Deliverable: **WP0**

Document: **Report**

Author: **Horia Ghionoiu Martínez**

Submitted on 1st August 2021

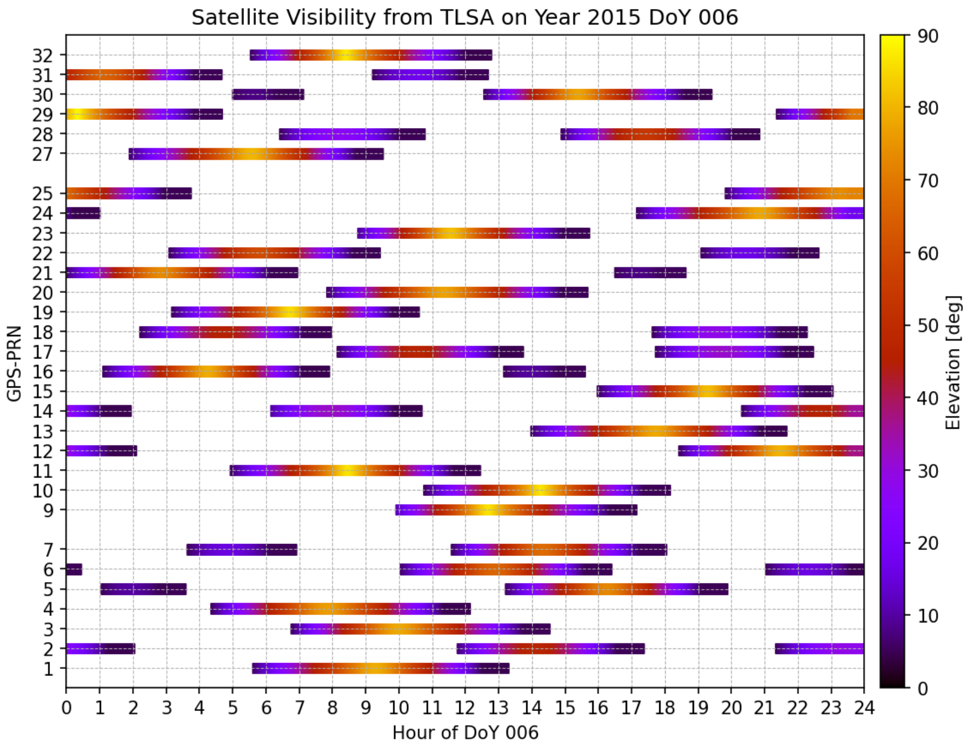
Introduction

This report presents the results asked in the WP0 statement of work. The initial Python code which was given to the student plotting the T2.1, T2.2, T2.3 plots, has been extended to plot the additional 18 figures presented following.

Next are presented the results, together with a brief explanation. The Python code is attached to this report in a tar file.

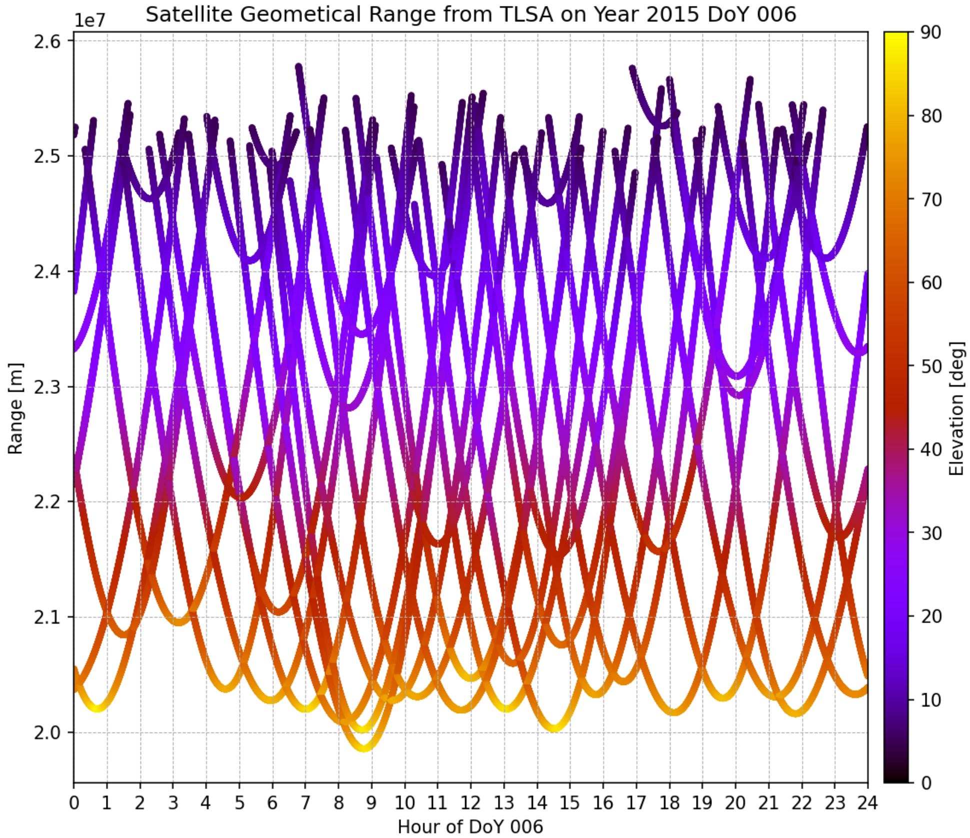
Results

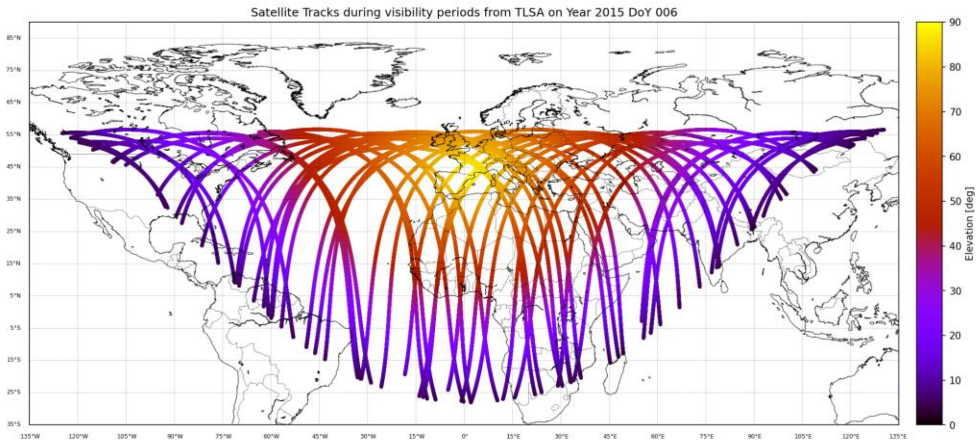
T2	Satellite AND Geometry related plots
T2.1	
Analysis	Figure shows that satellites are visible from Toulouse RIMS one or twice a day (e.g. PRN 27, and PRN 30). If a satellite passes twice a day, one of the passes is shorter and of poor quality (low elevation E<30º) (e.g. PRN 16), thus it may be discarded by the RCVR pre-quality checks. A pass lasts for 6-8h (e.g. PRN 16).

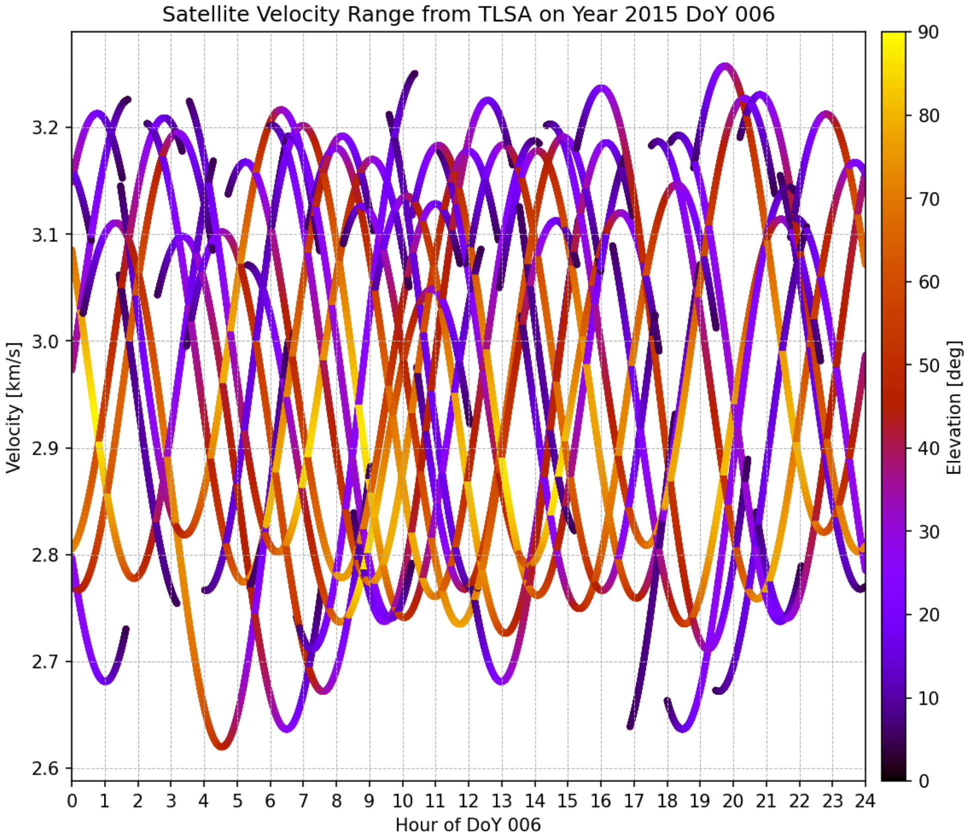
<table>
<tr><td>Output</td><td>
</td></tr>
<tr><td></td><td></td></tr>
<tr><td>T2.2</td><td></td></tr>
<tr><td>Analysis</td><td>Satellites range varies between 20 000-25 000km, as expected for a GPS constellation (~20 200km).

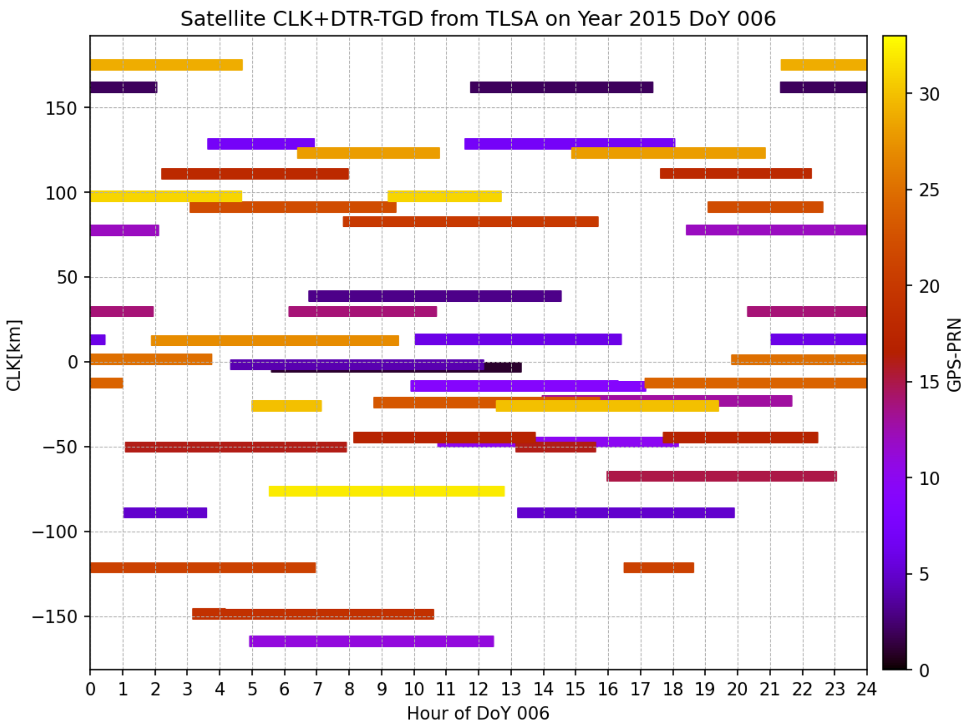
Range is greater for low elevation (E<30º) passes (Range=23 000-25 000km).

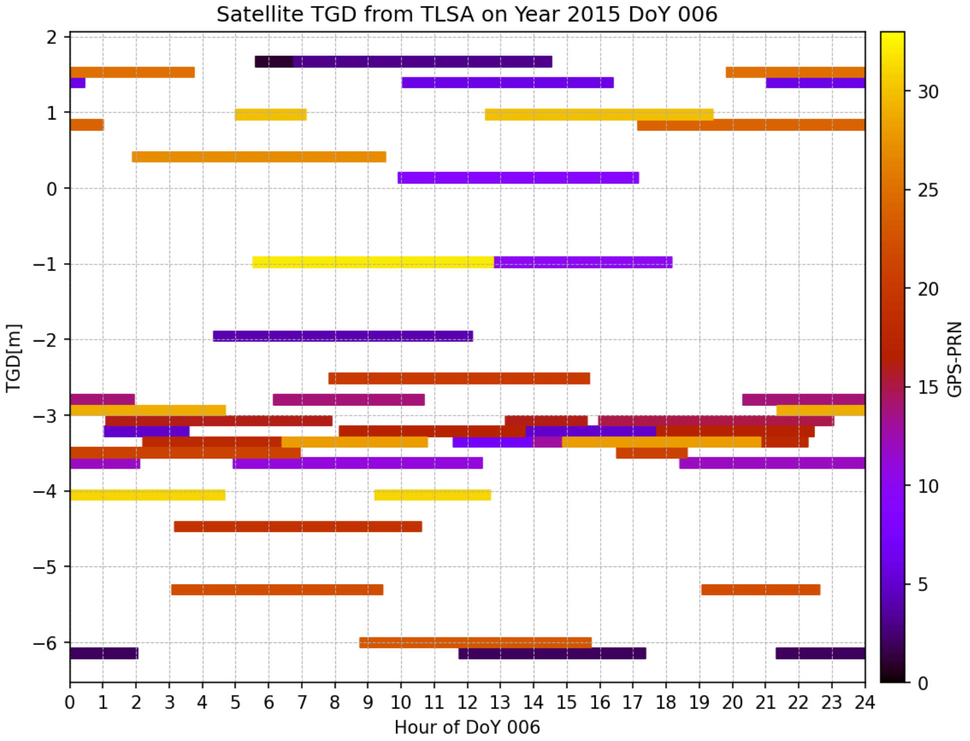
Range is smaller for high elevation passes (Range=20 000-23 000km).</td></tr>
</table>

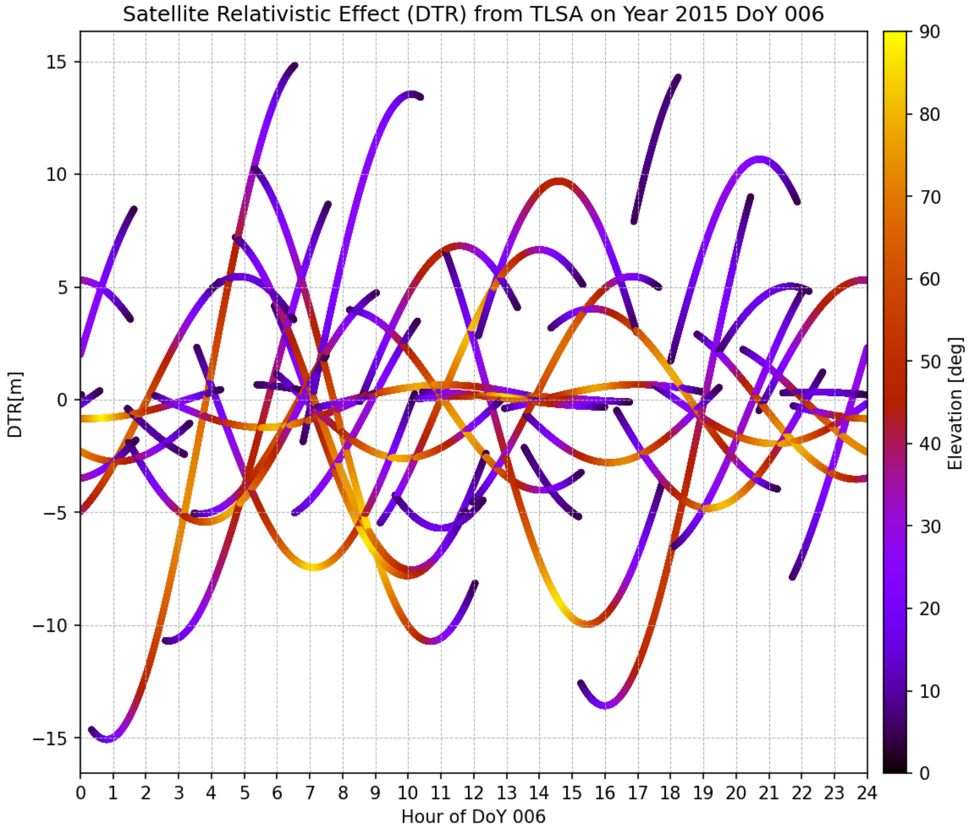
Output	
T2.3	
Analysis	The GPS constellation tracks CoG (Center of Gravity) seems located at west Europe (Spain), if you consider that the CoG is the center of the tracks plot and where the higher elevation falls. I was expecting the tracks to be centered around North America, as it's a military US project, because I consider that having the higher elevation passes above your territory will give you better performances within it. In any case, it remains clear that the coverage is marginal (or poorer) in high latitude regions (e.g. polar regions).

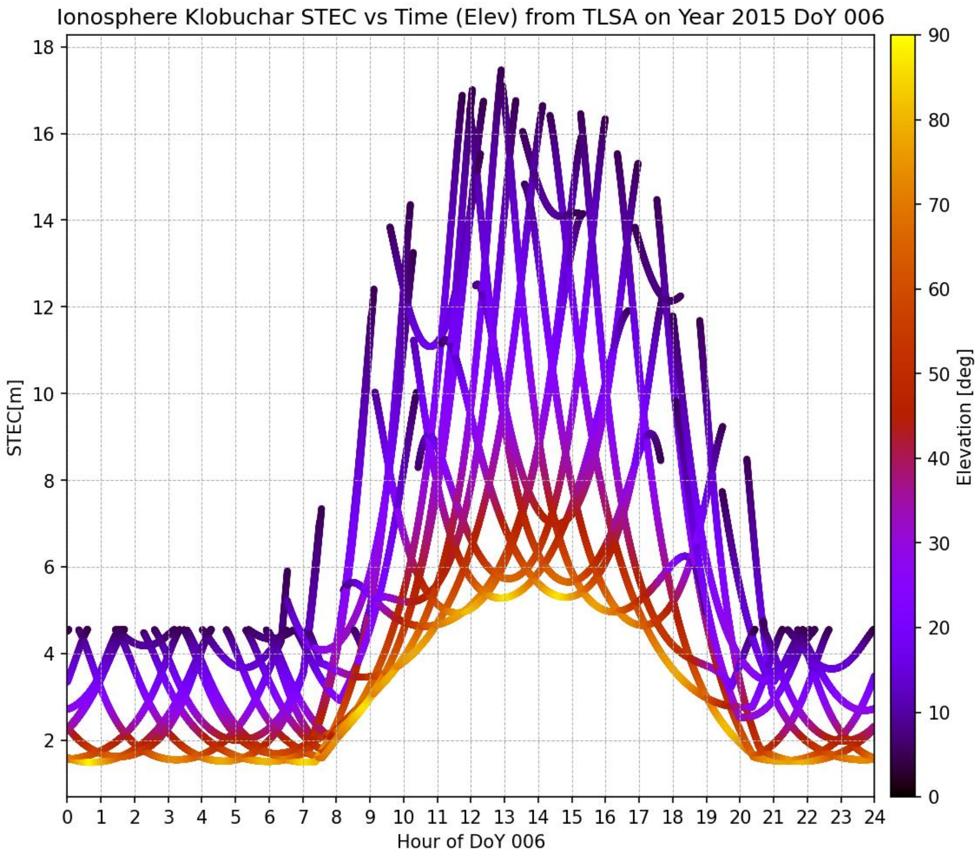
Output	
T2.4	
Analysis	The satellite's velocities vary between 2.6-3.2km/s, as expected for the GPS constellation. The velocities are not constant, as the orbits are not perfectly circular. No clear relation between satellite elevation and velocity.

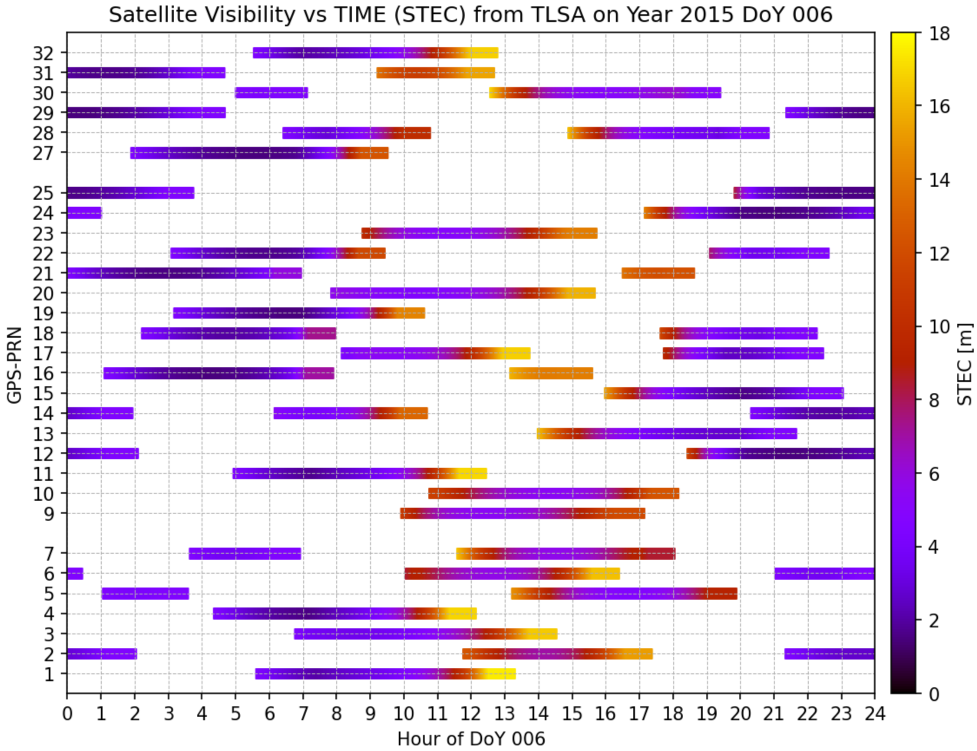
Output	
T2.5	
Analysis	The mono-frequency satellite clock is of the order of 1ms (1ms==300km). The values vary between +-200km. No correlation is found between satellite (PRN) and clock delay.

Output	
T2.6	
Analysis	The figure shows the typical value of the total group delay parameter TGD for the GPS constellation is in the range of 0-8 meters.

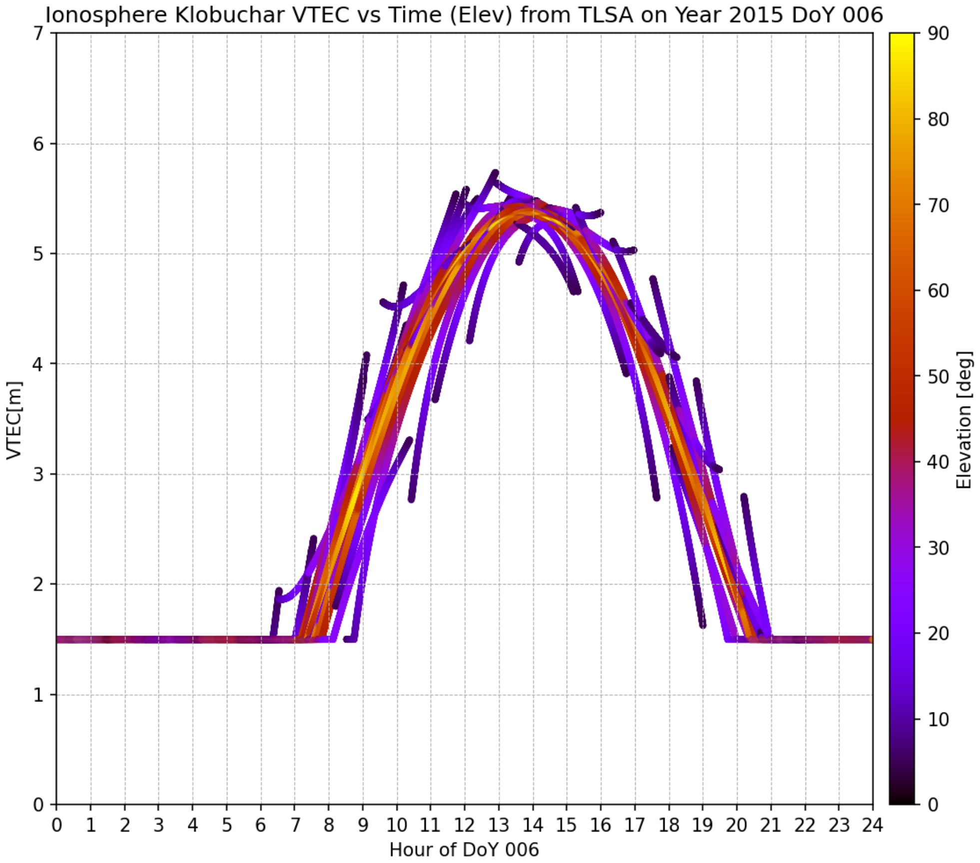
Output	
T2.7	
Analysis	The figure shows the typical value of the satellite relativistic clock error for the GPS constellation is in the range of 0-30 meters. This means that if RCVR doesn't correct accounting for the relativistic effect, it may end up with position errors of up to 30m.

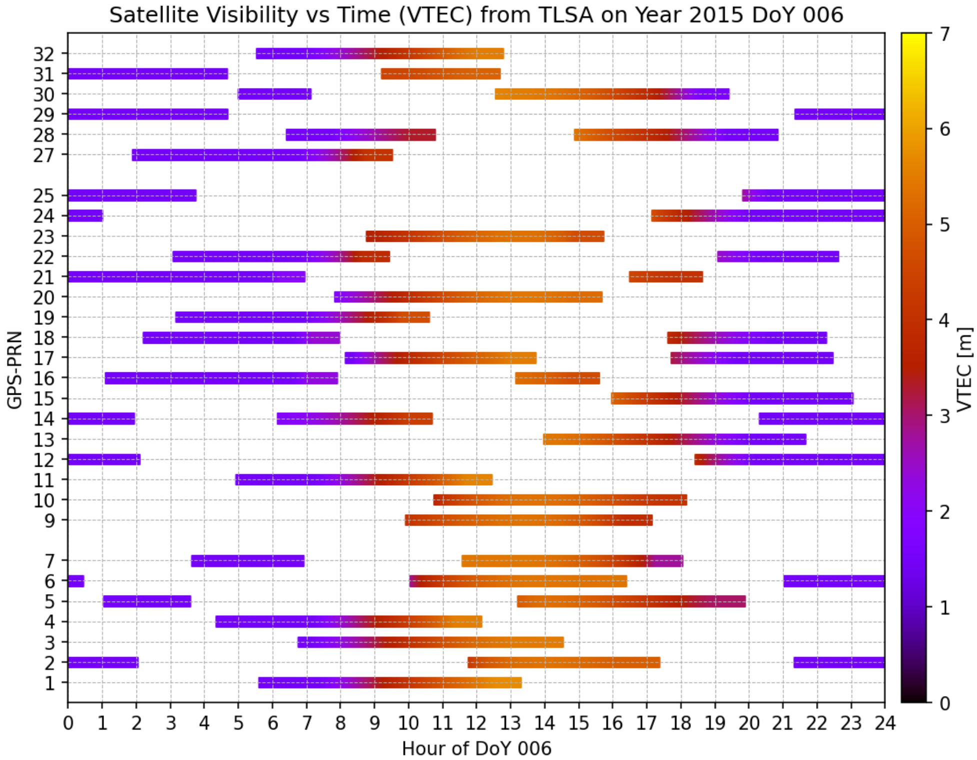
Output	
T3	**Ionosphere related plots**
T3.1	
Analysis	The figure shape is the expected, clearly following the Klobuchar Model constant-sinusoidal shape. It can be seen the STEC Ionosphere delay for a RCVR in Toulouse is in the range of 2-18m. During night, it is assumed a constant 9 TECU's, so delay remains constant around 2m (only varies with the elevation E). It has been a paper which concludes that this constant night value should be updated. See references. It is observed that lower elevations increase ionospheric delay up to three times (eg. 13h 5m@E90º vs 17m@E10º).

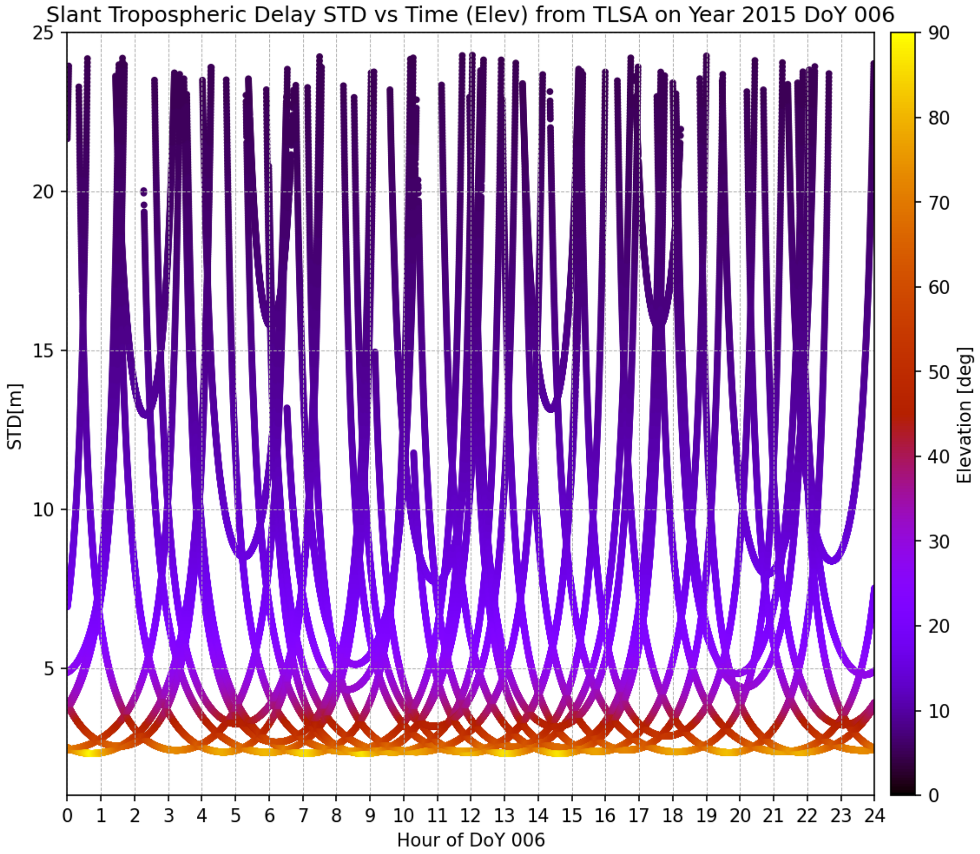
	It is observed that greater elevations reduce the ionospheric delay, as the STEC value tends to get closer to the VTEC, resulting in a shorter signal traveling path, so less delay due to ionospheric effects.
Output	
T3.2	
Analysis	Complementing the T3.1 figure, here can be clearly seen the peak in solar activity, and hence in ionospheric delay in the middle day hours (12-16h). The satellites which at peak solar hours (e.g. PRN 7) have low STEC value, is because of their higher elevation, and vice versa.

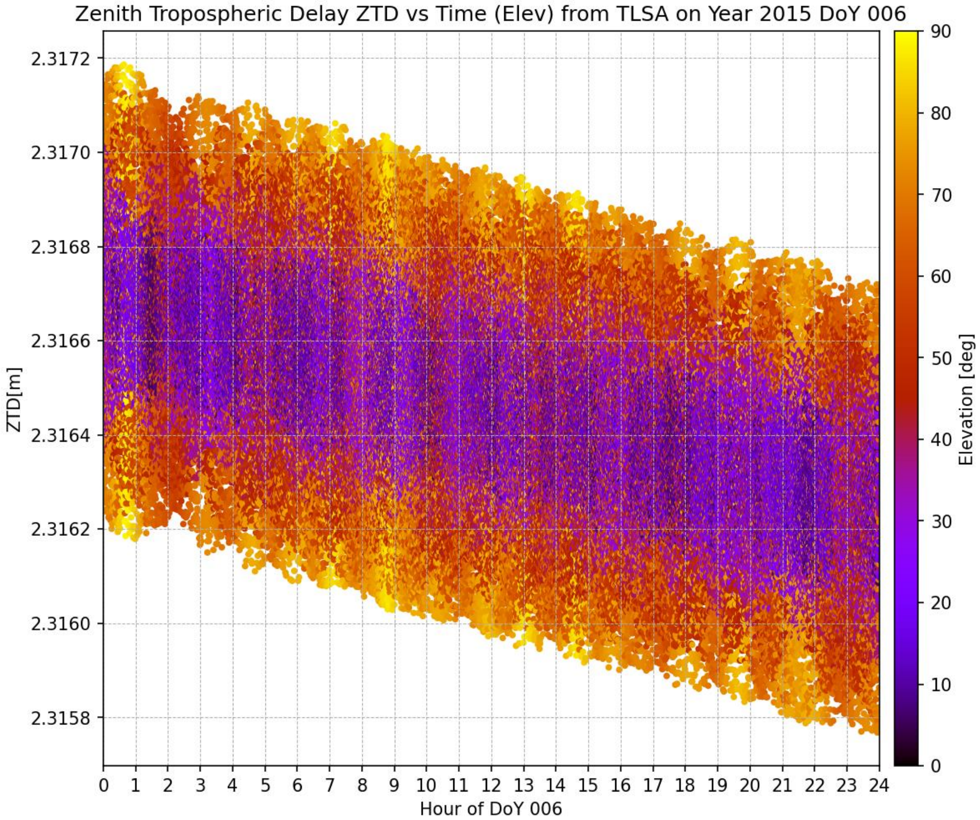
<table>
<tr><td>Output</td><td>
</td></tr>
<tr><td></td><td></td></tr>
<tr><td>T3.3</td><td></td></tr>
<tr><td>Analysis</td><td>As in figure T3.1, the Klobuchar Model shape is seen in the figure. In this figure the ranges vary from the constant Klobuchar Night value of 1.499m to around 6m.

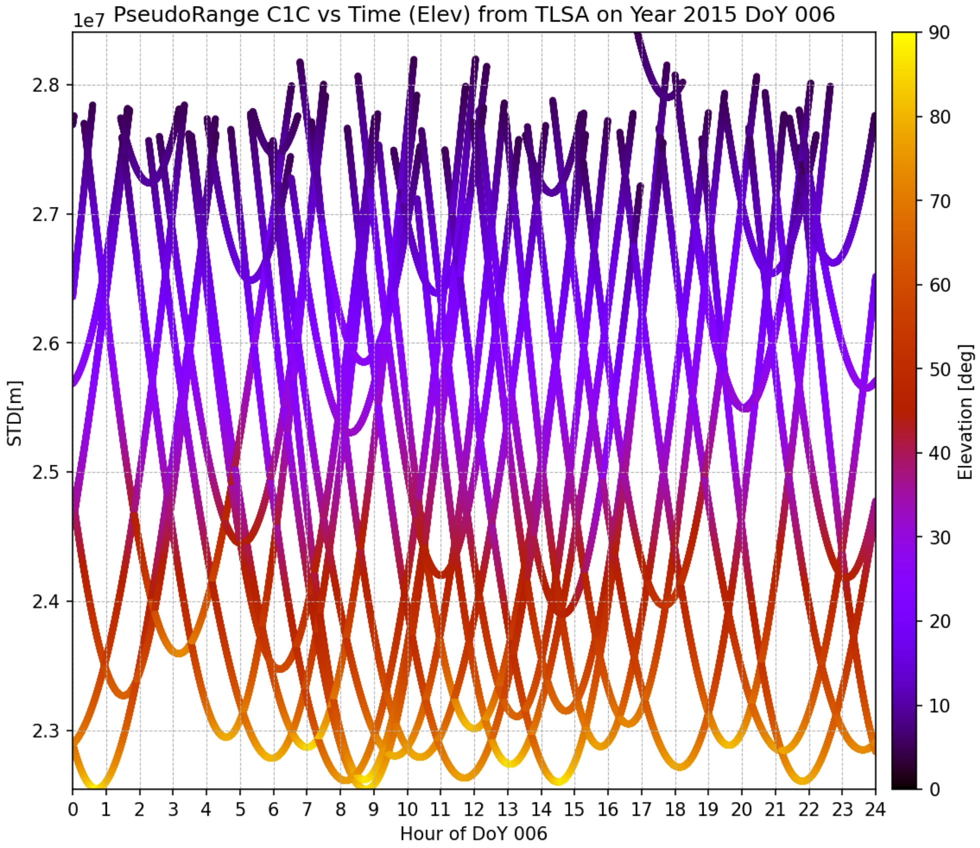
This figure is elevation dependent, as the STEC values are mapped with a mapping function which depends on the cosinus of E. This variation is lower in range as in the STEC plot.</td></tr>
</table>

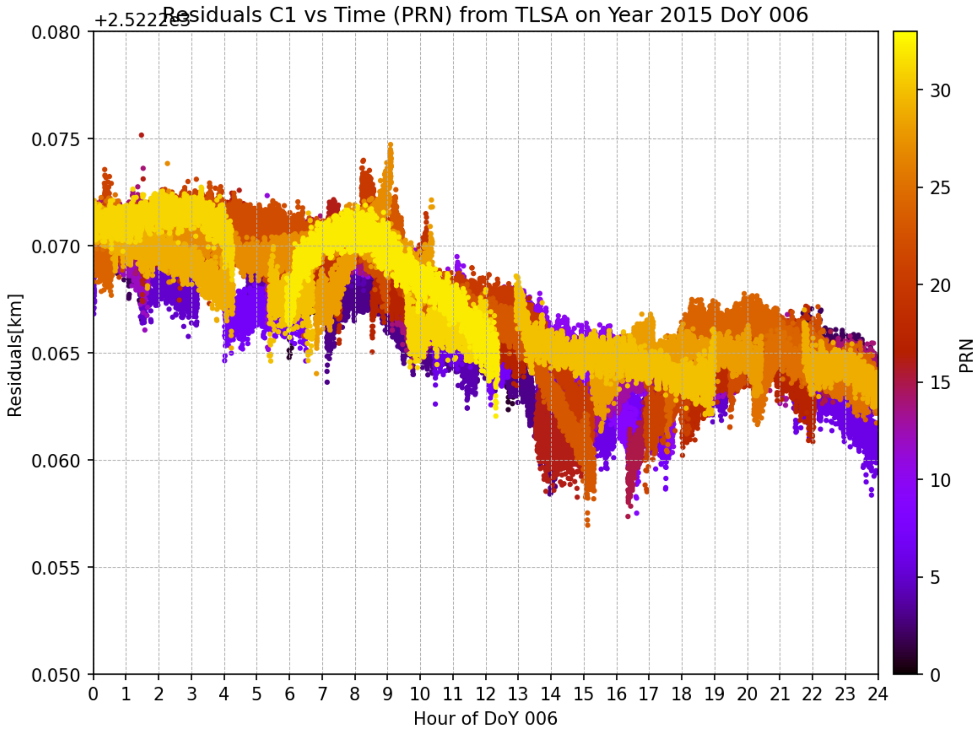
Output	
T3.4	
Analysis	This figure shows greater VTEC values when the solar activity is higher (e.g. 13-16h). It is also seen that the VTEC is less dependent on satellite elevation, which is consistent with the observations of the T3.3 figure.

Output	
T4	**Troposphere related plots**
T4.1	
Analysis	The tropospheric delay is up to 2-2.5m in the zenith direction, and up to 20-25m for very low elevations (E<10º).

Output	
T4.2	
Analysis	The tropospheric delay in zenith direction has a value which oscillates around 2.31m Its tendency throughout the day is to decrease. This is assumed to be because of the model used for the dry and wet components of the tropospheric delay.

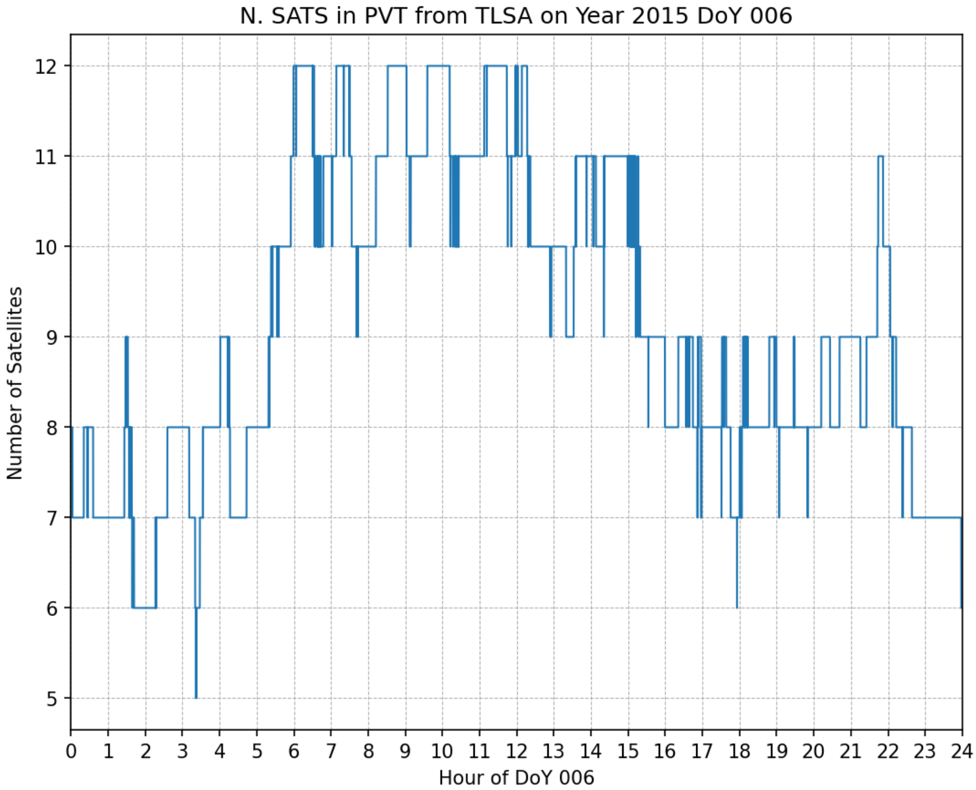
Output	
T5	**Measurements related plots**
T5.1	
Analysis	There is a typo in the y axis label of the plot, the correct label is ‘Pseudo-Range[m]. The GPS constellation pseudoranges are varying between 22 000km and 28 000km (approx). Low elevation passes tend to have larger pseudorange values.

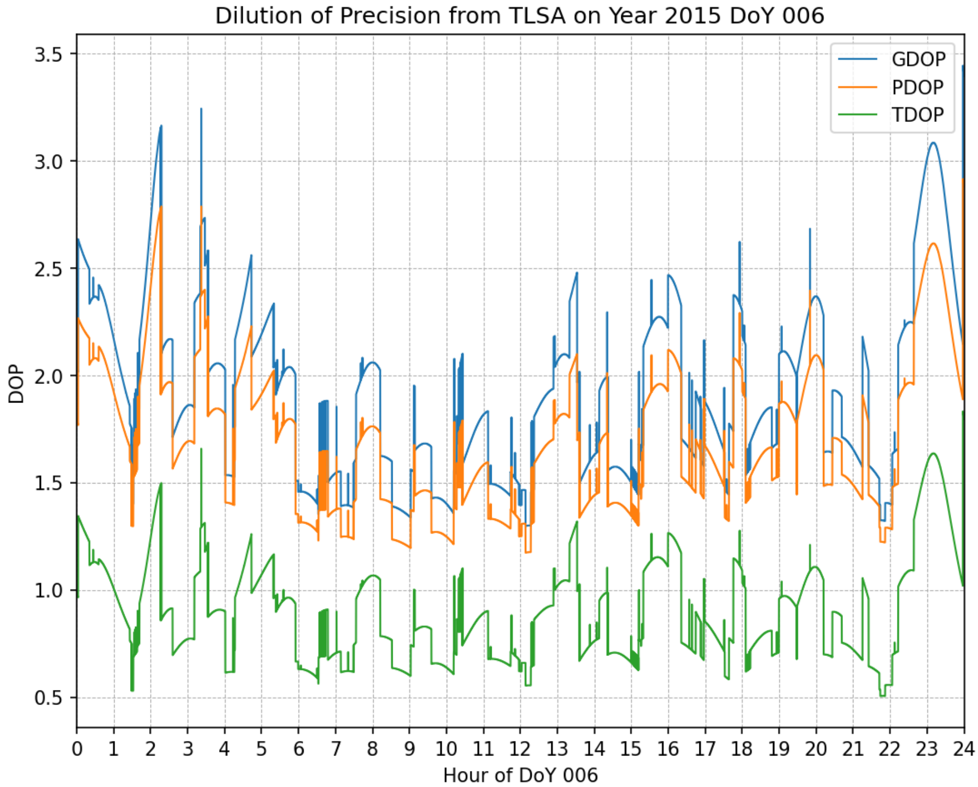
Output	
T5.2	
Analysis	I am not sure of fully understanding this figure. The y axis scale is weird. I have tried without success to accommodate the scale around 2500 in plain numbers, but Pyplot displays a weird scientific notation which makes the graph difficult to read. I apologise and I will try to solve this issue for the next occasions. It has a clear decreasing tendency throughout the day. The plot measures the size of the residual between the satellite pseudorange and the corrected geometrical range. So I conclude that it is a measure of the error I would obtain in the position if I wouldn't correct for the satellite clock, ionosphere, and troposphere, and I just would consider Range=c*travel time. I assume that the error is so large because it includes the receiver clock offset error (some hundreds kilometers) and other mismodeling errors.

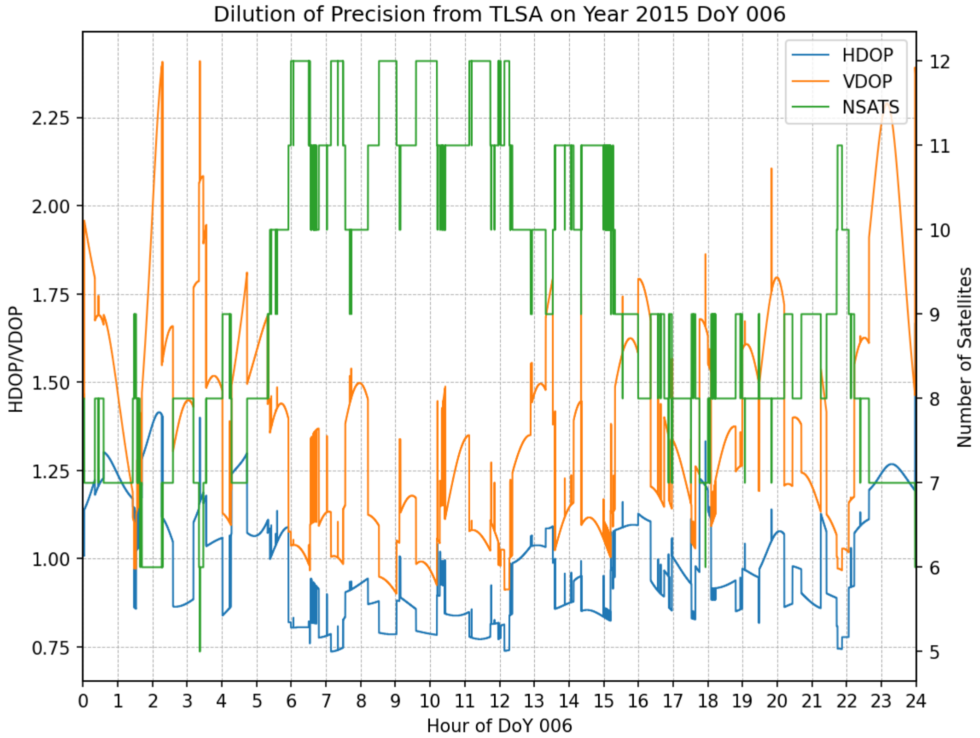
<table>
<tr><td>Output</td><td>
</td></tr>
<tr><td></td><td></td></tr>
<tr><td>T6</td><td>Position related plots</td></tr>
<tr><td>T6.1</td><td></td></tr>
<tr><td>Analysis</td><td>Very interesting plot, where one observes the number of satellites used for computing the PVT solution throughout the day.

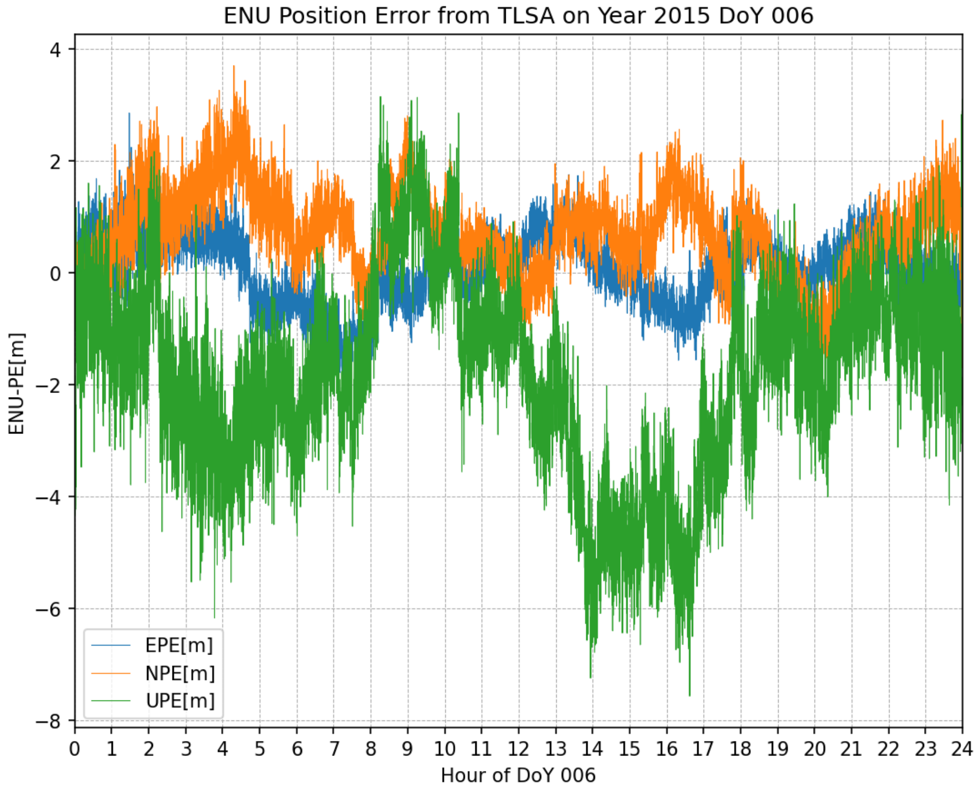
Its seen that the number of satellites used varies from 6-12.

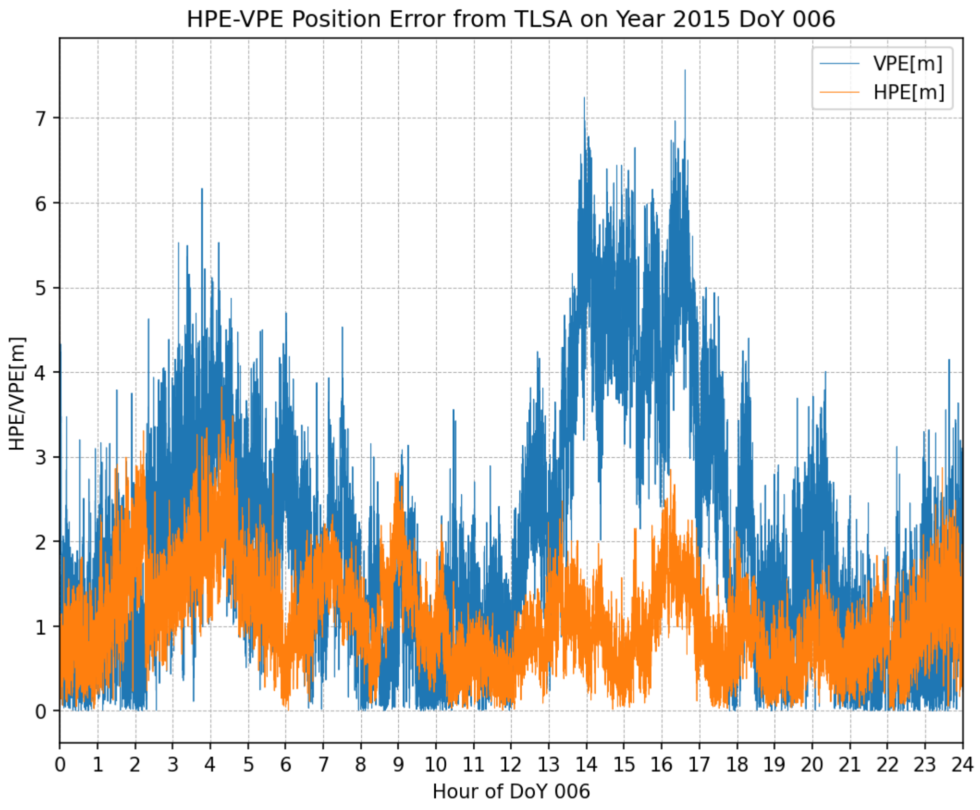
Its also notable that from the Toulouse RIMS station, a higher number of GPS satellites are in the line-of-sight between 6-13h, and a lower number of them between 14-5h.</td></tr>
</table>

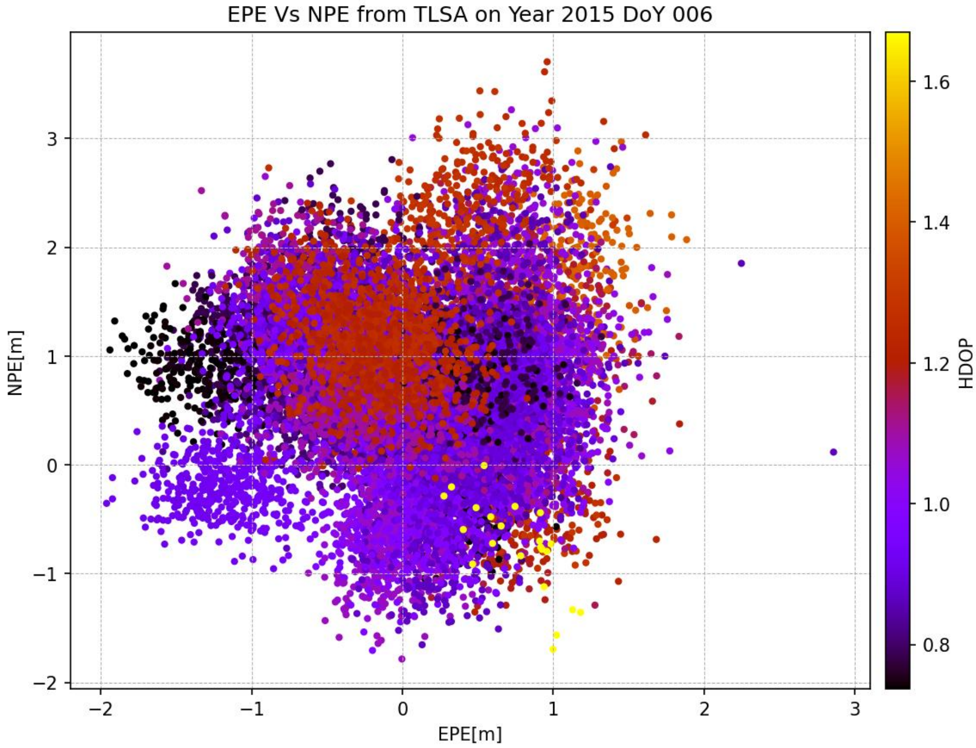
Output	
T6.2	
Analysis	I am not sure of fully understanding this figure. I understand that XDOPs are, to some extent, projections of the geometrical G matrix, which accounts for the geometric arrangement of the constellation of satellites used in the PVT computation. Their values range 0.5-3 (adimensional), and are rather constant and similar throughout the day (GDOP, PDOP) while TDOP follows a similar tendence, but with lower values.

Output	
T6.3	
Analysis	I am not sure of fully understanding this figure. It is seen an inverse tendency of the satellites used in the PVT solution and the HDOP/VDOP values. VDOP is in general greater than HDOP, which I assume would lead to greater position errors in the zenith direction.

Output	
T6.4	
Analysis	Consistently with the comments from T6.3, the vertical error (Up direction) seems larger than the East-Up errors, in the local geodetic coordinate system. I conclude from this and the previous figures, that the higher the number of satellites used in the solution, the better vertical position I will compute.

Output	
T6.5	
Analysis	Same tendency as in T6.4, and T6.3. In this case the previous figure data is mapped as absolute value in the zenith direction and the norm in the EN plane (RCVR tangent at surface).

Output	
T6.6	
Analysis	Very interesting graph, which shows from a bird's eye view the in-plane error, together with the horizontal dilution of precision HDOP value in the color bar. It is seen a clear relation between low HDOP values, and greater position error (blue dots).

Output	

Conclusions

In this report, there have been plotted and analysed 21 GNSS performance figures, related to satellites position, ionospheric and tropospheric delays, measurement computations, and positioning performance.

I am happy with the results, although I feel that I must study more GNSS theory, to fully understand all the figures. I have also practiced some Python programming and Linux terminal manipulation, which make me more confident for the next work packages.

References

Determination of nighttime VTEC average in the Klobuchar ionospheric delay model - https://www.sciencedirect.com/science/article/pii/S1674984716301872
Navipedia - https://gssc.esa.int/navipedia
GNSS Academy - JNSP Modules M1, M2, M3