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Compatibility and sharing studies related to NGSO satellite systems operating in the FSS bands 10.7-12.75 GHz (space-to-Earth) and 14-14.5 GHz (Earth-to-space)

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0 EXECUTIVE SUMMARY

This Report contains compatibility and sharing studies between the operations of non-Geostationary Satellite Orbit (NGSO) Fixed Satellite Service (FSS) systems in both space-to-Earth and Earth-to-space directions and the incumbent services. The Report also looks at the protection of aircraft from Earth stations deployed near airports.

The Report presents the studies of two NGSO FSS systems: OneWeb and SpaceX. The Report does not address compatibility between the two NGSO systems. Furthermore, it does not assess aggregate interference in the case of simultaneous operation of these two NGSO systems on other victim services.

The studies cover the compatibility of the operations in the FSS downlink allocation in the band 10.7-12.75 GHz with the radio astronomy service (RAS) and the EESS (earth exploration-satellite service) (passive), and the compatibility of the earth stations using the FSS uplink allocation in the band 14-14.5 GHz with the fixed service (FS) and the RAS.

Throughout this Report, reference will be made to findings from the study of the SpaceX system and the study of the OneWeb system, separately.

In the study of the OneWeb system, two kinds of earth station were considered, namely the fixed stations, and Earth Stations In-Motion (ESIM). The ESIM include mobile stations on land, ships and aircraft.

The study of the SpaceX system specifically focused on the compatibility of SpaceX's NGSO operations in the FSS downlink allocation in the 10.7-12.75 GHz band with the passive RAS and EESS services as well as the compatibility of fixed Earth Stations using the FSS uplink allocation in the 14-14.5 GHz band with the Fixed Service (FS) and the RAS.

Studies in the FSS downlink allocation in the 10.7-12.75 GHz band

With regard to OneWeb, studies have been conducted to determine unwanted emissions e.i.r.p. levels that have to be met in each beam of any satellite of this NGSO FSS constellation in order to meet the 2% data loss limit at radio astronomy stations performing observations in the band 10.6-10.7 GHz. These unwanted emission e.i.r.p. levels can be met by the NGSO FSS constellation through a careful design of the satellite payload using appropriate modulation shaping, Intermediate Frequency (IF) and Radio Frequency (RF) filtering, constraints on the SSPA design. However, these techniques would not be sufficient for the OneWeb frequency channel immediately adjacent to the passive band (10.7-10.95 GHz) and this channel would therefore have to be deactivated when in visibility of a RAS station performing observations in this band. The unwanted emission e.i.r.p. limits determined for this NGSO FSS system (OneWeb) also ensure protection of EESS (passive) sensors operating in the band 10.6-10.7 GHz.

With regard to SpaceX, the purpose of the studies conducted is to determine unwanted emissions e.i.r.p. levels that must be met by any individual spacecraft within the proposed SpaceX NGSO FSS constellation in order to meet the 2% data loss limit at radio astronomy stations performing observations in the 10.6-10.7 GHz band. These unwanted emission levels can be met through a careful design of the satellite payload itself by using appropriate modulation shaping and filtering and constraints on the PA design. Emissions from NGSO FSS satellites shall not produce a value exceeding -239.4 dBW/m²/(100 MHz) in the 10.6-10.7 GHz band for more than 2% of the time (with a 100m victim antenna using Recommendation ITU-R RA.1631 pattern). The same unwanted emissions e.i.r.p. levels also ensure protection of EESS (passive) sensors operating in the 10.6-10.7 GHz band. Note that meeting an e.i.r.p. limit of as low as -142.0 dBW/Hz prevents SpaceX from using the lowest Ku-band channel (10.7-10.95 GHz) on a global basis.

Studies in the FSS uplink allocation in the 14-14.5 GHz band

With regard to OneWeb, the studies related to NGSO FSS earth stations operating in the band 14-14.5 GHz at fixed locations concluded the following:

- The results of a survey conducted by CEPT show that so far only five administrations out of the 25 respondents have deployments of fixed service in the 14.25-14.5 GHz band. Compatibility with fixed service stations in the band 14.25-14.5 GHz used in a few CEPT countries will be achieved through the establishment of relevant areas around the fixed service station. In these areas, the FSS earth stations would have to avoid transmitting on frequency channels overlapping with the channel used by the FS station. The actual size of the area has to be determined on a case-by-case basis, taking into account the FS and FSS ES characteristics as well as the surrounding terrain. The typical size of these areas has been determined to be in the order of 58 to 77 km in a 37 dBi FS main beam direction assuming smooth Earth and FSS terminals with an e.i.r.p. towards the horizon of -20 dBW/(40 kHz), but decreases rapidly down to 11 km outside the pointing direction of the FS station, under the same assumptions;

- There are a limited number of RAS stations within the CEPT that perform observations in the secondary RAS allocation in the frequency band 14.47-14.5 GHz. The protection of these RAS stations can be achieved through areas around such stations where any NGSO FSS earth station will have to cease transmissions on channels overlapping with the band 14.47-14.5 GHz. The size of the areas has to be determined on a case-by-case basis taking into account the FSS and terrain characteristics. For FSS terminals with an e.i.r.p. towards the horizon of -20 dBW/(40 kHz) the size of the area can be up to 340 km (single entry analysis), thus not limiting it to a national issue for some of these RAS stations.

The compatibility studies related to land NGSO FSS ESIM operating in the band 14-14.5 GHz concluded the following:

- The compatibility with fixed service stations in the band 14.25-14.5 GHz used in few CEPT countries can be achieved through relevant exclusion zones. Once the earth station enters into a protection zone, it should cease transmitting on frequency channels overlapping with the channel used by the FS station. This cessation of transmission should be automatically performed by the network control unit of the NGSO FSS satellite system, and this action will be assisted by the GPS receiver incorporated in the earth station. The actual size of the exclusion area has to be determined on a case-by-case basis, taking into account the FS and NGSO FSS Earth Station characteristics, as well as the surrounding terrain. The typical size of these exclusion zones for the FSS terminals with an e.i.r.p. of -20 dBW/(40 kHz) towards the horizon has been determined to be in the order of 55 km in the 37 dBi FS antenna main beam direction (assuming smooth Earth), but decreases rapidly down to 10 km outside the pointing direction of the FS station;
- The protection of the RAS stations performing observations in the band 14.47-14.5 GHz can be achieved through areas around such stations where any NGSO FSS earth station will have to cease transmissions on channels overlapping with the band 14.47-14.5 GHz. The size of the areas has to be determined on a case-by-case basis taking into account the FSS and terrain characteristics. For FSS terminals with an e.i.r.p. towards the horizon of -20 dBW/(40 kHz) the size of the area can be up to 250 km (single-entry analysis). The GPS capability of the Earth station and the network control unit of the NGSO satellite system mentioned above should be able to automatically perform the cessation of transmissions.

The compatibility studies related to airborne NGSO FSS ESIM operating in the band 14-14.5 GHz concluded the following:

- Assuming that the airborne ESIM operate under the primary FSS allocation, the protection of fixed service stations in the band 14.25-14.5 GHz used in some CEPT countries can be achieved through a pfd mask. The proposed mask is the following:
  - -122 dB(W/(m² · MHz)) for $\theta \leq 5°$;
  - $-127 + \theta$ dB(W/(m² · MHz)) for $5° < \theta \leq 40°$;
  - -87 dB(W/(m² · MHz)) for $40° < \theta \leq 90°$.

where θ is the angle of arrival of the radio-frequency wave (degrees above the horizontal);

- The protection of the RAS stations observing in the secondary RAS allocation in the band 14.47-14.5 GHz can be achieved through a pfd mask. The proposed mask is the following:
  - $-185 + 0.5 \cdot \theta$ dB(W/(m² · 150 kHz)) for $\theta \leq 10°$;
  - -180 dB(W/(m² · 150 kHz)) for $10° < \theta \leq 90°$.

where θ is the angle of arrival of the radio-frequency wave (degrees above the horizontal);

Compliance with this mask can only be achieved by avoiding transmissions within the 14.47-14.5 GHz band when the aircraft enters in visibility of RAS stations performing observations in this band.

The compatibility studies related to shipborne NGSO FSS ESIM operating in the band 14-14.5 GHz show the following:

- There would be a need for separation distance from the shore to protect FS stations close to the coast assuming FSS terminals with a total e.i.r.p. of 0 dBW towards the horizon. In order to cover all kinds of NGSO FSS systems, a pfd limit at the shore could be defined, similarly to the one developed for ESOMPs in the Ka-band. The proposed level is -116 dBW/m²/MHz at 80 m above sea level with an associated percentage of time of 0.06% or 4.5%, depending on the retained short-term protection criterion. This would apply to shipborne earth stations located in national waters of CEPT countries;
- The protection of RAS stations observing in the secondary RAS allocation in the band 14.47-14.5 GHz and located close to the sea would require exclusion zones up to 3400 km for NGSO FSS terminals with e.i.r.p. of -20 dBW/(40 kHz) towards the horizon. The NGSO FSS operator would have to cease transmissions in the band 14.47-14.5 GHz when the ship enters within these exclusion zones, the size of which has to be determined on a case-by-case basis taking into account FSS characteristics as well as surrounding terrain. This would apply to shipborne earth stations located in national waters of CEPT countries.

The NGSO FSS satellite system will be able to maintain compatibility with fixed links and RAS stations deployed within an administration by establishing the exclusion zones (as stipulated above) for all fixed link receiving stations or RAS observatories and suppressing use of those frequencies, utilised with the fixed service, by fixed earth stations or land and shipborne ESIM. If an administration has deployed fixed links in the band 14.25-14.5 GHz and the specific locations of these fixed links cannot be established, then the exclusion zones could be established as the whole territory of the administration. The protection zone may include territories of neighbouring administrations. The satellite system, by suppressing the use by fixed earth stations of frequencies 14.25-14.5 GHz (or specific frequencies deployed by the fixed service or RAS) within the identified protection zone(s), will provide necessary compatibility with the fixed service and RAS. The OneWeb FSS satellite system will be able to deploy the "control of emission" function stipulated in the ETSI EN 303 980 [1] to ensure the suppression of relevant frequencies by fixed earth stations within the protection zone.

According to the findings in ECC Report 272 [2], NGSO earth stations with e.i.r.p. levels lower than 54.5 dBW would not be subject to restrictions on operations in the proximity of aircraft.

With regard to SpaceX, the studies related to Earth Stations operating in the 14-14.5 GHz band at fixed locations have concluded as follows:

- Compatibility with fixed service stations in the 14.25-14.5 GHz band used in a few CEPT countries (according to a questionnaire conducted in 2016 [3]) can be achieved through the establishment of relevant exclusion zones around the fixed service stations. In these areas, the FSS earth stations have to avoid transmitting on frequency channels overlapping with the channel used by the FS station. The actual size of the exclusion zone has to be determined on a case-by-case basis, taking into account the FS and FSS ES characteristics, as well as the surrounding terrain.
- Regarding aeronautical ESIM in the band 14-14.5 GHz, terrestrial services would be protected applying the PFD mask proposed by OneWeb but SpaceX can comply with the more stringent pfd mask as specified in section A2.5.3.2:
    - -122 dB(W/(m² · MHz)) for $\theta \leq 5°$;
    - $-127 + \theta$ dB(W/(m² · MHz)) for $5° < \theta \leq 15°$;
    - -112 dB(W/(m² · MHz)) for $15° < \theta \leq 90°$

  SpaceX aeronautical ESIM emissions towards the horizon are limited -75.26 dBW/Hz or -15.26 dBW/MHz.
- There are a limited number of RAS stations within the geographic area of CEPT Member States that perform observations in the secondary RAS allocation in the 14.47-14.5 GHz band. The protection of these RAS stations can be achieved through exclusion zones around such stations where any NGSO FSS earth station will have to cease transmissions on channels overlapping with the 14.47-14.5 GHz band. The size of the exclusion zones has to be determined on a case-by-case basis taking into account the FSS and terrain characteristics.
- The SpaceX NGSO FSS satellite system can be able to maintain compatibility with fixed links and RAS stations deployed within an administration by establishing the exclusion zones (as stipulated above) for all fixed link receiving stations or RAS observatories, and suppressing the use of those frequencies

utilized by the Fixed Service by fixed Earth Stations. The satellite system, by suppressing the use by fixed Earth Stations of frequencies 14.25-14.5 GHz (or specific frequencies deployed by the Fixed Service or RAS) within the identified protection zone(s), will provide necessary compatibility with the Fixed Service and RAS.

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LIST OF ABBREVIATIONS

Abbreviation	Explanation
ABW	Allocated Bandwidth
AES	Aircraft Earth Station
AMSS	Aeronautical Mobile Satellite Service
API	Advance Publication Information
ATPC	Adaptive Transmission Power Control
BER	Bit Error Rate
CEPT	European Conference of Postal and Telecommunications Administrations
CRAF	Committee on Radio Astronomy Frequencies
dB	Decibel
dBi	Decibel relative to an Isotropic antenna
dBW	Decibel relative to 1 W
DP	Degradation of Performance
ECC	Electronic Communications Committee
EESS	Earth Exploration-Satellite Service
EFIS	ECO Frequency Information System
e.i.r.p.	equivalent isotropically radiated power
epfd	equivalent power flux density
EMC	Electromagnetic Compatibility
EPO	Error Performance Objective
ES	Errored Second
ESA	European Space Agency
ESIM	Earth Stations in Motion
ESOMPs	Earth Stations On Mobile Platforms
ESV	Earth Stations on Vessels
ETSI	European Telecommunications Standards Institute
FDMA	Frequency Division Multiple Access
FDP	Fractional Degradation of Performance
FM	Frequency Modulation
FCC	Federal Communications Commission
FS	Fixed Service
FSS	Fixed Satellite Service
GLONASS	Global Navigation Satellite System

Abbreviation	Explanation
GPS	Global Positioning System
HEO	High Earth Orbit
IF	Intermediate Frequency
IMT	International Mobile Telecommunications
I/N	Interference to Noise
ITU-R	International Telecommunication Union – Radiocommunication Sector
LNA	Low Noise Amplifier
LEO	Low Earth Orbit
LTAN	Local Time of Ascending Node
MEO	Medium Earth Orbit
NCF	Network Control Facility
NEST	NGSO Earth Station
NGSO	Non-Geostationary Satellite Orbit
OBW	Occupied Bandwidth
PA	Power Amplifier
pfd	power flux density
RAS	Radio Astronomy Service
RF	Radio Frequency
RHCP	Right Hand Circular Polarisation
RR	ITU Radio Regulations
SES	Severely Errored Second
SRS	Space Research Service
SSPA	Solid State Power Amplifier
TT&C	Tracking Telemetry & Control
VSAT	Very Small Aperture Terminal
WRC	World Radiocommunication Conference
WST	Water Surface Temperature

1 INTRODUCTION

The frequency bands 14-14.5 GHz (Earth-to-space) and 10.7-12.75 GHz (space-to-Earth) allocated to the fixed satellite service (FSS) are available for deployment with Non-Geostationary Satellite Orbit (NGSO) satellite systems. The consideration in this Report is primarily focused on the earth stations in the 14-14.5 GHz (Earth-to-space) band deployed as user terminals. This Report provides study results on compatibility between these user terminals of NGSO satellite systems operating in the 14-14.5 GHz band and systems of other services with allocations in the same band and with deployments in Europe. These other services are the fixed service and the radio astronomy service (RAS). The space research, radio navigation and radio navigation-satellite services also have allocations within the band but there are no deployments within Europe, therefore were not subject to these compatibility studies. In addition, the Report also provides study results of adjacent band interference resulting from NGSO satellites operating in the band 10.7-12.75 GHz into the radio astronomy service (RAS) and Earth exploration-satellite service (EESS) in the band 10.6-10.7 GHz.

The Report also provides the conditions for the protection of aircraft from earth stations deployed near airports.

The assessment of compatibility between NGSO earth stations or a NGSO satellite system and systems of other incumbent services (i.e. fixed service and RAS) requires a detailed knowledge of relevant technical characteristics of systems considered. There were no ITU Recommendations that provided the technical characteristics of NGSO satellite systems required for compatibility assessments. Such characteristics could not be established on a generic basis due to disparate system characteristics of NGSO satellite systems.

When other NGSO satellite systems are considered for establishing sharing conditions in the frequency bands dealt with in this Report, particular attention should be given to the relevant sections of this Report that have drawn conclusions based on the specific system characteristics of the OneWeb and SpaceX NGSO satellite systems. Whenever possible, the studies on the NGSO FSS earth stations operating in the band 14-14.5 GHz have been identified as being also applicable to other NGSO systems.

2 ALLOCATIONS WITHIN THE 14-14.5 GHZ BAND

EFIS[1] offers information regarding harmonised spectrum allocations in Europe. These allocations will provide the basis for the consideration of compatibility between earth stations and systems of other services.

2.1 ALLOCATIONS GIVEN IN EFIS

The existing services are identified in the EFIS as:

Table 1: Allocations given in the EFIS for the band 14-14.5 GHz

Frequency band	Allocations
14-14.25 GHz (5.504)	Space Research Mobile-Satellite (Earth-to-space) (5.504B) (5.504C) (5.506A) FIXED-SATELLITE (EARTH-TO-SPACE) (5.457A) (5.457B) (5.484A) (5.506) (5.506B)
14.25-14.3 GHz (5.504)	FIXED-SATELLITE (EARTH-TO-SPACE) (5.457A) (5.457B) (5.484A) (5.506) (5.506B) Space Research Mobile-Satellite (Earth-to-space) (5.504B) (5.506A) (5.508A)
14.3-14.4 GHz	Mobile-Satellite (Earth-to-space) (5.504B) (5.506A) (5.509A) FIXED-SATELLITE (EARTH-TO-SPACE) (5.457A) (5.457B) (5.484A) (5.506) (5.506B)
14.4-14.47 GHz (5.504A)	FIXED-SATELLITE (EARTH-TO-SPACE) (5.457A) (5.484A) (5.506) (5.457B) (5.506B) Mobile-Satellite (Earth-to-space) (5.504B) (5.506A) (5.509A)
14.47-14.5 GHz (5.149) (5.504A)	FIXED-SATELLITE (EARTH-TO-SPACE) (5.457A) (5.484A) (5.506) (5.457B) (5.506B) Mobile-Satellite (Earth-to-space) (5.504B) (5.506A) (5.509A) Radio Astronomy

In addition, the deployment of fixed links within the band 14.25-14.5 GHz by a number of administrations is also identified in EFIS. The administrations with fixed links deployed in this band are identified in Section 2.2.1 of this Report.

2.2 DEPLOYMENT OF OTHER SERVICES BY CEPT ADMINISTRATIONS

The services deployed, other than satellite services, within the band 14-14.5 GHz are described below.

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[1] ECO Frequency Information System: https://efis.cept.org/

2.2.1 Fixed service (FS)

The band 14.3-14.5 GHz is allocated on a primary basis to the FS in the ITU Radio Regulations [4]. RR No 5.508 makes an additional allocation to the FS in the band 14.25-14.3 GHz to few countries, and they include the CEPT countries: France, Germany, Italy, and the former Yugoslav Republic of Macedonia and the United Kingdom.

A recent survey conducted by the CEPT towards the revision of ECC Report 173 [3] indicates that out of the 25 CEPT administrations who responded to the questionnaire only four administrations deploy fixed links in the band 14.25-14.5 GHz. These administrations are:

- United Kingdom 164 FS links;
- France 141 FS links;
- Germany < 50 FS links;
- Russia 30 FS links, existing links are planned to be taken out of service;
- Italy 1089 FS links.

In addition, Romania identified the heavy use of 15 GHz band with channel arrangement that starts with 14.4 GHz. Romania also mentioned the expected continued use by fixed links. However, information on the number of links was not provided to CEPT.

All other respondents stated that they had no use of FS in the band 14.25-14.5 GHz.

2.2.2 Space research service (SRS)

The allocation to SRS is on a secondary basis in the band 14-14.5 GHz.

No usage of this allocation has been identified in CEPT countries. In particular, ESA does not use this band for space research, and the Russian Federation uses the band above 14.5 GHz for Data Relay Satellites.

Recommendation ITU-R SA.1414 [6] (Characteristics of data relay satellite) indicates that the band is only used by the USA (NASA) for return links from the GSO data relay satellite down to Earth, and limited to the band 14-14.05 GHz. This being said, even if such a SRS earth station were to be deployed in Europe, it would operate under a secondary status and therefore cannot claim protection from FSS at fixed locations.

If an SRS earth station is to be based in a CEPT country and offered protection from FSS earth stations, it could be done by establishing the protection distance based on the technical characteristics of the systems concerned.

2.2.3 Radio astronomy service (RAS)

Radio astronomy observations in the 14.47-14.5 GHz band are carried out in several countries within the CEPT. The CRAF webpage[2] lists the radio astronomy stations operating within this band at the time this Report is being written. These are located in Germany (Effelsberg), Italy (Medicina), Sweden (Onsala), Russian Federation, Portugal and the United Kingdom (Cambridge and Jodrell Bank).

The 14.47-14.5 GHz band is mainly used for spectral line observations. At 14.4885 GHz, an important formaldehyde (H_2CO) spectral line exists, which has been observed in the direction of many galactic sources. Observation of this spectral line gives valuable information on the physical conditions of the interstellar medium, because the excitation energies required to produce the line are different from the energies required to produce the H_2CO line observed at the lower frequency of 4829.66 MHz.

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[2] http://www.craf.eu/

2.2.4 Radionavigation service

The radionavigation service is allocated on a primary basis in the band 14-14.3 GHz. There is no ITU-R Recommendation or other documentation providing technical characteristics for such systems.

There is also secondary allocation to the radionavigation-satellite service in the band 14.3-14.4 GHz, but it appears not to be used. An API has been published for the Global Navigation Satellite System (GLONASS system) in this band, however this band does not appear in the notification issued for the GLONASS system.

2.2.5 Summary of deployments in the 14-14.5 GHz band within CEPT

The deployments in the 14-14.5 GHz within the CEPT could be summarised as:

- 14.0-14.25 GHz: fixed-satellite service;
- 14.25-14.5 GHz: fixed-satellite service and fixed service;
- 14.47-14.5 GHz: radio astronomy service.

3 CHARACTERISTICS OF NGSO FSS SYSTEMS

There are several proposed NGSO satellite systems identifying the 14-14.5 GHz band for earth stations for Earth-to-space links. The corresponding space-to-Earth links would operate in the 10.7-12.75 GHz band. The NGSO satellite systems to be deployed using these bands invariably be proprietary systems with their own unique system characteristics. For instance, these NGSO satellite systems are unlikely to have in common those technical parameters needed for compatibility assessments. These technical parameters include (but not limited to these):

- type of orbit, LEO, MEO, HEO etc.;
- orbit altitude;
- orbit inclination (to the equatorial plane);
- number of planes;
- number of satellites per plane;
- satellite e.i.r.p. and antenna pattern;
- earth station e.i.r.p. and antenna pattern;
- minimum elevation of the earth station.

Since the compatibility assessments are linked to these technical characteristics, which are not common amongst NGSO systems, it is not possible to offer a "generic" case to describe compatibility between NGSO satellite systems and other services. In some cases, the results on such assessments are highly dependent on the NGSO characteristics and therefore are not be directly transposable to other NGSO systems. In some other cases, the results are applicable to other NGSO systems. For each of the cases studied, details are provided in the relevant sections to identify the applicability of the results.

4 CHARACTERISTICS AND PROTECTION CRITERIA OF OTHER SERVICES

Other services in the 14.25-14.5 GHz band operating within the CEPT that were identified in Section 2 are as follows:

- Fixed service in the 14.25-14.5 GHz;
- Radio astronomy service in the 14.47-14.5 GHz.

The criteria for the protection of systems operating within these services are identified below.

Characteristics and protection criteria of radio astronomy and EESS (passive) in the 10.6-10.7 GHz band are also provided in this section.

4.1 FIXED SERVICE IN THE 14.25-14.5 GHZ BAND

Recommendation ITU-R F.758-6 [7] provides characteristics for two fixed service systems in the band 14.4-15.35 GHz which are reproduced in Table 2.

Table 2: FS characteristics in the band 14.25-14.5 GHz contained in Recommendation ITU-R F.758-6

Parameter	Value	
Frequency range (GHz)	14.4-15.35	
Reference ITU-R Recommendation	F.636 [8]	
Modulation	FSK	128-QAM
Channel spacing and receiver noise bandwidth (MHz)	2.5, 3.5, 7, 14, 28	2.5, 3.5, 7, 14, 28
Tx output power range (dBW)	0	15
Tx output power density range (dBW/MHz)	−5.44	0.528
Feeder/multiplexer loss range (dB)	0… 6.0	0…5.0
Antenna gain range (dBi)	37	31.9
e.i.r.p. range (dBW)	31…37	41.9…46.9
e.i.r.p. density range (dBW/MHz)	25.6…31.6	27.4…32.4
Receiver noise figure typical		8
Receiver noise power density typical (=N_{RX}) (dBW/MHz)		−136
Normalised Rx input level for 1 × 10−6 BER (dBW/MHz)		−106.5
Nominal long-term interference power density (dBW/MHz)	N_{RX} + I/N	−136 + I/N

In CEPT, antenna gains up to 49 dBi are also reported. ECC Report 026 [19] related to studies between the AMSS and FS at 14 GHz considered an antenna gain of 43 dBi for the FDP analysis, and an antenna gain of 49 dBi for the short-term analysis. In addition, it should be noted that Recommendation ITU-R SF.1650 [18] (ESV) also considers an average antenna gain of 40.5 dBi. Both 37 and 49 dBi antenna gains have been considered for the aeronautical ESIM studies as well as for the shipborne ESIM studies. For the fixed or land ESIM terminals, the protection zone has in any case to be determined on a case-by-case basis taking into account the actual FS parameters used by the administrations.

The parameters generally used in the studies, extracted from Table 2 and from deployments in CEPT, are the following.

Table 3: FS parameters used in the studies

Parameter	Value
Bandwidth (MHz)	1
Antenna gain (dBi)	37, 49
Antenna pattern	Recommendation ITU-R F.699 [9]
Feeder/Multiplexer loss (dB)	0
Receiver noise figure (dB)	8
Antenna height above ground (m)	30
Elevation angle (°)	0 - 5

When the FS station is on the coast, an additional ground height above sea level of 50 m was considered.

4.1.1 Long-term criterion

The long-term protection criterion is based on an I/N of -10 dB not to be exceeded more than 20% of the time as described in Recommendation ITU-R F.758-6 [7]. In addition, the same recommendation states that sharing studies in the frequency bands where multipath fading is the dominant propagation impairment for FS receivers (mostly in frequency bands below about 15 GHz), the fading on the desired and interfering paths are uncorrelated. Under these conditions, Recommendation ITU-R F.1108 [20] introduced the Fractional Degradation in Performance (FDP) method, which shows that it is appropriate to use the average value of the interference power as the critical value for long-term interference power. By analogy with Recommendation ITU-R F.1494 [21] dealing with the protection of FS from time varying aggregate interference from other co-primary services in the 10.7-12.75 GHz band, it can be established that the FDP should not exceed 10%.

4.1.2 Short-term criterion

The determination of a short-term criterion shall be based upon the allowed degradation of performance of links as set forth in Recommendation ITU-R F.1565 [11] which replaces a number of other recommendations such as F.1241 [23] which were used back in 2000-2003.

The degradation due to a given interference short-term criterion is the probability of the simultaneous effect of this criterion and a fading higher than the net fade margin (F), defined as follows:

$$F = FM - ATPCrange - \frac{I}{N} \qquad (1)$$

The degradation of performance is linked to the percentage of time p associated with the protection criterion by:

$$DP(\%) = \frac{p(\%).A(\%)}{100} \qquad (2)$$

therefore

$$p(\%) = \frac{DP(\%)}{\mathrm{A}(\%)}100 \qquad (3)$$

Where:

- DP: allowed degradation of performance (%);
- EPO: error performance objective (%) p: percentage of time where the short-term I/N may be exceeded (%);
- A: percentage of time a given fade margin may be exceeded (%), (see Recommendation ITU-R P.530 [10]).

Recommendation ITU-R F.1565 [11] provides the values of degradation of performance allowed due to interference for international, national long-haul, short-haul, and access connections, respectively. The degradation values are also given in this Recommendation for the errored second (ES) and severely errored second (SES) objectives.

As indicated in other ITU-R Recommendations such as F.1494 [21] or F.1495 [22], the fade margin for SES is 1 dB below the fade margin for a 10^{-3} BER. The fade margin for ES is 5 dB below the fade margin for a 10^{-3} BER. A fade margin for a 10^{-3} BER of 24 dB without ATPC has been retained, based on previous calculations.

It is understood that FS links in this band are mainly used for national short-haul or access networks (e.g. backhauling to mobile IMT networks).

Table 4: Percentage of time based on the SES for a FS part of a national short haul or access network

Parameter	Value	Origin
Fade margin for BER 10-3 (dB)	24	From 2002 studies
Fade margin for SES (dB)	23	
I/N short-term (dB)	23	Maximum
Net fade margin for SES (dB)	0	
Allowed degradation of performance SESR (%)	0.0002 x 0.075 x 100 = 0.0015%	Recommendation ITU-R F.1565 Tables 4a, 4b, 5a and 5b
Probability that the fade margin is exceeded (%)	63%	Recommendation ITU-R P.530 with the net fade margin
Probability associated with the short-term criterion (%)	0.0024	

Table 5: Percentage of time based on the ES for a FS part of a national short haul or access network

Parameter	Value	Origin
Fade margin for BER 10-3 (dB)	24	From 2002 studies
Fade margin for ES (dB)	19	
I/N short-term (dB)	19	Maximum
Net fade margin for ES (dB)	0	
Allowed degradation of performance ESR (%)	0.001 x 7.5%= 0.0075%	Recommendation ITU-R F.1565 Tables 4a, 4b, 5a and 5b (worst case)

Parameter	Value	Origin
Probability that the fade margin is exceeded (%)	63	Recommendation ITU-R P.530 with the net fade margin
Probability associated with the short-term criterion (%)	0.0119	

For NGSO FSS studies, it is proposed to retain a I/N of +19 dB (lower value from Table 4 and Table 5), not to be exceeded more than 0.0119% of the time as determined in Table 5.

Alternatively, another short-term protection criterion was proposed, which is I/N of +19 dB not to be exceeded more than 2.7 x 10-4% of the time. It should be noted that the percentage of time associated with this protection criterion, used in Recommendation ITU-R SF.1650 [18] as well as in the studies related to AMSS, was derived using Recommendation ITU-R F.1241 [23] that has since been suppressed although both criteria have been addressed by the studies in this Report.

4.2 RADIO ASTRONOMY (RAS)

4.2.1 Characteristics for the band 10.6-10.7 GHz

The RAS station is basically described by its antenna, for which the average patterns and maximum gain is provided in Recommendation ITU-R RA.1631 [12]. The recommended patterns represent average side lobe levels to predict interference to a radio astronomy station from one or more fast moving stations seen under continuously variable angles such as NGSO systems. This Recommendation also provides a maximum antenna gain of 81 dBi for a 100 m diameter antenna at 10.6-10.7 GHz, which is considered in the epfd simulation in this Report.

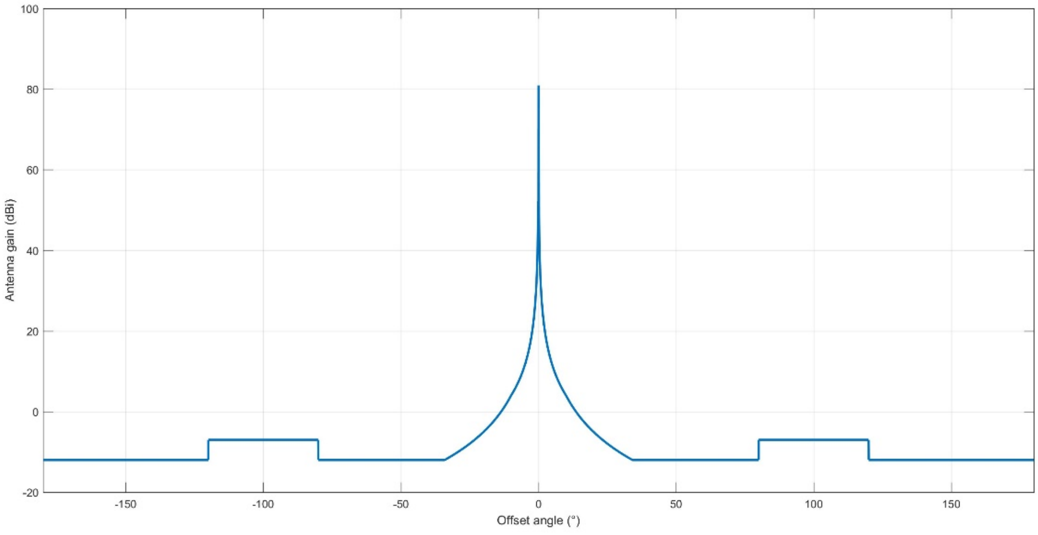

Figure 1: RAS antenna pattern (basic version)

The analysis in this Report uses the antenna pattern provided in the second Recommendation of ITU-R RA.1631 [12], which provides a more accurate representation of the main beam radiation pattern for frequencies above 150 MHz. The results of calculations provided in this paper are for the location of the Effelsberg radio telescope in Germany.

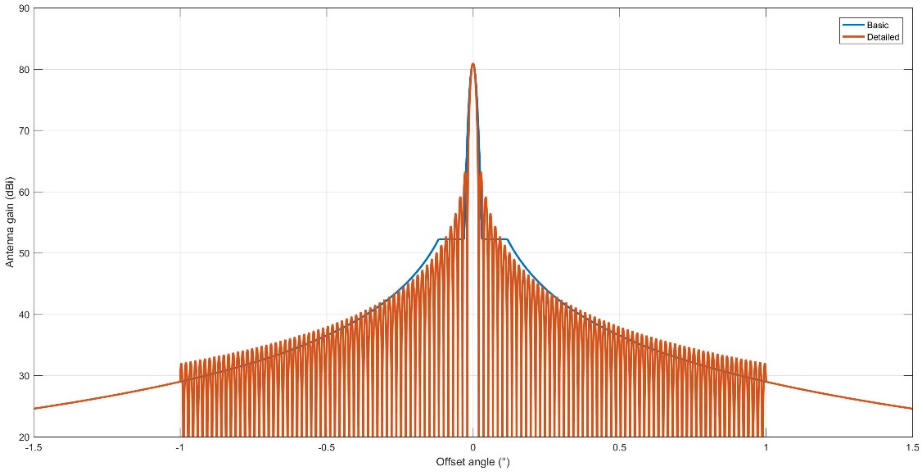

Figure 2: RAS antenna pattern (detailed version - zoomed around the main beam)

Table 6 lists the RAS stations in the CEPT countries that operate in the 10.6-10.7 GHz band.

Table 6: CEPT radio astronomy observatories using the band 10.6-10.7 GHz

Administration	Name	Longitude	Latitude	Diameter	Minimum elevation
Belgium	Humain	05° 15′ 12″	50° 11′ 31″	6 m	
Germany	Effelsberg	06° 53′ 01″	50° 31′ 29″	100 m	8°
	Stockert	06° 43′ 19″	50° 34′ 10″	25 m	-2°
	Wettzell	12° 52′ 38″	49° 08′ 42″	20 m	0°
Italy	Medicina	11° 38′ 49″	44° 31′ 15″	32 m	5°
	Sardinia	9°14’42’’	39°29’34’’	64 m	5°
	Matera-VGOS (planned)	16°42’	40°38’	Yet to be defined	Yet to be defined
	Noto	14° 59′ 20″	36° 52′ 33″	32 m	5°
Russia	Kalyazin	37° 54′ 01″	57° 13′ 22″	64 m	0°
	Puschino	37° 37′ 53″	54° 49′ 20″	22 m	6°
	Badari	102° 13' 16"	51° 45' 27"	32	
	Svetloe	29° 46' 54"	61° 05' 00"	32	
	Zelenchukskaya	41° 35' 12"	43° 49' 34"	32	
Portugal	Santa Maria	– 25° 07′ 33″	36° 59′ 07″	13.2 m	5°
France	Nançay	2°12’00’’	47°23’00’’	94 m	0°
Hungary	BEST (planned)	19°31’	47°54’	Yet to be defined	Yet to be defined
Spain	Yebes	– 03° 05′ 18.7″	40° 31′ 24.5″	13.2 m	5°
Sweden	Onsala (OTT)	11° 55′ 11″	57° 23′ 37″	13.2 m	0°
Turkey	Kayseri	35° 32′ 43″	38° 42′ 37″	12.8 m	10°

Administration	Name	Longitude	Latitude	Diameter	Minimum elevation
Norway	Ny-Ålesund	11°51'17	78°56'36	13.2 m	0°
United Kingdom	Jodrell Bank	-2° 18' 26"	53° 14′ 10"-	76 m	-1°
	Cambridge	52° 10’ 00”	00° 02’ 15”		
	Darnhall	53° 09’ 22”	–02° 32’ 07”		
	Defford	52° 06’ 01”	–02° 08’ 39”		
	Knockin	52° 47’ 24”	–02° 59’ 49”		
	Pickmere	53° 17’ 18”	–02° 26’ 38”		

4.2.2 Protection criteria for the band 10.6-10.7 GHz

The 10.6-10.7 GHz band involves two allocations. The lower end contains a primary allocation to RAS in 10.60-10.68 GHz, while the 10.68-10.7 GHz band is a passive band (No. 5.340). The calculation of data loss levels to radio astronomy observations and percentage-of-time criteria resulting from degradation by interference is described in Recommendation ITU-R RA.1513 [13].

Radio astronomy measurements can tolerate interference from any one network, which does not exceed the thresholds given in Recommendation ITU-R RA.769 [14] by more than 2% data loss and the aggregate interference from all networks must not exceed 5% data loss. The latter is usually very difficult to determine since it would mean taking the contribution of all GSO, NGSO satellite systems, as well as terrestrial systems operating in the band or in nearby bands.

Radio astronomy observations are categorised to two types: continuum and spectral lines. The 10.6-10.7 GHz band is used for continuum observations and the threshold interference level is given as a pfd of -160 dBW/m^2, assuming an integration time of 2000 seconds. To get the epfd threshold level, it is needed to subtract the maximum antenna gain, i.e., 81 dB, from the pfd level. The epfd threshold is therefore -241 dBW/m^2.

The value -241 dBW/m^2/(100 MHz) used in the OneWeb studies has been derived assuming that the RAS antenna has an efficiency of 100%, while a value of -239.4 dBW/m^2/(100 MHz) used in the SpaceX studies has been derived assuming that the RAS antenna has an efficiency of 70%.

4.2.3 Characteristics and protection criteria for the band 14.47-14.5 GHz

The 14.47-14.5 GHz band is used for spectral line observations with a typical resolution of 150 kHz. The interference threshold level is a received power of -214 dBW/150 kHz, leading to a pfd of -169 dBW/m^2/(150 kHz). When considering a 100 m diameter antenna such as Effelsberg, a maximum gain of 84 dBi should be considered, leading to an epfd criterion of -253 dBW/(150 kHz). This value will vary with the antenna diameter. The same data loss threshold value of 2% from ITU-R RA.1513 applies to this band.

A list of the RAS stations in the CEPT countries that operate in the 14.47-14.5 GHz band is provided in Table 7.

Table 7: CEPT RAS observatories using the band 14.47-14.5 GHz

Administration	Name	Longitude	Latitude	Diameter	Minimum elevation
Germany	Effelsberg	06° 53′ 01″	50° 31′ 29″	100 m	8°
Hungary	BEST (planned)	19°31’	47°54’	Yet to be defined	Yet to be defined

Italy	Medicina	11° 38′ 49″	44° 31′ 15″	32 m	5°
	Noto	14° 59′ 20″	36° 52′ 33″	32 m	5°
	Sardinia	9°14’42’’	39°29’34’’	64 m	5°
	Matera-VGOS (planned)	16°42’	40°38’	Yet to be defined	Yet to be defined
Russia	Kalyazin	37° 54′ 01″	57° 13′ 22″	64 m	0°
	Puschino	37° 37′ 53″	54°49′ 20″	22 m	6°
Portugal	Santa Maria	–25° 07′ 33″	36° 59′ 07″	13.2 m	5°
Sweden	Onsala (OTT)	11° 55′ 11″	57° 23′ 37″	13.2 m	0°
United Kingdom	Cambridge	00° 02′ 20″	52° 09′ 59″	32 m	2°
	Jodrell Bank	-02° 18' 26"	53° 14′ 10"	76 m	-1°

4.2.4 Other Characteristics and protection criteria

Incident radiation from strong emitters outside of the protected RAS bands can also cause problems, even if their out-of-band or spurious emissions do not exceed the RAS thresholds (e.g., as defined in Rec. ITU-R RA.769). The maximum input power into the receiving systems should therefore be limited in order to protect the RAS from harmful interference that would degrade the operation of the station. Otherwise, the low-noise-amplifiers (LNA) could be driven into the non-linear regime, which may lead to intermodulation (IM) products, saturation (non-linear gain), or even blocking. The issue can be taken into account and addressed in the national allocation table and/or the national frequency assignment. Further information can be found in the annex 4.

4.3 EESS (PASSIVE)

4.3.1 Characteristics

The characteristics of passive sensors operating in the band 10.6-10.7 GHz have been taken from Recommendation ITU-R RS.1861 [25]. They are given in Table 8.

Table 8: EESS (passive) sensor characteristics in the 10.6-10.7 GHz band

	Sensor C1	Sensor C2	Sensor C3	Sensor C4	Sensor C5
Sensor type	Conical scan				
Orbit parameters					
Altitude	817 km	705 km	833 km	835 km	699.6 km
Inclination	98°	98.2°	98.7°	98.85°	98.186°
Eccentricity	0	0.0015	0	0	0.002
Repeat period	N/A	16 days	17 days	N/A	16 days
Sensor antenna parameters					
Number of beams	1		2	1	
Reflector diameter	0.9 m	1.6 m	2.2 m	0.6 m	2.0 m
Maximum beam gain	36 dBi	42.3 dBi	45 dBi	36 dBi	44.1 dBi
Polarisation	H, V		H, V, R, L	H, V	
–3 dB beamwidth	2.66°	1.4°	1.02°	3.28°	1.2°
Instantaneous field of view	56 km × 30 km	51 km × 29 km	48 km × 28 km	76 km × 177 km	41 km × 21 km
Main beam efficiency		94.8%	95%		93%
Off-nadir pointing angle	44.3°	47.5°	47°	55.4°	47.5°
Beam dynamics	20 rpm	40 rpm	31.6 rpm	2.88 s scan period	40 rpm
Incidence angle at Earth	52°	55°	58.16°	65°	55°
–3 dB beam dimensions	56.7 km (cross-track)	27.5 km (cross-track)	42.9 km (cross-track)	N/A	23 km (cross-track)
Swath width	1 594 km	1 450 km	1 600 km	2 000 km	1 450 km
Sensor antenna pattern	See Recommendation ITU-R RS.1813 [24]	Fig. 8a	Fig. 8b	See Recommendation ITU-R RS.1813 [24]	
Cold calibration ant. gain	N/A	29.1 dBi	N/A		29.6 dBi
Cold calibration angle (degrees re. satellite track)	N/A	115.5º	N/A		115.5º
Cold calibration angle (degrees re. nadir direction)	N/A	97.0º	N/A		97.0º
Sensor receiver parameters					
Sensor integration time	1 ms	2.5 ms	2.47 ms	N/A	2.5 ms
Channel bandwidth	100 MHz	100 MHz centred at 10.65 GHz			
Measurement spatial resolution					
Horizontal resolution	38 km	27 km	15 km	38 km	23 km
Vertical resolution	38 km	47 km	15 km	38 km	41 km

4.3.2 Meteor-3M satellite system description

Meteor-3M satellite system comprises of three satellites, Meteor-M №1 (launched in 2009), Meteor-M №2 (launched in 2014) and Meteor-M №2-2 (launched in 2019), deployed in sun-synchronous circular orbit (LTAN 9:30) with orbit height of 835 km and inclination around 98.8°. Each satellite carries passive instrument, representing a multi-channel conical scan radiometer, using 0.63 m (-3 dB beamwidth is 2.9°) reflector receiving antenna (H, V polarisations are used) with maximum gain of 34.3 dBi and off-nadir pointing angle of 53.3°.

10.65 GHz channel is used to make measurements of Water Surface Temperatures (WST) and has a sensitivity (radiometric resolution) of 0.06 K, separate cold calibration channel is used to increase accuracy. Cold calibration channel receiving antenna (0.28*0.2 m, -3 dB beamwidth is 10 degrees, maximum gain is 25.4 dBi) is oriented in the upper hemisphere and measures the brightness temperature of sky. A next generation meteorological satellite, Meteor-MP, is planned for launch after 2021, which would carry an advanced conical scan radiometer with a 0.9 m reflector receiving antenna with improved side-lobe performance, reaching a sensitivity of 0.03 K in the 10.65 GHz channel.

4.3.3 Protection criteria

Recommendation ITU-R RS.2017-0 [26] specifies permissible interference level at the input of passive instrument receiver as 20% of the radiometer threshold power, which is based on radiometer sensitivity. For a typical value of 0.1 K, provided in Recommendation ITU-R RS.2017-0, the permissible interference level is 166 dBW/(100 MHz). For Meteor-M, for which the sensitivity is 0.06 K, the permissible interference level is -168 dBW/(100 MHz). For Meteor-MP, for which the sensitivity is 0.03 K, the permissible interference level is -171 dBW/(100 MHz). The above values should not be exceeded more than 0.1% of the time. The reference measurement area is a square on the earth of 10 000 000 km².

5 PROTECTION OF AIRCRAFT FROM ES DEPLOYED IN VICINITY OF AIRCRAFT

ECC Report 272 [2] specifies that there would be no additional constraint imposed on land mobile or airborne FSS earth stations operating with e.i.r.p. lower than 54.4 dBW in Ku-band. The e.i.r.p. of NGSO earth stations documented in this Report is 34 dBW, 20 below the e.i.r.p. limit. There would therefore be no restriction on the operation of NGSO earth station within or in the vicinity of aircraft.

6 CONCLUSIONS

This Report contains compatibility and sharing studies between the operations of non-Geostationary Satellite Orbit (NGSO) Fixed Satellite Service (FSS) systems in both space-to-Earth and Earth-to-space directions and the incumbent services. The Report also looks at the protection of aircraft from Earth stations deployed near airports.

The studies cover the compatibility of the operations in the FSS downlink allocation in the band 10.7-12.75 GHz with the radio astronomy service (RAS) and the EESS (earth exploration-satellite service) (passive), and the compatibility of the earth stations using the FSS uplink allocation in the band 14-14.5 GHz with the fixed service (FS) and the RAS. Two kinds of earth stations were considered in these studies, namely the fixed stations and earth stations in motion (ESIM). The ESIM include mobile stations on land, ships and aircraft.

With regard to the FSS downlink allocation in the band 10.7-12.75 GHz, the studies have only addressed two NGSO FSS systems (OneWeb and SpaceX) for which specific characteristics have been made available at the time this Report was written. The studies have been conducted to determine unwanted emissions e.i.r.p. levels that have to be met in each beam of any satellite of this NGSO FSS constellation in order to meet the 2% data loss limit at radio astronomy stations performing observations in the band 10.6-10.7 GHz. These unwanted emission e.i.r.p. levels can be met by the NGSO FSS constellation through a careful design of the satellite payload using appropriate modulation shaping, IF and RF filtering, constraints on the SSPA design. However, these techniques would not be sufficient for either the OneWeb, or SpaceX frequency channel immediately adjacent to the passive band (10.7-10.95 GHz), and this channel would therefore have to be deactivated when in visibility of a RAS station performing observations in this band. The unwanted emission e.i.r.p. levels determined for these two NGSO FSS systems (OneWeb and SpaceX) also ensure protection of EESS (passive) sensors operating in the band 10.6-10.7 GHz.

With regard to OneWeb, the studies related to NGSO FSS earth stations operating in the band 14-14.5 GHz at fixed locations concluded the following:

- The results of a survey conducted by CEPT show that so far only five administrations out of the 25 respondents have deployed fixed service in the 14.25-14.5 GHz band. Compatibility with fixed service stations in the band 14.25-14.5 GHz used in a few CEPT countries will be achieved through the establishment of relevant areas around the fixed service station. In these areas, the FSS earth stations would have to avoid transmitting on frequency channels overlapping with the channel used by the FS station. The actual size of the area has to be determined on a case by case basis, taking into account the FS and FSS ES characteristics, as well as the surrounding terrain. The typical size of these areas has been determined to be in the order of 58 to 77 km in a 37 dBi FS main beam direction assuming smooth Earth and FSS terminals with an e.i.r.p. towards the horizon of -20 dBW/(40 kHz), but decreases rapidly down to 11 km outside the pointing direction of the FS station, under the same assumptions;
- There are a limited number of RAS stations within the CEPT that perform observations in the secondary RAS allocation in the frequency band 14.47-14.5 GHz. The protection of these RAS stations can be achieved through areas around such stations where any NGSO FSS earth station will have to cease transmissions on channels overlapping with the band 14.47-14.5 GHz. The size of the areas has to be determined on a case-by-case basis taking into account the FSS and terrain characteristics. For FSS terminals with an e.i.r.p. towards the horizon of -20 dBW/(40 kHz) the size of the area can be up to 340 km (single entry analysis), thus not limiting it to a national issue for some of these RAS stations.

The compatibility studies related to land NGSO FSS ESIM operating in the band 14-14.5 GHz concluded the following:

- The compatibility with fixed service stations in the band 14.25-14.5 GHz used in few CEPT countries can be achieved through relevant exclusion zones. Once the earth station enters into a protection zone, it should cease transmitting on frequency channels overlapping with the channel used by the FS station. This cessation of transmission should be automatically performed by the network control unit of the NGSO FSS satellite system, and this action will be assisted by the GPS receiver incorporated in the earth station. The actual size of the exclusion area has to be determined on a case-by-case basis, taking into account the FS and NGSO FSS Earth Station characteristics, as well as the surrounding terrain. The typical size of these exclusion zones for the FSS terminals with an e.i.r.p. of -20 dBW/(40 kHz) towards the horizon has been determined to be in the order of 55 km in the 37 dBi FS antenna main beam direction (assuming smooth Earth), but decreases rapidly down to 10 km outside the pointing direction of the FS station;

- The protection of the RAS stations performing observations in the band 14.47-14.5 GHz can be achieved through areas around such stations where any NGSO FSS earth station will have to cease transmissions on channels overlapping with the band 14.47-14.5 GHz. The size of the areas has to be determined on a case-by-case basis taking into account the FSS and terrain characteristics. For FSS terminals with an e.i.r.p. towards the horizon of -20 dBW/(40 kHz) the size of the area can be up to 250 km (single-entry analysis). The GPS capability of the Earth station and the network control unit of the NGSO satellite system mentioned above should be able to automatically perform the cessation of transmissions.

The compatibility studies related to airborne NGSO FSS ESIM operating in the band 14-14.5 GHz concluded the following:

- Assuming that the airborne ESIM operate under the primary FSS allocation, the protection of fixed service stations in the band 14.25-14.5 GHz used in some CEPT countries can be achieved through a pfd mask. The proposed mask is the following:
  - -122 dB(W/(m² · MHz)) for $\theta \leq 5°$;
  - $-127 + \theta$ dB(W/(m² · MHz)) for $5° < \theta \leq 40°$;
  - -87 dB(W/(m² · MHz)) for $40° < \theta \leq 90°$

where θ is the angle of arrival of the radio-frequency wave (degrees above the horizontal);

- The protection of the RAS stations observing in the secondary RAS allocation in the band 14.47-14.5 GHz can be achieved through a pfd mask. The proposed mask is the following:
  - $-185 + 0.5 \cdot \theta$ dB(W/(m^2 · 150 kHz)) for $\theta \leq 10°$;
  - -180 dB(W/(m^2 · 150 kHz)) for $10° < \theta \leq 90°$.

where θ is the angle of arrival of the radio-frequency wave (degrees above the horizontal).

Compliance with this mask can only be achieved by avoiding transmissions within the 14.47-14.5 GHz band when the aircraft enters in visibility of RAS stations performing observations in this band.

The compatibility studies related to shipborne NGSO FSS ESIM operating in the band 14-14.5 GHz show the following:

- There would be a need for separation distance from the shore to protect FS stations close to the coast assuming FSS terminals with a total e.i.r.p. of 0 dBW towards the horizon. In order to cover all kinds of NGSO FSS systems, a pfd limit at the shore could be defined, similarly to the one developed for ESOMPs in the Ka-band. The proposed level is -116 dBW/m²/MHz at 80 m above sea level with an associated percentage of time of 0.06% or 4.5%, depending on the retained short-term protection criterion. This would apply to shipborne earth stations located in national waters of CEPT countries;
- The protection of RAS stations observing in the secondary RAS allocation in the band 14.47-14.5 GHz and located close to the sea would require exclusion zones up to 3400 km for NGSO FSS terminals with e.i.r.p. of -20 dBW/(40 kHz) towards the horizon. The NGSO FSS operator would have to cease transmissions in the band 14.47-14.5 GHz when the ship enters within these exclusion zones, the size of which has to be determined on a case-by-case basis taking into account FSS characteristics as well as surrounding terrain. This would apply to shipborne earth stations located in national waters of CEPT countries.

The NGSO FSS satellite systems will be able to maintain compatibility with fixed links and RAS stations deployed within an administration by establishing the exclusion zones (as stipulated above) for all fixed link receiving stations or RAS observatories and suppressing use of those frequencies, utilised with the fixed service, by fixed earth stations or land and shipborne ESIM. If an administration has deployed fixed links in the band 14.25-14.5 GHz and the specific locations of these fixed links cannot be established, then the exclusion zones could be established as the whole territory of the administration. The protection zone may include territories of neighbouring administrations. The satellite system, by suppressing the use by fixed earth stations of frequencies 14.25-14.5 GHz (or specific frequencies deployed by the fixed service or RAS) within the identified protection zone(s), will provide necessary compatibility with the fixed service and RAS. The OneWeb and SpaceX FSS satellite systems will have to be able to deploy the "control of emission" function stipulated in the ETSI EN 303 980 [1] to ensure the suppression of relevant frequencies by fixed earth stations within the protection zone.

According to the findings in ECC Report 272 [2], NGSO earth stations with e.i.r.p. levels lower than 54.5 dBW would not be subject to restrictions on operations in the proximity of aircraft.

With regard to SpaceX, the studies related to Earth Stations operating in the 14-14.5 GHz band at fixed locations have concluded as follows:

- Compatibility with fixed service stations in the 14.25-14.5 GHz band used in a few CEPT countries (according to a questionnaire conducted in 2016 [3]) can be achieved through the establishment of relevant exclusion zones around the fixed service stations. In these areas, the FSS earth stations have to avoid transmitting on frequency channels overlapping with the channel used by the FS station. The actual size of the exclusion zone has to be determined on a case-by-case basis, taking into account the FS and FSS ES characteristics, as well as the surrounding terrain.
- Regarding aeronautical ESIM in the band 14-14.5 GHz, terrestrial services would be protected applying the PFD mask proposed by OneWeb, but SpaceX can comply with the more stringent pfd mask as specified in section A2.5.3.2:
    - -122 dB(W/(m² · MHz)) for $\theta \leq 5°$;
    - $-127 + \theta$ dB(W/(m² · MHz)) for $5° < \theta \leq 15°$;
    - -112 dB(W/(m² · MHz)) for $15° < \theta \leq 90°$
- SpaceX aeronautical ESIM emissions towards the horizon are limited -75.26 dBW/Hz or -15.26 dBW/MHz. There are a limited number of RAS stations within the geographic area of CEPT Member States that perform observations in the secondary RAS allocation in the 14.47-14.5 GHz band. The protection of these RAS stations can be achieved through exclusion zones around such stations where any NGSO FSS earth station will have to cease transmissions on channels overlapping with the 14.47-14.5 GHz band. The size of the exclusion zones has to be determined on a case-by-case basis taking into account the FSS and terrain characteristics.
- The SpaceX NGSO FSS satellite system can be able to maintain compatibility with fixed links and RAS stations deployed within an administration by establishing the exclusion zones (as stipulated above) for all fixed link receiving stations or RAS observatories, and suppressing the use of those frequencies utilized by the Fixed Service by fixed Earth Stations. The satellite system, by suppressing the use by fixed Earth Stations of frequencies 14.25-14.5 GHz (or specific frequencies deployed by the Fixed Service or RAS) within the identified protection zone(s), will provide necessary compatibility with the Fixed Service and RAS.

ANNEX 1: ONEWEB NGSO FSS SYSTEM

A1.1 SATELLITE AND PAYLOAD CHARACTERISTICS IN THE 10.7-12.75 GHZ BAND

The OneWeb constellation has been filed to the ITU in Ku-band through Filing L5, ITU Publication Number CR/C/3413 MOD-9, BRIFIC / Published Date 2910/10 December 2019.

The satellite payload characteristics are established in order to facilitate the assessment of adjacent band interference resulting from NGSO satellites operating in the band 10.7-12.75 GHz into the radio astronomy and EESS (passive) services allocated in the band 10.6-10.7 GHz.

Studies have been performed for the OneWeb constellation, whose satellites are planned to be deployed in polar orbits as depicted in Figure 3. Table 9 lists the basic characteristics of this NGSO satellite system.

Table 9: Orbital characteristics of the OneWeb NGSO system

Parameter	Value
Number of satellites	588
Orbits	Polar orbits
Number of planes	12
Number of satellites per plane	49
Altitude (km)	1200
Inclination (°)	87.9
Note: Additional satellites will be launched as spare satellites but will not be active.	

The number of satellites visible from a point of the earth varies in time and with the latitude of the observing point considered. As an example, for the latitude of Effelsberg (50°N), the number of satellites above 0° elevation varies between 46 and 61. At the equator, this number is between 28 and 35.

The satellite antenna in Ku-band consists of 16 beams. Figure 3 provides the -3 dB aperture of each of the beams both along and across the satellite path.

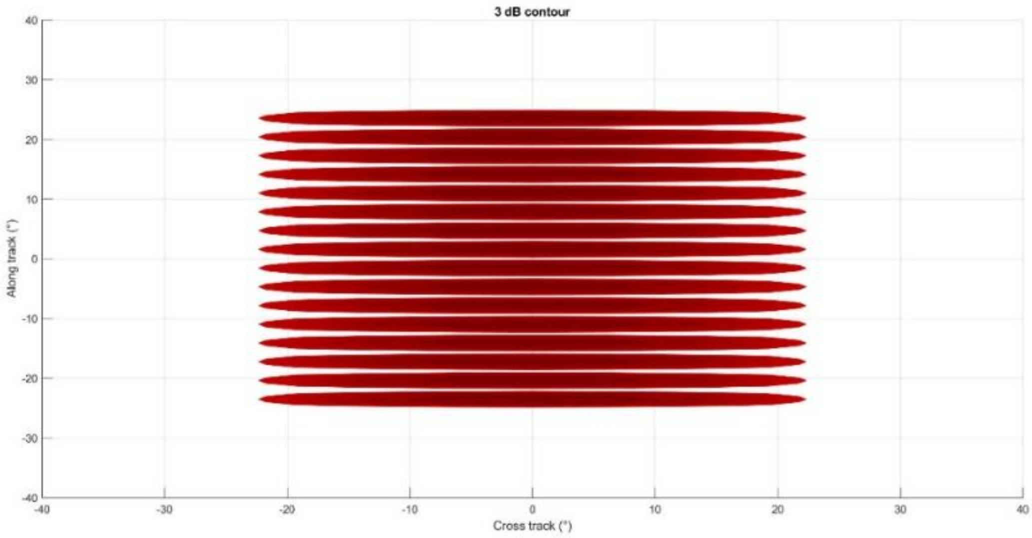

Figure 3: -3 dB composite antenna aperture

The orientation of these beams from the satellite nadir is provided in Table 10.Table 10: Orientation of each beam from Nadir

Beam	Orientation from Nadir (°)
1	-23.5
2	-20.4
3	-17.3
4	-14.1
5	-11.0
6	-7.8
7	-4.7
8	-1.6
9	1.6
10	4.7
11	7.8
12	11.0
13	14.1
14	17.3
15	20.4
16	23.5

It should be noted that not all of these beams are active. The number of beams active depends on the latitude (due to the use of progressive pitch around the equator to overcome interference to GSO networks). In particular, at latitudes corresponding to Europe, the extreme beams 1, 2, 15 and 16 are not used due to a change in the number of satellites per planes during the design phase from initially 40 to now 49. This is to avoid intra system interference between adjacent satellites within the same orbital plane.

The antenna pattern for each of these beams is provided in Table 11. It is a 3D pattern defined in two orthogonal directions, one along the satellite track (along track), and one perpendicular to the satellite track (cross-track). The offset angles corresponding to 10 different antenna gain roll off values are provided for both directions. The corresponding 3D antenna pattern is shown in Figure 4.

Table 11: Antenna pattern for all beams

Roll off (dB)	0	-0.2	-1	-4	-6	-8	-10	-15	-20	-20
Offset along track (°)	0	0.5	1	1.2	1.6	1.95	2.3	2.9	3.3	180
Offset cross track (°)	0	6	14	19	27.8	35.9	44.2	52.7	73.7	180

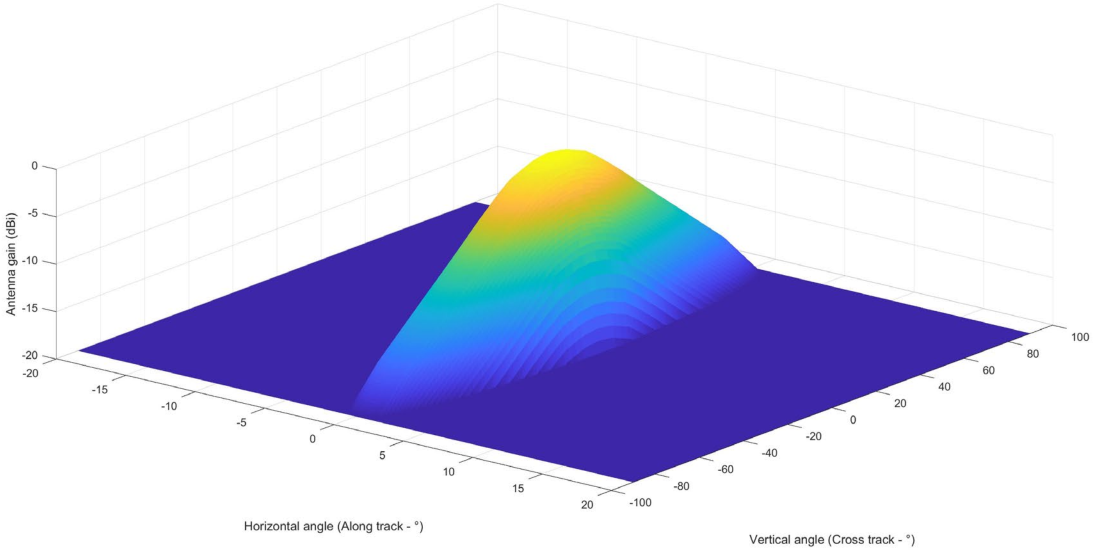

Figure 4: -3 dB composite antenna aperture

Each satellite beam will use a different frequency channel. The level of unwanted emission falling into the RAS band below 10.7 GHz would depend on the separation between the channel frequency and the edge of the FSS allocation, leading to different unwanted emission e.i.r.p. in the RAS band per beam.

A1.2 NGSO EARTH STATIONS IN THE 14-14.5 GHZ BAND

A1.2.1 Deployment of NGSO earth stations

OneWeb earth stations will be developed for fixed and nomadic or transportable applications, the latter falling within the category of Earth Stations In-Motion (ESIM). Such ESIM terminals are expected to be deployed on vehicles on land, on vessels and on aircraft. Specific deployments of fixed and ESIM earth stations for NGSO satellite systems will be contingent upon the position on their compatibility with other services in the 14-14.5 GHz band. The discussion in Section 3 identified that the use of the band 14-14.25 GHz is limited to the fixed satellite service. Therefore, the band 14-14.25 GHz is available for ubiquitous deployment of earth stations within CEPT. The upper part of the band 14.25-14.5 GHz is used by other services, namely the fixed service and radio astronomy service, therefore the use of the upper part of the band by earth stations is subject to relevant compatibility considerations.

With the above consideration, the deployment of NGSO earth stations in the 14-14.5 GHz band could be as follows:

- In the 14-14.25 GHz band: ubiquitous deployment of fixed earth stations and ESIM;
- In the 14.25-14.5 GHz band: deployment of fixed and ESIM earth stations subject to specific technical conditions in order to maintain compatibility with incumbent services using the band.

There are two types of earth stations considered for deployment:

- Fixed earth stations using parabolic antennas;
- ESIM on land vehicles, aircraft or ships using phased array antennas.

A1.2.2 General characteristics common to both types of earth stations

The OneWeb NGSO satellite system will operate with two types of terminals, identified as consumer and enterprise, whose characteristics are described in Table 12. For both types of terminals in Table 12 the maximum on-axis e.i.r.p. is 34 dBW/(20 MHz) or 37 dBW/(40 MHz) when two 20 MHz channels are simultaneously transmitted.

Table 12: Transmitter parameters

Parameter	Units	Consumer earth station	Enterprise earth station	Notes
Carrier Allocated Bandwidth (ABW)	MHz	20		6 carriers per transponder
Carrier Occupied Bandwidth (OBW)	MHz	18.2		
Symbol rate	MBds	18.2		
Data rate	Mbps	36.4		
Error Correction Coding		3GPP Turbo Convolutional Code		
Equivalent Parabolic Antenna Diameter	m	0.45	0.90	
Transmit Antenna Beamwidth	degrees	3.27	1.64	@ 14.25 GHz
Minimum Operational Elevation Angle	degrees	50 to 60		
Tx Antenna Gain (Gtx)	dBi	35	41	70% Efficiency @ 14.25 GHz
Feeder Loss (Lf)	dB	1.0	1.0	
Power input into antenna	dBW	0	-6	The input power scales with the carrier bandwidth (10 MHz carriers would have an input power of -1 dBW for the Consumer UT)
e.i.r.p.	dBW	34	34	
Note: For uplink carrier bandwidths less than 20 MHz the parameters in this table will scale accordingly, including a corresponding reduction in transmit power and e.i.r.p. for lower bandwidth carriers.				

With regard to unwanted emissions within the band 14-14.5 GHz, the Adjacent Channel Leakage Ratio in the first adjacent channel (ACLR1) is 22 dB measured in 18 MHz. The ACLR in the second adjacent channel (ACLR2) is 28 dB measured in 18 MHz.

A1.2.3 Control of the emissions from earth stations

The ETSI EN 303 980 (Harmonised EN for fixed and in-motion Earth Stations communicating with Non-Geostationary Satellite Orbit (NEST) in the 11 GHz to 14 GHz frequency bands covering essential requirements of article 3.2 of the Radio Equipment Directive 2014/53/EU) [1] identifies in its section 4.2.6.2.2 that the conditions for cessation of emissions, which include, amongst others, the location of the earth station working to a NGSO satellite system and the boundaries of the authorised operating area so that cessation of emissions occurs prior to entering any protection zone including any inaccuracy in determination of the geographic location of the NEST.

OneWeb earth stations, both fixed and ESIM, are expected to comply with EN 303 980. Consequently, OneWeb earth stations will be equipped with GPS receivers allowing them (or their Network Control facility (NCF)) to determine the position of each earth station with a high level of accuracy. The fixed earth stations will have the possibility to cease emissions over a given frequency band, either autonomously or through the Network Control Facility (NCF), when located within exclusion zones such as those determined around individual FS stations in the band 14.25-14.5 GHz, or RAS stations in the band 14.47-14.5 GHz. This aspect is further discussed in Section A1.5 below. Similarly, ESIM will be able to cease emissions prior to entering exclusion zones, determined for FS stations or RAS stations, which not only include the territory of a country but also the neighbouring territories. This may include territorial waters. These aspects are also further discussed in Section A1.6.

A1.2.4 Earth stations at fixed locations

The earth stations at fixed locations are expected to use a parabolic antenna. Such antennas are expected to be mounted on top of houses and buildings as shown in the example of Figure 5. For the subsequent studies, an antenna height of 20 m has been assumed.

Figure 5: Example of parabolic antenna

OneWeb earth stations can operate at the equator with a minimum elevation angle of 35° but operate within CEPT countries with a minimum elevation angle of 49° (based on Canarias Islands latitude). An e.i.r.p. mask for OneWeb fixed earth stations indicate that the off-axis e.i.r.p. between 49° and 90° offset angle varies between -20 dBW/(40 kHz) and -17 dBW/(40 kHz) depending on the offset angle, as shown in Figure 6.

Due to this elevation angle, the e.i.r.p. radiated towards the horizon, i.e. towards the victim, will be in the side lobes. Hence, no polarisation loss can be considered.

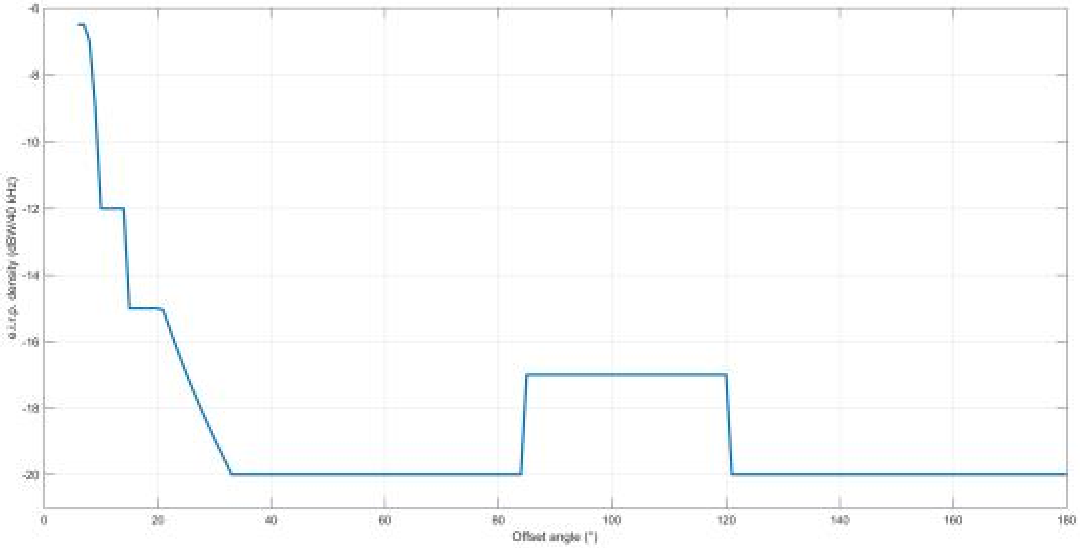

Figure 6: e.i.r.p. mask for parabolic antennas

This mask is a peak one, i.e. the output power plus the peak antenna gain have to meet this mask. However, in sharing studies involving NGSO satellites, the side lobes in the antenna patterns are averaged (3 dB below the peak side lobes) because the antenna is moving while tracking the satellites and hence the antenna gain shifts between the peaks and holes in the pattern. Considering this, an e.i.r.p. of -17 dBW/(40 kHz) – 3 dB has to be used for the studies.

A1.2.5 Earth Stations In-Motion (ESIM)

In the case of ESIM, apart from the fact that the earth station is moving, the antenna and emission power used differ from fixed earth stations. As shown in Figure 7 the antenna for terminals in motion is a phased array; therefore, the level of side lobes varies with the pointing angle of the antenna as shown in Figure 12.

Figure 7: Aircraft earth station

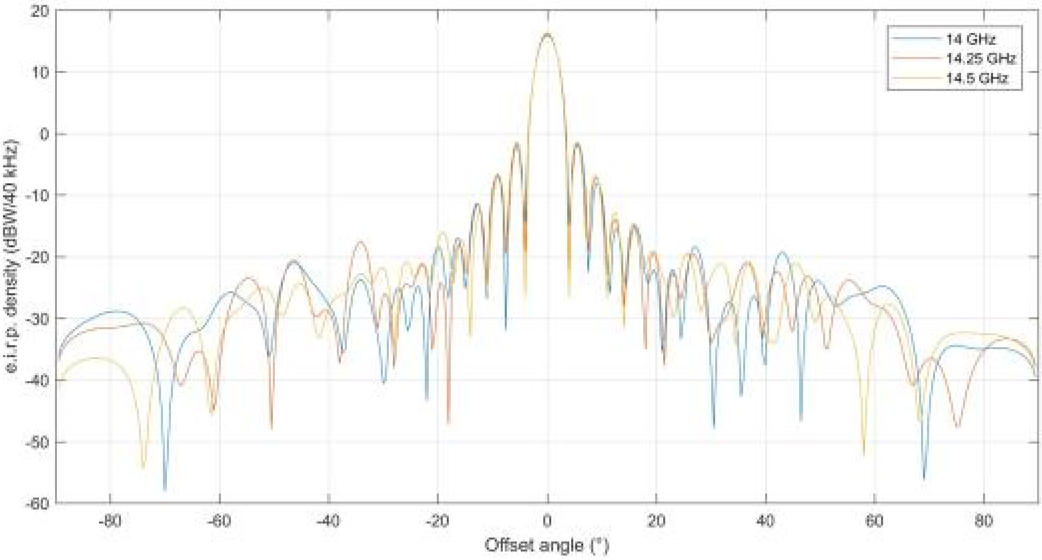

Figure 8: e.i.r.p. mask for the phased array antenna (dBW/(40 kHz)) for 90° elevation pointing for three frequencies (14, 14.25 and 14.5 GHz)

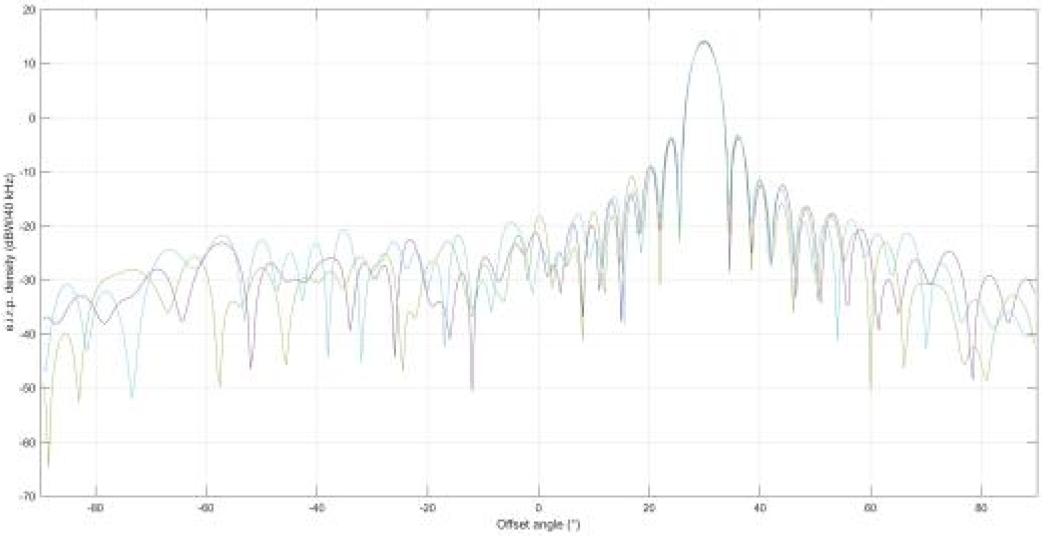

Figure 9: e.i.r.p. mask for the phased array antenna (dBW/(40 kHz)) for 60° elevation pointing for three frequencies (14, 14.25 and 14.5 GHz)

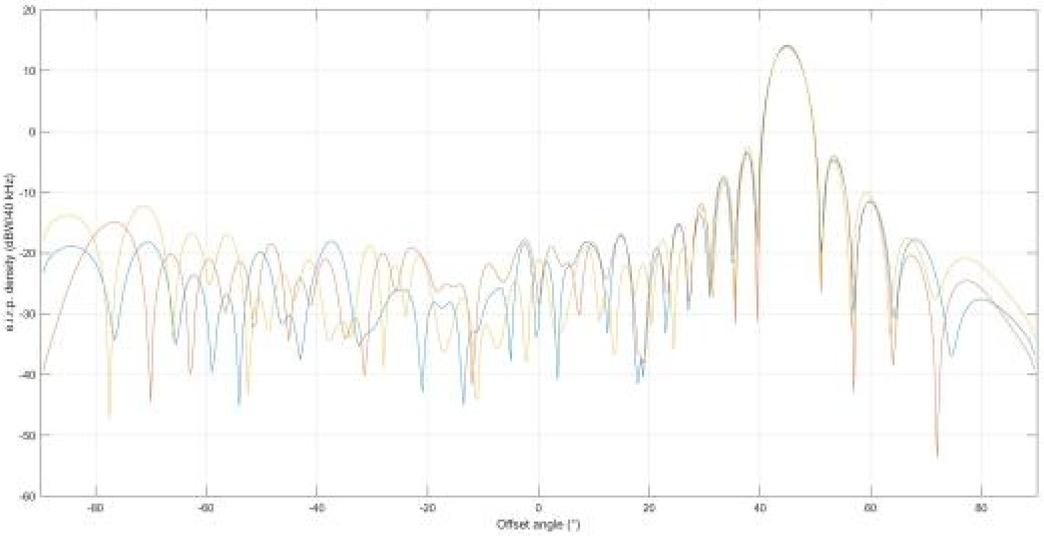

Figure 10: e.i.r.p. mask for the phased array antenna (dBW/(40 kHz)) for 5° elevation pointing for three frequencies (14, 14.25 and 14.5 GHz)

E.i.r.p. masks in Figure 8, Figure 9 and Figure 10 are plots produced from measurements when the OneWeb ESIM is set to transmit with a bandwidth of 2 MHz. The e.i.r.p. spectral density would be reduced when the bandwidth is increased to 20 MHz so that the total e.i.r.p. does not exceed 34 dBW.

OneWeb earth stations operate within CEPT countries with a minimum elevation angle of 49°. For the OneWeb ESIM, the peak e.i.r.p. radiated towards the horizon stays below the -30 dBW/(40 kHz) peak (-33 dBW/(40 kHz) average) for antenna pointing elevation angles above 60° with respect to the maximum antenna gain; this value increases up to -15 dBW/(40 kHz) for an antenna pointing elevation angle of 45°, due to appearance of grating lobes. However, this appearance of grating lobes would happen in one single azimuth, and the earth station will operate in such a way to track the satellite to obtain the best signal-to-noise ratio amongst all visible satellites, hence at high elevation angles. The modelling of such tracking leads to the distribution of elevation angles as shown in Figure 11 for land and shipborne ESIM; it is noted that, 70% of the time, the elevation angle stays above 60° and never goes below 49°. At 49° pointing elevation, the e.i.r.p value towards the horizon does not exceed -20 dBW/40 kHz.This assumption is not true for airborne ESIM since the aircraft can be inclined. However, the compatibility studies for this type of ESIM, a pfd mask on the ground is considered, which avoids the discussion on e.i.r.p. towards the horizon.

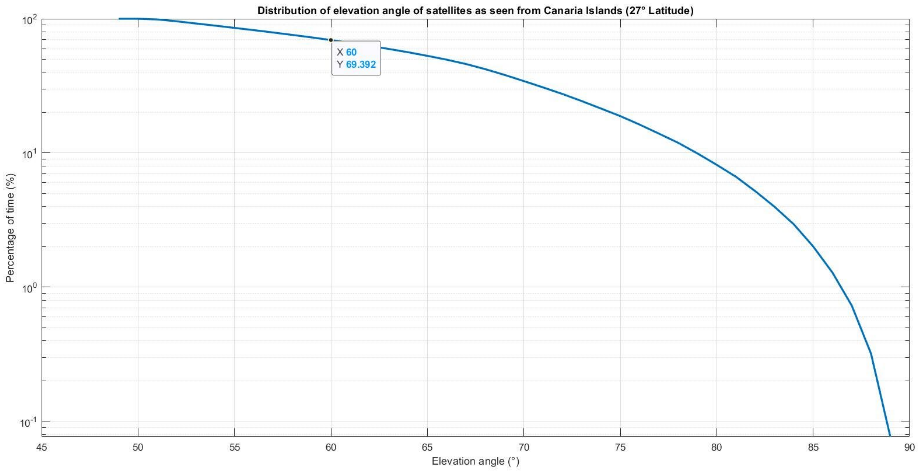

Figure 11: Distribution of FSS Earth station antenna pointing elevations

A peak e.i.r.p. of -17 dBW/(40 kHz) and an averaged e.i.r.p. of -20 dBW/(40 kHz) were considered for the land and shipborne ESIM studies, similar to the one considered for earth stations at fixed locations.

Additionally, when the earth station is installed on trains or vehicles, the antenna height is lower than the 20 m considered for fixed Earth stations, e.g. 5 m. For small ships, this would also be the case. A higher antenna height should be considered for bigger ships (e.g. an antenna on top of the mast). An antenna height of 40 m has been assumed as in previous ESV studies (see Recommendation ITU-R SF.1650 [18]).

A1.3 COMPATIBILITY BETWEEN NGSO FSS (SPACE-TO-EARTH) IN THE BAND 10.7-12.75 GHZ AND RAS IN THE BAND 10.6-10.7 GHZ

A1.3.1 Methodology

Recommendations ITU-R M.1583 [15] and S.1586 [16] provide methodologies to evaluate the percentage of data loss induced in a radio astronomy service (RAS) station by the emissions of a constellation of satellites operating respectively in the mobile satellite and radio navigation services, and in the fixed satellite service. The two Recommendations essentially apply the same methodology.

The methodology is based on a Monte Carlo simulation where the pointing of the RAS antenna and the initial time for integration is randomly changed from one trial to another. The position of all satellites of the constellation is determined from the integration time frame of 2000 seconds, which is a representative integration time for RAS. The equivalent power flux density (epfd) produced at the RAS station by all satellites in visibility during the integration time is then calculated, and averaged over the 2000 seconds. The value obtained is then compared to a specified interference threshold to determine if the data is considered lost or not. This process is then repeated for a sufficient number of trials in order to get an overall percentage of data loss over the sky.

The specificity of the methodology lies in the fact that the pointing of the RAS station is not randomly chosen with a uniform distribution in azimuth and elevation, but in solid angles. In addition, radio astronomers require a map of the sky where they can expect the worst-case data losses. This is done by dividing the sky in 2334 cells of nearly equal solid angles. The RAS antenna is pointed randomly in each of these cells, and the process described above is repeated for each cell. The study of the OneWeb system ran 100 trials per cell, this would give a total of 233400 trials sufficient to determine the overall percentage of data loss. A number of 10 trials per cell would also be sufficient but would not provide a detailed map of the sky. The study of the SpaceX system ran 1000 trials per cell were run, which gives a total of 2 334 000 trials sufficient to determine the overall percentage of data loss and provide a detailed map of the sky.

A1.3.2 Results

The unwanted emission levels derived from simulations, as a function of different combination of the satellite beams and the filter capabilities complying with the 2% data loss are provided below.

Table 13: Maximum unwanted emission e.i.r.p. levels per beam

Satellite beams	e.i.r.p. in the RAS band (dBW/100 MHz)
Beams 1, 5, 9, 13	-34.9
Beams 2, 6, 10, 14	-61.9
Beams 3, 7, 11, 15	-49.9
Beams 4, 8, 12, 16	-61.9

Referring to Table 13, it should be noted that not all of these beams are active. The number of beams active depends on the latitude (due to the use of progressive pitch around the equator to overcome interference to GSO networks). In particular, at latitudes corresponding to Europe, the extreme beams 1, 2, 15 and 16 are not used due to a change in the number of satellites per planes during the design phase from initially 40 to now 49. This is to avoid intra system interference between adjacent satellites within the same orbital plane.

For these e.i.r.p. levels in the RAS band, the overall data loss at Effelsberg is 1.25% distributed over the sky as shown in Figure 12.

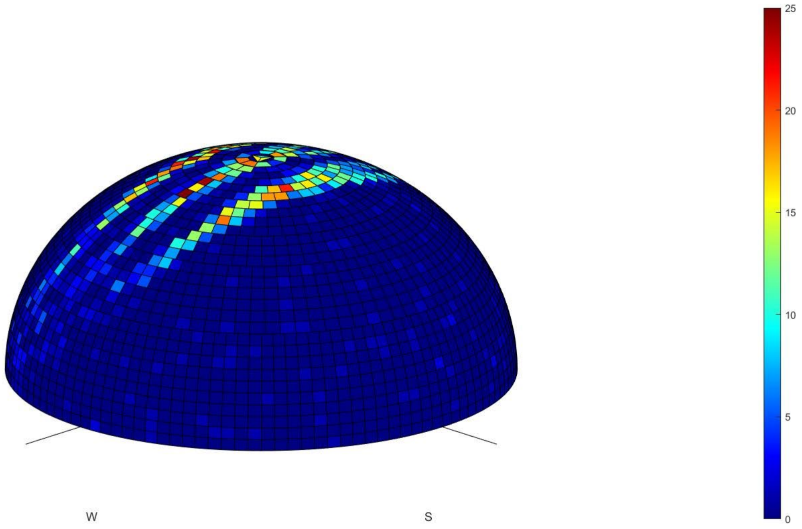

Figure 12: Plot of the data loss over sky

The maximum level of exceedance of the epfd threshold in dB over the sky over all trials is given in Figure 13.

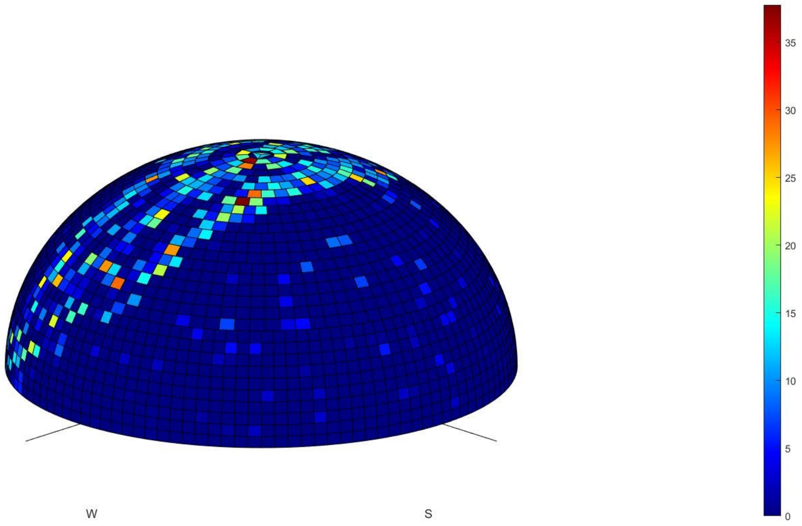

Figure 13: Maximum exceedance of epfd threshold

The maximum values of data loss in the 2000 seconds-long periods will appear where there is coupling between the RAS main beam or first side lobes with the satellite beams producing higher e.i.r.p., i.e. beams 5, 9 and 13. Otherwise, the RAS antenna will only see the beam where the e.i.r.p. is much lower (15 to 30 dB below). Beams 5, 9 and 13 have respectively an offset angle of -11°, 1.5° and 14.1° with respect to nadir.

This corresponds, when the satellite is going South to North, to elevation angles of respectively 77° (180° azimuth), 88° (0° azimuth) and 73° (0° azimuth). One also has to consider the descending orbits and in this case the azimuth will be reversed, with worst cases at respectively 77° (0° azimuth), 88° (180° azimuth) and 73° (180° azimuth). This shows why there will be 3 different stripes of highest data loss on the sky, spreading as follows:

- The largest one at 75° (from 73 to 77°) elevation and 180° azimuth;
- One at 90° (from 88 to 92°) elevation and 0 or 180° azimuth;
- Another large one at 75° elevation and 0° azimuth;

Figure 14 provides the evolution of the percentage of data loss when the unwanted emission power levels are increased or decreased over all beams by a given value.

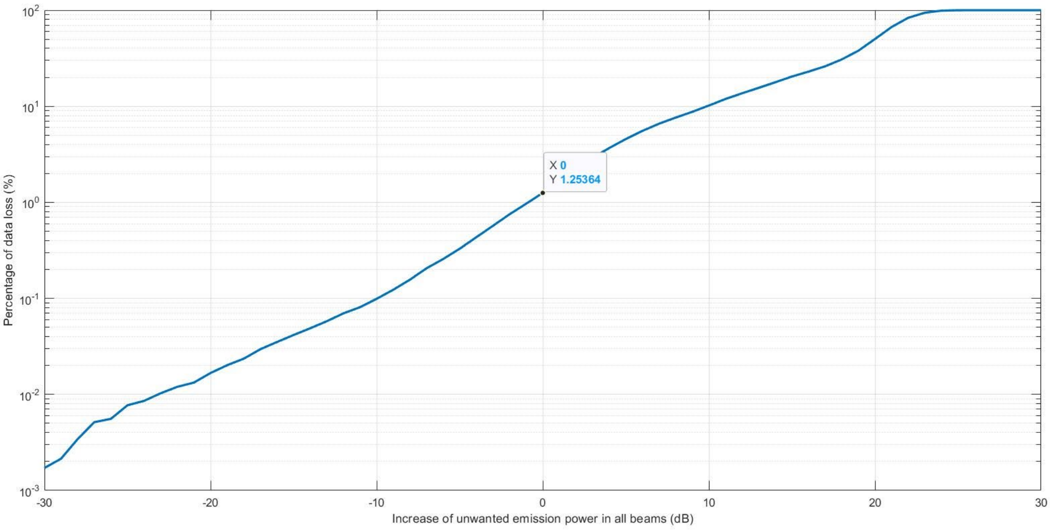

Figure 14: Evolution of the data loss when the unwanted emission level is decreased or increased over all beams

A1.3.3 Conclusions and discussions

The unwanted emission e.i.r.p. levels provided in Table 13 meet the 2% data loss criterion of RAS for the worst case considered in terms of maximum antenna gain (Effelsberg site with a 100 m antenna diameter) and constitute an additional requirement for the NGSO FSS payload for the OneWeb system. Indeed, those limits were obtained by taking into account the satellite antenna characteristics of the space stations in the OneWeb system, including the 16 beams with the corresponding antenna pattern presented in section 4.1.

Those e.i.r.p. levels may be achieved through a combination of modulation shaping, IF and RF filtering. The current design of the OneWeb constellation payload incorporates a combination of those techniques which permits to meet the levels indicated in Table 13 with additional margin. However, these techniques would not be sufficient for the frequency channel immediately adjacent to the passive band (10.7-10.95 GHz), for which an unwanted emission e.i.r.p. of -5 dBW in the 100 MHz of the passive band is expected, and this channel would therefore have to be deactivated when in visibility of a RAS station performing observations in this band. As shown in Figure 15 this would leave limited possibilities for the usage of this channel.

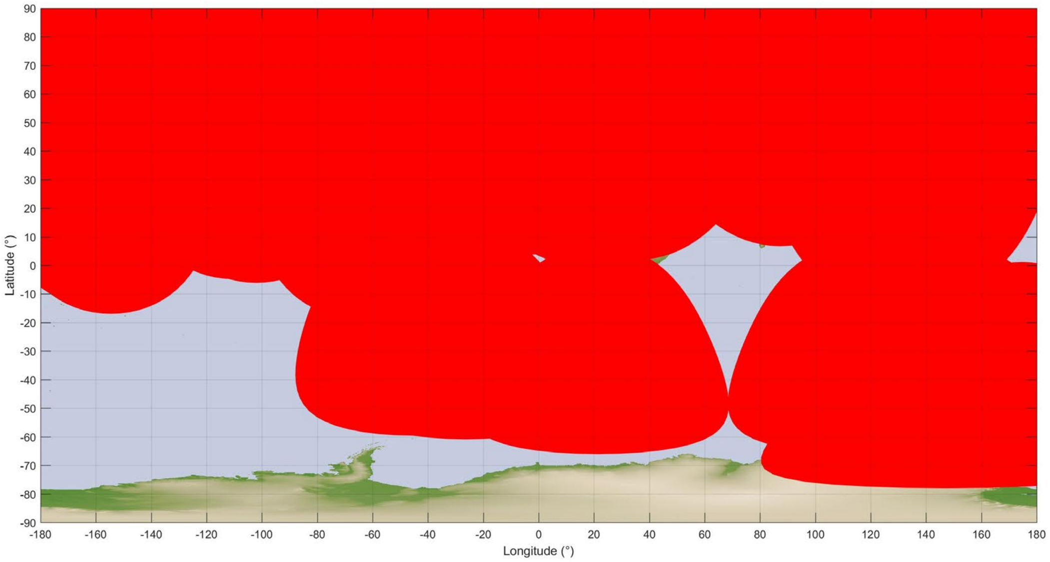

Figure 15: Visibility areas of RAS stations performing observations in the 10.6-10.7 GHz band

For a different NGSO FSS system, the particular satellite antenna characteristics should be considered in order to deduce the e.i.r.p. limitations allowing the protection RAS in the adjacent band; therefore, the results in this section are not transposable to other NGSO FSS systems. If another FSS NGSO system is considered to operate in this band, new analysis should be carried out.

A1.4 COMPATIBILITY BETWEEN NGSO FSS (SPACE-TO-EARTH) IN THE BAND 10.7-12.75 GHZ AND EESS (PASSIVE) IN THE BAND 10.6-10.7 GHZ

A1.4.1 Study 1: Assessment of Impact on passive sensors, provided in Recommendation ITU-R RS.1861

A1.4.1.1 Methodology

The unwanted emission e.i.r.p. levels required for the protection of radio astronomy as derived in Table 13 are expected to also protect the EESS (passive) sensors. In order to verify this, the worst-case unwanted emission e.i.r.p. in beams 1, 5, 9 and 13 has been considered and the interference from those beams into the side lobes of the EESS (passive) sensor, as well as within the main beam of the EESS (passive) sensor after reflection over the sea.

A1.4.1.2 Results

With regard to the interference received in the EESS sensor side lobes, the worst case EESS satellite was considered that leads to the shortest distance between the EESS satellite and one NGSO satellite located right above. This corresponds to a worst case EESS satellite altitude of 835 km. A 0 dBi EESS back-lobe antenna gain has been assumed, which again is a worst case as the antenna pattern in Recommendation ITU-R RS.1813 [24] gives a back-lobe gain value in the order of -10 dBi.

Table 14: Calculation of interference in EESS (passive) sensor backlobes

Parameter	Value	Unit
e.i.r.p.	-34.9	dBW/(100 MHz)
EESS gain	0.0	dBi
Altitude	835.0	km
Distance	365.0	km
Loss	164.2	dB
I	-199.1	dBW/(100 MHz)
Criterion	-166.0	dBW/(100 MHz)
Margin	33.1	dB

Even with these worst-case assumptions there would be more than 30 dB margin with regard to the EESS (passive) protection criterion.

With regard to the interference received in the EESS sensor main beam after reflection over the sea, a worst-case scattering coefficient of 120% has been assumed, which in theory would only occur at the NGSO satellite nadir during short period of time.

Table 15: Calculation of interference in EESS (passive) sensor main beam after reflection over sea

Parameter	Sensor C1	Sensor C2	Sensor C3	Sensor C4	Sensor C5
e.i.r.p. (dBW/(100 MHz))	-34.9	-34.9	-34.9	-34.9	-34.9
NGSO FSS satellite altitude (km)	1200.0	1200.0	1200.0	1200.0	1200.0
pfd (dBW/m²/(100 MHz))	-167.5	-167.5	-167.5	-167.5	-167.5
Area covered by the FSS satellite beam (km²)	75625.0	75625.0	75625.0	75625.0	75625.0
Backscatter coefficient (%)	120.0	120.0	120.0	120.0	120.0
Reflected power (dBW/(100 MHz))	-57.9	-57.9	-57.9	-57.9	-57.9
Distance ground − Satellite EESS passive (km)	1221.7	1123.50	2033.70	1766.10	1114.90
Propagation loss (dB)	174.7	174.0	179.2	177.9	173.9
EESS antenna gain (dBi)	36.0	42.3	45	36	44.1
Received power at the passive sensor (dBW/(100 MHz))	-196.6	-189.6	-192.1	-199.8	-187.7
Protection criterion (dBW/(100 MHz))	-166.0	-166.0	-166.0	-166.0	-166.0
Margin (dB)	30.6	23.6	26.1	33.8	21.7

Even with these worst-case assumptions there would be more than 20 dB margin with regard to the EESS (passive) protection criterion.

A1.4.2 Study 2: Assessment of Impact on METEOR-M passive sensor

A1.4.2.1 Interference scenarios

The following interference scenarios were considered in assessment of impact from FSS satellites:

- Aggregated interference from OneWeb FSS satellites mentioned in this Annex, resulting from unwanted emissions in 10.6-10.7 GHz, is received through far side lobes and back lobes of the main antenna of the passive instrument;
- Aggregated interference from OneWeb FSS satellites mentioned in this Annex, resulting from unwanted emissions in 10.6-10.7 GHz, is received through main beam of the cold calibration channel antenna of the passive instrument.

A1.4.2.2 Initial data and assumptions of the study

The OneWeb NGSO satellite constellation is to be modelled based on orbit parameters, provided in section A1.1. All sixteen beams excluding mentioned in A1.1 as inactive per satellite, employing 10.7-10.95 GHz band, are assumed to be active. Maximum unwanted emission e.i.r.p. was taken both from previous study and from table 13 of A.1.3.2 resulting in -5 dBW in the 100 MHz or -34.9 dBW in the 100 MHz for first row of Table 13 and other values as presented in Table 13. For all OneWeb satellites, the relative gain pattern from section A1.1 was used (Table 11). The Meteor-M/MP satellite antennas (primary antenna and secondary antenna for cold calibration channel) are calculated according to Recommendation ITU-R RS.1813 [24].

The main beam of Meteor-M/MP satellites has a scanning sector 105 degrees wide (off-nadir pointing angle beta is 53.3 degrees), scan period is 2.5 seconds. Secondary antenna for cold calibration channel has a fixed pointing, with orientation angle alpha of 315 degrees and orientation angle beta of 90 degrees. Protection criterion of -168 dBW/(100 MHz) not to be exceeded for more than 0.1% of time was used for Meteor-M satellite passive sensors. Protection criterion of -171 dBW/(100 MHz) not to be exceeded for more than 0.1% of time was used for Meteor-MP satellite passive sensors. It should be noted that this protection criterion is related only to data accuracy and reliability and is not considering possible hardware damage.

A1.4.2.3 Simulation results

Considering information provided in sections A1.1 and A1.4.2.2, dynamic studies were carried out by simulating OneWeb constellation with one Meteor-M-like satellite. Taking into account 2.5 second scan period of Meteor-3M primary sensor antenna, time step of 0.0349 second was used for the first interference scenario (interference into main beam through side lobes). This corresponds to Meteor primary beam alpha angle change of two degrees.

For the first interference scenario with -5 dBW/100 MHz, a peak interference of -170.75 dBW/100 MHz for Meteor-M and -167.63 dBw/100 MHz for Meteor-MP were recorded. On the other hand, 0.1% of time corresponds to -174 dBW/100 MHz for Meteor-M and -170.9 dBW/100 MHz for Meteor-MP.

On the other hand, interference into cold calibration channel is not exceeding -180 dBW/100 MHz due to updated constellation.

It should be noted that by changing maximum unwanted emission e.i.r.p. from -5 dBW to -34.9 dBW (thus disabling channel one and according to Table 13) in the 100 MHz will change peak interference to -200.5 dBW/100 MHz for Meteor-M and -197.1 dBW/100 MHz for Meteor-MP, which will be enough to comply with protection criteria on standalone basis.

A1.4.3 Conclusion

Meeting the epfd protection criterion for the protection of radio astronomy in the band 10.6-10.7 GHz leads to unwanted emission e.i.r.p. limits applied for the OneWeb satellites. Meeting these unwanted emission e.i.r.p. limits in vicinity of EESS satellites is also sufficient for the protection of passive sensors and no additional constraint for this system would be needed to ensure compatibility with EESS (passive) in the band 10.6-10.7 GHz. As the level of filtering for the channel adjacent to the passive band (channel 1) is currently not sufficient for the OneWeb constellation, this requires either to improve filtering, or the deactivation of this channel when in visibility of the EESS (passive) satellite. If other means, different from disabling channel one, are used to ensure protection of RAS, additional studies should be carried out to check compatibility between OneWeb and EESS (passive) systems.

For a different NGSO FSS system, the particular satellite antenna characteristics should be considered in order to deduce the e.i.r.p. limitations allowing the EESS protection in the 10.6-10.7 GHz band; therefore, the results in this section are not transposable to other NGSO FSS systems. If another FSS NGSO system is considered to operate in this band, new analyses should be carried out, including the aggregate effect of the NGSO and GSO systems.

A1.5 Sharing between NGSO FSS Earth Station at fixed location and incumbent services in the band 14-14.5 GHz

A1.5.1 Sharing with Fixed Service in the band 14.25-14.5 GHz

A1.5.1.1 Methodology

The methodology used in the study consists in determining an area around the FS station where any deployed FSS earth station will not be able to use one or several frequency channels overlapping with the channels used by the FS station.

The propagation loss needed in order to meet the FS protection criterion (long-term and short-term) is given by:

$$Lp = e.i.r.p. + G_R - N - \frac{I}{N} + 10\log\left(\frac{B}{0.040}\right) \qquad (4)$$

Where:

- Lp: Propagation loss required (dB);
- e.i.r.p.: FSS ES e.i.r.p. towards the horizon (dBW/(40 kHz));
- GR: FS antenna gain towards the FSS earth station (dBi);
- N: FS Noise level (dBW);
- I/N: FS protection criterion (dB);
- B: FS reference bandwidth considered (e.g. 1 MHz).

Once the required propagation loss is known, the corresponding distance can be determined using a propagation model. Recommendation ITU-R P.452-14 [5] was used to this effect. The size of protection areas around FS stations needs to be determined on a case-by-case basis to take into account actual FSS, FS parameters and surrounding terrain. An example is given in section A1.5.1.2 for the FS station in Table 3. Considering a higher antenna gain would lead to a larger distance in-axis, but with a narrower area, whereas the consideration of a lower antenna gain would lead to a smaller distance in-axis, but widening the overall area.

A1.5.1.2 Results

For the FS system in Table 3, the propagation loss required is 148 dB, with a percentage of time of either 0.0119% or 0.00027% depending on the considered short-term protection criterion (see section 4.1.2).

The minimum propagation loss becomes 177 dB with a percentage of time of 20% with regard to the long-term protection criterion.

Figure 16 shows the propagation loss calculated using the Recommendation ITU-R P.452-14 as a function of the separation distance. The receiver location is in United Kingdom (-1° longitude and 52° latitude).

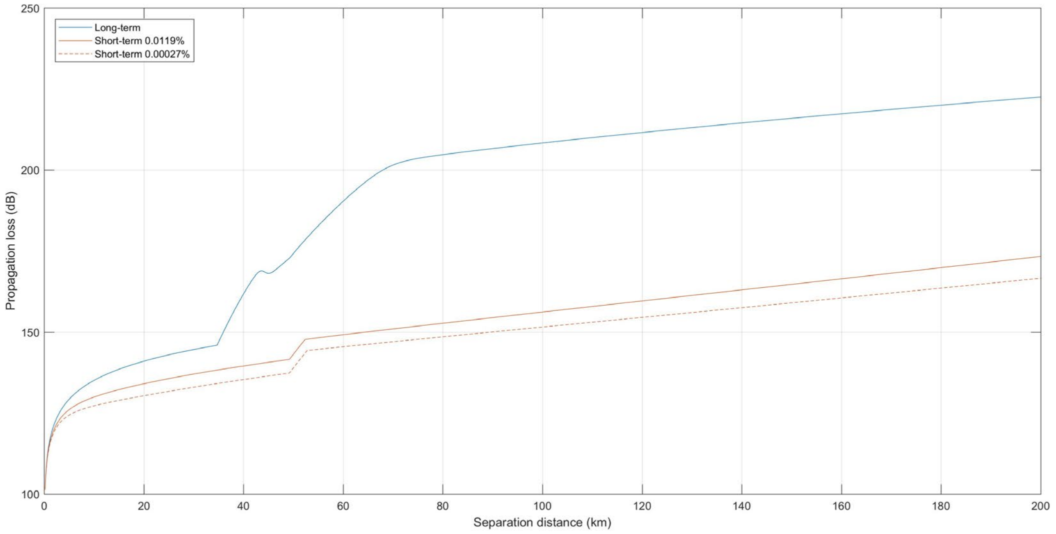

Figure 16: Recommendation ITU-R P.452 Propagation loss over flat terrain

The distance corresponding to a 148 dB loss for short-term is in the order of 58 km and 77 km for the percentages of time 0.0119% or 0.00027%, respectively. The distance corresponding to a 177 dB loss for long-term is in the order of 58 km. This would be in the axis of the FS receiver. However, off-axis, the antenna gain decreases rapidly, and so is the required propagation loss, and the separation distance, as shown in Figure 18 for a FS station pointing North.

Figure 18 also shows the separation distance for the same FS station located in United Kingdom, taking into account actual terrain elevation. The maximum distance is reduced to 11 km instead of 77 km but at the same time the angle of interference is widened due to terrain clutter and reflections.

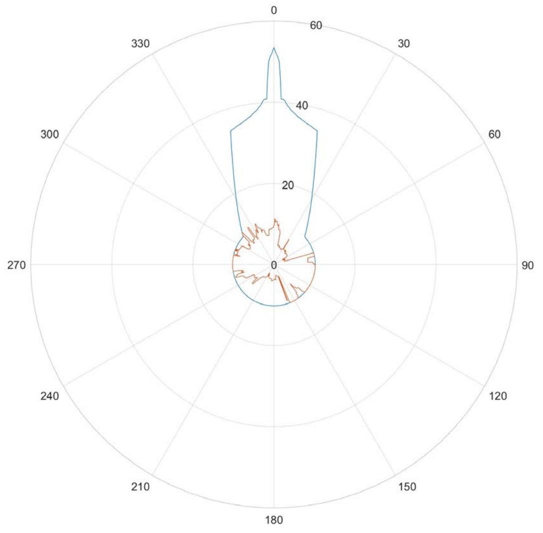

Figure 17: Protection contour for a percentage of time of 0.0119%

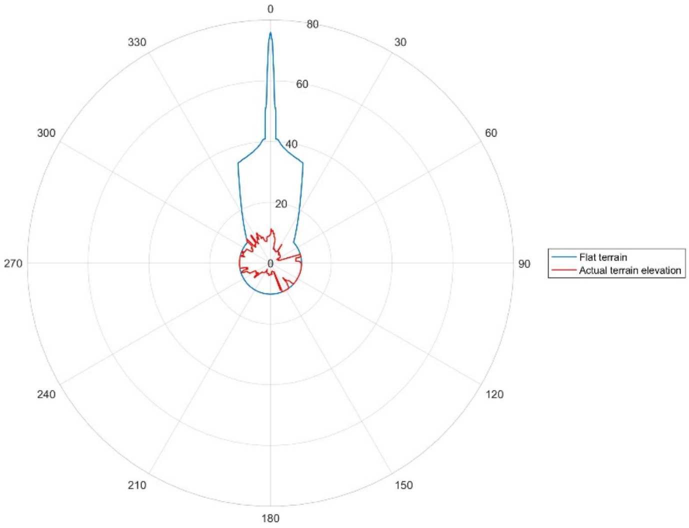

Figure 18: Protection contour for a percentage of time of 0.00027%

A1.5.1.3 Conclusions

The studies have shown that the protection of FS stations in the band 14.25-14.5 GHz from NGSO FSS Earth stations transmitting in the same band requires the establishment of exclusion zones around the FS stations. In order to avoid large exclusion zones determined from typical FS parameters, more accurate calculations can be performed by taking into account the real characteristics of both FS and FSS stations, including the frequency channel, as well as its geographical locations; this implies however a case by case analysis. If such approach is considered, then sharing can be achieved between the FS and any NGSO satellite system because the exclusion zones would be computed by utilising the real FS stations characteristics. The typical size of these exclusion zones has been determined to be for the OneWeb system in the order of 58 to 77 km in a 37 dBi gain of the FS station in the main beam direction (assuming smooth Earth and an FSS terminals with an e.i.r.p. towards the horizon of -20 dBW/(40 kHz)), but decreases rapidly down to 11 km outside the main beam direction of the FS station, under the same assumptions.

When establishing compatibility with fixed links with known locations deployed within an administration, the NGSO satellite system will initially identify the exclusion zones for all fixed link receiving stations using the methodology given above. If an administration has deployed fixed links in the band 14.25-14.5 GHz and the specific locations of fixed links cannot be provided, then the exclusion zones could be established as the whole territory of the administration. In both cases, the protection zone may extend beyond the national territory into the territories of neighbouring administrations.

The OneWeb NGSO satellite system will then be able to deploy the "control of emission" function, stipulated in the ETSI EN 303 980 [1] (see section A1.2.3 above) to ensure the suppression of relevant frequencies by fixed earth stations located within the protection zone. In this way, compatibility with the fixed service can be achieved.

A1.5.2 Sharing with the Radio astronomy service in the 14.47-14.5 GHz band

From a technical point of view, the study contained in this section uses the same approach as one that would be conducted between co-primary services; nevertheless, it is reminded that the RAS allocation in this band has a secondary status.

A1.5.2.1 Methodology

The methodology used in the study consists of determining an area around the RAS station where any single deployed FSS earth station will not be able to use the frequency channels overlapping with the frequencies observed by the RAS station in the 14.47-14.5 GHz band. This methodology does not take into account the effect of aggregate interference resulting from simultaneous operation of several FSS earth stations.

The propagation loss needed in order to meet the RAS interference threshold is given by:

$$Lp = e.i.r.p. + G_R - I + 10\log\left(\frac{B}{40}\right) \quad (5)$$

Where:

- Lp: Propagation loss required (dB);
- e.i.r.p.: FSS ES e.i.r.p. towards the horizon (dBW/(40 kHz));
- G_R: RAS antenna gain towards the FSS earth station (0 dBi);
- I: RAS interference threshold (dB);
- B: RAS reference bandwidth considered (150 kHz).

This simplifies to

$$Lp = \mathrm{e.i.r.p.} + 219.7 \quad (6)$$

With a -20 dBW/(40 kHz) e.i.r.p., this roughly leads to a required propagation loss of 200 dB, with an associated percentage of 2% of time.

Once the required propagation loss is known, the corresponding separation distance can be determined using a propagation model, in which case Recommendation ITU-R P.452-14 [5] was used to this effect.

The size of protection areas around RAS stations varies significantly and needs to be determined on a case-by-case basis to take into account actual FSS and RAS parameters and surrounding terrain by the administration where the RAS station operates.

A1.5.2.2 Results

Figure 19 shows the propagation loss calculated using Recommendation ITU-R P.452-14 function of the separation distance, for the RAS location at Effelsberg (Germany).

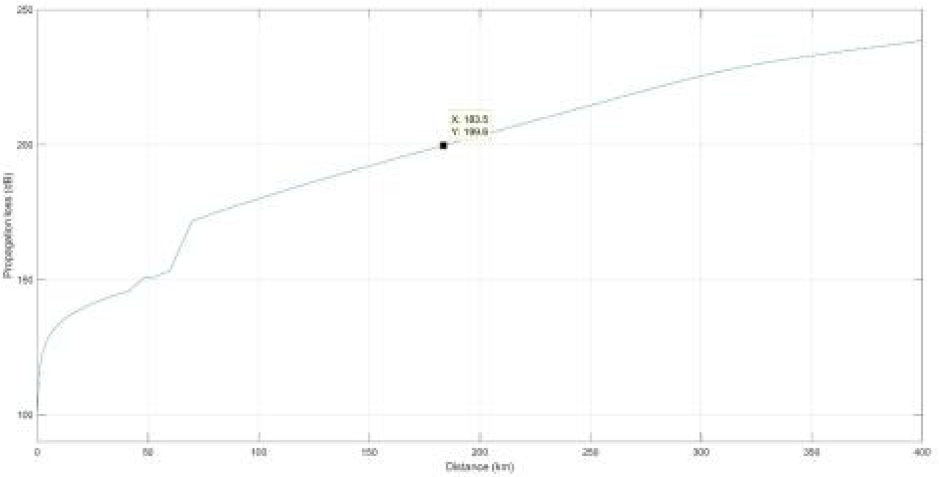

Figure 19: Recommendation ITU-R P.452 Propagation loss over flat terrain

The distance corresponding to a 200 dB loss is in the order of 184 km.

Using a similar approach, the next figures show the separation distances for the RAS stations in Table 7, taking into account the actual terrain profile.

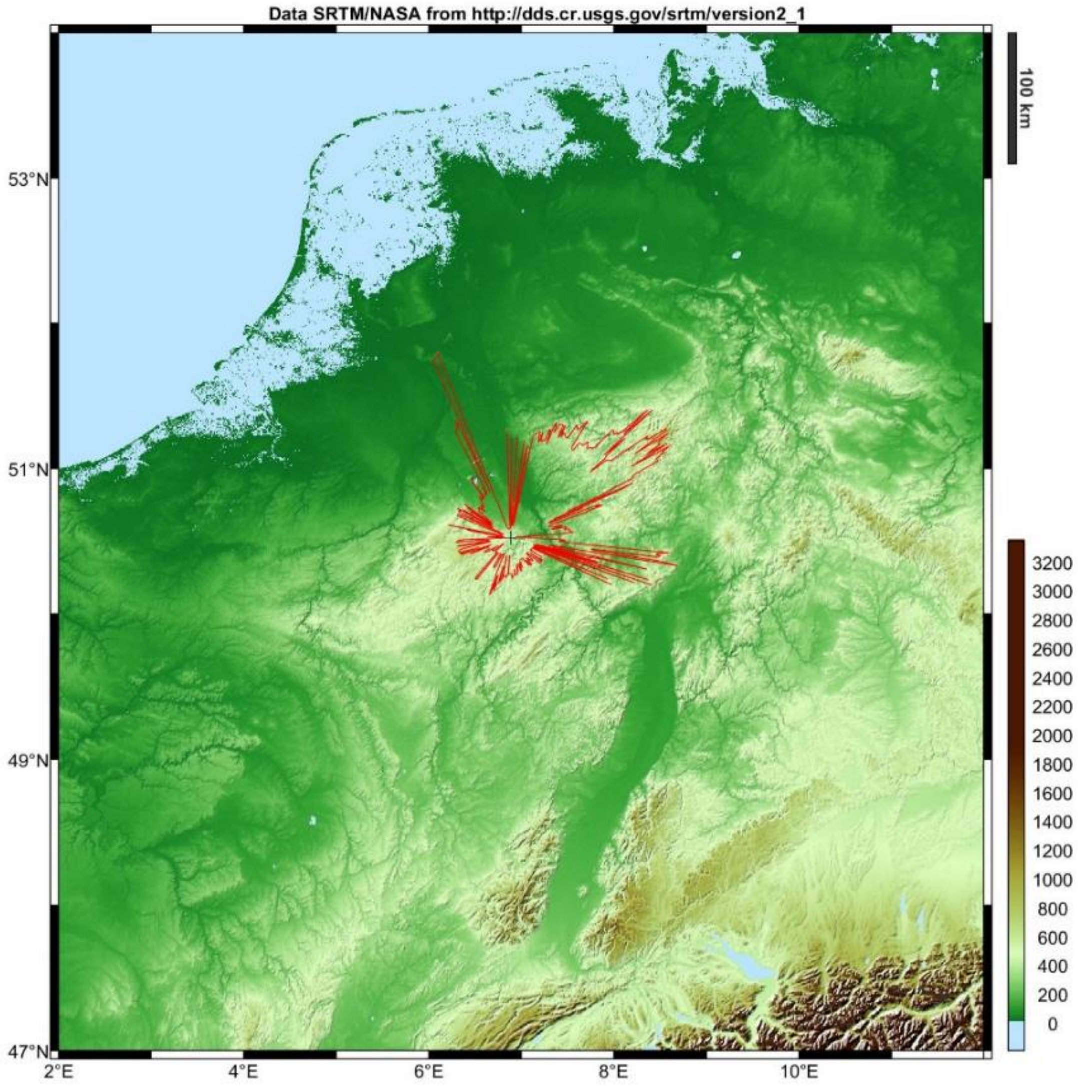

Figure 20: Effelsberg, Germany - max 152 km

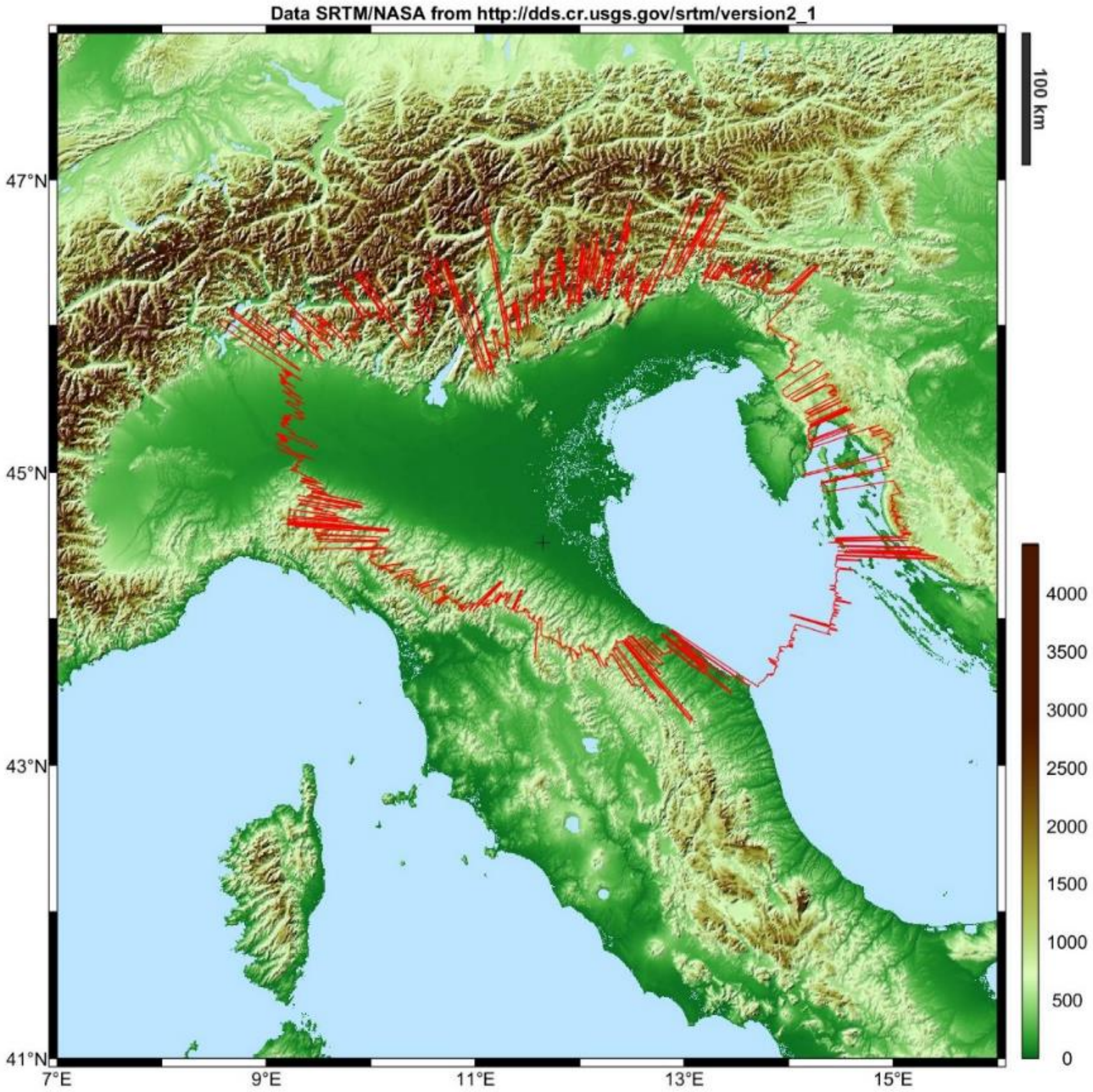

Figure 21: Medicina, Italy - max 300 km

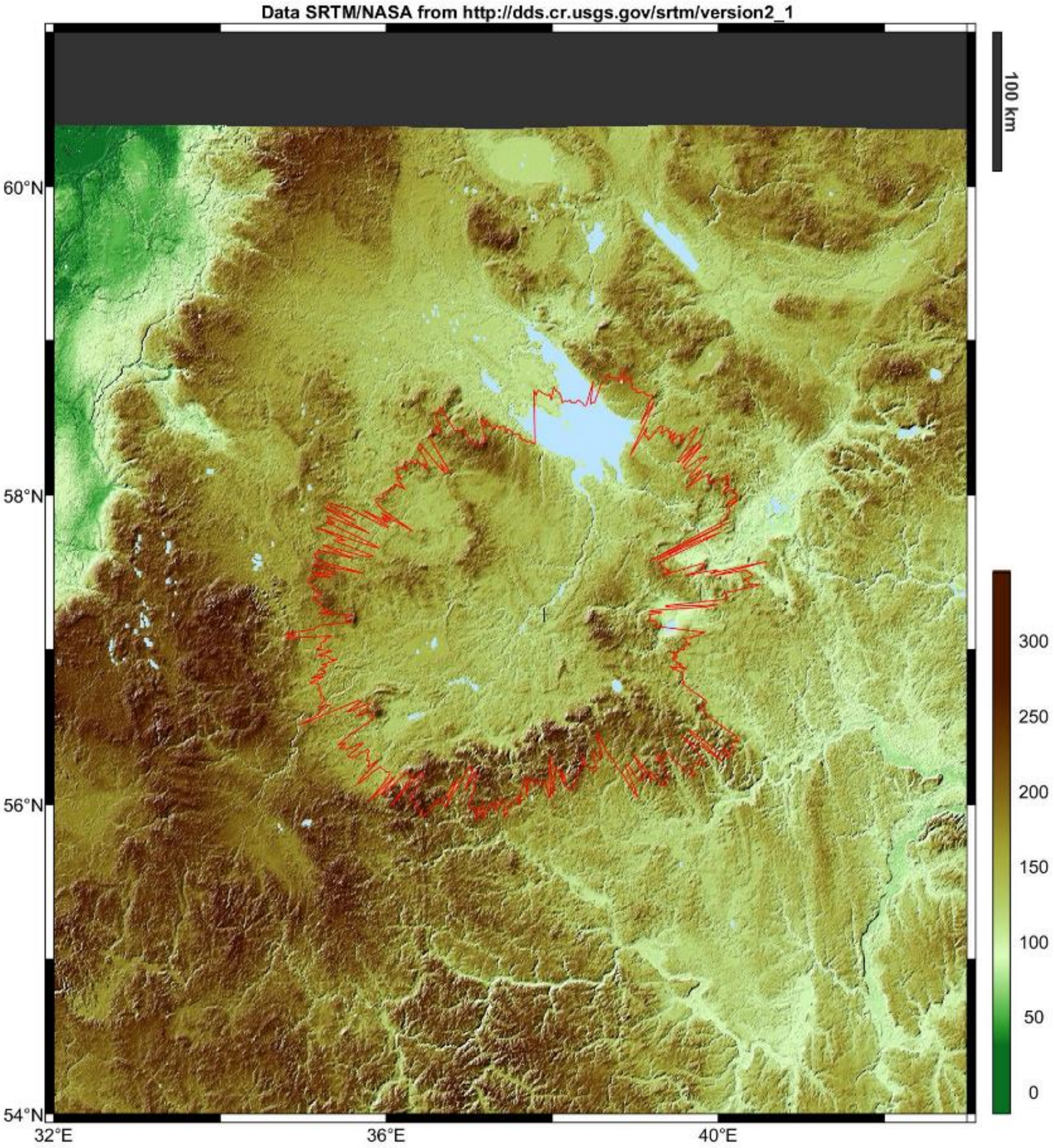

Figure 22: Kalyazin, Russia - max 200 km

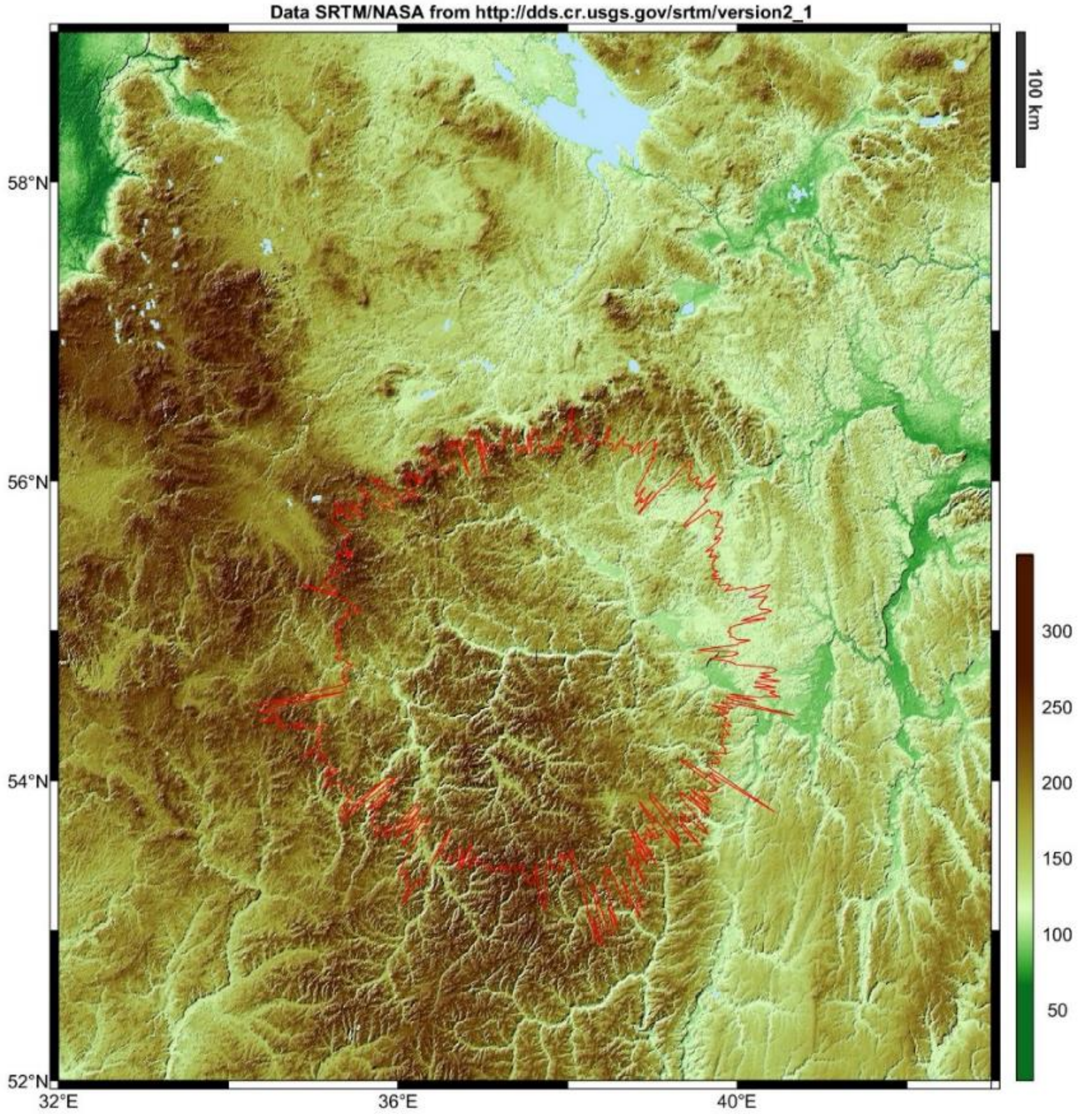

Figure 23: Puschino, Russia - max 220 km

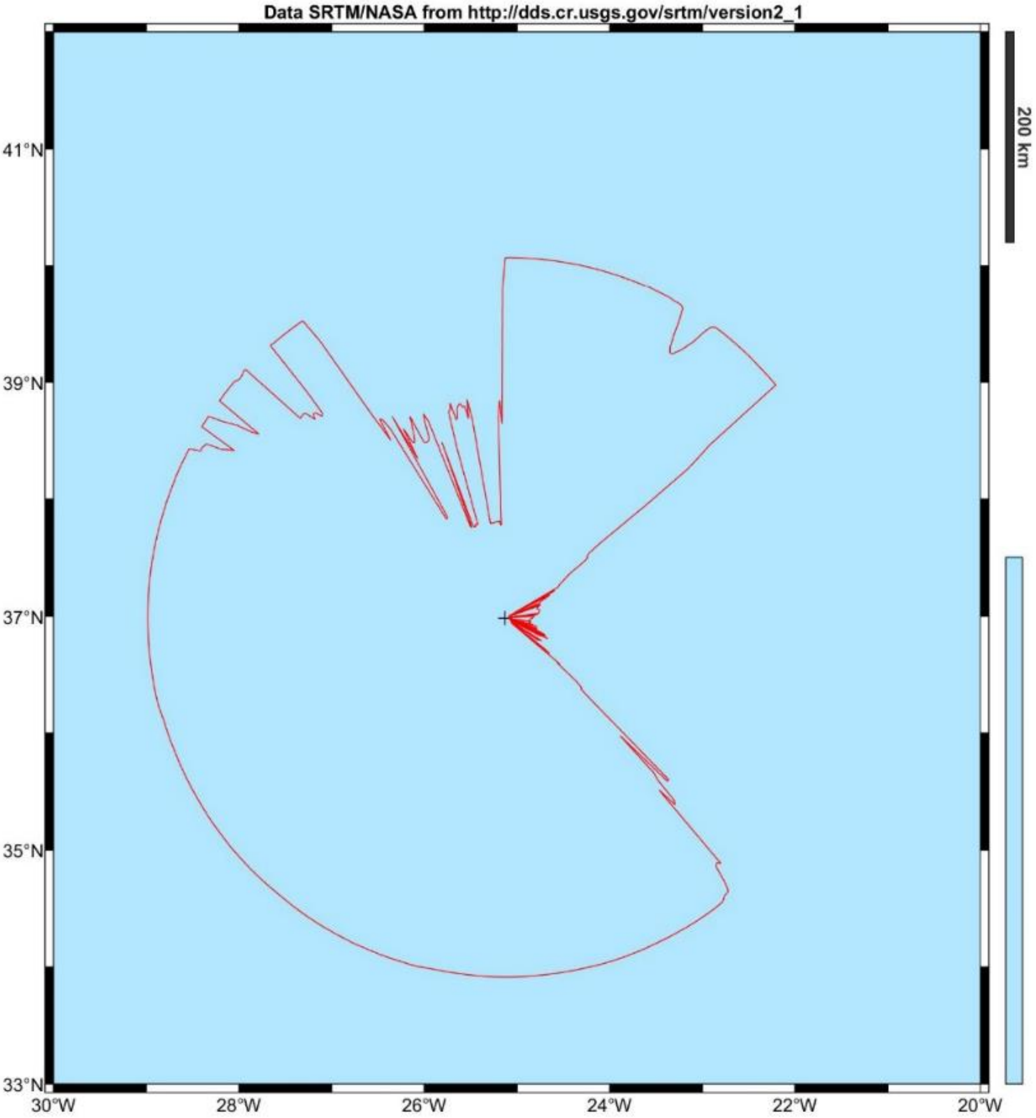

Figure 24: Santa Maria, Portugal – max 345 km, but over sea

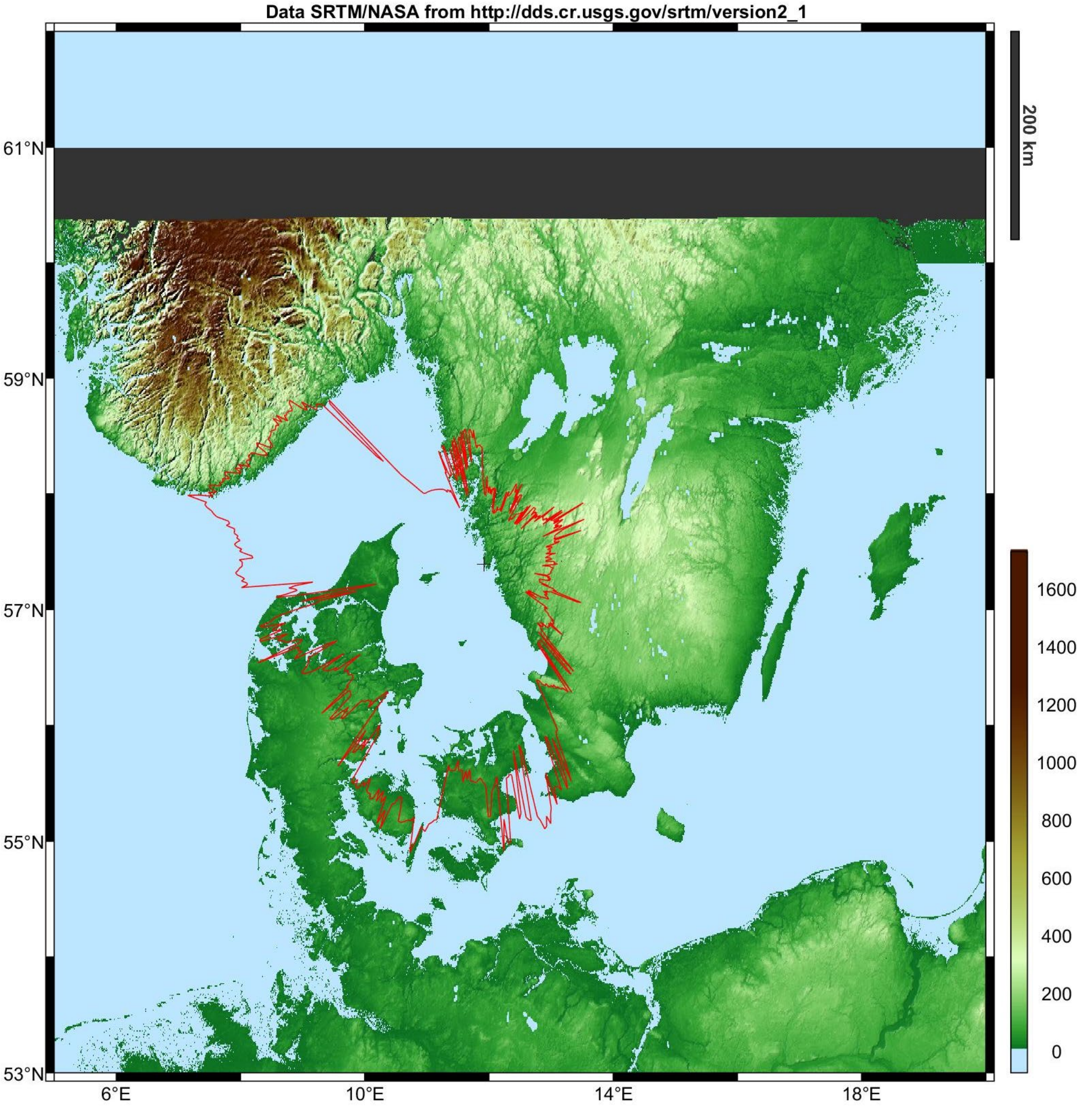

Figure 25: Onsala, Sweden – max 293 km

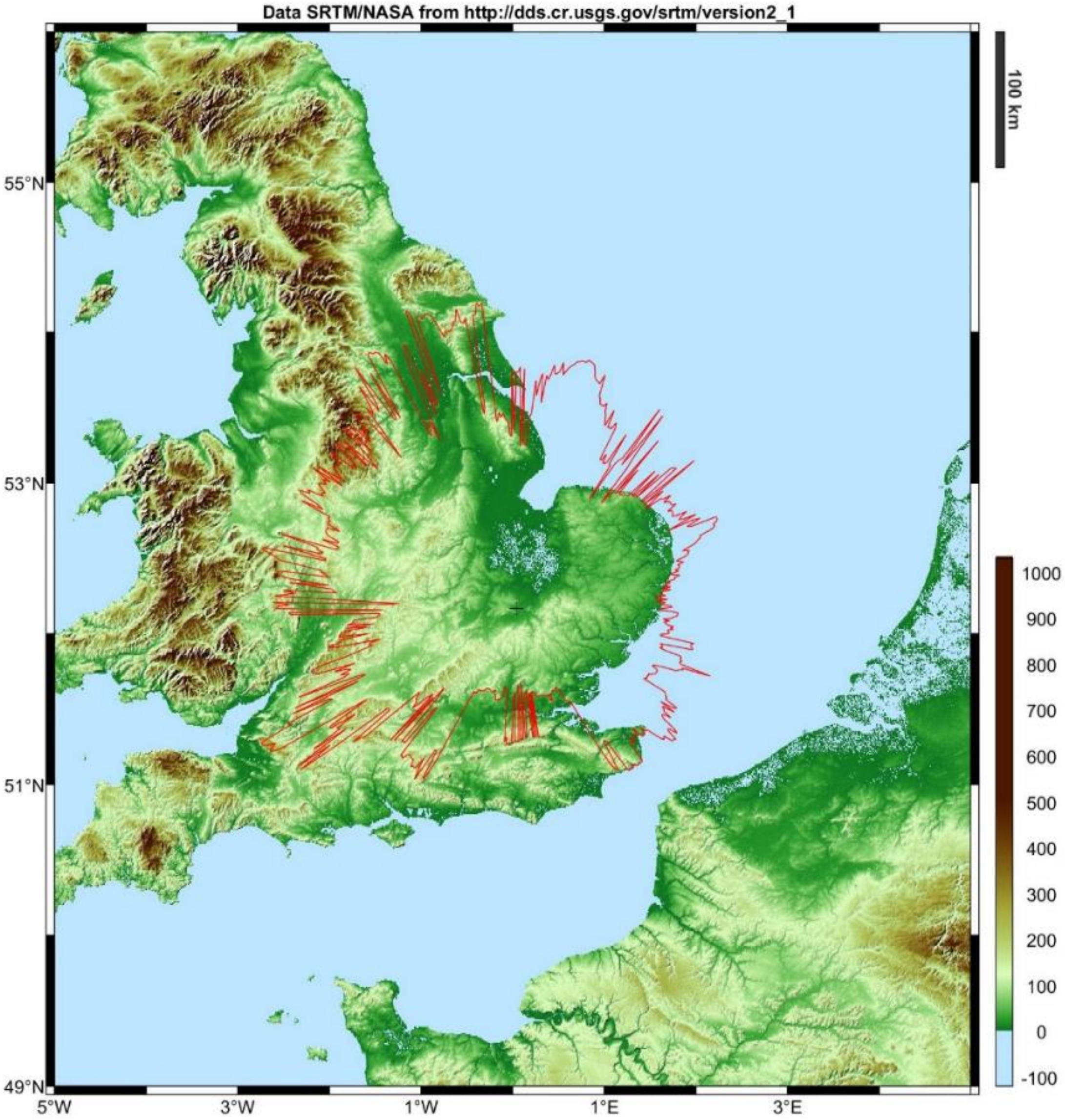

Figure 26: Cambridge, United Kingdom – max 235 km

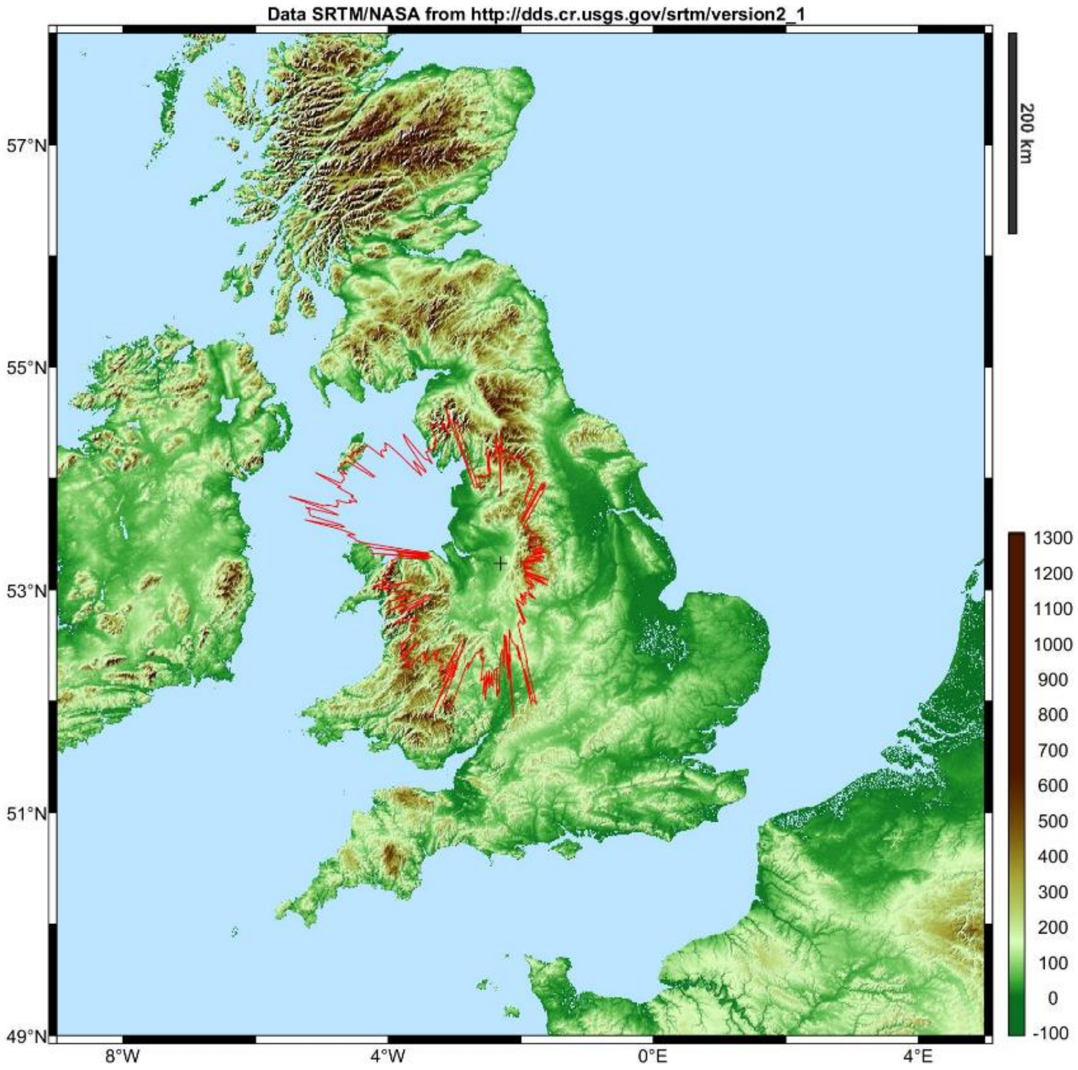

Figure 27: Jodrell Bank, United Kingdom – max 223 km

A1.5.2.3 Conclusions

The protection of the RAS stations observing in the secondary RAS allocation in the band 14.47-14.5 GHz can be achieved through areas around such stations where any single NGSO FSS earth station will not be able to transmit on frequency channels overlapping with this frequency band (the aggregate effect of several earth stations was not assessed).

The size of the areas has to be determined on a case-by-case basis taking into account the FSS and terrain characteristics. For OneWeb earth stations (with an e.i.r.p. towards the horizon of -20 dBW/(40 kHz)), the maximum distance can be up to 340 km thus not limiting it to a national issue for some of these RAS stations. For other kind of NGSO Earth stations, the distances would be computed with the relevant e.i.r.p. levels towards the horizon. Notwithstanding the conclusions in this subsection, calculations could be performed on a case-by-case basis and taking into account the actual FSS characteristics in order to determine the required protection zone.

When establishing compatibility with RAS observatories within an administration, the NGSO satellite system, could initially identify the protection zone for each of the RAS observatories using the methodology described in this section. It should be noted that the protection zone may extend beyond the national territory into the territories of neighbouring administrations. The OneWeb NGSO satellite system would be able to deploy the "control of emission" function stipulated in the ETSI EN 303 980 [1] (see Section A1.2.3 above) to ensure the suppression of relevant frequencies used by RAS observatories located within the protection zone.

A1.6 SHARING BETWEEN NGSO FSS ESIM AND INCUMBENT SERVICES IN THE BAND 14-14.5 GHZ

A1.6.1 Sharing with FS in the band 14.25-14.5 GHz

A1.6.1.1 Land FSS ESIM

Methodology

The methodology would not differ much from the one used for fixed FSS earth stations. The earth station is moving, but since its location is known by the Network Control Facility (NCF) thanks to the use of a GPS receiver within the earth station, this latter should be able to switch off emissions on the frequencies used by the FS stations as soon as the ES enters in their vicinity.

In order to ensure the most effective use of the available spectrum, the size of protection areas around FS stations is to be determined on a case-by-case basis, taking into account actual FS and FSS ES parameters as well as surrounding terrain.

Results

For the FS system in Table 3, the propagation loss required is similar to the one determined for the terminals at fixed locations, given that the e.i.r.p. towards the horizon of land ESIM is similar to the one of earth stations at fixed locations,.

When considering an FSS ESIM antenna height of 5 m, the maximum distance is 55 km. This would be in the axis of the FS receiver. However, off-axis, the antenna gain decreases rapidly, and so is the required propagation loss, and the separation distance, as shown in

Figure 28 for a FS station pointing North (blue curve).

Figure 28 also shows the exclusion area for the same FS station located in United Kingdom (-1° longitude and 52° latitude), taking into account actual terrain elevation (red curve). The maximum distance is reduced to 10 km but at the same time the angle of interference is widened due to terrain clutter and reflections.

It should be noted that in this case the contour is driven by the long-term criterion and therefore does not vary with the percentage of time associated to the short-term.

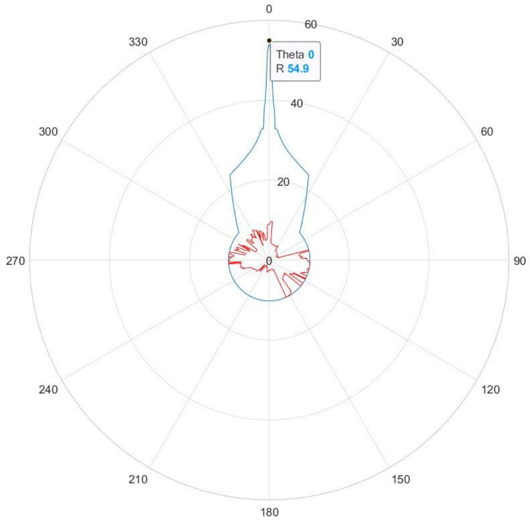

Figure 28: Protection contours

Conclusions

Compatibility with fixed service stations in the band 14.25-14.5 GHz used in few CEPT countries can be achieved through the establishment of exclusion zones around the fixed service station in which the FSS earth stations would have to cease transmitting on frequency channels overlapping with the channel used by the FS station. This cessation of transmission should be automatically performed by the network control facility of the NGSO FSS satellite system, and this action can be assisted by the GPS receiver incorporated in the earth station.

For the OneWeb earth stations with e.i.r.p. towards the horizon of -20 dBW/(40 kHz), the typical size of these areas has been determined to be in the order of 55 km in a 37 dBi FS main beam direction assuming smooth Earth. This size decreases rapidly, down to 10 km outside the pointing direction of the FS station, under the same assumptions.

The actual size of the area has to be determined on a case-by-case basis, taking into account the FS and NGSO FSS Earth Station characteristics, as well as the surrounding terrain.

When establishing compatibility with specific fixed links deployed within an administration, the NGSO satellite system should identify the exclusion zones for all fixed link receiving stations using the methodology described in this section. If an administration has deployed fixed links in the band 14.25-14.5 GHz, and the specific locations of fixed links cannot be established, then the exclusion zones could be established as the whole territory of the administration. In both cases, the protection zone may extend beyond the national territory into the territories of neighbouring administrations.

To ensure the suppression of relevant frequencies by land ESIM when entering the protection zone of FS stations, the NGSO satellite system should be able to deploy the "control of emission" function, stipulated in the ETSI EN 303 980 [1] (see section A1.2.3 above). In this way, the NGSO satellite system can avoid the use of the band 14.25-14.5 GHz or specific frequencies deployed by the fixed service within the FS protection zone and ensure compatibility with the fixed service.

A1.6.1.2 Sharing with airborne FSS ESIM

Methodology

The methodology chosen is similar to the one used for studies between AMSS and FS in the band 14-14.5 GHz described in ECC Report 026 [19]. A number of aircraft are deployed on air routes, some of them using NGSO FSS ESIM.

In 2002 the number of aircraft simultaneously transmitting over the same channel was determined as being 50 to 60 in average over France and United Kingdom. However, this was supposing that the access scheme was CDMA with all these aircraft transmitting over the same frequency channel and that all the traffic over this frequency channel was for aeronautical earth stations.

This would not be the case with OneWeb constellation since the access scheme is based on FDMA/TDMA and most of the traffic would be related to earth stations at fixed locations. Each aircraft within a satellite spot-beam would use a different frequency channel (of typically 20 MHz). The number of aircraft in visibility of the FS station to be considered at one moment in time in a 1 MHz bandwidth would therefore be directly given by the number of satellites that can be visible from the altitude where the aircraft are located (i.e. one channel per aircraft and satellite), multiplied by the number of beams using the same frequency channel (maximum 3 out of 12), multiplied by the ratio of aeronautical earth stations and the total number of earth stations.

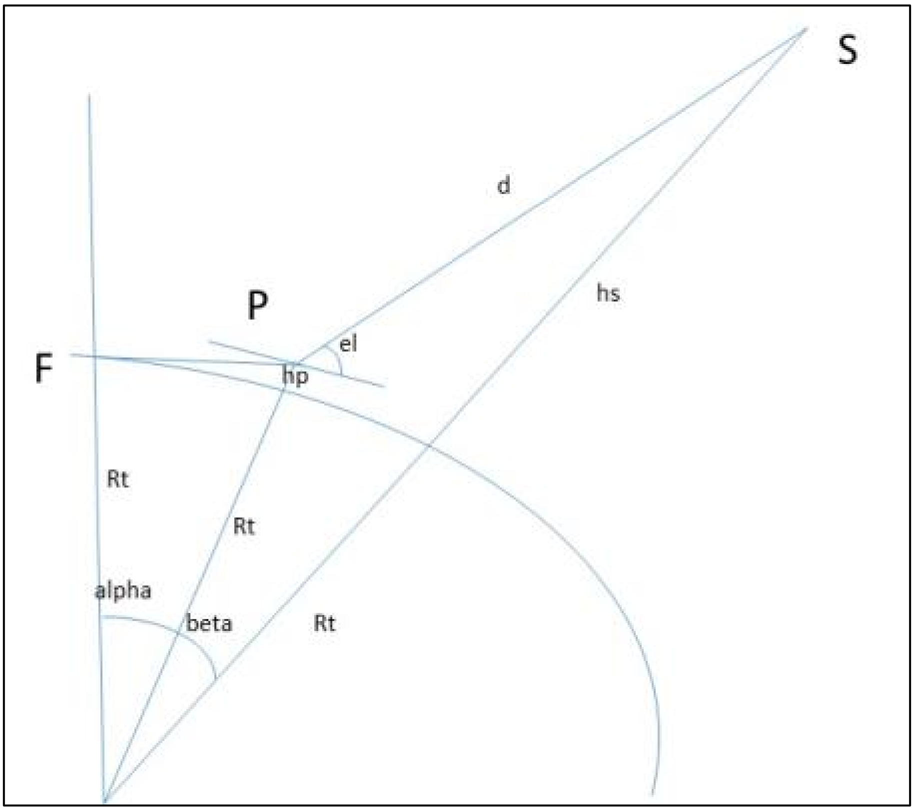

Figure 29: Geometry to determine the number of satellites in visibility above a given elevation angle

In Figure 29:

- F is the location of the Fixed Service station;
- P is the location of one aircraft seen from the FS station at the horizon (0° elevation);
- S is the location of one satellite seen at a given elevation el from the aircraft.

In order to determine the number of satellites that can be visible from a given altitude above 49° elevation it is necessary to first determine the angle alpha+beta, and then the number of satellites that would be contained within the cone of semi angle alpha+beta.

For an elevation of 49° and an aircraft altitude of 11 000m, the distance d (aircraft to satellite) is 1491 km, angles alpha and beta are 3.36° and 7.42° respectively. Therefore, alpha+beta=10.8°.

A simulation of the OneWeb constellation was run to determine the maximum number of satellites contained within a 10.8° half angle cone depending on the latitude, which would correspond to the maximum number of aircraft simultaneously transmitting, assuming that the satellite capacity is used 100% for these aircraft.

Table 16: Number of satellites visible within a 10.8° half angle cone depending on the latitude

Latitude (°)	Number of satellites visible
30	6
40	7
50	8
60	10

At higher latitudes, beams are being progressively switched off in order to avoid intra interference and reduce power consumption. Assuming a 49° minimum elevation angle and an aircraft altitude of 11000 m would lead to a maximum number of 10 visible satellites. Assuming that only 10% of the total traffic in the system is for aircraft stations, the total number of aircraft is 3 (10 satellites multiplied by 3 beams multiplied by 10%), which is 20 times less than in previous studies for AES in the AMSS. As a conservative approach, a number of 5 to 6 aircraft in visibility at each moment in time has been considered in the studies.

The simulation tool used for the AMSS previous studies has been developed again by taking into account even more air routes[3] than for the initial studies. One hundred trials have been performed, whereby the azimuth and elevation pointing angle of the FS station varies, as well as the location of aircraft. The simulation is run for a one day period and the aggregate I/N as well as the FDP are calculated at each second. The altitude of aircraft depends on the air route length. An altitude of 7000 m was assumed for air routes less than 800 km, 9000 m for air routes less than 2000 km and 11000 m otherwise. A sensitivity analysis has also been conducted for the worst-case FS pointing elevation angle of 5°, with altitudes ranging from 1000 to 11000 m.

The simulation tool was validated with the assumptions taken in 2001/2002 for fixed service and the pfd mask in Recommendation ITU-R M.1643 [17]. As shown in Figure 31, this pfd mask meets the I/N of -20 dB for 20% of the time[4] for all 100 trials. The average FDP is 0.7%, below the 1% criterion[5].

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[3] The air routes have been taken from the website http://openflights.org/data.html#route

[4] Long-term protection criterion for Fixed-service used in ECC Report 026 [19] (secondary status allocation)

[5] FDP criterion also assumed in ECC Report 026 for AMSS (secondary status allocation)

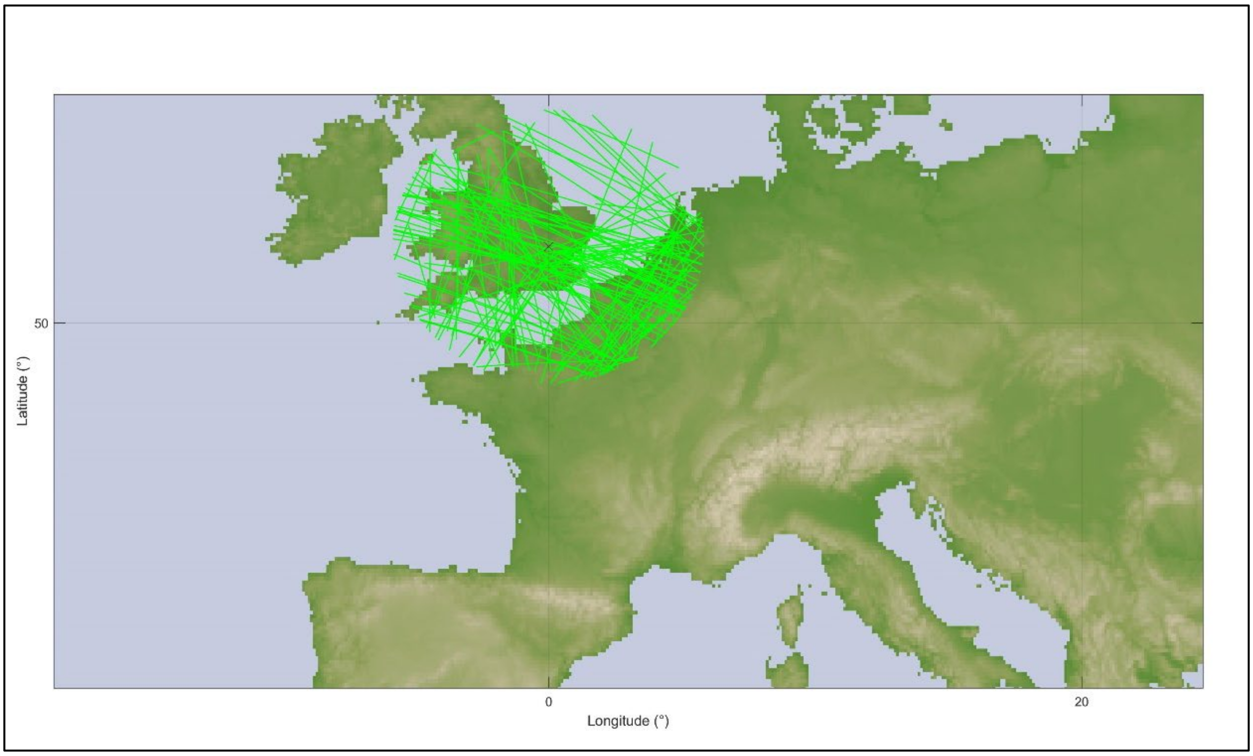

Figure 30: Air routes in visibility of the FS station

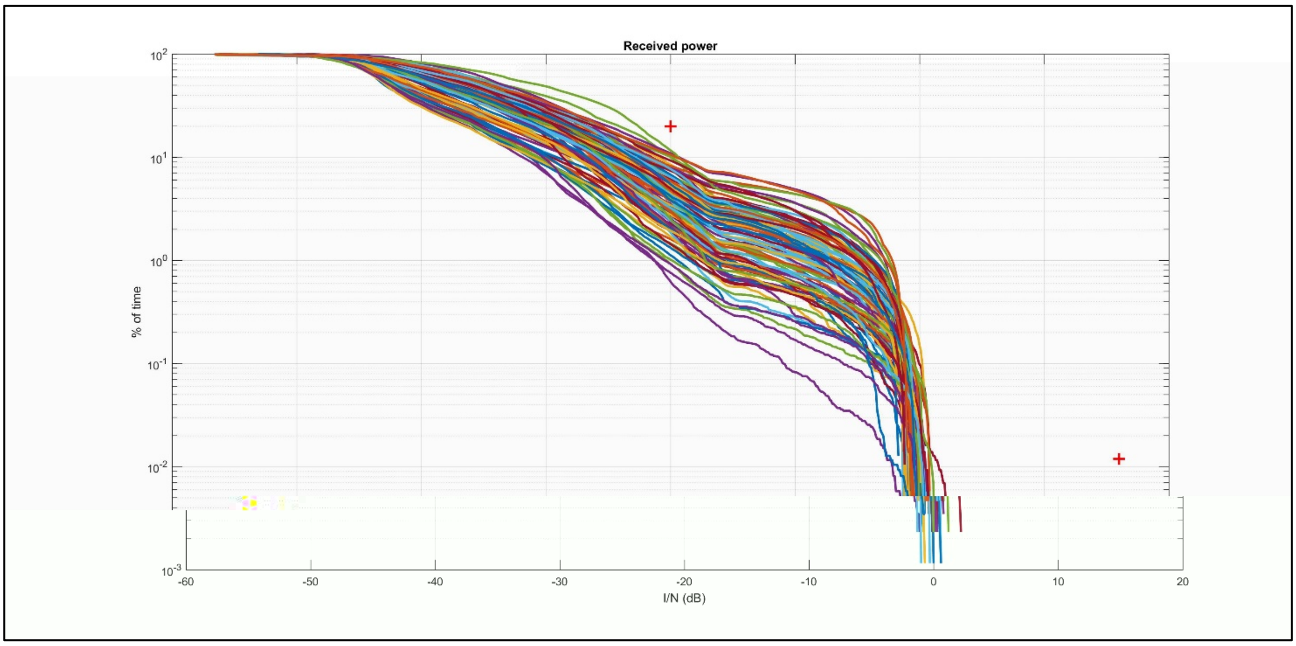

Figure 31: Validation tests with AMSS and previous assumptions

Short-term protection criterion

In order to evaluate the pfd corresponding to the short-term criterion, the following equation is used:

$$pfd = \frac{I}{N} + N - G - 10\log\left(\frac{\lambda^2}{4\pi}\right) + LF \qquad (7)$$

where

- pfd: Power flux density (dBW/m²/MHz);
- I/N: Short-term protection criterion (19 dB);
- N: Noise level (dBW/m²/MHz);
- G: Antenna gain (dBi);
- LF: Feeder loss (dB).

The application of this equation to the parameters contained in Table 3 gives a pfd level of -109 dBW/m²/MHz. The pfd value has been also calculated for the FS system with a 49 dBi, 4 dB feeder loss and 6 dB noise figure as in ECC Report 026 [19]. The result is a short-term pfd of -119 dBW/m²/MHz. There will therefore be a need to ensure that at least 10 dB margin is available with regard to the short-term criterion in order to encompass the 49 dBi FS system included in ECC Report 026.

This pfd value has to be met for angles of arrival of the radio-frequency wave from 0° to 5°.

Results of simulation

The pfd mask in part B of Recommendation ITU-R M.1643 [17], relaxed by 10 dB, has been first tested:

- $-122 + 0.5 \cdot \theta$ dB(W/(m² · MHz)) for $\theta \leq 40°$;
- -102 dB(W/(m² · MHz)) for $40° < \theta \leq 90°$.

where θ is the angle of arrival of the radio-frequency wave (degrees above the horizontal).

Figure 32 provides the results of simulations for a FS station located in the United Kingdom with the characteristics in Table 3 for different pointing angles.

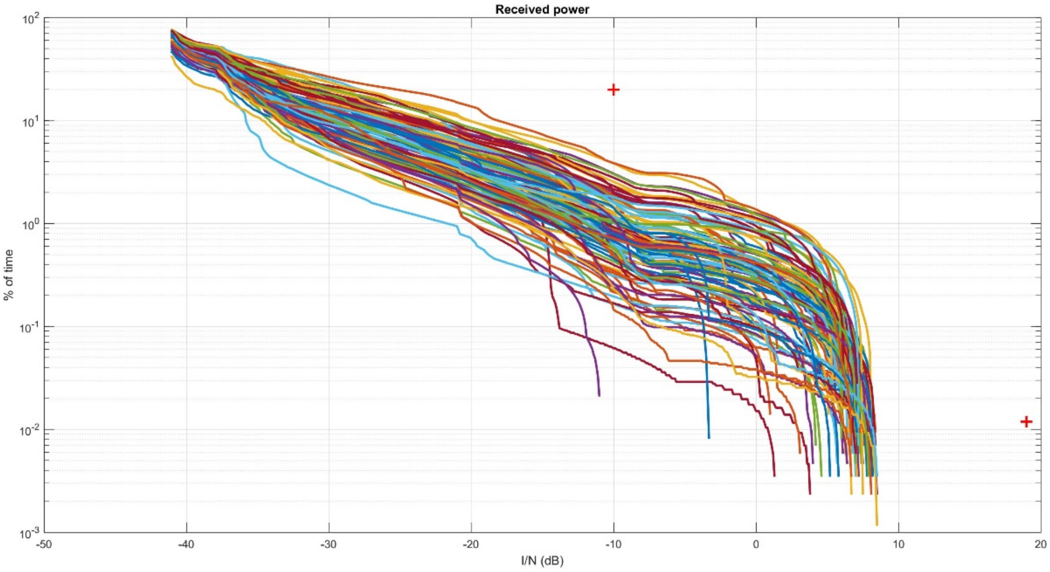

Figure 32: Recommendation ITU-R M.1643 [17] mask relaxed by 10 dB

The pfd mask in Recommendation ITU-R M.1643, part A relaxed by 10 dB for all elevation angles meets both the FS short-term and long-term protection criteria with an additional margin due to the reduction of the number of aircraft operating with the same carrier. The average FDP over all trials is 1.4%, well below the 10% criterion. It should be noted that with this pfd level of -122 dBW at 0° elevation up to -119.5 dBW at 5° elevation, the short-term criterion is met with 11 dB margin, which is sufficient to also encompass the 49 dBi FS system in ECC Report 026.

The following mask has also been tested and appears to afford protection to the FS system in Table 3, as shown in Figure 33.

- –122 + θ dB(W/(m² · MHz)) for θ ≤ 40°;
- –82 dB(W/(m² · MHz)) for 40° < θ ≤ 90°.

where θ is the angle of arrival of the radio-frequency wave (degrees above the horizontal).

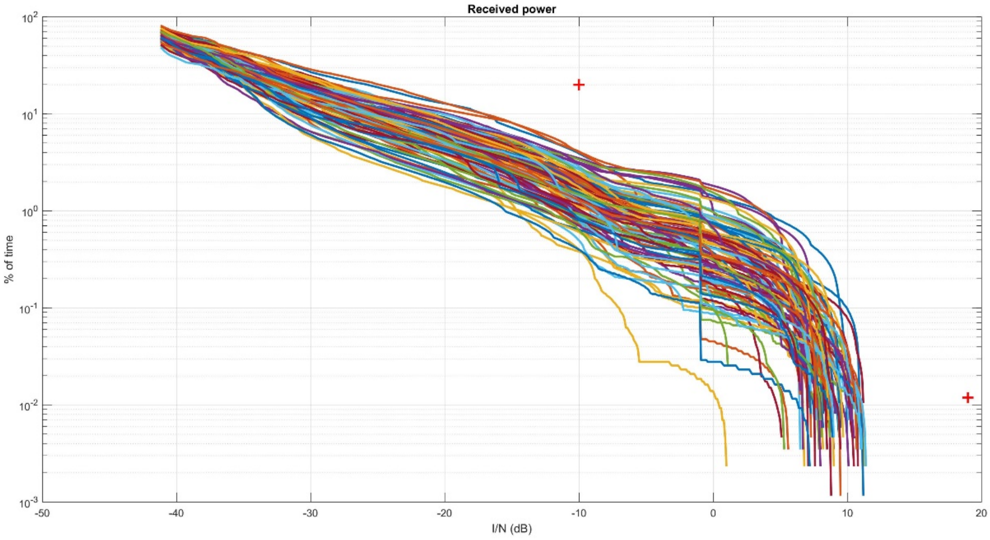

Figure 33: Pfd mask further relaxed by 20 dB for high elevations

There is still sufficient margin with regard to the long-term protection criteria. The average FDP is in this case 2%, well below the 10% criterion. There is however only 6.5 dB margin with regard to the short-term protection criterion, and 3.5 dB missing in order to encompass the 49 dBi FS system contained in ECC Report 026 [19].

To solve this issue, it is proposed to retain the following pfd mask:

- –122 dB(W/(m² · MHz)) for θ ≤ 5°;
- –127 + θ dB(W/(m² · MHz)) for 5° < θ ≤ 40°;
- –87 dB(W/(m² · MHz)) for 40° < θ ≤ 90°.

where θ is the angle of arrival of the radio-frequency wave (degrees above the horizontal).

Figure 34 gives the simulations results for the 37 dBi FS system contained in Table 3.

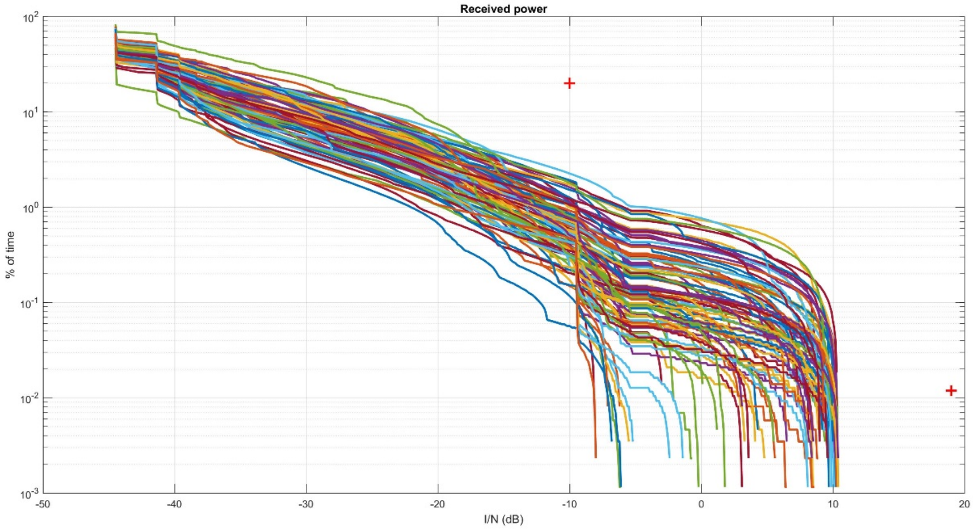

Figure 34: Pfd mask with a constant value below 5° elevation and a 37 dBi FS

Figure 35 gives the simulations results for the 49 dBi FS system contained in ECC Report 026.

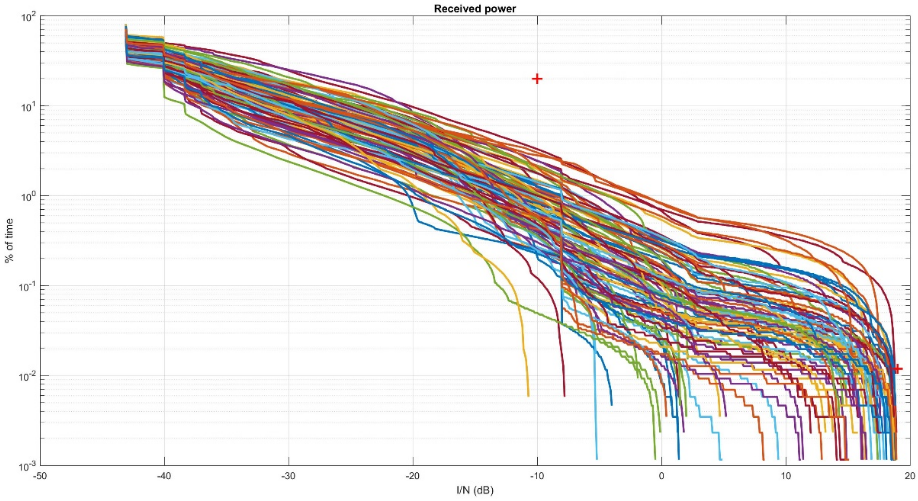

Figure 35: Pfd mask with a constant value below 5° elevation and a 49 dBi FS

It can be seen that both criteria are met. The average FDP is in this case respectively 2.48% and 2.24%, well below the 10% criterion, and there is still about 17 dB margin with regard to the long-term protection criterion.

Figure 36 provides a sensitivity analysis where the altitude of the aircraft is changed from 1000 m to 11000 m for a pointing elevation angle of 0° and a pointing azimuth of 90°, corresponding to a worst case in terms of long-term interference. It shows that the worst case actually appears for high altitudes, where the visibility time of aircraft as seen from the FS is longer. It should be noted however that meeting the pfd mask at low altitudes would be a constraint that could push the NGSO operator to limit the altitude above which an ESIM terminal can be activated in the band 14.25-14.5 GHz. The figure has been generated for the case in which the maximum gain of the FS station is 37 dBi.

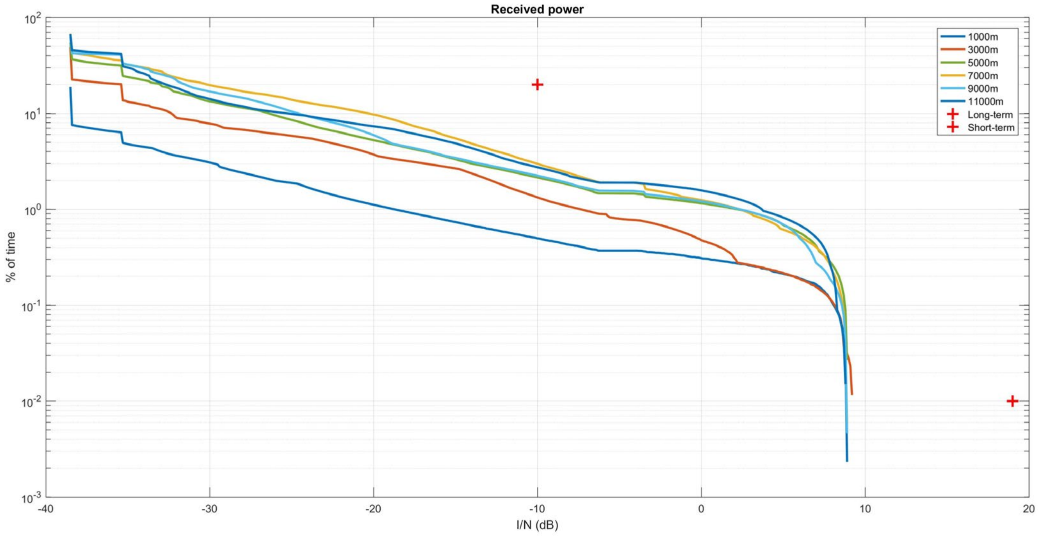

Figure 36: Sensitivity analysis vs altitude

Conclusions

The protection of fixed service stations in the band 14.25-14.5 GHz used in some CEPT countries can be achieved by imposing pfd limits on the Earth's surface to airborne ESIM.

The assessments have shown that for airborne ESIM operating in the OneWeb system under the FSS allocation, the following mask would protect FS station:

- –122 dB(W/(m² · MHz)) for θ ≤ 5°;
- –127 + θ dB(W/(m² · MHz)) for 5° < θ ≤ 40°;
- –87 dB(W/(m² · MHz)) for 40° < θ ≤ 90°.

where θ is the angle of arrival of the radio-frequency wave (degrees above the horizontal).

The method(s) to comply with the mask depend on the NGSO FSS operator. This can be achieved through control of the e.i.r.p. radiated in the backlobes of the airborne earth station, taking into account, as appropriate for the specific deployments, the available fuselage attenuation.

The simulations that resulted in the proposed mask have taken into account particular characteristics of the OneWeb NGSO system. If a different NGSO system has to be considered, the number of ESIM visible by the FS station and simultaneously transmitting over the same channel as the FS station has to be clearly specified. Such number may depend on the number of satellites visible by aircraft at a given altitude, the type of access scheme of the NGSO FSS system, the percentage of traffic carried by ESIM on board aircraft.

Once such number of earth stations is clearly identified, a new analysis should be performed to verify if the limits above can still protect the FS or if new limits should be established for ESIM aircraft in the relevant NGSO system.

A1.6.1.3 Sharing with shipborne FSS ESIM

Methodology

There is already a regulation for ESV with a maximum distance from the coast set at 125 km. The calculation of this distance has been done assuming a given FSS e.i.r.p., with the FSS ES pointing towards a GSO satellite. CEPT proposed at WRC-15 to modify this distance and set up a distance as a function of the FSS ES e.i.r.p. This was however not accepted by the conference.

In order to assess the separation distance from the coast that would be required to ensure the protection of FS from shipborne NGSO ESIM, the methodology contained in Recommendation ITU-R SF.1650 [18] has been applied. Similarly to the airborne ESIM, a MATLAB program has been developed and validated using the exact parameters contained in Recommendation ITU-R SF.1650. The separation distances and percentage of time obtained were similar to the ones obtained in this recommendation although the separation distances were slightly higher (in the order of 2 km).

Recommendation ITU-R P.452 [5] was used for the propagation model. The latitude has been arbitrarily set to 45° and the longitude to 0°, noting that no terrain elevation was considered. The FS receiver is located 15 km from the coast and pointing towards the sea. The FS station considered was the same as in Recommendation ITU-R SF.1650. Two different percentages of time associated to the short-term protection criterion have been considered namely 0.0119% and 2.7 10-4%.

The parameters for the FSS ES were then replaced by the e.i.r.p. of the NGSO earth station towards the horizon. It should be noted that the power spectral density of -20 dBW/(40 kHz) is valid assuming a transmission bandwidth of 2 MHz for the FSS earth station, which leads to a maximum e.i.r.p of 0 dBW towards the horizon when two channels are transmitted simultaneously, to be compared with the 2.2 to 16.2 dBW of the GSO FSS earth station in Recommendation ITU-R SF.1650.

Results

Applying the methodology described above results in a separation distance of 116.5 km from an FS station with a 49 dBi antenna. The separation distance from the FS is 42.7 km when considering the 37 dBi FS station in Table 3. Both distances result in respectively 101.5 and 27.7 km distance from the shore when subtracting the 15 km distance between the FS and the shore. The different results obtained are summarised in Table 17.

Table 17: Separation distance from the FS/from the shore obtained using Recommendation ITU-R SF.1650

	49 dBi FS with ps=0.00027%	49 dBi FS with ps=0.0119%	37 dBi FS with ps=0.00027%	37 dBi FS with ps=0.0119%
3 vessels per day	111.3 km / 96.3 km	84.7 km / 69.7 km	39 km / 24 km	23 km / 8 km
6 vessels per day	116.5 km / 101.5 km	86.4 km / 71.4 km	42.7 km / 27.7 km	25.3 km / 10 .3 km

Conclusions

The results showed, for the assumptions made, that OneWeb earth stations radiating with a total e.i.r.p of 0 dBW towards the horizon, need to maintain a separation distance from the shore as shown in the above table.

If required, a pfd limit at the low water mark could be defined similarly to the one developed in Ka-band. Assuming the FS characteristics and methodology specified in Recommendation ITU-R. SF.1650; such a pfd limit would be of -116 dBW/m²/MHz at 80m above sea level, with an associated percentage of time of 0.06% for the 0.00027% short-term protection criterion. For the protection criterion with associated percentage of time of 0.0119%, the same pfd is applicable (-116 dBW/m²/MHz) but it is associated to a percentage of time of 4.5%.

A pfd limit would apply to all NGSO FSS system, since it only depends on the FS characteristics, whereas a separation distance would require also the knowledge of the e.i.r.p. radiated towards the horizon by the NGSO FSS system.

A1.6.2 Sharing with Radio Astronomy Service (RAS) in the 14.47-14.5 GHz Band

From a technical point of view, the study contained in this section uses the same approach as one that would be conducted between co-primary services; nevertheless, it is reminded that the RAS allocation in this band has a secondary status.

A1.6.2.1 Sharing with land FSS ESIM

Methodology

The methodology does not differ much from the one used for fixed FSS earth stations. The earth station may be moving, but its location should be known by the Network Control Unit (NCU) and this latter should be able to cease emissions over the frequencies observed by RAS stations as soon as the ES enters in the protection zone identified for the RAS station.

The size of exclusion zones around RAS stations needs to be determined on a case-by-case basis to take into account actual FSS earth stations parameters and surrounding terrain by the administration where the RAS station operates.

Results

Figure 37 shows the separation distances around the Effelsberg RAS station (Germany), taking into account actual terrain elevation. The maximum distance is reduced in most directions, with the exception of a few azimuths where it reaches up to 150 km. This is due to the fact that Effelsberg is at a 369m altitude which adds to its antenna height above ground. In those directions where the separation distance reaches high values, the terrain elevation decreases down to 0m, and the results are similar to a flat terrain case with a 420m antenna height above ground instead of 50m.

The following figures show the same attenuation contour for the other RAS stations listed in Table 7.

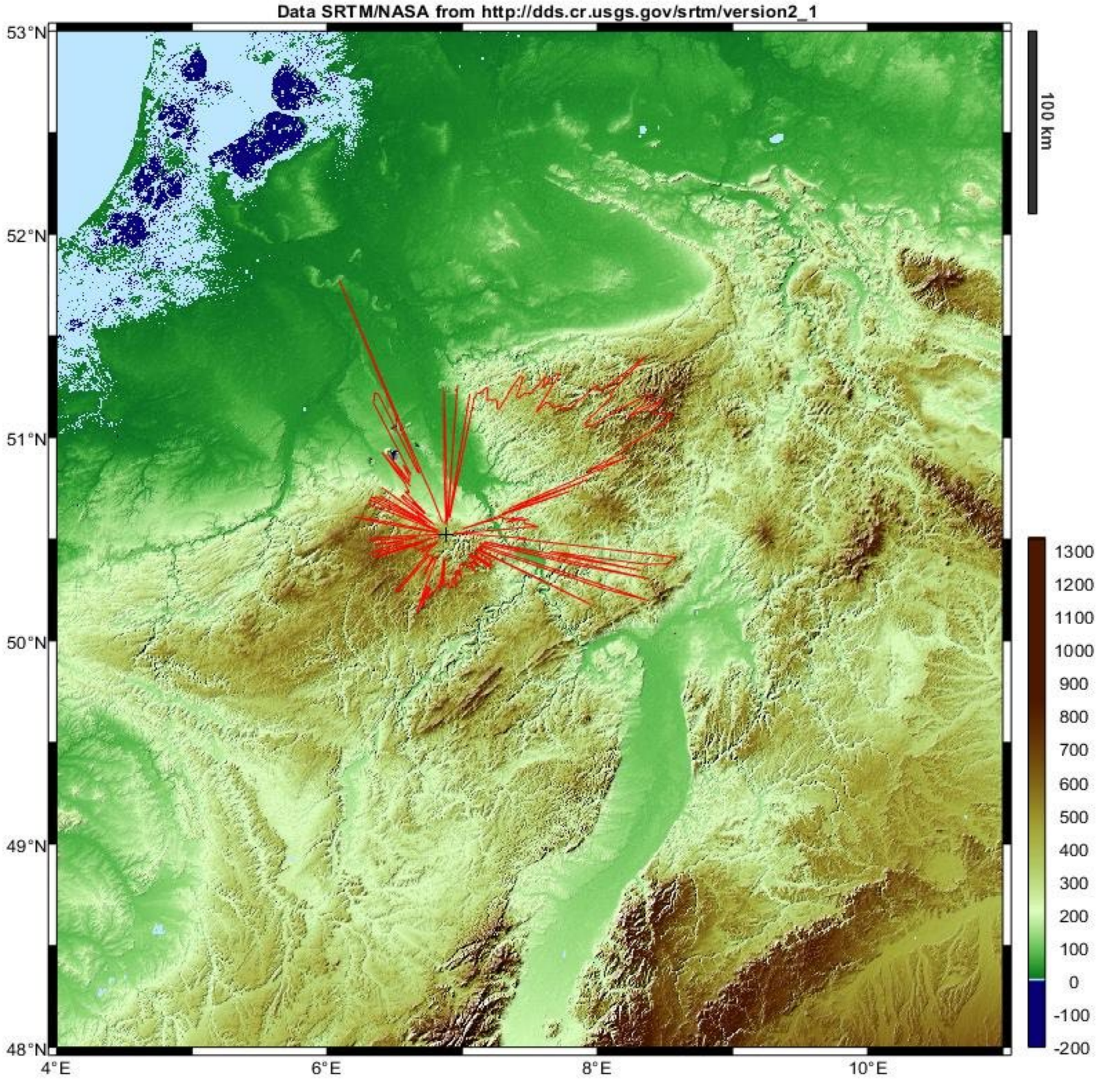

Figure 37: Effelsberg, Germany – max 150 km

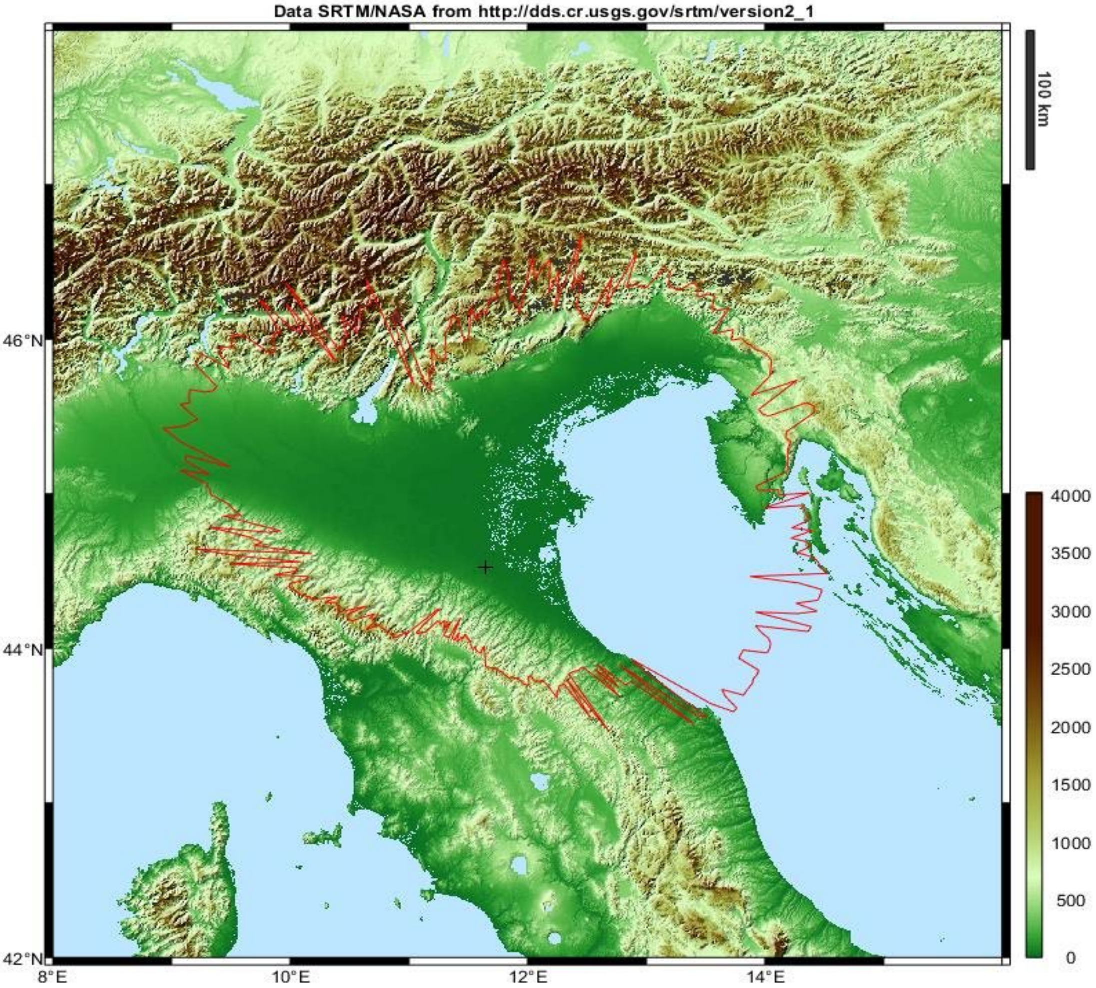

Figure 38: Medicina, Italy – max 250 km

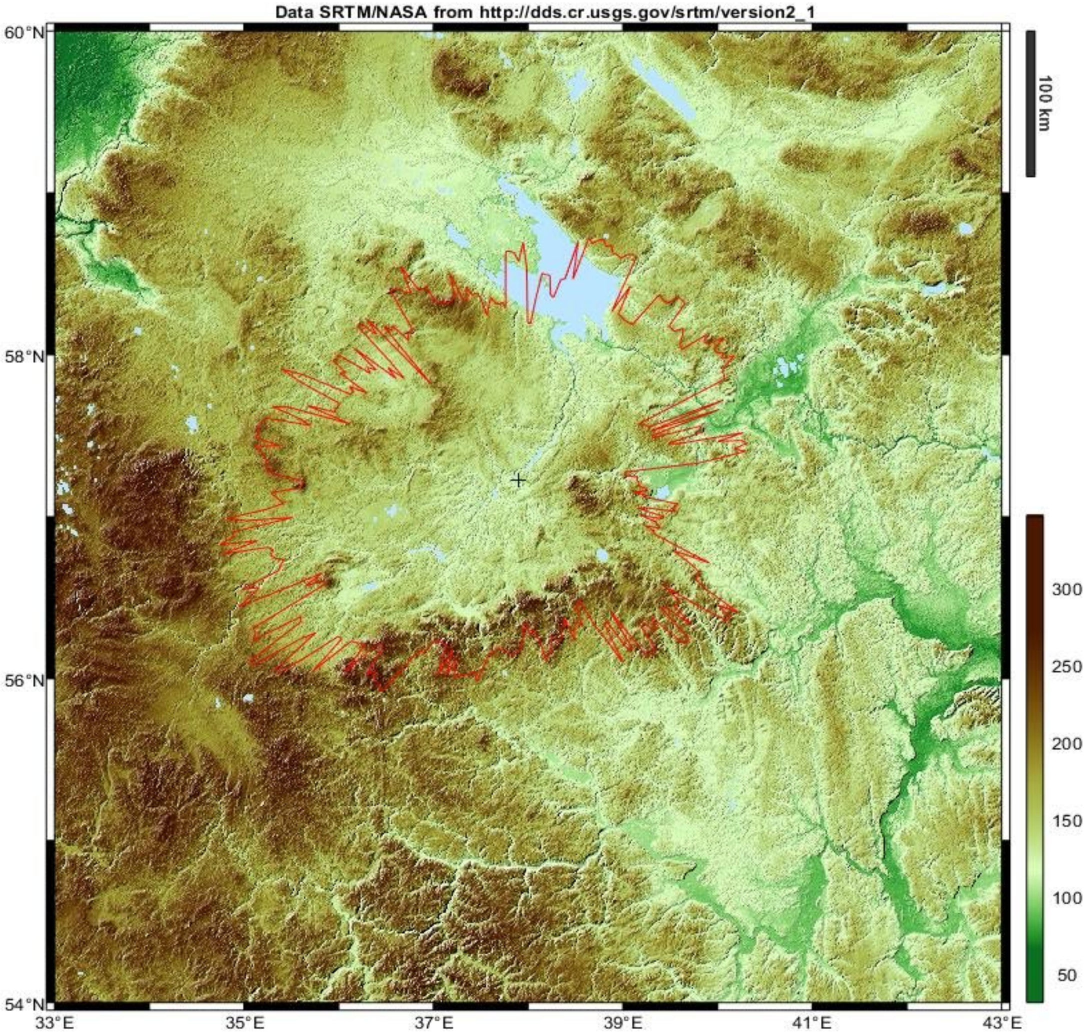

Figure 39: Kalyazin, Russia – max 202 km

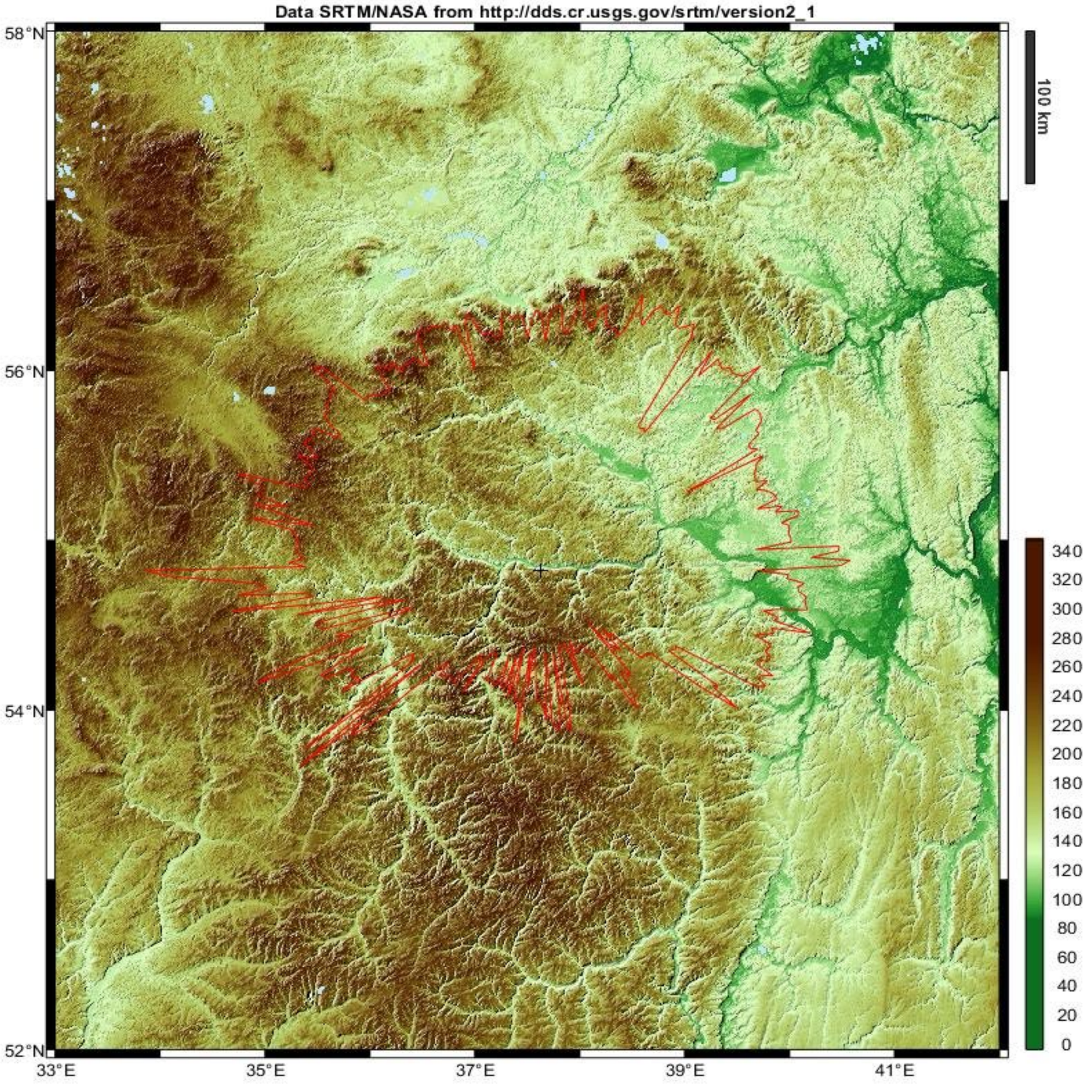

Figure 40: Puschino, Russia – max 251 km

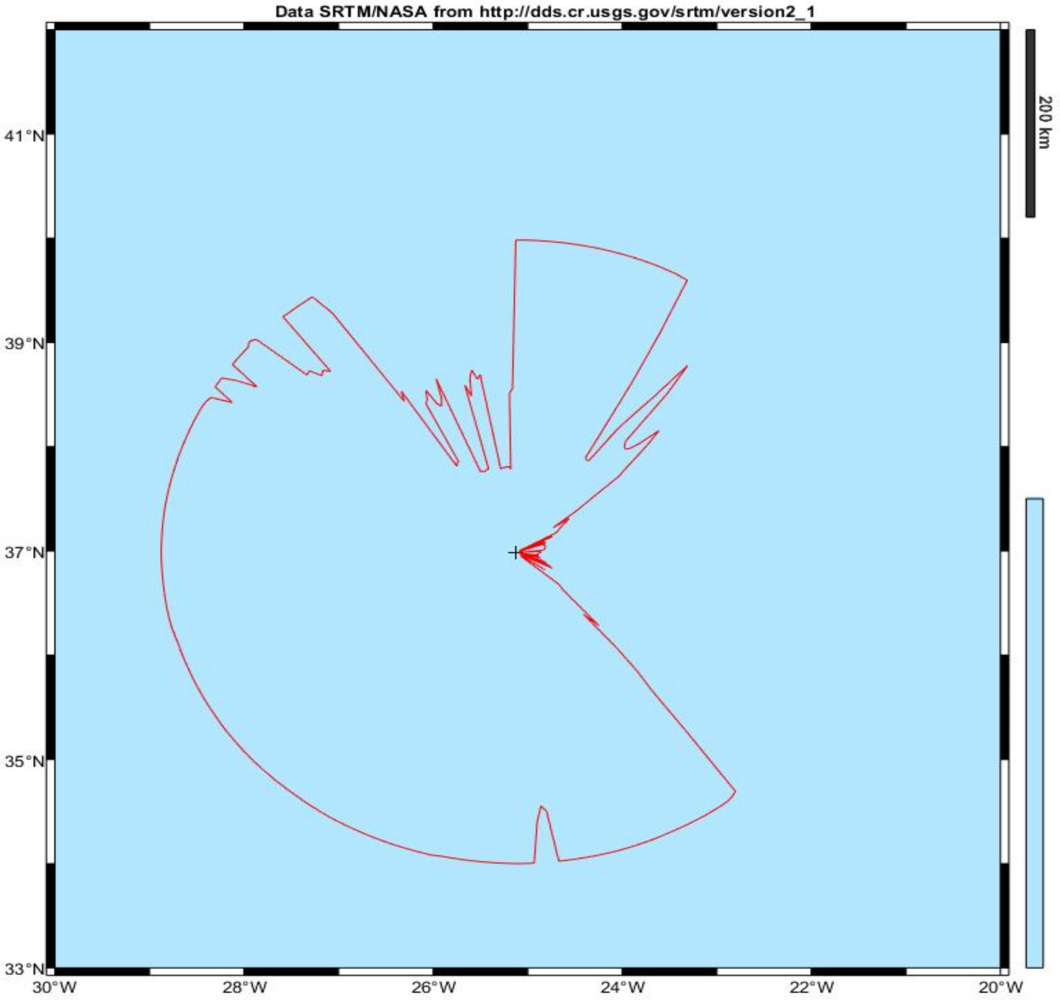

Figure 41: Santa Maria, Portugal – max 337 km, but over sea

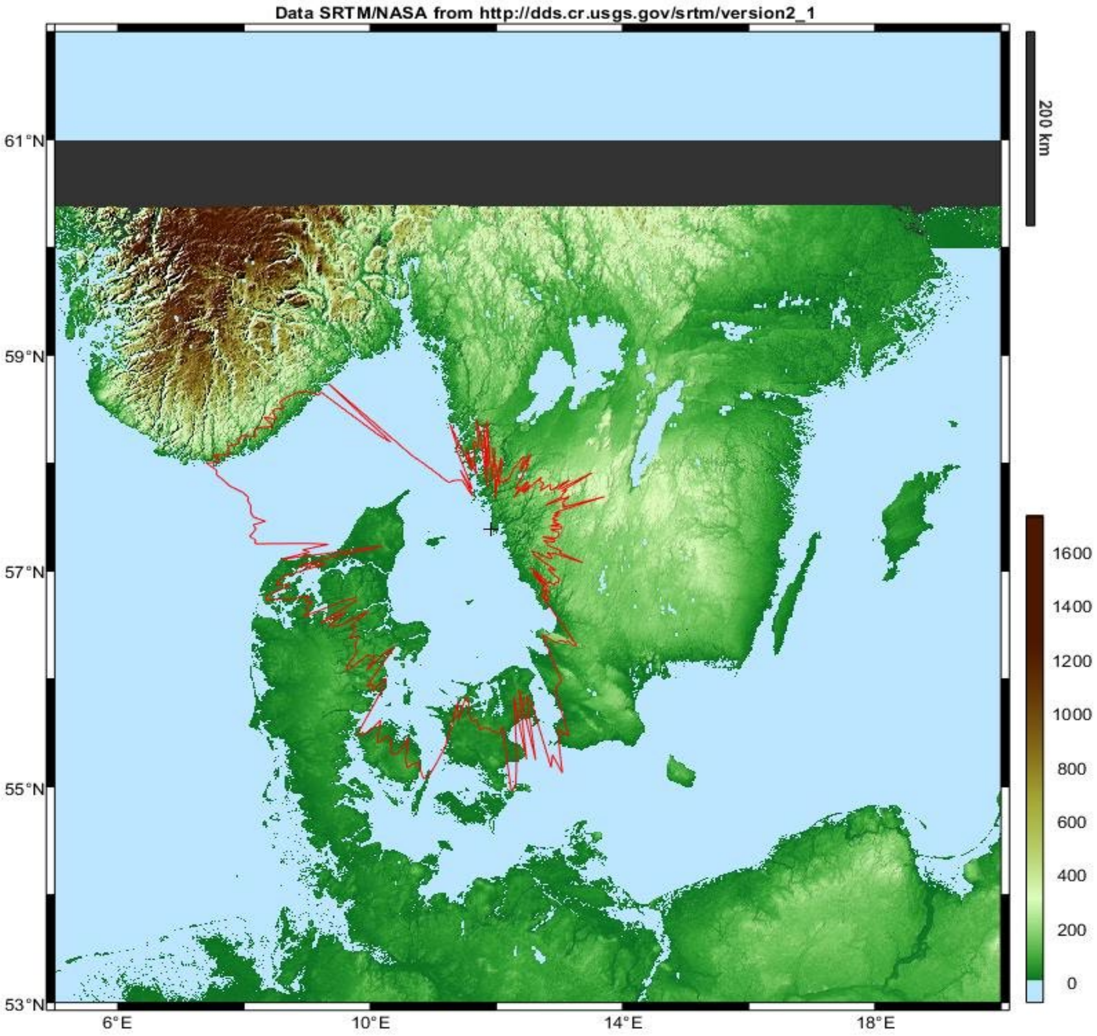

Figure 42: Onsala, Sweden – max 280 km

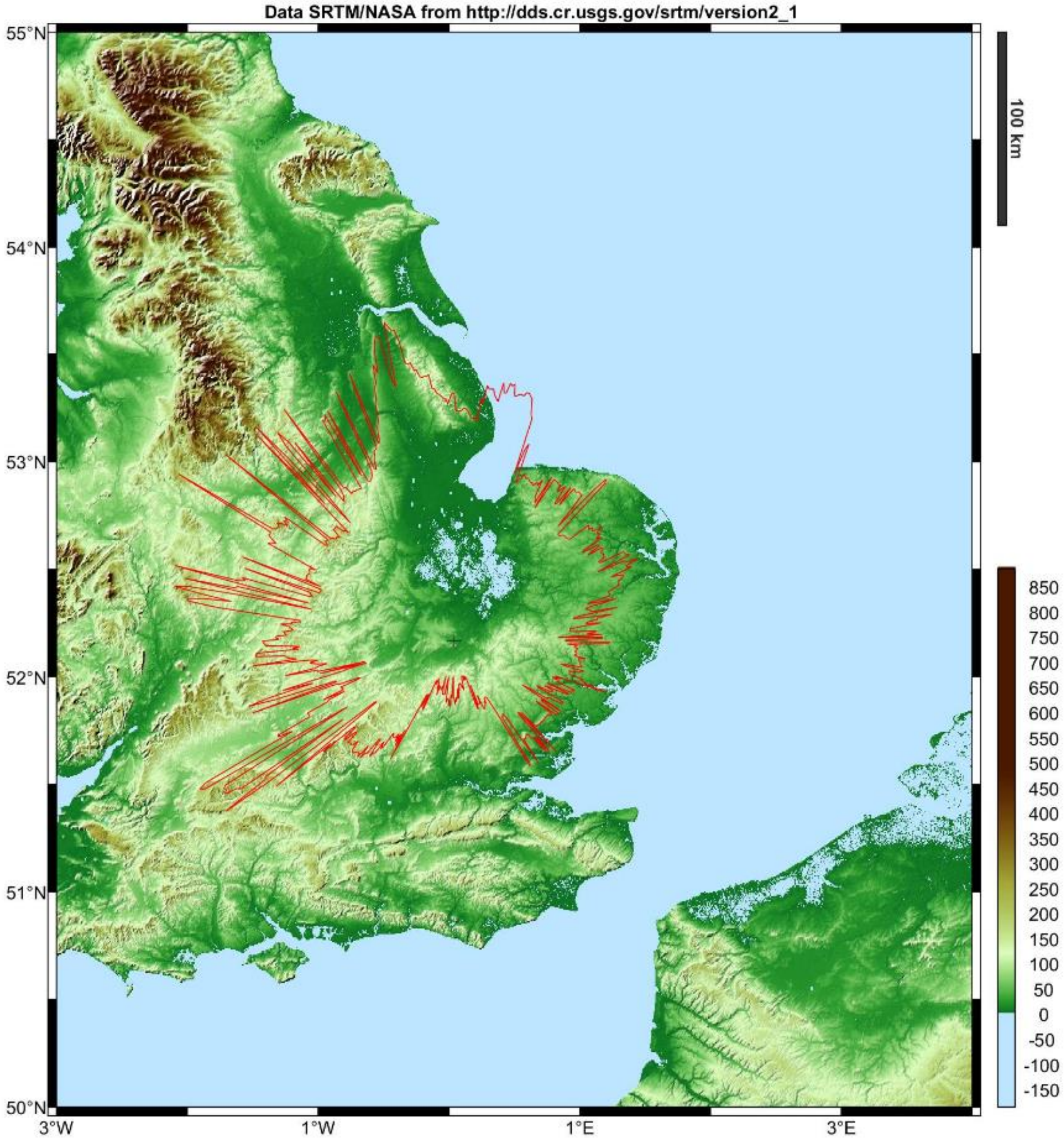

Figure 43: Cambridge, United Kingdom – max 183 km

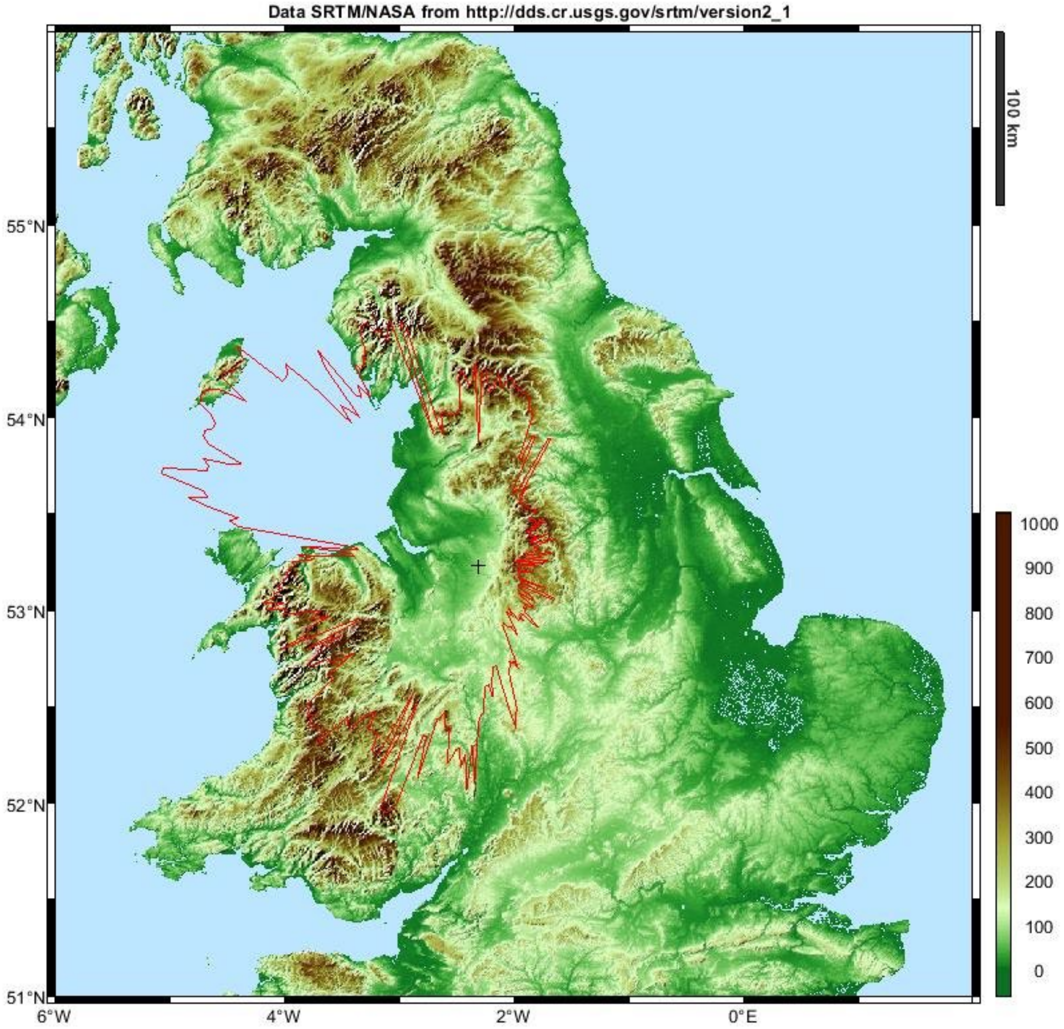

Figure 44: Jodrell Bank, United Kingdom – max 191 km

Conclusions

There are a limited number of RAS stations within the CEPT that perform observations in the secondary RAS allocation in the frequency band 14.47-14.5 GHz. The protection of these RAS stations can be achieved through exclusion zones around such stations where any single NGSO FSS earth station will have to cease transmissions on channels overlapping with the band 14.47-14.5 GHz (the aggregate effect of several FSS earth stations has not been assessed).

The size of the protection zone has to be determined on a case-by-case basis taking into account the FSS and terrain characteristics. For OneWeb terminals (with an e.i.r.p. towards the horizon of -20 dBW/(40 kHz)) the size of the zone can be up to 250 km. For other type of earth stations with different e.i.r.p. levels towards the horizon, the exclusion zones would not be the same as presented in this section. Notwithstanding this assessment, specific calculations on the exclusion zones for RAS should be computed on a case by case basis, taking into account the real FSS characteristics.

The NGSO satellite system, when establishing compatibility with RAS observatories within an administration, will initially identify the exclusion zones for each of the RAS observatories using the methodology described in this section. It should be noted that this protection zone may extend beyond the national territory into the territories of neighbouring administrations. The OneWeb NGSO satellite system should be able to deploy the "control of emission" function stipulated in the ETSI EN 303 980 [1] (see section A1.2.3 above) to ensure the suppression of relevant frequencies by land ESIM when entering the protection zone or when located within the protection zone. The NGSO satellite system, by suppressing the use by land ESIM (located within the protection zone) of frequencies 14.47-14.5 GHz (or specific frequencies deployed by the RAS observatory), will provide necessary compatibility with the RAS.

A1.6.2.2 Compatibility with airborne FSS ESIM

Methodology

The methodology chosen is similar to the one used for studies between AMSS and RAS in the band 14-14.5 GHz as documented in ECC Report 026 [19]. A number of aircraft are deployed on air routes, some of them using NGSO FSS ESIM.

Consistently with the studies related to the protection of FS in section 8.1 of this document, a number of 5 to 6 aircraft in visibility of the RAS station and operating on the same 150 kHz channel at each moment in time was considered.

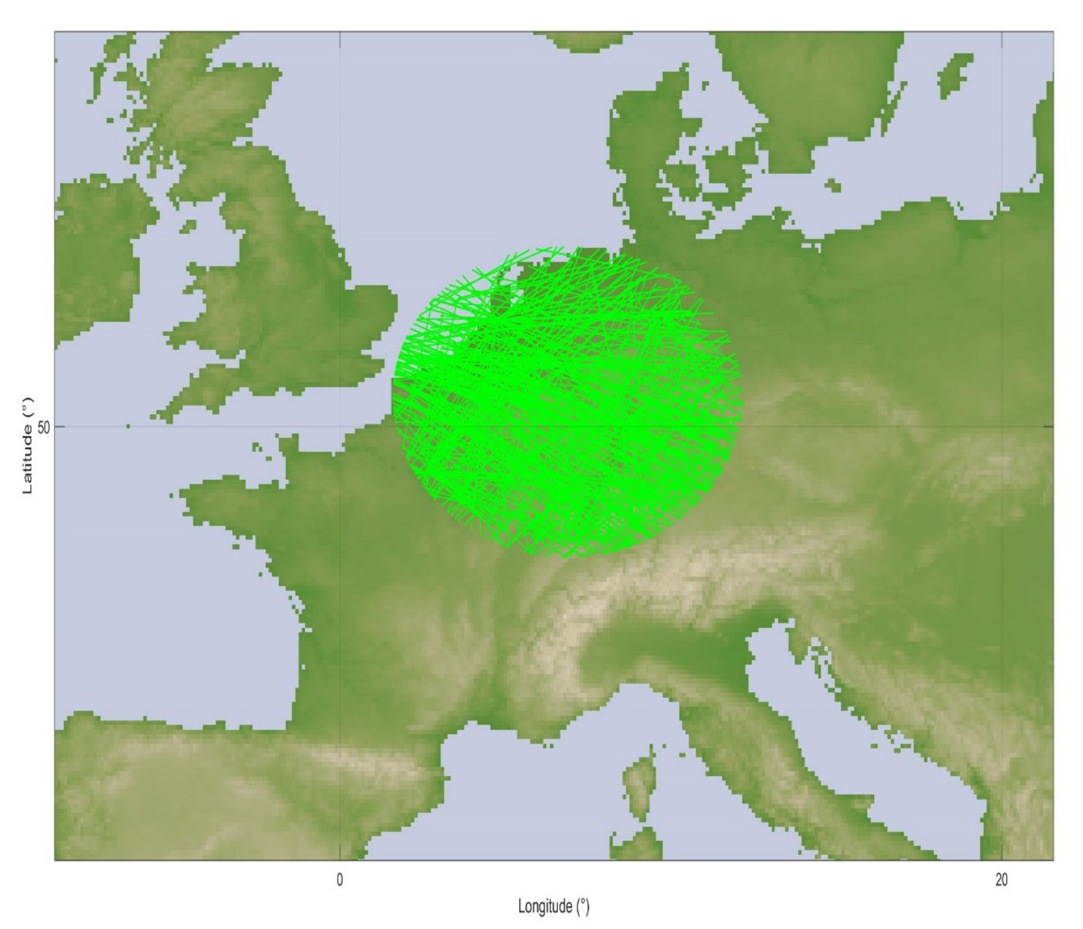

Figure 45: Air routes in visibility of the Effelsberg RAS station

Results

The pfd mask contained in part C of recommendation ITU-R M.1643 [17], relaxed by 5 dB, was considered in epfd simulations:

- $-185 + 0.5 \cdot \theta$ dB(W/(m2 · 150 kHz)) for $\theta \leq 10°$;
- -180 dB(W/(m2 · 150 kHz)) for $10° < \theta \leq 90°$.

where θ is the angle of arrival of the radio-frequency wave (degrees above the horizontal).

The following figures have been derived using this mask.

Figure 50 provides the results of simulations for the Effelsberg RAS station. The percentage of data loss is 0.4% above 8° elevation.

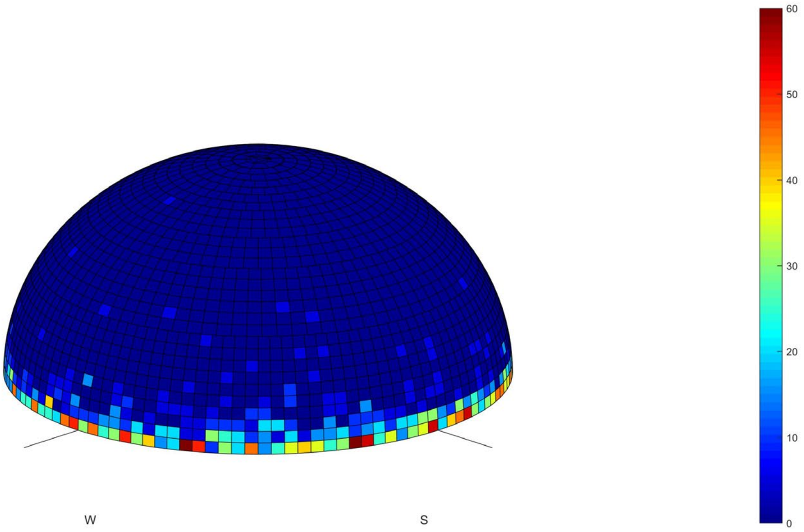

Figure 46: Data loss due to airborne ESIM over Effelsberg

Figure 47 provides the results of simulations for the Medicina RAS station. The percentage of data loss is 0.35% above 5° elevation.

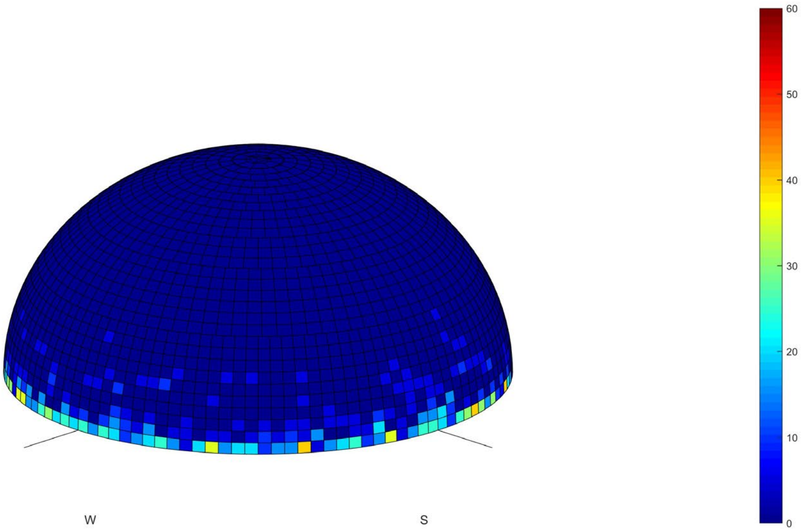

Figure 47: Data loss due to airborne ESIM over Medicina

Figure 48 provides the results of simulations for the Kalyazin RAS station. The percentage of data loss is 1.64% above 0° elevation.

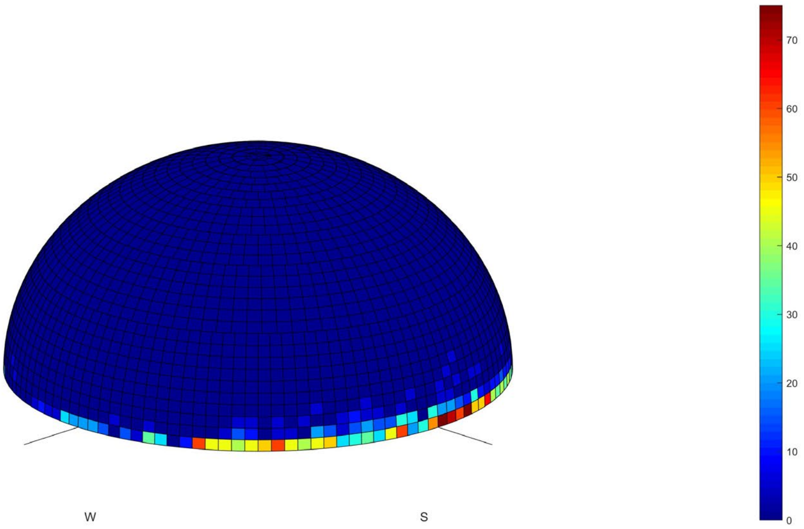

Figure 48: Data loss due to airborne ESIM over Kalyazin

Figure 49 provides the results of simulations for the Puschino RAS station. The percentage of data loss is 1.08% above 6° elevation.

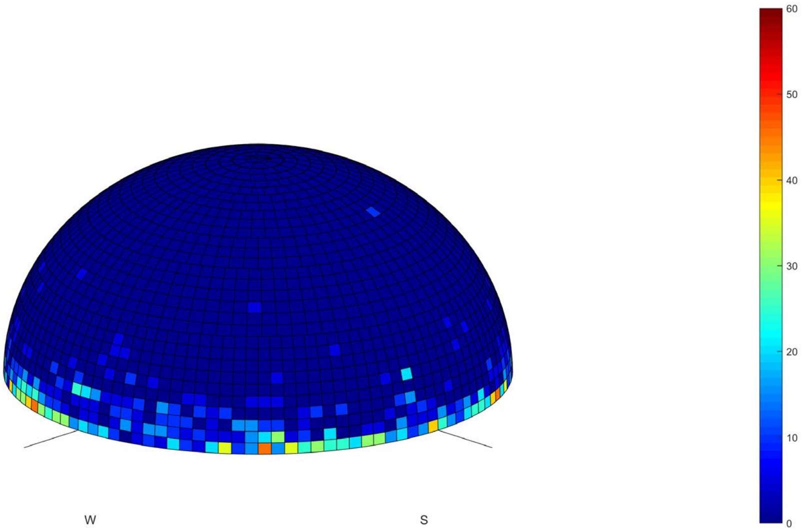

Figure 49: Data loss due to airborne ESIM over Puschino

Figure 50 provides the results of simulations for the Santa Maria RAS station. The percentage of data loss is 0.19% above 5° elevation.

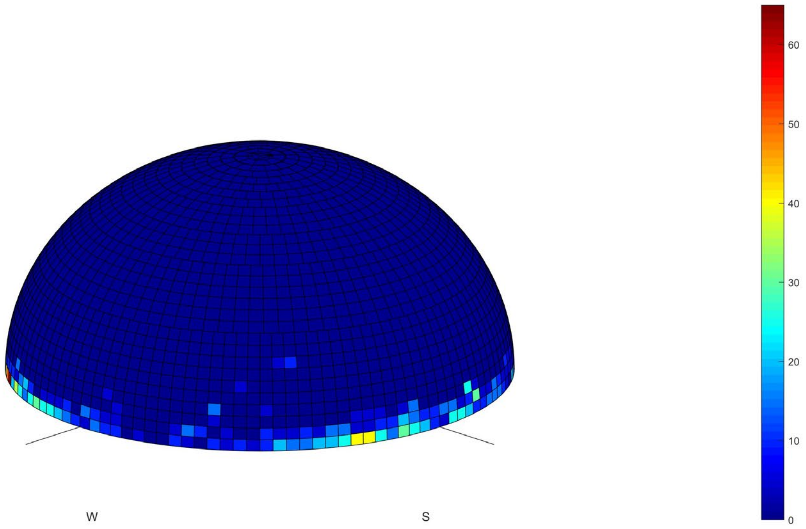

Figure 50: Data loss due to airborne ESIM over Santa Maria

Figure 51 provides the results of simulations for the Onsala RAS station. The percentage of data loss is 0.89% above 0° elevation.

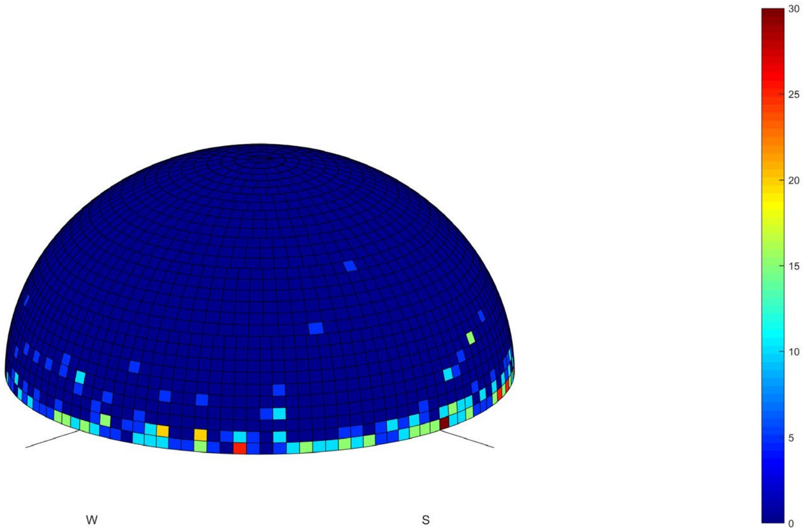

Figure 51: Data loss due to airborne ESIM over Onsala

Figure 52 provides the results of simulations for the Cambridge RAS station. The percentage of data loss is 0.89% above 2° elevation.

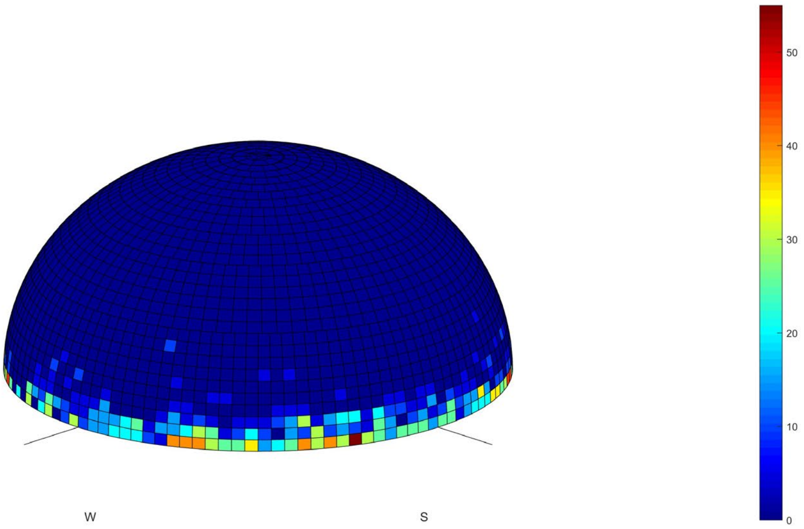

Figure 52: Data loss over Cambridge

Figure 53 provides the results of simulations for the Jodrell Bank RAS station. The percentage of data loss is 1.53% above 0° elevation.

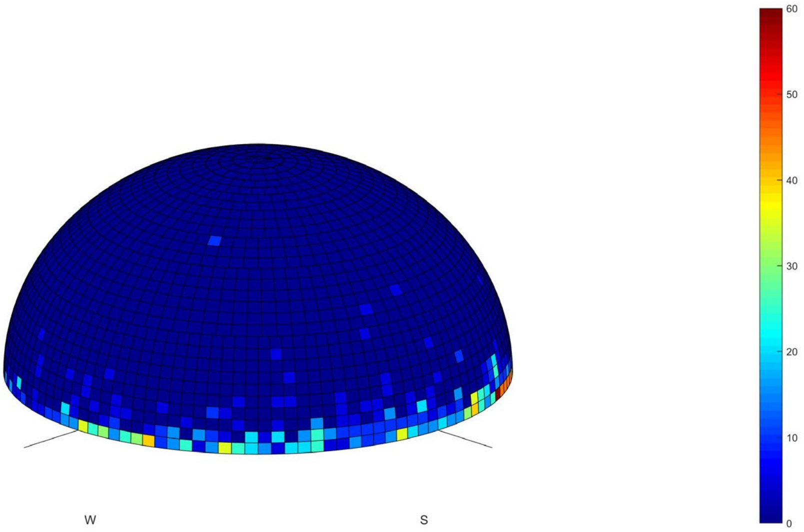

Figure 53: Data loss over Jodrell Bank

Conclusions

The protection of the RAS stations observing in the secondary RAS allocation in the band 14.47-14.5 GHz can be achieved through a pfd mask.

Taking into account the characteristics of the OneWeb system, the following pfd mask on the Earth's surface is proposed:

- $-185 + 0.5 \cdot \theta$ dB(W/(m2 · 150 kHz)) for $\theta \leq 10°$;
- -180 dB(W/(m2 · 150 kHz)) for $10° < \theta \leq 90°$.

where θ is the angle of arrival of the radio-frequency wave (degrees above the horizontal);

It should be noted that the previous pfd masks have been derived assuming 5 to 6 aircraft in visibility of an FS or RAS station and transmitting on the same 150 kHz channel. The number of aircraft depends on the number of visible satellites at the aircraft height, the number of beams of each satellite, the access scheme and the traffic estimated to be carried out by aircraft within the NGSO system. If a different NGSO FSS system is considered, a new analysis has to be performed by using the relevant parameters proper to that system that may lead to different number of aircraft and to different pfd values.

In view of the low pfd levels, the NGSO airborne stations may be required to cease emissions in the band 14.47-14.5 GHz when in visibility of a RAS station performing observations in this band and ensuring that unwanted emissions falling into the RAS band meet the pfd mask.

A1.6.2.3 Compatibility with shipborne FSS ESIM

Methodology

The methodology is similar to the one used for fixed ES and land ESIM, but would be limited to the following RAS stations close to the sea.

Table 18: CEPT RAS observatories located close to the sea and using the band 14.47-14.5 GHz

Administration	Name
Italy	Medicina
Portugal	Santa Maria
United Kingdom	Cambridge
	Jodrell Bank
Sweden	Onsala

Results

As the FSS terminal is similar to the one used for land ESIM, the results for small ships will be similar to the ones obtained in Figure 23, Figure 26, Figure 27, Figure 28 and Figure 29. The results for big ships will be a bit larger due to a higher antenna height.

Once again, since the distances largely depend on the FSS and RAS characteristics, as well as propagation conditions (Terrain, temperature and other parameters), the exclusion zones can be more accurately determined on a case-by-case basis.

Conclusion

The protection of RAS stations observing in the secondary RAS allocation in the band 14.47-14.5 GHz and located close to the sea would require exclusion zones. The NGSO FSS operator would have to cease transmissions in the band 14.47-14.5 GHz when the ship enters within these exclusion zones, the size of which has to be determined on a case-by-case basis taking into account FSS characteristics as well as surrounding terrain. This would also apply to shipborne earth stations located in CEPT countries national waters.

The size of the exclusion zones can be up to 340 km for OneWeb earth stations. Nevertheless, the sharing conditions for this sharing scenario can be extended to any NGSO FSS system since the real characteristics of the earth stations would be taken into account for calculating the exclusion zones.

When establishing compatibility with RAS observatories within an administration, the NGSO FSS system would initially identify the exclusion zones for each of the RAS observatories using the methodology described in this section. This cans be done by deploying the "control of emission" function stipulated in the

ETSI EN 303 980 [1] (see section A1.2.3 above) to ensure the suppression of relevant frequencies by shipborne ESIM when entering the protection zone or when located within the protection zone. By suppressing the use by shipborne ESIM (located within the protection zone) of frequencies 14.47-14.5 GHz (or specific frequencies deployed by the RAS observatory), the NGSO will be able to achieve compatibility with the RAS.

ANNEX 2: SPACEX NGSO FSS SYSTEM

A2.1 SATELLITE AND PAYLOAD CHARACTERISTICS

The SpaceX non-geostationary orbit (NGSO) satellite system (the SpaceX System), as filed at the Bureau and licensed by the U.S. Federal Communications Commission (FCC) on 29 March 2018, consists of a constellation of 4425 satellites (plus in-orbit spares)[6] operating in 83 orbital planes (at altitudes ranging from 1110 km to 1325 km), as well as associated tracking, telemetry and control (TT&C) ground facilities, gateway earth stations and end user earth stations. Subsequently, FCC authorized SpaceX's request to relocate 1584 previously authorised satellites from 1150 km to an altitude of 550 km in May 2019 and later allowed the 550 km planes to be re-spaced to expedite coverage in the southern part of CONUS. In April 2020, SpaceX has proposed to lower all remaining higher altitude orbits (1110 km or higher) in the range of 540 km to 570 km and introduce coverage in the polar areas. A modification request to the Bureau to lower the 1150 km to an altitude of 550 km has been filed on April 2019 and has already been found favourable by the Bureau. The overall modified constellation, as filed in April 2020, will be configured as follows:

Table 19: SpaceX Modified System Constellation[7]

Orbital Planes	Satellites per Plane	Altitude (km)	Inclination (º)
72	22	550	53
72	22	540	53.2
36	20	570	70
6	58	560	97.6
4	43	560	97.6

The SpaceX system is designed to provide a wide range of broadband and communications services. Phased array beam-forming and digital processing technologies within the satellite payload give the system the ability to make efficient use of Ku- and Ka-band spectrum resources and the flexibility to share that spectrum with other licensed users. User Terminals operating with the SpaceX System will use similar phased array technologies to allow for highly directive, steered antenna beams that track the system's low-Earth orbit satellites. Technically identical phased arrays will be used for both fixed user terminals and Earth Stations In Motion (ESIMs). Gateway earth stations also apply advanced phased array technologies to generate high-gain steered beams to communicate with multiple NGSO satellites from a single gateway site. The system will also employ optical inter-satellite links for seamless network management and continuity of

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[6] SpaceX will provision to launch up to two extra spacecraft per plane to replenish the constellation in the event of on-orbit failures. If a case arises wherein a spare is not immediately needed, it will remain dormant in the same orbit and will perform station-keeping and debris avoidance manoeuvres along with the rest of the active constellation. Because these spare satellites will not operate their communications payloads, and the TT&C facilities communicate in turn with a fixed number of satellites at all times, the addition of spare satellites will not affect the interference analyses presented here.

[7] Relevant ITU filings (Ku-band):

- STEAM-1, ITU Publication Number CR/C/3739 MOD-5, BRIFIC / Published Date 2920/12 May 2020
- USASAT-NGSO-3A-R, ITU Publication Number CR/C/4423 MOD-1, BRIFIC / Published Date 2926/4 Aug 2020

Relevant FCC filings:

- Initial License: SAT-LOA-20161115-00118, and subsequent MODs:
- SAT-MOD-20181108-00083
- SAT-MOD-20190830-00087
- SAT-MOD-20200417-00037, in process (as of 09/17/2020)

service, which will also aid in complying with emissions constraints designed to facilitate spectrum sharing with other systems.

The frequency ranges used by the proposed SpaceX System are summarised in Table 20 below.

Table 20: Frequency Bands Used by the SpaceX System

Type of Link and Transmission Direction	Frequency Ranges
User Downlink Satellite-to-User Terminal	10.7–12.75 GHz
Gateway Downlink Satellite to Gateway	17.8–18.6 GHz 18.8–19.3 GHz
User Uplink User Terminal to Satellite	14.0–14.5 GHz
Gateway Uplink Gateway to Satellite	27.5–29.1 GHz 29.5–30.0 GHz
TT&C Downlink	12.15–12.25 GHz 18.55–18.60 GHz
TT&C Uplink	13.85–14.00 GHz

A2.2 KU-BAND USER BEAMS

All Ku-band downlink spot beams on each individual SpaceX satellite in the NGSO constellation are independently steerable over the full field of view of the Earth. However, user terminals at the customers' premises communicate only with satellites at elevation angle greater than 25° from the horizon. Consequently, as shown in Figure 54 below, each satellite operating at an altitude of a = 550 km will provide service only up to α = 56.6° away from boresight (nadir), covering an area of about 2.87 million square kilometres (r = 956.7 km).[8]

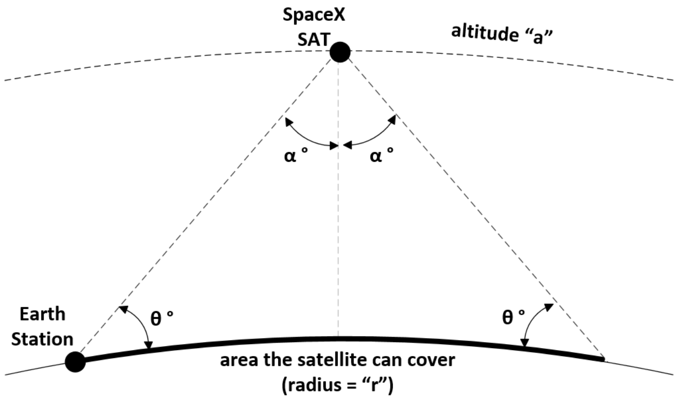

Figure 54: Steerable Service Range of Ku-band Beams

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[8] While the 25° minimum elevation angle remains the same from the earth station point of view, the maximum angle from boresight at which service can be provided from the satellite changes slightly depending upon altitude. Thus, satellites operating at 540 km, 560 km, and 570 km altitude provide service up to 56.7°, 56.4°, and 56.3° away from boresight, respectively.

Generally, beams from antennas using phased arrays widen incrementally as they are steered away from boresight[9]. However, this widening occurs only in the plane formed by boresight and the centre of the beam ("elevation"), and not in the plane normal to that plane formed by boresight and the centre of the beam ("azimuth"). As a result, the shape of a phased array beam at boresight is circular but becomes increasingly elliptical when steered away from boresight.

The intended coverage area for each beam is a cell inside the -3 dB contour, as illustrated in below. At a given frequency, only a single beam (with right hand circular polarisation (RHCP) on the downlink) would cover a single cell on the ground.

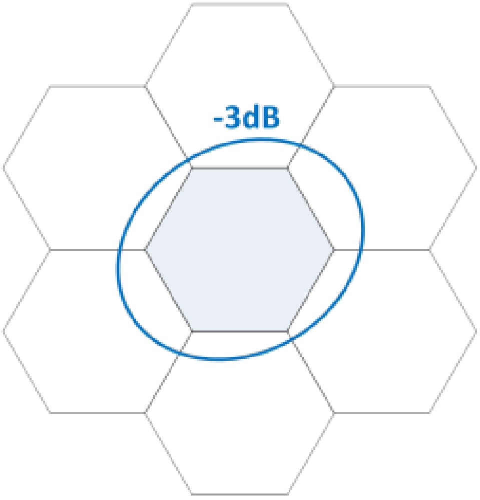

Figure 55: Intended Beam Coverage Area

As the transmitting beam is steered, the power is adjusted to maintain a constant power flux-density (pfd) at the surface of the Earth, compensating for variations in antenna gain and path loss associated with the steering angle. As illustrated in Figure 56 below, as a satellite at 540 km altitude steers the transmitting beam, it adjusts the power to maintain a constant PFD at the surface of the Earth. The highest equivalent isotropically radiated power e.i.r.p.) density (-15.0 dBW/4kHz for 570 km orbits) occurs at maximum slant.

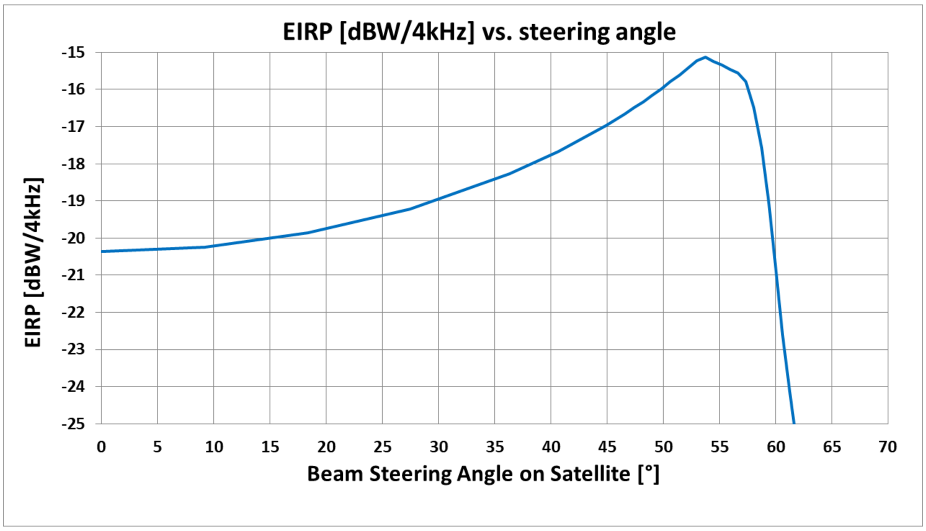

Figure 56: e.i.r.p. Density Variation by Beam Steering Angle

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[9] For this purpose, "boresight" refers to the direction normal to the phased array plane.

For receiving beams, the antenna gain drops slightly as the beam slants away from nadir. As a result, the maximum G/T (8.4 dB/K) occurs at nadir, while the minimum G/T (4.9 dB/K) occurs at maximum slant.

A2.3 GEOGRAPHIC COVERAGE

Upon the full deployment of the NGSO constellation, the SpaceX System will pass over virtually all parts of the Earth’s surface and therefore, in principle, have the ability to provide ubiquitous global service. Because of the combination of orbital planes used in the SpaceX System, including the use of near-polar orbits, every point on the Earth’s surface will see, at all times, a SpaceX satellite at an elevation no less than 25°.

A2.4 GENERAL CHARACTERISTICS OF SPACEX EARTH STATIONS

Specific deployments of fixed Earth Stations and Earth Stations In Motion (ESIMs) communicating with the SpaceX system will be contingent upon the position on their compatibility with other services in the 14-14.5 GHz band. The discussion in Section 2 identified that the use of the 14-14.25 GHz band is limited to the fixed satellite service. Therefore, the 14-14.25 GHz band is available for ubiquitous deployment of earth stations within the CEPT geographic region. The upper part of the 14.25-14.5 GHz band is used by other services, namely the fixed service and radio astronomy service, therefore the use of the upper part of the band by earth stations is subject to relevant compatibility considerations.

SpaceX user terminals emissions towards the horizon are limited to -72.76 dBW/Hz for fixed installations, land and maritime ESIM, and -75.26 dBW/Hz for aeronautical ESIM. Note that, in sharing studies involving NGSO satellites, the side lobes in the antenna patterns are averaged (3 dB below the peak side lobes) because the antenna is moving while tracking the satellites and hence the antenna gain shifts between the peaks and valleys in the pattern.

SpaceX fixed user terminals are generally expected to be mounted on top of houses and buildings. For the subsequent studies, an antenna height of 10 m has been assumed (where relevant). As stated before, SpaceX ESIMs for land, maritime and aeronautical applications will have identical RF performance to SpaceX fixed terminals. Land and maritime ESIMs will be mounted on top of the vehicles and will generally have antenna heights less than 10 m. Land and maritime ESIMS may operate in motion but may also operate for extended periods of time while stationary when they are parked or anchored. Aeronautical ESIMs are mounted on top of the aircraft and may operate between 0 m and 12000 m above the surface. Aeronautical ESIMs are never stationary while in flight.

As stated before, SpaceX Earth Stations point at a minimum elevation of 25°; the e.i.r.p. radiated towards the horizon (towards the victim), will be in its side lobes, thus no polarisation loss.

SpaceX earth stations will be equipped with GPS receivers allowing them to determine the position of each earth station with high accuracy. The earth stations will have the possibility to cease emissions over a given frequency band when located within exclusion zones such as those determined around individual FS stations in the 14.25-14.5 GHz band, or RAS stations in the 14.47-14.5 GHz band. This aspect is further discussed in Section A1.5 below.

Regarding the o.o.b. emissions, OOBE in the adjacent channel (ACLR1) are better than -32 dBc. and OOBE in the next adjacent channel (ACLR2) are better than -55dBc, based on a 62.5 MHz channel bandwidth.

The earth stations of SpaceX are in conformity with ETSI EN 303 981 [1].

A2.5 ASSUMPTIONS AND RESULTS OF STUDY OF THE SPACEX SYSTEM

A2.5.1 Compatibility between NGSO FSS (space-to-earth) in the band 10.7-12.75 GHz and RAS in the band 10.6-10.7 GHz

A2.5.1.1 Assumptions

In the simulation model, all 4408 satellites in the constellation are assumed at 100% utilisation transmitting at worst-case e.i.r.p. (all beams on all satellites are turned ON and steered at the maximum possible slant angle which corresponds to the maximum e.i.r.p.). The contributions from each satellite in the 10.6 - 10.7 GHz band are summed. The maximum e.i.r.p. of the 720 satellites (satellites launched or to be launched in first 12 launches) in the RAS band (10.6-10.7GHz) is -142.0 dBW/Hz. The maximum e.i.r.p. of the remaining satellites to be launched after 12 launches will be approximately 13 dB lower to -155.0 dBW/Hz in the same RAS band. These e.i.r.p. values are the result of measurements of the individual out of band emissions of single antenna elements combined to generate the complete array pattern. The e.i.r.p. are essentially flat within the band (over frequency). The out of band noise is not beamformed in a predictable way (for example in the direction of the desired beam - see a simulated representative radiation pattern at 10.65 GHz in Figure 57 below); for this reason, in these simulations, the out of band noise radiation pattern is assumed isotropical with an e.i.r.p. value equal to the peak e.i.r.p. value of the actual radiation pattern. Note that SpaceX's satellite system can serve the areas around RAS sites only with higher channels to minimise interference, or, if desired can place no beam in the area (cell size is approximately 25 km in diameter). Also note that meting the e.i.r.p. limits mentioned above prevents SpaceX from using the lowest Ku-channel (10.7-10.95 GHz) on a global basis.

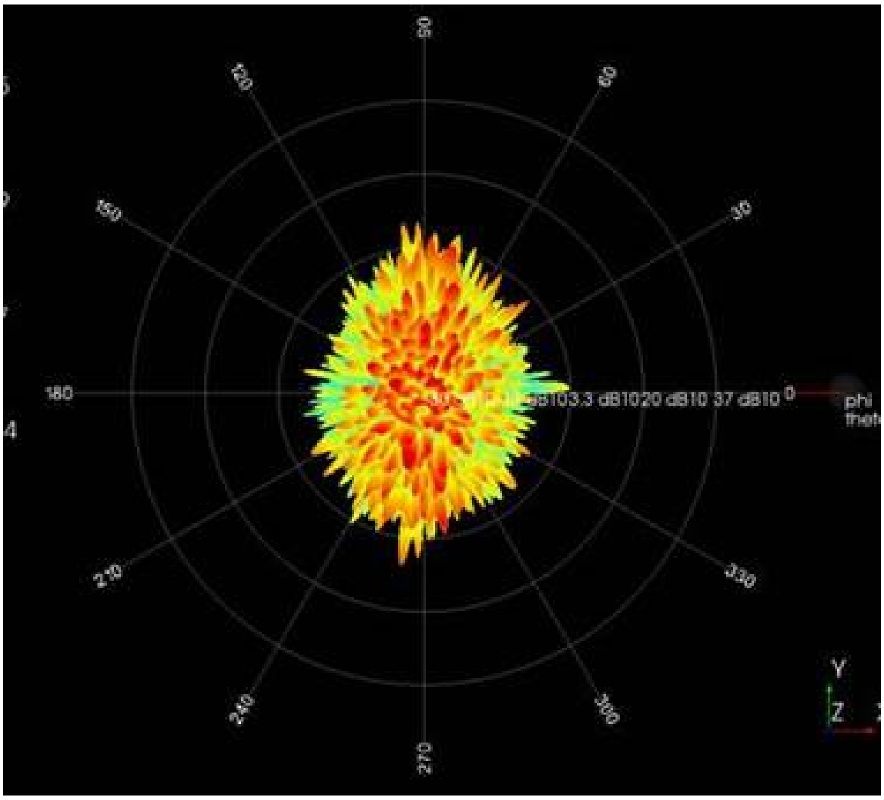


Figure 57: Typical radiation pattern for out of band noise

Note that this interference model is very conservative:

- Maximum possible e.i.r.p. at all times is unrealistic (even for a fully used satellite one would expect at least 1-1.5 dB less, on average);
- 100% utilisation for all satellites is not achievable, even for satellites over land;
- Many satellites will be inactive (over oceans and in dense inclination bands around 53° latitude).

Figure 58 and Figure 59 show a simulation over Effelsberg, for the RA antenna pointing to zenith. The epfd contributions of all the satellites above the horizon are summed and the average is calculated over 2000 sec. The average data loss is less than 2%. The peak loss occurs when the telescope is pointing towards the band of satellites at 53 - 53.2°. Note here that the other satellite shells also cause some data loss.

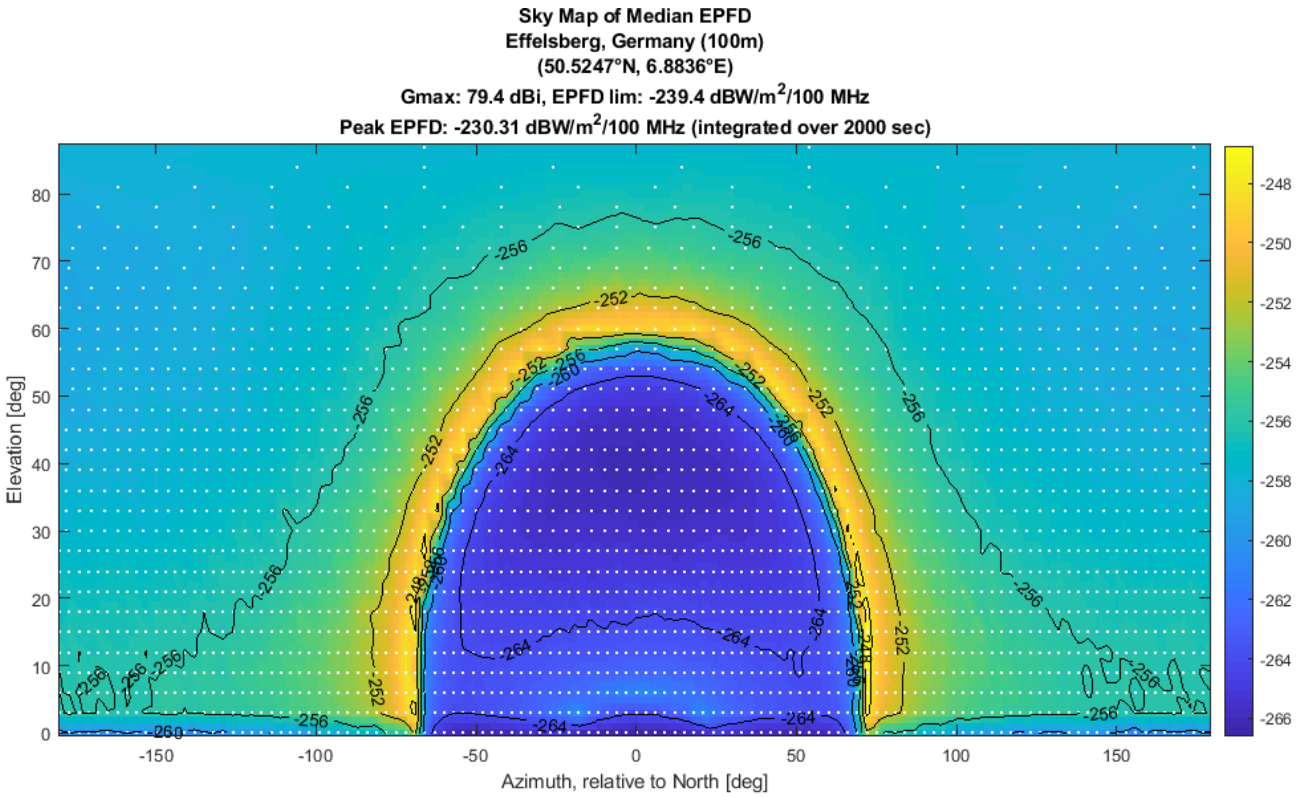


Figure 58: Effelsberg – Sky Map of Median epfd

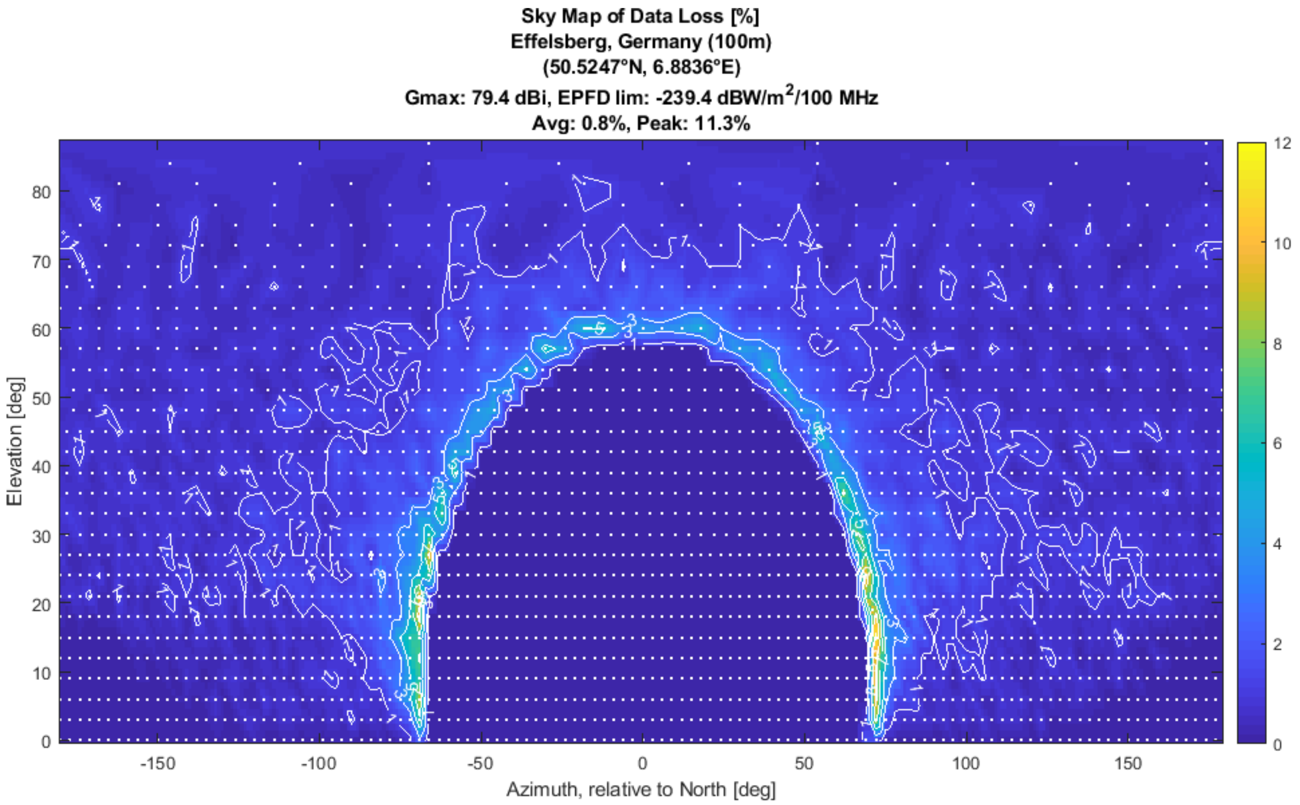


Figure 59: Effelsberg – Sky Map of Percent Data Loss

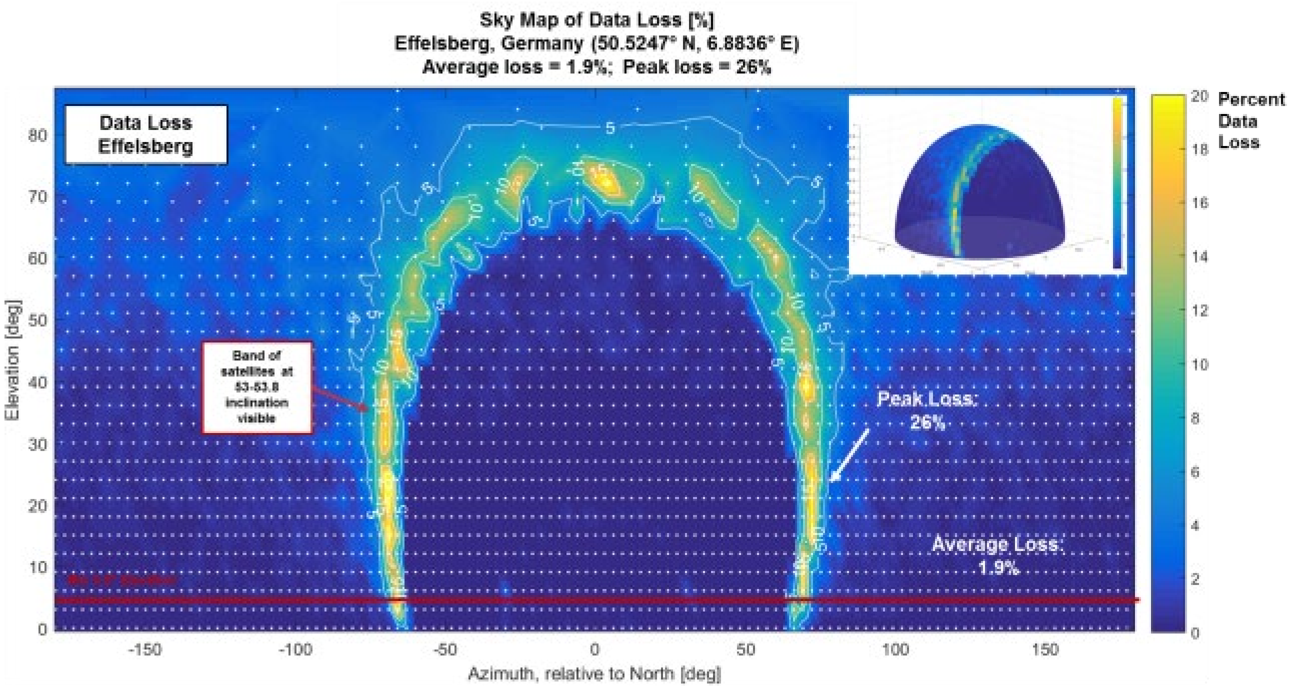


Figure 60: Effelsberg – Sky Map of Median epfd

Figure 61 shows the probability distribution for the average epfd samples; over 98% of these samples are below the -239.4 dBW/m²/(100 MHz) threshold.

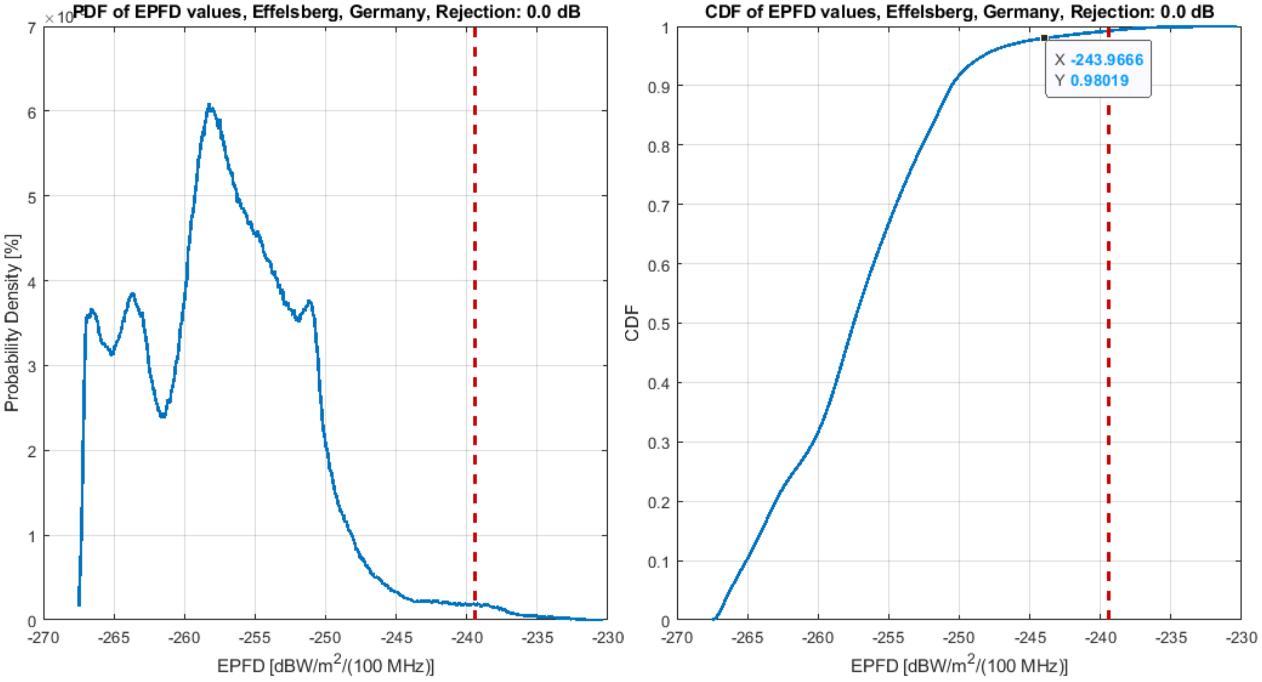


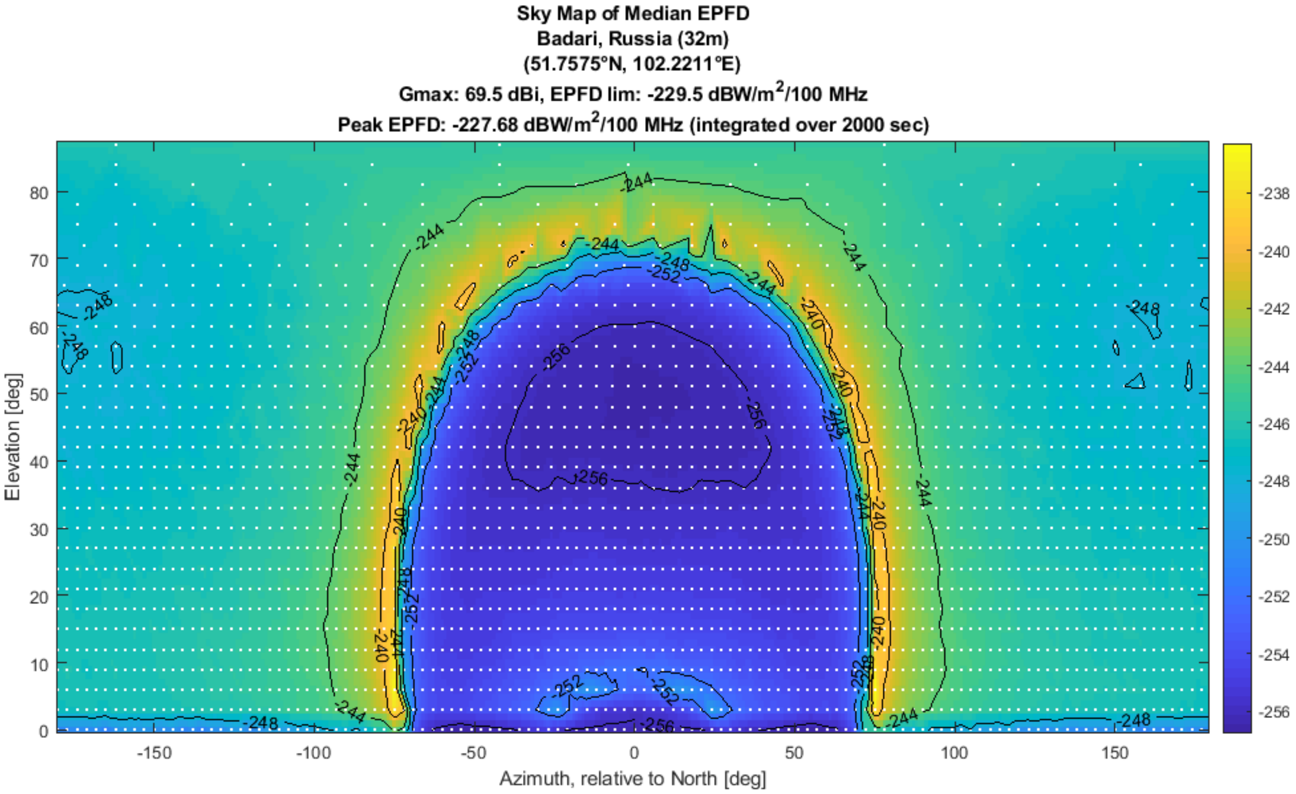
Figure 61: Effelsberg – Probability Distribution

The remaining figures in this section show the simulation results for:

- Badari, Russia
- Cambridge, UK
- Darnhall, UK
- Defford, UK
- Humain, Belgium
- Jodrell Bank, UK
- Kalyazin, Russia,
- Kayseri, Turkey
- Knockin, UK
- Medicina, Italy
- Noto, Italy
- Onsala, Sweden
- Pickmere, UK
- Puschino, Russia
- Zelenchukskaya, Russia

Given the orbits of the system considered, there are more satellites above those radio astronomy stations located at higher latitudes. For this reason a station is more interfered the higher its latitude. The stations studied in the report are considered, given their latitude, worst cases. Taking this into account, the following radio astronomy stations were not further studied.

- Santa Maria, Portugal
- Stockert, Germany
- Svetloe, Russia
- Wettzell, Germany
- Yebes, Spain



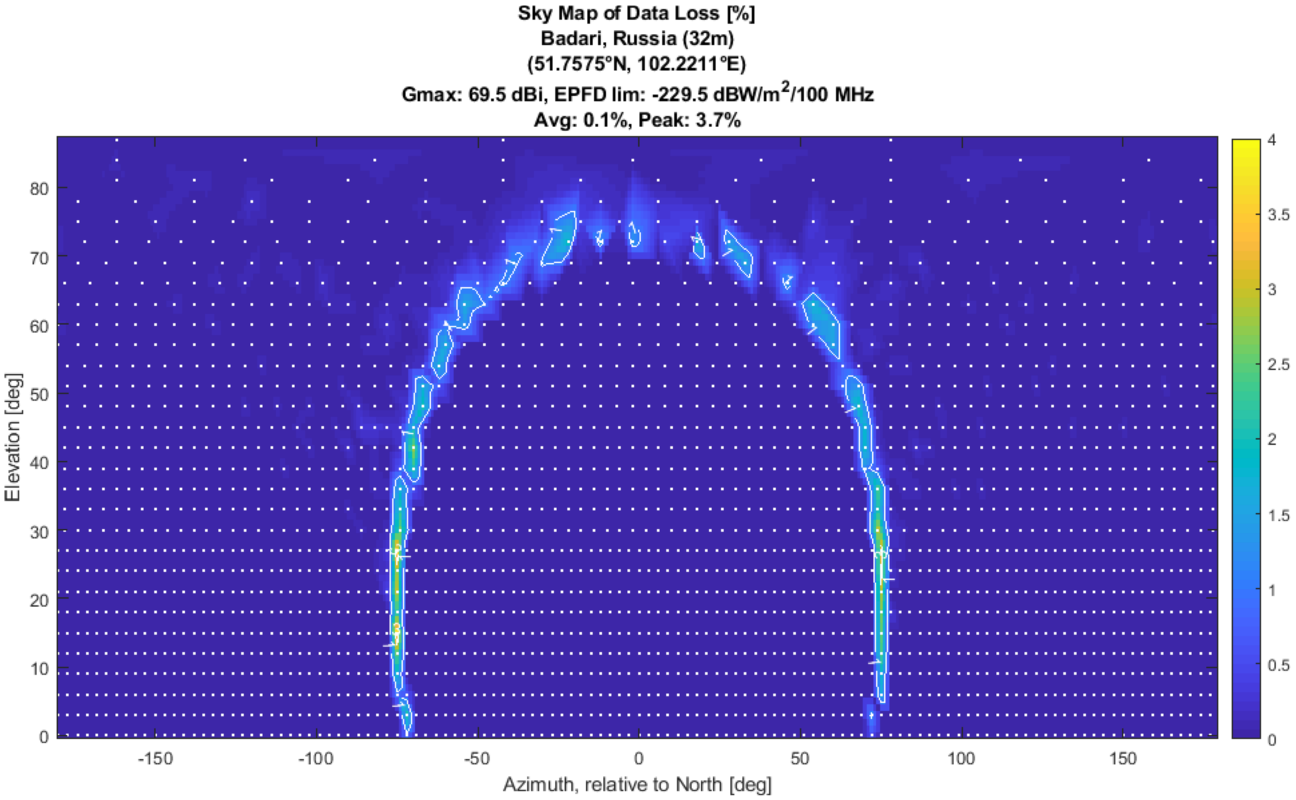


Figure 62: Badari, Russia – Sky Map of Median epfd and Percent Data Loss

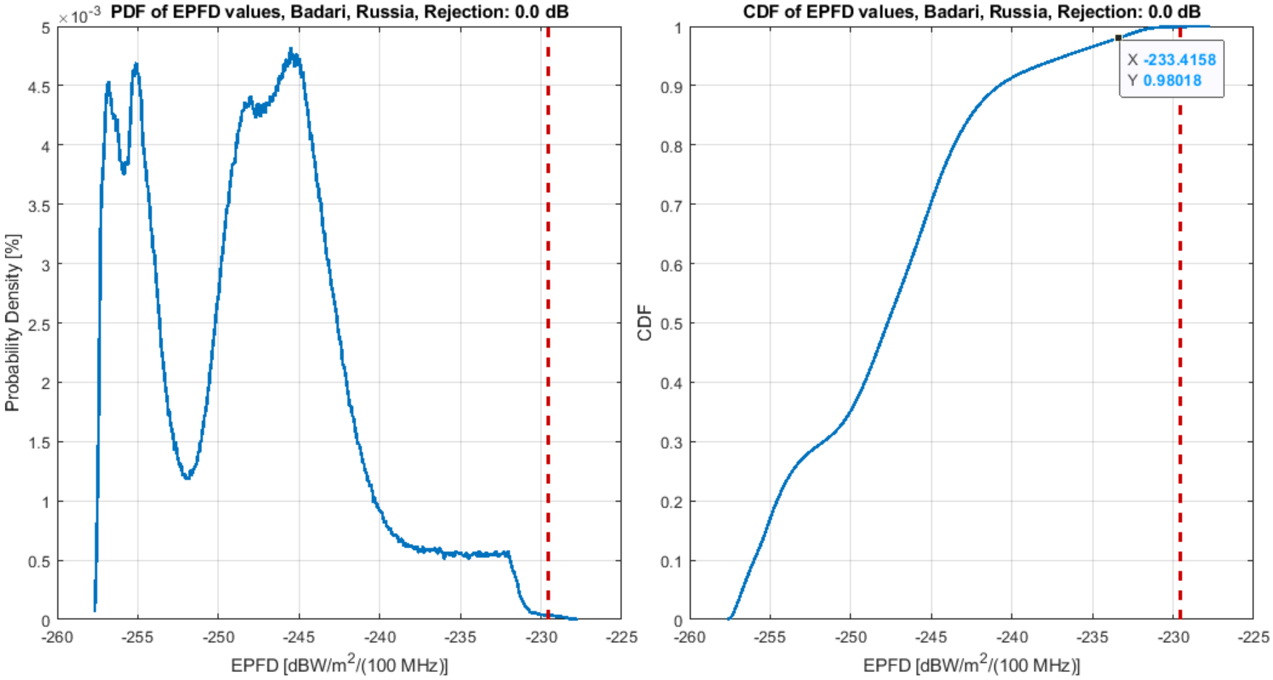


Figure 63: Badari, Russia – Probability Distribution

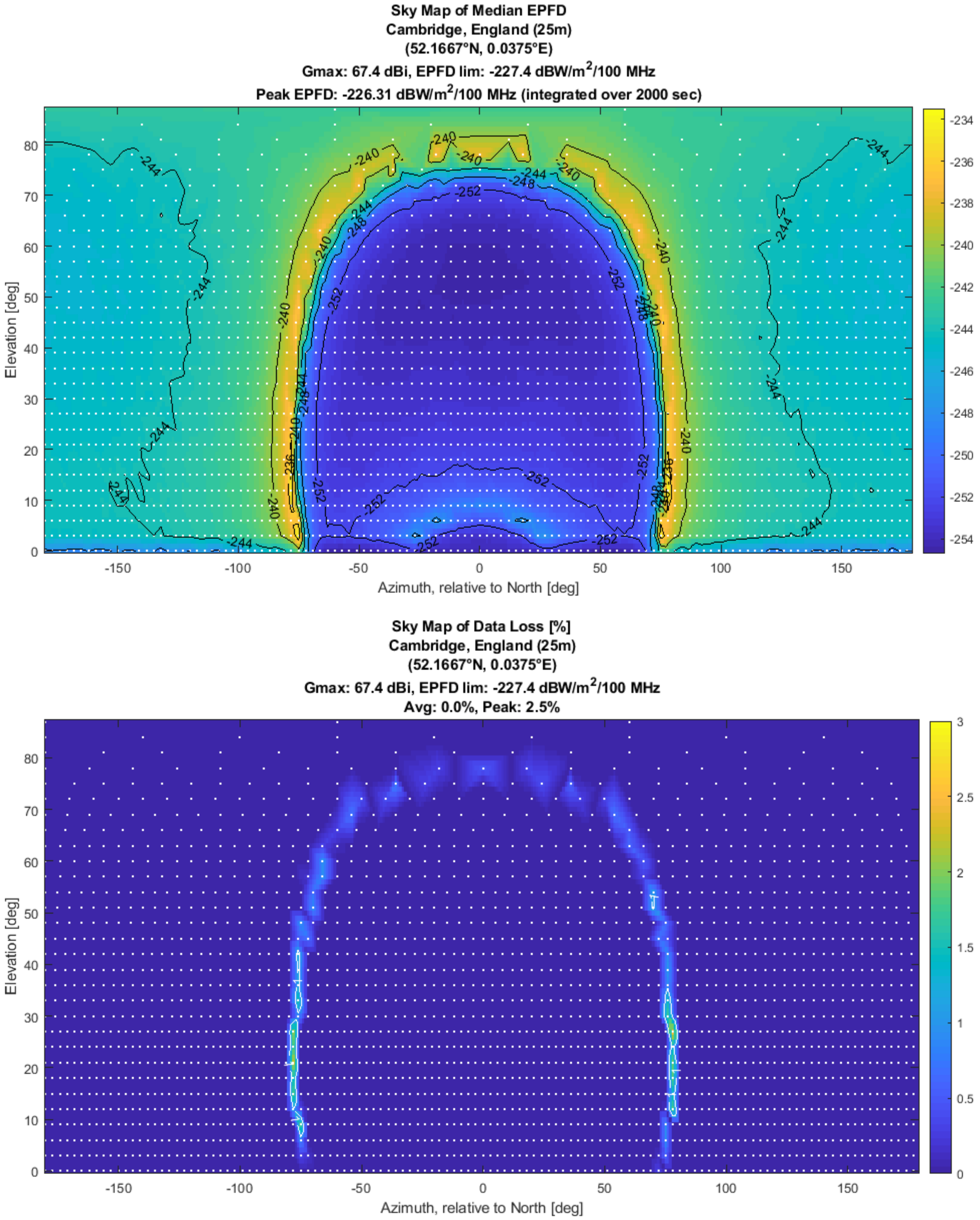


Figure 64: Cambridge, UK – Sky Map of Median epfd and Percent Data Loss

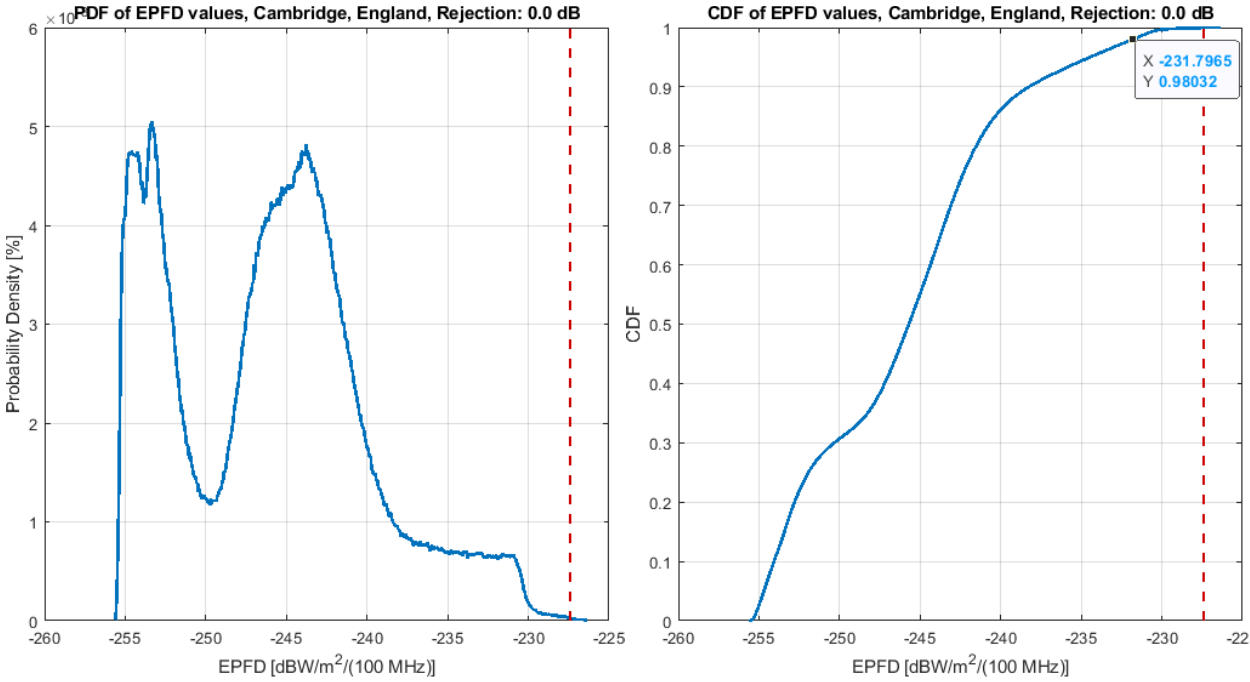
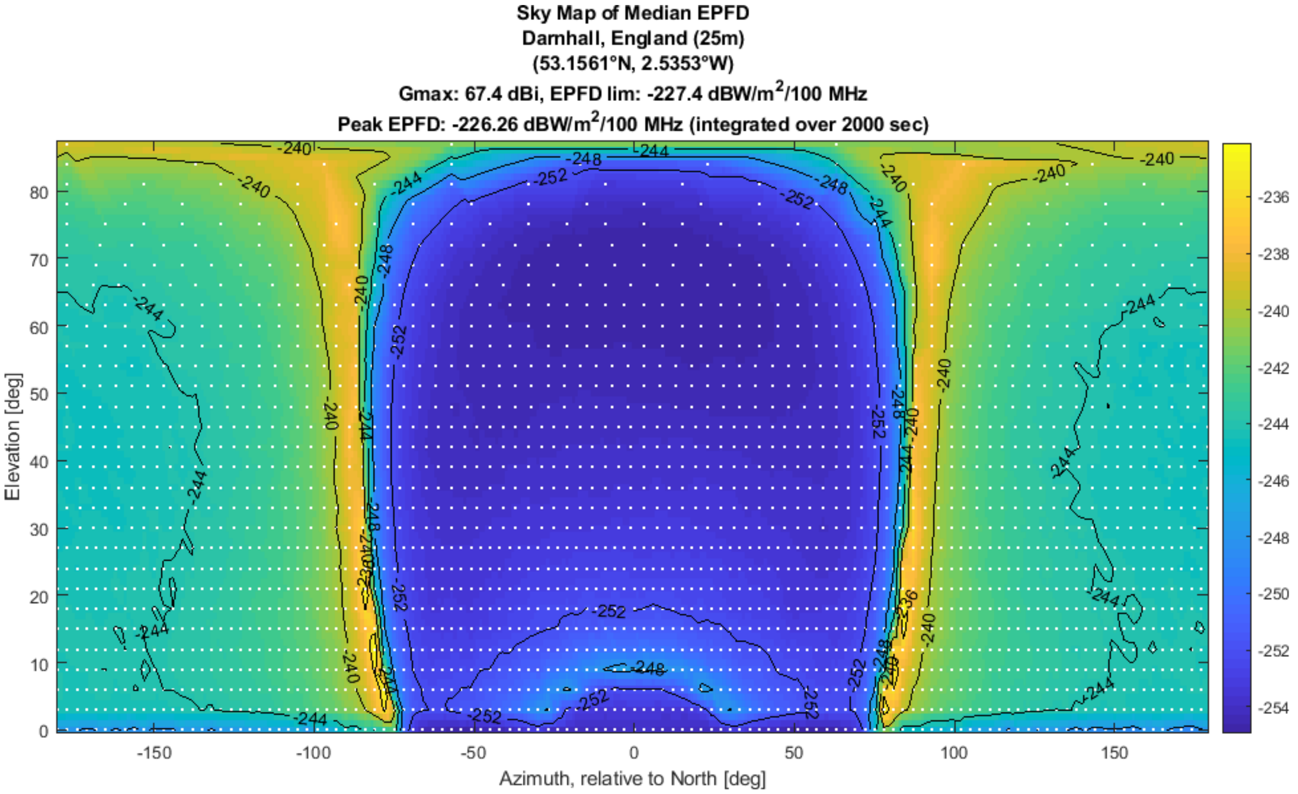


Figure 65: Cambridge, UK – Probability Distribution


Sky Map of Median EPFD
Darnhall, England (25m)
(53.1561°N, 2.5353°W)
Gmax: 67.4 dBi, EPFD lim: -227.4 dBW/m^2/100 MHz
Peak EPFD: -226.26 dBW/m^2/100 MHz (integrated over 2000 sec)

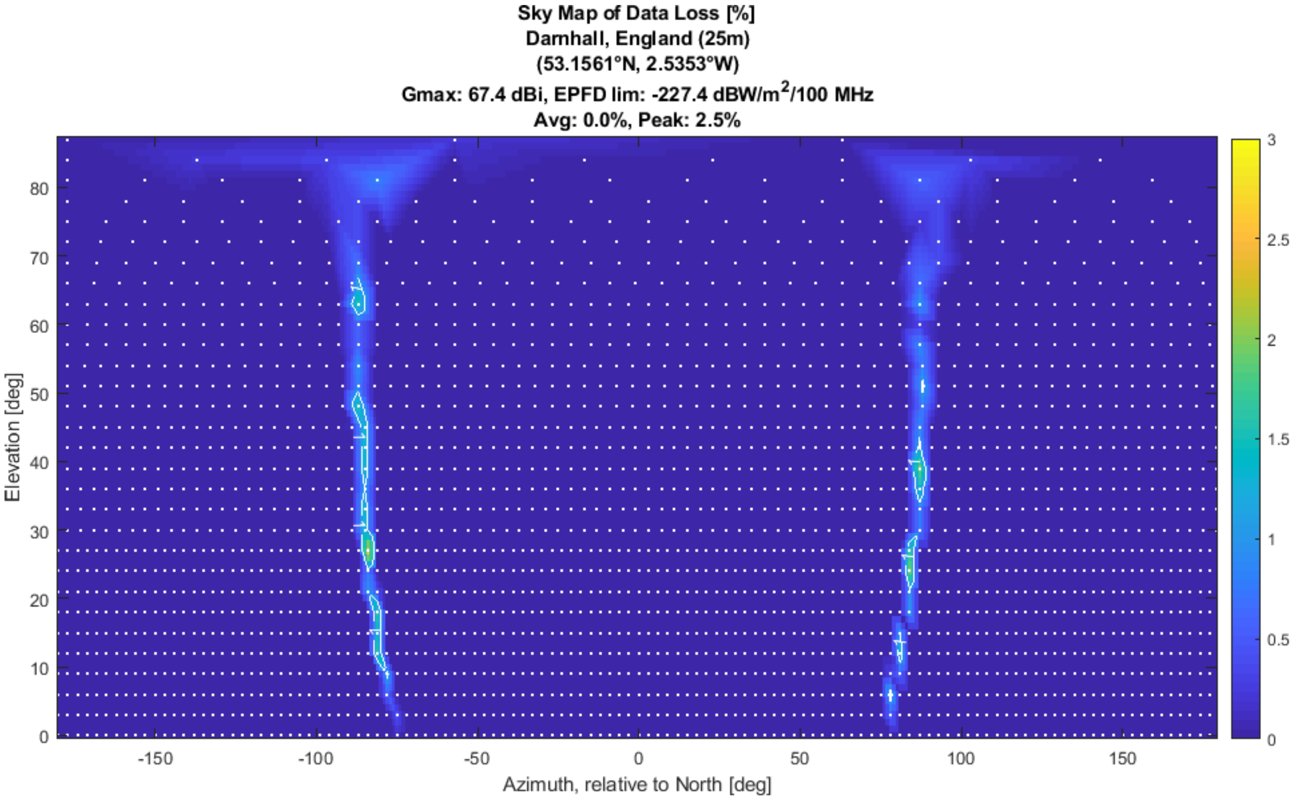

Sky Map of Data Loss [%]
Darnhall, England (25m)
(53.1561°N, 2.5353°W)
Gmax: 67.4 dBi, EPFD lim: -227.4 dBW/m^2/100 MHz
Avg: 0.0%, Peak: 2.5%

Figure 66: Darnhall, UK – Sky Map of Median epfd and Percent Data Loss

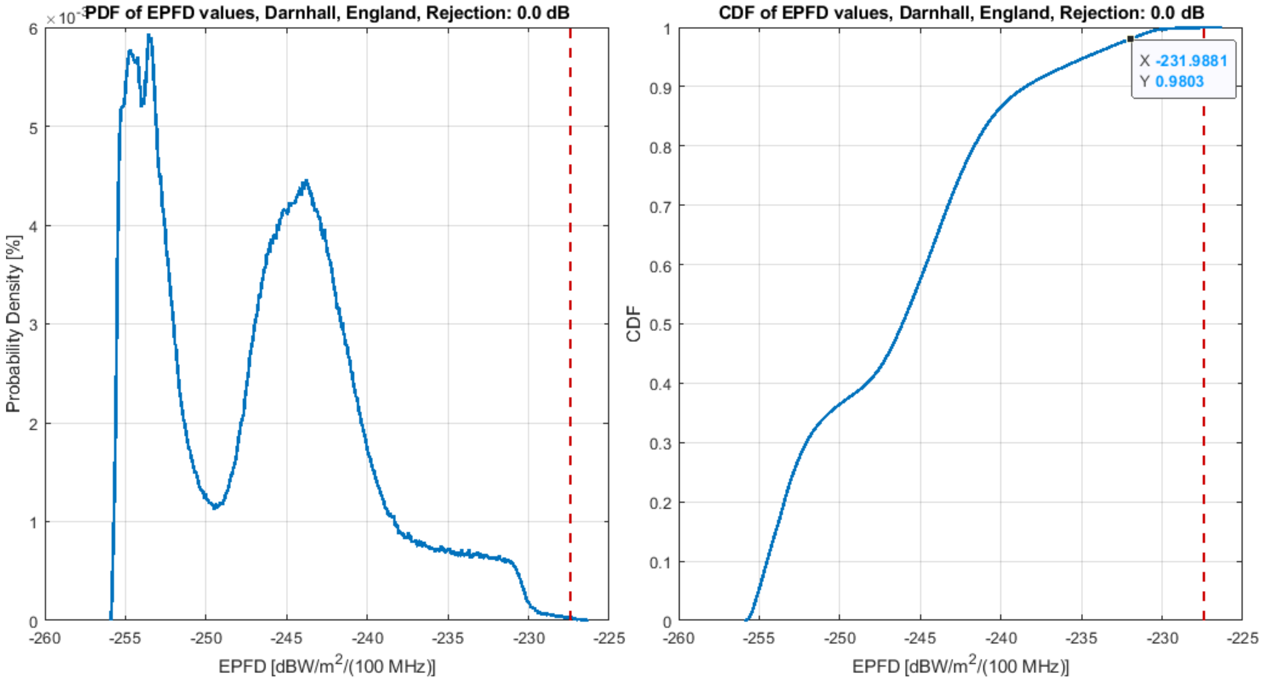
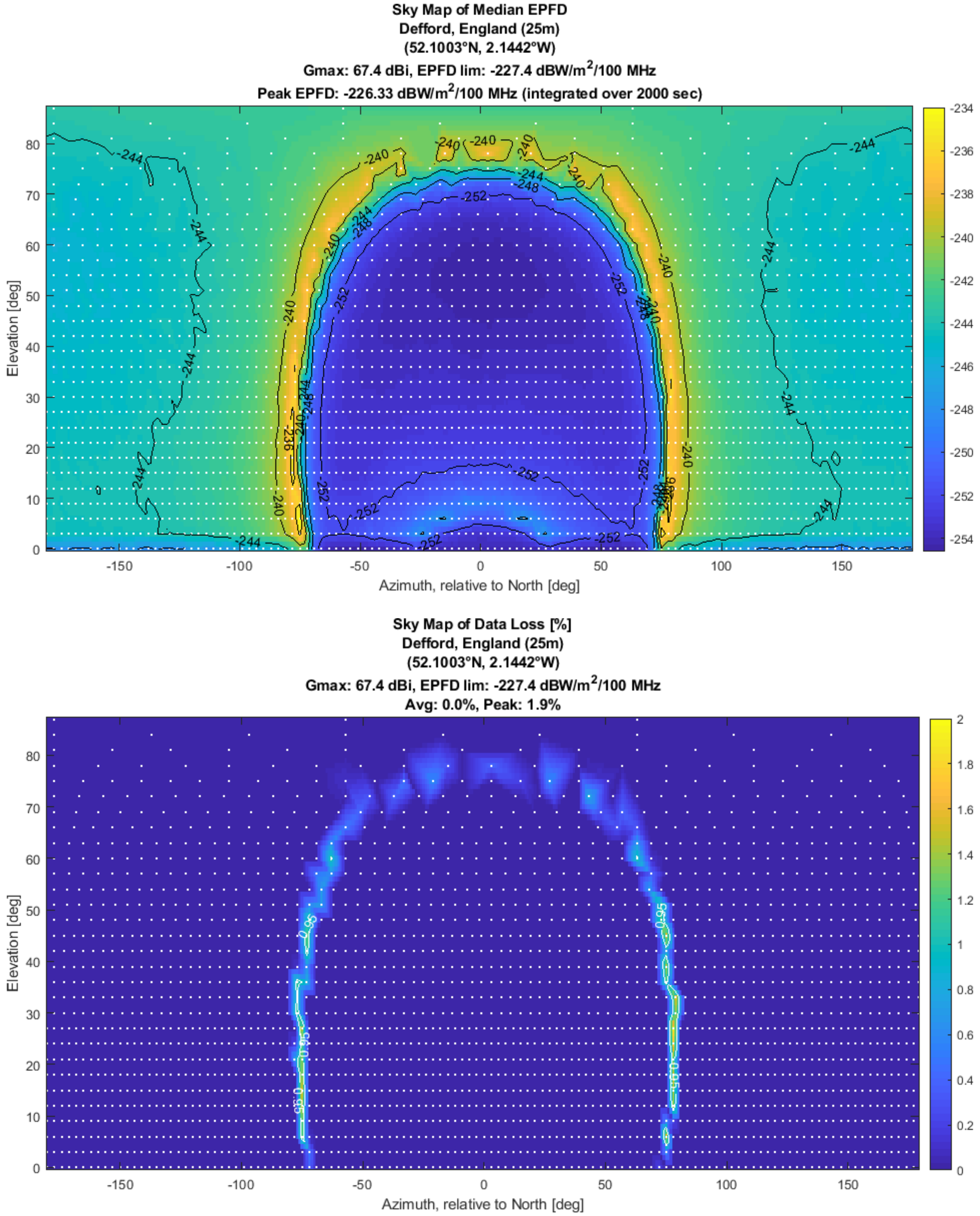


Figure 67: Darnhall, UK – Probability Distribution



Sky Map of Median EPFD
Defford, England (25m)
(52.1003°N, 2.1442°W)
Gmax: 67.4 dBi, EPFD lim: -227.4 dBW/m^2/100 MHz
Peak EPFD: -226.33 dBW/m^2/100 MHz (integrated over 2000 sec)

Sky Map of Data Loss [%]
Defford, England (25m)
(52.1003°N, 2.1442°W)
Gmax: 67.4 dBi, EPFD lim: -227.4 dBW/m^2/100 MHz
Avg: 0.0%, Peak: 1.9%

Figure 68: Defford, UK – Sky Map of Median epfd and Percent Data Loss

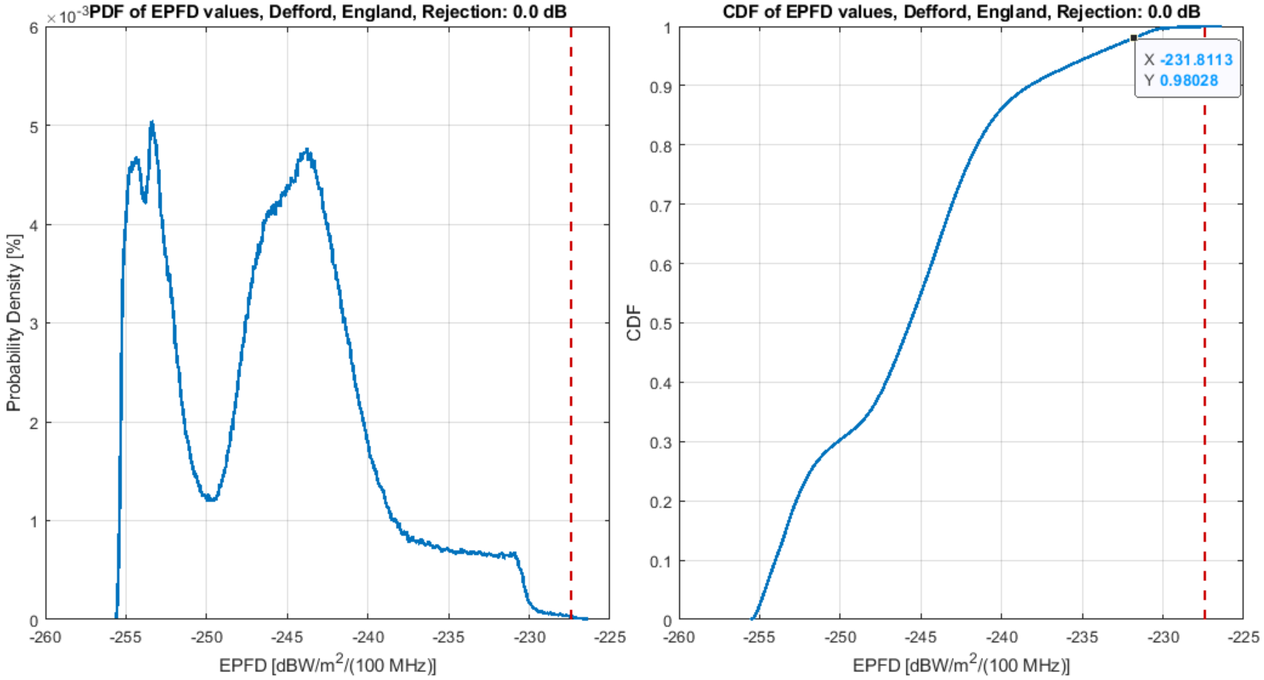


Figure 69: Defford, UK – Probability Distribution

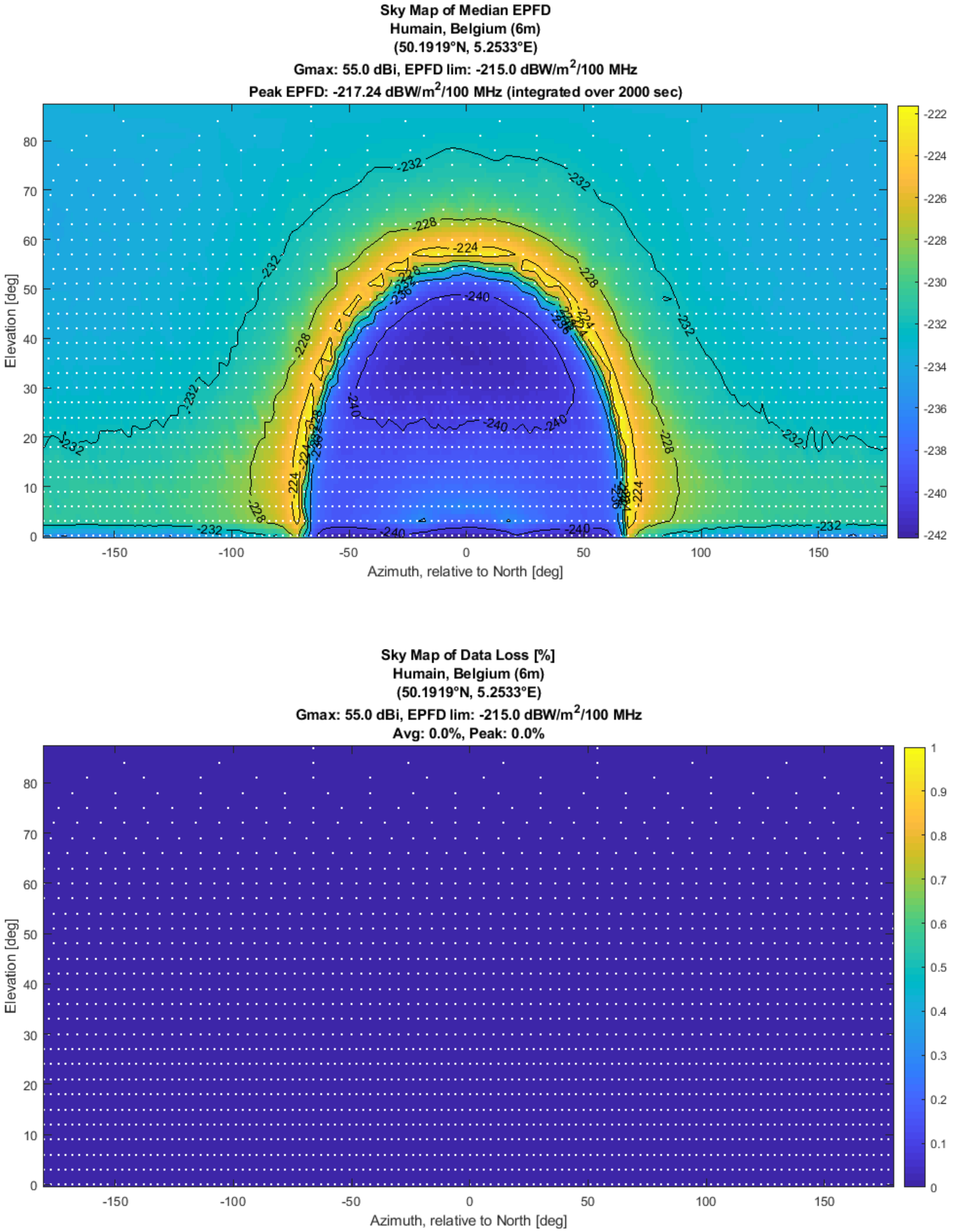


Figure 70: Humain, Belgium – Sky Map of Median epfd and Percent Data Loss

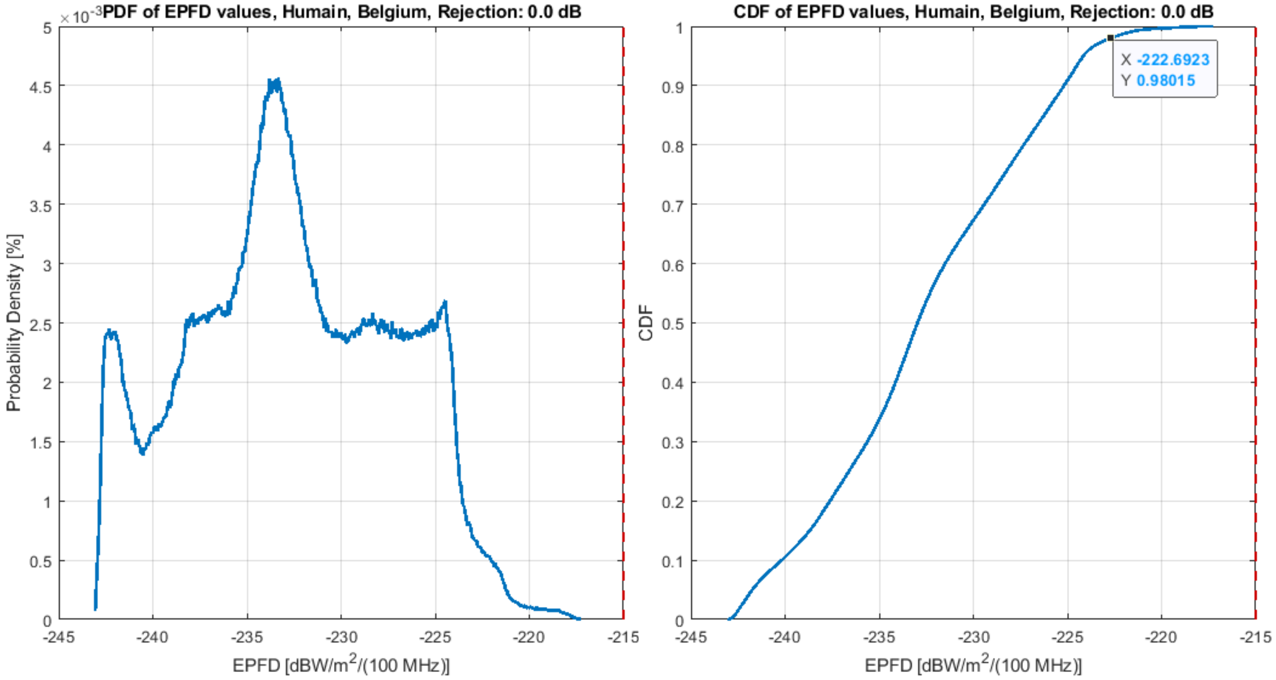
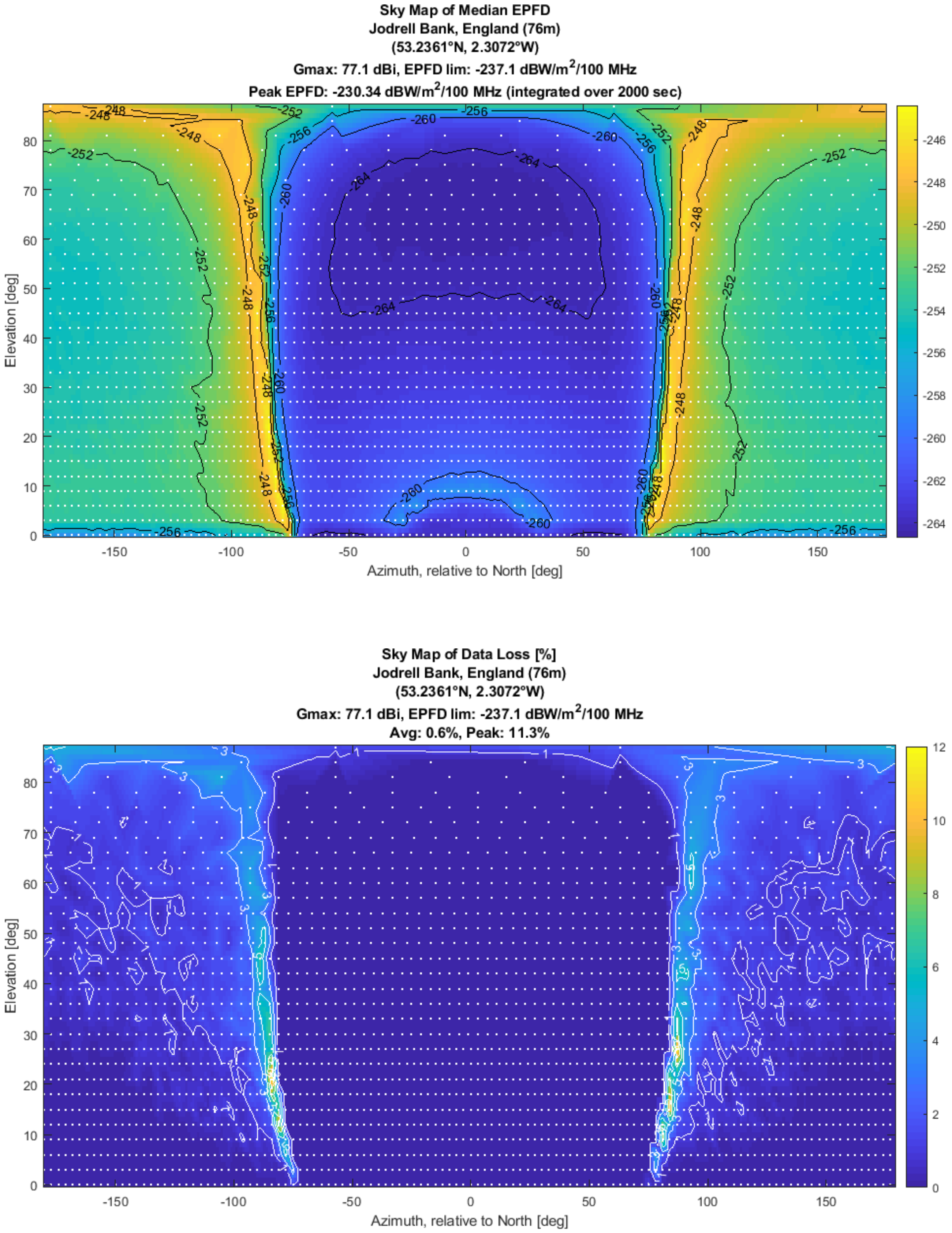


Figure 71: Humain, Belgium – Probability Distribution



Sky Map of Median EPFD
Jodrell Bank, England (76m)
(53.2361°N, 2.3072°W)
Gmax: 77.1 dBi, EPFD lim: -237.1 dBW/m^2/100 MHz
Peak EPFD: -230.34 dBW/m^2/100 MHz (integrated over 2000 sec)

Sky Map of Data Loss [%]
Jodrell Bank, England (76m)
(53.2361°N, 2.3072°W)
Gmax: 77.1 dBi, EPFD lim: -237.1 dBW/m^2/100 MHz
Avg: 0.6%, Peak: 11.3%

Figure 72: Jodrell Bank, UK – Sky Map of Median epfd and Percent Data Loss

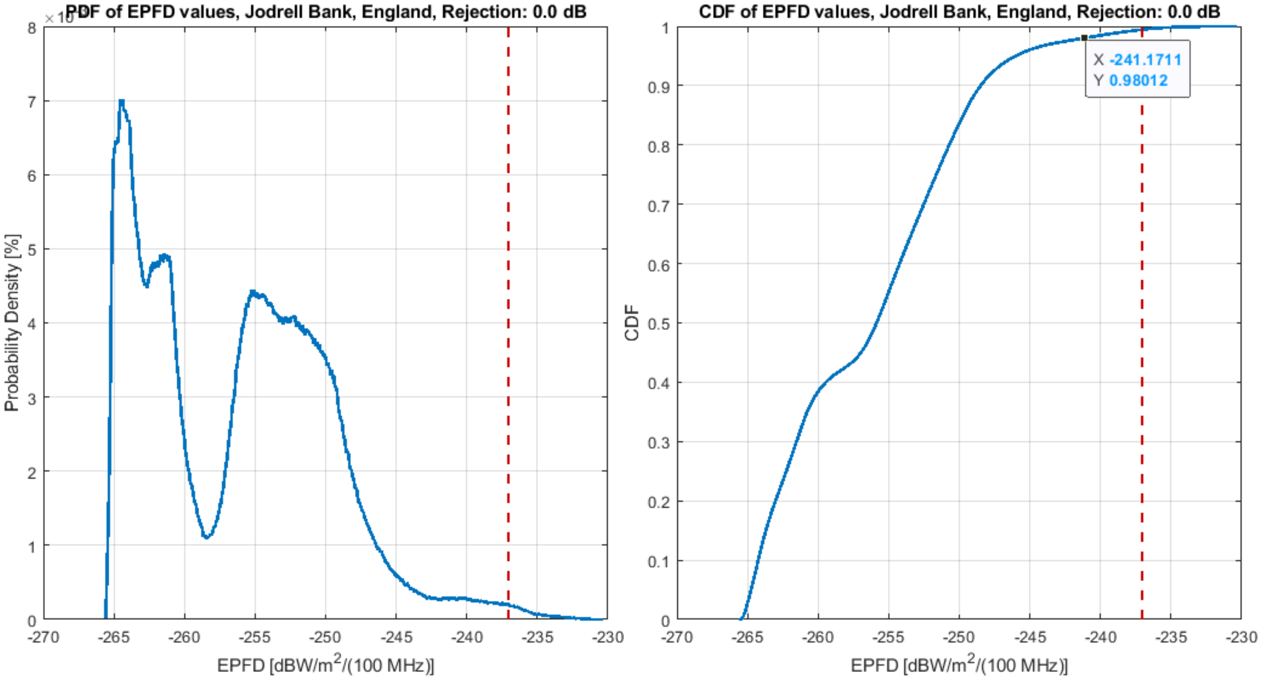
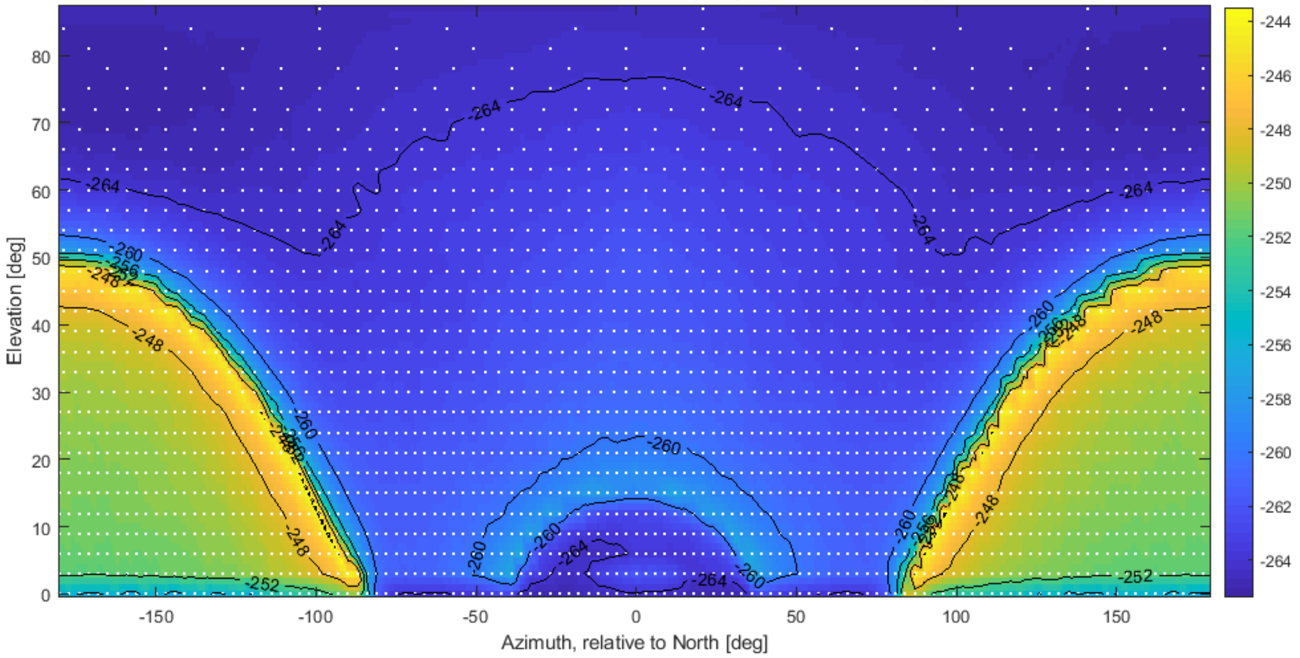
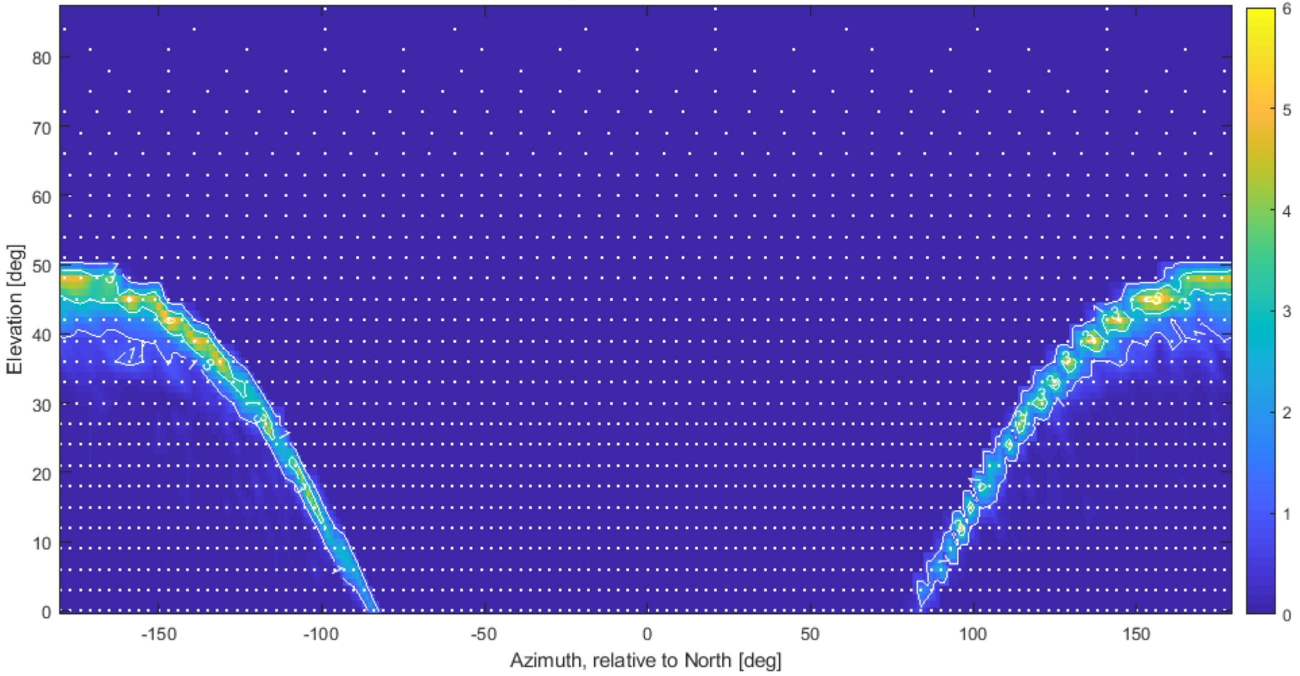


Figure 73: Jodrell Bank, UK – Probability Distribution



Sky Map of Median EPFD
Kalyazin, Russia (64m)
(57.2228°N, 37.9003°E)
Gmax: 75.6 dBi, EPFD lim: -235.6 dBW/m^2/100 MHz
Peak EPFD: -230.90 dBW/m^2/100 MHz (integrated over 2000 sec)



Sky Map of Data Loss [%]
Kalyazin, Russia (64m)
(57.2228°N, 37.9003°E)
Gmax: 75.6 dBi, EPFD lim: -235.6 dBW/m^2/100 MHz
Avg: 0.2%, Peak: 5.8%

Figure 74: Kalyazin, Russia – Sky Map of Median epfd and Percent Data Loss

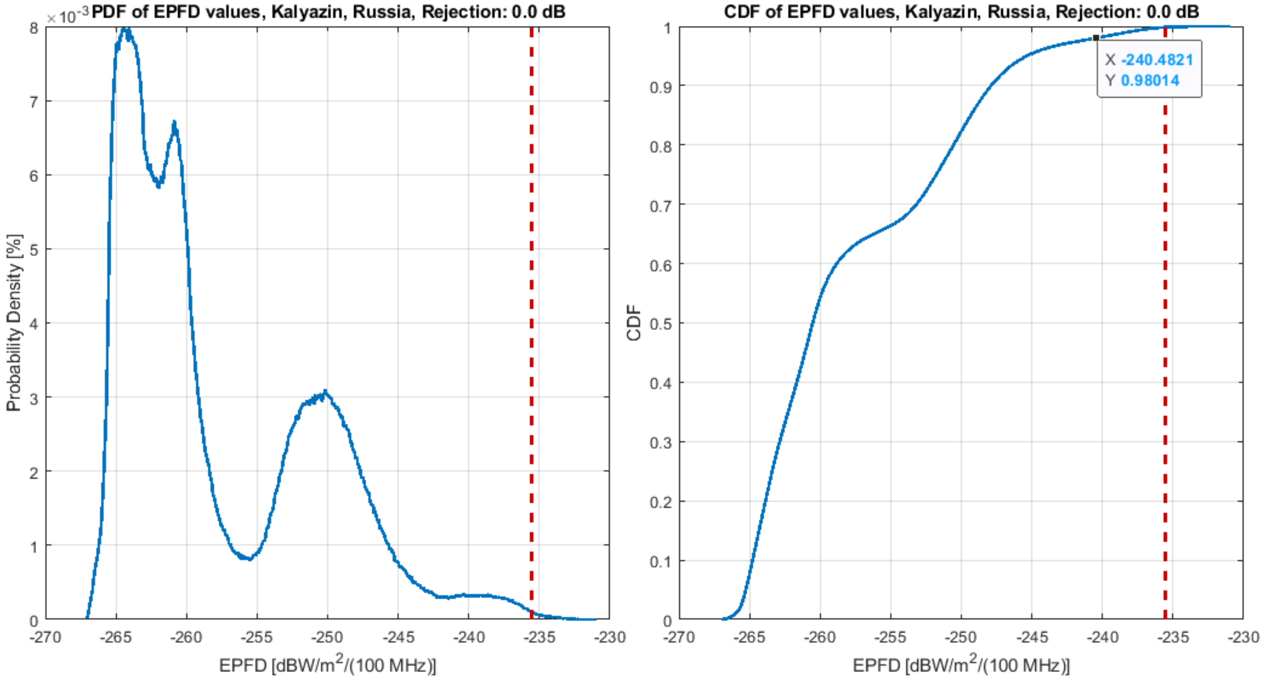


Figure 75: Kalyazin, Russia – Probability Distribution

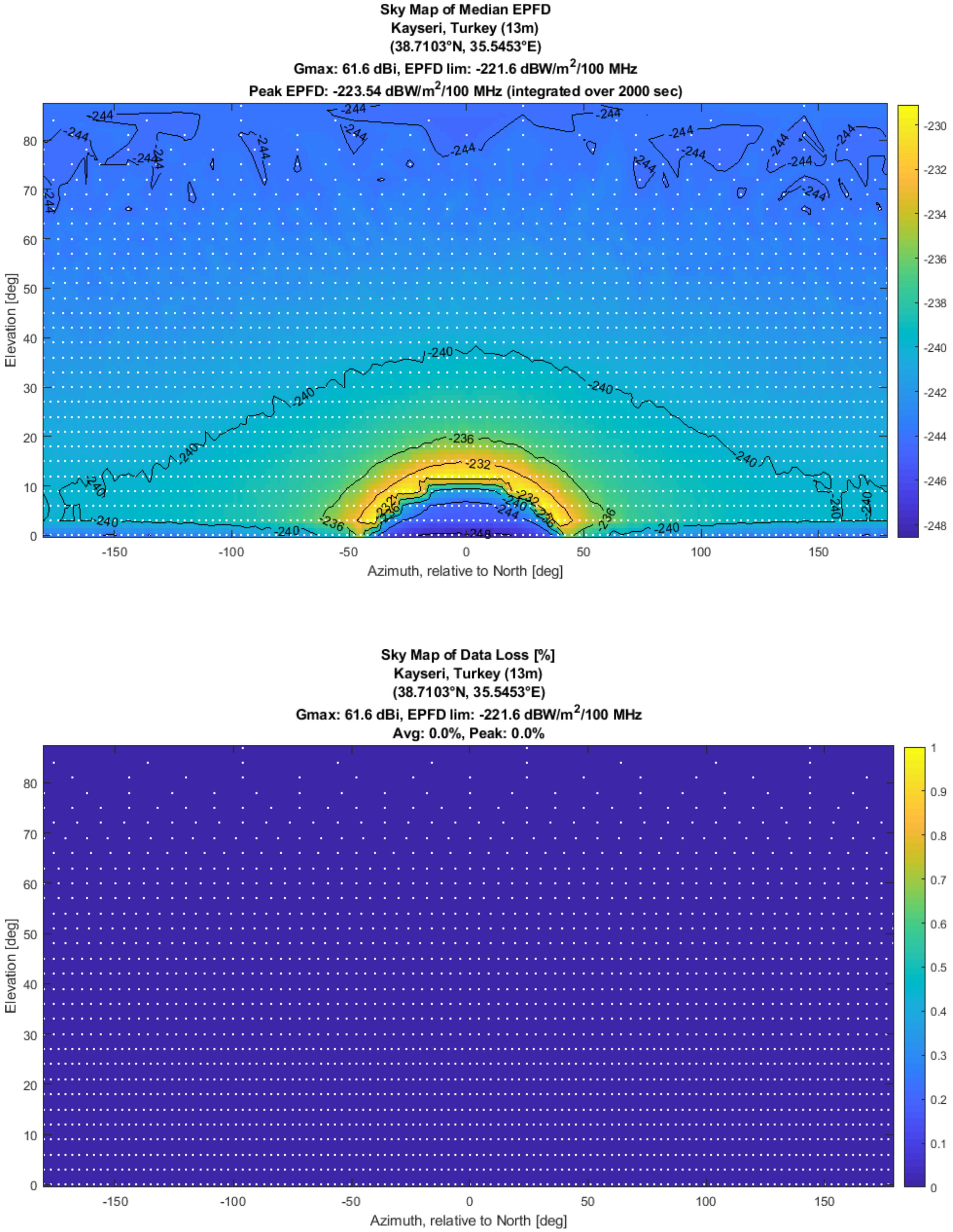


Figure 76: Kayseri, Turkey – Sky Map of Median epfd and Percent Data Loss

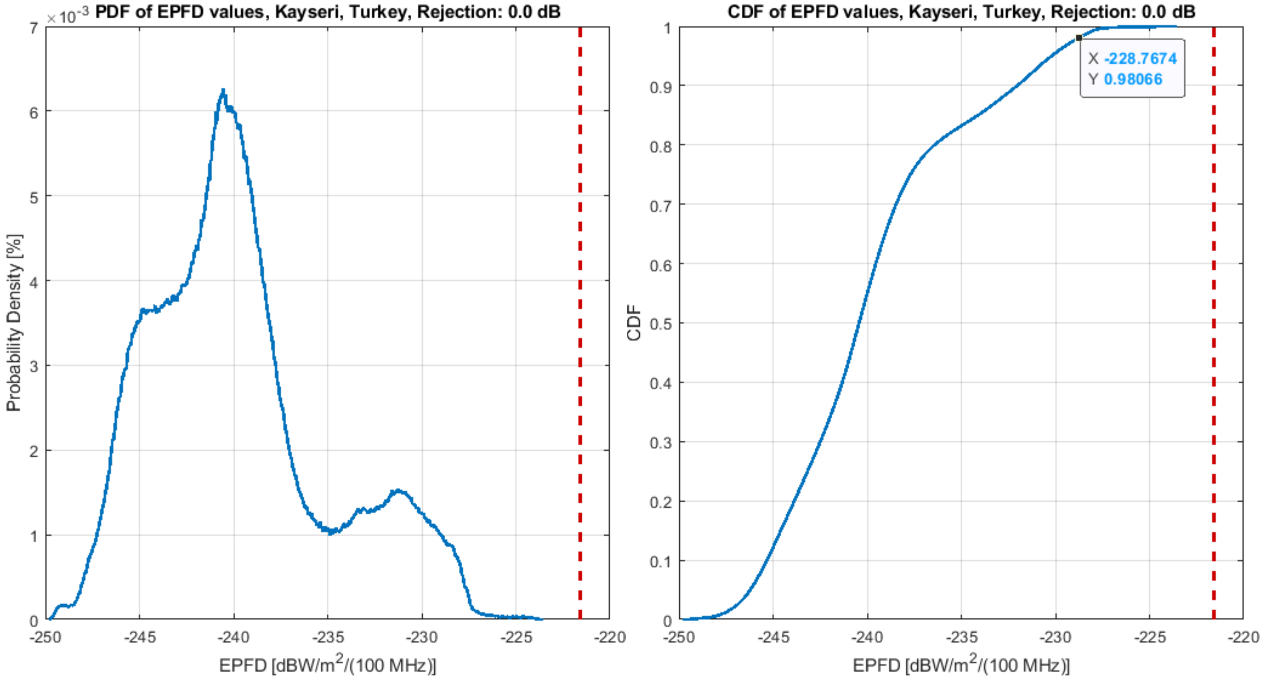
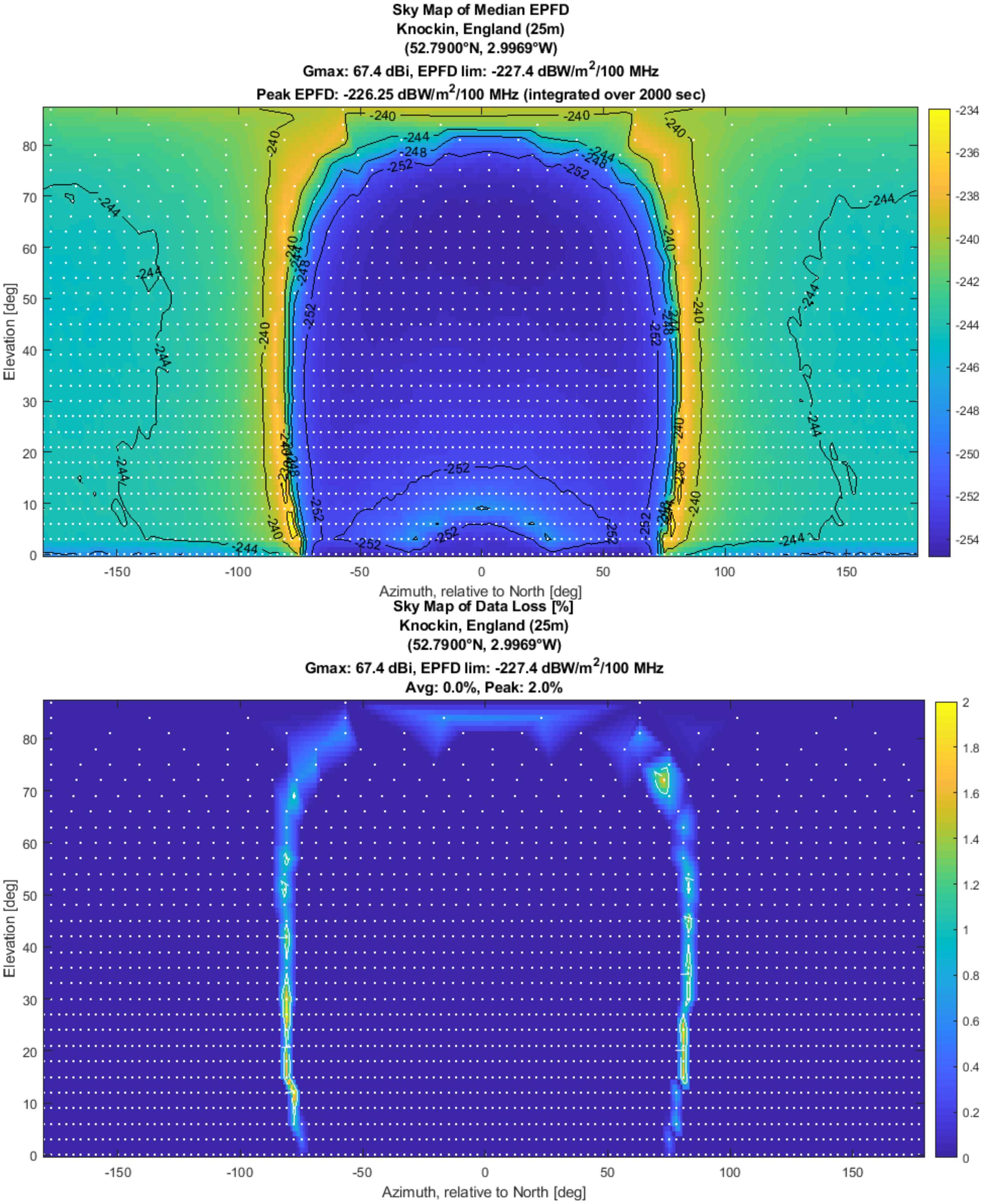


Figure 77: Kayseri, Turkey – Probability Distribution



Sky Map of Median EPFD
Knockin, England (25m)
(52.7900°N, 2.9969°W)
Gmax: 67.4 dBi, EPFD lim: -227.4 dBW/m^2/100 MHz
Peak EPFD: -226.25 dBW/m^2/100 MHz (integrated over 2000 sec)

Sky Map of Data Loss [%]
Knockin, England (25m)
(52.7900°N, 2.9969°W)
Gmax: 67.4 dBi, EPFD lim: -227.4 dBW/m^2/100 MHz
Avg: 0.0%, Peak: 2.0%

Figure 78: Knockin, UK – Sky Map of Median epfd and Percent Data Loss

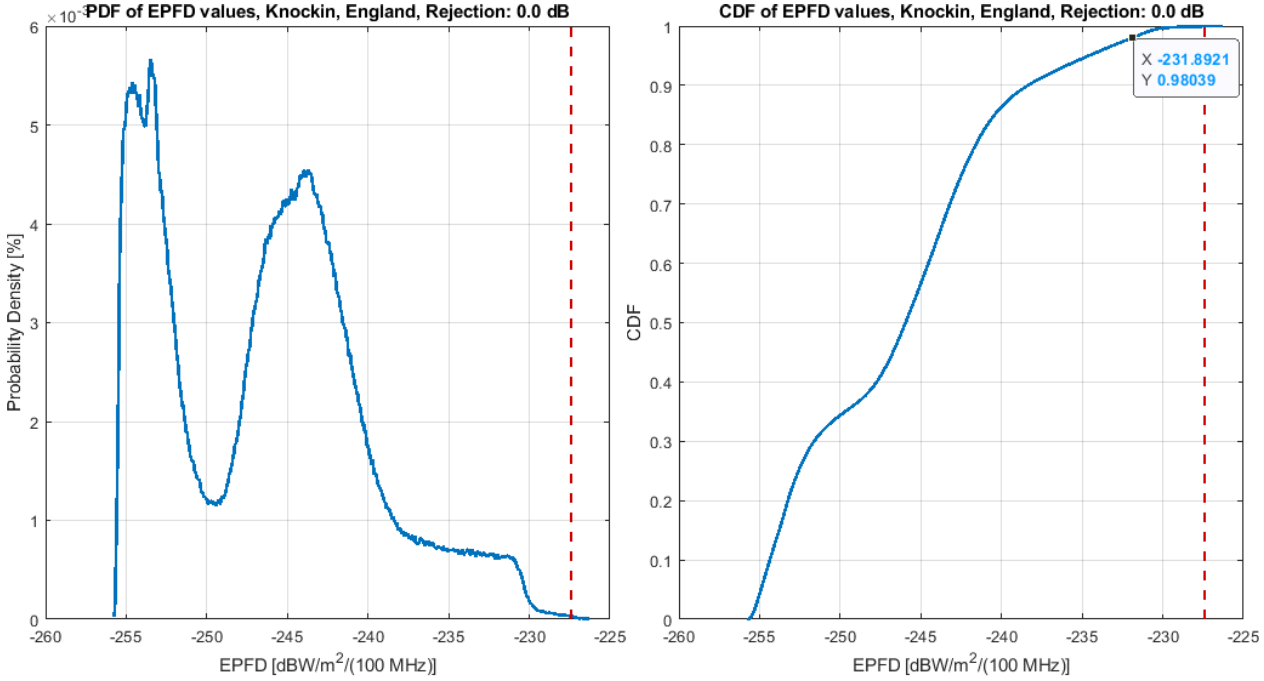
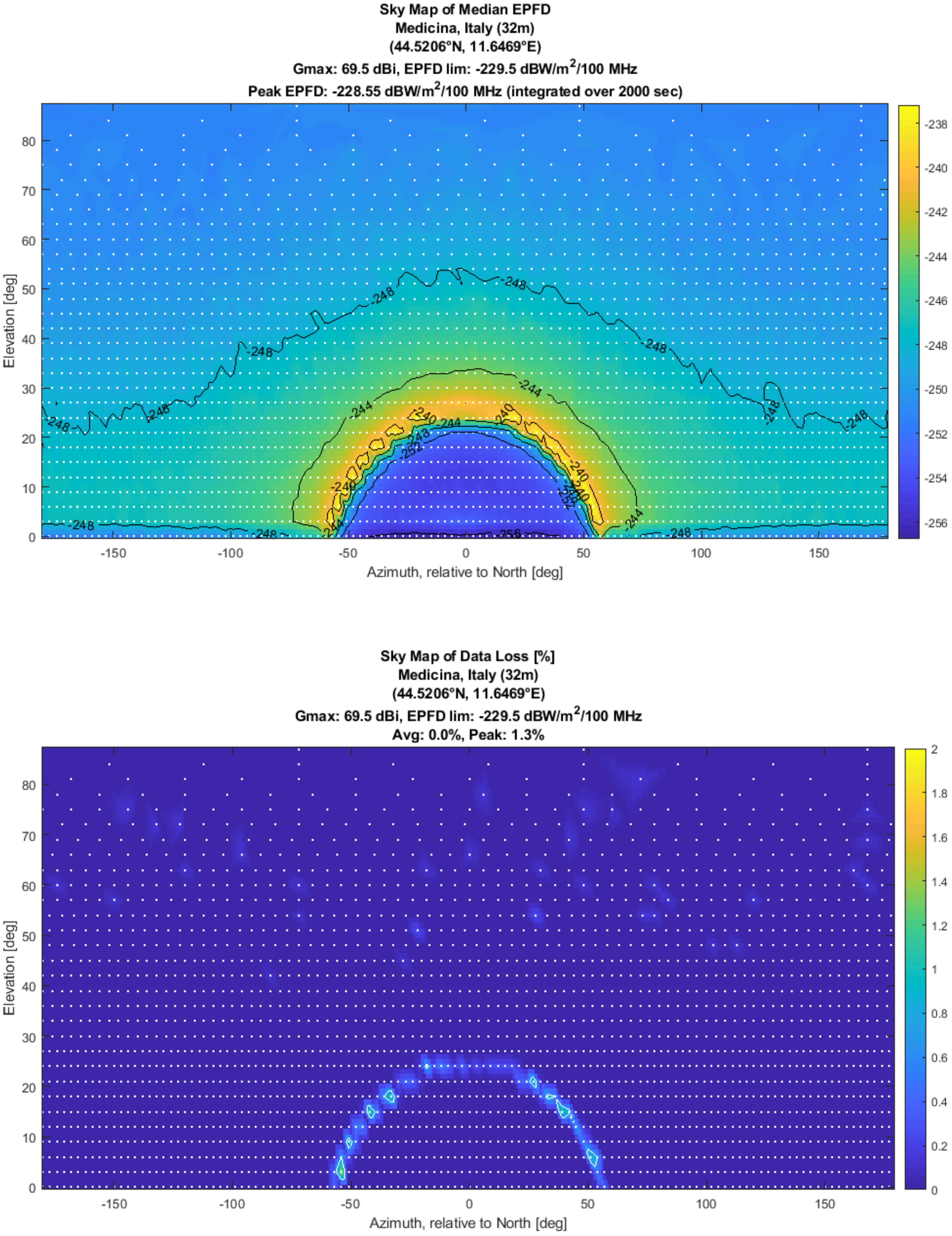


Figure 79: Knockin, UK – Probability Distribution



Sky Map of Median EPFD
Medicina, Italy (32m)
(44.5206°N, 11.6469°E)
Gmax: 69.5 dBi, EPFD lim: -229.5 dBW/m^2/100 MHz
Peak EPFD: -228.55 dBW/m^2/100 MHz (integrated over 2000 sec)

Sky Map of Data Loss [%]
Medicina, Italy (32m)
(44.5206°N, 11.6469°E)
Gmax: 69.5 dBi, EPFD lim: -229.5 dBW/m^2/100 MHz
Avg: 0.0%, Peak: 1.3%

Figure 80: Medicina, Italy – Sky Map of Median epfd and Percent Data Loss

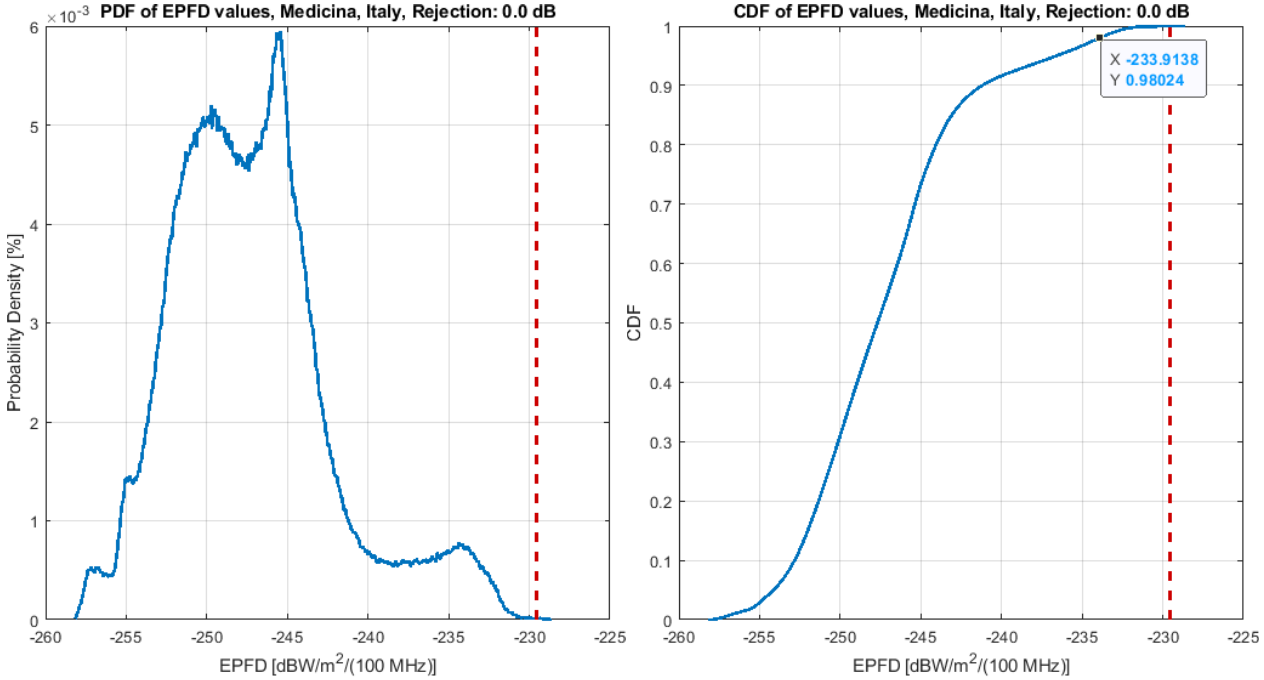
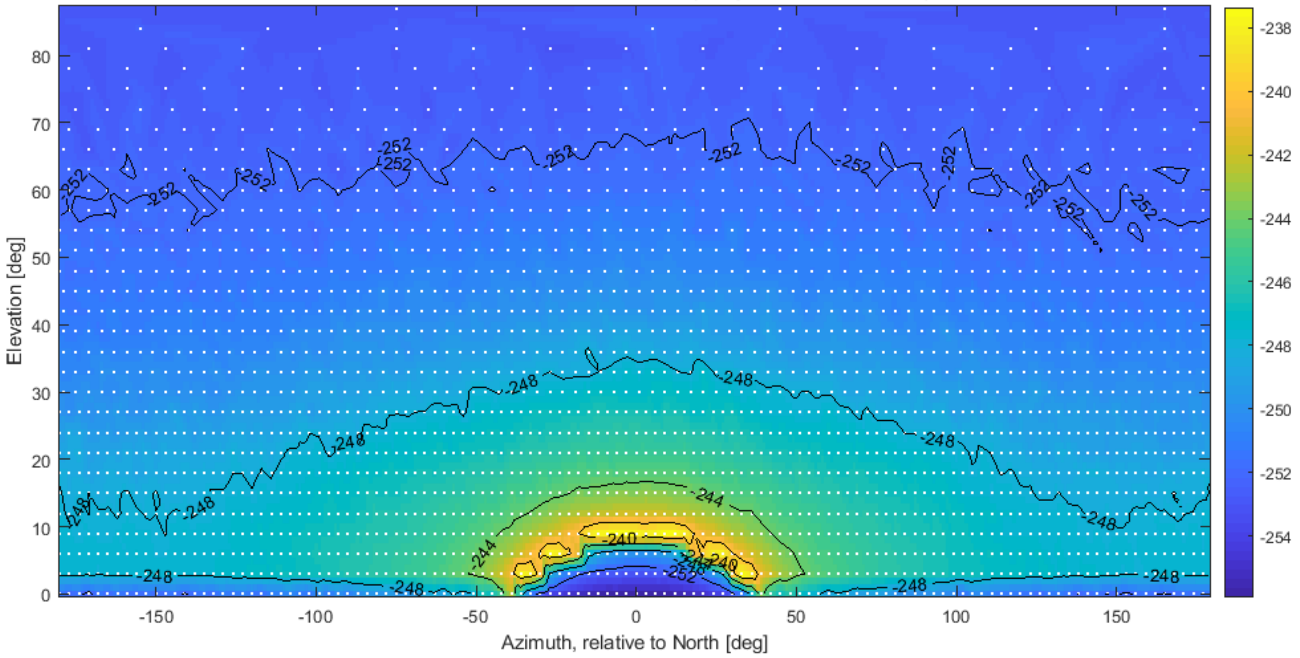
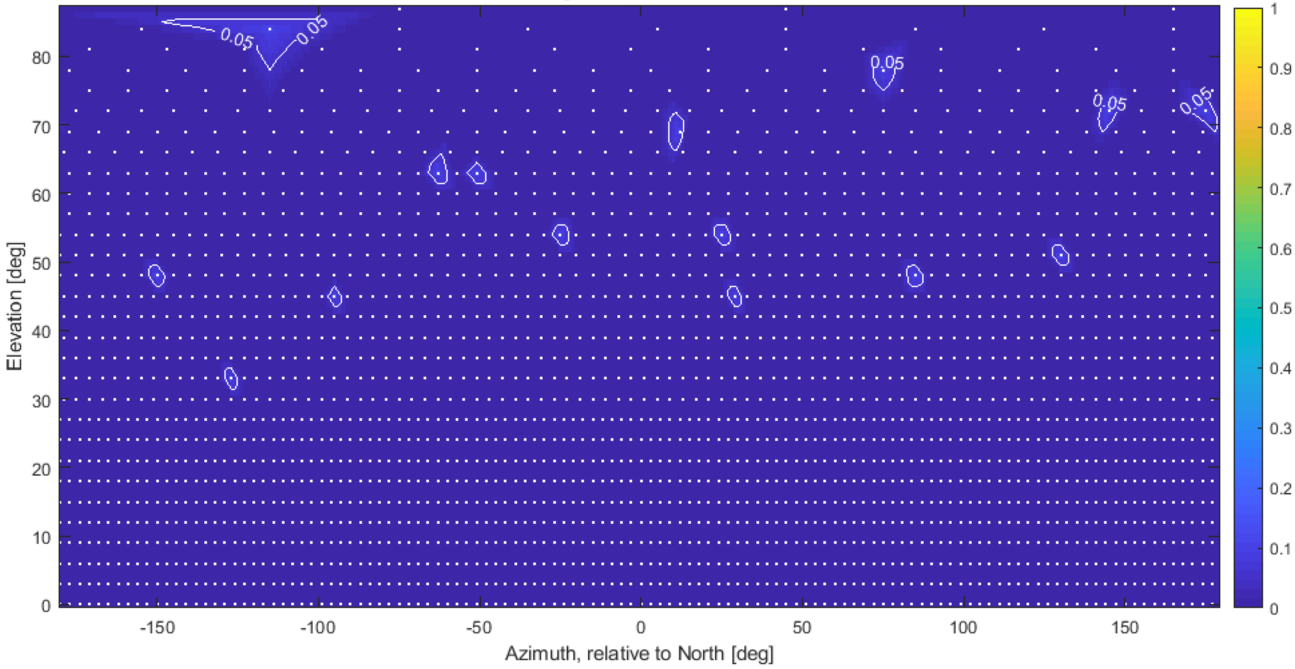


Figure 81: Medicina, Italy – Probability Distribution



Sky Map of Median EPFD
Noto, Italy (32m)
(36.8758°N, 14.9889°E)
Gmax: 69.5 dBi, EPFD lim: -229.5 dBW/m^2/100 MHz
Peak EPFD: -228.79 dBW/m^2/100 MHz (integrated over 2000 sec)



Sky Map of Data Loss [%]
Noto, Italy (32m)
(36.8758°N, 14.9889°E)
Gmax: 69.5 dBi, EPFD lim: -229.5 dBW/m^2/100 MHz
Avg: 0.0%, Peak: 0.1%

Figure 82: Noto, Italy – Sky Map of Median epfd and Percent Data Loss

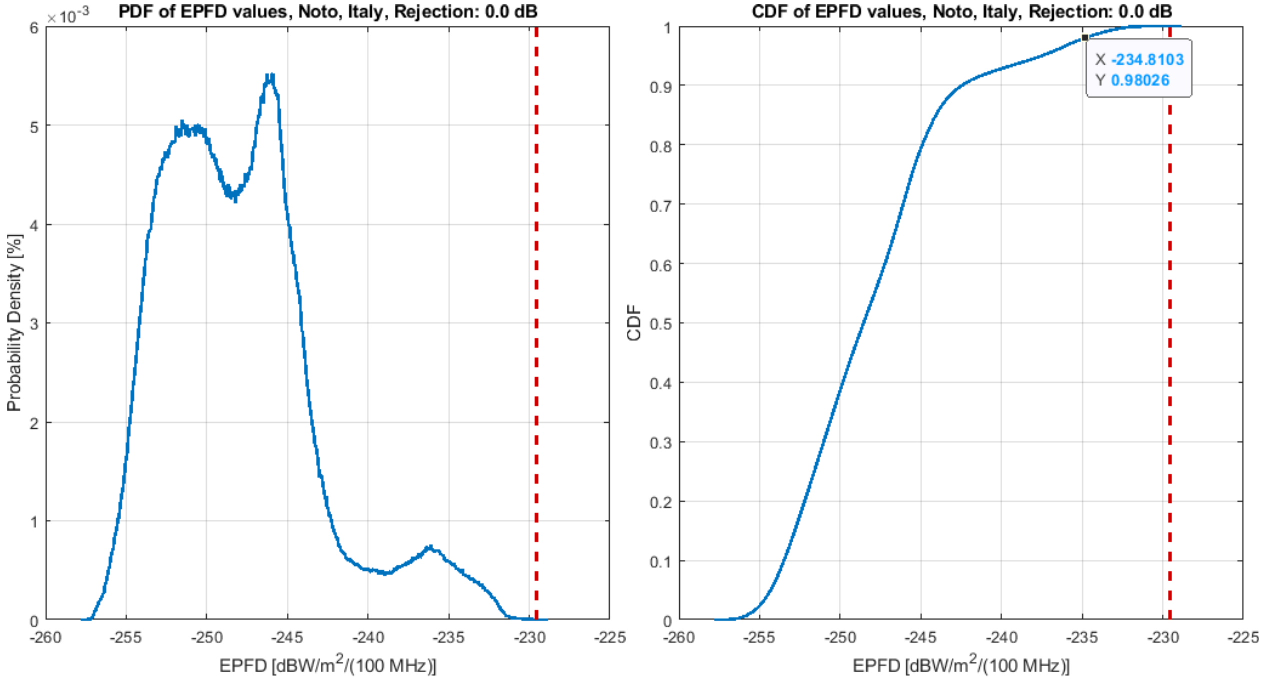
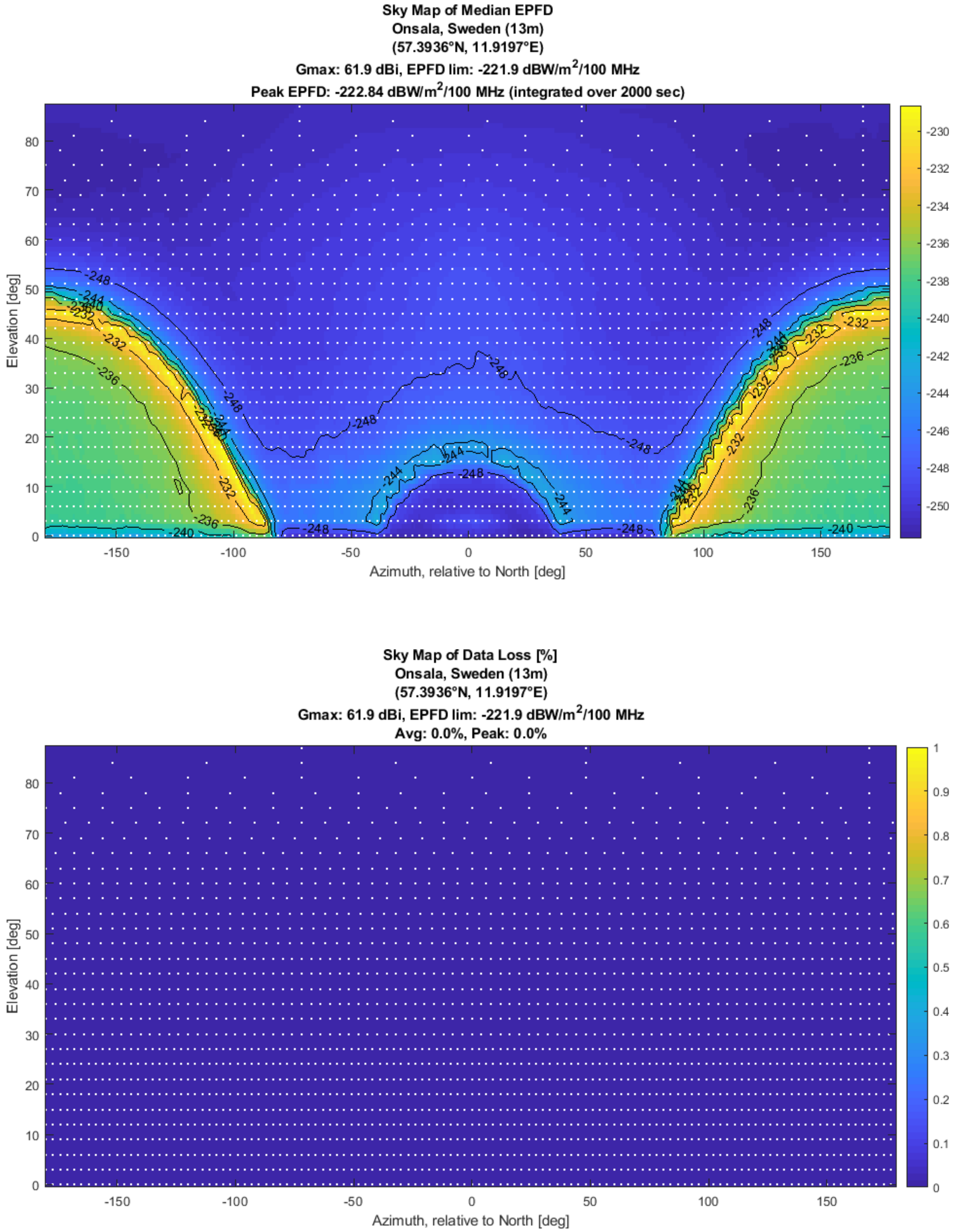


Figure 83: Noto, Italy – Probability Distribution



Sky Map of Median EPFD
Onsala, Sweden (13m)
(57.3936°N, 11.9197°E)
Gmax: 61.9 dBi, EPFD lim: -221.9 dBW/m^2/100 MHz
Peak EPFD: -222.84 dBW/m^2/100 MHz (integrated over 2000 sec)

Sky Map of Data Loss [%]
Onsala, Sweden (13m)
(57.3936°N, 11.9197°E)
Gmax: 61.9 dBi, EPFD lim: -221.9 dBW/m^2/100 MHz
Avg: 0.0%, Peak: 0.0%

Figure 84: Onsala, Sweden – Sky Map of Median epfd and Percent Data Loss

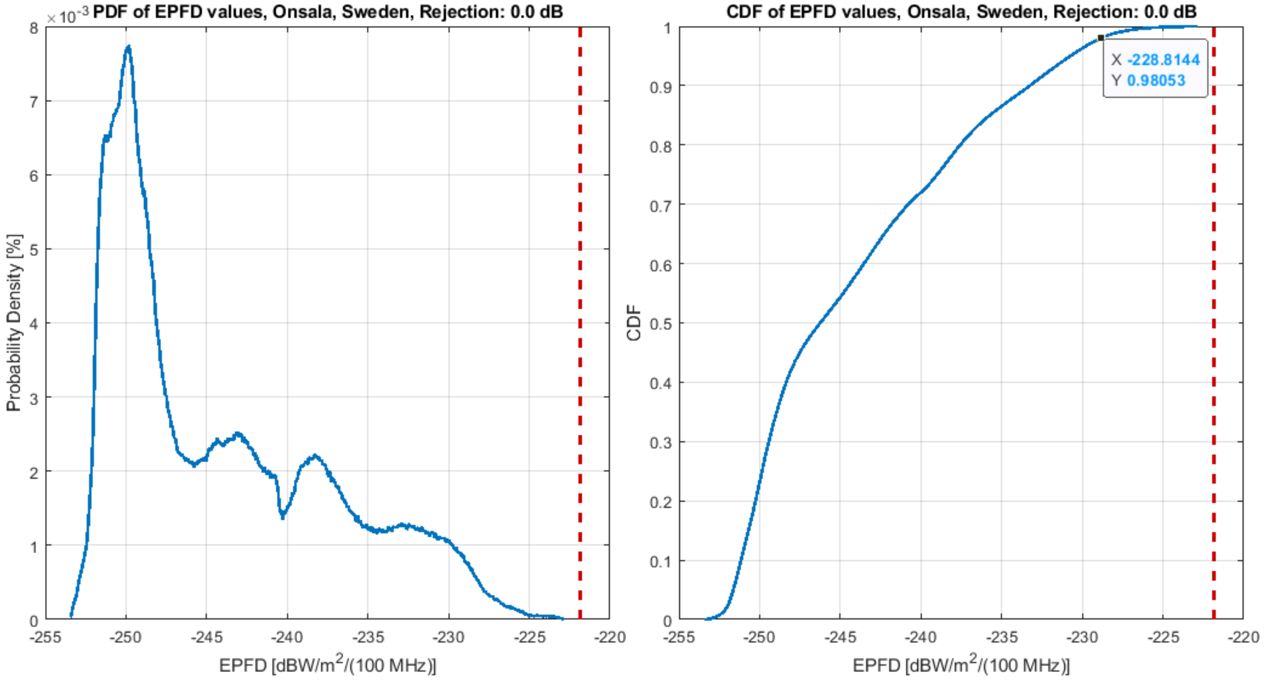


Figure 85: Onsala, Sweden – Probability Distribution

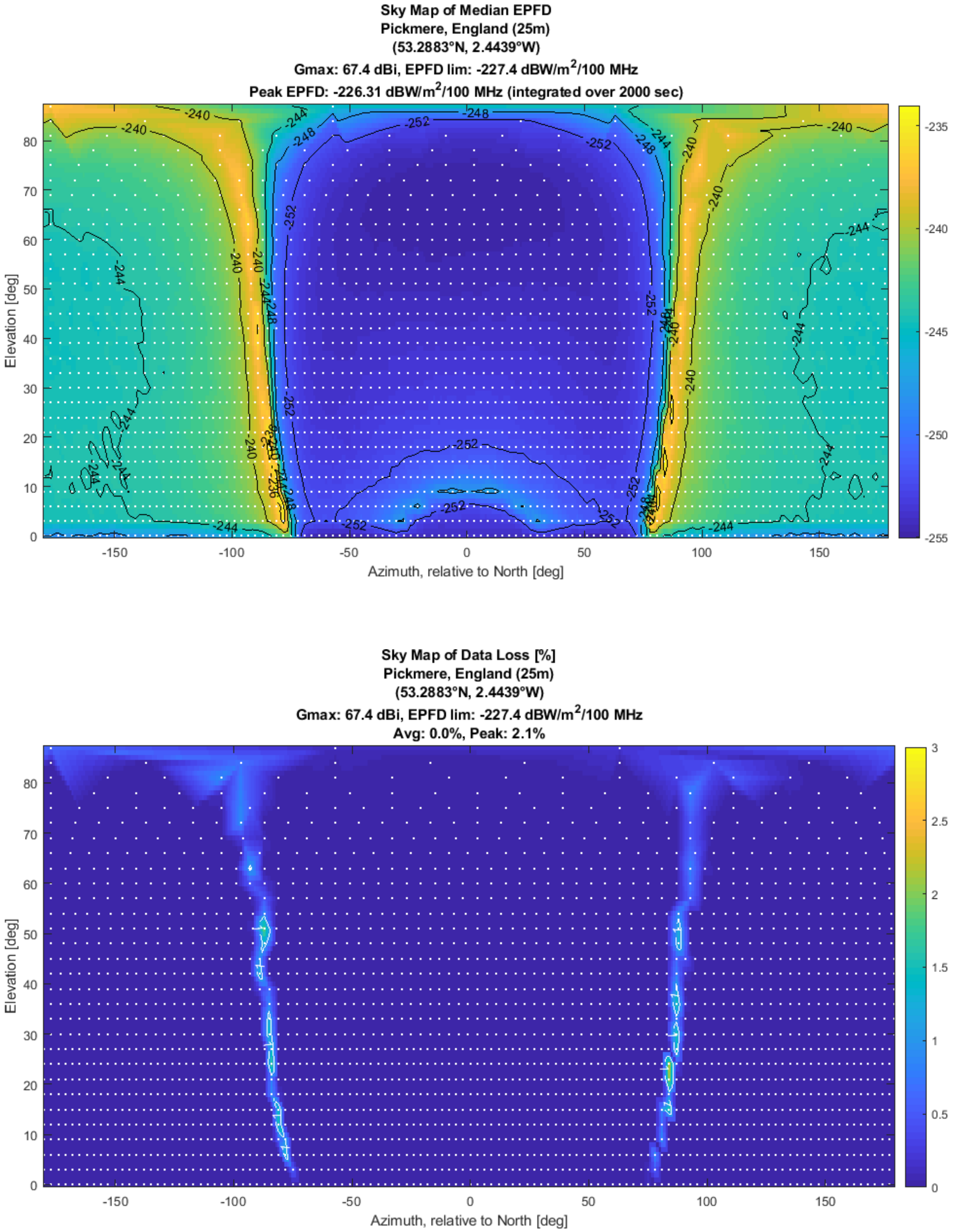


Figure 86: Pickmere, UK – Sky Map of Median epfd and Percent Data Loss

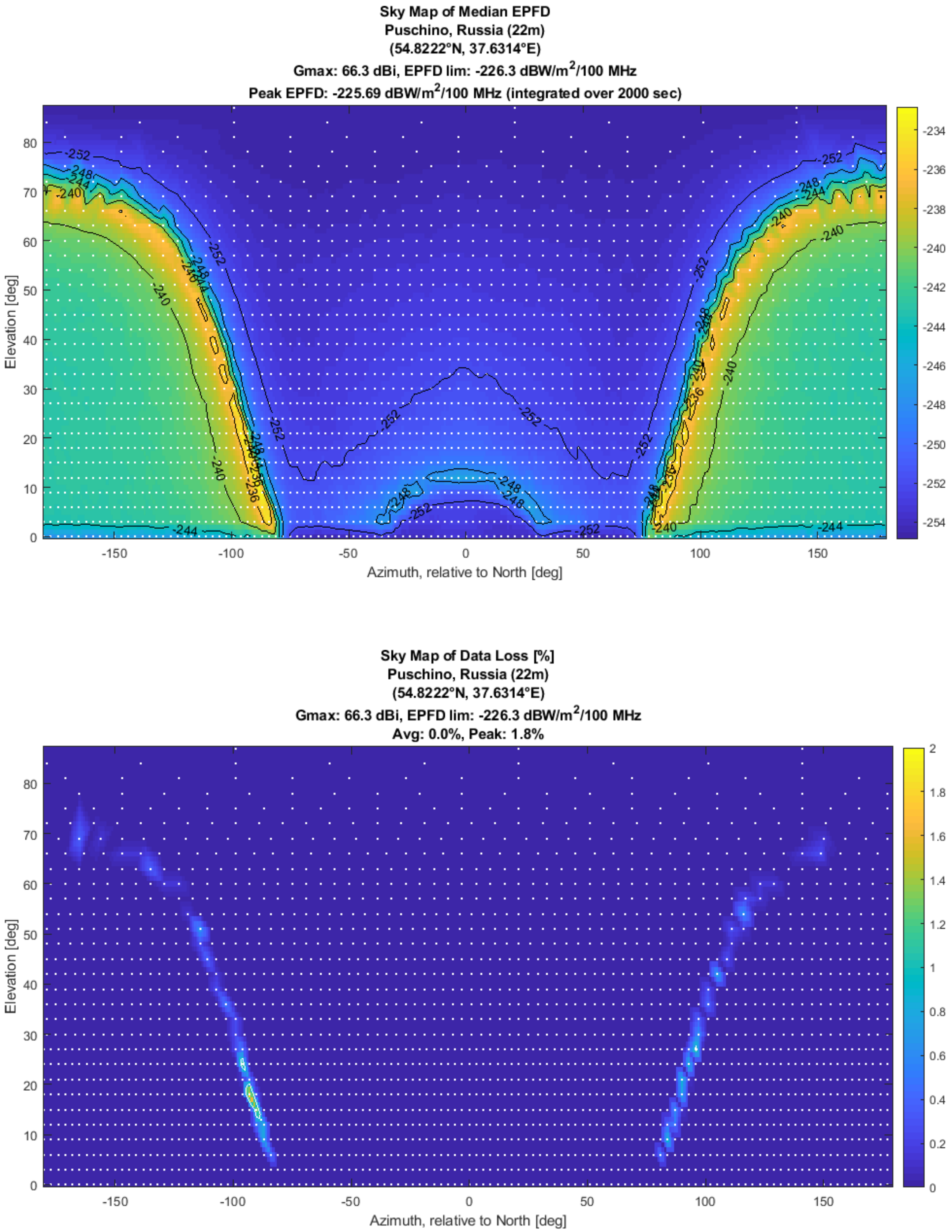


Figure 87: Puschino, Russia – Sky Map of Median epfd and Percent Data Loss

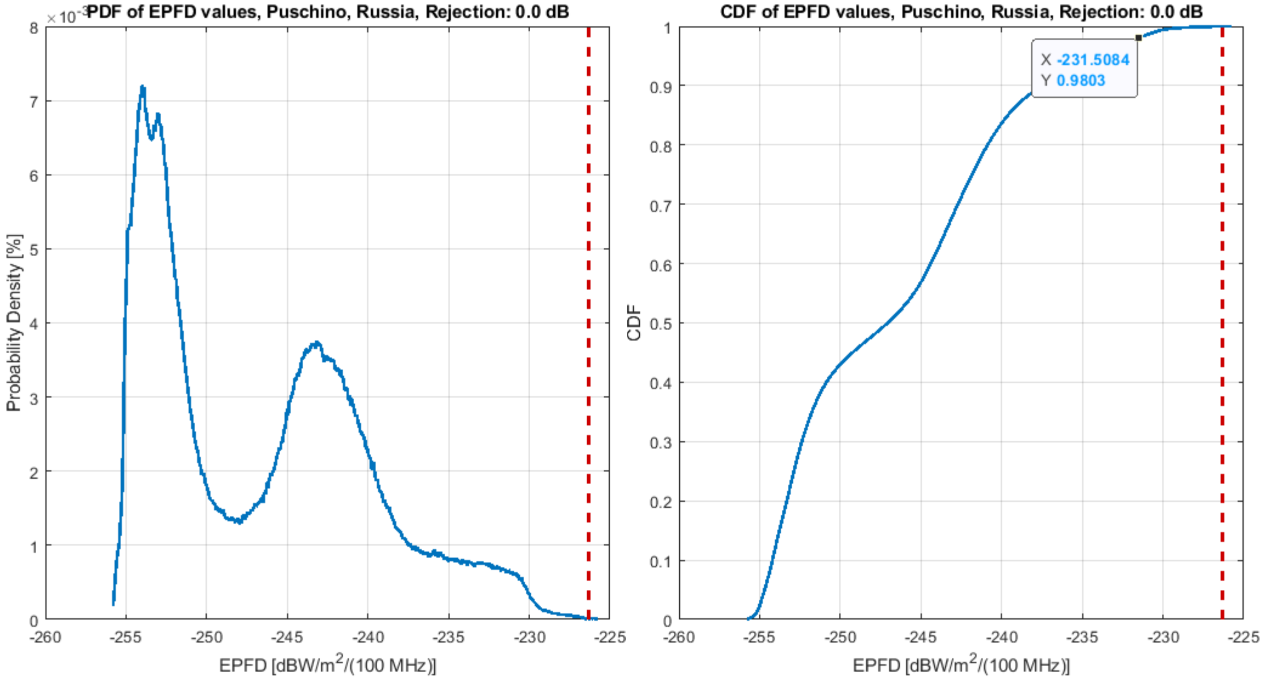


Figure 88: Puschino, Russia – Probability Distribution

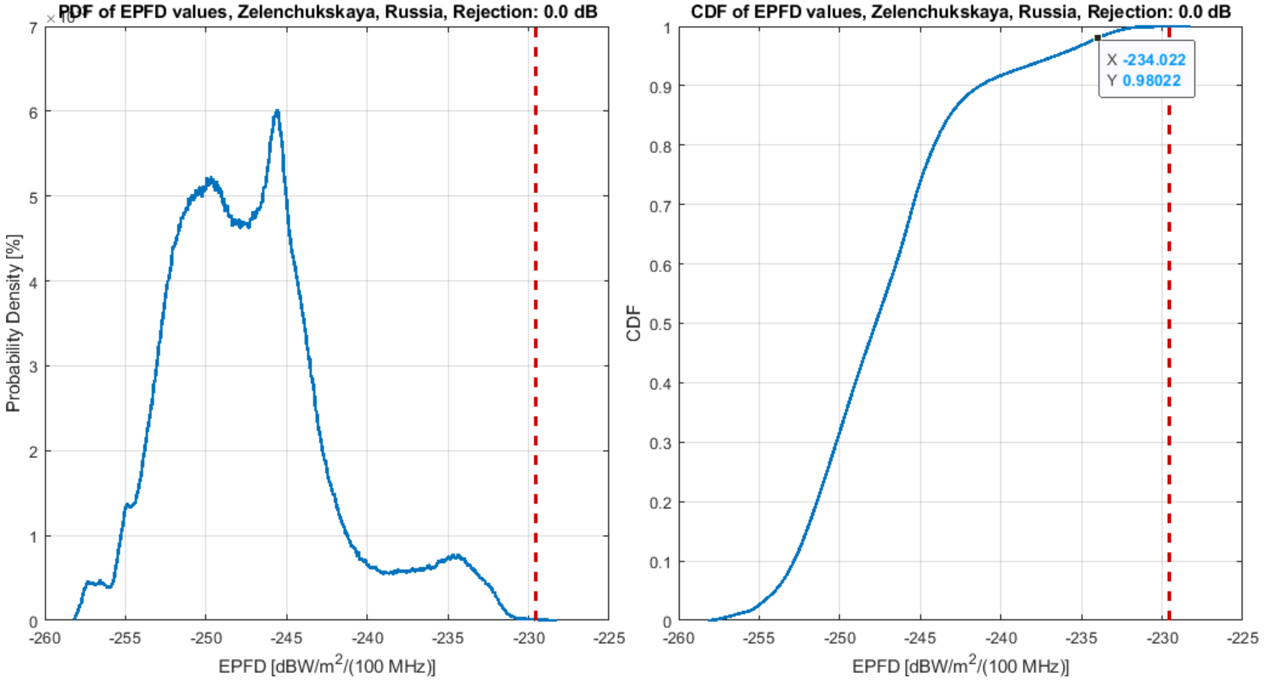


Figure 89: Zelenchukskaya, Russia – Probability Distribution

A2.5.1.2 Conclusions

The unwanted emission e.i.r.p. levels provided in this document meet the 2% data loss criterion of RAS for the worst case considered in terms of maximum antenna gain (Effelsberg site with a 100 m antenna diameter) and all other cases.

A2.5.2 Compatibility between NGSO FSS (space-to-earth) in the band 10.7-12.75 GHz and EESS (passive) in the band 10.6-10.7 GHz

A2.5.2.1 Assessment of impact on passive sensors, provided in Recommendation ITU-R RS 1861

Methodology

The unwanted emission e.i.r.p. levels required for the protection of radio astronomy are expected to also protect the EESS (passive) sensors. In order to verify this, the worst-case interference from SpaceX satellite beams into the EESS (passive) sensor has been calculated, as well as between the main beam of the EESS (passive) sensor after reflection over the sea.

Results

As a consequence of the SpaceX proposed orbit modification, all 4408 satellites will be in orbits (540 km - 570 km) lower than any of the EESS altitudes mentioned in Recommendation ITU-R RS.1861 [25]. The worst-case interference is from SpaceX satellites at 570 km to the mainbeam of the closest EESS sensors orbiting at 699.6 km altitude. With the proposed modification in effect, there will be no SpaceX satellites at higher altitudes than any of the EESS altitudes. Hence, SpaceX satellites will not interfere the EESS sensors through the back lobe.

Table 21: Calculation of interference in EESS (passive) sensor

Parameter	Value					Unit
	Sensor C1	Sensor C2	Sensor C3	Sensor C4	Sensor C5	
	Mainbeam					
Worst e.i.r.p. (one satellite)	-62.0	-62.0	-62.0	-62.0	-62.0	dBW/(100 MHz)
EESS gain	36	42.3	45	36	44.1	dBi
EESS altitude	817	705	833	835	699.6	km
SpaceX orbit altitude	570	570	570	570	570	km
Min. Distance	247.0	135.0	263.0	265.0	129.6	km
Min. Propagation Loss	160.8	155.6	161.4	161.5	155.2	dB
Max. Interference	-186.9	-175.3	-178.4	-187.5	-173.2	dBW/(100 MHz)
Protection Criterion	-166	-166	-166	-166	-166	dBW/(100 MHz)
Margin	20.9	9.3	12.4	21.5	7.2	dB

Even under worst-case assumptions there is sufficient margin with regard to the EESS (passive) protection criterion.

With regard to the interference received in the EESS sensor main beam after reflection over the sea, a worst-case scattering coefficient of 120% has been assumed, which in theory would only occur at the NGSO satellite nadir during short period of time. Note also that SpaceX satellites will not normally point beams to the open sea (except small islands / coastal regions, when a part of the beam illuminates the sea). Since reflection from SpaceX satellites at all altitudes generate same amount of reflected power with 120% backscattering, results of 550km altitude satellites are shown in Table 22.

Table 22: Calculation of interference in EESS (passive) sensor main beam after reflection over sea

Parameter	Sensor C1	Sensor C2	Sensor C3	Sensor C4	Sensor C5
Worst e.i.r.p. (dBW/(100 MHz))	-62.0	-62.0	-62.0	-62.0	-62.0
NGSO FSS satellite altitude (km)	550	550	550	550	550
pfd (dBW/m²/(100 MHz))	- 187.8	- 187.8	- 187.8	- 187.8	- 187.8
Instantaneous field of view (km2)	1680.0	1479.0	1344.0	13452.0	861.0
Backscatter coefficient (%)	120	120	120	120	120
Reflected power (dBW/(100 MHz))	- 94.8	- 95.3	- 95.8	- 85.8	- 97.7
Distance ground − Satellite EESS passive (km)	1221.7	1123.5	2033.7	1766.1	1114.9
Propagation loss (dB)	174.7	174.0	179.2	177.9	173.9
EESS antenna gain (dBi)	36.0	42.3	45.0	36.0	44.1
Received power at the passive sensor (dBW/(100 MHz))	- 233.5	- 227.0	- 229.9	- 227.7	- 227.5
Protection criterion (dBW/(100 MHz))	-166	-166	-166	-166	-166
Margin (dB)	67.5	61.0	63.9	61.7	61.5

Even with these worst-case assumptions there would be more than 63 dB margin with regard to the EESS (passive) protection criterion.

A2.5.2.2 Assessment of Impact on METEOR-M passive sensor

Interference scenarios

The following interference scenarios were considered to assess the impact from FSS satellites:

- Aggregated Interference from FSS satellites mentioned in this Annex, resulting from unwanted emissions in 10.6-10.7 GHz, is received through far side lobes and back lobes of passive instrument main antenna;
- Aggregated Interference from FSS satellites mentioned in this Annex, resulting from unwanted emissions in 10.6-10.7 GHz, is received through main beam of passive instrument cold calibration channel antenna.

Initial data and assumptions of the study

In the simulation model, all 4408 satellites in the constellation are assumed at 100% utilisation transmitting at worst-case e.i.r.p. (all beams on all satellites are turned ON and steered at the maximum possible slant angle which corresponds to the maximum e.i.r.p.). The contributions from each satellite in the 10.6 - 10.7 GHz band are summed and the maximum e.i.r.p. in the EESS (passive) band (10.6-10.7GHz) is -62.04 dBW/(100 MHz). The out of band noise is not beamformed in a predictable way (for example in the direction of the desired beam); for this reason, in these simulations, the out of band noise radiation pattern is assumed omnidirectional with an e.i.r.p. value equal to the peak e.i.r.p. value of the actual radiation pattern. Note that meeting the e.i.r.p. limit mentioned above (-62.04 dBW/(100 MHz)) prevents SpaceX from using the lowest Ku channel (10.7-10.95GHz) on a global basis.

Meteor-M satellite antenna gains (primary antenna and secondary antenna for cold calibration channel) are calculated according to Recommendation ITU-R RS.1813 [24].

The main beam of Meteor-M satellites has a scanning sector of 105° wide (angle alpha changing from 165 to 270°, off-nadir pointing angle beta is 53.3°), scan period is 2.5 seconds. Secondary antenna for cold calibration channel has a fixed pointing, with orientation angle alpha of 315° and orientation angle beta of 90°. A protection criterion of -168 dBW/(100 MHz) not to be exceeded for more than 0.1% of time was used for Meteor-M satellite passive sensors. It should be noted that this protection criterion is related only to data accuracy and reliability and is not considering possible hardware damage.

Results

Study A

Based on the assumptions above for this study, the aggregate interference from all visible SpaceX NGSO satellites (not blocked by Earth's curvature) to the Meteor-M satellite's main antenna, received through far side lobes and back lobes, has been computed for 5 days at 1 second interval.

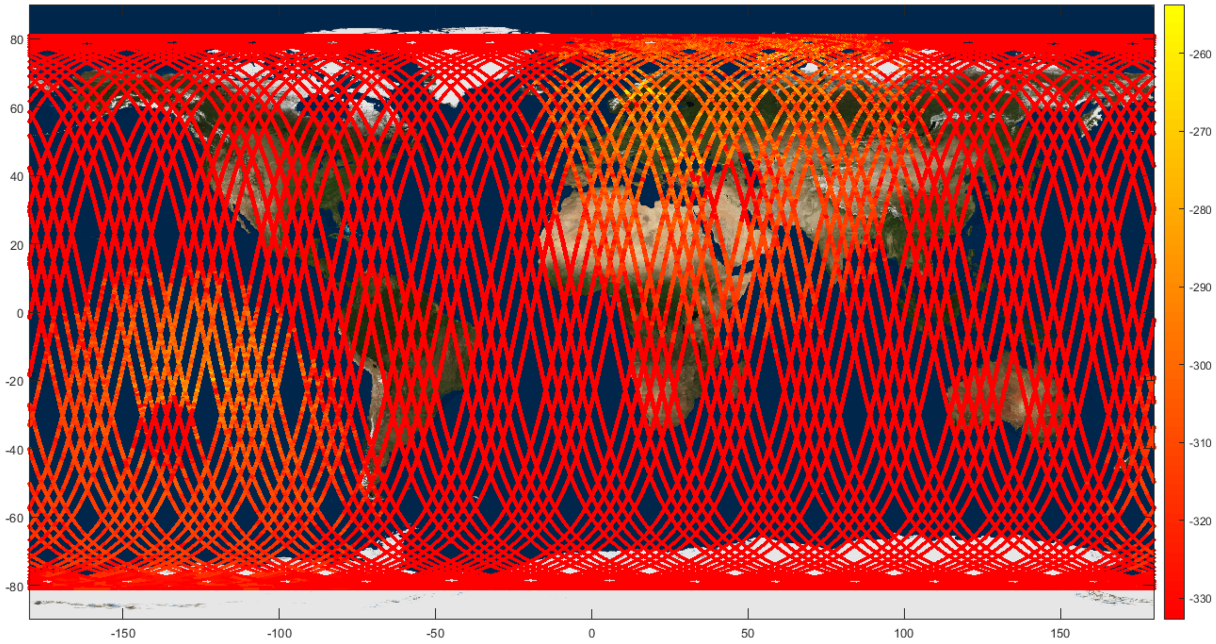


Figure 90: Interference level experienced by the Meteor-M satellite

Figure 90 shows the interference level experienced by the Meteor-M satellite along with its ground track. The maximum interference level is -253.7 dBW/100 MHz which leaves 85.7 dB margin from the protection criterion of -168 dBW/100 MHz.

Based on the assumptions above for this study, the aggregate interference from all visible SpaceX NGSO satellites (not blocked by the Earth's curvature) to the Meteor-M satellite's cold calibration channel antenna, received through the far sidelobes and backlobes, has been computed for 5 days at a 1 second interval.

In this case, the maximum interference level is -253.4 dBW/100 MHz. This leaves more than 85 dB margin from the protection criterion of -168 dBW/100 MHz.

Study B

Based on the assumptions above for this study, the aggregate interference from all visible SpaceX NGSO satellites (not blocked by the Earth's curvature) to the Meteor-M satellite's main antenna, received through the far sidelobes and backlobes, has been computed for 1 day at a 1.01 second interval.

In this case, the maximum interference level is -223.4 dBW/100 MHz. This leaves a 55 dB margin from the protection criterion of -168 dBW/100 MHz.

Even for calibration beam the maximum interference level was calculated to be -226.23 dBW/100 MHz.

Conclusion

The e.i.r.p. limits required to meet the epfd protection criterion for radio astronomy also ensure compatibility with the considered systems in EESS (passive) in the 10.6-10.7 GHz band.

A2.5.3 Sharing between NGSO ES at fixed location and incumbent services in the 14-14.5 GHz Band

A2.5.3.1 SpaceX FSS sharing with Fixed Service in the band 14.25-14.5 GHz

Methodology

The methodology used in the study consists in determining an area around the FS station where any deployed FSS earth station will not be able to use one or several frequency channels overlapping with the channels used by the FS station. The propagation loss needed in order to meet the FS protection criterion (long-term and short-term) is given by:

$$\mathrm{Lp} = \mathrm{e.i.r.p.} + \mathrm{G_R} - \mathrm{N} - \frac{\mathrm{I}}{\mathrm{N}} + 10\log\left(\mathrm{B}\right) \qquad (8)$$

Where:

- Lp: Propagation loss required [dB]
- e.i.r.p.: FSS ES e.i.r.p. towards the horizon [dBW/Hz]
- $\mathrm{G_R}$: FS antenna gain towards the FSS earth station [dBi]
- N : FS Noise level [dBW]
- I/N : FS protection criterion [dB]
- B : FS reference bandwidth considered (e.g., 1MHz)

Once the required propagation loss is known, the corresponding distance can be determined using a propagation model per Recommendation ITU-R P.452 [5]. The size of protection areas around FS stations needs to be determined on a case-by-case basis to take into account the actual ES and FS parameters and the surrounding terrain. An example is given below.

Example and Results

Figure 18 shows the exclusion zone for an FS station located in United Kingdom (Licence Number 0937852, Location 53.266280°, -2.1786744°) taking into account the actual terrain elevation, terrain clutter and reflections and using I/N = -10 dB, not to be exceeded more than 20% of the time as protection criterion (long term interference criterion).

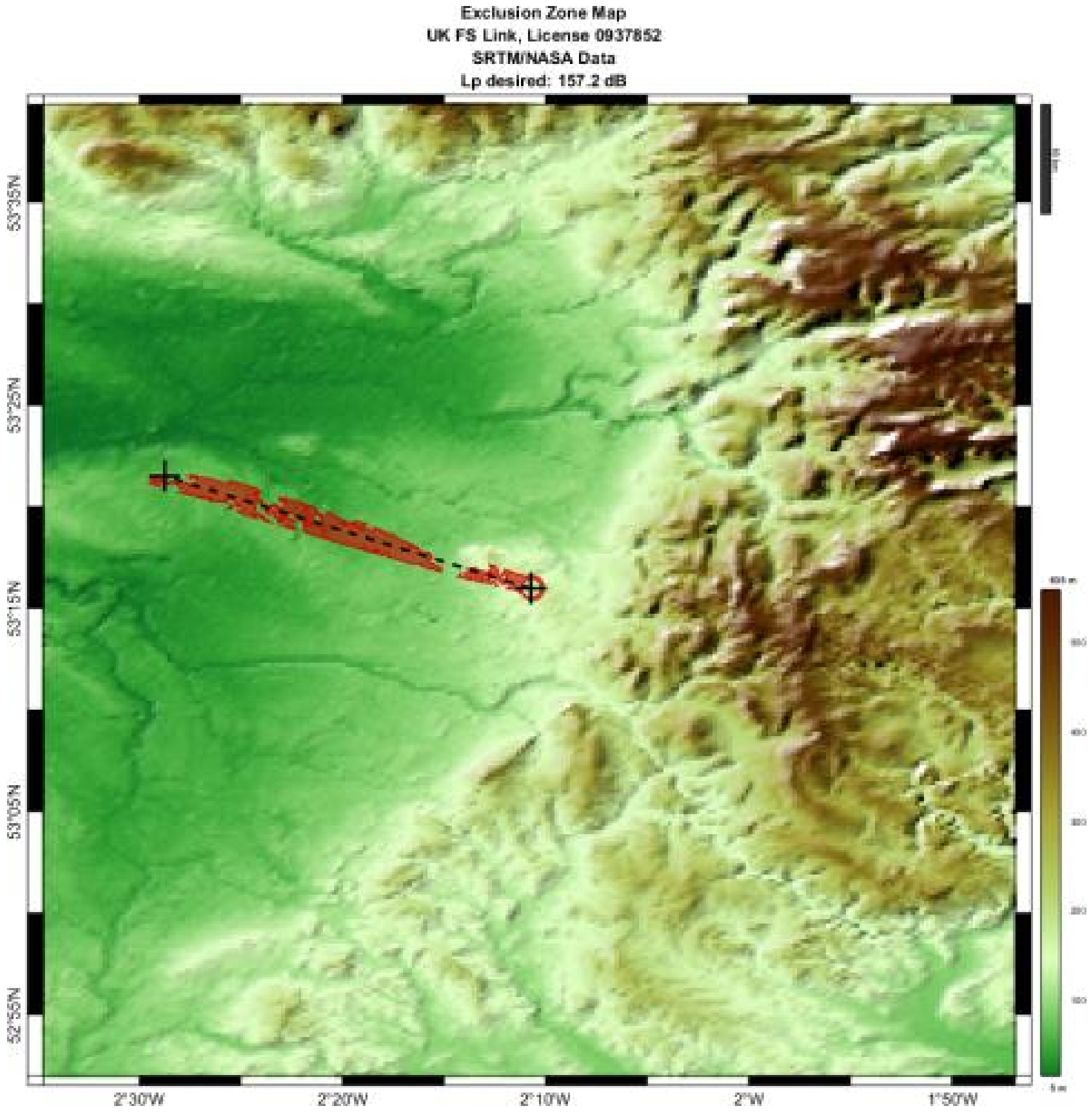


Figure 91: Exclusion zone for a SpaceX User Terminal

Conclusions

The studies outlined in this Report show that the protection of FS stations in the 14.25-14.5 GHz band from SpaceX Earth stations transmitting in the same band requires the establishment of geographic exclusion zones around the FS stations. Calculations were performed by taking into account the real characteristics of both FS and FSS stations, including the frequency, antenna patterns, as well as its geographical locations; note this implies a case by case analysis.

When establishing compatibility with fixed links with known locations deployed within an administration, SpaceX will initially identify the geographic exclusion zones for all FS link receiving stations using the methodology given above.

This study uses the same approach as the one that would be conducted between co-primary services; however, it should be noted that the RAS allocation in this band has a secondary status to FSS, rather than co-primary.

A2.5.3.2 SpaceX ESIM sharing with Fixed Service in the band 14.25-14.5 GHz

SpaceX's sharing analysis between FSS and FS showed that an exclusion zone would be required around FS stations to meet the long term interference criteria for fixed earth stations. These results apply equally well for land and maritime ESIMs. While these ESIMs do move at times the can also be parked or anchored for long periods of time making the long term protection criteria relevant. Land ESIMs are also generally closer to the surface of the earth than the 10 m antenna height assumed in the fixed earth station analysis, which will result in equal or higher path losses relative to the fixed earth stations. A 40 m antenna height is used for maritime ESIMs, as required by SF.1650.

The conditions are significantly different for sharing between aeronautical ESIMs and FS stations because aircraft can operate at up to 12000 m in altitude and are in continuous motion when flying. The height of aircraft above the ground greatly extends the range at which interference can be caused. Figure 92 shows the exclusion zone around a FS station for a terminal at 10000 m against the long term criteria, which is nearly 3 times larger than the original analysis for a fixed terminal with a 10 m antenna height. This illustrates the greater range at which interference can occur with aeronautical ESIMs but, of course, aeronautical ESIMs do not dwell in one place as fixed earth station do. A more sophisticated analysis is required to account for the motion of the ESIMs.

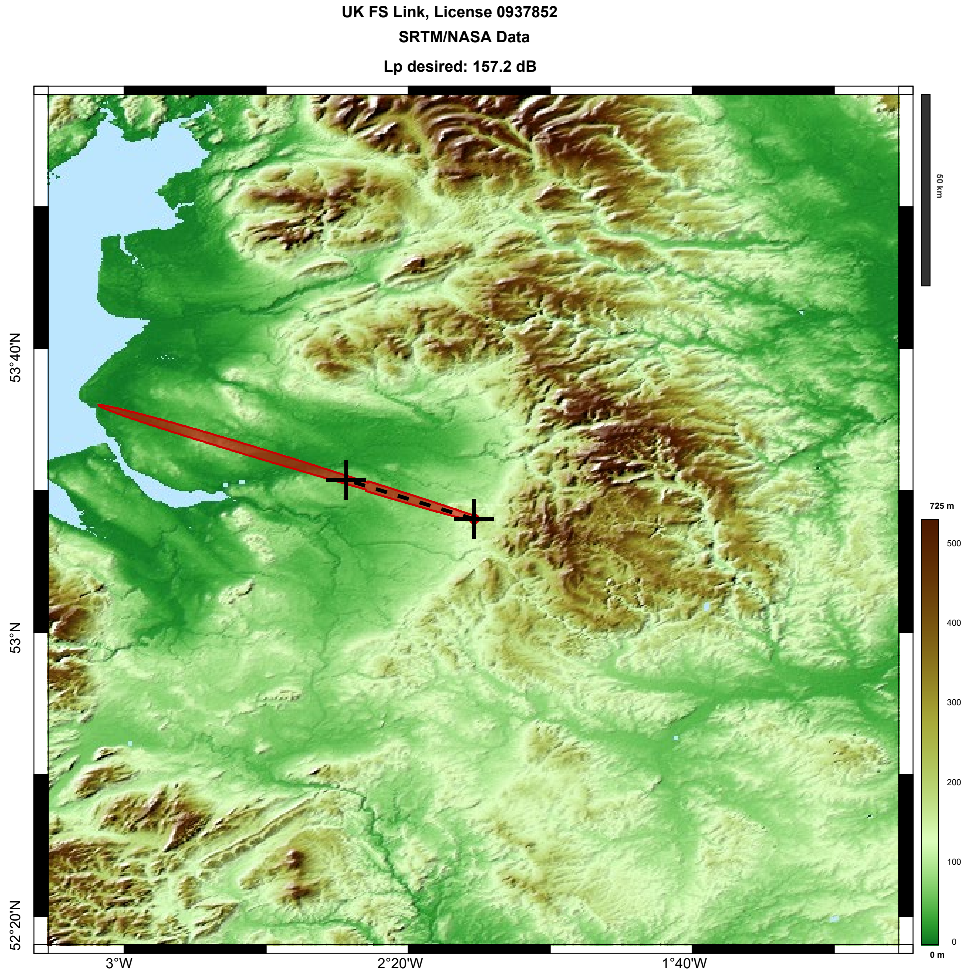


Figure 92: Long-Term Criteria Exclusion Zone Around an FS station for an ESIM at 10000 m

Extensive studies of interference from 14 GHz AMSS terminals into FS stations were conducted in the ITU-R study groups leading up to WRC-2003. These studies factored actual flight routes, FS deployments in Europe and both long-term and short-term interference criteria. These studies resulted in a PFD mask for protecting FS stations that was included in ITU-R Recommendation M.1643 [17].

OneWeb replicated and updated the ITU studies in Annex A1.6.1.2. The revised analysis used updated short term and long-term interference criteria and a more realistic number of co-frequency aircraft in view of the FS station but otherwise used the same analysis methodology. The conclusion of this analysis in Annex A1.6.1.3 was that FS stations can be protected by an aircraft PFD mask given by:

- –122 dB(W/(m² · MHz)) for $\theta \leq 5°$;
- –127 + θ dB(W/(m² · MHz)) for $5° < \theta \leq 40°$;
- –87 dB(W/(m² · MHz)) for $40° < \theta \leq 90°$.

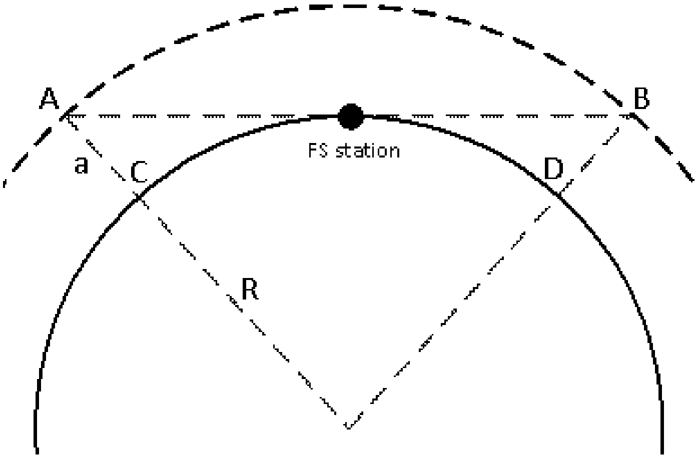
Where θ is the angle of arrival. This mask is 10 dB less restrictive than the ITU-R Recommendation M.1643 [17] mask for FS near the horizon and 25 dB less restrictive directly below the aircraft.

The difference between the mask in A1.6.1.3 and the one in ITU-R Recommendation M.1643 appears to be primarily due to the difference in short term and long-term interference criteria and to a lesser degree a reduced number of assumed co-frequency aircraft. Nothing else about this analysis is specific to OneWeb so the same results would be valid for SpaceX given a similar number of co-frequency aircraft in view (OneWeb used 6 aircraft in view).

Assuming the airplanes fly at an altitude a, the airplanes in the spherical sector between points A and B are visible from the FS station. With a = 12 km, the area of this sector is 481806 km^2.

These airplanes are getting service from beams pointing to ground in the spherical sector between points C and D. This area is 480148 km^2.

Given the cell size used by the SpaceX system (25km diameter), the number of Uplink frequencies (eight) and an expected system capacity allocation for aircraft ESIMs of 5%, the maximum number of co-frequency ESIMs in view is 480148 / (π/4*25^2) / 8 * 5% ≈ 6. Note this is a conservative estimate, as most aircraft will fly at lower altitudes.



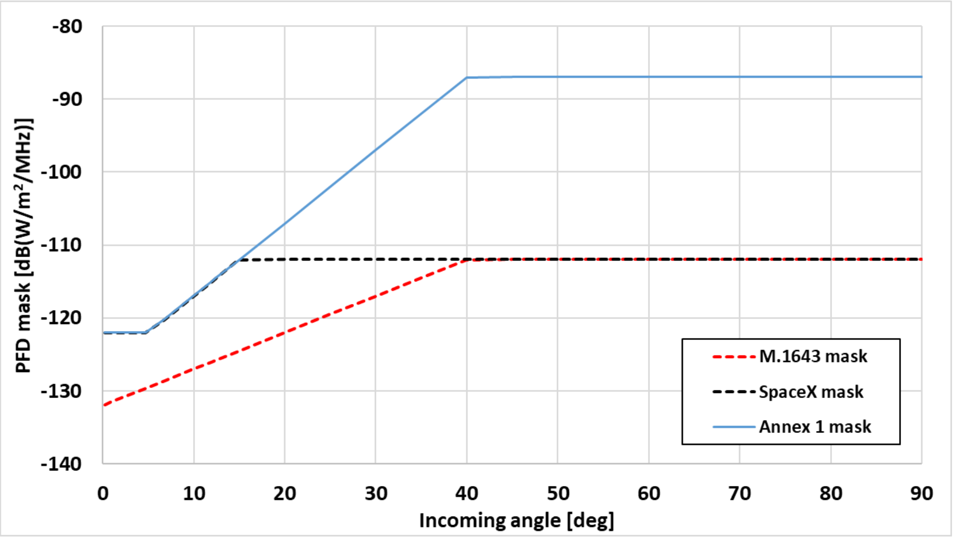


Figure 93: FS PFD Mask for Aeronautical ESIMS

Note this PFD mask is unnecessarily relaxed for high elevation angles. SpaceX propose to use the following mask:

- –122 dB(W/(m² · MHz)) for θ ≤ 5°;
- –127 + θ dB(W/(m² · MHz)) for 5° < θ ≤ 15°;
- –112 dB(W/(m² · MHz)) for 15° < θ ≤ 90°

which matches the ITU-R M.1643 [17] mask at elevations over 15deg.

This PFD mask can be converted into e.i.r.p. masks that vary with altitude using the method contained in ITU-R Recommendation M.1643 Annex 2, as shown in Figure 94. The e.i.r.p. mask becomes more restrictive at lower altitudes due to the closer proximity of the aeronautical ESIM to potential victim FS Stations.

For reference, Figure 94 presents the ITU-R M.1643 PFD, the SpaceX Aeronautical ESIM PFD Mask and the actual PFD for various altitudes. Note that the actual PFD produced by SpaceX ESIMs is well below the SpaceX PFD mask and the M.1643 mask for incoming angles above 20 degrees.

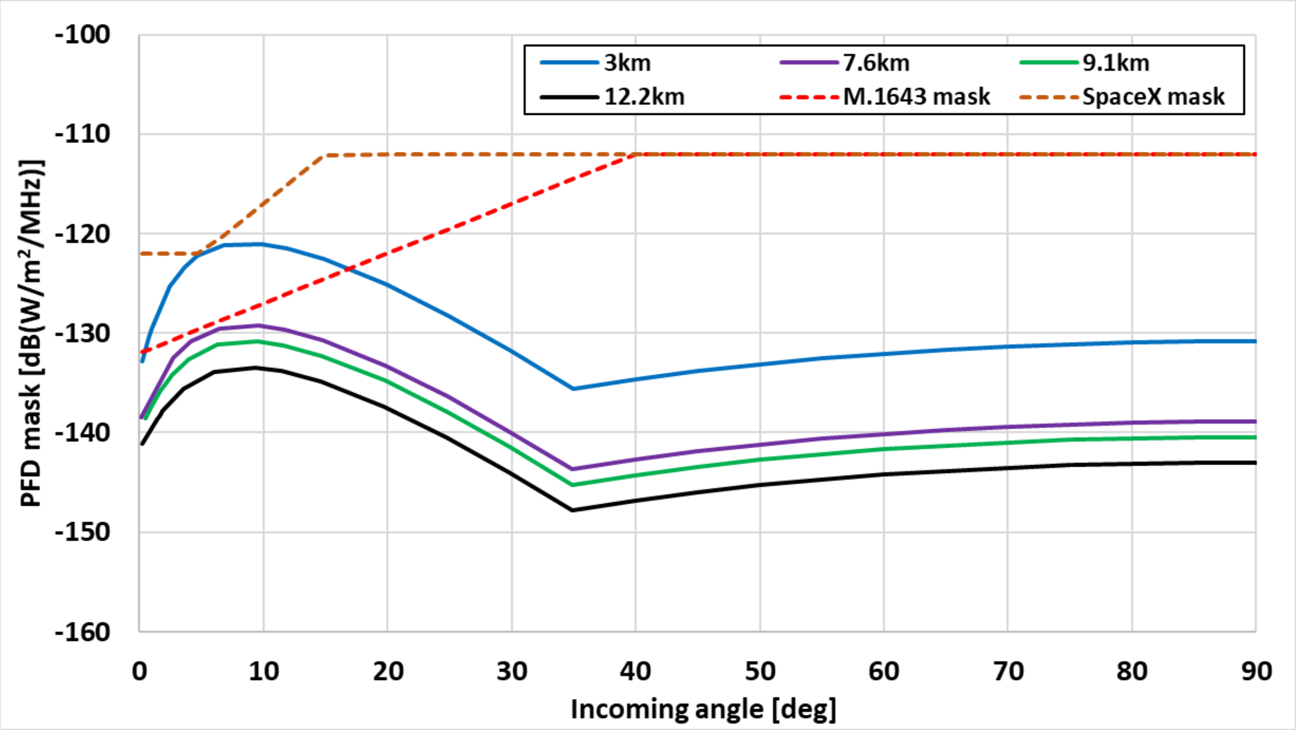


Figure 94: PFD corresponding to SpaceX e.i.r.p. mask

SpaceX ESIM emissions towards the horizon are limited to -75.26 dBW/Hz or -15.26 dBW/MHz. This e.i.r.p. spectral density would be sufficient to comply with the PFD mask for altitudes above 6000 m without any additional attenuation below the horizon. In fact, the fuselage of an aircraft provides substantial shielding of emissions below the horizon.

Simulations that were performed prior to WRC-2003 showed that the fuselage of a Boeing 737 sized aircraft would attenuate the side lobes of a 14 GHz phased array mounted on the crown of the aircraft by 1 dB per degree below the horizon up to 35 dB [27]. These simulations were later verified by flight testing. This additional attenuation below the horizon would allow the SpaceX aeronautical ESIM to operate at latitudes above 3000 m.

A minimum altitude of 3000 m is approximately the same altitude (10000 feet) above which passengers are permitted to use their laptops. Below this altitude, a SpaceX aeronautical ESIM operating co-frequency with

FS stations may have to reduce e.i.r.p., switch to a frequency not used by FS station in the area or cease transmission. Additional side lobe control may improve this.

Conclusions

The sharing conditions between land and maritime ESIMs and FS stations are similar to those between fixed earth stations and FS. Consequently, sharing can be achieved with and can operate under the same constraints derived for fixed earth stations. Aeronautical ESIMs, however, have considerably different sharing conditions with FS stations due to their altitude and speed. SpaceX generated an updated PFD mask for the protection of FS stations by aeronautical ESIMs that is applicable to SpaceX aeronautical ESIMs. SpaceX can comply with this mask at altitudes above 3000 m without any restriction and can address operation below 3000 m with other mitigations.

A2.5.4 Sharing with Radio Astronomy Service in the 14.47-14.5 GHz band

A2.5.4.1 SpaceX FSS Sharing with RAS in the 14.47-14.5 GHz band

The methodology used in the study consists of determining a geographic area surrounding a given RAS earth station where any single deployed FSS earth station will not be permitted by the SpaceX system to operate using the frequency channels overlapping with the frequencies observed by the RAS station in the 14.47-14.5 GHz band. This methodology does not take into account the effect of aggregate interference resulting from simultaneous operation of several FSS earth stations.

The propagation loss needed in order to meet the RAS interference threshold is given by:

$$\mathrm{Lp} = \mathrm{e.i.r.p.} + \mathrm{G_R} - \mathrm{I} + 10\log(\mathrm{B}) \qquad (9)$$

Where:

- Lp: Propagation loss required [dB]
- e.i.r.p.: FSS ES e.i.r.p. towards the horizon [dBW/Hz]
- $\mathrm{G_R}$: RAS antenna gain towards the FSS earth station [dBi]
- I : RAS interference threshold (0 dB)
- B : RAS reference bandwidth considered (150 kHz)

This simplifies to

$$\mathrm{Lp} = \mathrm{e.i.r.p.} + 219.7 \qquad (10)$$

Once the required propagation loss is known, the corresponding distance from the RAS earth station can be determined using a propagation model per Recommendation ITU-R P.452 [5]. The size of protection areas around RAS earth stations needs to be determined on a case-by-case basis to take into account the nature of the surrounding terrain. An example is given below.

The below figure shows the exclusion zone for the RAS location at Effelsberg (Germany).

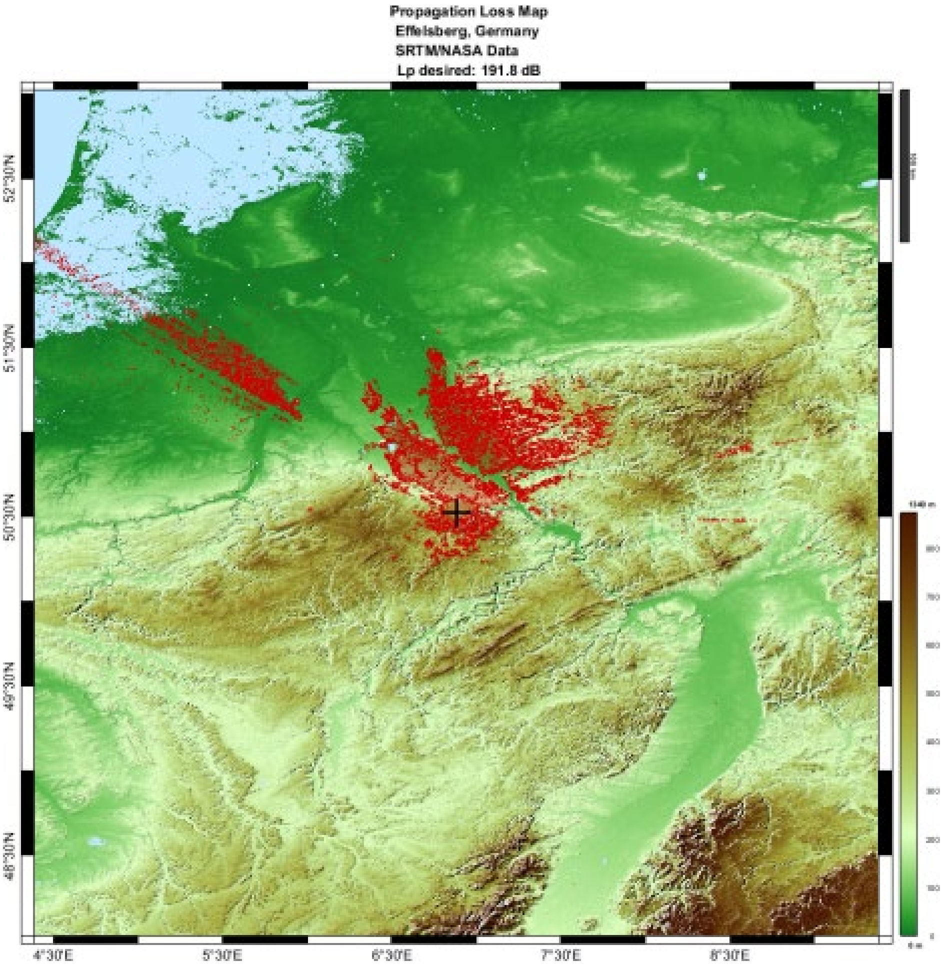


Figure 95: Exclusion zone for Effelsberg, Germany

The exclusion zone could be as large as 340 km in this case.

A2.5.4.2 SpaceX ESIM Sharing with RAS in the 14.47-14.5 GHz band

As was the case with Fixed Service, sharing between land and maritime ESIMs and Radio Astronomy Stations (RAS) is similar to sharing between fixed earth stations and RAS. As a result, the exclusion zones around RAS would be similar to those computed by SpaceX for RAS in Annex A1.1.1.1. Likewise, aeronautical ESIMS, which operate at altitudes of up to 12000 m above sea level pose a substantially different sharing scenario with RAS.

Extensive studies of interference from 14 GHz AMSS terminals into RAS stations were conducted in the ITU-R study groups leading up to WRC-2003. These studies factored actual flight routes, FS deployments in Europe and both long-term and short-term interference criteria and resulted in a PFD mask for AMSS earth stations that was included in ITU-R Recommendation M.1643 [17].

OneWeb replicated and updated the ITU studies in Annex A1.6.2.2. The revised analysis used more realistic number of co-frequency aircraft in view of the RAS station but otherwise used the same analysis methodology. The conclusion of these studies is that RAS stations can be protected by an aircraft PFD mask given by:

- $-185 + 0.5 \cdot \theta$ dB(W/(m2 · 150 kHz)) for $\theta \leq 10°$;
- -180 dB(W/(m2 · 150 kHz)) for $10° < \theta \leq 90°$.

Where θ is the angle of arrival. This mask is 5 dB less restrictive than the ITU-R Recommendation M.1643 mask for RAS.

The difference in the PFD mask derived in Annex A1.6.2.2 from the PFD mask in ITU-R Recommendation M.1643 appears to be primarily due to the difference in assumed numbers of co-frequency aircraft. Nothing else about this analysis is specific to OneWeb so the same results would be valid for SpaceX given a similar number of co-frequency aircraft as noted above.

However, this PFD mask is 57 dB to 87 dB more restrictive than the PFD mask derived for FS. Figure 96. The e.i.r.p. generated by a SpaceX ESIM will be 30 dB to 40 dB higher than the e.i.r.p. mask derived from the corrected FS PFD mask in Annex A2.5.4.2. In practice, this means that co-frequency operation within line of sight of an RAS is not possible. Operating on non co-frequency channels will be necessary to provide enough out-of-band attenuation to comply with the RAS PFD mask.

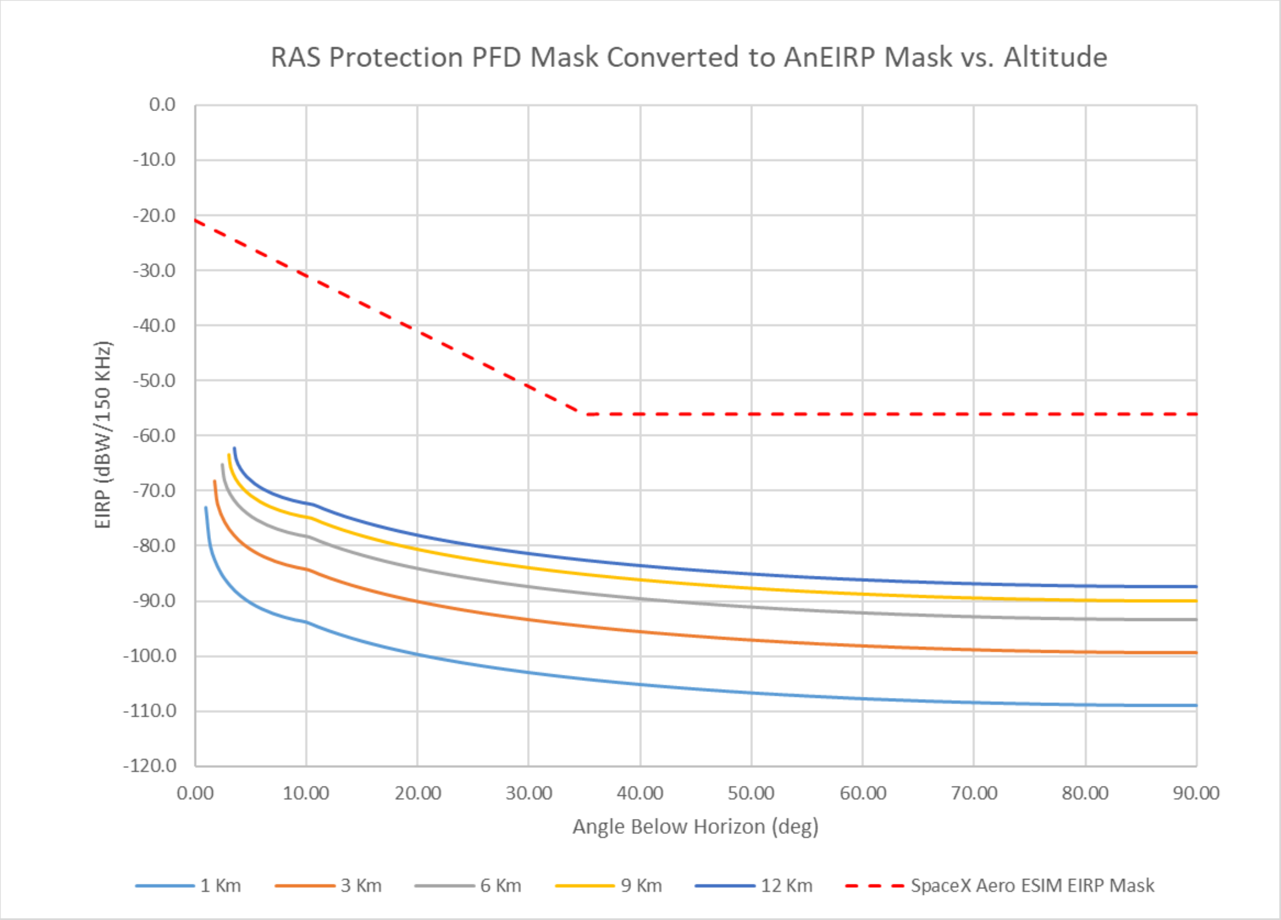


Figure 96: Annex A1.6.2.2 PFD Mask for RAS Converted to an e.i.r.p. Mask and the SpaceX Aeronautical ESIM e.i.r.p. Mask

Avoiding the RAS band in the 14.47-14.50 GHz band is the same strategy adopted by current GSO AMSS operators. In some cases, it has been necessary for them to add notch filter to meet the out-of-band requirements. In other cases, North American AMSS operators in the 14 GHz band have coordinated with RAS operators to use the 14.47-14.50 GHz band when RAS operators are not making observations in the band, which may be a model that can be adopted in other parts of the world.

Conclusions

The sharing conditions between land and maritime ESIMs and RAS stations are similar to those between fixed earth stations and RAS. Consequently, sharing can be achieved with and can operate under the same constraints derived for fixed earth stations. Aeronautical ESIMs, however, have considerably different sharing conditions with RAS stations due to their altitude and speed. OneWeb generated an updated PFD mask for the protection of RAS stations by aeronautical ESIMs that is applicable to SpaceX aeronautical ESIMs. In spite of being 5 dB less restrictive than RAS PFD mask from Recommendation ITU-R M.1643, this mask is several orders of magnitude more restrictive than is possible to meet with in-band emissions. As has been done by GSO AMSS operators, complying with the PFD mask will require avoiding the 14.47-14.50 band when within line of sight of an RAS stations that use this band.

A2.6 CONCLUSIONS ON SPACEX STUDIES

The SpaceX system can achieve protection of the RAS earth stations observing in the secondary RAS allocation in the band 14.47-14.5 GHz by setting geographic areas surrounding such RAS earth stations where any single NGSO FSS earth station will not be permitted to transmit on frequency channels overlapping with this frequency band. The aggregate effect of several earth stations was not assessed. The size of the individual geographic areas must be determined on a case-by-case basis taking into account the FSS and local terrain characteristics.

When establishing compatibility with RAS observatories within an administration, SpaceX would seek to initially identify the appropriate geographic protection zone for each of the RAS observatory sites by using the methodology described in this section. It should be noted that the range of the geographic protection zone may extend beyond the national territory of the Administration into the territories of neighbouring Administrations.

Based on the analysis and studies referenced above, this Report identifies specific technical and operational approaches to ensure radiofrequency compatibility and spectrum sharing between the operations of the SpaceX NGSO FSS system (10.7-12.75 GHz and 14-14.5 GHz) with incumbent systems in both space-to-Earth and Earth-to-space directions. The Report also identified means to protect aircraft from Earth stations deployed near airports.

Specifically, the studies contained in the Report assessed the compatibility of the operations in the FSS downlink allocation in the 10.7-12.75 GHz band with the radio astronomy service (RAS) and the EESS (earth exploration-satellite service) (passive), as well as the compatibility of the earth stations using the FSS uplink allocation in the 14-14.5 GHz band with the Fixed Service (FS) and the RAS. The studies determine unwanted emissions e.i.r.p. levels that the SpaceX system must meet in order to meet the 2% data loss limit at radio astronomy stations performing observations in the band 10.6-10.7 GHz. The Report identifies means to meet the unwanted emission e.i.r.p. levels through a careful design of the satellite payload using appropriate modulation shaping, RF filtering, and constraints on the satellite system (not using the first channel 10.7-10.95 GHz on a global basis). The unwanted emission e.i.r.p. levels determined for this NGSO FSS system will also ensure protection of EESS (passive) sensors operating in the band 10.6-10.7 GHz.

Studies related to NGSO FSS earth stations operating in the band 14-14.5 GHz at fixed locations (SpaceX user terminals emissions towards the horizon are limited to -72.76 dBW/Hz) concluded as follows: Compatibility with fixed service stations in the 14.25-14.5 GHz band will be achieved through the establishment of geographic exclusion zones around the fixed service stations. Regarding aeronautical ESIM in the band 14-14.5 GHz, terrestrial services would be protected applying the PFD mask proposed by OneWeb, but SpaceX can comply with the more stringent pfd mask as specified in sectionA2.5.3.2:

○ –122 dB(W/(m² · MHz))	for θ ≤ 5°;
○ –127 + θ dB(W/(m² · MHz))	for 5° < θ ≤ 15°;
○ –112 dB(W/(m² · MHz))	for 15° < θ ≤ 90°

SpaceX aeronautical ESIM emissions towards the horizon are limited to -75.26 dBW/Hz or -15.26 dBW/MHz.

Only five administrations out of 25 respondents have deployed fixed service in the 14.25-14.5 GHz band. In these zones, the FSS earth stations would have to avoid transmitting on frequency channels overlapping with the channel used by the FS station. The actual size of the area has to be determined on a case-by-case basis, taking into account the FS and FSS ES characteristics (SpaceX user terminals emissions towards the horizon are limited to -72.76 dBW/Hz), as well as the surrounding terrain.

The protection of RAS stations in the frequency band 14.47-14.5 GHz can be achieved through geographic exclusion zones around such stations where any NGSO FSS earth station will have to cease transmissions on channels overlapping with the band 14.47-14.5 GHz. There are a limited number of RAS stations within the CEPT that perform observations in the secondary RAS allocation. The size of each specific exclusion zone will need to be determined on a case-by-case basis taking into account the FSS earth stations and terrain characteristics.

Based on the studies noted in this Report and while satisfying the technical conditions identified in the Report, the SpaceX NGSO FSS satellite system (10.7-12.75 GHz and 14-14.5 GHz) will be able to maintain compatibility with both FS links and RAS earth stations deployed within CEPT member states by establishing exclusion zones for all Fixed Service receiving stations and RAS observatories, and suppressing the use of those frequencies by SpaceX end user terminals within those exclusion zones. The SpaceX satellite system will then meet the necessary protection and compatibility with the FS and RAS services, by suppressing the use of the 14.25-14.5 GHz (or specific frequencies deployed by the fixed service or RAS) by its gateway earth stations and end user terminals within the identified protection zone(s), Finally, if the e.i.r.p. levels of the user terminals are limited to 54.5 dBW there would be no restriction to the operation of NGSO earth stations within or in the vicinity of airfields.

Note that meeting an e.i.r.p. limit of -142.0 dBW/Hz prevents SpaceX from using the lowest Ku-band channel (10.7-10.95 GHz) on a global basis.

ANNEX 3: AGGREGATE IMPACT STUDIES

A3.1 COMPATIBILITY BETWEEN NGSO FSS (SPACE-TO-EARTH) IN THE BAND 10.7-12.75 GHZ AND EESS (PASSIVE) IN THE BAND 10.6-10.7 GHZ

A3.1.1 Assessment of Impact on METEOR-M passive sensor

A3.1.1.1 Interference scenarios

The following interference scenarios were considered to assess the impact from FSS satellites:

- Aggregated Interference from FSS satellites (both NGSO and GSO), resulting from unwanted emissions in 10.6-10.7 GHz, received through the far sidelobes and backlobes of the passive instrument main antenna;
- Aggregated Interference from FSS satellites (both NGSO and GSO), resulting from unwanted emissions in 10.6-10.7 GHz, received through the main beam of the passive instrument cold calibration channel antenna.

A3.1.1.2 Initial data and assumptions of the study

The parameters and assumptions for the NGSO FSS systems can be found in Annex 1 and 2.

The Meteor-M satellite antenna gains (primary antenna and secondary antenna for cold calibration channel) are calculated according to Recommendation ITU-R RS.1813 [24].

The main beam of Meteor-M satellites has a scanning sector of 105° wide (angle alpha changing from 165 to 270°, off-nadir pointing angle beta of 53.3°), and a scan period of 2.5 seconds. The secondary antenna for the cold calibration channel has fixed pointing, with an orientation angle alpha of 315° and an orientation angle beta of 90°. A protection criterion of -168 dBW/(100 MHz) not to be exceeded for more than 0.1% of time was used for the Meteor-M satellite passive sensors. It should be noted that this protection criterion is related only to data accuracy and reliability and does not consider possible hardware damage.

The frequency band 10.7-10.95 GHz is already used by FSS GSO satellites and its use is expected to grow in future due to the congestion of unplanned Ku bands, therefore the existing interference environment needs to be taken into account in the assessment of the aggregate impact to EESS passive sensors. Emission parameters for FSS GSO systems to be used in the study are provided in Table 23. Peak e.i.r.p. values were used so as to meet the pfd limits established in Article 21 of the RR [4]. Information about GSO satellite locations was taken from the Master International Frequency Register.

Table 23: Emission parameters of the typical GSO FSS systems

Parameter	Value
Peak e.i.r.p. (dBW)	54.5
Transponder bandwidth (MHz)	54
Peak e.i.r.p. density (dBW/Hz)	-22.8

Assessment of interference is to be made only with respect to a single transponder of each satellite, adjacent to the 10.6-10.7 GHz band. Taking into account possible loading options of the transponder (single-carrier/multi-carrier) it is assumed that at least 0.5% of the transponder power falls into the adjacent band. It should be noted that during these studies the reflection of FSS GSO signals from water surfaces was not studied.

A3.1.1.3 Results

Based on the assumptions above for this study, the aggregate interference from all visible NGSO satellites mentioned in previous Annexes (not blocked by the Earth's curvature) to the Meteor-M satellite's main antenna, received through far sidelobes and backlobes, has been computed for 1 day at a 1 second interval.

In this case, the maximum interference level from Ku NGSO systems is -203.1 dBW/100 MHz. This leaves a 34.9 dB margin from the protection criterion of -168 dBW/100 MHz. As a maximum aggregate interference from GSO FSS constellation reached -173.8 dBW/100 MHz, the maximum resulting interference level is still -173.8 dBW/100 MHz. This leaves a 5.8 dB margin from the protection criterion of -168 dBW/100 MHz.

Based on the assumptions above for this study, the aggregate interference from all visible NGSO satellites mentioned in the previous Annexes (not blocked by the Earth's curvature) to the Meteor-M satellite's cold calibration channel antenna, received through the far sidelobes and backlobes as well as the main beam direction, has been computed for 1 day at a 1 second interval.

In this case, the maximum interference level from Ku NGSO systems is -190.5 dBW/100 MHz. This leaves a 22.5 dB margin from the protection criterion of -168 dBW/100 MHz. As the aggregate interference from GSO FSS constellations exceeds the -168 dBW/100 MHz protection criterion, there is almost no impact from the Ku NGSO systems considered in this Report.

A3.1.1.4 Conclusion

The e.i.r.p. limits for each system mentioned in the previous Annexes required to meet the epfd protection criterion for the radio astronomy also ensure the compatibility with the considered systems in EESS (passive) in the 10.6-10.7 GHz band.

A3.1.2 Current interference situation for METEOR-M and other passive sensors in 10.6-10.7 GHz

A3.1.2.1 General Information

The aim of this analysis is to provide a baseline interference level against which to assess the impact of NGSO systems.

Various articles in IEEE journals indicate a lack of protection of passive sensors at least since 2004, as shown in Table 24 below.

Table 24: Interference impact on scientific data gain from METEOR-M

Source of interference	Impact on scientific data
GSO satellites	Data loss up to 30%
Stations on earth surface	Data loss up to 20%

The AMSR-E passive sensor installed on Aqua experienced similar problems.

A3.1.2.2 Interference snapshots

The history of the interference situation with METEOR-M satellites started in 2010, when interference was found on both polarisation channels (vertical and horizontal) in the North Atlantic region, the Norwegian sea and the North Sea. Information gathered about interference locations and frequencies shows that the sources of interference are the emissions from the Hotbird and Astra satellites reflected from the water surface. The strength of this interference highly depends on the wind conditions. For still weather, when there are almost no waves, interference tends to be stronger but is more localised. On the other hand, wind cause waves, which lead to a larger area being corrupted, but interference is weaker.

The following figures show snapshots of interference experienced by the AMSR-E sensor installed on Aqua and snapshots experienced by sensors installed on METEOR-M.

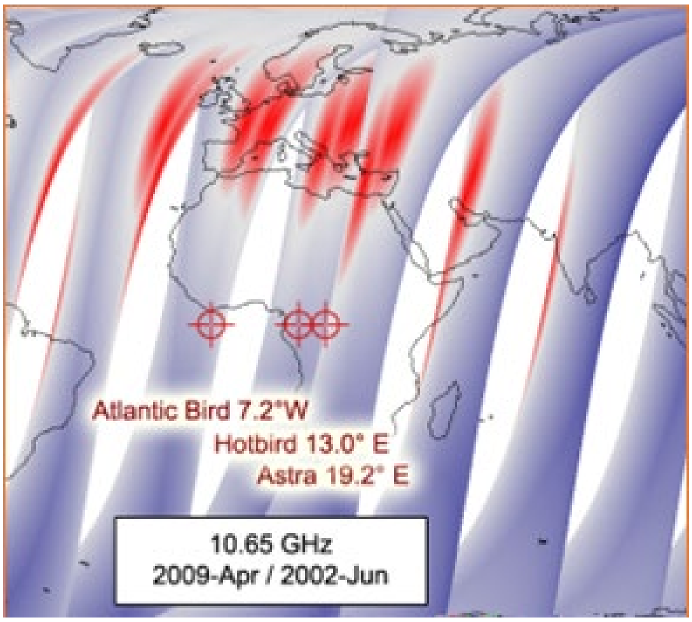


Figure 97: Interference measured by the AMSR-E sensor

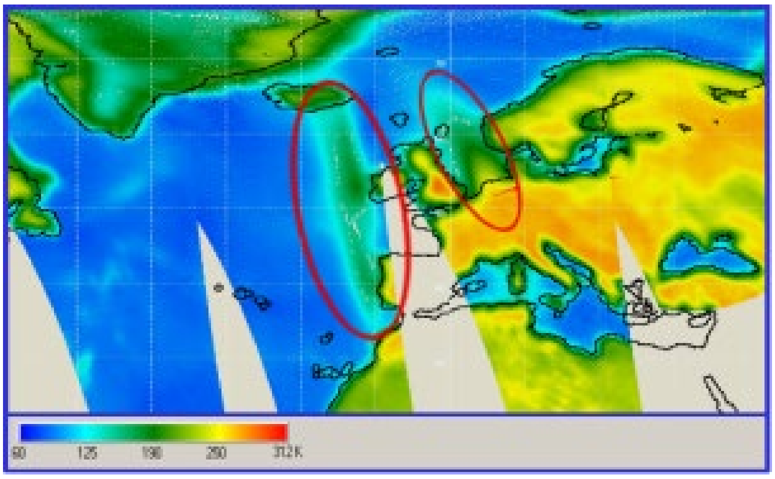


Figure 98: Interference measured by the sensor installed on METEOR-M

A3.1.2.3 Earth surface located sources

There were also found sources of interference in both polarisation channels (vertical and horizontal) on the ground, mainly located near cities with high population density. While strong and/or stable interference could be filtered out from observation data, weak and/or unstable interference could not be easily excluded without damaging the data.

Snapshots of interference made by the AMSR-E sensor installed on Aqua can be found in Figure 99, and snapshots made by sensors installed on METEOR-M can be found in Figure 100.

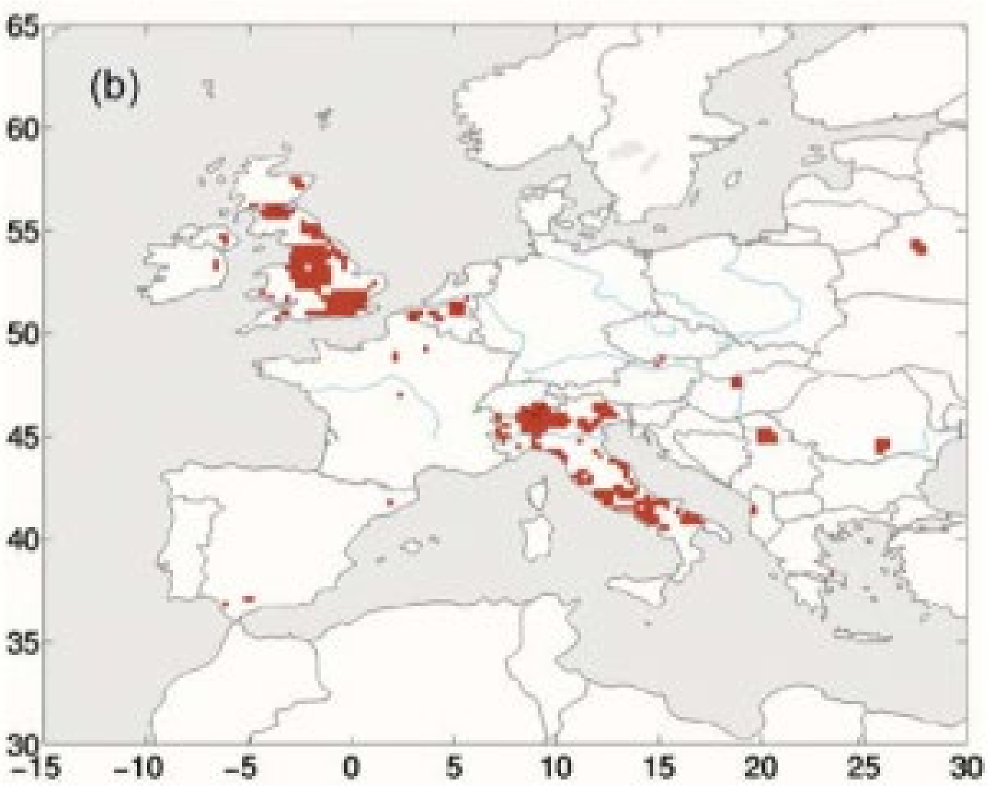


Figure 99: Interference measured by the AMSR-E sensor. Red areas represents areas with interference sources creating interference stronger than 3K for more than a month

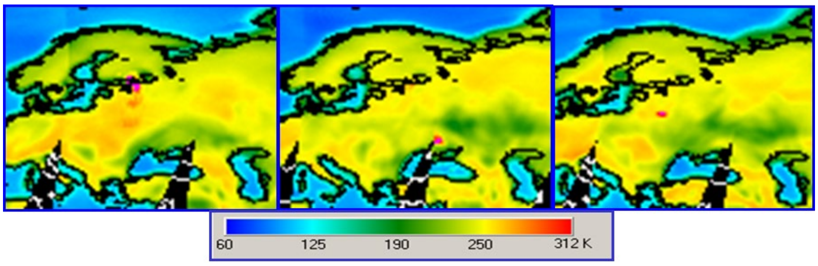


Figure 100: Interference measured by the sensor installed on METEOR-M

ANNEX 4: INTERMODULATION STUDIES

Radioastronomical receivers, especially the first-stage low-noise-amplifiers (LNA) are usually cryo-cooled to reach very low noise figures. The front-end parts are placed in dewars, which are evacuated with vacuum pumps and cooled to temperatures down to about 20 K. The resulting system temperatures can be as low as 15 K at some frequencies, and are mainly determined by non-Rx contributions, such as emission from the ground, the atmosphere, or the cosmic microwave background. While this increases the cost of RAS receivers significantly, it is worth the effort: improving the sensitivity by reducing the Rx noise leads to a substantially decreased radiometric noise in the recorded data. The only other means to achieve this would be to increase the antenna size (and thus antenna gain) – and for single dishes one has already reached the limits – or to integrate longer. The noise decreases however only with the square root of the integration time. Therefore, to lower the noise level of the data by a factor of two, one needs four times longer integration times. As cyro-cooled receivers often lead to system temperatures that are a factor of two or more lower than for an uncooled device, the same detections can be made in just a quarter or less of the time. Given that RAS telescopes are generally oversubscribed and expensive to operate, operating at the highest sensitivity level is very important for the efficient use of the radio astronomical spectrum.

Unfortunately, the increased sensitivity comes with a price, because the dynamic range of a sensitive receiver cannot be made arbitrarily high. RAS receivers will reach saturation at typical input power levels of −20 to −40 dBm. As modern RAS receivers cannot avoid featuring large input bandwidths, incident radiation from strong emitters outside of the protected RAS bands can also cause problems, even if their out-of-band or spurious emissions not exceed the RAS thresholds (e.g., as defined in Rec. ITU-R RA.769). LNAs themselves are usually broadband and filters in front of the LNA would increase the noise figure significantly by virtue of their insertion loss, thus counteracting the effort to obtain the very low system noise required for high sensitivities. The maximum input power into the receiving systems should therefore be limited in order to protect the RAS from harmful interference that would degrade the operation of the station. The LNA, mixer, or the analog-digital conversion in the back-end (or the Rx as a whole) would otherwise be driven into the non-linear regime, which may lead to intermodulation (IM) products, saturation (non-linear gain), or even blocking.

Two well-known parameters describe the susceptibility of an LNA or Rx to these effects: the 1-dB compression point (“P1dB”) and the third-order intercept point (“IP3”). A detailed explanation is beyond the scope of this document, but more information can be found in Rec. ITU-R SM.1134. The P1dB marks the point where the transfer function (gain) of the Rx is 1 dB below the linear behaviour, i.e., when the Rx has already started to go into saturation. The IP3, on the other hand parametrises how strongly third order intermodulation products will emerge as a function of the input power (consisting at least of two tones).

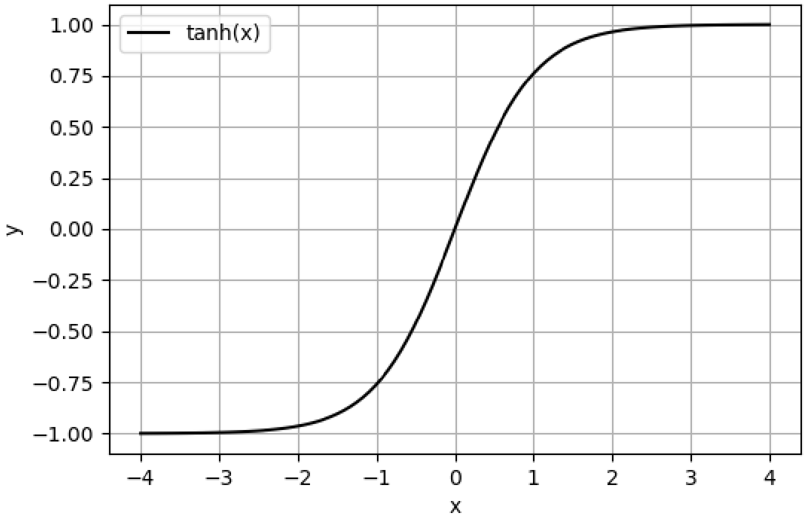


Figure 101: LNA transfer function used for numerical experiments to analyse intermodulation products

Technically, the gain of an amplifier is desired to be linear over as much of a range of input voltages as possible, but at some voltage the transfer function of the device, e.g., of a field effect transistor, will tend to flatten out. Real devices will have a variety of response curves, but none will feature perfect linearity, even below the saturation regime. Here, the effect of intermodulations was studied using an idealised unit gain transfer function such as the hyperbolic tangent (see Figure 102). For analysing (two-tone) intermodulation products one may calculate the Taylor expansion of the tanh-function to a certain order and feed two (co-)sine waves with different frequencies into the series. Apart from the fundamental waves at the two frequencies, $f_{1/2}$, one will find other products in the result with the difference and sum of the two input frequencies, multiples of each frequency ("harmonics"), and higher order products, e.g. $2f_1 - f_2$ or $2f_2 - f_1$.

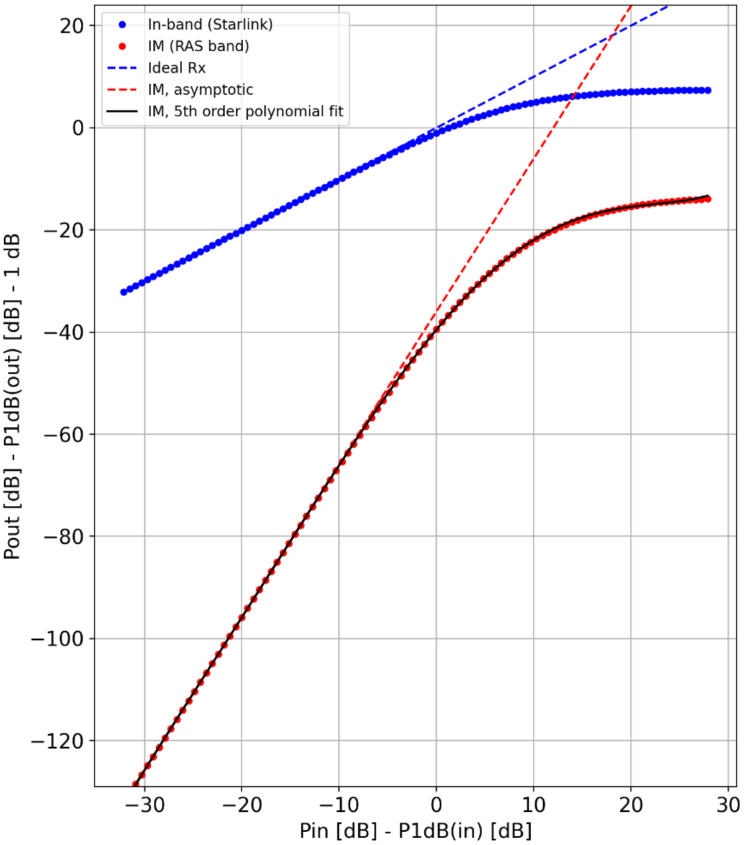


Figure 102: Results of numerical experiments to find the intermodulation product's average power in the RAS band 10.6-10.7 GHz

Modern communication uses broad band modulation schemes (e.g. ODFM) that have a greater spectrum efficiency than strong narrowband carriers. As an example, we set up a numerical simulation to determine the power of all possible intermodulation products caused by the SpaceX satellite constellation's large-bandwidth carriers affecting the RAS Rx at more than 100 MHz separation in frequency. In the first step a band-limited white noise signal is created, with edge frequencies of 10.95 and 12.75 GHz. This signal is then passed through into the tanh-transfer function simulating the response of the receiver. The result can be spectrally analysed and the power in the RAS band (10.6–10.7 GHz) relative to the Tx power is determined. The procedure is repeated for a range of input signal strengths, which leads to the IM curve in Figure 103. As a sanity check, the same procedure is used to measure the power in the Tx band, which should show the saturation effect at some input power level. As can be seen in Figure 103 this is indeed the case and the resulting curve can be used to determine the P1 dB. The IM curve is dominated by third order products at low input powers (i.e., the slope of the curve is three times steeper than for the output power in the Tx band), but at high input powers the curve also goes into a state of saturation.

A4.1 EPFD SIMULATIONS REGARDING INTERMODULATION PRODUCTS

For further application of the results in an EPFD simulation it is convenient to normalise the resulting curves to the P1 dB point. The horizontal axis in the plot is displayed relative to the input power level of the P1dB, while the vertical axis is with respect to the output power level of the P1dB plus 1 dB (i.e., it is normalized to the power level that an ideal receiver with a fully linear behaviour would yield, when the P1dB input power level is fed into the device). In the following, both, OneWeb and Starlink constellations were simulated and the effective pdf values in the RAS band owing to intermodulation products were determined.

A4.1.1 OneWeb constellation

For OneWeb the situation is more complex with respect to the intermodulation calculation. As each of the satellite beams serves only one carrier, the in-band spectrum received at the RAS receiver consists of several carrier bands that usually have different amplitudes. As the number of possible combinations of different amplitudes for these carriers is very high, it is not possible to pre-compute a transfer function as in the case of Starlink. For every iteration and time step in the EPFD simulation, the IM calculation has to be repeated based on the received power in each carrier band, which is very time consuming. The results are displayed in Figures Figure 115 to Figure 120.

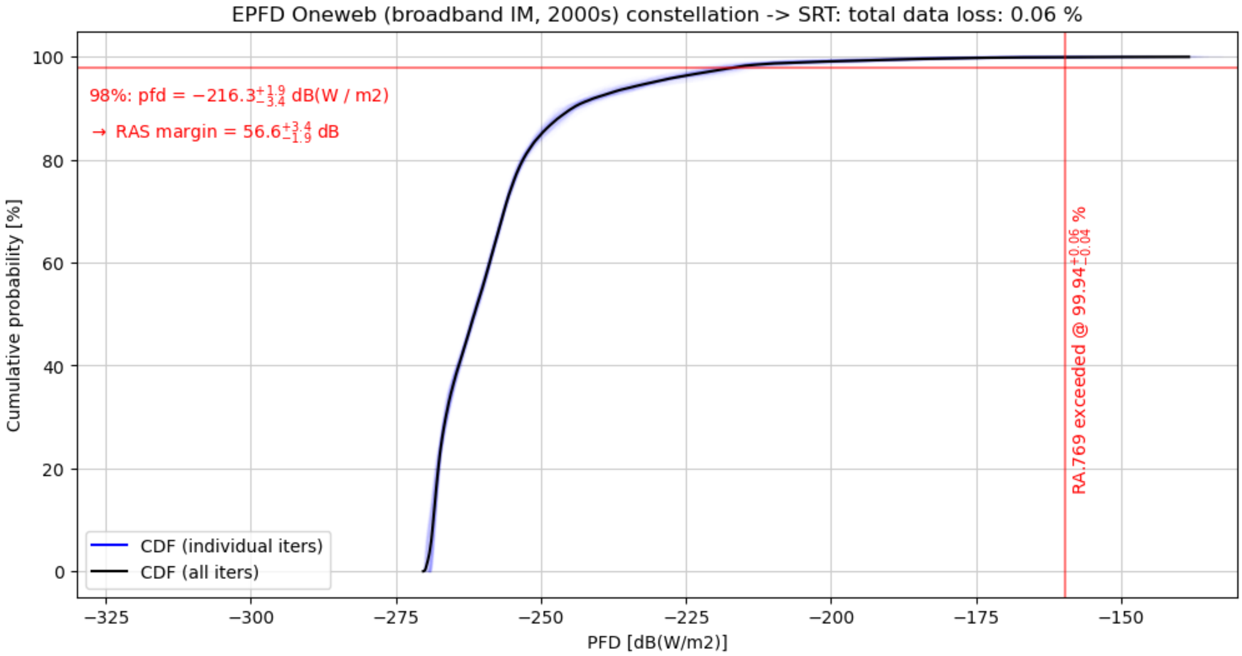


Figure 103: As Figure 115 but for the Sardinia Radio Telescope (SRT).

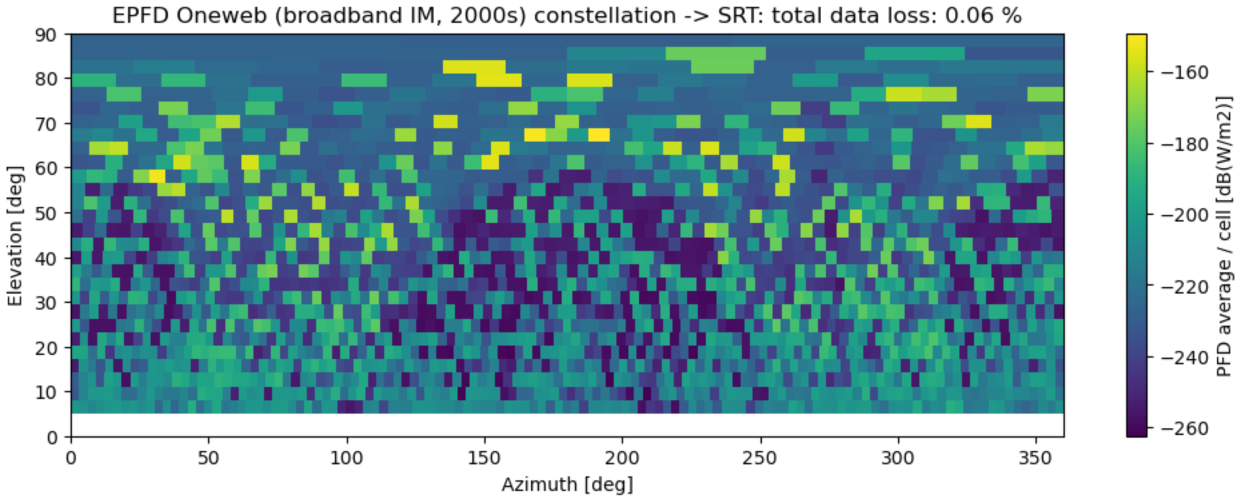


Figure 104: As Figure 116 but for the Sardinia Radio Telescope (SRT).

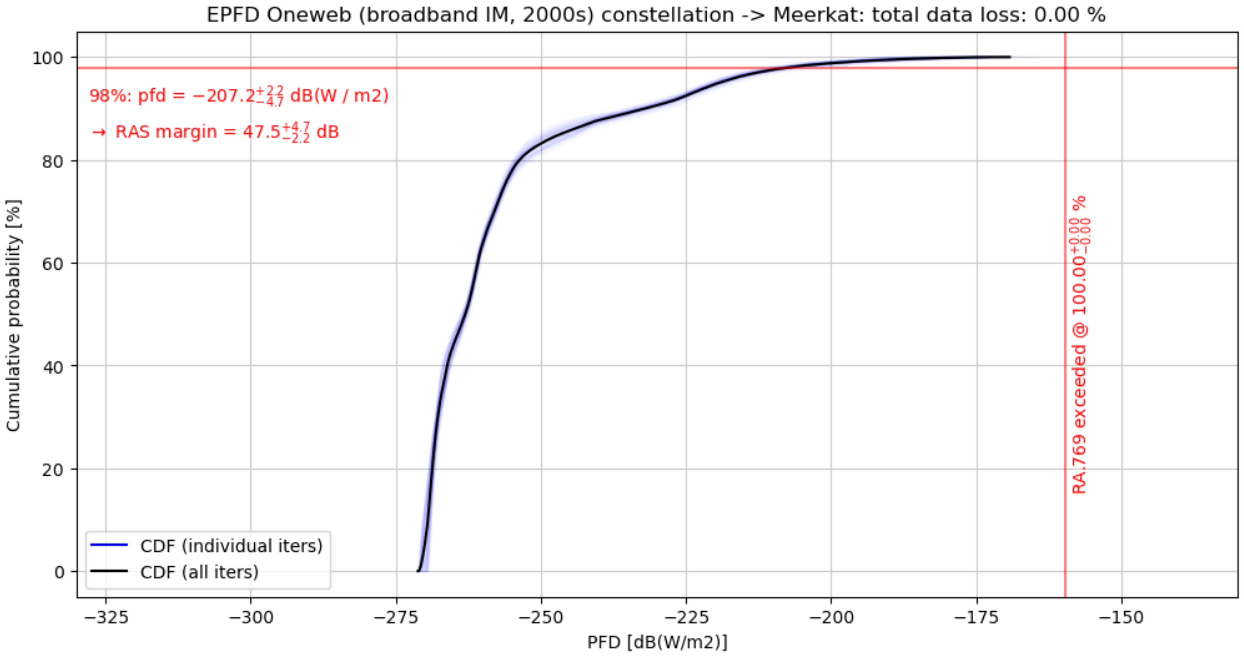


Figure 105: As Figure 115 but for the MeerKAT observatory.

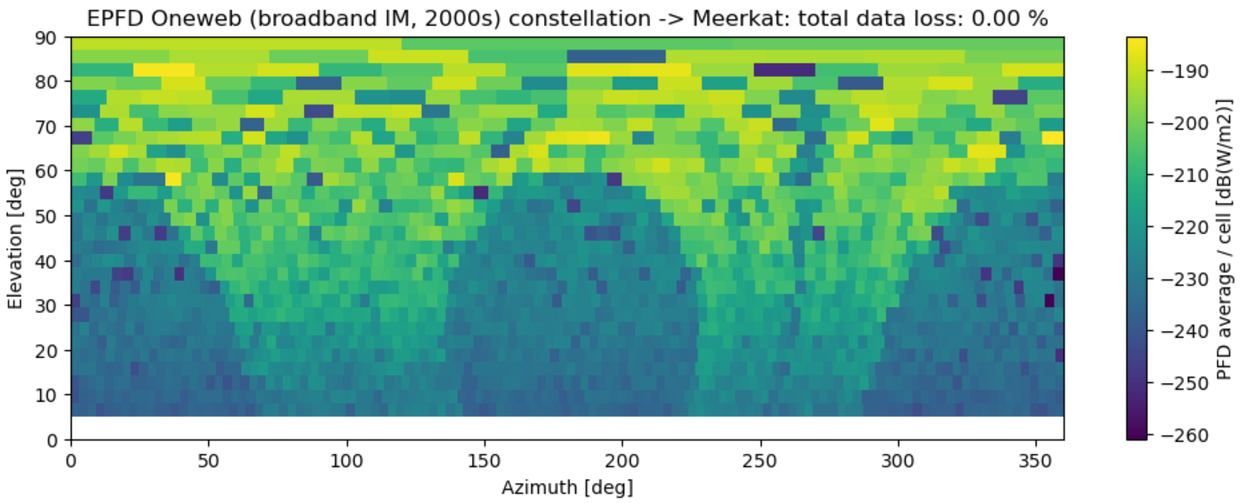


Figure 106: As Figure 116 but for the MeerKAT observatory.

A4.1.2 Starlink constellation

For Starlink, one can avoid the numerical complexity related to the IM calculation explained above by fitting the IM curve with a polynomial of 5th degree:

$$y = -39.52139 + 2.292161x - 4.664958 \cdot 10^{-2}x^2 - 9.219656 \cdot 10^{-4}x^3 + 1.567556 \cdot 10^{-5}x^4 + 5.394738 \cdot 10^{-7}x^5,$$

which can be easily converted to an equivalent input IM power indB[W] units, when the P1 dB is known.

$$IM_{input} = y(P_{in} - P1_{dB}) + P1_{dB}\ [dBW]$$

$$EPFD_{IM} = IM_{input} - A_{eff}\ \left[\frac{dBW}{m^2}\right]$$

For the analysis of the aggregated IM power by means of an EPFD simulation, the total in-band power over the full range of the downlink band (10.95 and 12.75 GHz) was used, again for the example of the SpaceX system (ECC Report 271, Figure 107 contains the spectral e.i.r.p. values for each individual satellite). The power received by the RAS station is then converted to the appropriate IM power. For this, it was assumed that the P1dB of the RAS Rx is about −30 dBm. It is important that this conversion is done before averaging in time, i.e., the instantaneous in-band power must be converted to IM power and then averaged over the 2000 s RAS integration time (see Rec. ITU-R RA.769). The results are shown in Figure 103 to Figure 129 for the Effelsberg observatory in Germany, which uses a 100-m telescope, the 64-m Sardinia Radio Telescope (SRT) in Italy, and the SKA pathfinder experiment MeerKAT in South Africa, which features a large array of 13.5-m dishes to test, how much the geographic position and telescope size influences the result. While the exact values of the total data loss vary a bit, the qualitative results are the same: about one quarter to one third of the data could be lost according to the numerical simulations.

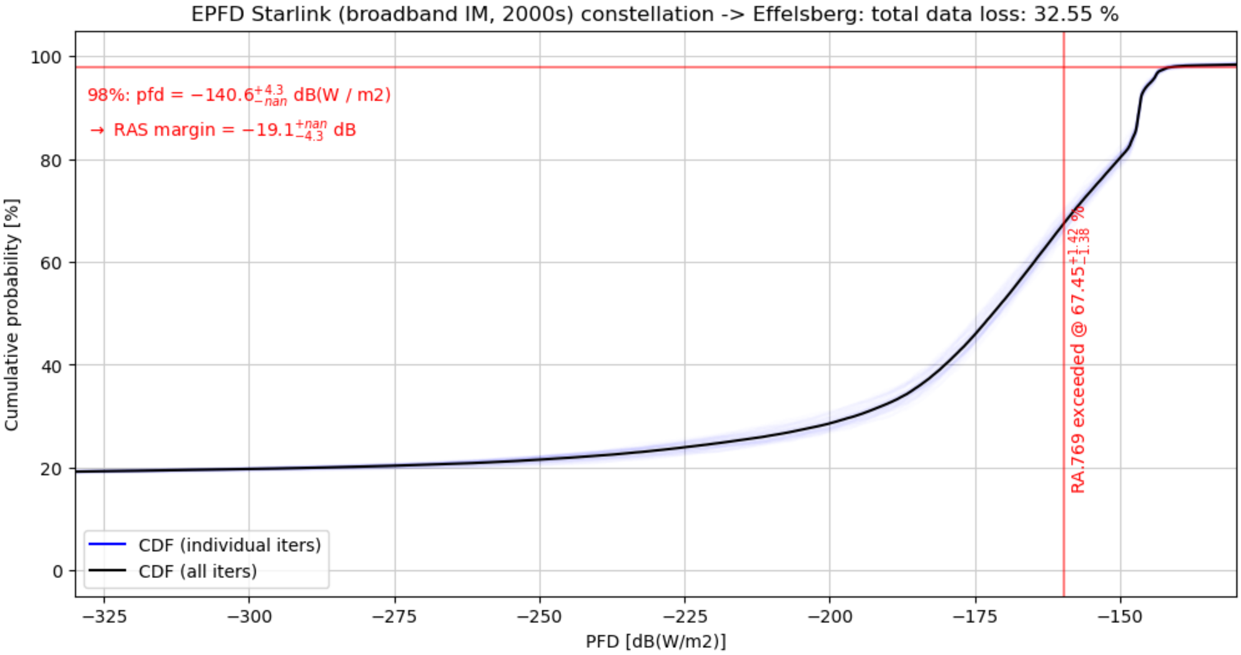


Figure 108: Cumulative probability distribution of the received power flux densities of each simulation run (blue curves) and the median of all runs (black curve) for the Effelsberg observatory.

As there are a few runs, where the total received power flux density was extremely low (no satellite passed close to the RAS pointing direction), lower error for the pfd (and upper error for the margin) are NaN (not a number) for numerical reasons.

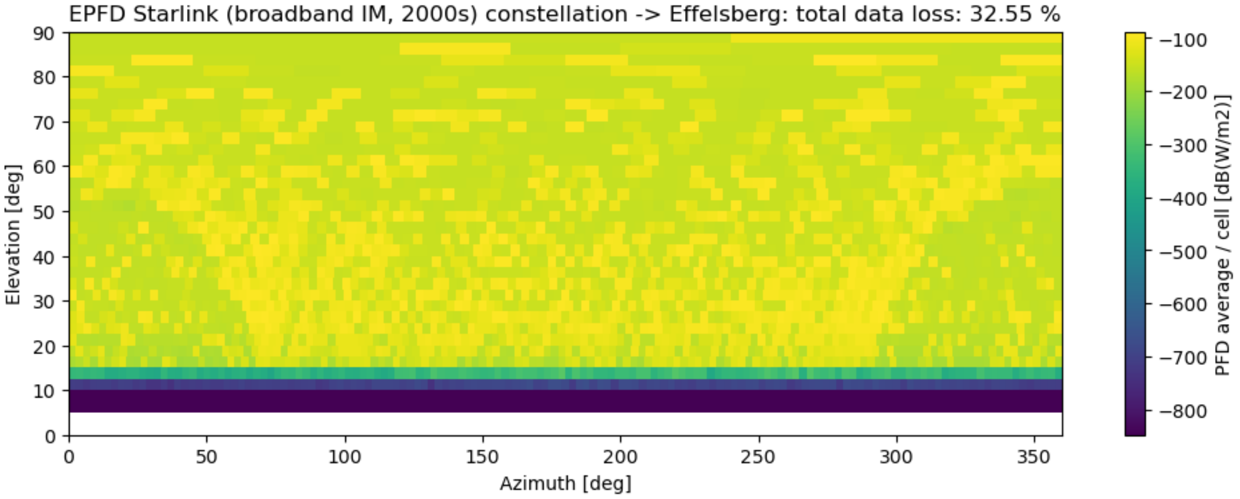


Figure 109: Average (over all Starlink simulation runs) received power flux density for each simulated sky cell for the Effelsberg observatory

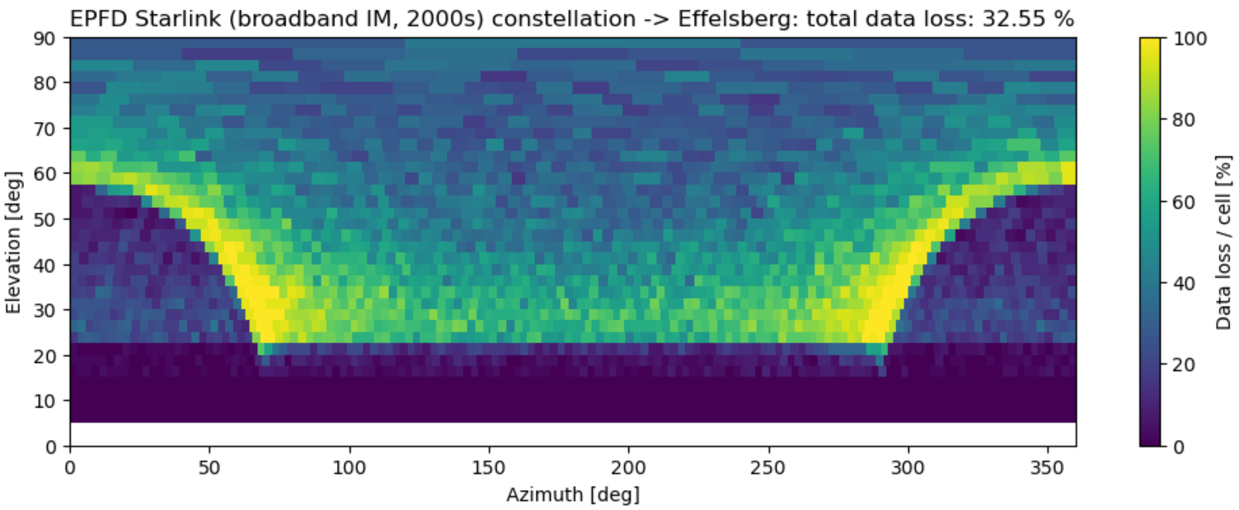


Figure 110: Data loss (percentage of the simulated Starlink runs, for which the received power flux density exceeded the RAS threshold) for each simulated sky cell for the Effelsberg observatory

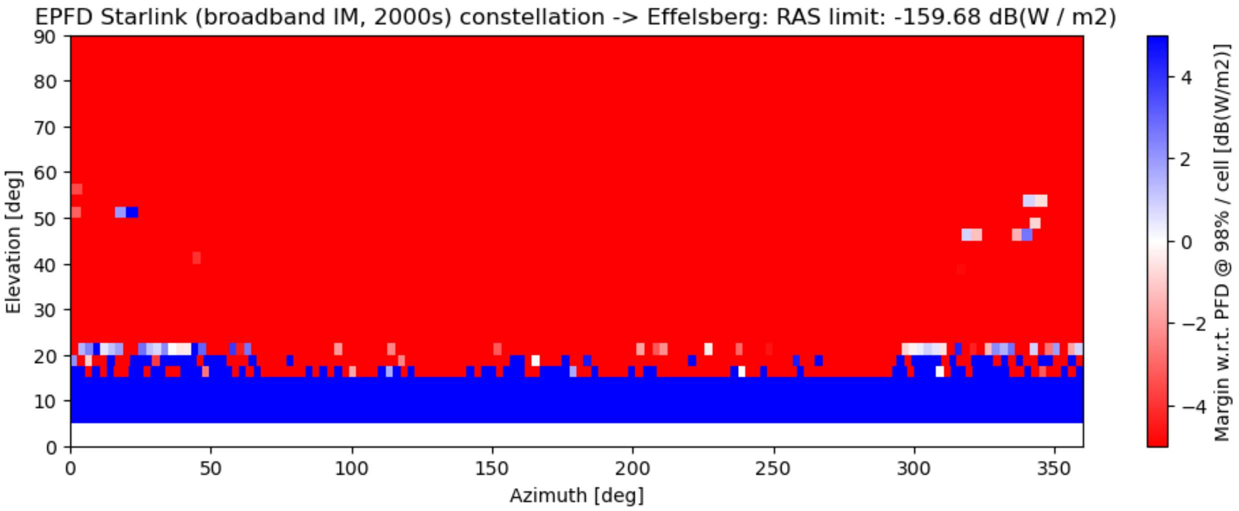


Figure 111: Margin for each sky cell, which is the difference of the 98% percentile of the received power flux density of all Starlink simulation runs to the RAS threshold level for the Effelsberg observatory. A negative margin means, that the threshold is exceeded in a given sky cell

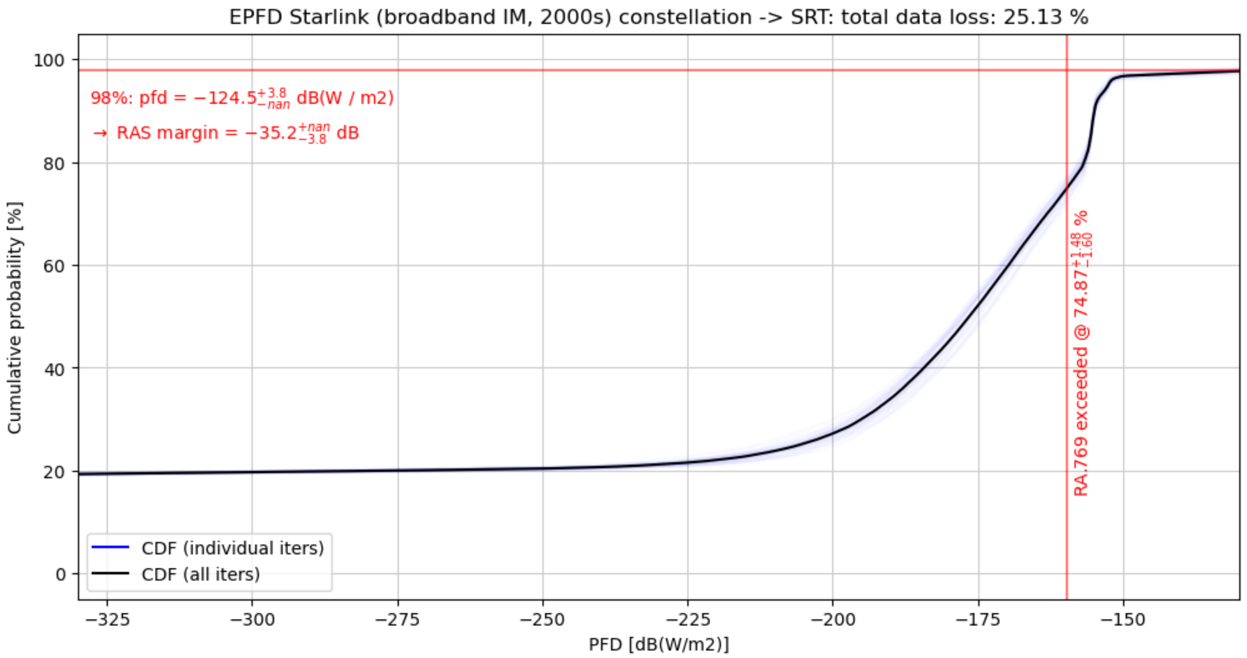


Figure 112: As Figure 103 but for the Sardinia Radio Telescope (SRT)

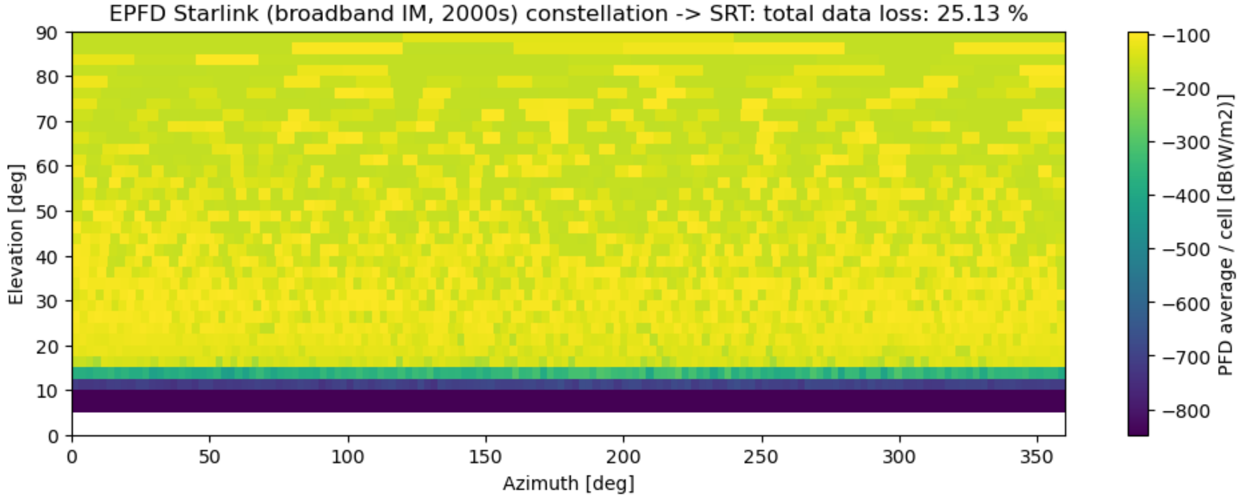


Figure 113: As Figure 104 but for the Sardinia Radio Telescope (SRT)

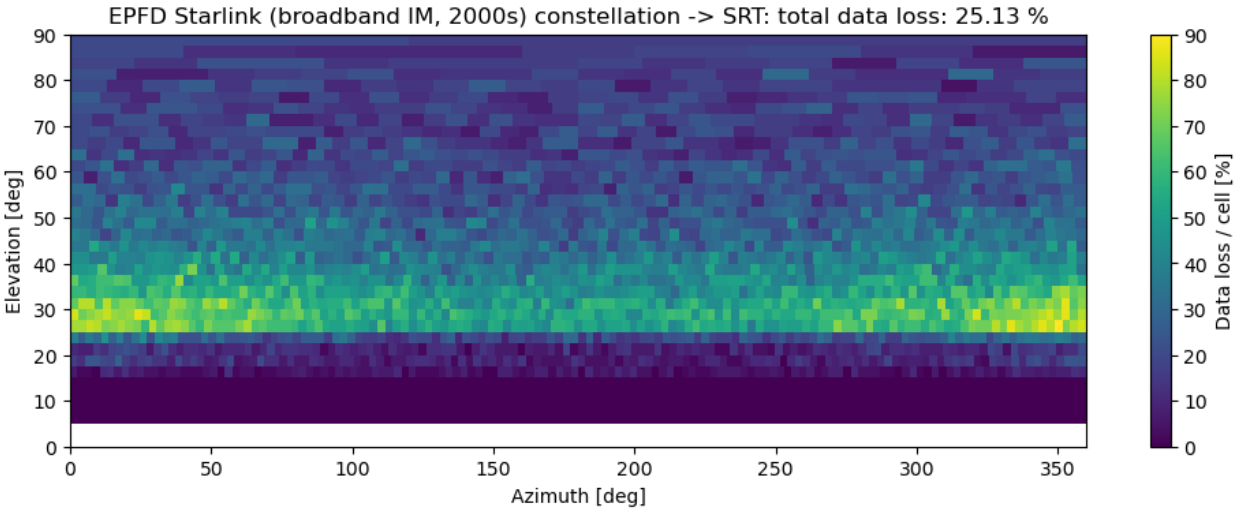


Figure 114: As Figure 105 but for the Sardinia Radio Telescope (SRT)

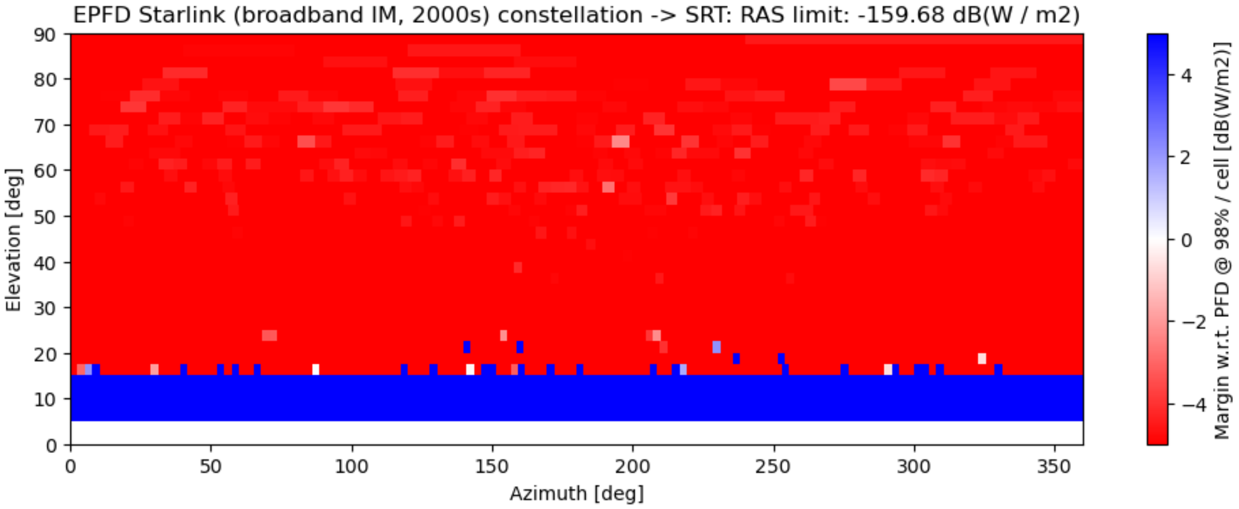


Figure 115: As Figure 106 but for the Sardinia Radio Telescope (SRT)

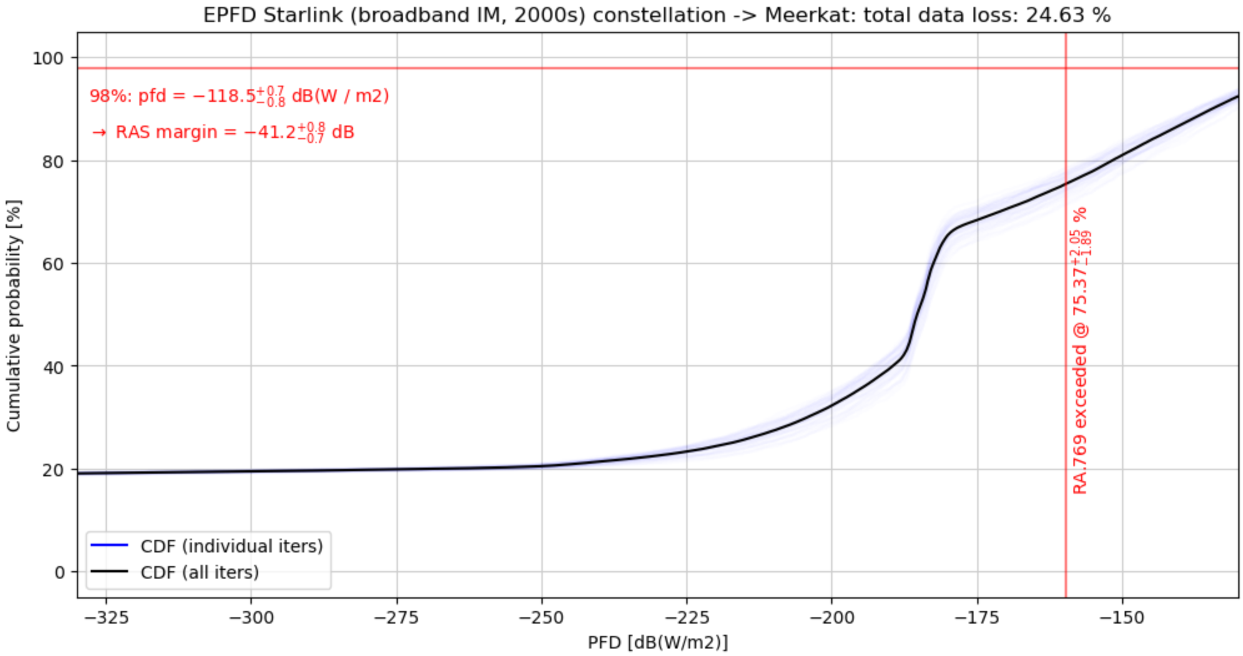


Figure 116: As Figure 103 but for the MeerKAT observatory

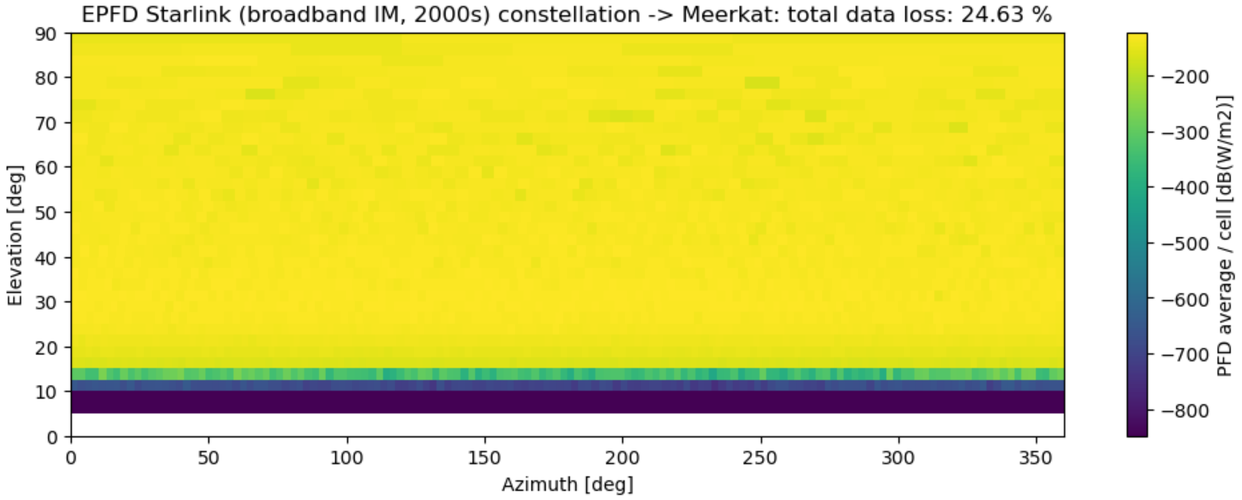


Figure 117: As Figure 104 but for the MeerKAT observatory

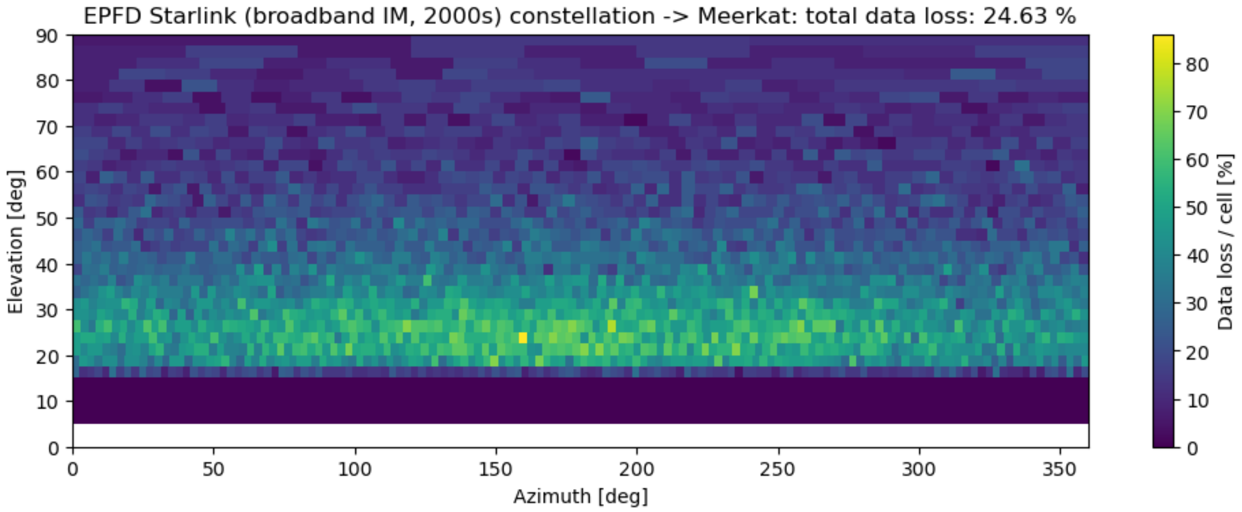


Figure 118: As Figure 106 but for the MeerKAT observatory

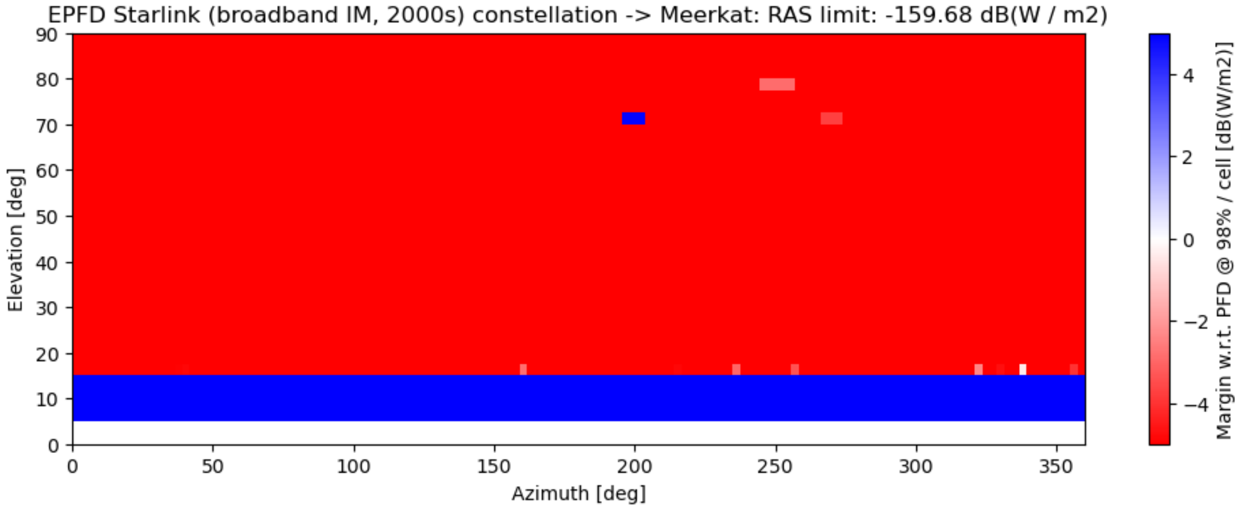


Figure 119: As Figure 106 but for the MeerKAT observatory

ANNEX 5: LIST OF REFERENCES

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[2] ECC Report 272: “Earth Stations operating in the frequency bands 4-8 GHz, 12-18 GHz and 18-40 GHz in the vicinity of aircraft”, January 2018

[3] ECC Report 173: "Fixed Service in Europe Current use and future trends post 2016”, updated April 2018

[4] ITU Radio Regulations Edition of 2016

[5] Recommendation ITU-R P.452: “Prediction procedure for the evaluation of interference between stations on the surface of the Earth at frequencies above about 0.1 GHz”

[6] Recommendation ITU-R SA.1414: “Characteristics of data relay satellite systems”

[7] Recommendation ITU-R F.758: “System parameters and considerations in the development of criteria for sharing or compatibility between digital fixed wireless systems in the fixed service and systems in other services and other sources of interference”

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[10] Recommendation ITU-R P.530: “Propagation data and prediction methods required for the design of terrestrial line-of-sight systems”

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[12] Recommendation ITU-R RA.1631: “Reference radio astronomy antenna pattern to be used for compatibility analyses between non-GSO systems and radio astronomy service stations based on the epfd concept”

[13] Recommendation ITU-R RA.1513: “Levels of data loss to radio astronomy observations and percentage-of-time criteria resulting from degradation by interference for frequency bands allocated to the radio astronomy service on a primary basis”

[14] Recommendation ITU-R RA.769: “Protection criteria used for radio astronomical measurements”

[15] Recommendation ITU-R M.1583: “Interference calculations between non-geostationary mobile-satellite service or radionavigation-satellite service systems and radio astronomy telescope sites”

[16] Recommendation ITU-R S.1586-1: “Calculation of unwanted emission levels produced by a non-geostationary fixed-satellite service system at radio astronomy sites”

[17] Recommendation ITU-R M.1643: “Technical and operational requirements for aircraft earth stations of aeronautical mobile-satellite service including those using fixed-satellite service network transponders in the band 14-14.5 GHz (Earth-to-space)”

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[20] Recommendation ITU-R F.1108: “Determination of the criteria to protect fixed service receivers from the emissions of space stations operating in non-geostationary orbits in shared frequency bands”

[21] Recommendation ITU-R F.1494: “Interference criteria to protect the fixed service from time varying aggregate interference from other services sharing the 10.7-12.75 GHz band on a co-primary basis”

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[26] Recommendation ITU-R RS.2017: “Performance and interference criteria for satellite passive remote sensing”

[27] ITU-R Document 7B/23-E:”WORKING DOCUMENT TOWARDS CPM TEXT REGARDING SHARING BETWEEN AMSS AND SPACE RESEARCH SERVICES IN THE 14-14.5 GHz BAND”, 1 May 2001

[28] Document 7E/46-E, “WORKING DOCUMENT TOWARDS CPM TEXT REGARDING SHARING BETWEEN AMSS AND SPACE RESEARCH SERVICES IN THE 14-14.5 GHz BAND”, 8 October 2001