2022

Active Spectrum Management with Passive Bands

Presented to CGMS-51 Working Group 1 session, agenda item 3.1

Coordination Group for Meteorological Satellites

Executive summary of the WP

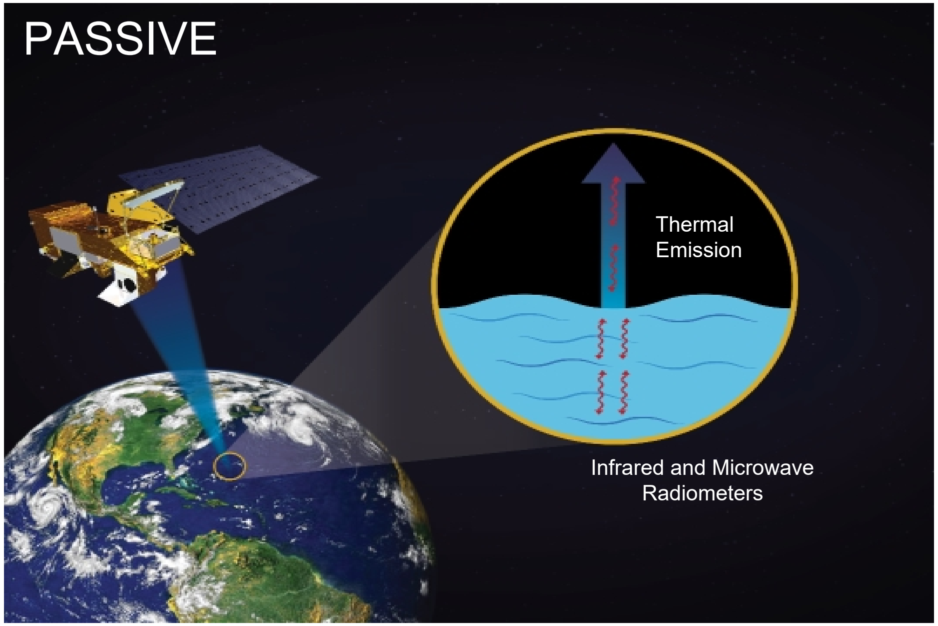
Spectrum is the lifeblood of Operational Meteorology – users need to be aware of proposals and plans for spectrum sharing that may impact meteorological and climatological data. It's clear that non-natural RF contamination will never go away and will most likely continue to increase.

The EESS (passive) bands are at a very significant risk of increased noise levels from the conditions of today. We've calculated that low anthropogenic noise levels will be indistinguishable from natural radiation and that levels of anthropogenic noise will simply eliminate observation data for that geographical area.

Predominantly, bands near and between 24 to 86 GHz are today's most significant risks for passive band degradation and corruption, however passive bands both below and above this range are also at or have been at risk.

It is recommended that there be an emphasis on the development and implementation of RFI identification and sensor robustness measures. It's clear that if we do nothing, we will not know when or how much the meteorological mission has been degraded by RF contamination.

Microwaving Remote Sensing



- **Every physical body (water, soil, clouds, oxygen, trees, people .. literally everything on earth) spontaneously and continuously emits electromagnetic radiation**
- **The energy (thermal emissions) are measured by microwave sounders (radiometers)**
- **The amount of energy a body emits is proportional to its temperature and tends to be very weak**
- **Example:**
  - Object at 100 Kelvin emits 0.1 pico-Watts (= 10^{-13} W) within 100 MHz
  - With a signal fluctuation on the order of 0.1-K → 0.1 femto-Watts (= 10^{-16} W)
- **The extreme sensitivity required makes it essential to maintain protected allocations and to properly manage use of the spectrum near the protected allocations.**

Future Use of MW Passive Sensing Bands (<59.3 GHz)

Band *WRC-23 AI*	Satellite Programs	Meteorological Organizations
Below 18.5 GHz	CIMR, FY-3F to I, GOSAT-GW, Meteor-M N2-3 to 6, Meteor-MP N1/2	CMA, ESA, JAXA, RosHydroMet
18.6-18.8 GHz ***AI 1.16 & 1.17***	CIMR, CRISTAL, FY-3F to I, GOSAT-GW, Meteor-M N2-3 to 6, Meteor-MP N1/2, Metop-SG-B1 to 3, Sentinel-6B,	CMA, ESA, EUMETSAT, JAXA, RosHydroMet
18.8-20.2 GHz ***AI 1.16***	Currently in use, no future programs identified	
22.21-22.5 GHz ***AI 1.10***	Currently in use, no future programs identified	
23.6-24 GHz	CRISTAL, FY-3F to J, GOSAT-GW, JPSS-3/4, Meteor-M N2-3 to 6, Meteor -MP N1/2, Metop-SG-A1 to 3, Metop-SG-B1 to 3, Quicksounder, Sentinel-3C/D, Sentinel-6B, Soundersat (NEON)	CMA, ESA, EUMETSAT, JAXA, NOAA, RosHydroMet
31.3-31.8 GHz	FY-3F to J, JPSS-3/4, Meteor-M N2-3 to 6, Meteor-MP N1/2, Metop-SG-A1 to 3, Metop-SG-B1 to 3, Quicksounder, Soundersat (NEON)	CMA, EUMETSAT, NOAA, RosHydroMet
34 GHz	CRISTAL, Sentinel-6B,	ESA,, EUMETSAT,
36-37 GHz ***AI 4 & 9.1 (D)***	CIMR, GOSAT-GW, Meteor-M N2-3 to 6, Meteor-MP N1/2, Sentinel-3C/D,	CMA, ESA, JAXA, RosHydroMet
42 & 48 GHz	Meteor-M N2-3 to 6	RosHydroMet
50.2-50.4 GHz ***AI 10***	AWS, FY-3F to J, JPSS-3/4, Metop-SG-A1 to 3, Metop-SG-B1 to 3, Quicksounder, Soundersat (NEON)	CMA, EUMETSAT, NOAA
51.56-51.96 GHz	AWS, FY-3F to J, JPSS-3/4, Meteor-MP N1/2, Metop-SG-A1 to 3, Metop-SG-B1 to 3, Quicksounder, Soundersat (NEON)	CMA, EUMETSAT, NOAA, RosHydroMet
52.6-59.3 GHz	AWS, FY-3F to J, JPSS-3/4, Meteor-M N2-3 to 6, Meteor-MP N1/2, Metop-SG-A1 to 3, Metop-SG-B1 to 3, Quicksounder, Soundersat (NEON)	CMA, EUMETSAT, NOAA, RosHydroMet

Red = Not protected for passive sensing
Blue = Protected for passive sensing
AI = WRC-23 agenda item may affect band

Coordination Group for Meteorological Satellites

Future Use of MW Passive Sensing Bands (>86 GHz)

Band *WRC-23 AI*	Satellite Programs	Meteorological Organizations
86-92 GHz ***AI 10***	AWS, CRISTAL, FY-3F to J, GOSAT-GW, JPSS-3/4, Meteor-M N2-3 to 6, Meteor-MP N1/2, Metop-SG-A1 to 3, Metop-SG-B1 to 3, Sentinel-6B, TROPICS-4 to 7, Quicksounder, Soundersat (NEON)	CMA, ESA, EUMETSAT, JAXA, NASA, NOAA, RosHydroMet
114-118.75 GHz	FY-3F to J, Metop-SG-B1 to 3, TROPICS-4 to 7, Soundersat (NEON)	CMA, EUMETSAT, NASA, NOAA
148.5-151.5 GHz	Currently in use, no future programs identified	
155.5-158.5 GHz	Currently in use, no future programs identified	,
164-167 GHz	AWS, FY-3F to J, GOSAT-GW, JPSS-3/4, Metop-SG-A1 to 3, Metop-SG-B1 to 3, Quicksounder, Soundersat (NEON)	CMA, EUMETSAT, JAXA, NOAA,
174.8-182 GHz	AWS, FY-3F to J, JPSS-3/4, Meteor-M N2-3 to 6, Meteor-MP N1/2, Metop-SG-A1 to 3, Metop-SG-B1 to 3, Quicksounder, Soundersat (NEON)	CMA, EUMETSAT, NOAA, RosHydroMet
182-185 GHz	AWS, FY-3F to J, GOSAT-GW, JPSS-3/4, Meteor-M N2-3 to 6, Meteor -MP N1/2, Metop-SG-A1 to 3, Metop-SG-B1 to 3, TROPICS-4 to 7, Quicksounder, Soundersat (NEON)	CMA, EUMETSAT, JAXA, NASA, NOAA, RosHydroMet
185-190 GHz	AWS, FY-3F to J, JPSS-3/4, Meteor-M N2-3 to 6, Meteor-MP N1/2, Metop-SG-A1 to 3, Metop-SG-B1 to 3, TROPICS-4 to 7,	CMA, EUMETSAT, NASA, NOAA, RosHydroMet
228-230 GHz	Metop-SG-A1 to 3, Soundersat (NEON)	EUMETSAT, NOAA
231.5-252 GHz ***AI 1.14 & 10***	Metop-SG-B1 to 3	EUMETSAT
Above 255 GHz	AWS, Metop-SG-B1 to 3	EUMETSAT

Red = Not protected for passive sensing
Blue = Protected for passive sensing
AI = WRC-23 agenda item may affect band

Coordination Group for Meteorological Satellites

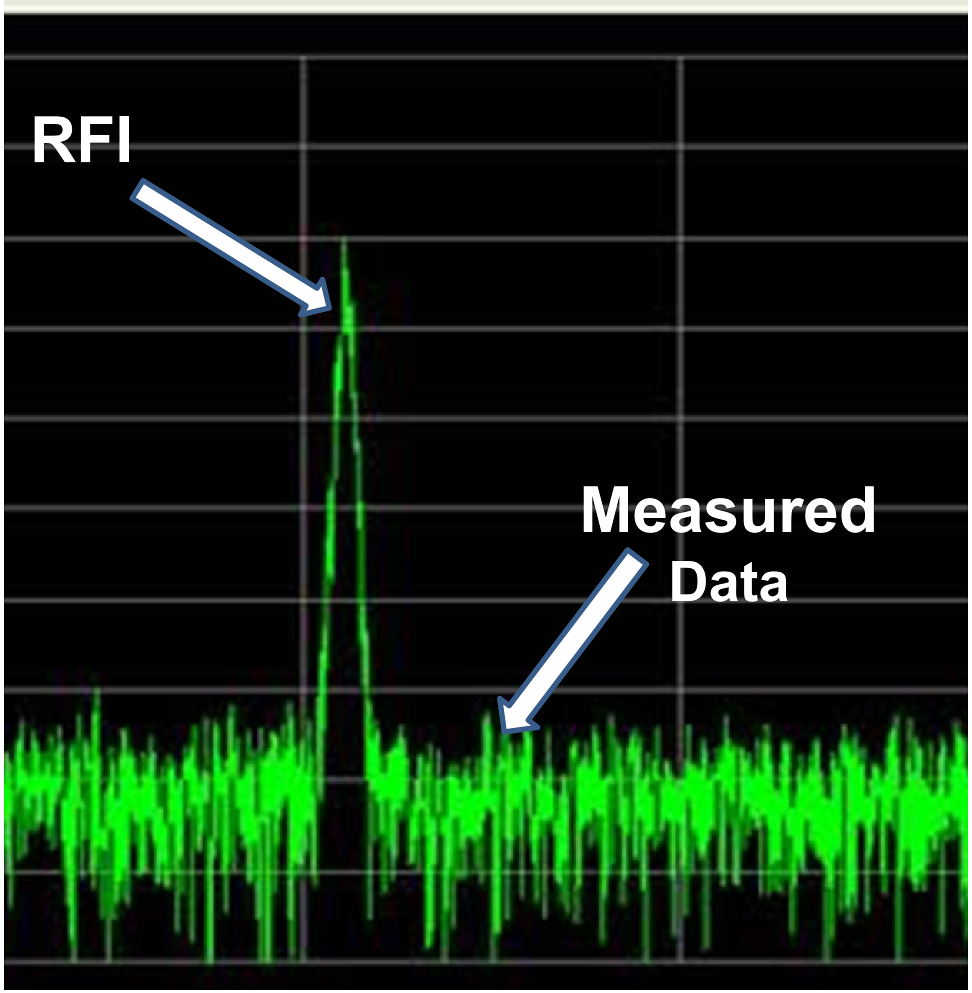
Remote Sensing in RF Passive Bands

- EESS (passive) bands continue to be recognized as being at high risk for anthropogenic sourced corruption.
- FCC, in NPRM (21-186), recognizes that passive sensors are not able to differentiate between natural and man-made sources of signals.
- An impact to weather models and forecasting accuracy is expected, the degree of impact is still unknown.
  - Introduction of 5G repeaters and growth of Integrated Access & Backhaul (IAB) functions may further corrupt EESS (passive) bands.
- Passive Band Sensors need an established set of standards to implement 'robustness' into their design.

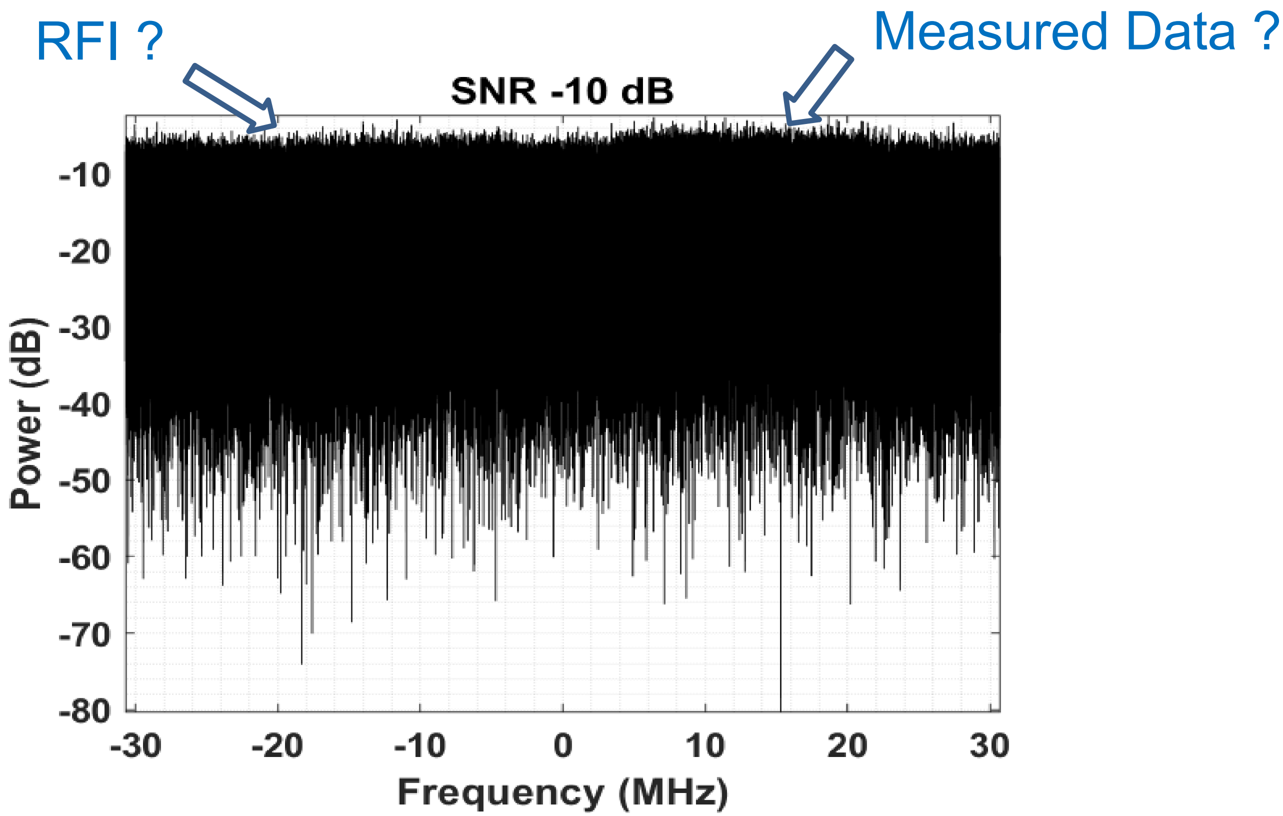
Passive Band Sensors cannot discern between natural and anthropogenic spectrum emissions

MWS – Microwave Sounder
EESS – Earth Exploration Satellite Service

This is NOT what 5G and related emissions will look like



It will probably look more like this:

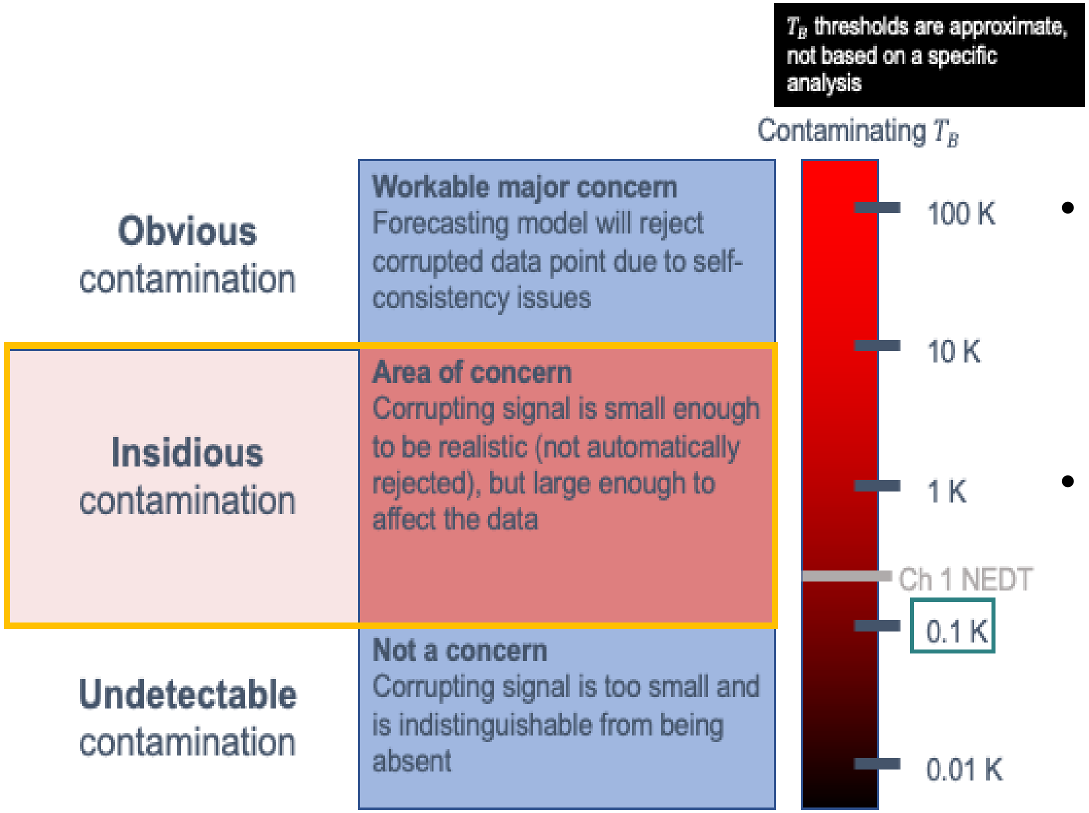


You can't see the difference!

Why is this a problem for MW Sounders?

- As designed, MW sounders only measure the total amount of radiative power coming into the antenna
  - 230 K of environmental signal + 5 K of RFI signal would be measured as 235 K
  - 235 K of environmental signal + 0 K of RFI signal would be measured as 235 K
  - The two cases are indistinguishable to current MW sounders
- 5G signals change due to varying factors (outside temperature, usage, power)
  - To a sounder, these changes look like changes in signal power and thus variations in ‘K’.

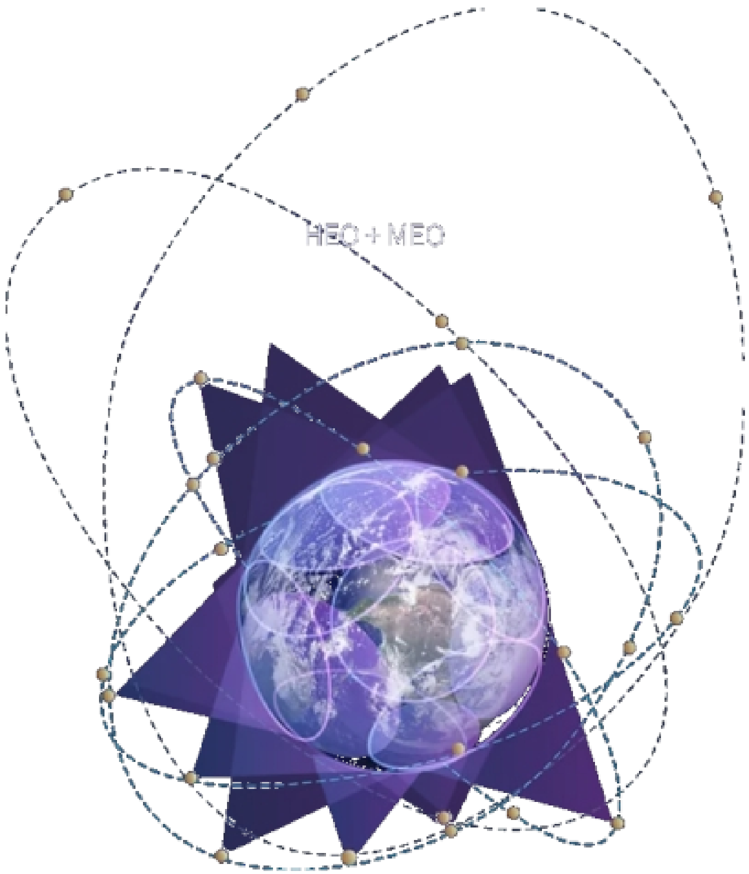
RF Passive Band Situation *as we see it*



- Non-natural RF contamination will only increase, both in intensity and in spectrum proliferation.
- Resolving RF contamination is not easy
  - Can't be 'removed' from background
  - Can only be identified and mitigated with the aid of several methods
- A broad and continuous effort is needed:
  - Regulatory – international & national
  - Policy – respond to changes
  - Technical (Scientific and Engineering) – Add new 'robustness' to future systems

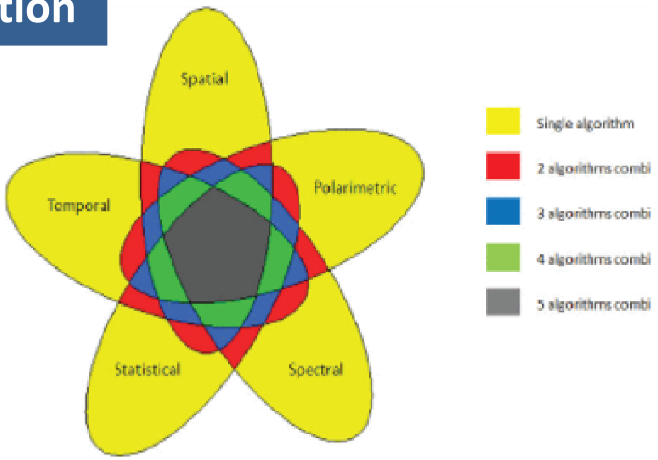
Other Potential Sources of Contamination (beyond 5G)

- NGSO Commercial Mega-constellations
  - Uplinks adjacent to 50.2-50.4 GHz Passive band
- Unknown sources of contamination
  - New systems being identified or soon to be identified
- Growth expected into 57-64 GHz and other bands adjacent to passive allocated bands



How to identify Known & Unknown Sources of Contamination

- Spectral / Frequency Division
  (sub-banding)
- Temporal / Time Division
  (sub-sampling of the pixel to identify powerful bursts of RFI)
- Statistical: Kurtosis
  (measurement of higher order noise statistics that are not Gaussian)
- Spectral Kurtosis
  (variation of Kurtosis in time domain or frequency domain)
- Spatial
  (adjacent pixel comparisons)
- Polarimetric:
  Use of Stokes parameters



Source: PhD Thesis of Dr. Sidharth Misra, JPL

Different Algorithms for known sources; multiple algorithms necessary for unknown sources, until known.

Once found, what can we do?

Some preliminary ideas include:

- Throw away bits (flagging data)
- Map areas of contamination (permanent/temporary)
- Determine impact on NWP
  - Always needs to be assessed as environment changes
  - At what point is NWP affected, or a passive band frequency no good?
- Learn to use higher frequencies (not the same performance)
- Constantly assess and modify product development to make maximum use of data
- Reach out to community to expand on mitigation approaches

NWP = Numerical Weather Prediction

Conclusion

Spectrum is the life blood of Operational Meteorology – Users Must Be Aware of Proposals or Plans for Sharing That Could Impact Data

- *Non-natural RF contamination will never go away*
  - *Will likely increase (i.e., 5G now, 6G next, etc.)*
- The EESS (passive) bands are at a very significant risk of increased noise levels from the conditions of today.
  - Low levels of noise may be indistinguishable from natural radiation
  - High levels of noise will eliminate measurement data in that observation area
- The implementation of 5G and following generations of broadband expected to affect the EESS (passive) bands.
  - Predominately bands near and between 24 to 86 GHz.
- There will be an impact to weather models and forecasting accuracy
- Recommend an emphasis on development and implementation of identification and sensor robustness measures

If we do nothing, we will not know when or how much the meteorological mission is degraded by RF contamination

Key issues of relevance to CGMS:

- ☐ Recommend CGMS members monitor WRC-23 AI 1.2, 1.6, 1.16, 1.17, 9.1d for protection of passive bands
- ☐ Continue to seek increased robustness in satellite passive sensors
- ☐ Reference to HLPP 2.2, Radio Frequency (RF) protection

To be considered by CGMS:

- ☐ **For actioning:** Recommend consideration by member administrations of WRC-23 agenda items that may affect satellite remote passive sensing.
- ☐ **For actioning:** Recommend consideration of alignment with SFCG and WMO WRC-23 findings for passive bands.
- ☐ **For actioning:** Continue actions by TGRFI for development of mitigation techniques for use by CGMS members.