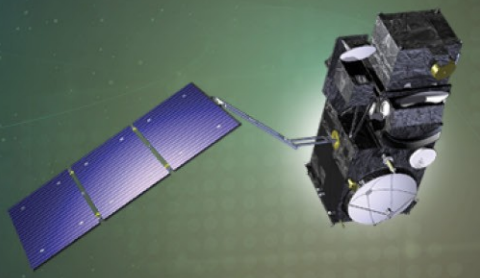
PROGRAMME OF THE EUROPEAN UNION

opernicus Europe's eyes on Earth

EUMETSAT

co-funded with esa

OSTST 2022 30 October – 04 November 2022 | Lido | Venice, Italy



On the Benefits of Stack-Masking in Delay-Doppler Altimetry over Non-Homogeneous Surfaces

Pierre Fabry (ALONG-TRACK), Marco Restano (ESA), Américo Ambrozio (ESA), Jerome Benveniste (ESA)

The HYDROCOASTAL Project

- HYDROCOASTAL is funded under the **ESA Science for Society Programme Element**.
- The aim is to maximise exploitation of SAR and SARin altimeter measurements in the **coastal zone** and **inland waters** : implementing + evaluating new approaches to process :
  - **SAR and SARin** data from **CryoSat-2**,studies will
  - **SAR** data from **Sentinel-3A** and **Sentinel-3B**.
- **New SAR and SARin processing algorithms** for the coastal zone and inland waters have been developed and tested.
- A processing scheme is being implemented to generate global **coastal zone products** + **river discharge data sets**.
- **15 partners**:

  SatOC (prime), isardSAT, National Oceanography Centre (UK), DTU Space, the University of Bonn, Aresys, Noveltis, DTU Environment, the Technical University of Munich, the University of Cadiz, Along-Track (with AltiHydro Lab), Consiglio Nazionale (ISP, IRPI and IBF), National University of Ireland – Maynooth, and the University of Porto and the Technical University of Delft

HYDROCOASTAL Overview

1. **Scientific Review and Requirements Consolidation (Completed 2021)**

   Review the current state of the art in SAR and SARin altimeter data processing as applied to the coastal zone and to inland waters.

2. **Implementation and Validation (July 2020 – July 2022)**

   Implement new SAR, SARin altimeter processing algorithms to generate 2-year test data set.

   Evaluate performance of the candidate algorithms.

   Selected algorithms used to generate “global” coastal zone and inland water final products

3. **Impact Assessment (October – December 2022)**

   The impact of global products assessed through a series of case studies

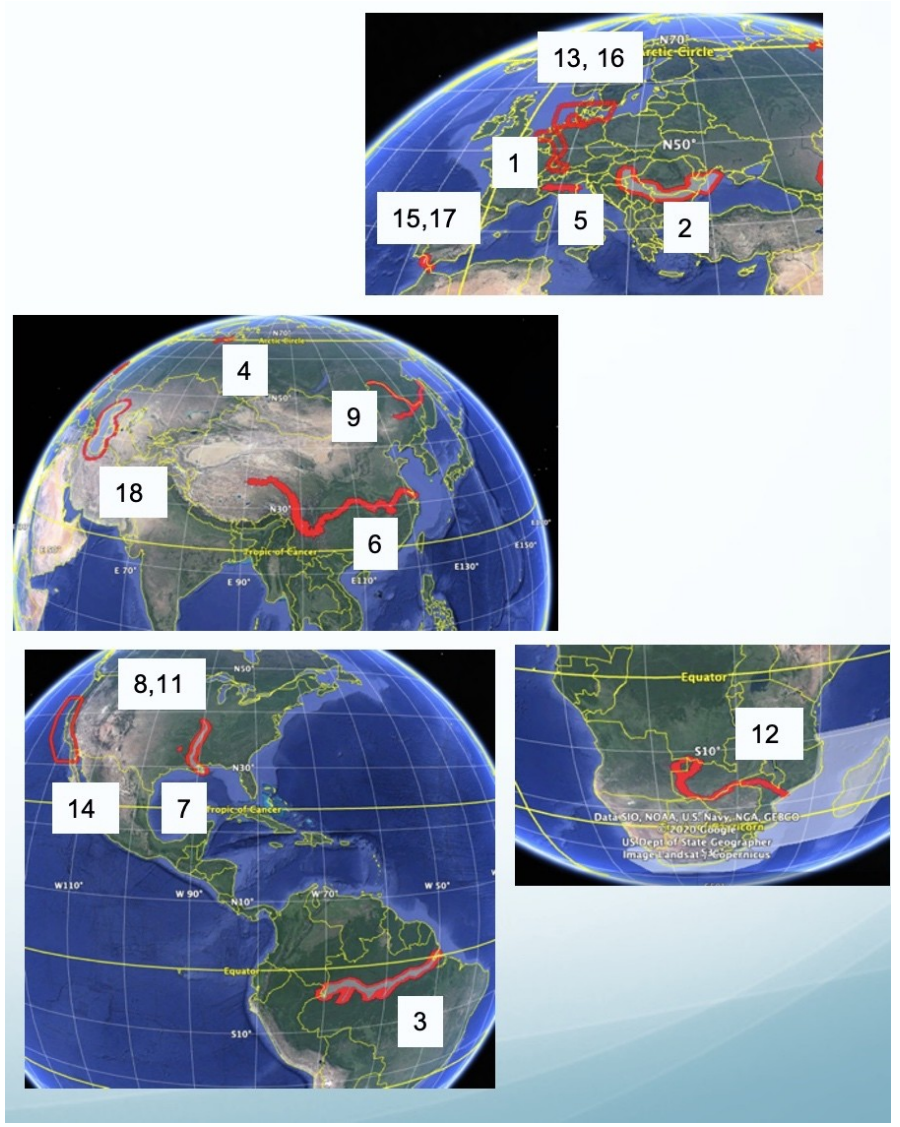
4. **Outreach and Road Map (April 2023)**

   Recommendations for further R&D and implementation in current and future SAR altimeter missions

1st HYDROCOASTAL Test Data Set

- **18 Regions of Interest** to cover a wide range of inland water and coastal zone characteristics.
- 2 years data 2018-2019 for **water heights**, 3 years for regions with **river discharge** estimates
- Inputs
  - **CryoSat FBR baseline D SAR** and SARin mode data.
  - **Sentinel 3A and 3B** SIRAL **L1A data**
- **Enhanced Wet and Dry Troposphere Corrections** (U Porto)
- Documented descriptions of processing schemes and products at ***www.satoc.eu/projects/hydrocoastal***
- Available on request by email to ***info@satoc.eu***

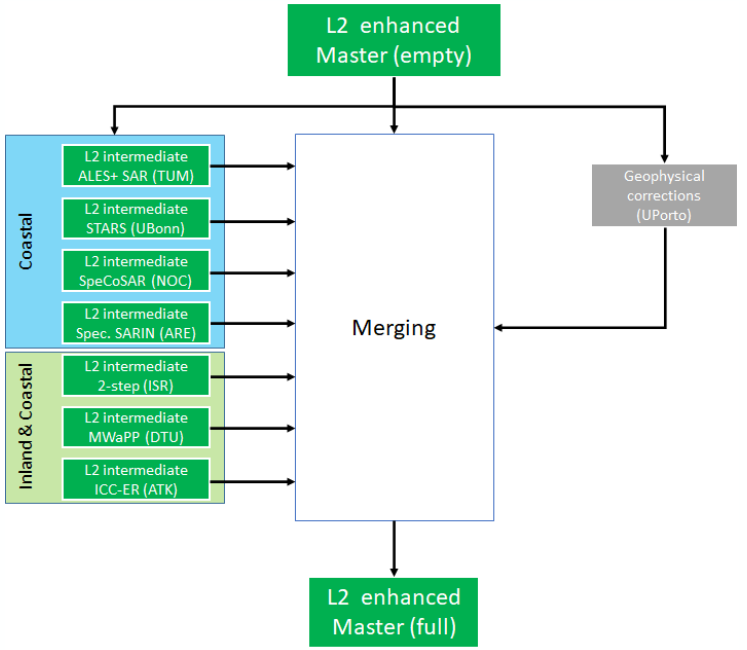
1st HYDROCOASTAL Test Data Set



Candidate L2 algorithms

Six candidate L2 processing algorithms have been implemented. Their performance has been evaluated, and the best performing algorithms have been selected to generate global coastal zone and inland water products in the second year of the project.

1. Two Step Analytical Processor – coastal and inland: isardSAT
2. Specialised SARin – coastal: Aresys*
3. MWaPP – Multiple Waveform Persistent Peak – inland: DTU Space
4. **ICC-ER (Isolate, Cleanse, Classify - Empirical Retracker – inland: ATK**)
5. Statistical Re-tracker STARS type – coastal: U Bonn
6. ALES+ for SAR - coastal: TU Munich*



HYDROCOASTAL L2 product merging. The L2 enhanced Master includes output from all L2 processors. (credit: isardSAT)

Retracker Validation Results – Inland Water

- Altimeter **water level** from 3 re-trackers (isardSAT, DTU, TU Munich), was validated (*The ICCER retracked files were delivered few weeks after the validation exercise*) from
  - Sentinel **3A and 3B** input data **against river gauge** data
  - across **11 river basins**, in North and South America, Europe, Asia and Africa
- → median root mean square errors across all stations and re-trackers were 33-34cm.
- The DTU re-tracker was found to be the best performing (lowest RMSE) when looking across all 3 data sets,
- although there were some locations with complex geomorphology, or during ice melt, where the DTU retracker did not provide good results.
- There is a **need to categorise different types of river / lake** environment and **apply different re-trackers** that were optimised to these environments, but so far for this project :

The validation team recommended selection of the DTU re-tracker for inland water processing in the next stage of the HYDROCOASTAL project

Why Stack based Retracking ?

→ To test the benefits of **cherry picking in the Stack** when retracking echoes over **non homogeneous surfaces** (inland waters and sea ice).

Radar echoes over non homogeneous surfaces:

- **specular**, **multi-peaks** (up to "**chaotic**" signals), **ghost** signals from the **antenna side lobes**, due to complex altimeter **footprint content** with huge variety and diversity:
- at the poles : **patchwork** of **water** and **sea ice** in different ages an rugosity,
- over inland : **patchwork** of **water** (bright), **vegetation** (diffuse), **man made structures** (bright), **sinuous river legs**, **calm waters** (specular), **turbulent water** (complex scattering),
  => May be hard to model for a fitting algorithm (geophysical retrackers).

In Delay-Doppler we have a variety of observations (roughly 240 beams / Stack) => let's take benefit of this !

The ICCER Retracker (algorithm overview)

- **Preprocessing**
  - Identify up to M (in our example M=3) **group of consecutive range gates** that are frequent **power contributors** (among the Stack beams),
  - Identify the **beams** that carry these major « peaks » of energy in the Stack,
- **Isolate** the **(range_gates, beams) blocks** for each **group of range gates** that has a sufficient extent (8 bins as a minimum) and a sufficient number of **contributing beams** (8 as a minimum) → 1 clean Stack per « group of range gates »
- **Cleanse** the Waveform :
  - Multi-look the clean Stacks → clean **Pseudo-WFs** (PWFs)
  - Sort the PWFs by **decreasing power** and keep up to **Mfinal** peaks (Mfinal=1 in SAR mode)
- **Classify** (based on Pulse Peakiness, not addressed here)
- **Empirically Retrack** (simple thresholding with the ICE-1 threshold)
-

Additional steps for the SARIN version:

- Get **cross-track angle from phase difference** @ retracked points (several per records)
- **Compute geolocation** of retracked points.

The ICCER algorithm (processing 1 record)

Pre-processing (to detect the most frequent AND most powerful blocks of range gate)

- stack **smoothing in range** : exponential moving average filter (typical value : alpha=0.3) : more stable boundaries for the powerful range gate blocks over noisy beams, *the doppler beams leak towards the far range gates*
- stack **smoothing in azimuth** : exponential moving average filter (typical value : alpha=0.6) : lowers the spurious signals and over-weights beams with powerful range gates, *the stack leaks towards along azimuth*
- IF smoothed_stack is **sparse** (proportion of NaN values in the stack > *max_nan_ratio = 0.75*) → **stop** (flag as failed)
- ELSE : **multi-look** the smoothed_stack → **smooth_waveform**
- **detect all atomic peaks and valleys** on the smoothed_waveform:
  - positive slope → **atomic_peak** → negative slope
  - negative slope → **atomic_valley** → positive slope
  - **atomic_valley** → positive slope (over m bins) → **atomic_peak** → negative slope (over m bins) → **atomic_valley**
- get **extended_atomic_peaks** by browsing the vicinity of the highest **atomic_peaks** and integrating the neighbor **atomic_peaks** with amplitude < max(atomic_peaks)**max_noise_to_peak_ratio* with *max_noise_to_peak_ratio* = 0.06
- when extended_atomic_peaks **overlap** each-other → **split** their overlapping tails at the lowest **atomic_valley**.

The ICCER algorithm (processing 1 record)

Pre-processing (now processing the **smoothed_stack**)

- look for **sparse beams**: beams with a proportion of (masked + NaN) values > *max_nan_ratio*
- look for "**chaotic**" **beams**: beams with **low Pure Peaks Peakiness** : *PPP < 6.0 :*

  PPP = peakiness(*atomic_peaks*) = max(*atomic_peaks*) / sum(*all_other_peaks*)

  ***PPP* is maximum with a single peak on a smooth signal and decreases with noise and additional peaks**

- if **too many sparse or chaotic beams** (same threshold : *max_nan_ratio*) → **stop** (flag as failed)
- keep only the long enough **extended_atomic_peaks** (min_peak_rg_extent = 8 bins)
- build a **stack_map** from these **valid_extended_peaks**
- multi-look the **stack_map** → waveform of **beam_counts_per_range_gate**
- refine the boundaries (the selected group of range gates) of the **valid_extended_peaks** by thresholding the waveform of **beam_counts_per_range_gate** (*min_contrib_beams_ratio = 0.25 → 0.25*240 = 60 beams*)

The ICCER algorithm (processing 1 record)

Isolate (now processing the initial **product_stack**)

- For each refined contiguous group of range gates (**valid_extended_peaks** == retracking candidate peak)
  - identify the **beams** that fully cover this group of bins in the initial **product_stack**
  - build 1 clean Pseudo-Stack per « group of range gates » with these contributions only

Cleanse

- multi-look the clean **Pseudo-Stack** → clean **Pseudo-WFs** (PWFs)
- sort the PWFs by **decreasing power**
- select up to **Mfinal** PWFs (**Mfinal=1** peak in SAR mode)

Retrack

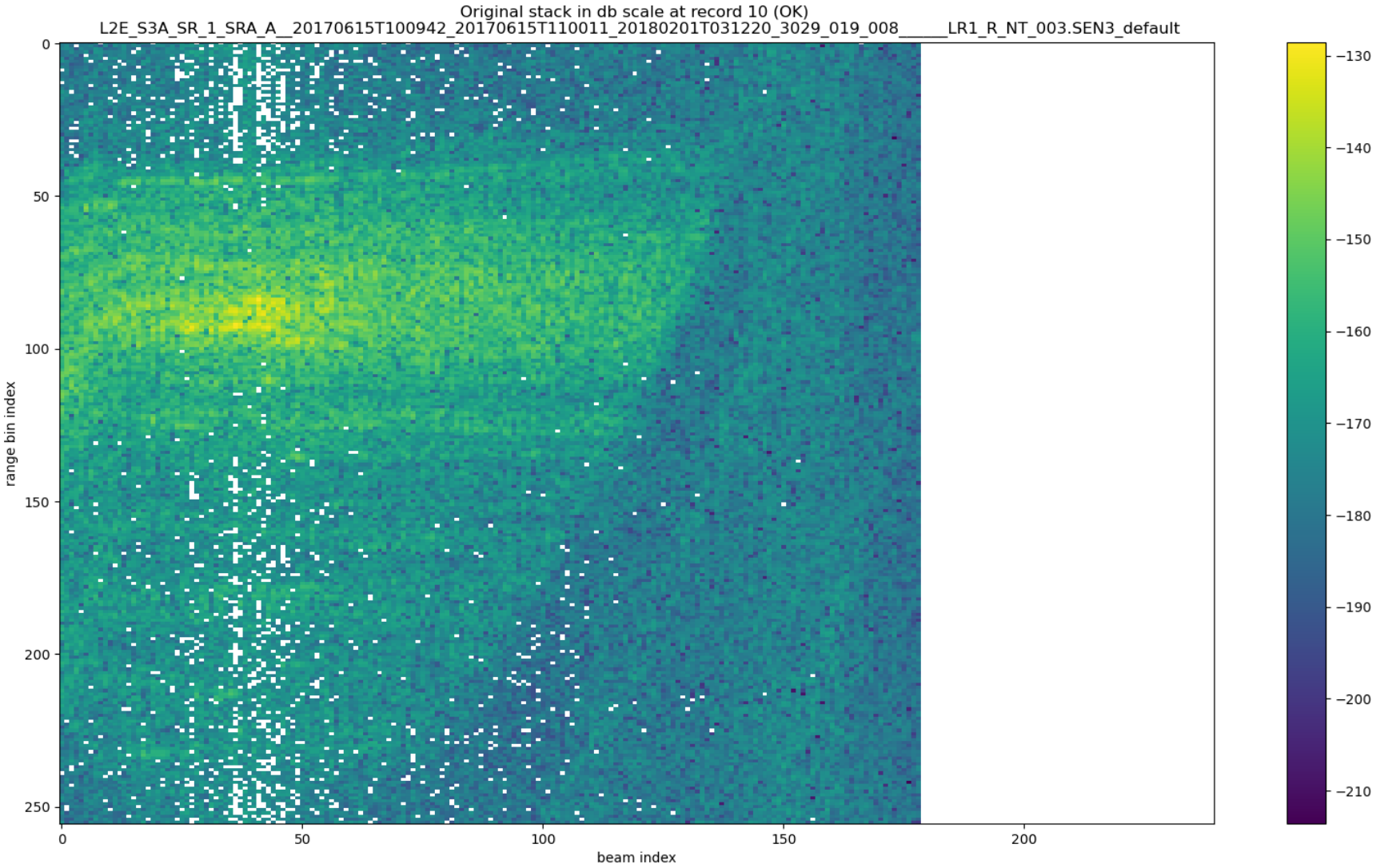
- apply a simple **thresholding** with the ICE-1 threshold → get **retracked point**(s) → get **retracked epoch**(s)

Step by step illustration with Sentinel-3 over the Rhine

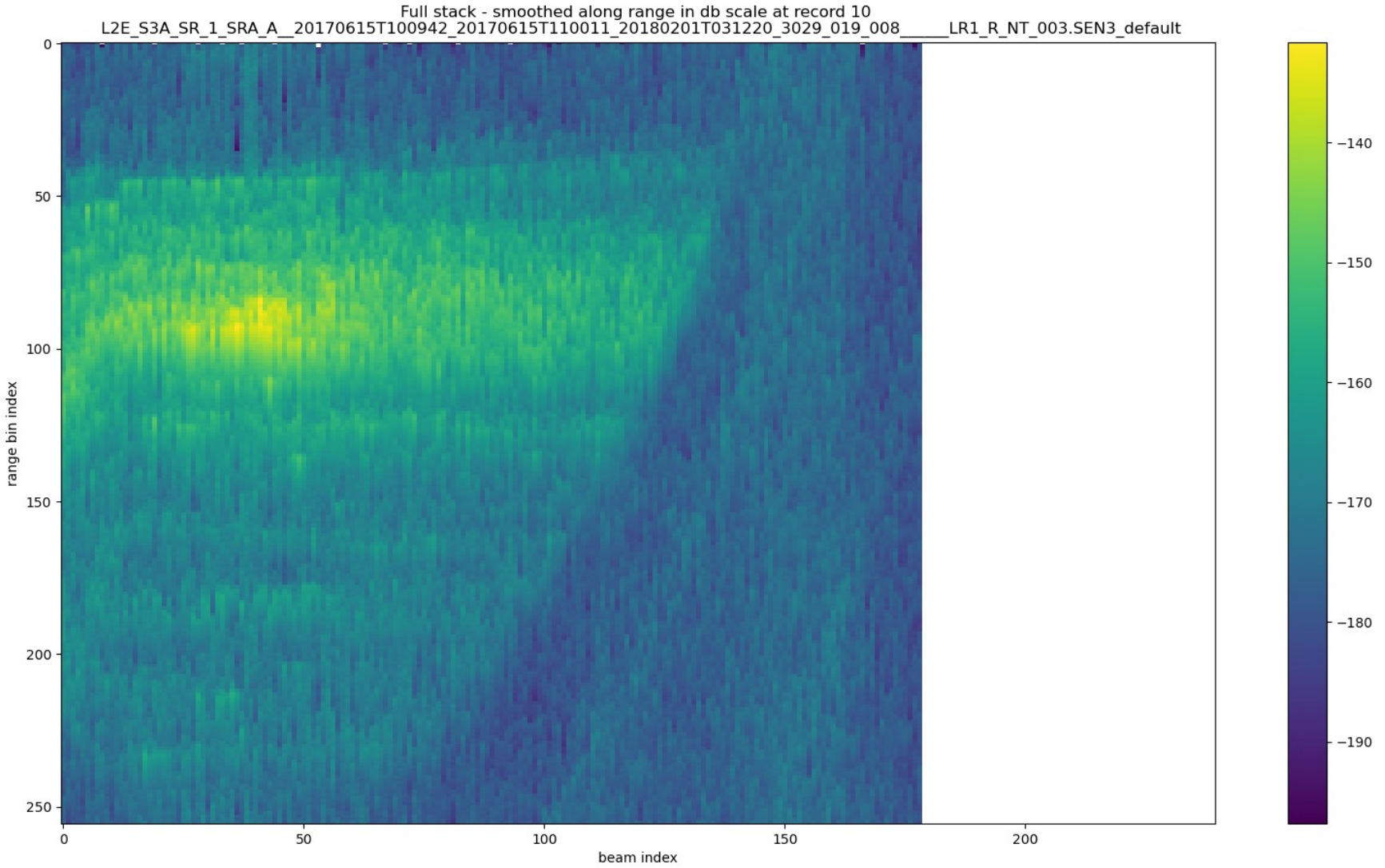
File : L2E_S3A_SR_1_SRA_A__20170615T100942_20170615T110011_20180201T031220_3029_019_008_____LR1_R_NT_003.SEN3

Record : 10

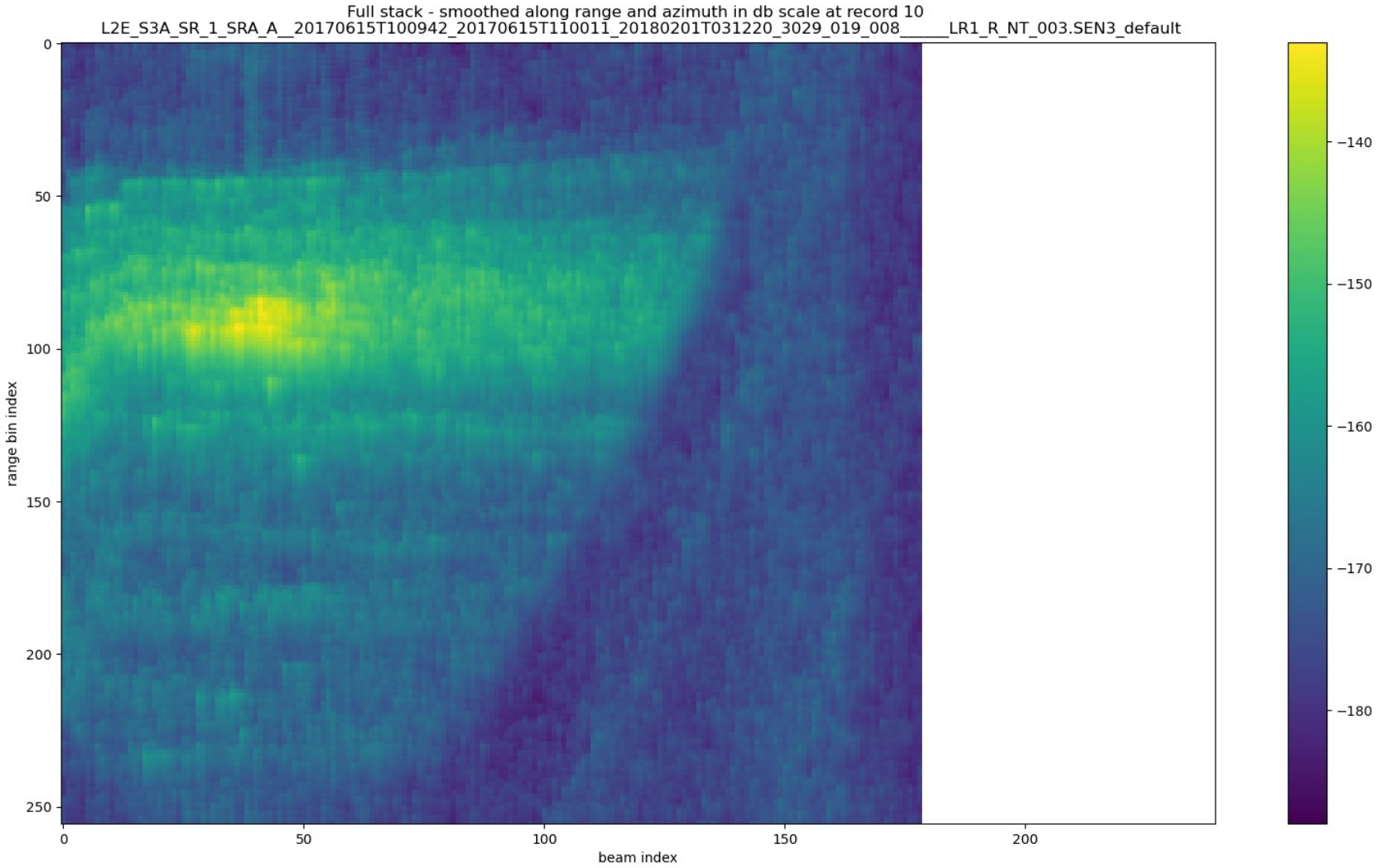
Initial Stack



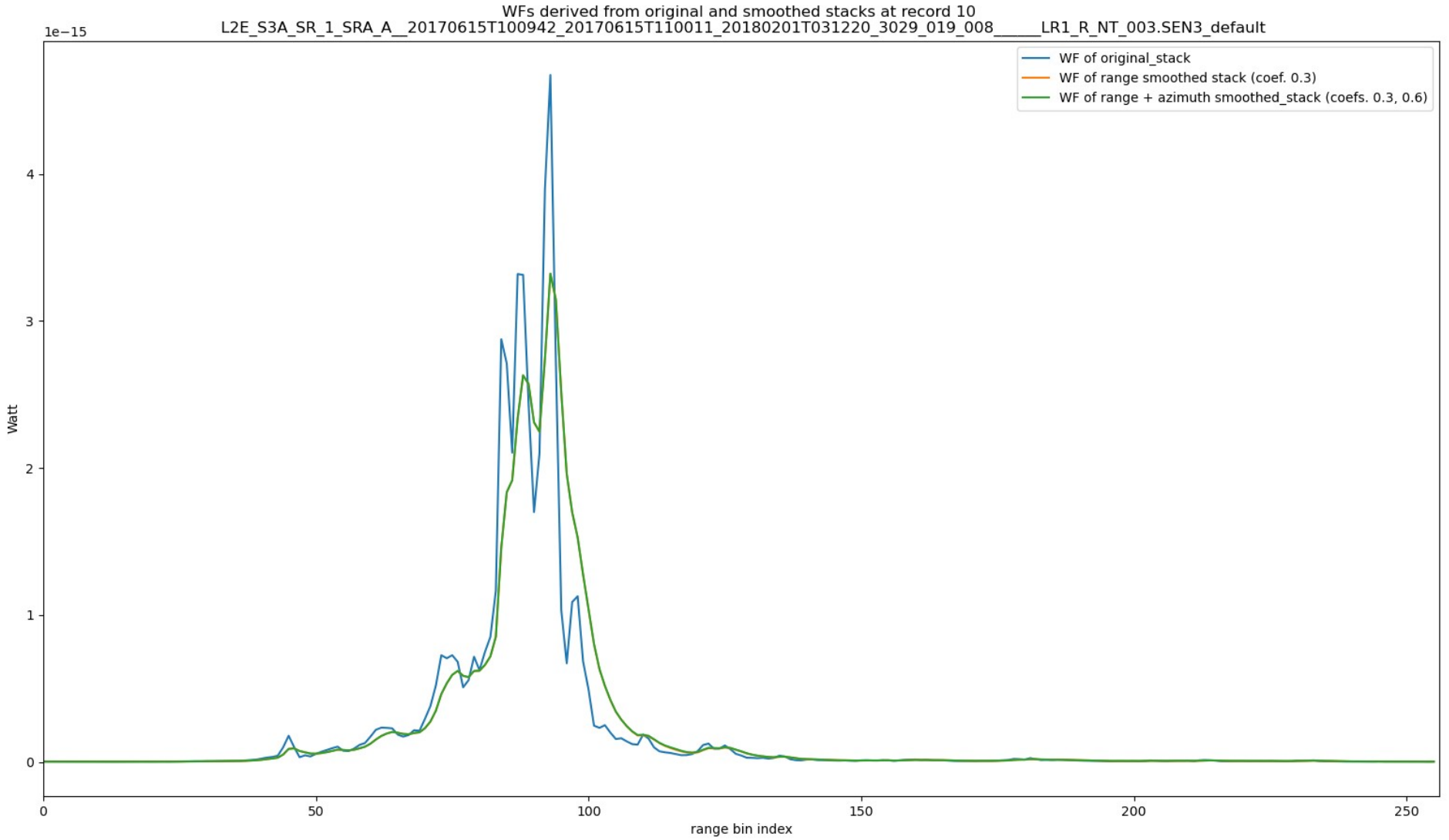
Range smoothed Stack



Range + Azimuth smoothed Stack



Original Product WF (blue) &
WFs from the smoothed stacks (orange, green)



2 missing figures for :

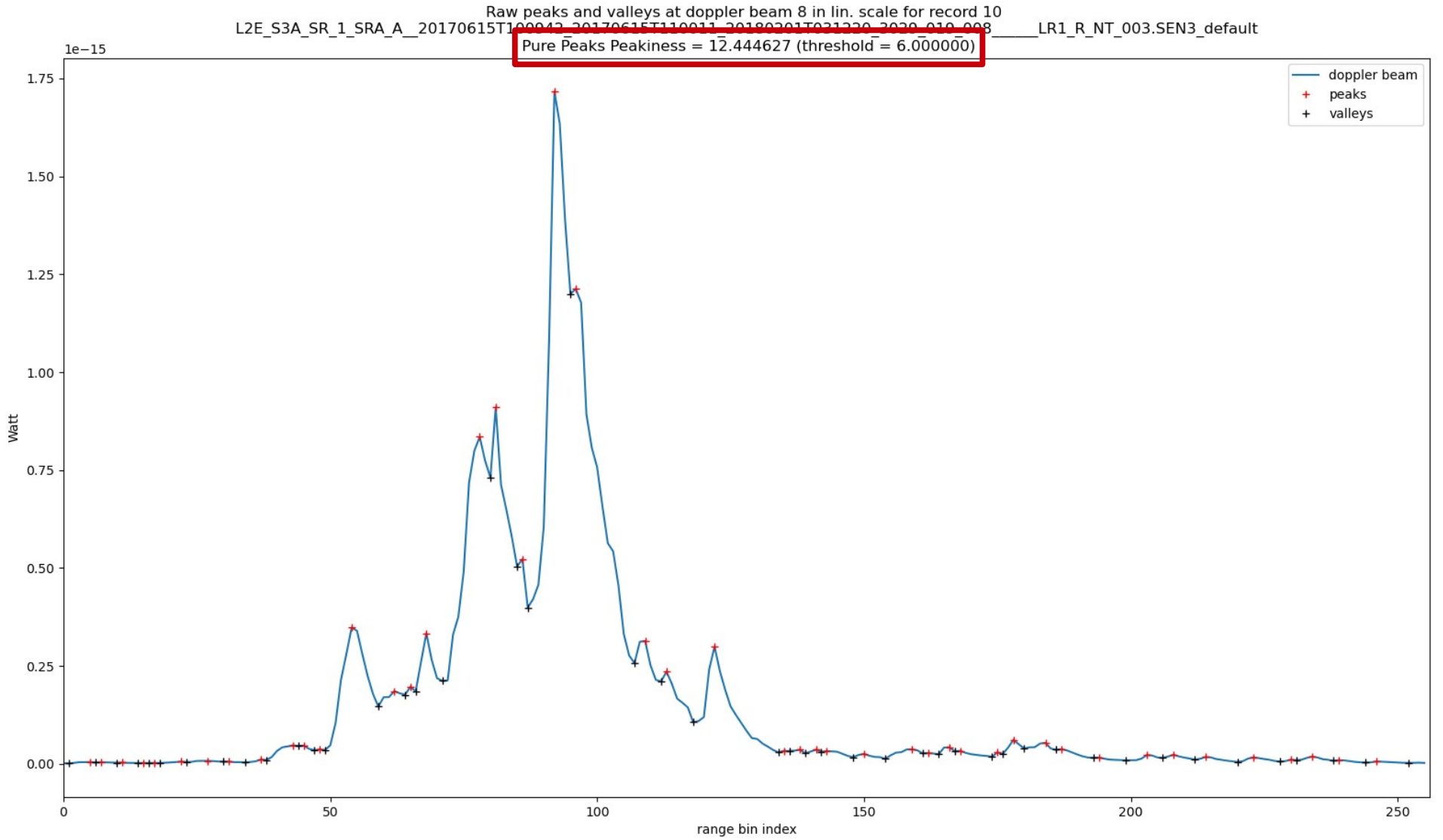
- **atomic peaks** & **atomic_valleys** of the **smoothed_waveform**

- **extended_atomic_peak**(s) of the **smoothed_waveform**
  → provides the pre-selected groups of bins for the future stack map of valid_extended_peaks

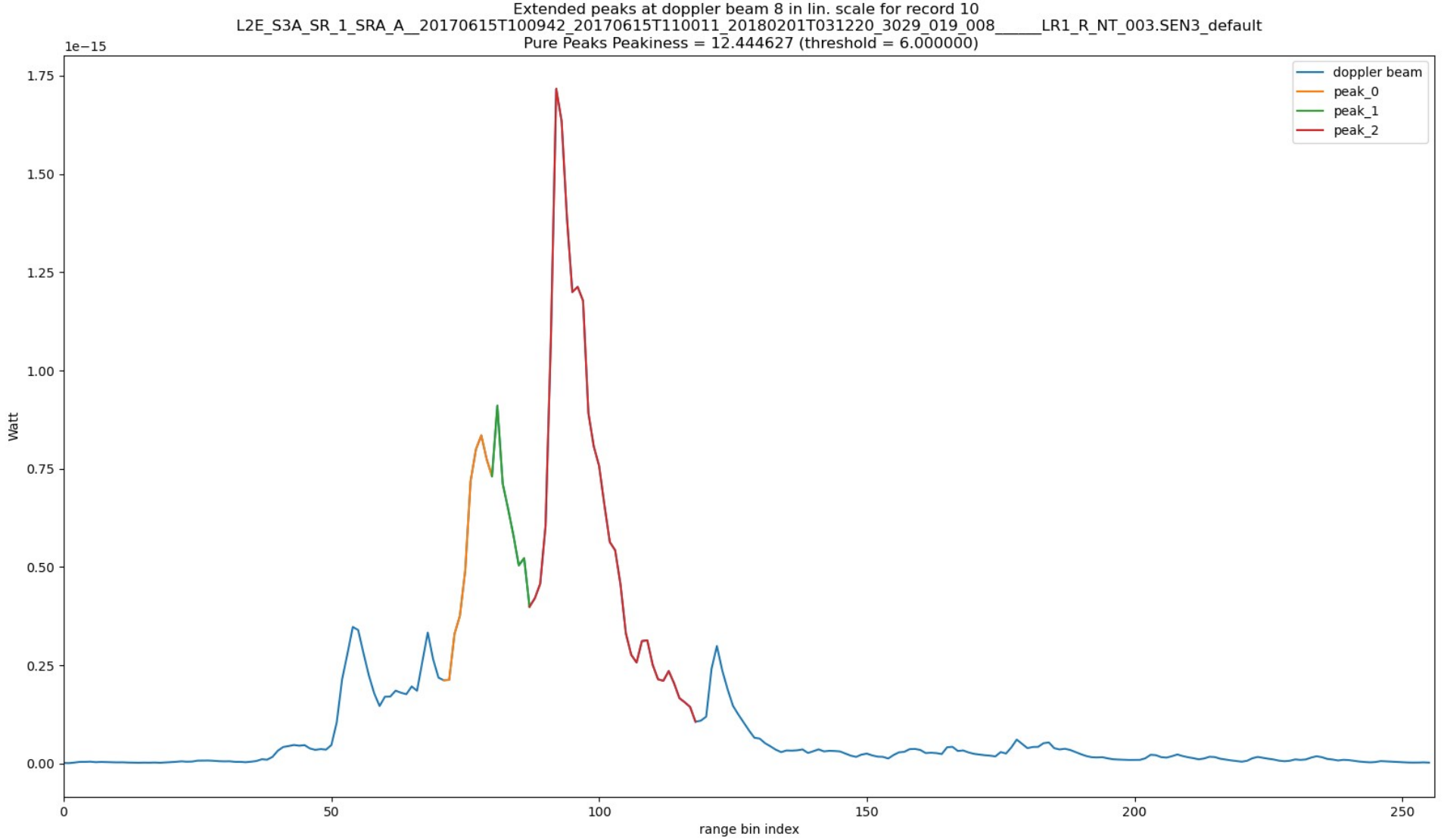
But, in fact, these limits are shown later on the WF of beam counts

Record 10, Beam 8

atomic_peaks & atomic_valleys
on beam 8 of the smoothed stack

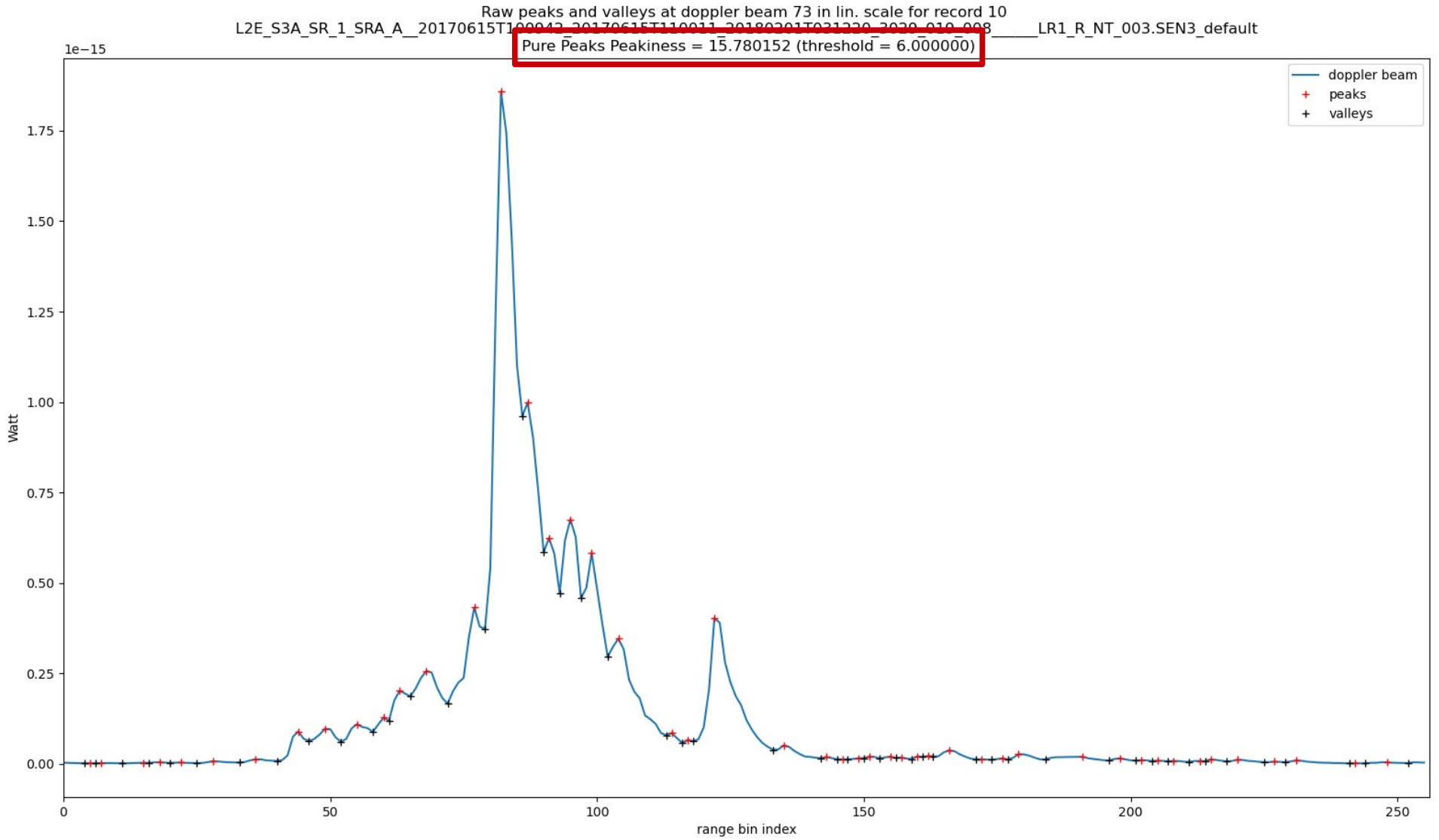


extended_atomic_peaks
on beam 8 of the smoothed stack

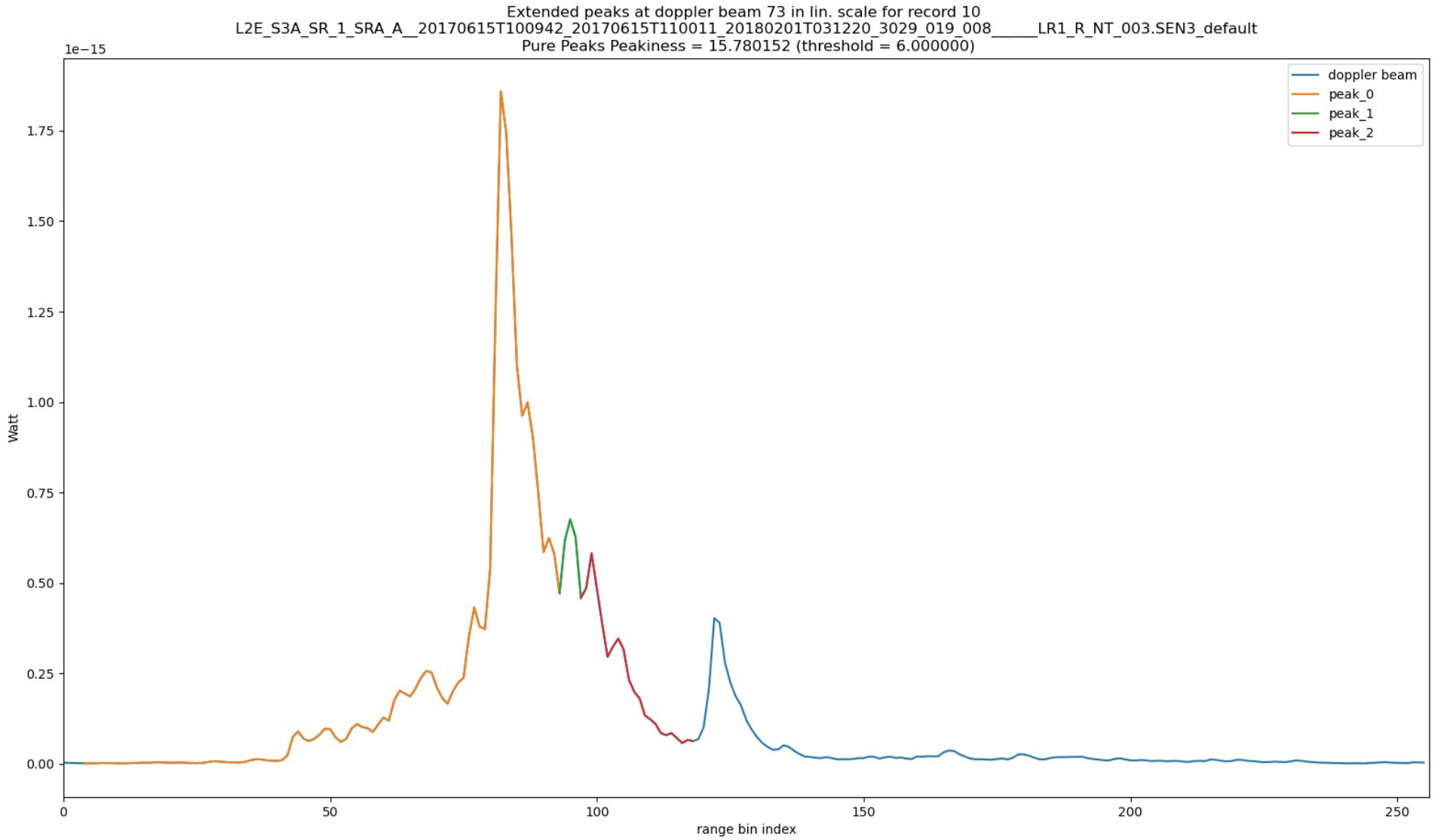


Record 10, Beam 73

atomic_peaks & atomic_valleys
on beam 73 of the smoothed stack

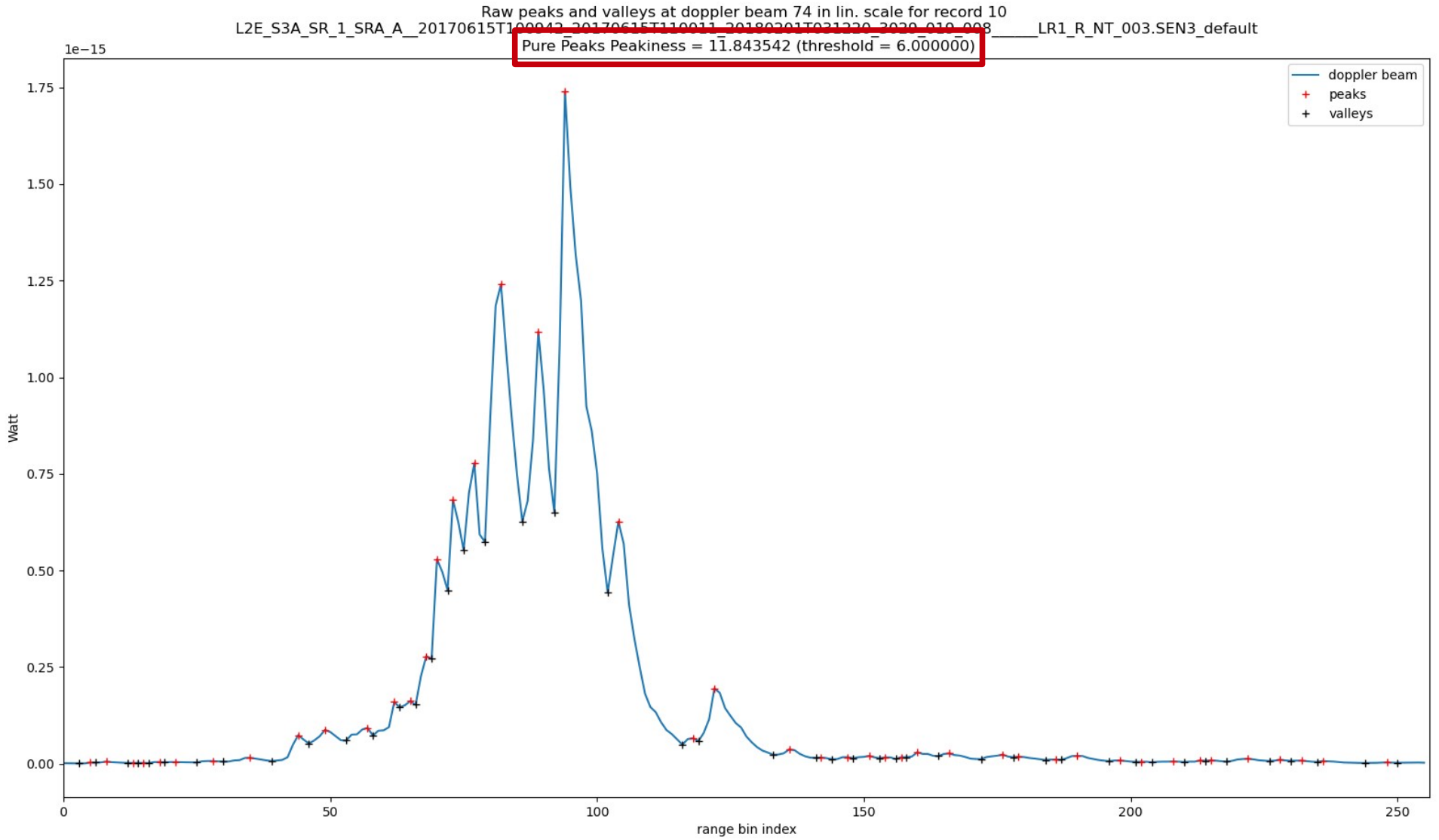


extended_atomic_peaks
on beam 73 of the smoothed stack

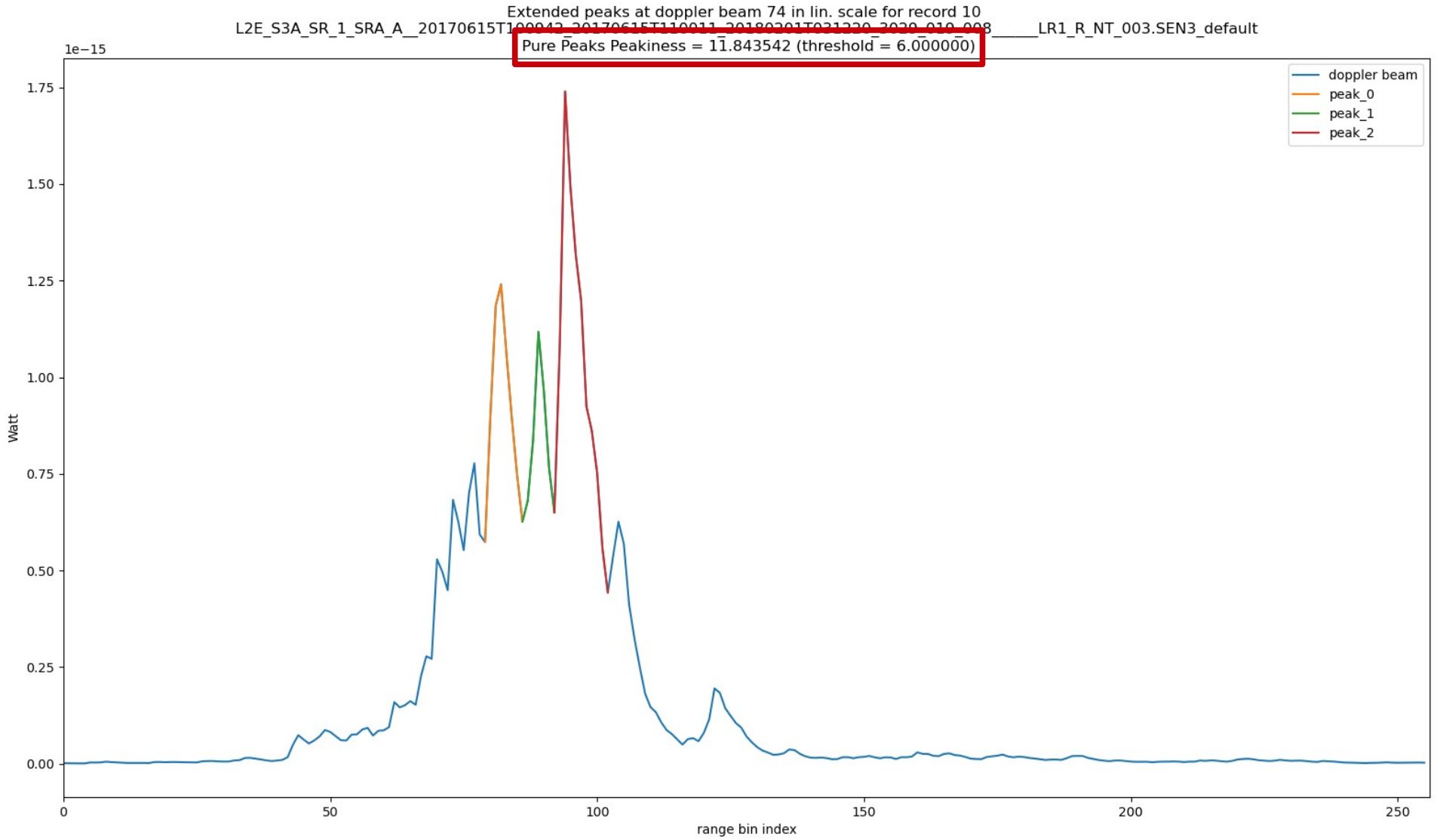


Record 10, Beam 74

atomic_peaks & atomic_valleys
on beam 74 of the smoothed stack

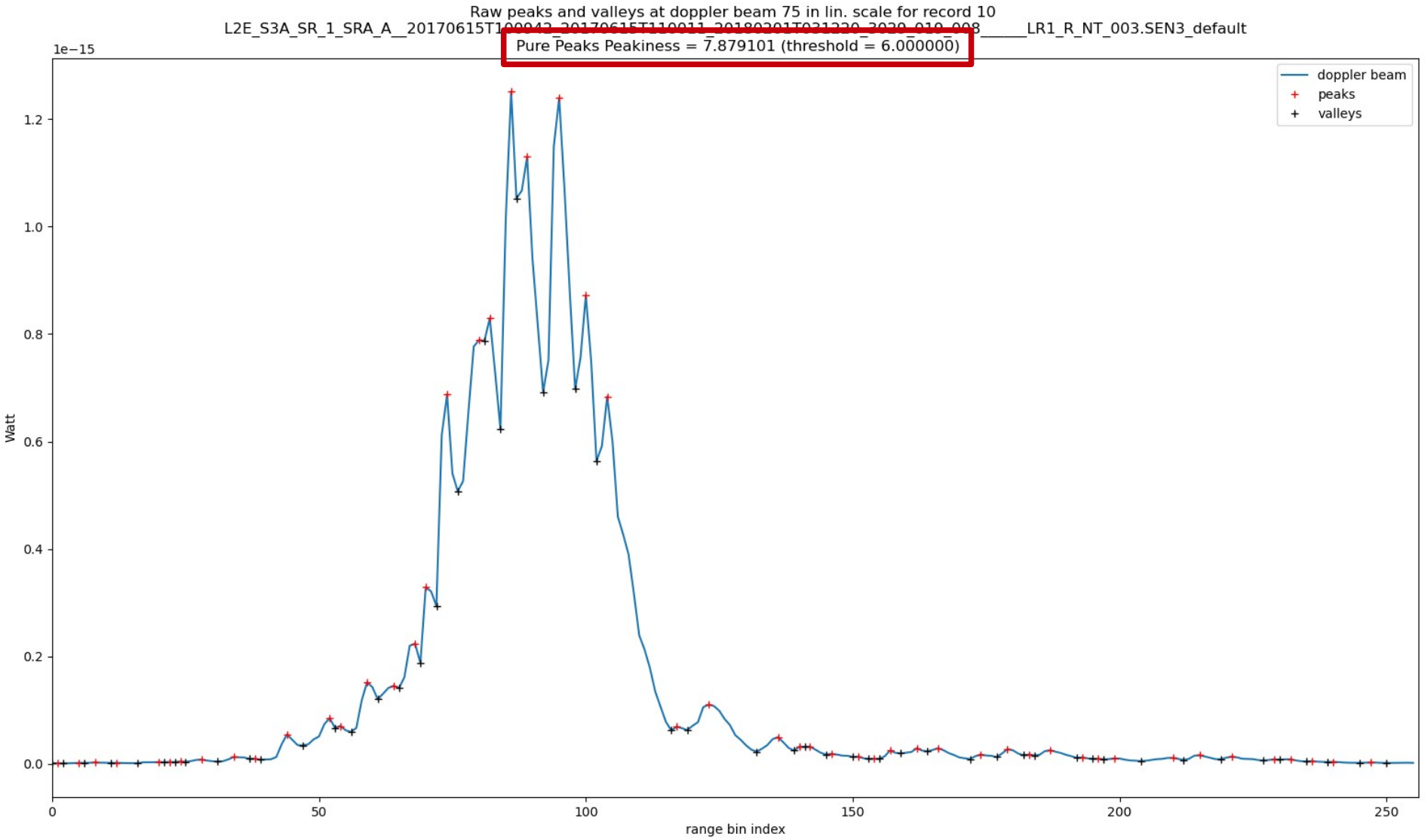


extended_atomic_peaks
on beam 74 of the smoothed stack

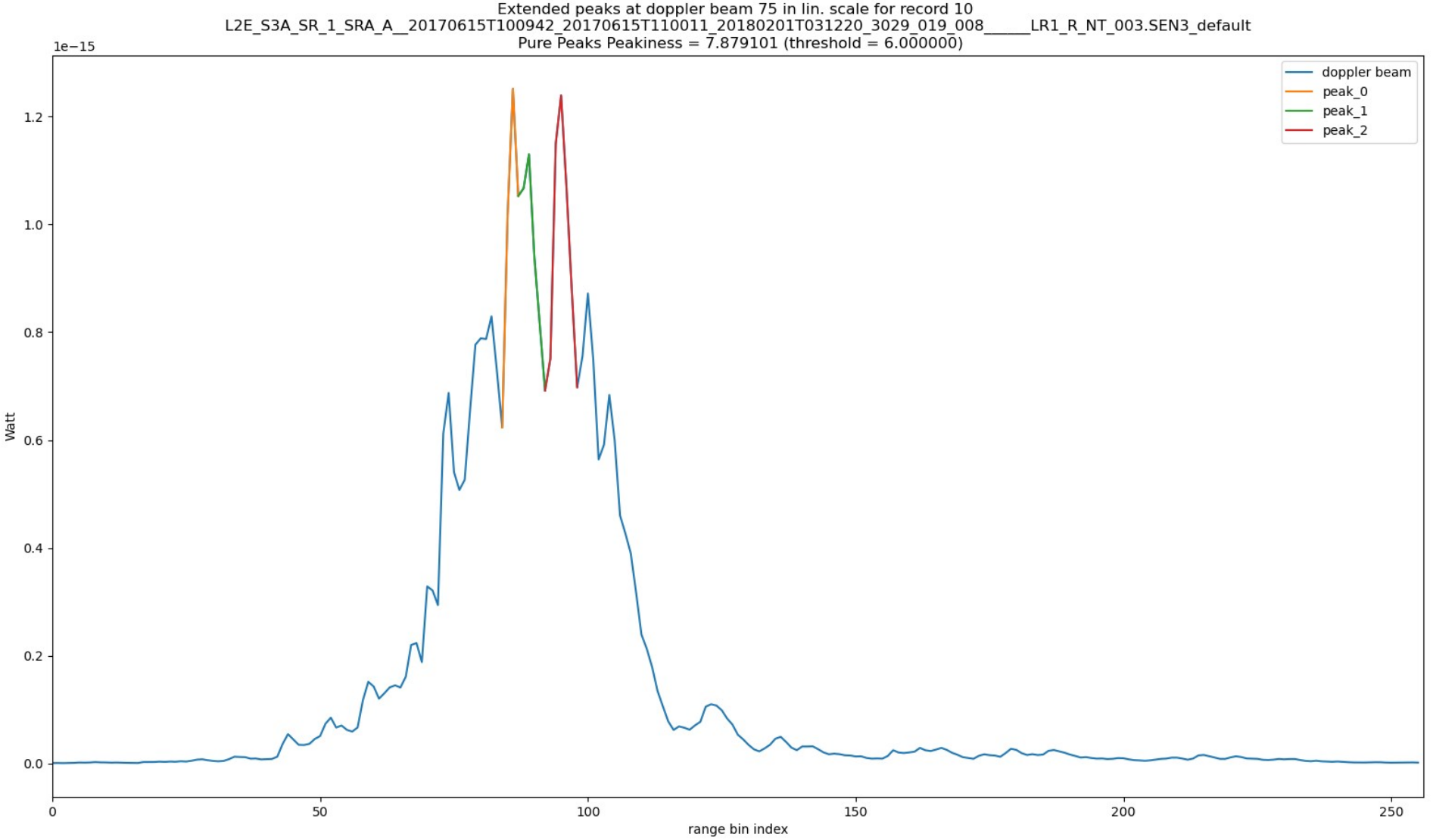


Record 10, Beam 75

atomic_peaks & atomic_valleys
on beam 75 of the smoothed stack

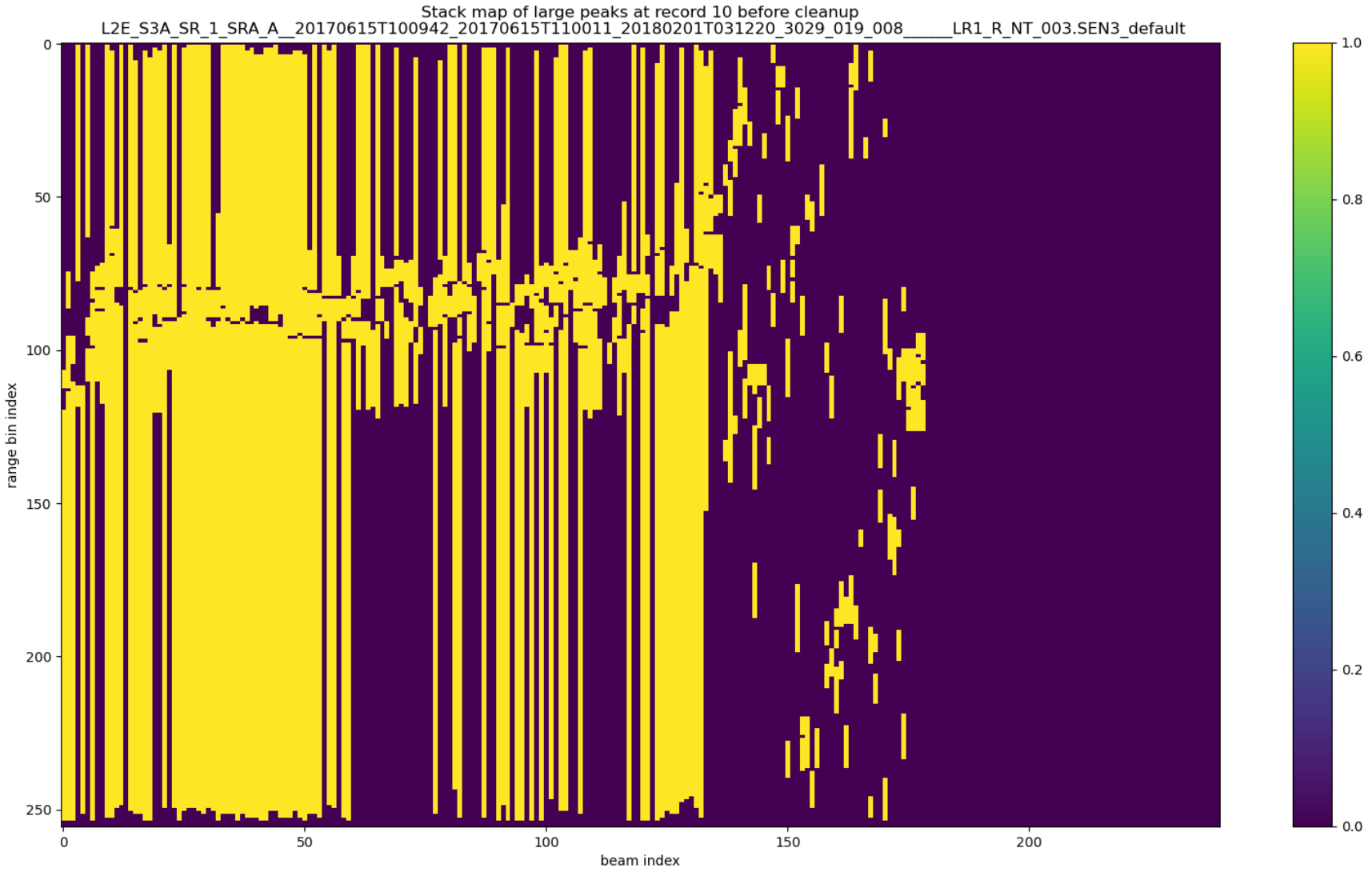


extended_atomic_peaks
on beam 75 of the smoothed stack

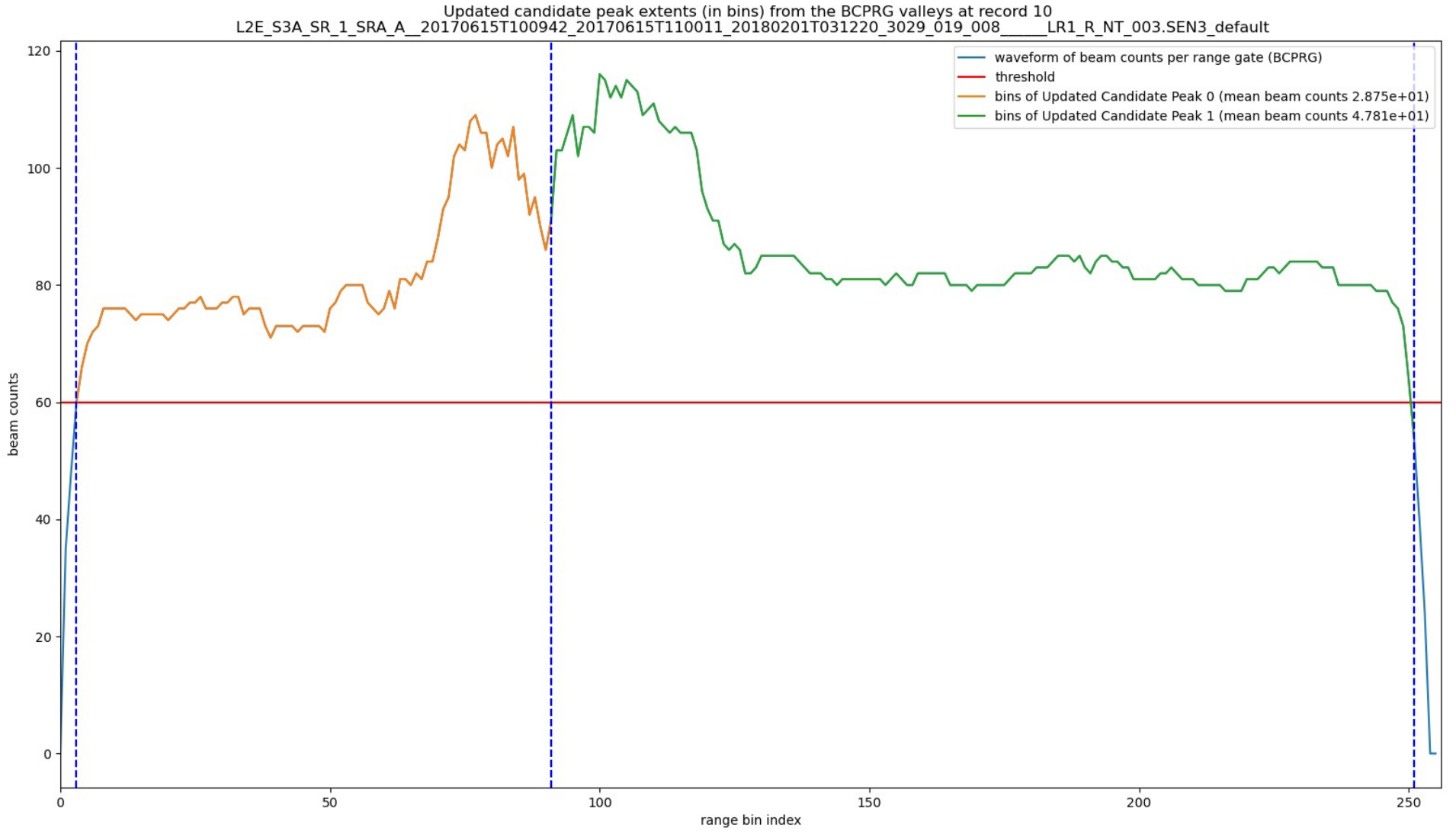


Stack Map of valid_extended_peaks
(all beams of record 10)

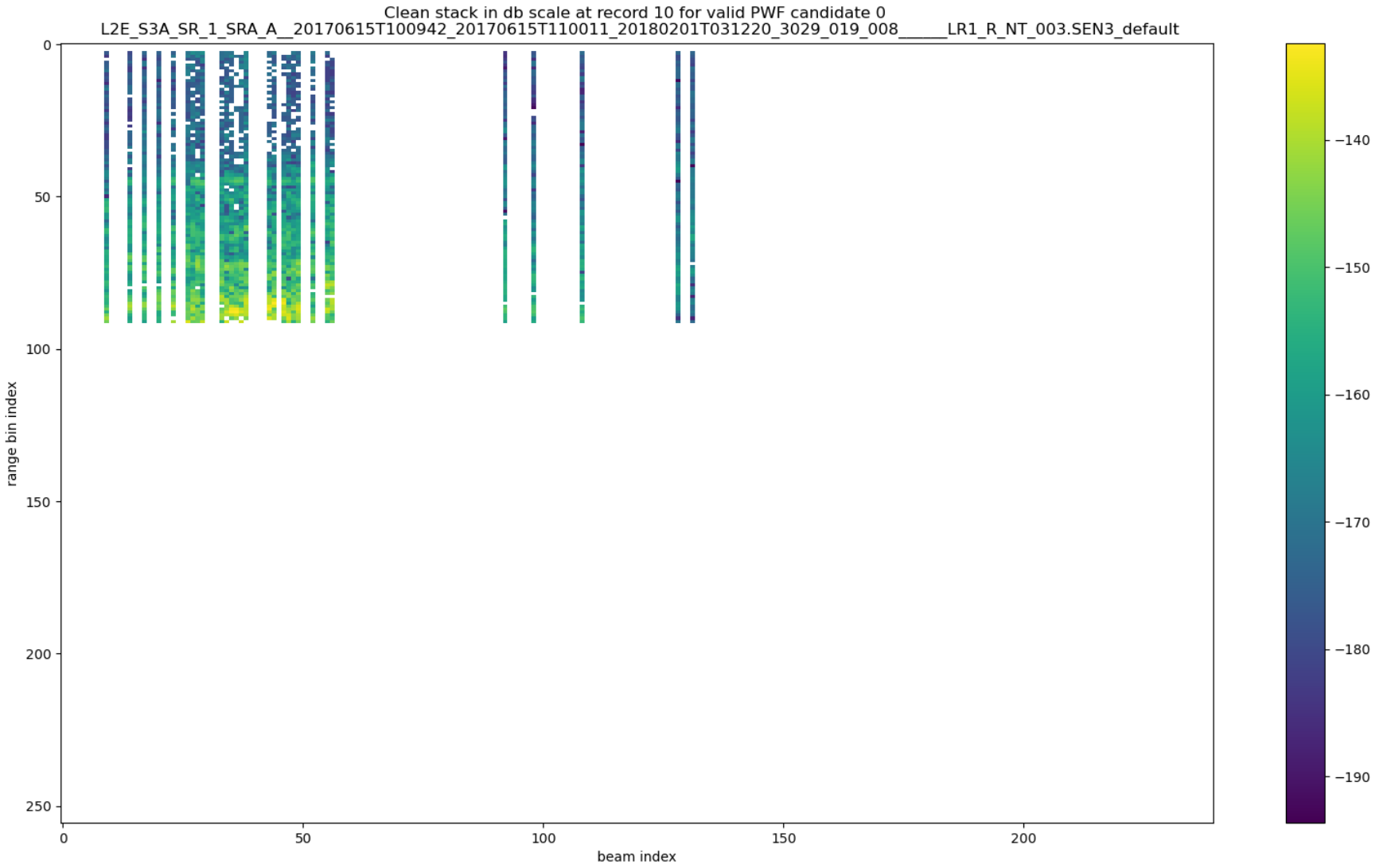
Stack Map of valid_extended_peaks
(all beams of record 10)



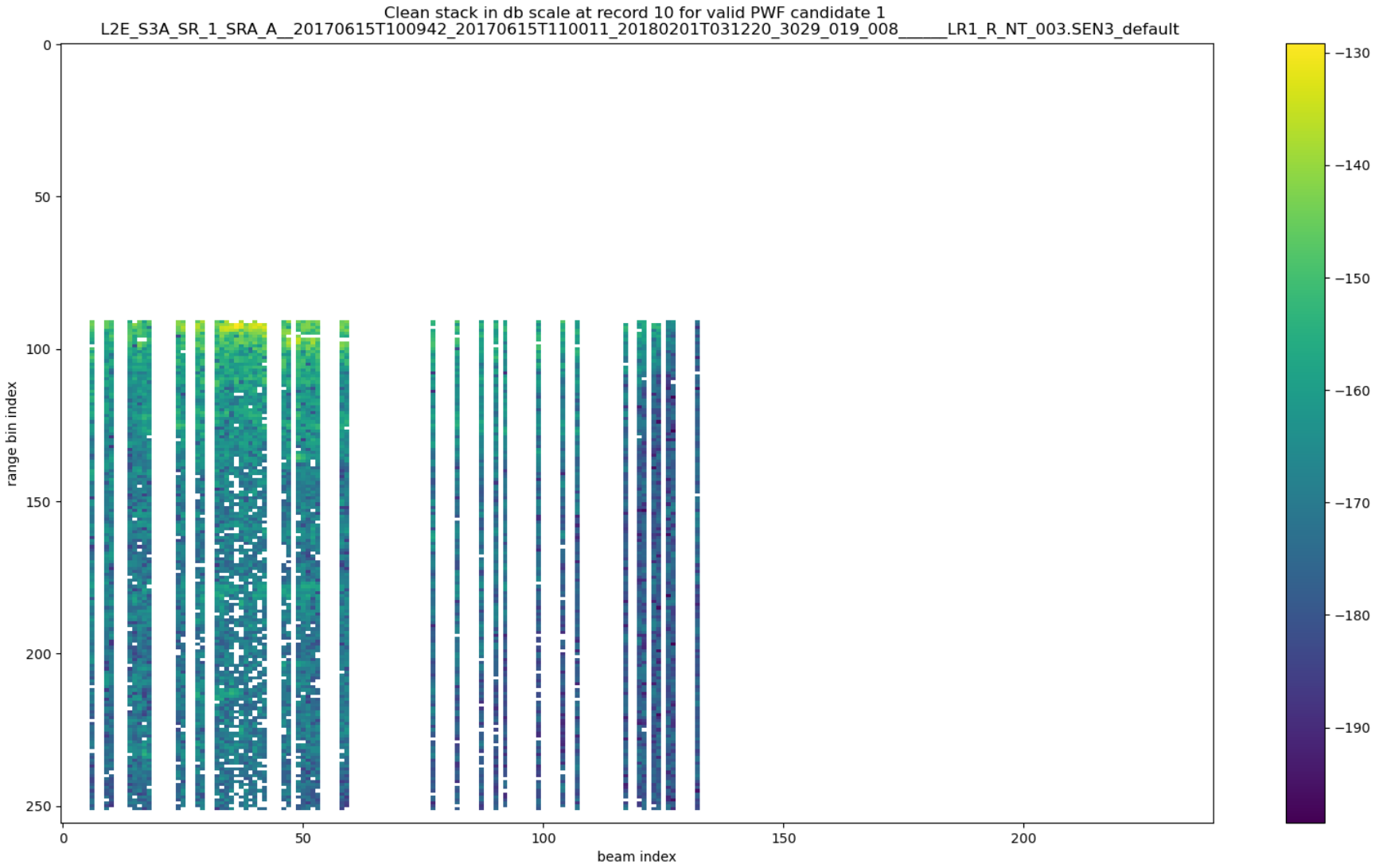
WF of Beam Count Per Range Gate
(Multi-looked Stack Map at record 10)



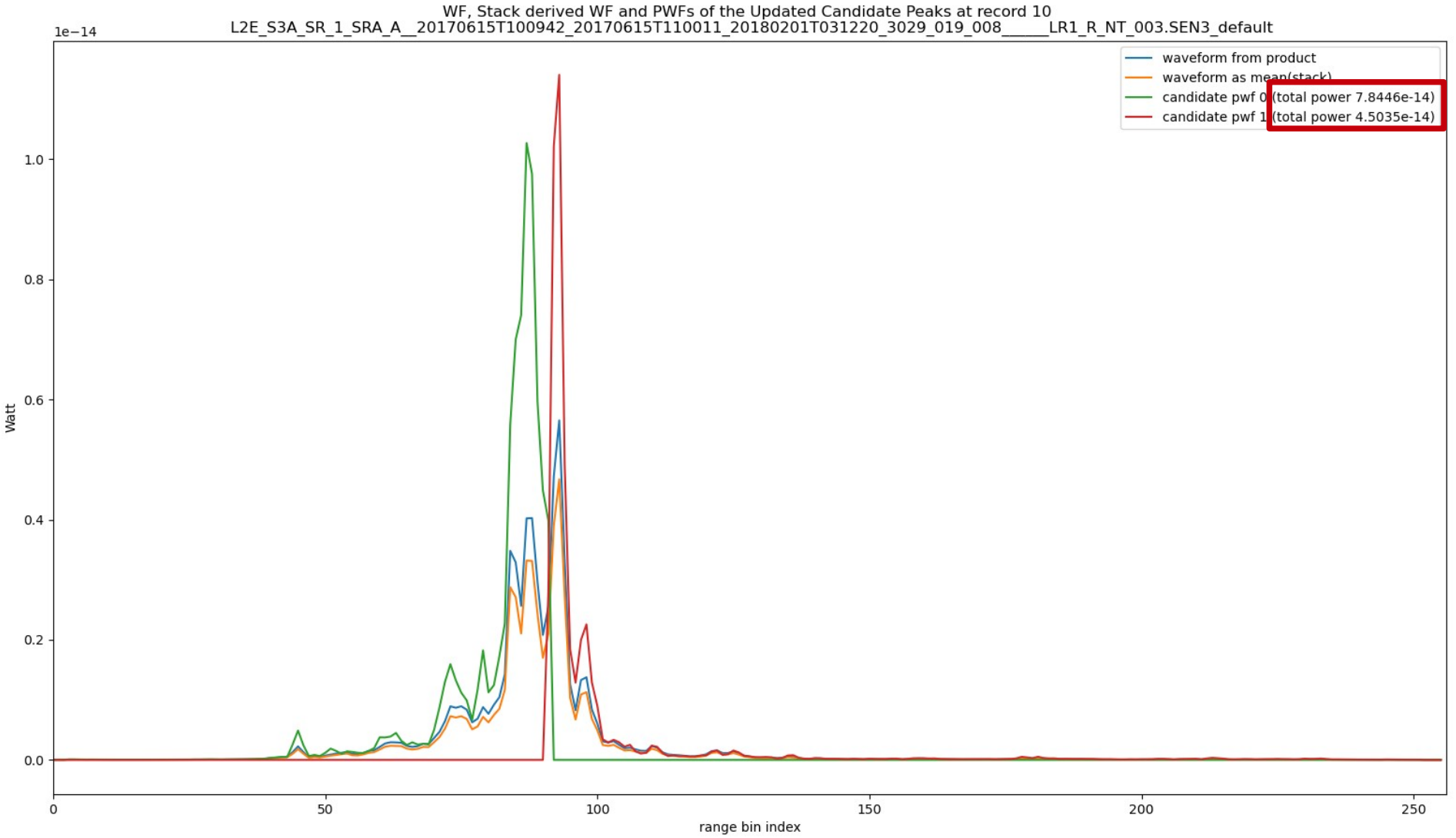
Clean Pseudo-Stack
for Final PWF candidate 0 @ record 10



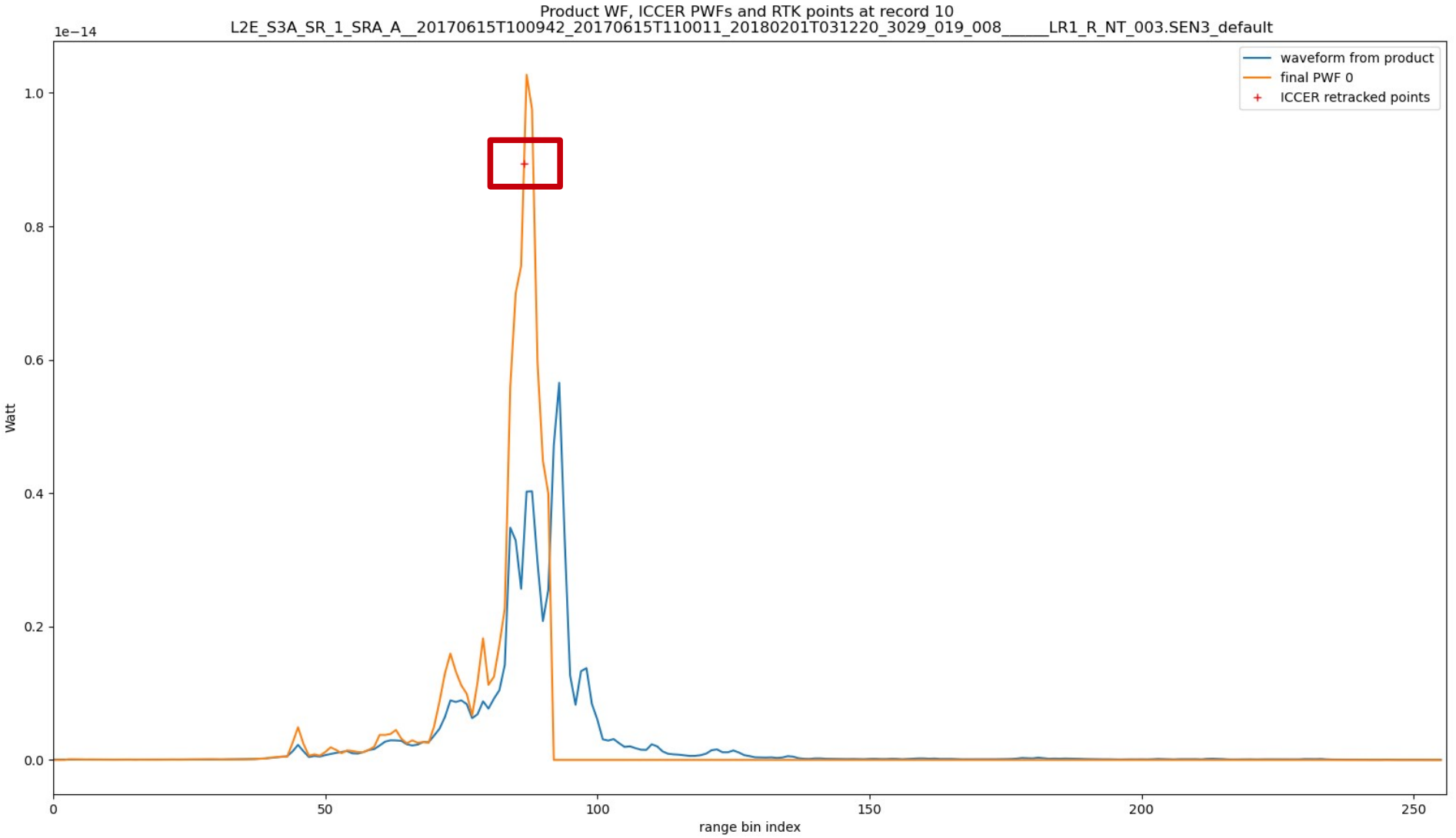
Clean Pseudo-Stack
for Final PWF candidate 1 @ record 10



Candidate PWFs at record 10
PWF 0 (green) and PWF 1 (red)



Original Product WF & Retracked PWF for record 10



Range Chronogram with Applicable Hydrocoastal Retrackers

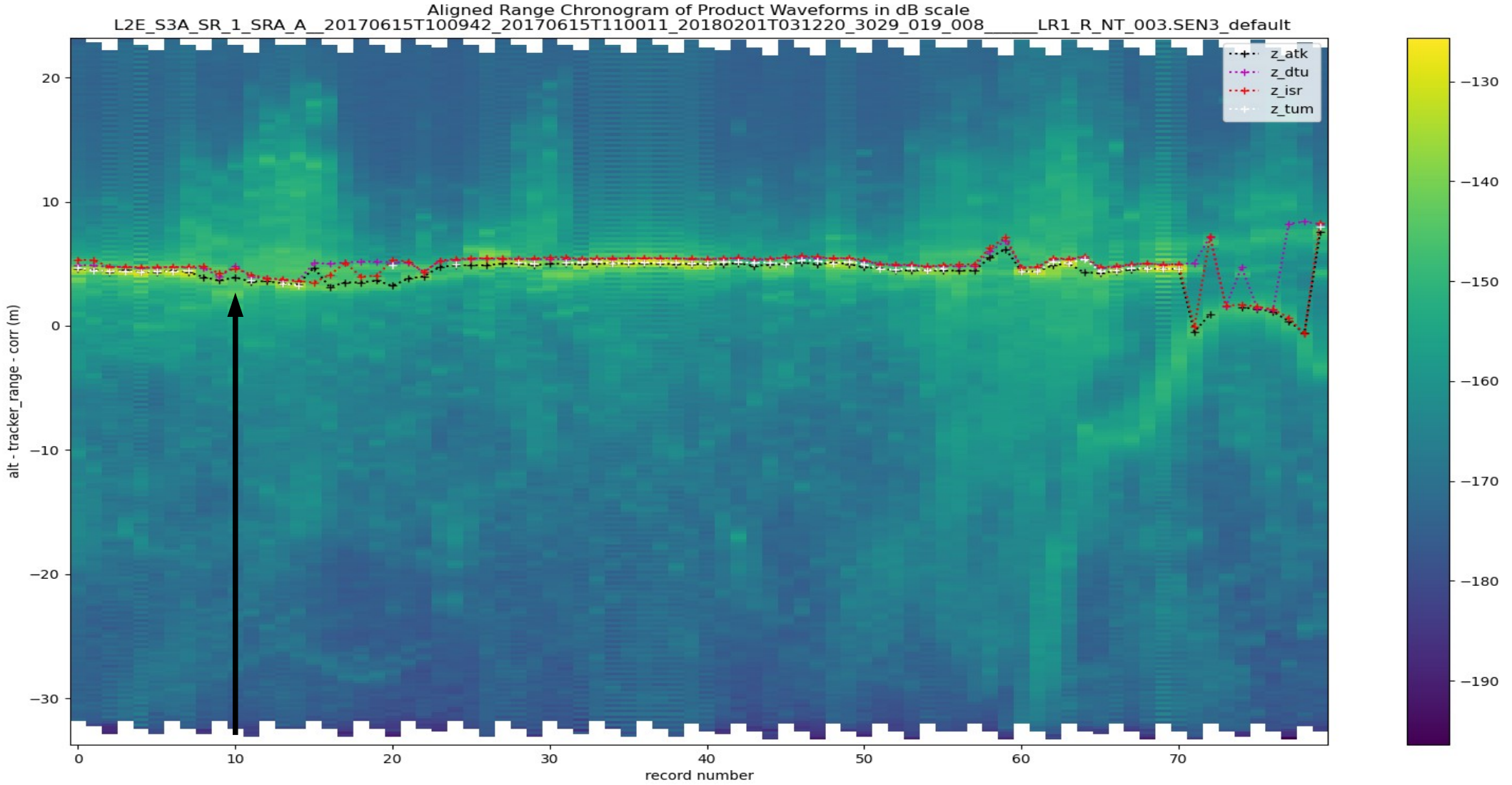
Retracked Range edited with the RTK self flags keeping only successful retracker outputs :

- ICCER: records with 'flags_atk' in [0, 1]
- DTU: records with 'flags_dtu' == 1
- IsardSAT: records with 'flags_isr' in [1, 2, 3, 4]
- TUM: records with 'flags_tum' == 0
- *BONN: not applicable over inland water*

Water Elevation computation: z_RTK = alt - retracked_range_RTK - range_corr_land

RCG aligned with the corrected Tracker Range: z_tracker_land = alt - tracker_range - range_corr_land

Corrections :
range_corr_land = GIM_iono + dry_tropo_UPT + wet_tropo_UPT + corr_solid_earth_tide + corr_polar_tide + geoid


Aligned Range Chronogram of Product Waveforms in dB scale
L2E_S3A_SR_1_SRA_A__20170615T100942_20170615T110011_20180201T031220_3029_019_008_____LR1_R_NT_003.SEN3_default
z_atk
z_dtu
z_isr
z_tum
alt - tracker_range - corr (m)
record number
20
10
0
−10
−20
−30
0
10
20
30
40
50
60
70
−130
−140
−150
−160
−170
−180
−190

More results ...

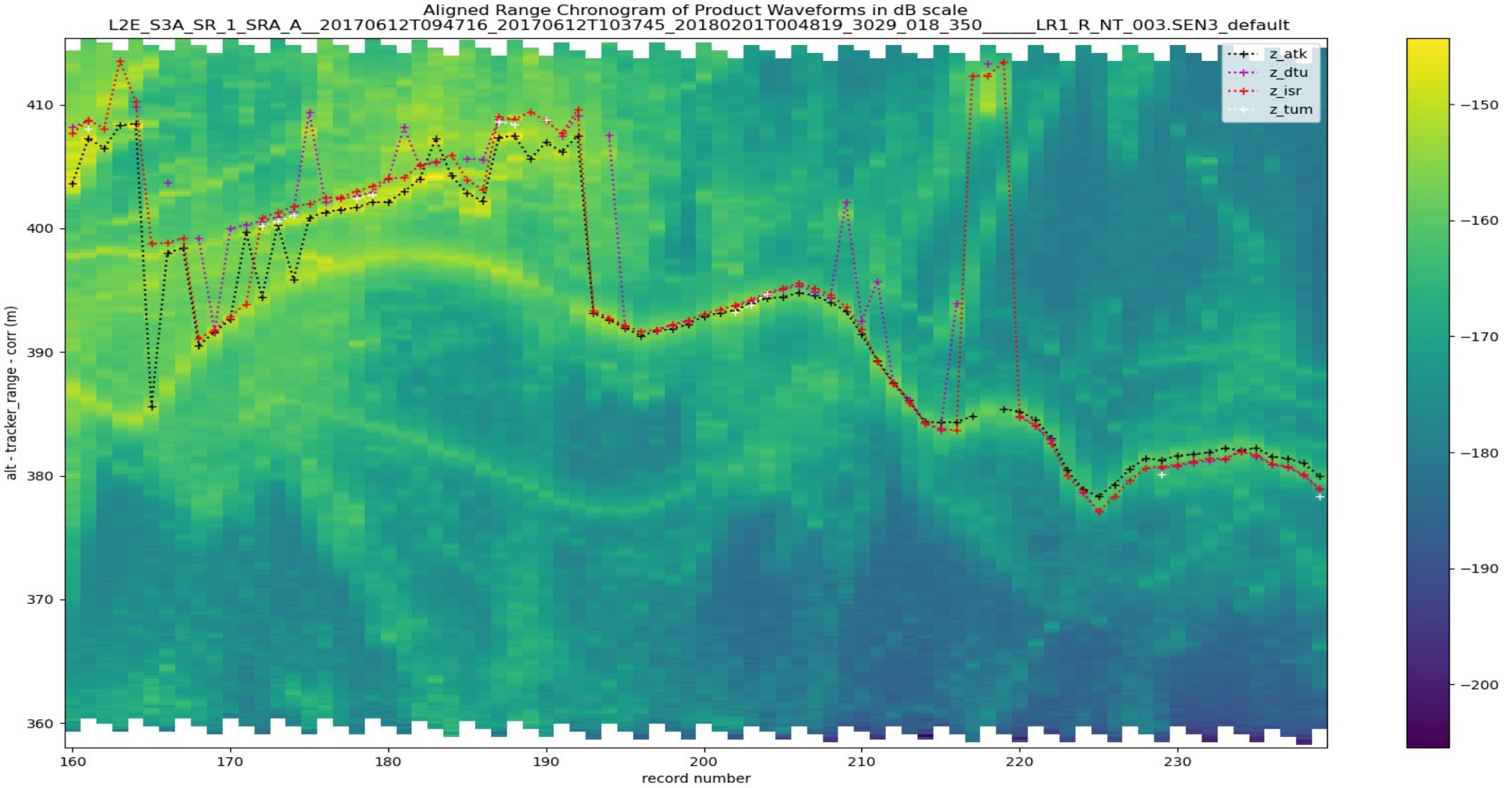
File : L2E_S3A_SR_1_SRA_A__20170612T094716_20170612T103745_20180201T004819_3029_018_350_____LR1_R_NT_003.SEN3

Range Chronogram over records 160 to 240

The ICCER retracker seems to be **able to follow a river leg that would slowly depart from the near nadir** :

NOT good for SAR mode ? But the other retrackers are also impacted !

But good for SARIN mode (the original aim of the design) … and the SARIN version is multi-peaks
=> will permit to follow multiple river legs with the same records.


Aligned Range Chronogram of Product Waveforms in dB scale
L2E_S3A_SR_1_SRA_A__20170612T094716_20170612T103745_20180201T004819_3029_018_350_____LR1_R_NT_003.SEN3_default
z_atk
z_dtu
z_isr
z_tum
alt - tracker_range - corr (m)
record number
410
400
390
380
370
360
160
170
180
190
200
210
220
230
−150
−160
−170
−180
−190
−200

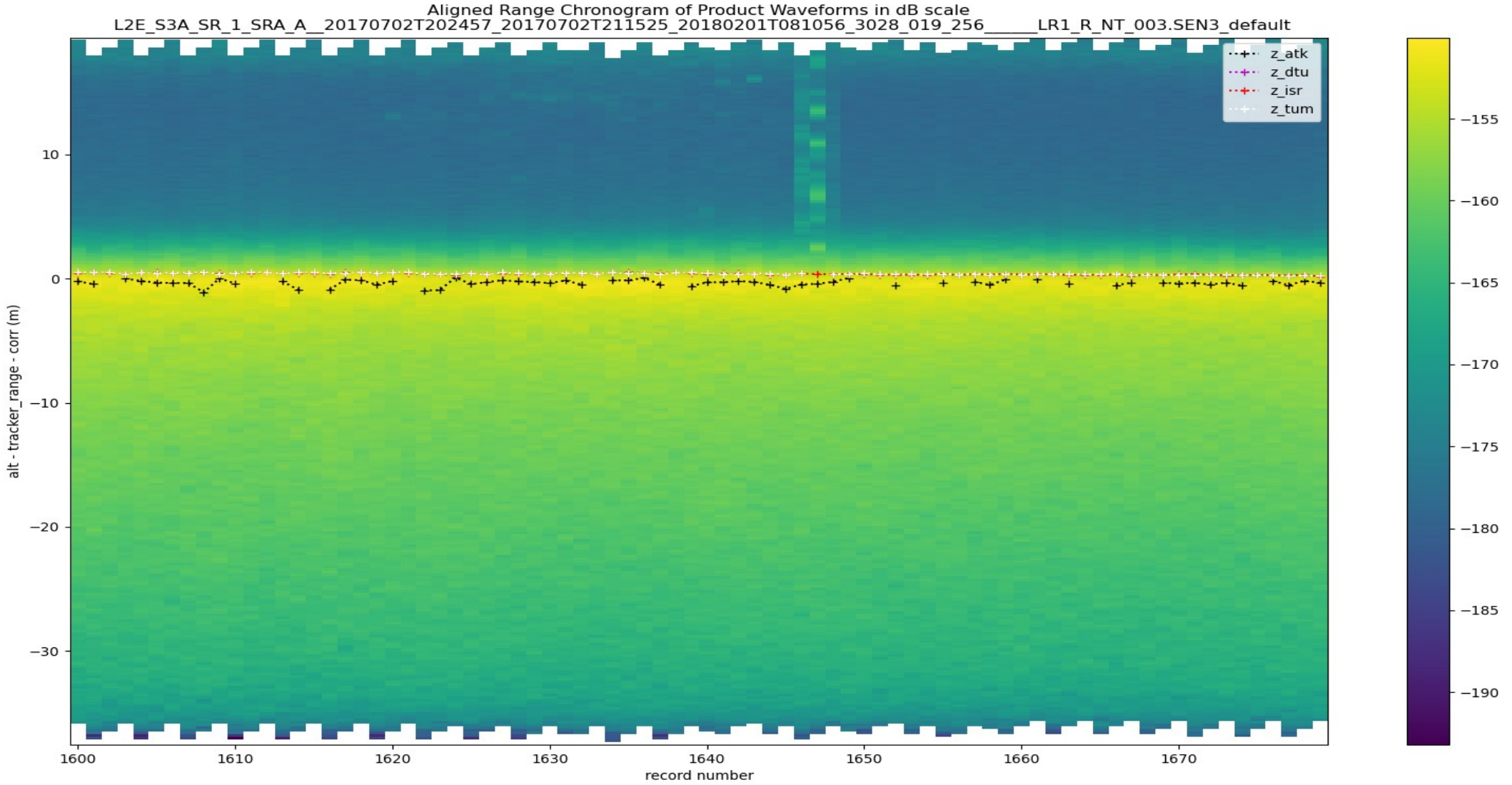
What about ocean-like echoes ?

File : L2E_S3A_SR_1_SRA_A__20170702T202457_20170702T211525_20180201T081056_3028_019_256_____LR1_R_NT_003.SEN3

Range Chronogram over records: 1600 to 1680.

NEXT SLIDE : ICCER is clearly not as good as other HYDROCOASTAL retrackers **on ocean-like Stacks / WFs** !

but **the initial aim of the design is to retrack non homogenous surfaces !**


Aligned Range Chronogram of Product Waveforms in dB scale
L2E_S3A_SR_1_SRA_A__20170702T202457_20170702T211525_20180201T081056_3028_019_256_____LR1_R_NT_003.SEN3_default
z_atk
z_dtu
z_isr
z_tum
alt - tracker_range - corr (m)
10
0
−10
−20
−30
1600
1610
1620
1630
1640
1650
1660
1670
record number
−155
−160
−165
−170
−175
−180
−185
−190

Conclusions

Thanks to the HYDROCOASTAL project (and internal funds) it has been possible to :

- Test the benefits of selective multi-looking of the stack over inland water surfaces:
  - Improved (cleaner) Pseudo-WF compared to product WFs,
  - ICCER is quite stable performance (from visual check) including with « degraded » Stacks / WF,
  - ICCER is closer to the main energy peak than other retrackers,
  - Overall ICCER compares well with the other retrackers,
  - ICCER is able to follow river legs that slowly or abruptly depart from nadir (as IsardSAT and DTU retrackers)
  - Pure Peaks Peakiness is a helpful criterion to detect chaotic echoes.
- But also observe degraded performance on ocean like echoes

Perspectives

- Improve the parameter settings (a wide variety of combinations as the parameters ar inter-dependent)
- Replace the “complex” Pre-processing step by a more elegant method (from Signal Processing point of view) : possible use of the Beams Correlation Matrix to detect persistent contributions over the whole Stack,
- Check why In some easy cases, ICCER fails (is blurred by other peaks)
- ICCER seems to be a good candidate for SRAIN mode

THANK YOU

HYDROCOASTAL Expected Outcomes

The outcomes of the HYDROCOASTAL will include:

State of the art review of SAR Radar Altimetry and current challenges.

Initial SAR / SARin satellite altimeter L2, L3 and L4 Test data set over 18 Regions of Interest.

Full descriptions of **processing algorithms** and **output products**.

Global Output products:

A Global L2 coastal and inland water SAR altimeter data set.

Time series (L3) and river discharge (L4) data sets for medium to large rivers

A **Scientific Road Map** including recommendations for further developments, implementations and research for SAR altimetry

https://www.satoc.eu/projects/hydrocoastal