Cross-Sensor Calibration of Sentinel-1 Noise Level for RFI Monitoring and Classification

AUTHORS

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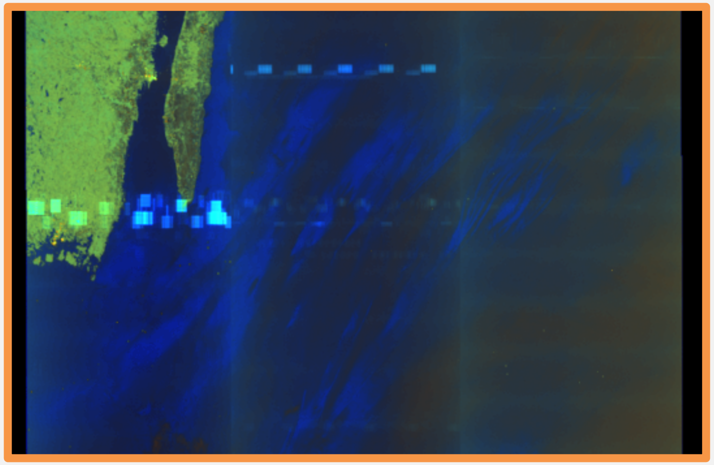
Outline

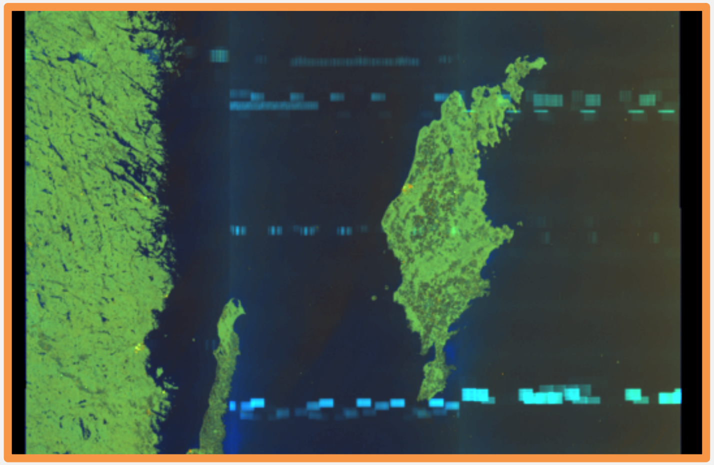
- **Impact of RFI on Sentinel-1 Data**
  - Examples of RFI
  - Detection strategies
- **New approach to measure noise level**
  - Using rank echoes as noise measures: advantages and known issues
  - Cross-sensor calibration with AMSR-2
- **Sentinel-1 as a passive radiometer**
- **Global RFI monitoring**

Acknowledgements
The current work has been funded within the framework of the Sentinel-1 Mission Performance Centre project (S-1 MPC).

Impact of RFI on Sentinel-1 Data

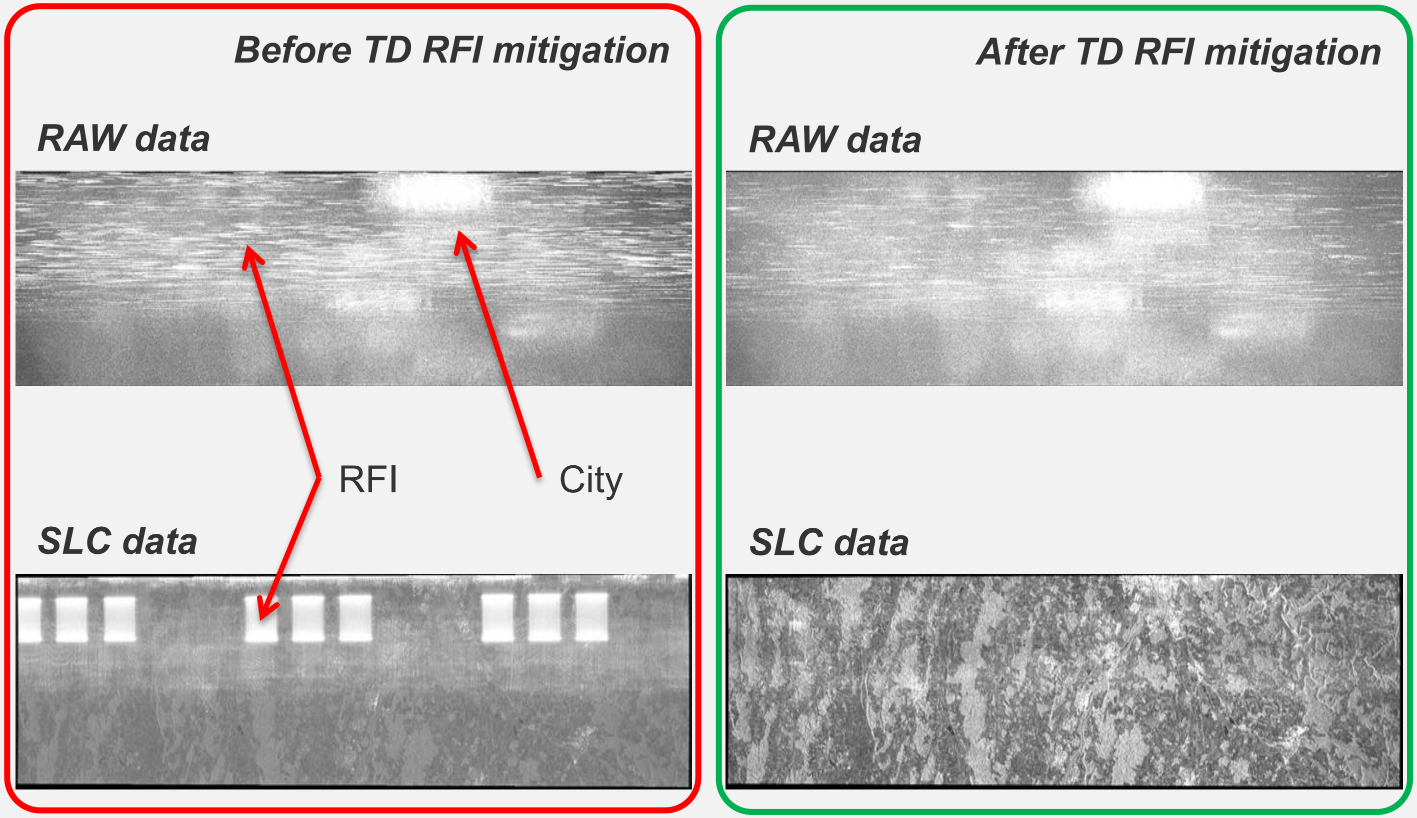
- Since the start of the S-1 mission, users have reported local image degradations related to radio frequency interferences (RFI).
- Known sources of RFI include: the Canadian RadarSAT system, ground radars and weather radars operating at the same wavelength.
- The level of interference could worsen in the near future, as the 5350-5470 MHz band may be shared with wireless LAN systems.





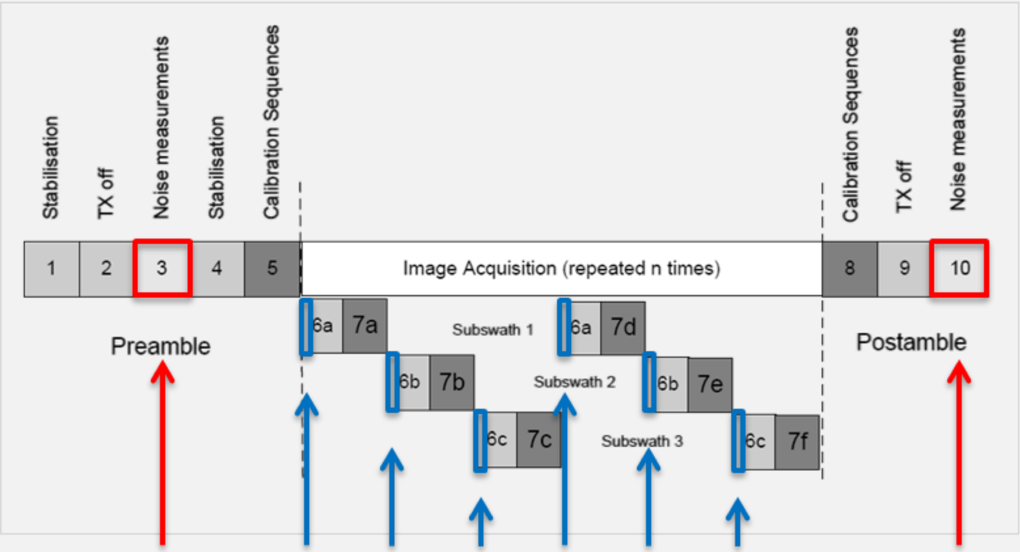
RFI Detection from SAR Data

- RFI **detection** can be performed **either in time or in frequency domain** on the raw data. However, it is a computationally expensive task.
- RFI detection would be much easier if no radar backscatter is present.



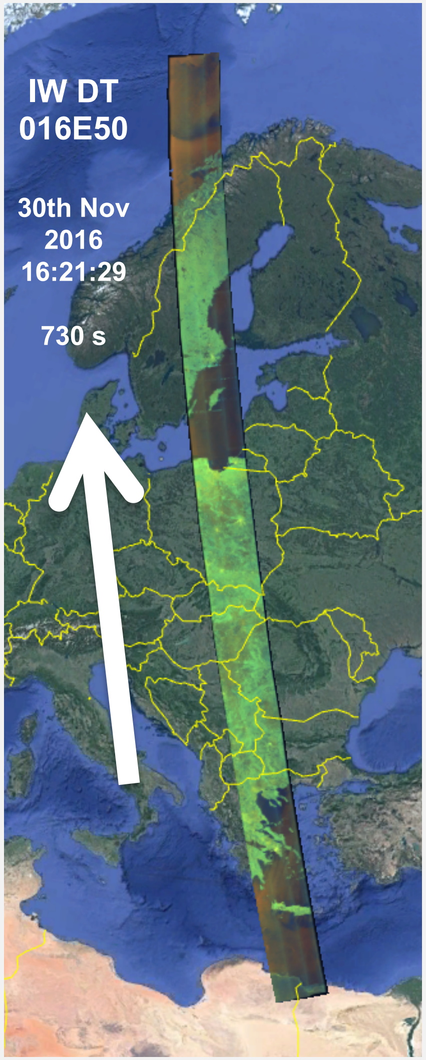
Taking Advantage of Rank Echoes

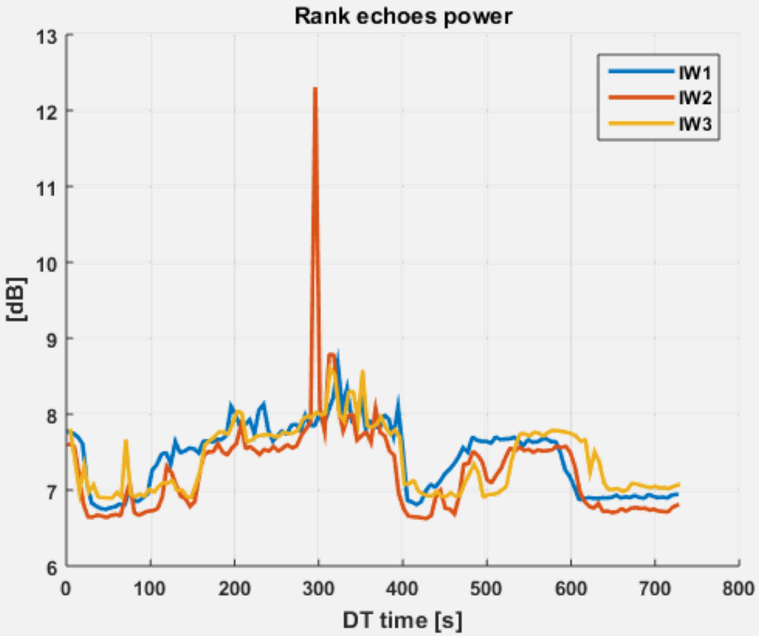
- Idea: Sentinel-1 noise measurements can be used for RFI detection and monitoring.
- **Noise measurements** are acquired at the beginning and at the end of each data-take. Unfortunately, these measurements are collected at a very low rate: approx. 2 estimates every 10 minutes.
- **Rank echoes** are the first measures of each burst, they are virtually equivalent to noise measures, because the radar pulses have not yet bounced back to the receiver. This way, a noise measure every 0.8s is collected.



Sentinel-1 Timeline. In red the noise measurements. In blue the rank echoes.

Information Extracted from Rank Echoes





PROS

- ✓ Much higher number of available noise measurements
- ✓ Continuous monitoring all along the data-take

CONS

- ✓ Influence of undesired return of adjacent calibration sequences

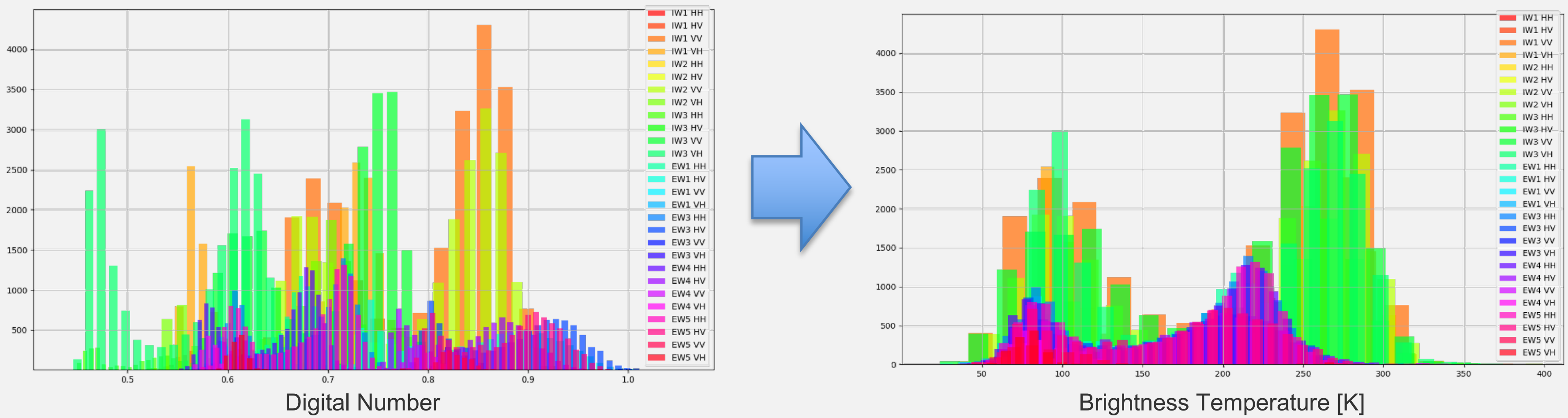
S-1 Noise Calibration

- **Relative calibration:** Different antenna beams have slightly different noise power levels. This is due to: BW and gain of the on-board decimation filter, attenuation of the SES, gain of the RX antenna pattern.

- **Absolute calibration:**

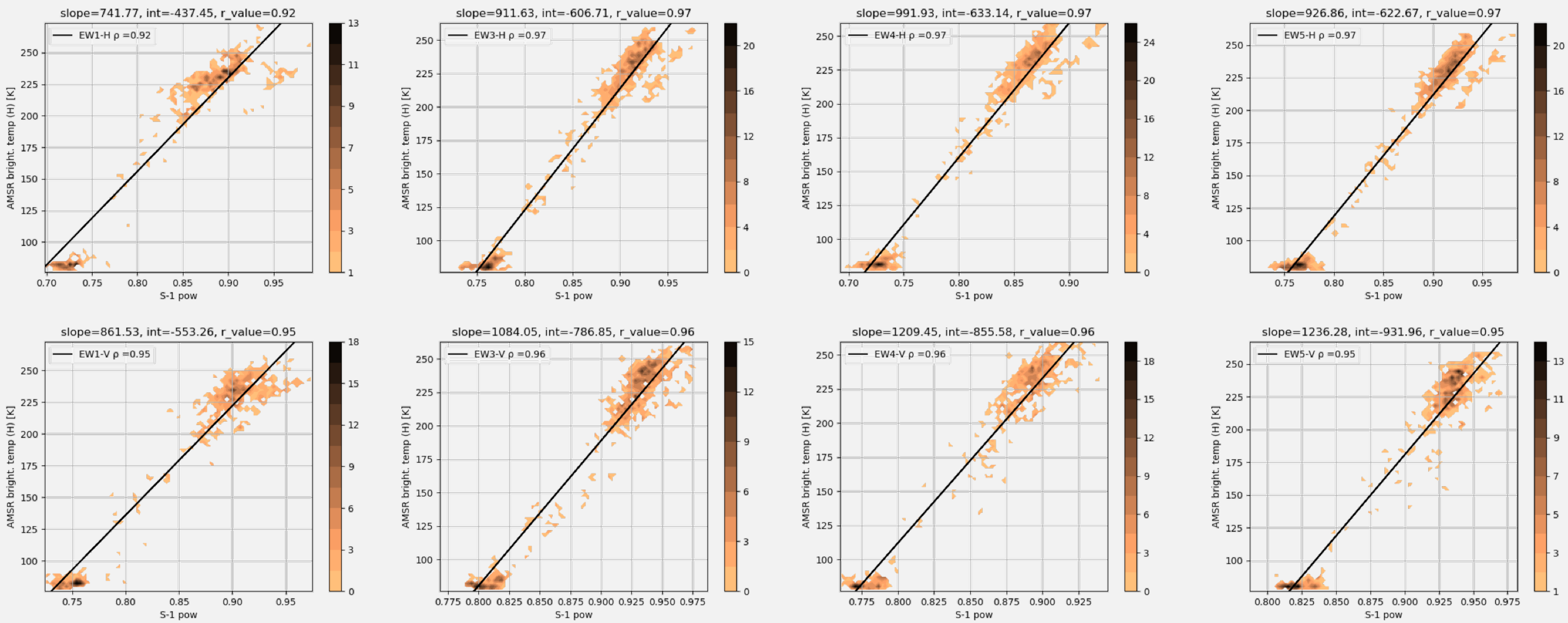
$$\hat{P} = P_n + P_e$$

Pn is the effective noise power and Pe is the power radiated from the Earth surface. P_e can then be converted to brightness temperature.



S-1 Noise calibration with AMSR-2 Data

- For eliminating the residual bias among the antenna beams and giving physical significance to the measures, **S-1 noise data was cross-calibrated using AMSR-2 radiometer** aboard JAXA's GCOM-W1. Despite AMSR-2 operates at 6.93GHz and S-1 at 5.4GHz, high correlation coefficients (**r=0.92-0.97**) are found.



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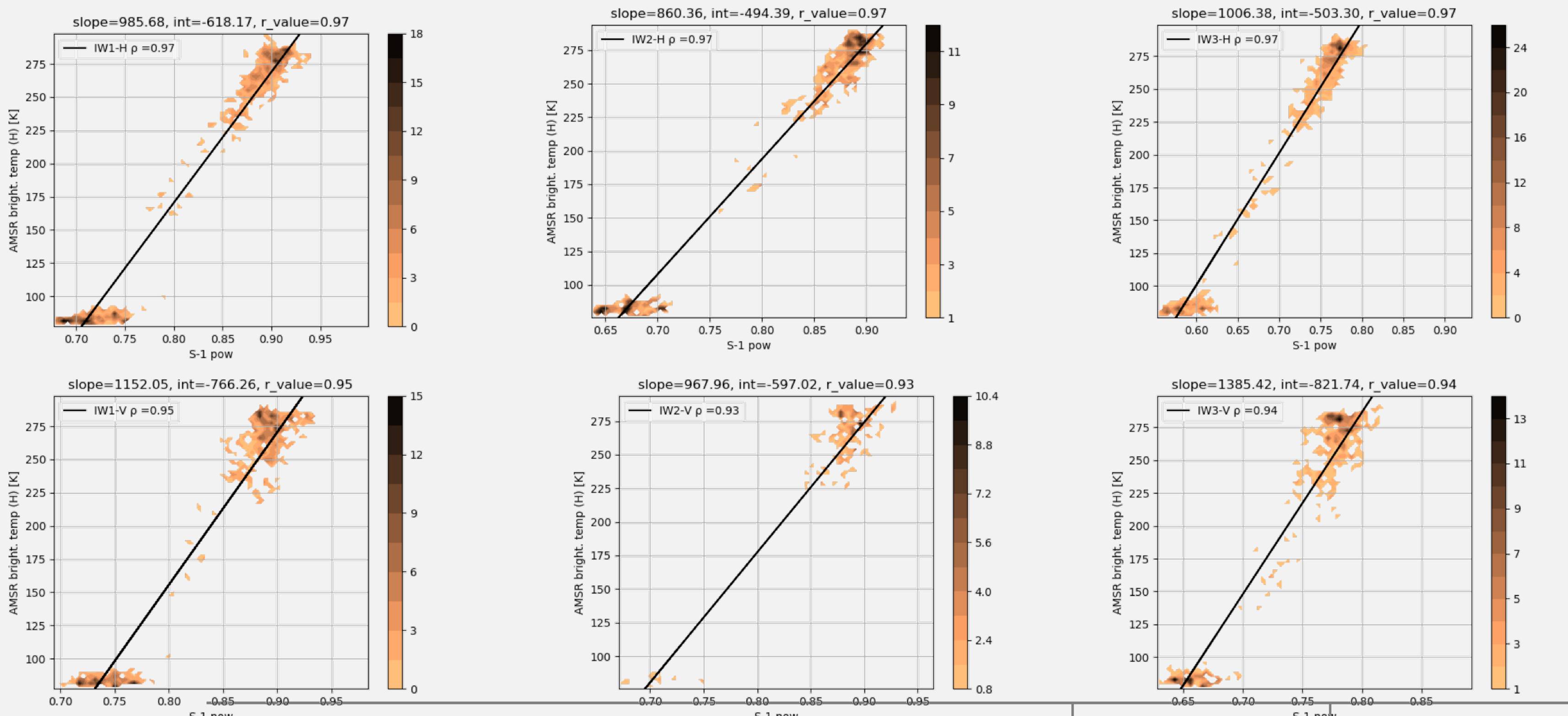
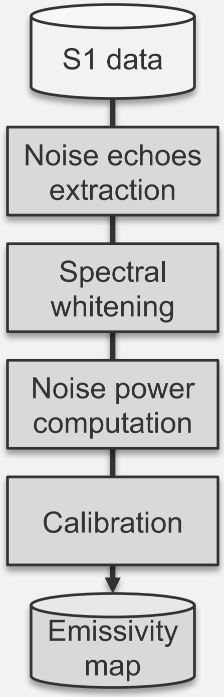


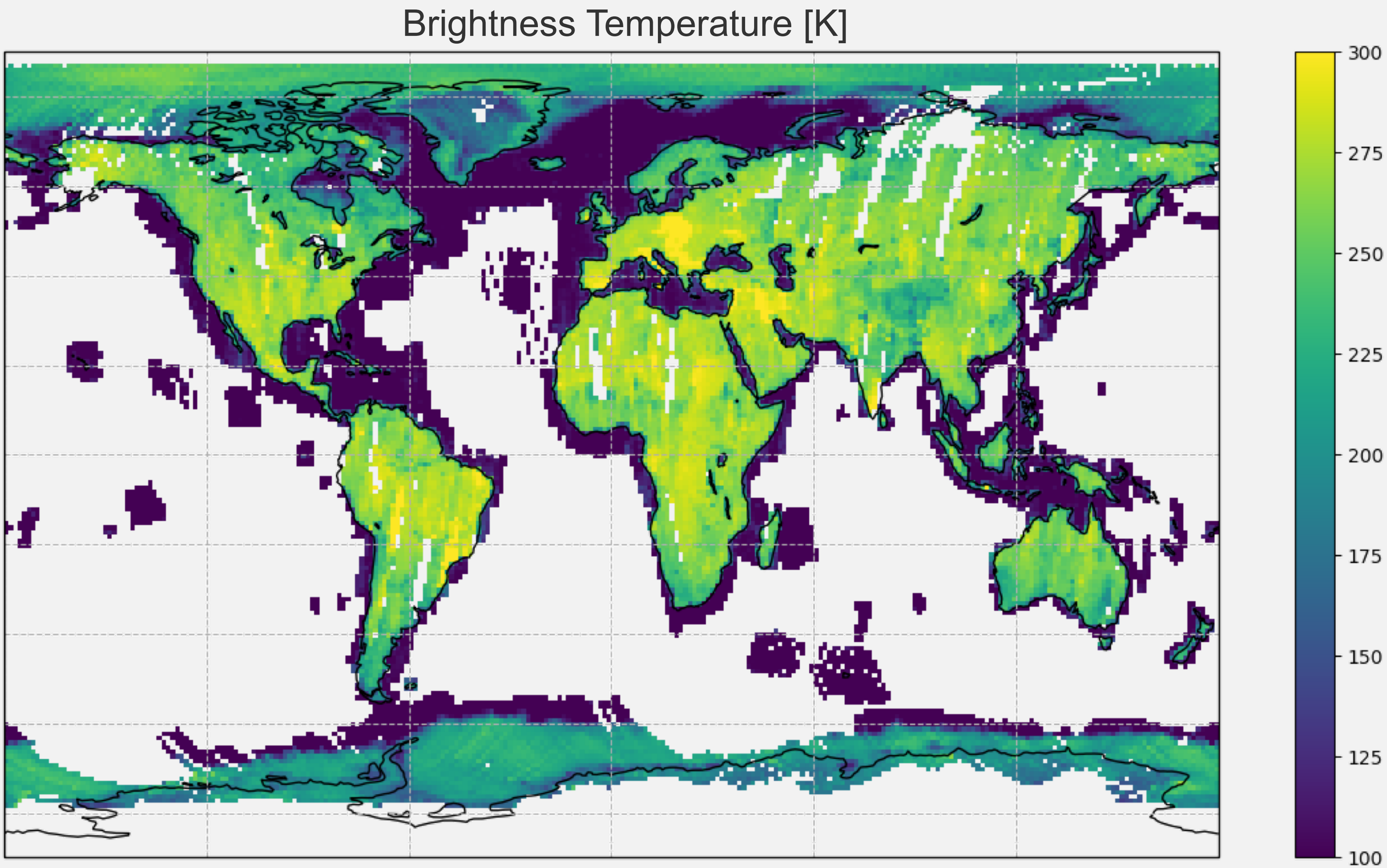
Monitoring Earth Emissivity Using Rank Echoes

- The availability of rank echoes inside the S-1 Level-0 noise products (starting from March 2018) enables the **continuous monitoring** of the noise measurements and the analysis of its variations
- The first objective it to produce **global emissivity maps** and study if and how noise power is influenced by land/sea/ice separation

- Some processing is needed:
  1. Noise and rank echoes extraction.
  2. On-board RX-filter compensation (spectral whitening) (an estimate of this filter is performed using Feb.2018 L0N data for both S1A and S1B).
  3. Noise power computation.
  4. Calibration:
     1. instrument gains compensations (FIR gain, noise BW, SES att., EBT gain pol. imbalance).
     2. Conversion to brightness temperature.

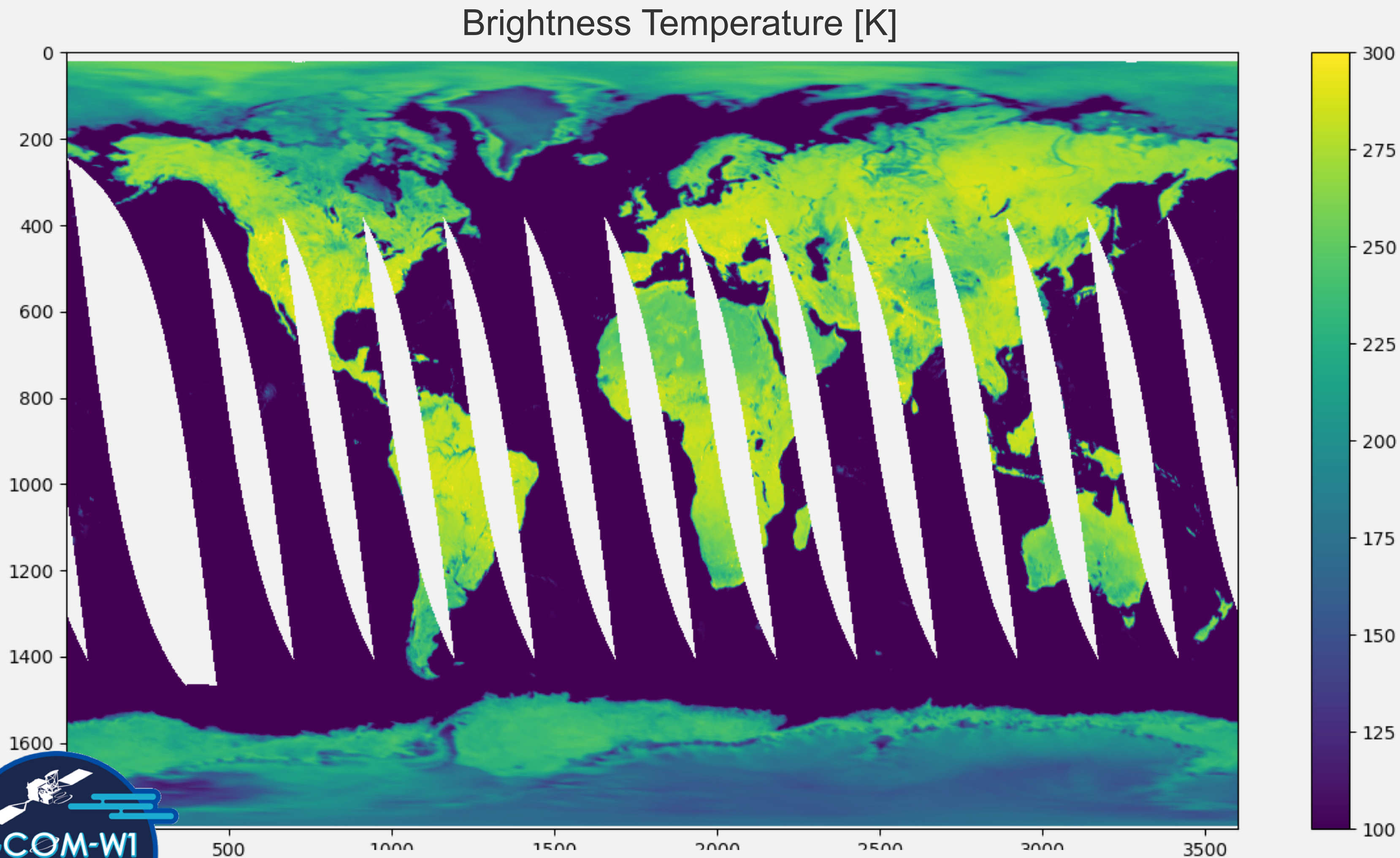


Sentinel-1 as a Passive Radiometer



S-1(A+B) Topsar data July 1-12, 2019.
Resolution: 1deg lat., 1.5deg lon.

Comparison with AMSR-2



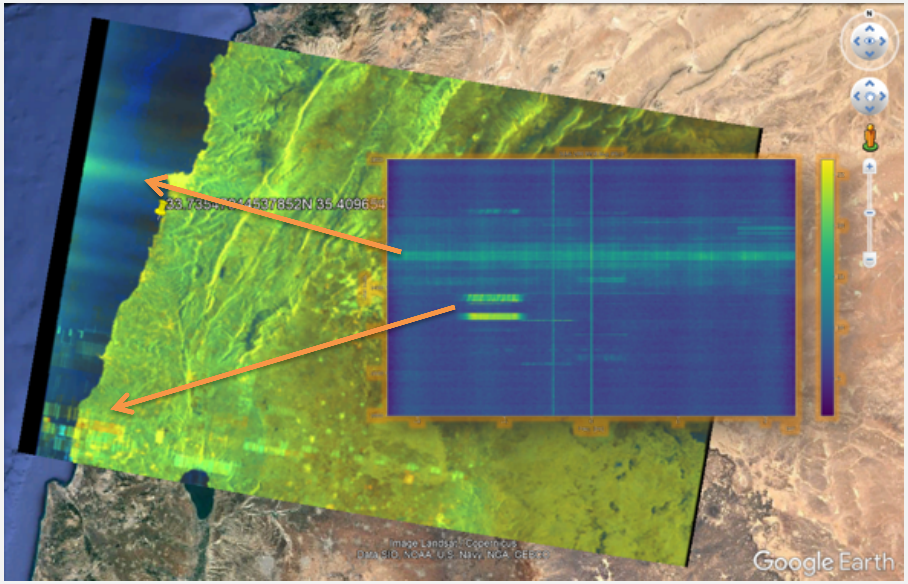
AMSR-2 Ascending July 1, 2019.
Resolution: 0.1deg lat., 0.1 deg lon.

RFI Detection Using S-1 Rank Echoes

- Another important application of rank echoes is the study and the detection of **Radio Frequency Interferences.**

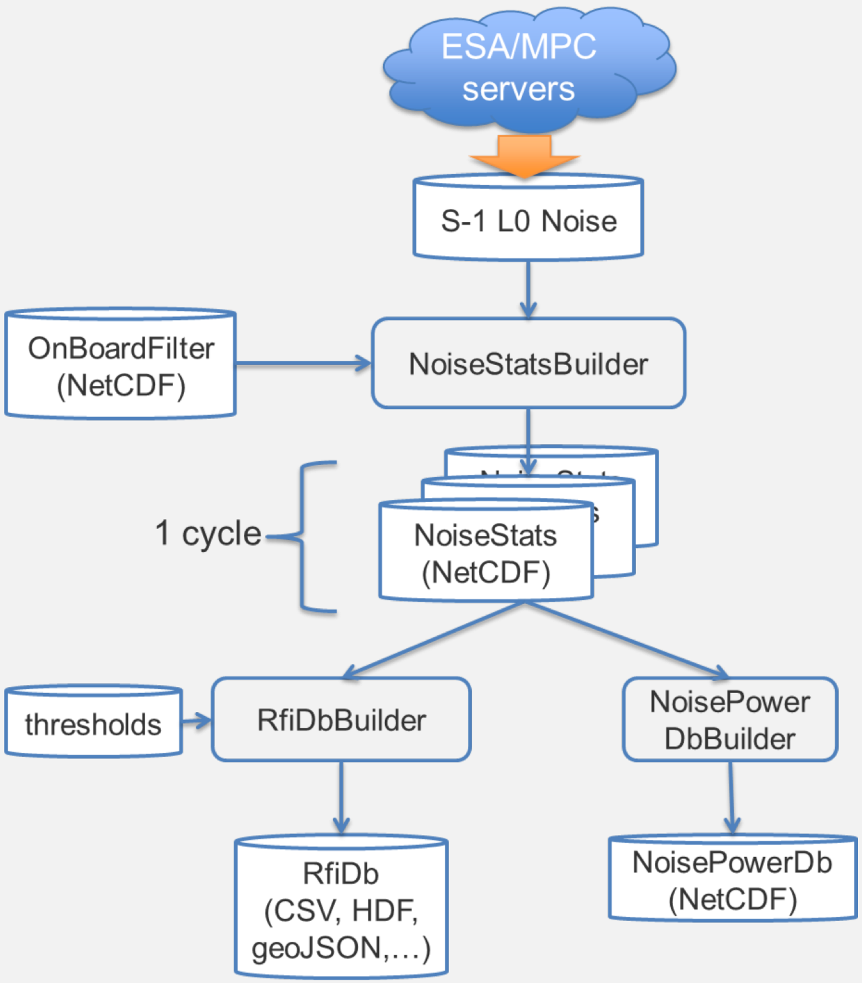
- The RFI detection algorithm [1] is based on three main steps:
  1. Offline calibration using noise data:
     - Estimation of the power transfer function of the RX filter.
  2. Processing of rank echoes:
     - PSD estimation
     - RX filter effect removal
     - Along-track time ripples removal
     - Multi-looking
  3. Detection:
     - Fisher Z Test (narrowband high-power)
     - KL divergence (wide-band low-power)

Example of RFI in the spectrum-along track domain.



[1] Monti-Guarnieri, A., Giudici, D., & Recchia, A., "Identification of C-Band Radio Frequency Interferences from Sentinel-1 Data", Remote Sensing, 9(11), 1183, 2017

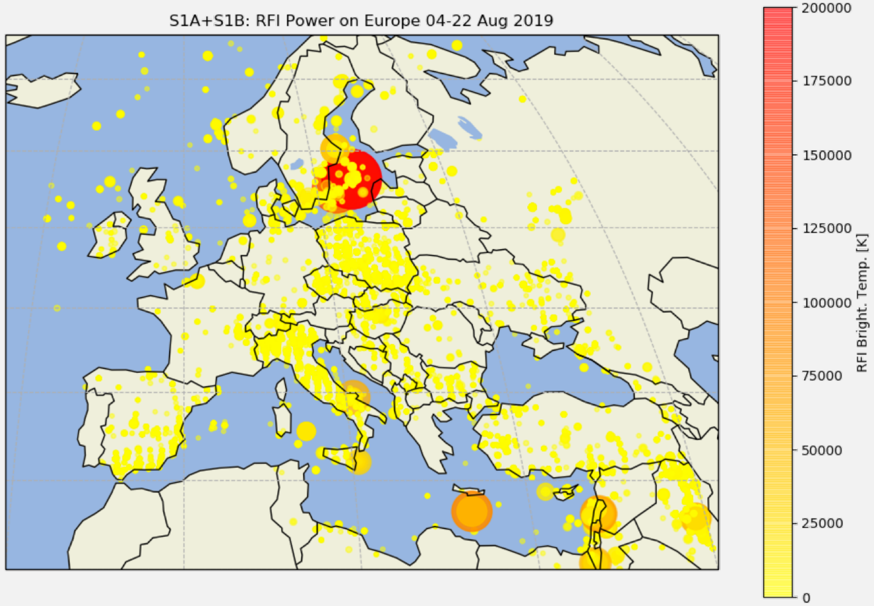
C-Band RFI Routine Monitoring

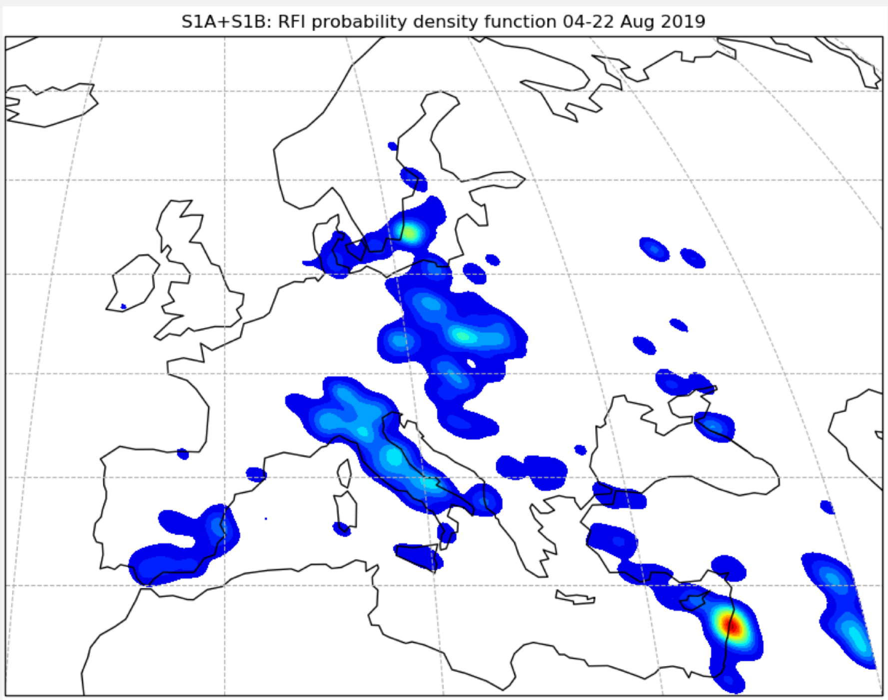


- An automatic C-band RFI monitoring system was put in place by Aresys.
- The L0 Noise data are downloaded from ESA's servers.
- The relevant noise statistics are extracted and processed using a-priori information: spurious freq. and RX filter shape.
- **Every 12 days** (one orbit cycle) **the noise statistics are used to produce the RFI database** and eventually the noise maps.
- The RFI DB stores all the relevant information about the events: time, latitude/longitude., center frequency, bandwidth, power.

Mapping the C-band RFI

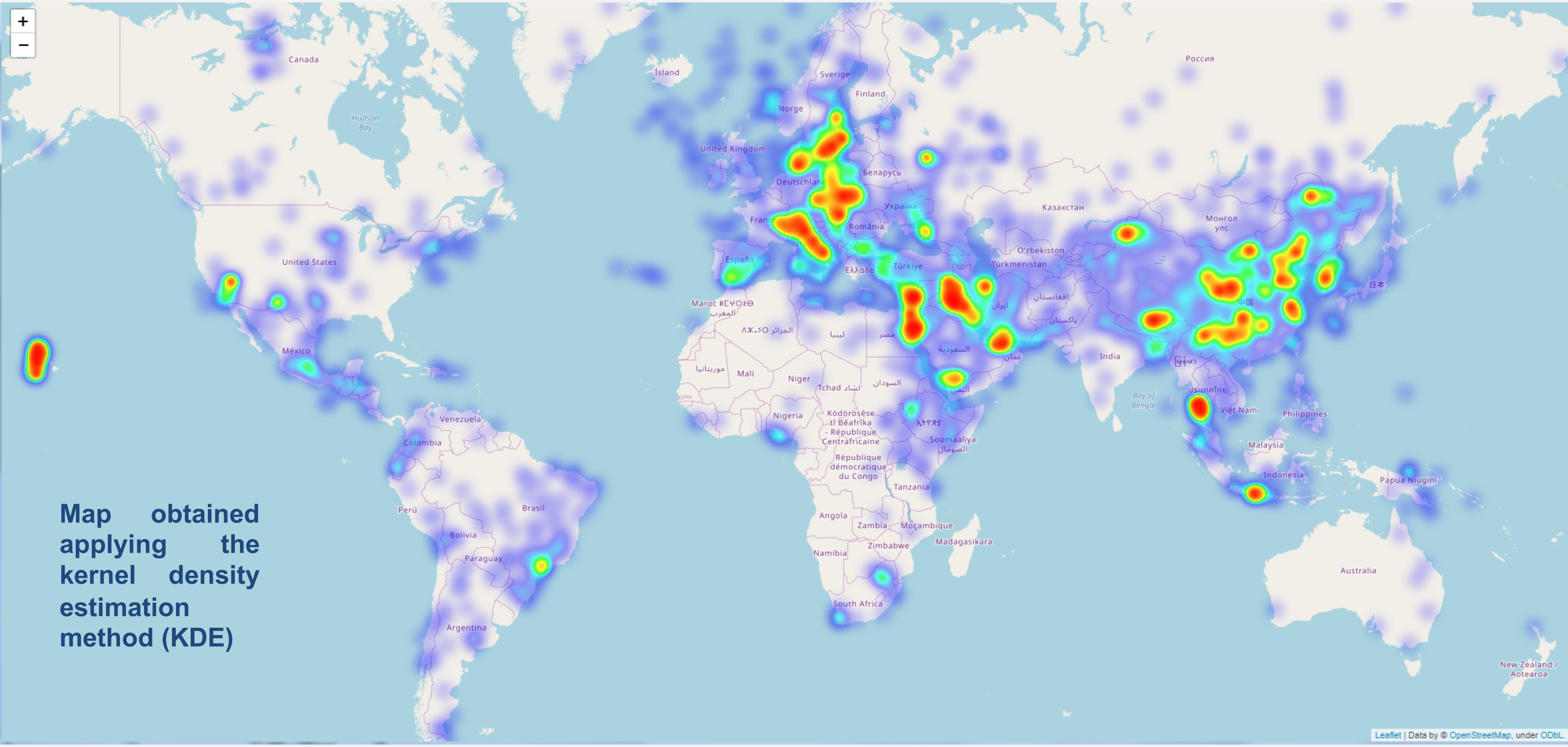
- All the RFI events can be pinpointed on the map as colored circles. The **radius** and the **intensity** of the color is **proportional to the RFI power**.





- The **RFI probability density function** over the geographical coordinates can also be estimated.

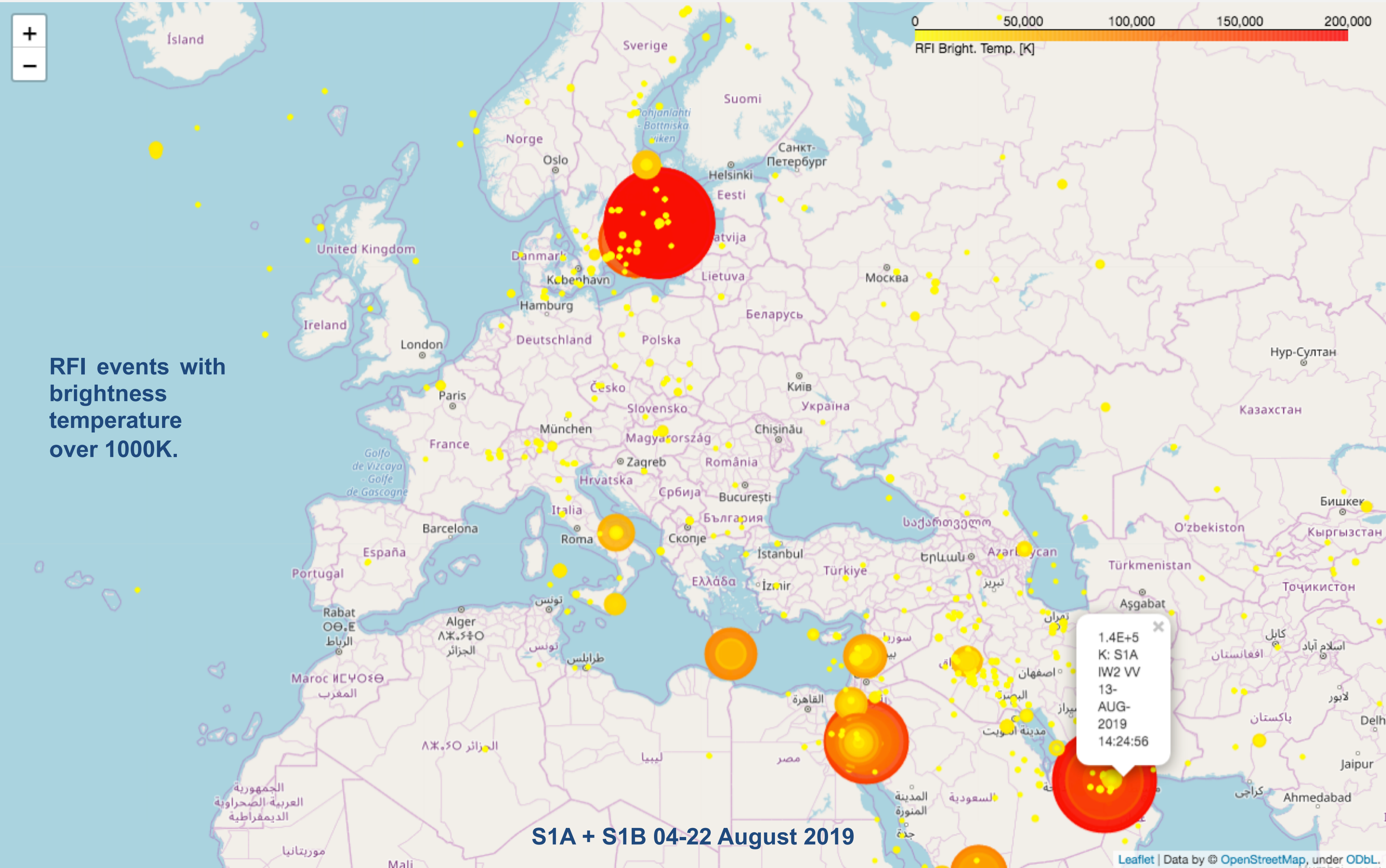
RFI Probability Density Function



Map obtained applying the kernel density estimation method (KDE)

S1A + S1B 04-22 August 2019 (interactive map)

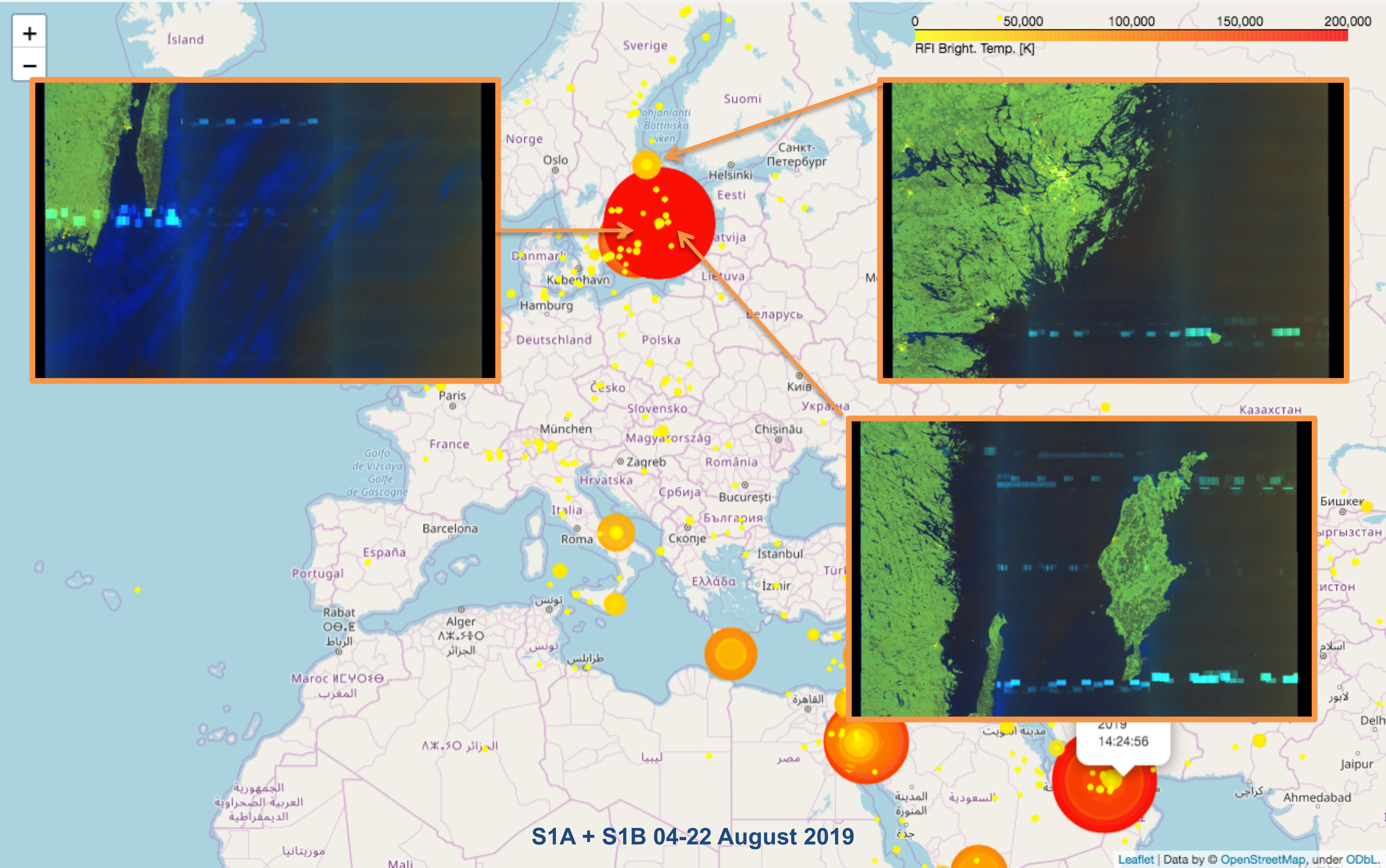
RFI Brightness Temperature



RFI events with brightness temperature over 1000K.

S1A + S1B 04-22 August 2019

RFI Brightness Temperature



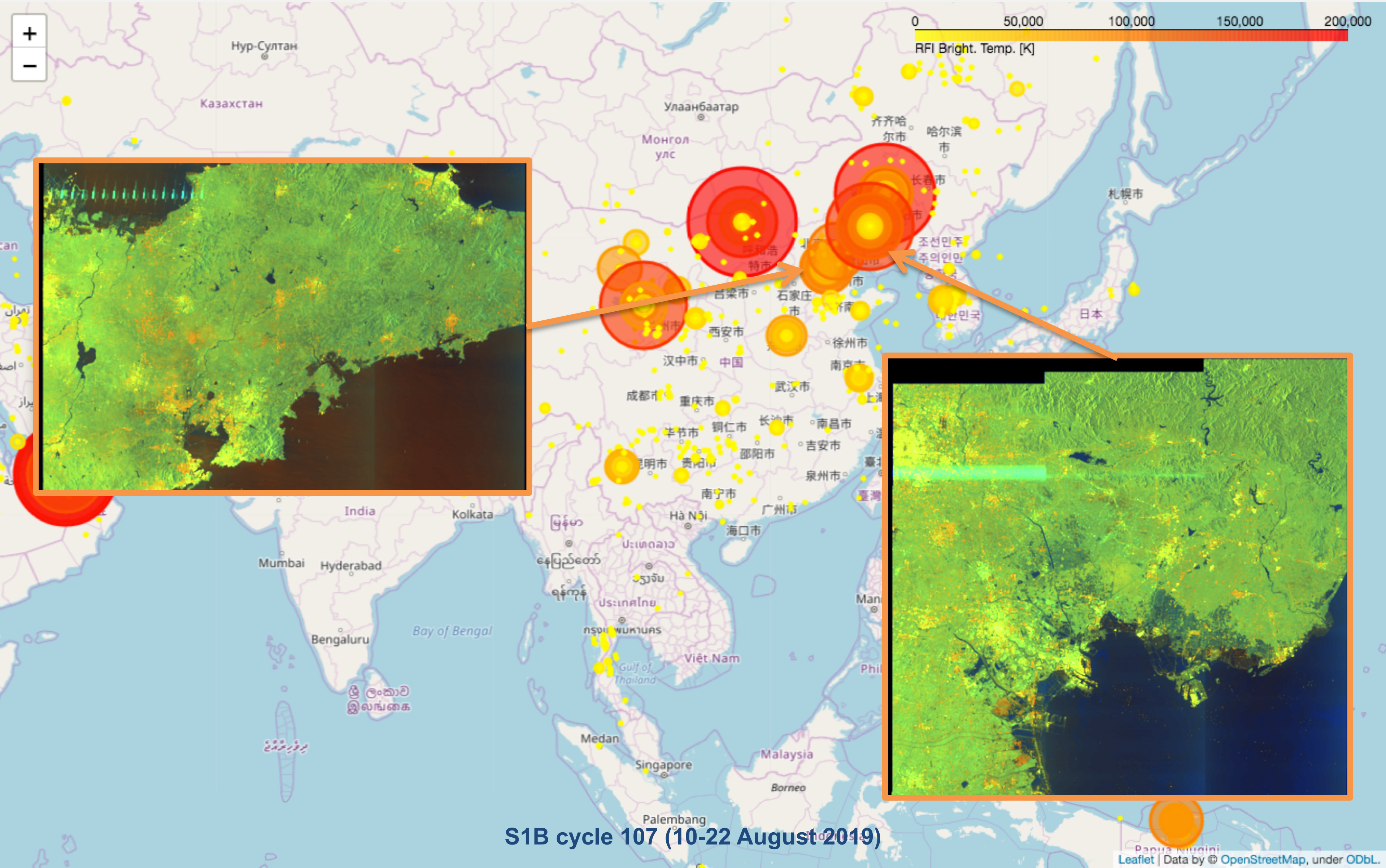
S1A + S1B 04-22 August 2019

RFI Brightness Temperature

RFI events with brightness temperature over 1000K.

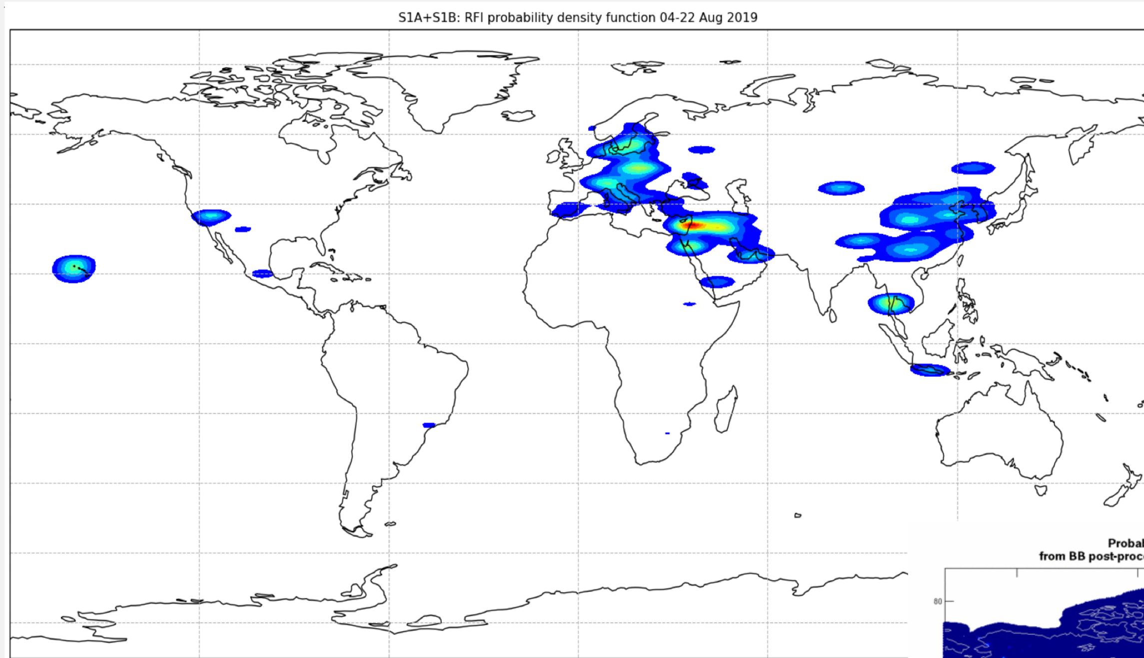
S1B cycle 107 (10-22 August 2019)

RFI Brightness Temperature



S1B cycle 107 (10-22 August 2019)

Sentinel-1 Vs SMOS RFI Probability Maps

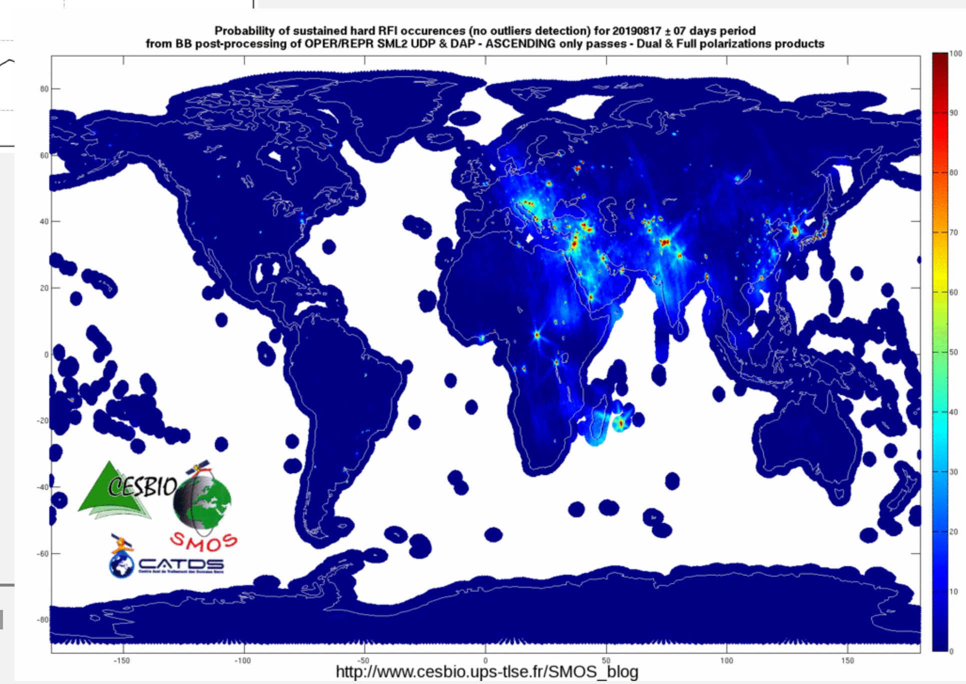


sentinel-1

(C-BAND)

SMOS

(L-BAND)



Conclusions

- Sentinel-1 rank echoes have proved to be a **valid instrument for RFI monitoring**. Using Fisher's Z and KL divergence, RFI can be detected using the statistical properties of the noise pulses, even with very few echoes (8-10) available.
- The S-1 noise power has been **calibrated** using data from the **AMSR-2** passive radiometer operating at 6.9GHz. This enables to give physical significance to the noise measures and express them in terms of brightness temperature.
- A qualitative comparison with L-band RFI maps by SMOS was given.
- **Way forward:** The measures of brightness temperature could be used to characterize the thermal noise level of the instrument. This could improve the quality of the denoising step in the Sentinel-1 processor.

