Proposed Best Practice on RFI detection, monitoring and mapping

Presented to CGMS-52 Working Group I session, agenda item 3.2

CMGS-52-WGI-WP12

Coordination Group for Meteorological Satellites

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Executive summary of the WP

Commercial RF spectrum advances within and near remote passive sensing frequencies have been identified as posing a significant risk to passive sensing data, due to the following concerns:

- Contamination of passive measurements is a possibility because of adjacent band use.
- It is uncertain precisely as to how interference will be manifested and to what extent.
- It is also unclear how to best minimize the impact of potential interference, and how effectively CGMS members can reduce its impact to the overall global measurements.

Currently only a small number of passive bands have the potential to be affected by planned commercial RF spectrum use. However, there is a very good potential for additional bands to be identified in the future for broadband wireless services and other RF uses as technologies continue to develop and be deployed.

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.

It can be assumed that the global level of RFI is gradually increasing over time with the aggregation of single low level interfering signals up to a point when RFI becomes obvious. Thus, RFI can be expected to move from undetectable levels, then to levels of “insidious” data corruption, and then to levels of blatant data contamination, such that the data can only be discarded. (See figure 2.) Insidious data corruption means there could be RFI (data corruption) induced into the measurements unnoticed for a significant period as the measurements are erroneously taken as correct measurements without any interference component.

Therefore, monitoring of the development of mass market RF intensive applications is a factor for consideration in the characterization process and as part of a best practice. This also requires building up monitoring records on measurements of already operational instruments to have reference data that can be later consulted and compared once the deployment of these RF intensive applications sufficiently increases. This allows for long term RFI trend observations.

Introduction

- As services in millimeter wave bands are implemented there are potential interference risks to passive sensors.
- ***Note:*** *Generally, one must differentiate between different types of RFI, such as the typical RFI in SMOS or SMAP data, where often a single source of interference causes obvious RFI (e.g. a powerful radar), and 5G-like systems, where multiple interfering sources in each measurement area aggregate towards RFI.*
- Commercial RF spectrum advances within and near remote passive sensing frequencies have been identified as posing a significant risk to passive sensing data, due to the following concerns:
  - Contamination of passive measurements is a possibility because of adjacent band use.
  - It is uncertain precisely as to how interference will be manifested and to what extent.
  - It is also unclear how to best minimize the impact of potential interference, and how effectively CGMS members can reduce its impact to the overall global measurements.

NOAA NESDIS Satellite Sensor Spectrum Use by Bands

	Active Sensing	5250-5570	13.25-13.75	Passive Sensing	18.6-18.8	18.8-20.2	22.21-22.5	23.6-24GHz	31.3-31.8	34GHz	36-37GHz	50.2-50.4	51.56-51.96	52.6-59.3	86-92GHz	114-118.75	148.5-151.5	155.5-158.5	164-167	174.8-182	182-185	185-190	228-230GHz
Argos-4																							
COSMIC-2																							
DMSP (Blk 5D-3)						U	A				A				A		A			A	A	A	
DSCOVR																							
GOES-NOP																							
GOES-R																							
GeoXO																							
JASON-3		A	A		A			A		U													
JASON-CS		A	A		A			A		U													
JPSS-1								A	A			A	U	A	A				A	A	A		
JPSS-2/3/4								A	A			A	U	A	A				A	A	A		
POES (15)								A	A			A		A	A		A			A	A		
POES (18/19)								A	A			A		A	A			A			A		
Oceansat-3																							
SounderSat (NEON)								P	P			P	U	P	P	P			P	P	P		P

Auth Freq	
Unallocated	
Planned	

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Best Practice Concepts (BPC): Frequency Selection

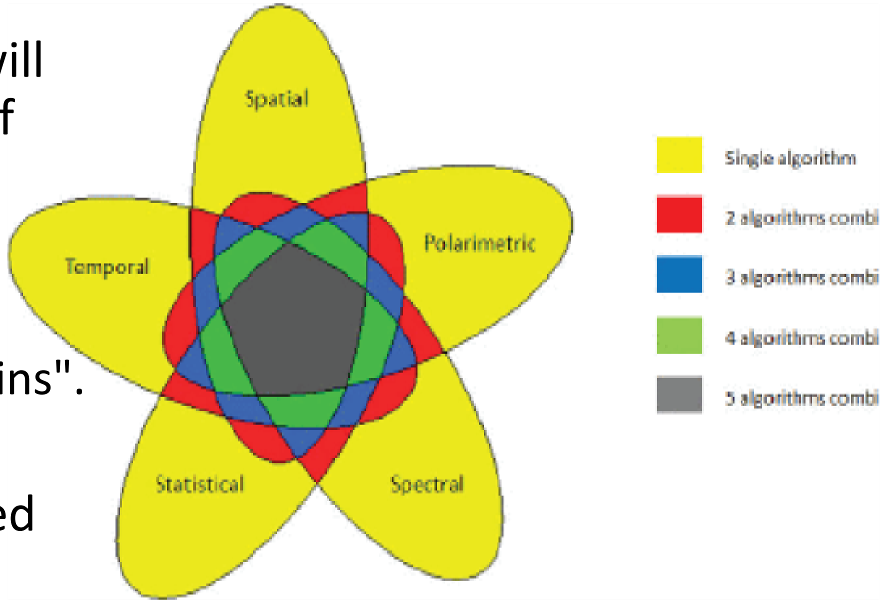
(Close Coordination Between Scientists & Spectrum Managers)

- Trade-off between scientific needs and regulatory/usage situation for the candidate bands.
  - An unfavorable regulatory status cannot be easily changed/improved, and it would require a long (at least 5 years) process through a World Radiocommunications Conference (WRC).
- Bandwidth staying strictly within the allocated frequency bands, with consideration of a bit of margin towards the edge of the allocated band to benefit from a bit of roll -off from the unwanted emissions of active services into the measurement bandwidth of the sensor.
  - The margin can also be asymmetrical, depending on the risk of RFI on both edges.
- 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.

BPC: 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.
- 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 assessment of what would or could be the impact of RFI on real measured data, the excess of protection criteria due to RFI can be backwards translated into a noise temp increase measured by the instrument on top of the naturally occurring thermal radiation.
- The most powerful mechanism to mitigate RFI is to prevent RFI before it starts at the point where the frequencies of potential future RFI sources are determined, and regulatory conditions are established at national, regional, and international (ITU) level.

BPC: Detection Mechanisms for Known and Unknown RFI

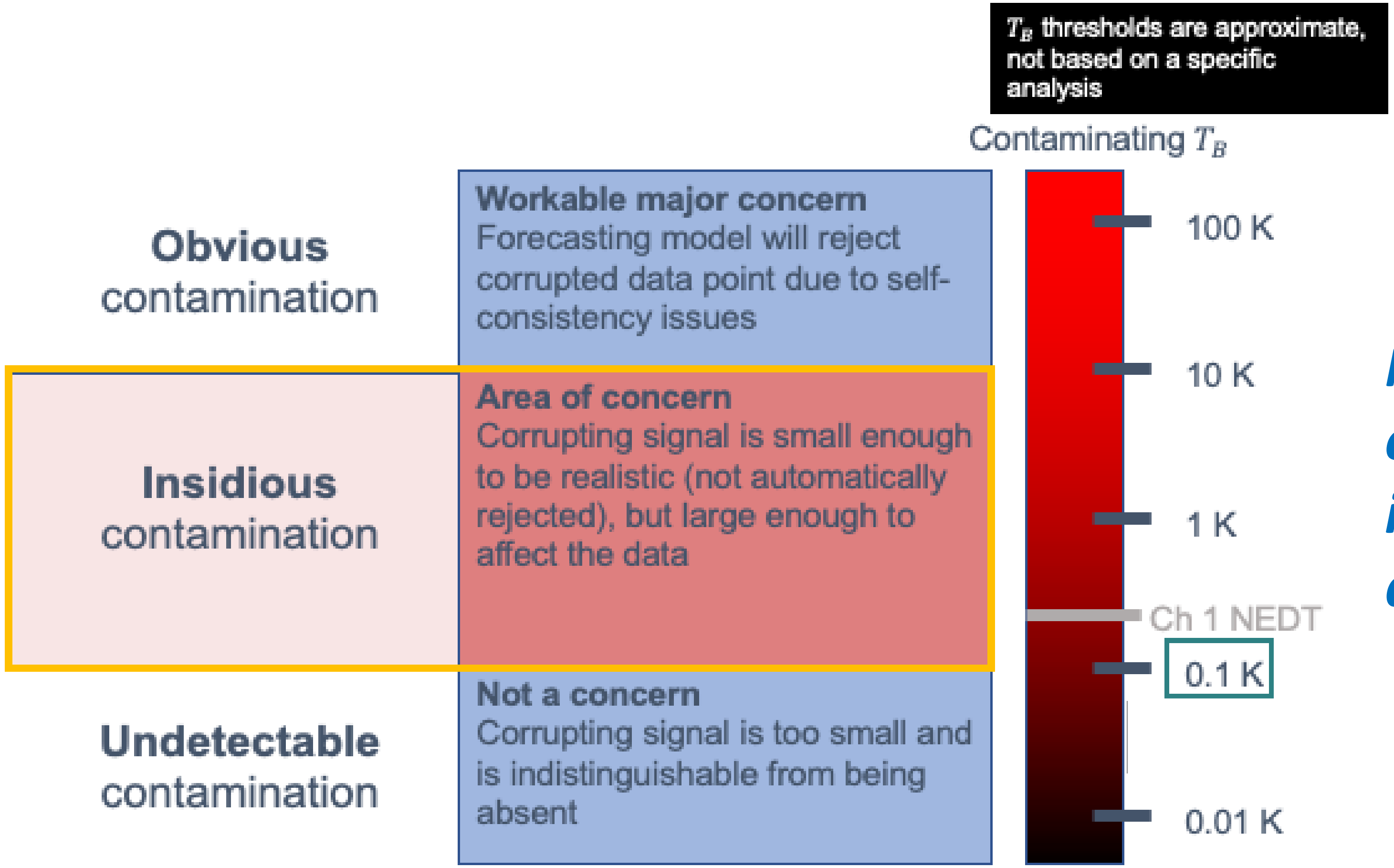


- To identify non or quasi gaussian noise from unknown sources will likely require many algorithms which in turn result in the need of greater processing capabilities/capacities.
- Known sources will only require specific, different, algorithms.
- Detection Mechanisms can be applied in various ways:
  - **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 distro of the desired signal characteristics – one created by nature, with the non-uniform distro that would be 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.

BPC: RFI Detection Through Sensor Technology

- 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.
    - Front-end radiometer.
    - Back-end processor (spectral algorithms).
    - Dual polarisation.
    - In-orbit technology for land surface RFI detection and mapping.
- Sensor calibration to improve robustness from RFI.
- Filtering outside of the measurement bandwidth to minimise RFI.
- RFI detection and mitigation techniques (other than identified above)
  - Specific module to be embarked on the satellite (e.g. was under discussion for FY-3, but not yet realized)
- 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.

BPC: RFI Detection Through Sensor Technology



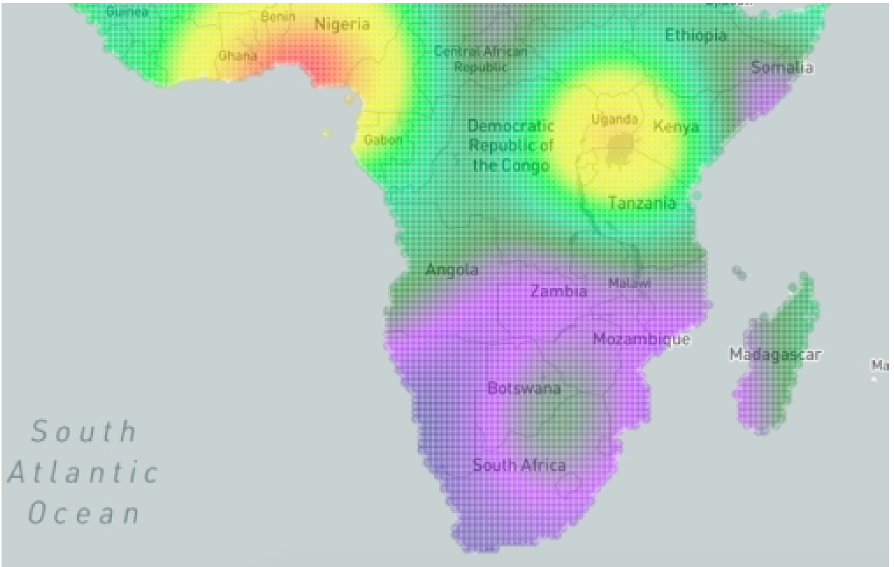
Non-natural RF contamination will only increase, both in intensity and in spectrum proliferation

BPC: 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.

BPC: RFI Detection Through Dedicated Instruments or Satellites/Constellations

- Monitor/mapping of RFI from existing sensors is somewhat limited.
- Monitoring and mapping are two dimensional, i.e. in time and geography.
  - 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 be monitored, and the progressing deployment can be compared over time with the instrument data acquired.
  - This comparison could be done at the level of “European Centre for Medium-Range Weather Forecasts” (ECMWF), the “Center for Satellite Applications and Research” (STAR), or equivalent.
  - Procedures for reporting an RFI assessment need to be established and globally used in the meteorological and climatological communities.



BPC: RFI Detection Through Dedicated Instruments or Satellites/Constellations *(2)*

- 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.)

Who and When

Best practice	Who is responsible	When it should happen
Set / update theoretical protection requirements	Frequency managers	Continuous work
Select frequencies	Project manager, supported by frequency managers & scientists	Phase 0
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.

- Spatial and spectral characterization of RFI requires the selection of a threshold level above which data are flagged as contaminated by RFI.
- The protection criteria in ITU-R Recommendation RS.2017, is a starting point to determine an absolute level of acceptable contamination.
- 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 (e.g. 5G) 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.
- Any RF source characterization should include spatial and temporal descriptions.
  - The characterization of a globally appearing interference source should consider monitoring mechanisms that could support global mapping, for example satellite-based monitoring facilities.
- Universal characterization also suggests possible standardization of monitoring facilities to be considered.
- Standards relevant to remote RF passive sensors do not currently exist for measuring, evaluating, and mitigating RFI affecting spaceborne Earth observation satellites.

Conclusion

It can be assumed that the global level of RFI is gradually increasing over time with the aggregation of single low level interfering signals up to a point when RFI becomes obvious. Thus, RFI can be expected to move from undetectable levels, then to levels of “insidious” data corruption, and then to levels of blatant data contamination, such that the data can only be discarded. Insidious data corruption means there could be RFI (data corruption) induced into the measurements unnoticed for a significant period as the measurements are erroneously taken as correct measurements without any interference component.

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Key issues of relevance to CGMS:

- ☐ Passive RFI can be expected at undetectable levels, levels of “insidious” data corruption, and blatant data contamination.
- ☐ Active or communication RFI mitigation procedures are moderately mature for established systems but should also be addressed.
- ☐ The global level of RFI is increasing with time and implementation of more spectrum dependent systems.
- ☐ Increasing RF robustness is an essential element for future sensor systems.
- ☐ Reference to HLPP 2.2 Radio Frequency (RF) Protection

To be considered by CGMS:

- ☐ For review
- ☐ For actioning to WGI: TGRFI to complete best practices for CGMS -53.