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

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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

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**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.

![Before TD RFI mitigation](image1)

- **RAW data**
- **SLC data**

![After TD RFI mitigation](image2)

- **RAW data**
- **SLC data**

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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:**

  \[ \hat{P} = P_n + P_e \]

  $P_n$ is the effective noise power and $P_e$ 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 is 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

Brightness Temperature [K]

S-1(A+B) Topsar data July 1-12, 2019.
Resolution: 1deg lat., 1.5deg lon.
Comparison with AMSR-2

Brightness Temperature [K]

AMSR-2 Ascending July 1, 2019.
Resolution: 0.1 deg 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:
     o Estimation of the power transfer function of the RX filter.
  2. Processing of rank echoes:
     o PSD estimation
     o RX filter effect removal
     o Along-track time ripples removal
     o Multi-looking
  3. Detection:
     o Fisher Z Test (narrowband high-power)
     o KL divergence (wide-band low-power)

Example of RFI in the spectrum-along track domain.

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
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

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http://www.cesbio.ups-tlse.fr/SMOS_blog
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.