International Telecommunication Union

ITU-R

Radiocommunication Sector of ITU

Report ITU-R RS.2492-0
(09/2021)

Global survey of radio frequency interference observed by SMOS radiometer in the EESS (passive) band 1 400-1 427 MHz

RS Series

Remote sensing systems

International Telecommunication Union

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The regulatory and policy functions of the Radiocommunication Sector are performed by World and Regional Radiocommunication Conferences and Radiocommunication Assemblies supported by Study Groups.

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***Note**: This ITU-R Report was approved in English by the Study Group under the procedure detailed in Resolution ITU-R 1.*

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REPORT ITU-R RS.2492-0

Global survey of radio frequency interference observed by SMOS radiometer in the EESS (passive) band 1 400-1 427 MHz

(Question ITU-R 255/7)

(2021)

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1 Introduction

The Soil Moisture and Ocean Salinity (SMOS) mission, launched in November 2009, is the European Space Agency's (ESA) second Earth Explorer Opportunity mission. The scientific objectives of the SMOS mission directly respond to the need for global observations of soil moisture and ocean salinity, two key variables used in predictive hydrological, oceanographic and atmospheric models. The payload of SMOS consists of the Microwave Imaging Radiometer using Aperture Synthesis (MIRAS) instrument, a passive microwave 2-D interferometric radiometer, operating in the 1 400-1 427 MHz band, which is allocated to the passive Earth exploration-satellite service (EESS) (passive).

Observations in L-Band from spaceborne sensors are fairly new for scientific user communities. These systems allow accurate global observations of surface emissions originating from land and ocean surfaces since the atmosphere is almost transparent in this spectral range. The sensitivity to changes of the water content in the soil and the salinity in the oceans is high for low microwave frequencies when compared to the one obtained for measurements at higher frequencies provided through operational sensors. The all-weather-all-surfaces capabilities address the needs of a large range of user communities and applications.

As soon as SMOS operations started in 2009, it became clear that radio-frequency interference (RFI) was polluting the band worldwide, in particular over large parts of Europe, Asia, and the Middle East. The RFIs have impact in the data quality of both the soil moisture and the sea surface salinity observations and is leading to significant amounts of data being discarded since they are unusable by scientific users or to incorrect measurements. Currently (February 2020), there are around 437 active RFI sources distributed world- wide, and in many cases the strongest RFI sources are masking weaker sources underneath. In recent years the situation in most European countries and in China has improved considerably.

2 Scope

This Report describes the radio-frequency interference environment experienced by the radiometer on board the mission SMOS, operating in the EESS (passive) purely passive band 1 400-1 427 MHz.

The interference problem in the 1 400-1 427 MHz band is impacting to several missions operating radiometers in the band. The RFI surveys for Aquarius and Soil Moisture Active Passive (SMAP) missions are included in the Reports ITU-R RS.2490-0 and ITU-R RS.2491-0.

3 Related ITU-R Recommendations and Reports

This Report describes the RFI environment experienced by:

– Resolution **750 (Rev.WRC-19)**: *Compatibility between the Earth exploration-satellite service (passive) and relevant active services*.

– Recommendation ITU-R RS.1859-1 (2018): *Use of remote sensing systems for data collections to be used in the event of natural disasters and similar emergencies*.

– Recommendation ITU-R RS.1883-1 (2018): *Use of remote sensing systems in the study of climate change and the effects thereof*.

– Recommendation ITU-R RS.2017-0 (2012): *Performance and interference criteria for satellite passive remote sensing*.

– Recommendation ITU-R RS.2106-0 (2017): *Detection and resolution of radio frequency interference to Earth exploration-satellite service (passive) sensors*.

– Report ITU-R RS.2490-0 (2021): *Global survey of radio frequency interference levels observed by the Aquarius scatterometer at 1 260 MHz and radiometer at 1 413 MHz*.
– Report ITU-R RS.2491-0 (2021): *Global survey of radio frequency interference levels observed by the SMAP radiometer at 1 413 MHz*.
– Report ITU-R RS.2178-0 (2010): *The essential role and global importance of radio spectrum use for Earth observations and for related applications*.
– Report ITU-R RS.2336-0 (2014): *Consideration of the frequency bands 1 375-1 400 MHz and 1 427-1 452 MHz for the mobile service – Compatibility with systems of the Earth exploration-satellite service (EESS) within the 1 400-1 427 MHz frequency band*.

4 List of acronyms and abbreviations

ANFR	*Agence nationale des fréquences*
BSS	Broadcasting-satellite system
BT	Brightness temperature
CEPT	European Conference of Postal and Telecommunications Administrations
CESBIO	*Centre d'études spatiales de la biosphère*
CNES	*Centre national d'études spatiales*
COSPAR	Committee on Space Research
DECT	Digital enhanced cordless telecommunications
ECC	Electronic Communications Committee
EESS	Earth exploration-satellite service
EO	Earth observation
ESA	European Space Agency
ESAC	European Space Astronomy Centre
EU	European Union
EUMETNET	European Meteorological Network
FS	Fixed services
IGARSS	International Geoscience And Remote Sensing Symposium
IMT	International Mobile Telecommunications
LNB	Low noise block
MIRAS	Microwave imaging radiometer using aperture synthesis
MS	Mobile services
NIR	Noise injection radiometers
RF	Radio frequency
RFI	Radio-frequency interference
RR	Radio Regulations
SIRRS	Satellite interference reporting and resolution system
SFCG	Space Frequency Coordination Group
SMAP	Soil moisture active passive

SMOS Soil moisture ocean salinity

URSI *Union radio-scientifique internationale*

WGFM Working Group on Frequency Management

WRC World Radiocommunication Conference

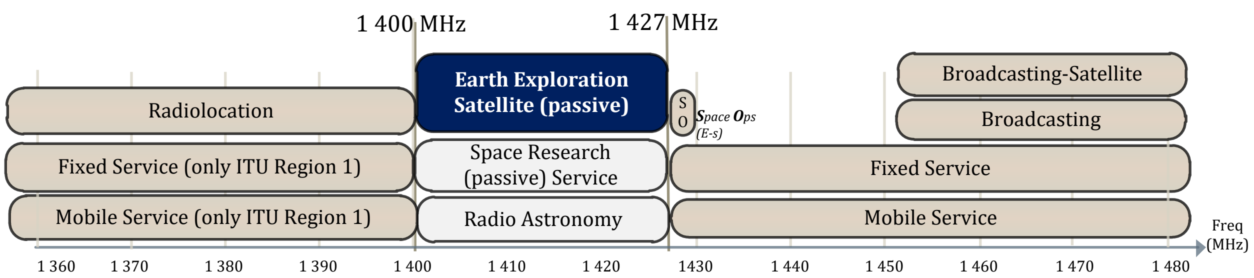
5 Regulatory framework for the 1 400-1 427 MHz EESS (passive) band

5.1 Frequency allocations and Radio Regulations

The band 1 400-1 427 MHz is allocated on a primary basis exclusively to the EESS (passive), the space research service (passive) and the radio astronomy service (see Fig. 1). All emissions are prohibited in this band according to the ITU-R Radio Regulations (RR) footnote No. **5.340**. In addition, ITU-R Resolution **750** (**WRC-07** and **Rev.WRC-19**) addresses the compatibility between the EESS (passive) and the relevant active services operating in the adjacent bands. Resolution **750 (Rev.WRC-19)** determines the limits for unwanted emissions of IMT systems brought into use in the 1 427-1 452 MHz mobile service band and identifies the recommended maximum unwanted emission levels applicable to the whole range of ITU-R services allocated in the adjacent bands. This Resolution also urges administrations to take all reasonable steps to ensure that the recommended maximum levels are not exceeded, noting that EESS passive sensors provide worldwide measurements that benefit all countries.

FIGURE 1

ITU-R frequency allocations in the 1 400-1 427 MHz range and adjacent frequency bands



5.2 Regulatory tools to support the reporting of harmful interference

Section VI of Article **15** of the RR, titled *Procedure in a case of harmful interference*, includes general provisions relevant to the occurrence of harmful interference. In particular, it includes, as Appendix **10** to the RR, a list of parameters of the interfering and victim systems that need to be provided to the administration responsible for the interfering system. However, RR Appendix **10** was designed for interference involving terrestrial systems and its applicability to interference involving satellite systems is limited.

For this reason, Recommendation ITU-R RS.2106 – Detection and resolution of radio frequency interference to Earth exploration-satellite service (passive) sensors, was developed. This Recommendation provides, in Annex, a form with a list of parameters describing the EESS (passive) sensor (victim system) and the characteristics of the RFI sources as they can be estimated from typical EESS (passive) sensors.

In addition to the form in Recommendation ITU-R RS.2106, the Radiocommunication Bureau has developed an online application that aims at facilitating the report and resolution of cases of RFI. This application, called SIRRS (Satellite Interference Reporting and Resolution System), can be found at: https://www.itu.int/en/ITU-R/space/SIRRS/Pages/default.aspx.

Since January 2019, all RFI cases experienced by EESS (passive) sensors should be reported through SIRRS, and each online report should include a document containing all the relevant characteristics of the victim and interfering systems as specified in the annex of Recommendation ITU-R RS.2106.

5.3 Other regulatory considerations

The evidence of RFI levels that prevent geophysical measurements is the rationale for having compulsory (not only recommended) limits to protect the purely passive bands. In Europe, the CEPT Electronic Communications Committee (ECC) approved in March 2011 a new decision ECC/DEC/(11)01) on the protection of the EESS (passive) service in the 1 400-1 427 MHz band. This ECC decision, which was proposed with the support of ESA, CNES, ANFR, and EUMETNET, translates the compatibility criteria recommended by ITU into mandatory limits and intends to give a clear signal to the international community about the recognition by CEPT of the societal and economical values of the EESS (passive) applications related to climate change and natural disasters prediction.

The limits for unwanted emissions apply to stations in the active services operating in CEPT countries in the 1 350-1 400 and 1 427-1 452 MHz bands brought into use after 1 January 2012. Each CEPT administration decides on the implementation of the ECC decision.

By July 2019, 19 European countries had implemented this decision. SMOS, Aquarius, SMAP and other future Earth observation (EO) missions operating in the 1 400-1 427 MHz passive band, will benefit from this decision.

To increase the awareness of the impact of RFI in the passive sensors, the SMOS RFI issue was also brought to the attention of the European Commission, who underlined the importance of strengthening the cooperation of all EU Member States in the investigation of the RFI sources over their territories.

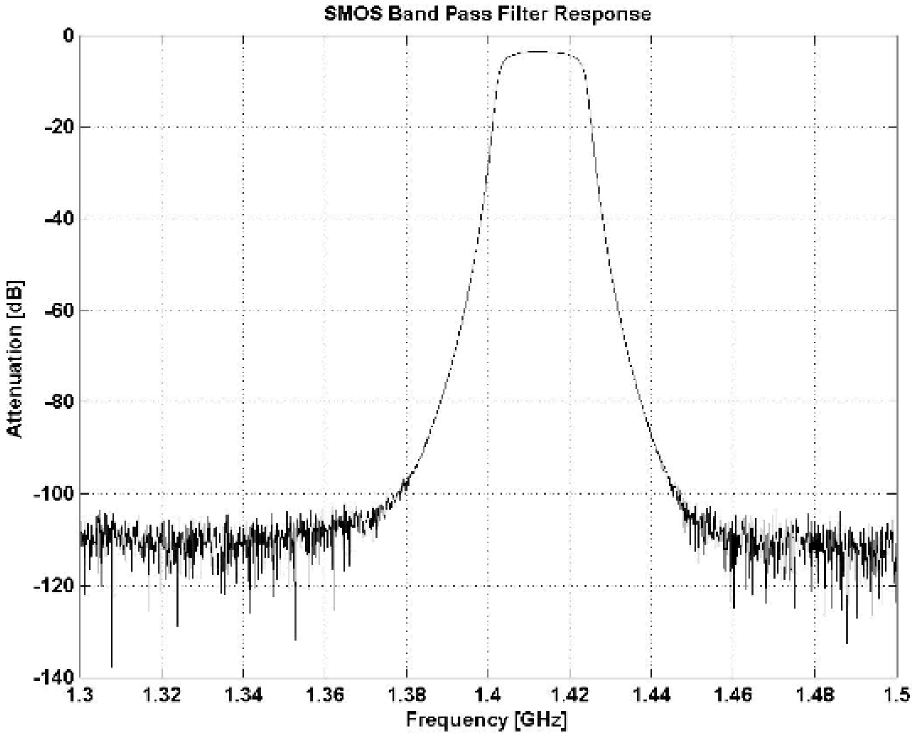
6 Description of SMOS

6.1 The SMOS mission

ESA’s SMOS mission was launched on 2 November 2009 and became operational in May 2010. The main scientific objective of SMOS is to observe soil moisture over land and sea surface salinity over oceans. The SMOS mission is based on a sun-synchronous orbit (dusk-dawn 6 a.m./6 p.m.) with a mean altitude of 758 km and an inclination of 98.44°. SMOS has 149-day repeat cycle with a three-day revisit-cycle.

FIGURE 2

SMOS filter response



6.2 Characteristics of the payload

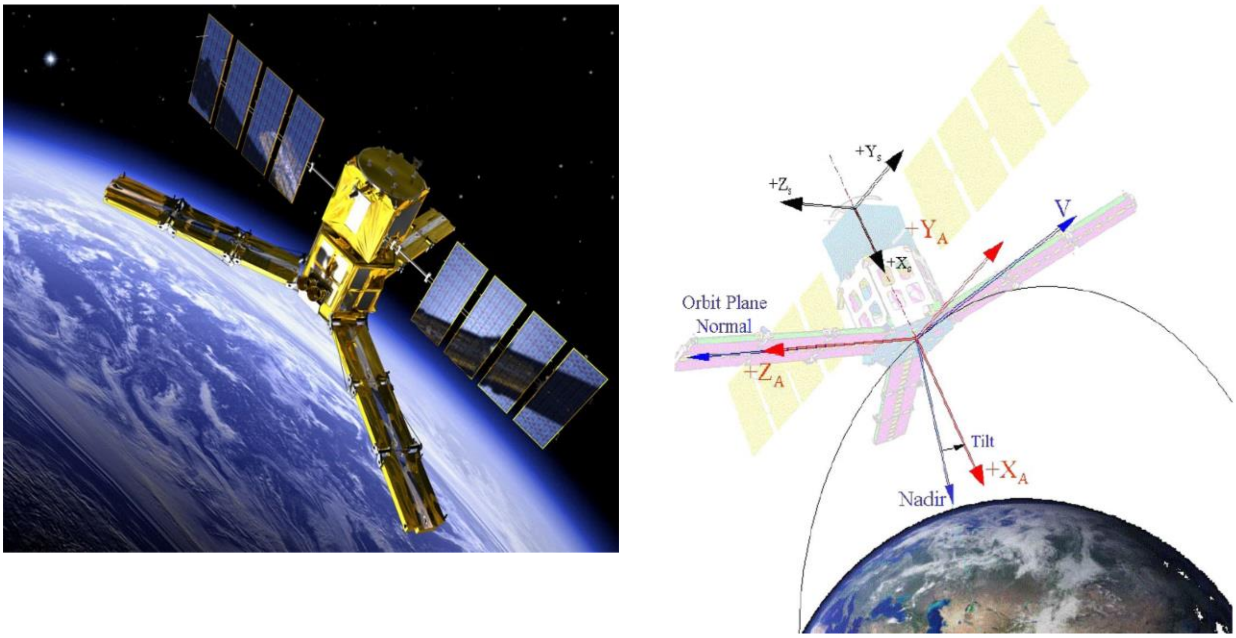
SMOS has a single payload on board which consists of a MIRAS. MIRAS is a passive microwave 2-D interferometric radiometer comprising a central hub (1.3 m diameter), and three deployable arms extending up to 8 m in diameter. Each arm comprises eighteen receivers, complemented by a further twelve receivers, and three noise injection radiometers (NIR) in the central hub. In total, the MIRAS payload comprises 69 antenna elements.

SMOS measures the brightness temperature emitted from the Earth in the 1 400-1 427 MHz band over a range of incidence angles (0 to 65º) across a swath of up to 1 400 km with a spatial resolution of 35 to 50 km. The SMOS brightness temperatures are the so-called Level 1 data products, based on which two level 2 data products are retrieved, namely the Level 2 soil moisture and Level 2 ocean salinity. A key requirement in the design of the receivers was the rejection of signals outside the 1 400-1 427 MHz passive band. The SMOS RF band pass filter response actually implemented on board the satellite is shown in Fig. 2. The centre frequency of the filter is 1 413.5 MHz with a −3 dB bandwidth of 19 MHz. Furthermore, additional rejection is achieved due to the overall receiver selectivity response (complete receive chain): 32 dB at 1 400 MHz and 77 dB at 1 397 MHz.

The instrument topology and imaging geometry for nominal measurement mode is shown in Fig. 3. The satellite control utilises local normal pointing and yaw steering. The normal to the face of the instrument (the $+x_A$ axis) is offset from the nadir direction by a 32-degree tilt in the orbital plane (i.e. a pitch rotation). Yaw steering ensures that the trajectory of all targets is parallel to the ground track velocity vector.

FIGURE 3

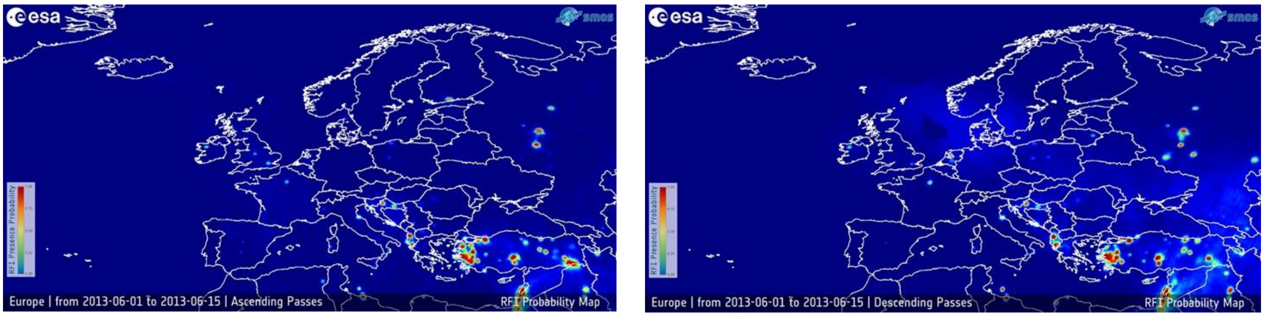
Geometry of SMOS observation mode



Because of this 32-degree tilt angle, the RFI contamination seen by SMOS in a certain region might be different for ascending and descending passes. This is illustrated in Fig. 4, which shows the RFI probability maps for ascending and descending passes in Europe in June 2013.

FIGURE 4

Europe RFI probability maps for a 2-weeks window in June 2013

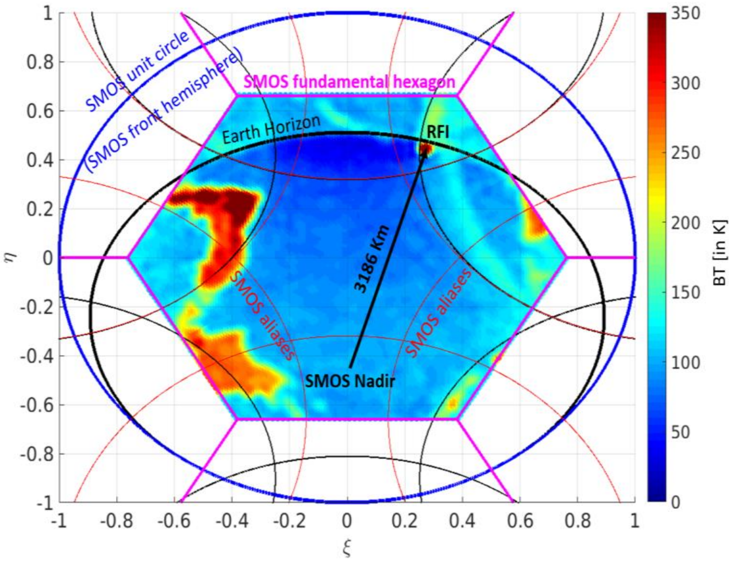


(Ascending passes) (Descending passes)

The instrument observes everything that is in front of the antenna plane. However, only a smaller part is used, as it corresponds to the alias-free field of view regions. Because of SMOS' large field of view and tilt angle, strong RFI can affect measurements thousands of kilometers away from the antenna source, as it can be seen in Fig. 5, where an RFI close to the Earth's horizon is affecting the measurements thousands of kilometres away from the sub-satellite (i.e. nadir) point.

FIGURE 5

SMOS field of view. RFI sources can affect SMOS measurements even when they are thousands of kilometres away from the nadir point



7 RFI detection and characterization

7.1 Detection process

A pre-requisite to successfully switching off RFI sources is precisely locating their position. The SMOS team uses the outputs of three different detection algorithms in order to consolidate the location of the RFI sources. This is done in order to avoid false alarm detection and provide the best location accuracy to the spectrum management national teams in order to facilitate the on-ground teams' work. Even though the SMOS spatial resolution (35-55 km) is relatively coarse, the localization algorithms rely on the large amount of observations to improve the accuracy of the geographical co-ordinates of the antenna emitter. Considering that during one pass, each point on-ground is measured several times under different incidence angles (as the satellite moves forward) and that at least two weeks of measurements over that region (i.e. ~10 passes) are used to infer the RFI position, the final accuracy of this technique is on the order of 1 to 2 km in most cases.

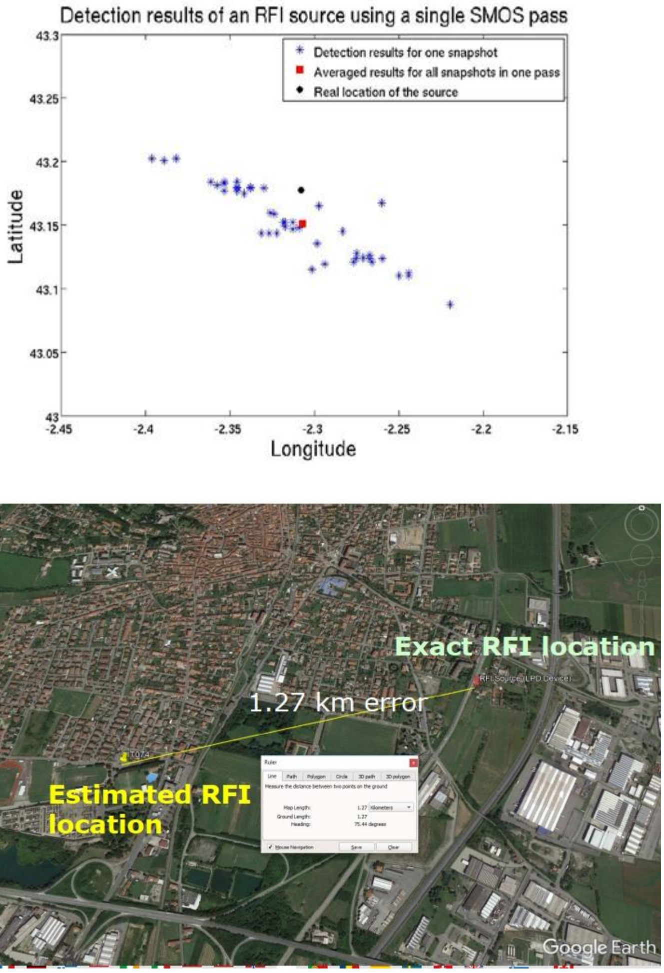
The first step in all these detection processes is to identify all the pixels affected by RFI contamination. For example, all measurements of brightness temperature that exceed 350 K are considered as affected by RFI, since 350 K is above the level of emission that can be expected from natural sources. The regions with excessive emission are then clustered in order to identify the origin of the source. This is where most of the differences between the three algorithms rely. Once a cluster of pixels is identified as belonging to the same source, the location of this source is estimated by barycentric estimation or by a fitting of the instrument impulse response to the signal under consideration, since RFI signals appear as a sort of a delta signal on top of the mostly flat natural background.

This process is repeated for each snapshot (or satellite image, taken every 1.2 seconds) in which the RFI source was present. The results from the individual snapshots are averaged in order to obtain the best estimate of the location of the RFI source (see Fig. 6).

The final RFI location consolidated by the three different detection methods are then stored in a database.

FIGURE 6

Example of SMOS RFI detection



7.2 RFI characterisation

The analysis of the SMOS observations allows gathering information on the nature of the source causing the RFI. Typically, the following parameters are stored in the database and provided by ESA to the national spectrum management authorities so that investigations can be initiated:

– Unique ID for each RFI

– Location coordinates (typical accuracy is better than 2 km)

– Brightness temperature

– Observation dates

– Geocoding information (continent, country, region, city)

– Images of the observations affected by RFI.

Table 1 is an example of the information typically included in a SMOS RFI report. Recommendation ITU-R RS.2106 is used as a reference for Table 1.

TABLE 1

Example of information provided in the SMOS RFI reports submitted to national authorities

Id	Location & characteristics from satellite measurements					STATUS	First SMOS observation
	LON (*Deg*)	LAT (*Deg*)	BT (*K*)	Region	Observations		
ES009	-3.708	40.409	555	Madrid	*Madrid*	ON	2010-05-01
ES042	1.755	41.812	412	Catalunya	*Súria*	OFF	2015-10-07
ES044	2.011	41.547	466	Catalunya	*Rubí*	ON	2012-05-15
ES060	0.803	41.670	350	Catalunya	*Bellvís*	OFF	2017-03-18
ES061	2.042	41.607	384	Cataluña	Castellar del Vallés	OFF	2018-04-13
ES062	-1.100	40.310	1207	Aragón	*Teruel*	OFF	2018-04-24
ES063	-0.780	38.652	440	Comunidad Valenciana	*Alicante*	OFF	2018-07-01
ES064	-3.042	37.027	406	Andalucía	*Válor*	OFF	2018-06-08
ES065	0.405	41.066	392	Cataluña	*Gandesa*	OFF	2018-07-01
ES066	2.273	41.659	466	Cataluña	*Barcelona*	OFF	2018-07-06
ES069	-6.253	36.646	475	Andalucía	*El Puerto de Santa María*	OFF	2018-07-16
ES071	-5.598	37.166	427	Andalucía	*Morón de la Frontera*	ON	2019-02-13
ES073	-2.067	39.703	390	Castilla-la Mancha	*Cuenca*	ON	2019-10-06
ES075	-5.652	41.972	1217	Castilla y León	*Zamora*	OFF	2020-04-25
ES076	1.688	41.326	577	Catalunya	*Barcelona*	OFF	2020-05-09
ES077	-1.666	42.329	476	Andalucía	*Cádiz*	OFF	2020-02-18
ES079	-1.146	41.588	870	Aragón	*Zaragoza*	ON	2020-09-14
ES080	-1.666	42.329	404	Navarra	*Navarra*	ON	2020-09-08

7.3 Types of maps used for RFI representation

Radio-frequency interference, which originate from active man-made emitters, disturbs observations of the natural microwave emission in L-band rendering the satellite observations in some cases entirely unusable. The power received from RFI signals can be several times as large as the natural thermal radiation emitted from the Earth. But even when the power of RFI is low it can cause significant issues as the presence of RFI becomes harder to detect and therefore it is easier for RFI-contaminated data to be processed and used in scientific studies, which can lead to wrong or inaccurate conclusions. Hence limiting the effect of RFI and detecting RFI sources is essential to ensure adequate quality in the retrieved data products as well as for the identification of the RFI emitters.

Due to the large number of RFI instances detected by SMOS over the world, RFI represents a major concern for the mission. ESA has set up a dedicated SMOS RFI team to perform regular RFI monitoring worldwide, and that analyses SMOS data for detection, geolocation and characterisation of the RFI sources. The RFI sources are sorted per country and stored in an RFI database. The global RFI catalogue is a key tool to support the interference reporting process established with the different Administrations. The ESA SMOS RFI team is mainly based at the ESA's facilities at the European Space Astronomy Center (ESAC, Madrid, Spain).

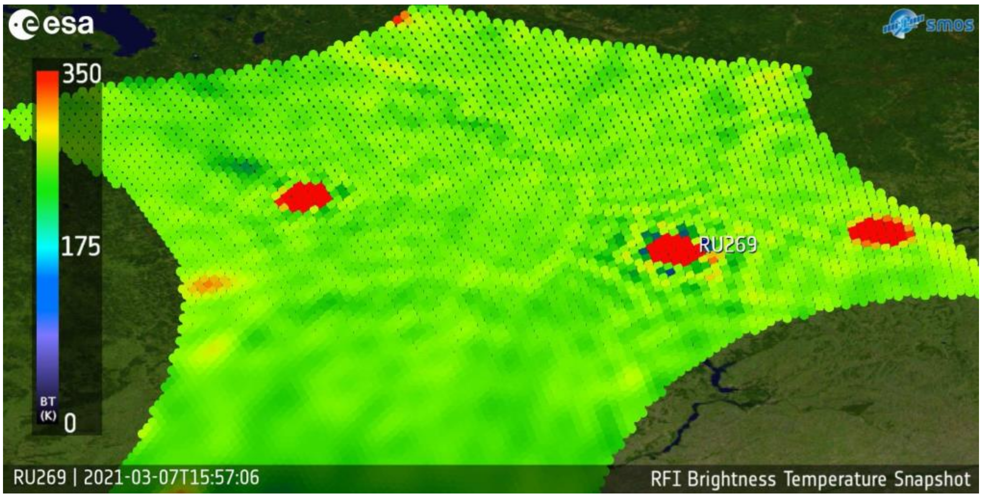
The impact of interference in SMOS science data is also analyzed and monitored by the SMOS RFI team at the *Centre d'études spatiales de la biosphère* (CESBIO, Toulouse (France)). Amongst other activities related with RFI detection and mitigation, CESBIO maintains a SMOS blog where RFI probability maps are posted bi-weekly since the beginning of the mission.

The two main tools used for the assessment of RFI contamination worldwide are:

– **Brightness temperature maps:** RFI sources can be characterized according to their position, brightness temperature and persistence. This is done identifying the local maxima in each snapshot (see Fig. 7) using adaptive thresholds on the brightness temperature (BT) and the BT gradients.

FIGURE 7

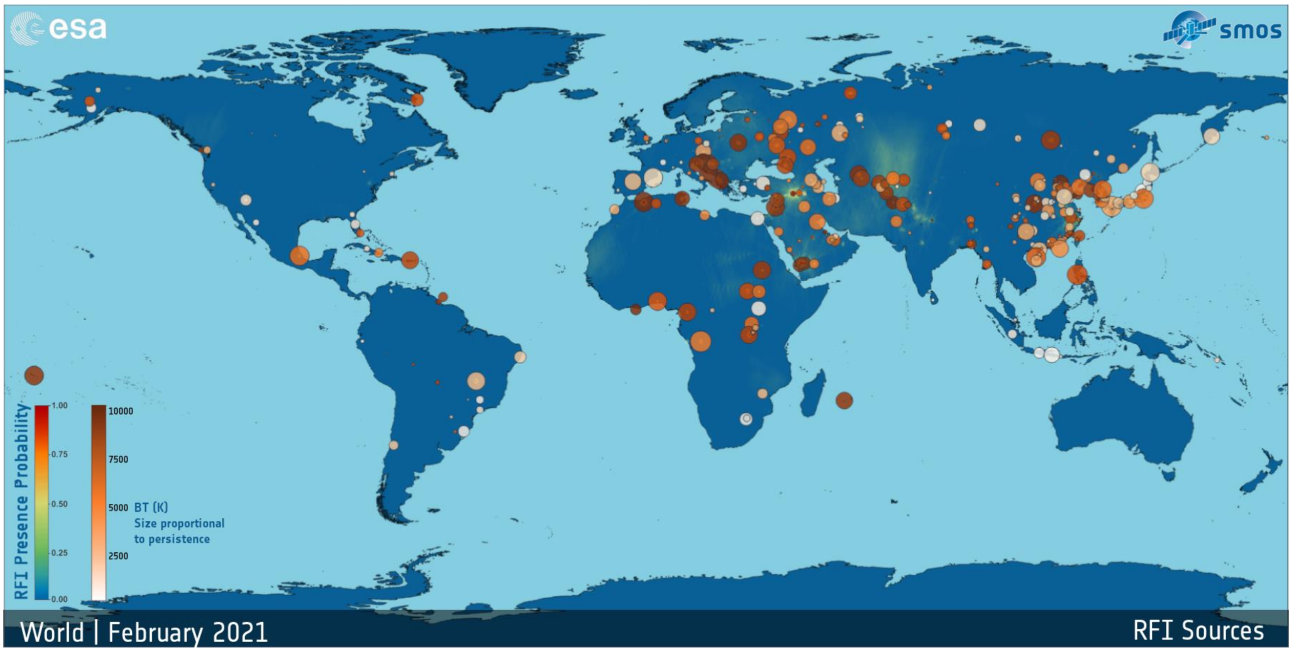
Example of SMOS RFI brightness temperature map



– **RFI source maps:** The RFI characterization from SMOS observations using data from 20 July to 3 August 2017 is shown in Fig. 8. The **color** of each RFI is proportional to its averaged BT. As RFI BTs are the sum of the natural thermal noise and the man-made emission, BT lower than 300 K are not represented. The maximum of the color-bar is fixed at 10 000 K in all images for consistency, but in many cases stronger RFI are present. The **size** of each point is proportional to RFI persistence in SMOS data, i.e. the number of times the RFI was detected. Because of SMOS polar orbit, RFI sources at high latitudes tend to be bigger, since they are observed more often.

FIGURE 8

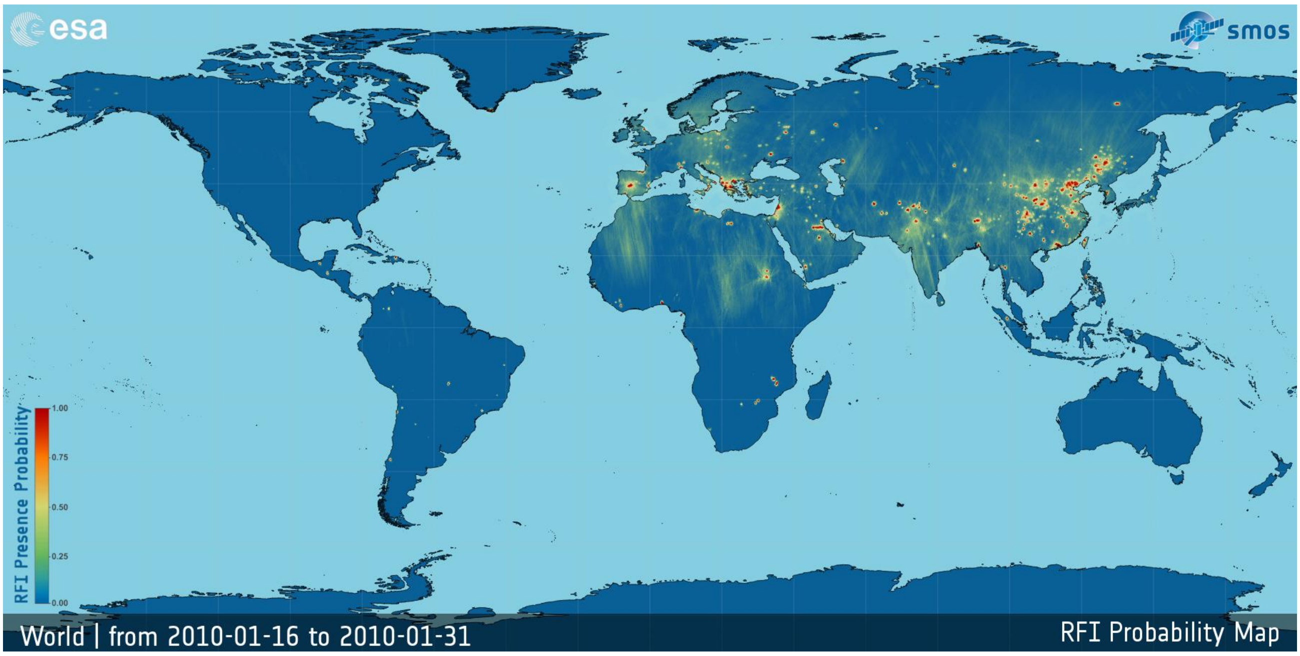
Worldwide RFI brightness temperature from 20 July 2017 to 3 August 2017 in February 2021



– **RFI probability maps:** The Level-2 soil moisture processor allows retrieving statistical information of the SMOS pixels affected by RFI and this data can be presented as **probability maps of RFI occurrences**. The basis of probability maps is to count the number of times each location on the surface is observed and the number of times each location corresponded to measurements affected by RFI. Both these counts are made daily since the beginning of the mission. The color bar in the scale ranges from red (1), indicating that RFI is always present and means that there are no RFI-free BT measurements during the 15-day period, to deep blue (0), indicating little or no probability of interference, and thus almost all BT measurements were kept as usable for retrieval. Intermediate values (between 0 and 1) indicate certain proportion of RFI presence but do not tell when the occurrences appeared within the time window considered. For the 15 days time window illustrated in these maps, a probability of 50% (green) is equally obtained by 7.5 days of continuous strong emissions followed by 7.5 days of no emission at all or by alternating one day with strong RFI followed by one day RFI off or any other combinations. Figure 9 shows the RFI probability map for January 2010.

FIGURE 9

Probability map of sustained RFI occurrence in January 2010



7.4 Type of emissions vs the RFI strength

The RFI detection included in soil moisture retrieval algorithms allows detecting strong RFI emitters but also weaker sources. The RFI sources are detected when their BT are outside of the geophysical expectation range. The BT is the product of the physical temperature times the emissivity. The physical upper limit of the emissivity is equal to 1. The maximum physical temperature ever recorded is approximately 71°C. The maximum BT that can be expected from the natural scene (worst case for both the emissivity and the physical temperature) is approximately 344 K. Therefore, BTs values above 344 K indicate that there is a man-made emission in the band.

The RFI emissions can be categorized as low, moderate, strong or very strong, based on their impact on SMOS data:

– **Low RFI emissions** have levels similar to natural sources and are difficult to detect, leading to incorrect physical retrieval.

– **Moderate RFI emissions** are easily detectable, but their effects are limited to the area near the location of the ground emitter. The quality of the data will be negatively affected, with less data available for the retrieval leading to a degradation of accuracy. These man-made emissions within the passive band are observed by SMOS as strong point source emissions (see Fig. 10).

– **Strong RFI emissions** influence larger areas through the secondary lobes tails, which need to be discarded for scientific retrieval, thus leading to a significant data loss (see Fig. 11).

– **Very strong RFI emissions** essentially hide the full SMOS field-of-view and can blank out any natural signal over a range of several hundreds of km, causing significant loss of data for scientific retrievals and saturating some of SMOS receivers. Recurring examples of this type of RFI have been observed in Europe (see Fig. 12).

FIGURE 10

SMOS BT map showing detection of moderate RFI point source emission

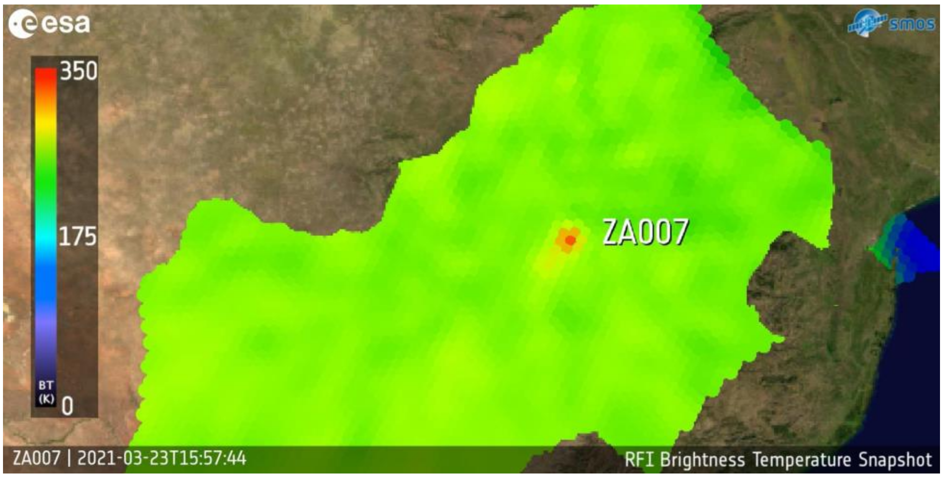


FIGURE 11

SMOS BT map showing detection of strong RFI emission

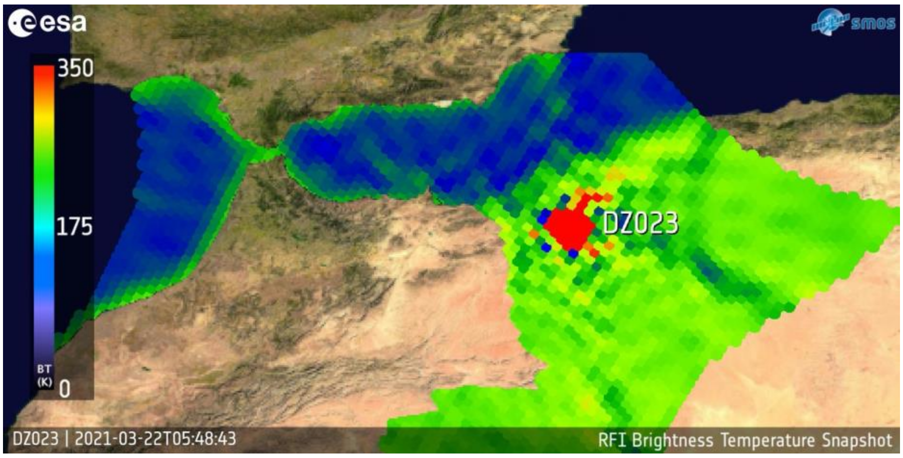
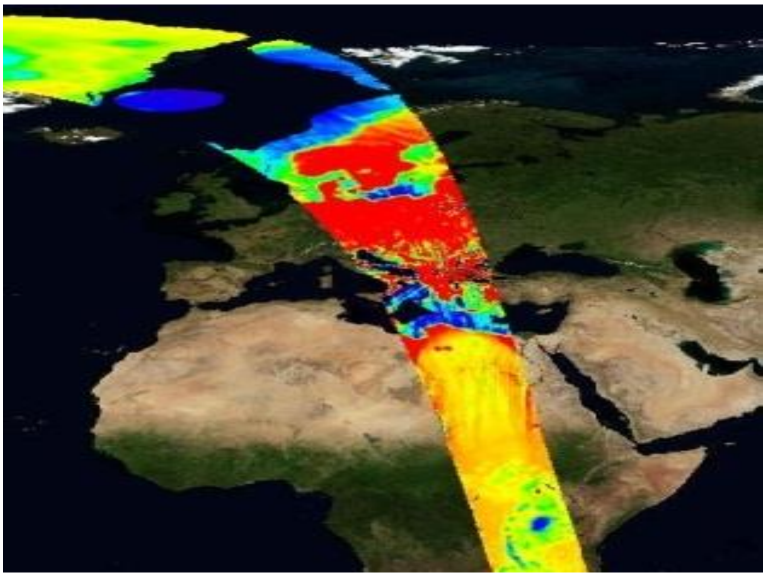


FIGURE 12

SMOS BT map showing the impact of very strong RFI emission



7.5 Type of emissions vs the RFI source

The RFI sources can also be grouped into two main categories depending on if the RFI emission is produced by a transmitter operating within the passive band or in the adjacent bands, as it is depicted in Fig. 13.

– *In-band emissions in the protected band*. These RFIs are caused by unauthorized radio links, TV and FM broadcast stations, wireless monitoring cameras, malfunctioning DECT phone terminals and other equipment with poor maintenance whose frequency of operation has drifted over time. In these cases, the interfering emitters are supposed to be operating in bands allocated to the terrestrial fixed and mobile services (FS/MS), which are adjacent to the 1 400-1 427 MHz EESS (passive) band.

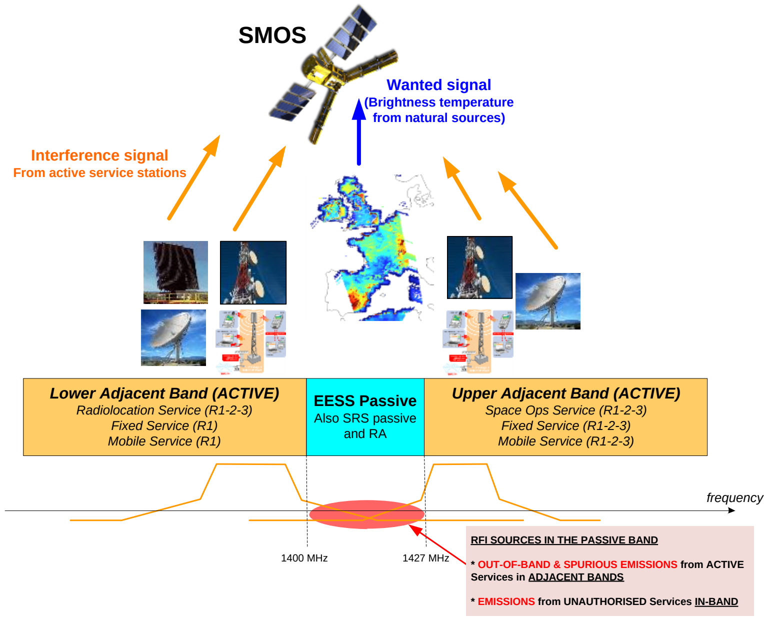
  Harmful interference in-band may also be caused by excessive radiations at the intermediate frequency from electronic equipment with insufficient isolation/shielding. For example, direct-to-home 12 GHz satellite TV receiver equipment with intermediate frequency for some channels overlapping the 1 400-1 427 MHz EESS (passive) band. (See also § 10.2.2.)

– *Excessive unwanted emissions from systems operating in the adjacent bands*. Typically, these interferences are due to excessive out-of-band emissions of radar systems. The spurious emissions of radio link equipment operating in adjacent bands are also a common source of interference.

The distinction between these two types of emission cannot be made based only on the satellite observations. The feedback received from the national spectrum management authorities is key to be able to better characterise the RFI source and establish some statistics and to further improve the interference detection, mitigation, and cancellation techniques.

FIGURE 13

Graphic representation of EESS allocation and neighbouring services in the 1 400-1 427 MHz band



8 Approaches to improve the RFI situation

Several strategies have been put in place to improve the RFI scenario observed and to minimise the negative impact in the scientific retrievals worldwide.

8.1 In the short/medium term: Regular RFI Monitoring and Reporting

– **RFI reporting to the Regulatory Authorities** of the different Administrations, in accordance with Recommendation ITU-R RS.2106 – Detection and resolution of radio frequency interference to Earth exploration-satellite service (passive) sensors. Since January 2019, the RFI reports are handled via the online ITU SIRRS (https://www.itu.int/ITU-R/space/sirrs/).

  The national regulatory authorities are requested to cooperate and take the necessary actions to resolve the RFI cases with the cancellation, or at least mitigation, of the interference source. Typically, the authorities will send their RF monitoring units to localize the potential interferers at the approximate locations provided, and these RFI sources will be switched-off once it is confirmed that they are the cause of the interference. The RFI reporting process requires close follow-up by ESA and regular communication with the administrations to assess the results of actions initiated.

– **Improvement of interference detection, data flagging and geolocation processes.** Continuous efforts are dedicated to improving the detection, flagging and geolocation of RFI contamination. Part of this effort consists in approaching the RFI issue early on in the data processing chain, to limit the impact of RFI in the different data products that are distributed to the users. However, improvements in the RFI detection and flagging do not address the fundamental issue of useful measurements being lost due to interference.

– **Systematic RFI monitoring worldwide, including manual RFI analysis when necessary.** The global RFI monitoring is updated regularly and stored since the beginning of the mission. The RFI worldwide scenario is analysed and considered as baseline to set the priorities for dealing with RFI cases.

– **Definition and maintenance of the SMOS RFI database**, containing the RFI tables per country (including RFI ID, coordinates, RFI strength, location, log dates and RFI characterization), RFI statistics per country and continent, 15 days RFI probability maps, brightness temperature maps, RFI identification considering multiple detection methods, Google Earth files, RFI reports and logs of the communications with all administrations.

8.2 In the medium/long term: Increase awareness and improve the regulatory framework

– **Increase awareness of the international community about the RFI problem for passive sensors** and the impact in the scientific return of satellite missions. The RFI environment encountered by the SMOS radiometer was presented at the Space Frequency Coordination Group (SFCG), the CEPT Working Group on Frequency Management (WGFM), and at several international scientific events (e.g. IGARSS, URSI, COSPAR).

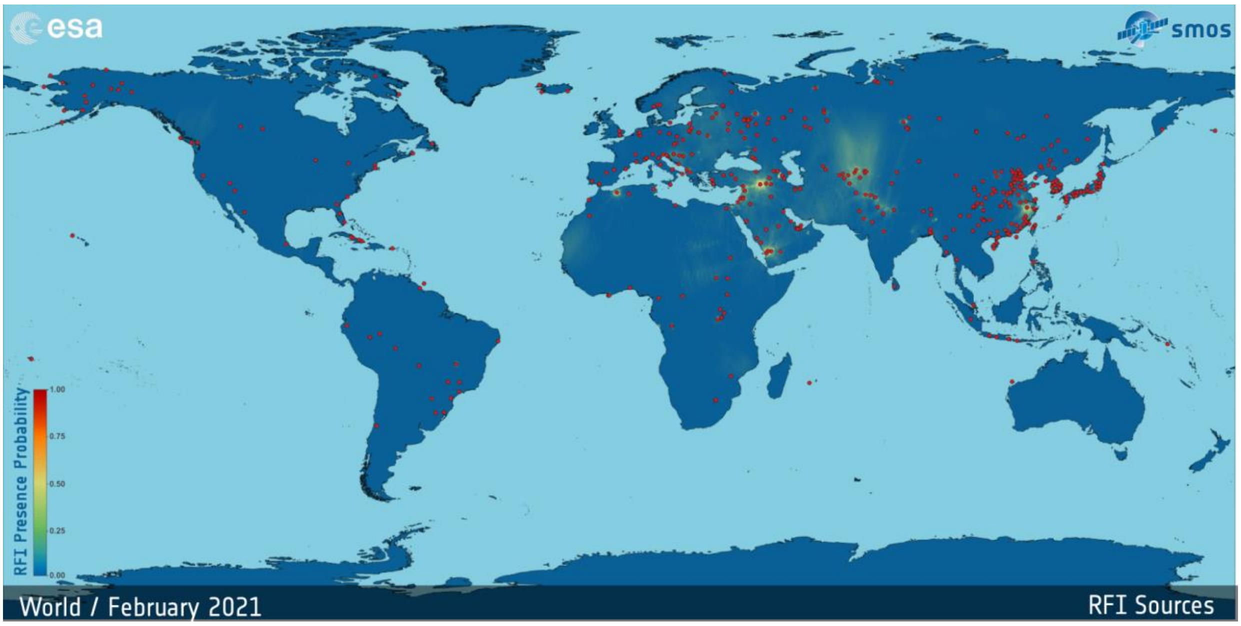
– **Improvement of the regulatory framework within ITU and the CEPT** (i.e. European region). This is achieved through ESA's participation in ITU-R Study Groups, the World Radiocommunication Conference and at European level, the CEPT working groups.

9 Survey of observed RFI events

The overall situation of SMOS RFI as observed in February 2021 is presented in a worldwide inventory depicted in Fig. 14. The position of an RFI is obtained averaging all its localizations made within a pre-defined period. As RFI BTs are the sum of the natural thermal noise and the man-made emissions, BT lower than 300 K are not represented.

FIGURE 14

Worldwide inventory of RFI observed by SMOS in February 2021



Figures 15 and 16 include some statistics on the number and intensity of RFI sources per continent (in Fig. 15) and per country (limited to Europe, in Fig. 16). Most RFI sources are currently in Asia. In Europe, although many countries have at least some RFI, the strongest RFI are concentrated in the territories of a few administrations.

FIGURE 15

Distribution of worldwide RFI (February 2021)

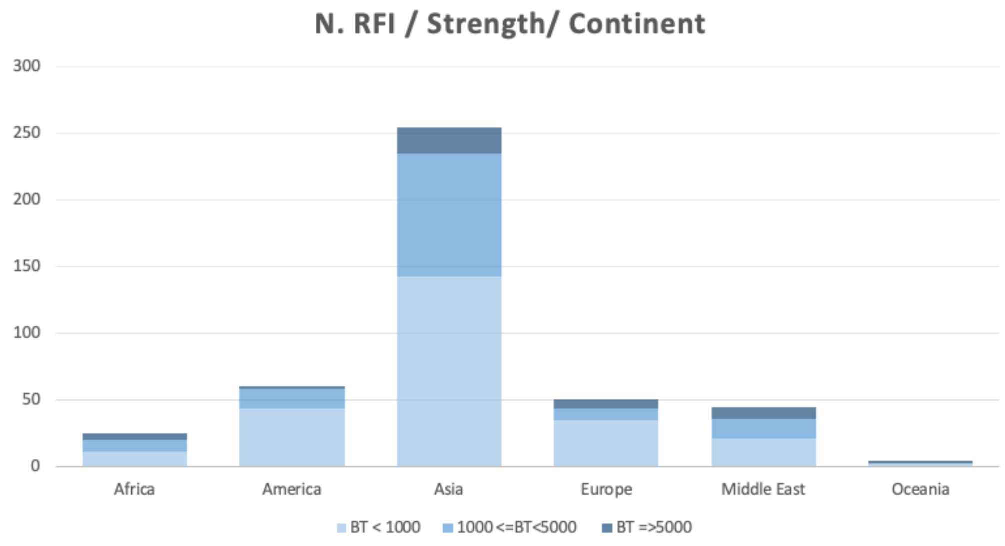
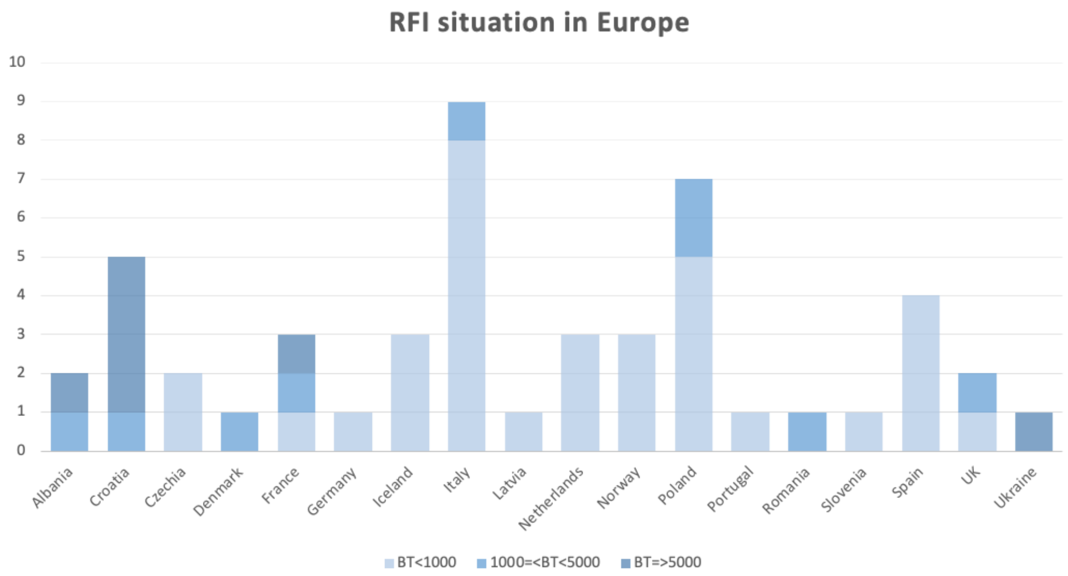


FIGURE 16

Overview of the number of RFI over Europe (February 2021)



10 Evolution of the RFI scenario

10.1 Global RFI evolution

As of 28 February 2021, more than 3 800 RFI occurrences have been observed worldwide. In some cases, the interference is only observed during a limited period of time. The approach followed in the investigation of RFI has been to focus the efforts in the RFI cases that are observed regularly, giving priority to the investigation of those interferences more detrimental to the scientific objectives of the mission.

As of 28 February 2021, ESA has contacted 54 administrations worldwide, as RFI occurrences are distributed in all regions. In general, there has been a good cooperation of the spectrum management authorities of most countries, in particular in Europe but also in Canada, United States of America and Japan. Unfortunately, this is not always the case and some administrations have not taken any action to investigate the RFI cases reported in their territory.

As of February 2021, up to 3 811 constant RFI have been detected at some point during the mission but only 437 RFI sources remain active (11%). In some cases, the RFI sources have been turned off as a direct consequence of the investigations of the SMOS team and the help of the national spectrum management authorities. In other cases, intervention has not been necessary, which just reflects that the RFI scenario is dynamic and some RFI disappear after some time.

Most RFI sources are detected over Asia and Middle East, as presented in Fig. 17. The overall situation is slowly improving. Figure 18 shows the impact of pixels over land affected by RFI contamination is reducing when strong RFI sources are switched off. However, the total number of active RFI sources remains fairly constant as it has been observed that very strong RFIs may be masking other RFI sources underneath.

As a response to the actions initiated by ESA it has been observed a noticeable improvement in the RFI environment over Europe and North America, and some improvement is also observed over China (see Figs 17 and 18).

FIGURE 17

RFI probability maps in January 2010 (top) and February 2021 (bottom)

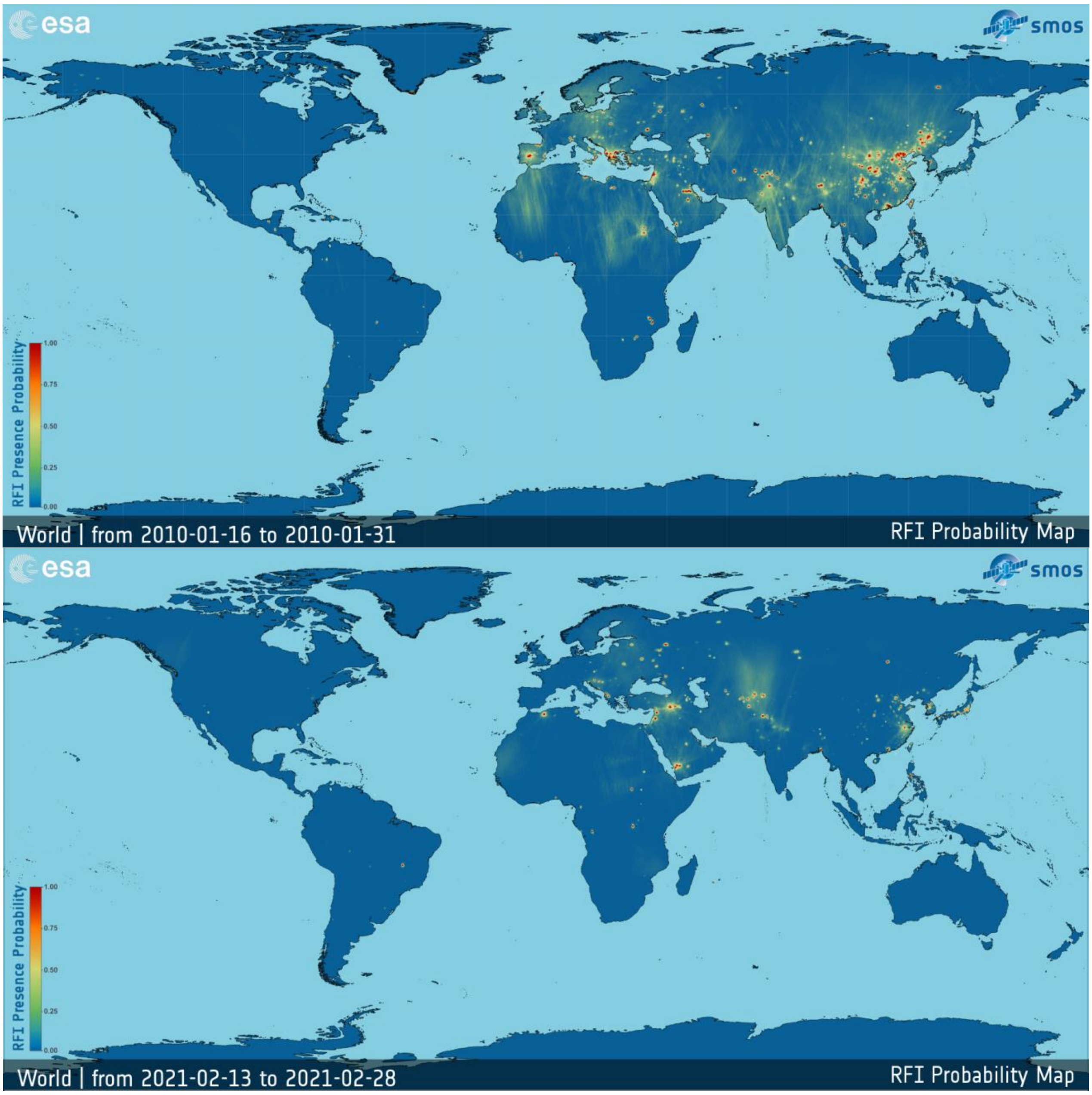
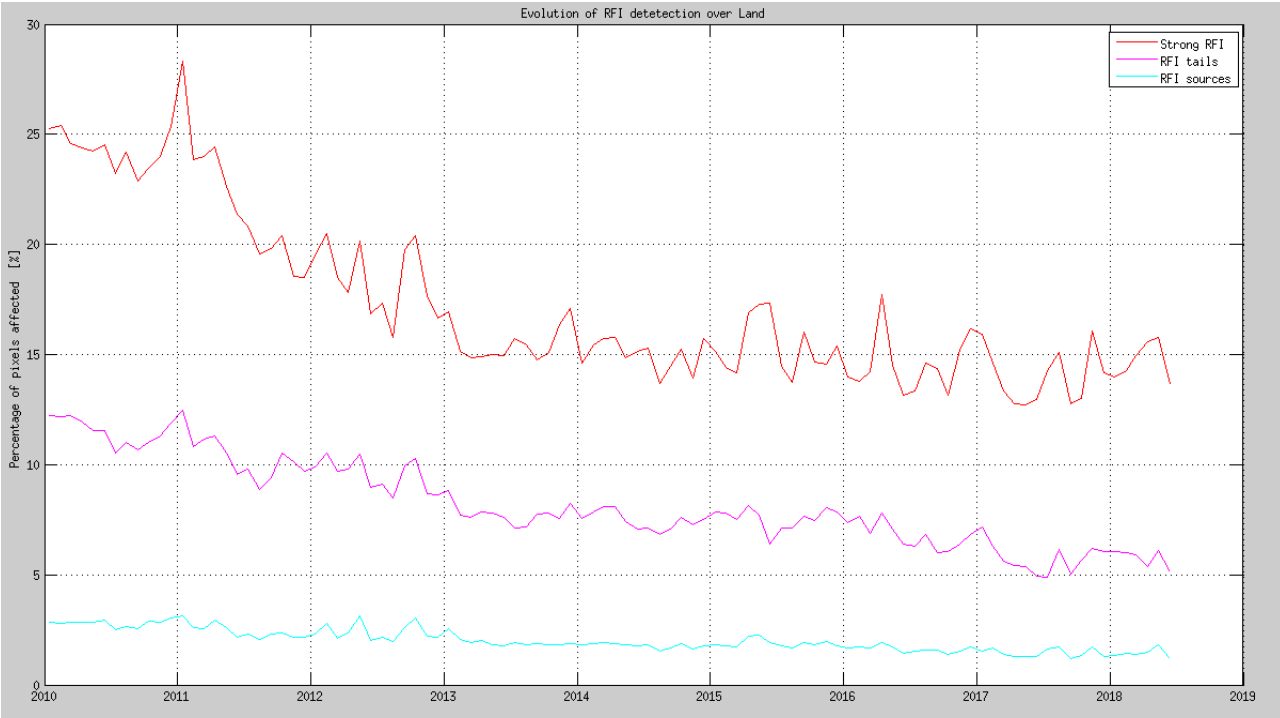


FIGURE 18

Evolution of RFI sources over land



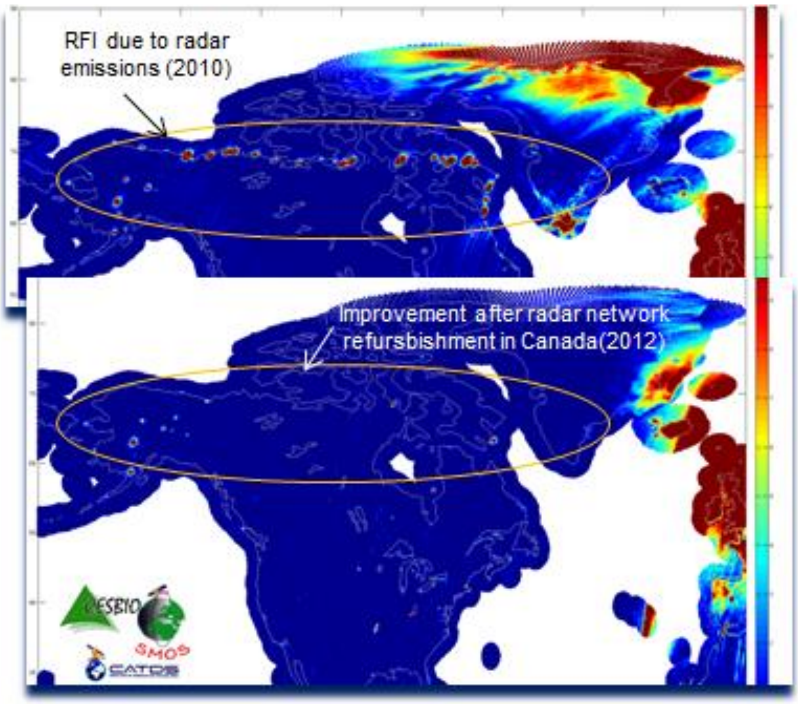
10.2 Example of RFI cases

10.2.1 Radar system in Canada

A significant improvement has been observed in North America following the refurbishment of several radar systems in Canada. The cooperation of the Canadian authorities to investigate this RFI case and then to upgrade the radar network to reduce the level of unwanted emissions was very important. This improvement had impact not only in the soil moisture measurements but also in the sea salinity monitoring in the arctic areas (see Fig. 19).

FIGURE 19

Evolution of SMOS RFI in North America following the refurbishment of the L-Band radars

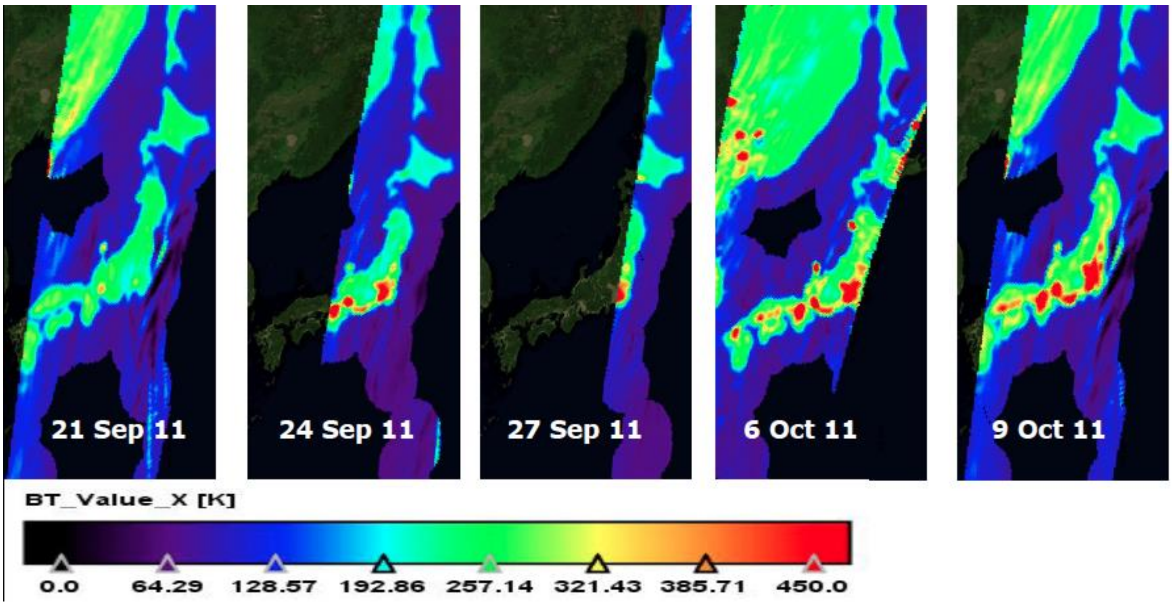


10.2.2 Extended RFI emissions: Japan

A sudden RFI increase observed as extended RFI source emissions has been observed over Japan since September 2011 over main urban areas (see Fig. 20). The spectrum monitoring authorities in Japan helped in the investigation of this case. It was concluded that the emissions come from excessive radiations at the intermediate frequency from satellite TV antenna electronic equipment with insufficient isolation/shielding.

FIGURE 20

Evolution of SMOS RFI over Japan in September 2011

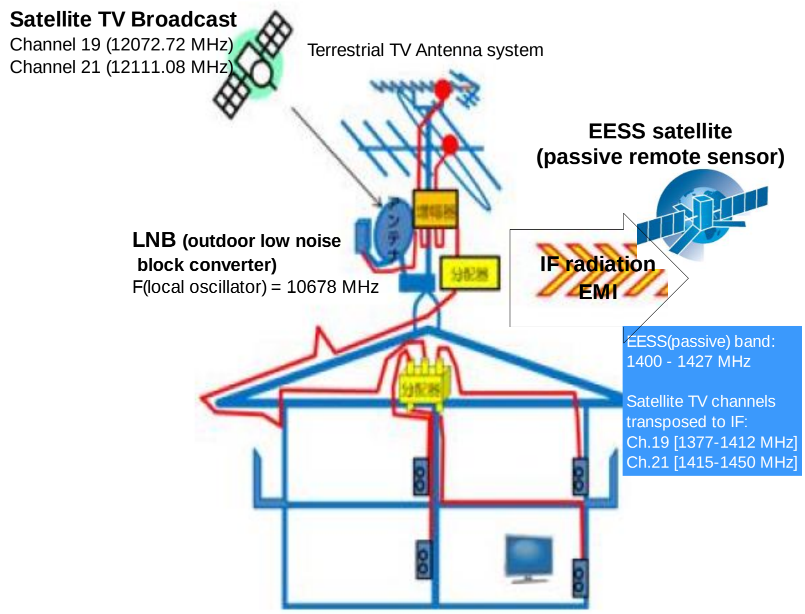


The RFI appeared suddenly over Japan when a new broadcasting-satellite system (BSS) initiated operations in two new BSS channels: No. 19 in October 2011 (downlink frequency f = 12 072 MHz) and No. 21 in March 2012 (f = 12 111 MHz). The interference was observed as an extended RFI source distributed over most urban areas of Japan.

As shown in Fig. 21, the outdoor LNB unit of the home-TV satellite receiving systems down-converts the received broadcast satellite frequencies to an intermediate frequency block. This transposed TV signal is then routed and distributed indoors. The intermediate frequency range for the BSS channels Nos. 19 and 21 are overlapping the 1 400-1 427 MHz frequency range.

FIGURE 21

Schematic of the interference case



This harmful RFI case is having a negative impact on ESA's SMOS mission and NASA's SMAP mission.

10.2.3 Really strong RFI sources: Poland and China

There have been some cases in which a single RFI source blinded the instrument and caused loss of data over very large portions of the globe.

One such case affected central Europe and lasted for several months. The cause was high power emissions from an old radar system operating very close to 1 400 MHz. The national authorities that studied this case took action and the case could be solved (see Fig. 22).

FIGURE 22

Example of RFI case due to high unwanted emission levels from a radar system (*source: ESA/ESAC*)

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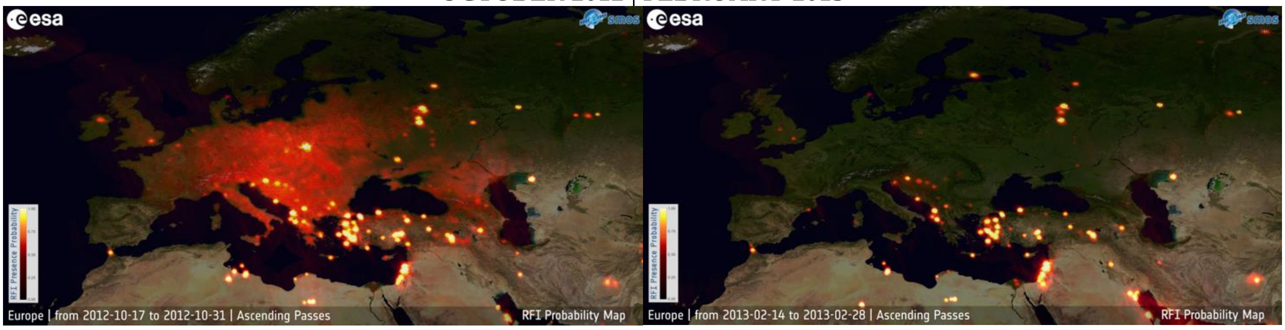

Another similar case occurred in China in 2020. The brightness temperature measured by SMOS at the location of this RFI sources reached as much as 1.75 MK and it caused data loss over an area including the Yellow Sea, eastern China and the Philippines. This RFI was reported to the relevant national authorities. As of February 2021, this RFI source is still active, but the brightness temperature measured at its location has decreased to approximately 10 000 K (with some peaks up to 50 000 K).

FIGURE 23

Example of RFI case due to high unwanted emission levels from a radar system (*source: ESA/ESAC*)

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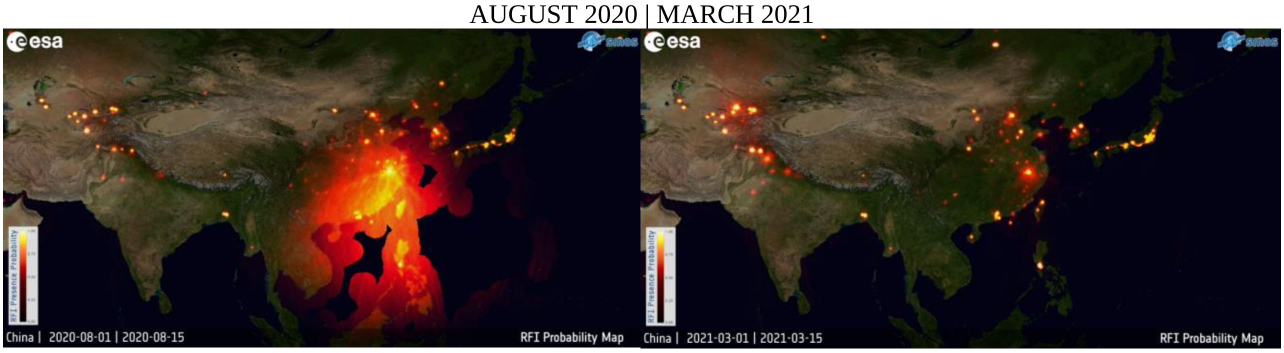
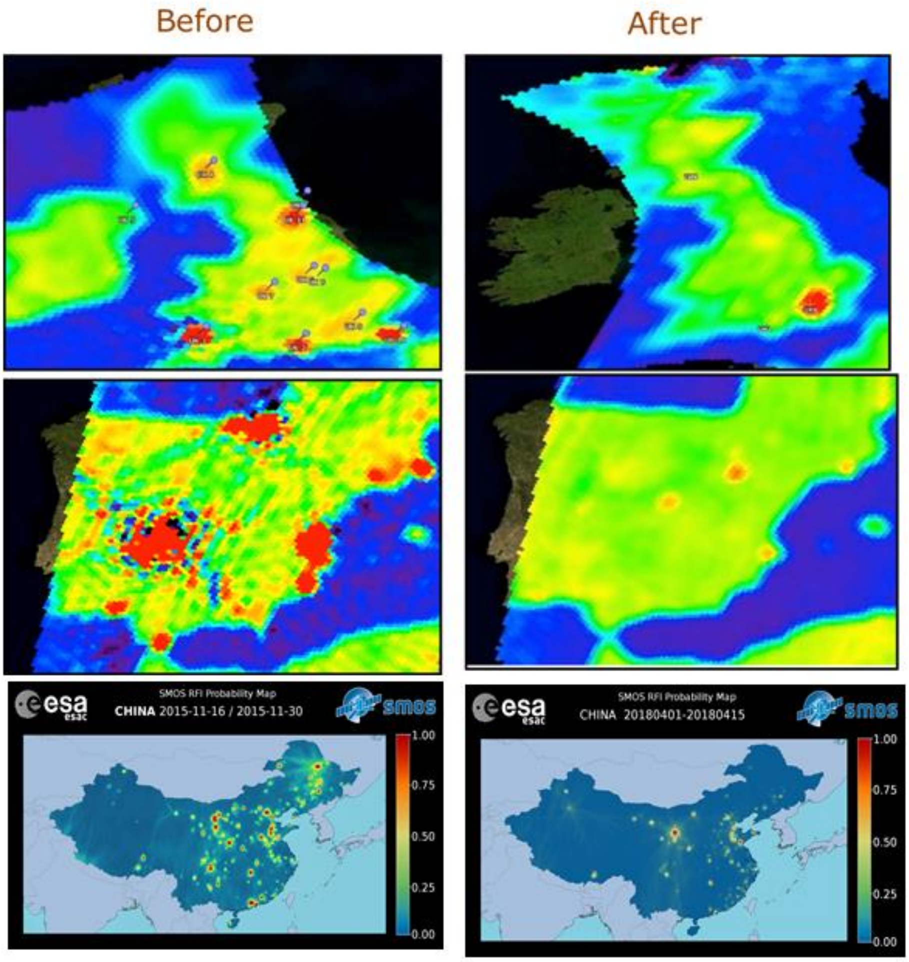


10.2.4 Improvement in RFI scenario: Europe, China

The support of the administrations is very important to improve the RFI situation, as solved in the examples presented in Fig. 24. In many countries in Europe, and recently also in China, the RFI scenario has improved substantially thanks to the effort of the national authorities in tracking down the illegal RFI sources.

FIGURE 24

Example of RFI case successfully solved thanks to the cooperation of the spectrum management authorities of different countries



11 Conclusion and way forward

It is essential to protect the passive band 1 400-1 427 MHz from both prohibited in-band emissions and excessive unwanted emissions. While the solution of the RFI due to prohibited in-band emissions can be achieved with the cooperation of the national authorities, the solution of the excessive unwanted emissions problem requires regulatory action and compliance with the levels adopted in Resolution **750 (Rev.WRC-19)**. This effort has to be continued and intensified by raising awareness among the different administrations.

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