Modelling Interference from non-GSO Systems into the Radio Astronomy Service using Visualyse Professional

Abstract: One of the WRC-27 Agenda Items (AIs) is AI 1.16 which relates to interference from constellations of non-GSO satellites into stations of the radio astronomy service. In particular, it considers scenarios in which a non-GSO system is operating in frequency bands close to or adjacent to those used by the RAS. This White Paper shows how studies of scenarios under AI 1.16 can be undertaken using Visualyse Professional tool using the results from ECC Report 363 as a comparison.

1. Background

The Radio Regulations provides protection for the radio astronomy service (RAS) under Article 5.149, where for a range of frequencies, administrations are urged to take all practicable steps to protect the RAS from harmful interference.

One potential source of harmful interference comes from the recent growth in the number of non-GSO satellites and constellations providing fixed satellite service (FSS) and mobile satellite service (MSS). These systems will typically operate in frequency bands allocated to the FSS or MSS, though operation has also been considered in some bands under Article 4.4, i.e. on a no harmful interference, no protection basis. These allocations can be close to those used by the RAS, such as:

- 10.6 – 10.68 GHz: RAS primary allocation and identified for protection by 5.149
- 10.68 – 10.7 GHz: RAS primary allocation
- 10.7 – 11.7 GHz: FSS space-to-Earth primary allocation where 5.441 applies (operation of non-GSO FSS) and there are EPFD limits in Article 22.

There is therefore the potential for interference into the RAS from unwanted emissions from non-GSO systems operating in the lower end of Ku band.

WRC-23 agreed WRC-27 AI 1.16 which references Resolution 681 to study this scenario and in particular the aggregate interference from single and multiple non-GSO satellites systems into RAS stations operating in radio quiet zones (RQZ). The Resolution invites WRC-27 to consider appropriate technical and/or regulatory measures based upon studies of this scenario. A number of frequency bands are identified to be studied, including RAS operating in the 10.6 – 10.7 GHz and the 42.5 – 43.5 GHz bands.

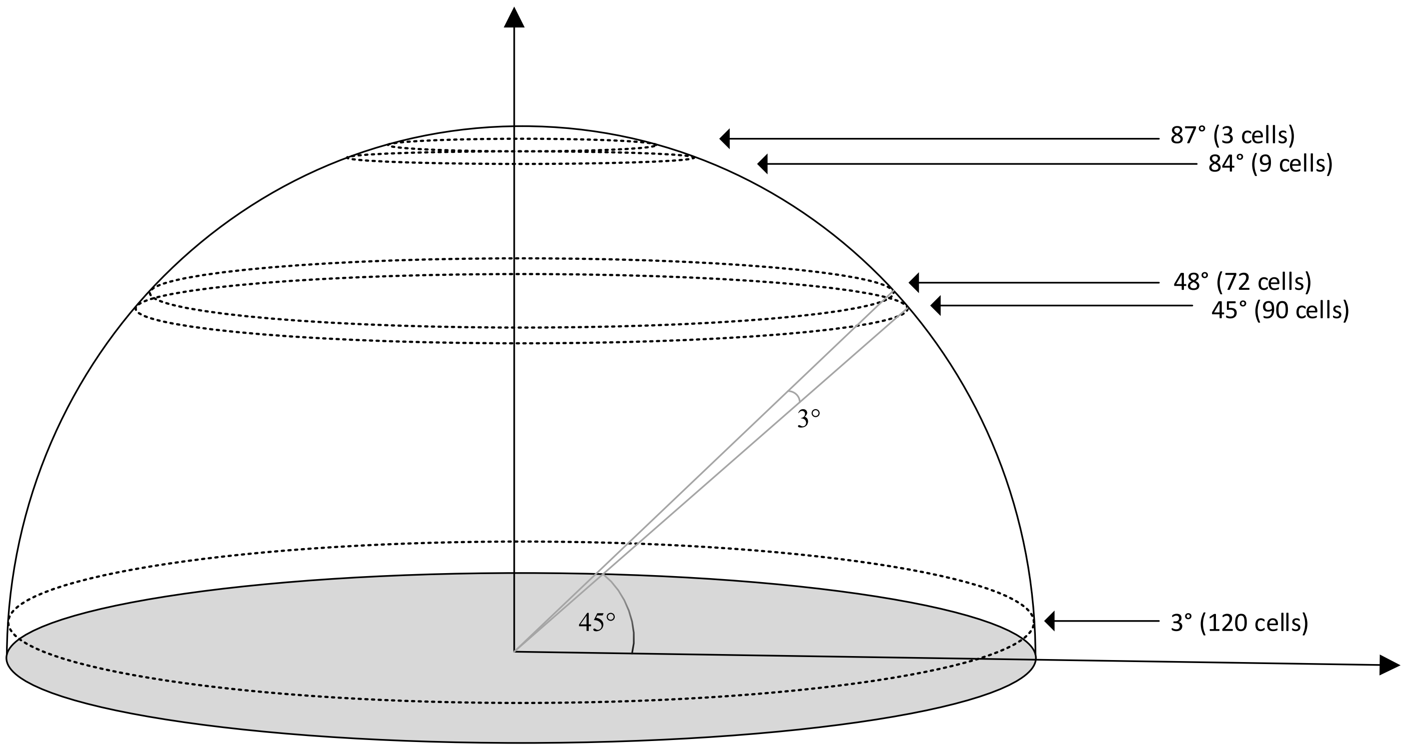
But how should this scenario to be modelled and how can the Visualyse Professional tool be configured to analyse it?

2. Modelling Methods and ITU-R Recommendations

A method to calculate unwanted emissions levels produced by a non-GSO FSS system at a radio astronomy site is given in Recommendation ITU-R S.1586.

This approach is based upon dividing the sky into 2,334 cells of approximately equal solid angle, as shown in the figure below. Each cell covers an elevation angle range of 3° and then the range in azimuth varies by elevation angle. So, for the lowest ring of cells between elevation angles of 0° and 3° there are 120 cells with azimuth range of 3° but at an elevation angle of 87° there are 3 cells of 120°. Each cell will have central (azimuth, elevation) pointing angle offset by half the range in azimuth and elevation.

It is possible that not all pointing directions would be used: for example, an observatory might have a minimum elevation angle of (say) 30°. In this case, all the cells with elevation angle of 30° or greater would be considered.



For each pointing direction considered, the interference is calculated using the metric of the equivalent power flux density (EPFD) using the equation from RR 22.5C.1:

$$EPFD = 10log_{10}\left(\sum_{i=1}^{i=N} 10^{P_{tx,i}/10} \frac{G_{tx,i}(\theta_i)}{4\pi d_i^2} \frac{G_r(\varphi_i)}{G_{rx,max}}\right)$$

This is effectively the PFD of the transmitting satellite at the RAS site multiplied (in W) by the receive relative gain of its antenna. The EPFD in dBW of each contribution is therefore:

$$EPFD_i = PFD_i + G_{rx,rel}(\varphi_i)$$

The total EPFD from one non-GSO system is the summation over all beams of all satellites. The aggregate from all non-GSO systems is then the summation over all these systems.

The transmit power term, $P_{tx,i}$, is the power of the unwanted emission at the input of the antenna in the relevant reference bandwidth. The gain of the RAS antenna can be calculated using Recommendation ITU-R RA.1631. As the non-GSO satellites move, the EPFD calculated using these equations will vary.

Thresholds for interference are found in Recommendation ITU-R RA. 769, which at the 10.65 GHz are:

- Mean PFD = -160 dBW/m^2/100 MHz assuming an integration time of 2,000 seconds.

Note that this PFD threshold is assuming an isotropic antenna. When used as an EPFD threshold, as in the equation above, it should therefore be adjusted to take account of the peak gain of the RAS antenna.

The mean EPFD over 2,000 seconds is then calculated for a set of trials so that a distribution can be derived. A percentage of the samples of 2,000 seconds that exceeds this threshold can then be calculated.

This process can be repeated for each of the cells for which the RAS service is operating to derive an average. As stated in Recommendation ITU-R RA.1513:

> *Over the sky, for elevations higher than the minimum operating elevation angle of the radio telescope, the epfd threshold level defined above should not be exceeded for more than 2% of the time*

Hence the average calculated using the method above should be no more than 2%.

3. Modelling in Visualyse Professional

Visualyse Professional's flexible architecture means there are a number of approaches that could be used to model this scenario. A key question is how to model the set of 2,334 cells (pointing directions), and there are a couple of approaches that could be considered, in particular:

1) Create a RAS Station with an Antenna Type with 2,334 Beams using the set of (azimuth, elevation) angles from Rec. ITU-R S.1586.
2) Create a RAS Station with a single Beam Antenna Type and then use a set of Define Variables to change the (azimuth, elevation) pointing angles to match the set in Rec. ITU-R S.1586

The first approach has the benefit of a degree of parallelization, in that the non-GSO constellation needs to be updated and configured once for each of the 2,334 cells, while the second approach would require the non-GSO constellation to be updated 2,334 times.

The beam, whether a single one or each of the 2,334 beams, can be modelled using the gain pattern in Recommendation ITU-R RA. 1631 using an appropriate dish size.

The non-GSO constellation's transmit powers could be defined in a number of ways:

1) Create a grid of non-GSO ES and then links from them to the non-GSO satellites. This approach can take account of details of the system including tracking strategies (e.g. include the minimum elevation and GSO arc avoidance angles), use of power control and phased array antennas
2) Use a PFD mask, where the PFD could be defined by elevation angle or alpha angle.

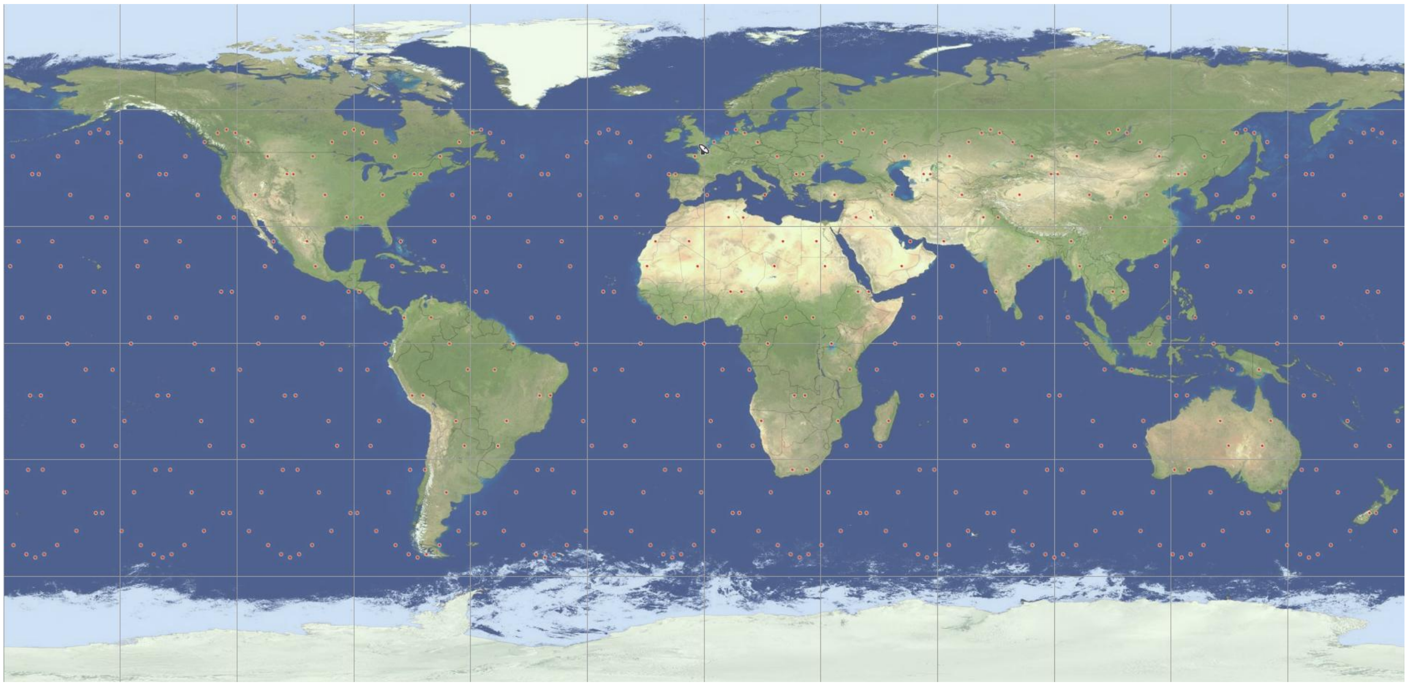
The non-GSO satellite's transmit power could be defined:

- In the receiver bandwidth
- In the interferer bandwidth, but with a term in the interference path to define the attenuation compared to in-band power
- In the interferer bandwidth but using a transmit spectrum mask and integrating over the RAS receiver filter, i.e. deriving the net filter discrimination (NFD).

The mean EPFD over an integration time of 2,000 seconds can be calculated using the EPFD statistics object and (for example) averaged over 2,000 time steps of 1 second. Note that the averaging should be done in linear i.e. Watts not dBW. The average EPFD over multiple trials can be determined by logging the mean EPFD to file and then post processing, and from this a distribution was generated.

4. Example Simulation in Visualyse Professional

The screen shot below shows an example Visualyse Professional simulation of interference from a non-GSO FSS system into a RAS site. The analysis was based upon the parameters in ECC Report 363.



4.1. Creating the RAS Site

An Earth Station was created to be the RAS site, located at a (latitude, longitude) = (50°, 0°). A single Antenna was configured to point at an (azimuth, elevation) = (0°, 0°). This Antenna used an Antenna Type with 2,334 identical Beams, each using the gain pattern in Recommendation ITU-R RA.1631 with antenna diameter of 25m. Initially, these were created with fixed pointing of (azimuth, elevation) = (0°, 0°). Then a single Receive Link was created using a frequency = 1 400 MHz into the first Beam of the RAS site Antenna. This resulted in a peak gain of 51.28 dBi.

This was then duplicated to create a further 2,333 Receive Links.

This initial configuration was saved as a text file and macros used to:

1) Set each of the Beam (azimuth, elevation) to be the values from Recommendation ITU-R S.1586 array. This was done for both the Antenna Type and also for the RAS Station's Antenna's Beams.
2) Set each of the Receive Links to use a different Beam on the RAS Station's Antenna.

This was then loaded back into Visualyse Professional.

The threshold was set to -180 dBW/m^2 from Rec. ITU-R RA.769. Note that this threshold did not include the peak gain of the RAS site, which should be included as:

> *Since the threshold levels of detrimental interference in Tables 1 and 2 correspond to pfd received with an antenna gain of 0 dBi, it is necessary to compare them with values of (epfd + Gmb), where Gmb is the main beam gain, to determine whether the interference exceeds the detrimental level.*

In this case, the adjustment was made to the non-GSO constellation transmit power.

4.2. Creating the Non-GSO Constellation

The Constellation Wizard was run to create 484 satellites (22 planes of 22 satellites) at an altitude of 500 km with inclination angle 55° and phasing between planes of 8.18°. Eash satellite was assumed to be transmitting with an isotropic antenna and transmit power of -44 dBm = -74 dBW.

As noted in the previous section, this power was then adjusted to take account of the peak gain of the RAS antenna. Hence the power used in the simulation was -74 dBW + 51.28 dBi = -22.72 dBW.

4.3. Creating the Scenario

As well as the Interference Path, the scenario was configured as follows:

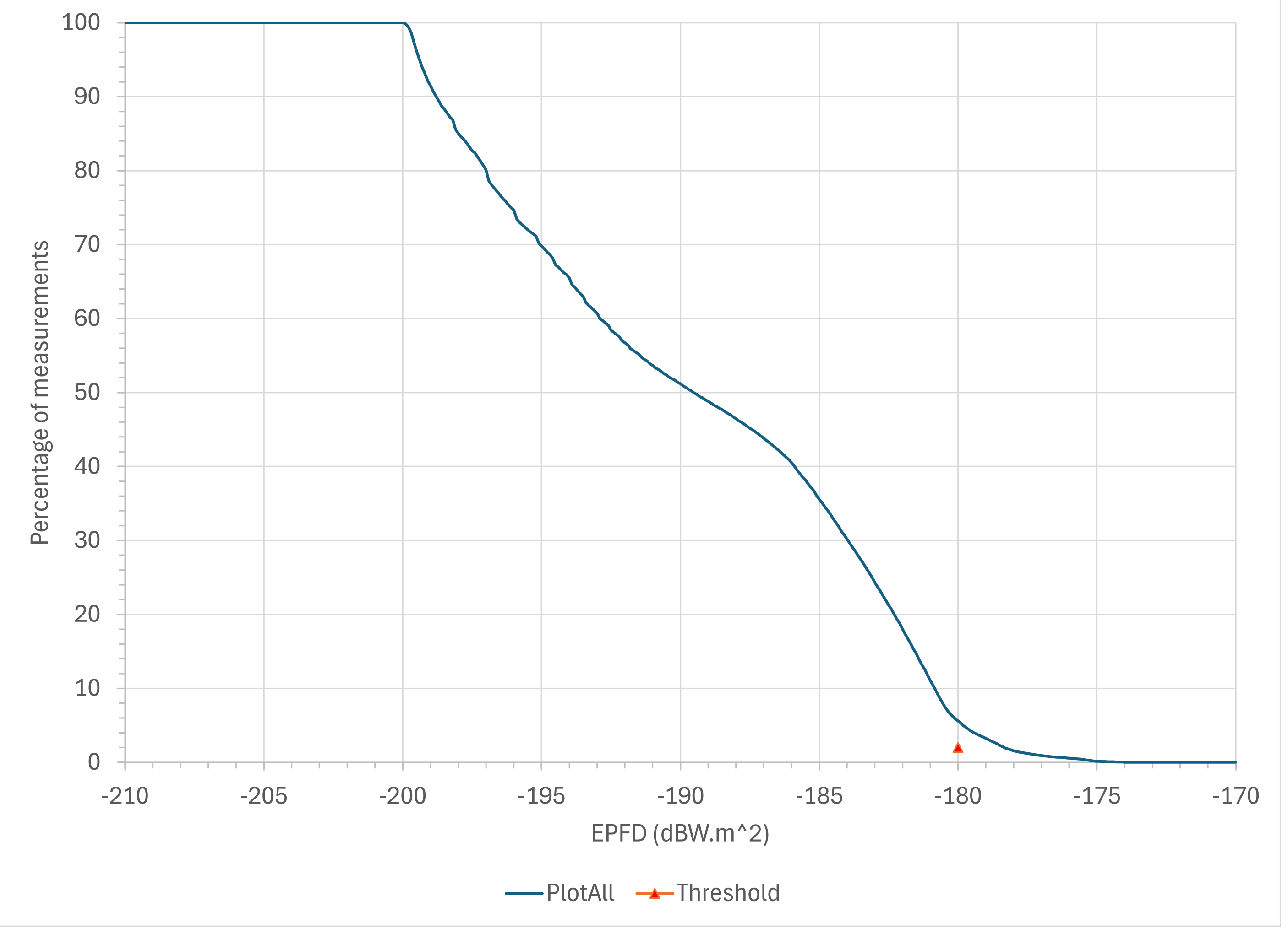
- Set the propagation models to be free space only

- Calculate EPFD statistics, averaging in linear rather than dB
- Set the time step to be 1 second
- Log the average EPFD for each RAS Receive Link every 2,000 time steps
- Run for 500 samples of the average EPFD, i.e. a total run time of 1,000,000 seconds

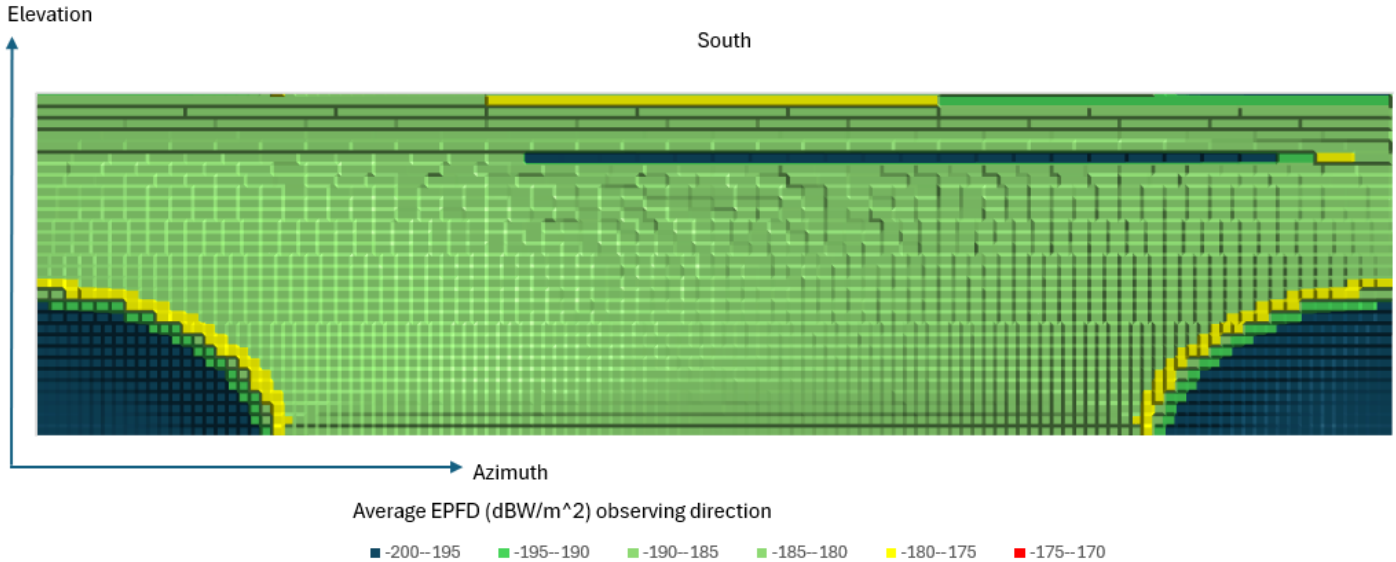
The time step of 1 second was calculated to be sufficiently fine to be able to capture main beam events for the RAS antenna's narrow beam.

4.4. Results

The result was a set of 2,334 cumulative distribution functions (CDFs) of average EPFD over an observation of 2,000 seconds, one per pointing direction. Each CDF contained 500 samples. The total CDF over all pointing active directions is shown in the graph below:



The percentage of observations that exceeded the limit over the observed sky was 5.4%. This is greater than the threshold of 2% and hence mitigation would be required. While this represents an average over the observed sky, the value was higher in some directions, in particular towards the east and west, as shown in the figure below.



Some differences were noted with the results presented here and those in ECC Report 363: these are currently being discussed with the authors of this report.

4.5. Mitigation

A number of mitigation methods could be used to reduce interference from non-GSO FSS systems in the RAS, including:

1. Switching off non-GSO satellites when they are in the main beam of the RAS antenna
2. Reducing non-GSO system's transmit power, resulting in lower PFD on the Earth's surface
3. Increasing the filtering at the non-GSO satellite to reduce out-of-band emissions and/or filtering at the RAS site.

The first approach requires information to be available on the pointing direction of the RAS antenna which could be used by the non-GSO operator to switch off satellites when they are close to the antenna's boresight. The other approaches would require changes to the satellite and/or RAS design or service provided.

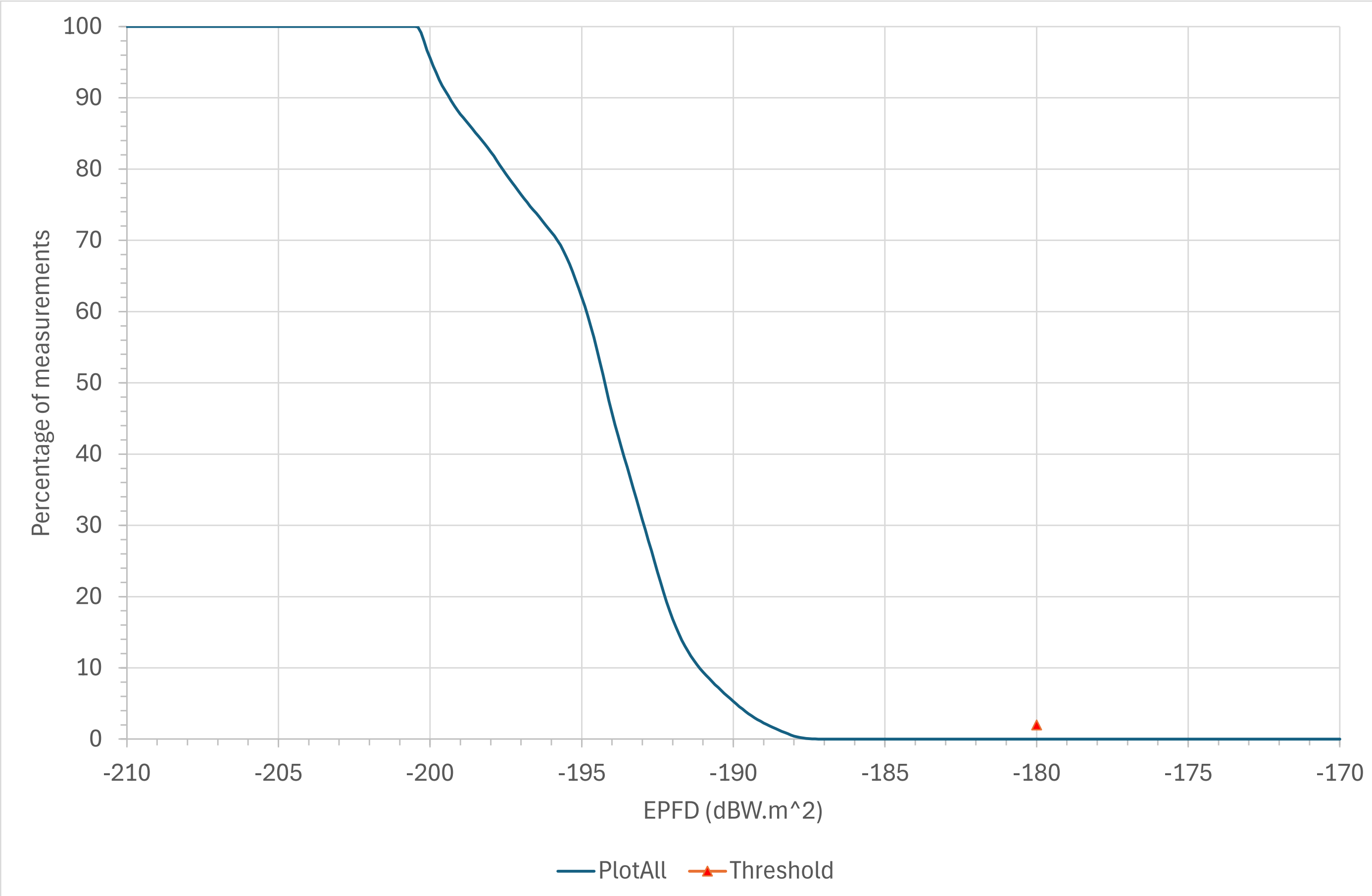
The non-GSO satellite switch-off in the main beam approach was simulated by changing the RAS gain pattern to have a very low gain in the cone where the angle from the boresight vector is less than 1°. As the peak or boresight gain is used in the EPFD calculation, in this run the EPFD was derived from the interfering signal using:

$$EPFD = I - G_{peak} - A_{ISO}$$

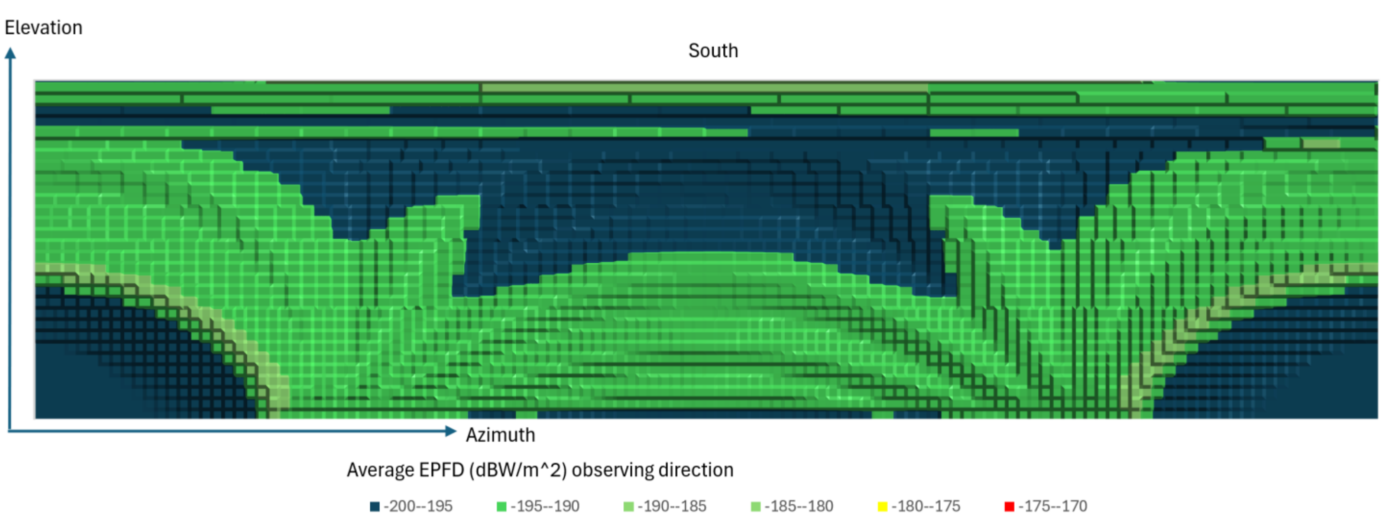
Where:

$$A_{ISO} = 10log_{10}\left(\frac{\lambda^2}{4\pi}\right)$$

The result was a significant reduction in interference, in particular for low percentages of time, to be below the threshold, as can be seen in the figures below.



The impact on the 3D plot of interference is shown below.



4.6. Extending the Model

The model could be extended in a number of ways, including calculating the non-GSO satellite transmit power from a grid of non-GSO ES, tracking strategies and power control, using the NFD in the non-co-frequency interference path and including additional non-GSO constellations to calculate aggregate EPFD.

5. Conclusions

This document has shown how Visualyse Professional can be used to:

- Model RAS sites using ITU-R Recommendations including Rec. ITU-R S.1586
- Model non-GSO satellite systems using a variety of methods which take into account tracking strategies, power control etc.
- Model the non-GSO scenario including bandwidth adjustment and calculation of NFD using satellite transmit mask
- Model interference from non-GSO satellite systems into RAS sites using the mean EPFD metric and array of observation pointing angles
- Compare the resulting mean EPFD values against thresholds in ITU-R Recommendations
- Introduce mitigation and identify impact on the mean EPFD calculation.

This type of analysis can be used to support ITU-R Studies under WRC-27 Agenda Item 1.16 and other scenarios involving the RAS.