

L-band Active and Passive Mission Updates and Interference Protection

Rajat Bindlish, Priscilla Mohammed
NASA GSFC

Mohammad Al-Khaldi, Joel Johnson
Ohio State University



Outline

- L-band Science and Applications
- Radio Frequency Interference (RFI) analysis
 - Passive Radiometry (SMAP)
 - Reflectometry (CYGNSS)
 - Active Radar (NISAR)
- Summary

L-band Science

Soil Moisture

- High-resolution and frequent-revisit
- Understand processes that link the terrestrial water, energy and carbon cycles
- Estimate global water and energy fluxes at the land surface
- Enhance weather, flood and drought prediction

Ocean Surface Salinity

- Ocean circulation governed by salinity + temperature
- Global water cycle: Salinity reflects balance between precipitation and evaporation
- Freshening due to ice melt in Arctic
- Balance between Atlantic and Pacific
- Changes in coastal salinity due to increased run off

Ocean Surface Winds

- Effective in intense tropical cyclones
- L-band not affected by rain or clouds
- L-band does not saturate with wind speed

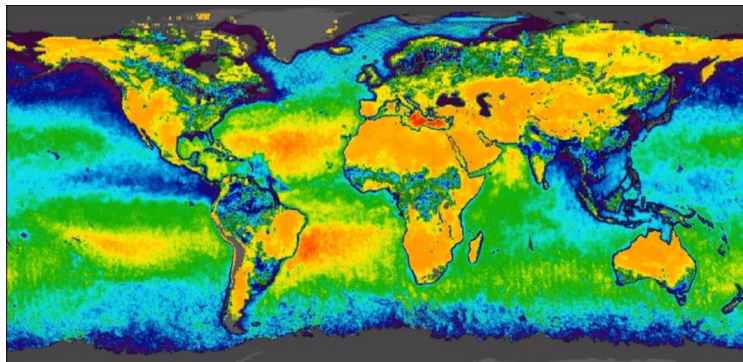
Vegetation Biomass

- Radar observations provide all-weather vegetation biomass
- Microwaves observations saturate at higher biomass
- Food security and agriculture
- Quantify net carbon flux in boreal landscapes

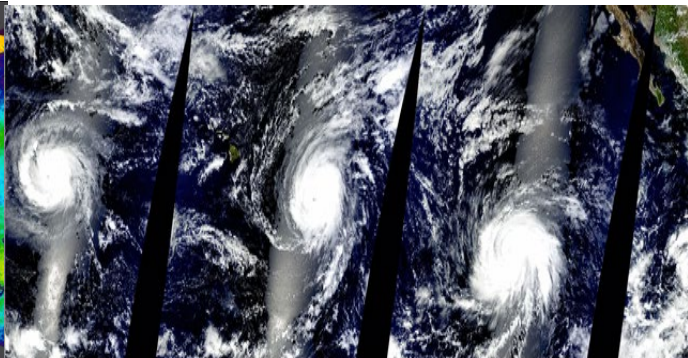
Thin Sea Ice

- Sea ice thickness up to 0.5 m
- Complementary observations to altimeter - thin sea ice
- Summer melt of sea ice and ice sheets can cause freshwater lenses

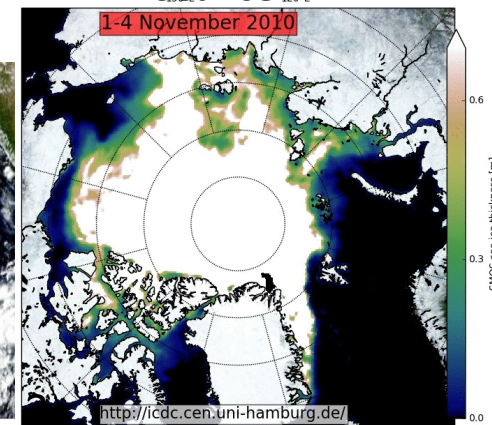
Soil Moisture and SSS from SMAP



Ocean Winds using L-band

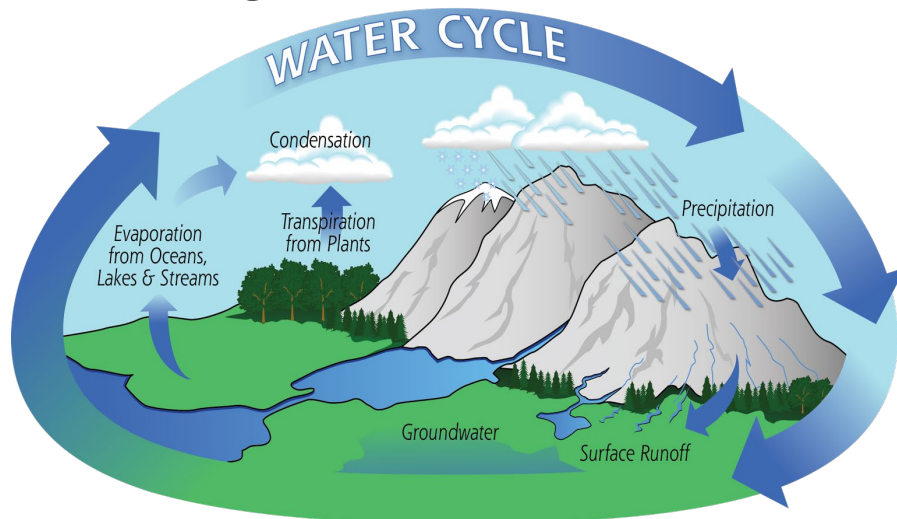


Sea Ice



Soil Moisture Applications

- Terrestrial Water Cycle
- Agriculture and food security
- Weather forecasting
- Water resources
- Disasters – Floods, drought, wildfires, landslides
- Trafficability
- Other – SSS, Thin sea ice, Ocean winds, vegetation water content



SMAP Mission Summary

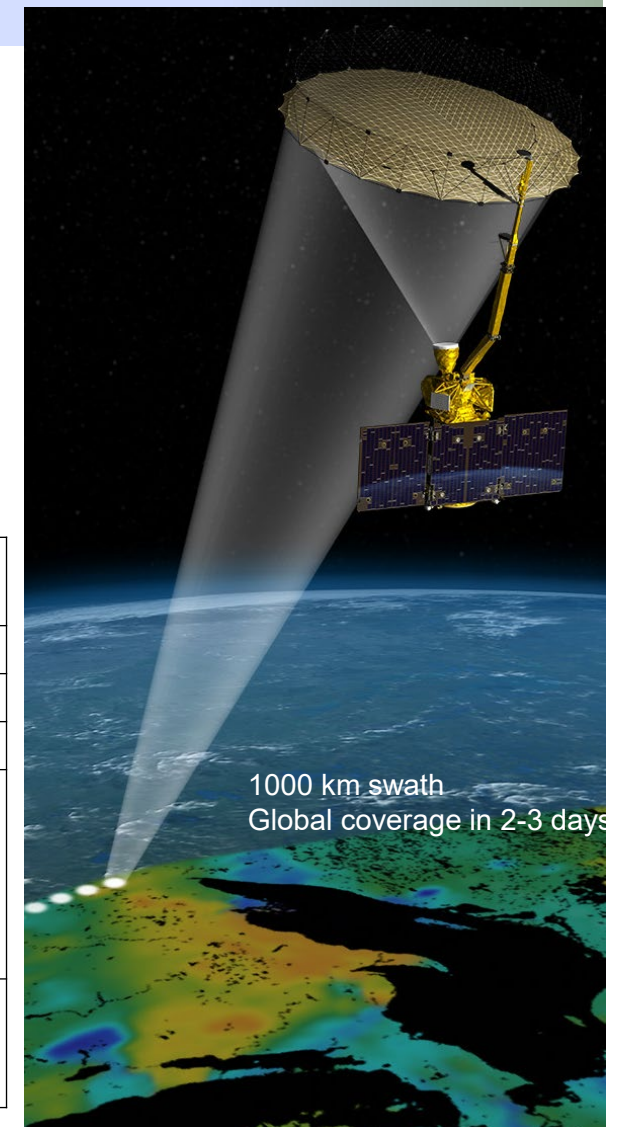
Primary Science Objectives:

Global mapping of soil moisture and its freeze/thaw state to

- Link terrestrial water, energy, and carbon-cycle processes
- Estimate global water and energy fluxes at the land surface
- Quantify net carbon flux in boreal landscapes
- Extend weather and climate forecast skill
- Develop improved flood and drought prediction capability

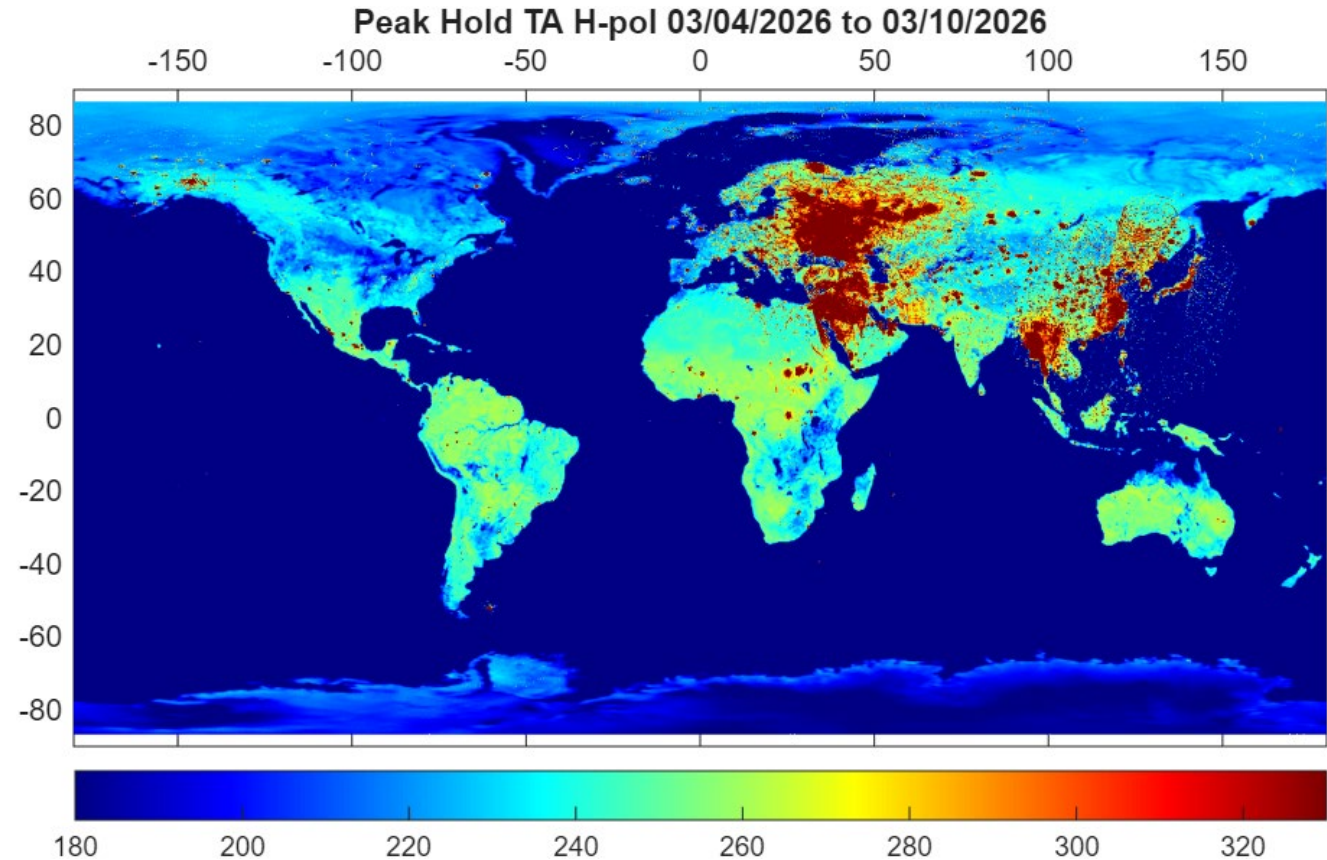
Mission Implementation:

Partners	<ul style="list-style-type: none"> • JPL (project & payload management, science, spacecraft, radar, mission operations, science processing) • GSFC (science, radiometer, science processing)
Risk	<ul style="list-style-type: none"> • 7120.5E Category 2; 8705.4 Payload Risk Class C
Launch	<ul style="list-style-type: none"> • January 31, 2015 on Delta 7320-10C Launch System
Orbit	<ul style="list-style-type: none"> • Polar Sun-synchronous; 685 km altitude
Duration	<ul style="list-style-type: none"> • Prime mission: 3 years (2015–2018) • Extension phase#1: 2018–2020 • Extension phase#2: 2021–2023 • Extension phase#3: 2024–2026 • Extension phase#4: 2027–2029
Payload	<ul style="list-style-type: none"> • L-band (non-imaging) synthetic aperture radar (JPL) (ceased transmitting on July 7, 2015; Now in receive-mode) • L-band radiometer (GSFC): Built-in RFI mitigation mechanism • Shared 6 m rotating (14.6 rpm) antenna (JPL)



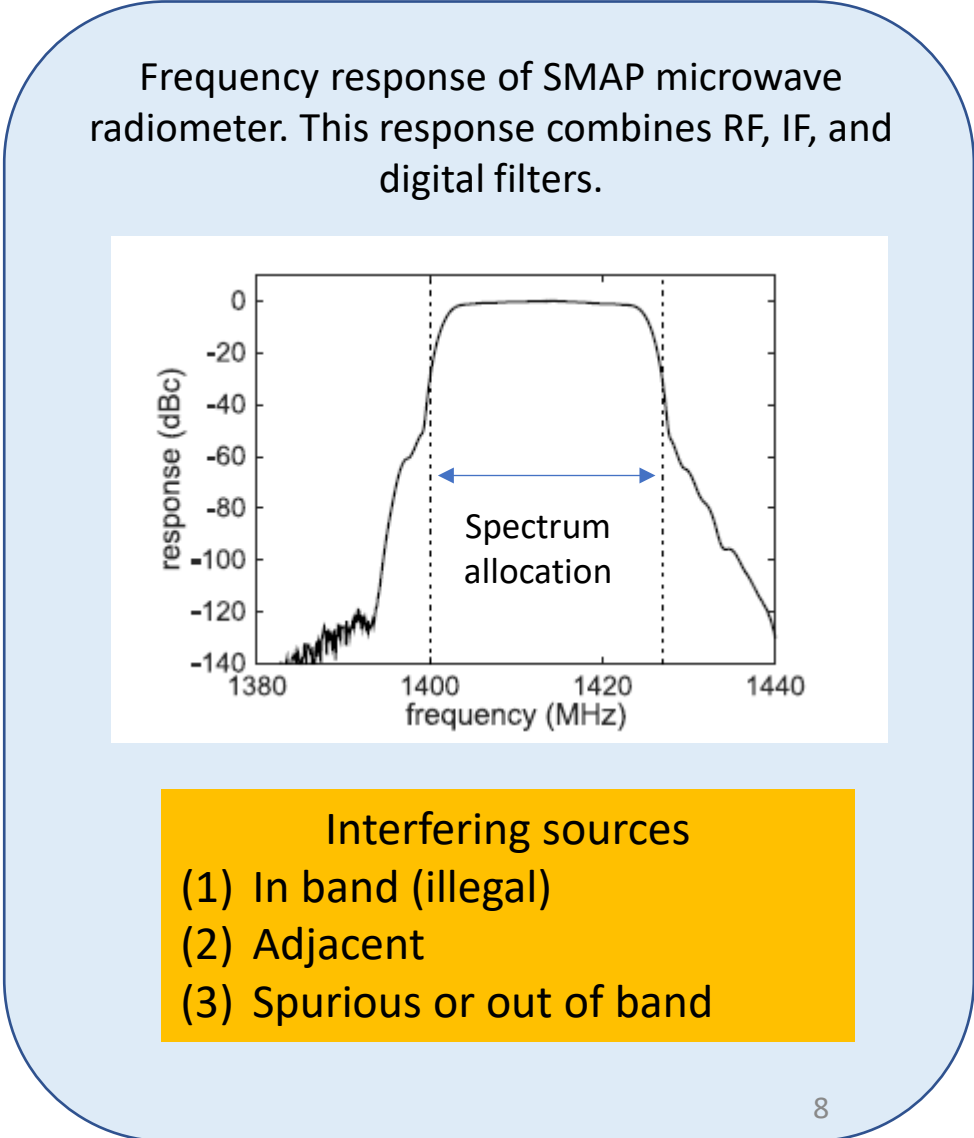
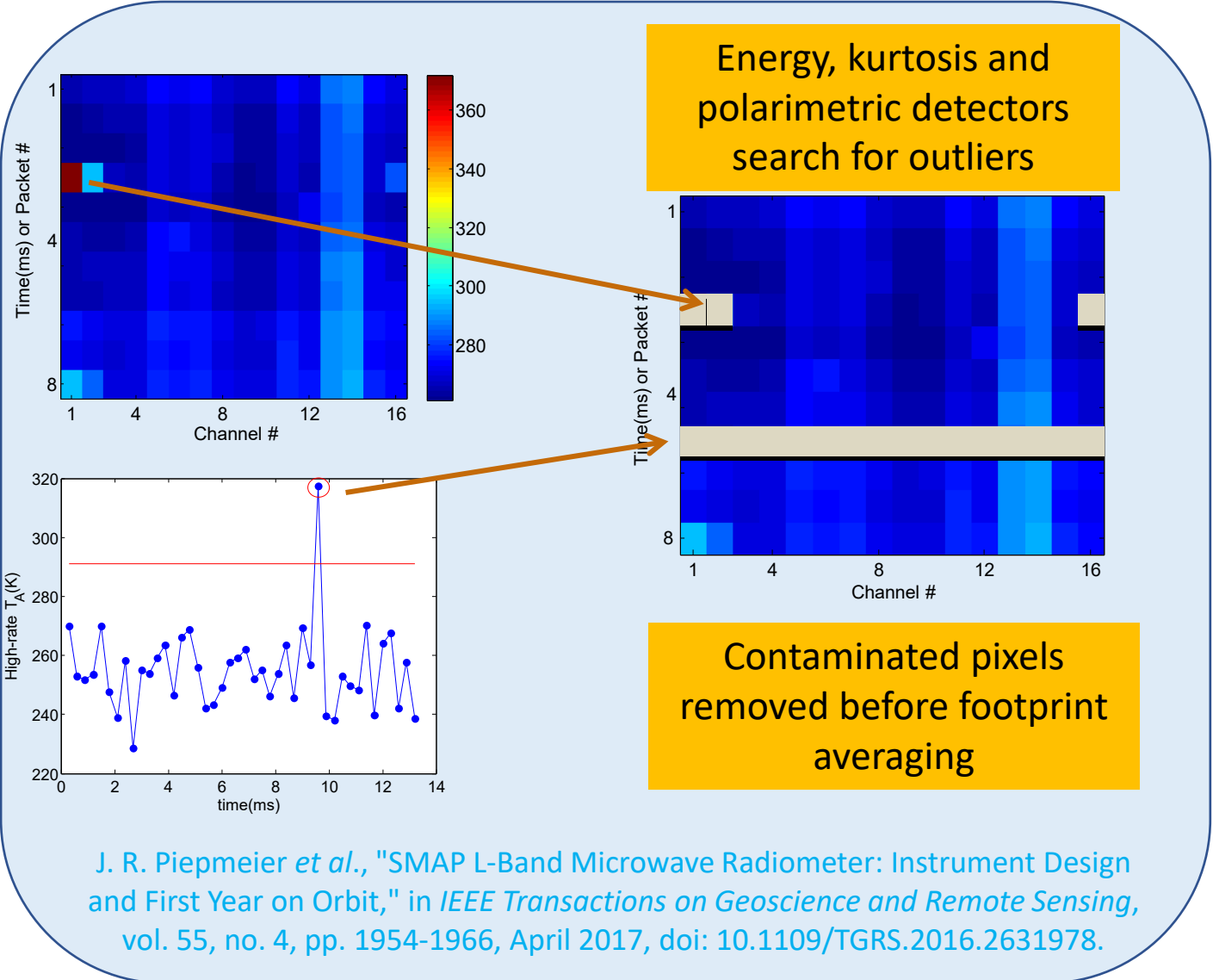
SMAP observed Radio Frequency Interference (RFI)

- SMOS and Aquarius provided a good indication of the RFI environment at L-band
- SMAP Radiometer includes a digital backend
- SMAP uses 16 sub-bands over 1400-1427 MHz
- Multiple RFI detection algorithms plus filtering
- Detection and filtering performed in ground processing
- SMAP L1B footprint is the average of the clean spectrogram (32 PRI and 16 sub-bands)
- <https://salinity.oceansciences.org/smap-radiometer.htm>



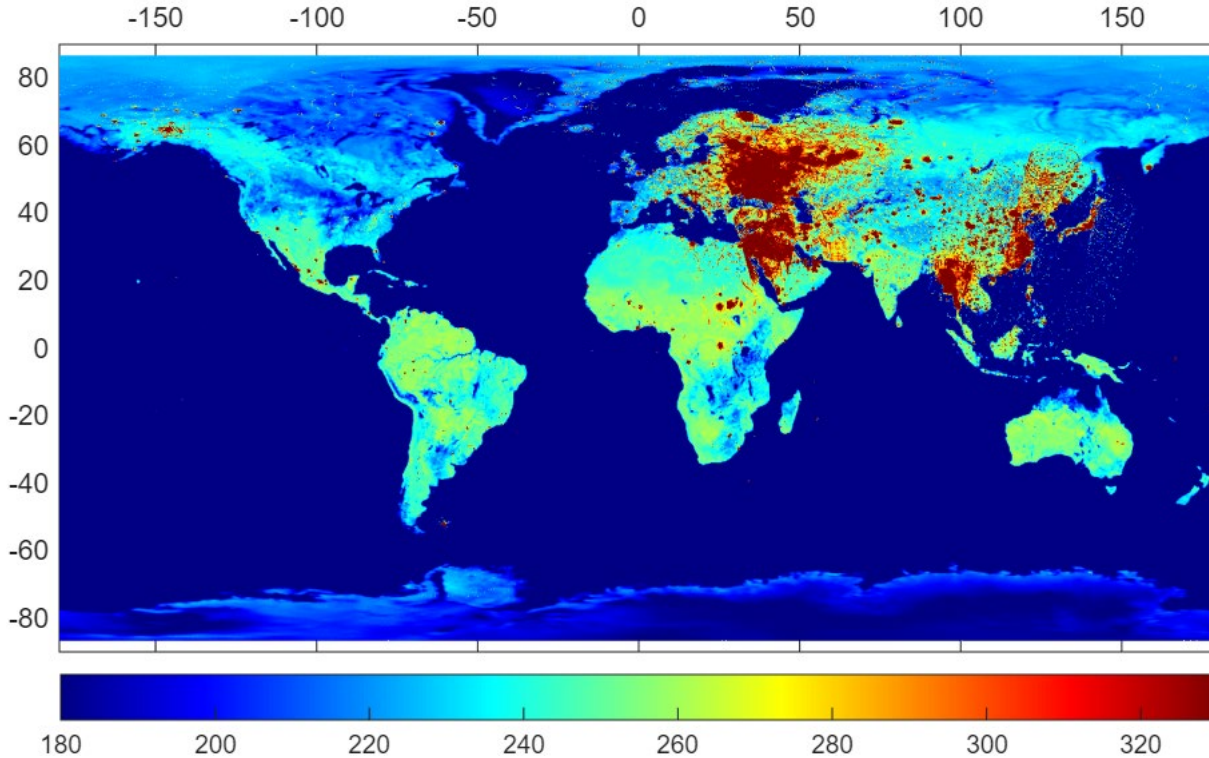
TAs > 330 K is RFI

SMAP RFI Detection and Filtering

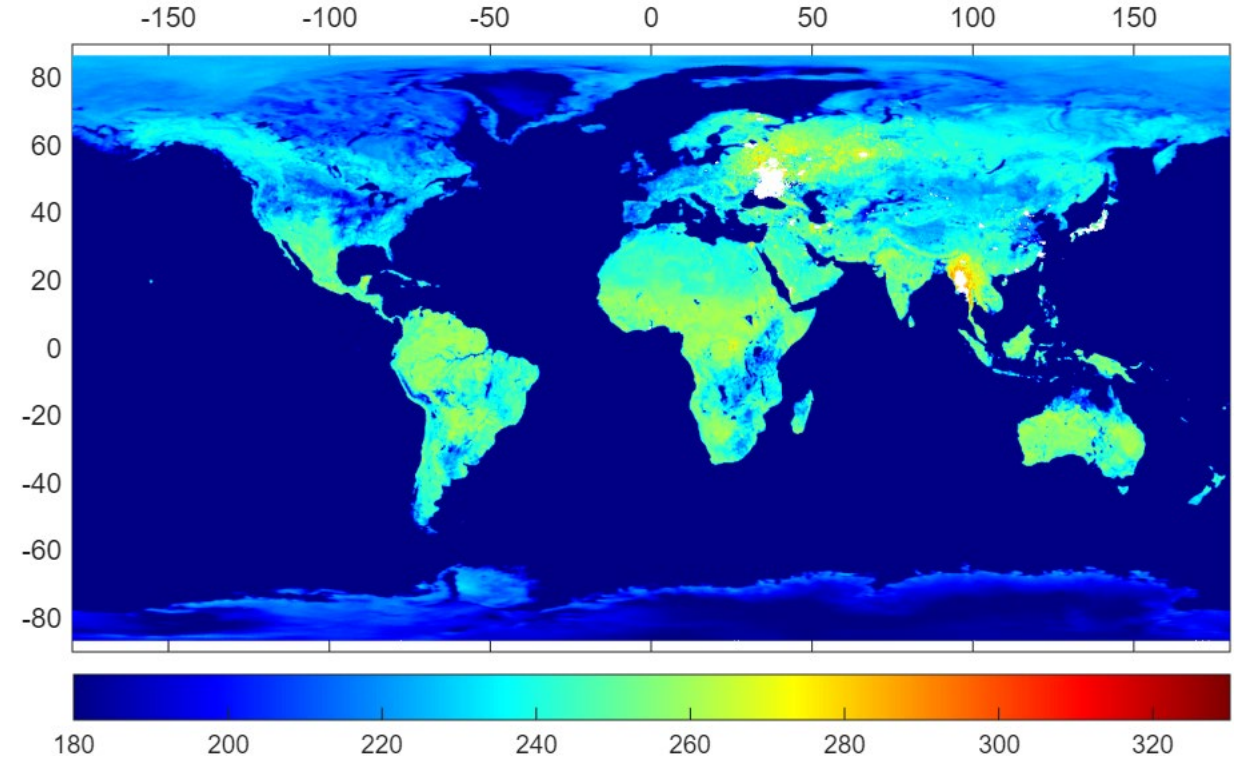


SMAP RFI Detection and Filtering

Peak Hold TA H-pol 03/04/2026 to 03/10/2026



Peak Hold TA filtered H-pol 03/04/2026 to 03/10/2026



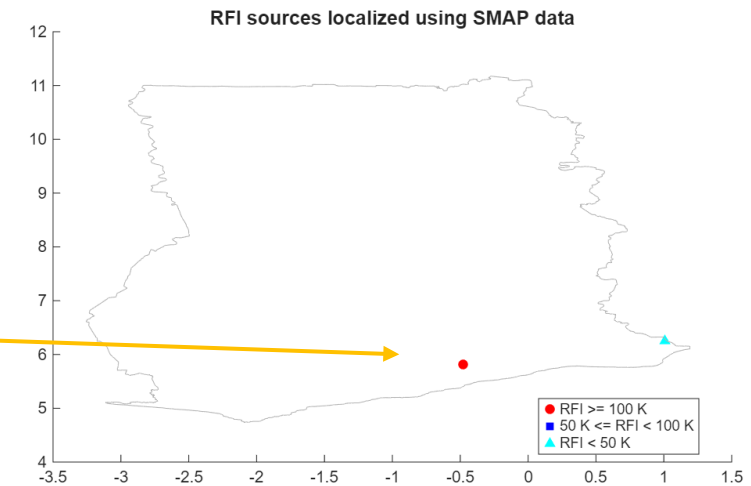
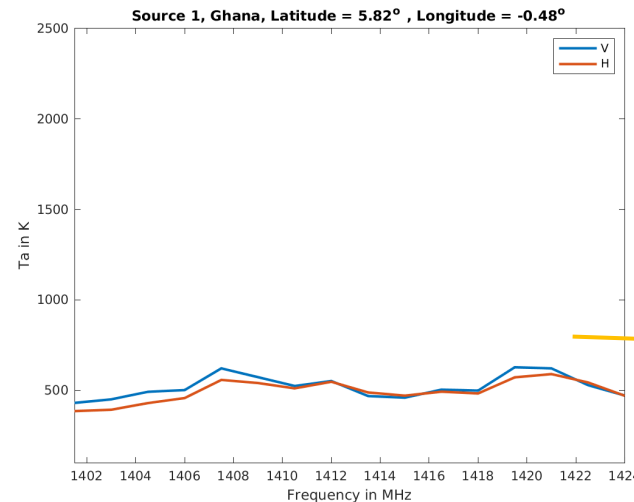
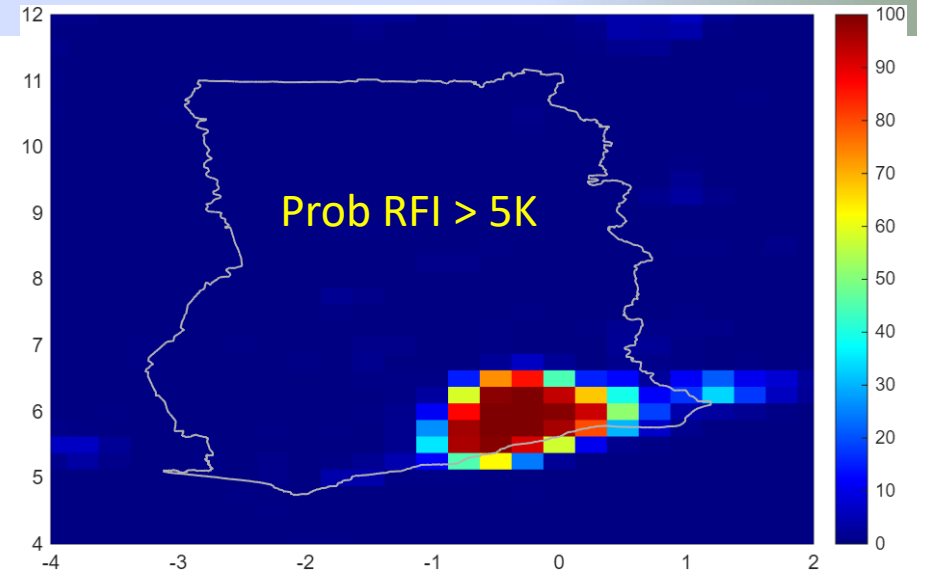
- SMAP detection algorithms work well to reduce the impact of RFI on data
- RFI is further addressed by reporting interfering sources through official spectrum management channels using ITU interference reports (Recommendation ITU-R RS.2106)

RFI Reporting

Ghana March Report 2026

- Interference reports generated for individual administrations based on Recommendation ITU-R RS.2106
- NASA reports interference sources in the ITU Satellite Interference Reporting and Resolution System (SIRRS)
- Report a different country every month
- SMAP and SMOS agree to report on the same country every month
- Report contains
 - Peak hold and probability plots of country being reported
 - Each source
 - Location coordinates
 - RFI level in K
 - Estimate of EIRP
 - # of observations over analysis period
 - Date source was last seen
 - Spectral plot

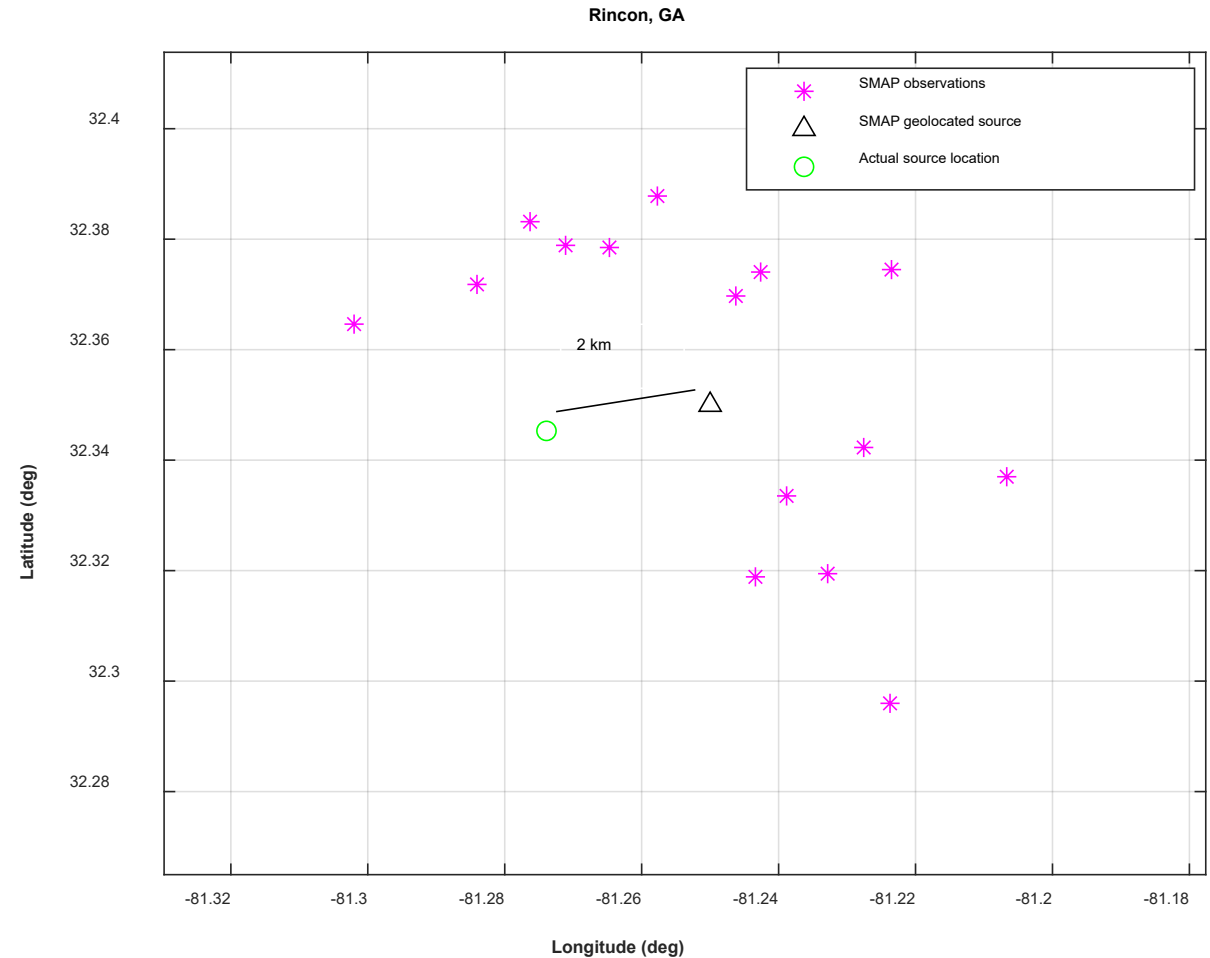
3-month analysis period



Locating RFI sources with SMAP data

- The **pink stars** are all the RFI localizations from individual passes obtained from SMAP data
- Centroid (**black triangle**) is found using a clustering algorithm to geolocate the source
- The **green circle** is the known source location

Y. Soldo *et al.*, "Location of Radio-Frequency Interference Sources Using the SMAP L-Band Radiometer," in *IEEE Transactions on Geoscience and Remote Sensing*, vol. 56, no. 11, pp. 6854-6866, Nov. 2018, doi: 10.1109/TGRS.2018.2844127.



Localization of an RFI source in the Georgia, USA with known location in January 2023.

Sources Located by National Regulators

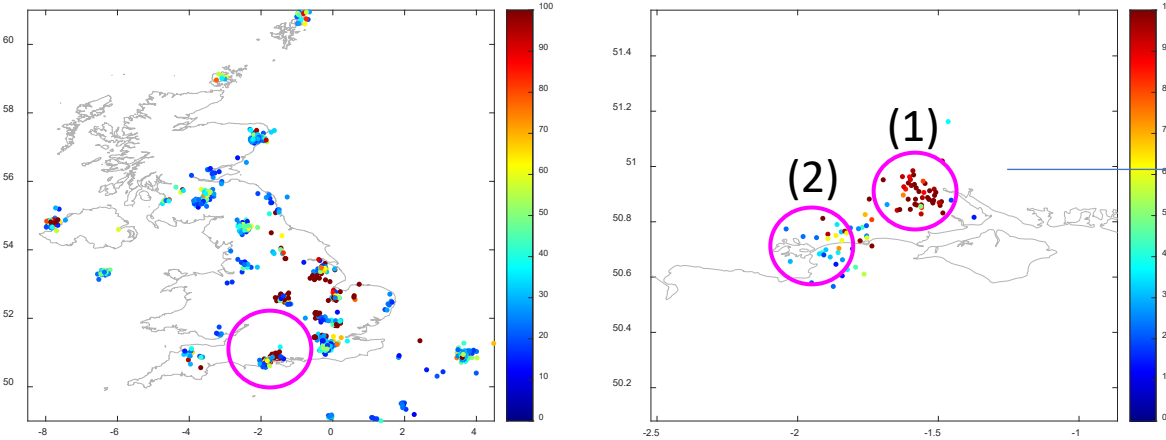
Country	Date	Source
Canada	2021 2025	Surveillance camera, CCTV camera Air surveillance radar
UK	2020	Redundant CCTV transmitter
UK	2021	Faulty DECT phone
UK	2022	CCTV camera, Faulty indoor amplified tv antenna, Faulty DECT phone
UK	2023 2025	Jammer, 2 CCTV systems, multiband jammer, Radiating powered indoor television antenna DECT phone
USA	2022	Camera on farm, wireless security camera, security system, faulty TV amplifier
USA	2023	TV amplifier at resident's house, broadcast studio transmitter link
USA	2024	Malfunctioning cable modem at residence
Malaysia	2025	Chinese RF ID device
DRC	2025	Fixed wireless transmitter

- SMAP RFI reports began in 2016
- To date, 88 reports have been filed, with 46 administrations



Some examples of the types of equipment found

UK Examples



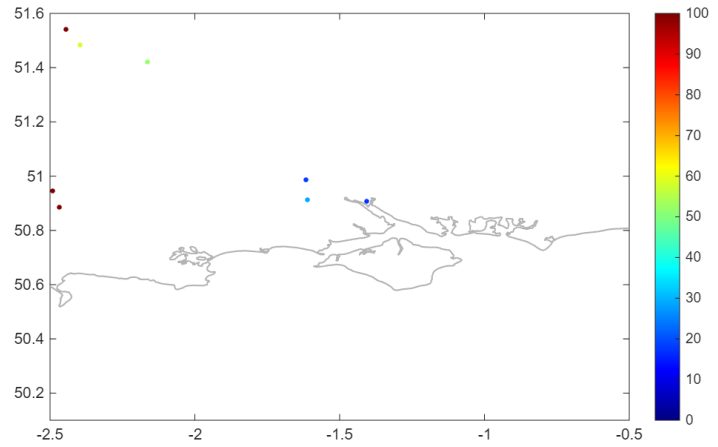
11/11/2020 – 02/10/2021



- (1)
- Found Nov 2020
 - Redundant CCTV transmitter found 2 km from SMAP location
 - Signal detected at 1401.8 MHz

- (2)
- Found Jan 2022
 - CCTV camera drifting between 1412.8 – 1422.2

Picture of similar (not actual) device found

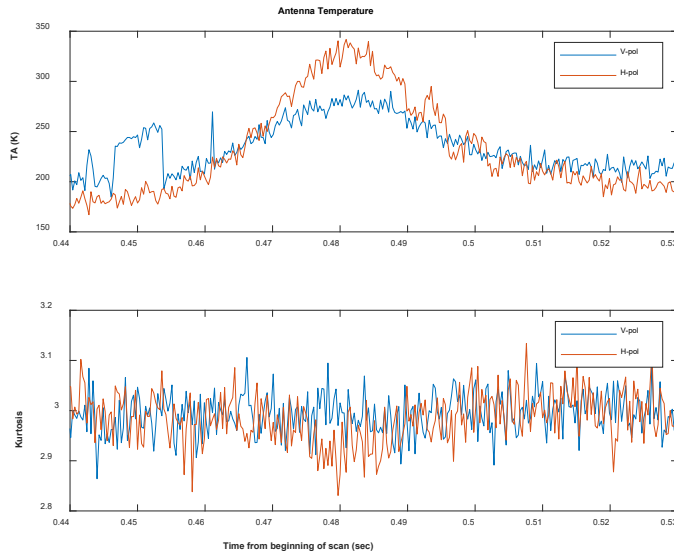


No more detections in this area after sources removed by OfCom

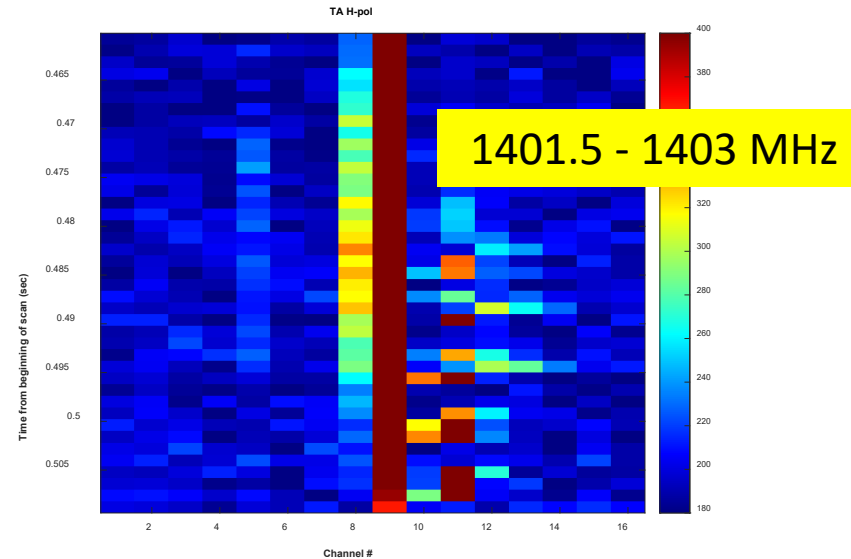
01/11/2026 – 03/12/2026

CCTV Transmitter - UK

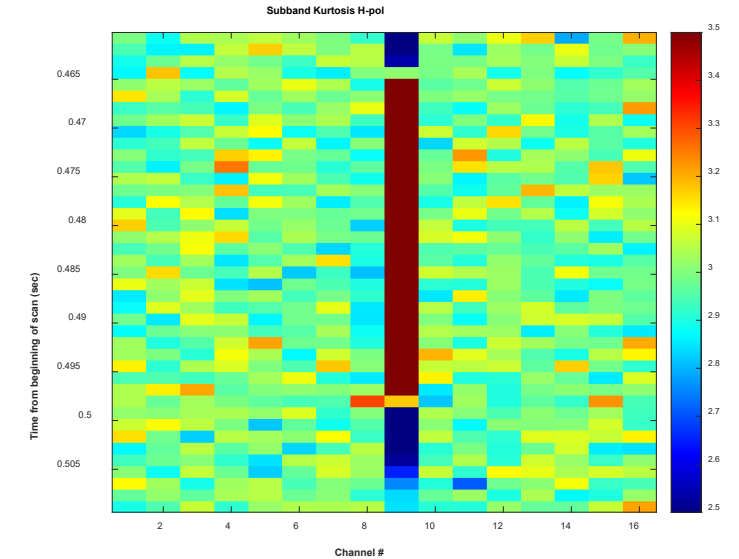
Fullband TA



Subband TA H-pol



Subband Kurtosis H-pol

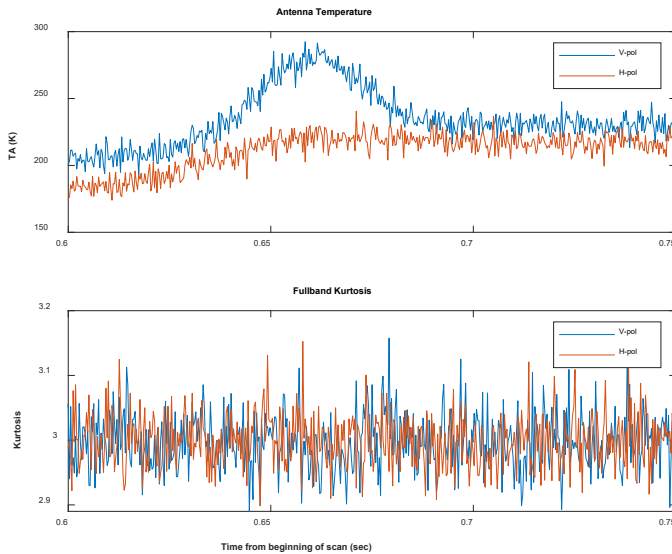


Fullband Kurtosis

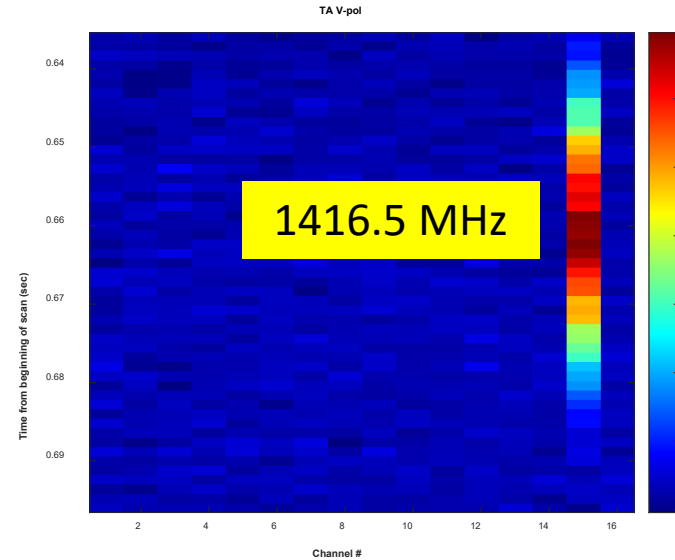
- Found Nov 2020
- Redundant CCTV transmitter found 2 km from SMAP location
- Signal detected at 1401.8 MHz

Source Found (TV Antenna) – Rincon, GA

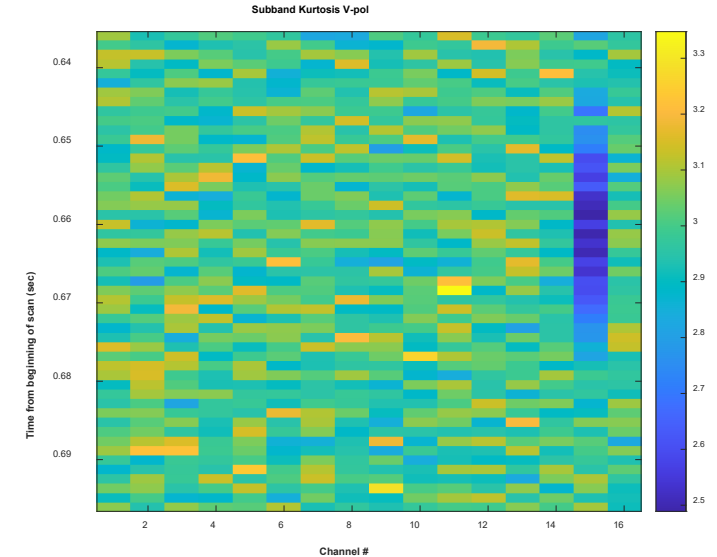
Fullband TA



Subband TA V-pol

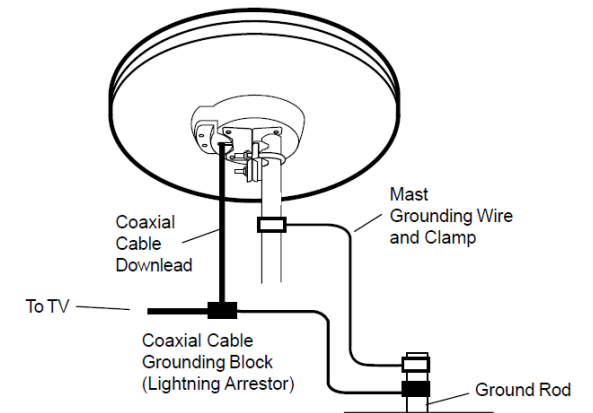


Subband Kurtosis V-pol



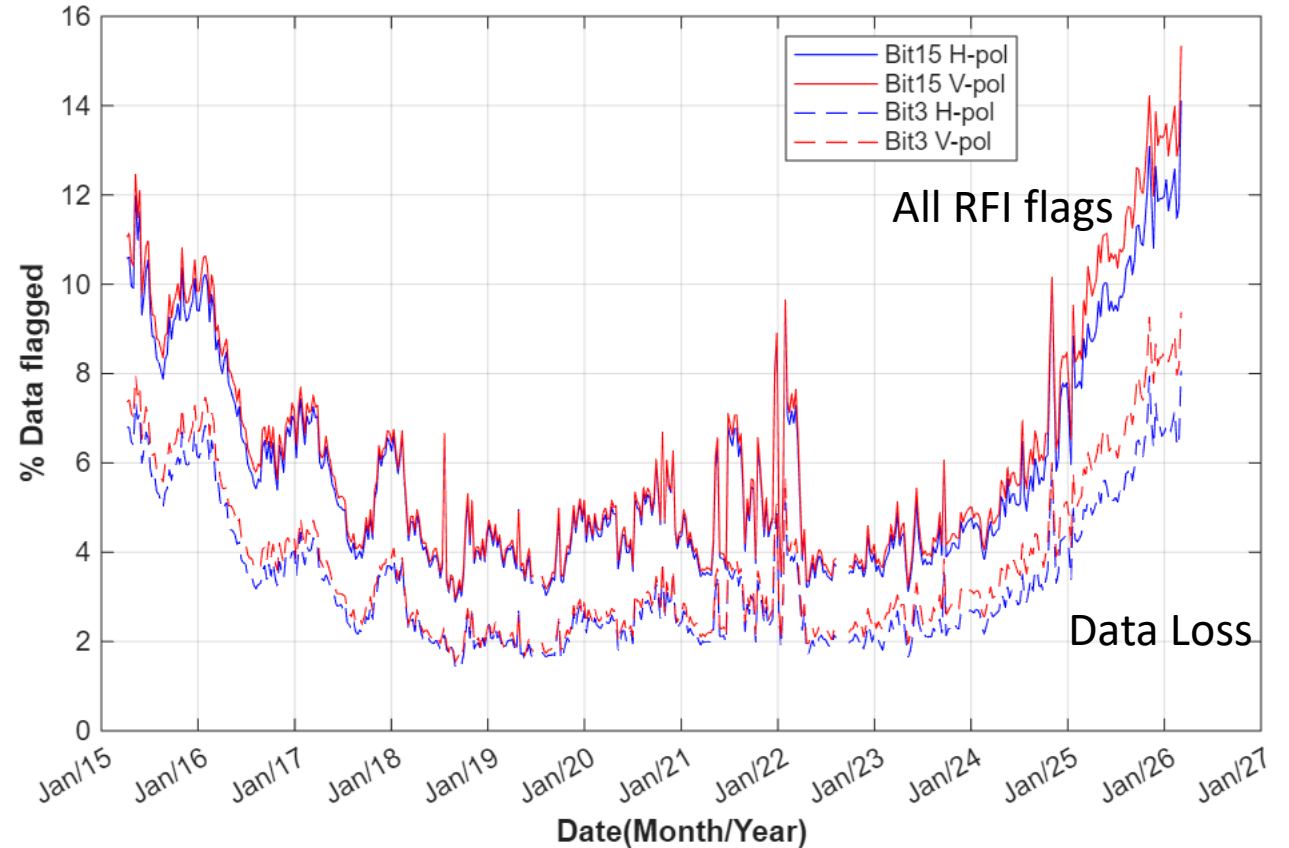
Fullband Kurtosis

- Amplified TV antenna found 2 km from SMAP coordinates, transmitting an unmodulated carrier at **1416.78 MHz**
- The resident said the antenna was not currently being used and was already installed on the home when he purchased it about 10 years prior
- The resident disconnected the antenna, and the source was not observed anymore



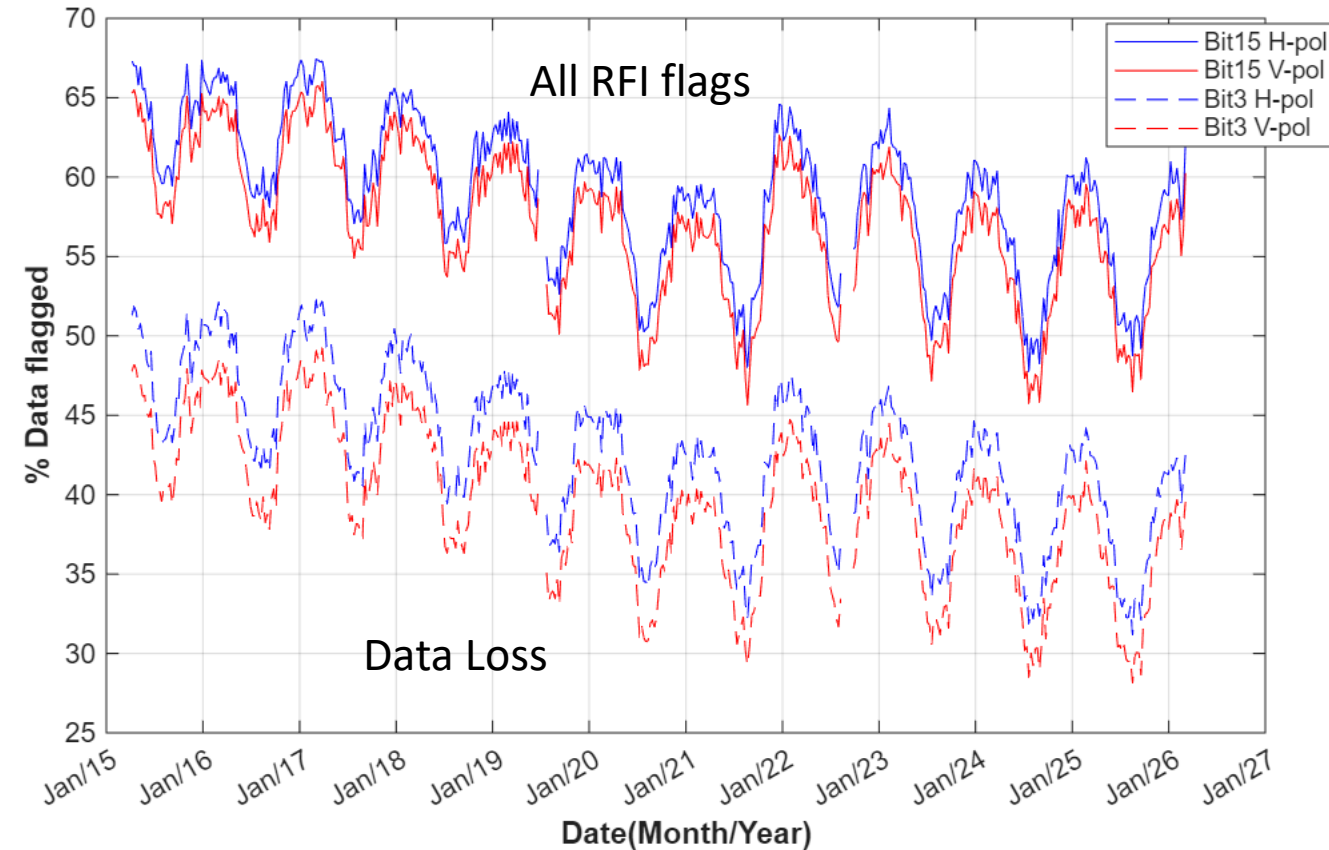
Observations over China

- Decreasing RFI trend over China until 2020
 - RFI observations appear to cycle
 - Several RFI sources still present
- **Bit 15** of TB quality flag captures persistent high level RFI
 - TB is out of range (>330 K)
 - Includes **Bit 3**: RFI cannot be corrected (all pixels flagged, only 1 pixel left in the footprint)
 - NEDT > 2 Kelvin
 - RFI > 100 Kelvin
- Several high-level sources still present globally

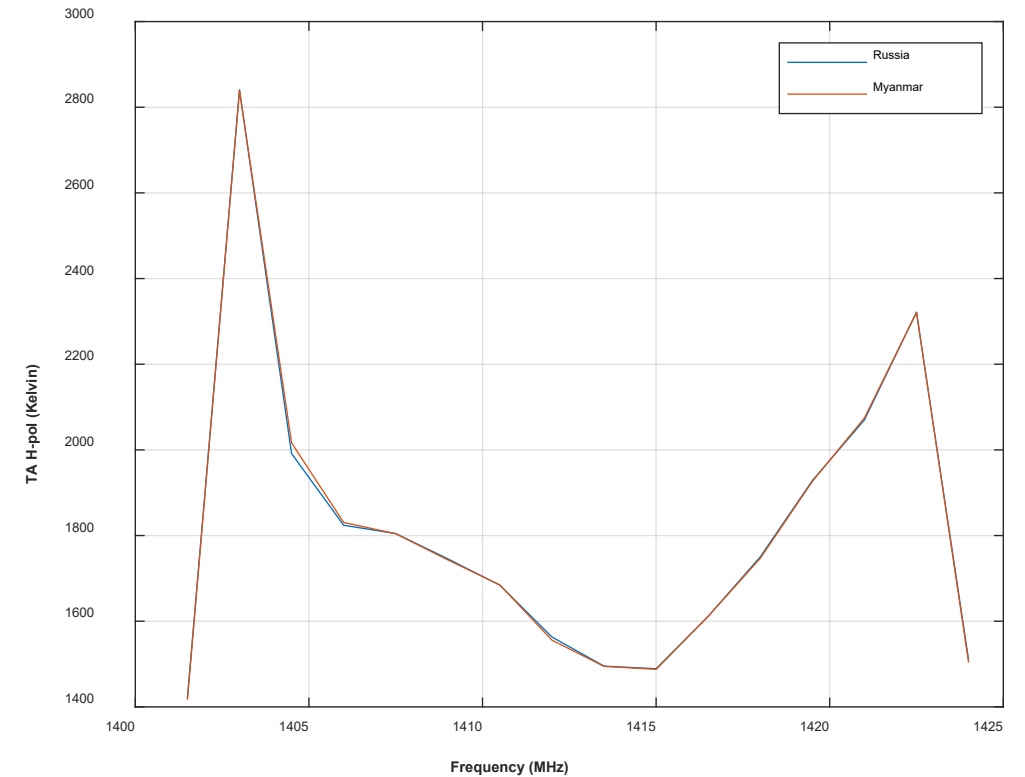
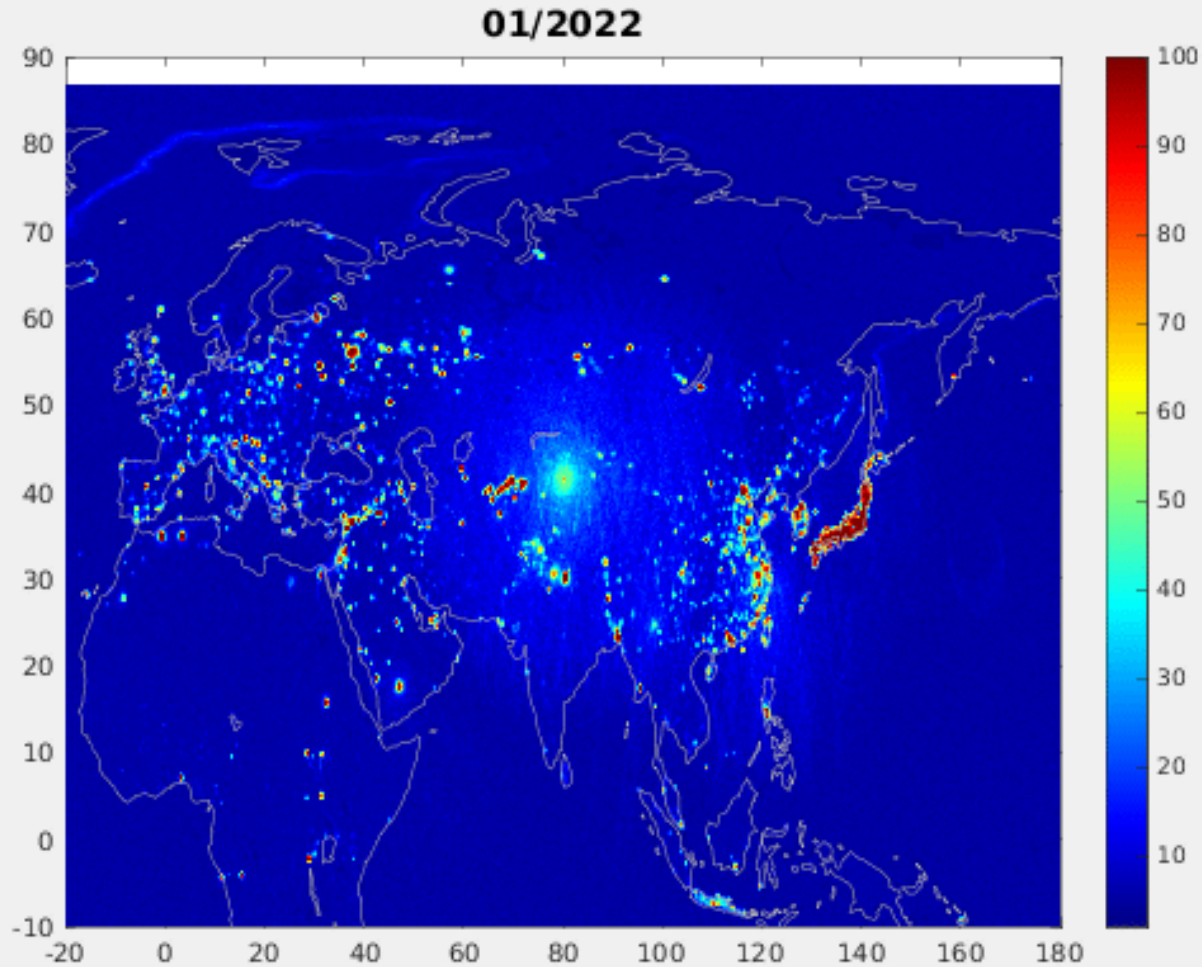


Japan – BSAT Interference

- It was established that widespread RFI over Japan is caused by faulty cables of the receiver systems for BSAT
- Decreasing RFI trend over Japan until 2022
 - RFI flagged data appear to cycle
 - Higher in winter than summer
 - Japanese Ministry of Affairs and Communications (MIC) distributed 21 million compliant devices from 2018-2021
 - April 2018 to March 2022 – 128 K households used a subsidy to replace existing faulty systems



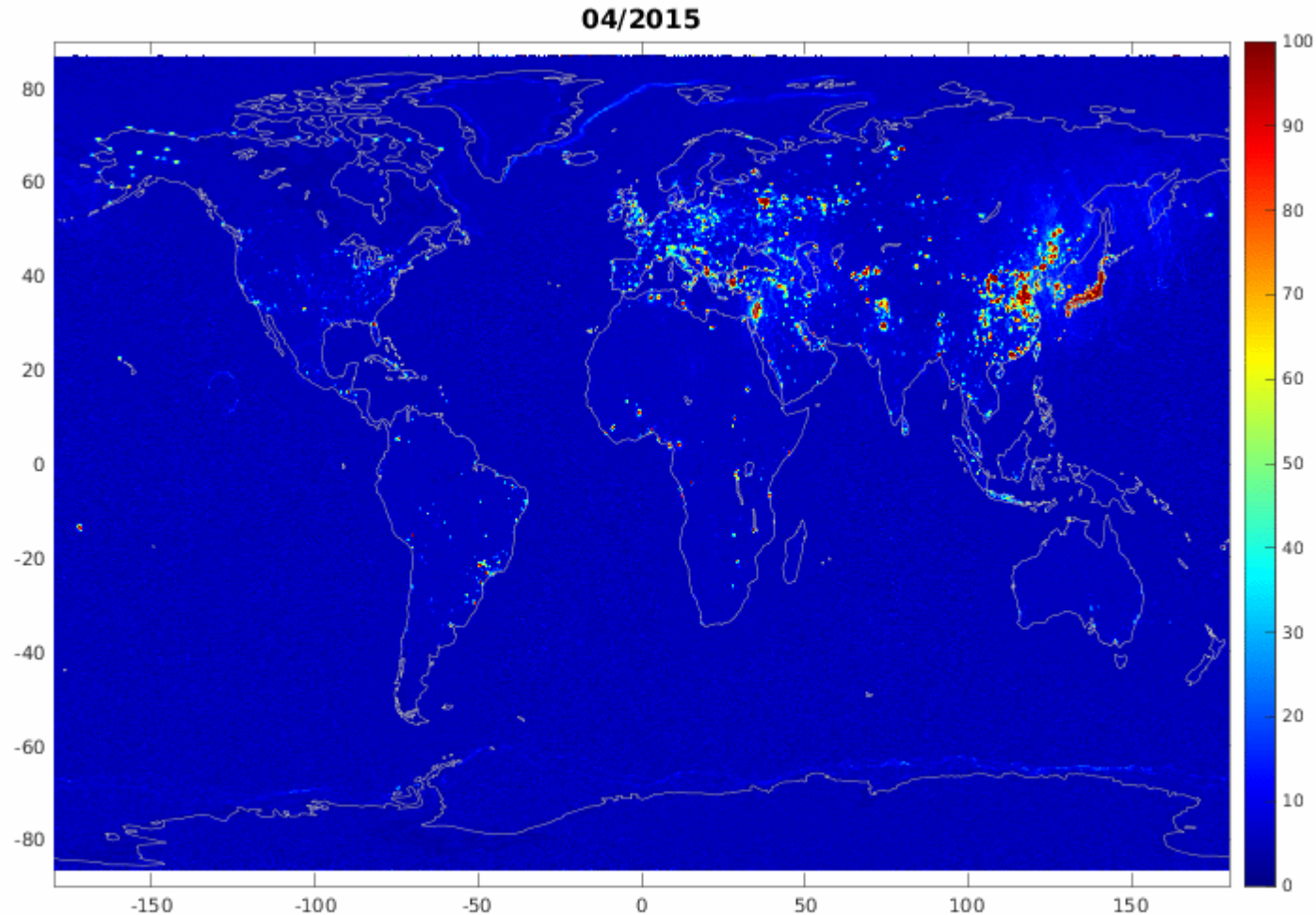
Regions of Geopolitical Conflict



Spectral properties of RFI over Russia and Myanmar, reduction at edges due to SMAP filter shape

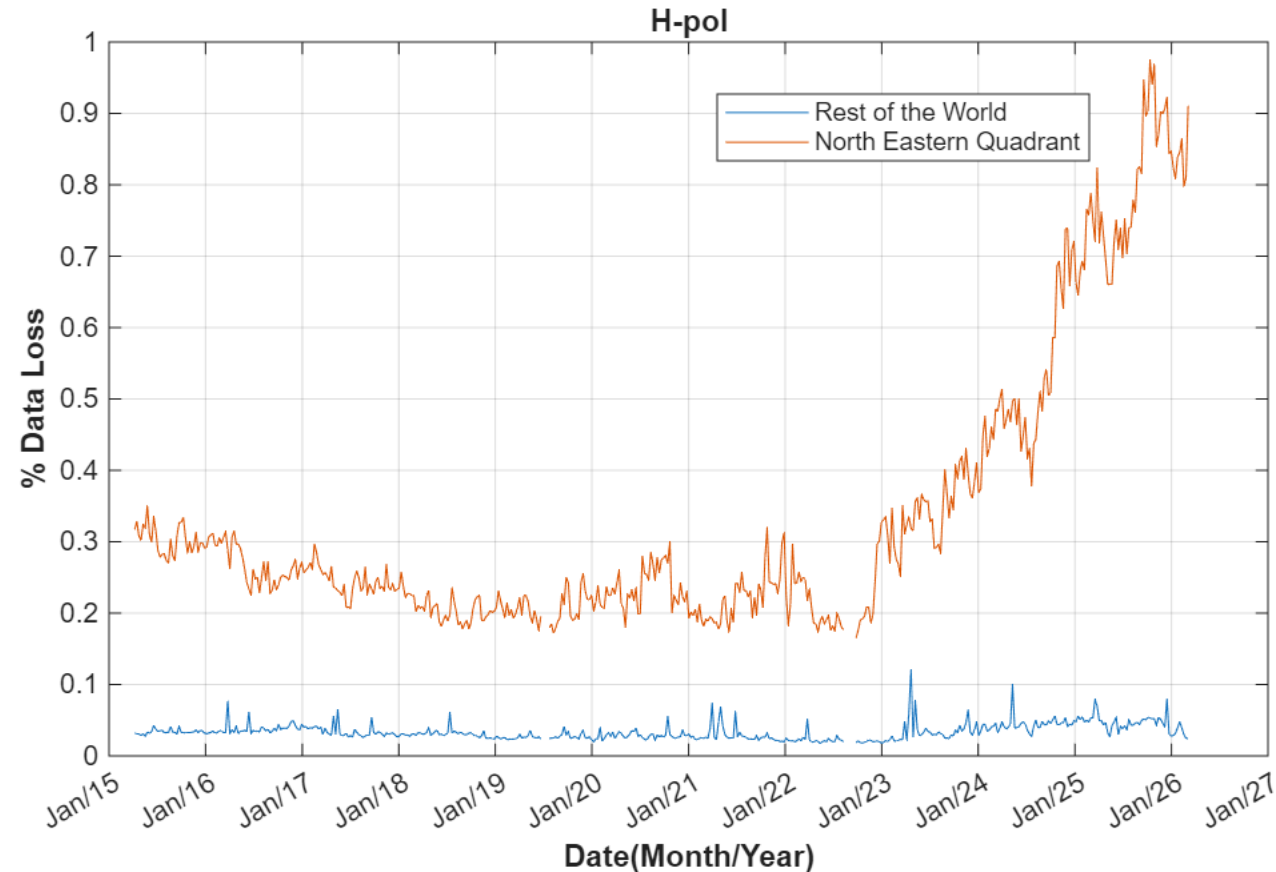
Mission Lifetime Global RFI Detection H-pol

Monthly maps on a 0.25-degree grid showing % pixels flagged as RFI and removed during ground processing



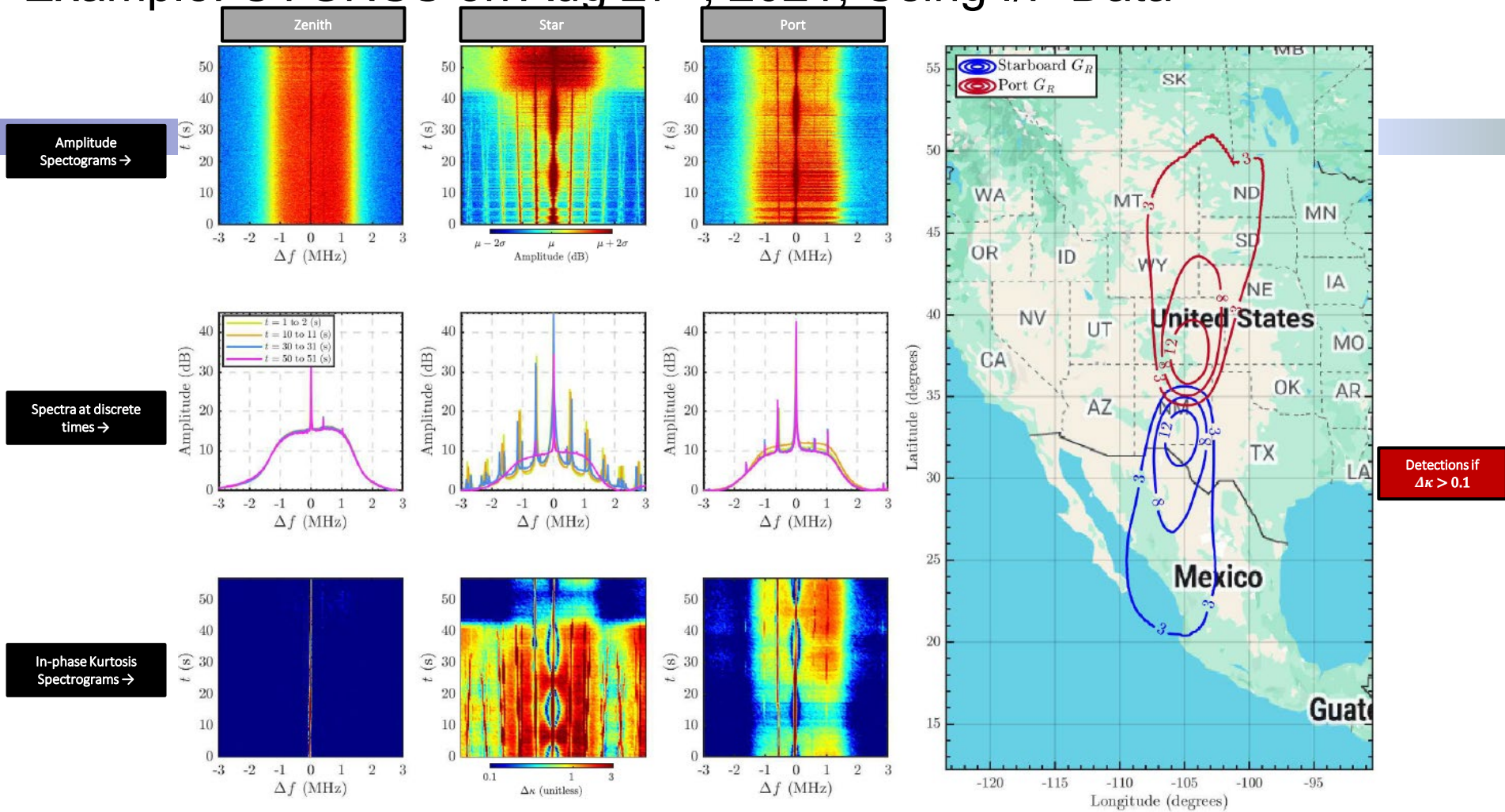
Global RFI Trend Over Mission Lifetime

- Global RFI was generally decreasing over the mission lifetime until 2023.
- Increase in RFI directly correlated to increase in geo-political conflict globally.



- SMAP ground processing algorithm works well to reduce impact of RFI and produce science quality data
- The global environment is stable except for increased levels due to geopolitical conflict (Russia/Ukraine, Myanmar, middle-east)
- Monthly SMAP RFI reports submitted to the ITU; reporting efforts help reduce levels (recent success in UK, US, Canada, DRC)

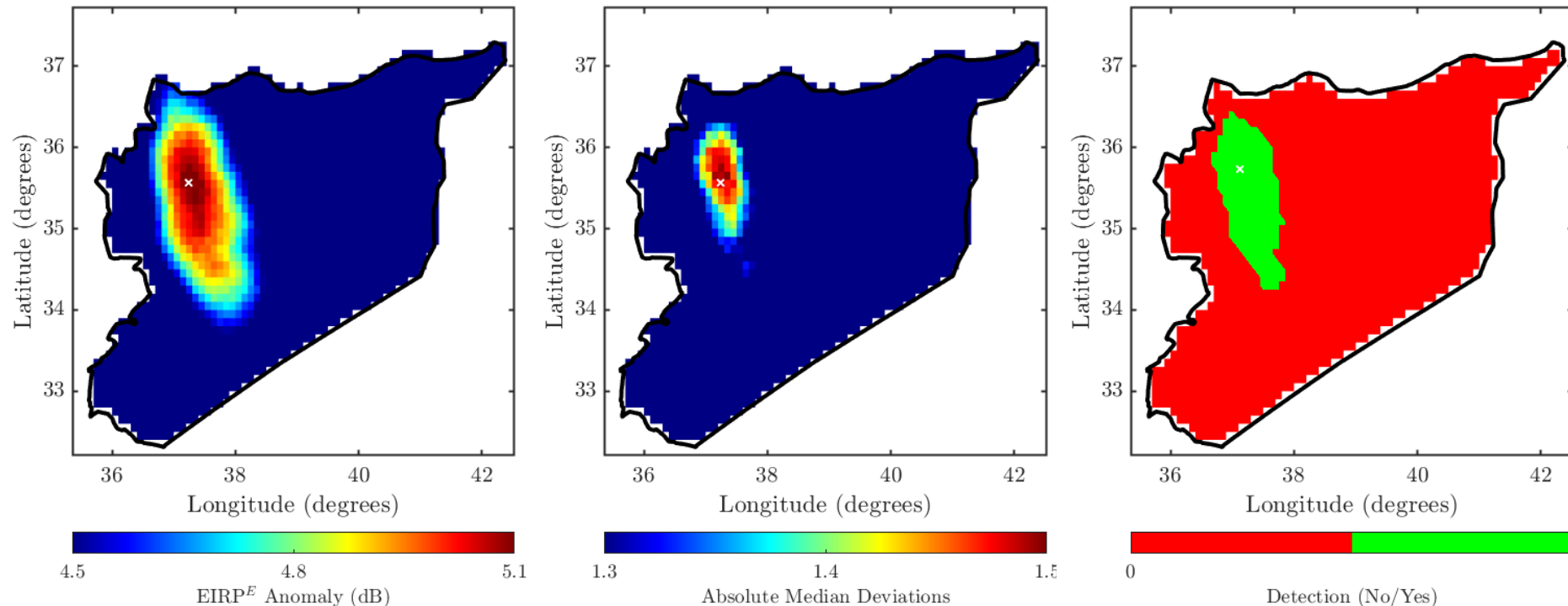
Example: CYGNSS on Aug 27th, 2021, Using I/F Data



- Interference detected over the USA originates from some of the world's highest powered transmitters
 - Similar behavior observed with numerous other collections including 08/19/2019 and 07/27/2021
 - Coincides with the issuance of NOTAMs by the FAA on disruption to navigation signals

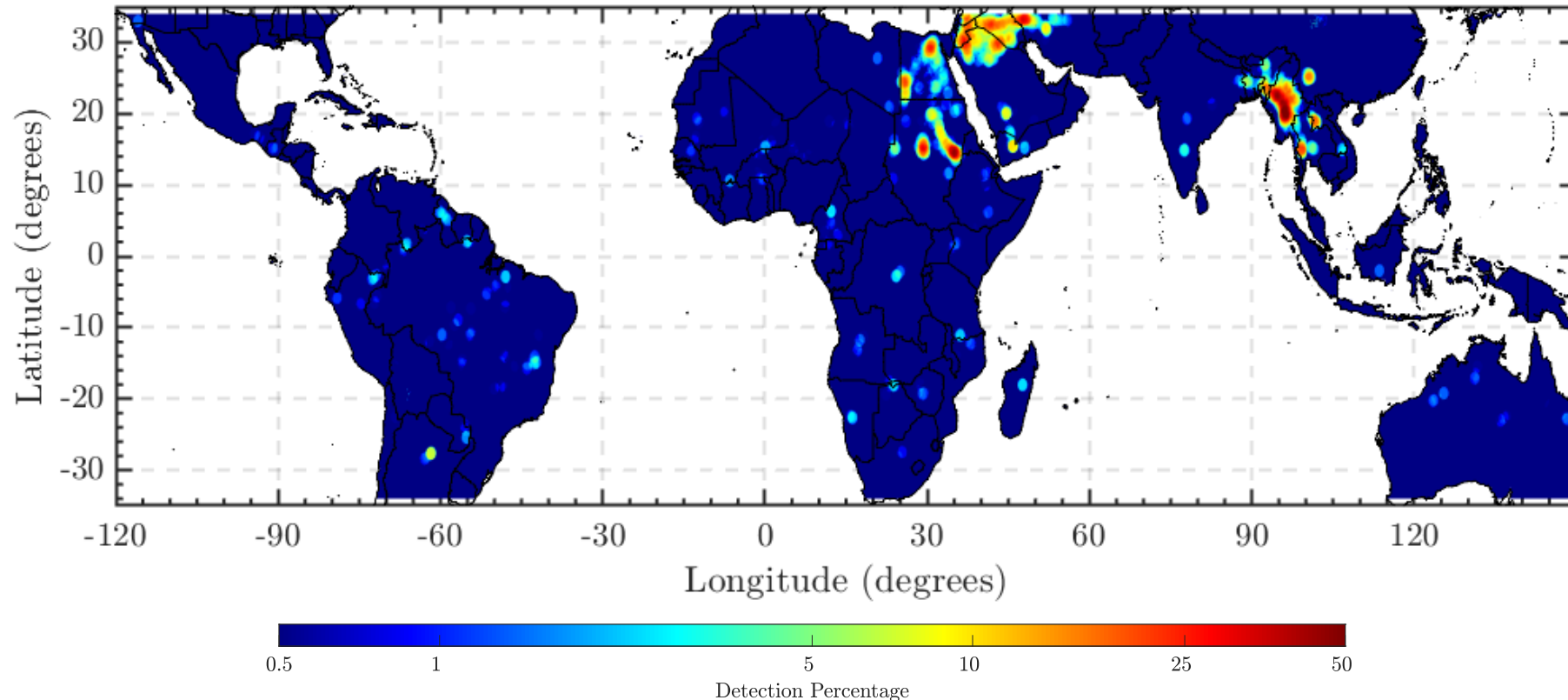
Example: CYGNSS, Using Level-1 Data

- An example over Syria is depicted below where a detection on October 17th, 2019 for a transmitter located 35.56N 37.23E in an area 60 km south of Aleppo is made
 - It is also noteworthy that the detection is made in an area ≈ 25 km from the Abu al-Duhur Military Air Base
- **Detections** can be made by various **spatial pulse finding algorithms** while **geolocations** can be made via various **clustering/centroid finding algorithms**



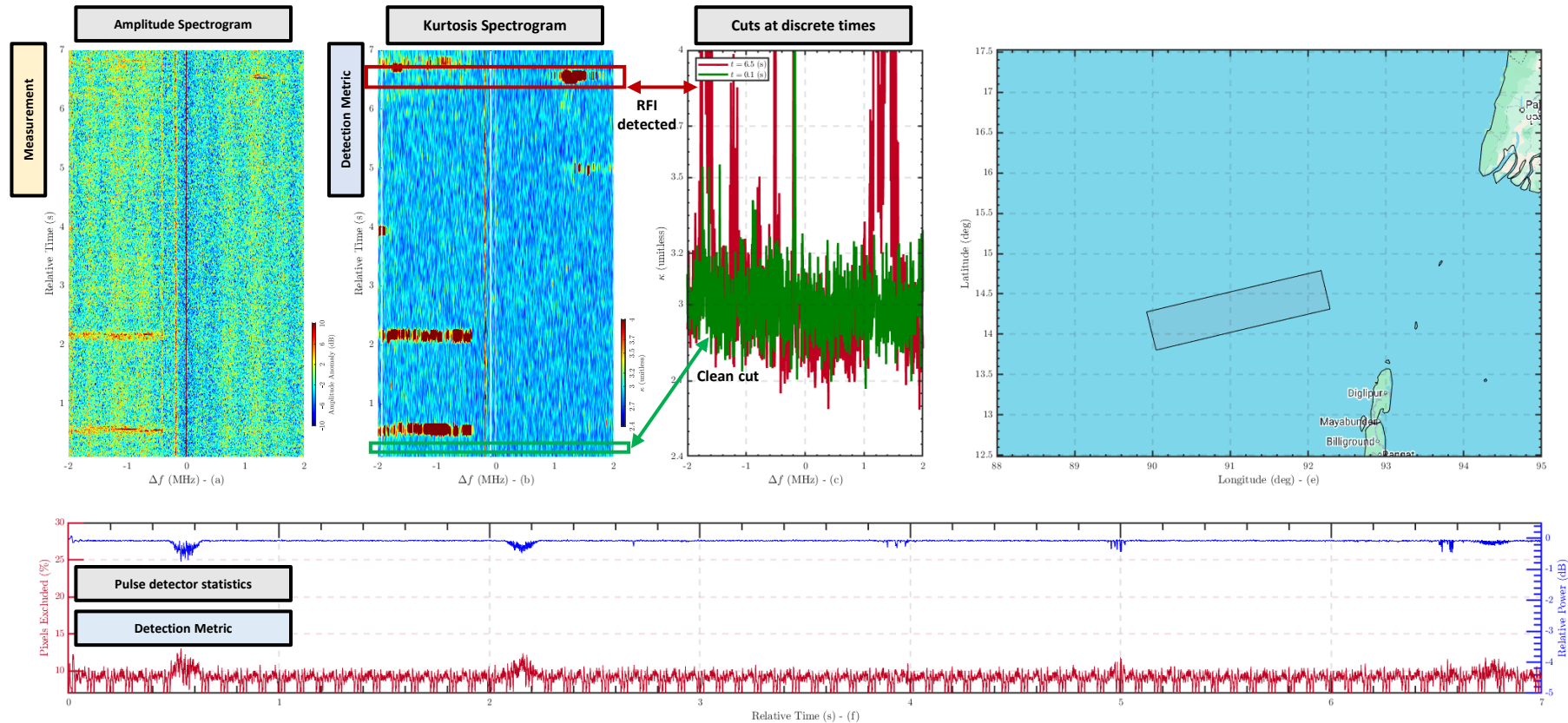
Global Trends: CYGNSS, Using Level-1 Data During 2024

- To investigate global trends, the figure below depicts the frequency with which interference was detected over the period August 1st, 2019 to April 1st, 2025
 - The detection frequency reported is the percentage of time a pixel is identified as containing a transmitter annually
 - It is observed that the majority of transmitters are located in the MENA region and Myanmar
 - More intermittently operated transmitters were detected in Niger, Sudan and with a significantly lower frequency in Venezuela, Guyana, Brazil and Argentina

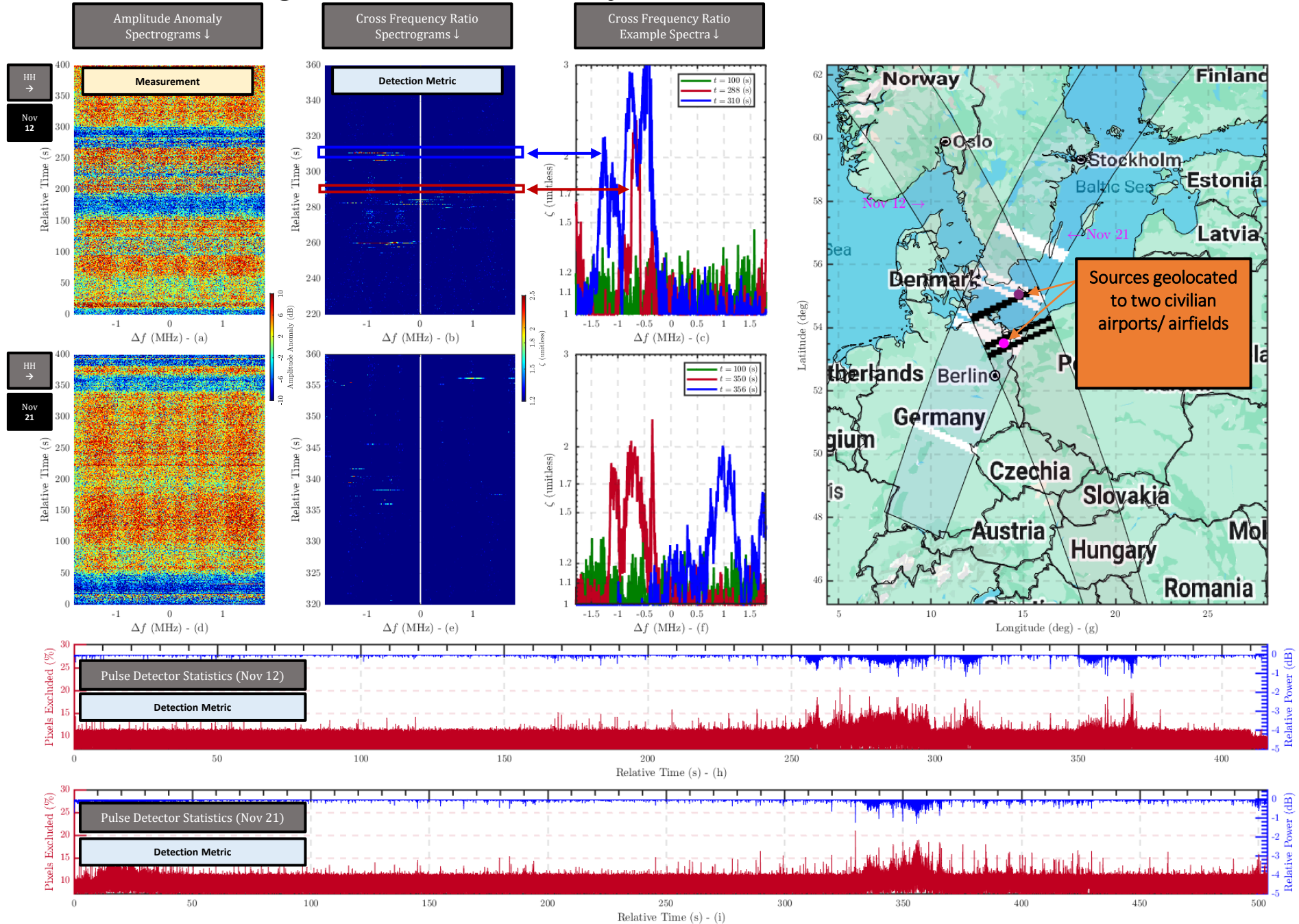


NISAR (LOB data)

- Kurtosis highly effective when applied over homogenous scenes
 - Example detection in Bay of Bengal; signature appears to correspond to a marine radar
 - Acquisition made on Nov 9, 2025 at 23:27:15 UTC at a 1.2935 GHz center frequency
 - Interference sources have $\Delta\kappa$ deviations that exceed 1.0
- Source or sources observed occur at distinct times and with frequencies offset either to positive or negative values from the band center

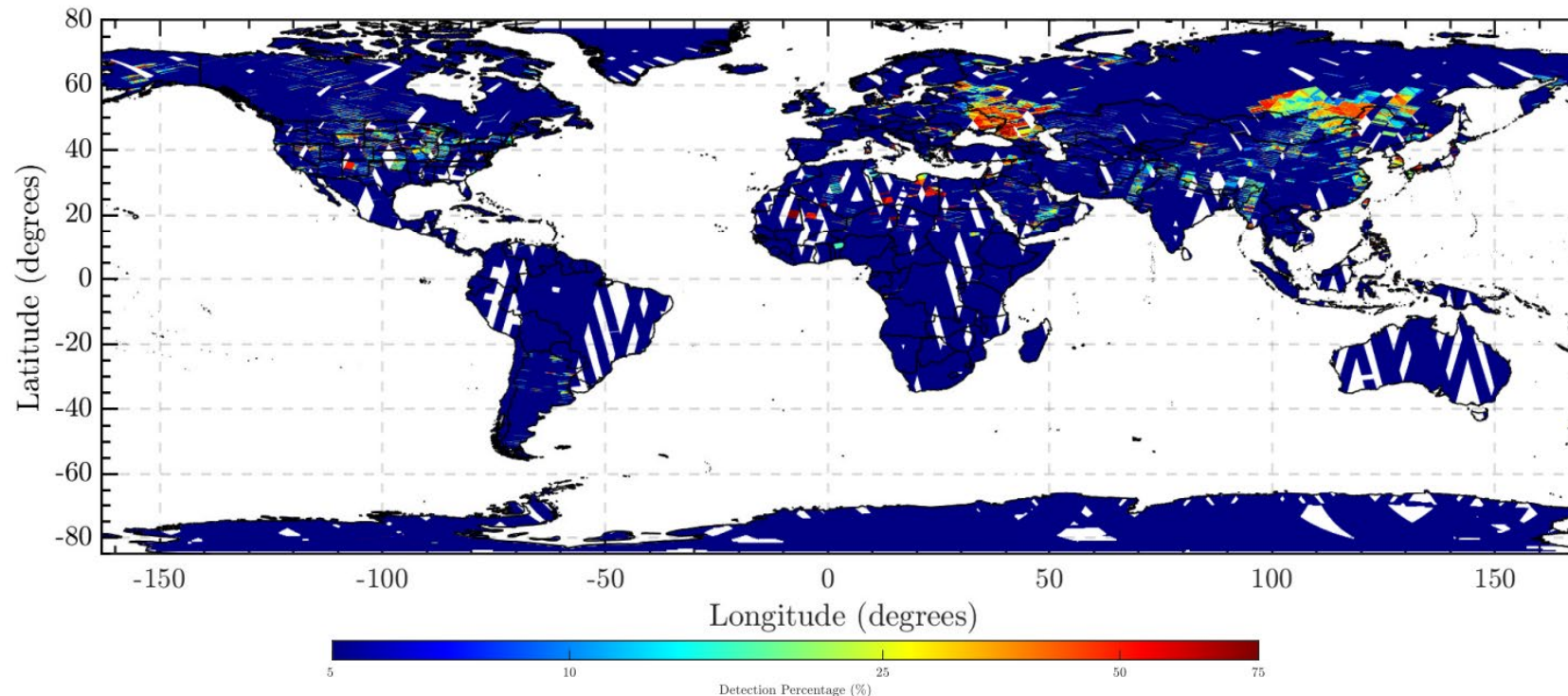


NISAR, Using L0B in Germany/Denmark



NISAR - Global Trends

- The cross-frequency detection methodology was applied to 10,851 NISAR granules facilitating ~25,000 acquisitions of varied polarizations, center frequencies, bandwidths and chirp durations across the globe
 - The resulting spatial patterns, given a $\Delta\zeta = 0.75$ threshold, are depicted below
- The largest, highest powered and most persistent sources of interference appear to exist along Ukraine's eastern provinces, Russia's western provinces, and Belarus as evidenced by the detection percentages >80%





Summary

- L-band observations are used to estimate soil moisture, ocean surface salinity, thin sea ice, vegetation biomass, ocean surface winds among other variables
- RFI negatively impacts estimation of these key variables
- The use of sub-banding allows RFI detection
- State-of-the-art methods cannot fully mitigate RFI impacts
 - Data is lost in presence of wide-spread RFI
 - Higher NeDT when part of the spectrogram can be used
- Critical to protect the primary allocation for passive radiometry at 1400-1427 MHz