THE OHIO STATE UNIVERSITY

Radio Frequency Interference Observed In 500-2000 MHz Microwave Radiometer Measurements

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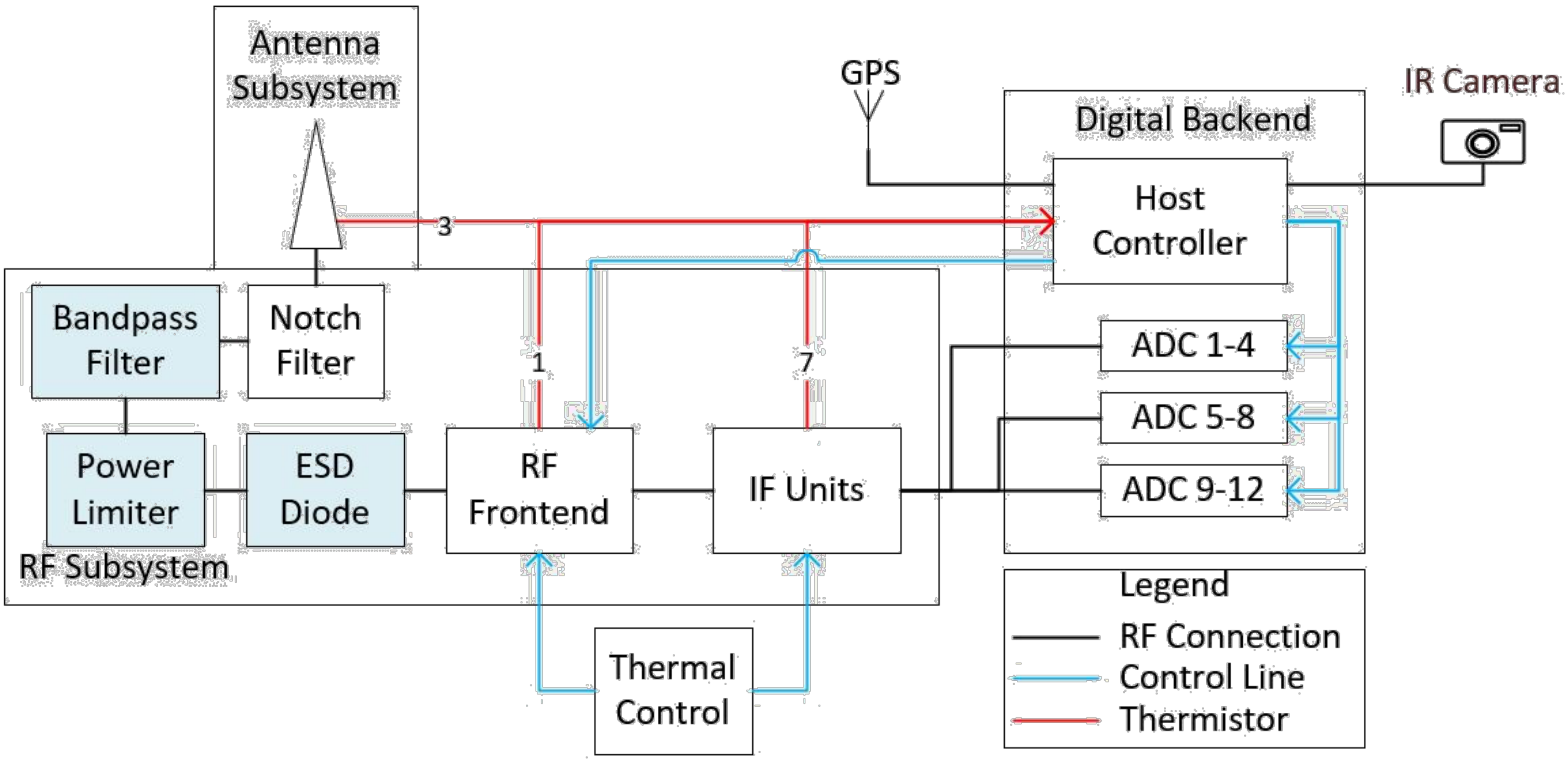
Introduction

- UWBRAD is an airborne 500-2000 MHz radiometer that was developed through the National Aeronautics and Space Administration's (NASA) Instrument Incubator Program (IIP)
- These wideband radiometer measurements can be used to monitor geophysical parameters such as physical temperatures within ice sheets, the thickness and salinity of sea ice, and other medium properties
- After the initial results showed promise, the UWBRAD instrument was repackaged for two additional ground-based measurements
    1. A reduced channel version was part of the Multidisciplinary Drifting Observatory for the Study of Arctic Climate (MOSAiC) expedition to the Arctic in 2020
    2. The full channel version was used as part of a project at Keweenaw Research Center in Calumet, Michigan in 2020-2021
- This presentation will summarize the RF environments encountered on these missions across the 500-2000 MHz range

UWBRAD Instrument Description

- UWBRAD is a 500-2000 MHz radiometer that measures twelve channels with one stop band from 1000-1100 MHz
  - The MOSAIC version only viewed four channels with center frequencies 540 MHz, 900 MHz, 1380 MHz, and 1740 MHz
- UWBRAD's primary components are:
  - Wideband conical log spiral antenna (circular polarization)
  - RF Frontend
  - IF Downconverters
  - Analog-to-Digital Conversion
  - Software-defined Data Backend
- Other auxiliary components (e.g., thermal control, a downward-facing IR camera, 3-axis GPS, etc) are also included as part of the system for different missions

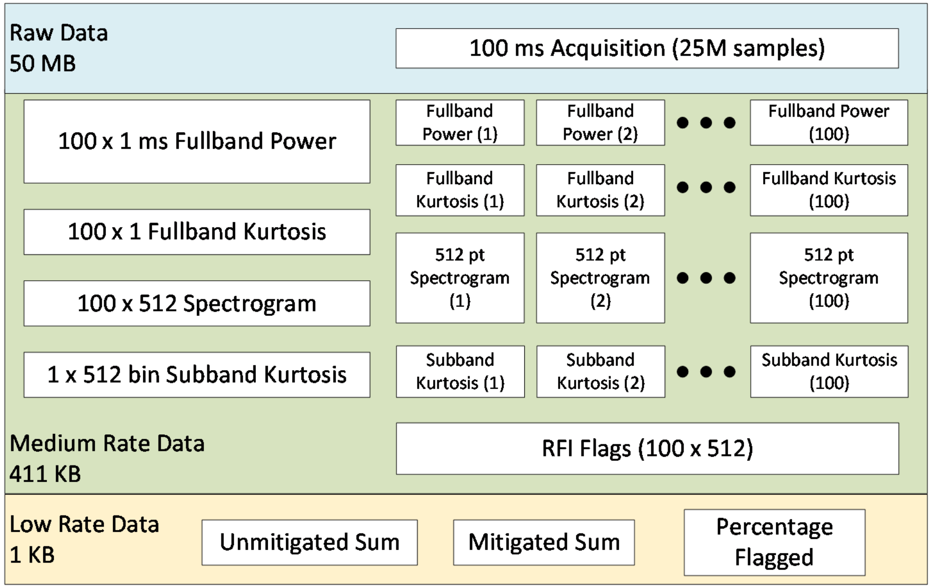
UWBRAD Block Diagram



UWBRAD Block Diagram – Units in blue added after 2016 Greenland Campaign

Data Description

- Each of UWBRAD's twelve channels acquires 100 msec of data at 250 Msamples/sec (16 bits/sample)
- Kurtosis and a 512 point power spectrum are computed at 1 msec intervals, resulting in an overall 100x512 brightness spectrogram with a pixel resolution of 1 msec x 244 kHz
- Four different algorithms are applied to identify and remove RFI (in the following order): fullband kurtosis, subband kurtosis, pulse blanking, and cross-frequency
  - Algorithms inspired by those used on SMAP radiometer



Fullband Kurtosis

- The fullband kurtosis algorithm is applied first and its primary goal is to identify and ignore intervals with large RFI
- The threshold for this algorithm is set such that its false alarm rate (FAR) is near zero so that data that may be flagged more precisely by subsequent algorithms is not discarded
- Each 1 msec interval with kurtosis κ_{FB} is flagged as RFI if:

$$|\kappa_{FB} - 3| > 0.06$$

- To prevent total loss from persistent RFI, if over 80 msec of data are flagged in one acquisition, none of the intervals are flagged

Subband Kurtosis

- After the fullband kurtosis flags are applied, the remaining algorithms use spectrogram data
- A maximum overall FAR of 7.5% was chosen so that a NEDT of 1.0 K would not increase NEDT to greater than 1.04 K for a 100 msec integration in one channel $\left(\frac{1}{\sqrt{0.925}} = 1.04\ \mathrm{K}\right)$
- UWBRAD allocates 2.5% false alarm rate individually to each of the remaining three algorithms to achieve this
- The kurtosis of the subband power for each 1 msec interval is calculated
- Each frequency bin with kurtosis κ_{SB} is flagged as RFI if:

$$|\kappa_{SB} - 3| > 0.057$$

Pulse Blanking

- After the kurtosis algorithms have removed non-Gaussian behavior, any remaining outliers in time and frequency are identified with the pulse blanking and cross-frequency algorithms respectively
- These algorithms are based on the Median Absolute Deviation (MAD) Method [Peck]
- For pulse blanking, the median value of each bin is subtracted from the spectrogram, and then the median of the absolute value of this deviation is calculated to give the MAD, δ_{PB}
- Pixels with power P in frequency bin with median power μ are flagged as RFI if:

$$|P - \mu| > 4.01 * \delta_{PB}$$

Cross-Frequency

- The cross-frequency algorithm is similar to the pulse blanking algorithm but applied across frequency instead of time
- To prevent natural power differences across frequency from being flagged as outliers, a moving 1 minute median filter is applied to the frequency bins over time and subtracted from the frequency response, centering values around zero
- After this centering, the MAD method is applied to calculate median power across frequency μ_{CF} and δ_{CF}
- Frequency bins with power P in frequency bin with median power μ are flagged as RFI if:

$$\left|P - \mu_{CF}\right| > 3.5 * \delta_{CF}$$

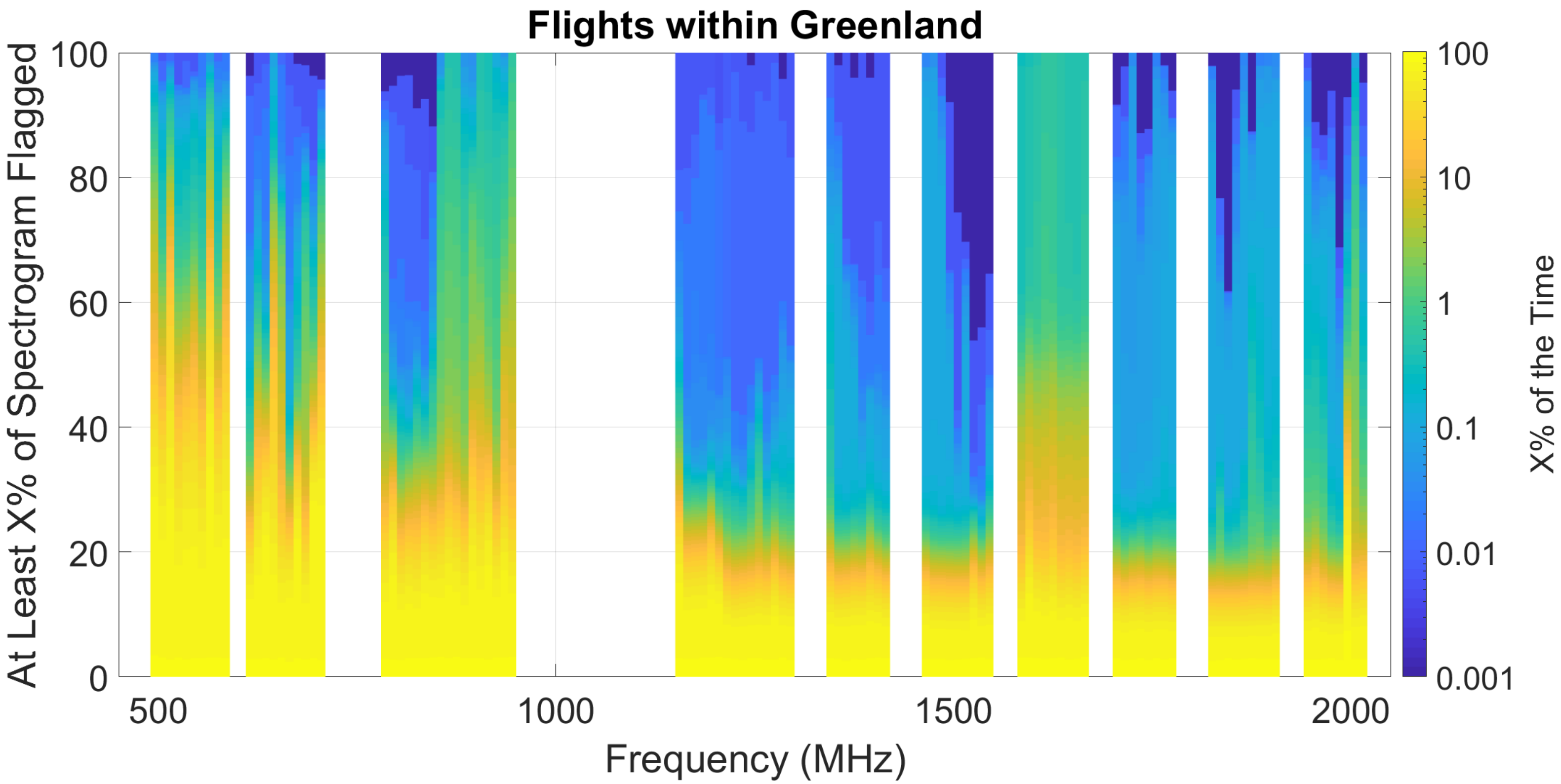
Research Contributions

- UWBRAD's calibration procedure was developed and shown to be stable and accurate through liquid nitrogen testing
- The order of operations and thresholds for each of UWBRAD's RFI algorithms were defined to allow a FAR of ~7.5%
- These techniques were used to analyze the UWBRAD campaign data

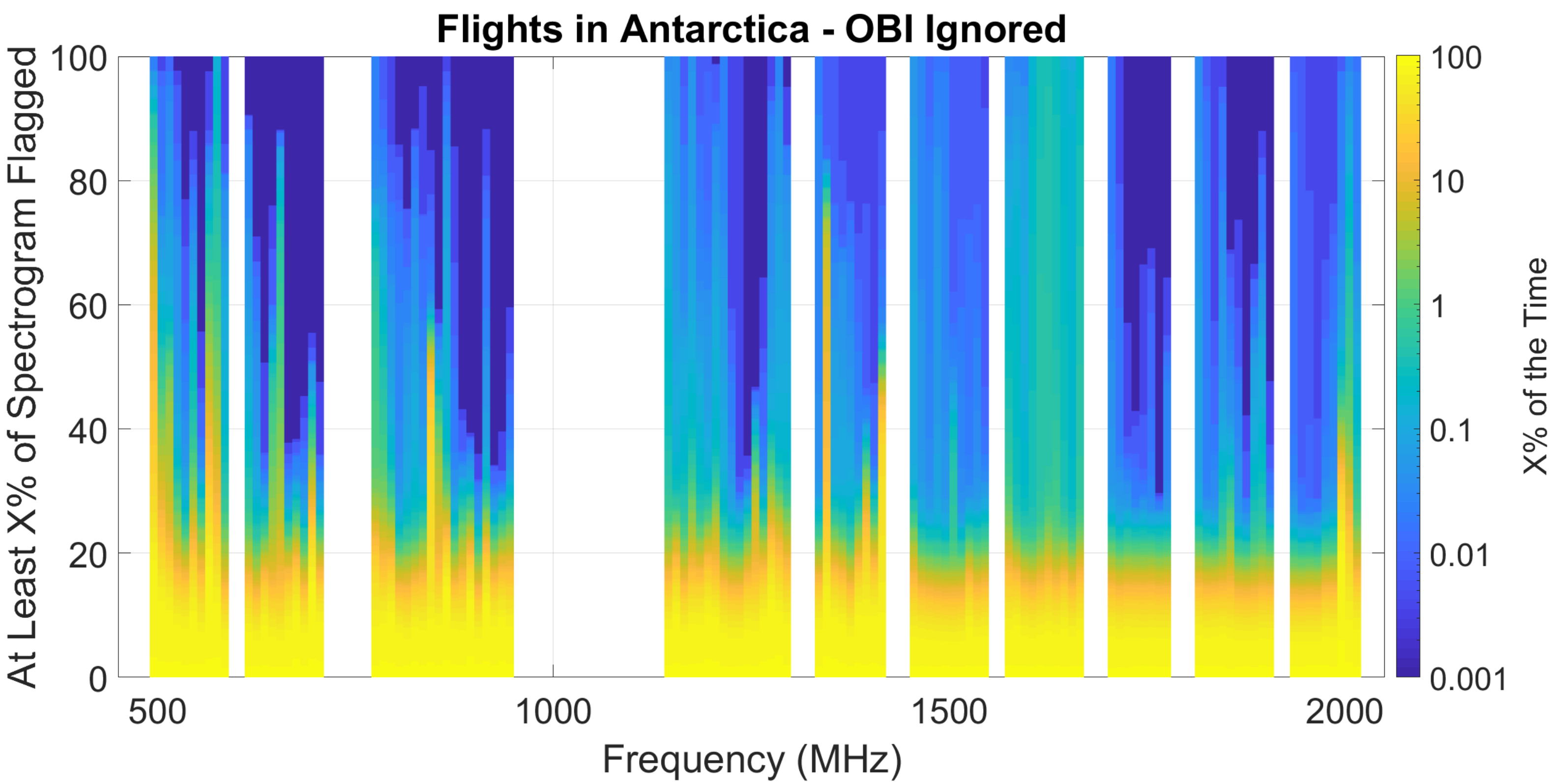
RFI Environment Results Interpretation

- Due to the wideband nature of UWBRAD, quantitative results involve far too much information for a conference presentation
- The following images are Complementary Cumulative Distribution Functions (CCDFs) presented at 10 MHz resolution
  - The CCDF (color scale) can be interpreted as "In this frequency band, X% of the spectrogram was flagged as RFI Y% of the time", where X is the height of the bar and Y is the color
- Qualitatively, "blue" means rarely, "green" is ~1% of the time, and ""yellow" means frequently
- Since most of these bands are unprotected, this is more of an "RF" environment than "RFI" environment

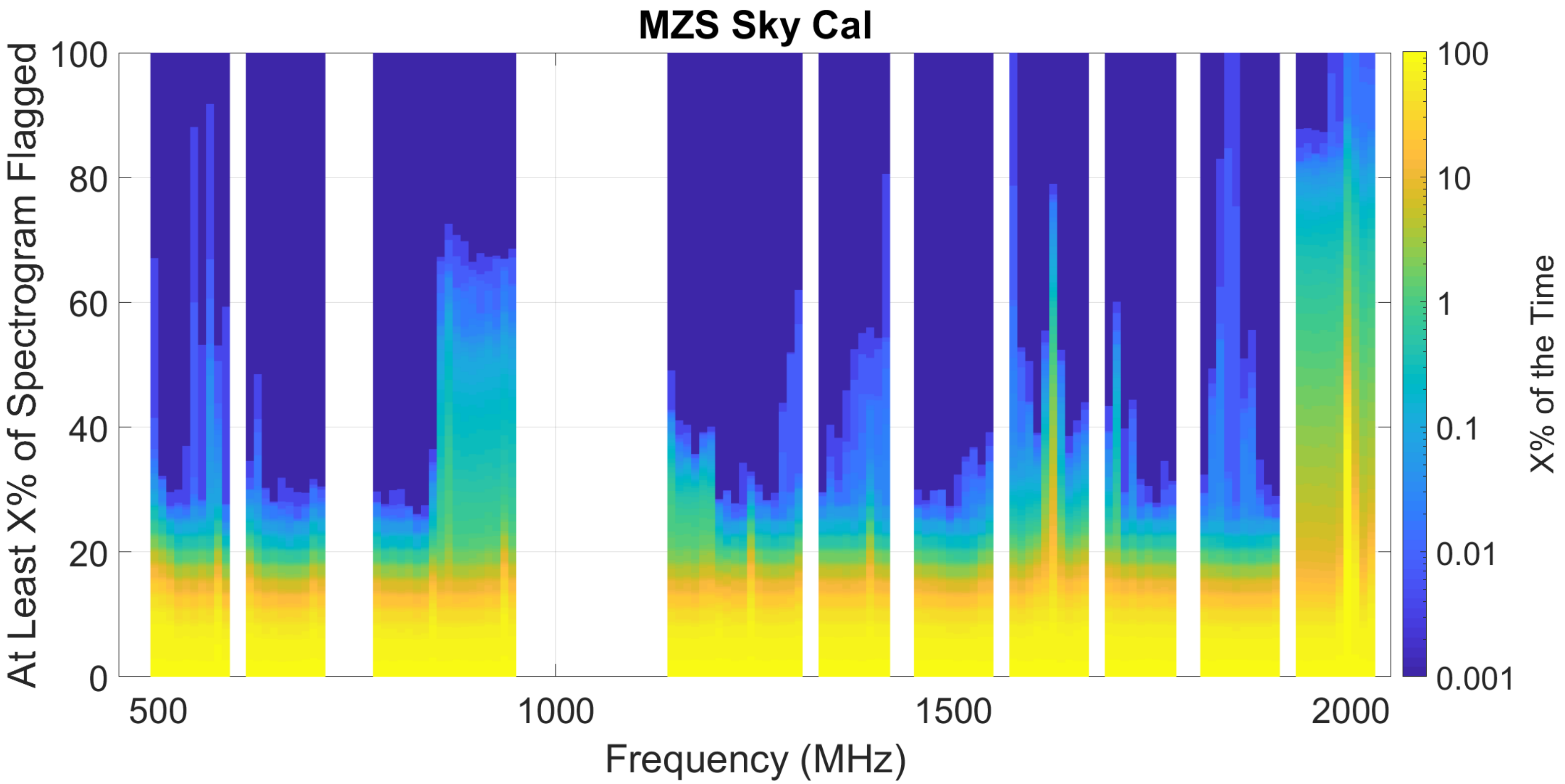
Greenland 2017



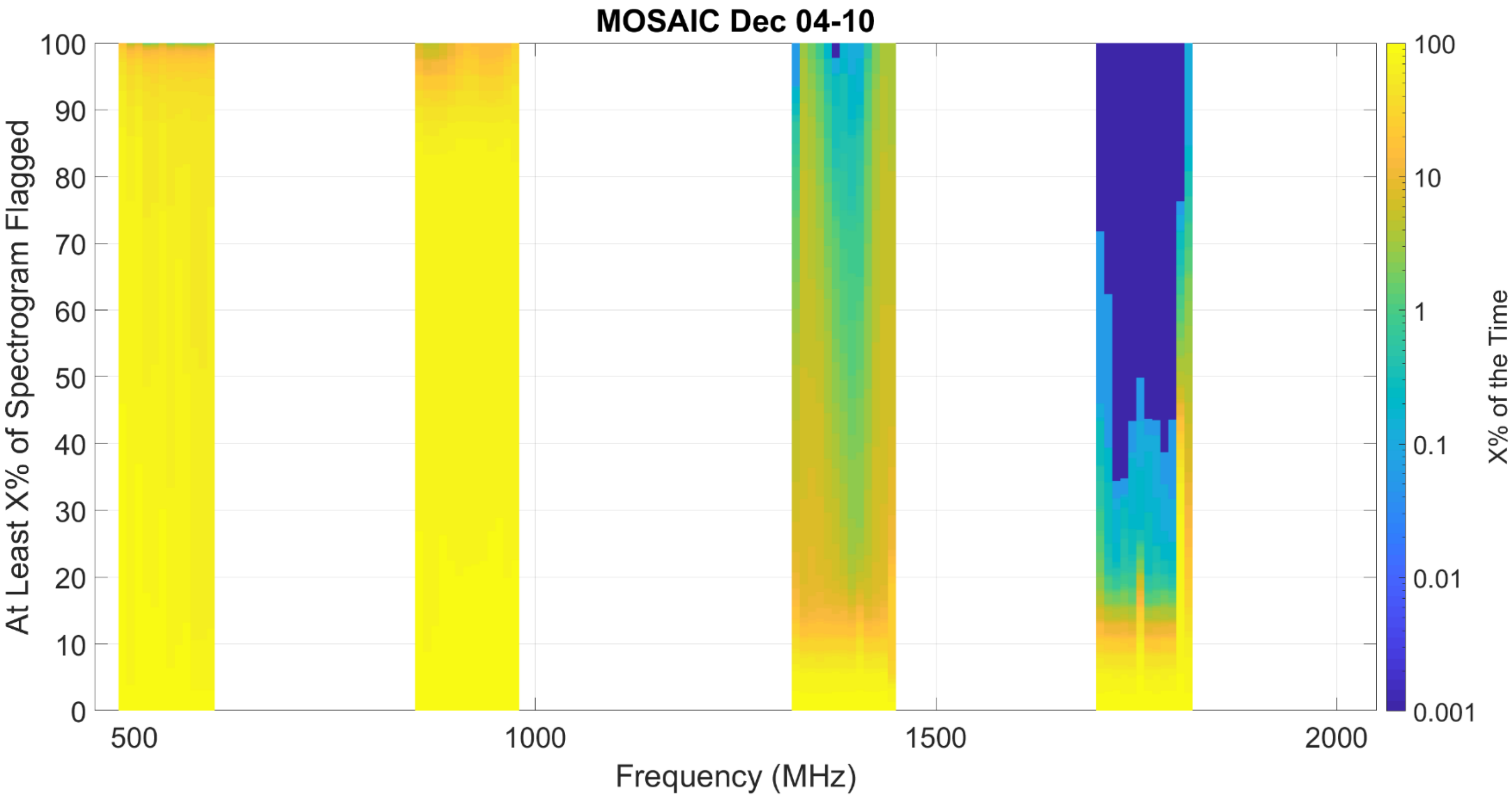
Antarctica 2018



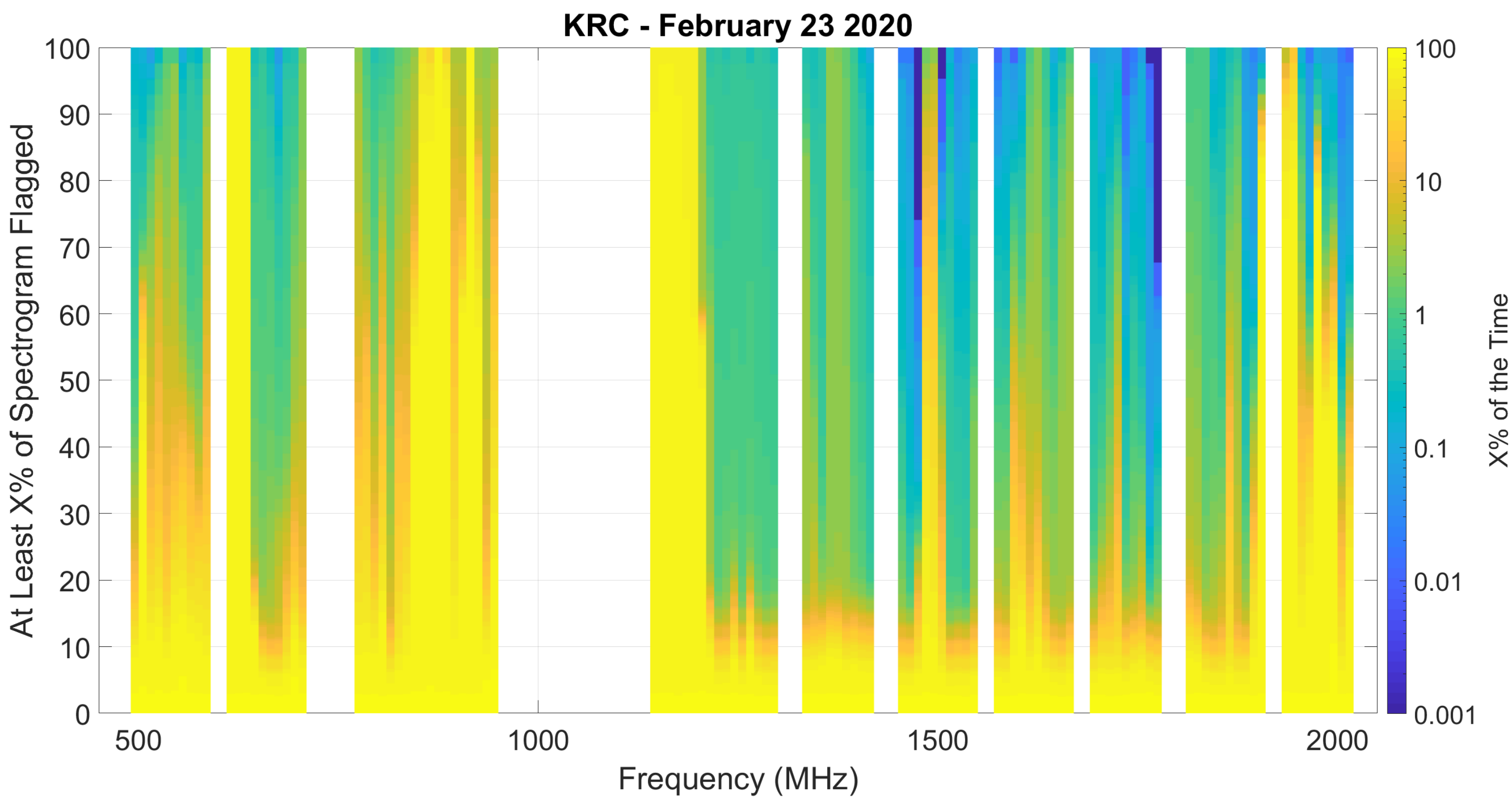
Antarctica Ground Test 2018



MOSAIC 2020


MOSAIC Dec 04-10
At Least X% of Spectrogram Flagged
100
90
80
70
60
50
40
30
20
10
0
500
1000
1500
2000
Frequency (MHz)
100
10
1
0.1
0.01
0.001
X% of the Time

KRC 2020


KRC - February 23 2020
At Least X% of Spectrogram Flagged
100
90
80
70
60
50
40
30
20
10
0
500
1000
1500
2000
Frequency (MHz)
100
10
1
0.1
0.01
0.001
X% of the Time

Results Discussion

- RFI in the original UWBRAD missions was lower in Antarctica than in Greenland, and lower still on the ground in Antarctica than in the aircraft
- RFI was more prevalent below 1 GHz than from 1-2 GHz, but results were obtainable in all 12 channels
- The packaging of the MOSAIC instrument resulted in significant self-interference in the lower frequency bands
- Clean measurements below 1200 MHz are much more difficult to obtain in Michigan, results above that frequency still lose approximately 1% of the data to RFI

Conclusions

- Wideband radiometry presents an opportunity to passively observe and collect measurements that can reveal more information than narrowband measurements
- Operation outside protected bands requires some knowledge of the RF environment the instrument will be operating in to protect against excessive interference or even damage to equipment
- Using commercial off the shelf equipment may lead to self-interference
- Most bands are able to operate with <1% data loss, and usable data is still recoverable in the other bands