Electronic Communications Committee

ECC Report 271

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 EES 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.

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. In general, any NGSO FSS satellite emissions shall not exceed an epfd value of -241 dBW/m² in the band 10.6-10.7 GHz for more than 2% of the time. 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.

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 in the 10.6-10.7 GHz band for more than 2% of the time (with a 100m victim antenna using Recommendation ITU-R S.1428 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 -142 dBW/Hz prevents SpaceX from using the lowest Ku-band channel (10.7-10.95GHz) on a global basis.

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 protection 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 ES characteristics, as well as the surrounding terrain. The typical size of these protection zones for the FSS terminals with an e.i.r.p. of -33 dBW/(40 kHz) towards the horizon has been determined to be in the order of 33 km in the 37 dBi FS antenna main beam direction (assuming smooth Earth), but decreases rapidly down to 2 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 -33 dBW/(40 kHz) the size of the area can be up to 200 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 no need for any separation distance from the shore to protect FS stations close to the coast assuming FSS terminals with a total e.i.r.p. of -13 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 protection zones up to 200 km for NGSO FSS terminals with e.i.r.p. of -33 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 protection 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 protection 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 protection 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.

The studies related to SpaceX 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.
- 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 protection 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
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
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.

[1] ECO Frequency Information System: www.efis.dk

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.

[2] 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:

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

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

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

therefore

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

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.

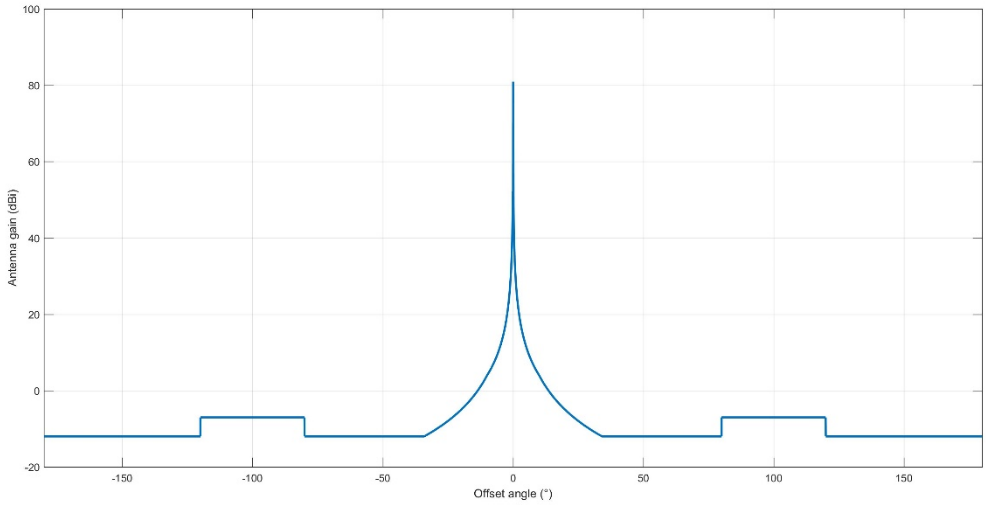

Figure 1: RAS antenna pattern (basic version)

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.

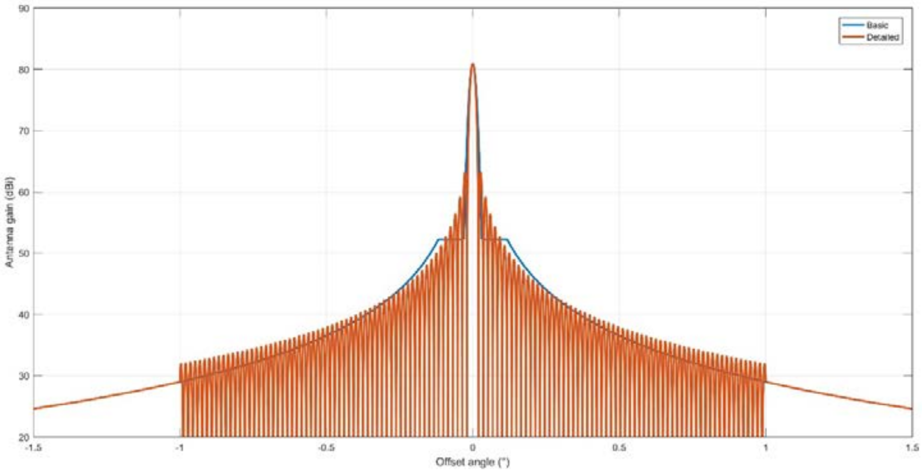

Figure 2: RAS antenna pattern (detailed version - zoomed around the main beam)

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°
	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°
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°
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/m², 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/m².

The value -241 dBW/m^2 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 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/m²/(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°
Italy	Medicina	11° 38′ 49″	44° 31′ 15″	32 m	5°
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°

4.3 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 two satellites, Meteor-M №1 (launched in 2009) and Meteor-M №2 (launched in 2014), 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 0.65 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 applied to increase accuracy. Cold calibration channel receiving antenna (0.24*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). The above values should not to 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. In general, any NGSO FSS satellite emissions shall not exceed an epfd value of -241 dBW/m^2 in the band 10.6-10.7 GHz for more than 2% of the time. 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.

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 protection 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 ES characteristics, as well as the surrounding terrain. The typical size of these protection zones for the FSS terminals with an e.i.r.p. of -33 dBW/(40 kHz) towards the horizon has been determined to be in the order of 33 km in the 37 dBi FS antenna main beam direction (assuming smooth Earth), but decreases rapidly down to 2 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 -33 dBW/(40 kHz) the size of the area can be up to 200 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 no need for any separation distance from the shore to protect FS stations close to the coast assuming FSS terminals with a total e.i.r.p. of -13 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 protection zones up to 200 km for NGSO FSS terminals with e.i.r.p. of -33 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 protection zones, 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 protection 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 protection 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.

ANNEX 1: ONEWEB NGSO FSS SYSTEM

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

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	720
Orbits	Polar orbits
Number of planes	18
Number of satellites per plane	40
Altitude (km)	1200
Inclination (°)	87.9
Note: Additional satellites will be launched as spare satellites but will not be active.	

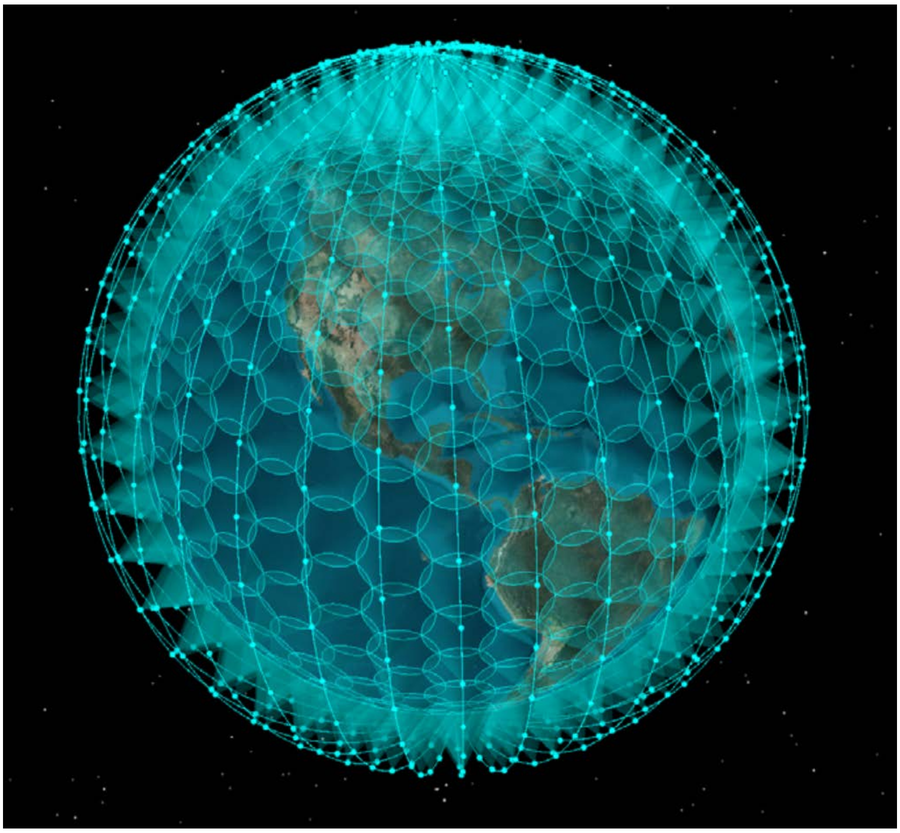

Figure 3: Configuration of the OneWeb NGSO satellite constellation

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 58 and 77. At the equator, this number is between 35 and 43.

The satellite antenna in Ku-band consists of 16 beams. Figure 2 provides the -3 dB aperture of each of the beams both along and across the satellite path.

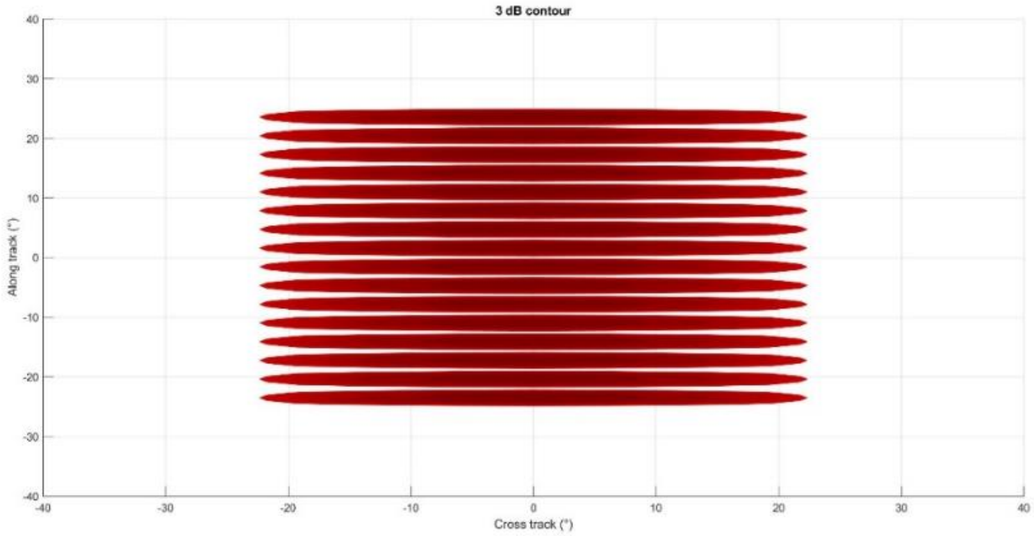

Figure 4: -3 dB composite antenna aperture

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

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 5.

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

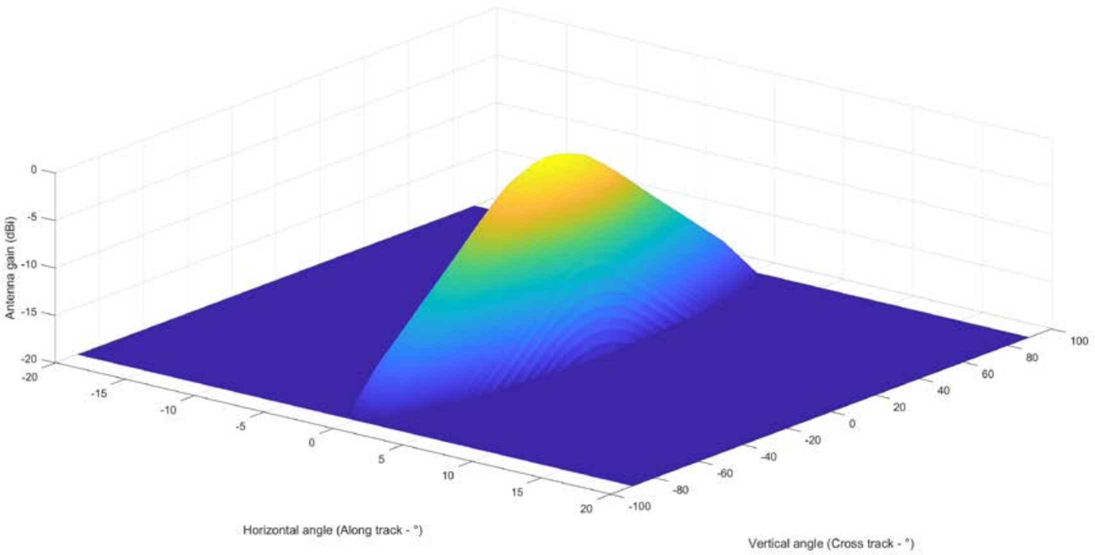

Figure 5: -3 dB composite antenna aperture

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

As shown in Figure 6, the OneWeb satellite antenna covers an area of about 1100 km x 1100 km on the earth. Given the orbit altitude of 1200 km it can be calculated that the NGSO FSS earth stations will point at a minimum elevation of 57°, which is much higher than the minimum elevation that could be used by a GSO VSAT for instance.

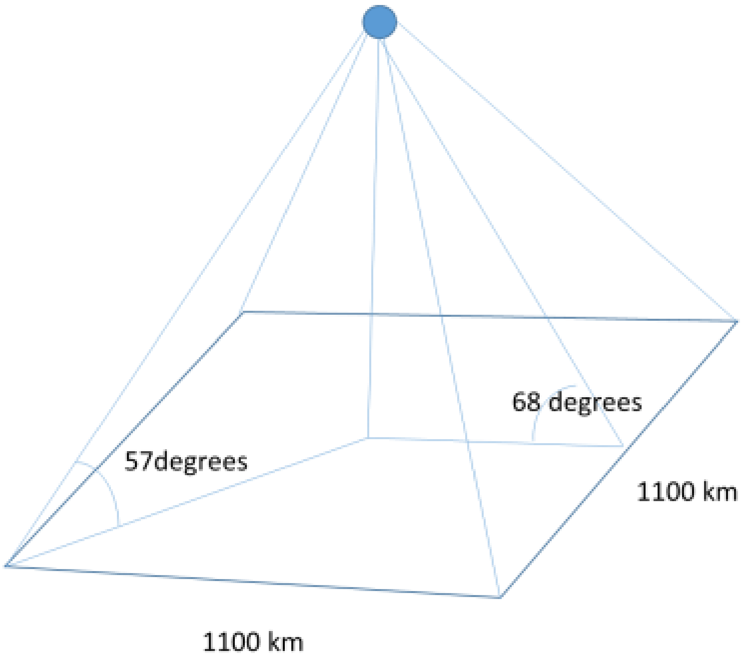

Figure 6: Determination of the minimum elevation angle

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.

It should be noted that OneWeb NGSO satellite system plans to deploy 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		

Parameter	Units	Consumer earth station	Enterprise earth station	Notes
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.				

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 protection 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 protection 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 6. For the subsequent studies, an antenna height of 20 m has been assumed.

Figure 7: Example of parabolic antenna

An e.i.r.p. mask for OneWeb fixed earth stations indicate that the off-axis e.i.r.p. within this domain varies between -20 dBW/(40 kHz) and -17 dBW/(40 kHz) depending on the offset angle, as shown in Figure 8.

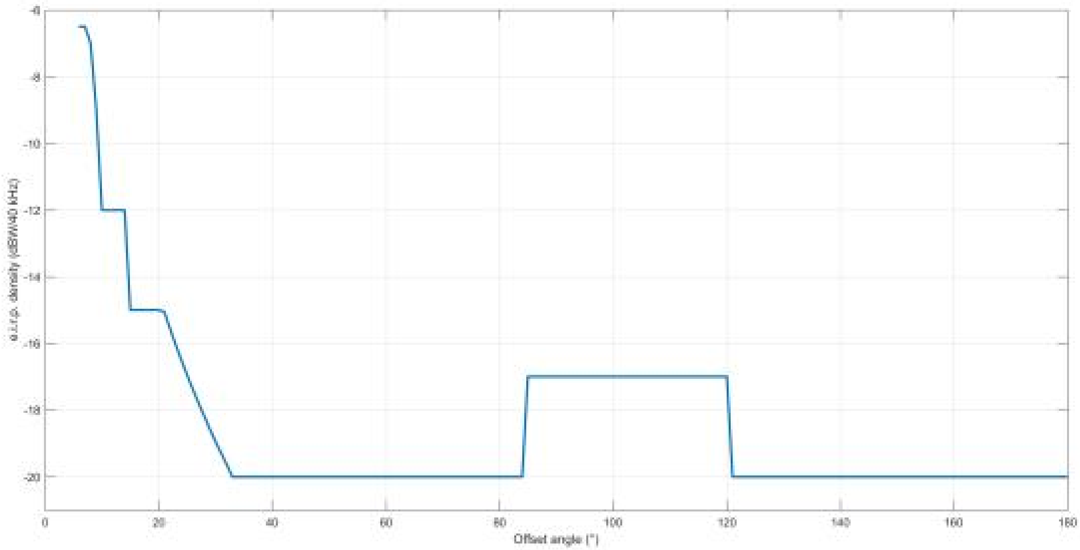

Figure 8: e.i.r.p. mask for parabolic antennas

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 9 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 9: Aircraft earth station

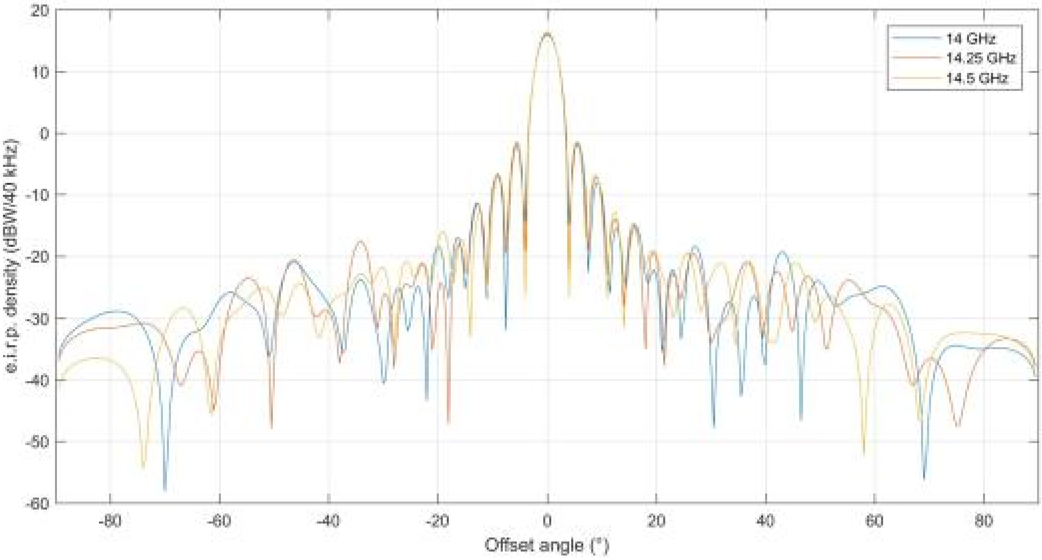

Figure 10: e.i.r.p. mask for the phased array antenna (dBW/(40 kHz)) for 90° pointing for three frequencies (14, 14.25 and 14.5 GHz)

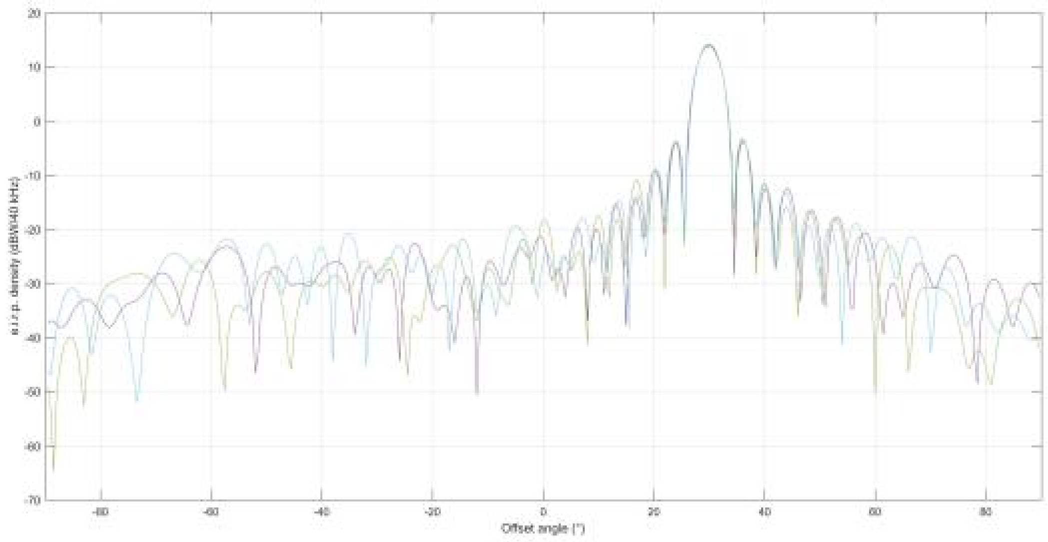

Figure 11: e.i.r.p. mask for the phased array antenna (dBW/(40 kHz)) for 120° pointing for three frequencies (14, 14.25 and 14.5 GHz)

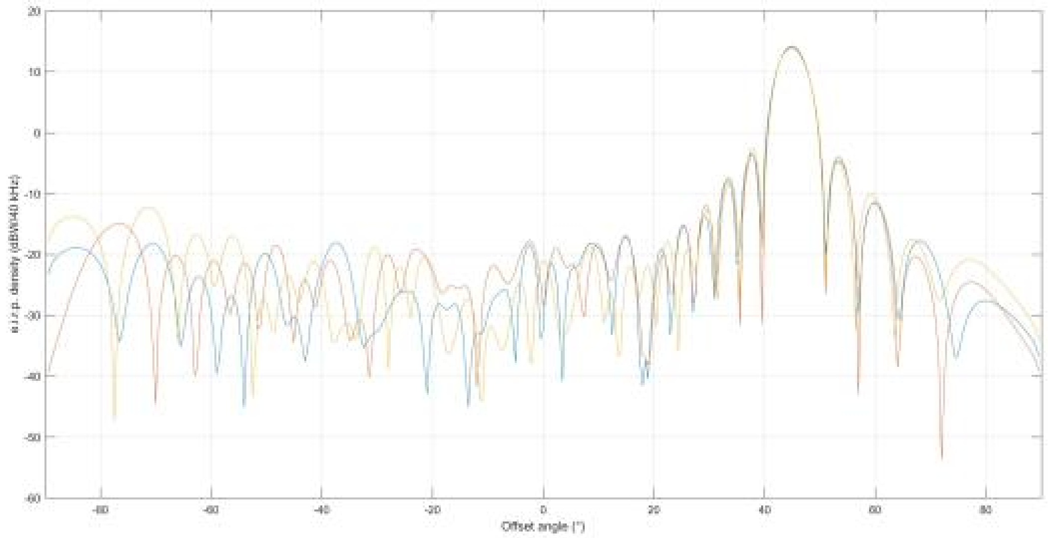

Figure 12: e.i.r.p. mask for the phased array antenna (dBW/(40 kHz)) for 45° pointing for three frequencies (14, 14.25 and 14.5 GHz)

E.i.r.p. masks in Figure 10, Figure 11 and Figure 12 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.

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 elevation angles with an offset above 60° with respect to the maximum antenna gain; this value increases up to -15 dBW/(40 kHz) for elevation angles lower than 60°, due to appearance of grating lobes. This is 5 dB higher than the -20 dBW/(40 kHz) considered for earth stations at fixed location. However, 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. The modelling of such tracking leads to the distribution of elevation angles as shown in Figure 13 for land and shipborne ESIM; it is noted that, most of the time (99.5%), the elevation angle stays above 60° and never goes below 57°. This is consistent with

Figure 6, which demonstrated the minimum elevation angles of the earth station at the edges of the coverage area of an OneWeb satellite.

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.

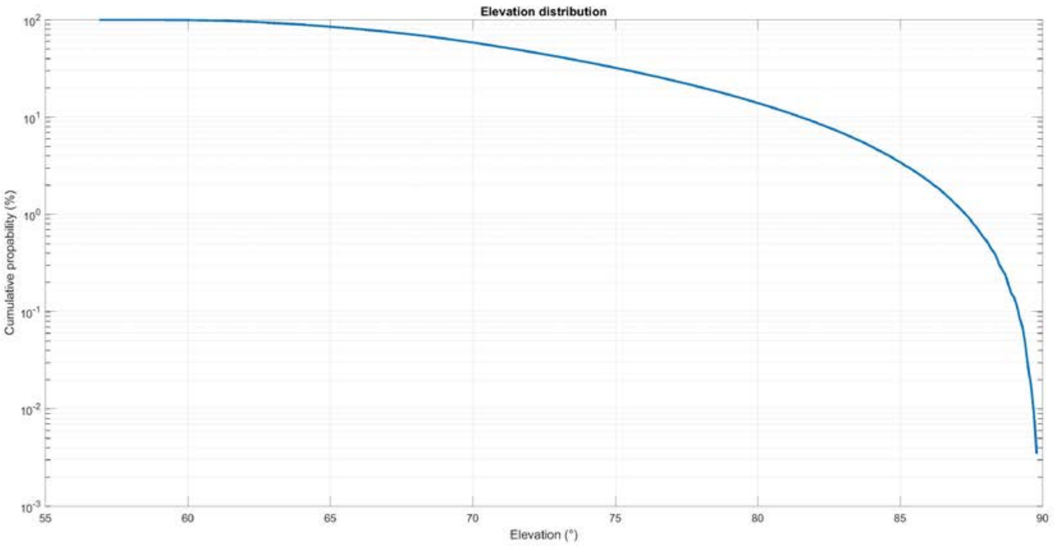

Figure 13: Distribution of FSS Earth station antenna pointing elevations

A peak e.i.r.p. of -30 dBW/(40 kHz) and an averaged e.i.r.p. of -33 dBW/(40 kHz) were considered for the land and shipborne ESIM studies.

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

For these e.i.r.p. levels in the RAS band, the overall data loss at Effelsberg is 1.93% distributed over the sky as shown in Figure 14.

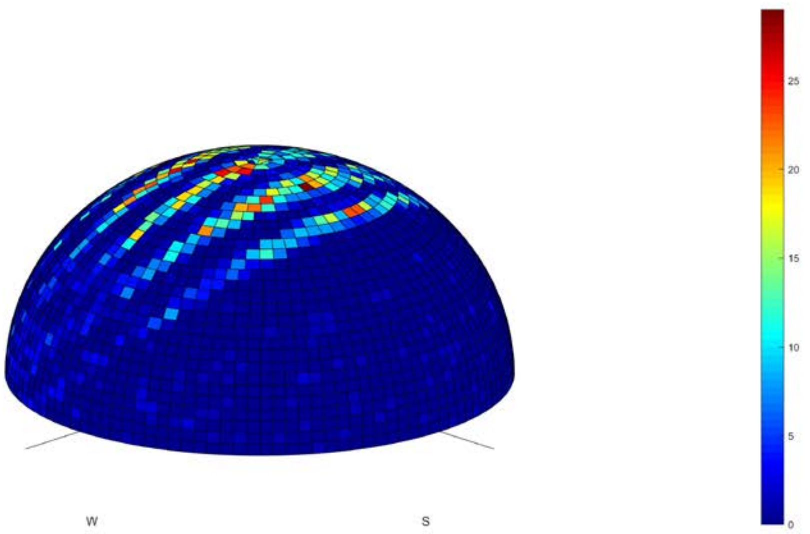

Figure 14: Plot of the data loss over sky

The maximum level of exceedance of the epfd threshold in dB over the sky over all trials is given in Figure 15.

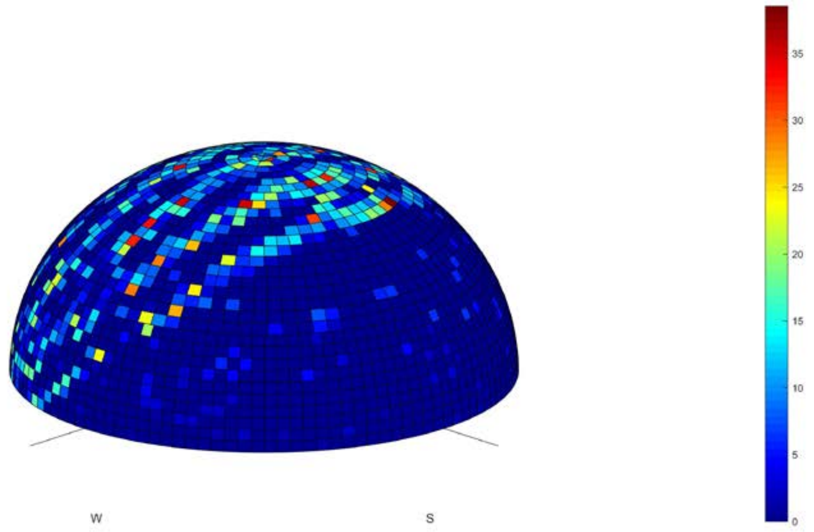

Figure 15: Maximum exceedance of epfd threshold

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 1 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 1, 5, 9 and 13 have respectively an offset angle of -23.5°, -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 62° (at about 180° azimuth), 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 62° (at about 0° azimuth), 77° (0° azimuth), 88° (180° azimuth) and 73° (180° azimuth). This shows why there will be 5 different stripes of highest data loss on the sky instead of 4, spreading as follows:

- One at 62° elevation and 180° azimuth;
- 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;
- One at 62° elevation and 0° azimuth.

Figure 16 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.

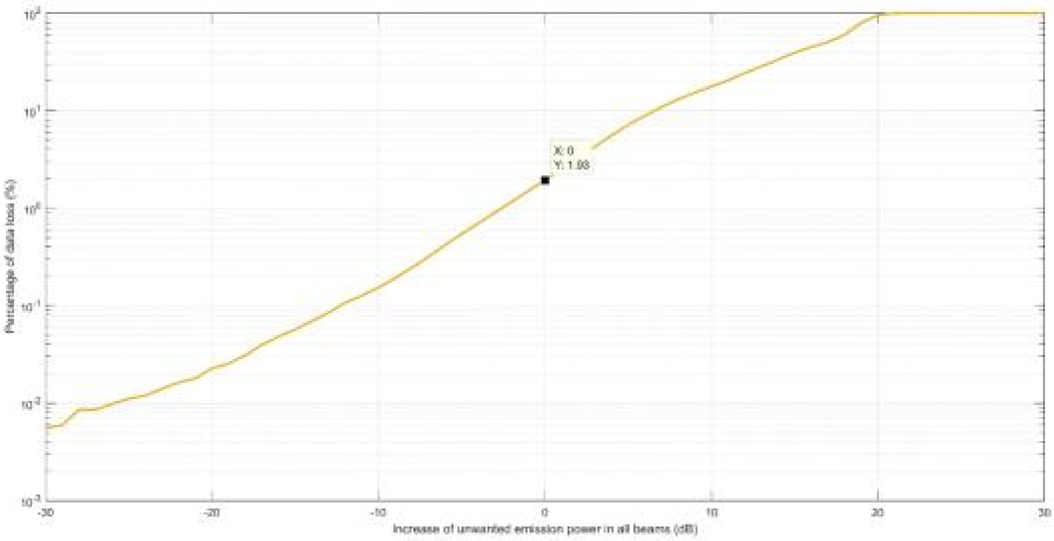

Figure 16: Evolution of the data loss when the unwanted emission level is decreased or increased over all beams

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 17 this would leave limited possibilities for the usage of this channel.

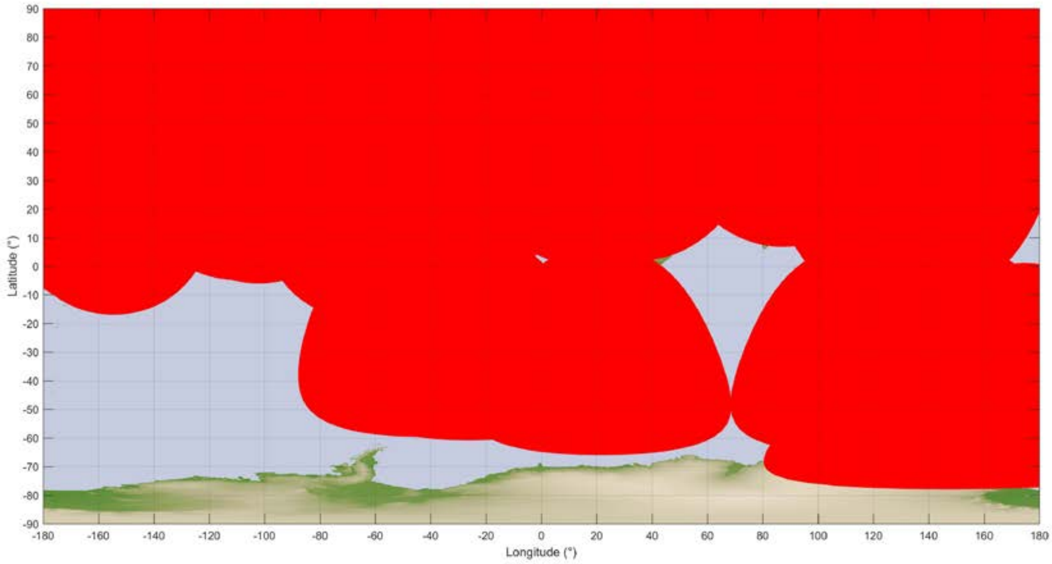

Figure 17: Visibility areas of RAS stations performing observations in the 10.6-10.7 GHz band

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 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 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 4.1. All four beams per satellite, employing 10.7-10.95 GHz band, are assumed to be active. A maximum unwanted emission e.i.r.p. of -5 dBW in the 100 MHz is assumed for OneWeb NGSO satellites. For all OneWeb satellites, the relative gain pattern from section 4.1 was used (Table 4). The Meteor-M 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 satellites has a scanning sector 105 degrees wide (angle alpha changing from 165 to 270 degrees, 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. 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 satellite. Taking into account 2.5 second scan period of Meteor-3M primary sensor antenna, time step of 0.1 second was used for the first interference scenario (interference into main beam through side lobes). For the second interference scenario (interference into cold calibration channel), a time step of one second was used. Due to the relation between the orbital periods of OneWeb and Meteor M satellites, it is preferable to run the simulation during at least ten times more than Meteor-3M orbital period (36 Hours).

For the first interference scenario, a peak interference of -177.9 dBW/100 MHz was recorded, which is about 10 dB lower than protection criterion and therefore should only be considered when interference from GSO systems is close to the threshold level. Maximum aggregate interference from GSO FSS constellation reached -173.8 dBW/100 MHz, which in total is around – 172.4 dBW/100 MHz.

On the other hand, interference into cold calibration channel is exceeding -166 dBW/100 MHz for 6.7% of time and interference level of -168 dBW/100 MHz is exceeded in 13.5% of time. Peak interference in this case will be -160.8 dBW/100 MHz, which may lead to significant degradation of measurements. 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) in the 100 MHz will change peak interference to -190.7 dBW/100 MHz, 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:

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

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 18 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).

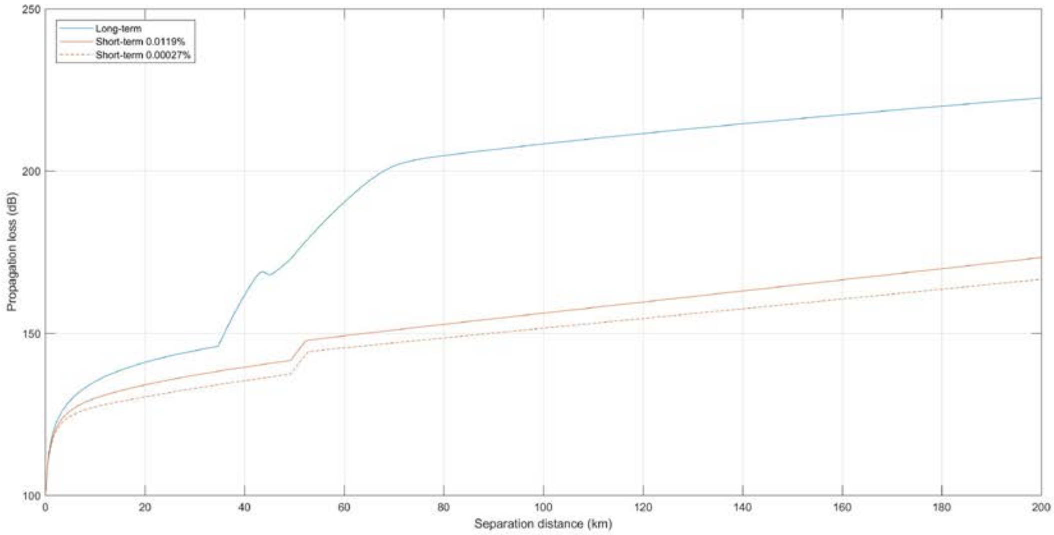

Figure 18: Recommendation ITU-R P.452 Propagation loss over flat terrain

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 20 for a FS station pointing North.

Figure 20 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.

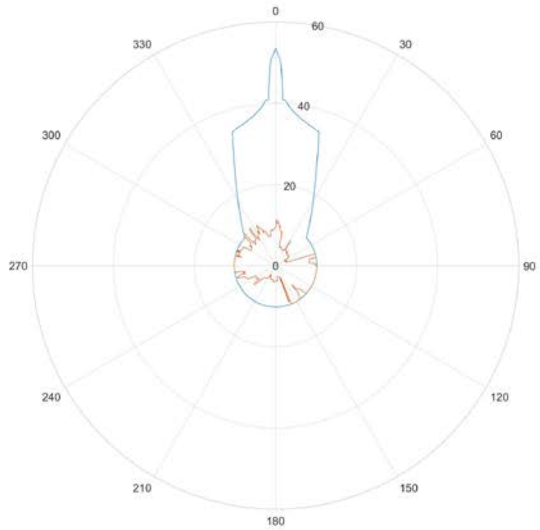

Figure 19: Protection contour for a percentage of time of 0.0119%

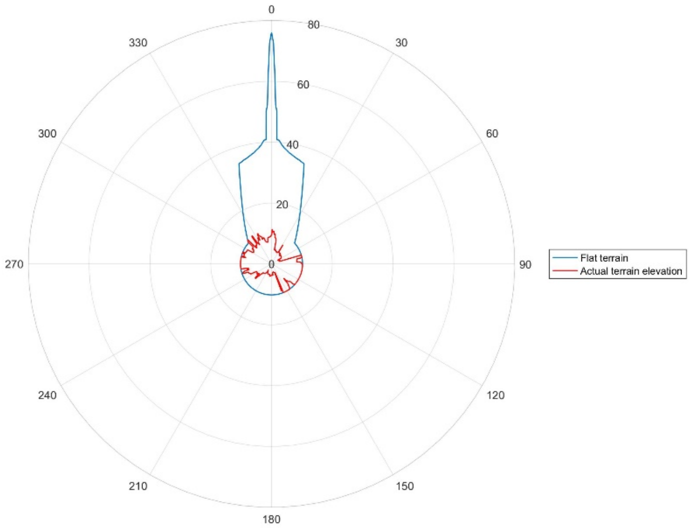

Figure 20: Protection contour for a percentage of time of 0.00027%

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 protection zones around the FS stations. In order to avoid large protection 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 protection zones would be computed by utilising the real FS stations characteristics. The typical size of these protection 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 protection 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 protection 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 21 shows the propagation loss calculated using Recommendation ITU-R P.452-14 function of the separation distance, for the RAS location at Effelsberg (Germany).

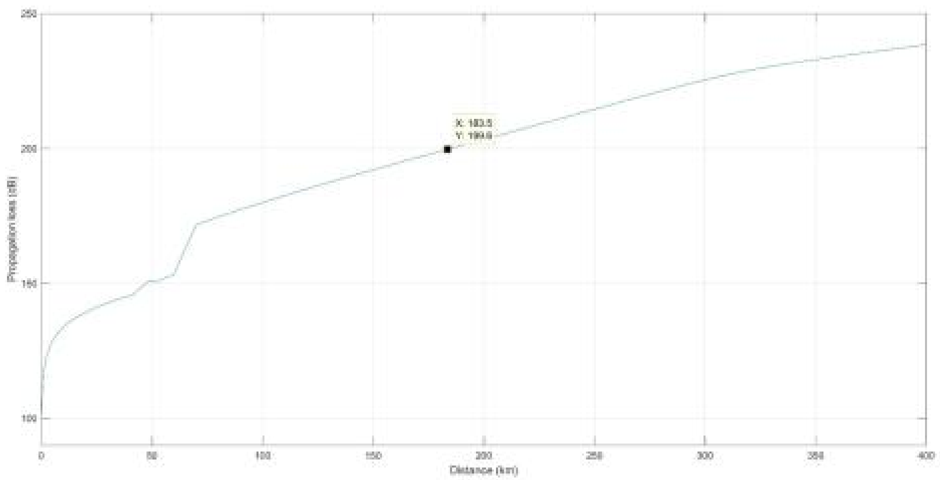

Figure 21: Recommendation ITU-R P.452 Propagation loss over flat terrain

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.

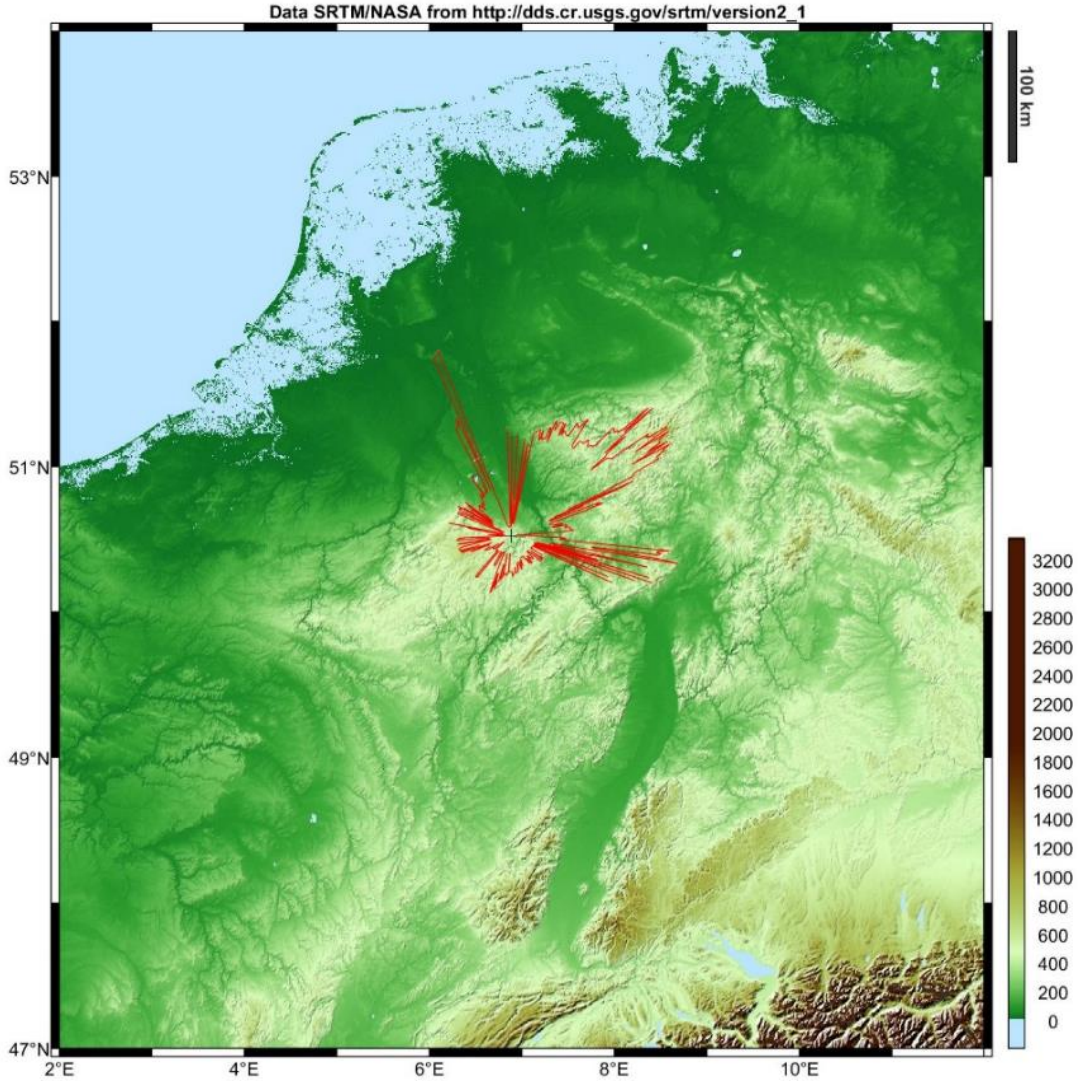

Figure 22: Effelsberg, Germany - max 152 km

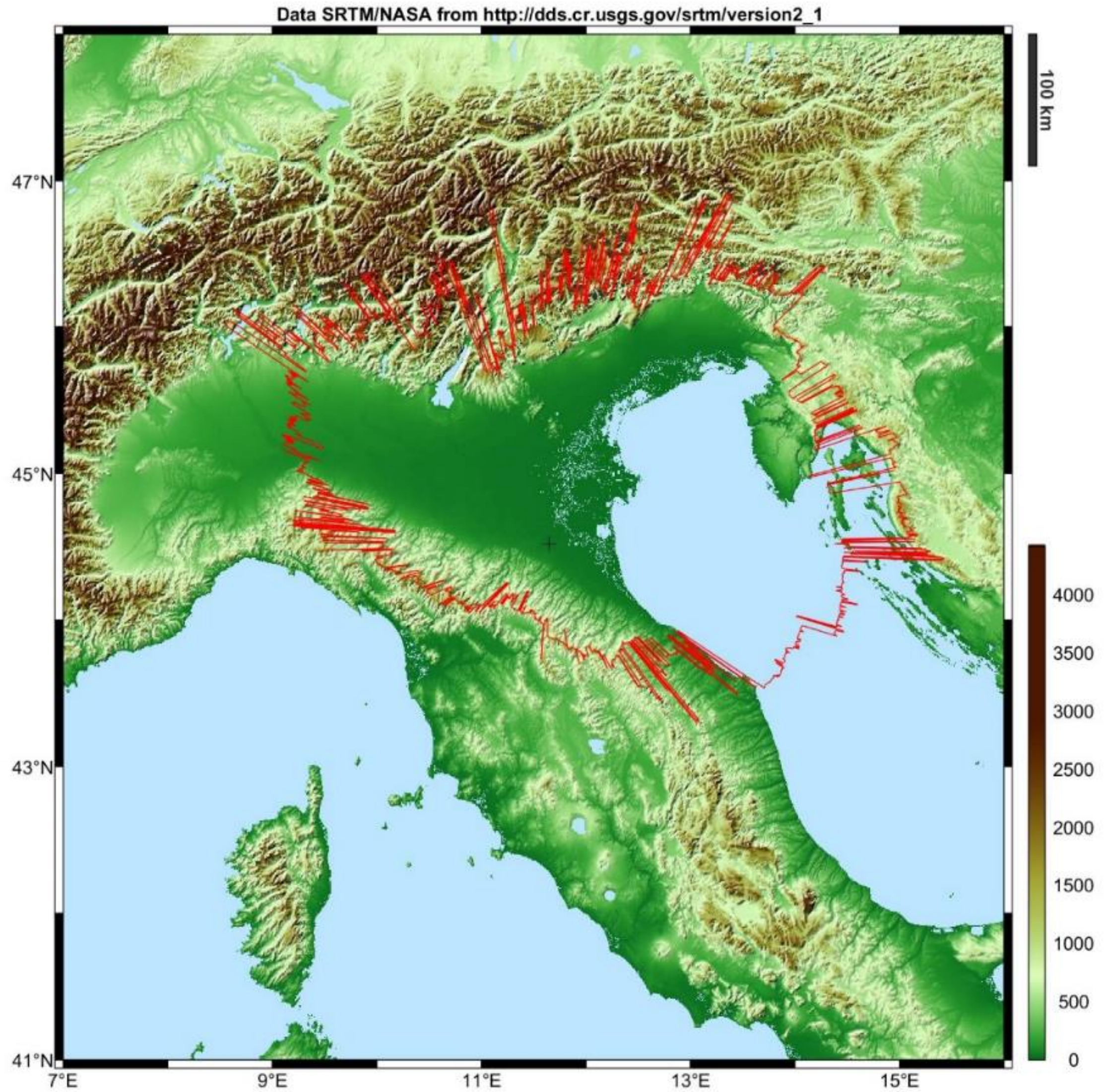

Figure 23: Medicina, Italy - max 300 km

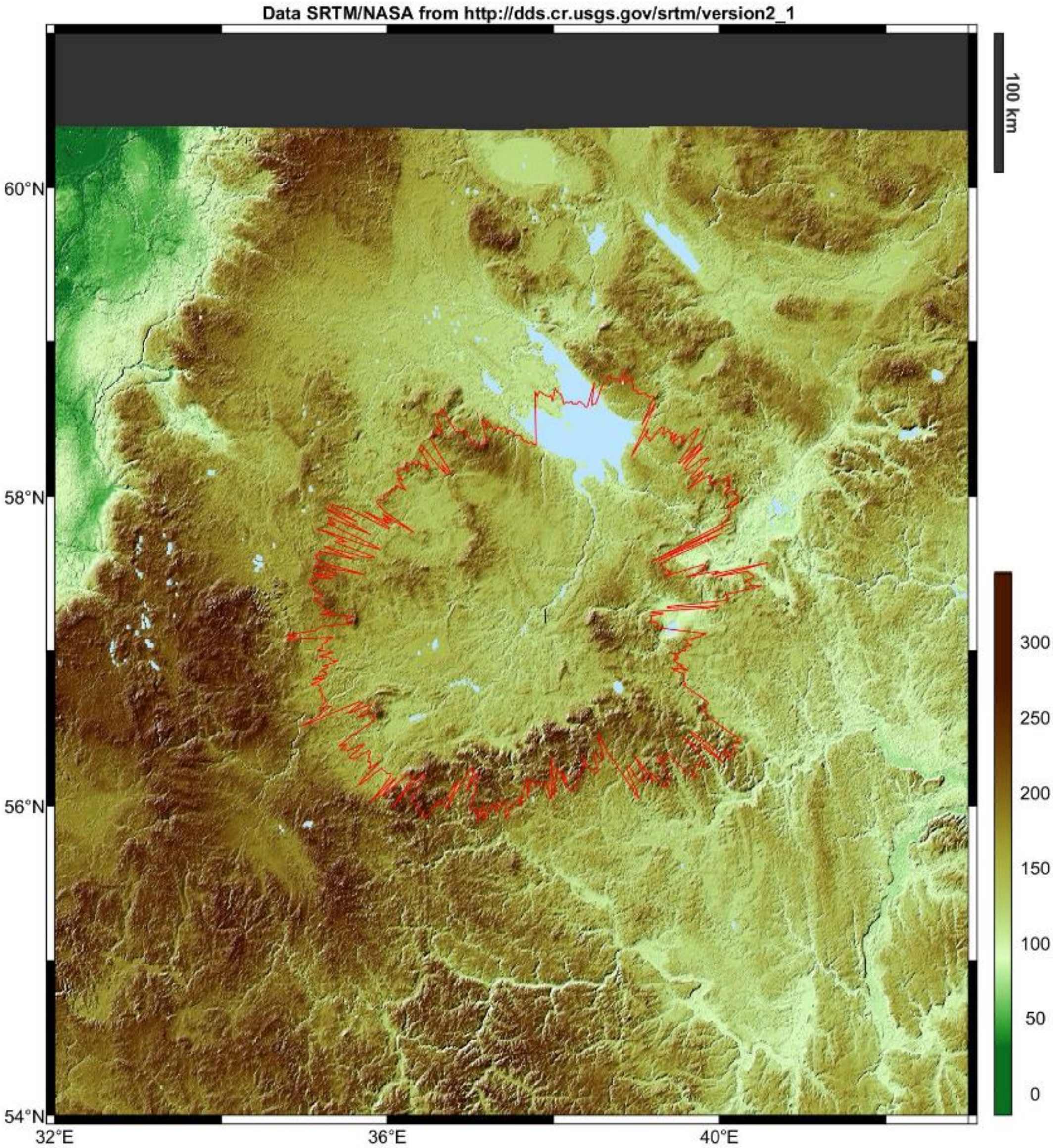

Figure 24: Kalyazin, Russia - max 200 km

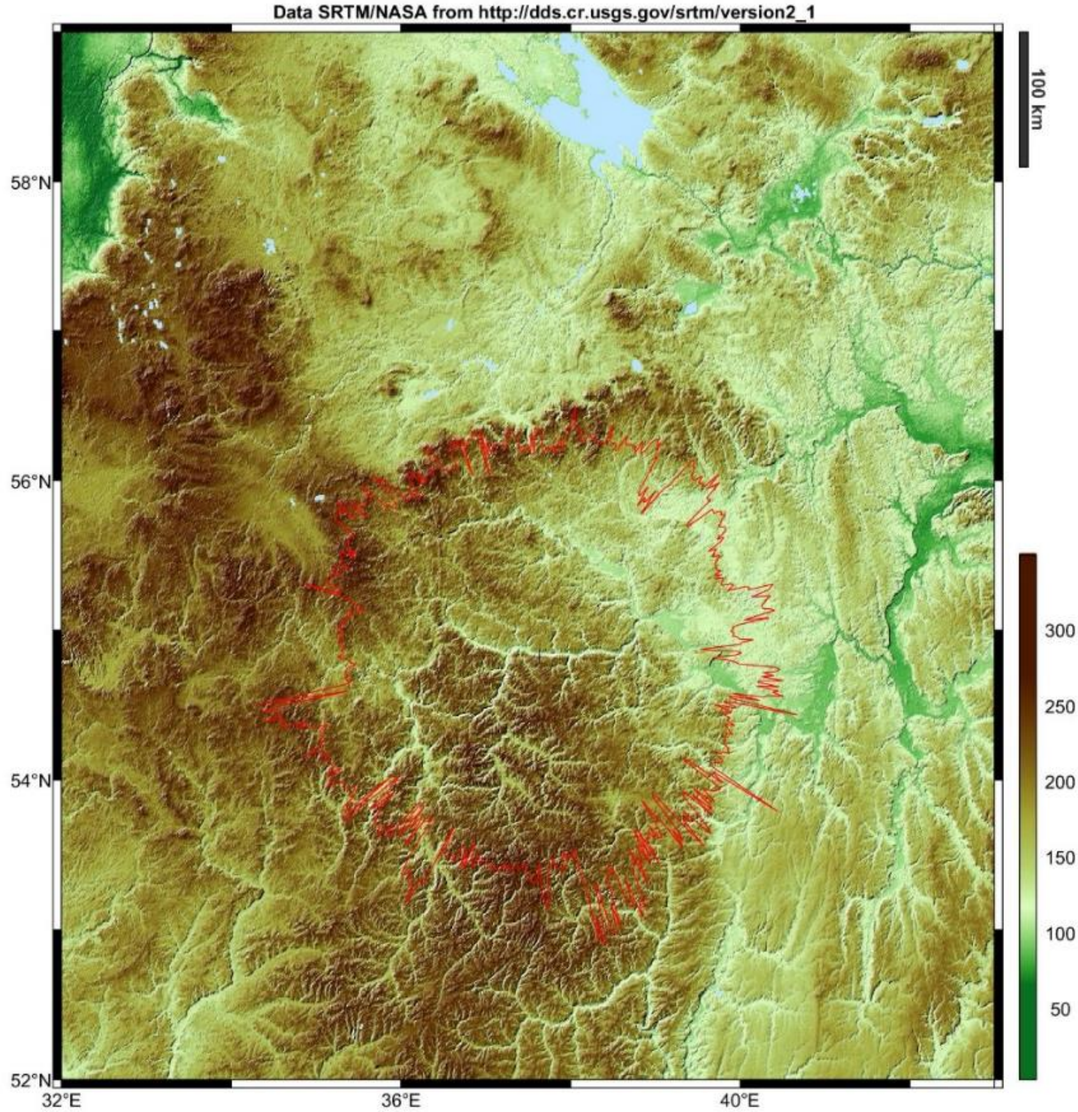

Figure 25: Puschino, Russia - max 220 km

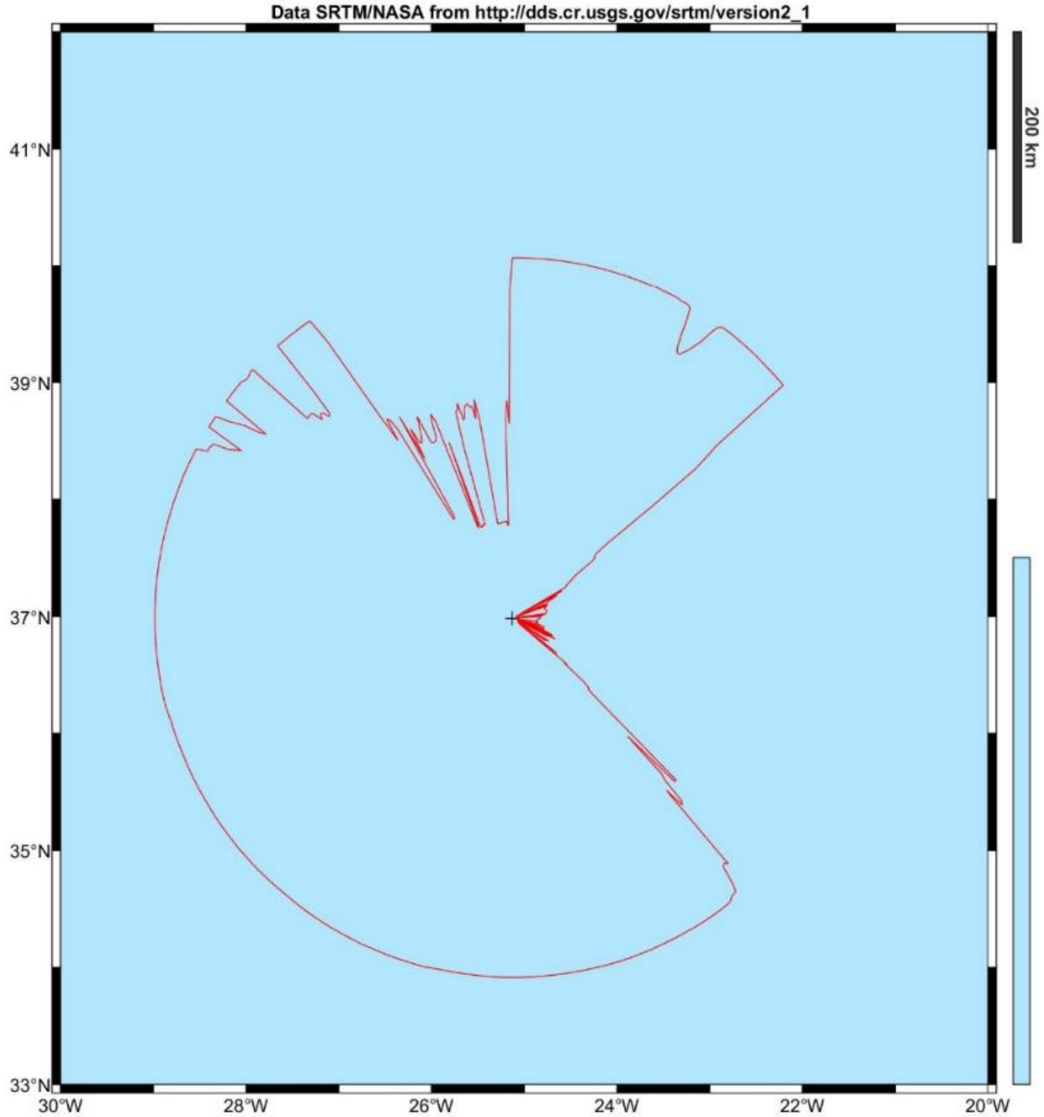

Figure 26: Santa Maria, Portugal – max 345 km, but over sea

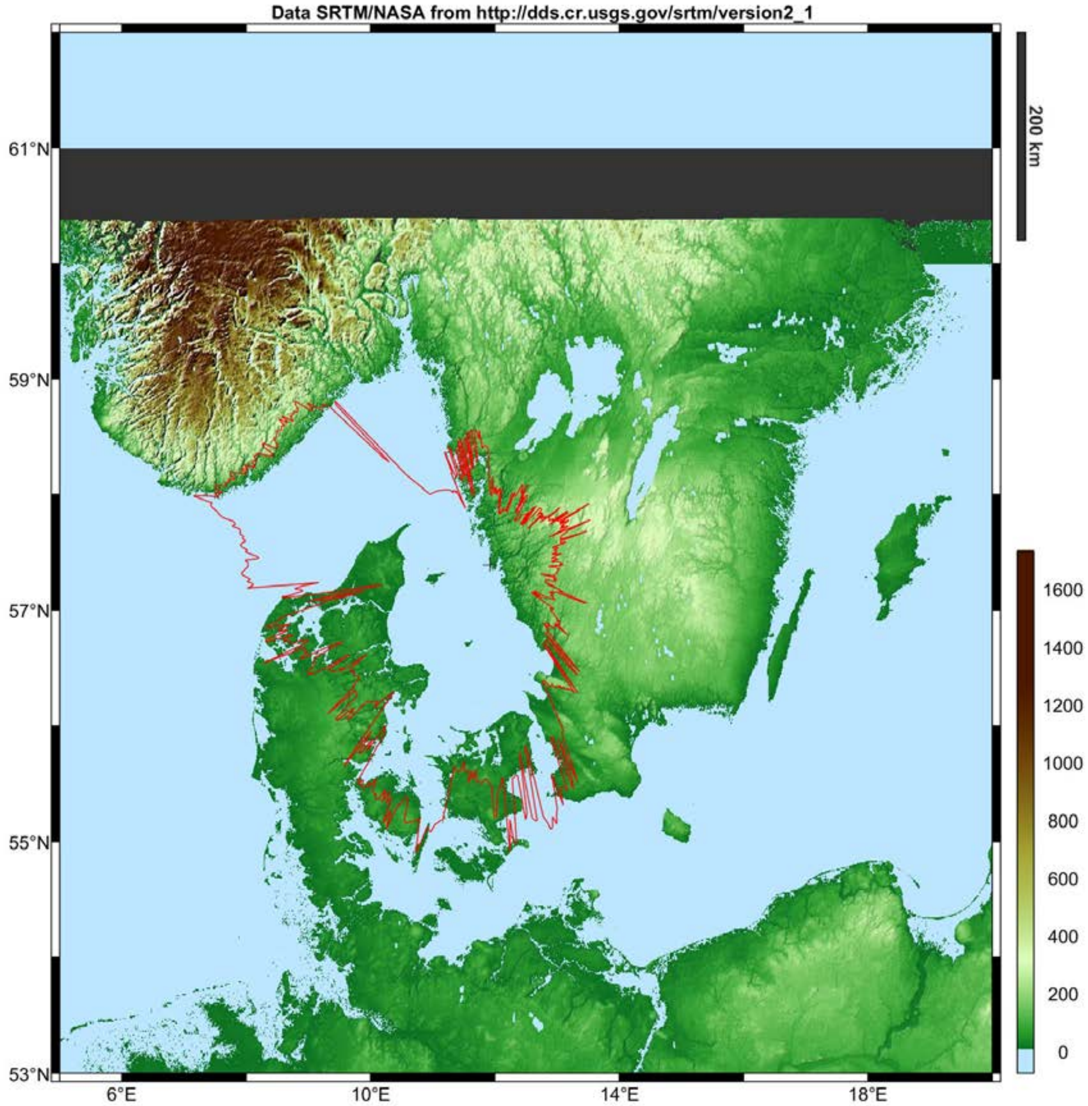

Figure 27: Onsala, Sweden – max 293 km

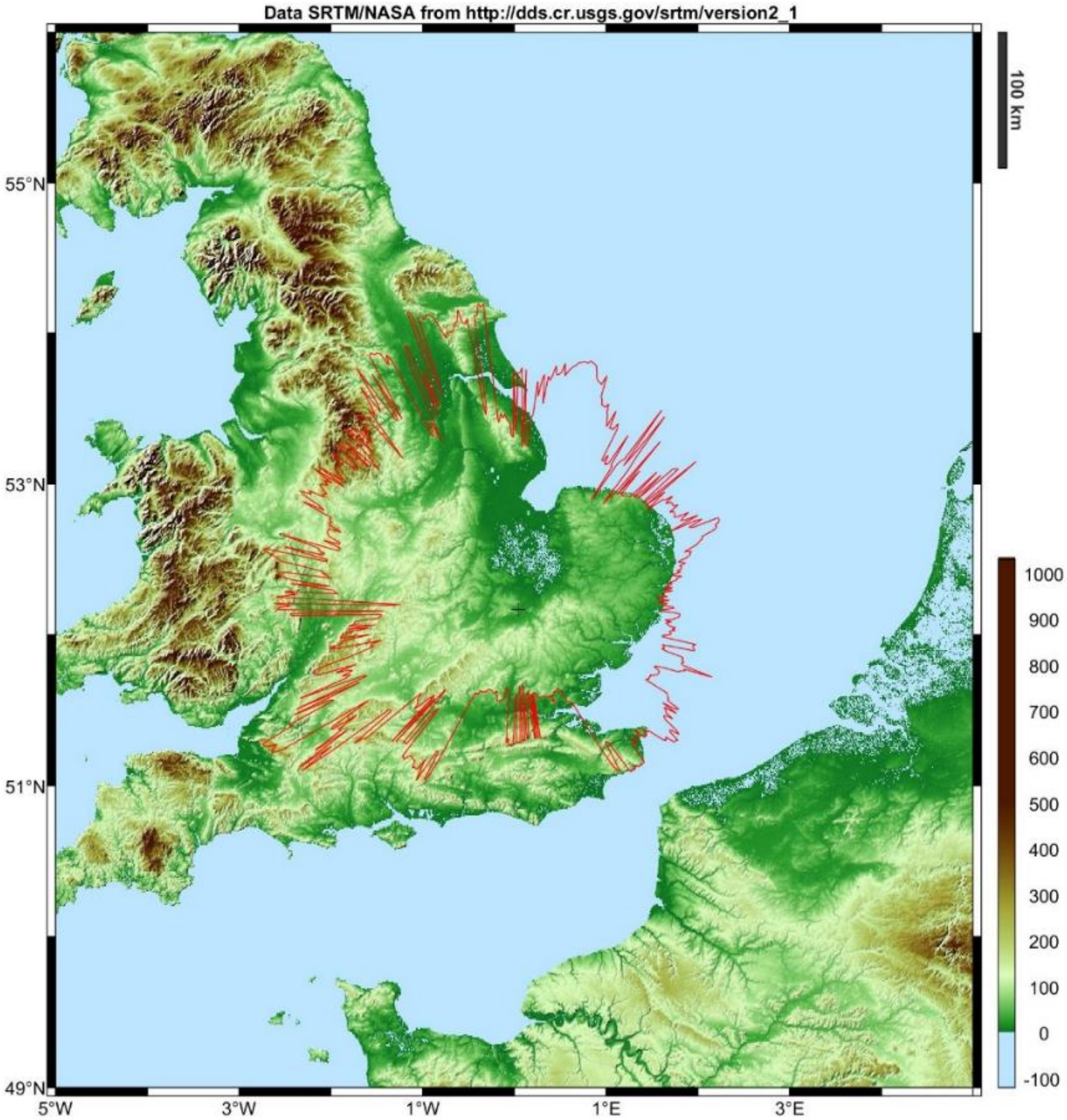

Figure 28: Cambridge, United Kingdom – max 235 km

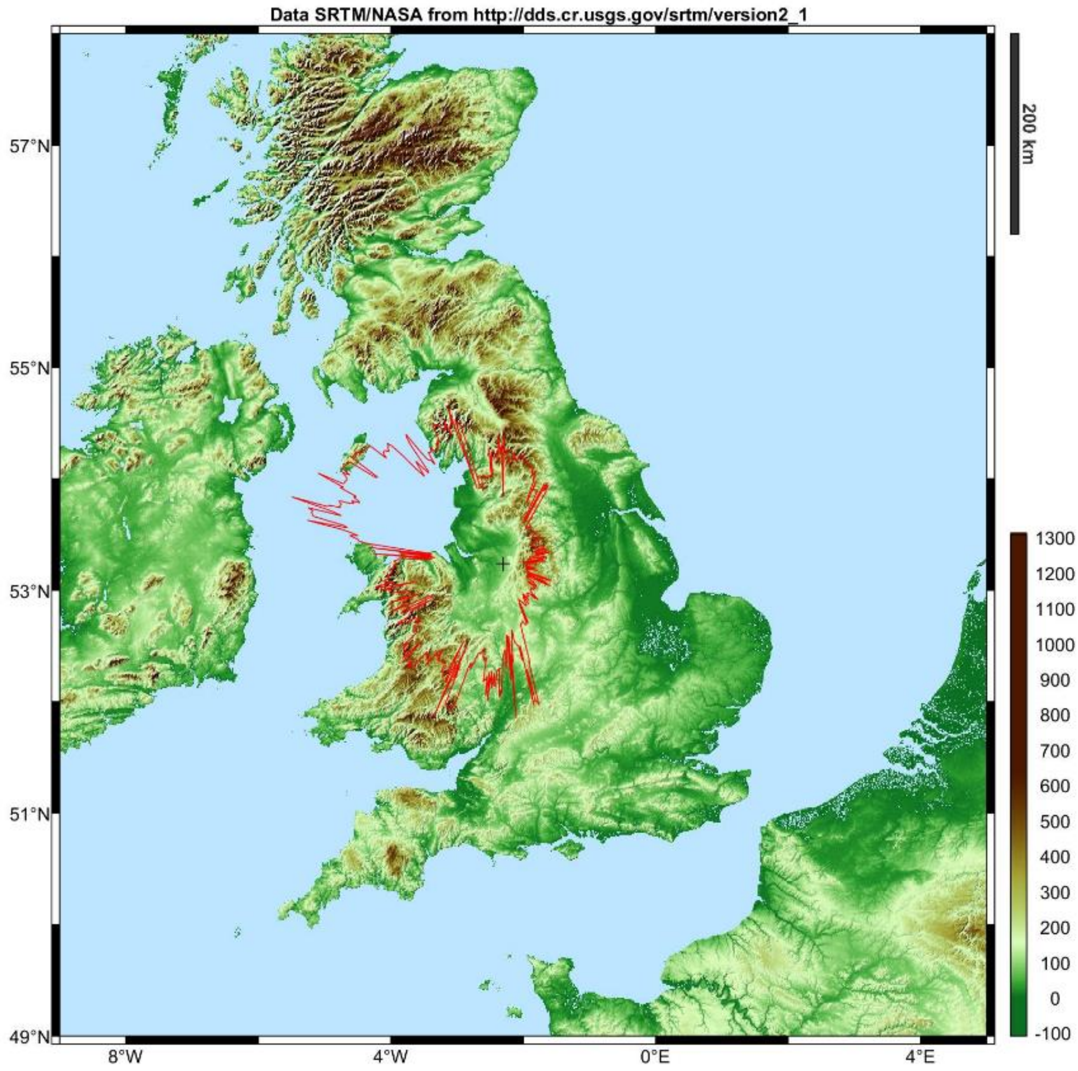

Figure 29: Jodrell Bank, United Kingdom – max 223 km

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 A1.2.2.1 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. The section below provides an example of determination of such area surrounding the FS station in Table 3.

Results

For the FS system in Table 3, the propagation loss required is 135 dB with percentage of time of 0.0119% and 0.00027%, depending on which short-term protection criterion is considered. The required propagation loss becomes 164 dB with a percentage of time of 20% with regard to the long-term protection criterion.

Figure 30 shows the propagation loss calculated using ITU-R Recommendation P.452-14 [5] function of the separation distance.

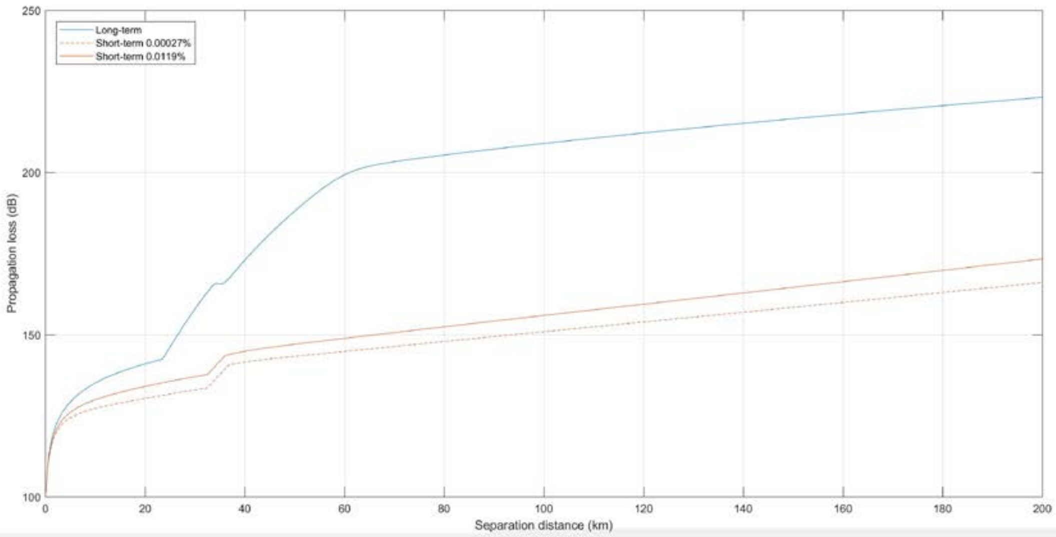

Figure 30: Recommendation ITU-R P.452 Propagation loss over flat terrain

The distance corresponding to a 135 dB loss for short-term is in the order of 33 km and 23 km, for the percentages of time of 0.00027% and 0.0119%, respectively. The distance corresponding to a 164 dB loss for long-term is around 33 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 31 for a FS station pointing North (blue curve). Figure 31 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.

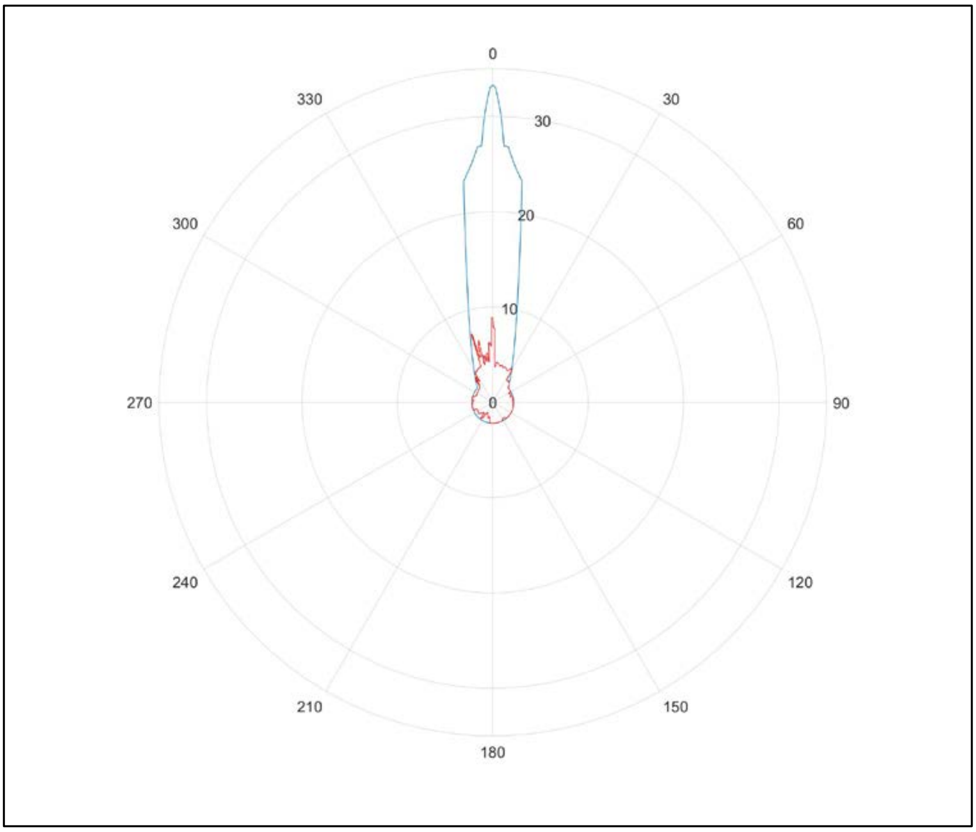

Figure 31: Protection contours

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 protection 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 -33 dBW/(40 kHz), the typical size of these areas has been determined to be in the order of 57 to 77 km in a 37 dBi FS main beam direction assuming smooth Earth. OneWeb This size decreases rapidly, down to 11 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 ES 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 protection 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 protection 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 (4 out of 16), multiplied by the ratio of aeronautical earth stations and the total number of earth stations.

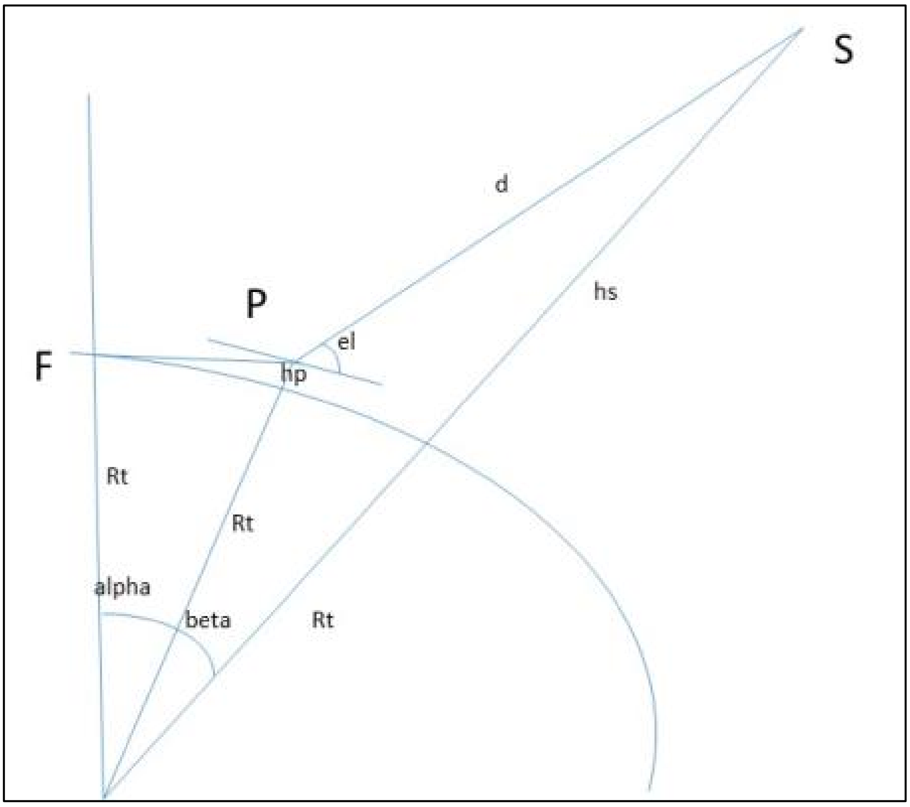

Figure 32: Geometry to determine the number of satellites in visibility above a given elevation angle

In Figure 32:

- 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 57° 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 57° and an aircraft altitude of 11 000m, the distance d (aircraft to satellite) is 1374 km, angles alpha and beta are 3.36° and 5.67° respectively. Therefore, 2.(alpha+beta)=18.06°.

At 0° latitude, since the satellite planes are separated by 20°, one single plane is contained within this 18.06° cone. The satellites are separated by 9° on a plane and therefore up to 3 satellites may be visible at one moment in time. At 45° latitude, the planes are separated by 14° and 2 planes are contained within the 18.06°. In this case the number of visible satellites becomes 6. At higher latitudes, some of the satellites are shut down since a number of them are covering the same area.

Assuming a 57° minimum elevation angle and an aircraft altitude of 11000 m would lead to a number of 6 visible satellites. Assuming that only 10% of the total traffic in the system is for aircraft stations, the total number of aircraft is 2 to 3, which is 30 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 34, 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)

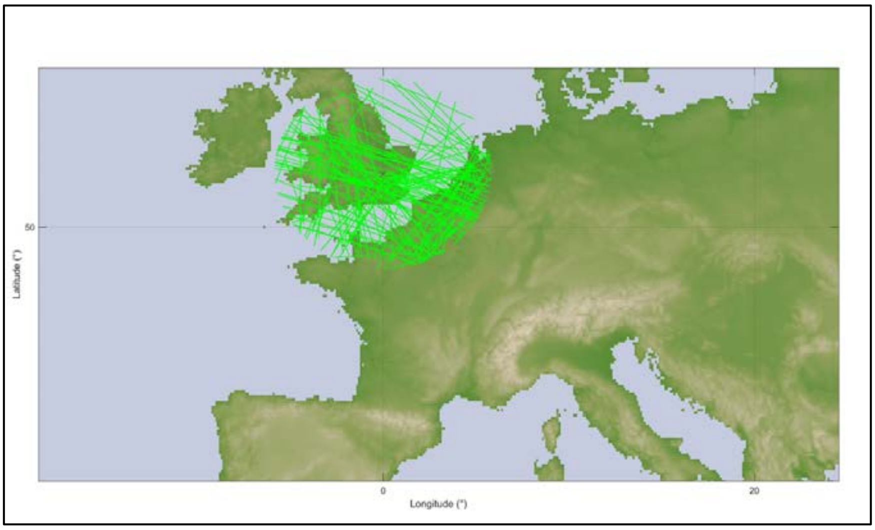


Figure 33: Air routes in visibility of the FS station

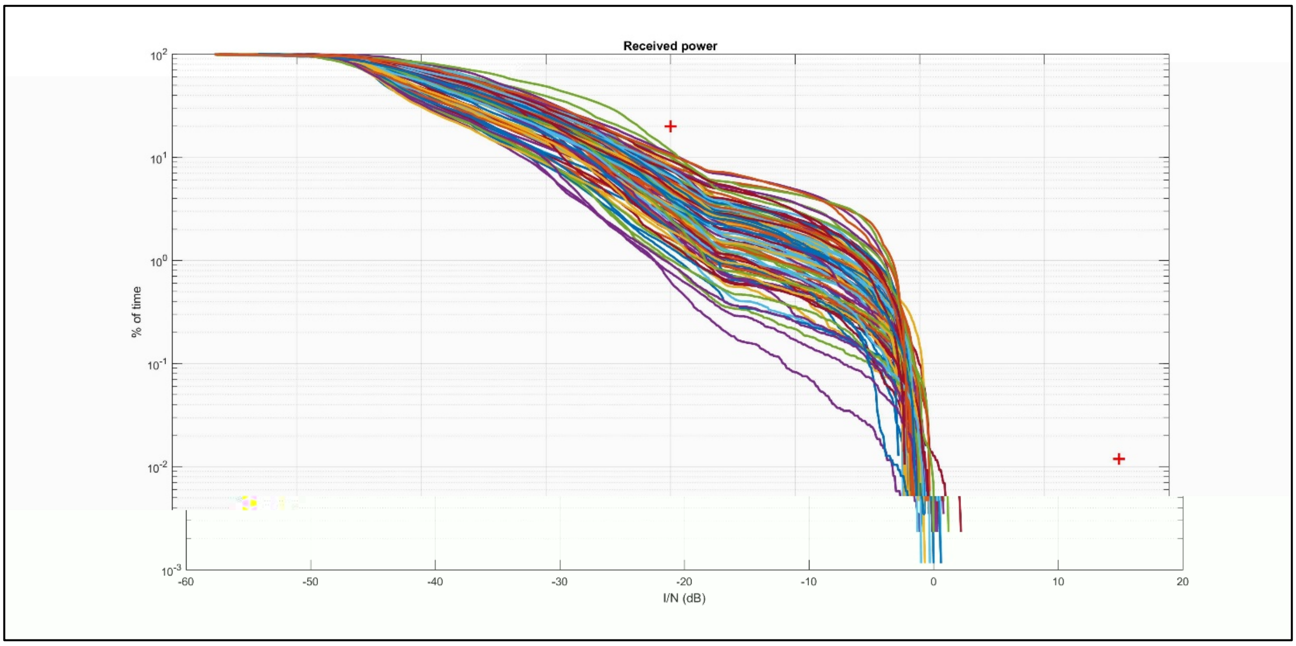


Figure 34: Validation tests with AMSS and previous assumptions

Short-term protection criterion

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

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

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

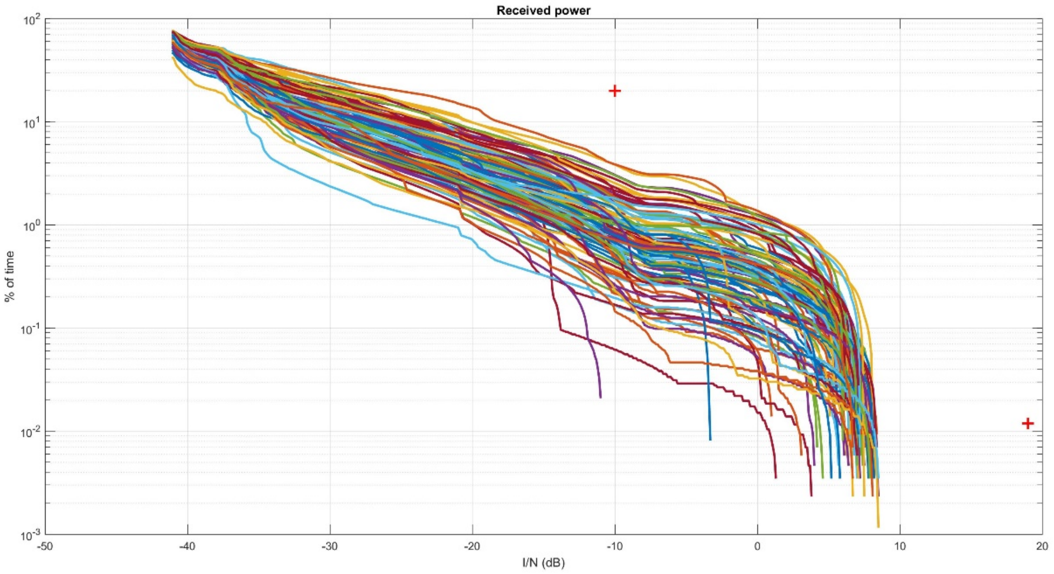


Figure 35: Recommendation ITU-R M.1643 mask relaxed by 10 dB

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 36.

- $-122 + \theta$ dB(W/(m² · MHz)) for $\theta \leq 40°$;
- -82 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).

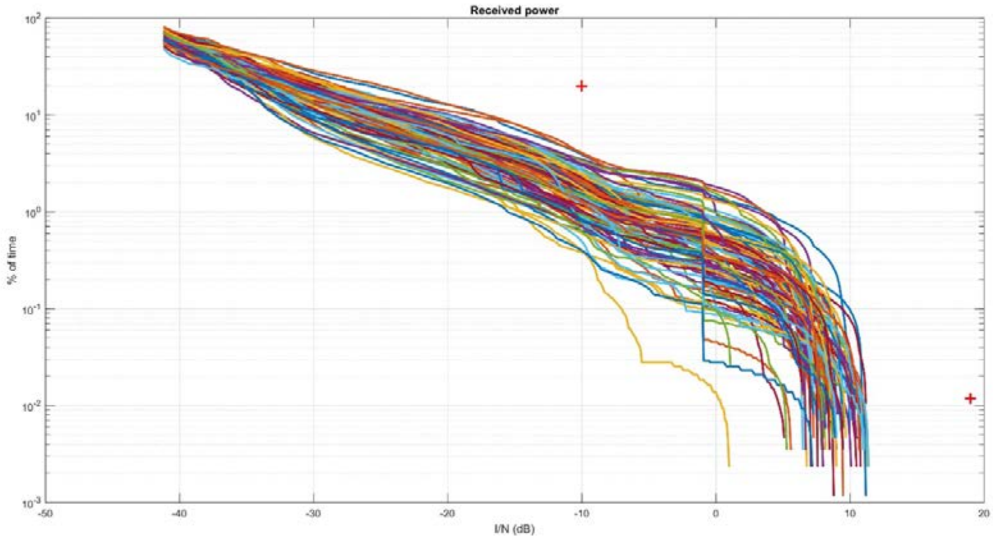


Figure 36: Pfd mask further relaxed by 20 dB for high elevations

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 $\theta \leq 5°$;
- –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 of the radio-frequency wave (degrees above the horizontal).

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

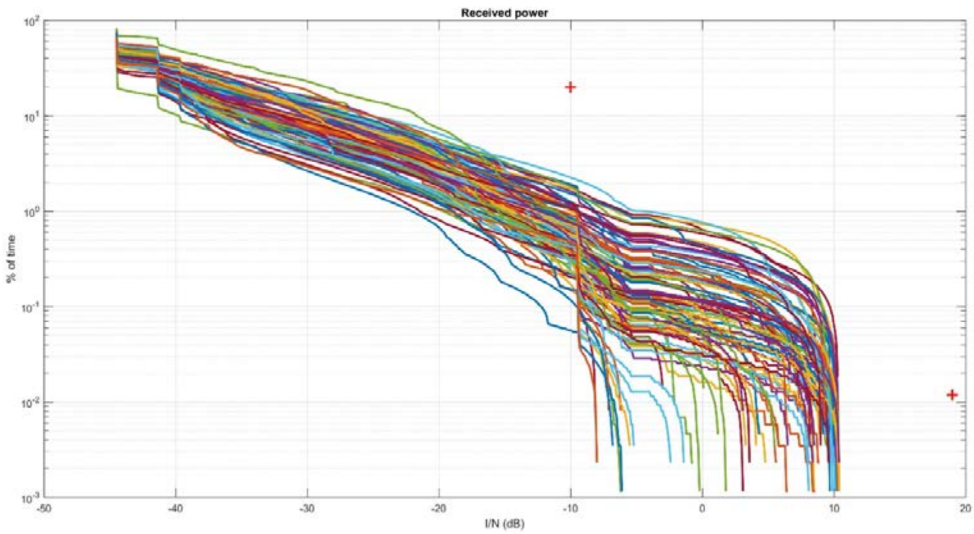


Figure 37: Pfd mask with a constant value below 5° elevation and a 37 dBi FS

Figure 38 gives the simulations results for the 49 dBi FS system contained in ECC Report 026.

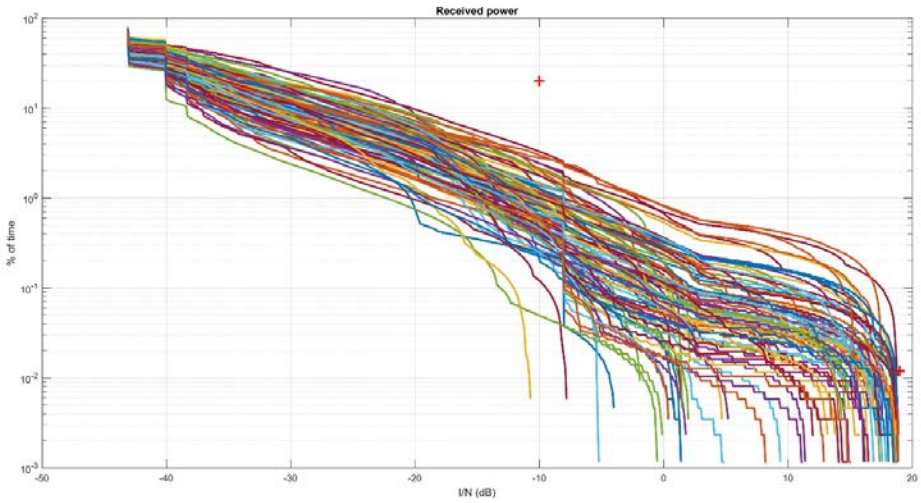


Figure 38: Pfd mask with a constant value below 5° elevation and a 49 dBi FS

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 39 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.

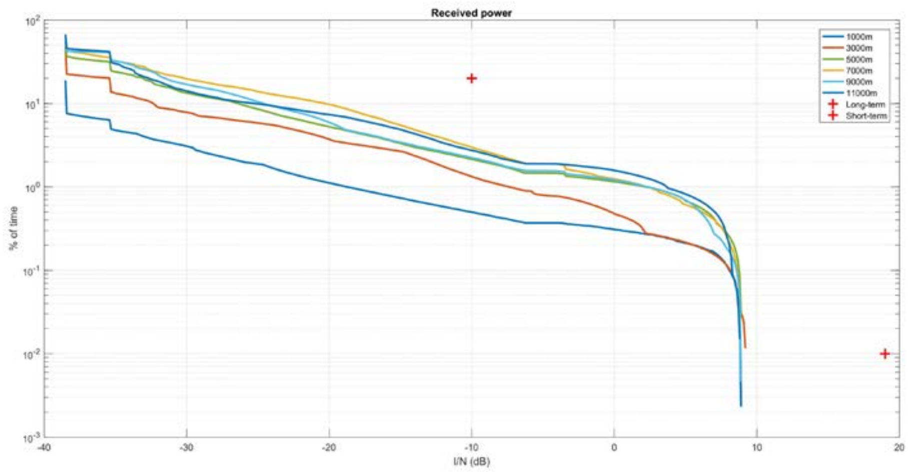


Figure 39: Sensitivity analysis vs altitude

A1.6.1.3 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:

- –119.5 dB(W/(m² · MHz)) for $\theta \le 5°$;
- –124.5 + θ dB(W/(m² · MHz)) for $5° < \theta \le 20°$;
- –84.5 dB(W/(m² · MHz)) for $20° < \theta \le 90°$.

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.

A1.6.1.4 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 -33 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 -13 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 14.6 km from an FS station with a 49 dBi antenna. The separation distance from the FS is 4.9 km when considering the 37 dBi FS station in Table 3. Both distances result in a 0 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 16: 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	13.4 km / 0 km	8.7 km / 0 km	4.6 km / 0 km	3.7 km / 0 km
6 vessels per day	14.6 km / 0 km	9.2 km / 0 km	4.9 km / 0 km	3.9 km / 0 km

Conclusions

The results showed, for the assumptions made, that OneWeb earth stations radiating with a total e.i.r.p of -13 dBW towards the horizon, do not need to maintain any separation distance from the shore.

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 protection 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 40 shows the propagation loss calculated using P.452-14 [5] function of the separation distance, for a RAS location at Effelsberg (Germany).

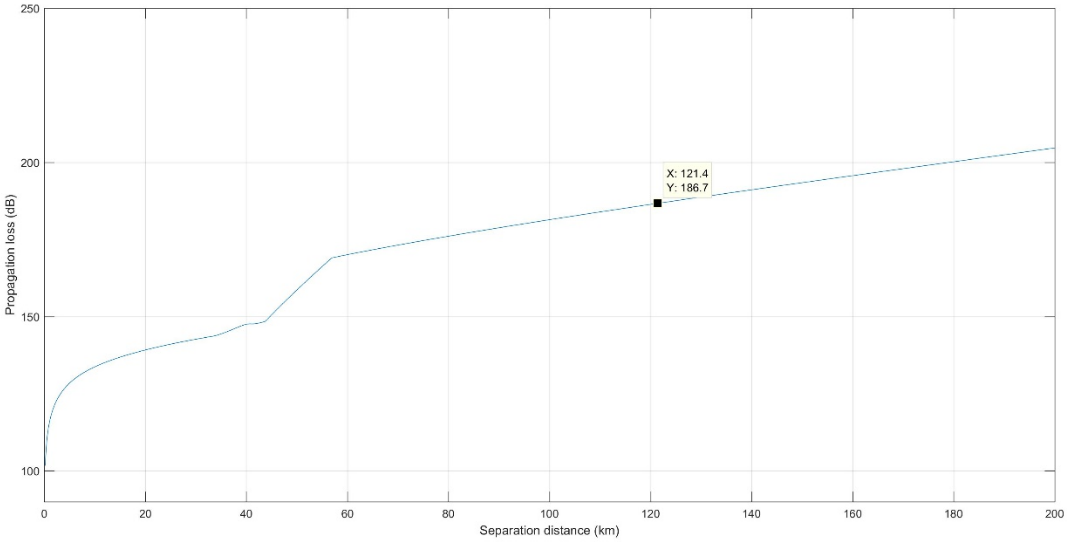


Figure 40: Recommendation ITU-R P.452 Propagation loss over flat terrain

The distance corresponding to a 183 dB loss is in the order of 121 km.

Figure 41 shows the separation distances around the same RAS station, 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.

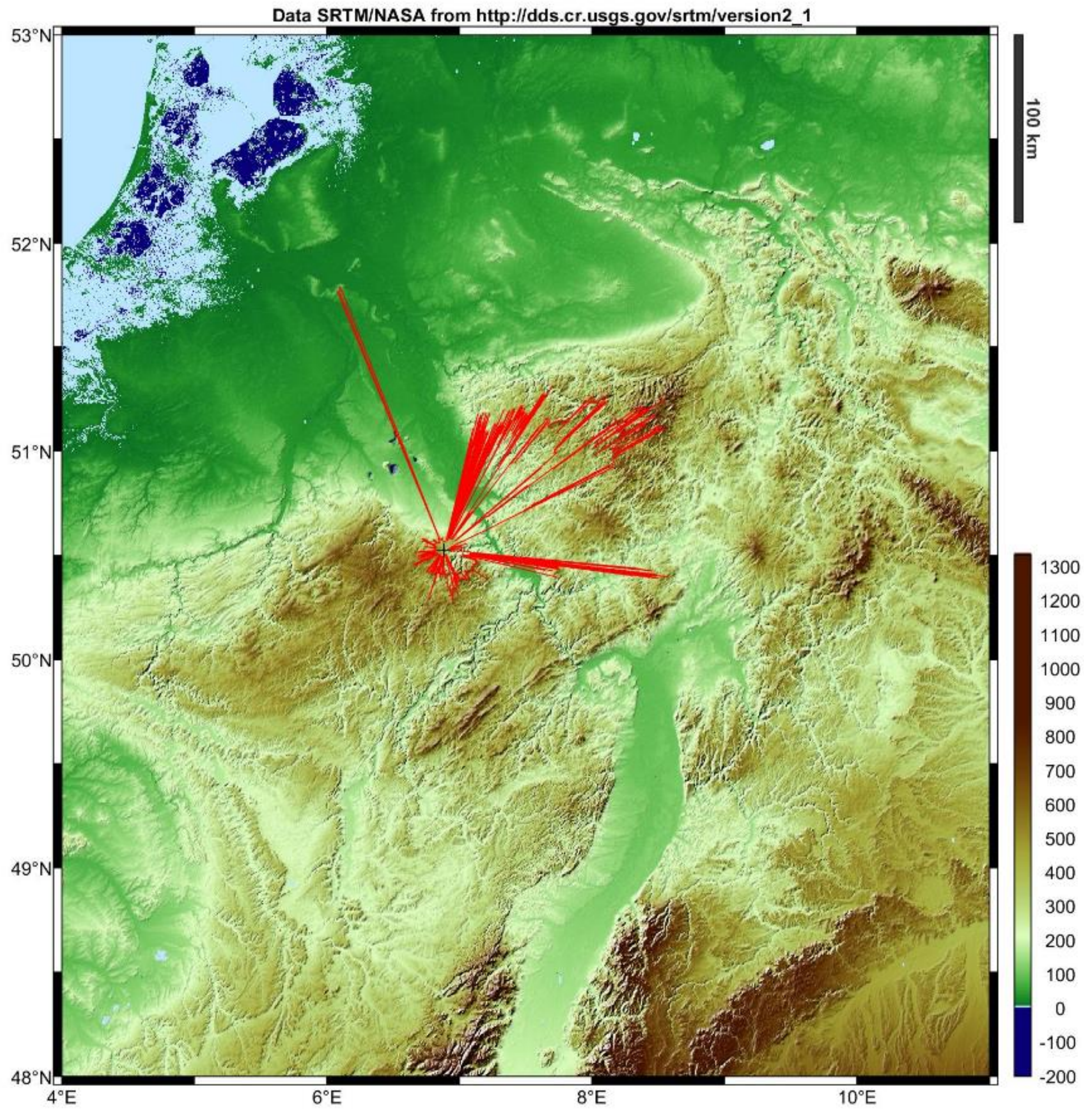


Figure 41: Effelsberg, Germany – max 150 km

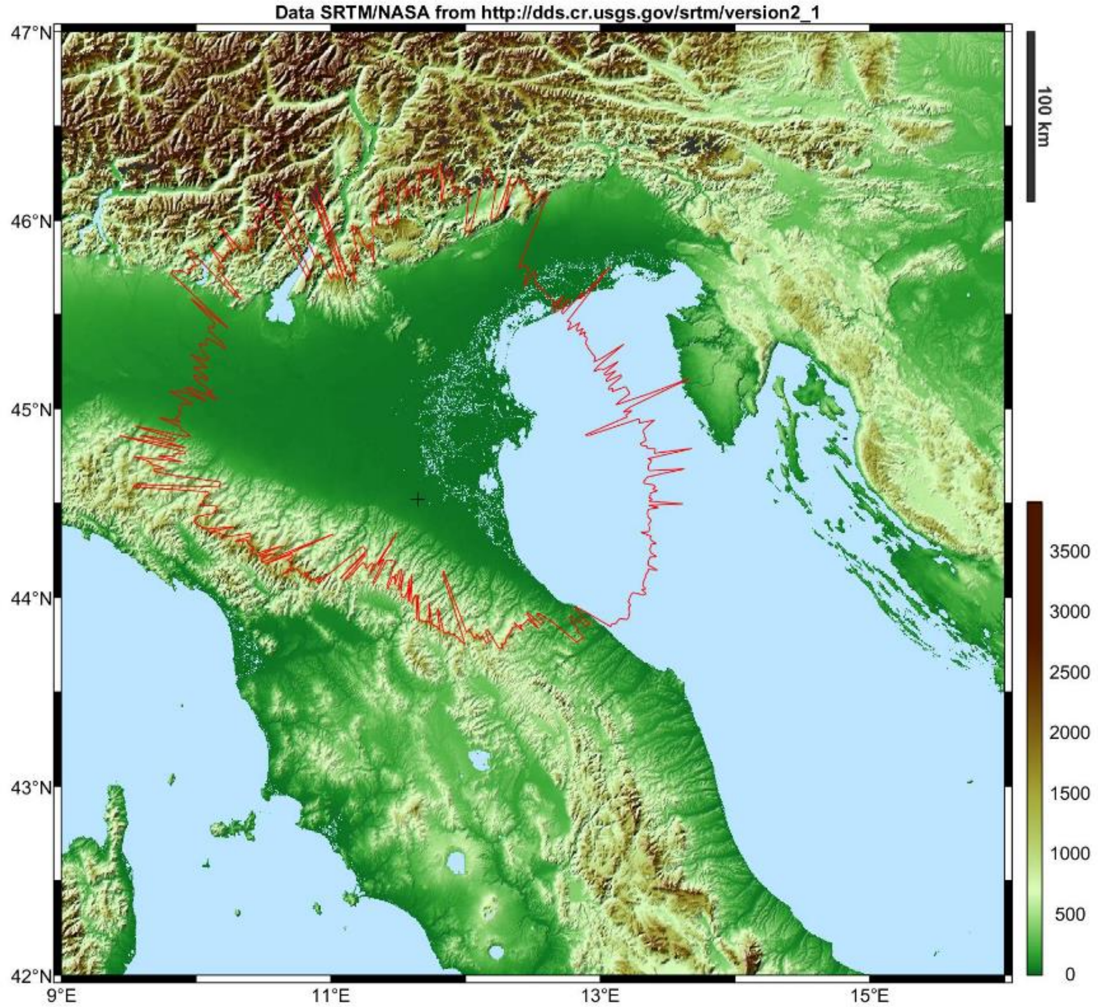


Figure 42: Medicina, Italy – max 200 km

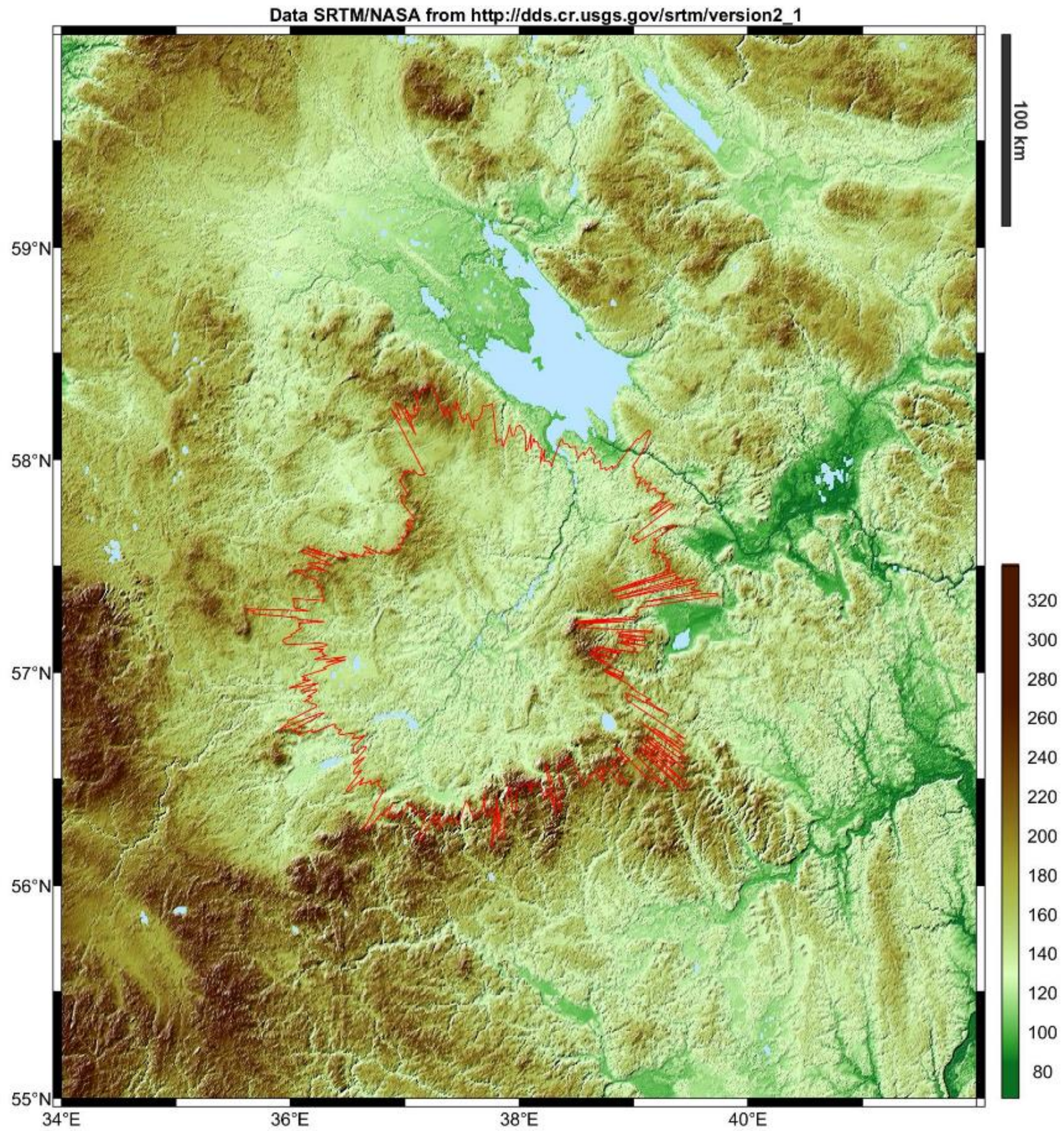


Figure 43: Kalyazin, Russia – max 140 km

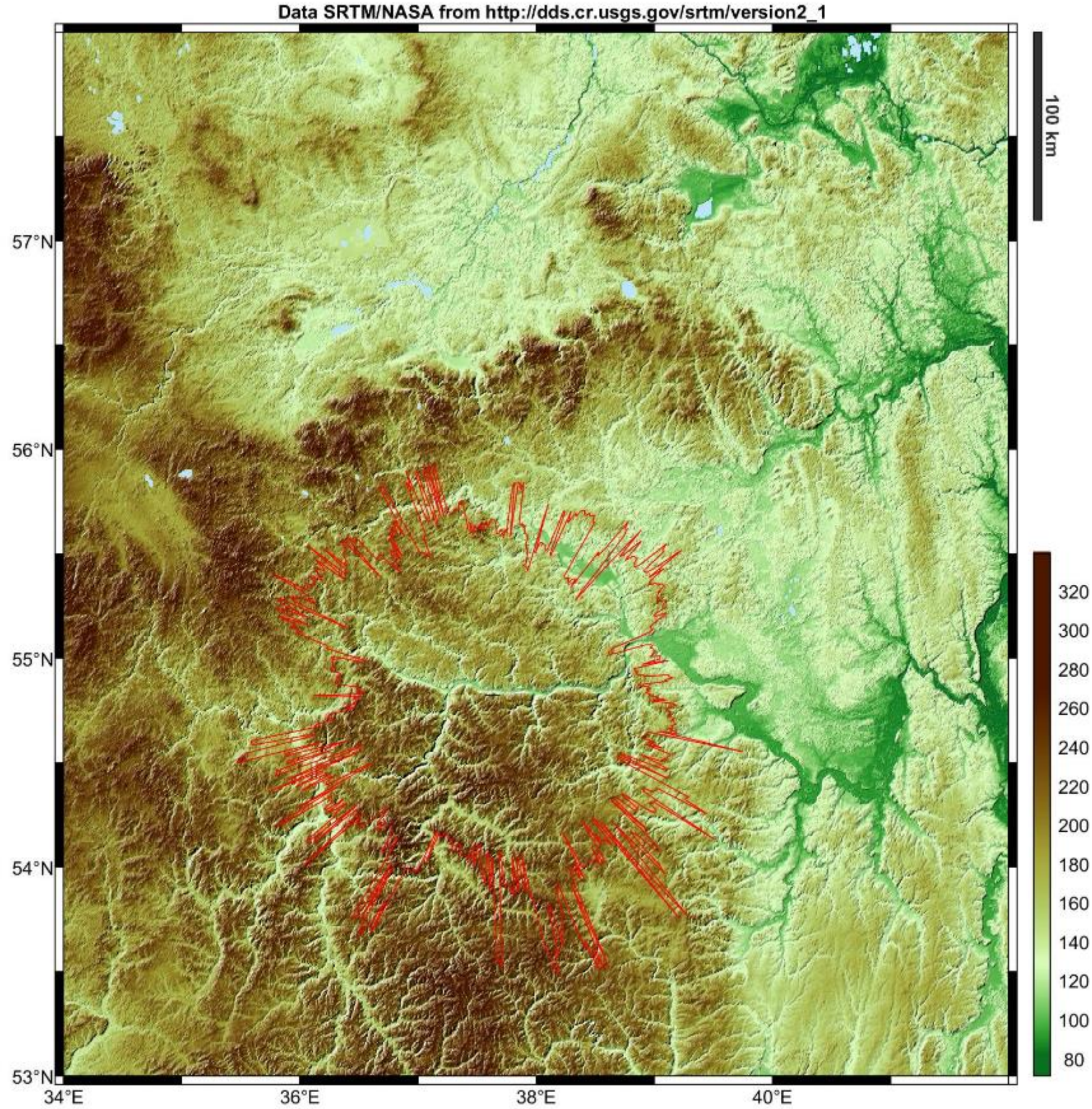


Figure 44: Puschino, Russia – max 160 km

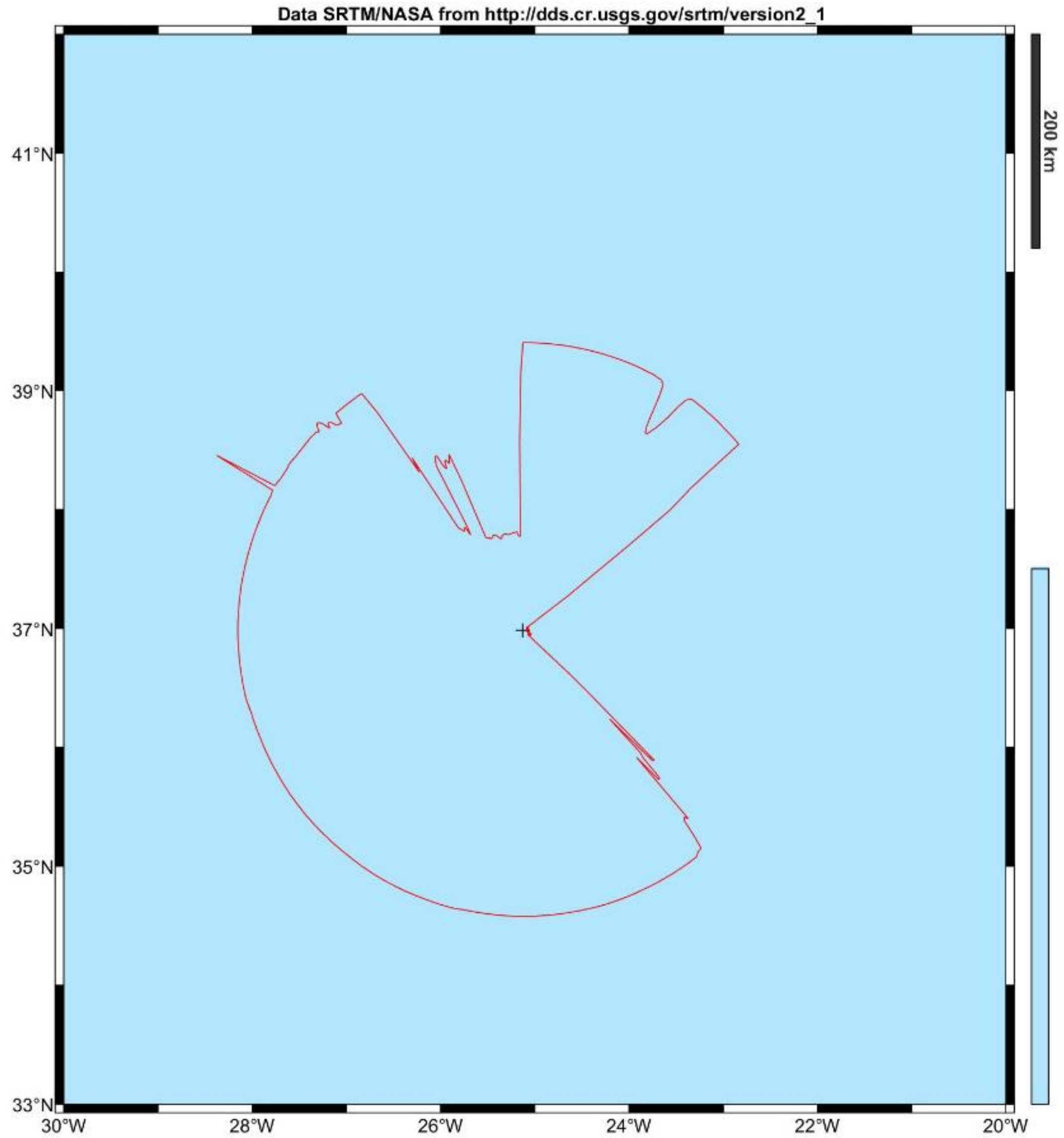


Figure 45: Santa Maria, Portugal – max 332 km

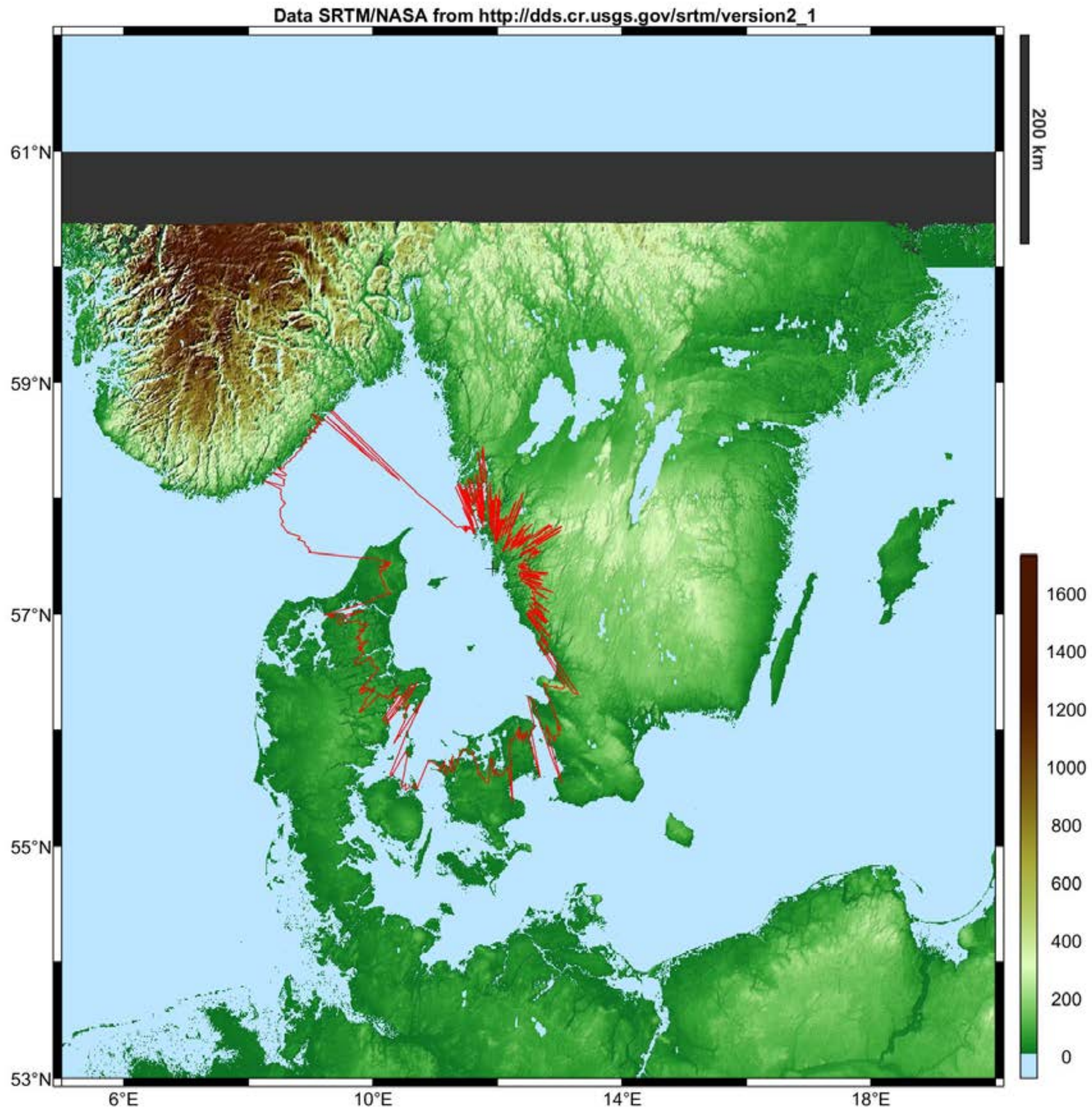


Figure 46: Onsala, Sweden – max 170 km

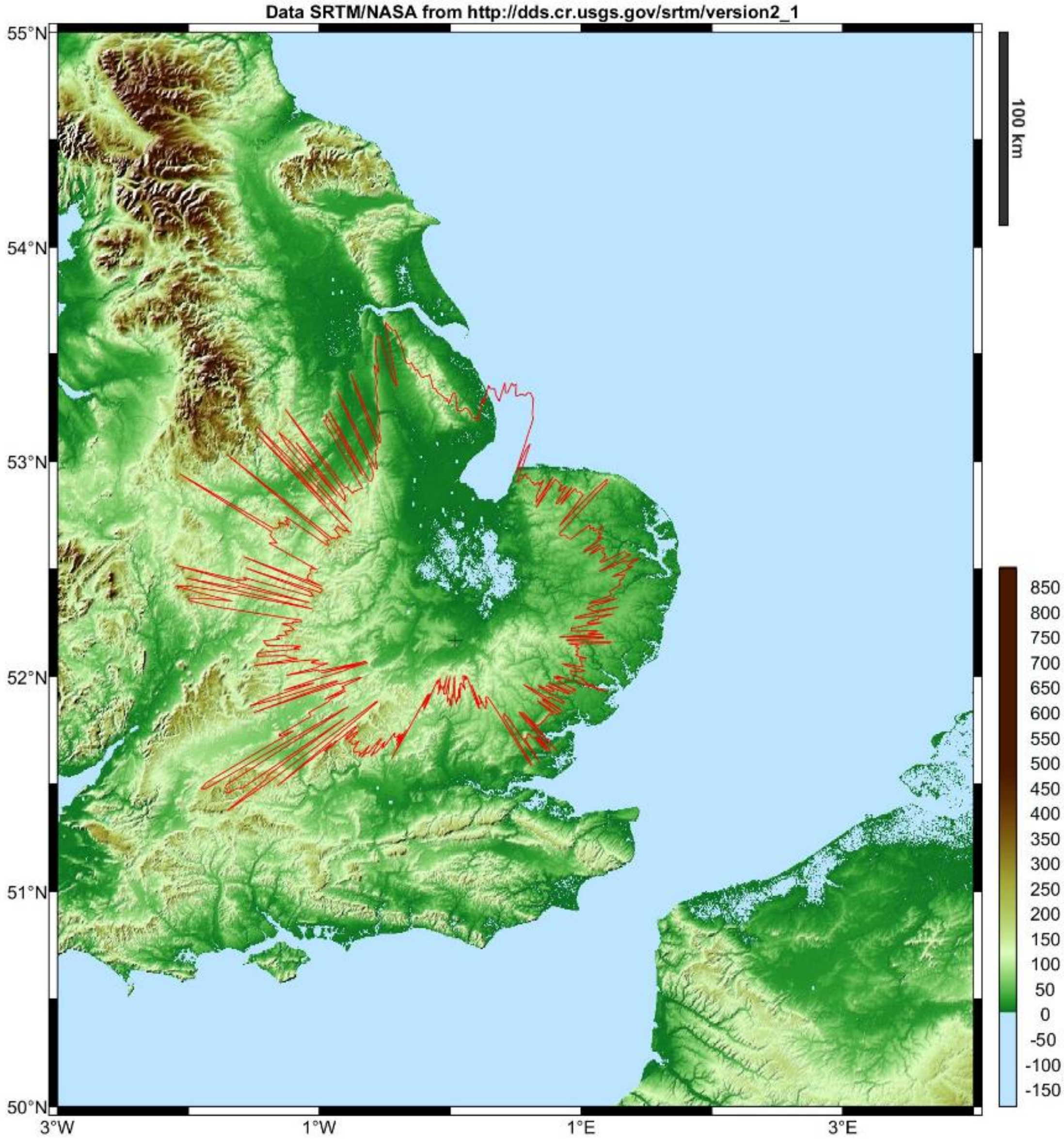


Figure 47: Cambridge, United Kingdom – max 170 km

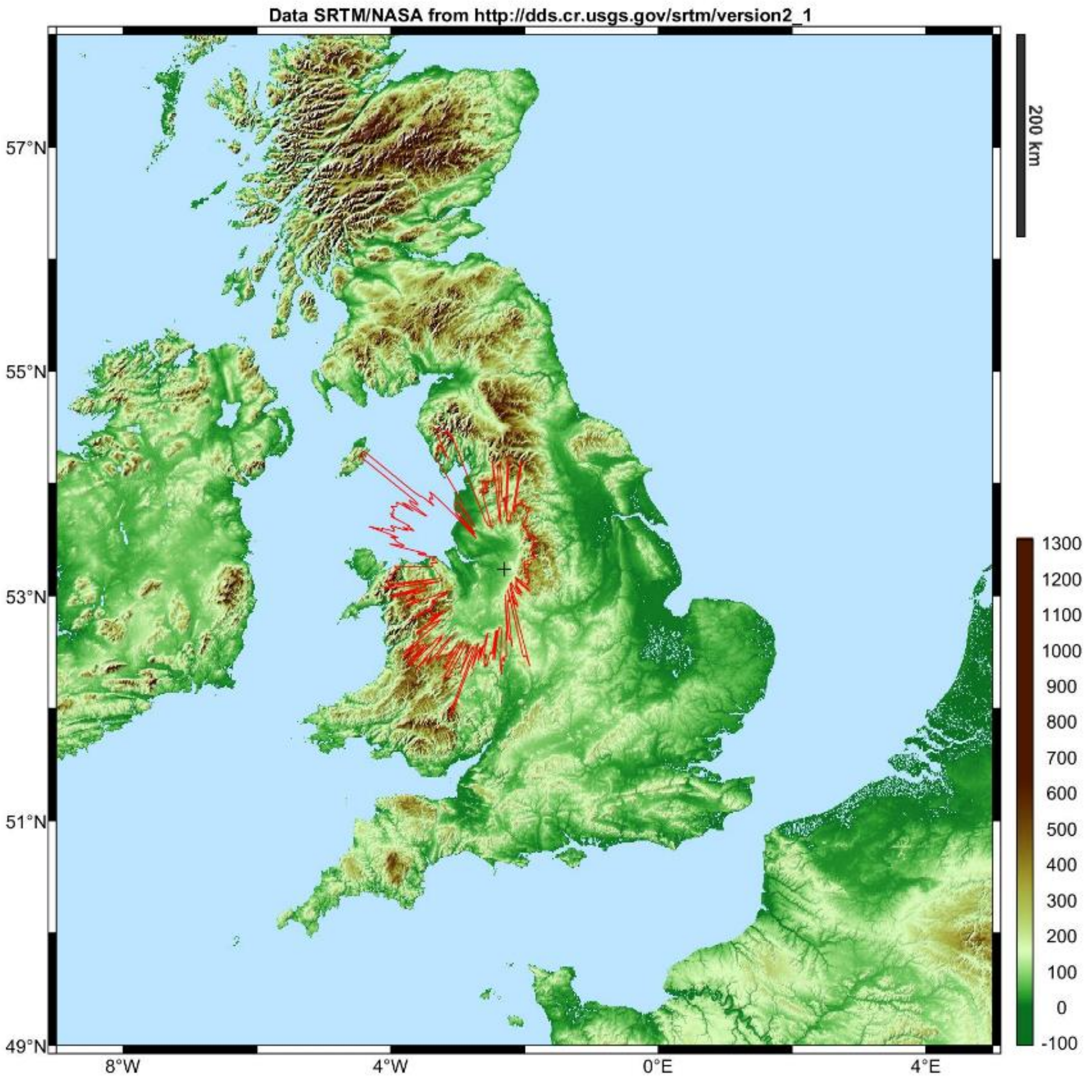


Figure 48: Jodrell Bank, United Kingdom – max 180 km

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 protection 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 -33 dBW/(40 kHz)) the size of the zone can be up to 200 km. For other type of earth stations with different e.i.r.p. levels towards the horizon, the protection zones would not be the same as presented in this section. Notwithstanding this assessment, specific calculations on the protection 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 protection 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.

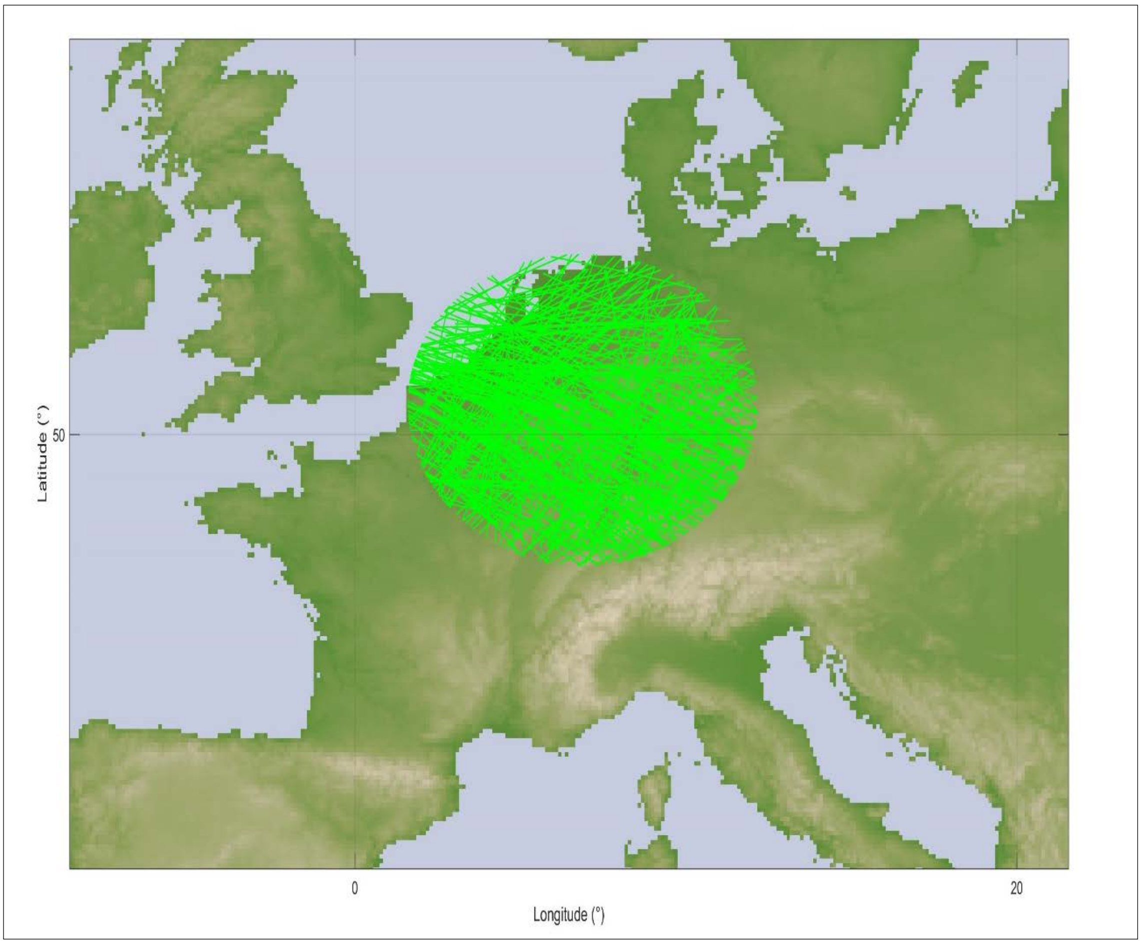


Figure 49: Air routes in visibility of the Effelsberg RAS station

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 · θ dB(W/(m2 · 150 kHz)) for θ ≤ 10°;
- –180 dB(W/(m2 · 150 kHz)) for 10° < θ ≤ 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.

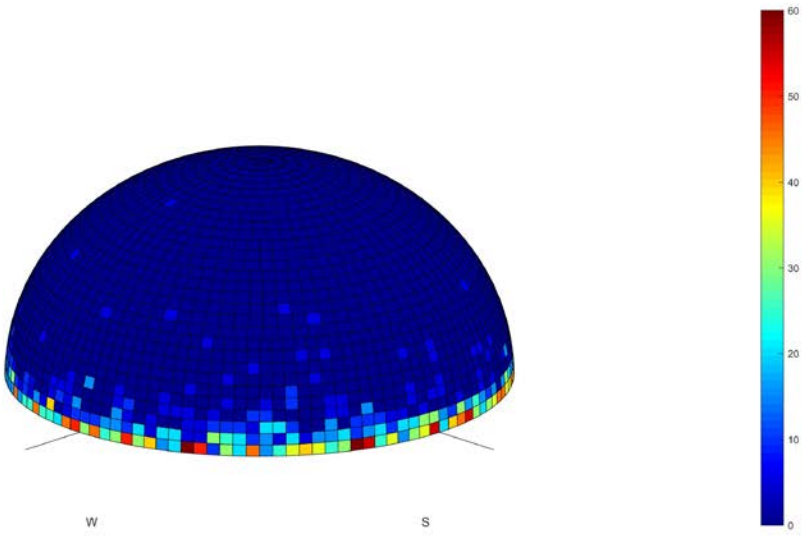


Figure 50: Data loss due to airborne ESIM over Effelsberg

Figure 51 provides the results of simulations for the Medicina RAS station. The percentage of data loss is 0.35% above 5° elevation.

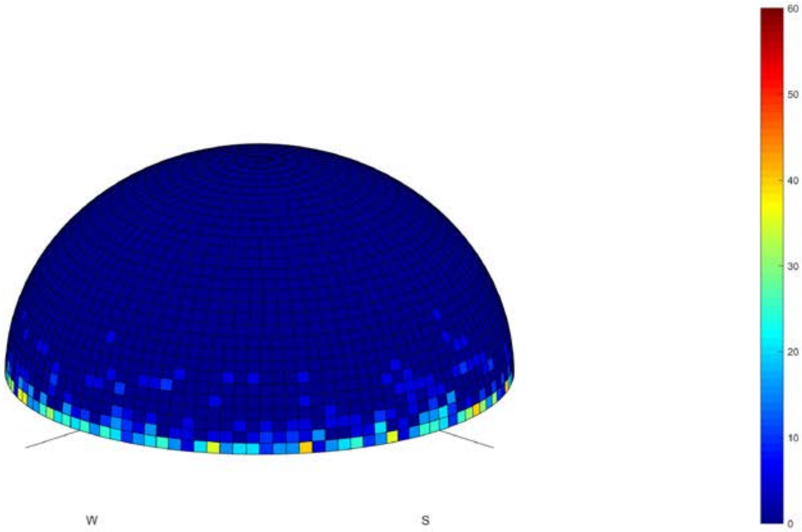


Figure 51: Data loss due to airborne ESIM over Medicina

Figure 52 provides the results of simulations for the Kalyazin RAS station. The percentage of data loss is 1.64% above 0° elevation.

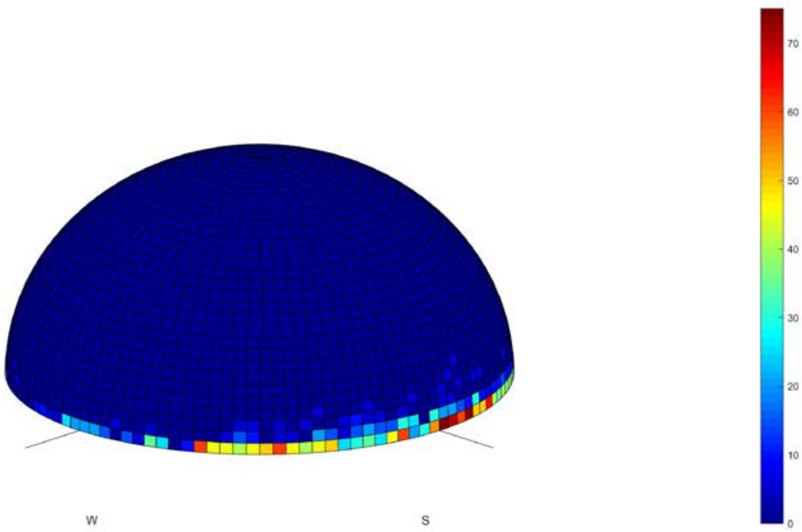


Figure 52: Data loss due to airborne ESIM over Kalyazin

Figure 53 provides the results of simulations for the Puschino RAS station. The percentage of data loss is 1.08% above 6° elevation.

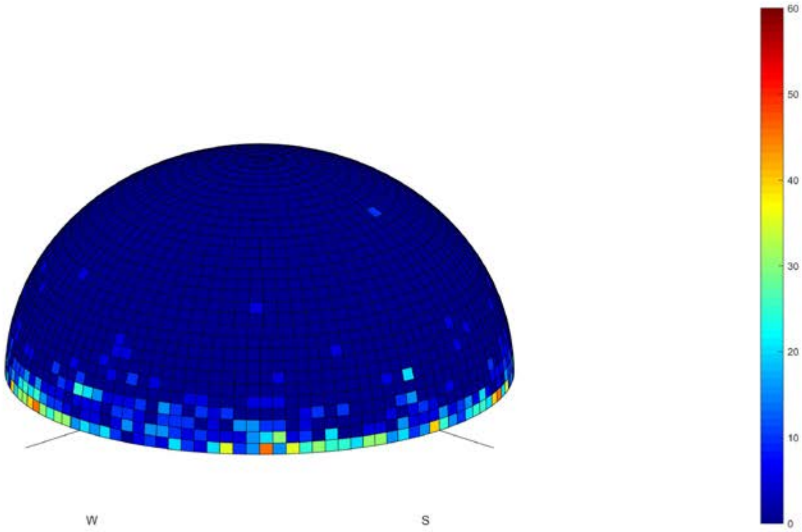


Figure 53: Data loss due to airborne ESIM over Puschino

Figure 54 provides the results of simulations for the Santa Maria RAS station. The percentage of data loss is 0.19% above 5° elevation.

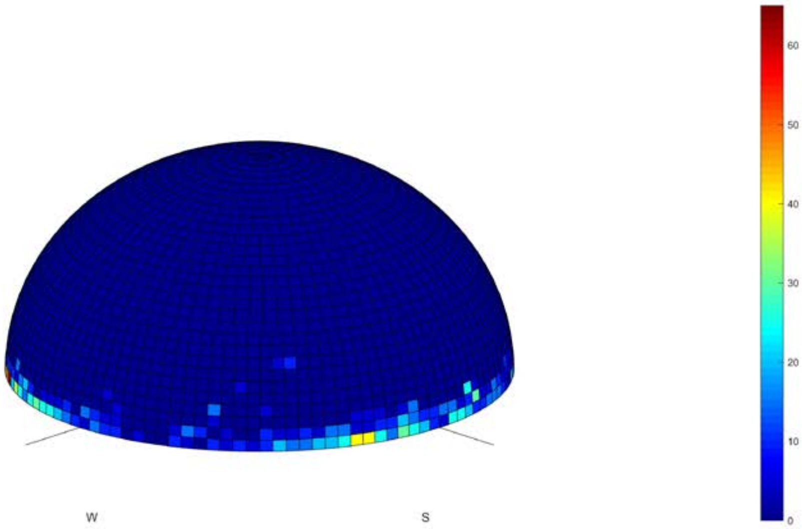


Figure 54: Data loss due to airborne ESIM over Santa Maria

Figure 55 provides the results of simulations for the Onsala RAS station. The percentage of data loss is 0.89% above 0° elevation.

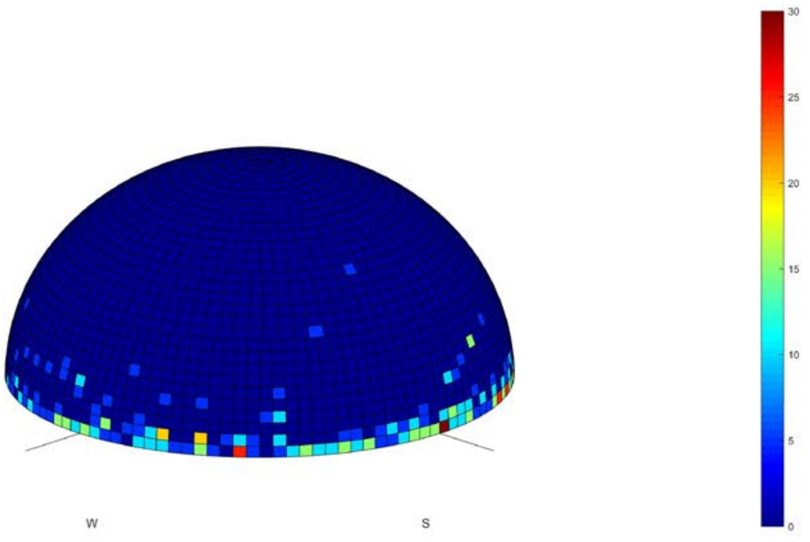


Figure 55: Data loss due to airborne ESIM over Onsala

Figure 56 provides the results of simulations for the Cambridge RAS station. The percentage of data loss is 0.89% above 2° elevation.

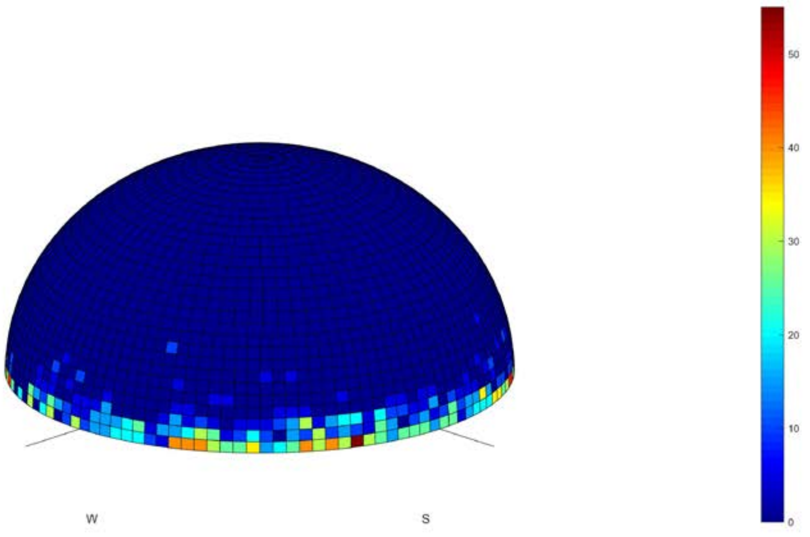


Figure 56: Data loss over Cambridge

Figure 57 provides the results of simulations for the Jodrell Bank RAS station. The percentage of data loss is 1.53% above 0° elevation.

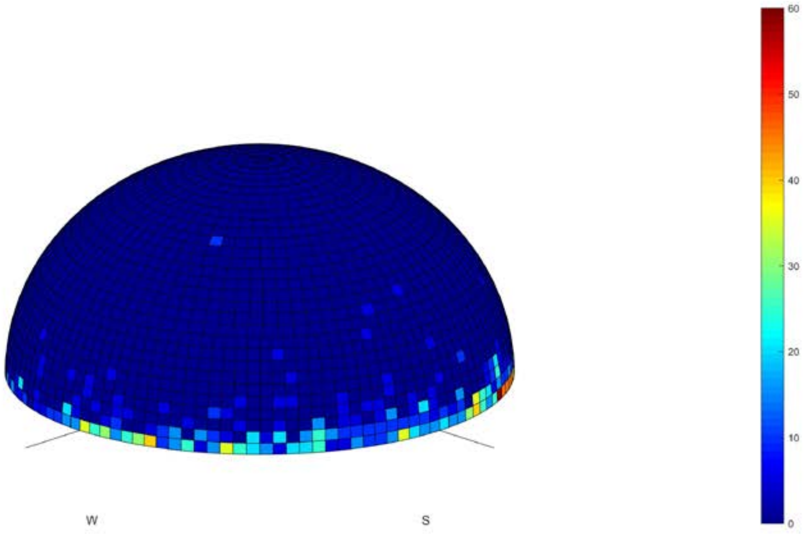


Figure 57: Data loss over Jodrell Bank

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 · θ dB(W/(m2 · 150 kHz)) for θ ≤ 10°;
- –180 dB(W/(m2 · 150 kHz)) for 10° < θ ≤ 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 17: 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 protection 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 protection zones. The NGSO FSS operator would have to cease transmissions in the band 14.47-14.5 GHz when the ship enters within these protection 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 protection zones can be up to 200 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 protection zones.

When establishing compatibility with RAS observatories within an administration, the NGSO FSS system would initially identify the protection 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 ITU and licensed by the U.S. Federal Communications Commission (FCC), 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. The overall constellation as filed will be configured as follows:

Table 18: SpaceX System Constellation

Orbital Planes	Satellites per Plane	Altitude (km)	Inclination (º)
32	50	1150	53
32	50	1110	53.8
8	50	1130	74
5	75	1275	81
6	75	1325	70

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. 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 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 19: Frequency Bands Used by the SpaceX System

Type of Link and Transmission Direction	Frequency Ranges
User Downlink Satellite-to-User Terminal	10.7–12.7 GHz
Gateway Downlink Satellite to Gateway	17.8–18.6 GHz 18.8–19.3 GHz

[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.

Type of Link and Transmission Direction	Frequency Ranges
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 40° from the horizon. Consequently, as shown in Figure 58 below, each satellite operating at an altitude of 1150 km will provide service only up to 40.46° away from boresight (nadir), covering an area of about 3.5 million square kilometres (1060 km radius).[7]

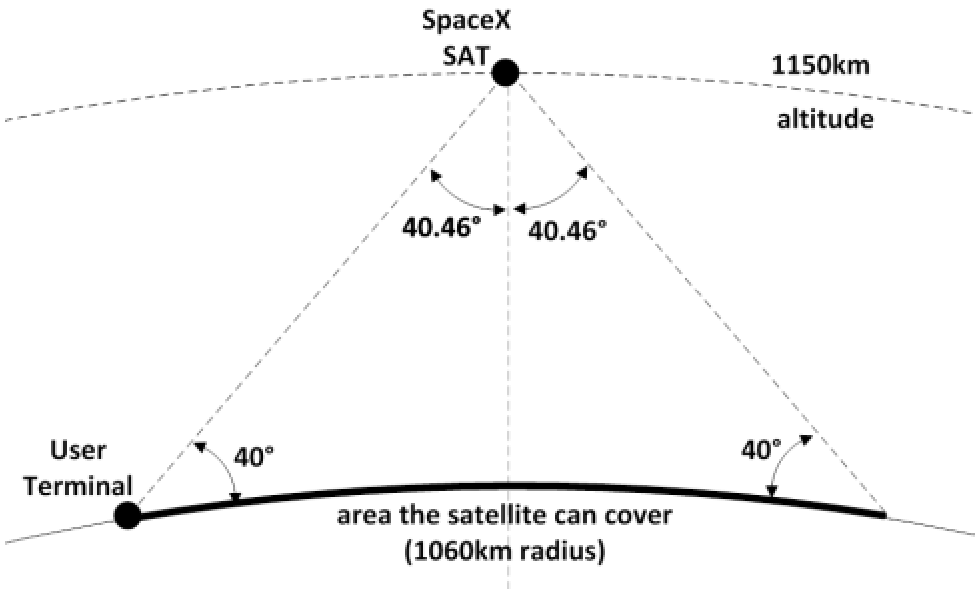


Figure 58: Steerable Service Range of Ku-band Beams (1150 km)

Generally, beams from antennas using phased arrays widen incrementally as they are steered away from boresight[8]. 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.

[7] While the 40° 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 1,110 km, 1,130 km, 1,275 km, and 1,325 km altitude provide service up to 40.72, 40.59, 39.67, and 39.36° away from boresight, respectively.

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

This beam widening behaviour with phased array antennas creates several effects that must be offset in order to achieve efficient use of spectrum through frequency re-use. As the beam widens, the size of the spot on the ground increases due to the increased distance to the Earth's surface, and the curvature of the Earth enhances this effect. For transmitting antennas, this results in transmission of radiofrequency energy over a wider area, which increases both the potential to interfere with other systems and the potential for interference with other beams of the SpaceX System using the same frequencies. Conversely, for receiving antennas, this results in reception of radiofrequency energy from a wider area, which increases both the susceptibility to interference from other systems and the potential for self-interference from user terminal uplink transmissions.

The SpaceX System offsets these beamwidth variations by switching antenna elements in the phased array on and off at certain steering angles. By ensuring that radio energy is transmitted in the desired direction, this switching helps to mitigate interference with other systems. Specifically, as shown in Figure 59 below, additional elements are turned on when the angle reaches 23°, and then again when it reaches 32°. Note this applies for both transmit and receive antennas on each satellite.

Figure 59: Beamwidth Variation at Various Steering Angles

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.

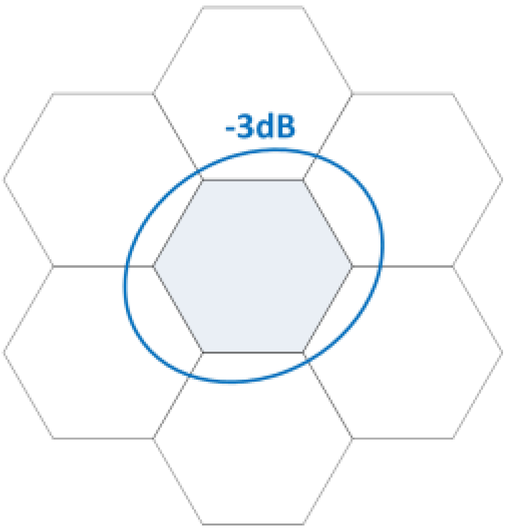


Figure 60: Intended Beam Coverage Area

As illustrated in Figure 61 below, 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. The highest equivalent isotropically radiated power e.i.r.p.) density (-11.07 dBW/4kHz for 1110 km orbits) occurs at maximum slant.[9]

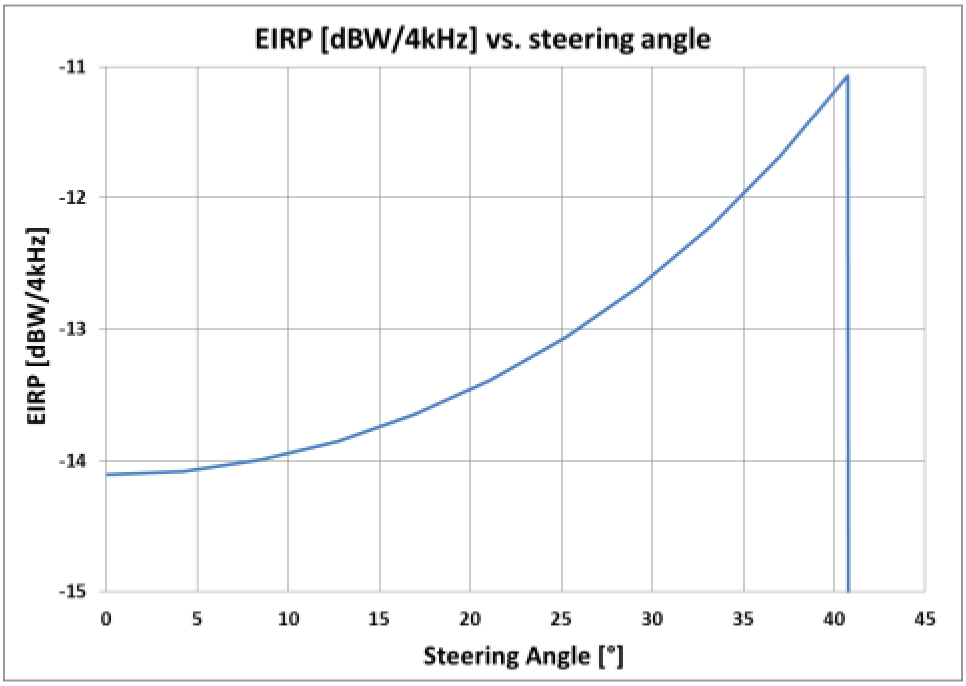


Figure 61: e.i.r.p. Density Variation by Beam Steering Angle

For receiving beams, the antenna gain drops slightly as the beam slants away from nadir. As a result, the maximum G/T (9.8 dB/K) occurs at nadir, while the minimum G/T (8.7 dB/K) occurs at maximum slant.

Table 21 below shows the difference in space station e.i.r.p. levels for different frequency bands and latitudes.

Table 20: e.i.r.p. for Ku FSS and BSS bands at nadir and slant for various orbits

Parameter	Ku FSS band				Ku BSS band			
Latitude	≤ 55°		> 55°		≤ 55°		> 55°	
pfd (dBW/m^2/4kHz)	-146.0		-148.0		-147.5		-151.0	
	nadir	slant	nadir	slant	nadir	slant	nadir	slant
1110 km orbit								
distance to ground	1110.0	1574.7	1110.0	1574.7	1110.0	1574.7	1110.0	1574.7
spreading loss (dB/m^2)	131.9	134.9	131.9	134.9	131.9	134.9	131.9	134.9

9 This maximum e.i.r.p. level occurs at maximum slant for beams in the 10.7-12.2 GHz band at latitudes below ±55º. At higher latitudes, the maximum e.i.r.p. in this band is -13.07 dBW/4kHz. In the 12.2-12.7 GHz band, the maximum e.i.r.p. is -12.57 dBW/4kHz and -16.07 dBW/4kHz for latitudes below and above ±55º, respectively. Because the 10.7-12.2 GHz band at latitudes below ±55º provides a worst case Figure 61, relates to that scenario.

Parameter	Ku FSS band				Ku BSS band			
e.i.r.p. (dBW/4kHz)	-14.1	-11.1	-16.1	-13.1	-15.6	-12.6	-19.1	-16.1
1130 km orbit								
distance to ground	1130.0	1601.1	1130.0	1601.1	1130.0	1601.1	1130.0	1601.1
spreading loss (dB/m^2)	132.1	135.1	132.1	135.1	132.1	135.1	132.1	135.1
e.i.r.p. (dBW/4kHz)	-13.9	-10.9	-15.9	-12.9	-15.4	-12.4	-18.9	-15.9
1150 km orbit								
distance to ground	1150.0	1627.4	1150.0	1627.4	1150.0	1627.4	1150.0	1627.4
spreading loss (dB/m^2)	132.2	135.2	132.2	135.2	132.2	135.2	132.2	135.2
e.i.r.p. (dBW/4kHz)	-13.8	-10.8	-15.8	-12.8	-15.3	-12.3	-18.8	-15.8
1275 km orbit								
distance to ground	1275.0	1790.7	1275.0	1790.7	1275.0	1790.7	1275.0	1790.7
spreading loss (dB/m^2)	133.1	136.1	133.1	136.1	133.1	136.1	133.1	136.1
e.i.r.p. (dBW/4kHz)	-12.9	-9.9	-14.9	-11.9	-14.4	-11.4	-17.9	-14.9
1325 km orbit								
distance to ground	1325.0	1855.5	1325.0	1855.5	1325.0	1855.5	1325.0	1855.5
spreading loss (dB/m^2)	133.4	136.4	133.4	136.4	133.4	136.4	133.4	136.4
e.i.r.p. (dBW/4kHz)	-12.6	-9.6	-14.6	-11.6	-14.1	-11.1	-17.6	-14.6

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 40°, with increasing minimum elevation angles at lower latitude.

A2.4 GENERAL CHARACTERISTICS OF SPACEX EARTH STATIONS

Specific deployments of fixed Earth Stations 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. 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 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 Earth Stations point at a minimum elevation of 40°; 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 protection 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.

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 4425 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. in the RAS band (10.6-10.7GHz) is -142 dBW/Hz and is 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); 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 SpaceX's satellite system can serve the areas around RAS sites only with high channels to minimise interference, or, if desired can place no beam in the area (cell size is 45km diameter). Also note that meeting the e.i.r.p. limit mentioned above (-142dBW/Hz) prevents SpaceX from using the lowest Ku channel (10.7-10.95 GHz) on a global basis.

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 62 shows 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.

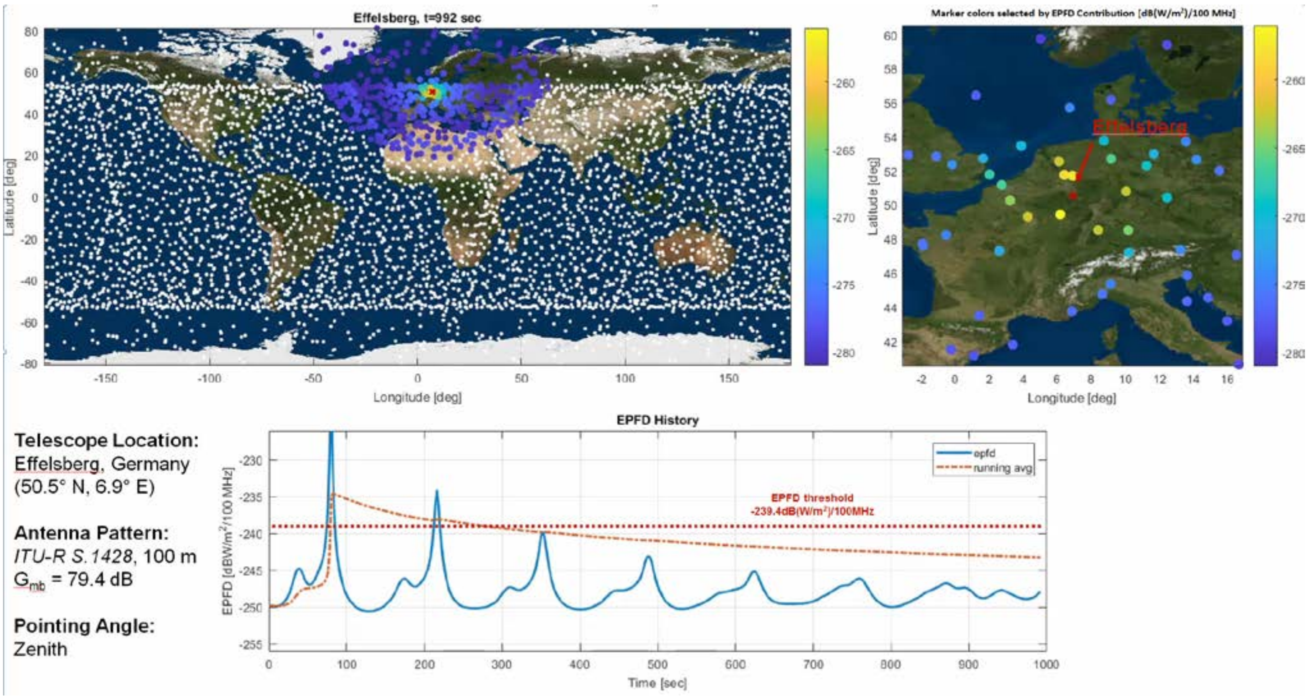


Figure 62: SpaceX Simulation: Effelsberg Radio Telescope

The simulation results are shown in Figure 63 and Figure 64. The average data loss is less than 2%. The peak loss occurs when the telescope is pointing towards the band of satellites at 53-53.8°. Note here that the satellite shells at 70, 74, and 81° inclination also cause some data loss (visible in figure below to some extent - see the light green lines at low elevation looking North).

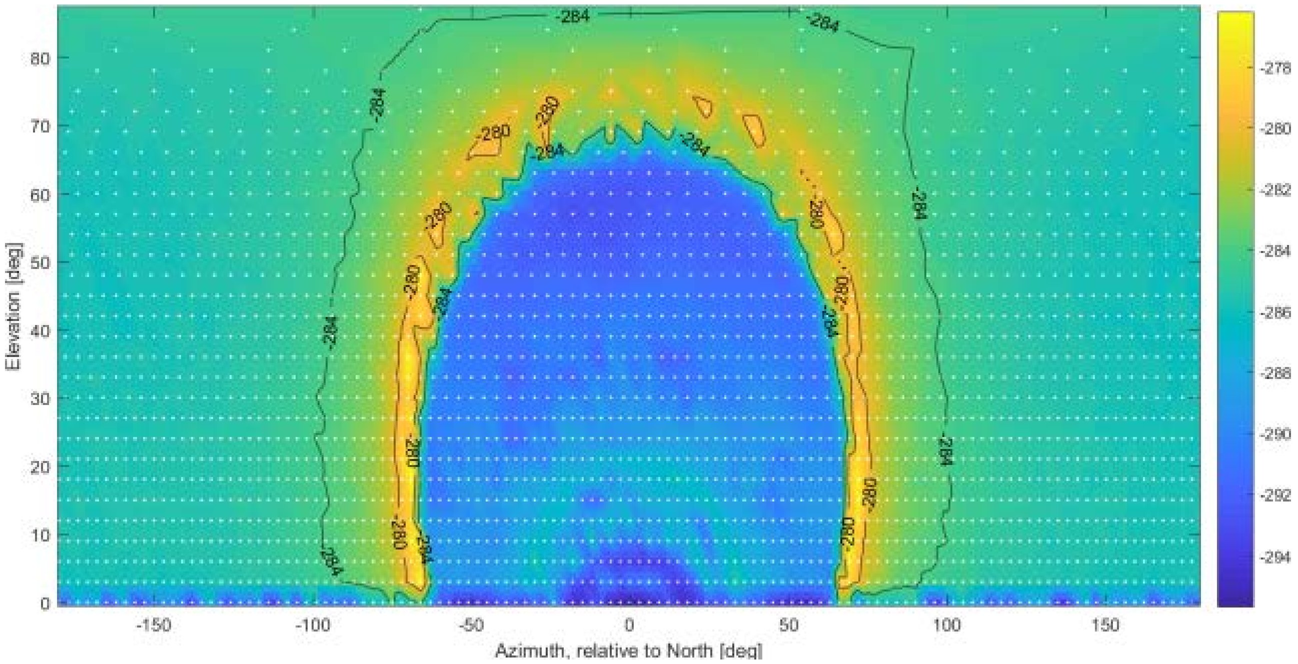


Figure 63: Effelsberg – Sky Map of Median epfd

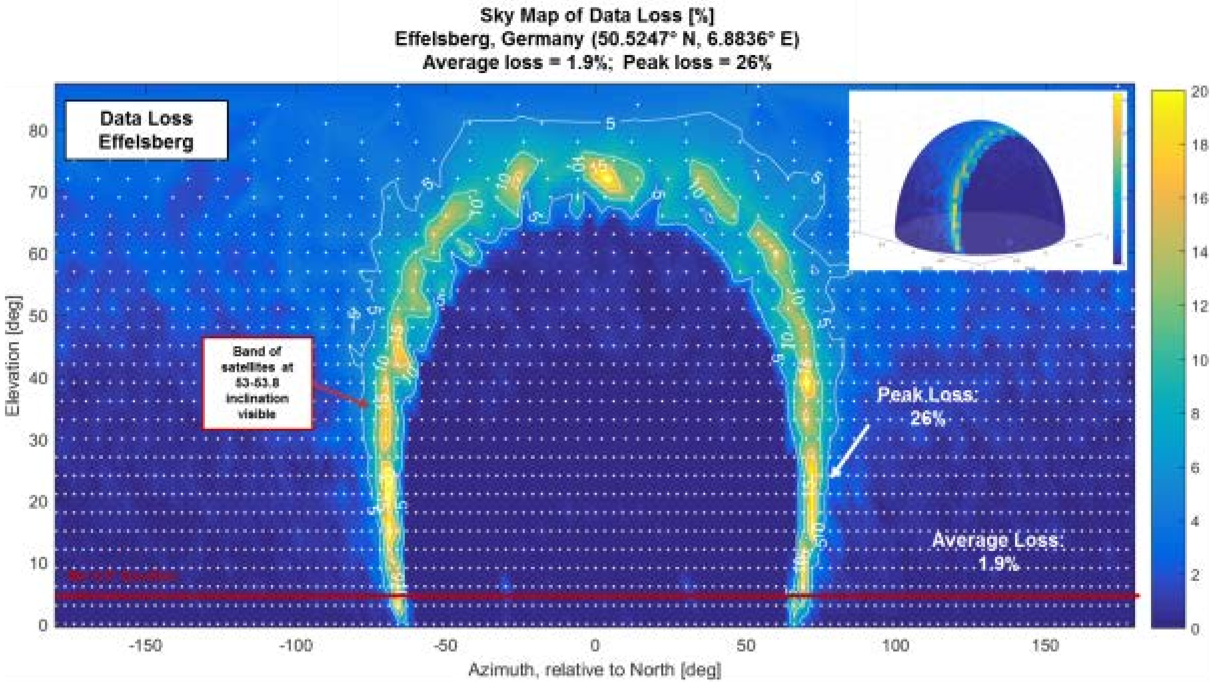


Figure 64: Effelsberg – Sky Map of Percent Data Loss

Figure 65 shows the probability distribution for the average epfd samples; over 98% of these samples are below the -239.4 dBW/m²/100MHz threshold. Figure 66 shows statistics on peak instantaneous epfd for all possible orientations of the antenna (2334 cells of 9 square degrees of solid angle, 1000 runs of 2000 seconds each, with 0.1sec time step). The maximum instantaneous epfd could be as high as -193.9 dBW/m²/100MHz, but that occurs very rarely.

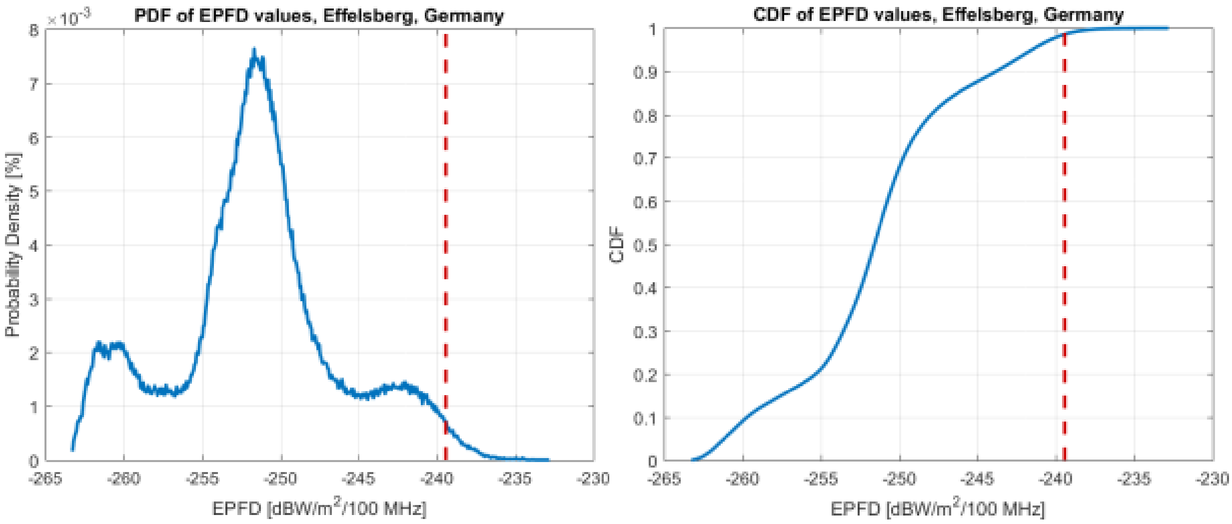


Figure 65: Effelsberg – Probability Distribution

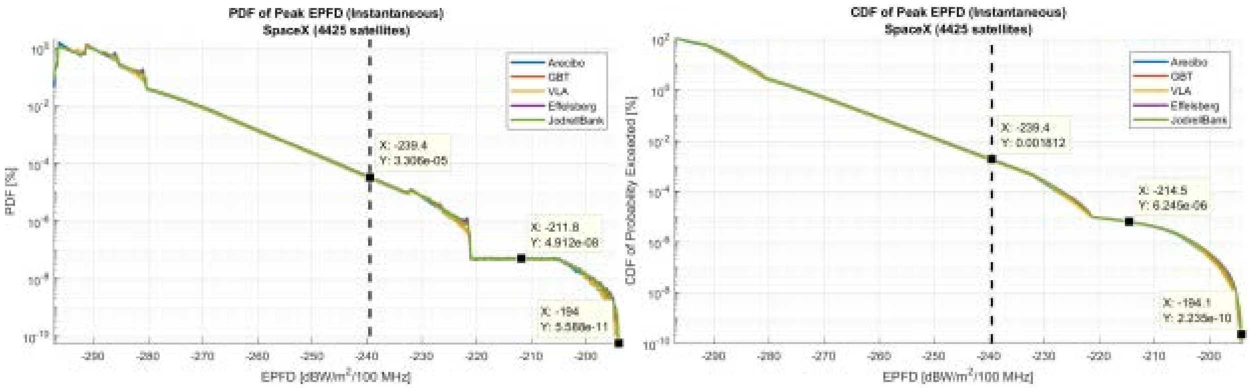


Figure 66: Statistics on Peak Instantaneous epfd

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

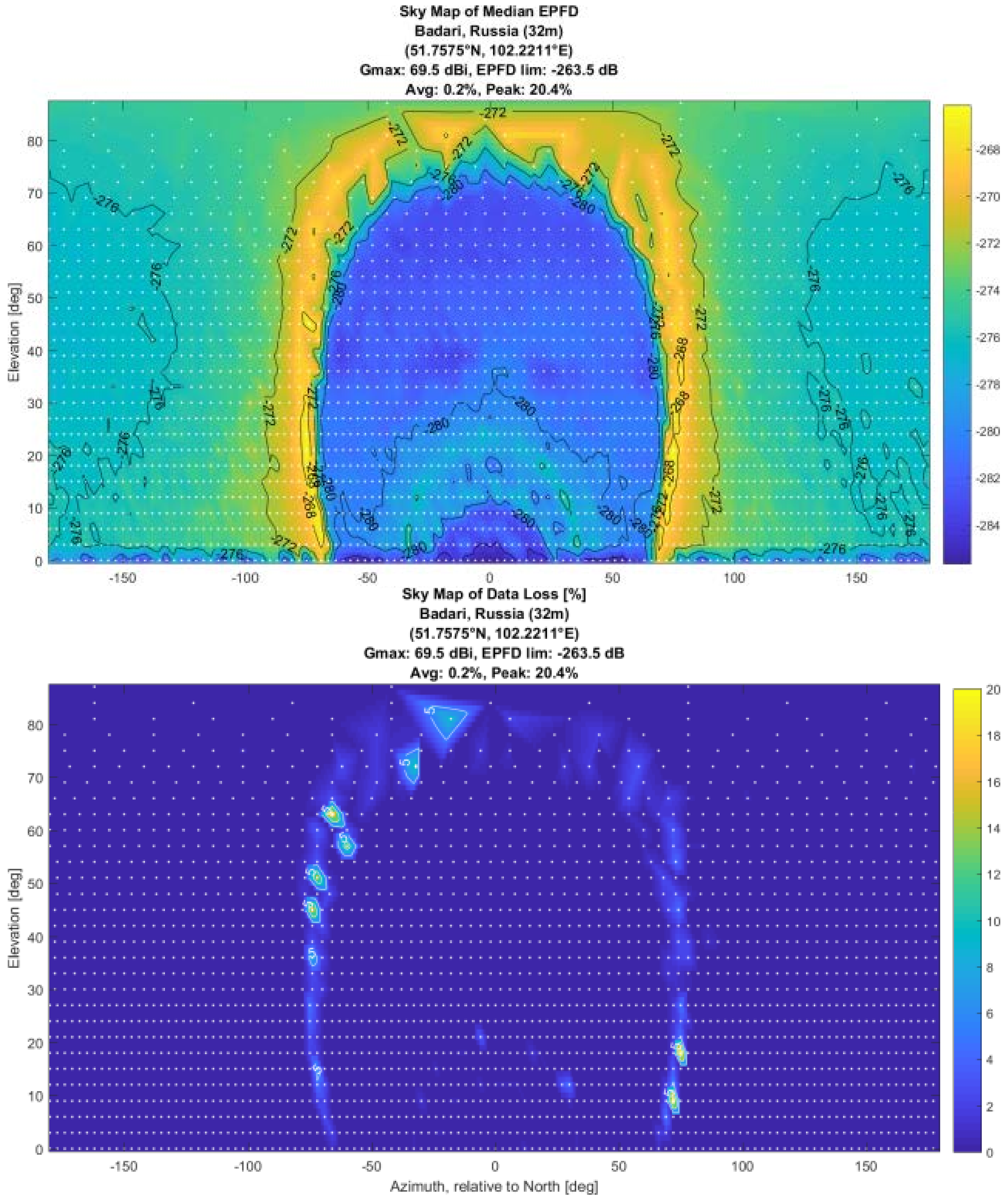


Figure 67: Badari, Russia – Sky Map of Median epfd and Percent Data Loss

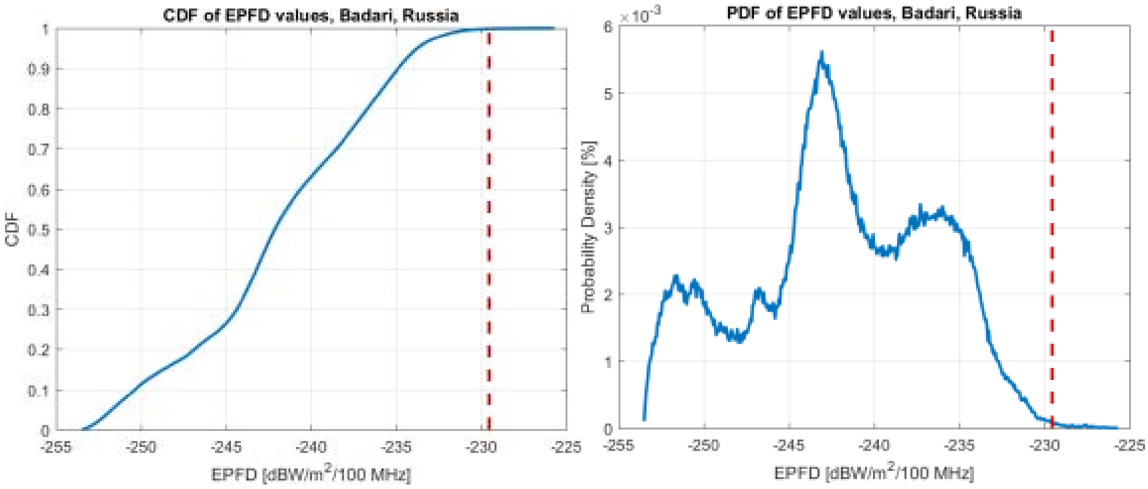


Figure 68: Badari, Russia – Probability Distribution

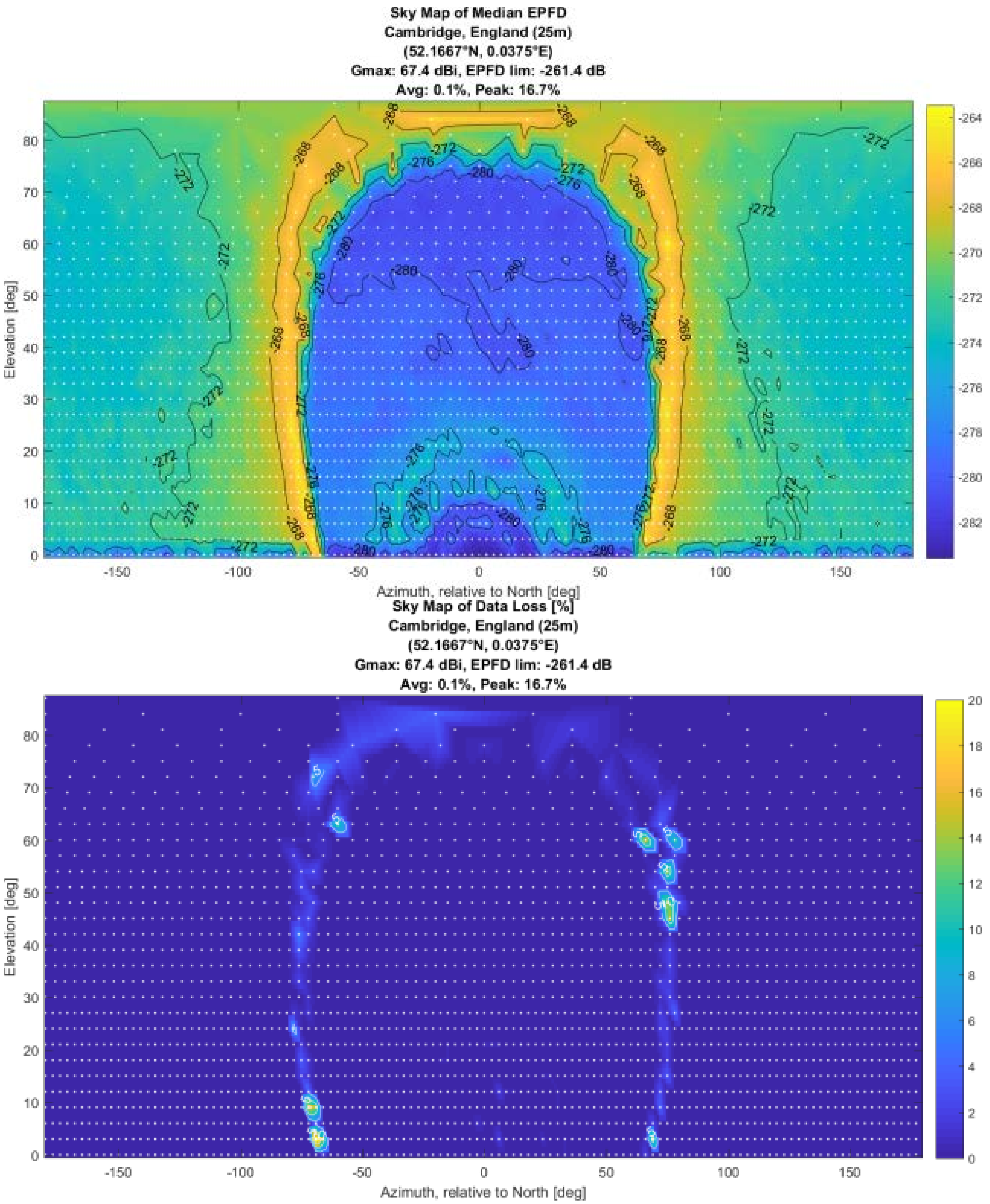


Figure 69: Cambridge, UK – Sky Map of Median epfd and Percent Data Loss

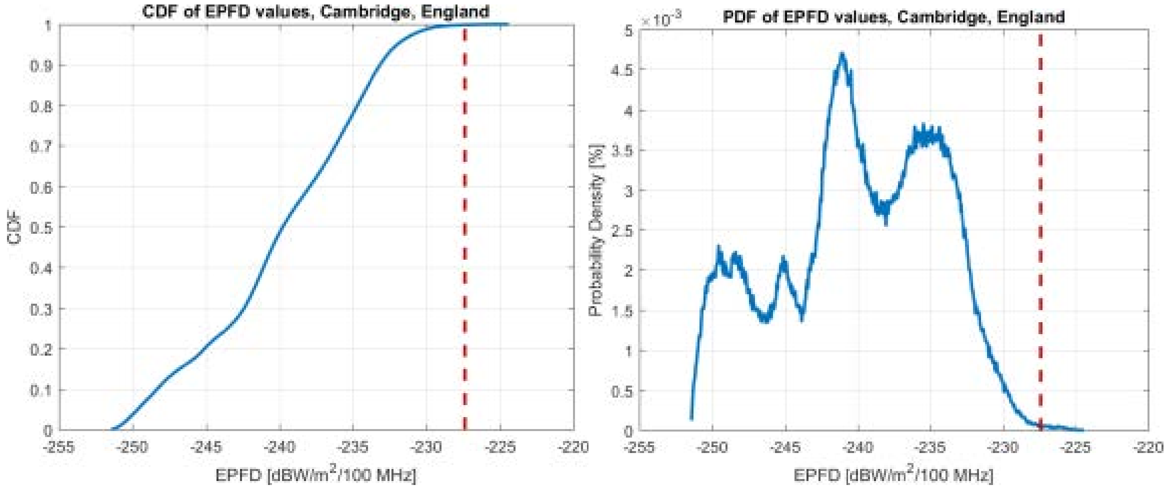


Figure 70: Cambridge, UK – Probability Distribution

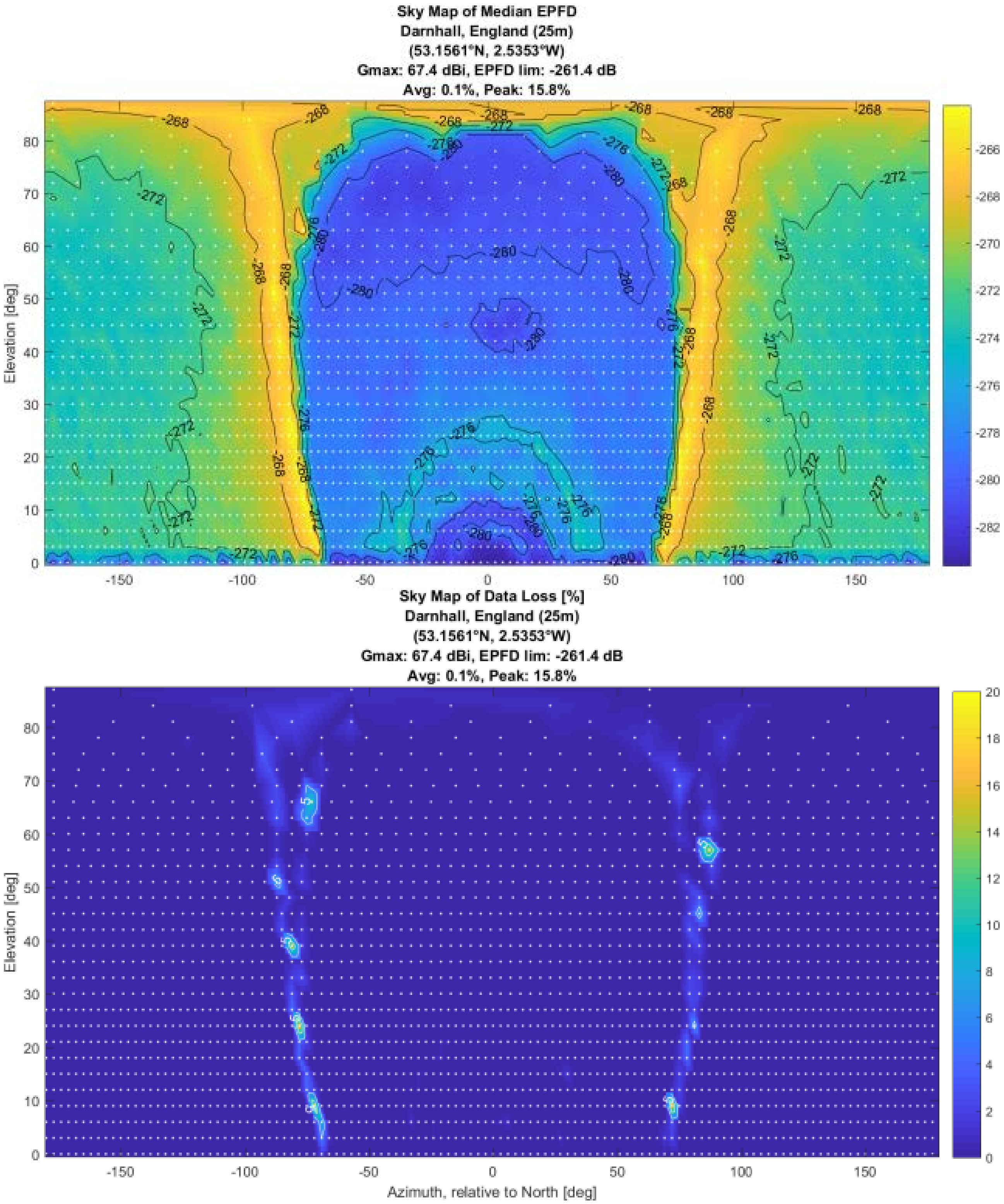


Figure 71: Darnhall, UK – Sky Map of Median epfd and Percent Data Loss

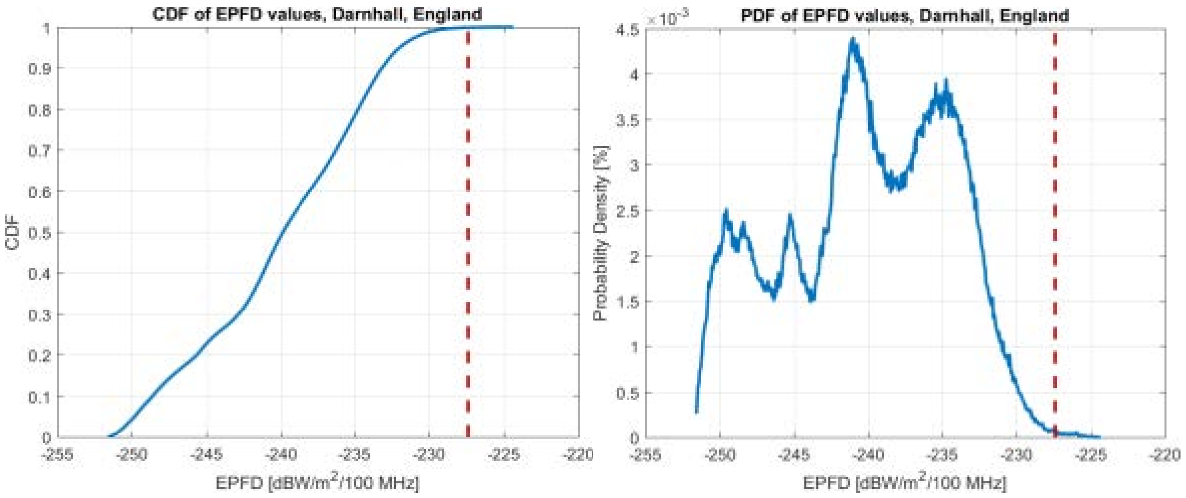
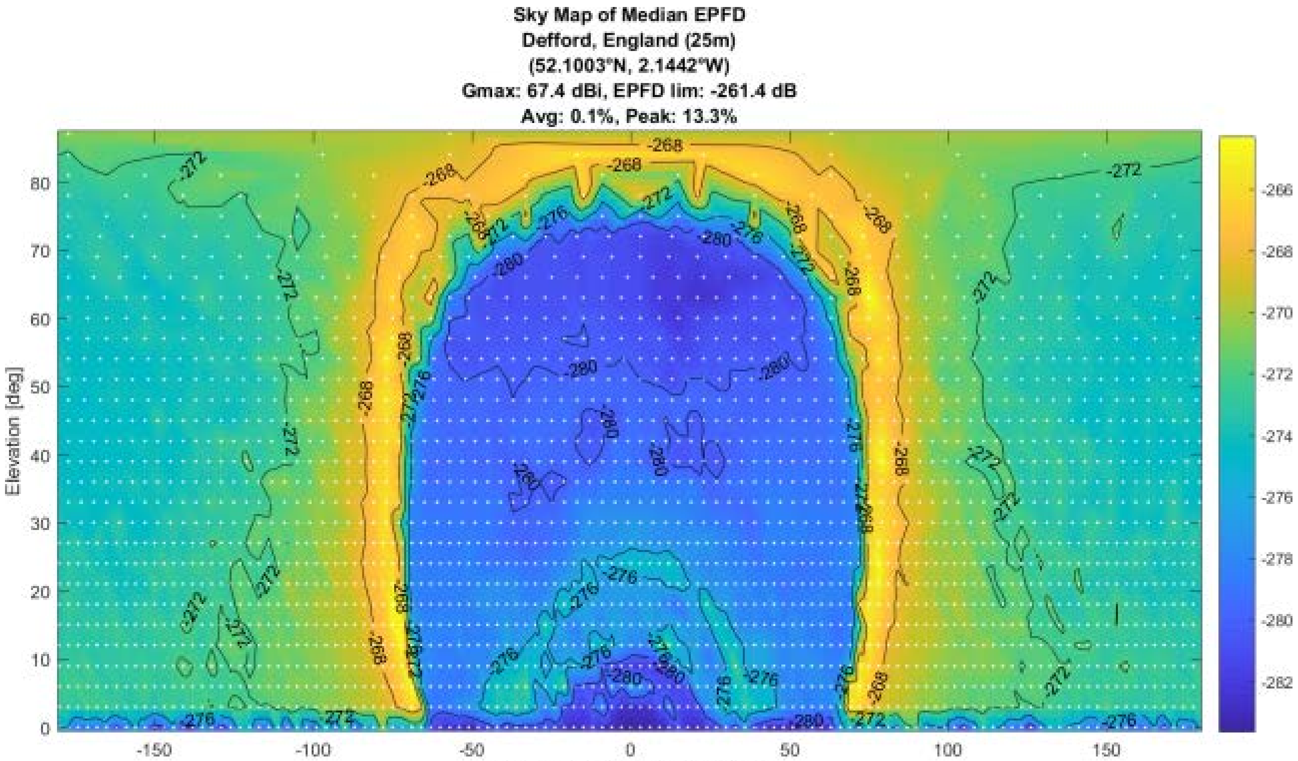


Figure 72: Darnhall, UK – Probability Distribution



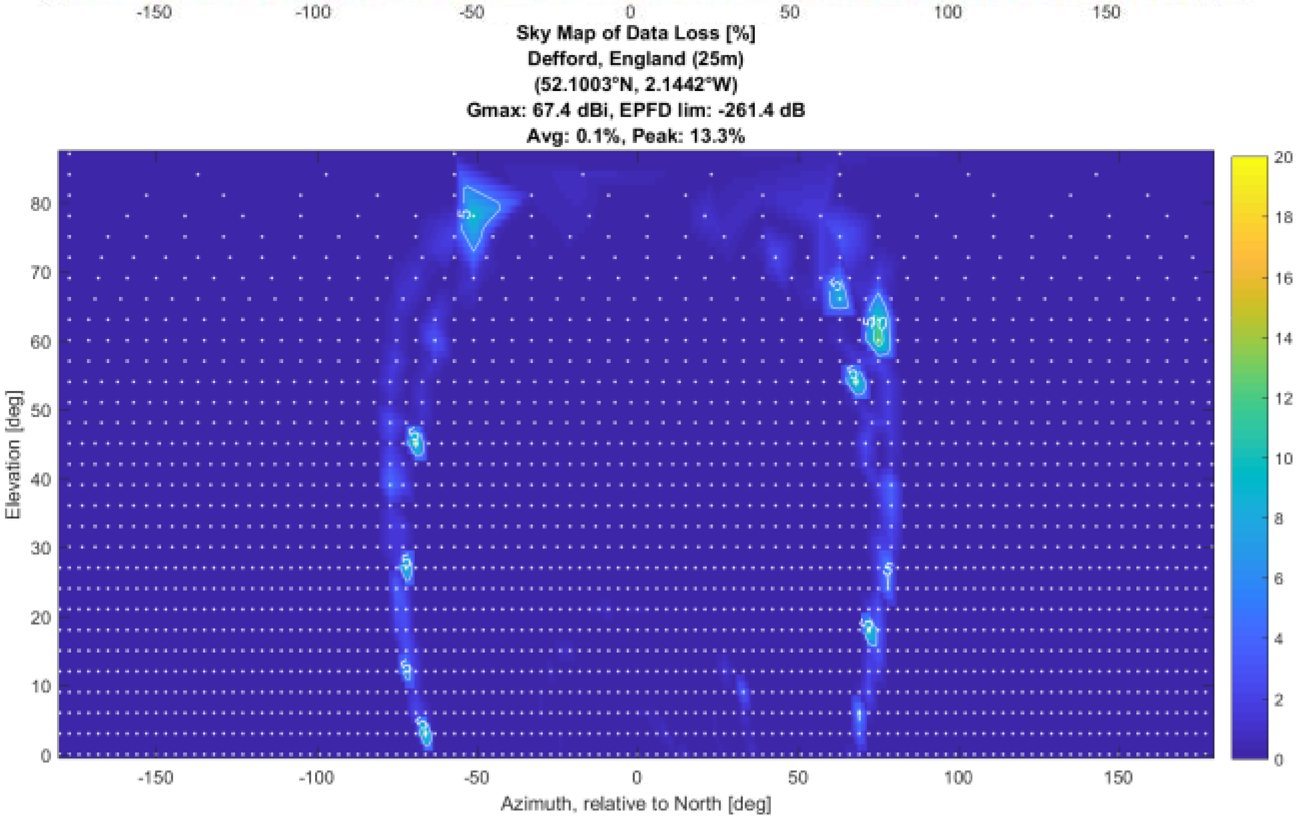


Figure 73: Defford, UK – Sky Map of Median epfd and Percent Data Loss

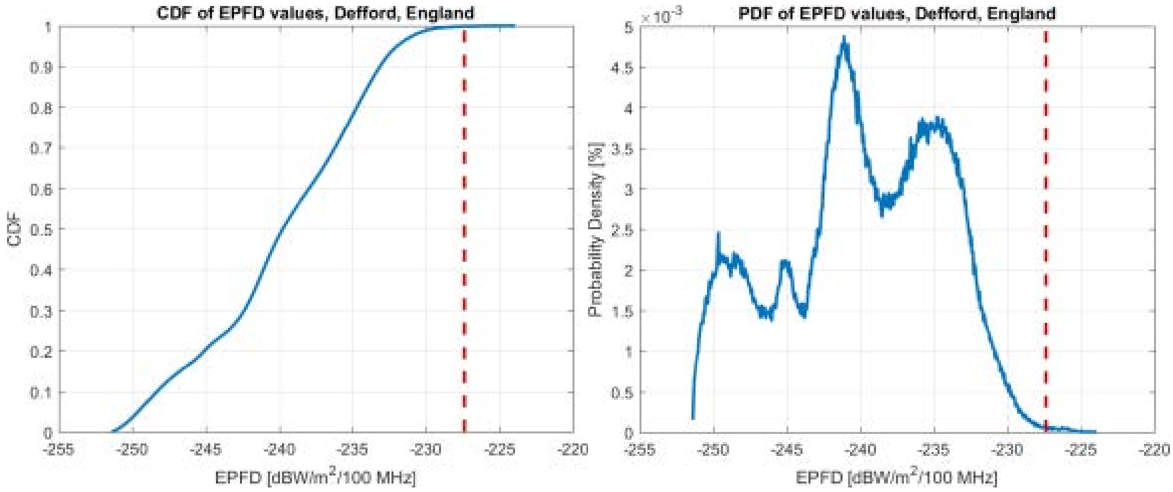


Figure 74: Defford, UK – Probability Distribution

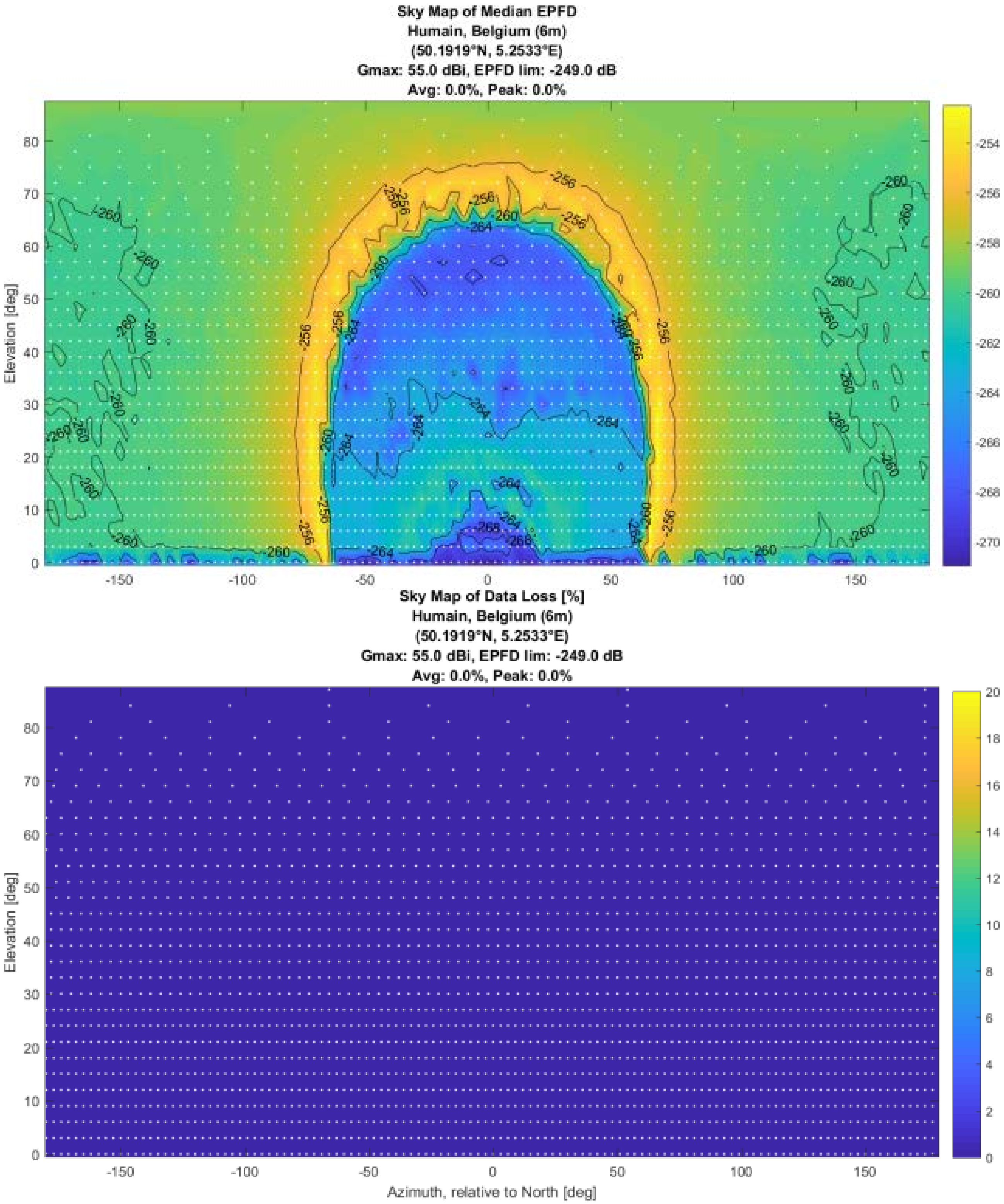


Figure 75: Humain, Belgium – Sky Map of Median epfd and Percent Data Loss

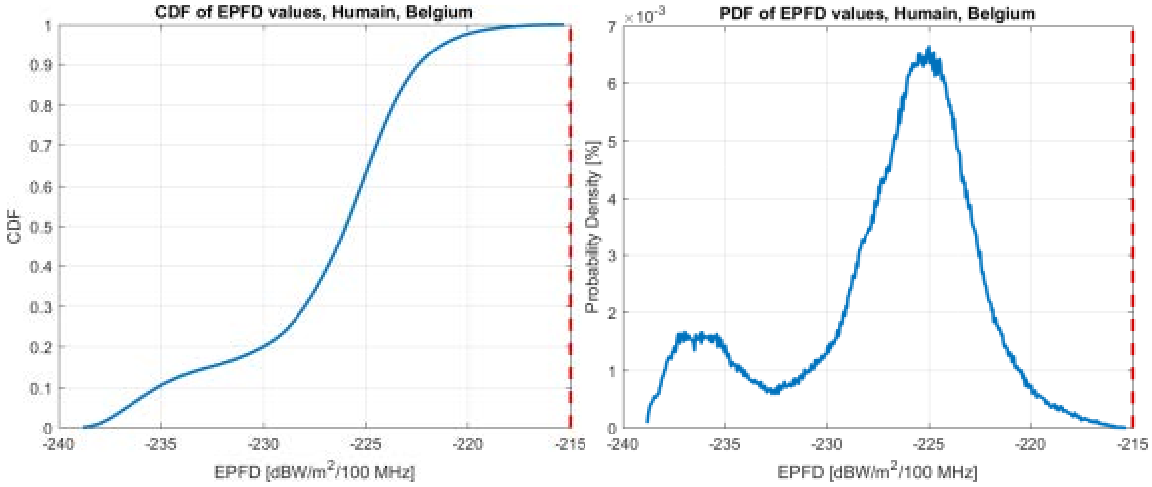


Figure 76: Humain, Belgium – Probability Distribution

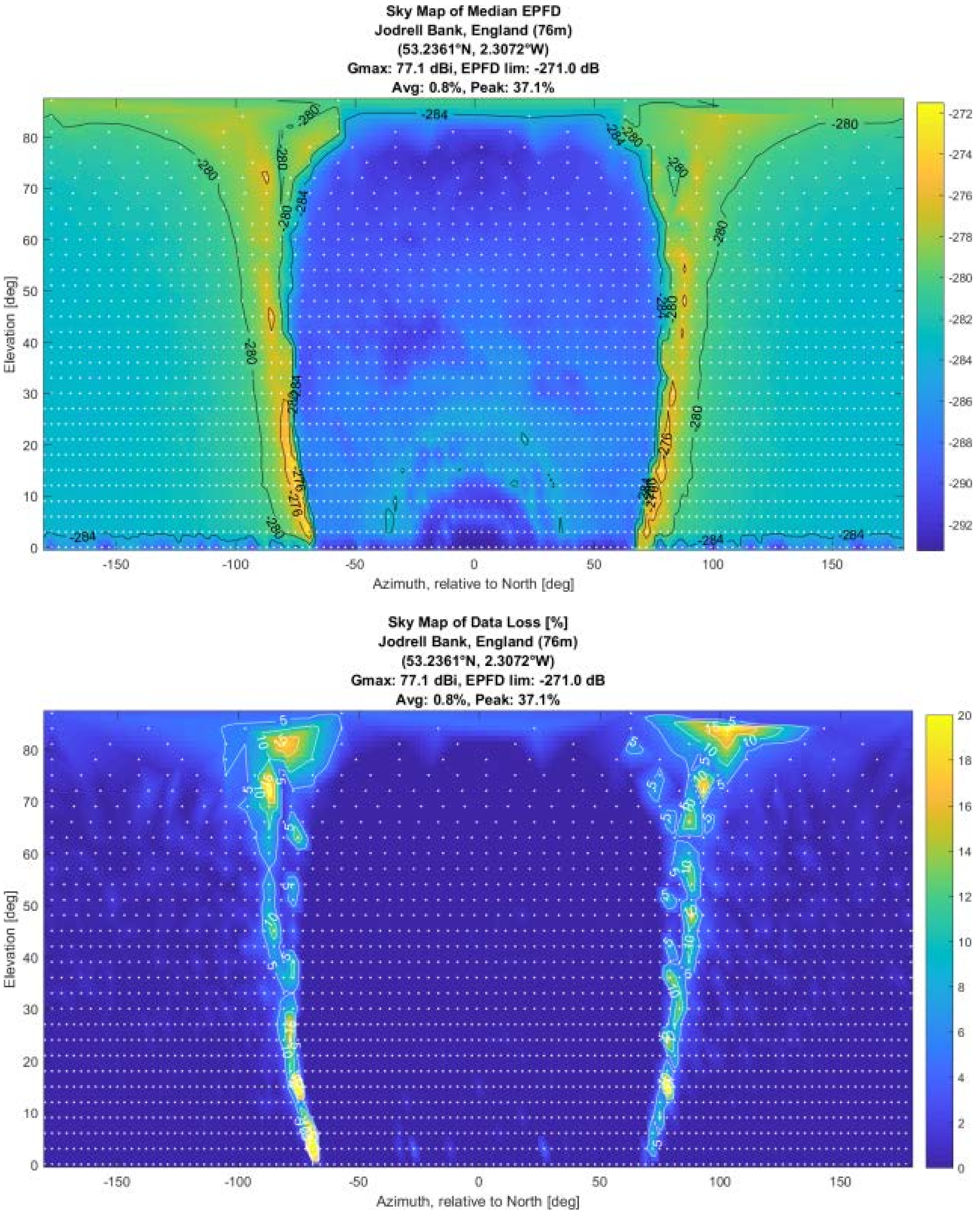


Figure 77: Jodrell Bank, UK – Sky Map of Median epfd and Percent Data Loss

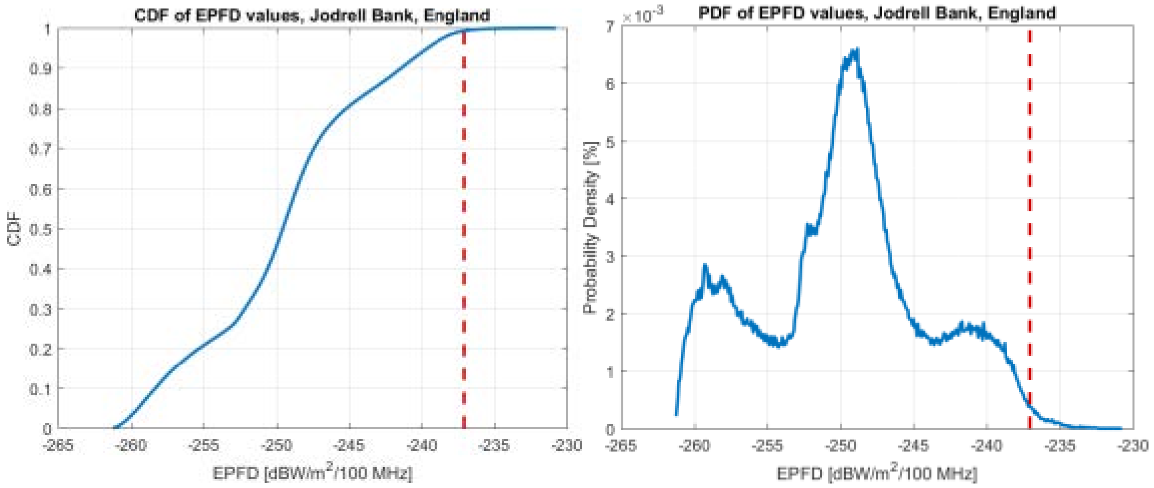


Figure 78: Jodrell Bank, UK – Probability Distribution

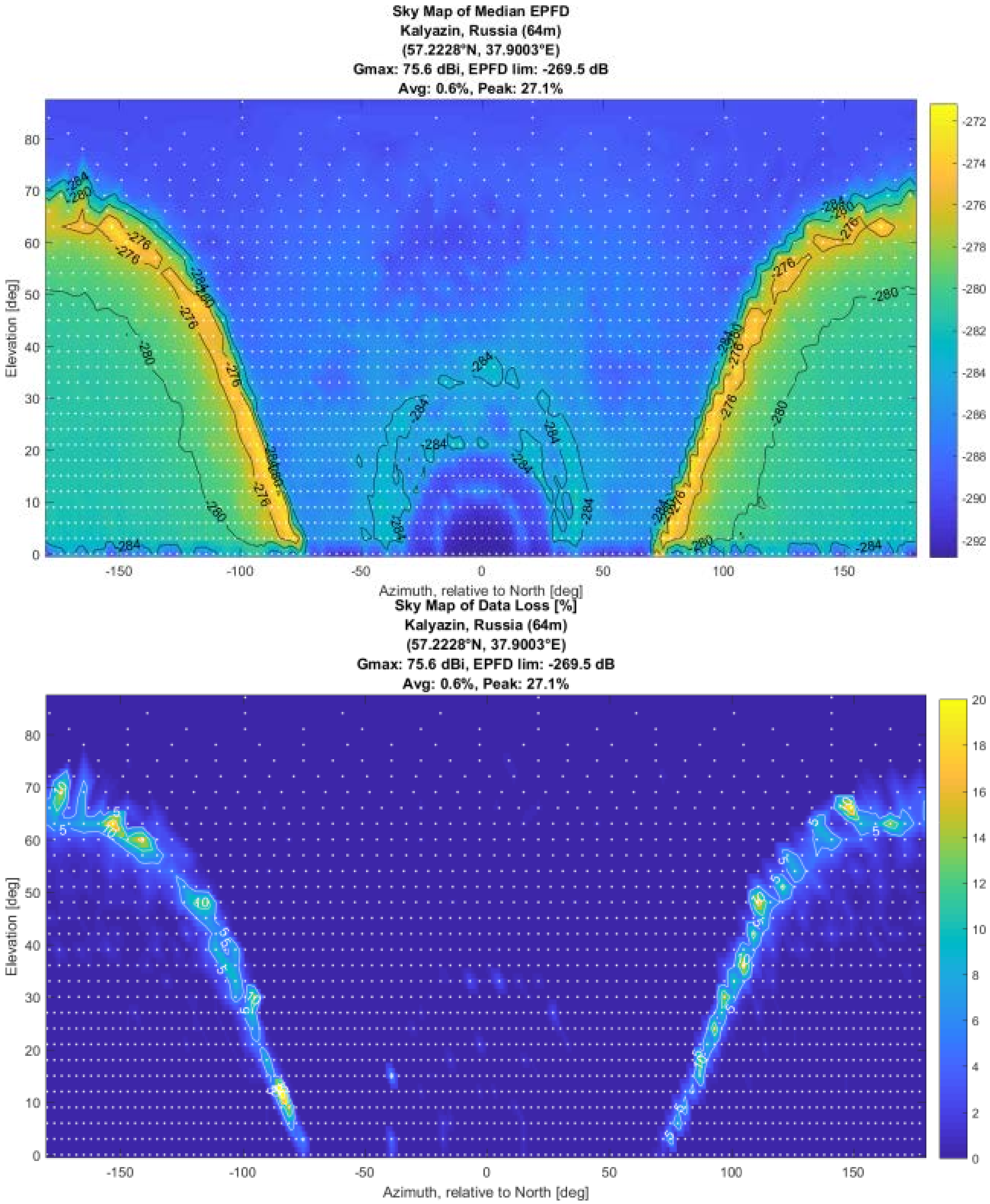


Figure 79: Kalyazin, Russia – Sky Map of Median epfd and Percent Data Loss

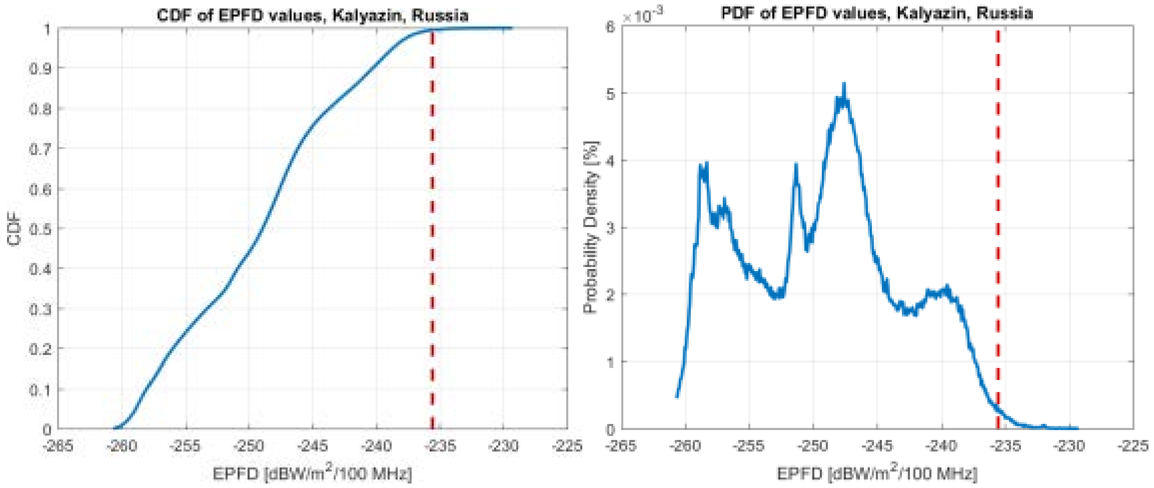


Figure 80: Kalyazin, Russia – Probability Distribution

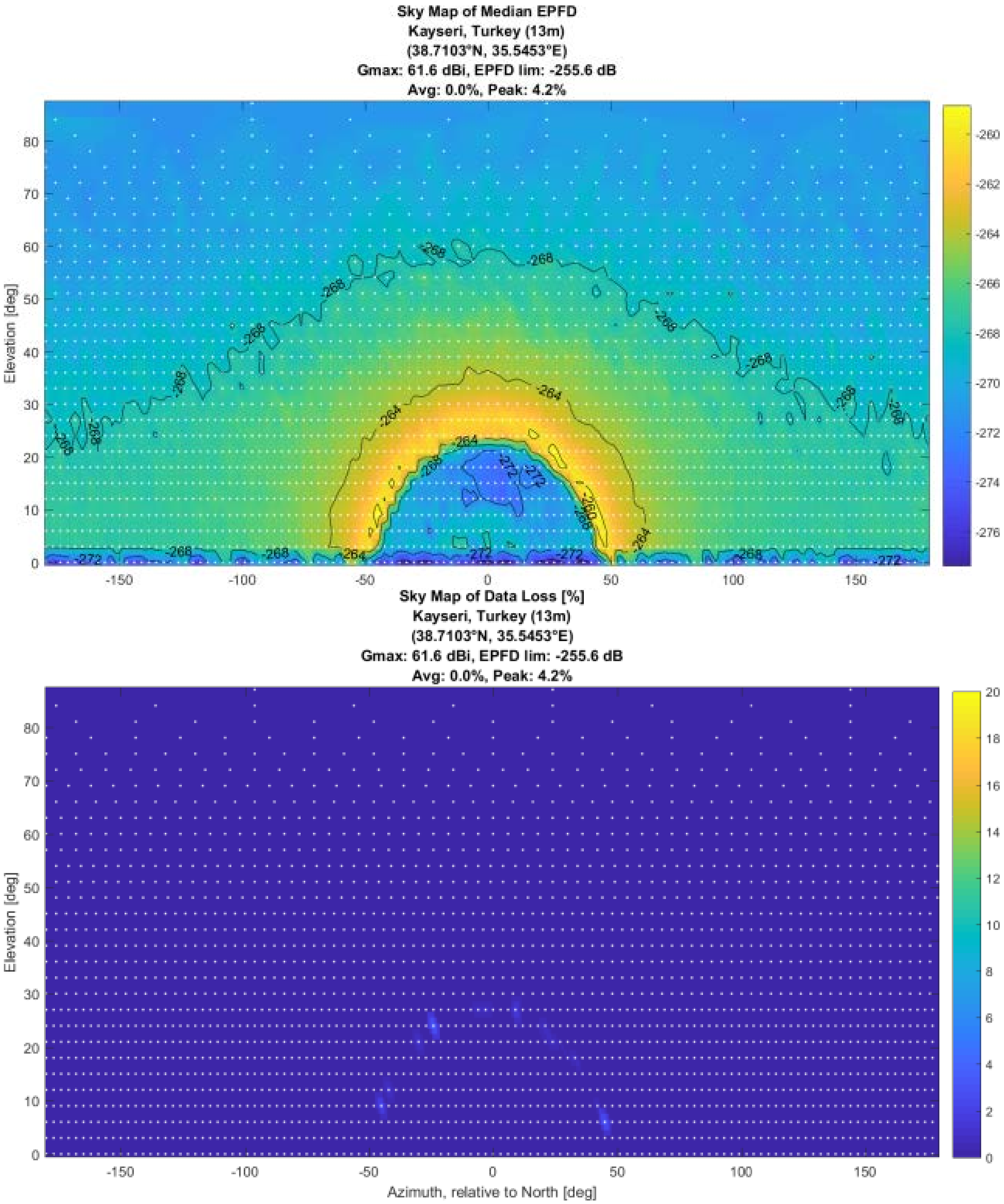


Figure 81: Kayseri, Turkey – Sky Map of Median epfd and Percent Data Loss

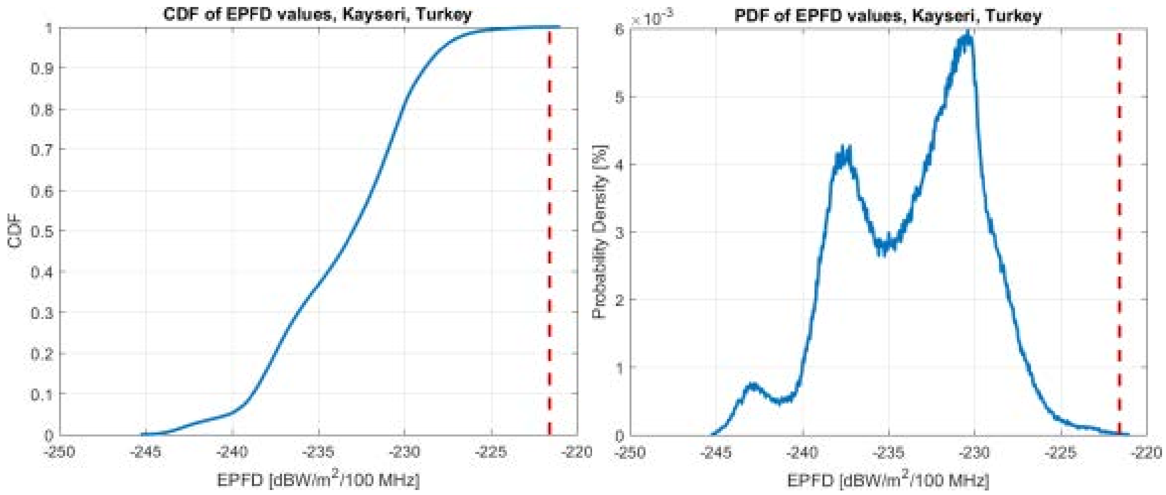


Figure 82: Kayseri, Turkey – Probability Distribution

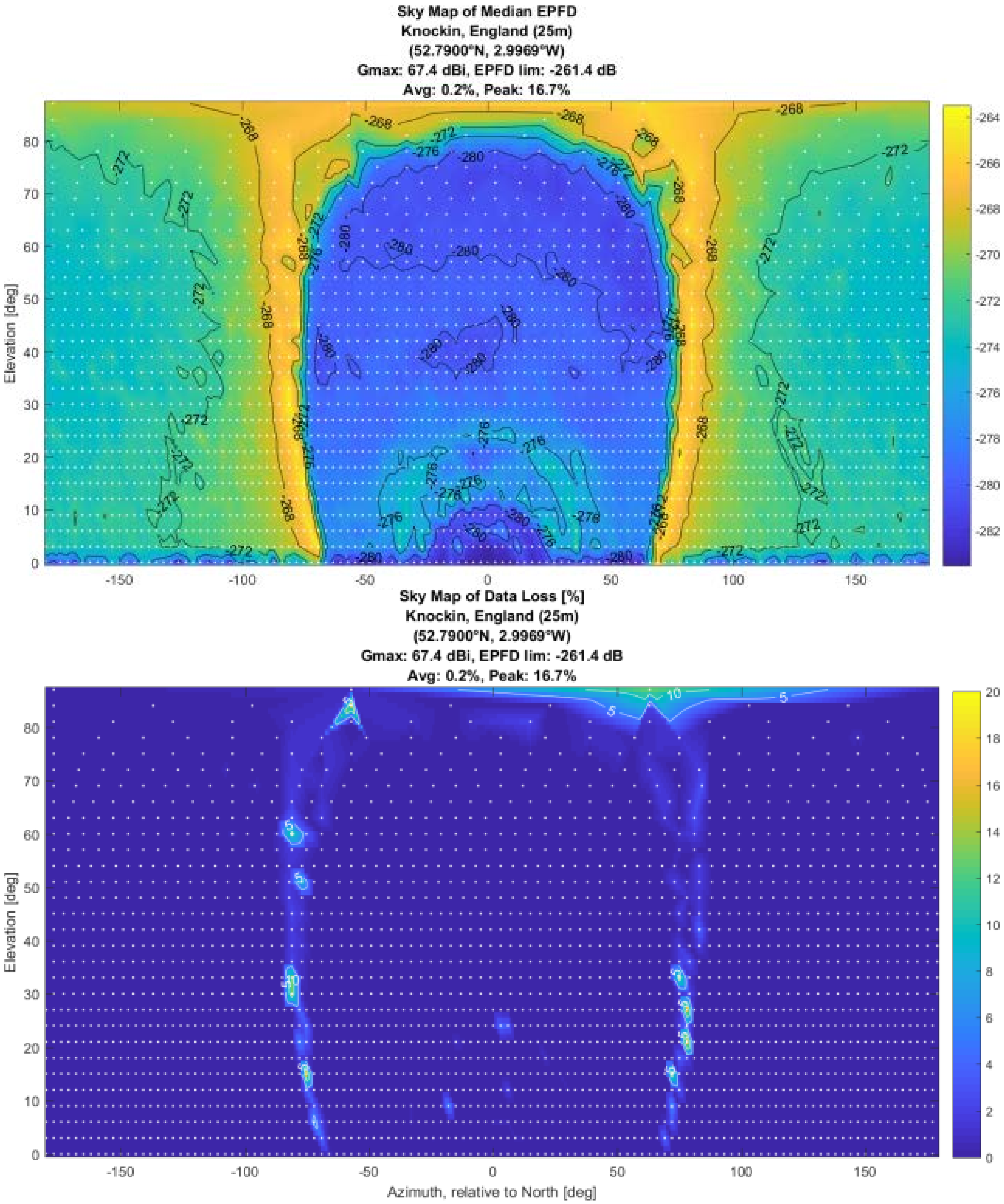


Figure 83: Knockin, UK – Sky Map of Median epfd and Percent Data Loss

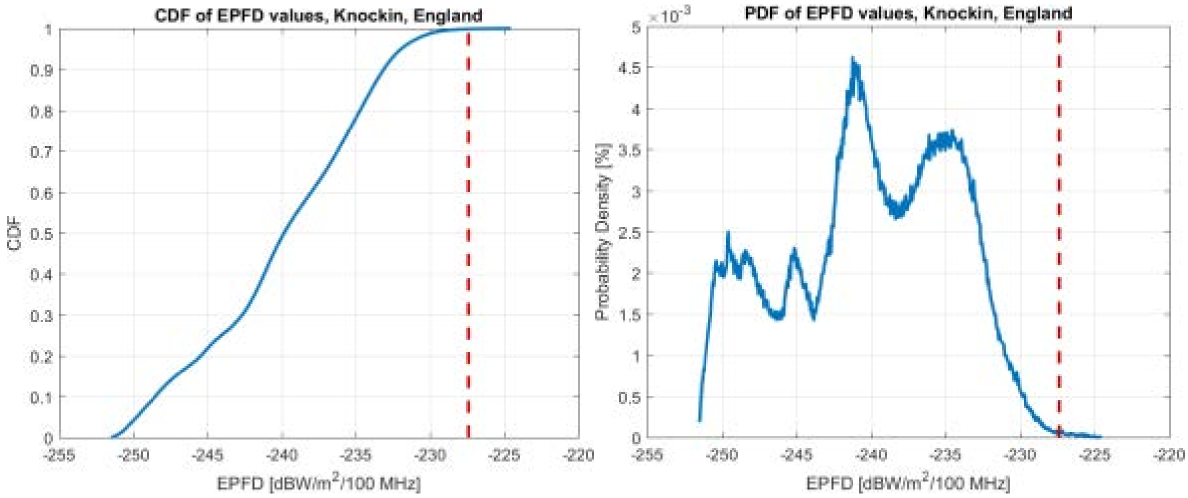


Figure 84: Knockin, UK – Probability Distribution

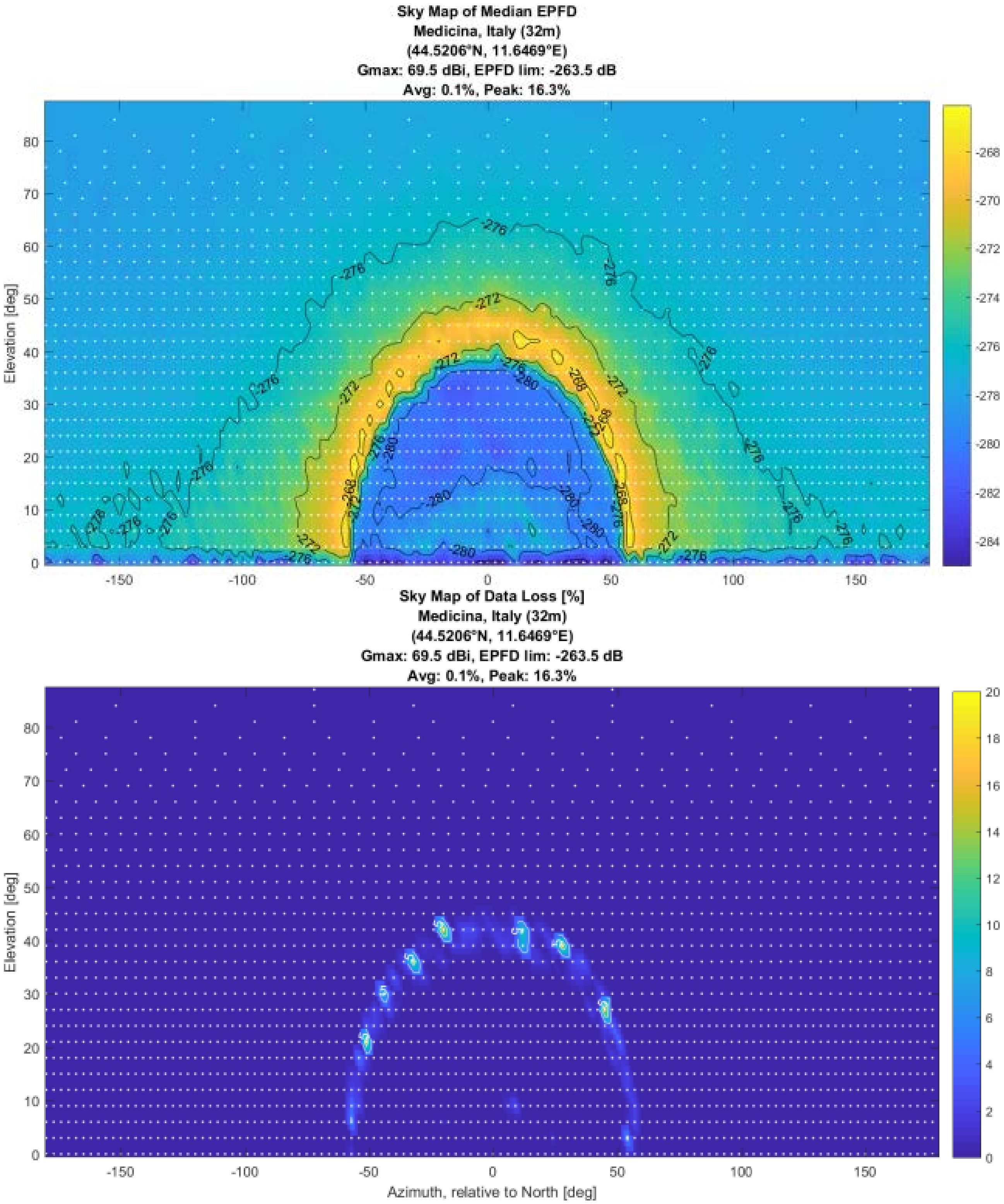


Figure 85: Medicina, Italy – Sky Map of Median epfd and Percent Data Loss

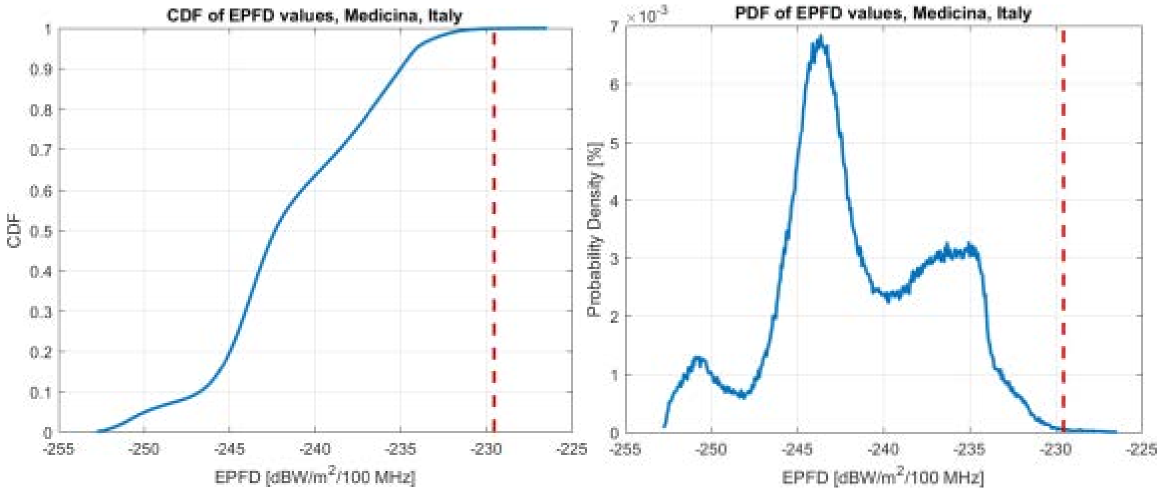


Figure 86: Medicina, Italy – Probability Distribution

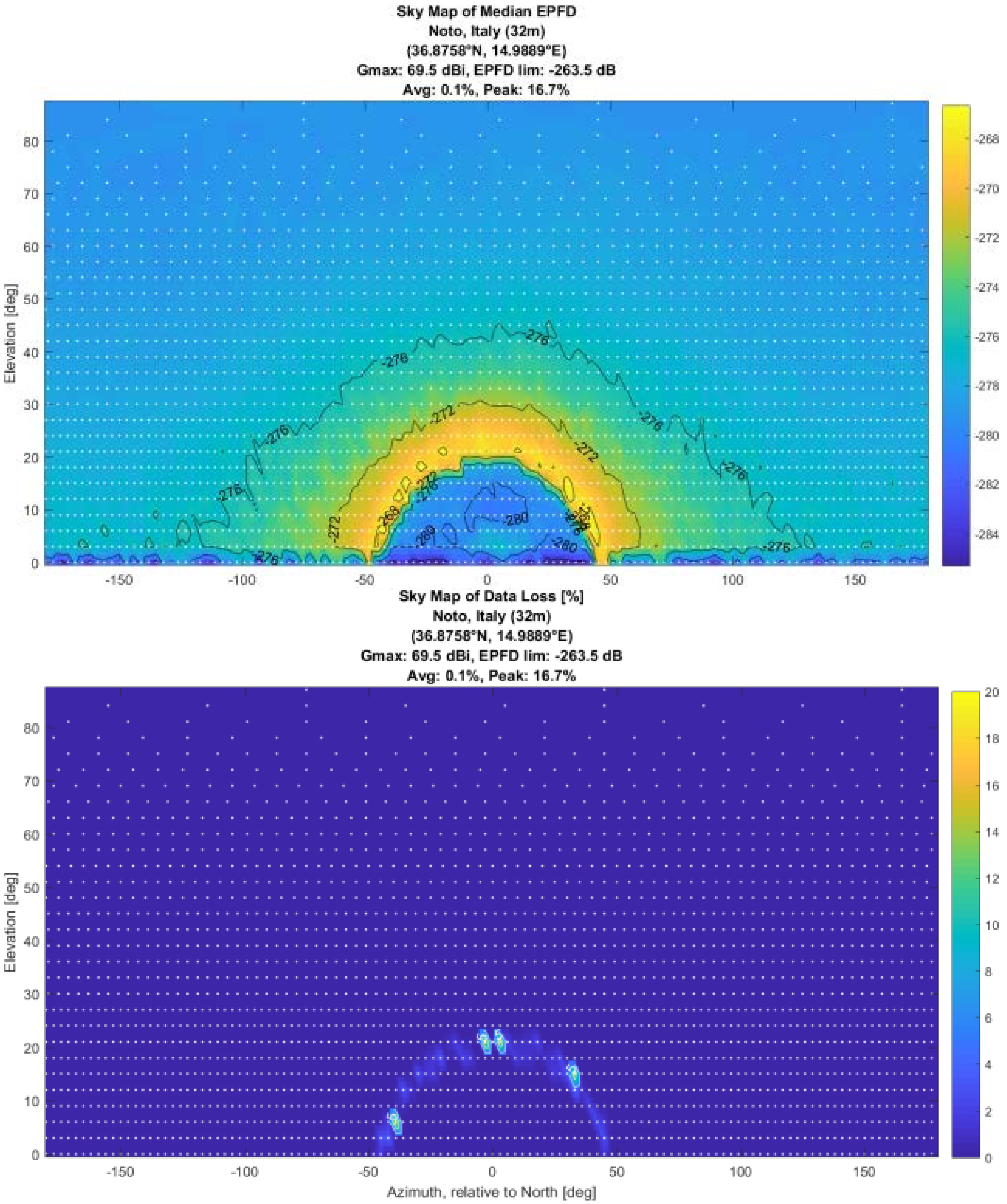


Figure 87: Noto, Italy – Sky Map of Median epfd and Percent Data Loss

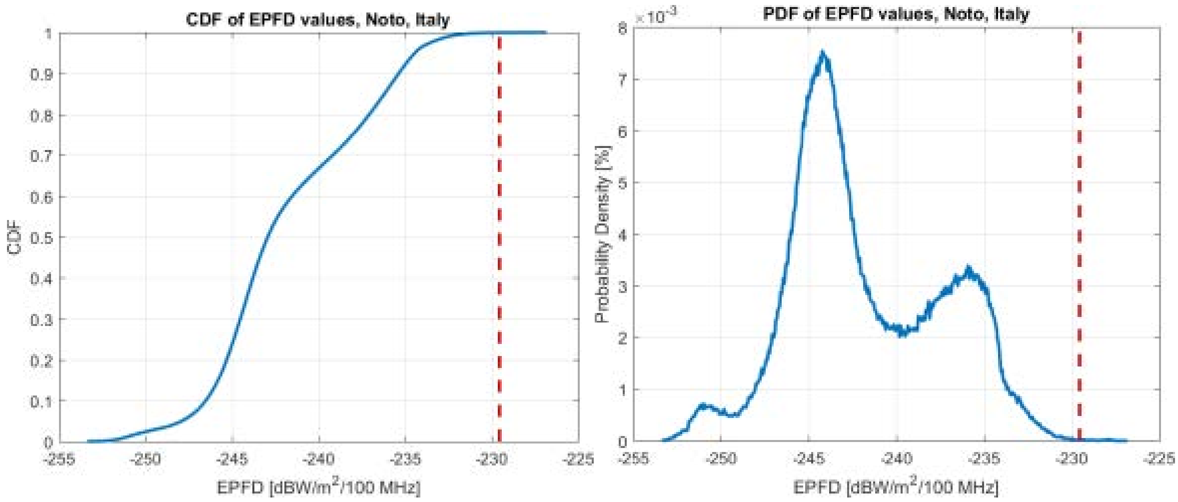


Figure 88: Noto, Italy – Probability Distribution

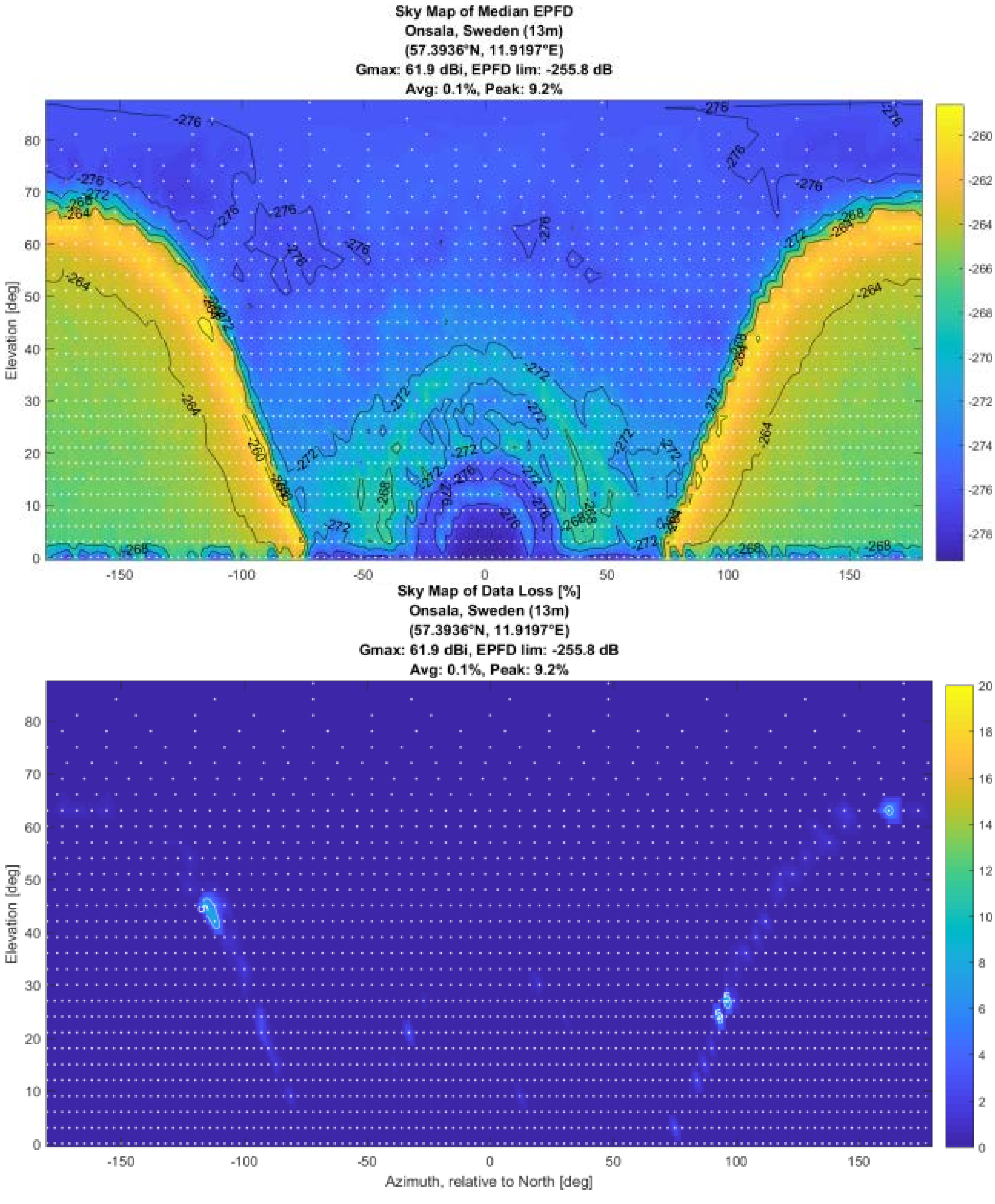


Figure 89: Onsala, Sweden – Sky Map of Median epfd and Percent Data Loss

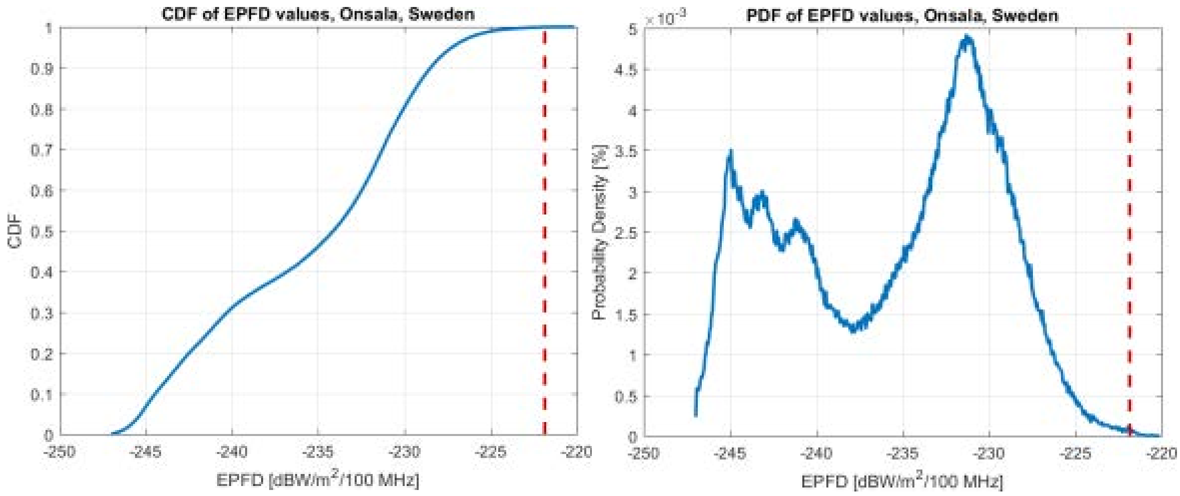


Figure 90: Onsala, Sweden – Probability Distribution

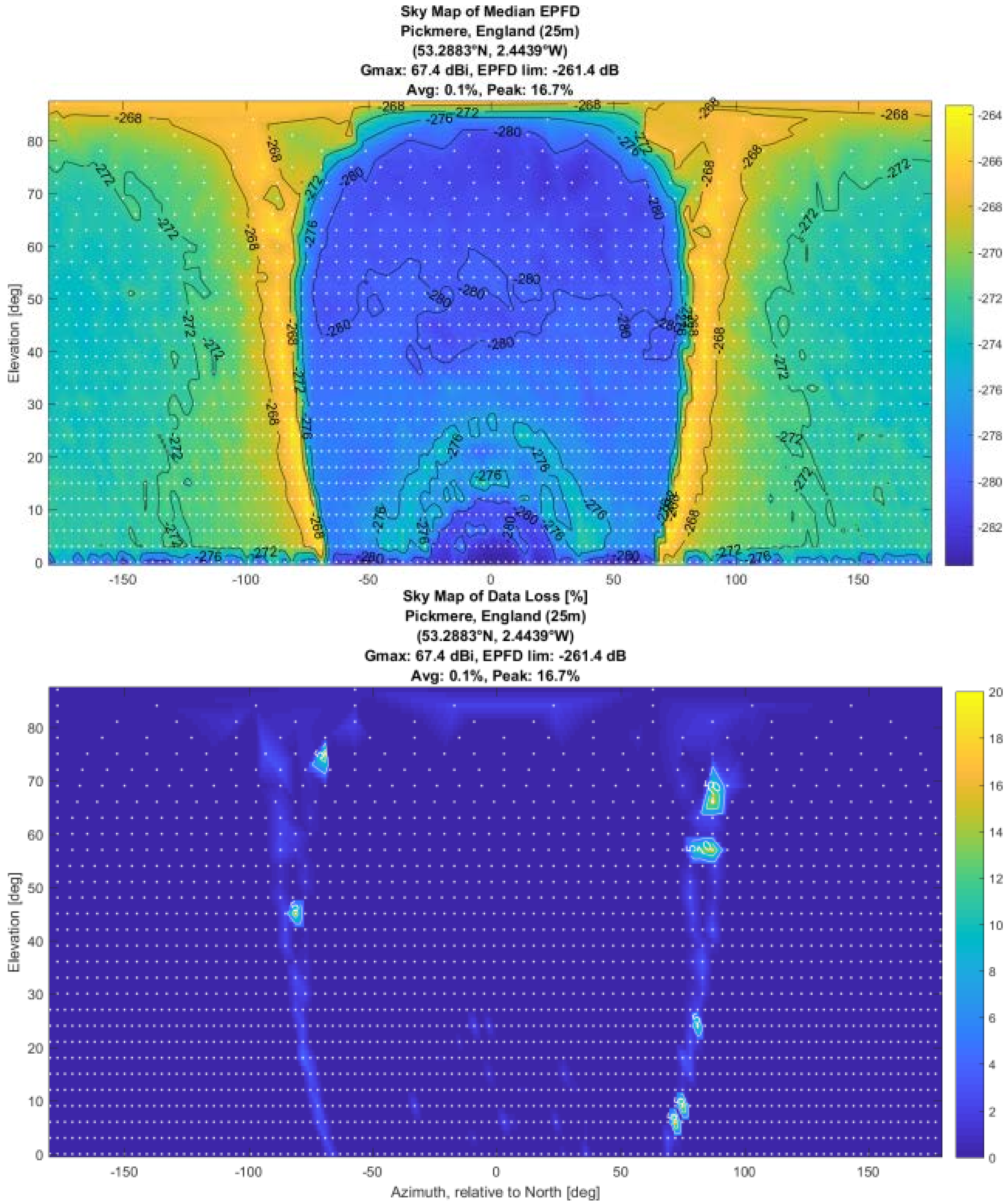


Figure 91: Pickmere, UK – Sky Map of Median epfd and Percent Data Loss

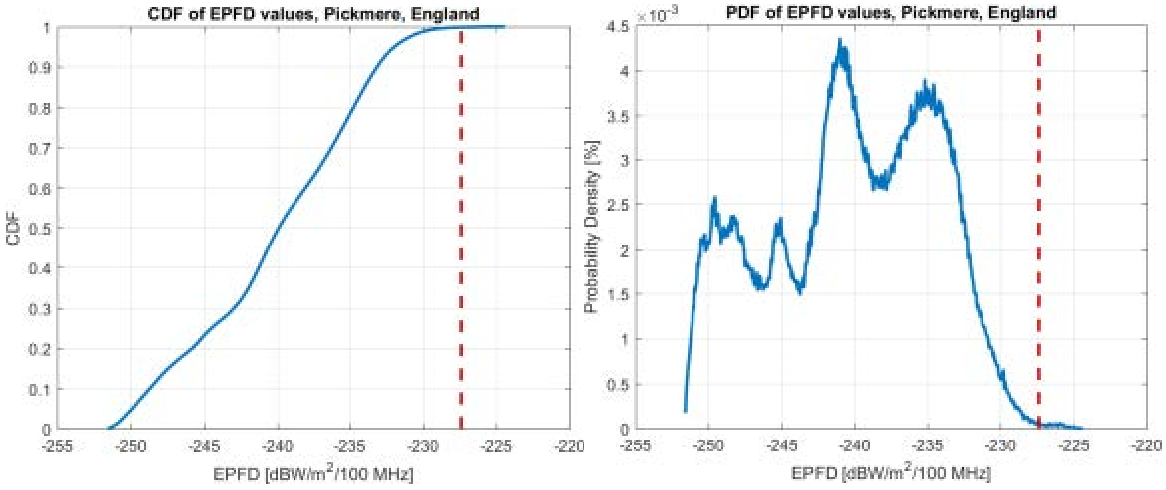


Figure 92: Pickmere, UK – Probability Distribution

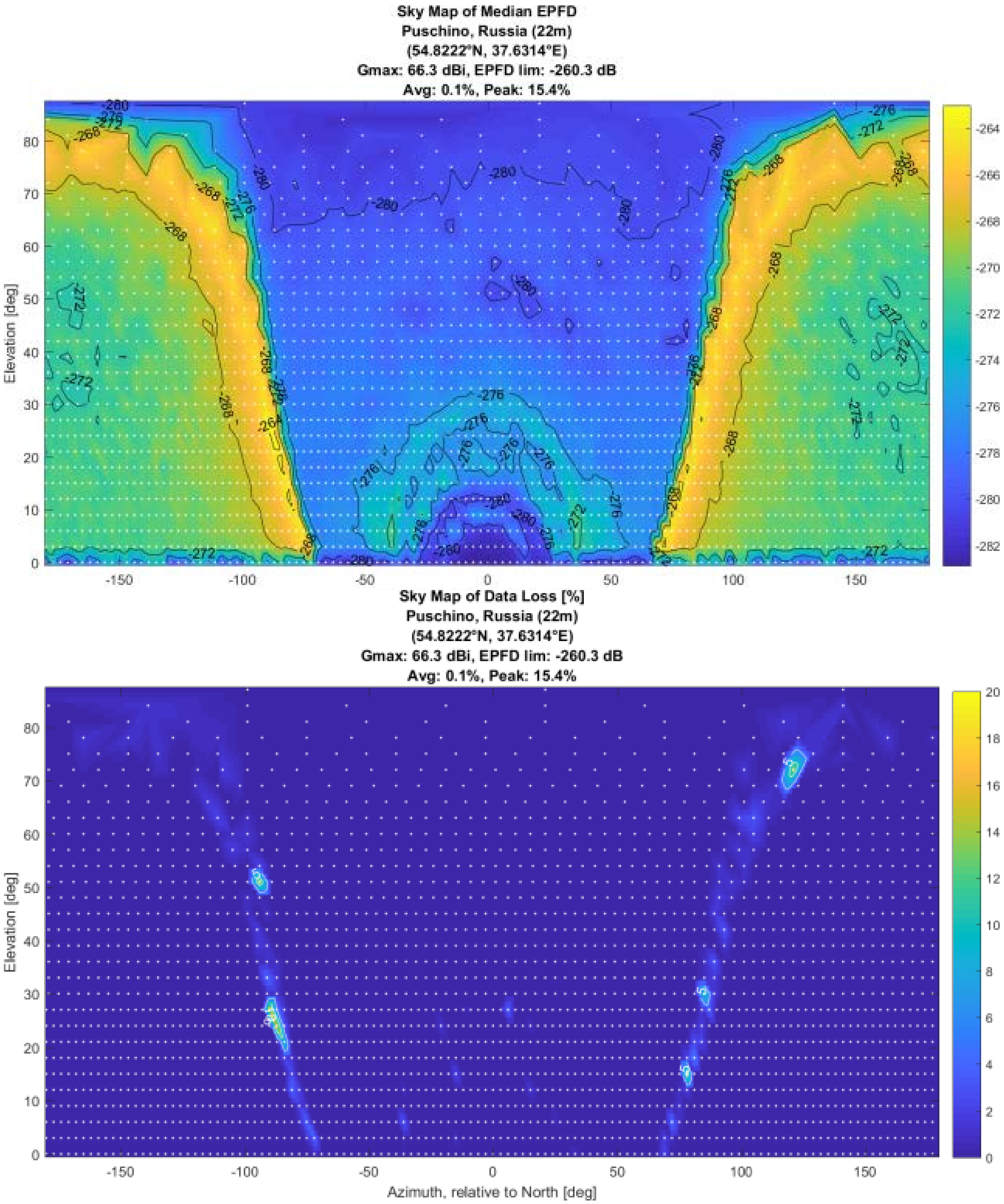


Figure 93: Puschino, Russia – Sky Map of Median epfd and Percent Data Loss

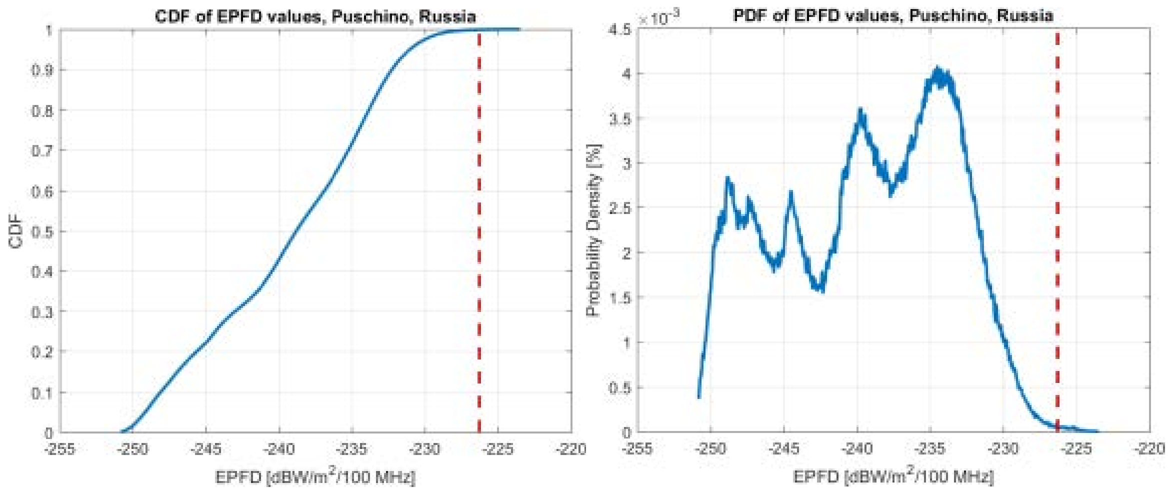


Figure 94: Puschino, Russia – Probability Distribution

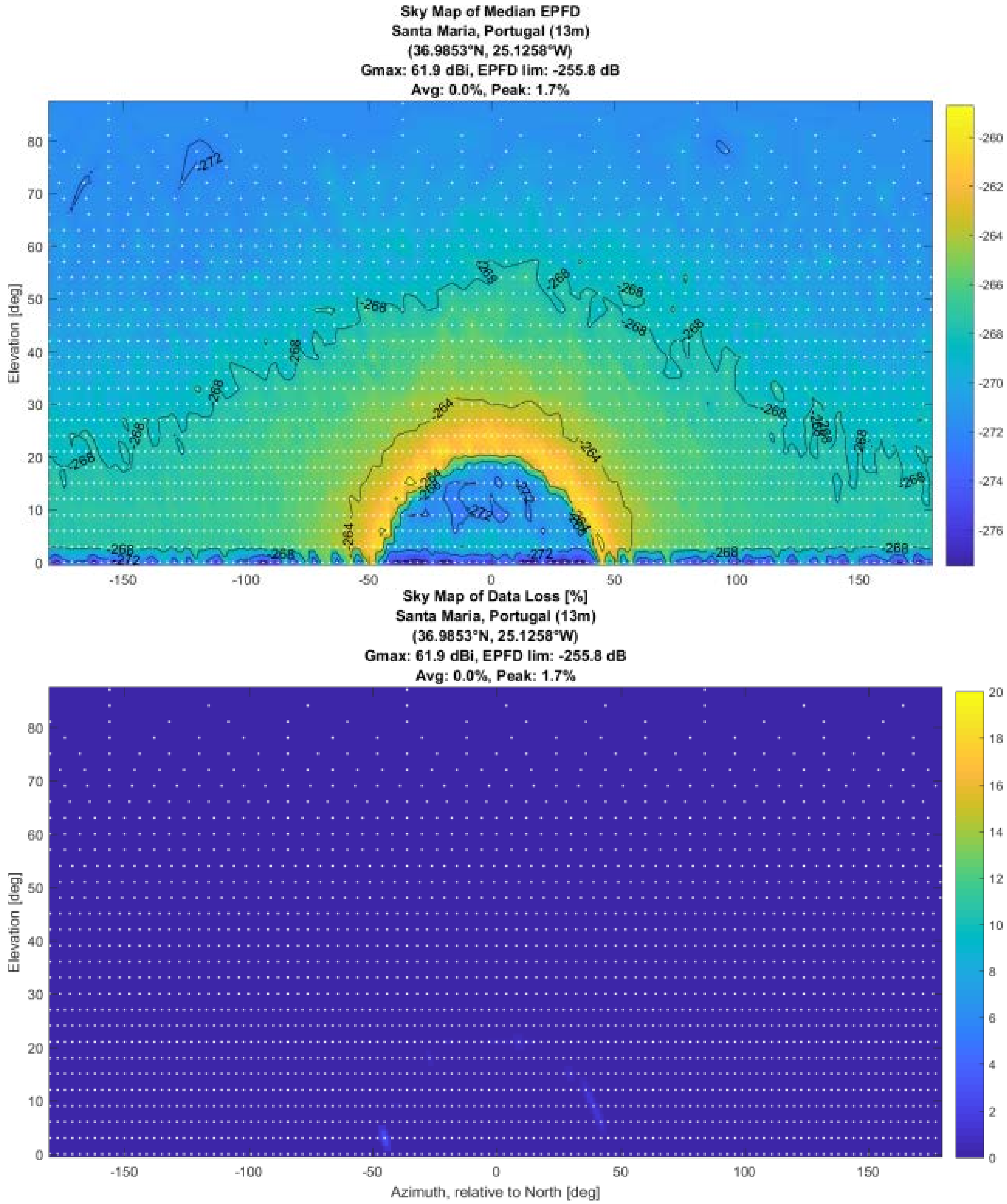


Figure 95: Santa Maria, Portugal – Sky Map of Median epfd and Percent Data Loss

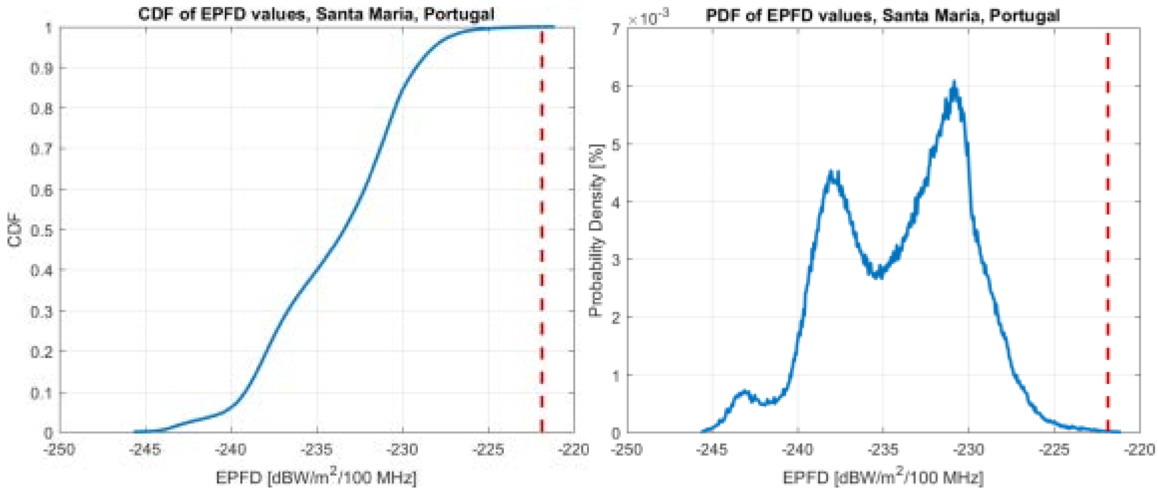


Figure 96: Santa Maria, Portugal – Probability Distribution

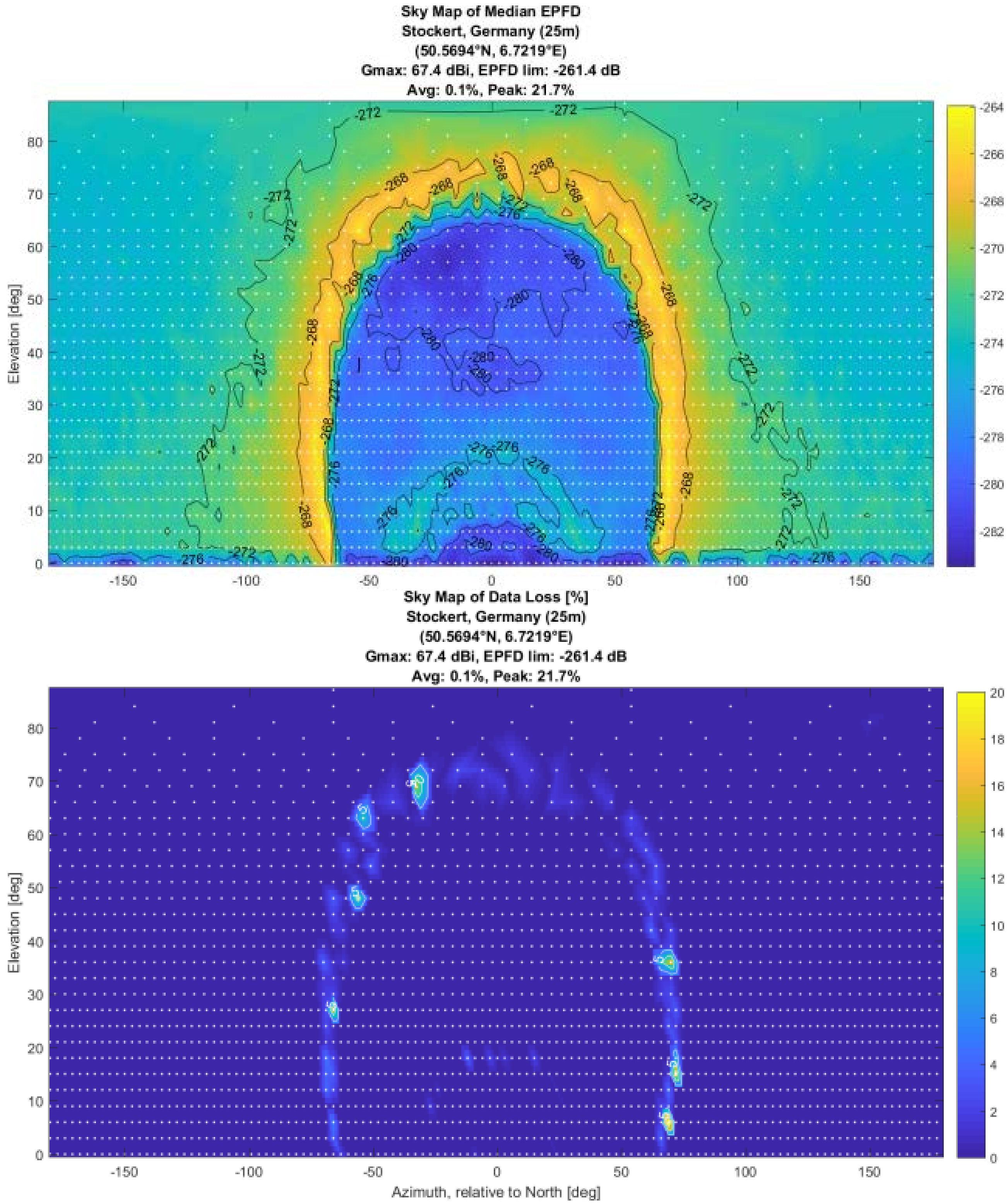


Figure 97: Stockert, Germany – Sky Map of Median epfd and Percent Data Loss

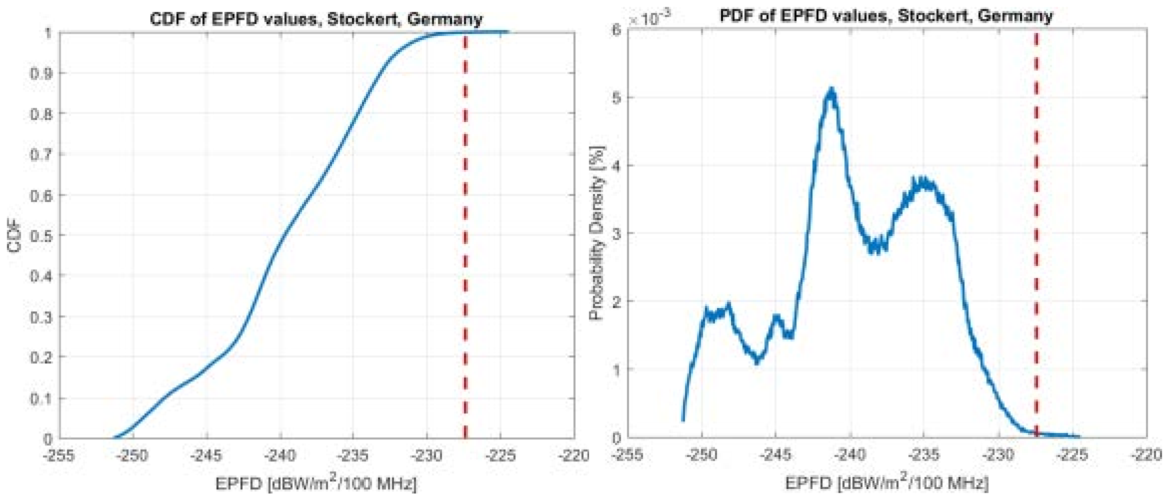


Figure 98: Stockert, Germany – Probability Distribution

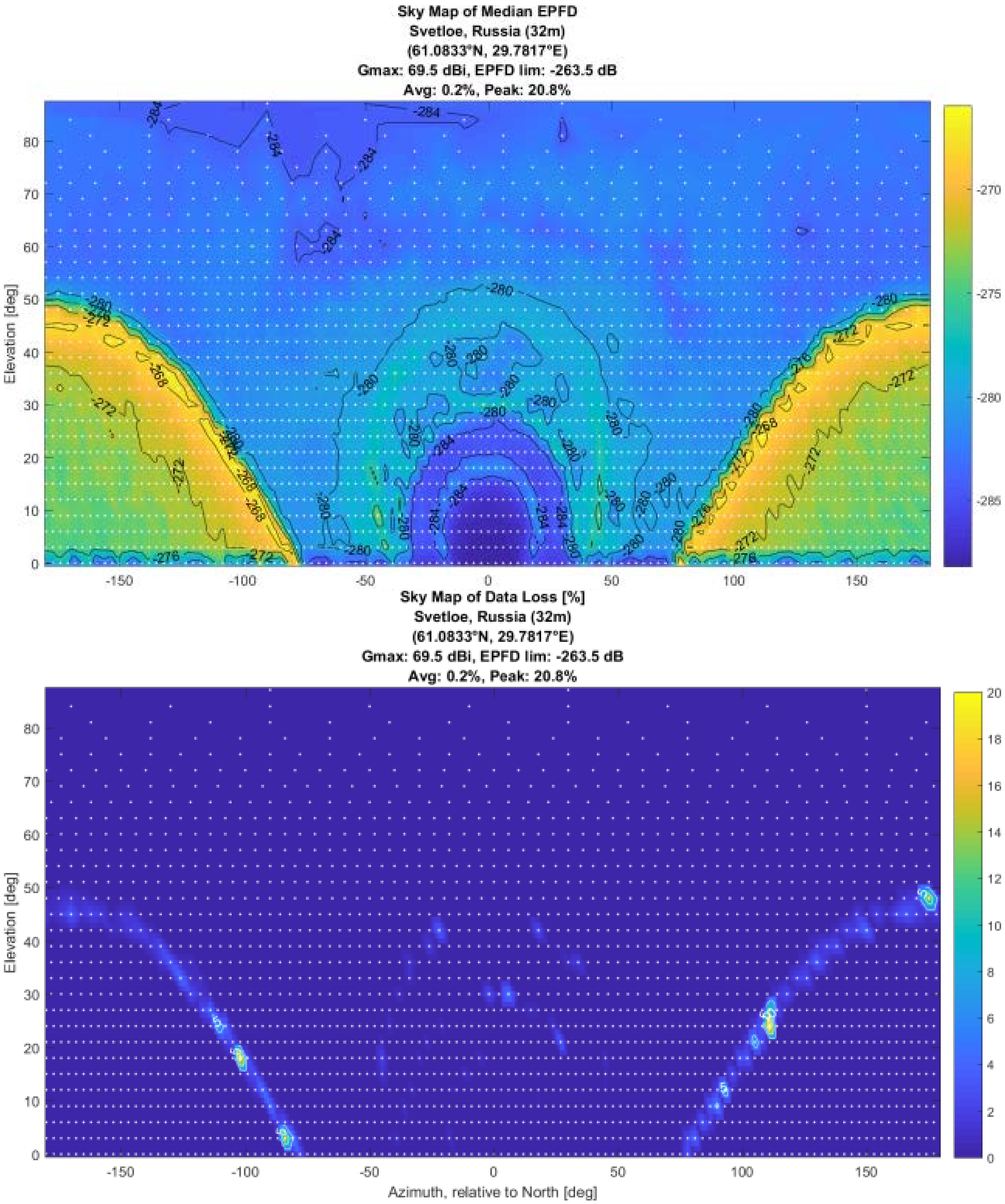


Figure 99: Svetloe, Russia – Sky Map of Median epfd and Percent Data Loss

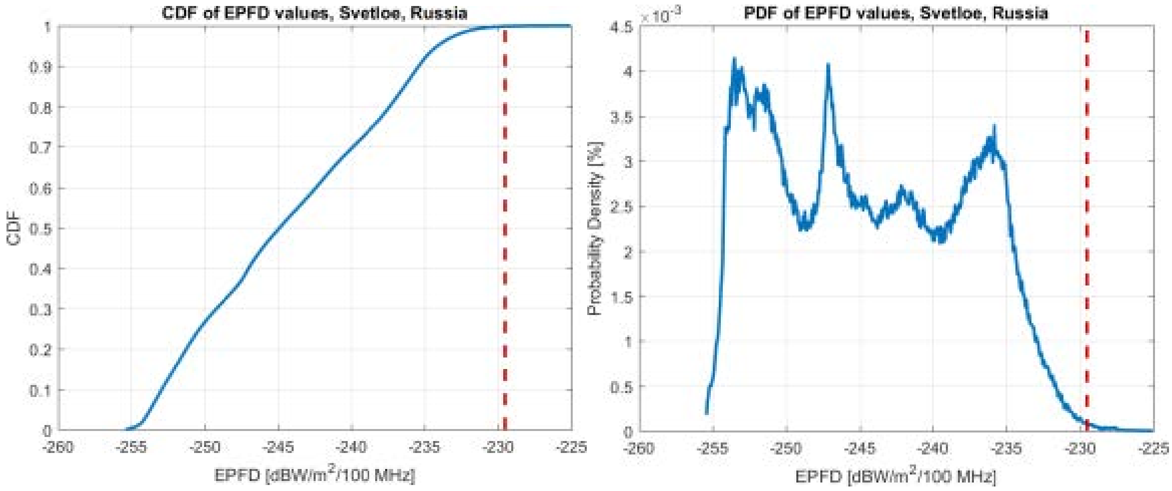


Figure 100: Svetloe, Russia – Probability Distribution

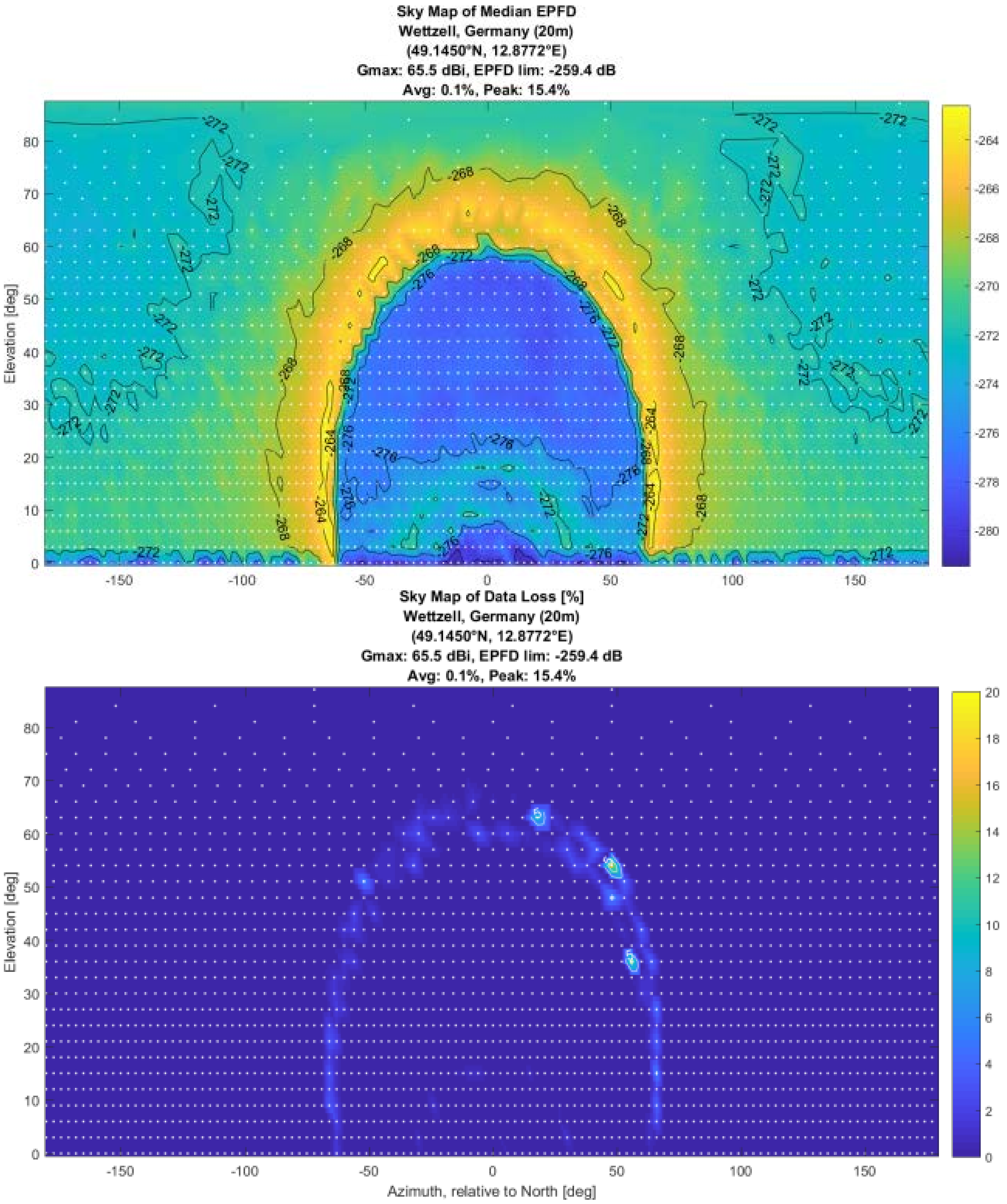


Figure 101: Wettzell, Germany – Sky Map of Median epfd and Percent Data Loss

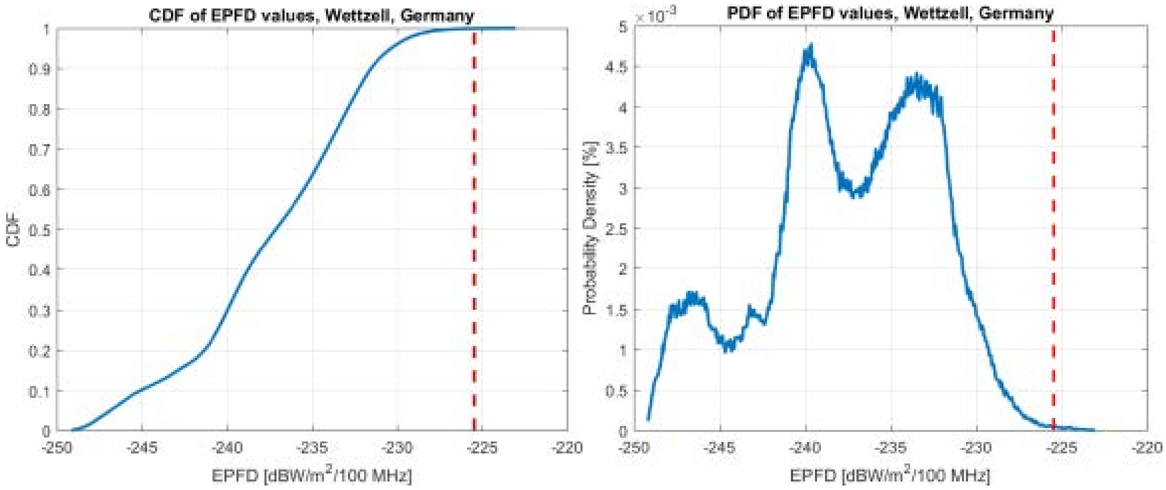


Figure 102: Wettzell, Germany – Probability Distribution

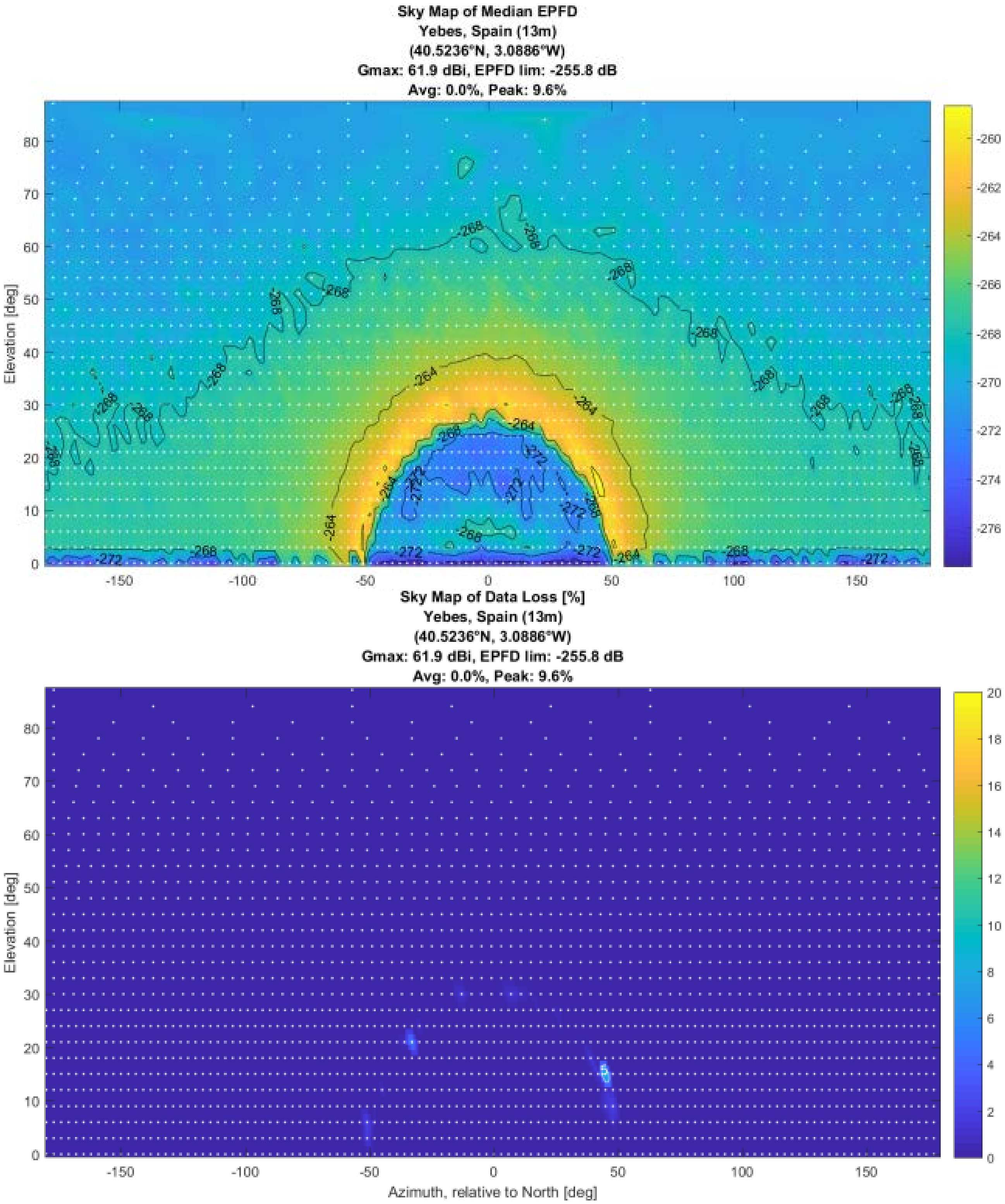


Figure 103: Yebes, Spain – Sky Map of Median epfd and Percent Data Loss

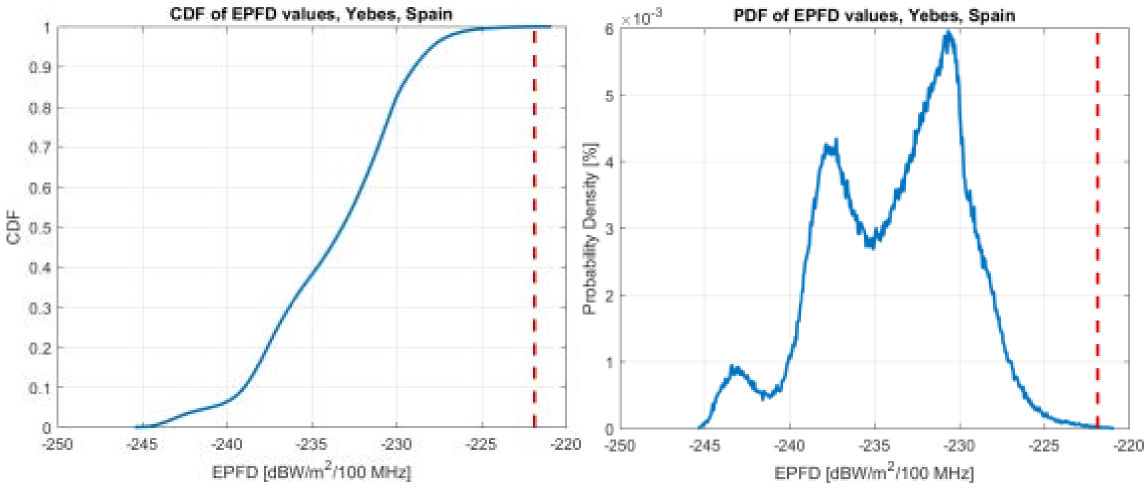


Figure 104: Yebes, Spain – Probability Distribution

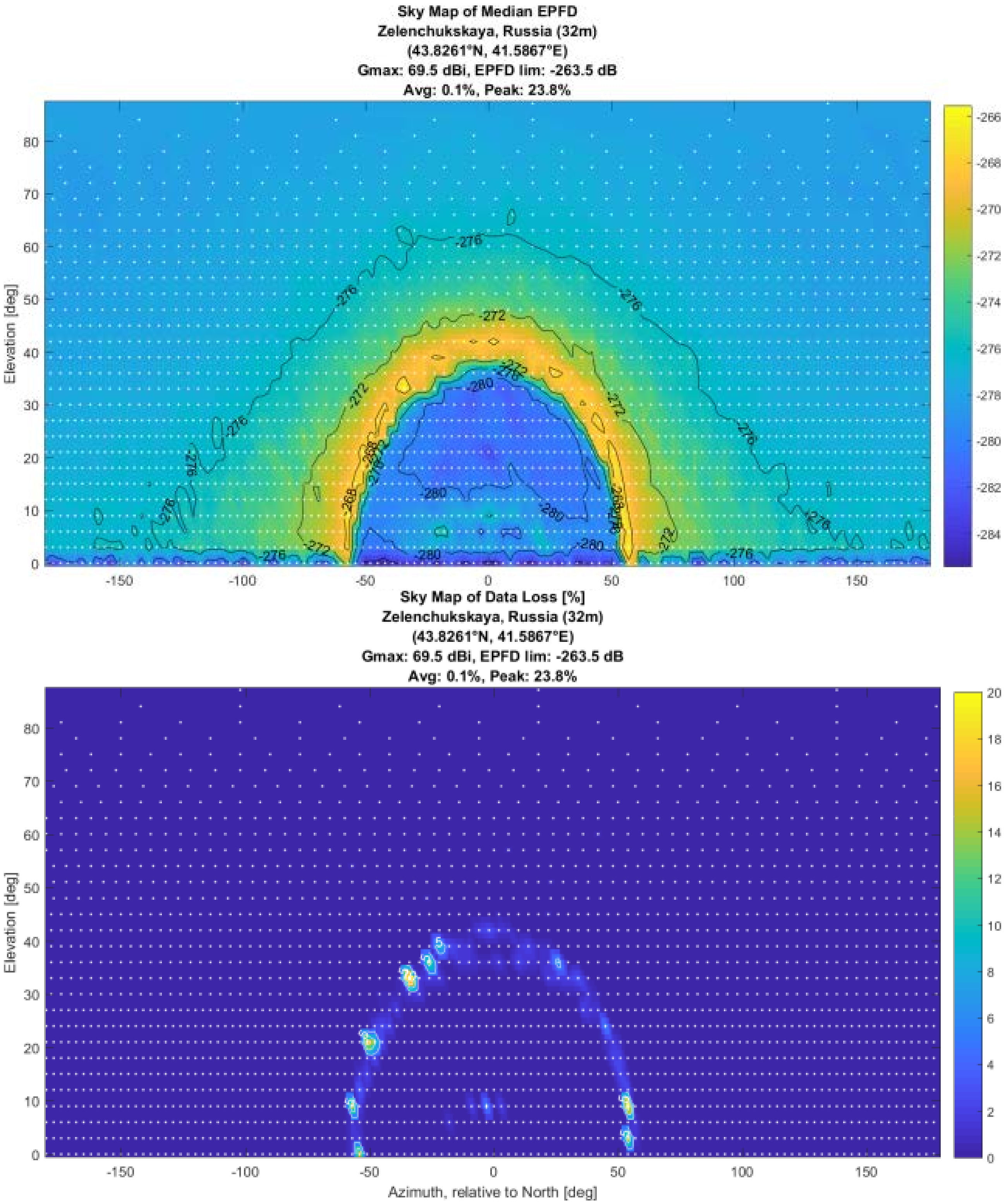


Figure 105: Zelenchukskaya, Russia – Sky Map of Median epfd and Percent Data Loss

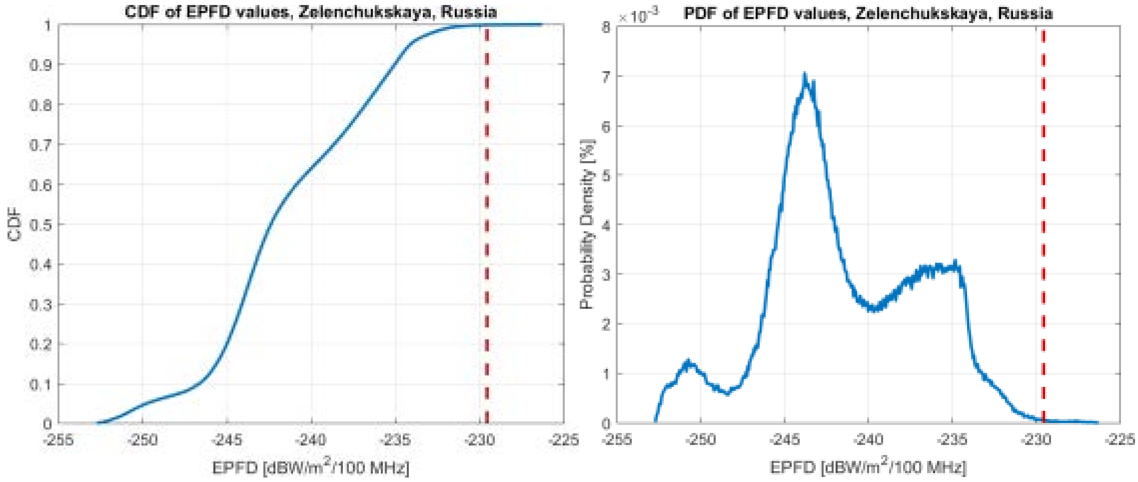


Figure 106: Zelenchukskaya, Russia – Probability Distribution

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 side lobes of the EESS (passive) sensor was calculated, as well as between the main beam of the EESS (passive) sensor after reflection over the sea.

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 and SpaceX satellite altitude of 1110 km. Per antenna pattern in Recommendation ITU-R RS.1813 [24], a back-lobe gain value of -10 dBi is used for the EESS gain.

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

Parameter	Value	Unit
e.i.r.p.	-62.0	dBW/(100 MHz)
EESS gain	-10.0	dBi
EESS altitude	835.0	km
Distance	275.0	km
Loss	162.4	dB

Parameter	Value	Unit
Interference	-234.4	dBW/(100 MHz)
Protection Criterion	-166.0	dBW/(100 MHz)
Margin	74.4	dB

Even under worst-case assumptions there is significant 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).

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
e.i.r.p. (dBW/(100 MHz))	-62.0	-62.0	-62.0	-62.0	-62.0
NGSO FSS satellite altitude (km)	1110	1110	1110	1110	1110
pfd (dBW/m²/(100 MHz))	-193.9	-193.9	-193.9	-193.9	-193.9
Area covered by the FSS satellite beam (km²)	1493	1493	1493	1493	1493
Backscatter coefficient (%)	120.0	120.0	120.0	120.0	120.0
Reflected power (dBW/(100 MHz))	-81.4	-81.4	-81.4	-81.4	-81.4
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	36	44.1
Received power at the passive sensor (dBW/(100 MHz))	-220.1	-213.1	-215.6	-223.3	-211.2
Protection criterion (dBW/(100 MHz))	-166.0	-166.0	-166.0	-166.0	-166.0
Margin (dB)	54.1	47.1	49.6	57.3	45.2

Even with these worst-case assumptions there would be more than 40 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 4425 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 -62dBW/(100MHz). 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 (-62dBW/(100MHz)) 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 a day at 10 second interval.

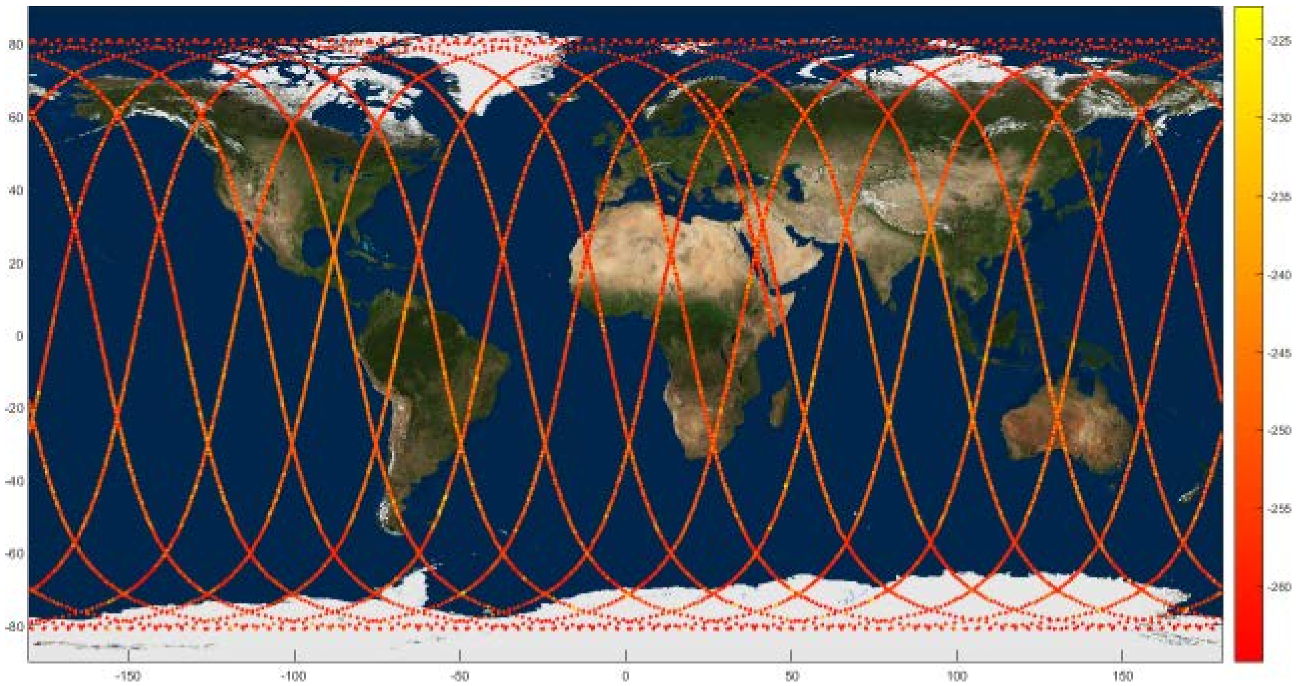


Figure 107: Interference level experienced by the Meteor-M satellite

Figure 107 shows the interference level experienced by the Meteor-M satellite along with its ground track. The maximum interference level is -222.89 dBW/100MHz which leaves 54.89 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 10 second interval.

In this case, the maximum interference level is -221.34 dBW/100MHz. This leaves a 53.34 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 1 day at a 10 second interval.

In this case, the maximum interference level is -205 dBW/100MHz. This leaves a 37 dB margin from the protection criterion of -168 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 FSS ES at fixed location and incumbent services in the 14-14.5 GHz Band

A2.5.3.1 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:

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

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 20 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).

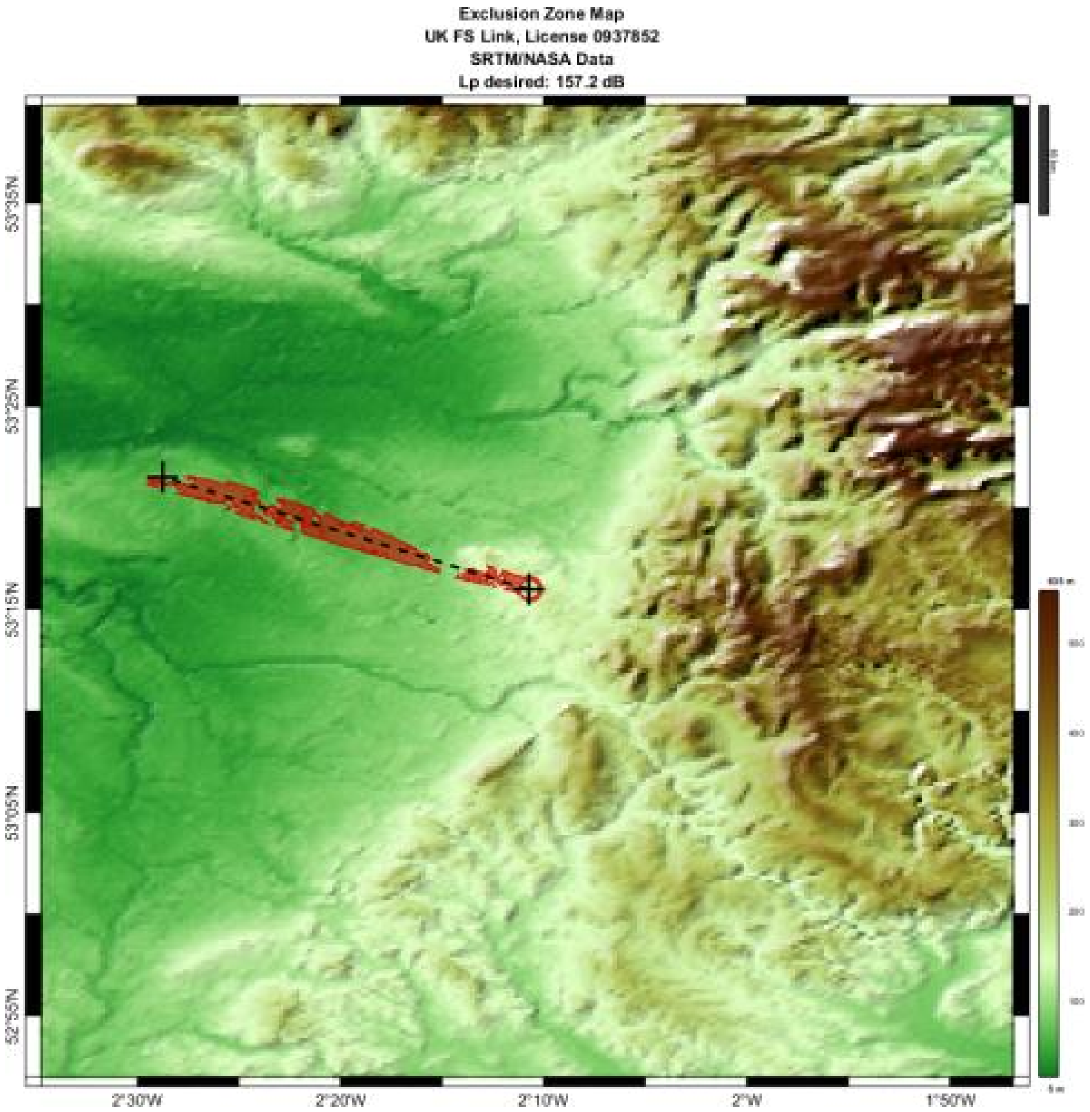


Figure 108: Exclusion zone for a SpaceX User Terminal

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 protection 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 protection 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.

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

A2.5.4.1 Methodology

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.

A2.5.4.2 Example and Results

Figure 109 shows the exclusion zone for the RAS location at Effelsberg (Germany).

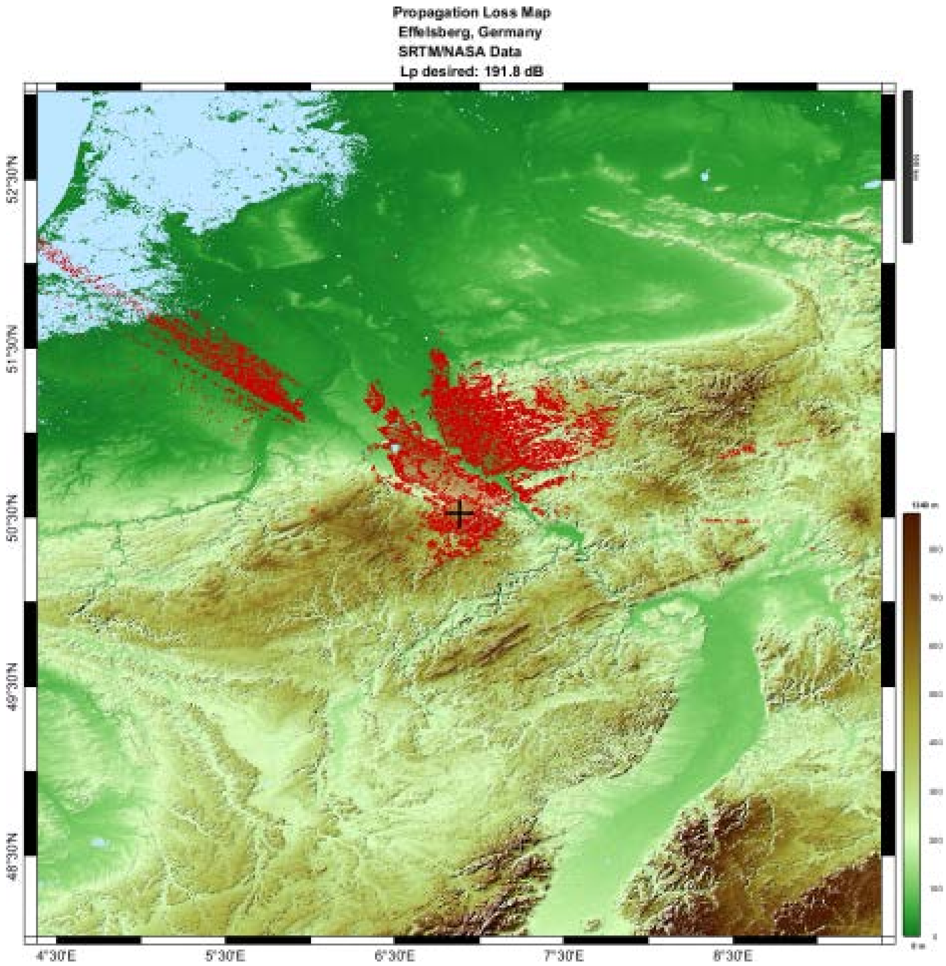


Figure 109: Exclusion zone for Effelsberg, Germany

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

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 (-142 dBW/Hz) 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.

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 protection 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 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/100MHz. 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/100MHz. 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

A3.1.2.3 _Satellite sources

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.

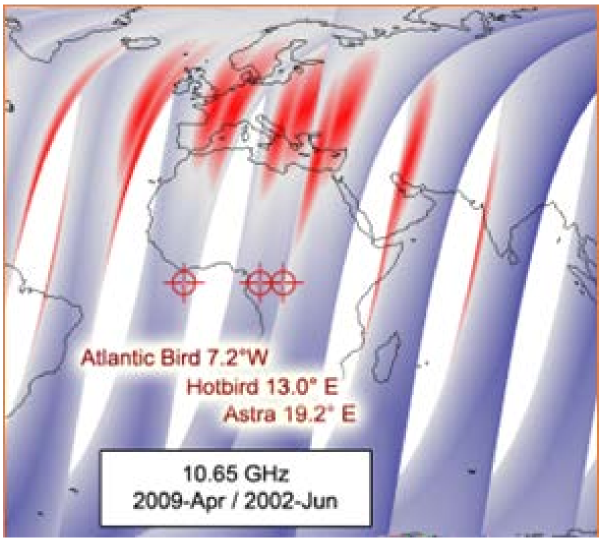


Figure 110: Interference measured by the AMSR-E sensor

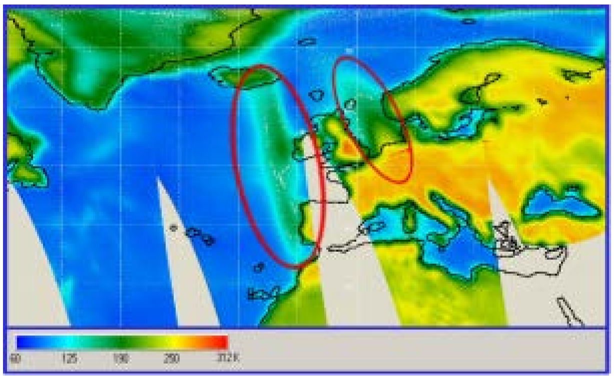


Figure 111: Interference measured by the sensor installed on METEOR-M

A3.1.2.4 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 116, and snapshots made by sensors installed on METEOR-M can be found in Figure 117.

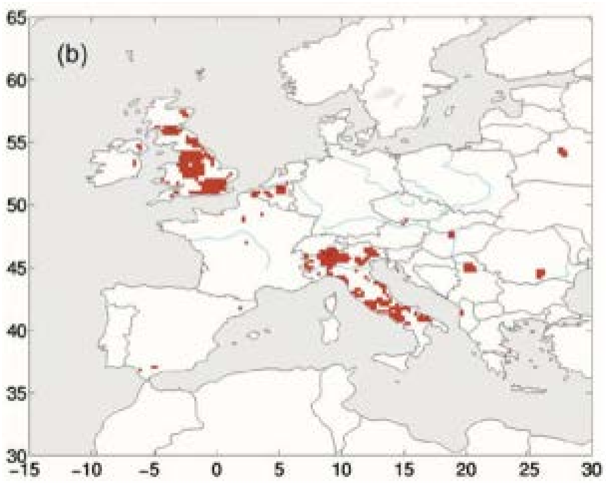


Figure 112: Interference measured by the AMSR-E sensor. Red areas represents areas with interference sources creating interference stronger than 3K for more than a month

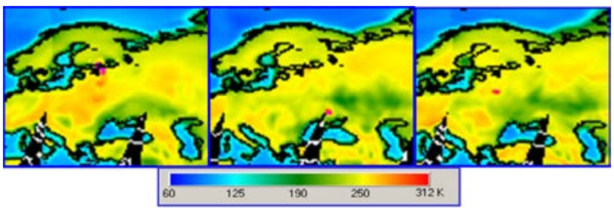


Figure 113: Interference measured by the sensor installed on METEOR-M

ANNEX 4: LIST OF REFERENCES

[1] ETSI EN 303 980: “Harmonised EN for fixed and in-motion Earth Stations communicating with non-geostationary satellite systems (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”

[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”

[8] Recommendation ITU-R F.636: “Radio-frequency channel arrangements for fixed wireless systems operating in the 14.4-15.35 GHz band”

[9] Recommendation ITU-R F.699: “Reference radiation patterns for fixed wireless system antennas for use in coordination studies and interference assessment in the frequency range from 100 MHz to about 70 GHz”

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

[11] Recommendation ITU-R F.1565: “Performance degradation due to interference from other services sharing the same frequency bands on a co-primary basis with real digital fixed wireless systems used in the international and national portions of a 27 500 km hypothetical reference path at or above the primary rate”

[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)”

[18] Recommendation ITU-R SF.1650: “The minimum distance from the baseline beyond which in-motion earth stations located on board vessels would not cause unacceptable interference to the terrestrial service in the bands 5 925-6 425 MHz and 14-14.5 GHz”

[19] ECC Report 026: “The compatibility and sharing of the aeronautical mobile satellite service with existing services in the band 14.0-14.5 GHz”, May 2003

[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”

[22] Recommendation ITU-R F.1495: “Interference criteria to protect the fixed service from time varying aggregate interference from other radiocommunication services sharing the 17.7-19.3 GHz band on a co-primary basis”

[23] Recommendation ITU-R F.1241: “Performance degradation due to interference from other services sharing the same frequency bands on a primary basis with digital radio-relay systems operating at or above the primary rate and which may form part of the international portion of a 27 500 km hypothetical reference path”

[24] Recommendation ITU-R RS.1813: “Reference antenna pattern for passive sensors operating in the Earth exploration-satellite service (passive) to be used in compatibility analyses in the frequency range 1.4-100 GHz”

[25] Recommendation ITU-R RS.1861: “Typical technical and operational characteristics of Earth exploration-satellite service (passive) systems using allocations between 1.4 and 275 GHz”

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