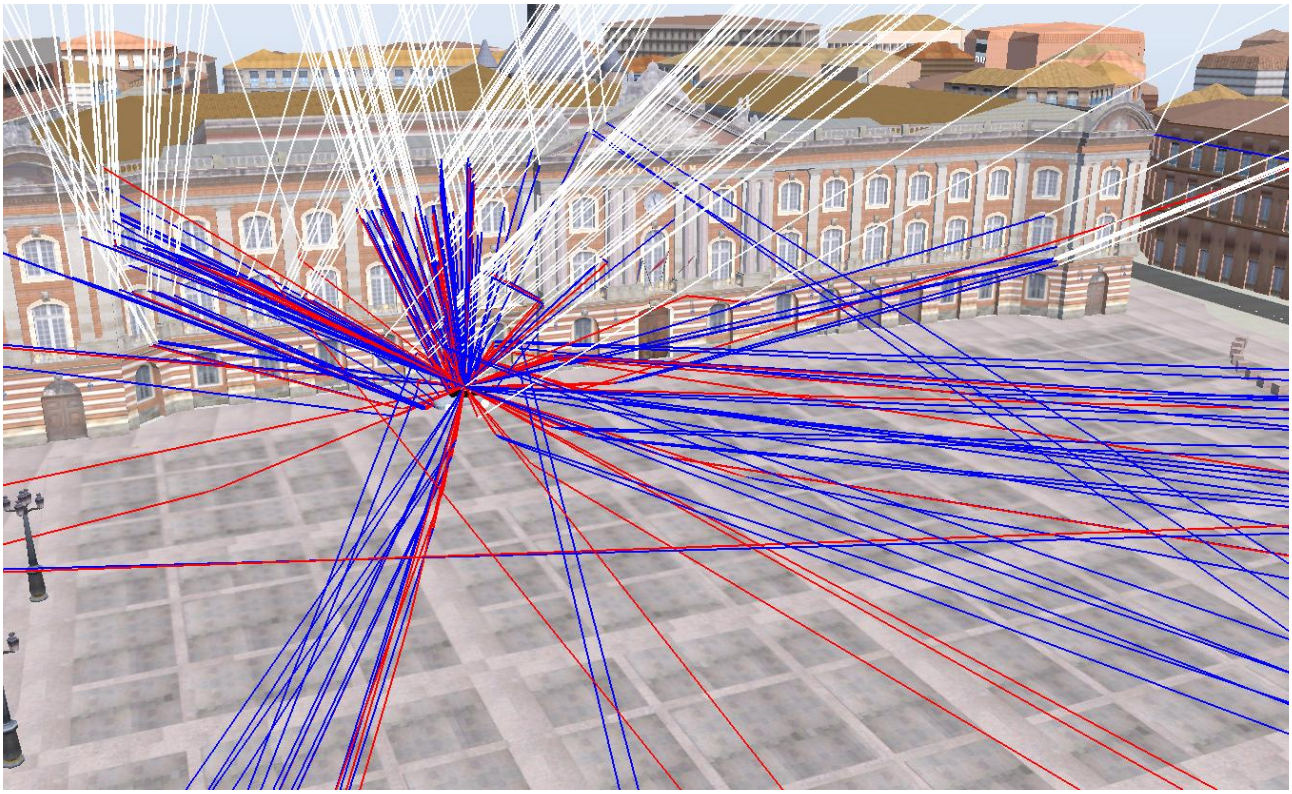
SE-NAV / Sim3D Validation report



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1 - Introduction

This document is a report on the validation and certification of SE-NAV, both theoretically and phenomenologically, thanks to the expertise of OKTAL-SE, ONERA and GUIDE GNSS in this field. This study and documentation are financed by Region Occitanie.

2 - Description of Sim3D / SE-NAV

SE-NAV takes into account transmitters corresponding to one or more GNSS satellite constellations (GPS, GLONASS, GALILEO, BEIDOU), as well as low-orbit constellations (such as the future LEO-PNT constellation) and ground transmitters (Beacon or Jammer). SE-NAV's added value lies in its ability to simulate the propagation channel realistically, taking into account the multipath created by the environment and/or the object carrying the GNSS receiver.

2.1 - Deterministic simulator

SE-NAV simulates the propagation of radio navigation signals (L-band in particular) in constrained environments. A constrained environment is an environment that interferes with signal propagation:

- By masking it (problem of system availability in these white zones).
- By creating multipaths (reflections, transmissions, diffractions). In navigation, multipaths reduce localization accuracy by adding a (geometric) delay to the geolocation algorithm. Multipaths also induce fading effects by interacting with each other.

SE-NAV uses a deterministic method, Ray Tracing, to determine the masking and compute the different multipaths received by the receiver. OKTAL-SE has developed its own ray tracing engine using the resources of the graphics card (no third-party libraries). The Ray Tracing method is coupled with Geometrical Optics and the Uniform Theory of Diffraction to compute:

- Reflections on surfaces.
- Transmissions through walls.
- Diffractions on edges.

The maximum number of reflections and transmissions per multipath is theoretically unlimited. The maximum number of diffractions is limited to one per multipath.

2.2 - Synthetic environment modeling

SE-NAV uses Synthetic Environments to perform computations. These are realistic 3D models of:

- The geometry of buildings or objects.
- Material physics (in the case of SE-NAV, EM coefficients: permittivity, conductivity, building thickness, etc.).

Synthetic environments can be divided into two categories:

- Geotypical environments: these models represent a realistic but not necessarily real environment (e.g. a dense urban environment, a mountainous environment, etc.).
- Geospecific environments: these model a real environment (e.g. a district of New York City).

These environments are created using proprietary tools such as:

- SE-AGETIM-LIGHT: semi-automatic modeler for simplified creation of synthetic geotypical environments.
- Plugin for the SketchUp modeler (https://www.sketchup.com/fr): this plugin converts any scene built by the SketchUp modeler into the proprietary SE-NAV format.

2.3 - Propagation simulation

SE-NAV integrates the CNES MSLIB library to compute satellite orthography from almanac data.

SE-NAV computes atmospheric crossing (ionosphere, troposphere) using classical theoretical models (RTCA, Klobuchar, ...).

SE-NAV uses synthetic environments (geometry and materials) to compute masking and multipath due to the near environment. The software performs ray tracing, available in CPU and GPU versions, which is combined with geometrical optics and uniform diffraction theory (UDT) to perform these computations. The computation of reflection and diffraction coefficients is based on a physical characterization of the materials (permittivity, conductivity, thickness) of the various scene elements (environment and moving entities). SE-NAV also includes a model for calculating propagation through vegetation.

The physical models implemented in SE-NAV have been the subject of several validation campaigns in partnership with GUIDE and SPIRENT. These validation activities have been the subject of publications which are available on the OKTAL-SE website (http://www.oktal-se.fr/website/publications.php?topic=4).

2.4 - SE-NAV output results

SE-NAV produces output in the form of:

- Scilab/Matlab file. For each multipath, SE-NAV return (among others):
  - Receive power
  - Phase shift
  - Geometric delay
  - Geometry (impact position - reflection points)
  - Doppler
  - Losses

- For each channel, SE-NAV returns (among other things):
  - Receive power (vector sum of incident fields)
  - Signal-to-noise ratio (C/N0)

- Availability and visibility maps (Figure 1 and Figure 2).

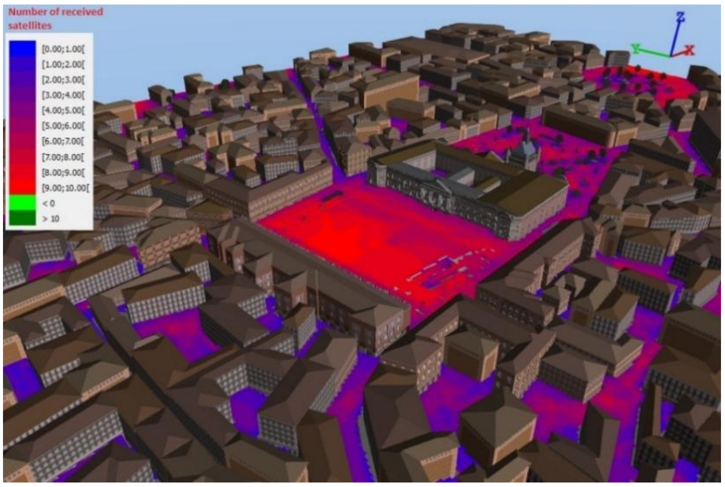


Figure 1 : SE-NAV map showing the number of satellites received

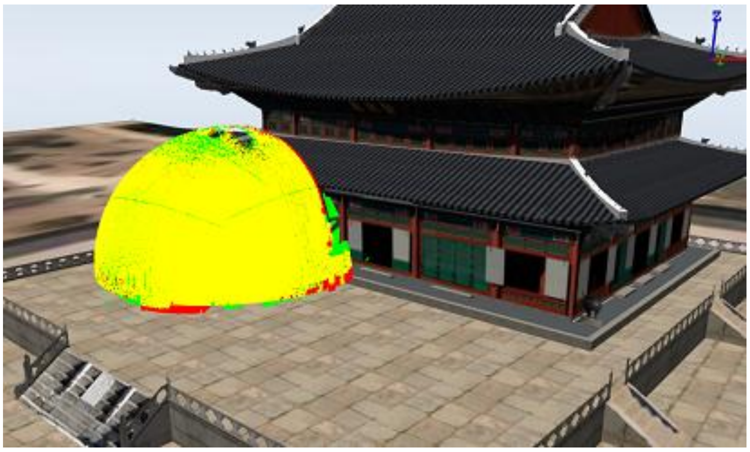


Figure 2 : LOS/NLOS visibility diagram

3 - Effective validation work

This document is a validation report of the SE-NAV results, which will then be sent to the PosApp simulator. This validation is carried out on two terrains, a hangar and a field area. The aim of this study is to provide a limited amount of work (a few hours) for field modeling. Indeed, by spending more time modeling a terrain more precisely, we could have results closer to reality. Rather, these results reflect an average level of simulator performance, i.e. the level of performance that a conventional user might expect.

3.1 - Hangar

The first was a hangar. In fact, this type of building is easily found in suburban areas, and can lead to multipath, due to their relatively high height, their proximity to the roadway, and their metal construction with protruding edges.
We chose the BUT store in the Labège, France area.

Figure 3 : Labège area

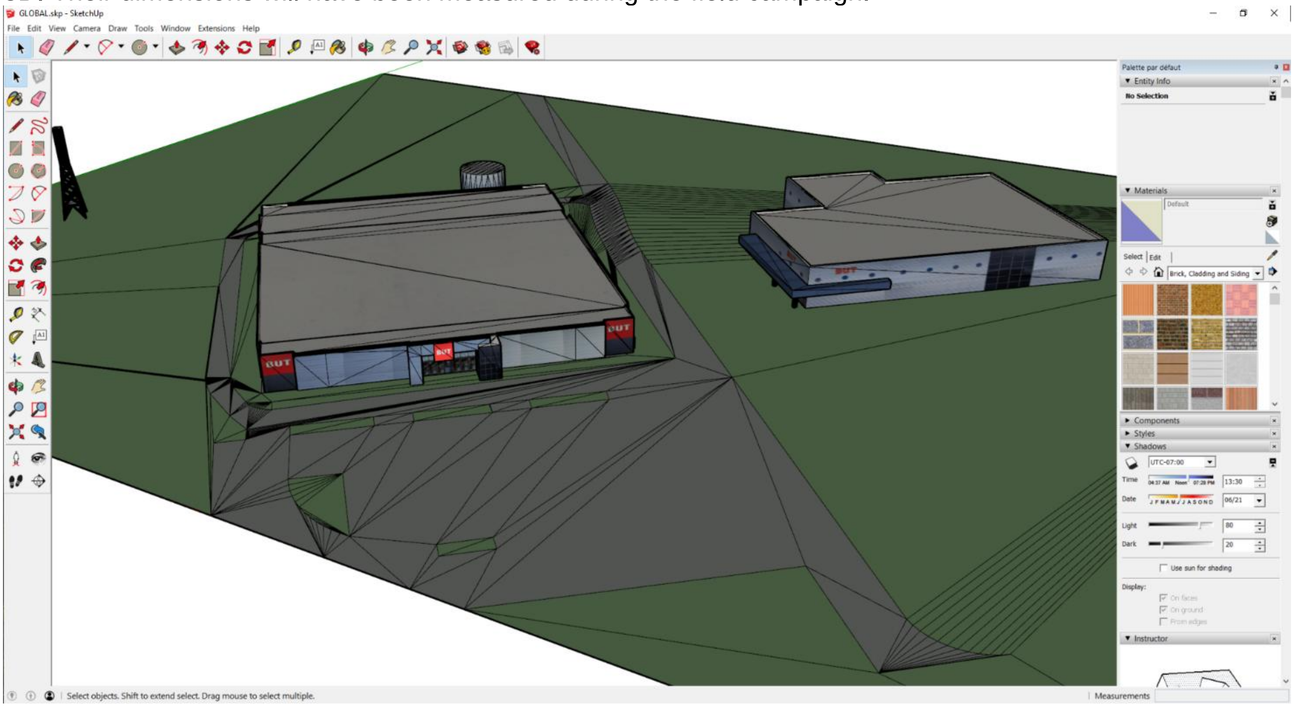
The building is easy to model and is surrounded by a small road.
It will enable us to study a classic suburban area.

The method used to create this database will be called “geospecific”. A computer graphics designer will model the entire area in 3D, using photographs and measurements taken on site, satellite photography and the SketchUp 3D modeler.

3.1.1 - Modeling choices

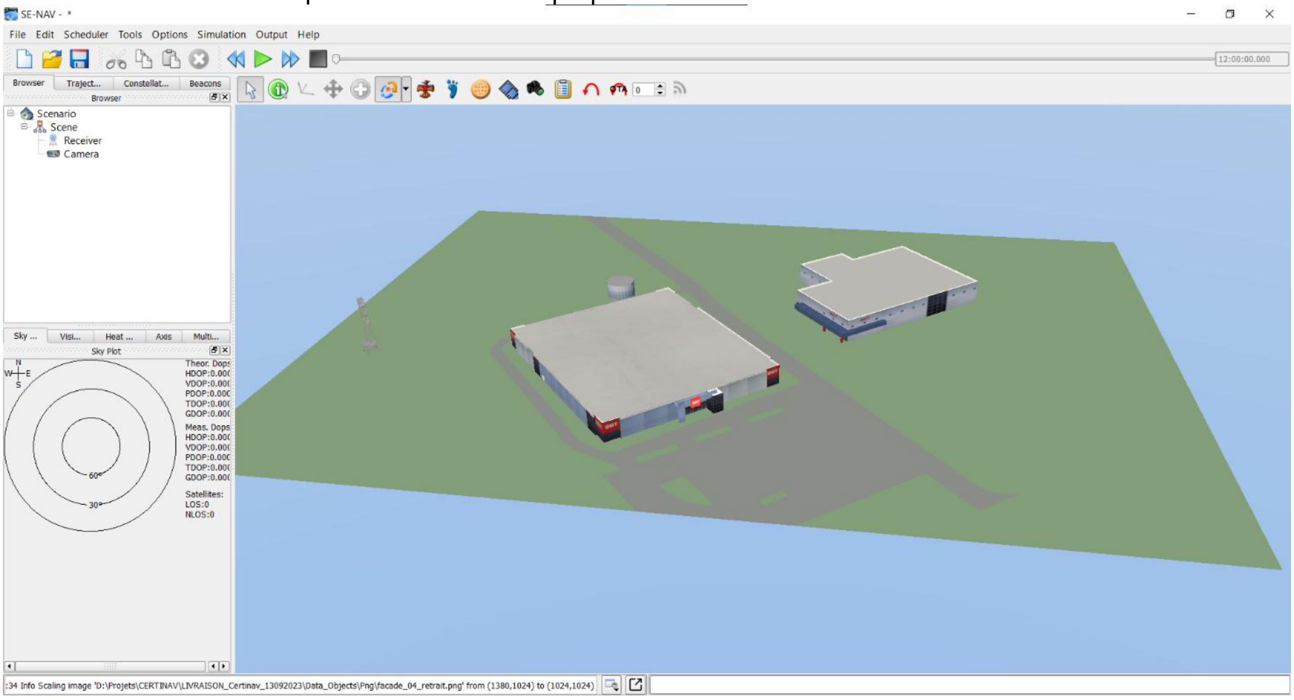
We got together with GUIDE GNSS to take measurements. OKTAL-SE took measurements of the terrain, while GUIDE GNSS took GNSS and positioning measurements. In fact, their vehicle is fitted with GNSS signal recording equipment, as well as an IMU system to establish a precise position. Signal recording enables “Record and Playback”, i.e. replay of these signals through different GNSS receivers and in different configurations: multi-frequency or not, multi-constellation or not, RTK or not, or various correction algorithms. Two segments were recorded.

The 3D database was created in SketchUp by OKTAL-SE.
Starting from a georeferenced aerial photograph of the terrain, the buildings are placed and then modeled in 3D. Their dimensions will have been measured during the field campaign.



This terrain is then exported in SDM format (3D format for OKTAL-SE products).

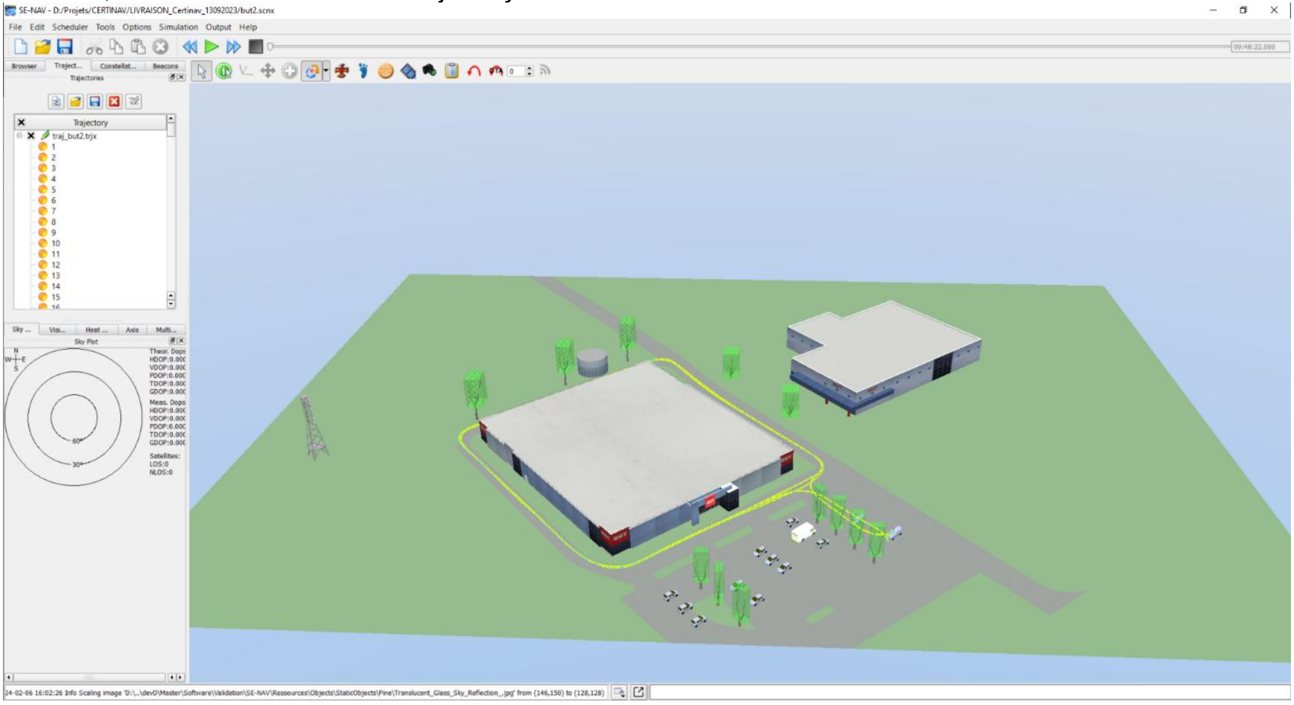
This terrain can then be opened in SE-NAV to prepare the scenario.



The vegetation and cars in the parking lot are then created using SE-NAV's scripting capabilities.

Then the user has to set the geo-reference in the database, and the date and time of the scenario.

Finally, the user imports the ephemeris (satellite position and velocity at a given time) corresponding to the scenario, as well as the receiver's trajectory.



3.1.2 - Results

The measurement campaign has been realized twice, enabling us to analyze two sets of data, thus strengthening the consistency of our analyses.

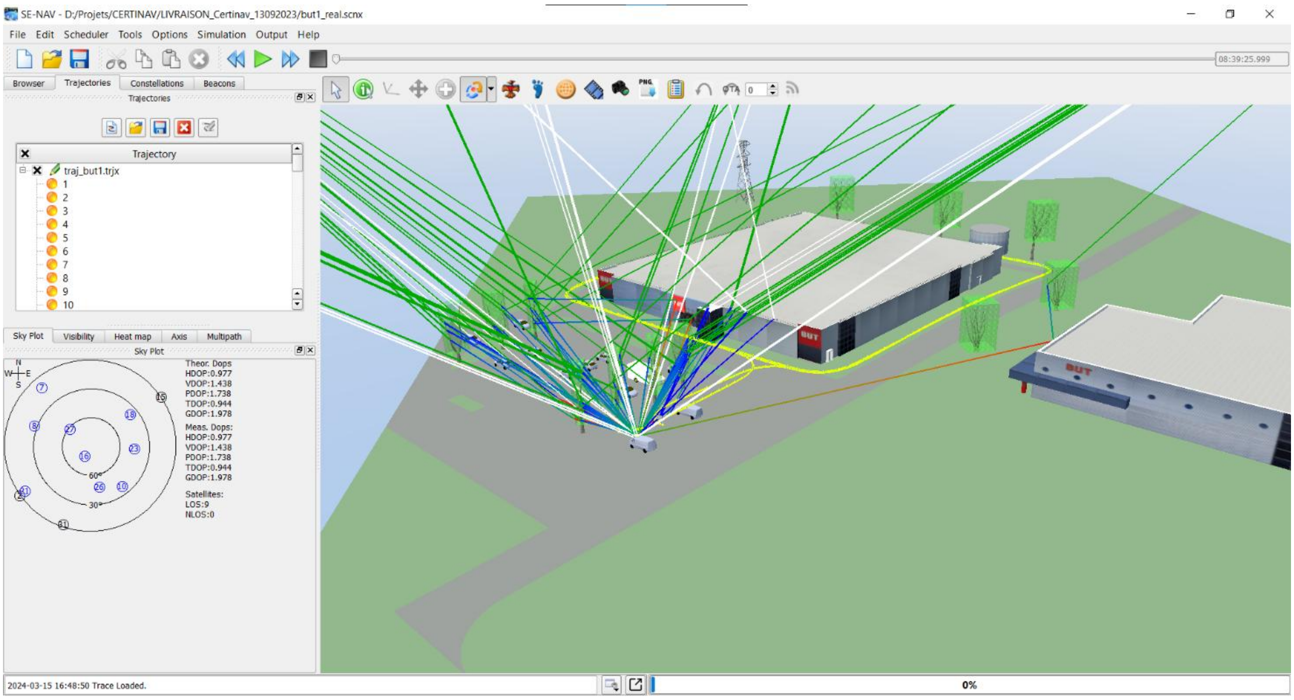
In each scenario, the car remains parked at the start of the trajectory, then makes three slow laps around the store.

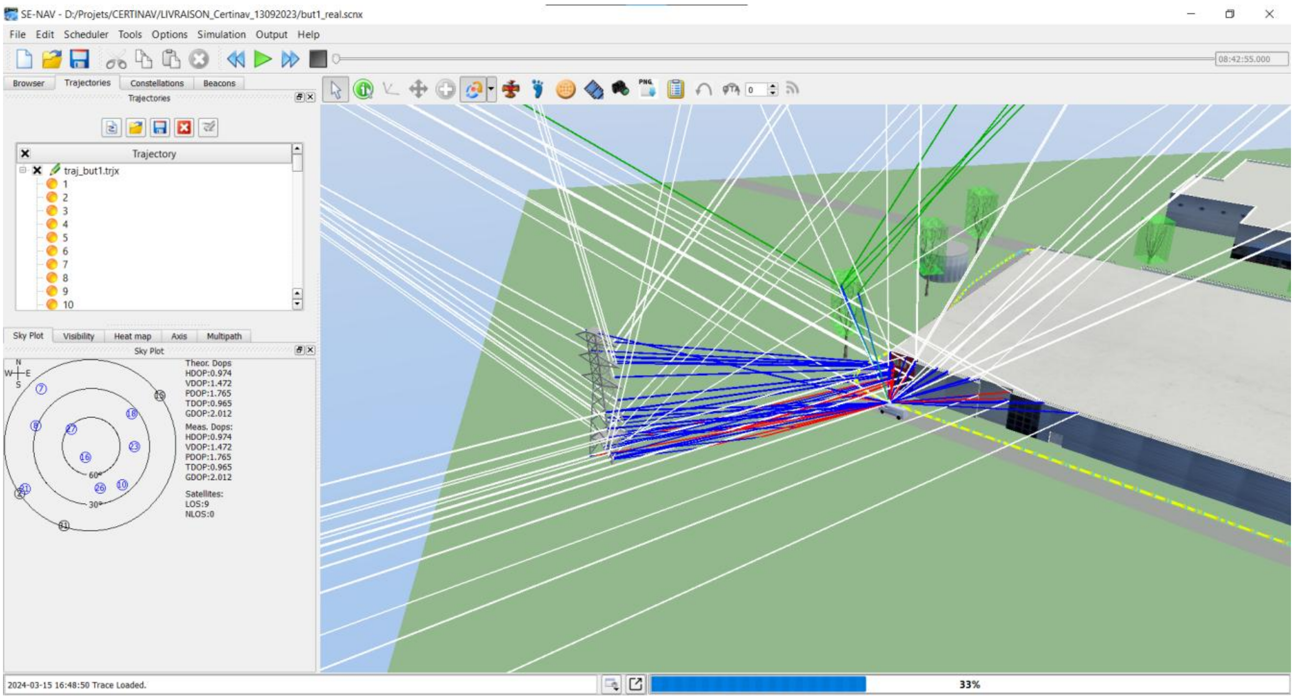
During the measurement campaigns, the GNSS signal was recorded, enabling us to replay the signal at will, using several different receivers with different settings. As a result, simulation in a synthetic environment no longer competes with, but rather complements, the “record and playback” approach.

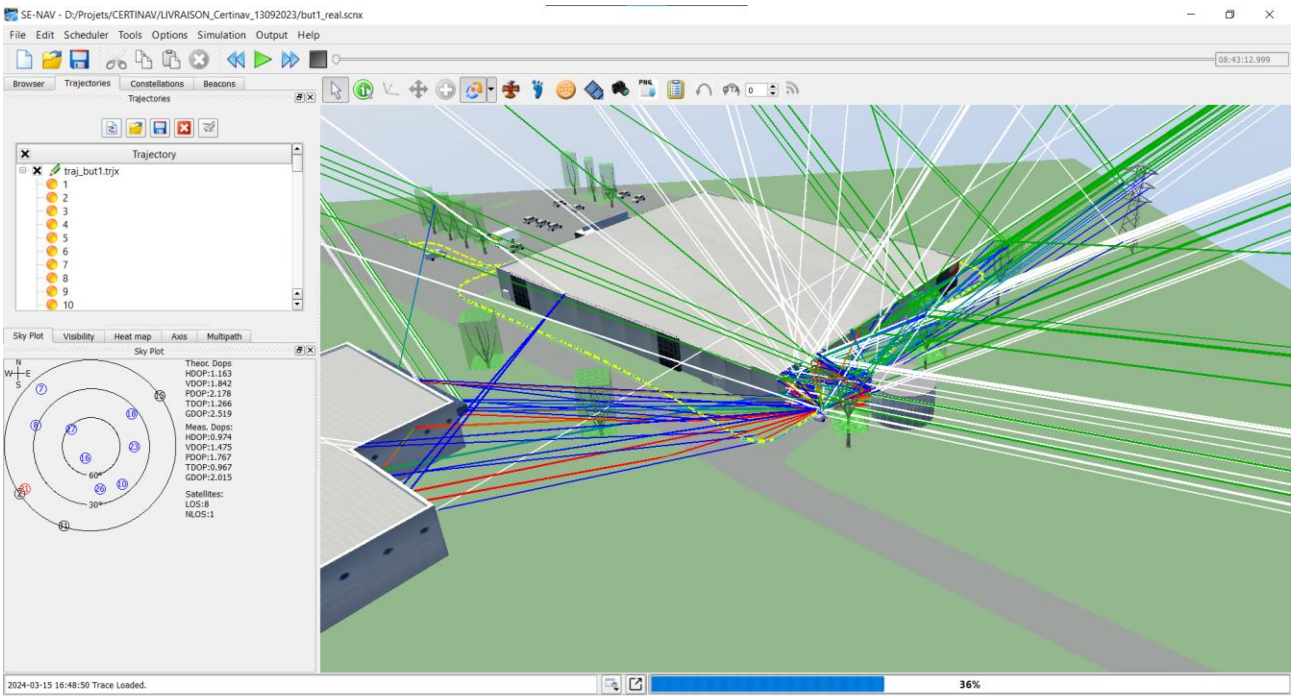
3.1.3 - SE-NAV analysis alone

We want to qualify the results of a classic SE-NAV computation, i.e. the computation of the Doppler shift attenuations of each multipath. To do so, we're going to compare the results obtained by simulation with those obtained by measurement.
We don't try to compare the delays of each multipath, as this observable is not directly and easily accessible in the results of a receiver.

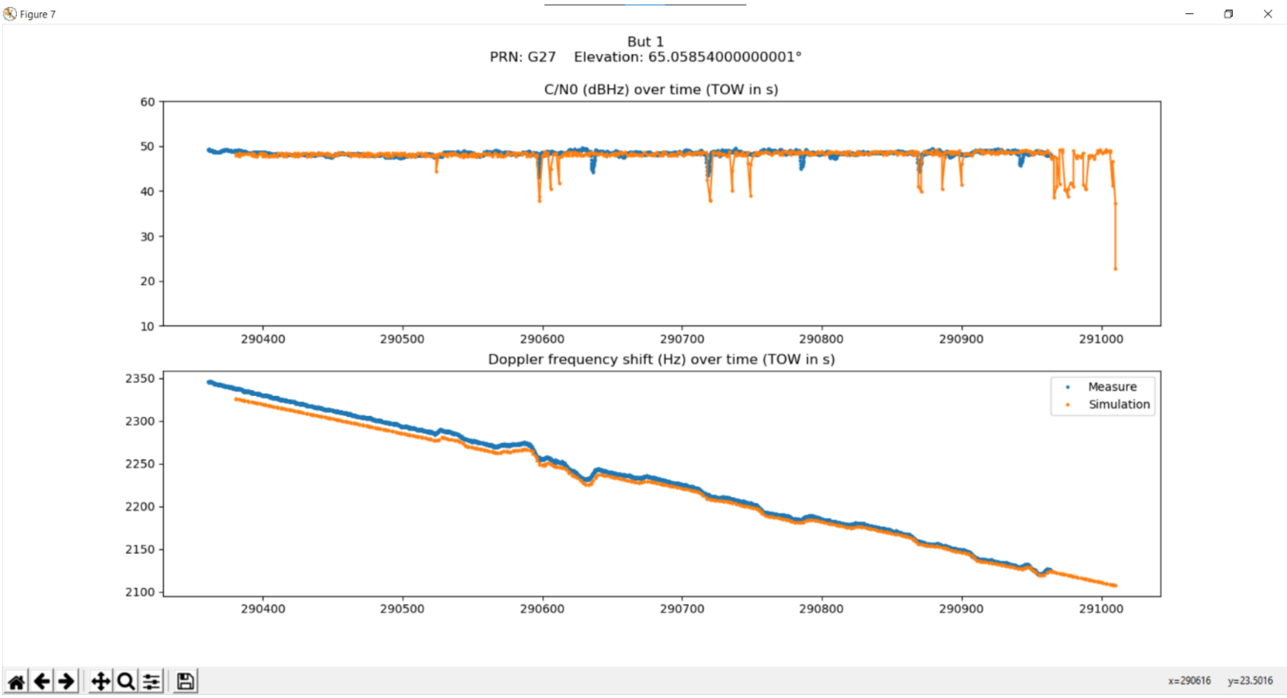
So, when we run the simulation, we can follow the car carrying the receiver and visualize the rays between the satellites and the receiver. As a reminder, red rays are reflected, blue rays are diffracted, and green rays are transmitted through vegetation (the color of the last interaction).



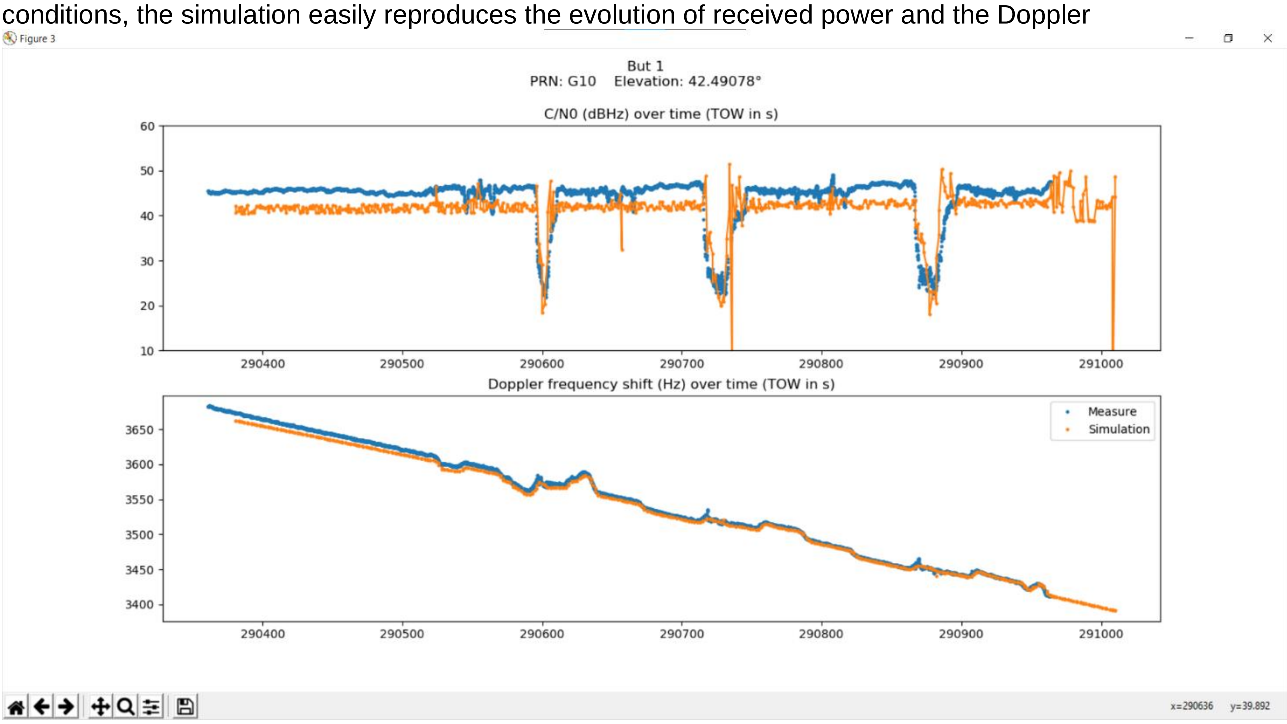


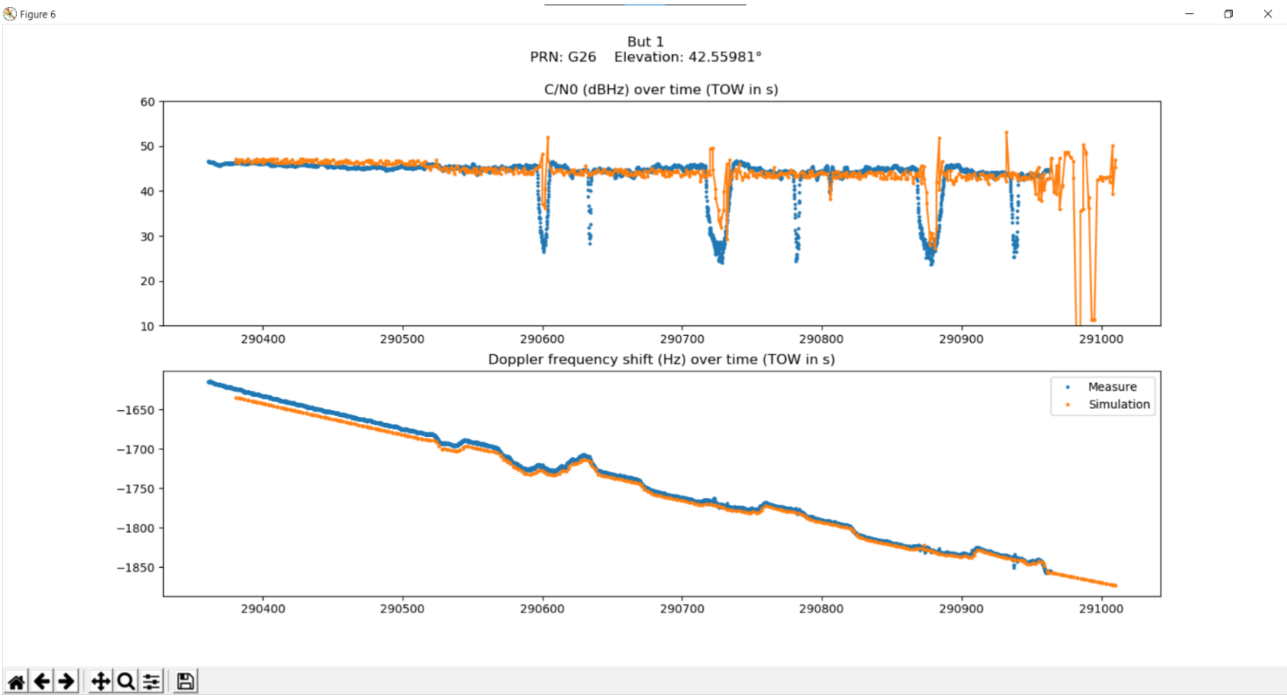


At the end of the scenario, result files are produced. After a few manipulations, you can compare the output of SE-NAV

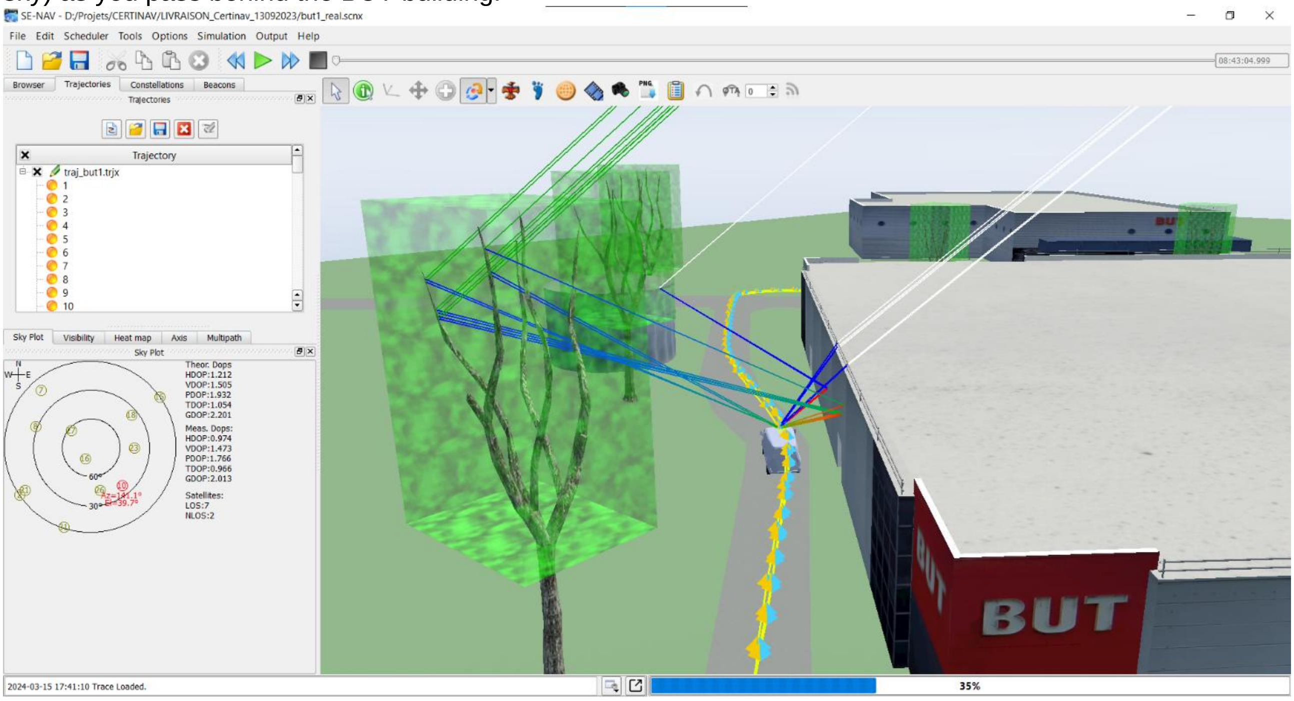


We can see that at high elevation, the G27 satellite undergoes very little power variation. Under these conditions, the simulation easily reproduces the evolution of received power and the Doppler

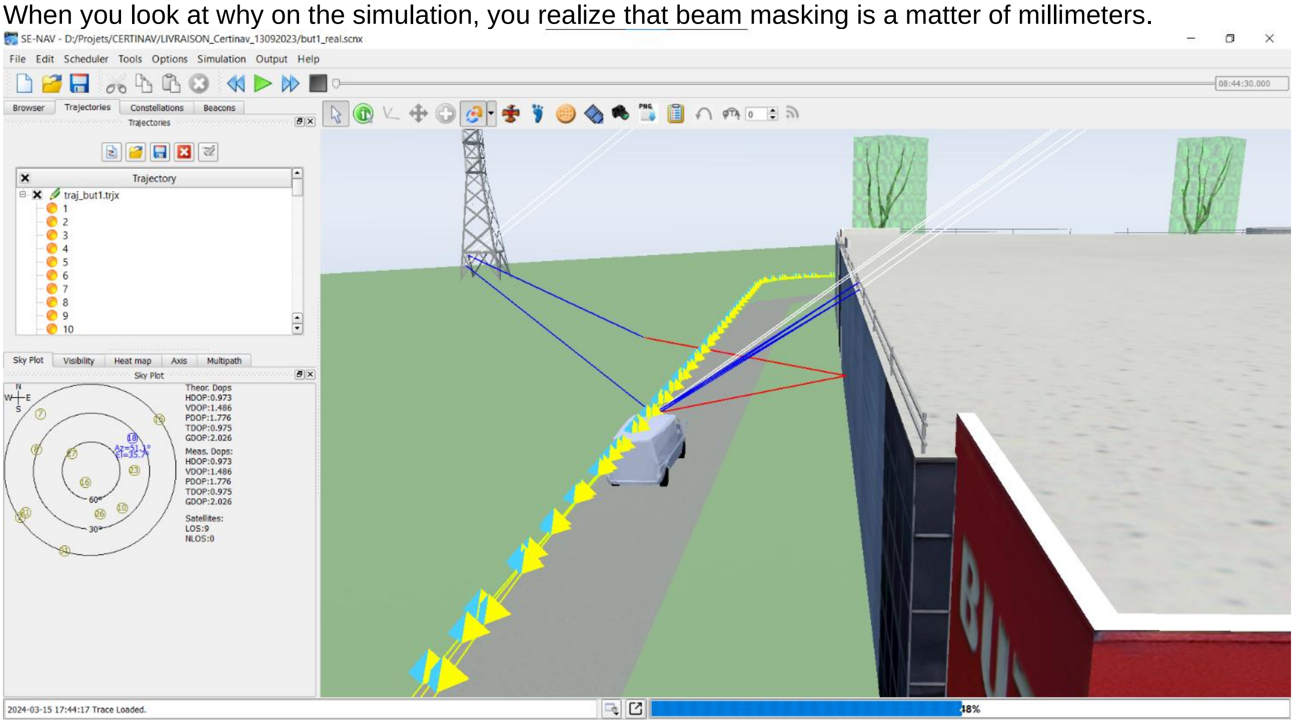




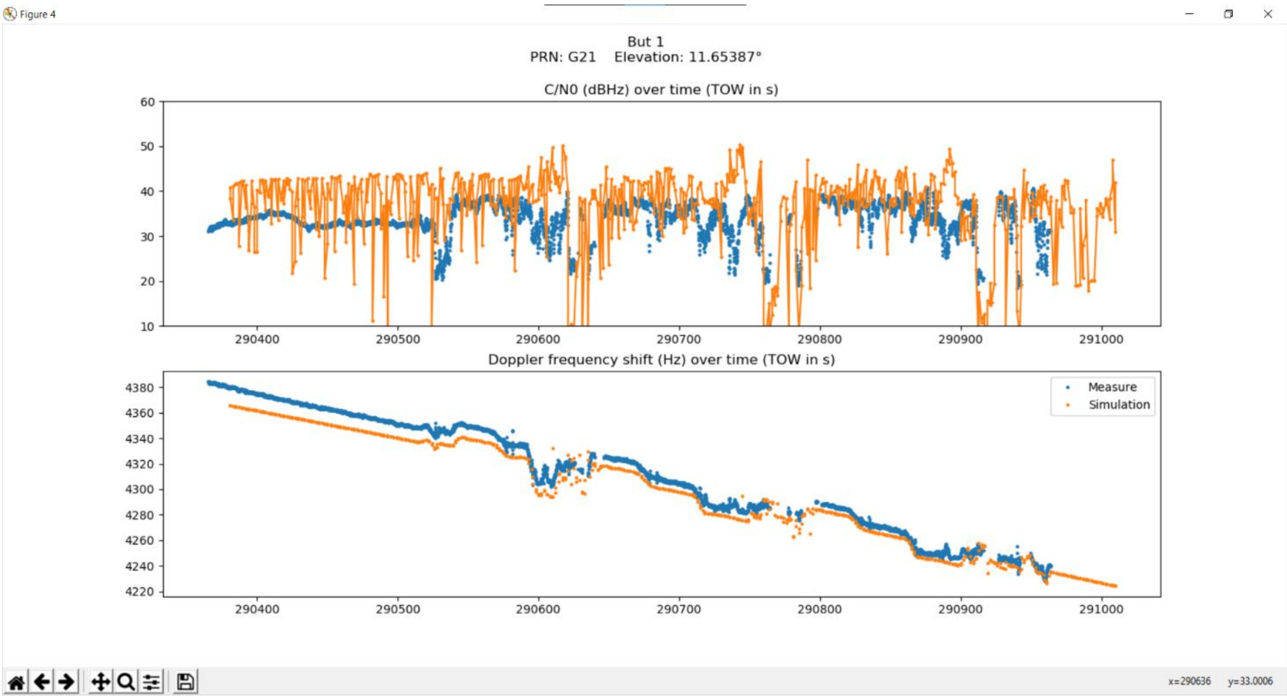
The three stalls of satellites G10 and G26 are clearly visible here (they are located in the same area of the sky) as you pass behind the BUT building:



For the G18 satellite, the stalls are not reproduced.
When you look at why on the simulation, you realize that beam masking is a matter of millimeters.



This underlines the importance of building heights, which are not so easy to acquire precisely.



For G21, the low elevation of the satellite makes it difficult to reproduce the high variability of received power, due to the lack of detail on our horizon scene, and the impact of tropospheric attenuation, which is poorly estimated in SE-NAV (the model used is still fairly simple).

More or less the same phenomena were observed during the second session of the measurement campaign (see appendix).

In conclusion, the results are very satisfactory, but this was to be expected, given the simplicity of the scene. It would be interesting to push the simulation a little further by choosing scenes with more complex geometry.

3.2 - Countryside

For our second terrain, we chose to model a country road, in the middle of hills, alternating between open terrain and forest cover, which allowed us to drive on a fairly long carriageway.
This variety is interesting because it will enable us to test the quality of our vegetation model for the first time. We'll be modeling this terrain with vegetation. This terrain will enable us to study a typical hilly rural area.

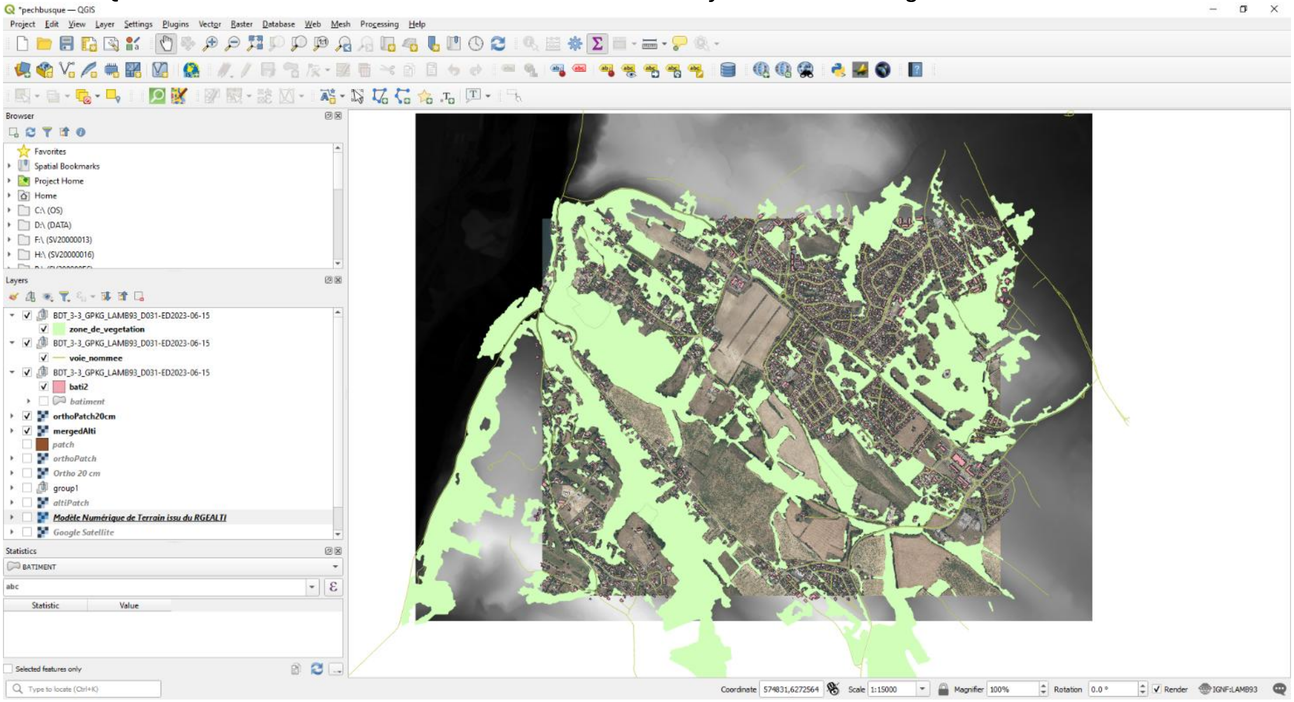
The method used to create this database will be called "generated". Unlike the Hangar, the area to be modeled here is much larger. We'll be using OKTAL-SE's terrain generator, SE-AGETIM-LIGHT. Based on photographic, altimetric and planimetric data (buildings, roads, vegetation), SE-AGETIM-LIGHT generates a 3D database, where aerial photography is plotted on the 3D terrain, and building bases are extruded to give them shape. Vegetation and roads are also integrated into the generated terrain.

Figure 4 : Pechbusque, France area

3.2.1 - Modelling choices

Data were acquired on the same day and under the same conditions as for the first database. Only one segment was recorded.

We use QGIS to search, select and download the various layers we need to generate the terrain.

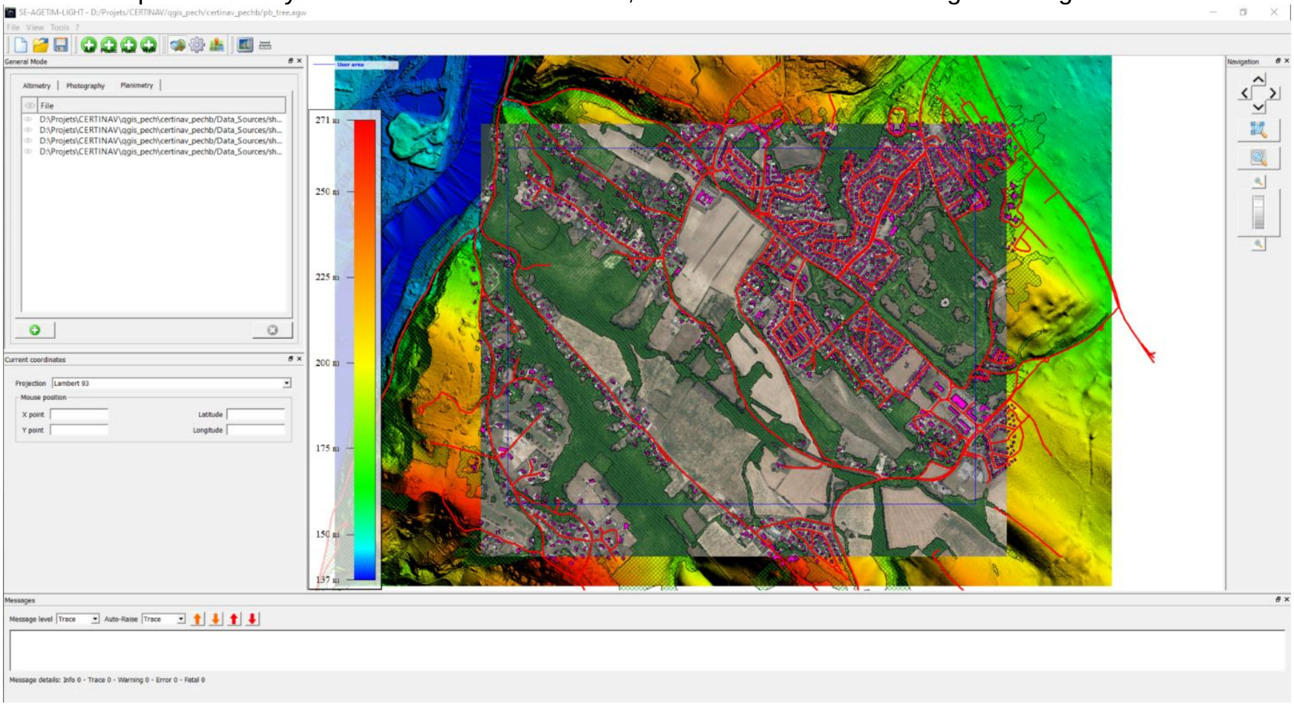


The various layers selected all come from IGN, French geographic institute:

- Aerial photography: BD ORTHO®
- Altimetry: RGE ALTI®
- Planimetry: BD TOPO®

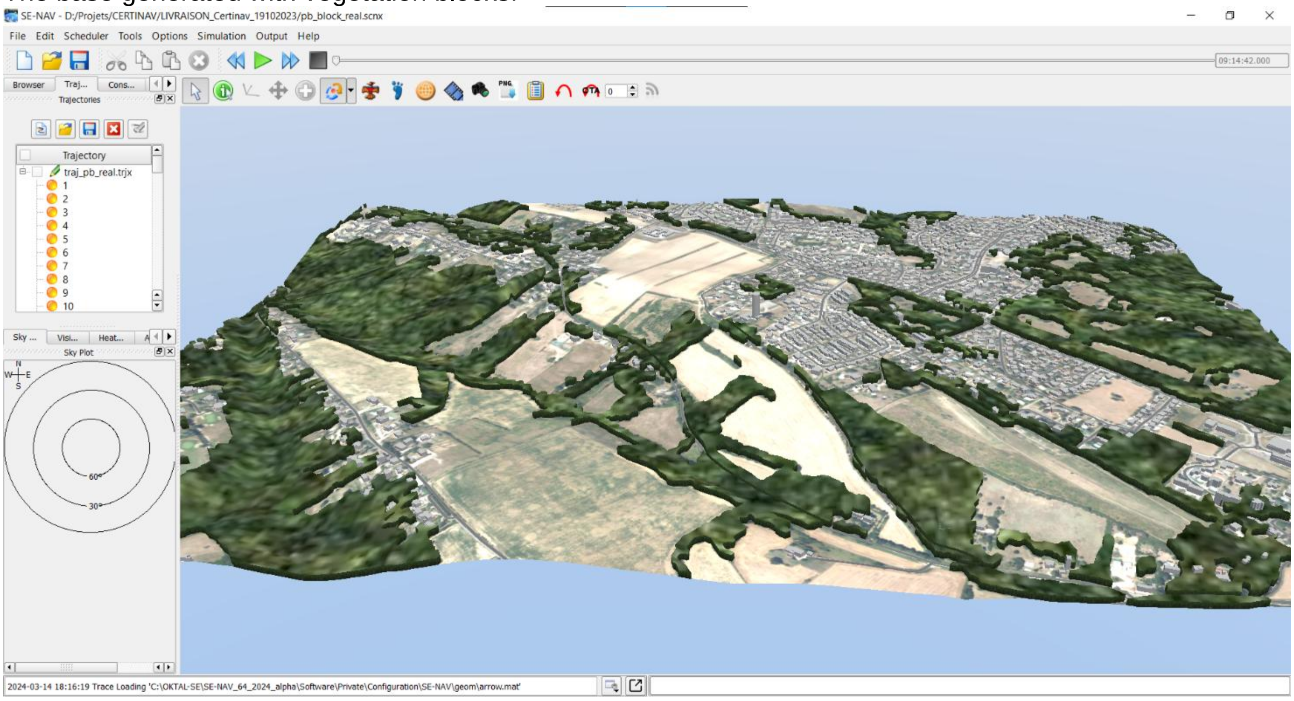
QGIS allows us to overlay these layers, edit them, and download only the areas of interest to us.

We then import these layers into SE-AGETIM-LIGHT, OKTAL-SE's software for generating 3D terrain.



Generation consists of creating 3D buildings, roads and vegetation from the planimetric map.

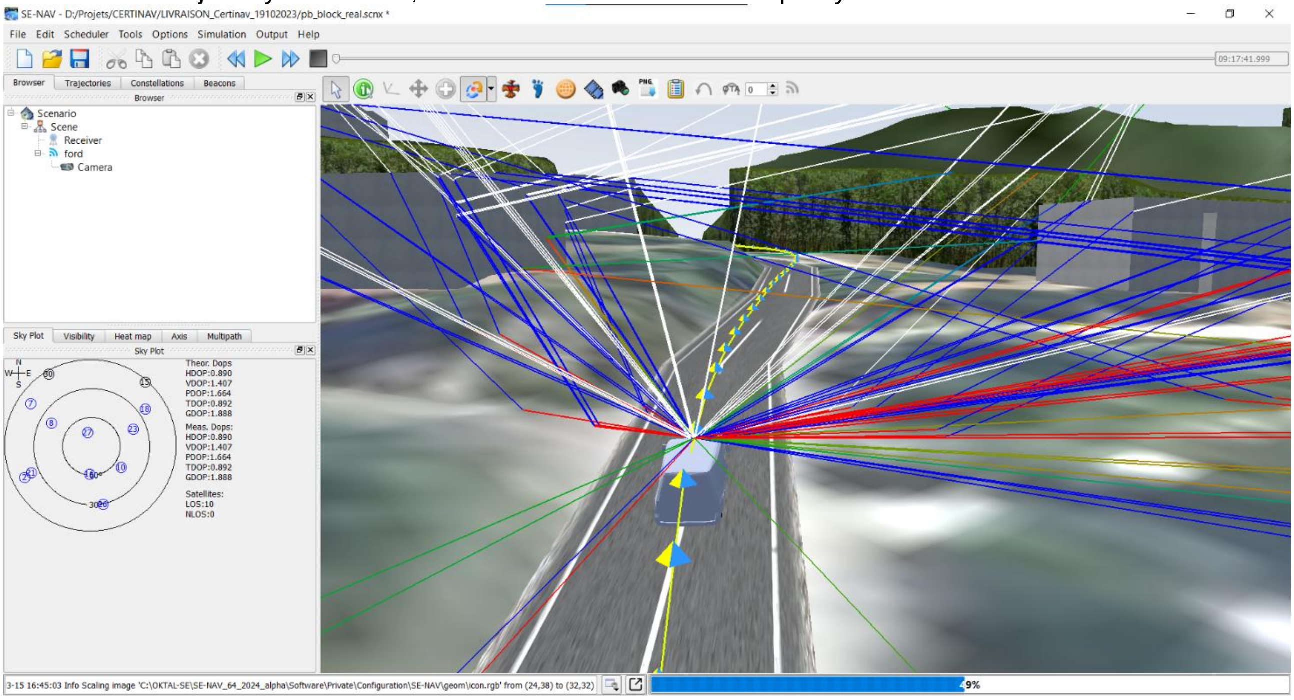
The base generated with vegetation blocks:

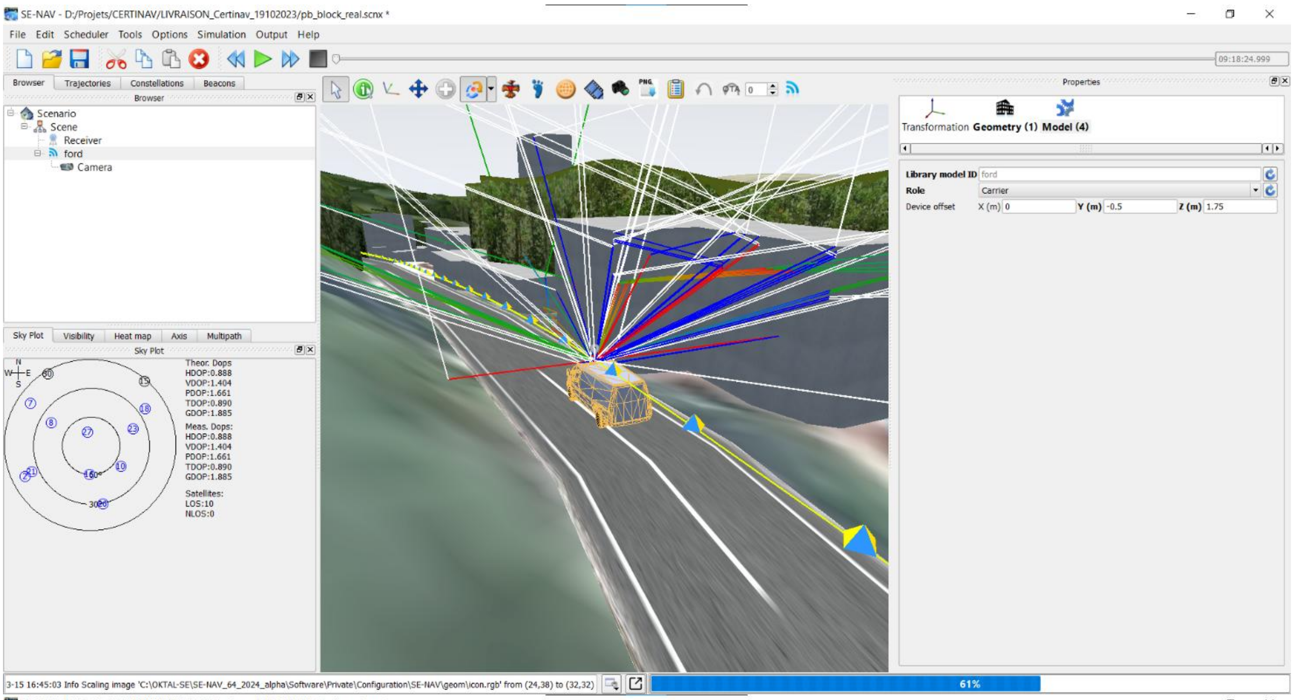


As before, all that remains is to enter the georeference in the database, and the date and time of the scenario. We then import the ephemeris corresponding to the scenario, as well as the receiver's trajectory.

3.2.2 - Results

We apply the same method as for the hangar. We can see that the planimetric source data (road layout) and the reference trajectory match well, which reassures us as to the quality of the source data.

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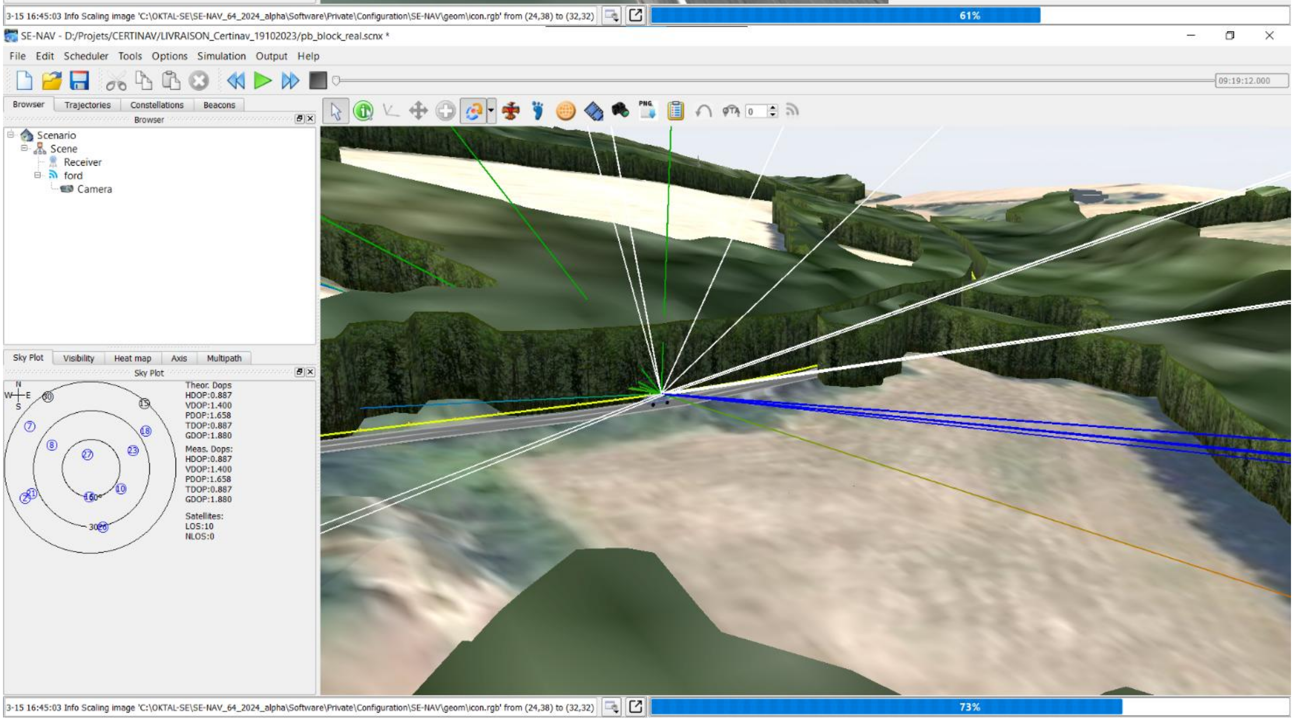
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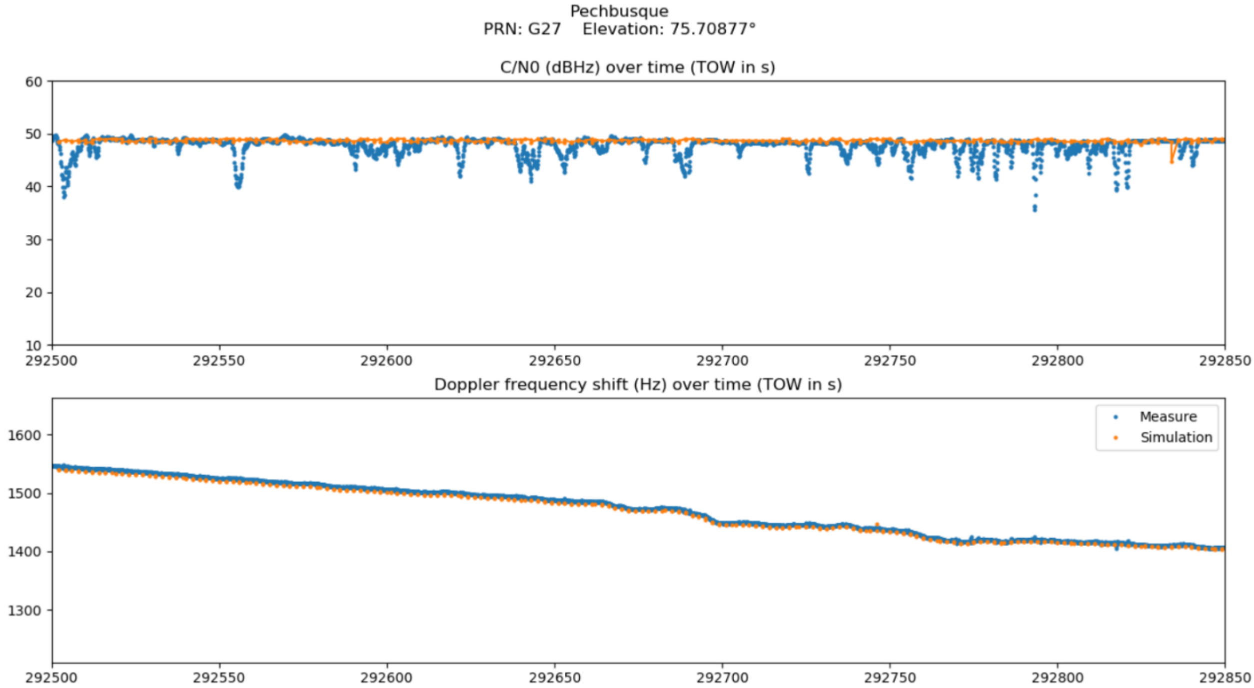
3.2.3 - Analysis of SE-NAV alone

Finally, to analyze the performance of SE-NAV, we chose to use the vegetation blocks with the European broad-leaved tree model.

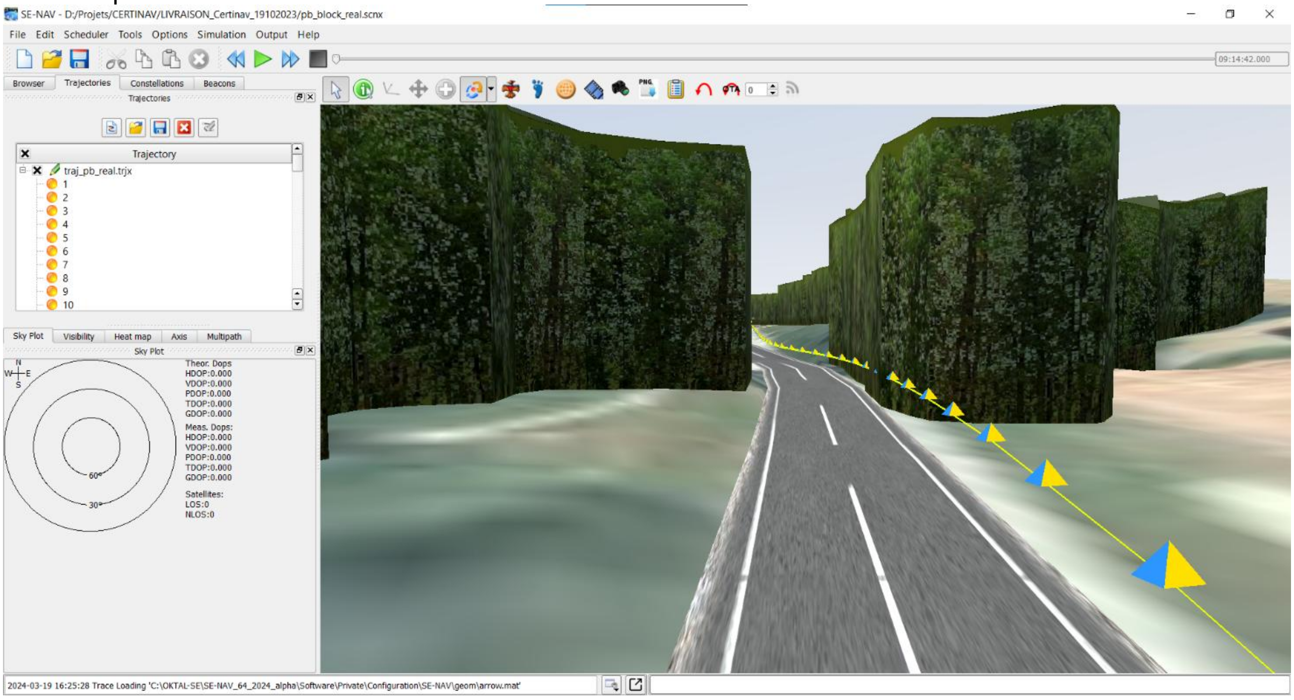
As a reminder, this terrain should be less favorable for a SE-NAV simulation. It contains much more vegetation, is much larger, and was generated automatically from open-access data.

Representativeness is therefore more uncertain.

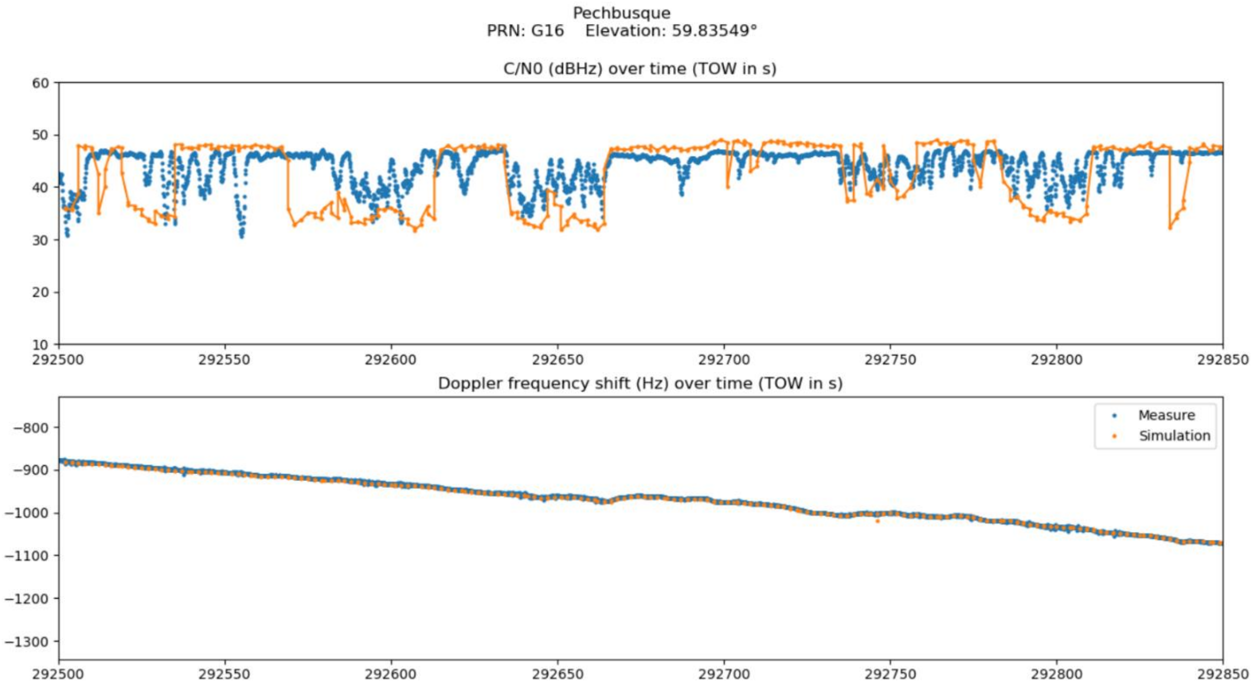
As before, let's plot the evolution of C/N0 over time, and compare the results of the simulation with those of the measurement.



For G27, no problem, the elevation is 75°, so it's quite significant. There are a few passages where the received power drops a little. This can be explained by the fact that, in our generation model, the foliage does not pass over the road:



So short masking by foliage over the road that happens in reality is not reproduced for a satellite with a high elevation.



For G16, there are no false alarms and the masking zones are well predicted. On the other hand, the mean attenuation is a little low in the simulation, but the standard deviation is too low in the attenuated areas.

As for the slightly low mean attenuation, this is probably due to a defect in the vegetation model parameters. We could modify these parameters a little to increase the correspondence between simulation and measurement, but that's not the aim of this project. On the other hand, for another scenario in a similar forest, without the possibility of collecting measurements, it would be wise to use the modified parameters obtained thanks to this project.
For G26, which is closer to the horizon, once again the masking zones are fairly well reproduced.

4 - Conclusion

This project demonstrates the capacities of SE-NAV to simulate GNSS availability and multipath parameters in various constraint environments, with a short time spent in the environment modelling. It shows that a user is able to create a scene on its own, that will accurately reproduce the signal obtained with a Record and Playback method. Deterministic simulation can be alternative to Record and Playback, with some advantages, like not use any hardware, be receiver independent, control the parameters of the scenario, etc.

SE-NAV is able to be interfaced natively with Spirent's PosApp, SE-NAV feeding the generator with multipath parameters, faster than real-time.