2022

CGMS Agency Guidance for RFI Detection, Monitoring, and Mapping for Remote Passive Sensors

Presented to CGMS-53 Plenary, agenda item x.x

Coordination Group for Meteorological Satellites

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Executive summary of the WP

International radio regulations contain frequency ranges where radio frequency transmissions are not allowed, although it's possible that excessive anthropogenic energy may be present regardless, such as 5G mentioned earlier. Adjacent frequency band services often have regulatory limits regarding the level of out-of-band emissions that are allowed from those services that may fall into a nearby passive band. As current and future telecommunication services, satellite and broadband-aviation uplinks in millimeter wave bands are implemented, there are potential interference risks to passive sensors, to include operational microwave sensors used by Earth observation satellite systems. This interference could degrade the data used by Numerical Weather Prediction (NWP) Models and other applications, with resulting accuracy degradation. It is desired that members of the Coordination Group of Meteorological Satellites (CGMS) formulate a comprehensive long-term solution through guidance and, where available, best practices, to efficiently and adequately handle radio frequency interference as public demand, new technology system needs, and passive instrument technologies continue to evolve.

This RFI guidance includes a focus on passive band Radio Frequency Interference (RFI) due to the aggregation of multiple sources of RFI, such as from 5G, where the level of RFI increases over time from a negligible to an insidious and finally to an obvious level of RFI.

INTRODUCTION

- **Problem:** Increasing amounts and risk of RFI, especially from AWS (5G), impacting Earth observation data and applications like Numerical Weather Prediction (NWP).
- International regulations exist, but anthropogenic energy can still cause interference.
- New telecommunication services (satellite, broadband-aviation) in millimeter wave bands pose potential interference risks.
- RFI has various types, such as single-source (e.g., radar) and multiple-source (e.g., 5G) RFI, which we need to be able to distinguish
- Commercial RF poses significant risk due to adjacent band use and uncertainty in interference impact.
- The current impact is somewhat limited, but there is significant potential for increased impact as technology advances.
- **Goal:** Develop long-term solutions and guidance to assist in RFI management.

1 - FREQUENCY SELECTION

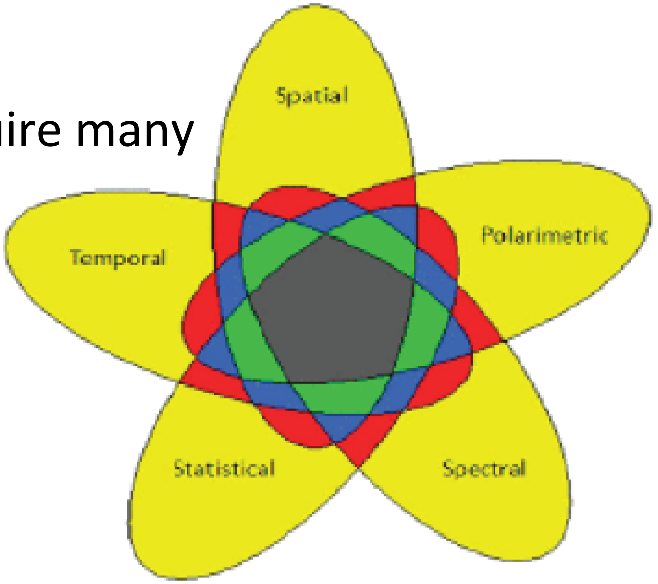
(Close coordination between scientists and frequency managers)

- Trade-off between scientific needs and regulatory/usage situation for the candidate bands.
  - An unfavorable regulatory status (e.g., a weak protection or missing allocation) cannot be easily changed/improved
  - It would require a long (at least 5 years) process through a World Radiocommunications Conference (WRC).
- Bandwidth staying strictly within the allocated frequency bands
  - Consideration of a bit of margin towards the edge of the allocated band
- Trade-off at the level of instrument sensitivity to increase robustness against RFI.
- End-to-end rejection levels at the edges of the allocation need to be sufficiently low.

2 - SETTING OF THEORETICAL PROTECTION REQUIREMENT AND OPERATIONAL REQUIREMENT

- The protection requirement is translated from the Noise-Equivalent Delta Temperature (NEDT) to a limit at RF level for a determined percentage of time or area in the footprint size of the sensor.
  - To be able to determine regulatory conditions for services that operate in or adjacent to frequency bands allocated to passive sensors, a protection criterion for spaceborne passive sensors in form of a power density level is established in ITU-R Recommendation RS.2017.
- The protection level/limit for a potential RFI source is simulated for a given deployment scenario of the interferer based on the sensor characteristics and protection criteria available in the ITU-R:
- For the assessment of what would or could be the impact of RFI on real measured data, the excess of protection criteria (RF noise floor increase) due to RFI can be backwards translated into a noise temperature increase...
- The most powerful/important mechanism to mitigate RFI is to prevent RFI before it starts at the point where the frequencies of potential future RFI sources are determined.
  - In this context, one important vehicle to achieve this is the establishment of relevant provisions in the Radio Regulations.

3A - DETECTION MECHANISMS FOR KNOWN AND UNKNOWN RFI



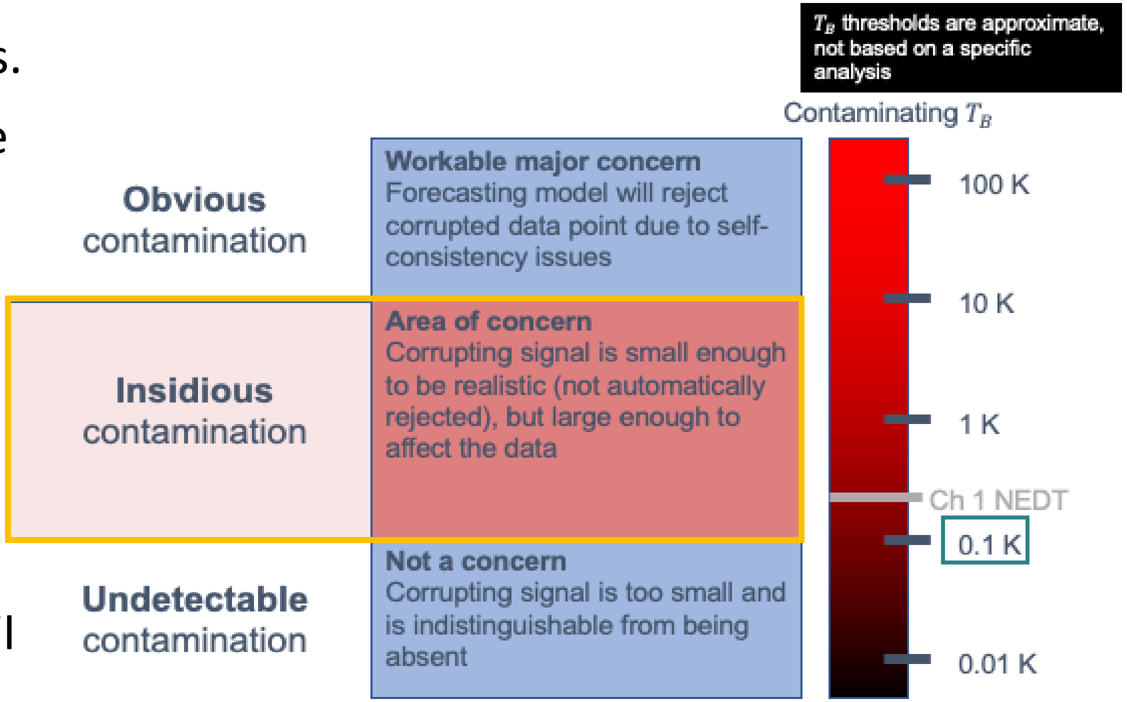
- To identify non or quasi gaussian noise from unknown sources will likely require many algorithms which in turn result in the need of greater processing capabilities/capacities.
- Known sources will only require specific, different, algorithms.
- Detection Mechanisms can be applied in various ways:
  - **Spectral** algorithms divide up the signal in smaller frequency "bins".
  - **Temporal** algorithms divide up the signal in snapshots of time.
  - **Statistical** compares the natural, uniform distribution of the desired signal characteristics – one created by nature, with the non-uniform distribution created by an anthropogenic signal.
  - **Spatial** would compare each pixel in an image, looking for dramatic changes in brightness intensity.
  - **Polarimetric** utilizes the geometric orientation of radio signals to differentiate between natural and anthropogenic.
  - **Machine learning** techniques can be used to classify data samples as “RFI-free” or “RFI-contaminated”.

3B - RFI DETECTION THROUGH SENSOR TECHNOLOGY

- Monitor/mapping of RFI from existing sensors is somewhat limited.
- Methodologies for flagging potentially corrupted data due to RFI, already at instrument level
  - System/technology embedded into the sensor, looking for non-gaussian elements of the signals received by the sensor.
  - By means of Kurtosis algorithms it will be possible to differentiate non-Gaussian noise (RFI) from Gaussian noise (natural emission).
  - Some parameters of the Kurtosis algorithms can be changed by on ground telecommand.
- In-orbit technology for land surface RFI detection and mapping.
- Sensor calibration to improve robustness from RFI.
- Filtering outside of the measurement bandwidth to minimize RFI.
- RFI detection and mitigation techniques (other than identified above)
- On board selection on which data to downlink (when some RFI detection capability is available on board) – trade-off between data rate and details about the RFI environment.

4 - RFI DETECTION THROUGH DEDICATED INSTRUMENTS OR SATELLITES/CONSTELLATIONS

- Globally standardized satellite-based monitoring facilities.
  - Constellation of small satellites or drones to map the RF environment by area/time.
- Dedicated sensor for a specific RFI source (e.g. 5G RFI identification sensor).
  - In some bands, RF monitoring is commercially available.
  - This may provide an opportunity for making "commercial" buys of RFI information to facilitate RFI mapping and related RFI data completer and more current.
- Preliminary studies ongoing to address this possible detection approach and its multiple challenges, to cover various and larger RF bands and geographical areas.



Non-natural RF contamination will only increase, both in intensity and in spectrum proliferation

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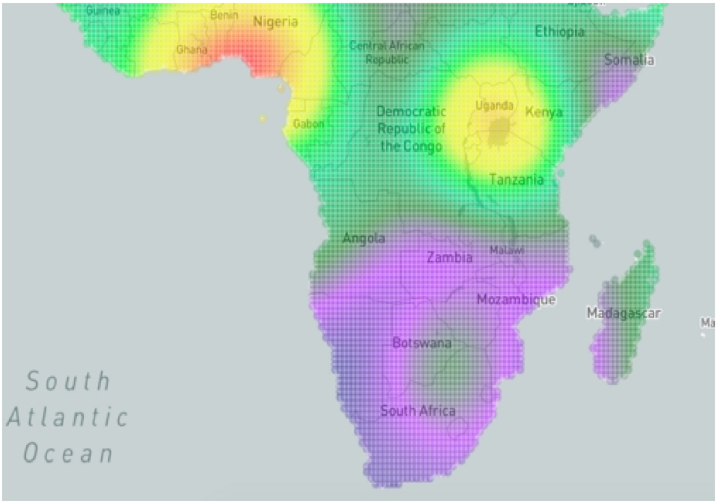
5 - MONITORING/MAPPING OF THE DEPLOYMENT DENSITY OF THE POTENTIAL SOURCE OF RFI

- Energy is a significant aspect of RFI and is a factor in all RFI occurrences. This issue of energy characteristics relating to the RFI determines the approach towards monitoring and mapping of the RFI.
- Monitoring and mapping are three dimensional, i.e. in time, geography, and energy.
    - Mapping of a globally appearing interference source requires monitoring mechanisms that could support global mapping, for example satellite-based monitoring facilities.
        - Global mapping also raises the question of possible standardization of the monitoring facilities?
- The deployment density can then be monitored, and the progressing deployment can be compared over time with the instrument data acquired.
    - Procedures for reporting an RFI assessment need to be established and globally used in the meteorological and climatological communities.

5 - MONITORING/MAPPING OF THE DEPLOYMENT DENSITY OF THE POTENTIAL SOURCE OF RFI

- Once the deployment density reaches the theoretically determined critical density in each area, the monitoring of the acquired data can be intensified, consequentially.
  - Determine methodologies/algorithms for flagging potentially corrupted data due to RFI.
  - Forecast Sensitivity - Observation Impact (FSOI) statistics may be a way to compare observational data with the theoretical simulations and then compared to maps of RFI once established.
  - Monitoring based on comparison with other observation frequency channels, recording the evolution of the BIAS (or error) over time.
  - Trend observations over a longer period over more than one instrument.
  - Monitoring results would be more conclusive when analyzing over a longer period (e.g. 10 years) at specific areas (e.g. densely populated, hot spots, coastal areas, etc.)



Map areas of contamination.

SUMMARY

Guidance	Who is responsible	When it should happen
Select frequencies, considering the level of regulatory protection	Project manager, supported by frequency managers & scientists	Phase 0
Set / update theoretical protection requirements and establishment of regulatory limits to be protected from RFI as globally as possible	Frequency managers [supported by scientists]	Continuous work
Define hardware and software for RFI detection	Project manager, supported by frequency managers & engineers	Phase A/B1
Map, monitor and report RFI	Agency personnel, supported by frequency managers	Phase E
Develop payloads/missions dedicated to RFI detection	Agency personnel, supported by frequency managers	Continuous work

CONCLUSION

As mass market RF intensive applications approach, reach, or even exceed the tolerable numbers of deployment for those applications, sophisticated monitoring processes and systems will be needed for determining and monitoring where RFI occurs:

- Consideration must be given to the aggregate level of RFI that may originate from one service with many transmissions at the same time and in the same area or from several different radio services.
- As the data are acquired by a global network of sensors on meteorological satellites, exchanged and fed into global forecast models, also the threshold selection should ideally be decided collectively by the international partners for global consistency.
- Standards relevant to remote RF passive sensors do not currently exist for measuring, evaluating, and mitigating RFI affecting spaceborne Earth observation satellites.
- Remote passive sensor design, development and implementation should consider RFI detection and mitigation as an aspect of their system design.

CONCLUSION

- RFI is increasing globally over time.
- RFI progresses from undetectable to insidious to blatant.
- Insidious RFI causes unnoticed data corruption.
- Monitoring RF-intensive applications is crucial.
- Building RFI measurement records is necessary.
- Long-term RFI trend observations are essential

To be considered by CGMS:

- CGMS agencies are invited to take note of “CGMS Agency Guidance for RFI Detection, Monitoring, and Mapping for Remote Passive Sensors” for further analysis and consideration in their internal processes as appropriate.
- As a next step, we are enlarging this guidance to also include additional types of RFI, such as communication link RFI (i.e. DCS).
- Reference to HLPP 2.2 Radio Frequency (RF) Protection.