics, Volume 70, Issue 6, pages 836–853, doi:10.1016/j.jastp.2007.02.016.

[4] Verhulst, T., Stankov, S.M. (2015), Ionospheric specification with analytical profilers: Evidences of non-Chapman electron density distribution in the upper ionosphere, Advance in Space Research, Volume 55, Issue 8, Pages 2058–2069, doi:10.1016/j.asr.2014.10.017.

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Key words: Solar eclipse, High time-resolutions observations, Digisonde observations, Single station VTEC