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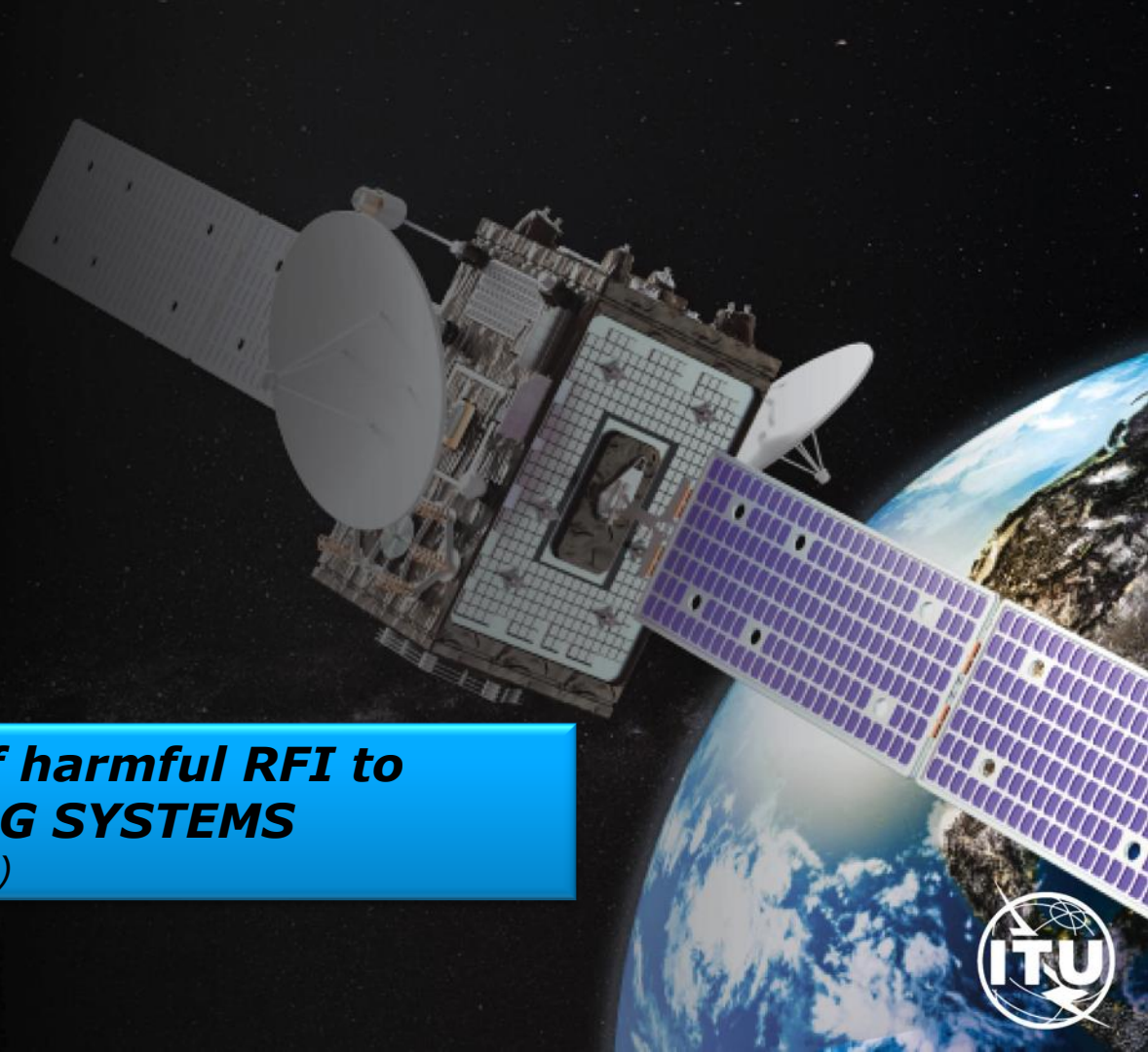
Episode #1: Interference to satellite systems: preventing or protecting?

16 September 2020
15h00 -16h30 CET



The increasing problem of harmful RFI to PASSIVE REMOTE SENSING SYSTEMS

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The Increasing Problem of harmful RFI to Passive Remote Sensing Systems

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Introduction: About the importance of EESS satellites

- **Earth Exploration and Meteorological satellite systems** use **active and passive REMOTE SENSORS** to gather data about the Earth and its natural phenomena.

- **Unique capabilities** of Earth Exploration Satellite Service (EESS) satellites:
  - ✓ Global **measurements of the Earth's land, oceans and atmosphere**
  - ✓ Ability to rapidly target remote and inhospitable places
  - ✓ Continuity of observations over long periods of time

- Important to stress the **importance of radio spectrum for all Earth Exploration activities,** either ground or space based, passive or active:
  - ✓ In particular to support global warming and climate change activities…
  - ✓ but also for multiple applications that are nowadays taken for granted such as the daily weather forecast and prediction, and providing data during natural disasters.

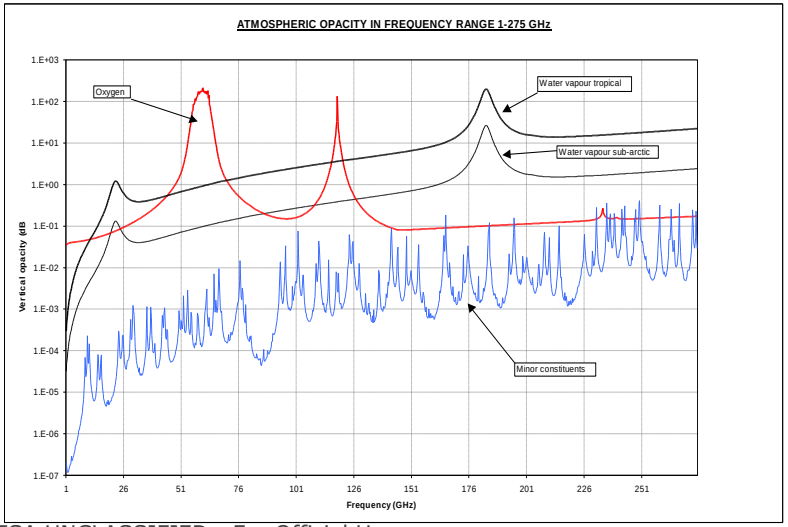
- EESS brings many **benefits to society** in both the non-profit and commercial sectors.

Source: Report ITU-R RS.2178 (Essential Role and Global Importance of radio spectrum for Earth observations and for related applications)

Passive Remote Sensing Bands

SENSOR DATA PRODUCTS ➔ Environmental information obtained through the sensor measurements

- ✓ EESS(passive) bands are determined by fixed physical properties (molecular resonance)
- ✓ Information **cannot be duplicated in other frequency bands**
- ✓ **Multiple bands are generally required** to resolve parameters such as sea surface temperature, sea surface winds, soil moisture, rain, snow /ice cover, etc.



- Passive Remote Sensing takes advantage of **absorption in the Earth's atmosphere** to probe temperature and moisture profiles.
- **Passive sensors require very sensitive low noise receivers**.
- **Emissions above a certain level may constitute HARMFUL interference** as passive sensors may not be able to differentiate the wanted signal from the interference.

Main ITU recommendations and reports for passive remote sensing

Article 1.183 -- passive sensor: A measuring instrument in the earth exploration-satellite service (…) by means of which information is obtained **by reception of radio waves of natural origin.**

Recommendation ITU-R RS.2017
(05/2012)

Performance and interference criteria for satellite passive remote sensing

Recommendation ITU-R RS.1861
(01/2010)

Typical technical and operational characteristics of Earth exploration-satellite service (passive) systems using allocations between 1.4 and 275 GHz

Recommendation ITU-R RS.515-5
(08/2012)

Frequency bands and bandwidths used for satellite passive remote sensing

Report ITU-R RS.2165
(09/2009)

Identification of degradation due to interference and characterization of possible interference mitigation techniques for passive sensors operating in the Earth exploration-satellite service (passive)

https://extranet.itu.int/brdocsearch/R-REC/Forms/folders_inforce.aspx

EESS(passive) bands with PRIMARY allocations PURELY PASSIVE

1400-1427 MHz	50.2-50.4 GHz	164-167 GHz
2690-2700 MHz	52.6-54.25 GHz	182-185 GHz
10.68-10.7 GHz	86-92 GHz	190-191.8 GHz
15.35-15.4 GHz	100-102 GHz	200-209 GHz
23.6-24 GHz	109.5-111.8 GHz	226-231.5 GHz
31.3-31.5 GHz	114.25-116 GHz	250-252 GHz

1400-1427 MHz ➔ used by SMOS @ESA, SMAP & AQUARIUS @NASA.
With SMOS, ESA has gained broad experience about RFI location worldwide, type of sources and also formally reporting to administrations these cases for removal of illegal transmitters or adjustment of settings (radars) to minimise RFI impact.

10.68-10.7 GHz (typically combined with 10.6-10.68 GHz allocation) ➔ used by AMSR-E/2 @JAXA+NASA, MWRI @China, WindSat @USA DoD, GMI @NASA, MTVZA-GY @Roscosmos.
Multiple RFI cases reported for these sensors.

- ITU RR No 5340 applies ➔ All man-made emissions are prohibited in these bands.
- **Resolution 750** set restrictions to the unwanted emissions from active services operating in adjacent bands.
- In Europe, the restrictions to unwanted emissions wrt L-Band (1400-1427 MHz) are MANDATORY.

ITU Resolution 750 (rev WRC-19):
EESS(passive) protection (Extract for 1.4 GHz and 24 GHz bands)

TABLE 1-1

EESS (passive) band	Active service band	Active service	Limits of unwanted emission power from active service stations in a specified bandwidth within the EESS (passive) band[1]
1 400-1 427 MHz	1 427-1 452 MHz	Mobile	−72 dBW in the 27 MHz of the EESS (passive) band for IMT base stations −62 dBW in the 27 MHz of the EESS (passive) band for IMT mobile stations[2, 3]
23.6-24.0 GHz	22.55-23.55 GHz	Inter-satellite	−36 dBW in any 200 MHz of the EESS (passive) band for non-geostationary (non-GSO) inter-satellite service (ISS) systems for which complete advance publication information is received by the Bureau before 1 January 2020, and −46 dBW in any 200 MHz of the EESS (passive) band for non-GSO ISS systems for which complete advance publication information is received by the Bureau on or after 1 January 2020
	24.25-27.5 GHz	Mobile	−33 dBW[a] in any 200 MHz of the EESS (passive) band for IMT base stations[5] −29 dBW[b] in any 200 MHz of the EESS (passive) band for IMT mobile stations[5]

Mandatory limits for IMT and ISS stations (Table 1)

In the 1.4 GHz band Recommended limits for other active services in adjacent bands (Table 2)

TABLE 2

EESS (passive) frequency band	Active service frequency band	Active service	Recommended maximum level of unwanted emission power from active service stations in a specified bandwidth within the EESS (passive) frequency band[1]
1 400-1 427 MHz	1 350-1 400 MHz	Radiolocation[2]	−29 dBW in the 27 MHz of the EESS (passive) band
		Fixed	−45 dBW in the 27 MHz of the EESS (passive) band for point-to-point
		Mobile	−60 dBW in the 27 MHz of the EESS (passive) band for mobile-service stations except transportable radio-relay stations −45 dBW in the 27 MHz of the EESS (passive) band for transportable radio-relay stations
	1 427-1 429 MHz	Space operation (E-to-s)	−36 dBW in the 27 MHz of the EESS (passive) band
	1 427-1 429 MHz	Mobile except aeronautical mobile	−60 dBW in the 27 MHz of the EESS (passive) band for mobile-service stations except IMT stations and transportable radio-relay stations[3] −45 dBW in the 27 MHz of the EESS (passive) band for transportable radio-relay stations
		Fixed	−45 dBW in the 27 MHz of the EESS (passive) band for point-to-point
	1 429-1 452 MHz	Mobile	−60 dBW in the 27 MHz of the EESS (passive) band for mobile-service stations except IMT stations, transportable radio-relay stations and aeronautical telemetry stations −45 dBW in the 27 MHz of the EESS (passive) band for transportable radio-relay stations −28 dBW in the 27 MHz of the EESS (passive) band for aeronautical telemetry stations[3]
		Fixed	−45 dBW in the 27 MHz of the EESS (passive) band for point-to-point

EESS (passive) bands with PRIMARY allocations but shared with active services

10.6-10.68 GHz	54.25-59.3 GHz
18.6-18.8 GHz	116-122.25 GHz
21.2-21.4 GHz	155.5-158.5 GHz
22.21-22.5 GHz	174.8-182 GHz
31.5-31.8 GHz*	185-190 GHz
36-37 GHz	235-238 GHz

* in Regions 1 & 3 only

10.6-10.68 GHz ➔ used by AMSR-E/2 @JAXA+NASA, MWRI @China, WindSat @USA DoD, GMI @NASA, MTVZA-GY @Roscosmos. Multiple RFI cases reported.

18.6-18.8 GHz ➔ used by AMSR-E/2 @JAXA+NASA, MWRI @China, WindSat @USA DoD, GMI @NASA, MTVZA-GY @Roscosmos, MWI @NSOAS. Multiple RFI cases reported.

36-37 GHz ➔ used by AMSR-E/2 @JAXA+NASA, MWRI_FY3A/C @China, WindSat @USA DoD, GMI @NASA, MTVZA-GY @Roscosmos, MWR Envisat @ESA, MWR Sentinel-3 ESA. RFI cases reported.
ESA has direct experience of RFIs w Sentinel-3 radiometer, mainly due to high-power radars in adjacent bands.

- These bands are shared typically with:
  - Terrestrial Fixed and Mobile Services
  - LEO/GEO Fixed Satellite Service downlinks
- The ITU Radio-Regulations set the conditions to ensure that EESS(passive) and the active services can simultaneously share the band without causing harmful interference to the passive sensors.
  - Interference protection criteria ITU Rec. RS.2017
- Potential RFI sources that could be expected ➔ In-band systems operating in services sharing the band:
  - RFI characterisation is important
  - EESS(passive) can claim protection ➔ RFI reporting
- However, excessive unwanted emissions into the EESS(passive) band from adjacent bands (typically radars) also need to be taken into account.

RFI: Which actions can be taken?

- **PREVENTIVE:** Application of the Radio Regulations and all relevant Recommendations, Reports and Resolutions, providing international recognition and protection to the EESS(passive) sensors.
- **CORRECTIVE:** Reporting of harmful interference to the administration, with ITU BR in cc. for information

RR: Art .15 and App 10
The template in Rec RS.2106 can be used for the RFI Reporting of EESS(passive) sensors.

ITU SIRRS online system is now facilitating this process.

Recommendation ITU-R RS.2106-0
(07/2017)

Detection and resolution of radio frequency interference to Earth exploration-satellite service (passive) sensors

RS Series
Remote sensing systems

https://www.itu.int/en/ITU-R/space/SIRRS/Pages/default.aspx

Types of Interference Sources for some typical EESS(passive) bands

RFI source	1.4 GHz Purely passive band	10.6 GHz, 18.6 GHz and 36 GHz Shared passive bands
Emissions from a transmitter operating in-band	Illegal transmitter. EESS(passive) can claim protection Required RFI reporting /RS2106.	Some in-band active service allowed in RR. Two possibilities: 1) System characteristics of interfering system comply with regulatory restrictions ➔ Further investigations needed. 2) System characteristics do NOT comply with regulatory restrictions ➔ Required RFI reporting /RS2106 Active service has NO allocation in that band, therefore unauthorized transmission➔ Required RFI reporting /RS2106
Excessive unwanted emissions into the passive band from a transmitter operating in adjacent band (or nearby)	Identity type of active service and compliance with Resolution 750: 1) Yes ➔Further investigations needed. Important to look for cooperation with the admin to identify possible solutions. 2) No ➔ Required RFI reporting /RS2106	These unwanted emissions are typically lower than those from active services authorised in-band. Main exception to consider is the radiolocation service (radars). Its main impact is the pollution of the sensor observation, which could even saturate or damage the receiver chain.
Emissions outside the passive band, from a transmitter operating in adjacent band (or nearby)	These emissions cannot be avoided and have to be taken into account to design the **selectivity** of the channel. Its impact may range from pollution of the sensor observation (degraded performance), to saturating or even damaging the receiver chain.	

Sizing the RFI problem: the reporting issue

ACTIVE DEVICES EVOLUTION

Market demands leading to an increasing number of new commercial applications oriented to the **mass-market**

Increasing spectrum needs covering the already congested RF spectrum and also higher frequencies

+

REGULATORY ENVIRONMENT

Deregulation trend pushed by the commercial market

Proliferation of unlicensed low-cost devices: Difficulty to guarantee the enforcement of the Radio-regulations

RFI to passive sensors comes from the aggregation of multiple small interferers

→

Increasing number of RFIs to passive space sensors, each time pushing to higher frequencies

Sizing the RFI problem: the reporting issue (cont.)

The number of RFI events to space sensors is **sizably increasing**

Unfortunately it is not easy to go beyond a qualitative assessment of the phenomenon for several main reasons:

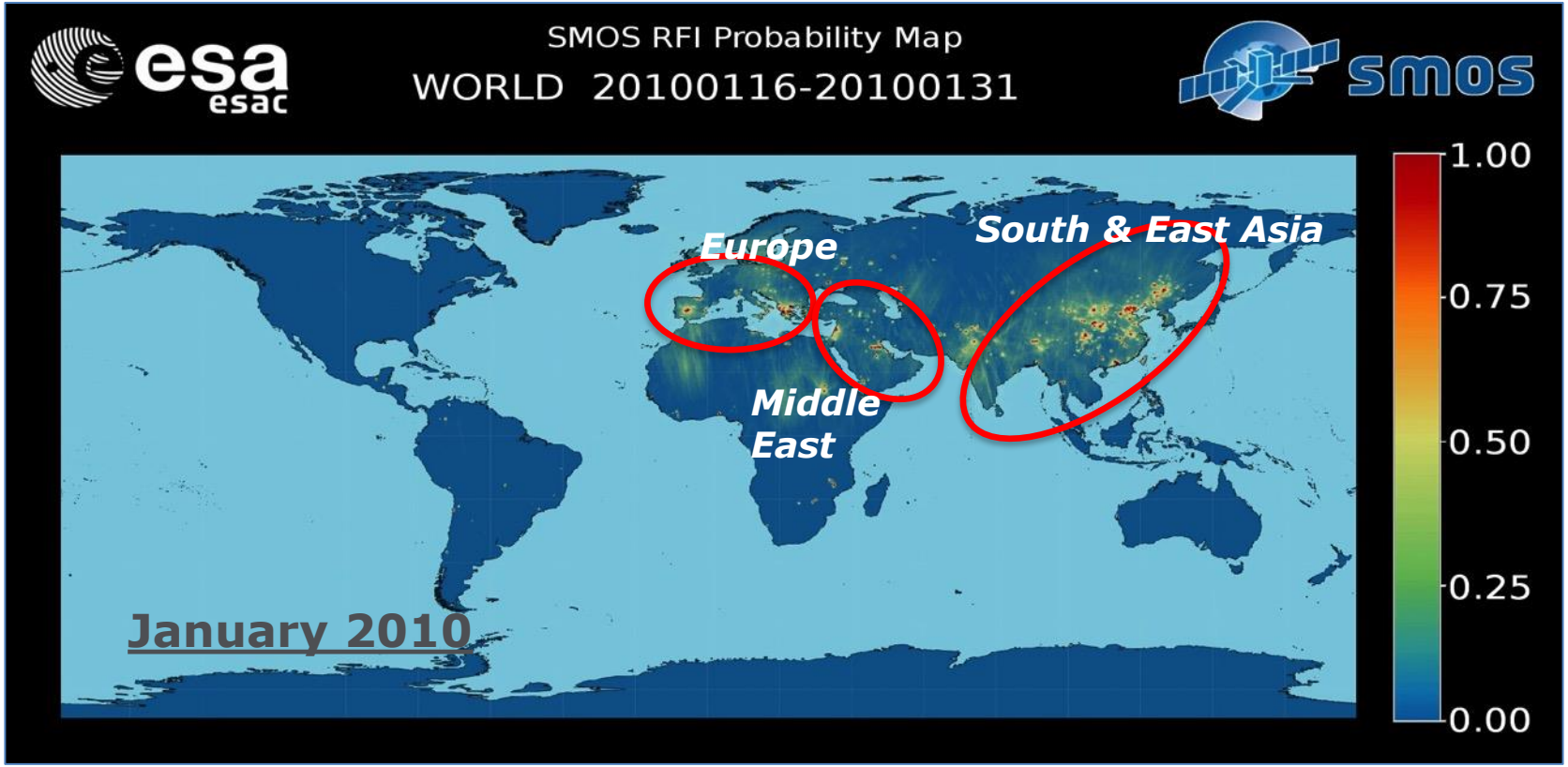
1. Only recently the ITU SIRRS system was made available for reporting of RFI to sensors **➔ Excellent tool as international RFI recording mechanism ➔ Increase awareness of the RFI problem detected by PASSIVE SENSORS**
2. TYPICALLY there is <u>no regular **reporting**</u> of these events within the space agencies and other sensor operators affected.
3. Not enough awareness about the **Radio-Regulations PROCEDURES** available to fight harmful RFI to sensors

RFI mitigation: Avoiding wrong messages

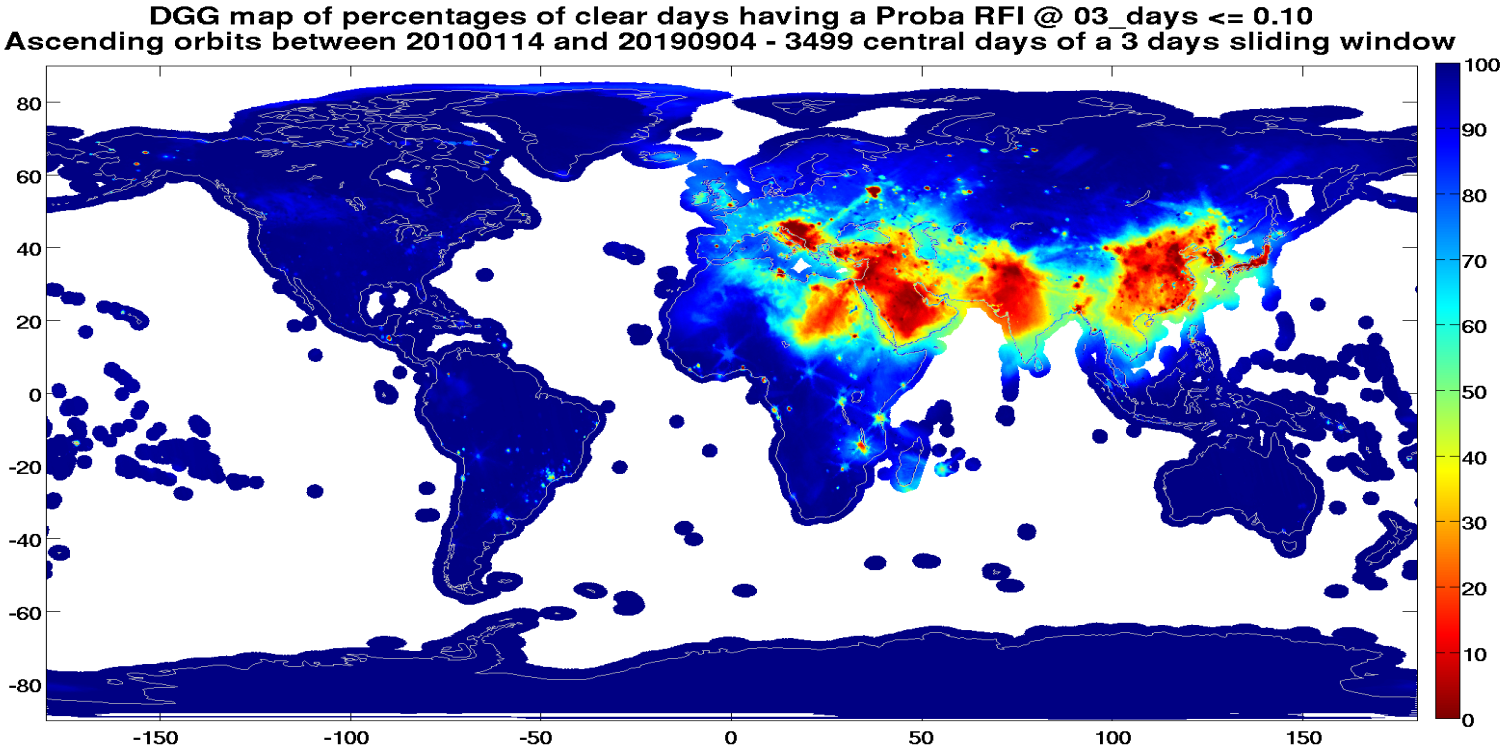
- Any RFI mitigation technique leads to **some quality degradation** of the acquired data ➔ sometimes that is not specified in scientific papers
- RFI from a concentrated interfering signal with a specific frequency characterization (e.g terrestrial radar or radiolink) may be relatively easy to suppress with reduced data degradation.
- … But **aggregate interference** from a large number of incoherent sources is seen by the sensor as an indistinguishable noise level and **cannot be properly mitigated**.
- If the RFI relates to the deployment of mass market equipment, very high cost, time and manpower is needed to resolve the case ➔ Extremely difficult to handle for EESS(passive)

Furthermore, low-level RFI cannot be always identified when it results in a measurement that is scientifically plausible

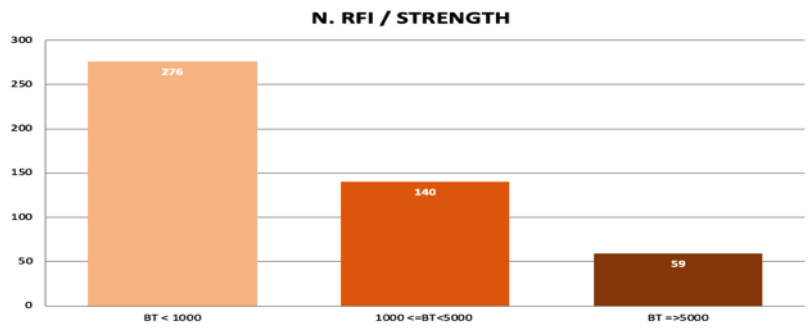
ESA SMOS RFI problem (1400-1427 MHz)

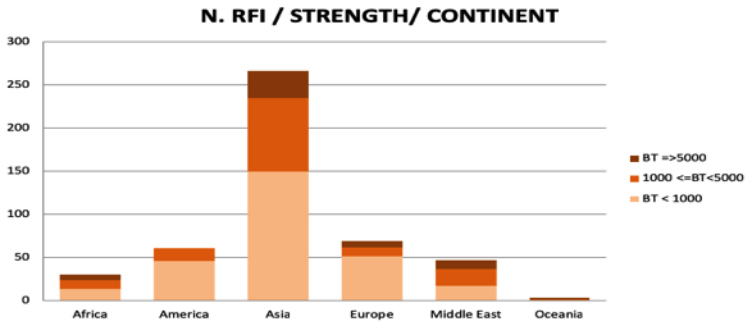


Maps of clear days percentages over long period of time integrating RFI occurrences probability maps

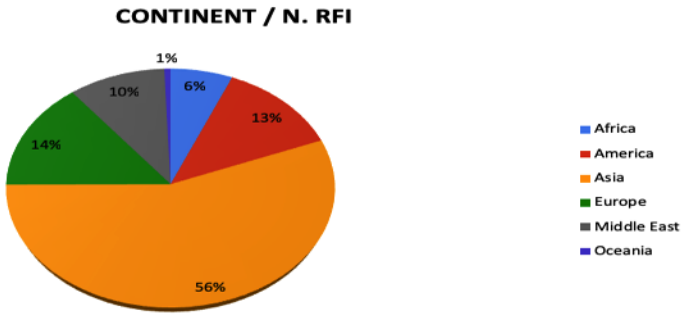


RFI global statistics





Worldwide RFI strength distribution. Total active RFI sources: 475 (updated on August, 31st 2019)



Worldwide RFI distribution per country (updated on August, 31st 2019)

RFI reporting process

Contacted Administrations

Typical systems causing harmful interference passive sensors in the 1400-1427 MHz band

IN-BAND→ All missions are prohibited by ITU-R RR. No 5.340

CCTV cameras for surveillance (non-certified, low cost equipment)

Unauthorised Radiolinks and TV repeaters

12 GHz Satellite home-TV receiver installations (leakage of circuits/cables at the intermediate frequnecy IF)

Malfunctioning equipment (wireless phones and radiolinks)

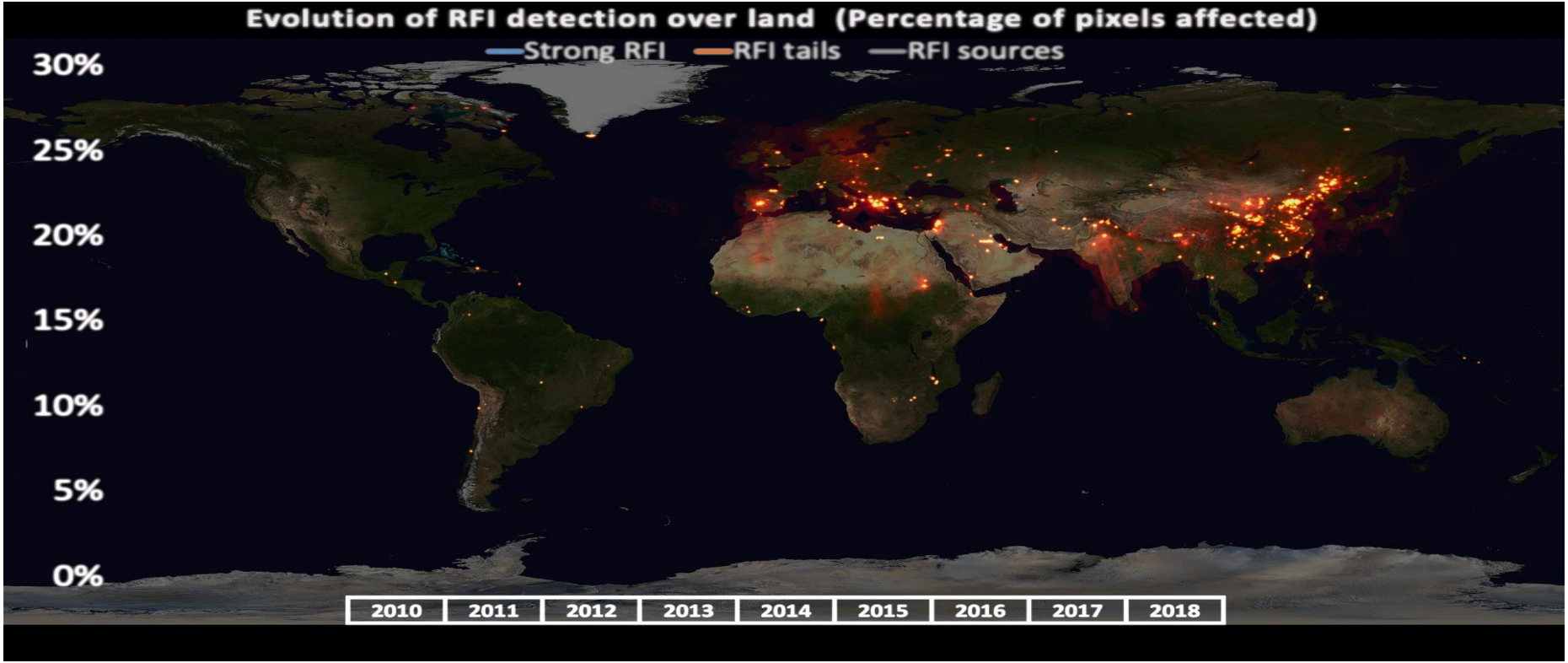
Typical systems causing harmful interference passive sensors in the 1400-1427 MHz band (cont)

OUT-OF-BAND➔ Recommended levels by Res. 750

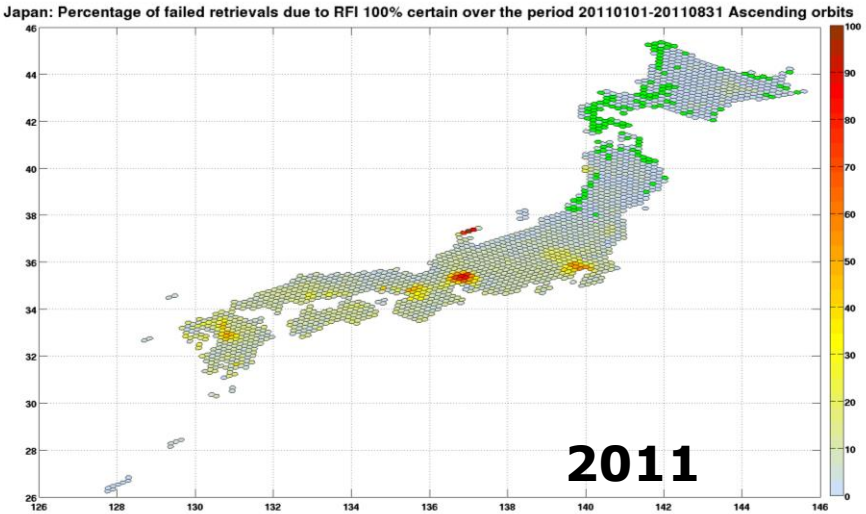
Radars with excessive unwanted emission levels

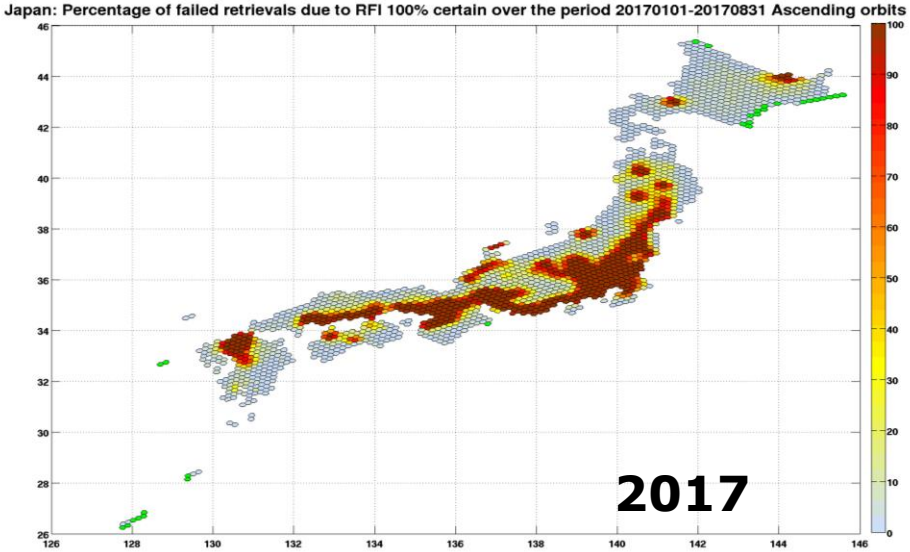
- ✓ Some administrations are more cooperative and consider to implement some changes to the radar settings or introducing some guard band to reduce unwanted emissions in the passive bands;
- ✓ Unfortunatelly, this is not always the case.

SMOS RFI impact from a scientific perspective



RFI impact from the scientific perspective: Example of SMOS failed data retrieval due to interference after 2011





Credits: P Richaume, CESBIO

The impact of the RFIs to the scientific return of SMOS can be quantified as **the percentage of failed data retrieval due to RFIs**. These figures show the comparison of failed retrievals due to 100% certain interference in 2011 (when just few individual RFI sources were detected) and in 2017 (when an extended RFI sources are detected is the most populated areas).

Main Conclusion:

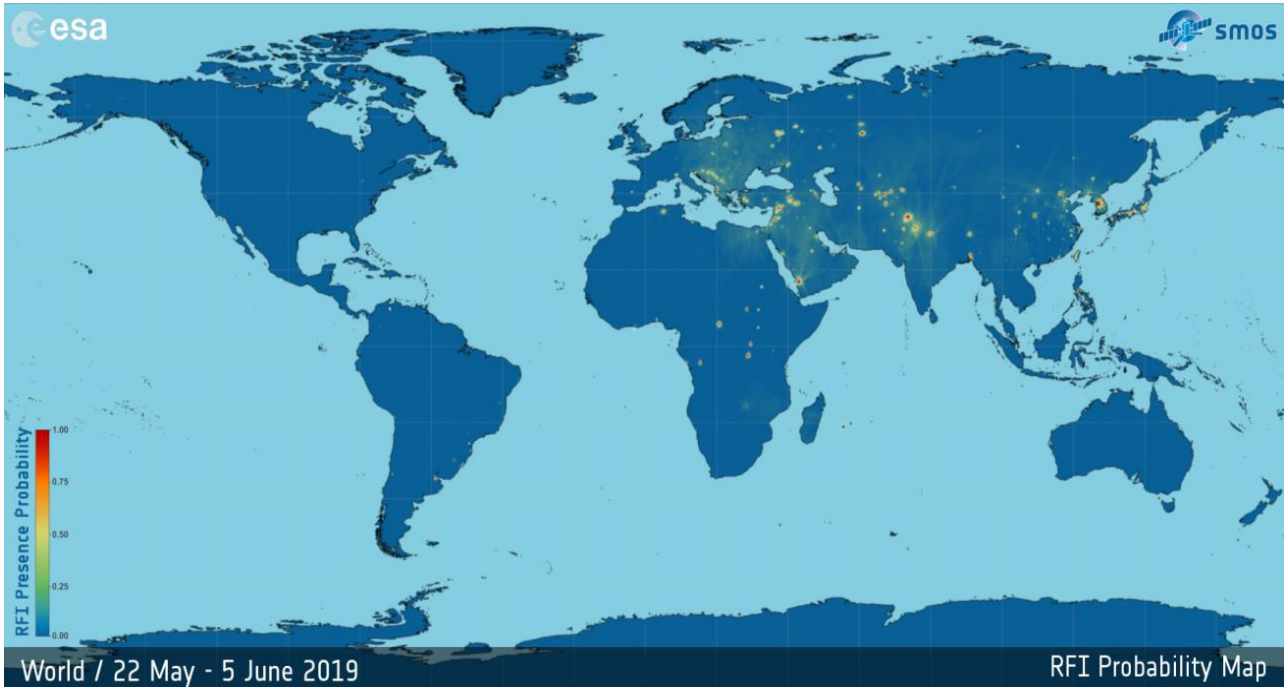
For EESS(passive) sensors the real solution to the RFI problem is PREVENTION, and hence the requirement for defining and ensuring relevant limits

1. It is **essential to protect the passive remote sensing bands** from both, illegal and excessive unwanted emissions
2. **The solution of the RFI due to illegal emissions** can be achieved with the cooperation of the national regulatory authorities.
3. **However, the solution of the excessive unwanted emissions** problem requires regulatory action and compliance with levels adopted in ITU-R Res 750.
4. **Efforts have to be continued** and intensified by raising concern among the different countries and organisations about the negative impact of RFI in scientific return of scientific space missions.
5. **Need to understand the limitations of any "RFI mitigation/ cancellation" techniques**.

Backup slides

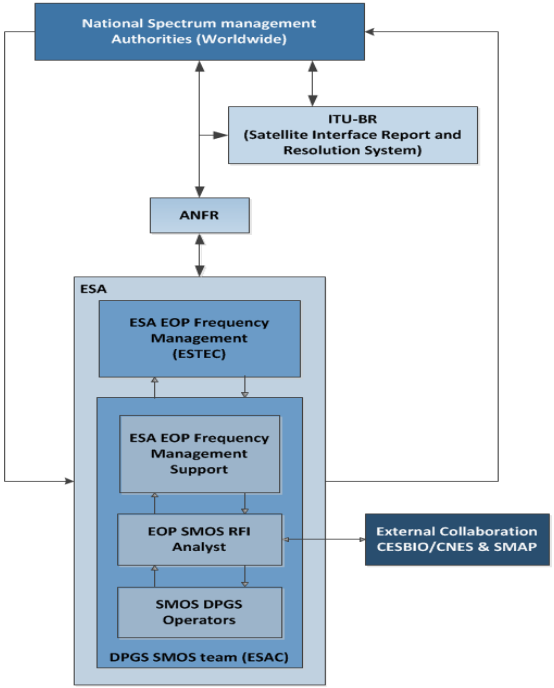
RFI maps: Evolution

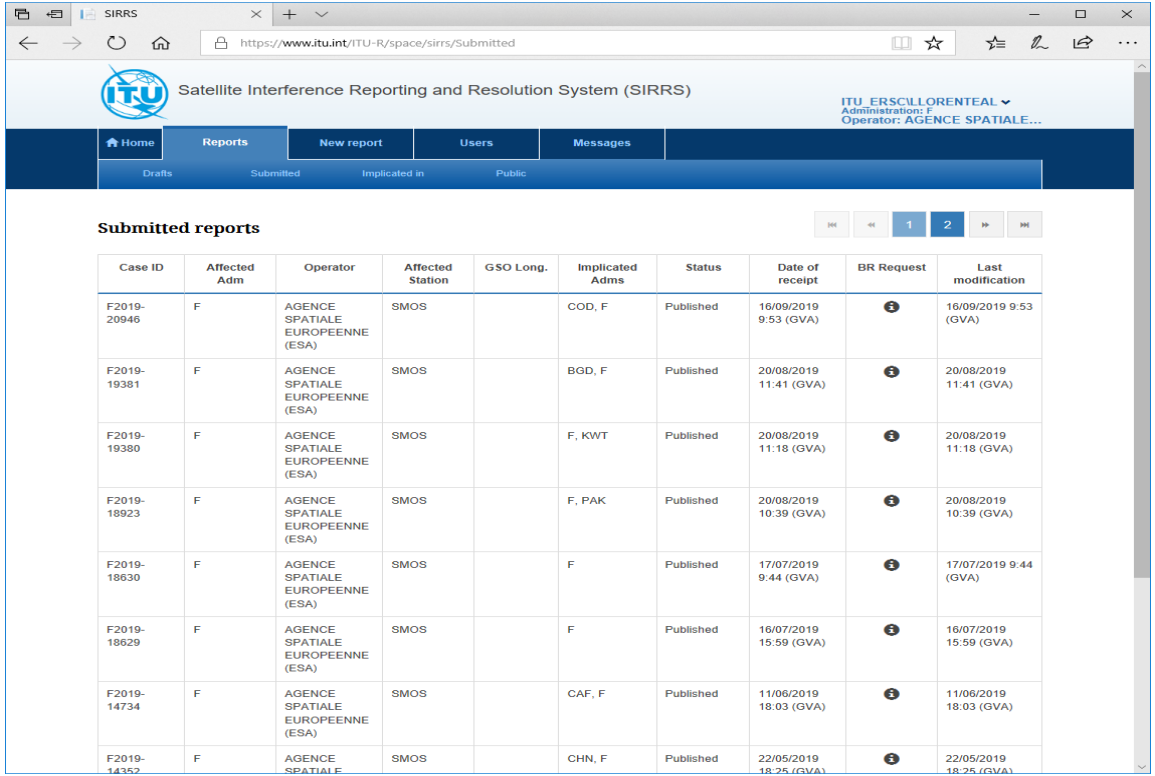
Probability Maps



Case Study: SMOS Radiometer
RFI scenario and reporting process

SIRRS





Case ID	Affected Adm	Operator	Affected Station	GSO Long.	Implicated Adms	Status	Date of receipt	BR Request	Last modification
F2019-20946	F	AGENCE SPATIALE EUROPEENNE (ESA)	SMOS		COD, F	Published	16/09/2019 9:53 (GVA)		16/09/2019 9:53 (GVA)
F2019-19381	F	AGENCE SPATIALE EUROPEENNE (ESA)	SMOS		BGD, F	Published	20/08/2019 11:41 (GVA)		20/08/2019 11:41 (GVA)
F2019-19380	F	AGENCE SPATIALE EUROPEENNE (ESA)	SMOS		F, KWT	Published	20/08/2019 11:18 (GVA)		20/08/2019 11:18 (GVA)
F2019-18923	F	AGENCE SPATIALE EUROPEENNE (ESA)	SMOS		F, PAK	Published	20/08/2019 10:39 (GVA)		20/08/2019 10:39 (GVA)
F2019-18630	F	AGENCE SPATIALE EUROPEENNE (ESA)	SMOS		F	Published	17/07/2019 9:44 (GVA)		17/07/2019 9:44 (GVA)
F2019-18629	F	AGENCE SPATIALE EUROPEENNE (ESA)	SMOS		F	Published	16/07/2019 15:59 (GVA)		16/07/2019 15:59 (GVA)
F2019-14734	F	AGENCE SPATIALE EUROPEENNE (ESA)	SMOS		CAF, F	Published	11/06/2019 18:03 (GVA)		11/06/2019 18:03 (GVA)
F2019-14352	F	AGENCE SPATIALE	SMOS		CHN, F	Published	22/05/2019 18:25 (GVA)		22/05/2019 18:25 (GVA)

SMOS RFI impact from a scientific perspective: brightness temperatures (BTs) loss due to RFI

Numerical Facts, worldwide: Since Jan 2010, SMOS has produced over the land:

- **1.1×10^{12}** XX and YY Brightness Temperatures in L1C products.
- **5.5×10^{11}** XY Brightness Temperatures in L1C products.

Detected by **L2 Soil Moisture RFI hard levels screening as unusable BTs**:

- **5.4×10^{10}** XX and YY BTs **were eliminated** before attempting retrievals.
- It represents **5.0% of the total observed** up to now

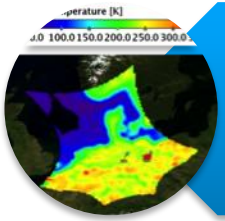
Key concepts to consider in the RFI assessments involving EESS(passive) sensors

For consideration in sharing and compatibility analysis.

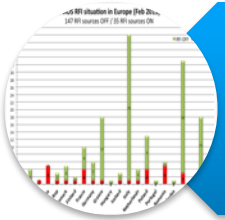
- **AGGREGATE EFFECT** of multiple interferers,
- **IMPACT OF UNWANTED EMISSIONS** of active services in adjacent bands, and
- **APPORTIONMENT OF THE RFI BUDGET** amongst multiple types of interferers out-of-band and/or in-band, depending on the case.

How to improve the RFI scenario suffered by space sensors

Early warning to the frequency managers, when the RFI problem is still at a manageable level



Characterization of the RFI cases with suitable technical data to facilitate the formal reporting of harmful interferences



Be ready to provide **regular monitoring** of the overall RFI scenario to enable a dynamic exchange with the administrations responsible of the interfering emissions.