4th Weather Radar Calibration and Monitoring Workshop

WXRCalMon2023

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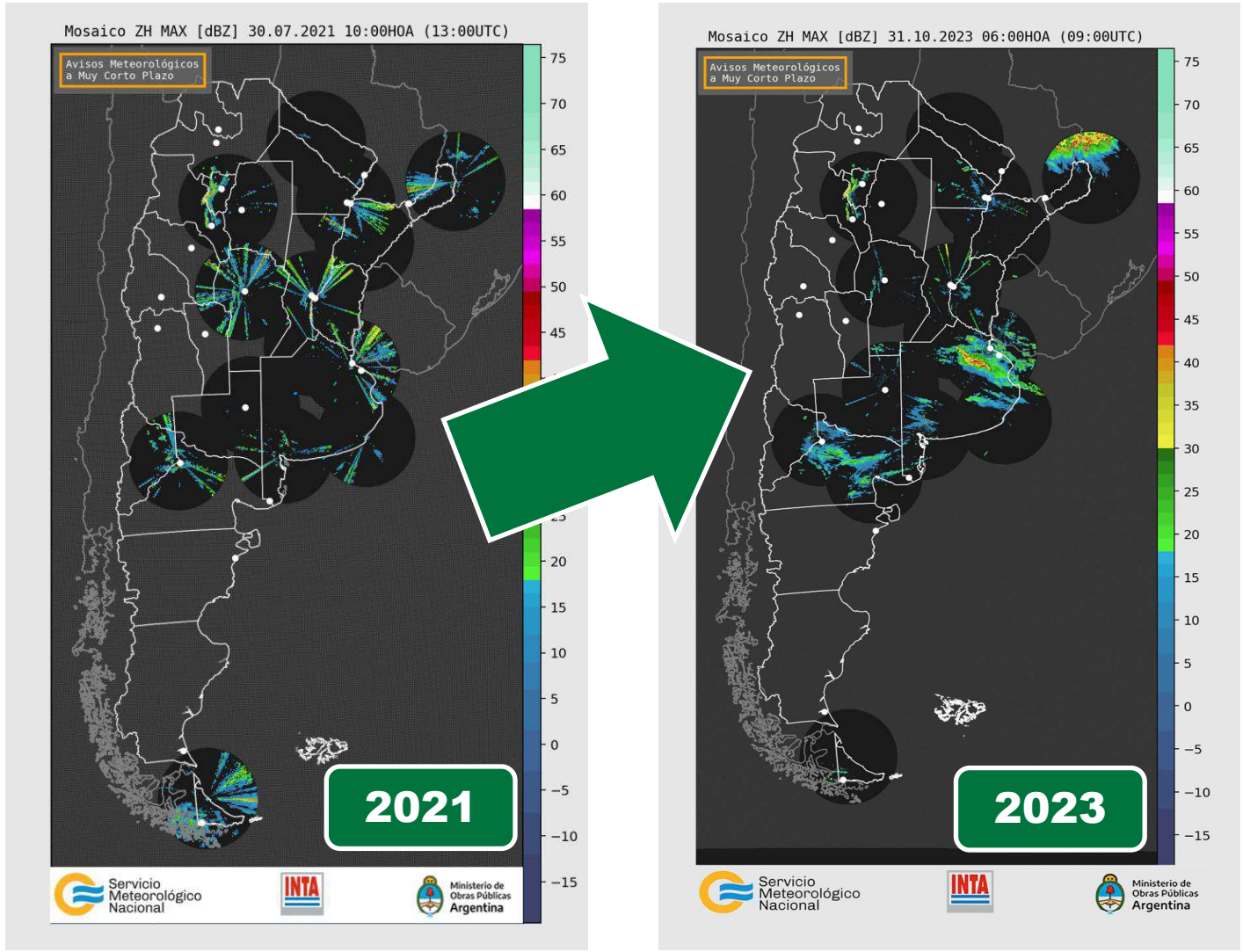

THE ARGENTINIAN METEOROLOGICAL RADAR

Real time RFI digital filter operational data quality impact analysis

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www.invap.com.ar/en/divisions/defense-security-and-environment/c-band-weather-radar/

1. Introduction (1/6)

The SINARAME network

- Argentina's network of weather radars, *Sistema Nacional de Radares Meteorológicos* (***SINARAME***), is an ongoing, long-term, multi-stage government project.
  - **Stage 1** of SINARAME project started in September 2011, delivering: 2 radars (RMA0 and RMA1) and the radar data center.
  - **Stage 2** of the project was carried out between 2014 and 2019, extending the network with 10 new radars (RMA2 to RMA11).
  - **Stage 3** of the project is underway to add up 10 new radars to the network, reaching a total of 21 RMA units by the end of 2024.

- The ultimate goal of ***SINARAME*** is to cover Argentina's surface with modern dual-pol weather radars, managed from a central location in Buenos Aires thereby enhancing hazardous weather forecast and alerts; resulting in better decision making by authorities, emergency managers and the general population.

1. Introduction (2/6)

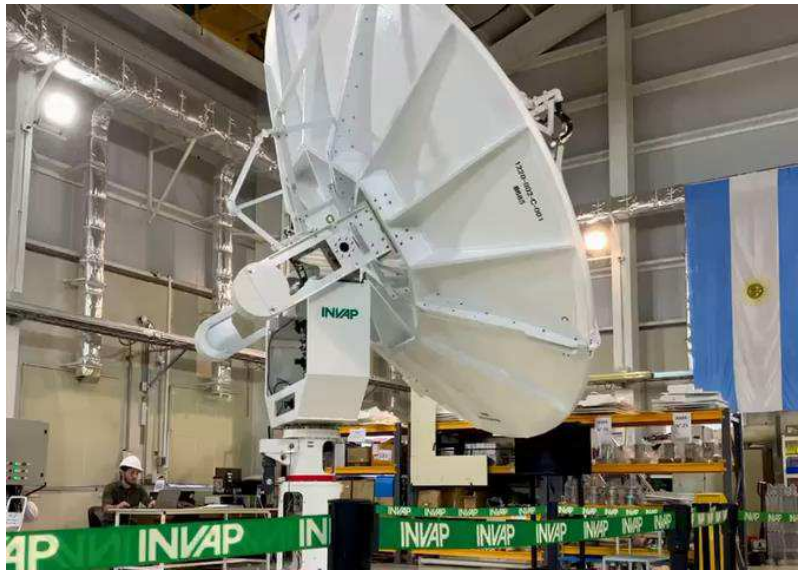
The RMA radar

- The *Argentinian Meteorological Radar* (***RMA***) is a modern, dual–pol weather radar designed and manufactured entirely in Argentina by INVAP S.E.

- ***SINARAME*** network is currently composed of 15 C-band weather radars, the oldest 3 units were acquired abroad prior to SINARAME while the newer 12 are ***RMA*** units.

- RMA0, the first commissioned unit in *SINARAME* stage 1, is dedicated to research, testing of new technologies and personnel training.

- By the end of 2024, a total of 21 *RMA* units will be operational.



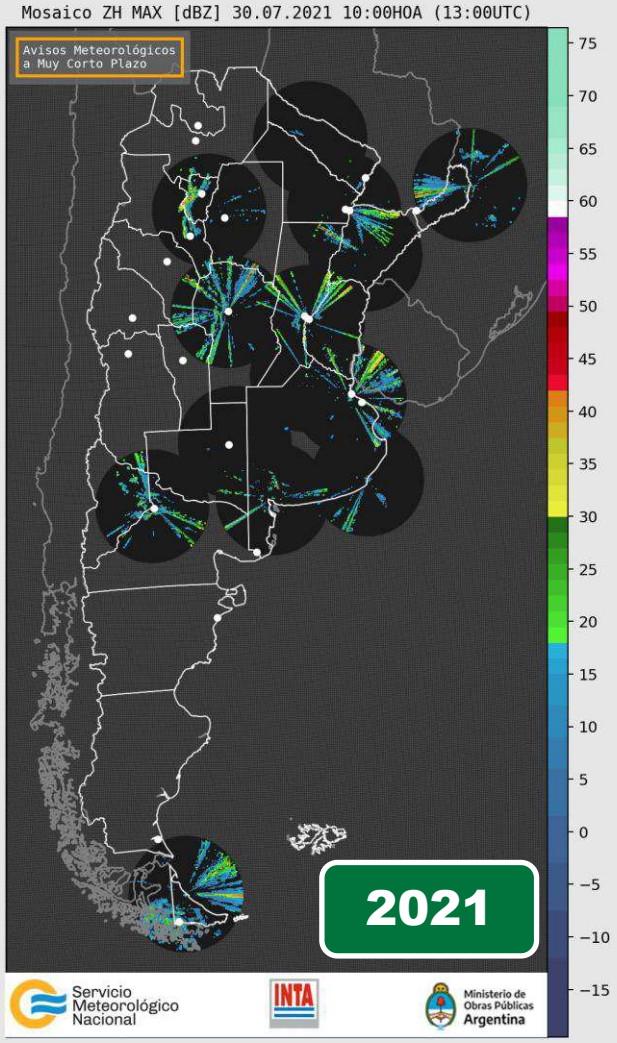
1. Introduction (3/6)

The Threat to Weather Radars by Wireless Technology

- C-band radars operate in the same frequency band as wireless technology such as local area telecommunication networks and surveillance cameras therefore **all *SINARAME* radars** are **affected by *Radio Frequency Interference*** (***RFI***), with some sites exhibiting severe *RFI* contamination.

- Different mitigation alternatives were explored, with limited success, such as:
  - Tuning the radar on different operating channels within the band reserved for weather radars (5600 to 5650 MHz).
  - Installation of narrowband analog filters at the input of the receivers.

- And others more effective but quite expensive to implement and sustain in the long term, such as:
  - Hunting down interference sources and requesting that they be modified to work outside the reserved band.

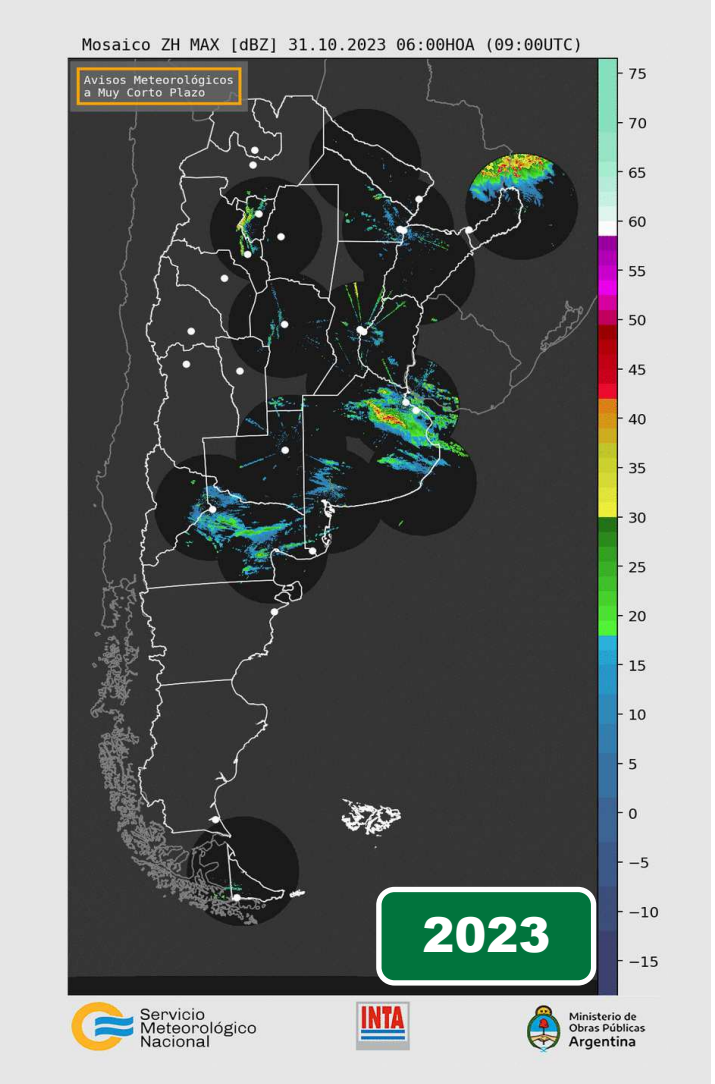


https://www.smn.gob.ar/radar

1. Introduction (4/6)

Real time RFI digital filter

- The best approach, so far, has been the commissioning of a real time *RFI* digital filter in all *SINARAME RMA* radars.
- This work reports on the overall validation process and in particular on the evaluation of data quality improvement achieved with this new *RFI* filter.
- While the scope of the project to combat *RFI* contamination covers all *SINARAME RMA* units, in this presentation we will share only a handful of representative samples.



https://www.smn.gob.ar/radar

1. Introduction (5/6)

Validation and commissioning

The validation plan was composed of the following phases:

- PHASE 1 – Processing archives of real weather data synthetically contaminated with archives real RFI data, to analyze:
  - The impact of RFI contamination on data quality
  - The suppression capabilities of the filter
  - The level of data quality recovery
- PHASE 2 – Processing archives of real radar data, to study:
  - The RFI filter performance (misses and false detections) under different weather conditions
  - The RFI filter performance (misses and false detections) under different levels of RFI contamination
- PHASE 3 – Running the filter on an operational site, to study:
  - The processor performance (CPU usage, RAM usage) under real system load
  - The RFI filter performance under real RFI contamination variability (day vs night, summer vs winter, workdays vs weekends)

1. Introduction (6/6)

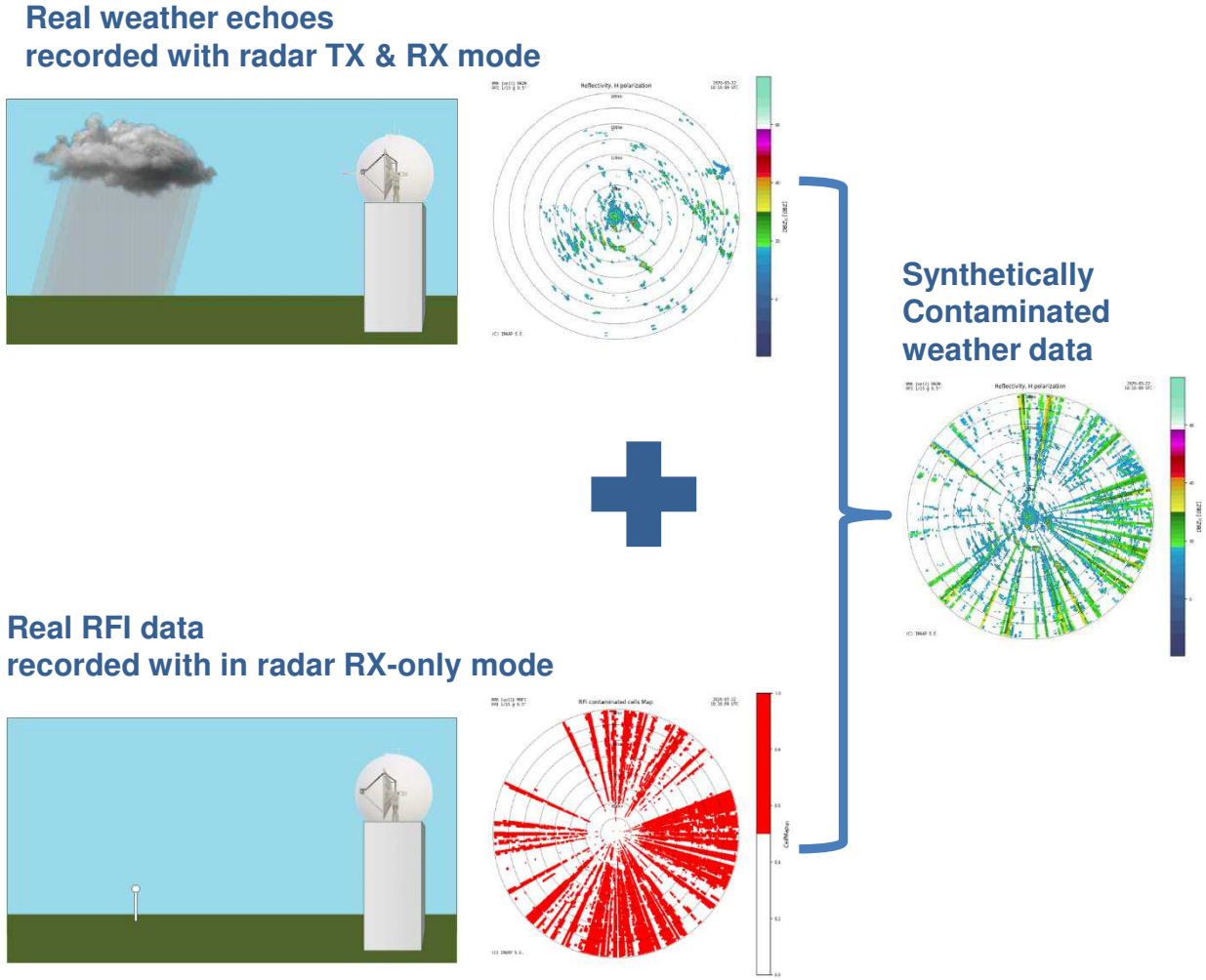
Validation and commissioning

- At the end of the first two phases, the results were discussed with specialists from:
  - *Servicio Meteorológico Nacional* (***SMN***), Argentina's National Meteorological Service
  - The Córdoba Radar Group at *Facultad de Matemática, Astronomía, Física y Computación* (***FAMAF***) from *Universidad Nacional de Córdoba* (***UNC***).
  - *Secretaría de Infraestructura y Política Hídrica* (***SIYPH***), the institution that manages and provides funds for the SINARAME project.
- After selecting an appropriate filtering level for the intended use of the data, a plan was designed to activate the filter in the different sites, one at a time, followed by a monitoring period to study the filter impact on data quality by members of those institutions.

2. PHASE 1 – Methodology (1/6)

Processing real weather synthetically contaminated with real RFI data

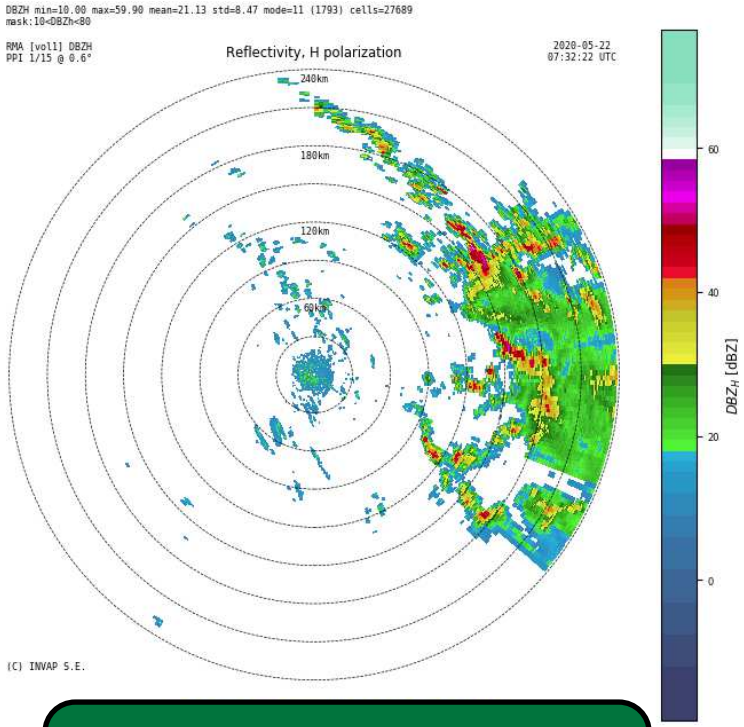
- ❶ Records of I/Q time series of **uncontaminated weather signals, (**RFI-free**)**, were hand picked from an almost RFI-free site in the north of Argentina (RMA3) and chosen as **the reference dataset**.
- ❷ Records of **pure *RFI* signals** were collected from some of the most heavily RFI-contaminated sites, using the radar in receive-only mode.
- ❸ Recorded signals were **numerically combined at the I/Q level**, thus generating a new set of real-world weather data synthetically contaminated with real *RFI* signals.
- The overall impact of contamination on data quality and the suppression capabilities of the filter were tested by applying the *RFI* filter to the artificially contaminated dataset and comparing the results with the reference (RFI-free) dataset.



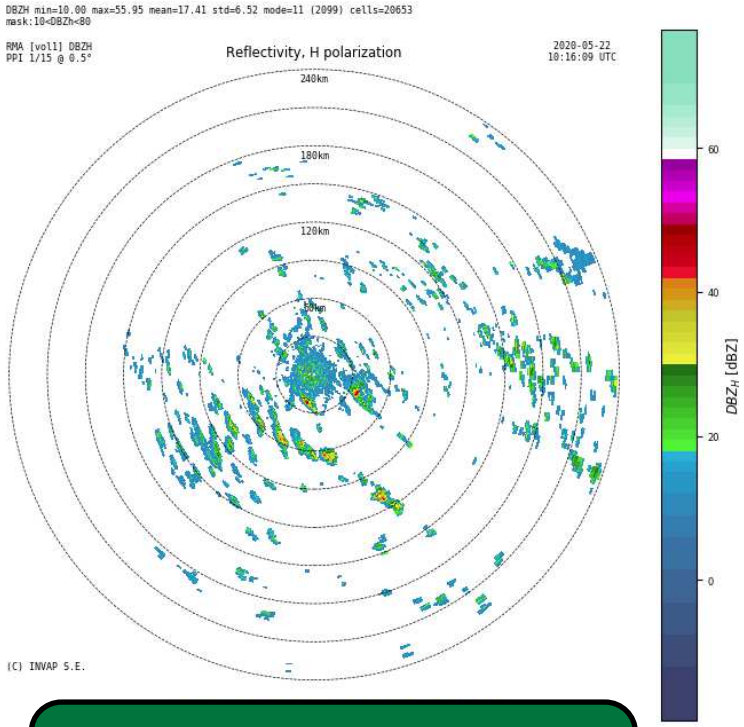
2. PHASE 1 – Data: Uncontaminated weather (2/6)

Three data sets of real uncontaminated weather echoes were selected for this study.

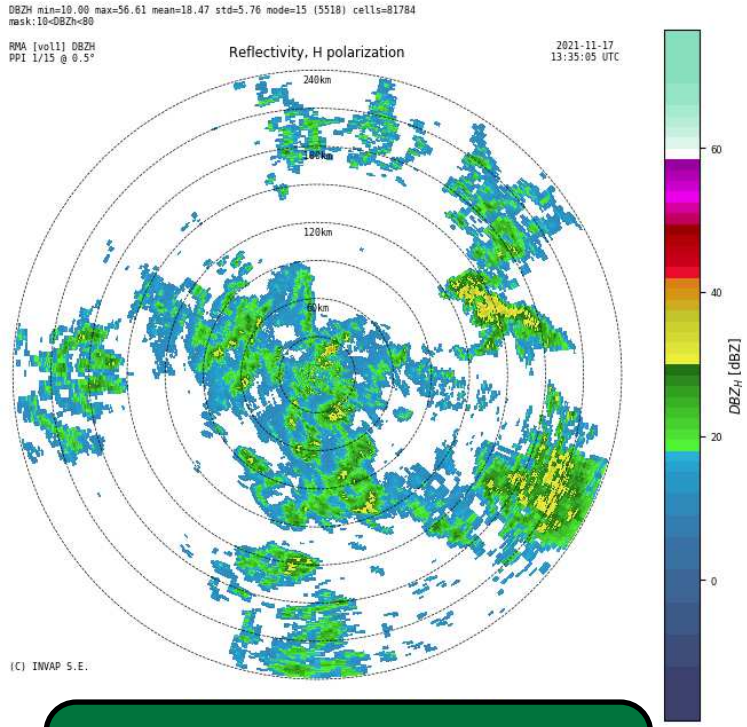
Note: These images display cells only where SNR > 1.0dB



Dataset 1
Uncontaminated data



Dataset 2
Uncontaminated data



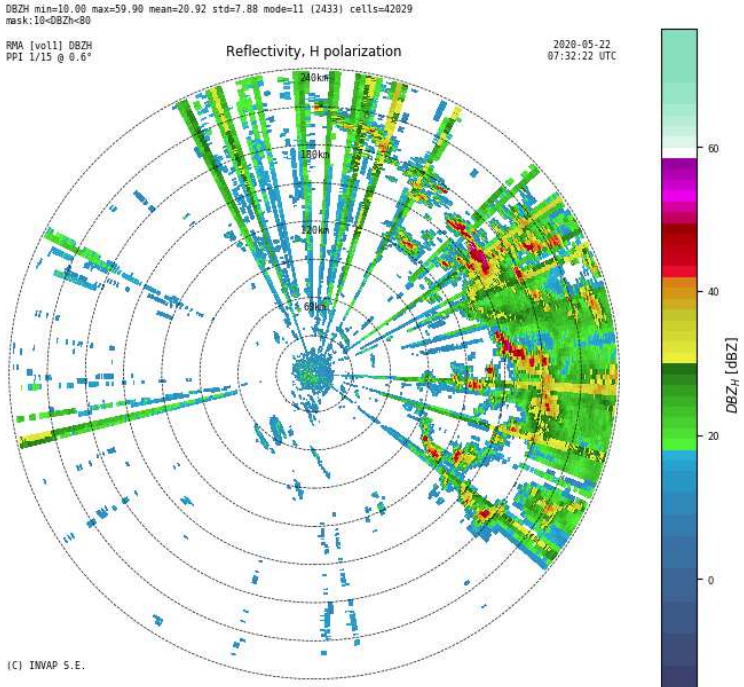
Dataset 3
Uncontaminated data

2. PHASE 1 – Data: Synthetically contaminated (3/6)

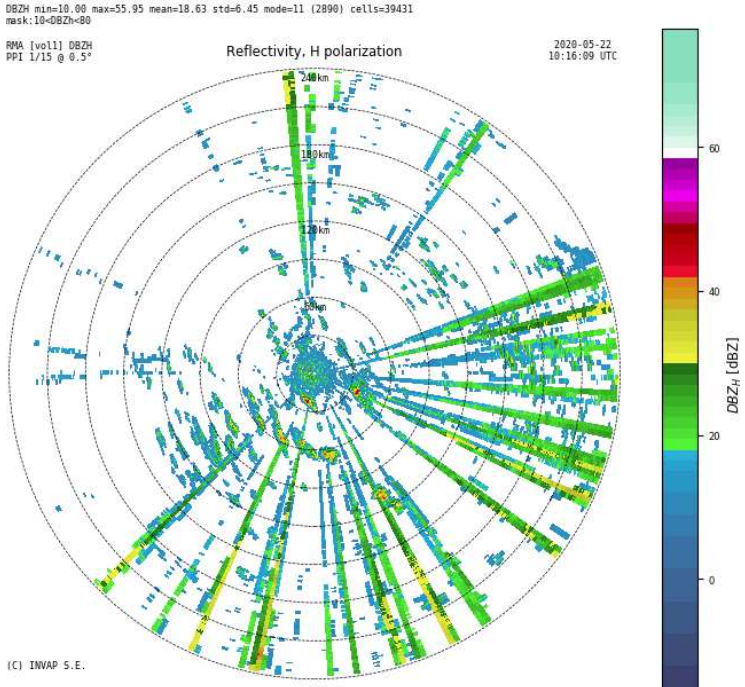
The uncontaminated weather echoes were synthetically contaminated with the recordings of real *RFI* data.

While several sets of *RFI* data were used, only one is shown in this presentation.

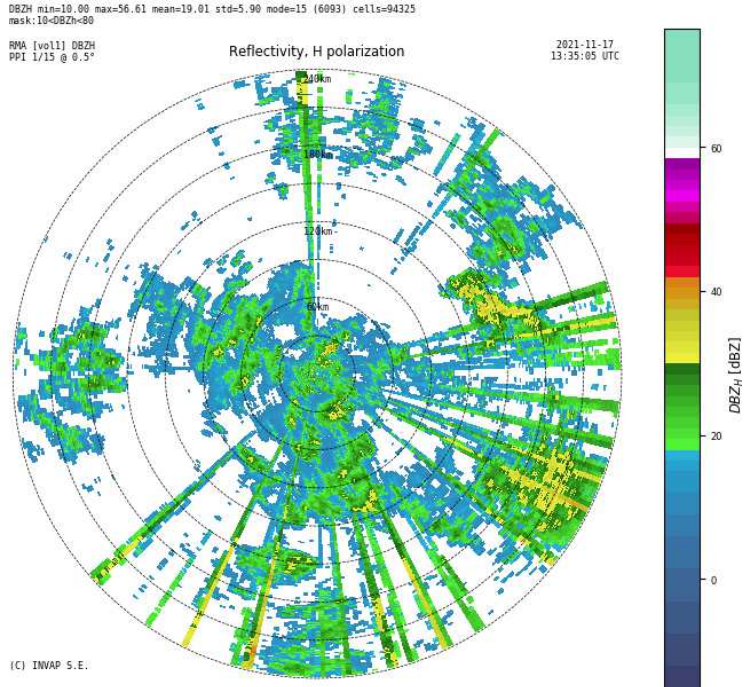
Note: These images display cells only where SNR > 1.0dB



Dataset 1
Contaminated data
Weather + RFI
Filter: Off



Dataset 2
Contaminated data
Weather + RFI
Filter: Off

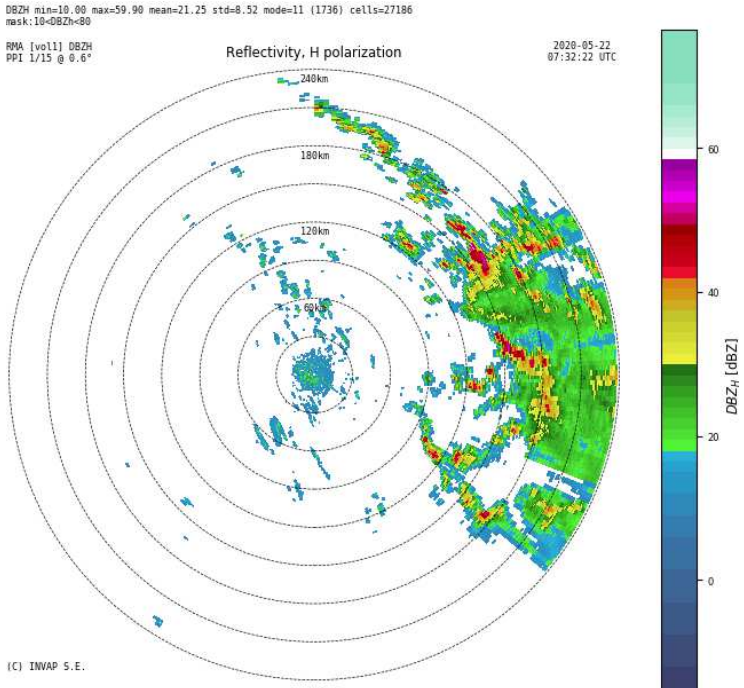


Dataset 3
Contaminated data
Weather + RFI
Filter: Off

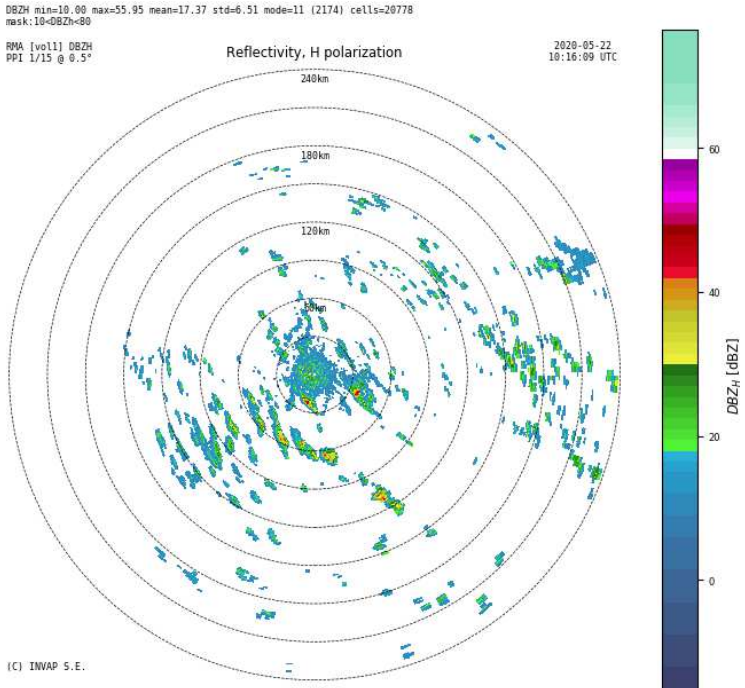
2. PHASE 1 – Results: Weather plus RFI, Filtered (4/6)

The new *RFI* filtering algorithm was applied to the synthetically contaminated data sets.

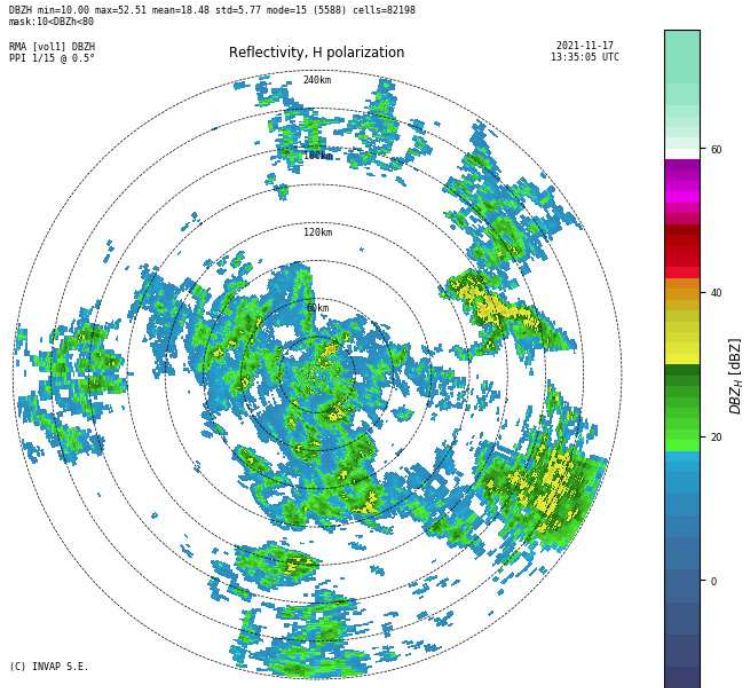
Note: These images display cells only where SNR > 1.0dB



Dataset 1
Contaminated data
Weather + RFI
Filter: On



Dataset 2
Contaminated data
Weather + RFI
Filter: On

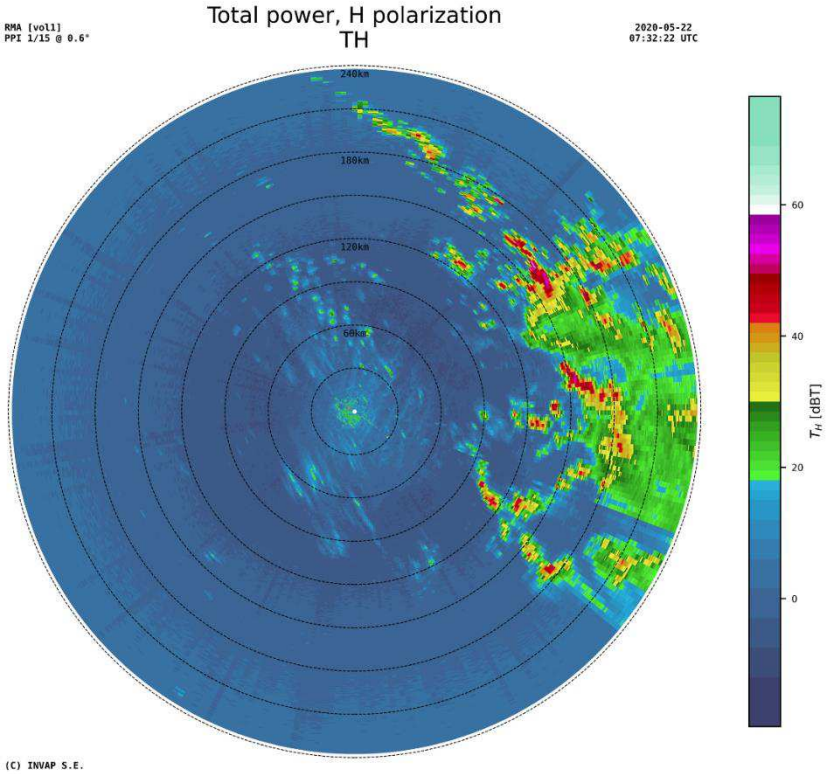


Dataset 3
Contaminated data
Weather + RFI
Filter: On

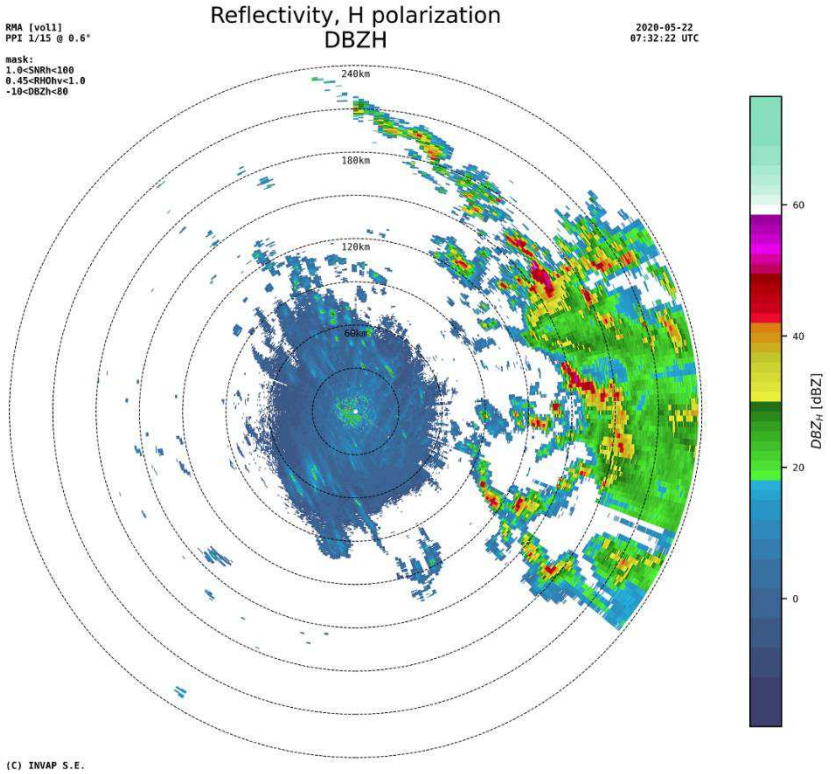
2. PHASE 1 – Results: DBZH (5/6)

The arithmetic difference of *Filtered* data minus *Uncontaminated* data was calculated to evaluate filter performance.

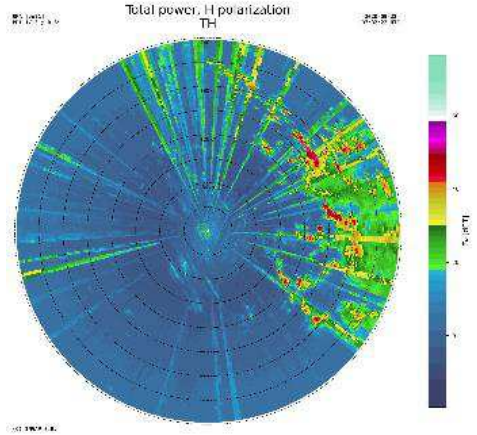
Note: The images with filter on, display cells only where SNR > 1.0dB



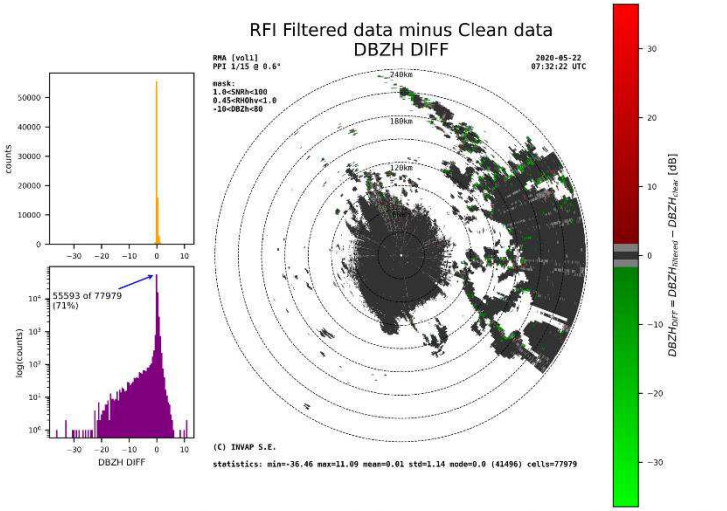
DATASET 1 - UNCONTAMINATED WEATHER
Filter: off



DATASET 1 - WEATHER PLUS RFI 1
Filter: on



DATASET 1 - WEATHER PLUS RFI 1
Filter: off

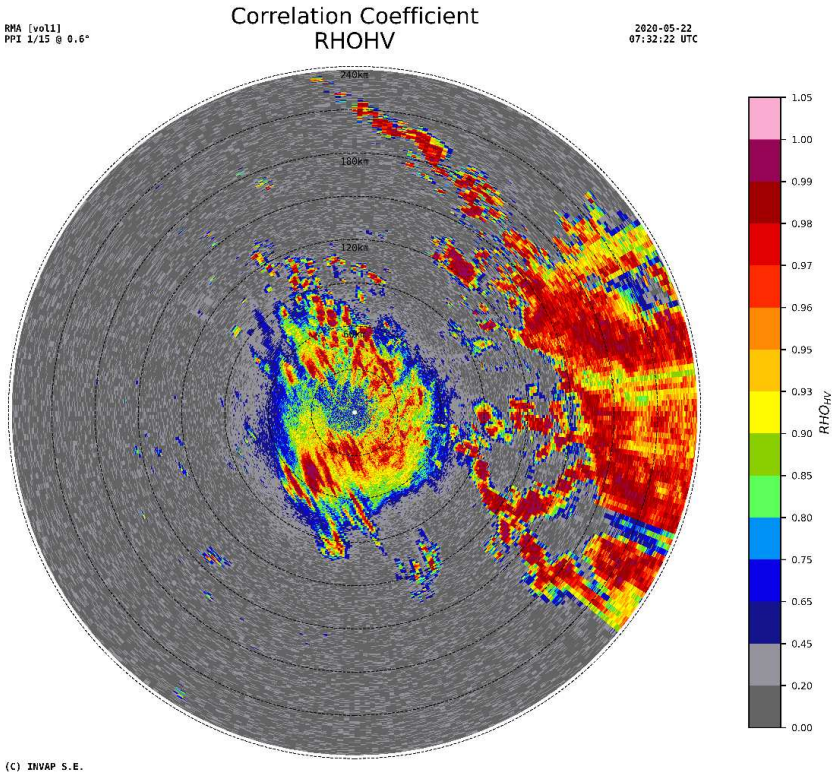


DATASET 1, RFI 1 - FILTER PERFORMANCE

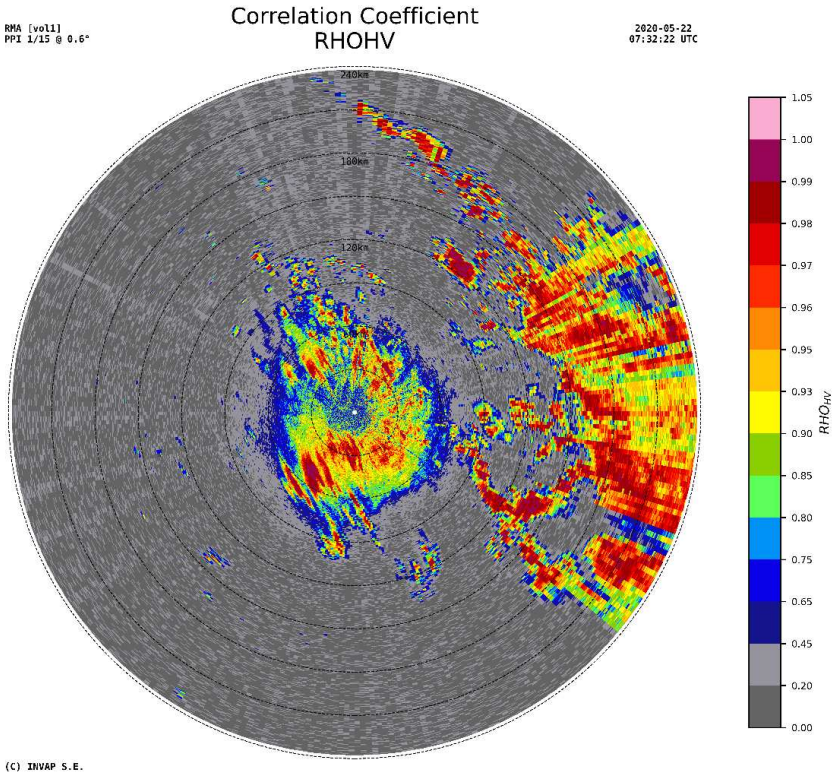
2. PHASE 1 – Results: RHOHV (6/6)

The arithmetic difference of *Filtered* data minus *Uncontaminated* data was calculated to evaluate filter performance.

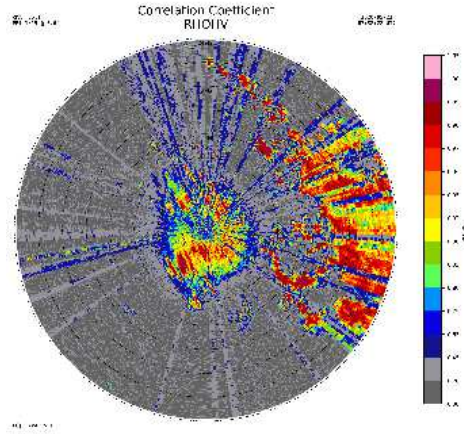
Note: The image of the difference display cells only where SNR > 1.0dB



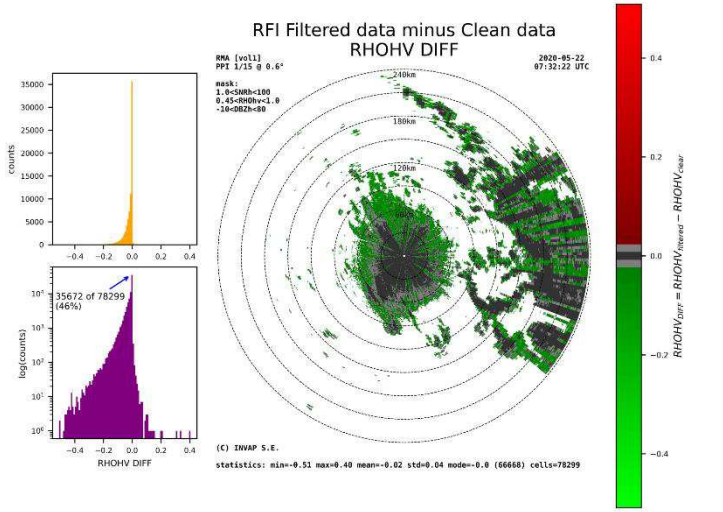
DATASET 1 - UNCONTAMINATED WEATHER
Filter: off



DATASET 1 - WEATHER PLUS RFI 1
Filter: on



DATASET 1 - WEATHER PLUS RFI 1
Filter: off



DATASET 1, RFI 1 - FILTER PERFORMANCE

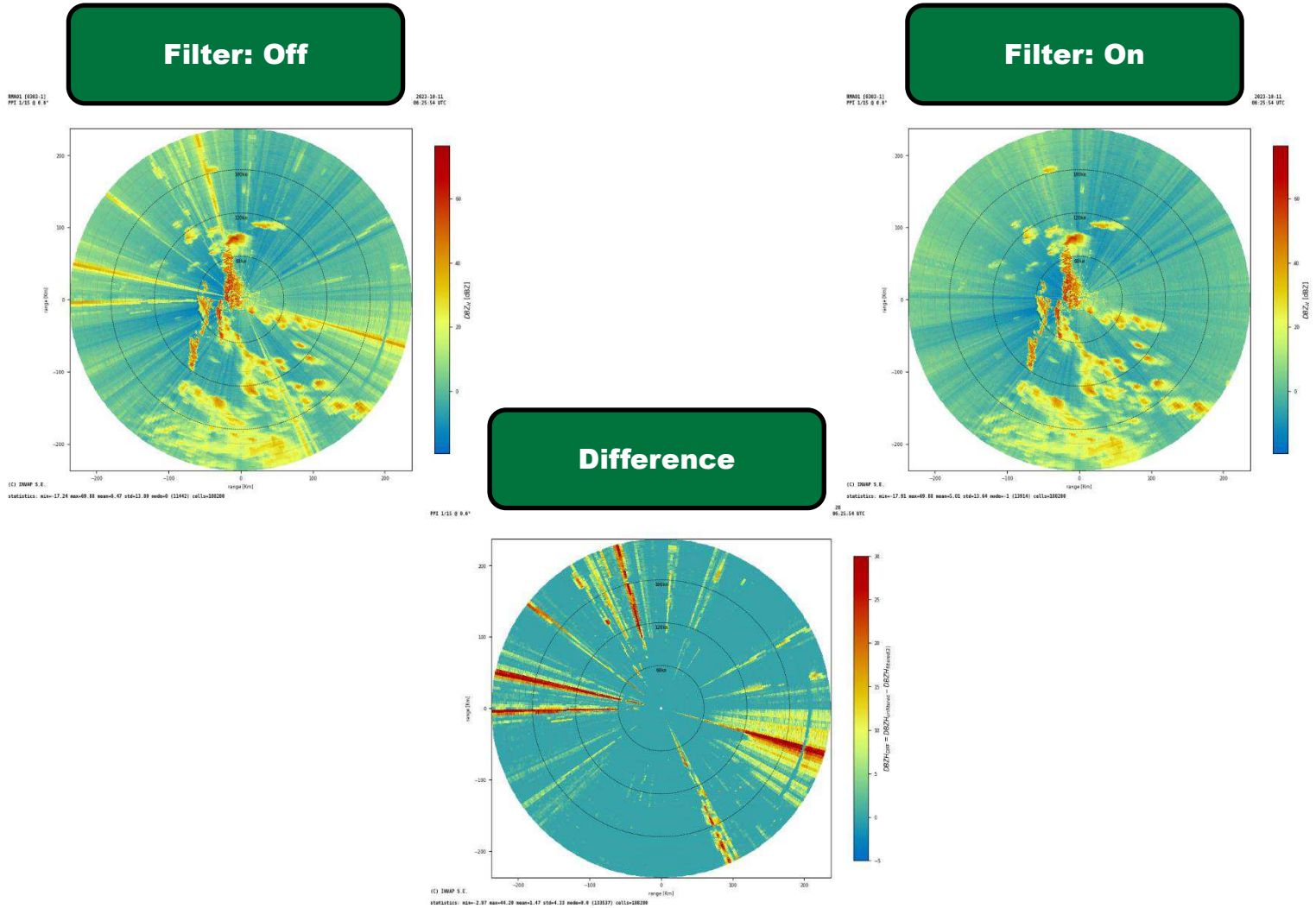
3. PHASE 2 – Methodology

Processing real data (RFI contaminated)

- A collection of several hours of I/Q data recorded at different *RMA* sites were processed to study the *RFI* filter performance under **different weather conditions** and **levels of *RFI* contamination**.

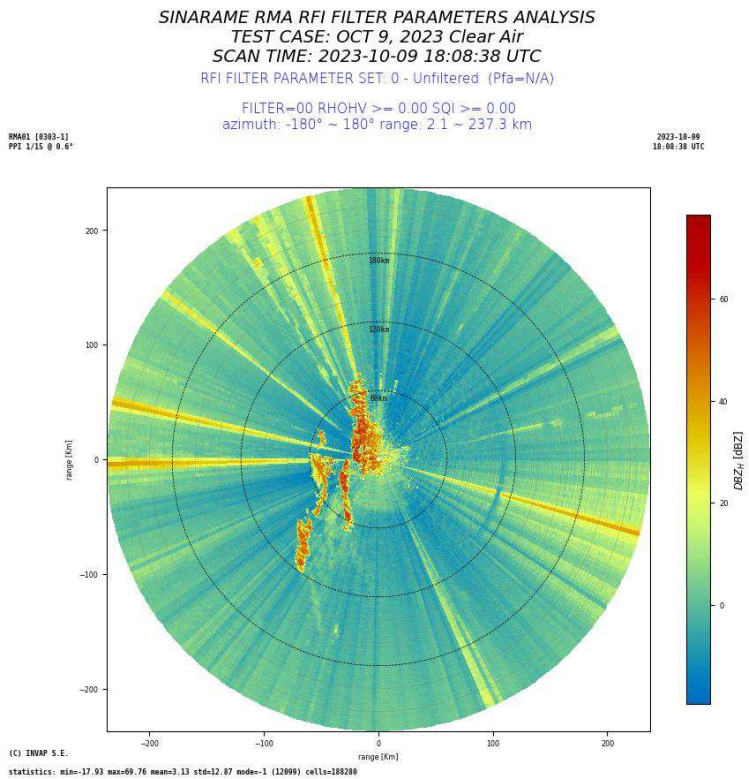
- Different sets of values for the *RFI* filter parameters were tested, with increasing levels of **filtering aggressiveness** ranging from relaxed to extreme.

- Cell to cell **arithmetic difference** was calculated.

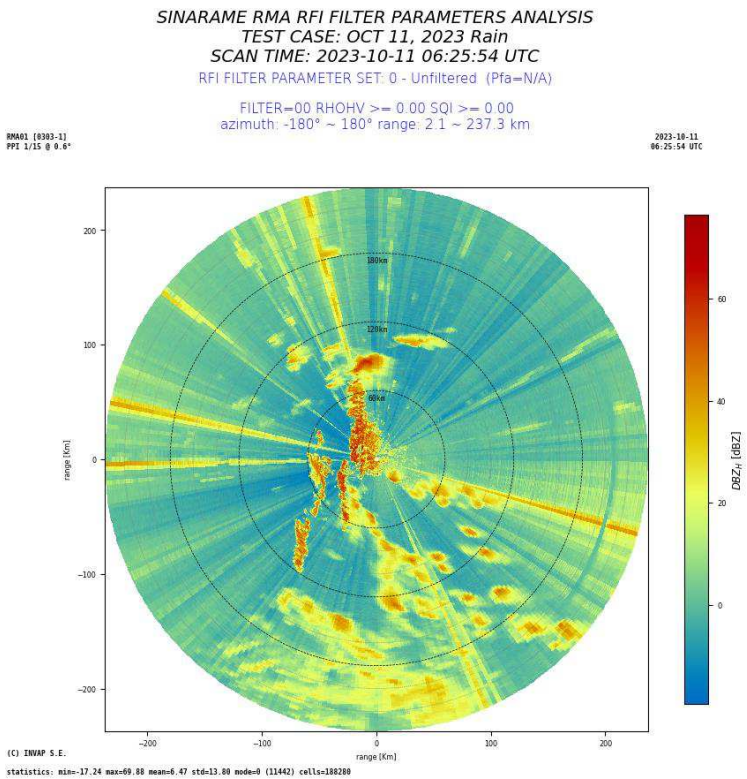


3. PHASE 2 – Data: DBZH contaminated

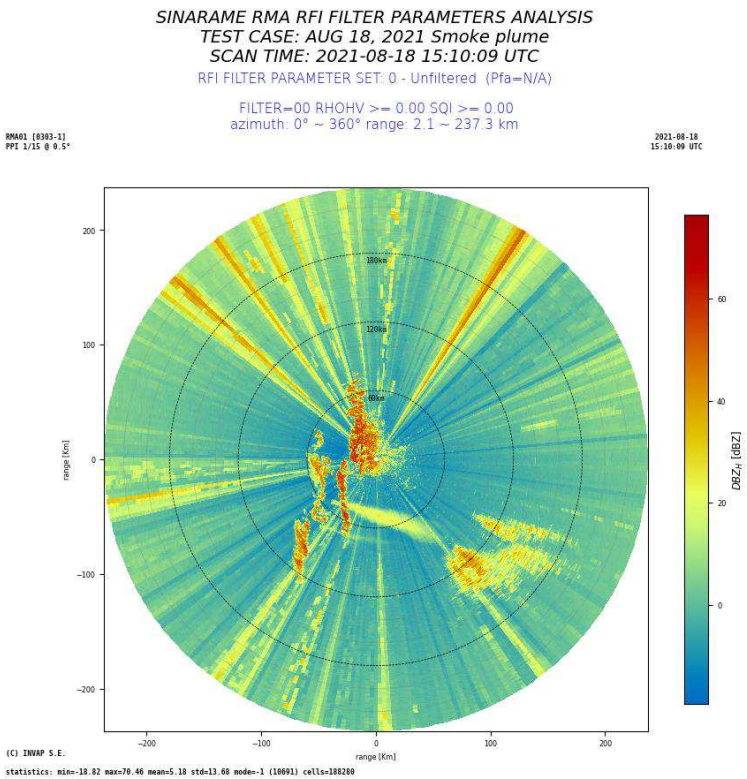
Test cases: Clear air, Rain and Smoke plume (non-meteorological echoes)



Clear air
Filter: Off



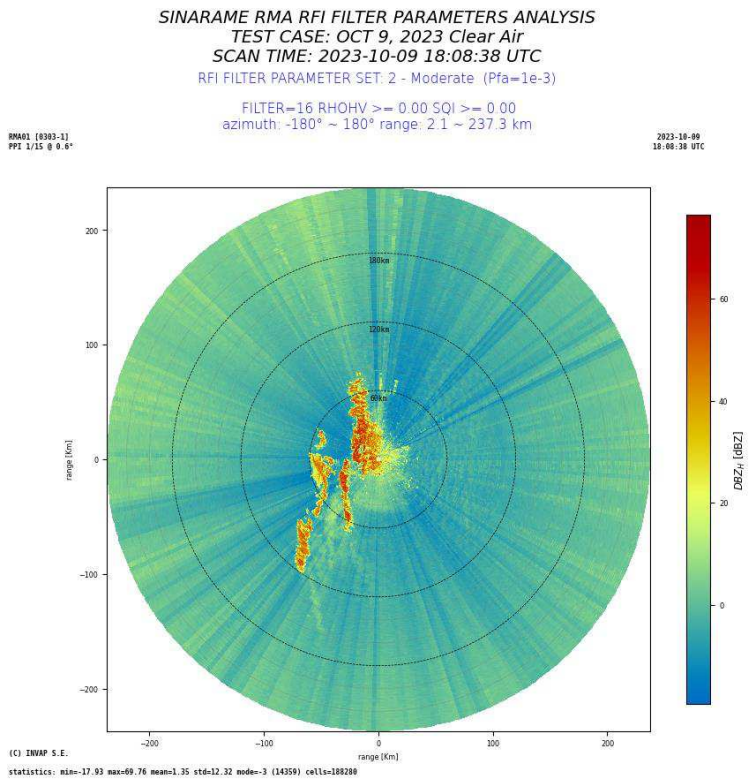
Rain
Filter: Off



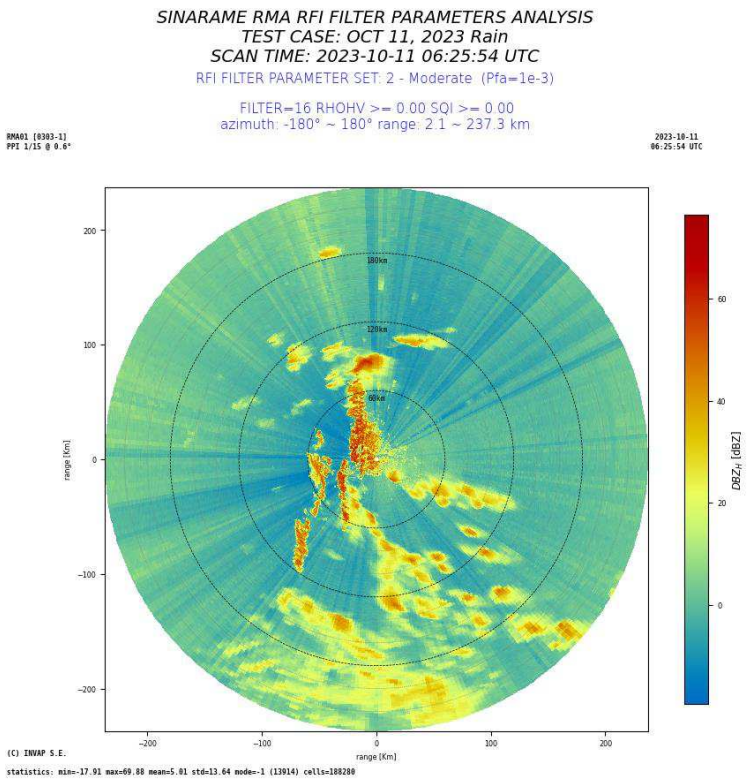
Smoke plume
Filter: Off

3. PHASE 2 – Results: DBZH filtered

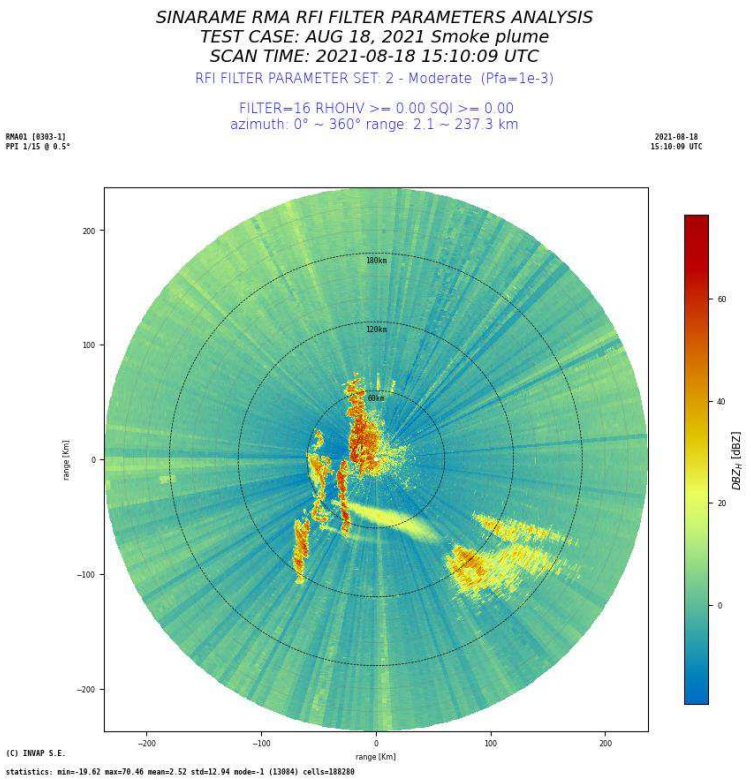
Test cases: Clear air, Rain and Smoke plume (non-meteorological echoes)



Clear air
Filter: On



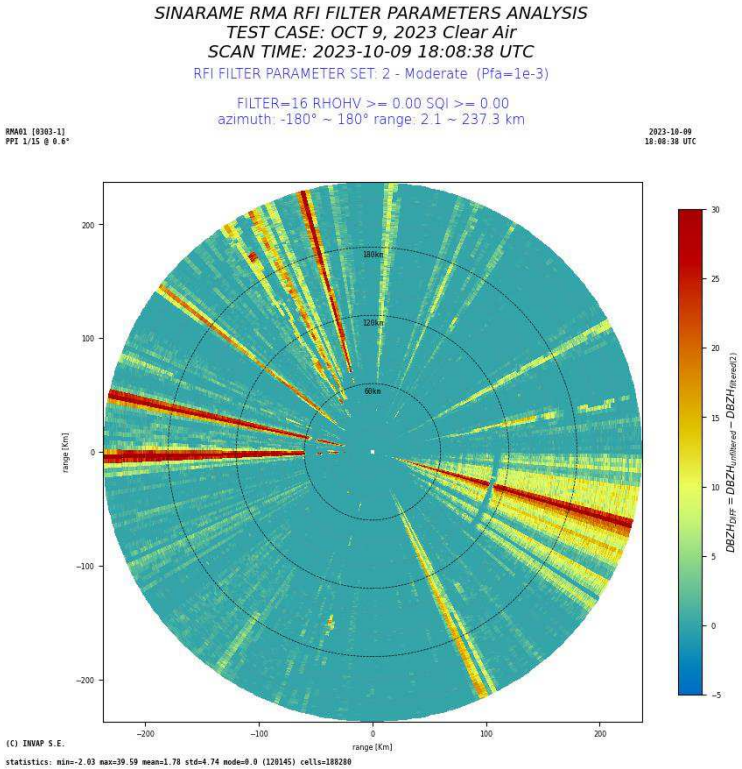
Rain
Filter: On



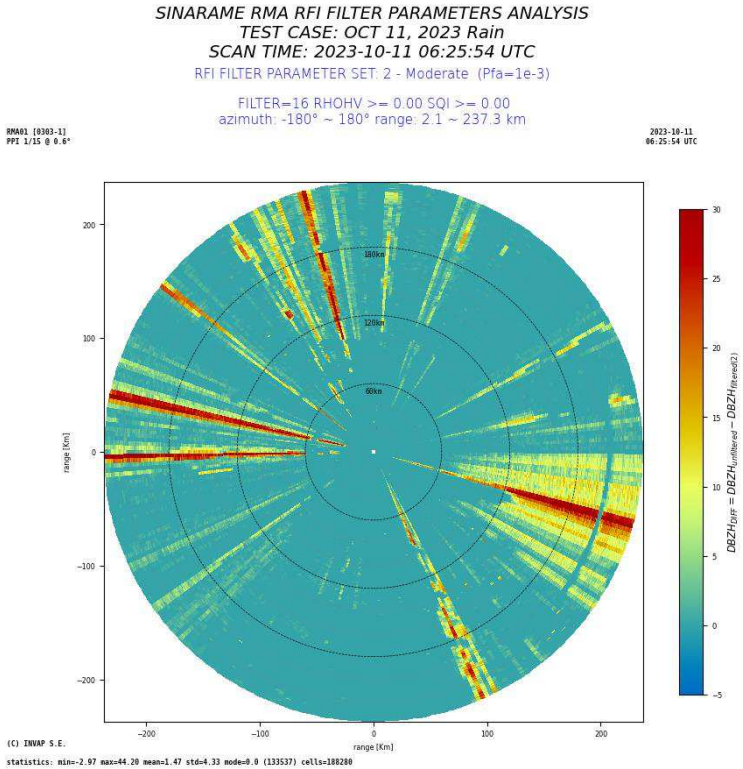
Smoke plume
Filter: On

3. PHASE 2 – Results: DBZH difference

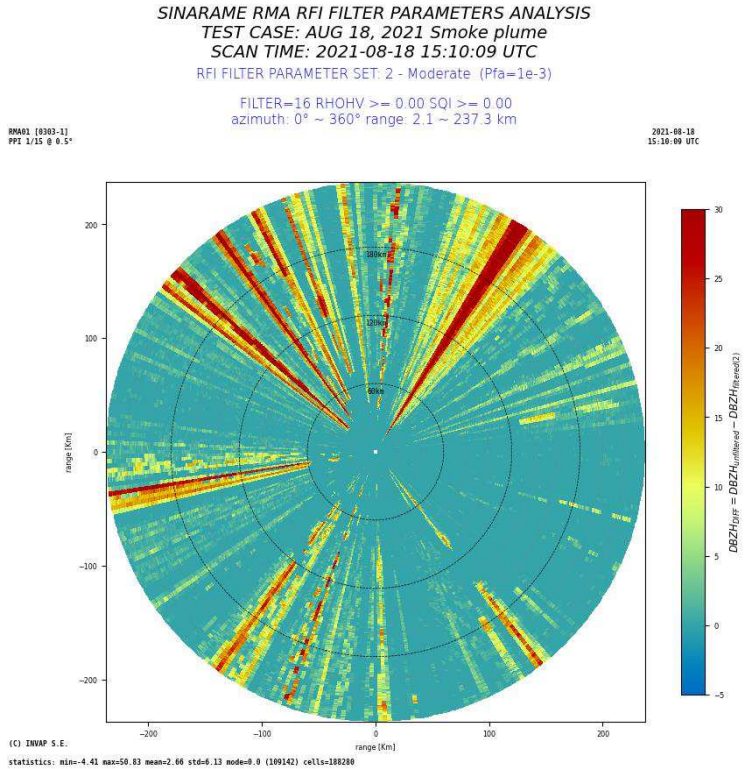
Test cases: Clear air, Rain and Smoke plume (non-meteorological echoes)



Clear air
Diff: Filter Off – Filter On
Min: -2dB
Max: 40dB



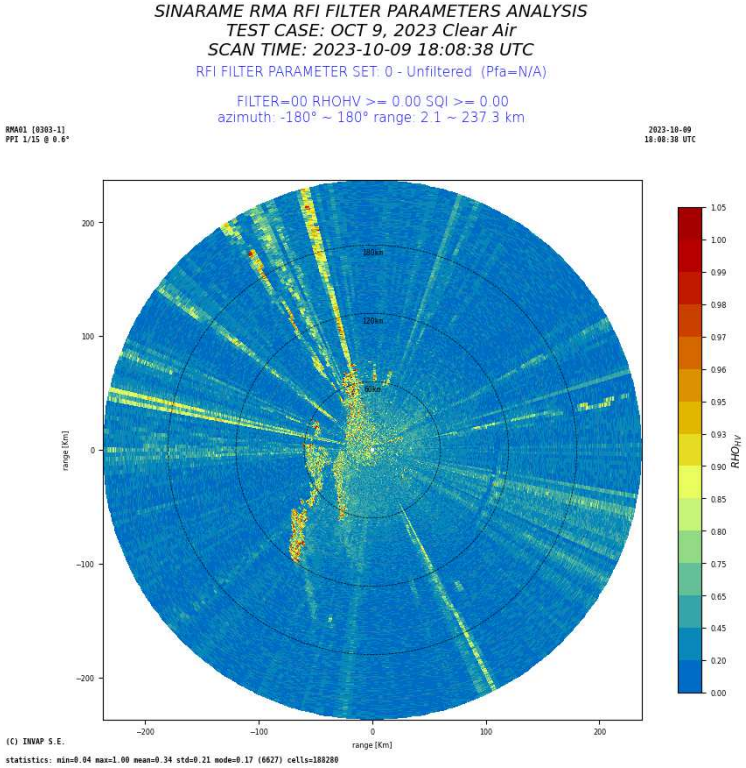
Rain
Diff: Filter Off – Filter On
Min: -3dB
Max: 44dB



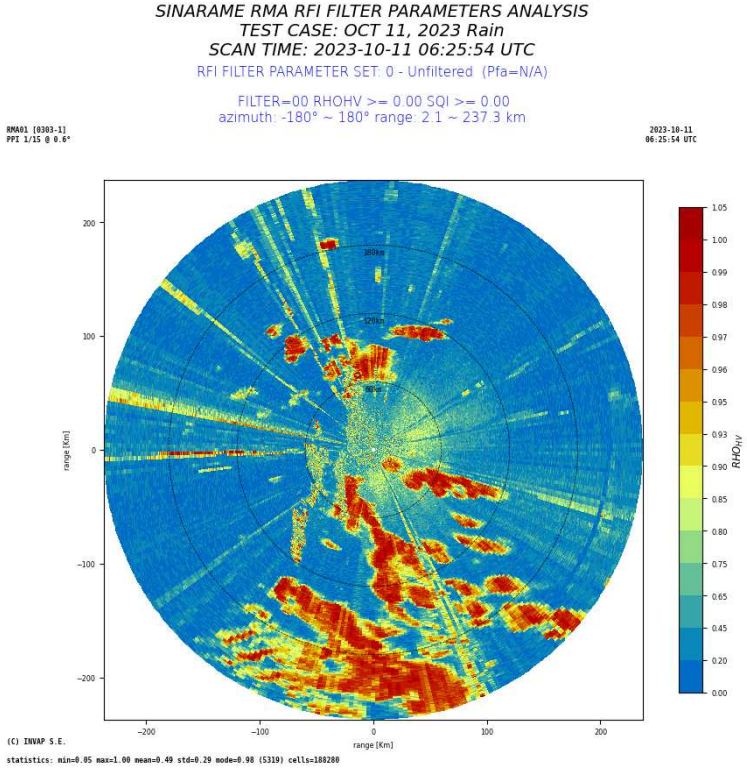
Smoke plume
Diff: Filter Off – Filter On
Min: -4dB
Max: 51dB

3. PHASE 2 – Data: RHOHV contaminated

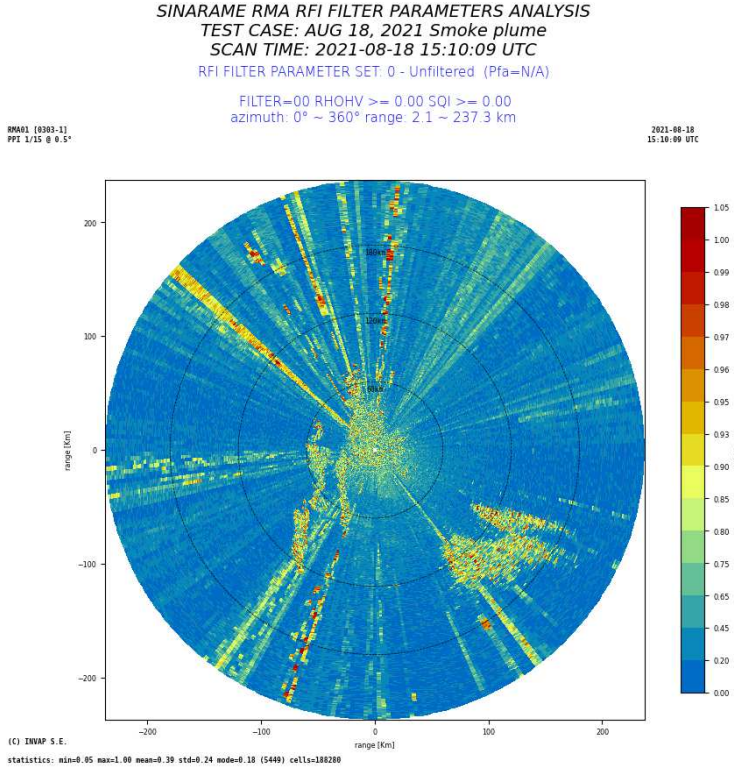
Test cases: Clear air, Rain and Smoke plume (non-meteorological echoes)



Clear air
Filter: Off



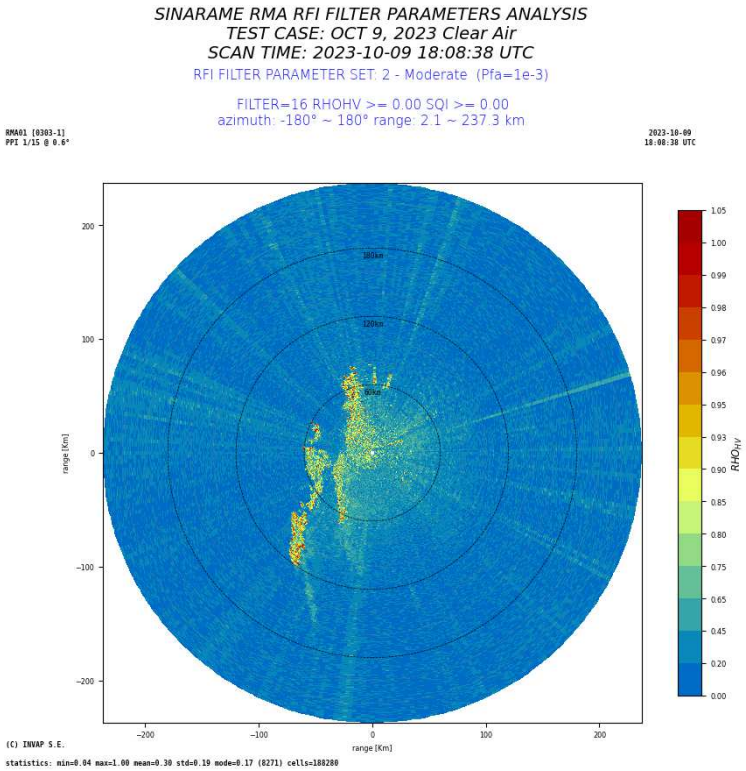
Rain
Filter: Off



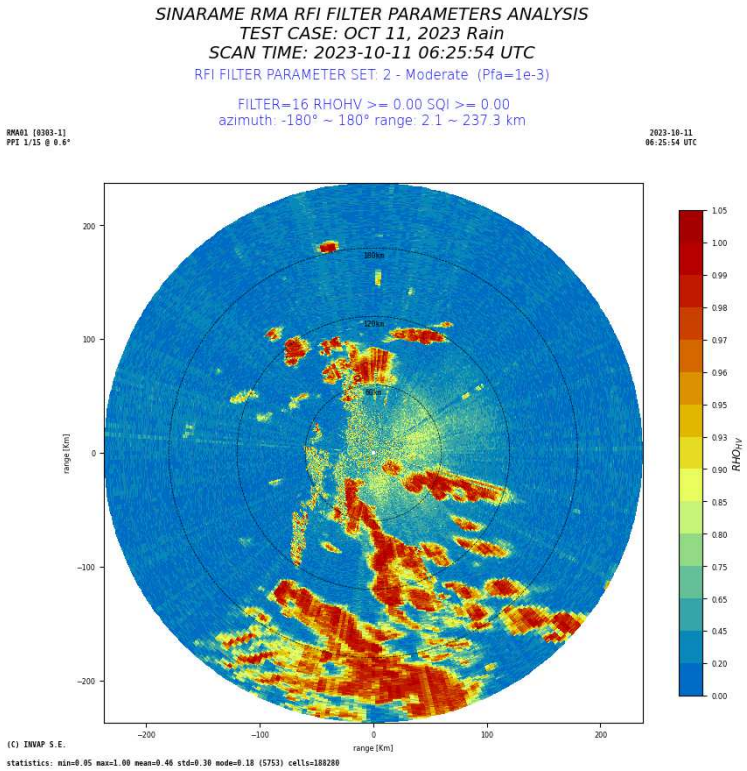
Smoke plume
Filter: Off

3. PHASE 2 – Results: RHOHV filtered

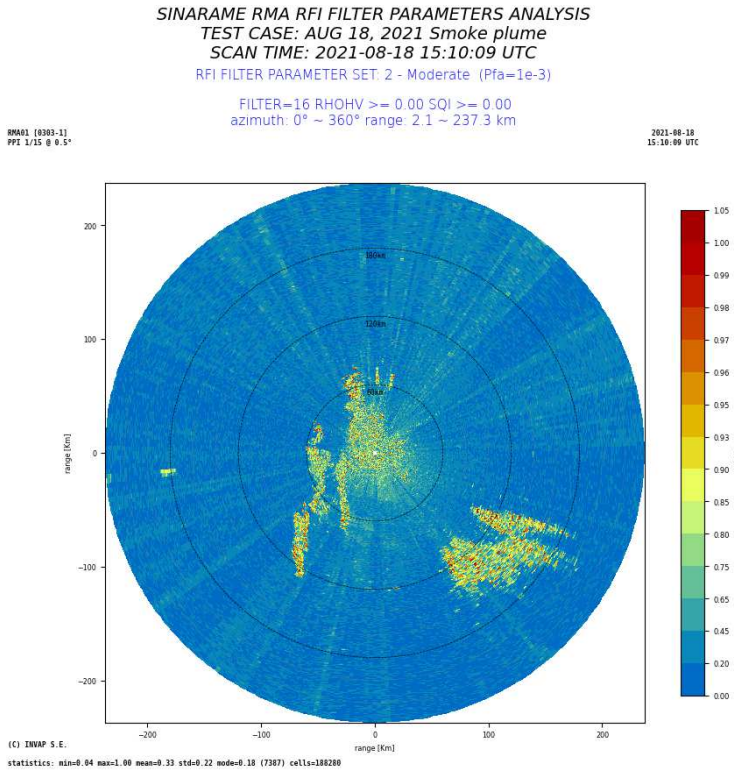
Test cases: Clear air, Rain and Smoke plume (non-meteorological echoes)



Clear air
Filter: On



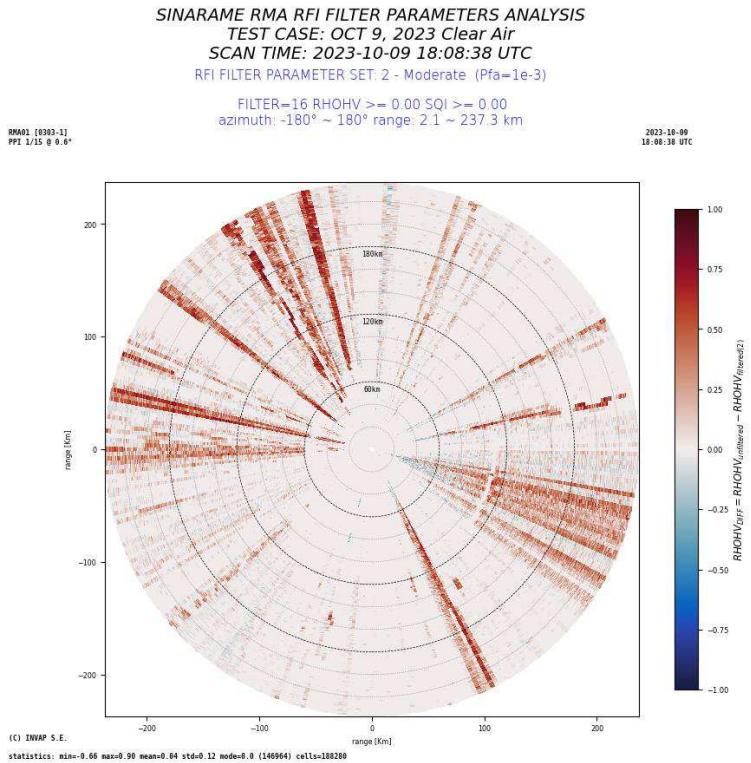
Rain
Filter: On



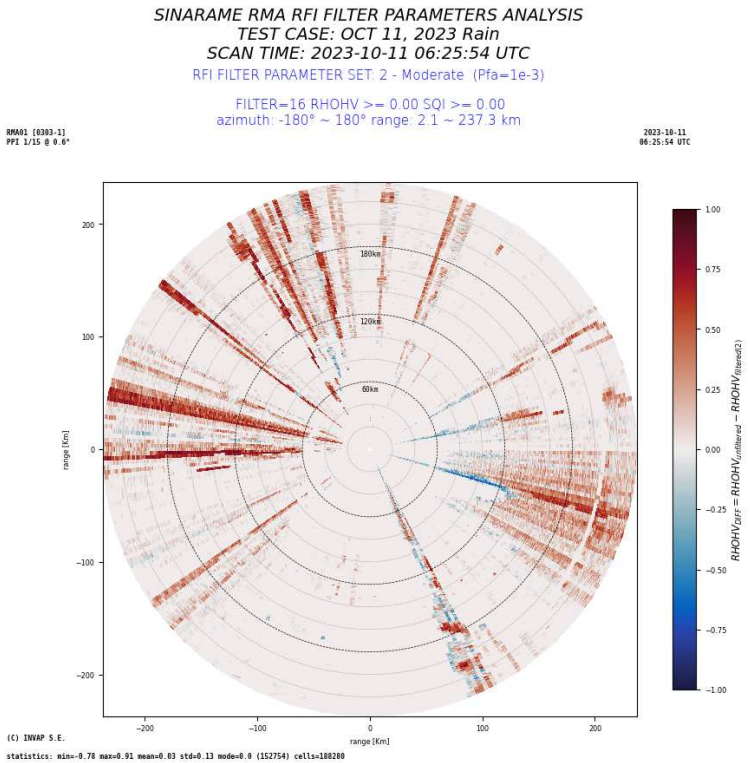
Smoke plume
Filter: On

3. PHASE 2 – Results: RHOHV difference

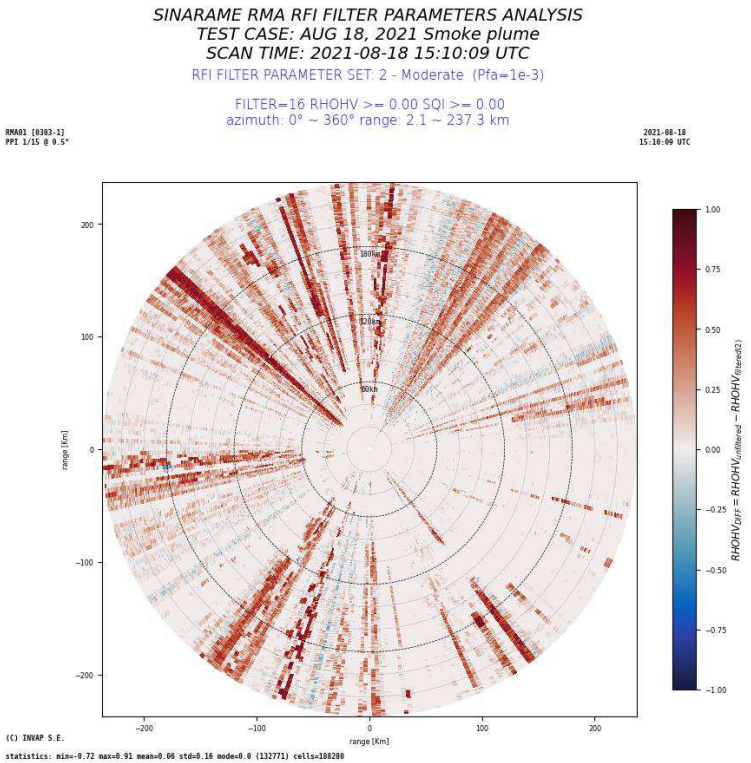
Test cases: Clear air, Rain and Smoke plume (non-meteorological echoes)



Clear air
Diff: Filter Off – Filter On
Min: -0.66
Max: 0.90



Rain
Diff: Filter Off – Filter On
Min: -0.78
Max: 0.91



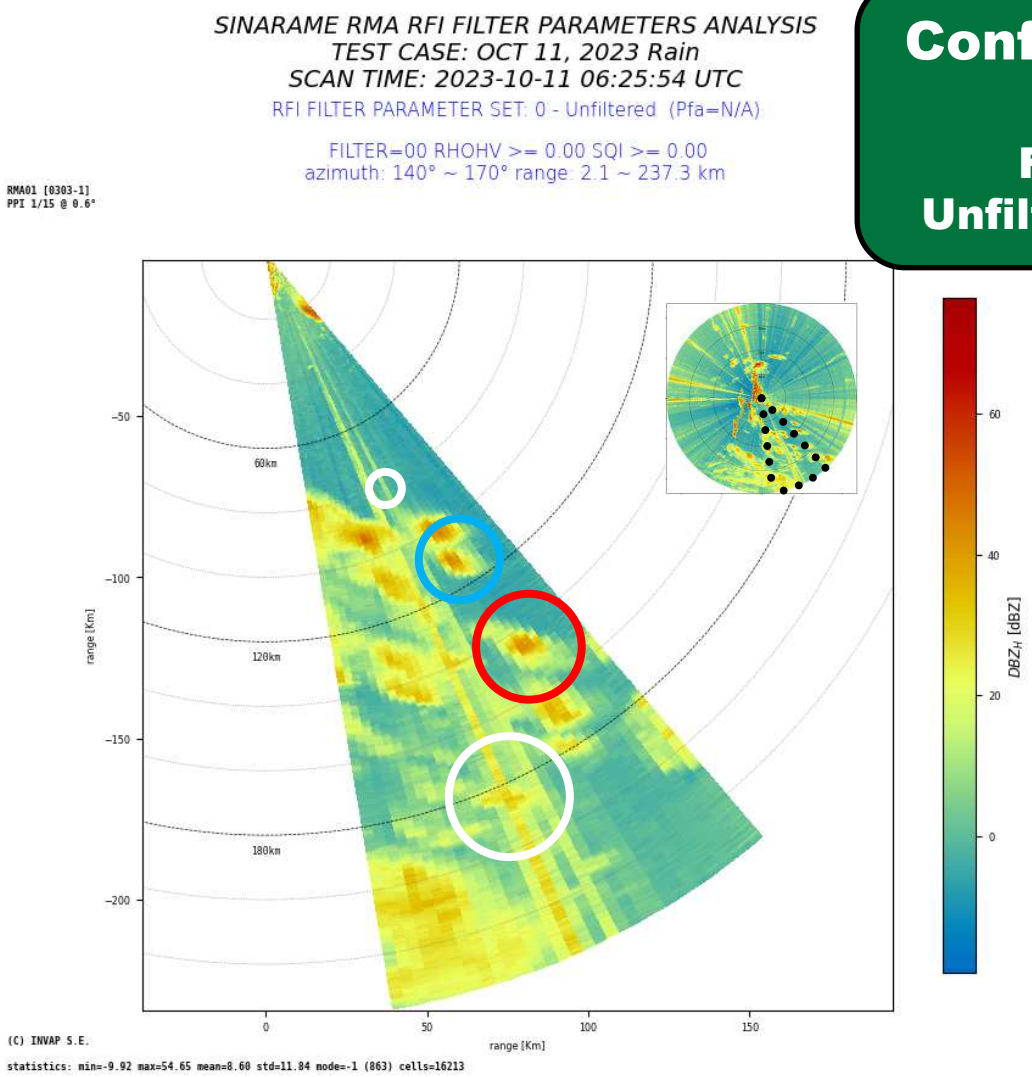
Smoke plume
Diff: Filter Off – Filter On
Min: -0.72
Max: 0.91

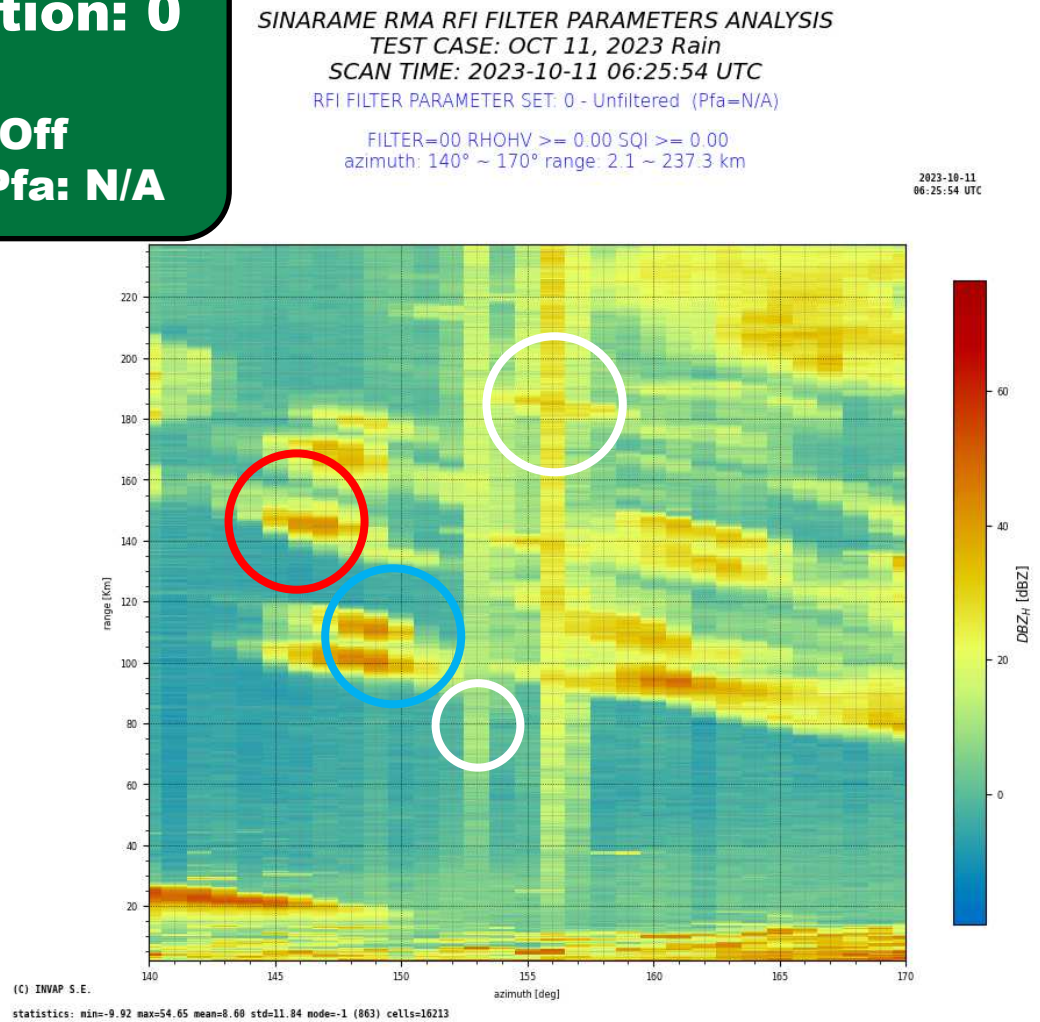
3. PHASE 2 – Results: DBZH contaminated (details)

Test case: Rain

Configuration: 0

Filter: Off
Unfiltered Pfa: N/A



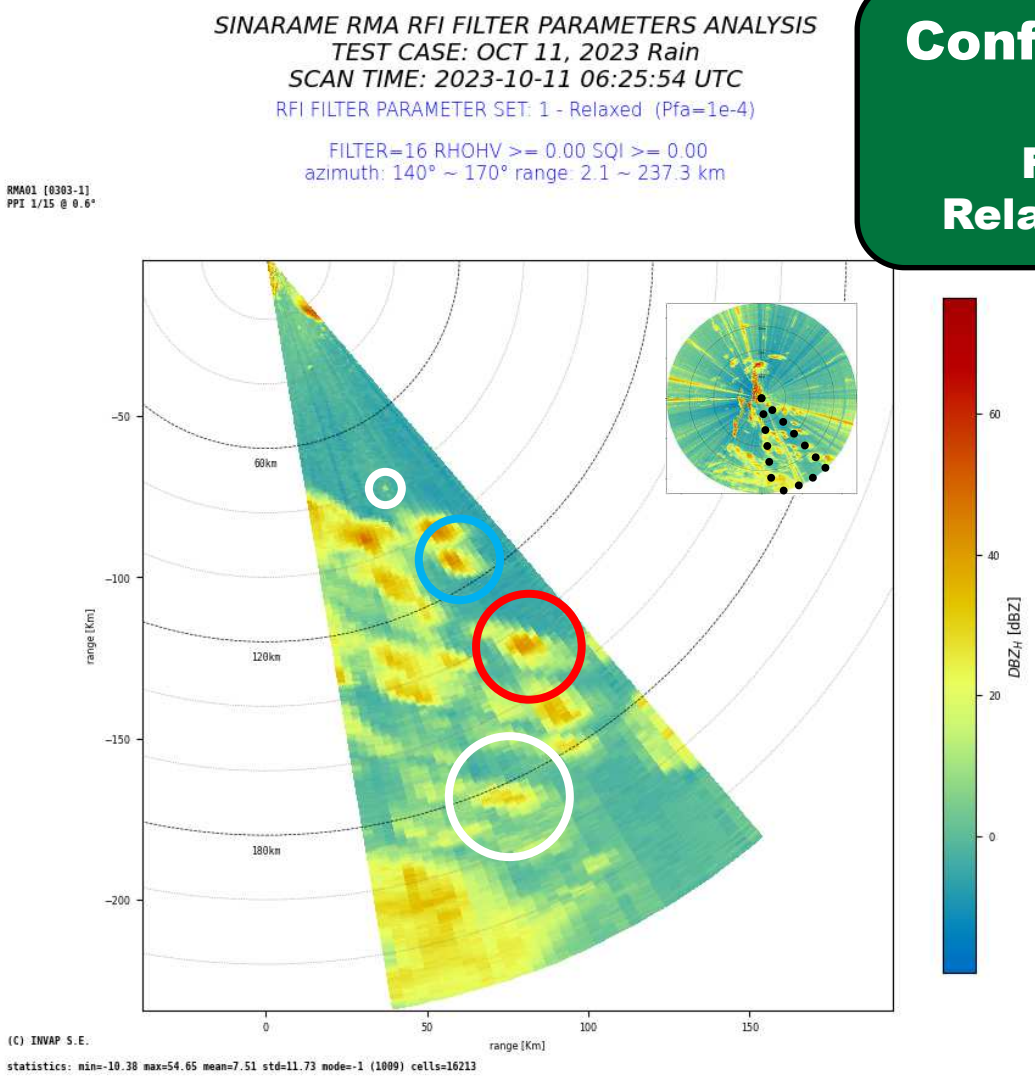


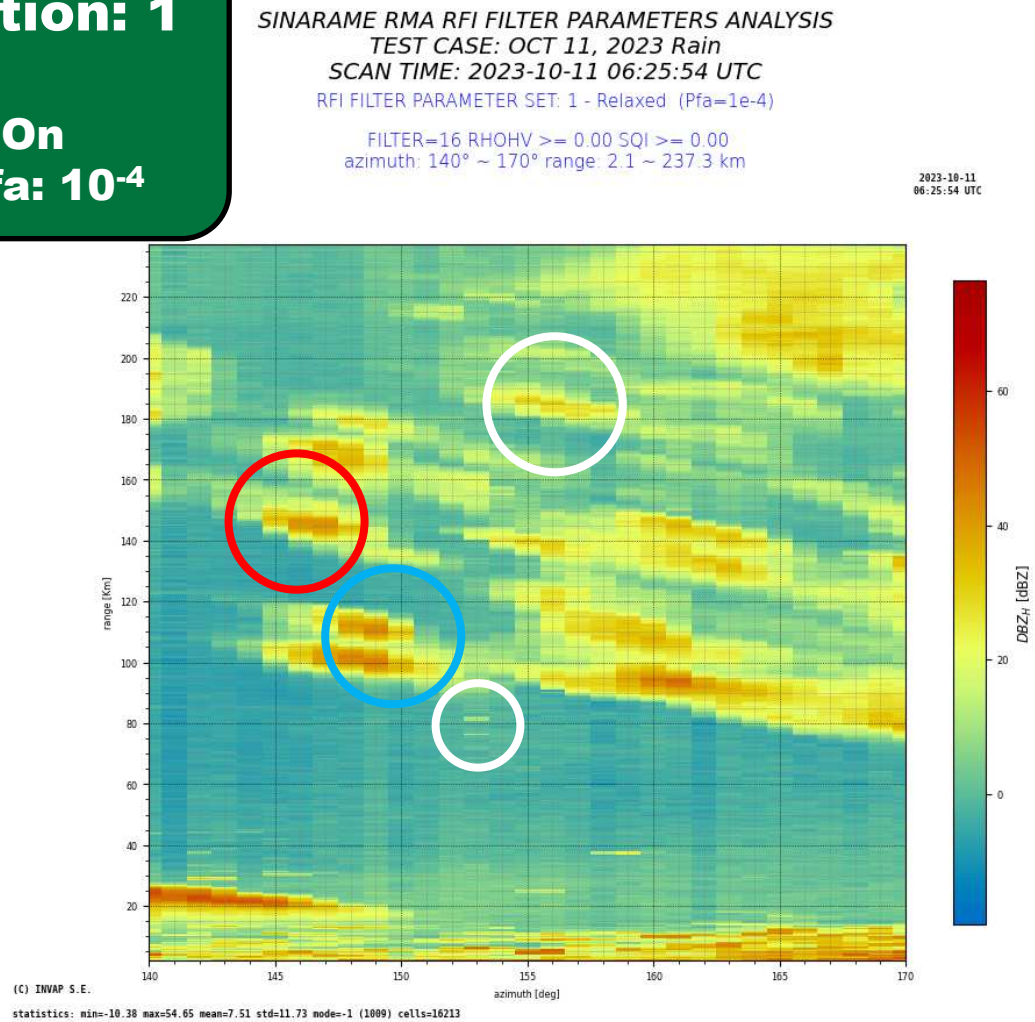
3. PHASE 2 – Results: DBZH filtered (details)

Test case: Rain

Configuration: 1

Filter: On
Relaxed Pfa: 10^{-4}



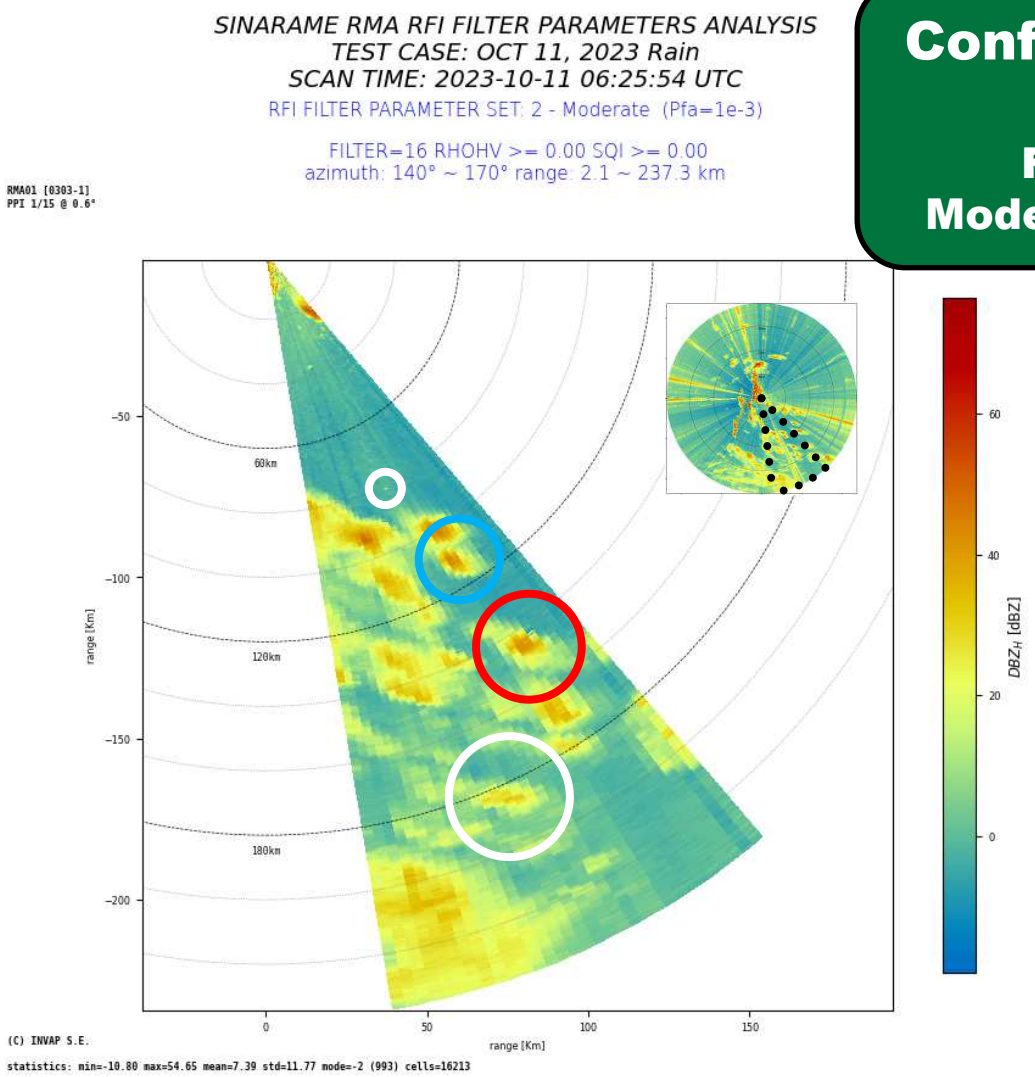


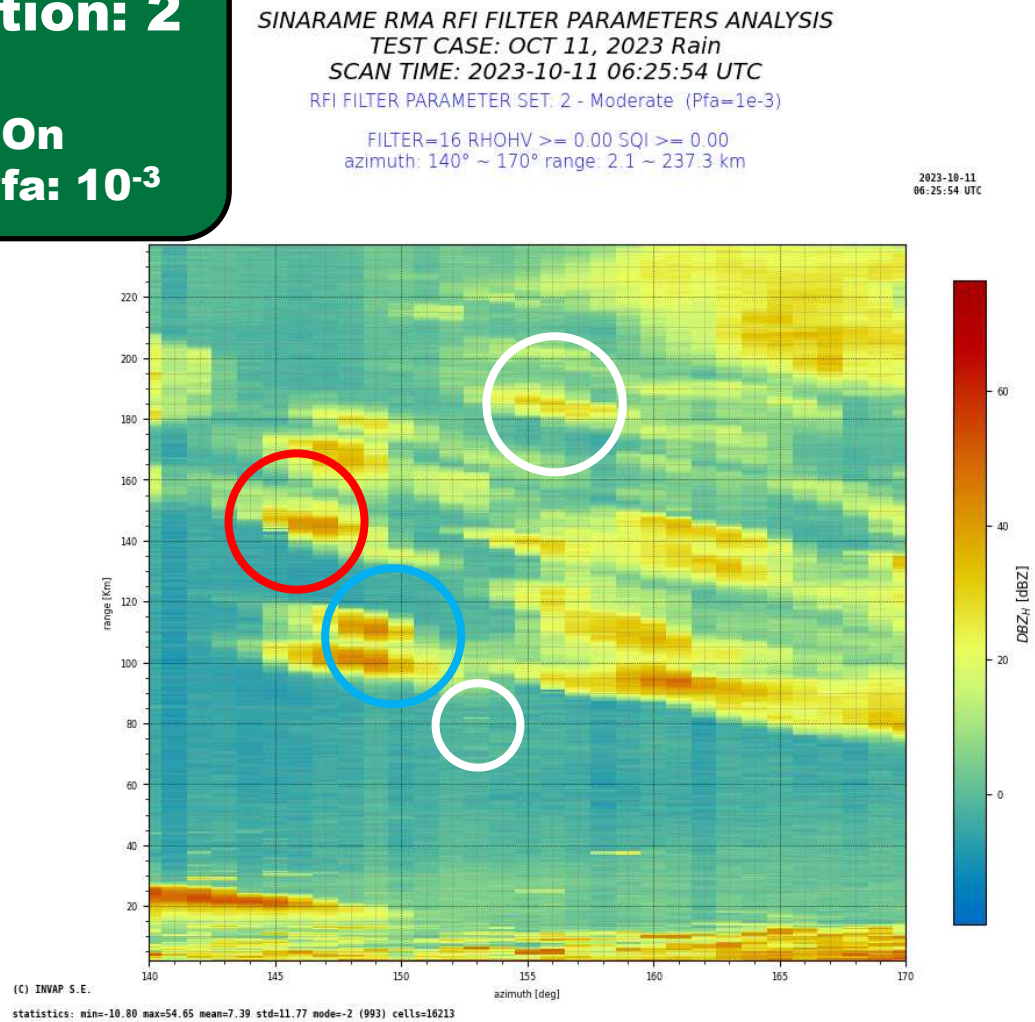
3. PHASE 2 – Results: DBZH filtered (details)

Test case: Rain

Configuration: 2

Filter: On
Moderate Pfa: 10^{-3}



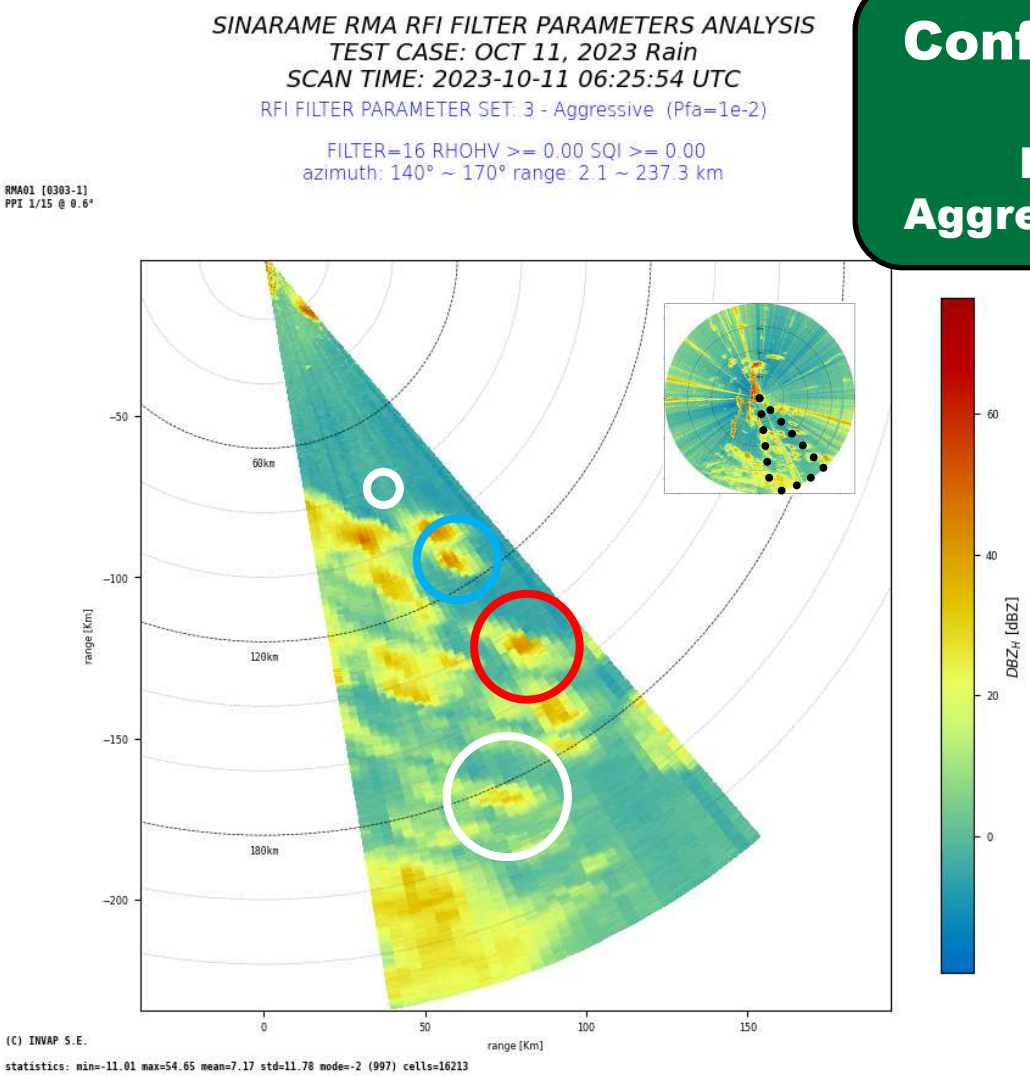


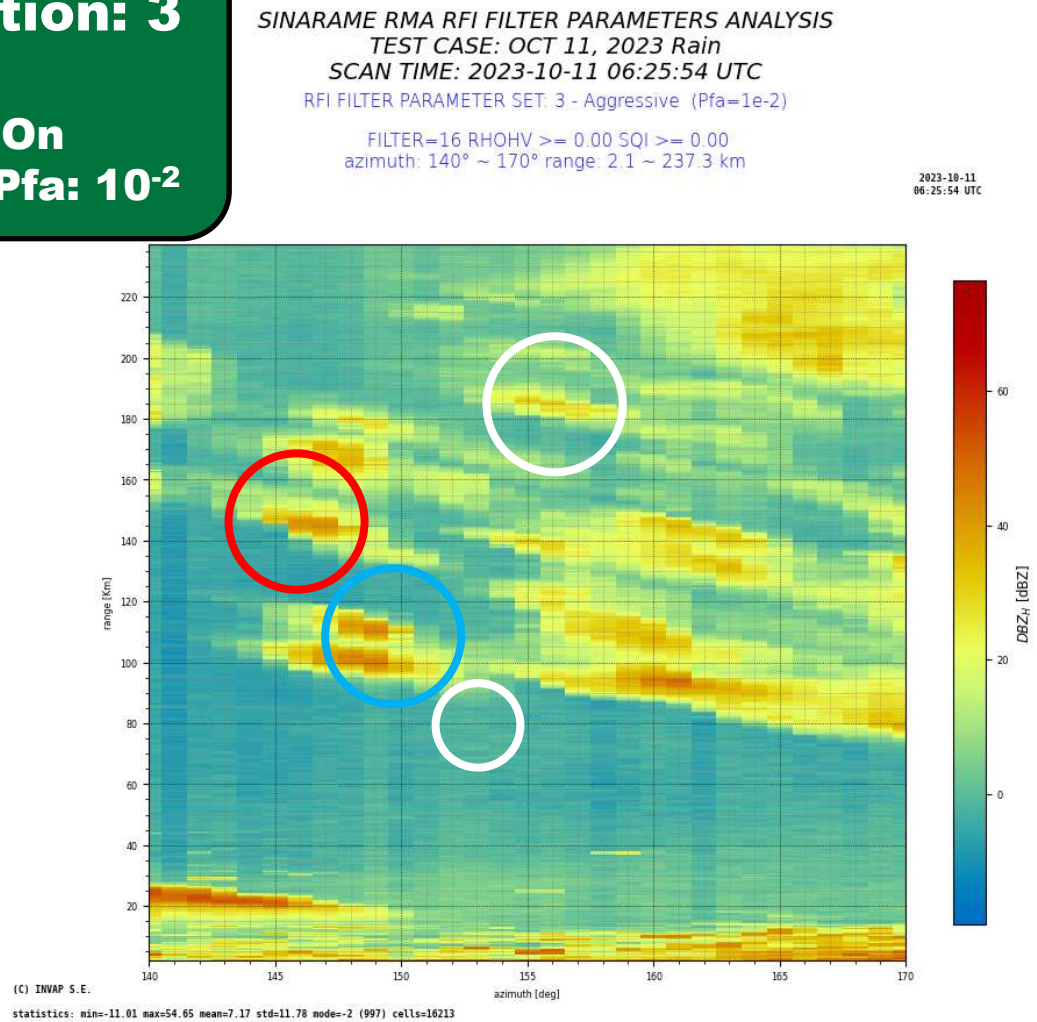
3. PHASE 2 – Results: DBZH filtered (details)

Test case: Rain

Configuration: 3

Filter: On
Aggressive Pfa: 10^{-2}



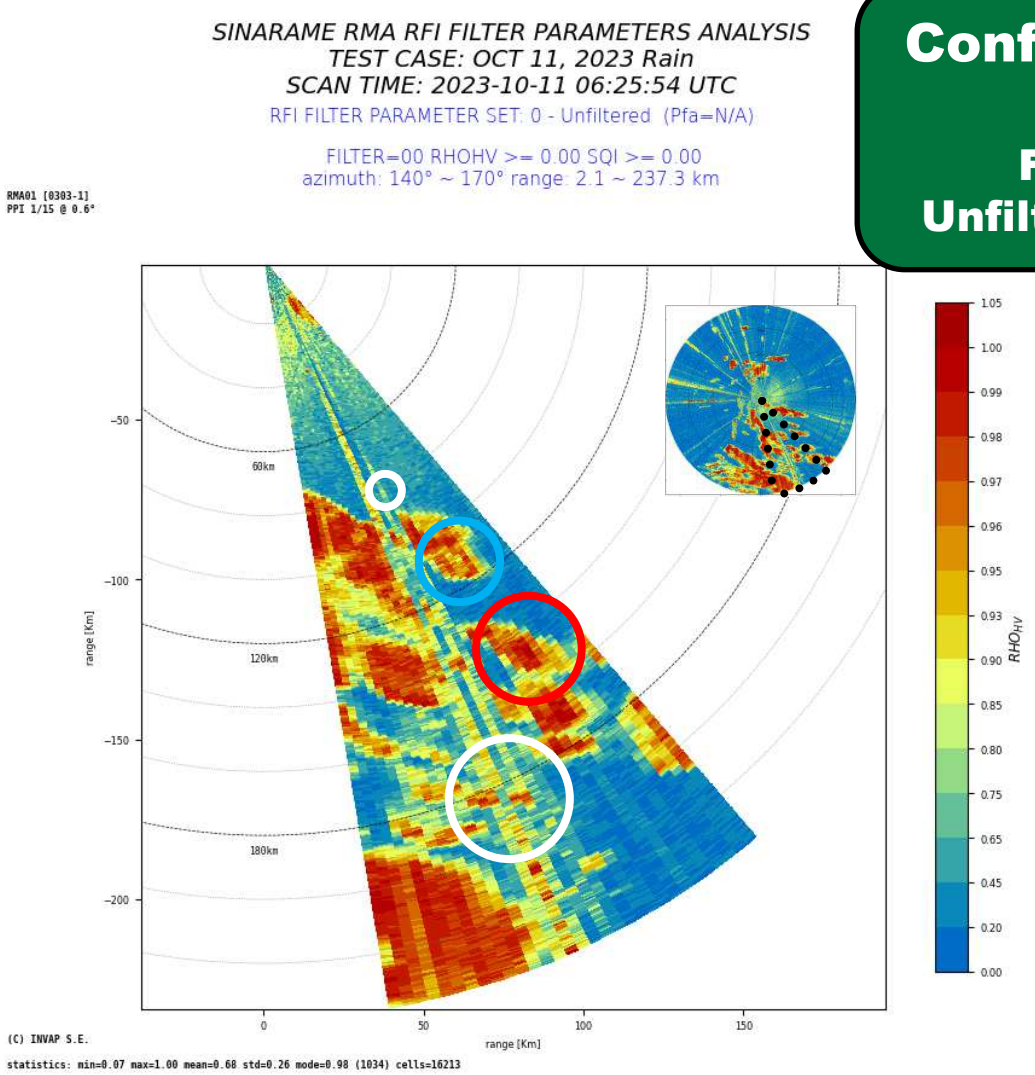


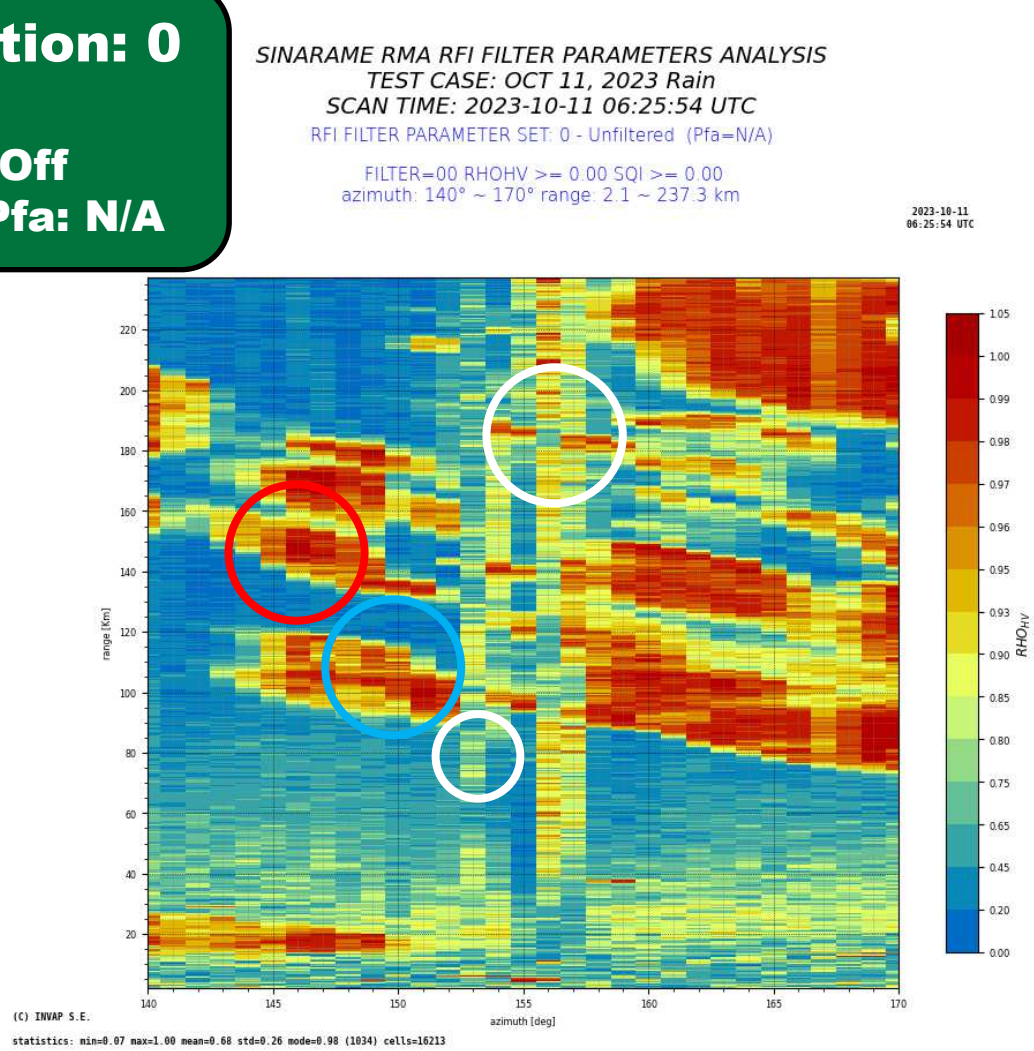
3. PHASE 2 – Results: RHOHV contaminated

Test case: Rain

Configuration: 0

Filter: Off
Unfiltered Pfa: N/A



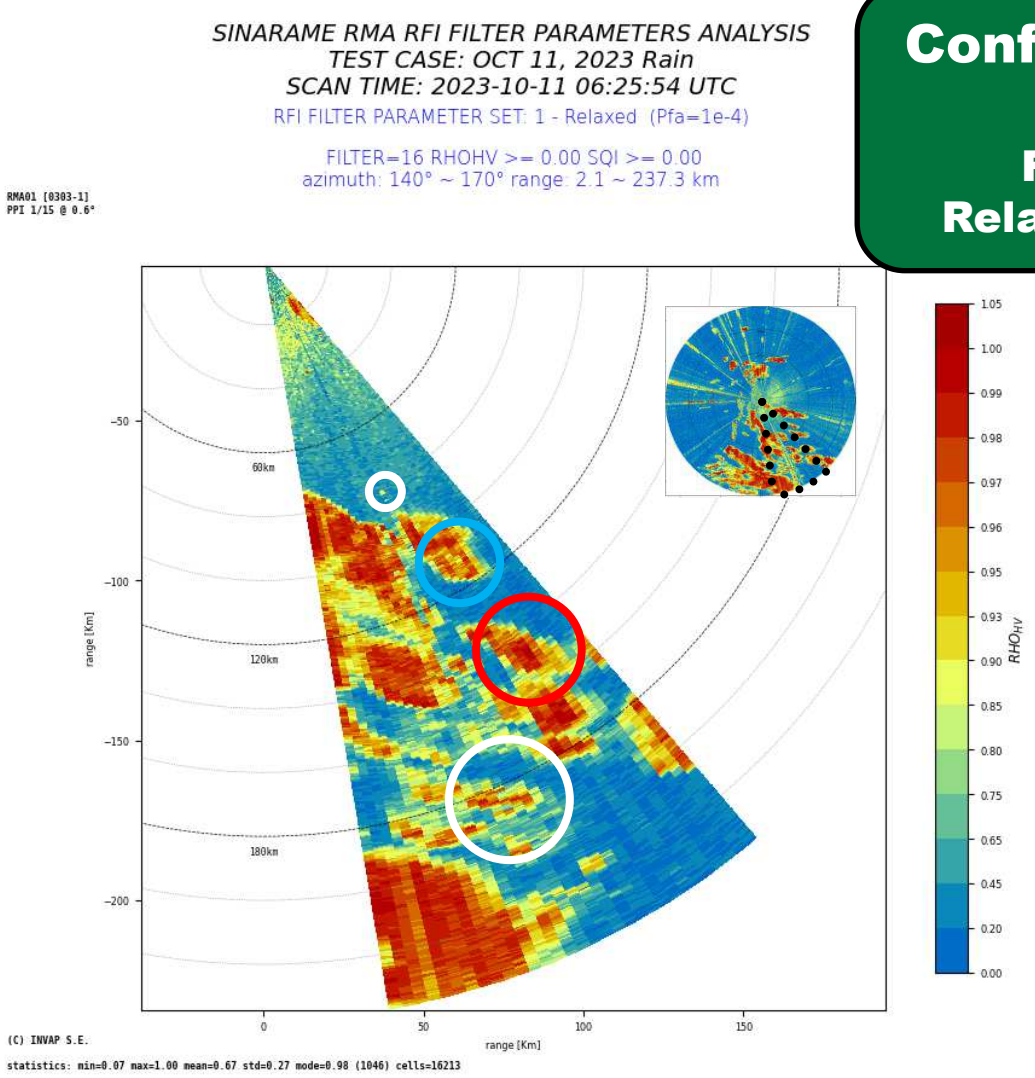


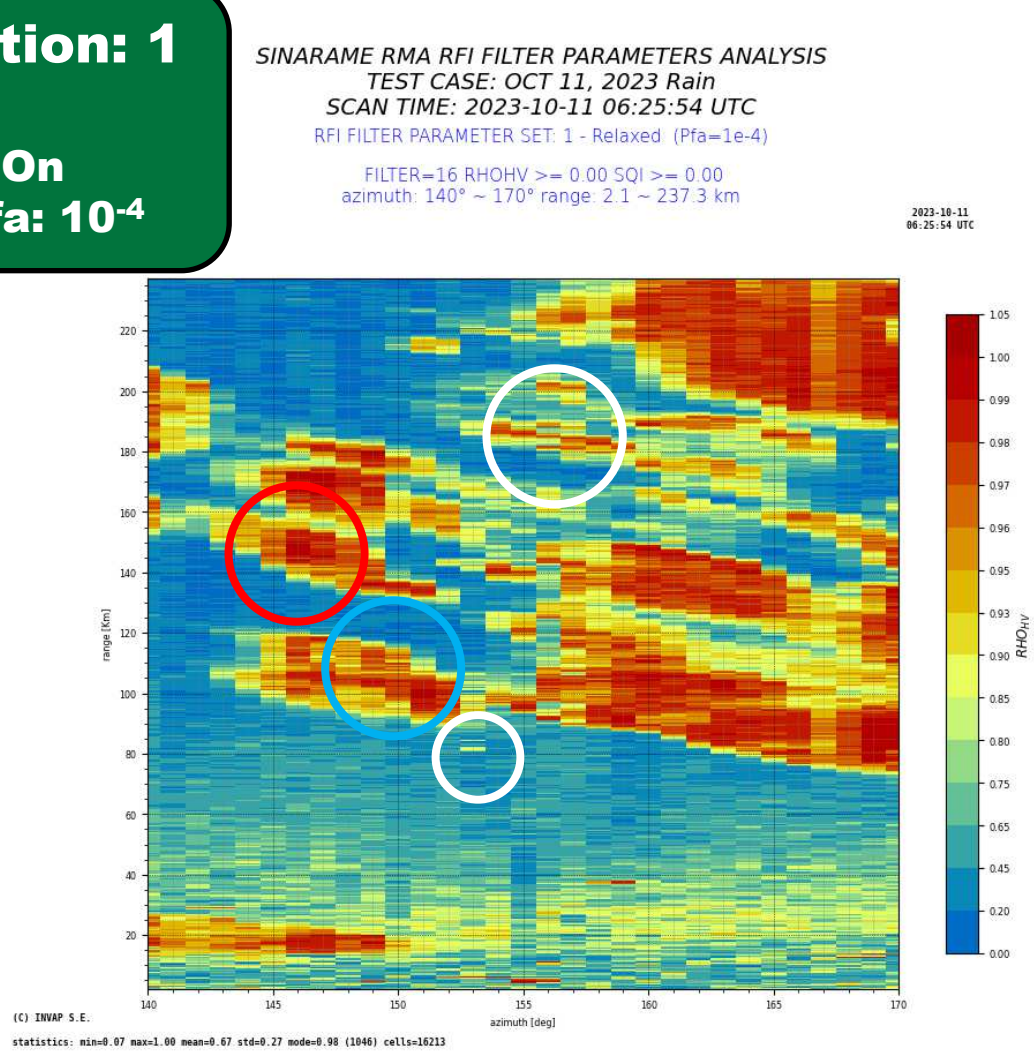
3. PHASE 2 – Results: RHOHV filtered (details)

Test case: Rain

Configuration: 1

Filter: On
Relaxed Pfa: 10^{-4}



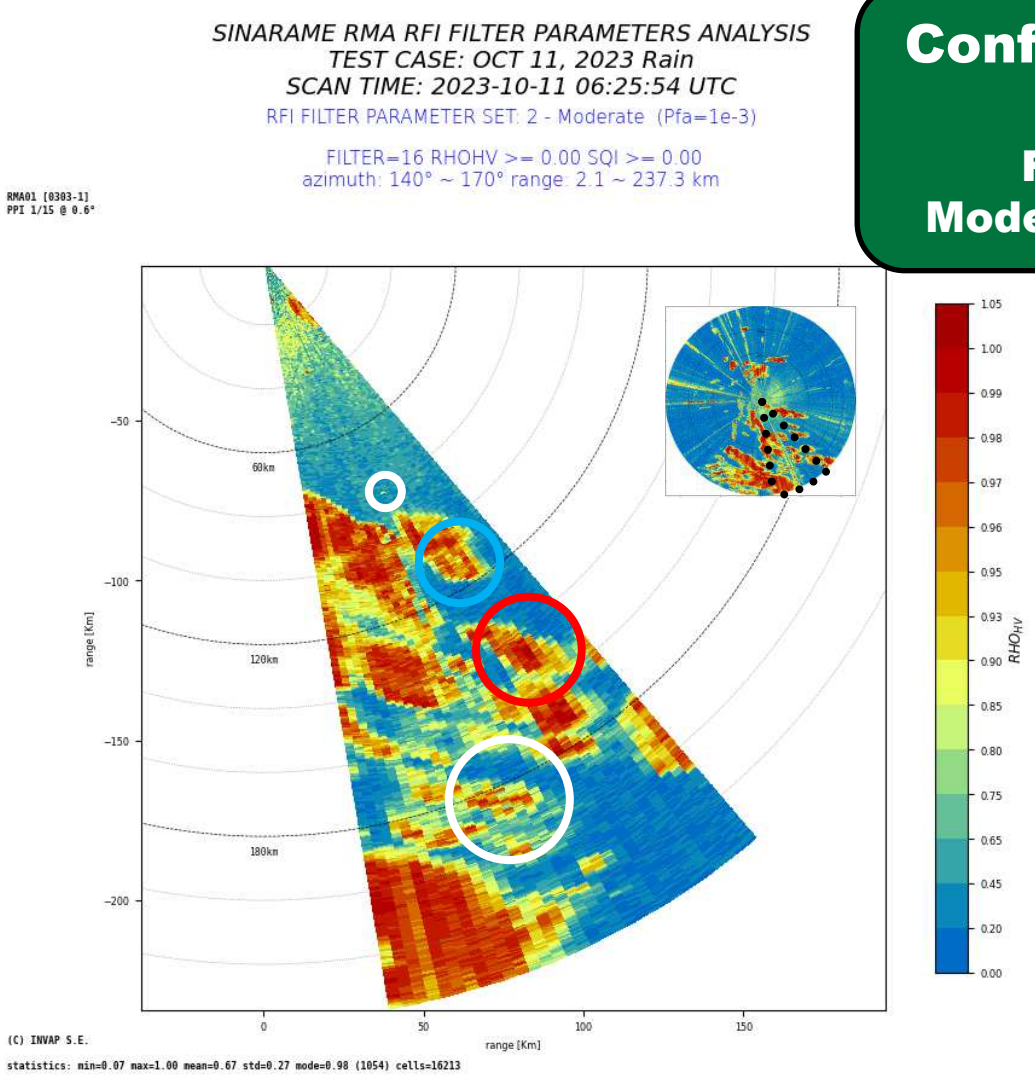


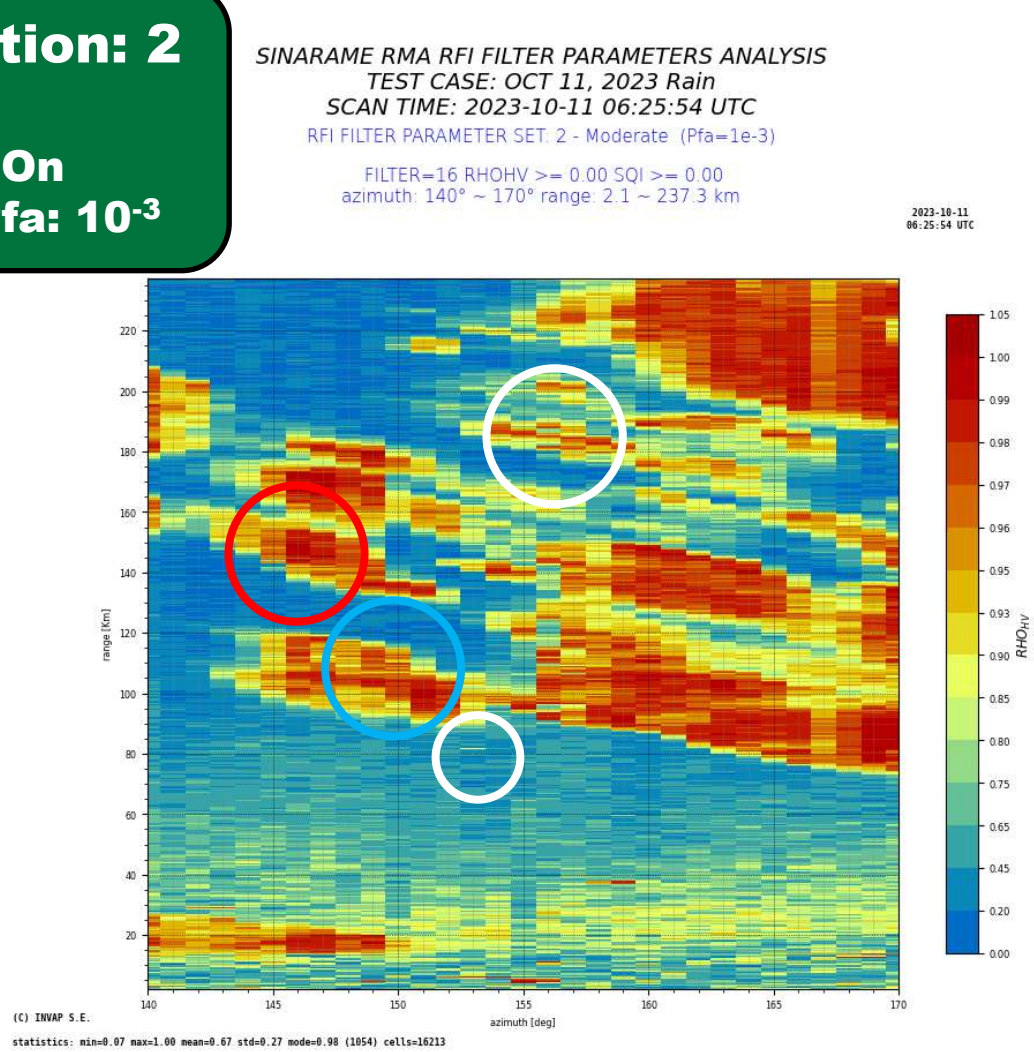
3. PHASE 2 – Results: RHOHV filtered (details)

Test case: Rain

Configuration: 2

Filter: On
Moderate Pfa: 10^{-3}



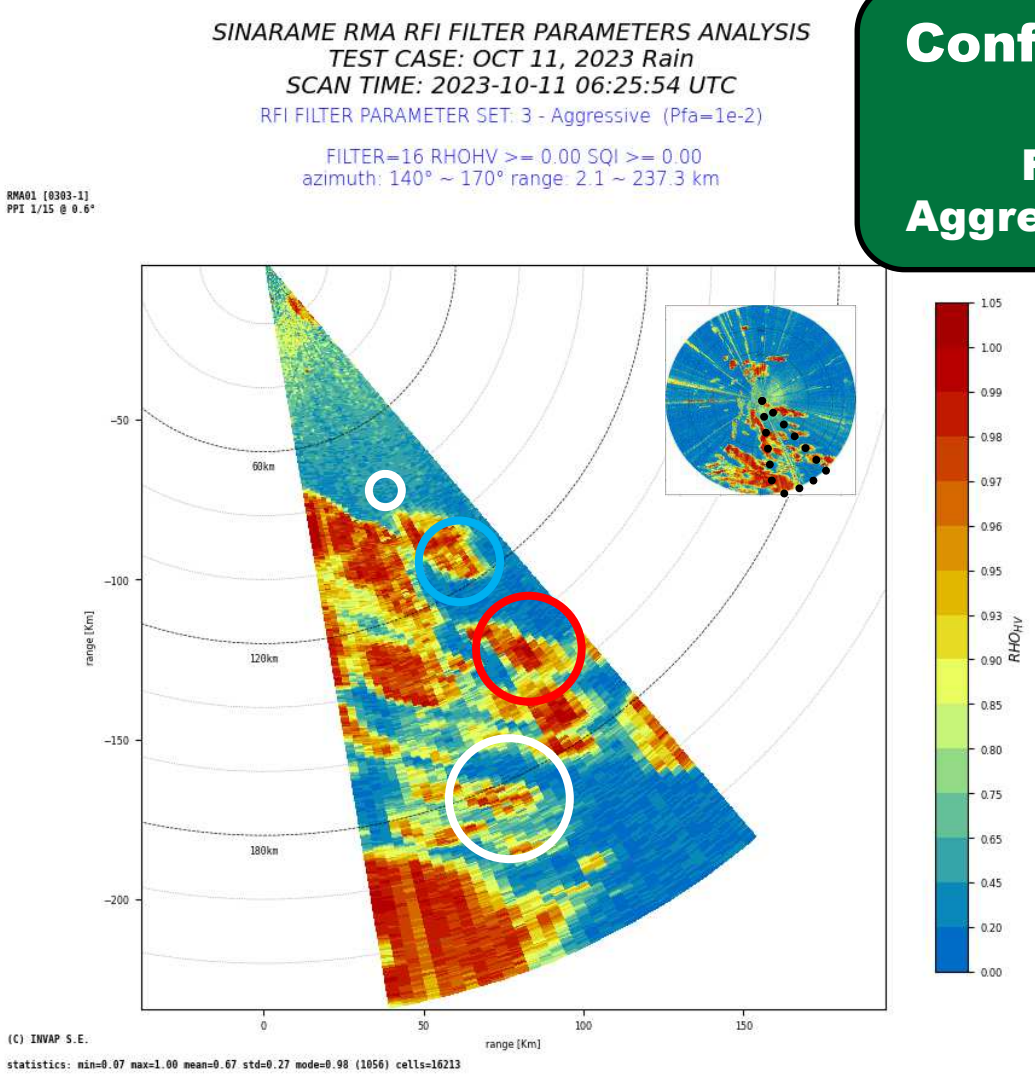


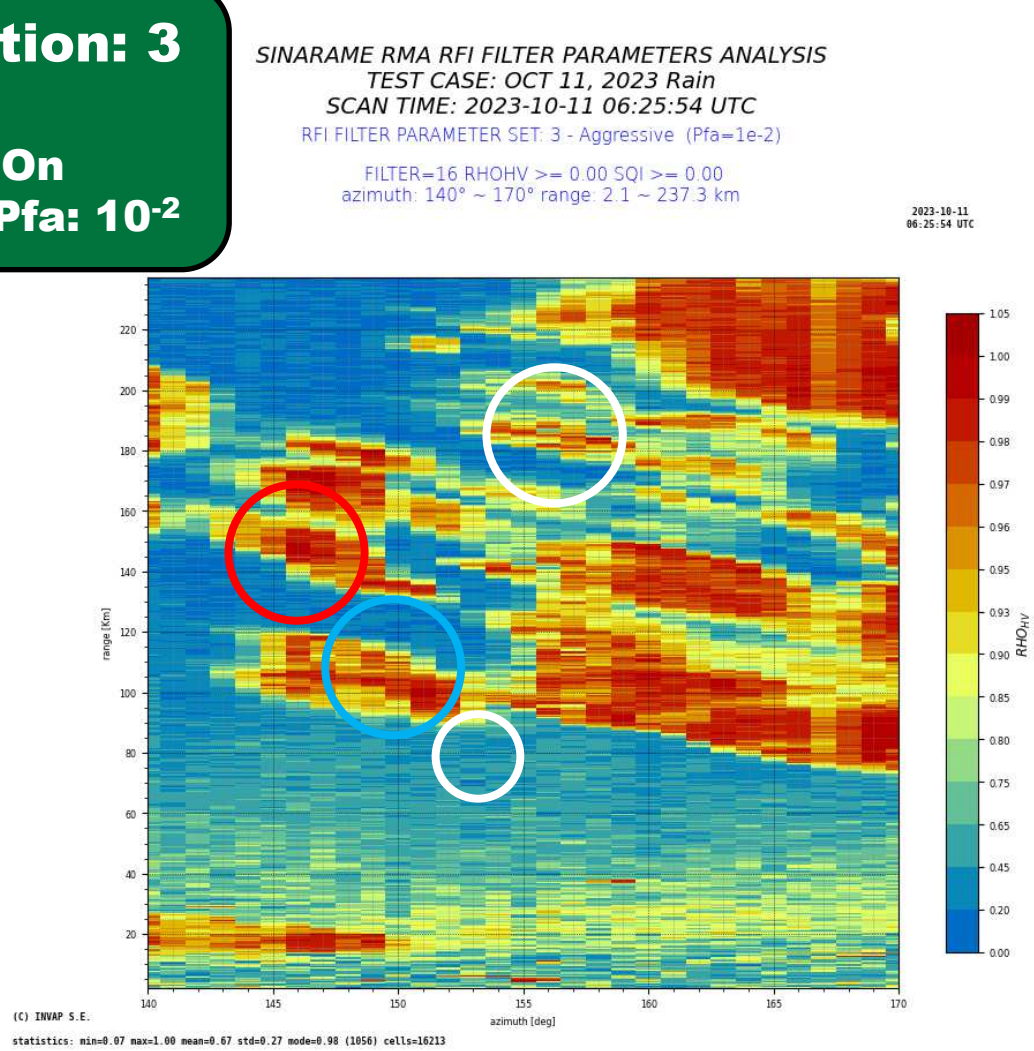
3. PHASE 2 – Results: RHOHV filtered (details)

Test case: Rain

Configuration: 3

Filter: On
Aggressive Pfa: 10^{-2}



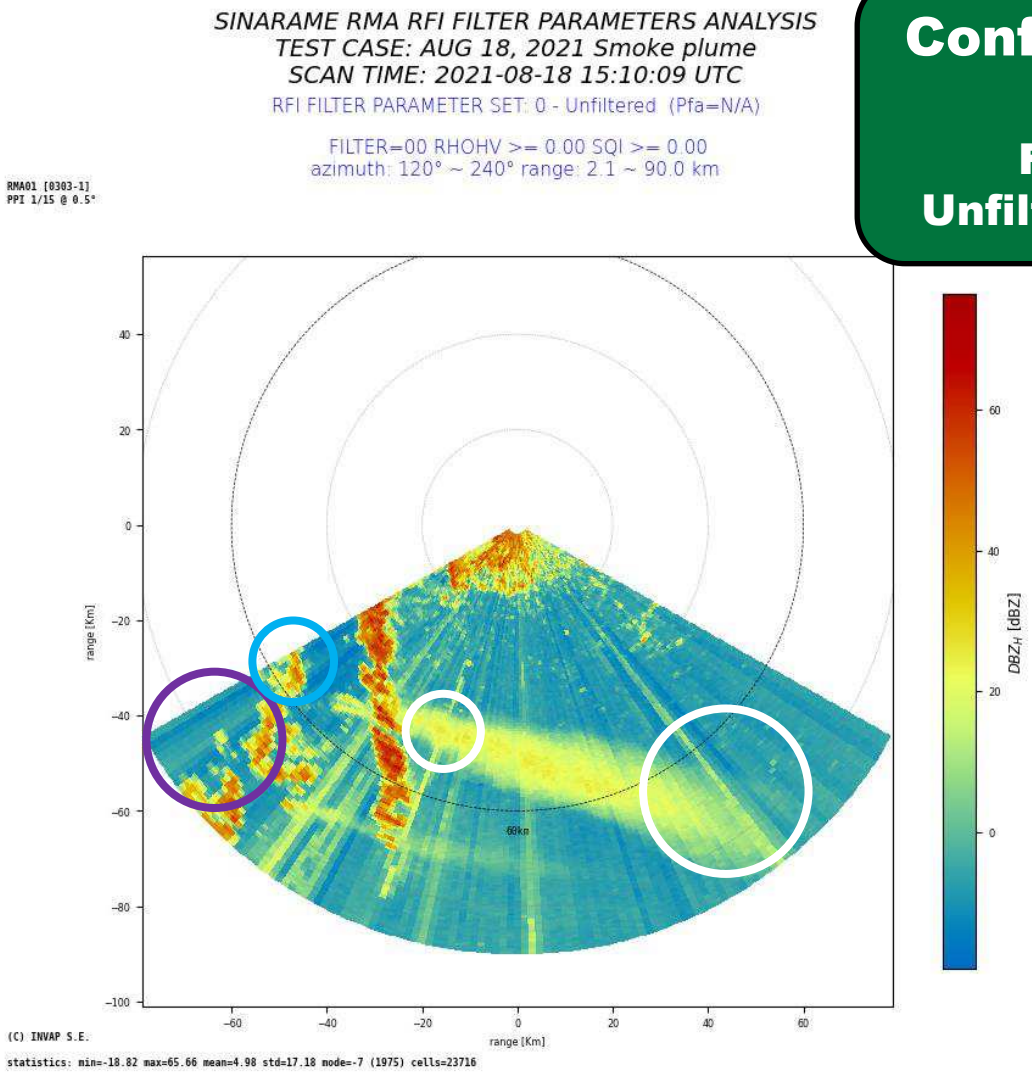


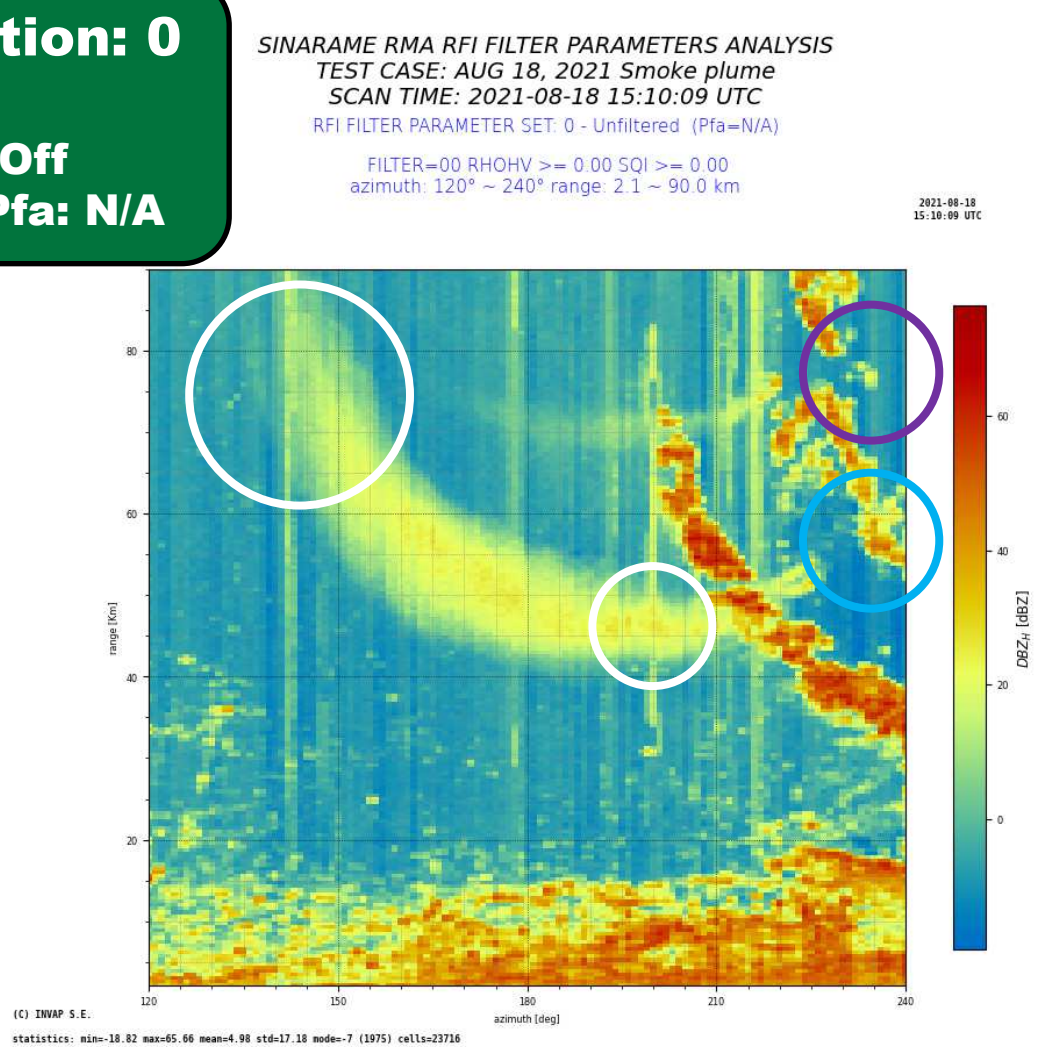
3. PHASE 2 – Results: DBZH contaminated

Test case: Smoke plume (non-meteorological echoes)

Configuration: 0

Filter: Off
Unfiltered Pfa: N/A



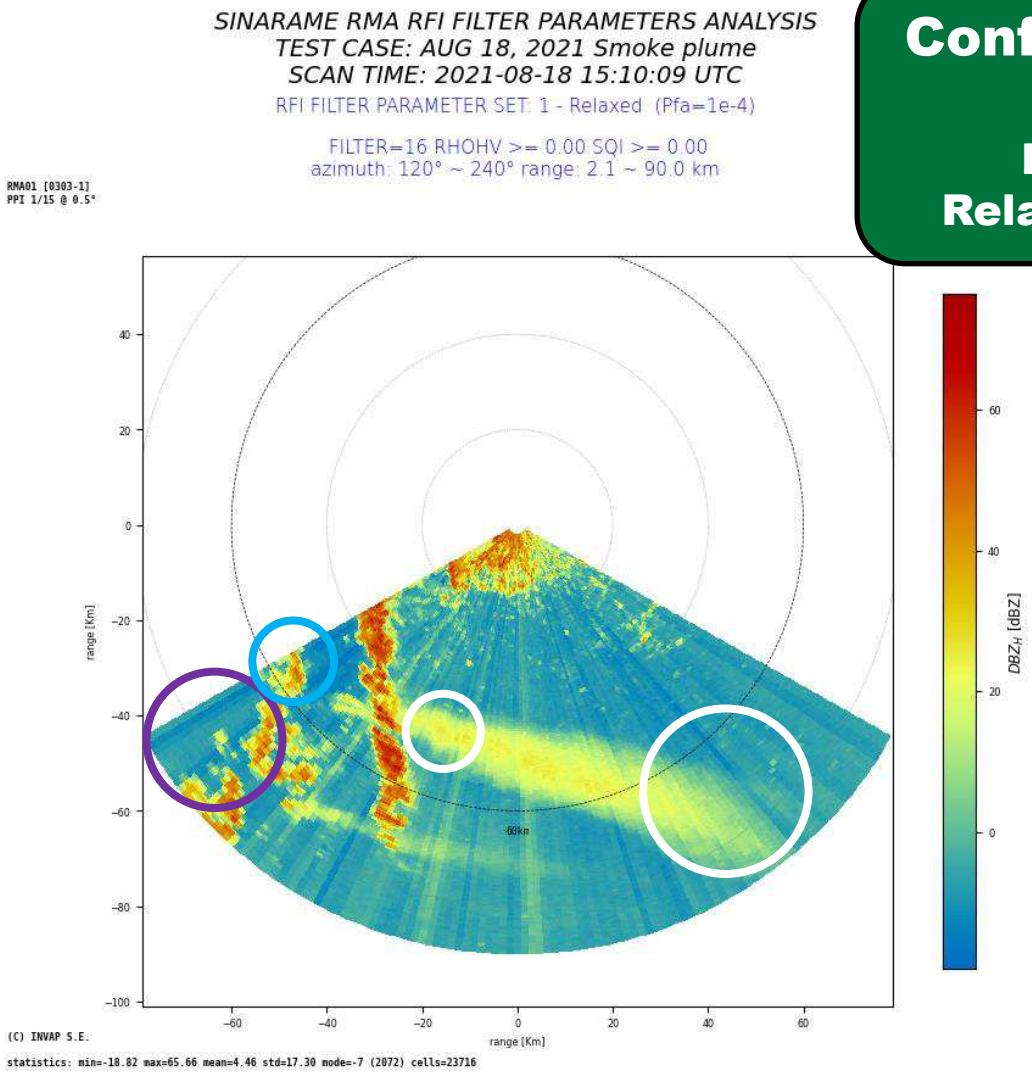


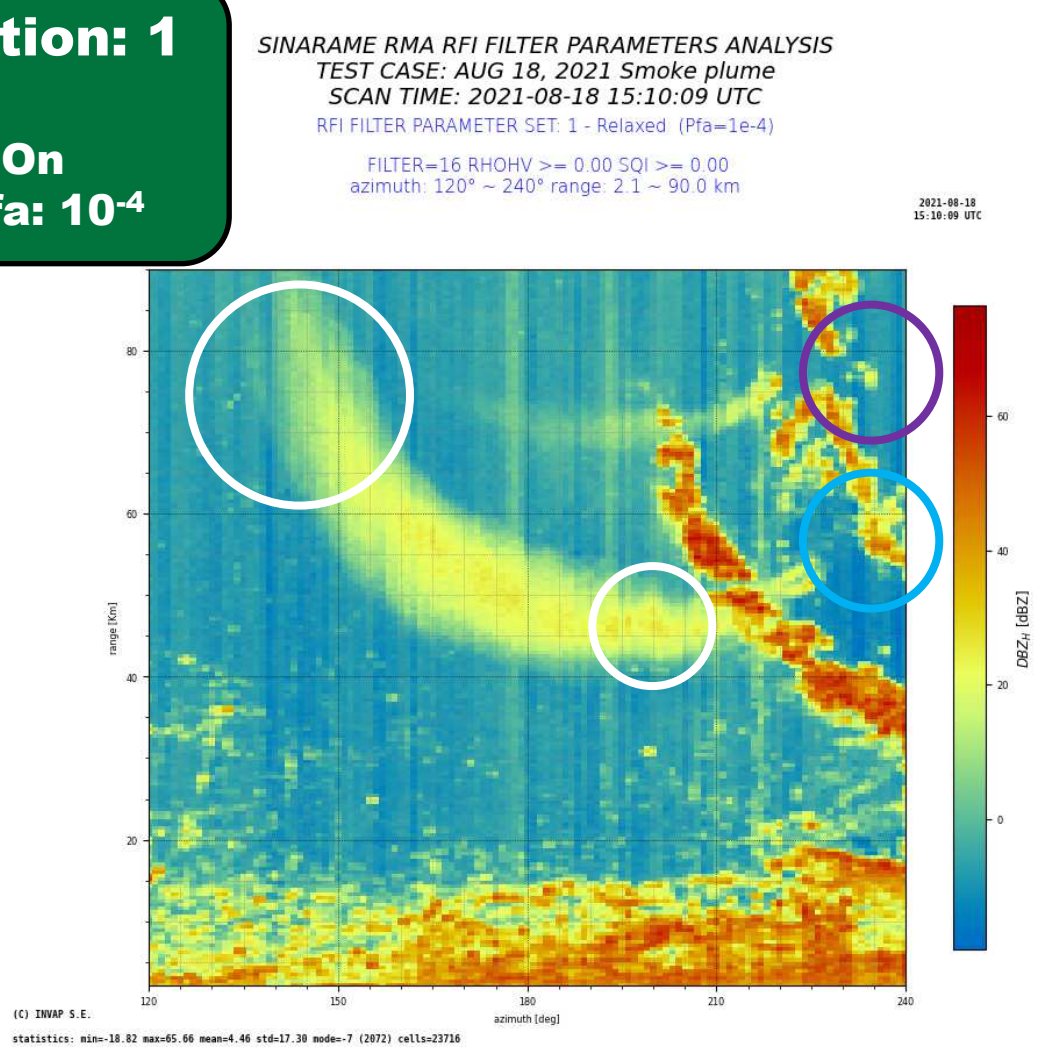
3. PHASE 2 – Results: DBZH filtered (details)

Test case: Smoke plume (non-meteorological echoes)

Configuration: 1

Filter: On
Relaxed Pfa: 10^{-4}



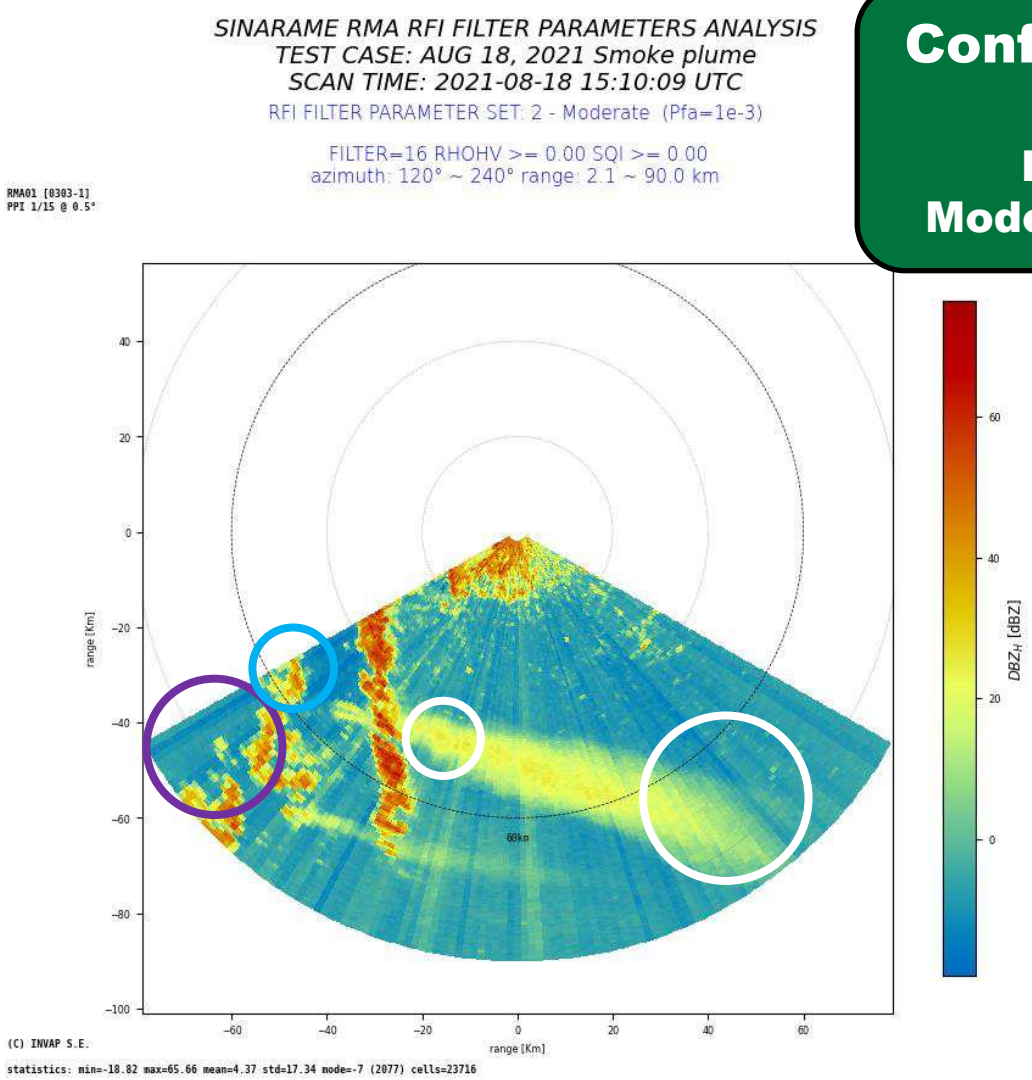


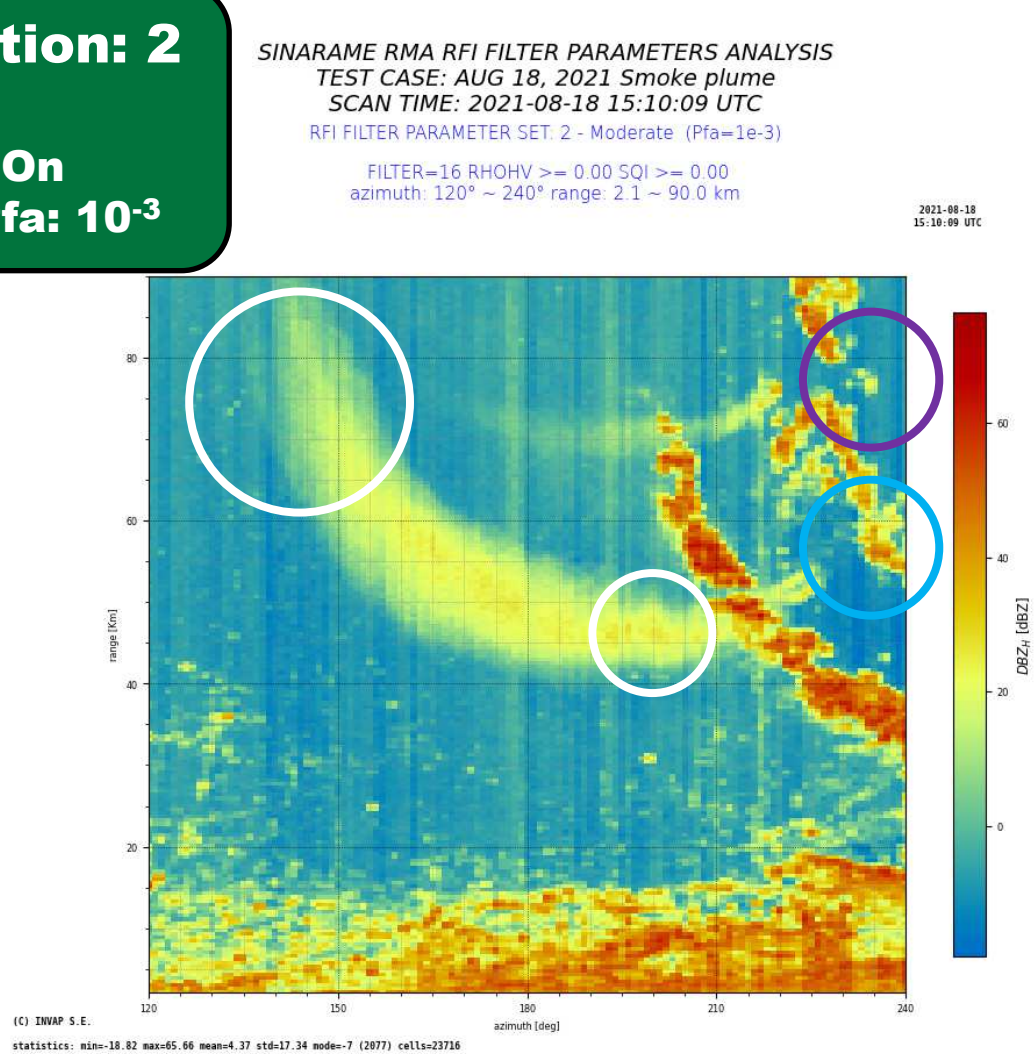
3. PHASE 2 – Results: DBZH filtered (details)

Test case: Smoke plume (non-meteorological echoes)

Configuration: 2

Filter: On
Moderate Pfa: 10^{-3}



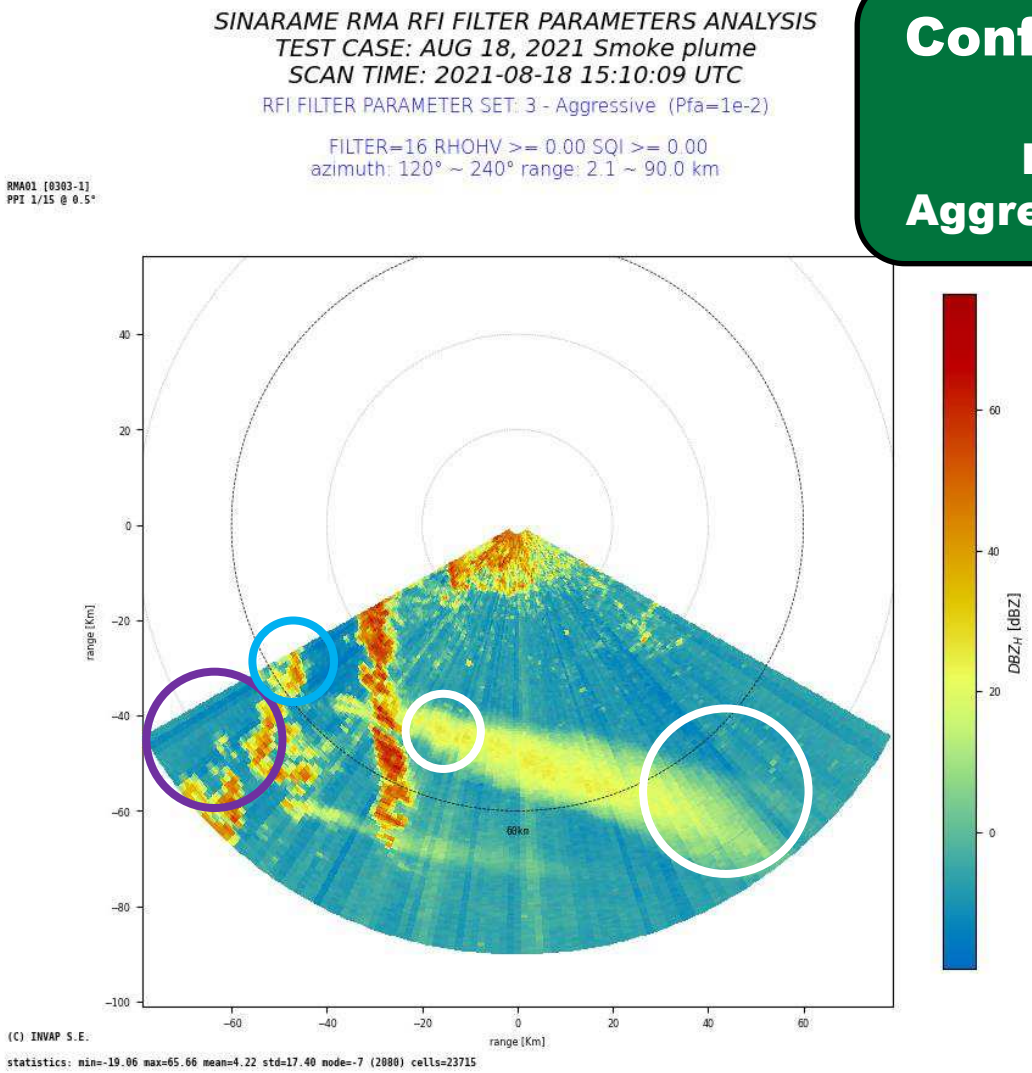


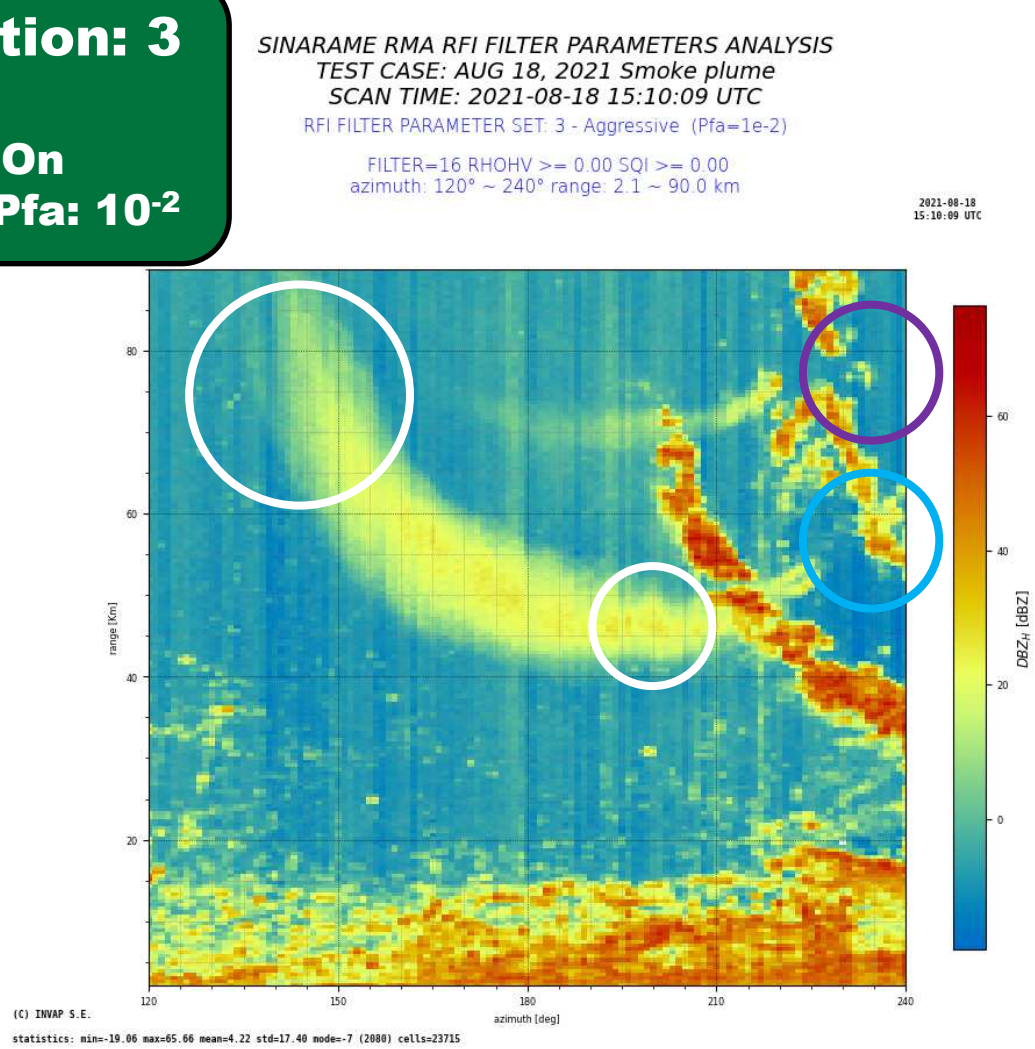
3. PHASE 2 – Results: DBZH filtered (details)

Test case: Smoke plume (non-meteorological echoes)

Configuration: 3

Filter: On
Aggressive Pfa: 10^{-2}



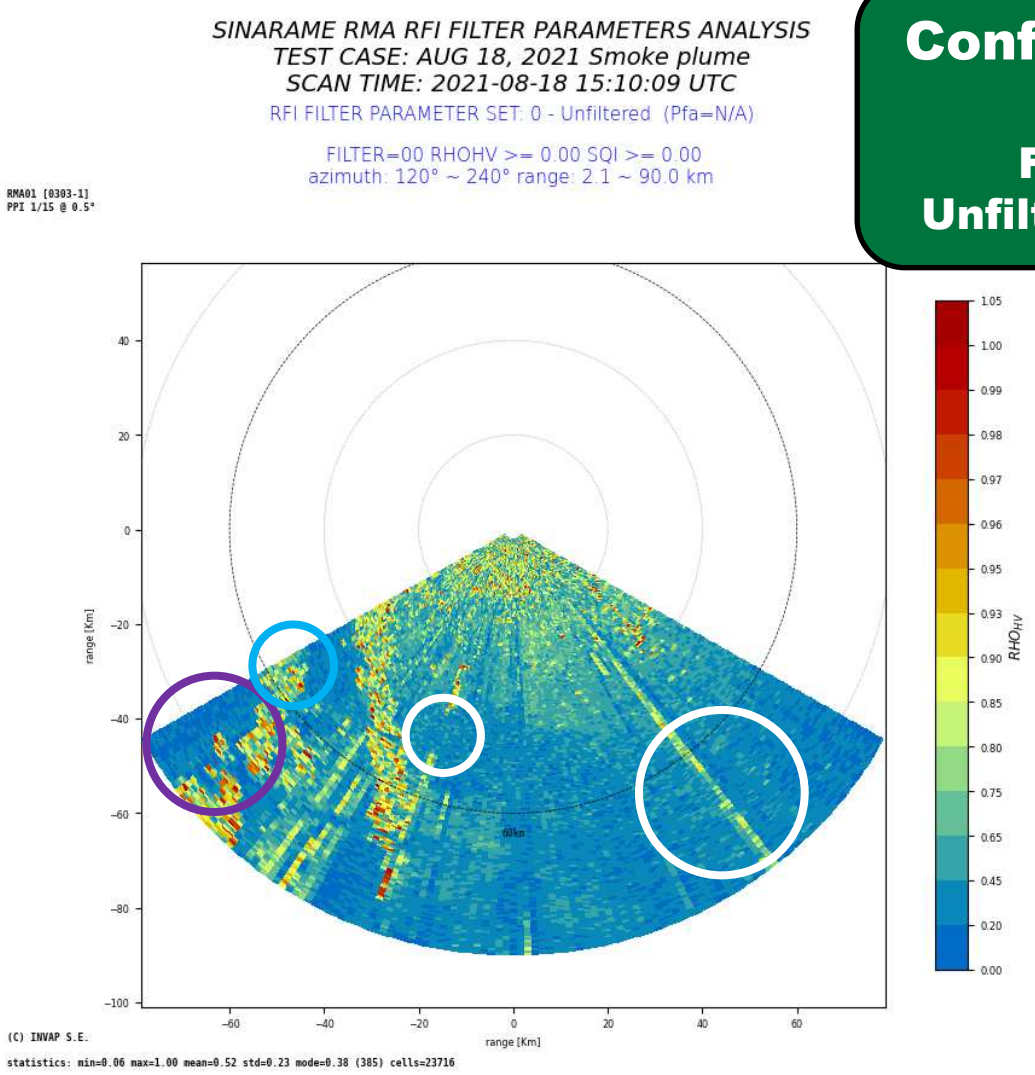


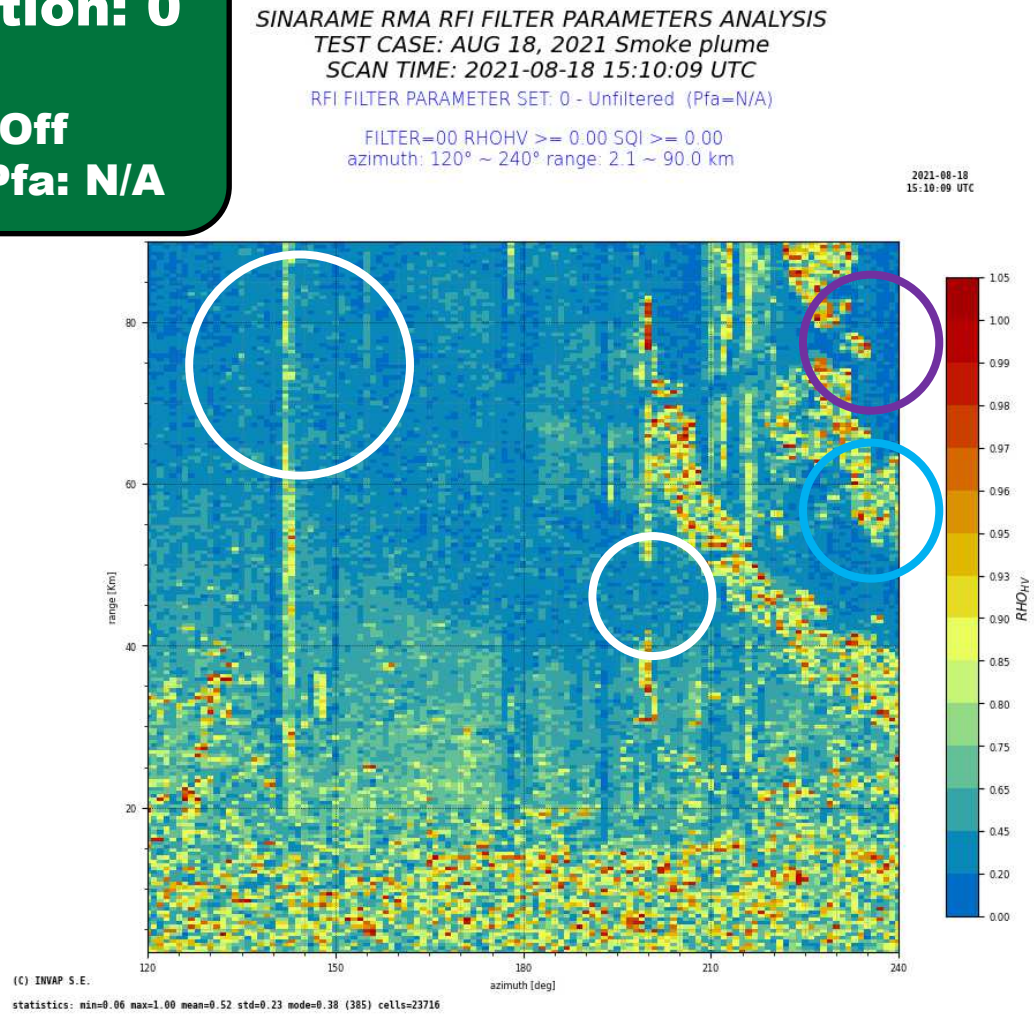
3. PHASE 2 – Results: RHOHV contaminated

Test case: Smoke plume (non-meteorological echoes)

Configuration: 0

Filter: Off
Unfiltered Pfa: N/A



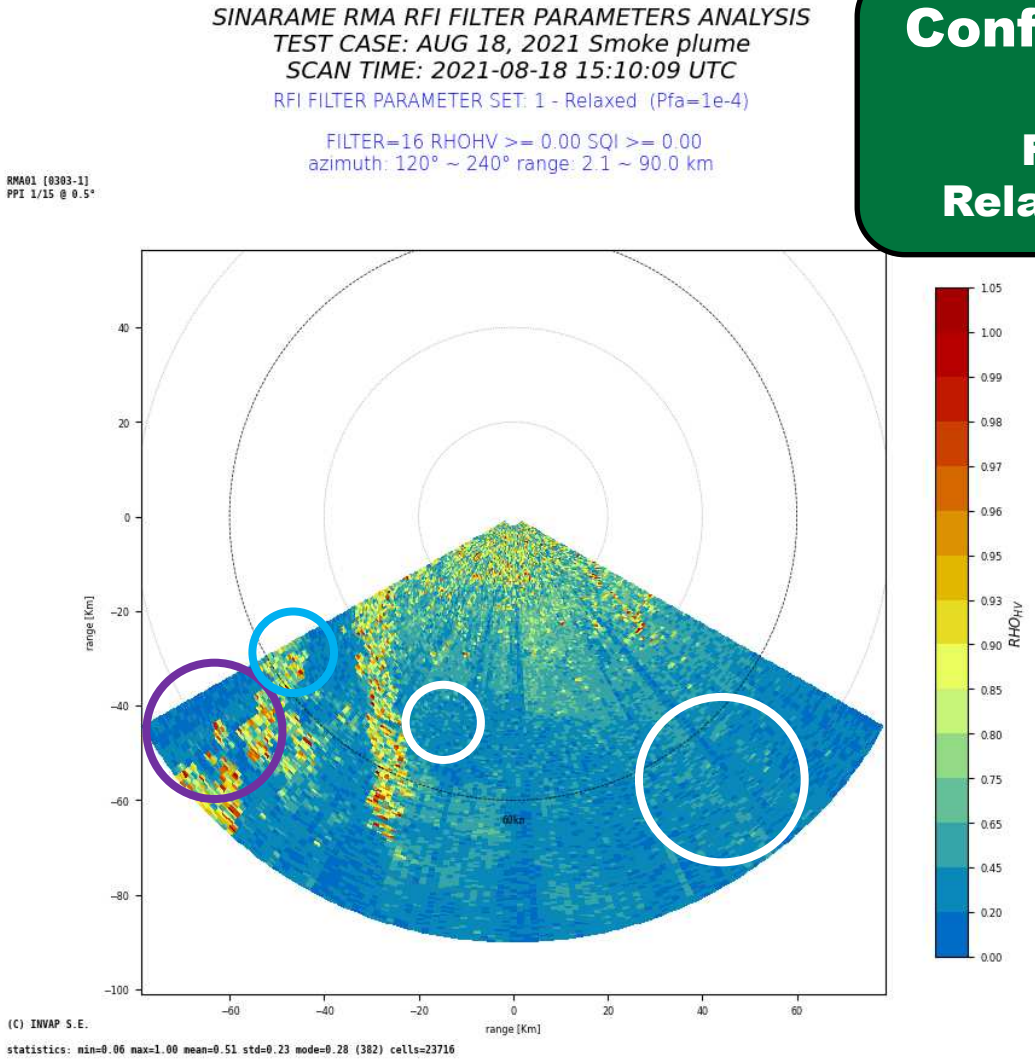


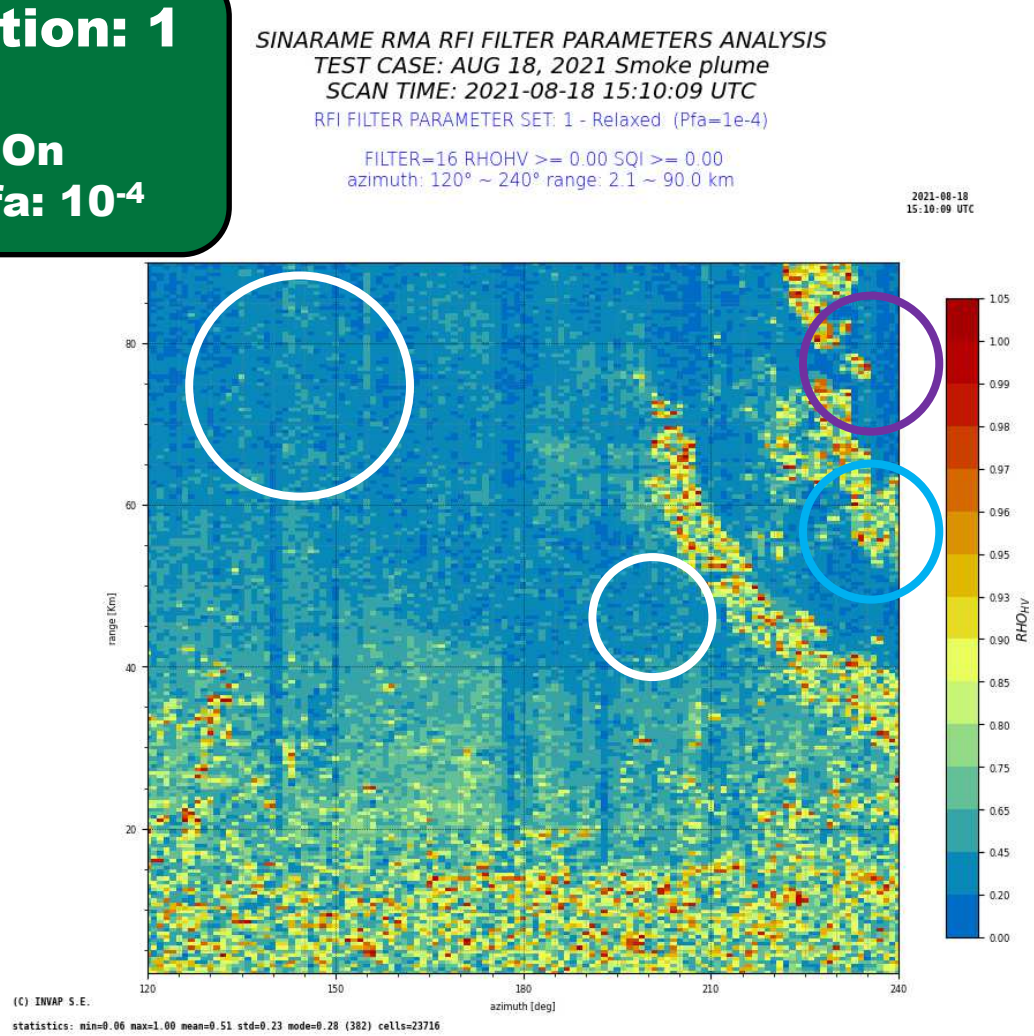
3. PHASE 2 – Results: RHOHV filtered (details)

Test case: Smoke plume (non-meteorological echoes)

Configuration: 1

Filter: On
Relaxed Pfa: 10^{-4}



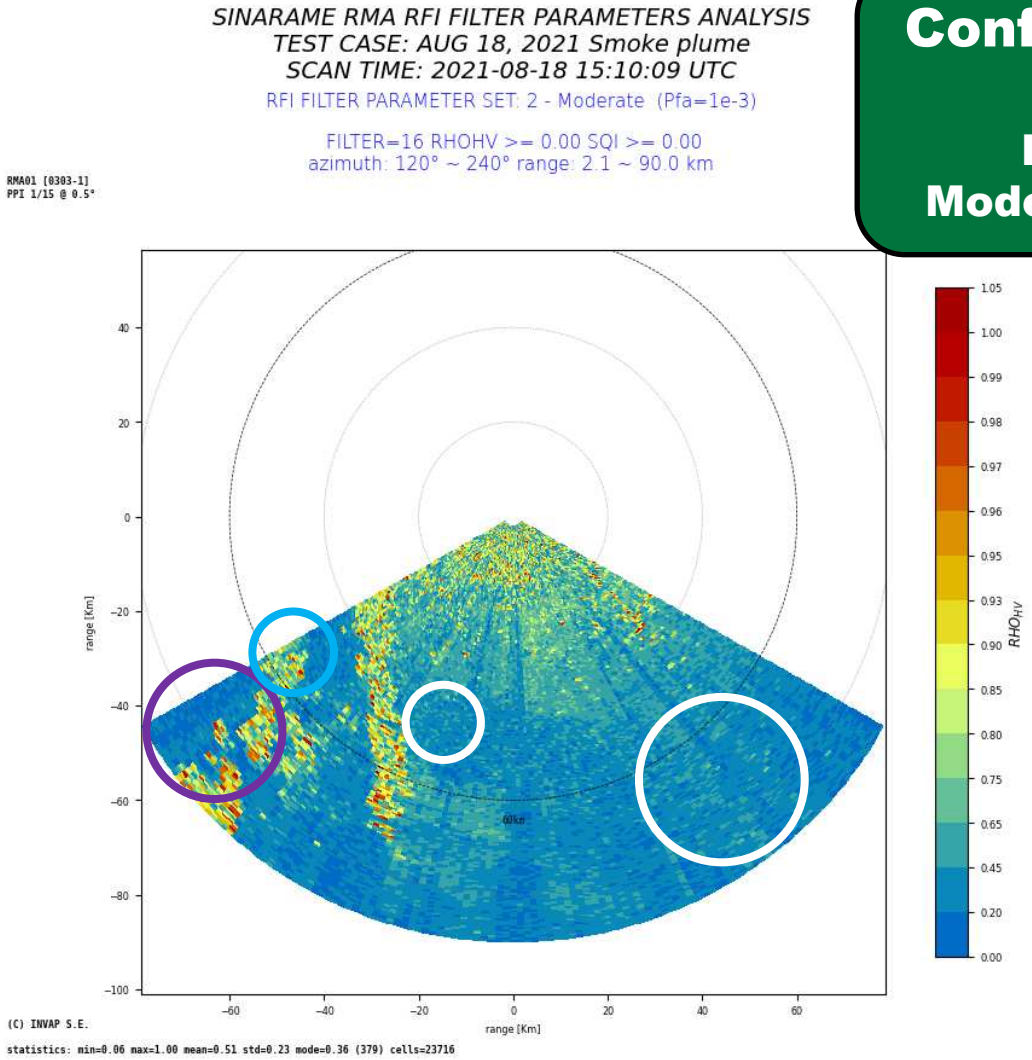


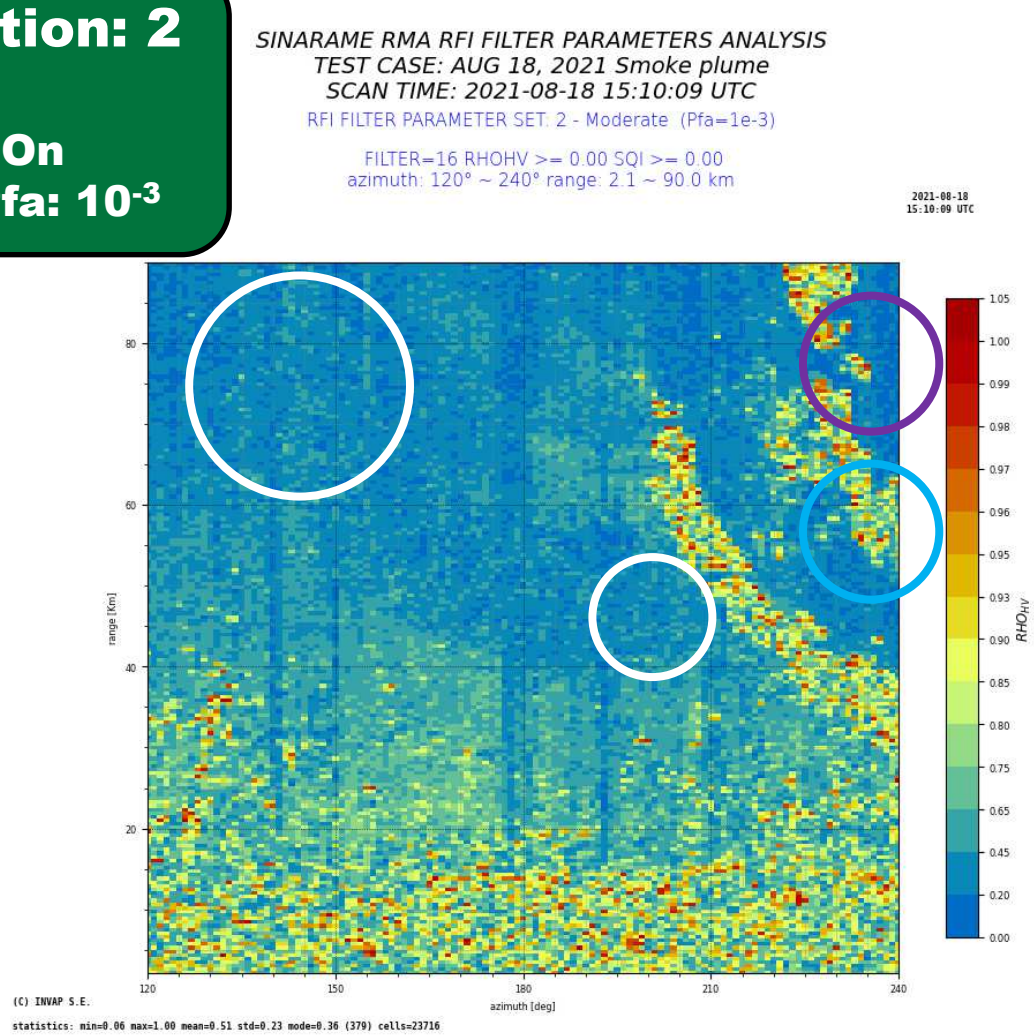
3. PHASE 2 – Results: RHOHV filtered (details)

Test case: Smoke plume (non-meteorological echoes)

Configuration: 2

Filter: On
Moderate Pfa: 10^{-3}



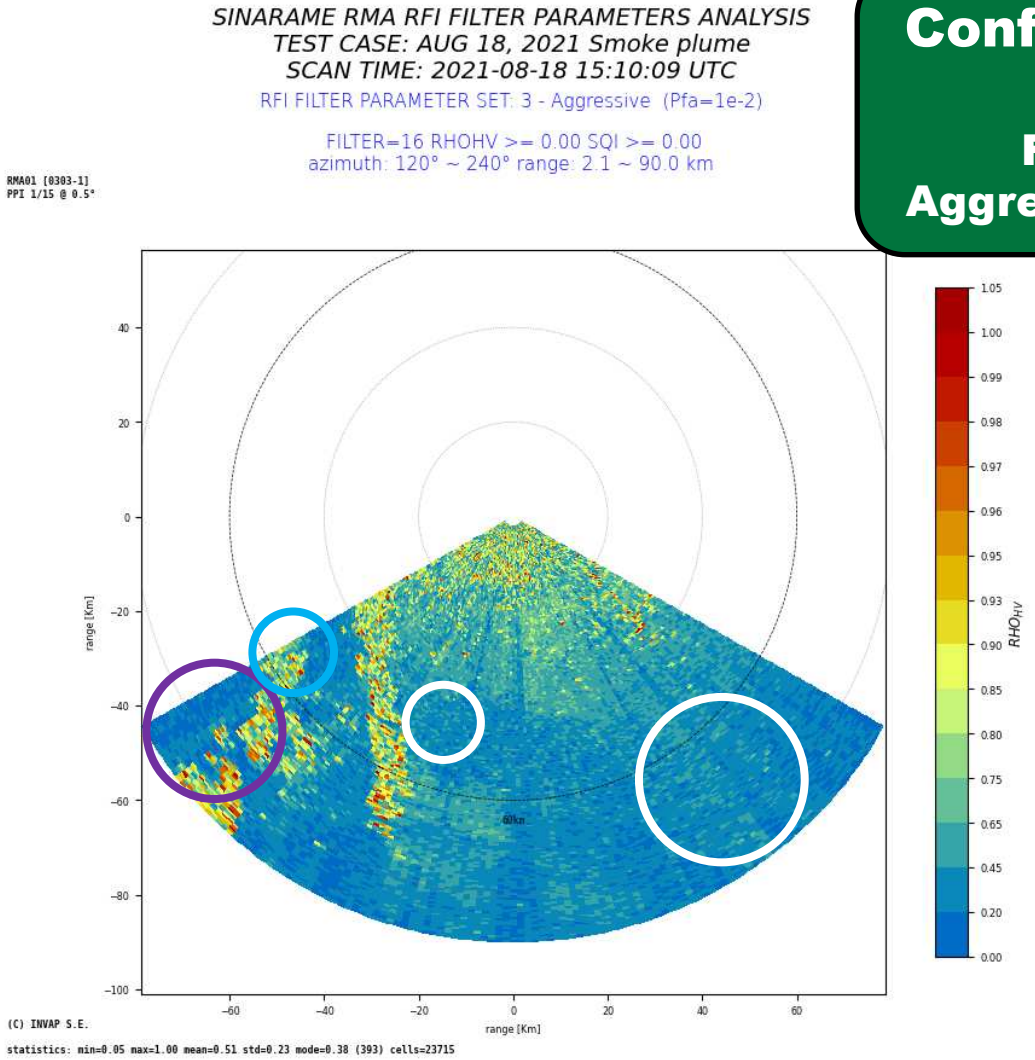


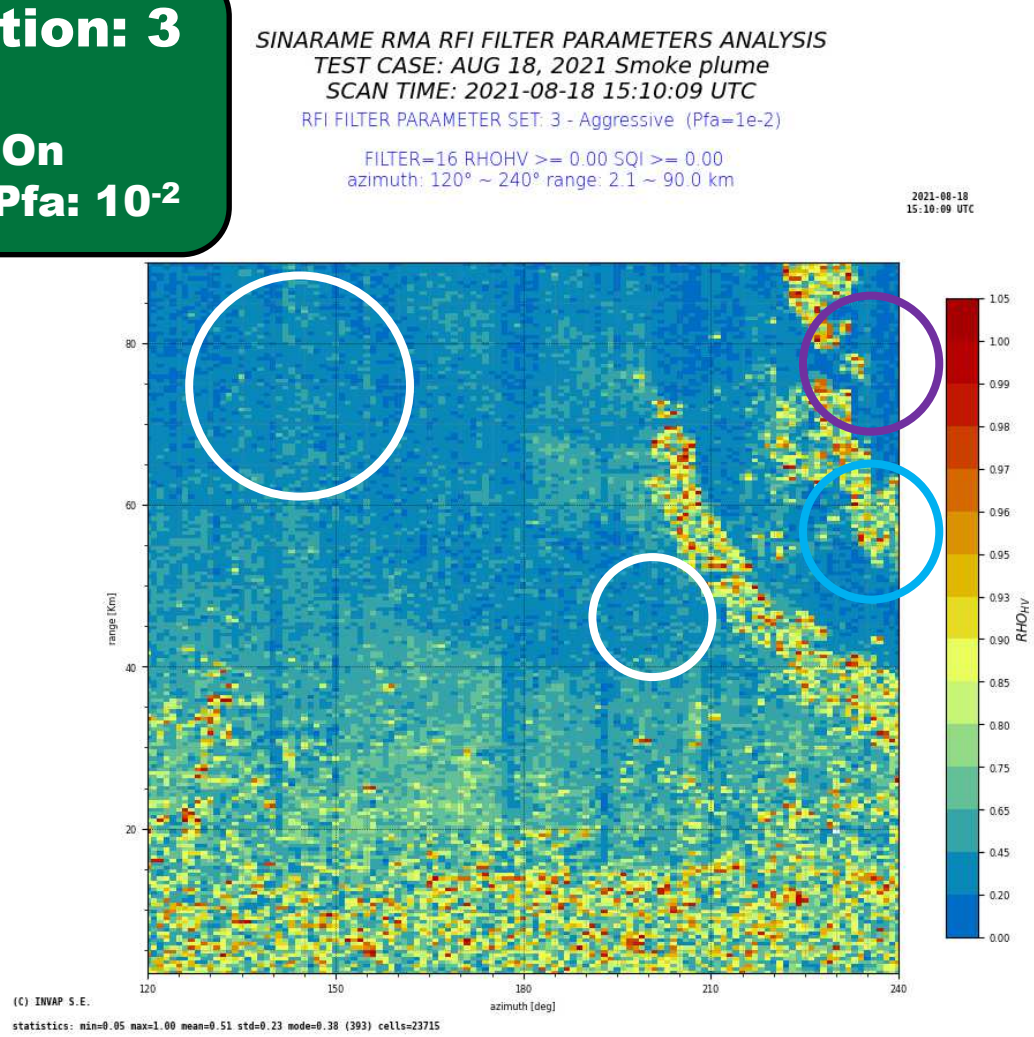
3. PHASE 2 – Results: RHOHV filtered (details)

Test case: Smoke plume (non-meteorological echoes)

Configuration: 3

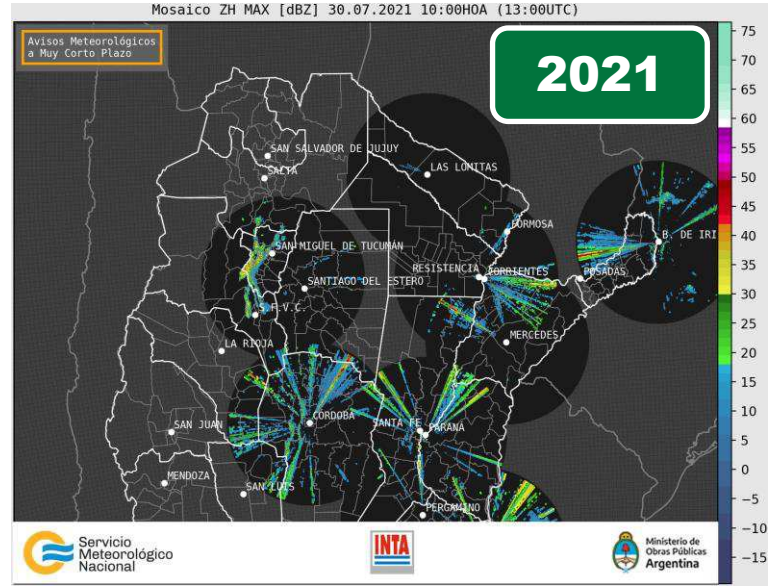
Filter: On
Aggressive Pfa: 10^{-2}





4. Remarks and Conclusions

- The activation of the *RFI* filter on all operational *SINARAME RMA* radars significantly improved data quality.
- *RFI* contamination is greatly reduced while echoes of interest remain mostly unaffected for all the studied cases after matching the filter parameters to the scanning strategy and an appropriate level of probability of false alarm (filtering aggressiveness) selection.
- The radar composite is available to the community at Argentina's *National Weather Service* portal: https://www.smn.gob.ar/radar



- All the involved institutions are actively evaluating the data quality of the radars of the *SINARAME* network.
- A second iteration of the configuration tuning process is planned to adjust filter performance based on feedback from end users.
- Filtering algorithm improvements are under consideration.

5. Acknowledgments

This work is part of a greater joint project to improve the overall quality of the SINARAME data and has been done in close collaboration with the following institutions:

- *Secretaría de Infraestructura y Política Hídrica*, the institution that manages and provides funds for the SINARAME project.
- *Servicio Meteorológico Nacional*, Argentina's National Meteorological Service and the principal user of the network data.
- *Facultad de Matemática, Astronomía, Física y Computación* from *Universidad Nacional de Córdoba*.

Ministerio de Obras Públicas Argentina

Secretaría de Infraestructura y Política Hídrica

Servicio Meteorológico Nacional Argentina

FAMAF Facultad de Matemática, Astronomía, Física y Computación

UNC Universidad Nacional de Córdoba

- The author of this presentation would like to thank Stephen Nesbitt, Sebastian Torres, Paola Salio, Dušan Zrnic and Roberto Costantini for their selfless guidance, advice and recommendations over the years.

Thanks for your attention

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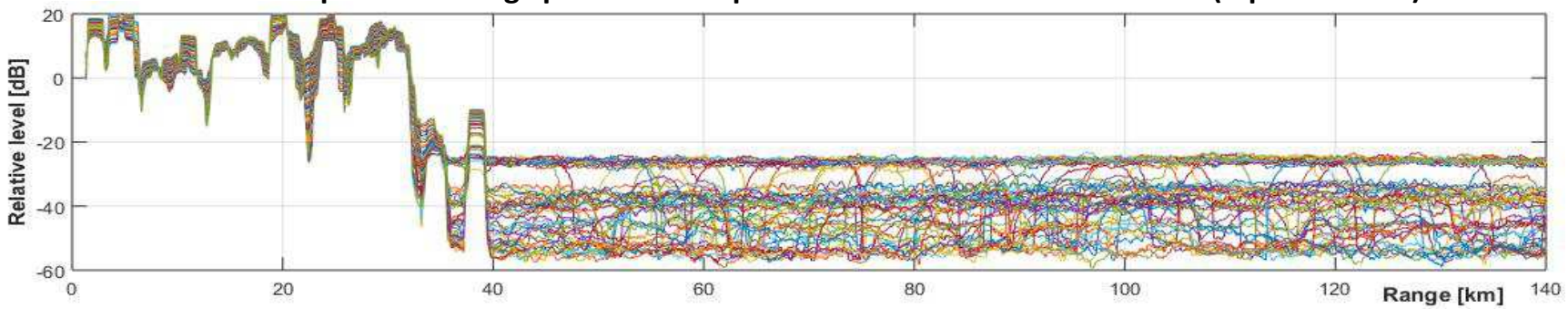
Backup slides

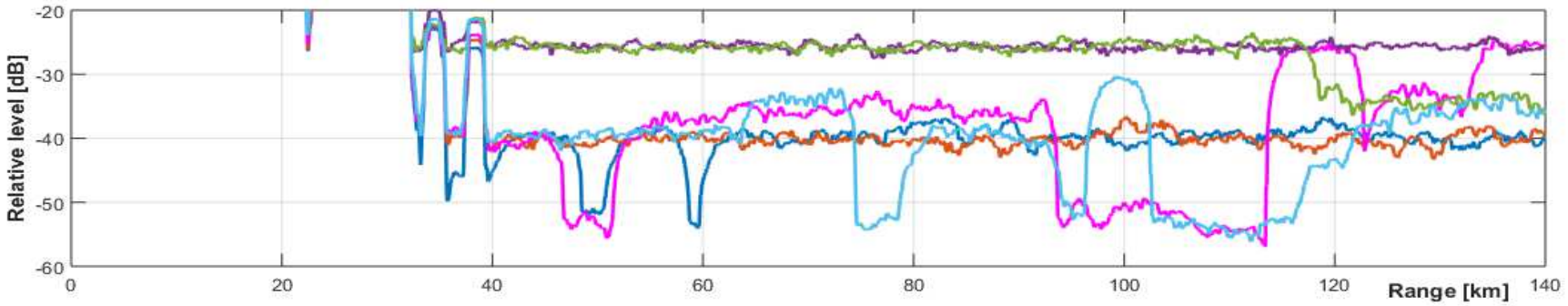
A case of interference

- These A-Scope figures present smoothed power versus range of real radar data contaminated with RFI.
- Presence of interference pulses from several sources is visible from 40km, where the power level of the received echoes is below the RFI.

Smoothed power vs. range plot of the 54 pulses of the burst at azimuth 324° (V polarization).



Same as above, only 6 consecutive pulses are shown in expanded dB scale.



RMA-C320 – Technical specifications

Parameter	Value
Brand and Model	INVAP RMA-C320 (Doppler, dual polarization)
Operational frequency	C-Band, 5600 - 5650 MHz (1 MHz steps)
Dual Pol transmission mode	Simultaneous transmission and reception (H + V)
System Sensitivity (ISO/DIS 19926-1:2019)	Better than -7 dBZ at 50 km with 1us pulse and for SNR=0 dB including atmospheric attenuation and radome and waveguide losses
Radome losses	0.4 dB (dry, one way)
Transmitter	Coaxial Magnetron, solid state modulator
Peak power	250 to 320 kW (10kW steps)
Pulse duration	0.5 to 2.0 us (100 ns steps)
Max duty cycle	0.001 (0.1%)
Antenna	Parabolic, center feed, 4.48 meters
Gain	45.4 dBi +/- 0.5dB @5625 MHz
Beam width @ -3dB (typical)	0.90° @5625 MHz
side lobes	Better than -27 dB
cross-pol isolation	Better than -35 dB
Receiver	Antenna mounted, over azimuth, double conversion superheterodyne
Intermediate Frequency (IF):	First: 905 MHz, Second: 70 MHz
noise figure	Better than 3 dB