Improvement of interferometric coherence through RFI mitigation in Sentinel-1 products

Andrea Recchia[1], Niccolò Franceschi[1], Laura Fioretti[1], Alessandro Cotrufo[1], Hajduch Guillaume[2], Pauline Vincent[2], Muriel Pinheiro[3], Clement Albinet[3], Antonio Valentino[4]

FRINGE 2023

University of Leeds, UK | 11 - 15 September 2023.

→ THE EUROPEAN SPACE AGENCY

Outline

- ➤ Impact of RFI on Sentinel-1 data

- ➤ S-1 operational RFI mitigation

- ➤ RFI mitigation and data quality preservation

- ➤ RFI mitigation and interferometry

- ➤ Conclusion

- ➤ Further material

→ THE EUROPEAN SPACE AGENCY

Impact of RFI on Sentinel-1 data

- Since the start of the mission, users reported local image degradations related to radio frequency interferences (RFI).

- Known sources of RFI include: military radars, meteorological radars and other spaceborne active instruments

- In the future, new emitters could compete with C-band SAR:

  - agenda item 1.16 of WRC-19: RLAN deployment outside the 5150-5925 MHz band → not successful;

  - potential migration of European meteorological radars from 5.6 GHz to 5365-5470 MHz → currently under consideration within the CEPT

→ THE EUROPEAN SPACE AGENCY

Operational S-1 RFI mitigation

➢ Operational mitigation of RFI contamination in Sentinel-1 data was **activated on March 23, 2022**.

➢ Two steps:

  1. **Pre-screening** of noise measurements (few lines, fast)

  2. If pre-screening positive, activation of the **detection/mitigation module** (pixel-by-pixel, slow)

➢ RFI Detection/mitigation module uses two independent algorithms in time-domain and in frequency domain.

➢ **Destructive step** it corrects unfocused (raw) data!

➢ New annotation data file provides statistics about affected samples/lines and bandwidth.

→ THE EUROPEAN SPACE AGENCY

RFI pre-screening from rank echoes

- RFI mitigation is computationally demanding and would affect S-1 IPF throughput if applied to all products

- A pre-screening step has been introduced based on rank echoes -> "noise like" echoes at the begin of each burst

- S-1C will replace rank echoes usage with dedicated noise pulses within the timeline

Sample map of RFI mitigation activation and statistics

S1A SLC products		
	IW	EW
Products	36564	1150
% RFI affected bursts	1.17%	0.02%
% mitigated products	17.65%	1.74%

False
True

Sentinel-1 A/B

Sentinel-1C&D

THE EUROPEAN SPACE AGENCY

- • **Input:** raw data

- • **Output:** corrected raw data

- • **Assumption:** SAR raw amplitude is Rayleigh distributed

1. Median filtering

2. Std deviation $\sigma(i,j)$ locally estimated

3. Compute threshold corresponding to F-th percentile

$$Thr_F(i,j) = \sigma(i,j)\sqrt{-2ln(1-F)}$$

4. Compute the detection mask and corrected data

$$Mask(i,j) = \begin{cases} 1, if \ |RAW(i,j)| > Thr_F(i,j) \\ 0, if \ |RAW(i,j)| \leq Thr_F(i,j) \end{cases}$$

$$RAW(i,j) = \begin{cases} RAW(i,\tilde{j}), if \ Mask(i,j) = 1 \\ RAW(i,j), if \ Mask(i,j) = 0 \end{cases}$$

Original

Corrected

Operational detection/mitigation: frequency domain

- **Basic idea:** compare the RX spectrum with the transmitted chirp

- Two types of **detection**:

  → **Persistent:** detection based on mean FFT of the block

  → **Isolated:** detection based on line-by-line PSD estimated by Welch's method

- **Mitigation:** force to zero the affected freq. bins + power loss compensation

Original

Corrected

Operational RFI mitigation: L1 products

Standard RFI contamination detected and mitigated

Long RFI contamination from «unknown source» detected and mitigated

Operational mitigation: L2 products

OWI wind speed | Intensity | RVL

RFI mitigation: impact on interferometric quality

- RFI mitigation has two goals:

  → Remove radiometric artifacts from L1 products by correcting raw data

  → Leave data quality unaffected when RFI contamination is not present

- Next slides show the effect of RFI mitigation on L1 products comparing two S-1A products processed with and without RFI mitigation

- Analysed S-1A products: DT 04C354 – 20/10/2021 – descending pass – slice 1 of 25

No RFI mitigation

RFI mitigation

RFI mitigation: data intensity preservation

- Comparison of data intensity with and without RFI mitigation

- Main impact on data is observed for:

  → Bursts affected by RFI (bright yellow regular stripes)

  → Low back-scatter areas

- Comparison of data coherence (auto interferogram of data with and without RFI mitigation)

- Main impact on data is observed for:

  → Bursts affected by RFI

  → Low back-scatter areas

- Overall coherence is very high -> data phase is preserved

- Dubai area often shows strong RFI contamination

- Two S-1A products were processed with and without RFI mitigation

- The resulting SLC products were used to generate two sets of interferograms and coherence maps:

  → Interferogram from products with no RFI mitigation

  → Interferogram from products with RFI mitigation

- The results of the interferometric processing are reported in the next slides

S-1A products analyzed

- Descending acquisition

- Last slice of the DT

- RFI observed in the same data portion -> likely same ground emitter

- Interferometric processing performed on IW1 and IW2 sub-swaths (IW3 mostly over water)

- Area in the red box shown in next slides

Primary Image – 10/09/2021 – DT 04AED0

Secondary Image – 22/09/2021 – DT 04B4BE

No RFI mitigation

RFI mitigation

Interferogram
RFI mitigation not activated

→ THE EUROPEAN SPACE AGENCY

Interferogram
RFI mitigation activated

→ THE EUROPEAN SPACE AGENCY

Coherence
RFI mitigation not activated

→ THE EUROPEAN SPACE AGENCY

Coherence
RFI mitigation activated

→ THE EUROPEAN SPACE AGENCY

Conclusion

- RFI contamination of S-1 products has been observed since the begin of the mission

- RFI mitigation affects both radiometry-based applications and phase-based applications (e.g., interferometry and RVL)

- RFI mitigation is operationally applied to S-1 products since March 2022 (IPF 340)

- The applied RFI mitigation:

  → has **negligible impact** on data quality if no RFI is present

  → **improves data quality** when RFI is present ensuring better results from higher level applications

Further reading

- Further documentation on RFI detection and mitigation available on Sentinel Online:

- https://sentinel.esa.int/web/sentinel/user-guides/sentinel-1-sar/document-library

  - **Detailed processing model**:

    - explaining how the processor detects and mitigate the RFI

  - **S-1 RFI technical note**:

    - Description of RFI related format and usage

  - **S-1A & B annual performance report**:

    - Provide examples of RFI and list of known space to space source with location of possible occurrences

→ THE EUROPEAN SPACE AGENCY