RFI DISCUSSION PART 2

Edward Kim
Alexandra Bringer
NASA/GSFC
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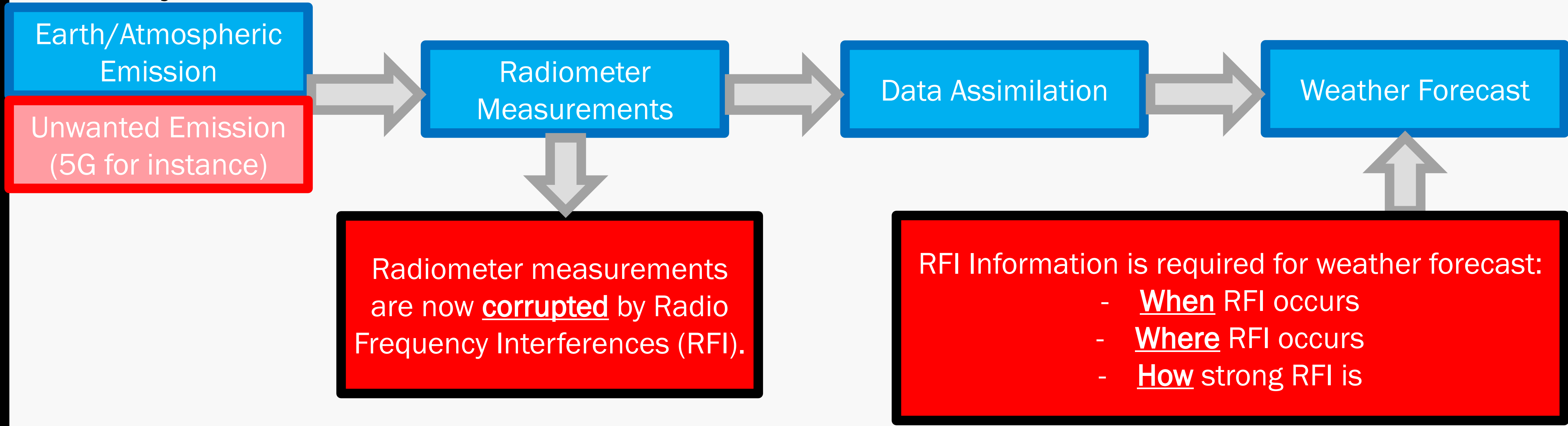
5G Radio Frequency Interference Threat

In Reality:



- Once RFI is detected by the algorithms, for each footprint, a flag will be set and be provided along with the radiometer measurements to be assimilated into weather forecast models.
- To set this **RFI flag accurately**, the following work has to be performed:
  - *Analysis of 5G signals to determine 5G signal **characteristics***
  - ***Simulation tool** to analyze the impact of 5G signal on sounder measurements*
  - *Implementation of **RFI detection algorithms** in the simulation tool to provide the **probability of detection** and the **false alarm** rate of those detectors as function of RFI characteristics*

RFI Detection

- RFI Detectors are characterized by their **probability of detection** and their **false alarm rate**. For instance, the figure on top presents the probability of detection for each of SMAP RFI detection algorithm as function of RFI strength.

- Studies were performed before launched to chose the algorithm thresholds in order to set the false alarm rate. Those thresholds were adjusted post launch when real RFI data were measured.

- Adjusting this threshold comes with a **trade off**:
  - *A **more conservative** threshold **lowers** the **False Alarm Rate** BUT results in **higher data loss***
  - *A **less restrictive** threshold **increases** the **False Alarm Rate** BUT results in smaller data loss*

- A dialogue is necessary between Researchers implementing RFI detection algorithms and Researcher from NWP Forecast to find the best compromise that **ensures** the **quali**ty of weather forecasts with a **minimal data loss**

- A **simulation tool** including RFI detection algorithms combined with real world data is also needed to **characterize 5G signals** and to produce **realistic False Alarm Rate** and exceedance probability curves (bottom figure)

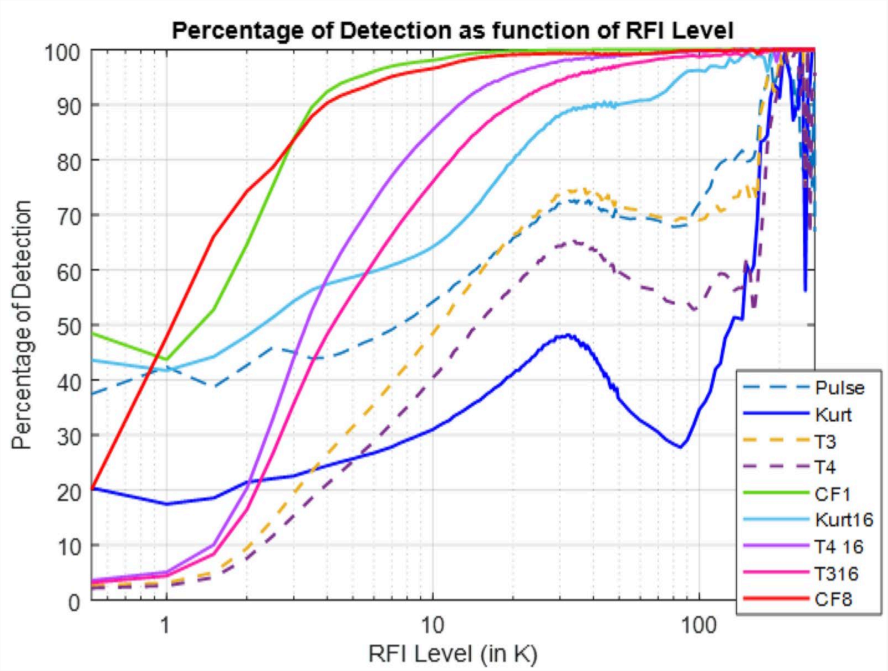
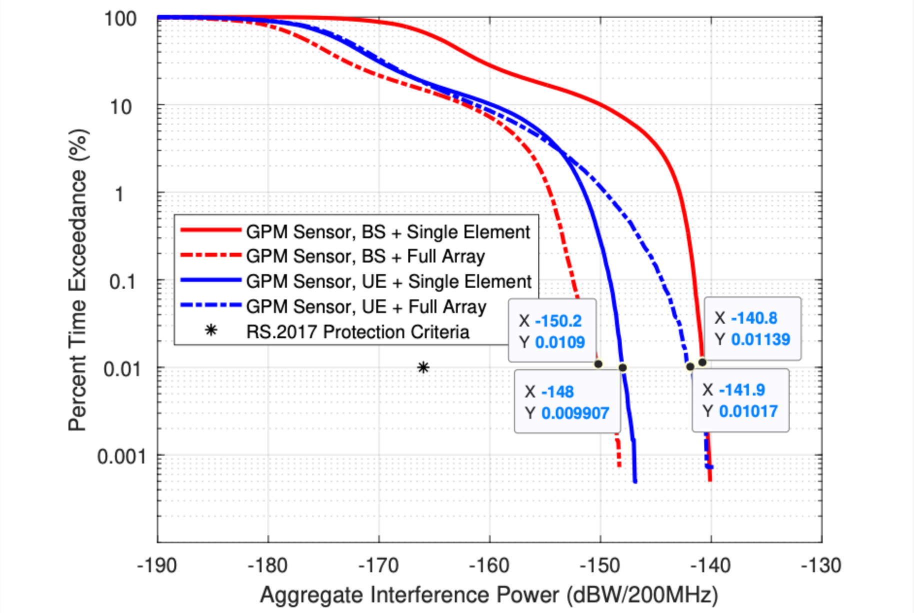


Figure 19: Interference CCDF for GPM Sensor (Out-of-Band Limits)



Ref: NASA and NOAA 24 GHz Sharing Studies GPM

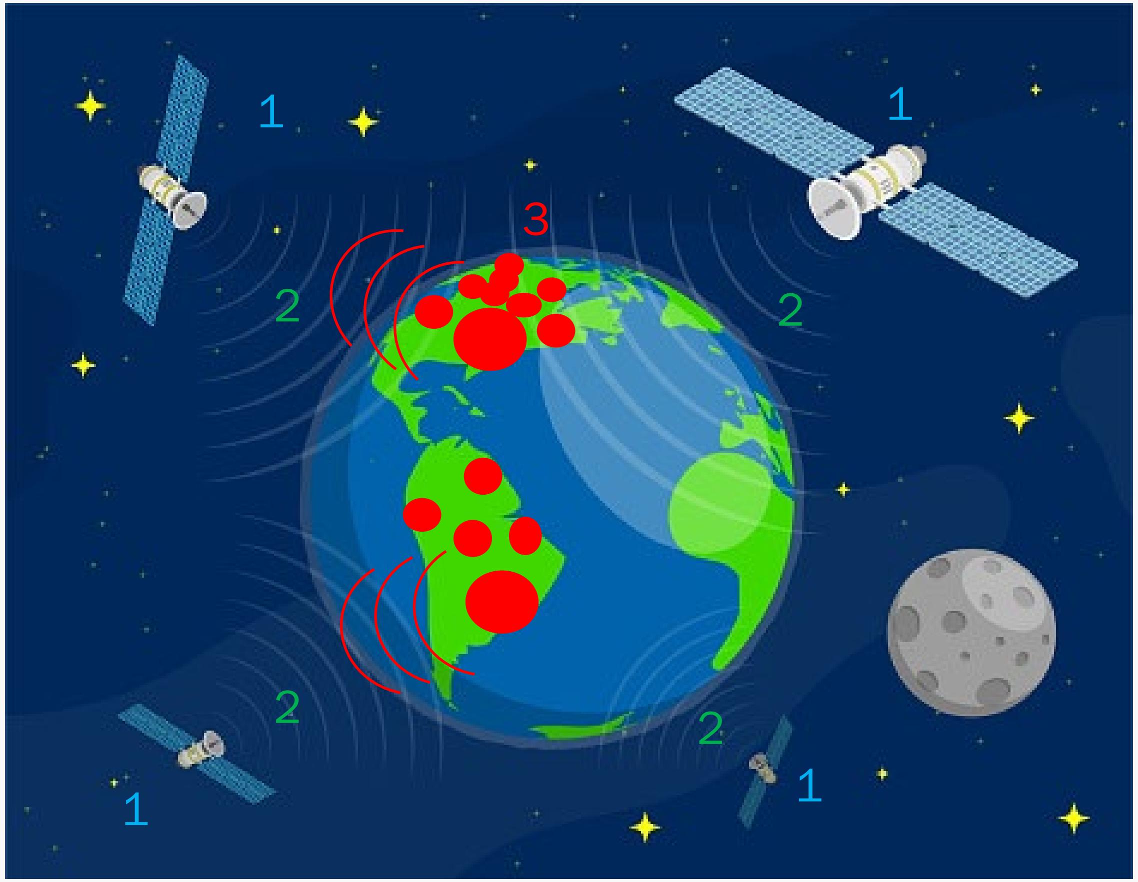
RFI Simulation Tool

Module 1: Orbit Generation
- Generate Orbit Geometry
- Choice of Satellite Platforms
- Constellations vs Single satellite

Module 2: Instrument
- Instrument Characteristics
- Antenna Pattern Characteristics
- Footprint Projection on Earth

Module 3: Deployment of RFI Sources
- Deployment of 5G Base Stations and User Equipment
- Calculation of the radiated Power
- Simulation of Instrument measurements in presence of RFI

Module 4: RFI Detection Algorithms
- Implementation of existing RFI algorithms
- Implementation of new RFI algorithms
- Adaptable RFI detection algorithms depending on locations



RFI Simulation Tool:
- Simulation of any configurations of satellite constellations
- Simulation of any instrument characteristics
- Simulation of any RFI characteristics

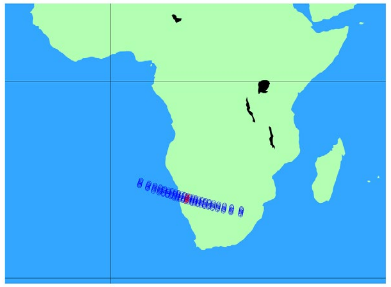
⇨ Assessing the probability of detection & false alarm rate of RFI for any system configuration

RFI Simulation Tool: Development Underway

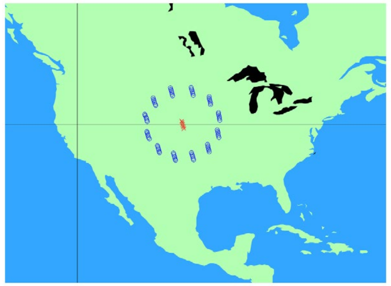
Simulation Tool Inputs

Orbit and Instruments

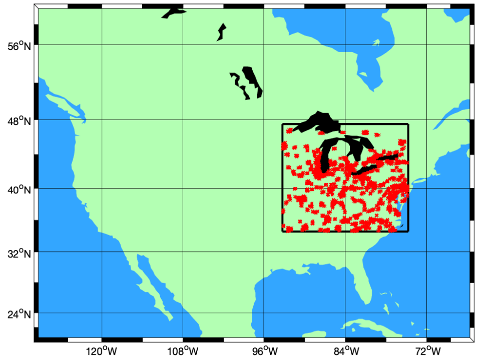
ATMS



SMAP



5 G Network Deployment



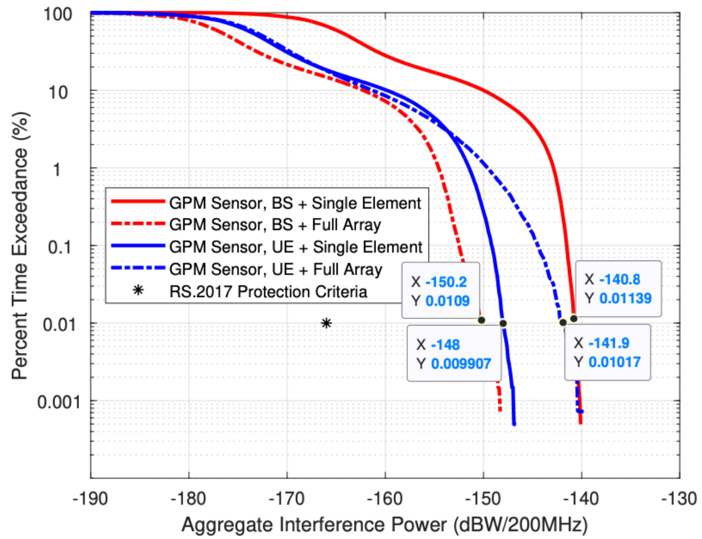
Test

- Variation of number of base stations, user equipment
- Variation of input power of base stations and user equipment
- Variation of frequency channels impacted by RFI
- Implementation of RFI detection algorithms

Simulation Tool Outputs

- The simulation will provide **the probability of RFI detection** as function of **instrument characteristics** (frequency impacted, number of frequency channels…), **RFI characteristics** (amplitude, spatial and temporal distribution)

Figure 19: Interference CCDF for GPM Sensor (Out-of-Band Limits)

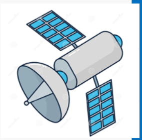


Ref: NASA and NOAA 24 GHz Sharing Studies GPM

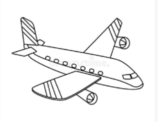
Real World RFI Surveys Needed

- 3 Joint Venture hyperspectral projects were recently awarded. The teams will demonstrate hyperspectral sounders on 3 different platforms:
  - *An aircraft*
  - *A balloon*
  - *A satellite*

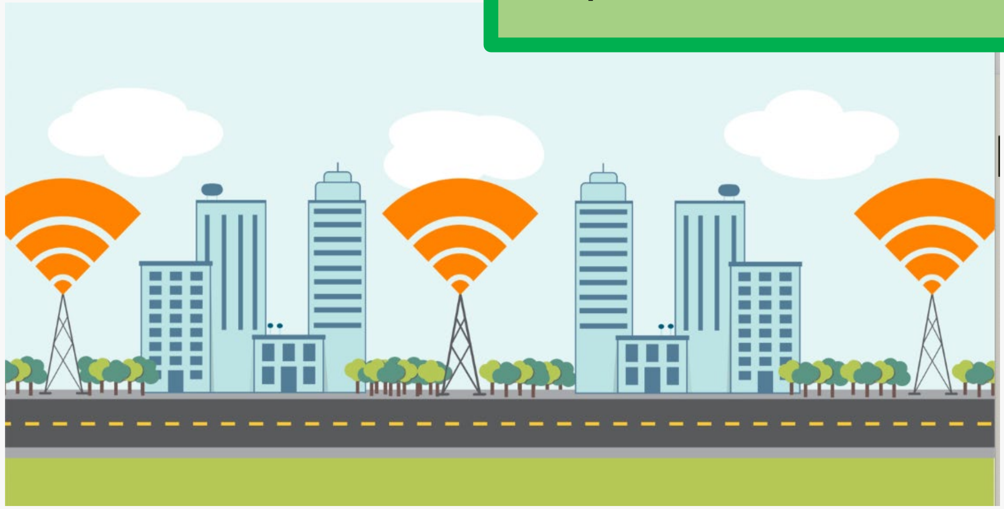
- The hyperspectral hardware can be used to:
  - ***Measure real world RFI; verify RFI simulation tool accuracy***
  - ***Possibly test RFI detection algorithms***
- These RFI data sets will be used to:
  - *Characterize spatial and temporal distribution*
  - *Test RFI detection algorithms*
  - *Evaluate detection in ground processing vs. on board processing*



Using RFI Observations from satellites may be useful to **test RFI detection algorithms**



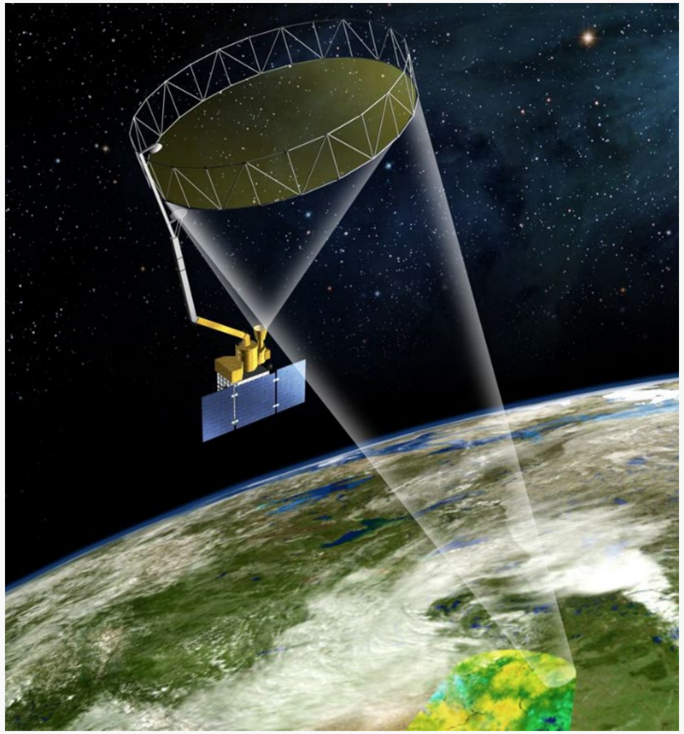
Airborne RFI Surveys close to the source to better characterize **spatial** and **temporal** distribution



Real World RFI Surveys Needed

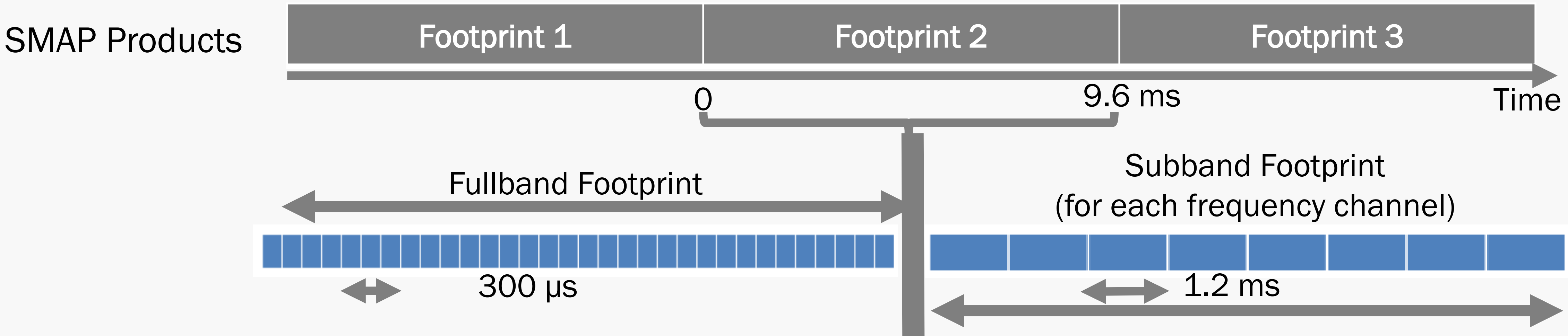
- Leverage assets and activities to characterize real world RFI
  - *Near future activities:*
    - Joint Venture Hyperspectral demos
    - 2024 timeframe, short duration projects
    - 50 GHz likely, but 24 GHz unsure
    - limited geographic coverage
  - *Longer term needs:*
    - Ongoing characterization RFI info as it evolves
    - Observe key bands (e.g. 24, 50, 88 GHz)
- Leverage existing RFI survey tools
  - *Goddard RF Explorer (GREX): a 24TB real-time RF signal recorder; requires RF front ends*
  - *RF front ends from AESMIR (airborne mw radiometer, 24, 36, 89 GHz; add 50 GHz)*

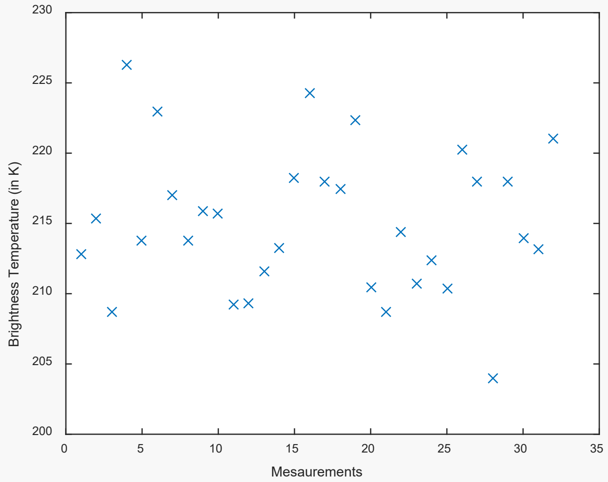
RFI Detection Algorithms



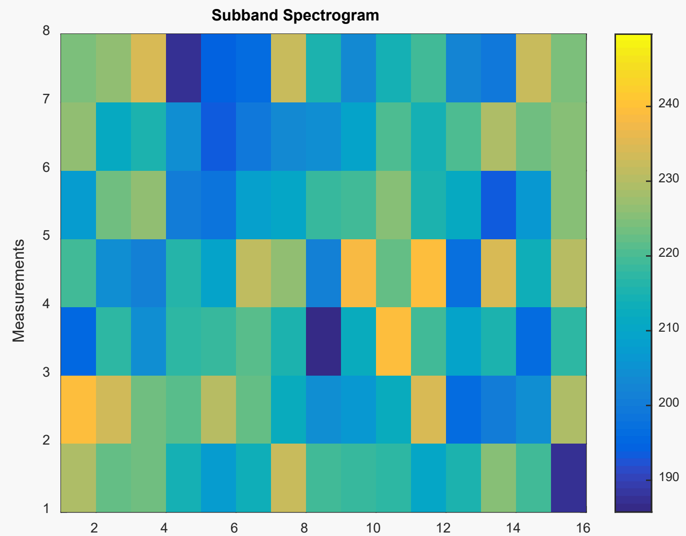
- RFI Detection algorithms were developed for the Soil Moisture Active/Passive Mission (SMAP)
- SMAP was especially designed to include a digital back end that allows for RFI detection and filtering.
- SMAP measures the four Stokes parameters and performs RFI detection on each four Stokes parameters in both time (fullband) and frequency (subband) domains.
- Within the SMAP brightness-temperature ground algorithm, RFI mitigation (detection and removal) is performed after radiometric calibration and before conversion of antenna temperatures TA to surface-referenced brightness temperatures.
- SMAP RFI Detection and Filtering are performed in ground processing.

SMAP RFI Algorithm Example





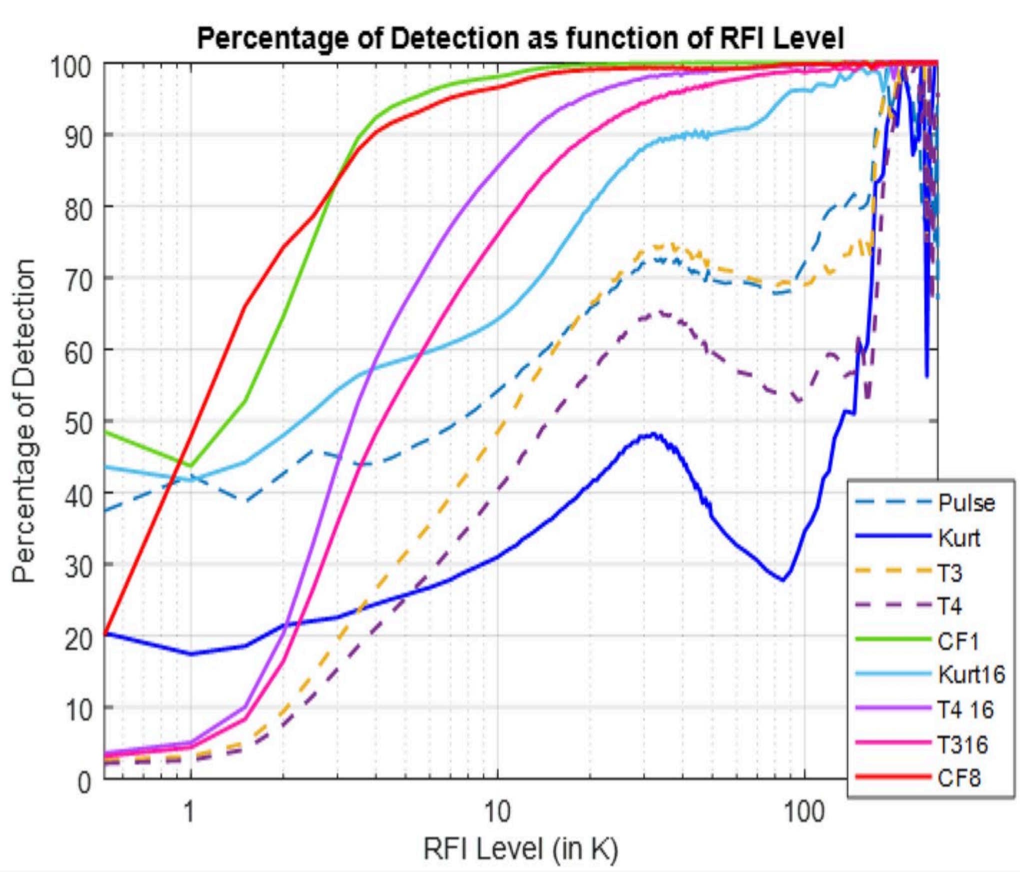
Example of a Fullband footprint



Example of a Subband footprint (Spectrogram)

SMAP RFI Algorithms

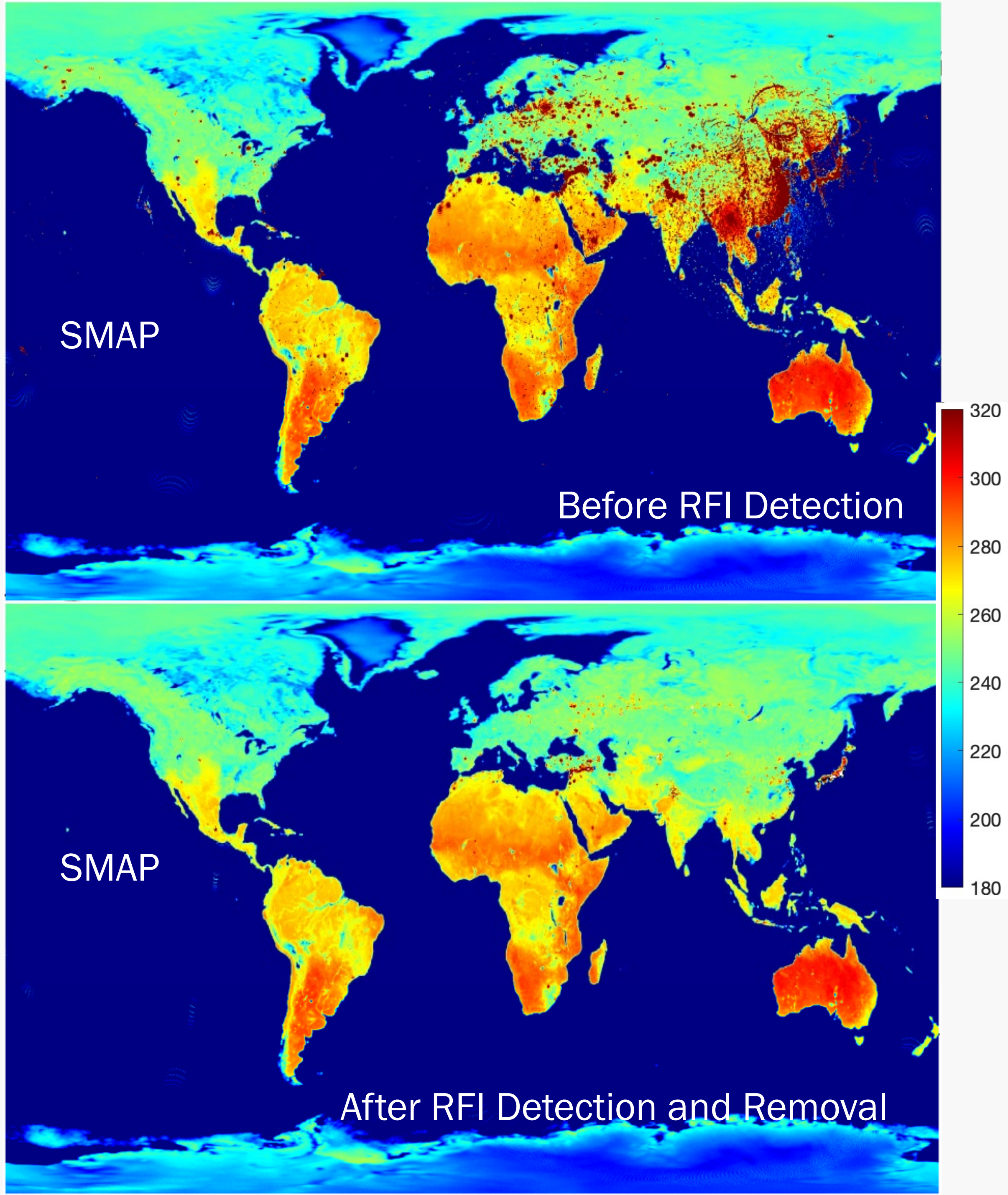
- Time/Frequency domain detectors (Pulse, CF1,CF8):
  - *These detectors search in time or frequency domain for abnormal increase in antenna temperature levels*
  - *These detectors are particularly suitable to detect short pulses (in time domain) and narrowband RFI (in frequency domain)*
- Statistical detectors (Kurt, Kurt16):
  - *These detectors work on the statistical distribution of the raw signal. In presence of RFI, the statistical distribution of the signal differs from the expected Gaussian distribution. Any deviation of the nominal kurtosis value for a Gaussian distribution is identified as RFI.*
  - *These detectors are particularly suitable to short pulses (in time domain) or continuous RFI (in frequency domain).*
- Polarization Detectors (T3, T4, T3 16, T4 16):
  - *These detectors operate on the 3rd and 4th Stokes parameters. They compare those parameters to a fixed threshold that was set from a post-launch data analysis*
  - *These detectors were turned on post launch to complement the other detectors.*
- Maximum Probability Detector:
  - *The Maximum Probability Detector is an OR combination of all the fullband and subband RFI detectors*



Anomaly Detectors + Statistical detectors + Polarization Detectors = MPD

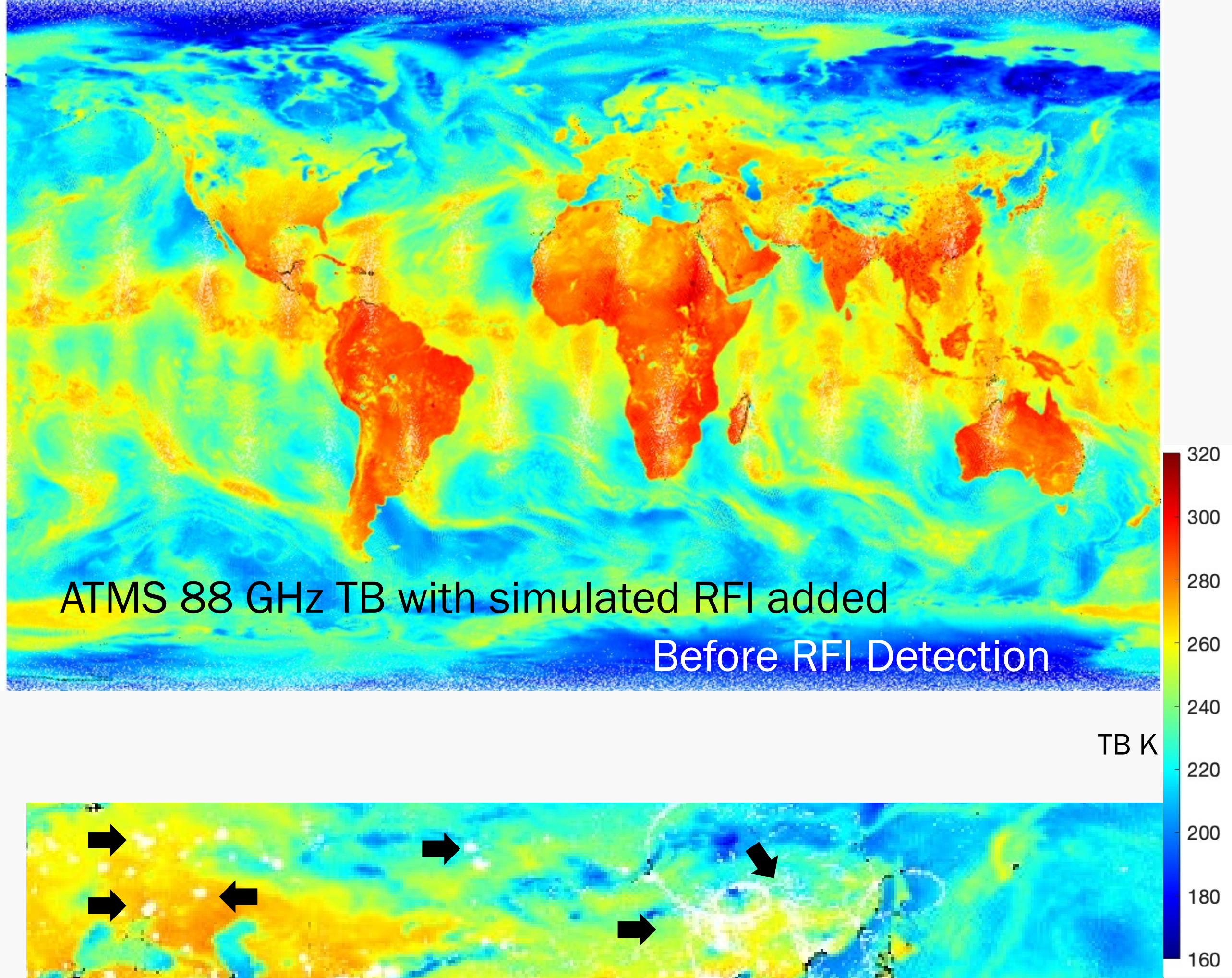
SMAP RFI Algorithms

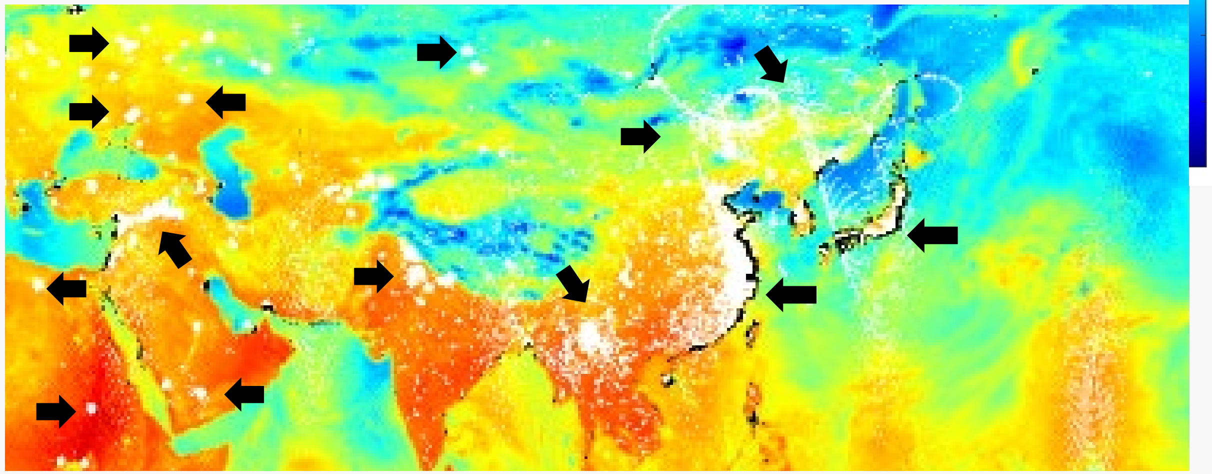
- **Max-hold** map of **SMAP** Brightness Temperature before (top) and after (bottom) RFI detection and excision for January 2022
- The ”**hot spots**” on the top map represent the **RFI** observed by SMAP over the month of **January 2022**.
- After RFI detection, **most** of the hot spots have been identified as RFI and the RFI was **excised.** However, some **residual RFI** (or undetected RFI) are still **visible** on the map, in Spain or Turkey for instance. → detection and excision are not perfect
- After analysis, the residual RFI were often found to be **medium wideband continuous RFI**. The current SMAP RFI detection algorithms are not designed to detect this type of RFI (which is more like 5G RFI).
- This example demonstrates the **necessity** of **implementing** RFI detection **algorithms**. However, the RFI encountered by microwave sounders such as ATMS will be **more diffuse** and **not as obvious.** New RFI detection algorithms need to be designed in order to detect such **low continuous RFI**.
- **It is important to note that RFI *excision* is practical for SMAP. However, in the case of microwave sounders, only RFI *detection* will be possible.**



Simulation of Sounder Data Loss Due to RFI

- This is an example of how ATMS observations might appear when RFI contamination is present.
- The top map represents **ATMS TB observations** for channel 16 (88 GHz). **RFI** (~ 15 K) was **added** in locations where SMAP has observed RFI.
- The bottom map illustrates the data **after RFI detection**. Since RFI *excision* won't be practical in case of microwave sounders measurements, RFI detection will result in **data loss** (white areas).
- **Data loss** can occur over **large areas** as seen for China. 5G RFI are expected to be strongest in **urban areas** and might result in significant data loss in and near those regions.





After RFI Detection & Data Deletion (white areas)

Won't Existing RFI Algorithms Fix Everything?

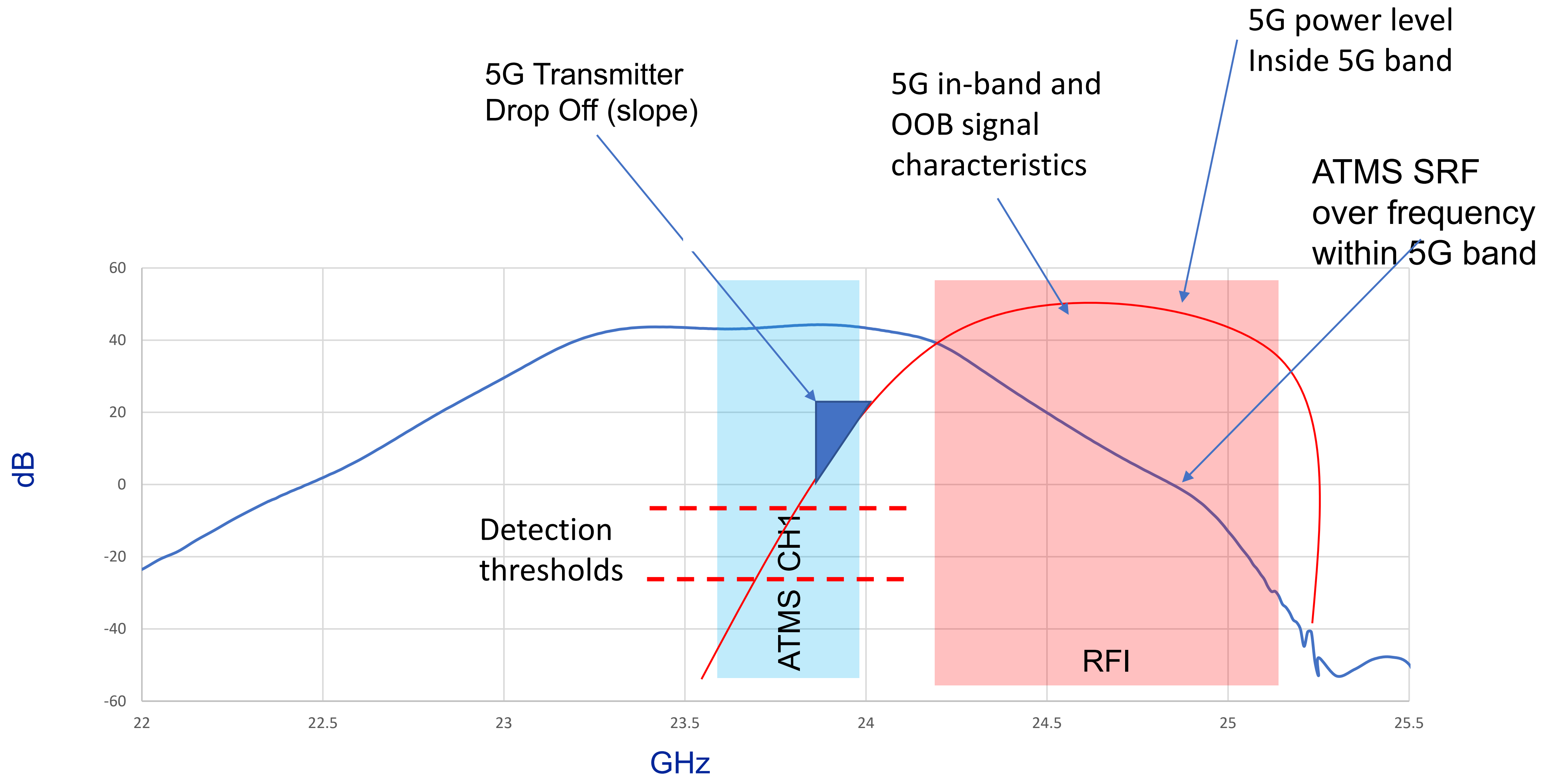
- The SMAP-style algorithms are not expected to work so well for detecting 5G RFI:
  - *5G signal characteristics are expected to be different from the RFI observed by SMAP in ways that will make them hard to detect by SMAP-style RFI algorithms*
  - *5G signal power levels are expected to be much smaller than RFI observed by SMAP*

Time/Frequency Detectors	Statistical Detectors	Polarization Detectors
These detectors work well for high-power RFI and localized (either in time or frequency) RFI. Therefore, these detectors are not expected to perform well for wideband low-power 5G RFI.	The detectors work well for short pulses. Therefore, these detectors are not expected to perform well for 5G RFI as they are expected to be continuous signals.	These detectors work well for RFI presenting significantly polarized signals. These detectors are not expected to work well for 5G RFI as 5G signals are expected to be nearly unpolarized. Plus, most sounders don't discriminate among polarizations.

New RFI Detection Strategies

- New Detection Strategies are needed to address two key expected differences of 5G RFI
  - ***Different characteristics of 5G signals*** *(vs. SMAP-like RFI)****:***
    - 5G signal characteristics must be studied to identify candidate detection algorithms
    - This must include the propagation effects of urban environments, which will be challenging to determine without real-world RFI surveys
  - ***Lower Amplitude Signals: :***
    - In-Band Detection: this is the traditional (direct) approach—look within the science channel itself. However, the RFI amplitude may be near the noise floor and the false detection rate is a concern
    - Out-of-Band Detection: look for the 5G signal in the 5G band where it is expected to be the strongest, and infer the presence of RFI in the science band (an indirect approach—recall that in-band RFI is "leakage" from out-of-band)

How to Characterize the Detection Scenario?



Summary and Suggestions

- Future microwave sounders will require RFI detection capabilities in order to keep providing highly accurate measurements (already in draft requirements for future sounders)
- RFI Detection will produce a flag for each footprint. In order to set this flag, a simulation tool is needed to implement RFI Detection Algorithms and assess the probability of detection vs the false alarm rate of the detectors
- The simulator needs accurate input information: 5G signal characteristics, satellite configurations, sensor configurations. Some of this is difficult to obtain (e.g., proprietary)
- Satellite-based RFI surveys must be interpreted with extreme care; results can/will be misconstrued
- Real world 5G RFI data is needed to test detection algorithms, estimate the false alarm rate and the probability of detection, and generally validate the simulation tool
- The Joint Venture hyperspectral demos is an opportunity to collect some initial RFI survey data
- RFI surveys covering additional bands, locations, etc. will be needed. Existing RF survey tools can be leveraged to reduce cost, shorten lead time, reduce risk
- Intercomparing RFI survey results from mulitple sensors requires attention to absolute (inter)calibration
- New 5G RFI detection algorithms must be designed and tested
- The earlier the RFI surveys start, the sooner
- A combination of technological and scientific approaches should be explored
- ‘5G’ is only one kind of RFI…losing a band sets a precedent we might not want…