Excerpts from 5G Study Outbrief to Griffin and Mandt on Oct 14, 2020

Findings and Recommendations

NOAA

Oct. 31, 2022

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This presentation is for information and discussion. It does not reflect official plans of NESDIS and should not be taken as such

Special Thanks and Apologies to:

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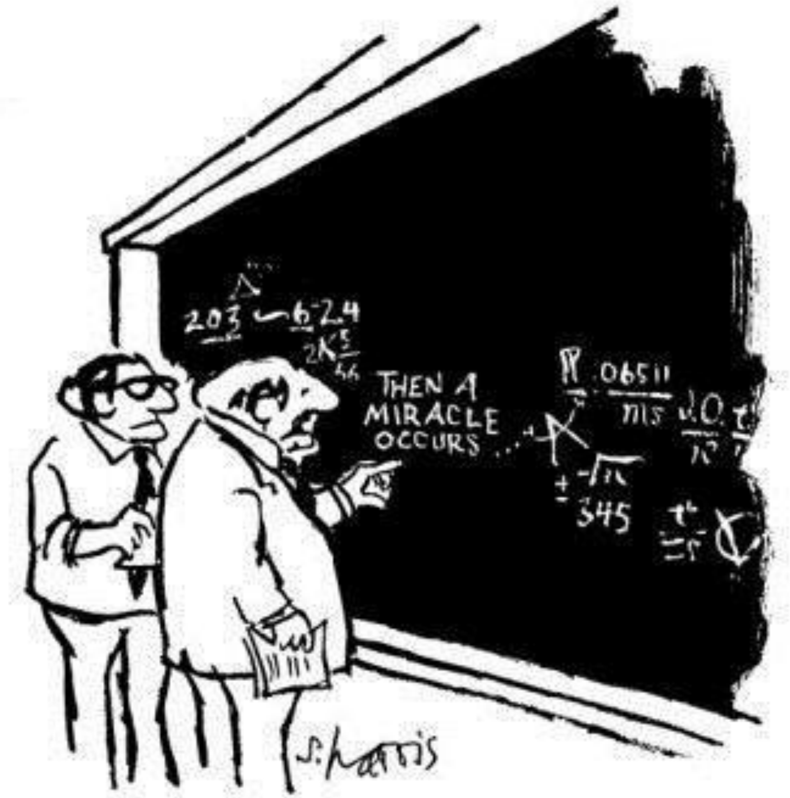
- Quanhua Liu, STAR
- Kevin Garrett, STAR
- Ralph Ferraro, STAR
- Changyong Cao, STAR



"I think you should be more explicit here in step two."

Agenda

- Review:
  - Study Scope and Process
- Bottom Line Up Front
- Situation Overview:
  - Passive Band Contamination
  - Path Forward Approaches
- Other Organization Activities
- Recommendations
- Next Steps
- Concerns and Challenges
- Conclusion

Review of Study Scope and Process

5G Contamination Study:

- Problem Statement: Fifth Generation (5G) advanced wireless services degrades the use of passive microwave sensing frequencies and poses a potential risk to atmospheric moisture and temperature sounding data critical to Numerical Weather Prediction.
  - It is uncertain precisely how the interfering energy will be manifested and to what extent it may contaminate data
  - Therefore, it is unclear how the potential contamination will be mitigated*, if at all

*"mitigation," refers to reducing the impact of contaminating non-natural emissions and should not be considered as fully correcting contaminated RF spectrum

Study Mission

- Develop a plan for identifying, characterizing, and mitigating potential 5G interference with NESDIS satellite microwave sounding performance.

- Complete the task by considering:
  - Risk and Near-term approach to current systems
    - Affect on ATMS channels
  - Long-term comprehensive solution
    - All passive bands between 6 and 100GHz
  - Space-based solutions
  - Non-satellite solutions, e.g. post-processing, drones, aircraft, machine learning
  - Leverage relevant work planned by our foreign partners
  - Leverage current ongoing efforts: LEO BAA, JPSS, 5GIIS
- Completion date: Sept. 30, 2020.

Sequence of study – "Identify, then characterize, then mitigate"

1. What are the manifestations of the potential contamination?
2. What is available to identify, characterize, and mitigate the contamination?
   - Near term approach for current systems
   - Long term comprehensive solution
3. How do we determine which technical approach is 'best'?
   - 'best' involves cost/schedule/risk (near term / long term)
4. Based upon the approach, what is 'best' plan to recommend for NESDIS implementation
   - 'best' involves cost/schedule/risk/politics (near term / long term)

Bottom Line Towards Front

Situation:

- Non-natural RF contamination will never go away
  - Will likely increase *(i.e. 5G now, 6G next, etc.)*
- Resolving contamination is not an easy fix
  - Can't be 'removed' from background
  - Can only be identified and mitigated with the aid of several methods
- If we do nothing, we will not know when or how much NWP (and NOAA mission) is degraded by RF contamination

Recommendations:

- Start now to minimize the risk
  - Continue current efforts
  - Start Contamination Mapping
  - Develop enterprise mitigation for sensors, products, NWP

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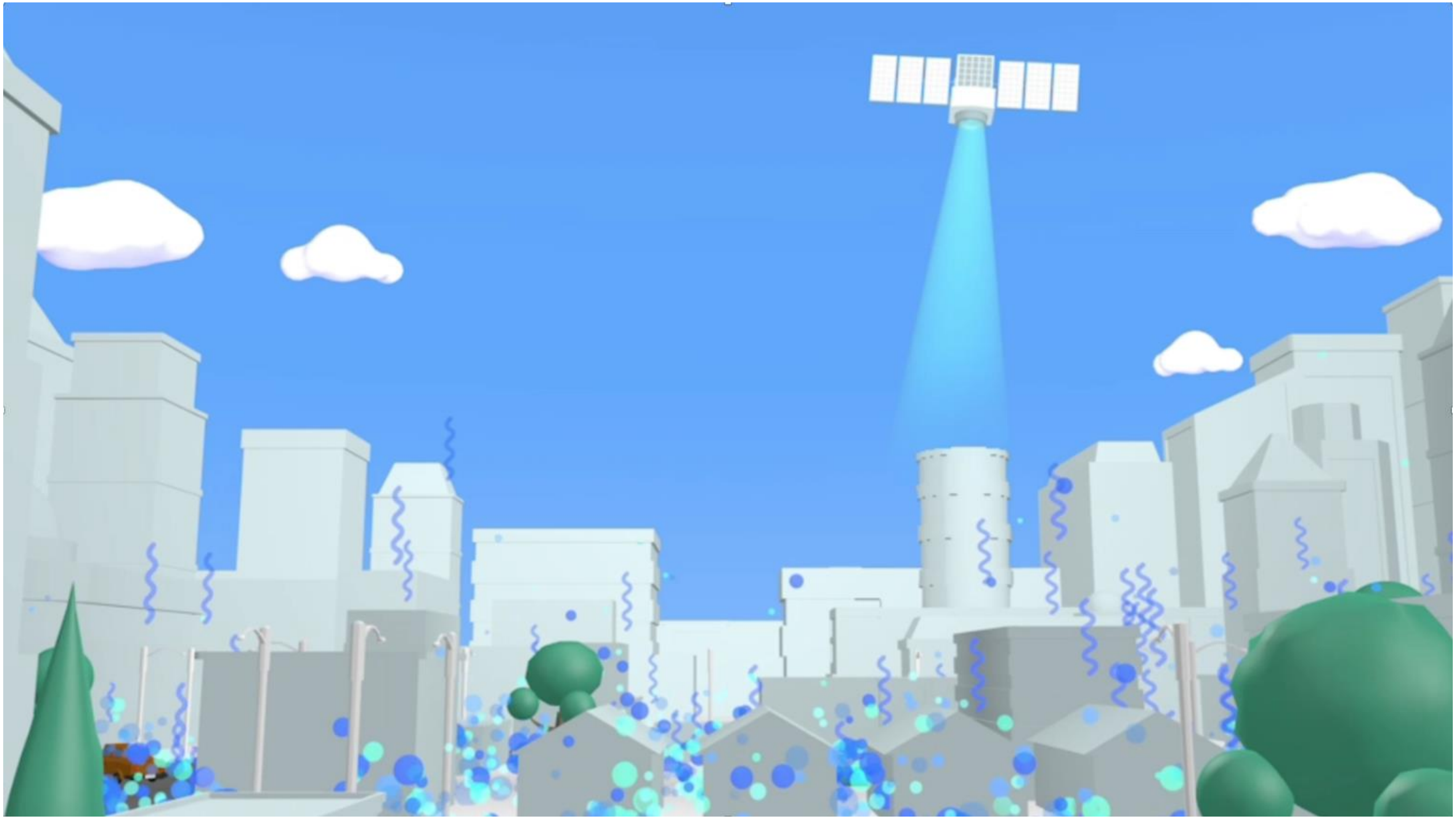
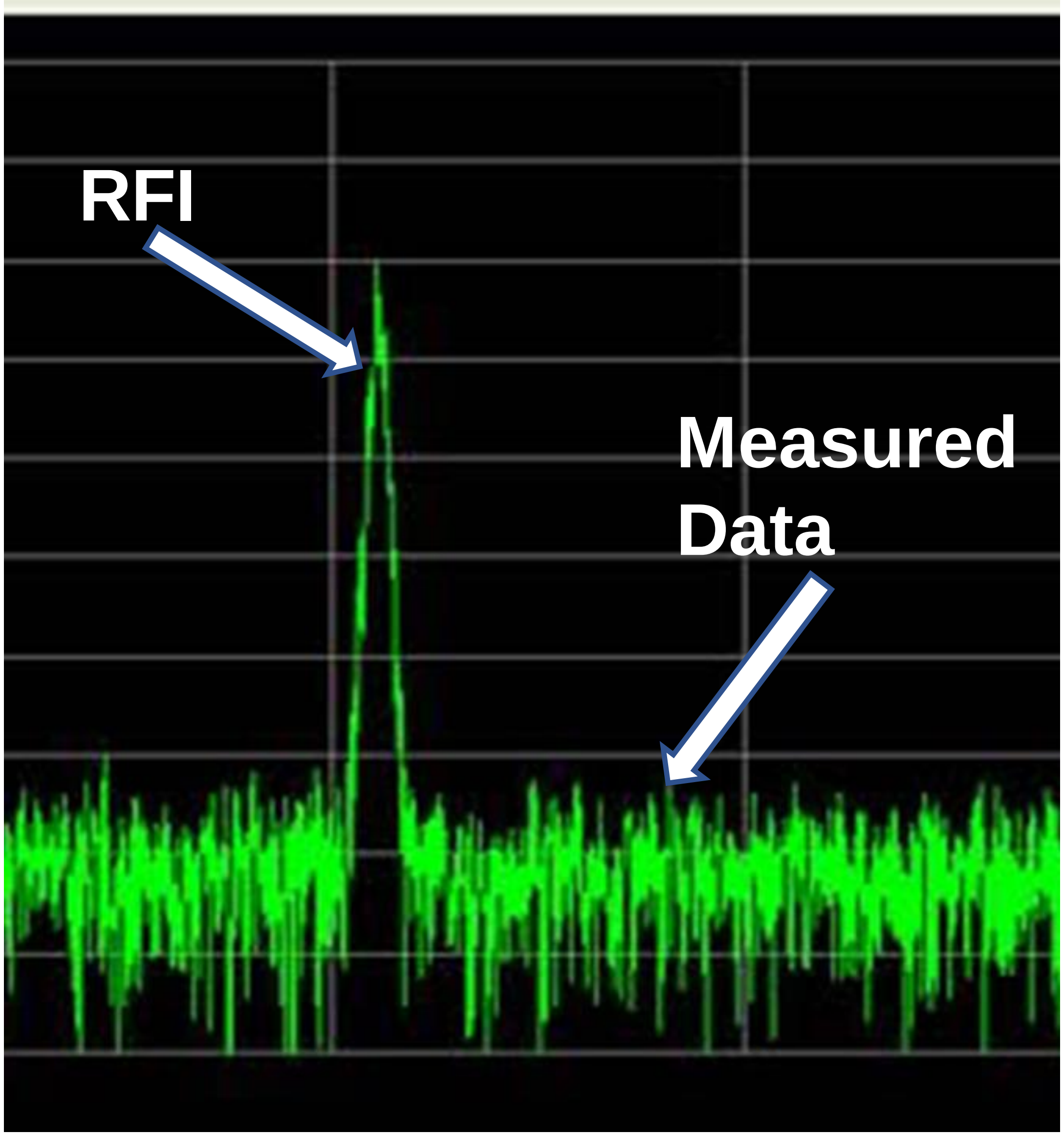
What is the passive band problem?

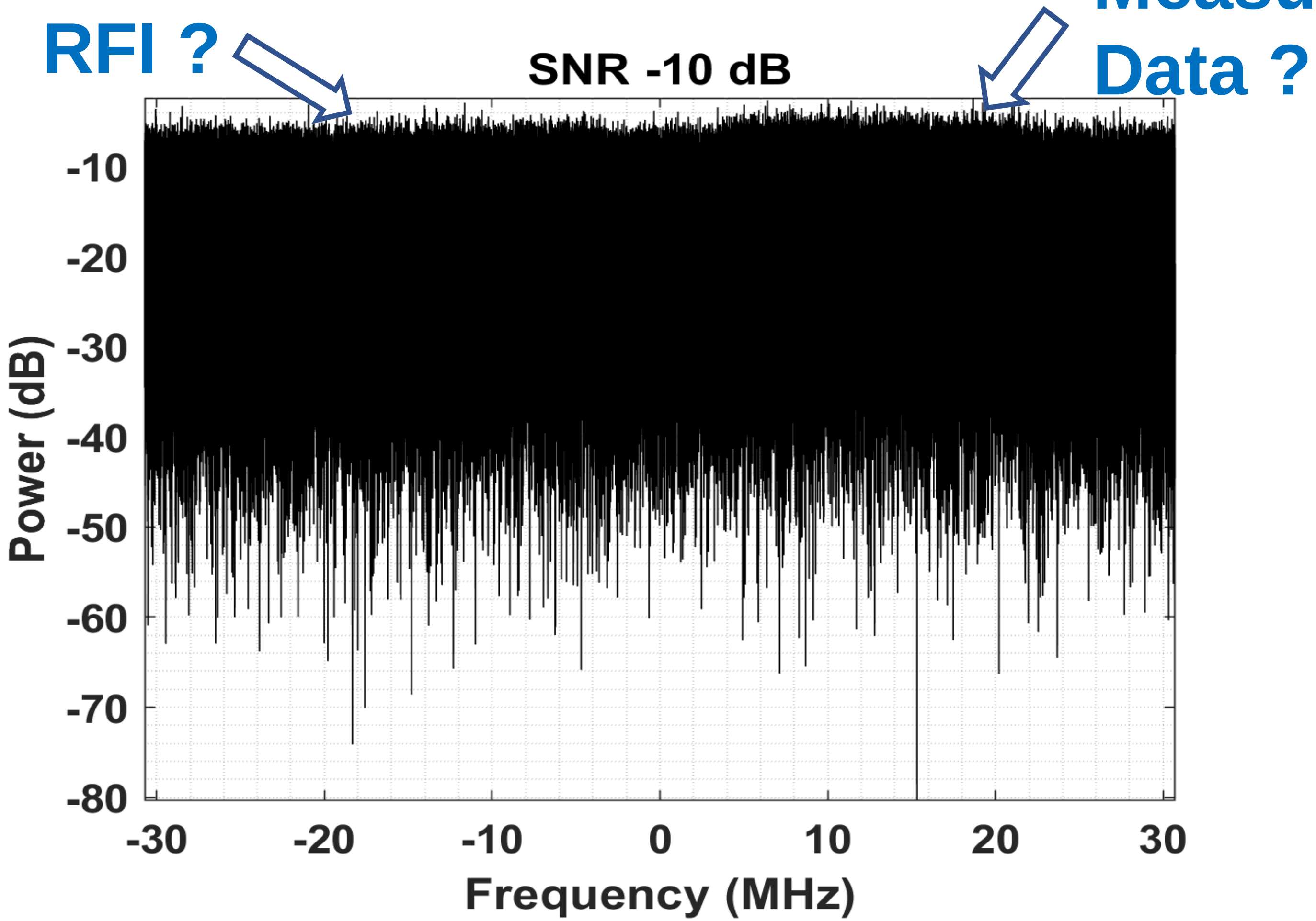
- Video demonstrating 5G effects to MW sounding



This is NOT what 5G will look like



It will probably look more like this:



You can't see the difference!

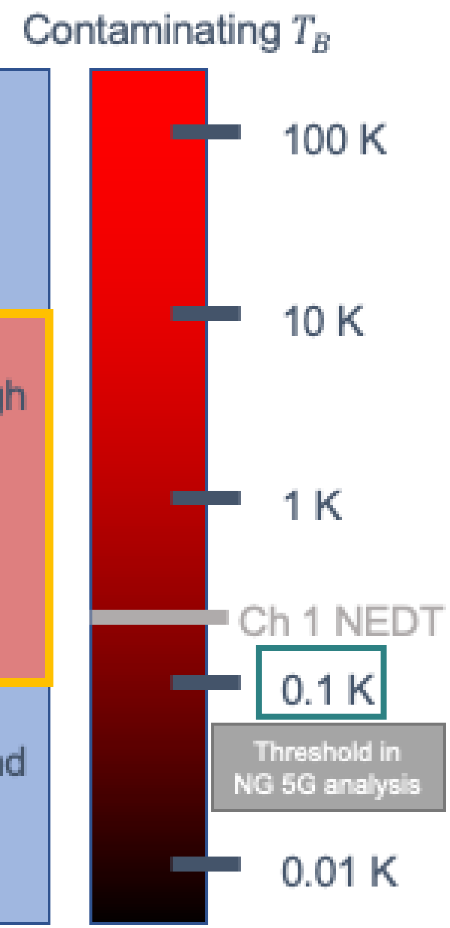
Why is this a problem for MW Sounders?

- 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 2 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'.

Various Levels of Contamination

T_B thresholds are approximate, not based on a specific analysis

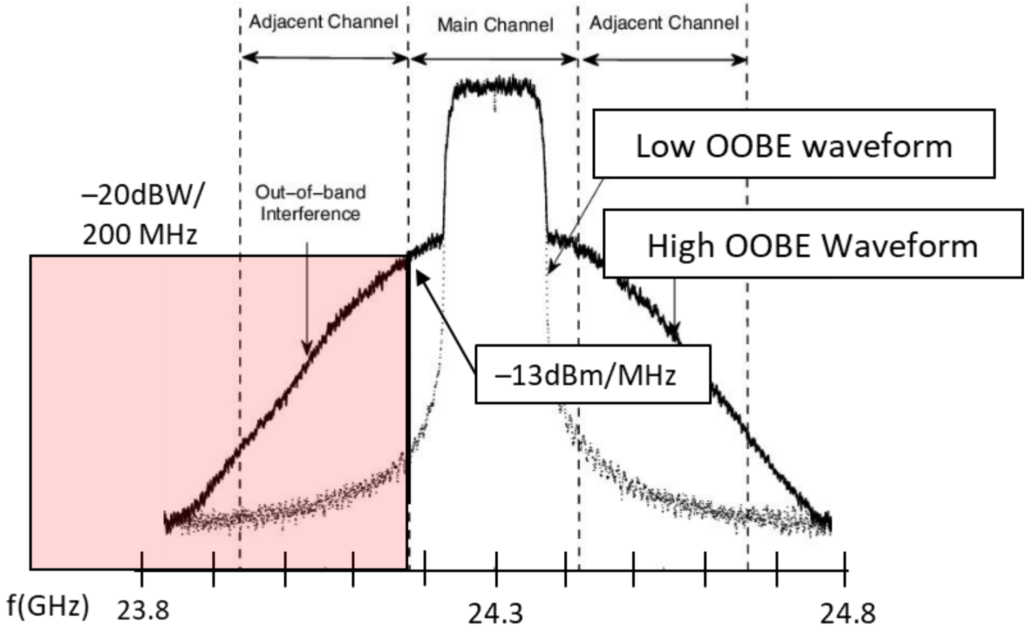
Obvious contamination	**Workable major concern** Forecasting model will reject corrupted data point due to self-consistency issues
Insidious contamination	**Area of concern** Corrupting signal is small enough to be realistic (not automatically rejected), but large enough to affect the data
Undetectable contamination	**Not a concern** Corrupting signal is too small and is indistinguishable from being absent



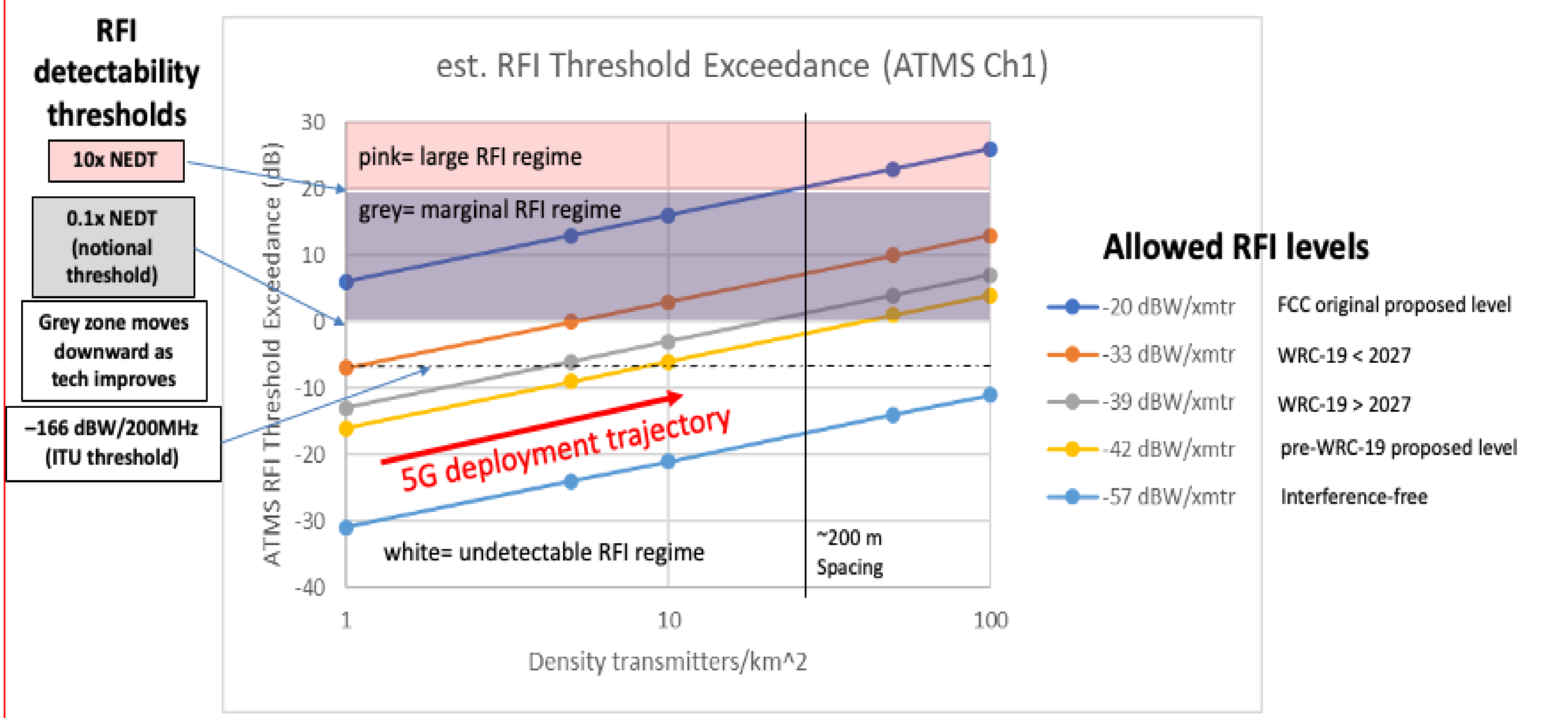
Emissions ‘Roll-off’

(not in original presentation)

- Out-of-band (OOB) emissions from adjacent sources of energy, such as 5G transmissions from 24.25GHz into the 23.8 GHz band



Why don't we know how much 5G contamination we'll have?

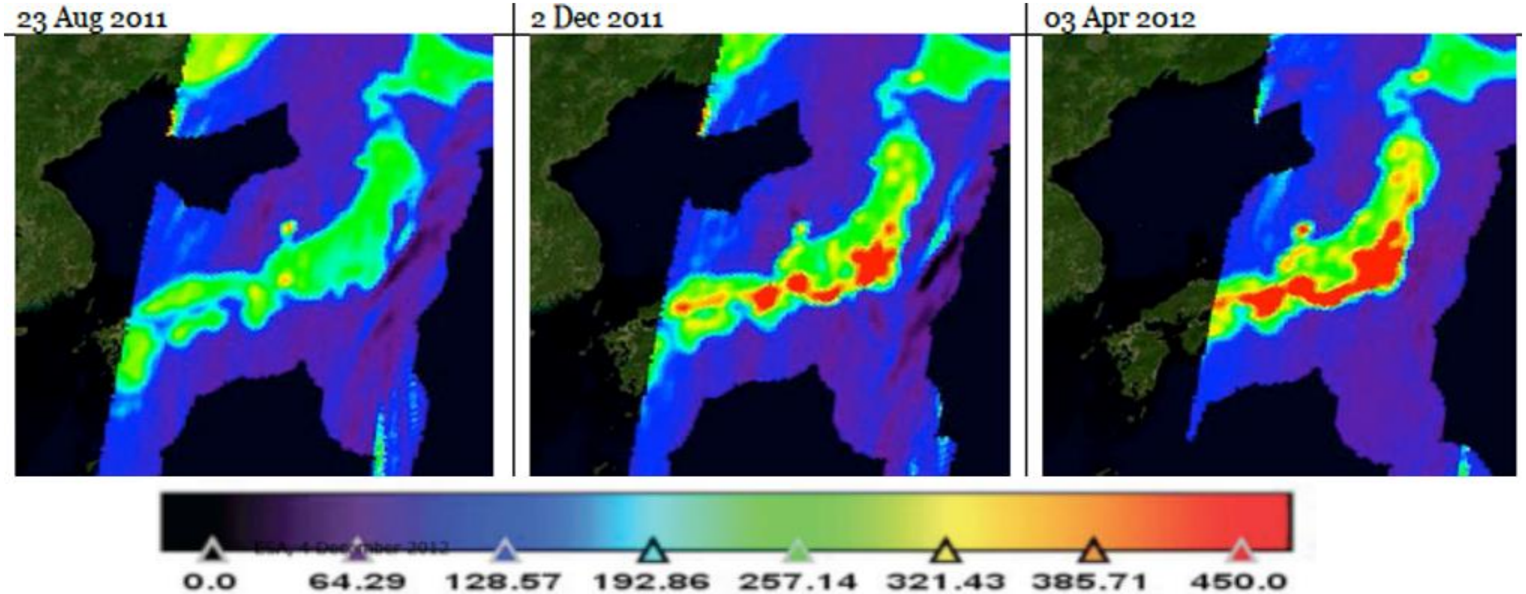


NOTE! Relative vertical positions of RFI regimes vs. allowed RFI levels not exactly known. Exact analysis requires RFI surveys + simulation.

What level of 5G deployment will be made? Where? When?

Here's how quick this could happen

SMOS data corruption caused by RFI

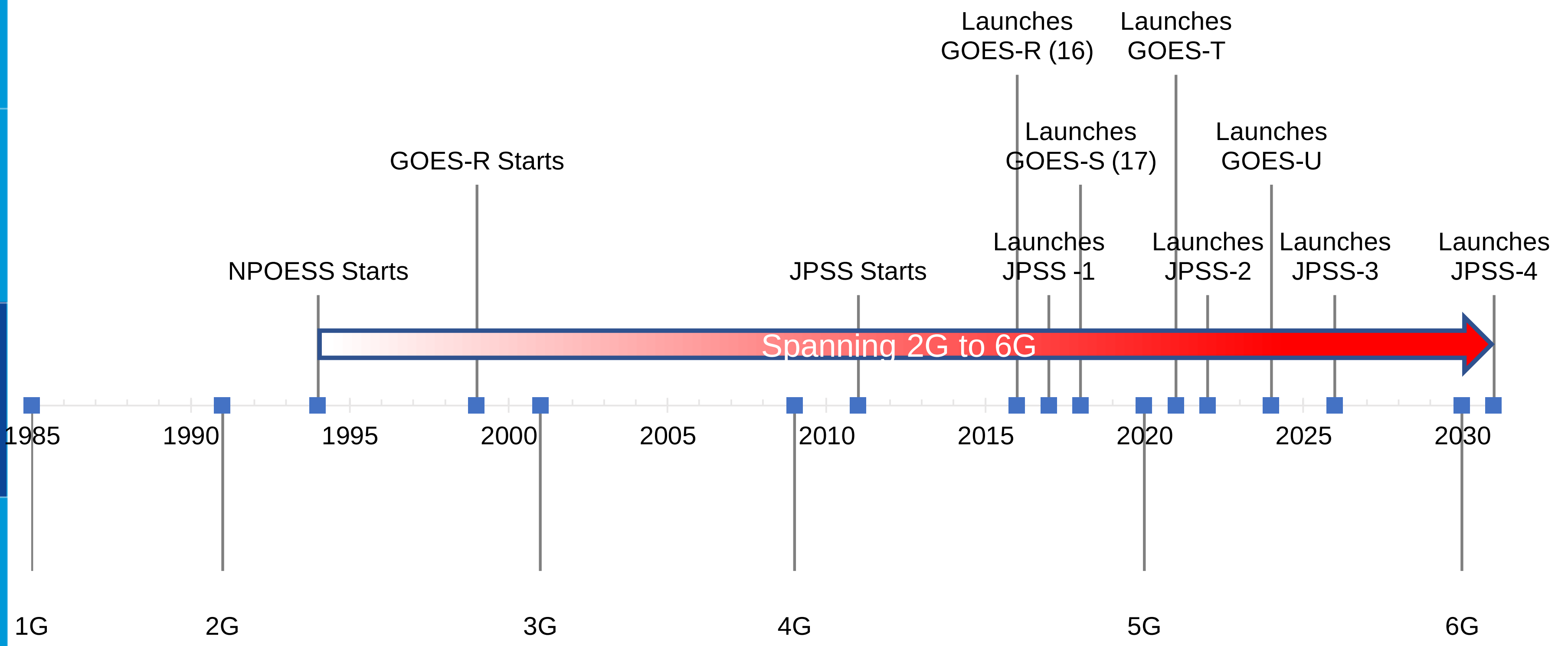


Japanese broadcasting satellite home TV receiver added low noise block converter (1.415 – 1.450 GHz for channel 21) started from October 2011. The band partially overlaps SMOS passive band 1.400 – 1.427 GHz. The RFI heavily affected SMOS brightness temperatures in these maps vary between 500 and 700 K.

Daganzo et al., 2019: IGARSS paper, DOI: 10.1109/IGARSS.2019.8897873

TV broadcast application was rolled out in 9 months!

Vastly Different Timeline for MetSats vs Com'l Broadband Development



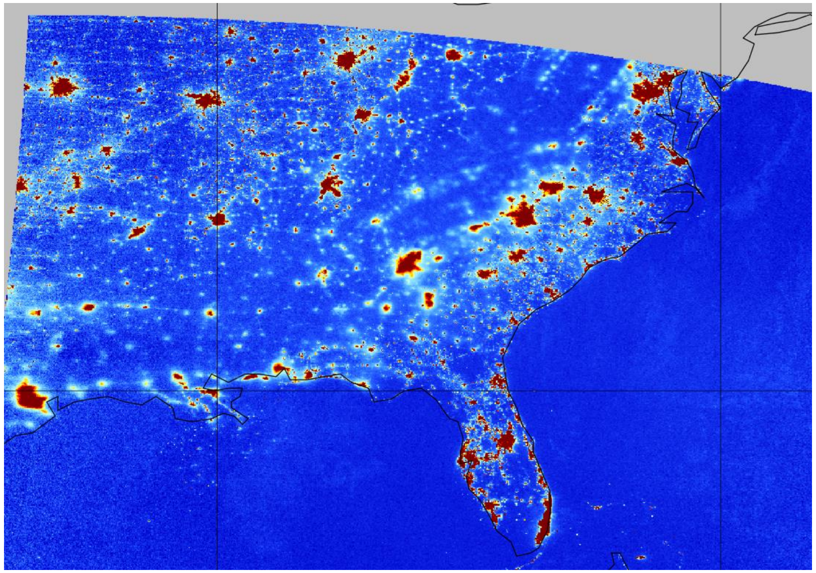
5G is just the next step for Telecom

G\Info	Year	Data rate mbps	Technology	Frequency (GHz)	Service
1G	1980	0.002	Analog, AMPS	0.8	voice
2G	1991	0.064	digital modulation, GSM	0.9, 1.8 (GSM) 0.8 (CDMA)	1G + text message
3G	2001	2	digital modulation, WCDMA	1.8 – 2.5	2G + web browsing, TV streaming, navigational maps and video services
4G	2009	1,000	IP based network, LTE, WiMax	2 – 8	3G + digital video broadcasting, high definition TV content and video chat, wireless services at anytime and anywhere through automatic roaming
5G	2020	20,000	MIMO	3.3 – 4.2, 6, 24.25 – 52, 64 - 86	4G + self driving, remote surgeries, automated factories, smart automation for homes and cities
6G	2030 ?	1,000,000	3 D communication	+ > 100 GHz	5G + fully intelligent connection

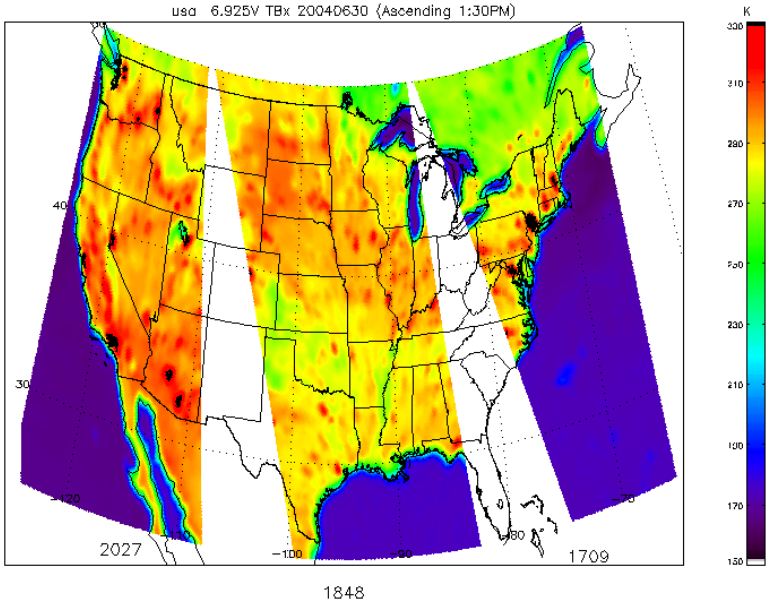
Result of RFI within 23.8-GHz Band

RFI from 5G transmitters will be a function of 5G station density

- Impacts to measurements will be highly correlated with DNB ‘lights at night’ and AMSR-E RFI example images
    - *Examples shown below from DNB (representative image) (left) and AMSR-E RFI (right)*
    - *ASMR-E 6-GHz channel RFI from Fixed Stations (note: lower spatial resolution)*
    - *Red and black spots represent corrupted data that will have to be identified and removed*

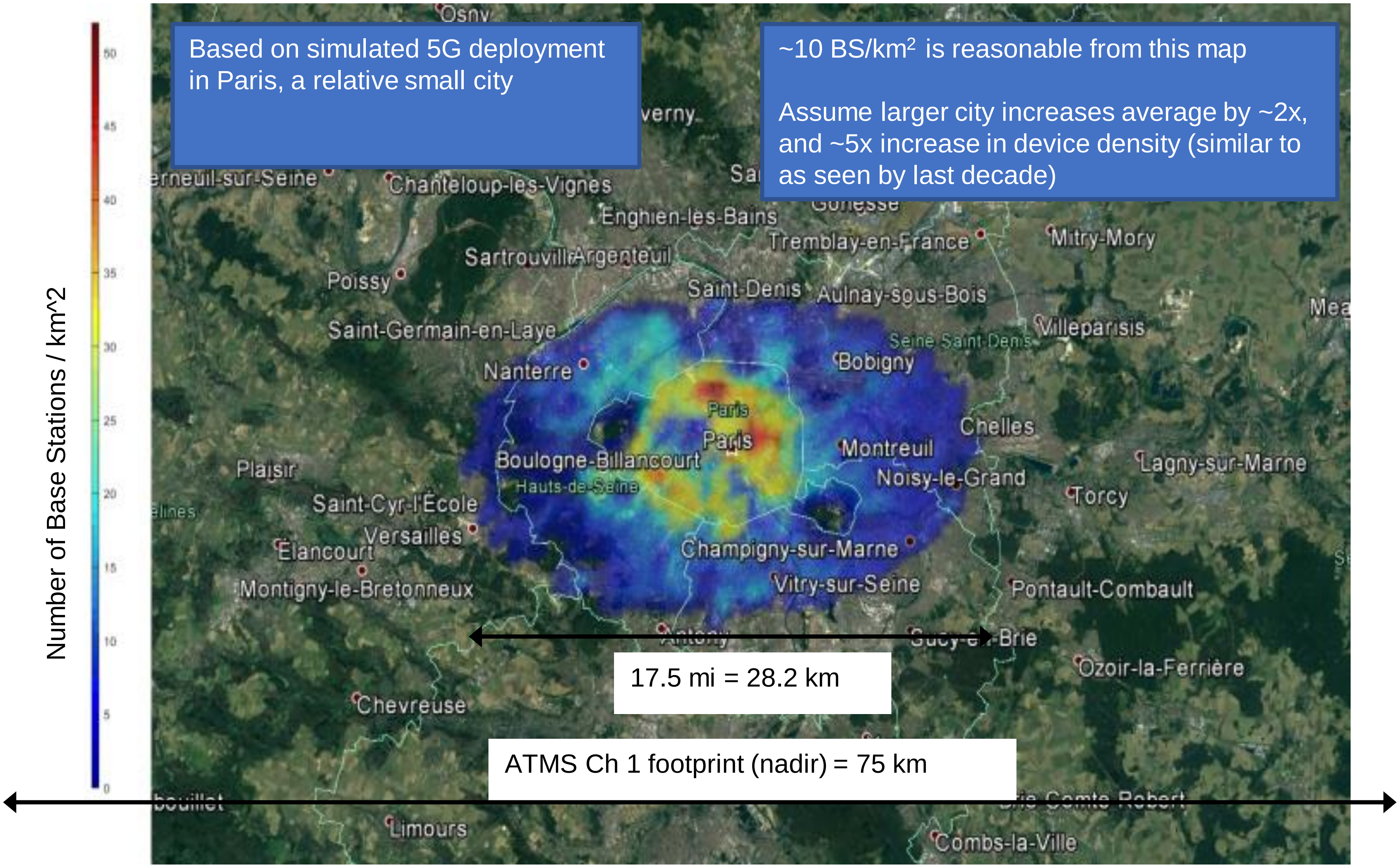


From NOAA point source calculation Changyong Cao 4/1/19



6-GHz AMSR-E Data from 30-Jun-2004

What does city-wide 5G look like to ATMS?



Based on simulated 5G deployment in Paris, a relative small city

~10 BS/km^2 is reasonable from this map

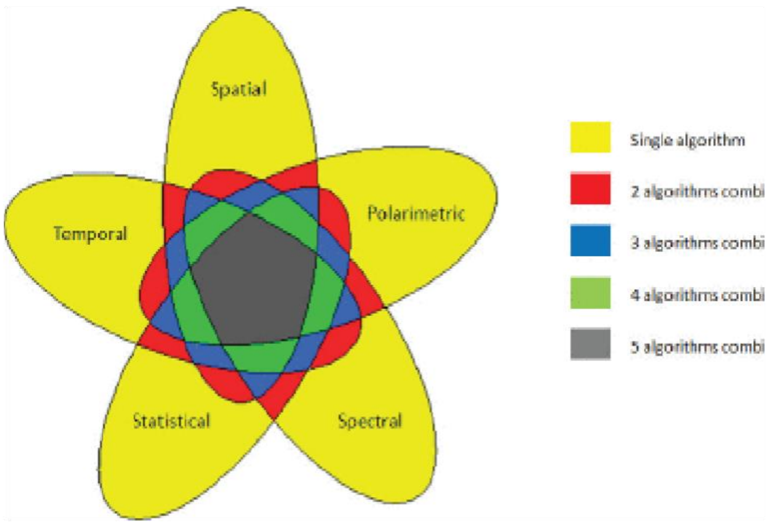
Assume larger city increases average by ~2x, and ~5x increase in device density (similar to as seen by last decade)

Other Potential Sources of Contamination (other than 5G)

- NGSO Commercial Mega-constellations
  - Example: Mangata Networks with 791 Satellites in MEO and HEO
  - Uplinks adjacent to 50.2-50.4 GHz Passive band
- Unknown sources of contamination
  - New systems yet to be identified
- Bad actors

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

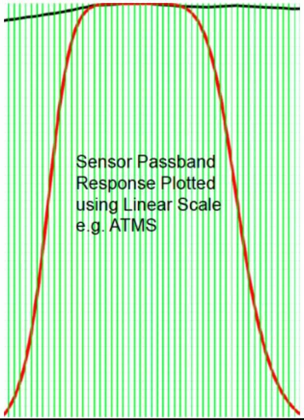


Source: PhD Thesis of Dr. Sidharth Misra, JPL

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

How can these methods be applied?

- **Spectral** algorithms divide up the signal in smaller frequency “bins”
- Each green line is a frequency bin
- **Use Digital Back-end**



- **Temporal** algorithms divide up the signal in snapshots of time
  - This kind of algorithm is more suited to detecting a signal that changes over time like a radar beam consisting of pulses of energy
  - **Identify and map short radar-like pulses**

- **Statistical** compares the natural, uniform distribution of the desired signal characteristics – one created by nature,
- With the non-uniform distribution that would be created by a man-made or artificial signal
- The technical term here is kurtosis
- **Typically combined with other algorithms for improving tests for detecting man-made emissions.**

- **Spatial** would compare each pixel in an image, looking for dramatic changes in brightness intensity.
  - **Mapping of areas of concern**.
- **Polarimetric** utilizes the geographic orientation of radio signals to differentiate
  - Adjust the “rabbit ears” antenna wrong on a television, generally causes loss of signal.
  - Changing properties of polarized sunglasses also illustrates the geometric features of light
  - **Dual polarization of sensor required**.

Once found, what can we do?

- 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 23GHz channel no good?
- Learn to use higher frequencies (not the same performance)
- Constantly assess and modify product development to make maximum use of data

The Case for Mapping and Modeling

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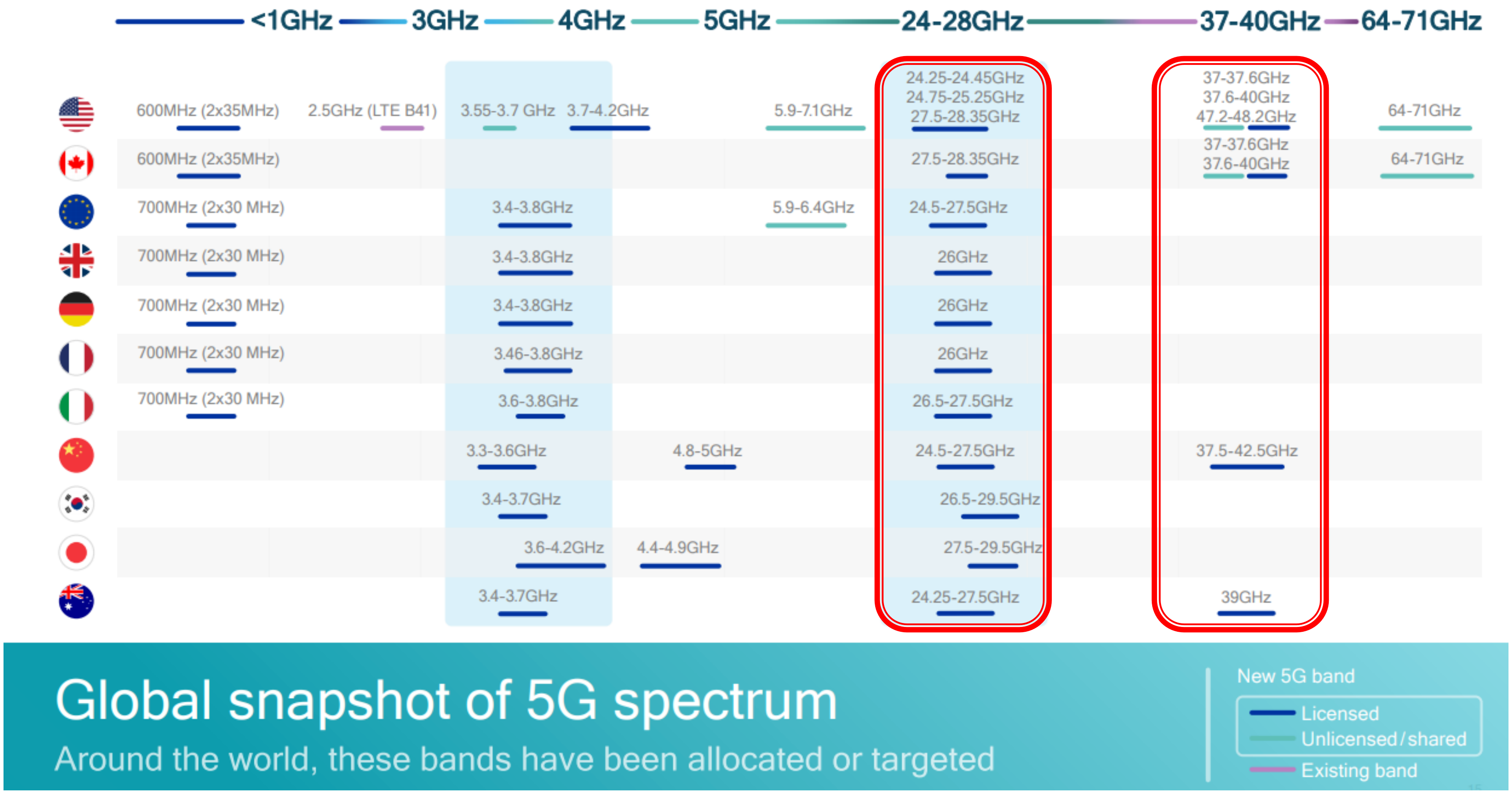
The 5G Signal will vary in different ways

- 5G signal usage will vary over the course of 24 hours
- 5G signal usage will vary over the course of the business week (which is not always Monday-Friday in all parts of the world)
- We do not know how the out of band emissions (OOBE) from 5G might vary with loading changes over time.
- We need to establish a baseline now to characterize 5G as it rolls out

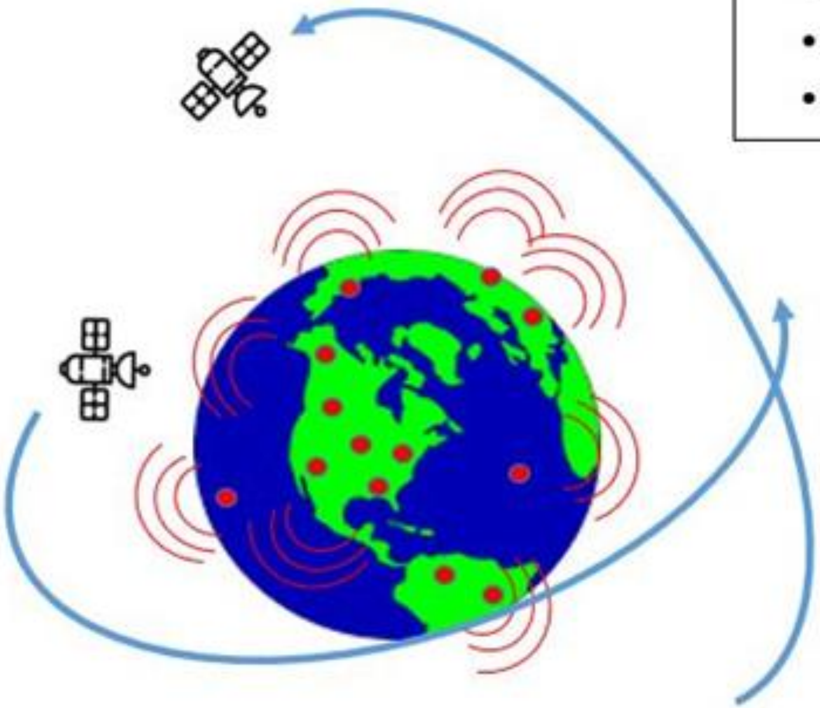
5G at a Global Level



Different countries will license different portions of the adjacent bands for 5G; not all will be directly adjacent to passive remote sensing.

From: https://www.qualcomm.com/media/documents/files/spectrum-for-4g-and-5g.pdf

Modeling and Simulation (space and airborne)



Required Ingredients (puzzle pieces)

- RFI source characteristics
- RFI victim characteristics
- Propagation from source to victim

Outputs

- RFI amplitude at victim
- Location/time statistics of exceedances
- Predict when RFI source deployment will exceed thresholds at victim

Mapping determines the Contamination Threshold for flagging bad data

- Selection of the threshold level is crucial
  - Setting it too high still allows contamination into models and products
  - Setting it too low discards too much data and distorts the mapping process
- Threshold selection must be done in concert with international partners to provide global consistency
  - E.g. If NCEP/EMC and ECMWF do not treat data contamination with similar approaches as NOAA, then model outputs may differ further because of contamination
  - Different contamination processes could impact different products

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Why do we have to do mapping?

- Global contamination map has at least two dimensions:
  - Time
  - Geography
- Primary Sources:
  - Airborne and Spaceborne RF Surveys, regularly updated
    - Airborne provides local data likely unseen by satellite as well as the ability to capture much more data
    - Space provides global overview of contamination sources
- Downstream systems will develop methods to de-weight data based on mapping database(s) and modelling.
- Mapping standards need to be developed so that partner data would be comparable to NOAA data

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Why do other mapping if a digital back pack (DBP) is implemented?

- JPSS 2 ATMS won't have DBP, will need other methods of mapping to flag contamination
- Other microwave sounders may not have flagging capability
- *Even with hyperspectral MW, we won't know if/when a specific channel is corrupted unless mapping is done.*

Findings
Path Forward Approaches

JPSS 3 & 4 – Digital Backpack (DBP)

•No change to ATMS instrument function and operation

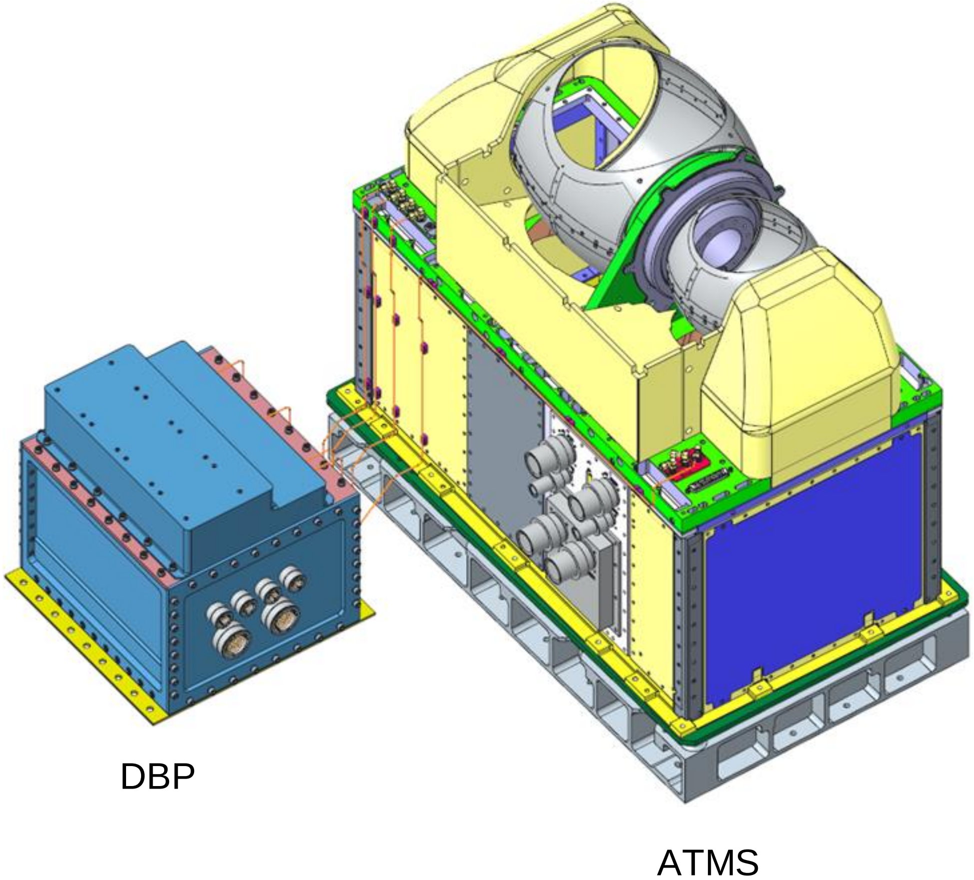
•By implementing a complementary system, the Digital Backpack (DBP), 5G RFI detection, could be performed in parallel with the main mission requirements of ATMS

•DBP addition is simple and operates independently of ATMS instrument

•DBP Instrument would provide its own separate data stream

•DBP technical solution consists of the following:

- DBP receiver design is flight proven
- Signal processing uses flight proven, high speed ADC and electronics parts.



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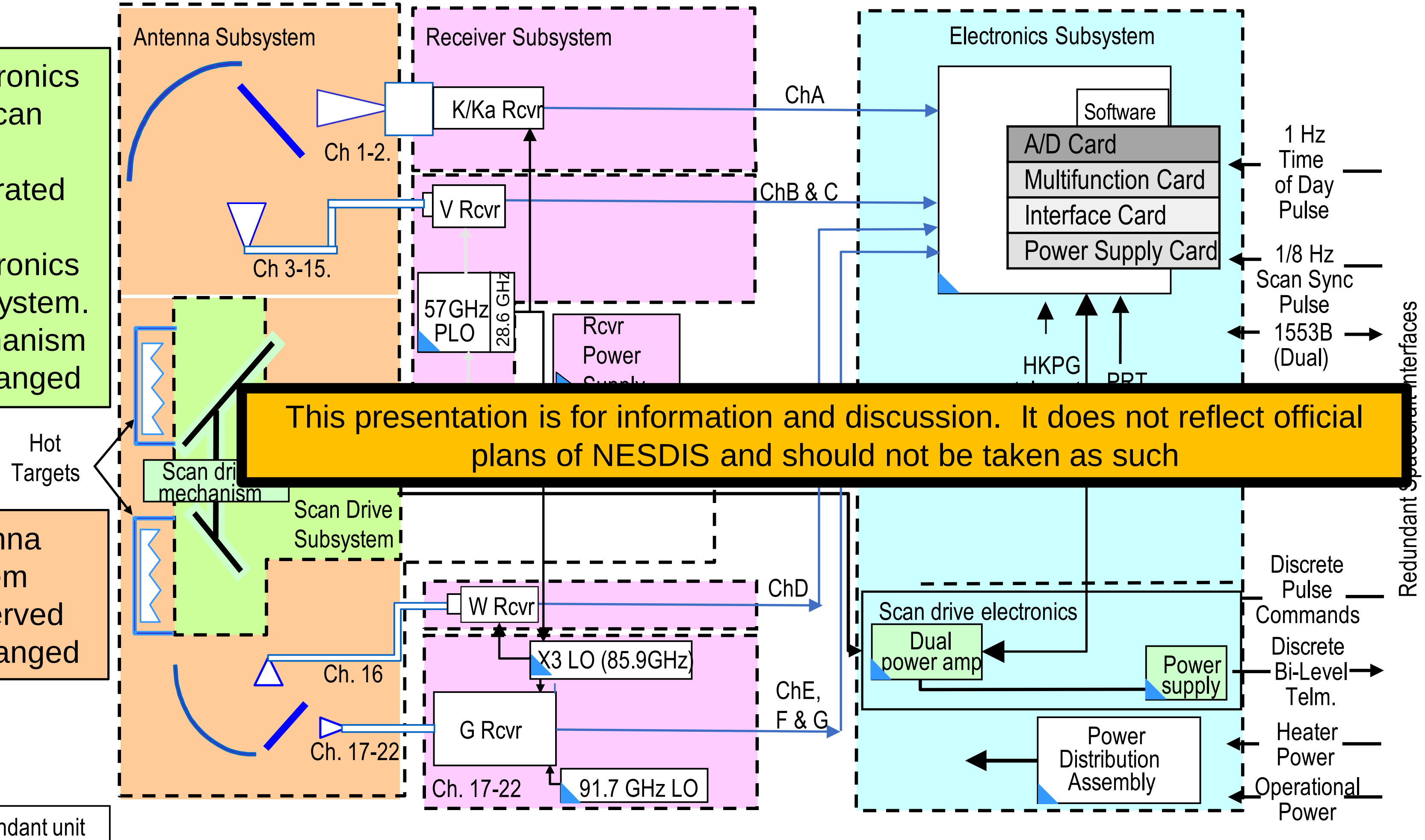
Digital ATMS (DATMS)

Electronics for Scan Drive integrated with Electronics Subsystem. Mechanism unchanged

Antenna System preserved unchanged



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Significantly simplified receiver architectures with fewer components (reduced cost)

Advanced electronics significantly reduce the number of components, circuits and cost, while dramatically improving performance and capability

5G Interference Identification Sensor (5GIIS)

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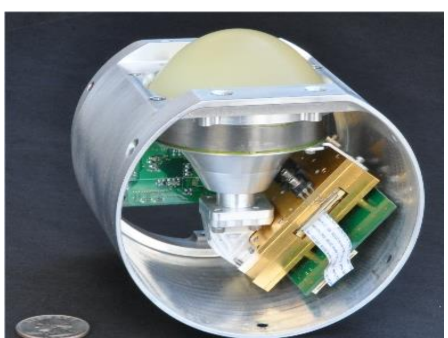
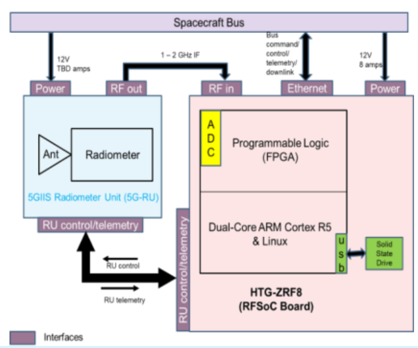
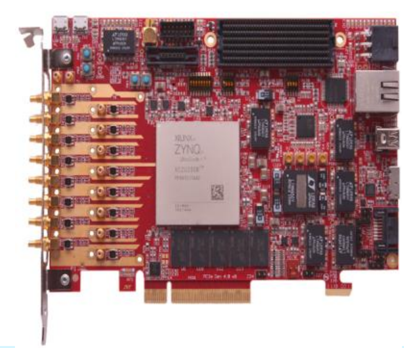
- Sensor Hardware
  - Composed of two parts: RF Unit (RFU) and Digital Back-end Unit (DBU)
  - Assembled into a CubeSat form factor to enable transition from airborne to space-based sensor
- Approach:
  - Low-cost RFI spectrometer for airborne/space studies to characterize RFI from 5G systems
  - Calibrated radiometer with digital RFI detecting receiver with characteristics matching ATMS
  - Follows path of NASA CubeRRT mission, but focusing on 5G and with upgraded technology
  - Utilizes State-of-the-art RF System-on-a-chip (RFSoC) and available RFI detection algorithms







A Critical & Continual Role for NESDIS

Laboratory verification of identification methods:

- How well do the methods work to identify 5G and other interference.

Flagging:

- Identify criteria for flagging, based upon aerial surveys & other sources
- JPSS program responsible for flagging & transmitting to STAR

Mapping (post-processing):

- Constant assessments of partner data from other organizations
- Modeling and adjusting algorithms based upon real world inputs

NWP Implication:

- Measuring effect on NWP

Collaboratively Verifying Partner Data

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What Are Other Organizations Doing?

- International Partners (CHANGED)
  - EUMETSAT (Dreis) & their 18 GHz back end processor
  - WMO
- DoD
  - SMC
    - Contamination unaddressed
    - WSF-M at 37 GHz
  - NRL
    - Using similar methods as NOAA
- NASA
  - HQ
  - Goddard (Cacciatore) (CHANGED)
  - JPL (CubeRRT, basis for 5GIIS framework)
- Commercial (Eichen)
  - Examining methods to interact between 5G and METSAT

All share similar concerns as NOAA, nothing significantly different noted.

Recommendations

- Minimize future risks
  - Mapping to characterize environment
    - Airborne testing
    - Dedicated Space missions
  - Ensure data Flagging Capability
- Make Sensors more Robust in Passive Bands
  - Develop mitigation standards for future passive sensors
    - Hardware, software, post-processing
- Establish a Strategic RF contamination group
  - Guides contamination mapping & mitigation efforts for NESDIS implementation
  - Permanent effort (contamination isn't going away)

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Mapping effort

- Determine best ways to map 5G as it rolls out
  - What is most efficient, but effective approach?
  - Can this really be done with airplanes?
    - Where? How often? With what planes?
  - What about stratospheric balloons?
  - Will mapping work without a space platform also?
  - What is the best way to model the environment?
  - Will influence or validate the design and implementation of all of our digital back end options
  - Define other available assets for airborne mapping

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Concerns and Challenges

- Funding
- Availability of resources
  - Which office develops, implements, and conducts mapping
  - Which office conducts airborne surveys
  - Development of post detection effort
- How to coordinate with Foreign Partners

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Conclusion

- Passive Band Contamination issue is not going away
- Technology evolves rapidly
  - "Skate to where the puck is going, not where it has been" - Wayne Gretzky

Status as of October 2022

- Efforts currently on hold until funding identified
- Discussions are planned with LEO to determine ways to address the risk actively
- OSAAP /JV has several contracts under a BAA based upon Hyper Spectral Microwave sounding that may inform our path

Questions?