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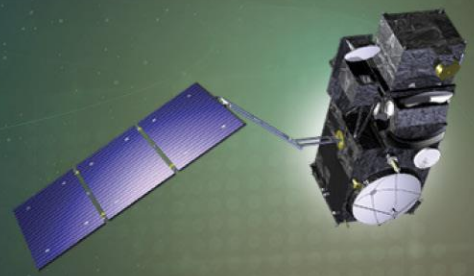

7th Sentinel-3 Validation Team Meeting 2022

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GPD+ wet tropospheric corrections for the Sentinel-3 SRAL/MWR B04 and B05 collections

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Scope

- Work performed under EUMETSAT Contract EUM/CO/21/4600002527/CLo Order 4500021007, in response to the EUMETSAT Request for Quotation RFQ 221050 S3 Altimetry GPD + Wet Tropospheric Correction

  (https://www.eumetsat.int/S3-altimetry-GPD-WTC)

- Contract previews several Phases:

➔ **Baseline Activity: Computation and assessment of the GPD+ WTC products for the Copernicus Sentinel-3A (S3A) and Sentinel-3B (S3B), from mission start until end of April 2021.**

➔ **Phase 1: Implementation and verification of the operational service for the provision of GPD+ WTC.**

➔ **Phase 2: Operational provision of the GPD+ to S3 NTC products - since August 2022.**

Outline

- Motivation
- Why GPD+ for Sentinel-3?
- GPD+ for Sentinel-3 Baseline Collection (BC) 004
- BC 005 versus BC 004
- Conclusions

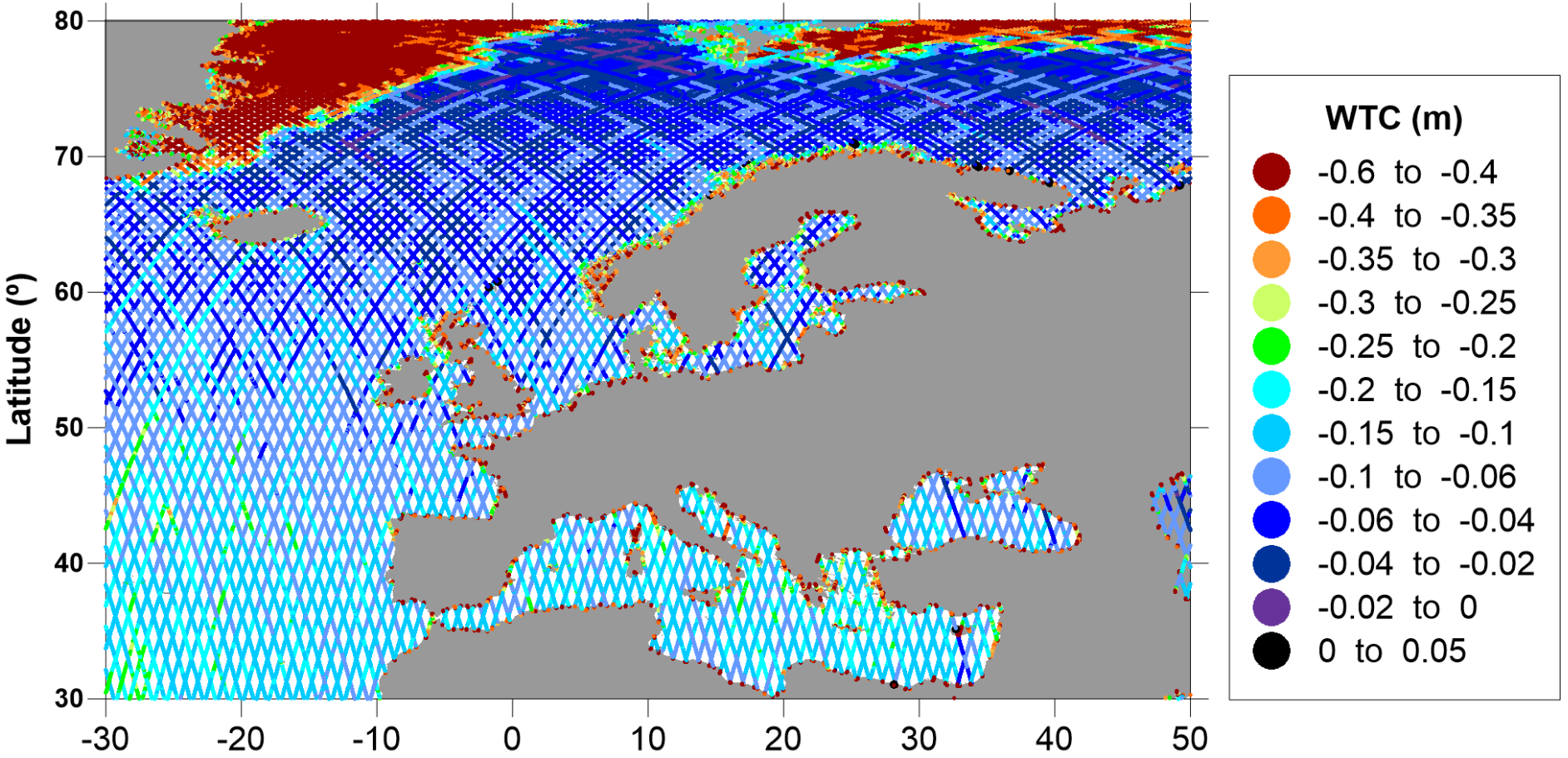
Motivation

- In ocean satellite altimetry, the Wet Tropospheric Correction (WTC), accounting for the path delay in the altimeter signal due to water vapour and cloud liquid water in the atmosphere, is best determined from measurements from passive Microwave Radiometers (MWR), collocated with the altimeter observations.
- MWR possess large footprints (10-40 km), depending on frequency, and current retrieval algorithms are tuned for open ocean conditions.

➔ Consequently, MWR observations become invalid when other type of surfaces (e.g. land or ice), are present in the MWR footprint, leading to the rejection of altimeter observations in coastal zones and polar regions.

➔ There is scope for improving the WTC for S3 in these regions.

WTC from MWR



MWR WTC (m) for Sentinel-3B cycle 32. Land and ice contamination can be observed.

Why GPD+ for S3?

- **GPD+ (GNSS-derived Path Delay Plus)** is an algorithm for estimating the WTC of radar altimeter observations, using **data combination**, by space-time objective analysis (OA) of **all available valid observations** in the vicinity of the estimation point.
- The algorithm takes into account the accuracy of each observation (white noise) and the variability of the WTC field (spatial and temporal correlation scales).

- In the context of this activity, the purpose is to derive an improved WTC for Sentinel-3 that:
  - ➔ Preserves the valid observations from the best available source (on-board MWR);
  - ➔ Extends the validity of the correction to points where the former WTC is invalid, by estimating new values from external sources.

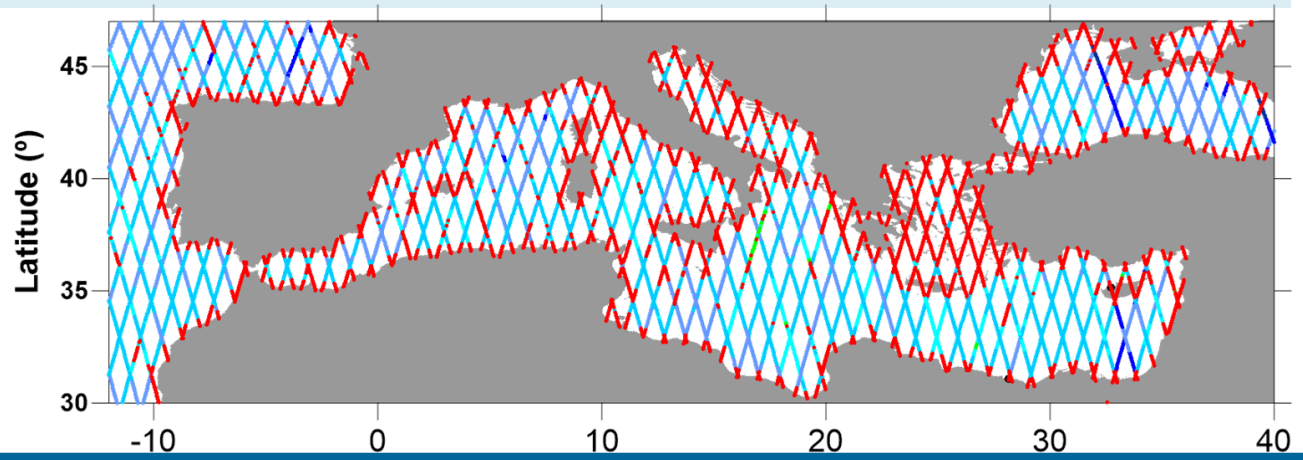
GPD+ inputs

- Sentinel-3A/3B STC/NTC products:
  - time, latitude, longitude;
  - MWR WTC (rad_wet_tropo_cor_01_ku, from 3 parameters: TB 23.8, TB 36.5, Ku band σ0 from SAR retrievals);
  - quality flags
- Available WTC sources used in the data combination (OA) procedure:

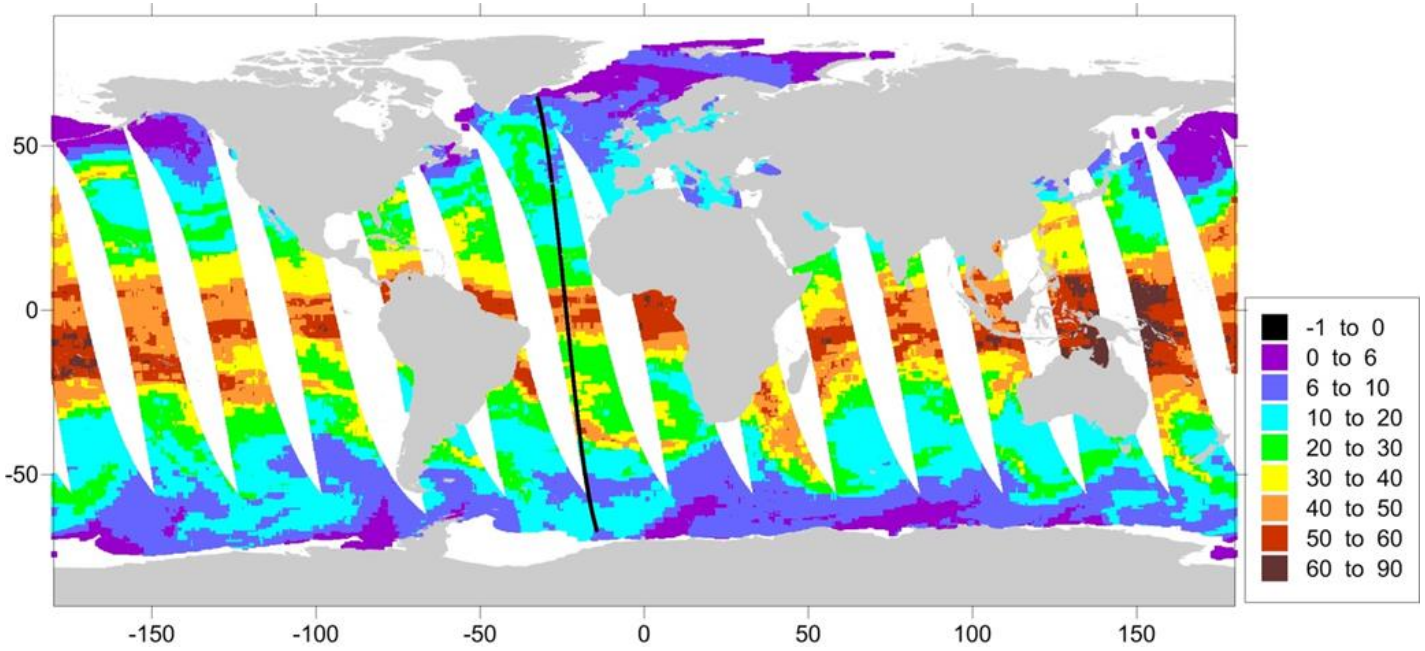
1) WTC from a NWM (currently **ERA5**) as **first guest;**
2) V**alid on-board MWR** WTC values from the neighbouring points;
3) WTC from scanning imaging MWR (**SI-MWR**) products from other remote sensing missions (available from RSS and NOAA CLASS);
4) WTC from **GNSS** (from **IGS, EPN and Suominet**).

Valid on-board MWR values

Location of S3B points for cycle 32 over the Mediterranean. Blue/green points represent valid MWR values, while red points represent invalid observations.

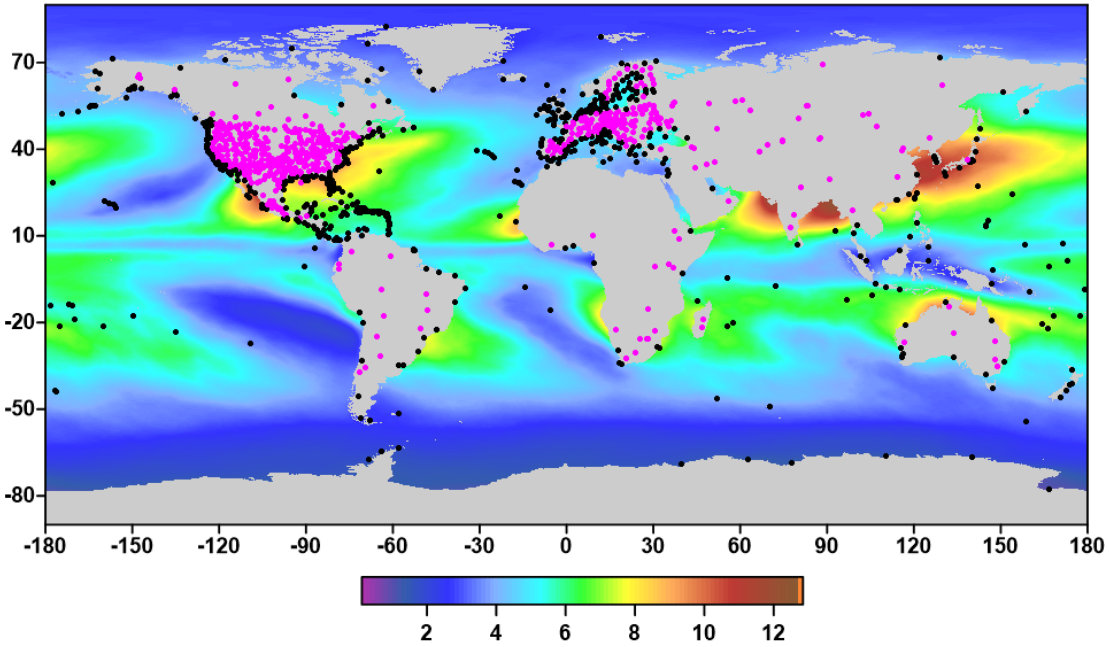


GPD+ inputs: external MWR and GNSS



SI-MWR products

Example of a TCWV product (in mm) from Coriolis (WindSat), ascending passes over one day.



Location of GNSS stations from IGS, EPN and SuomiNet. Black points represent stations with distance from coast <100 km. The background map represents the WPD SD, in cm**.**

Data pre-processing steps

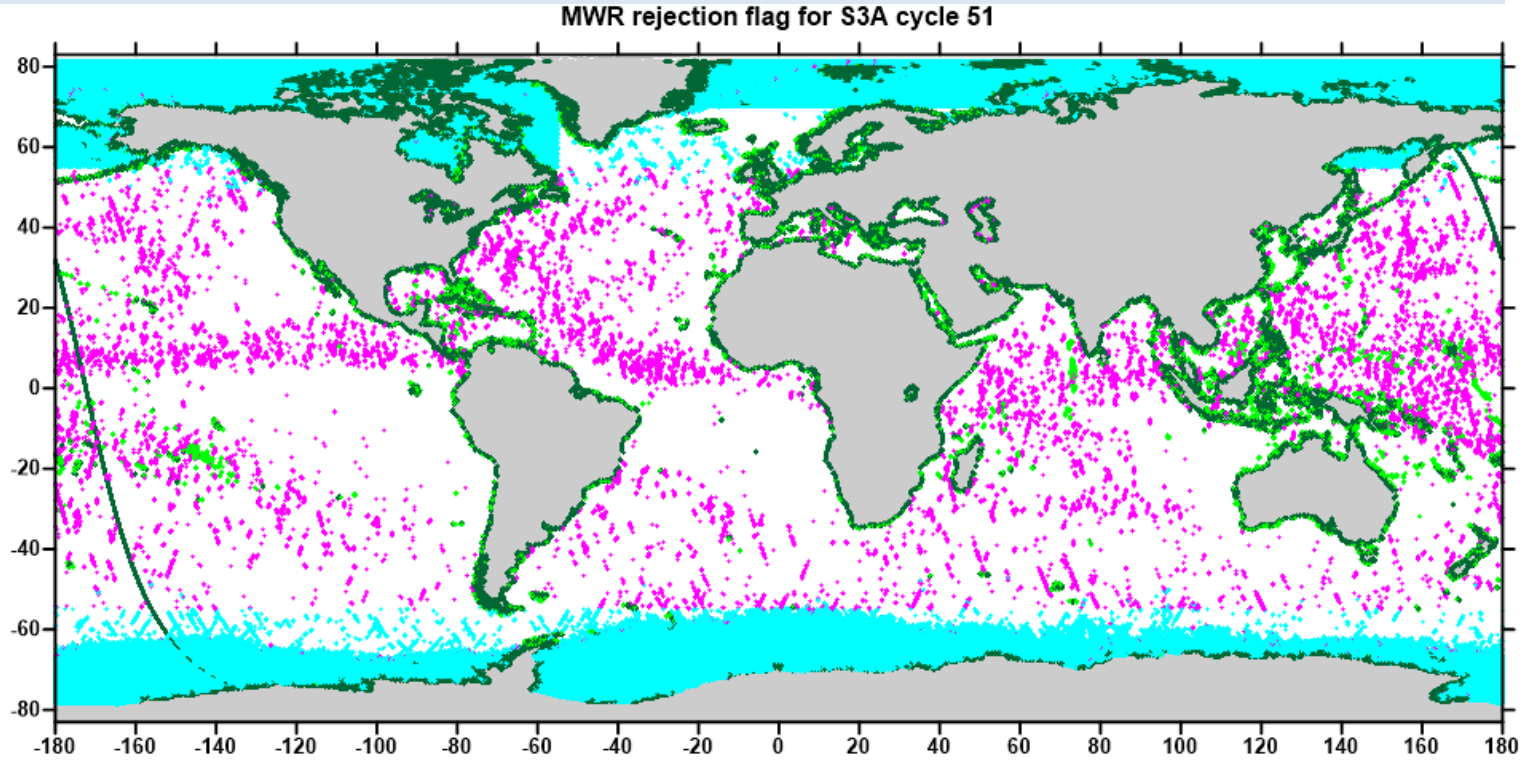
To ensure **consistency** and c**ontinuity** of GPD+ WTC estimates, various pre-processing steps are required:

- **Quality control** and **calibration** of various input datasets;

  This ensures that no large discontinuities should exist in the transition between WTCs that are estimated from GPD+ (using different data sources) or between these and model/MWR values.

- **Computation of the MWR_rej flag** – determines which points are going to be estimated and which preserve the WTC from the on-board radiometer.

S3A points for Sentinel-3A cycle 51 with invalid MWR observations: **green** and **green** – land contamination; **blue** – ice contamination; **pink** – rain or outliers (**23% of all points, 14% of the points with valid SLA**).



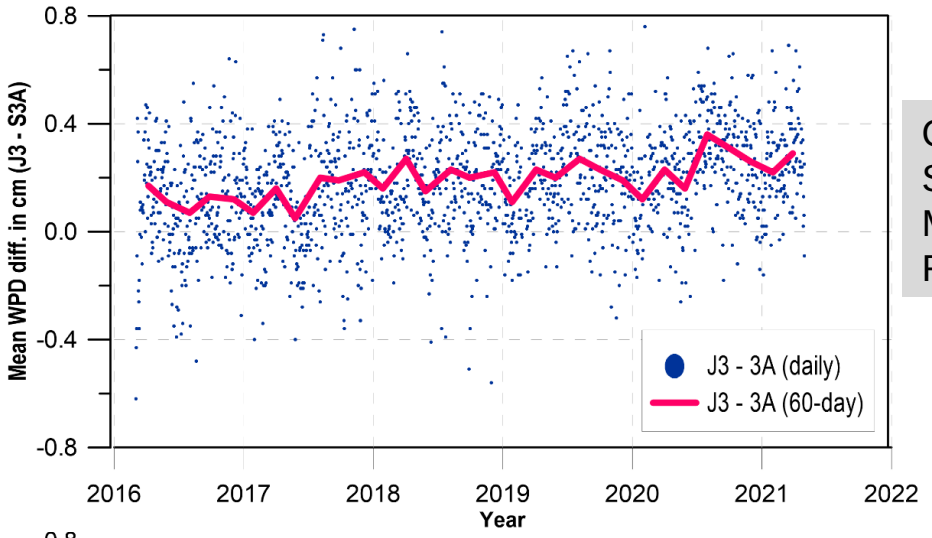
Calibration: S3A, S3B ➔ J3

All radiometers used in GPD+ are calibrated against **SSM/I** and **SSM/IS.**

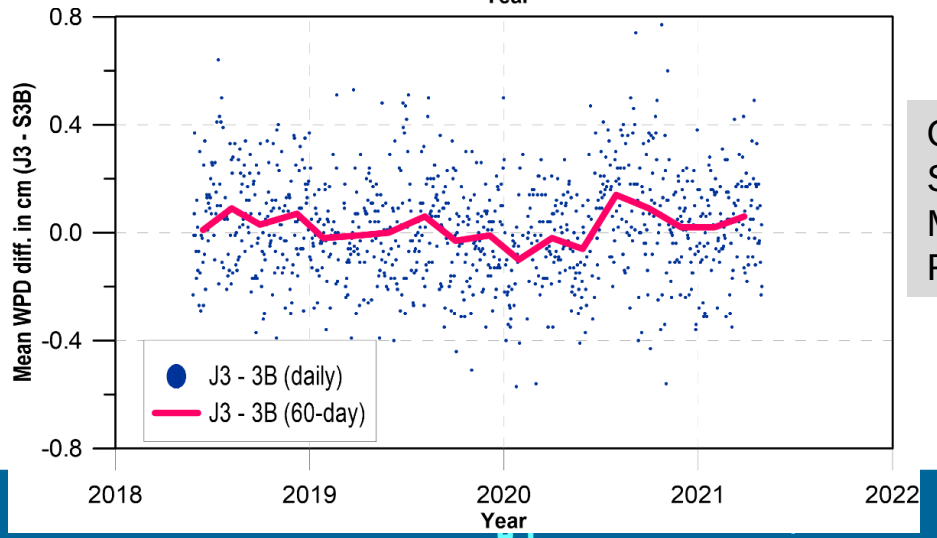
Calibration is performed in 3 steps:

- **Step 1 – TP, J1, J2, J3 ➔ SSMI** (using matching points)
- **Step 2 – remaining SI-MWR ➔ TP, J1, J2, J3** (using matching points)
- **Step 3 – non-reference altimeter missions (3A, 3B) ➔ TP, J1, J2, J3** (using crossovers)
- Calibration usually uses 3 parameters: offset, scale factor and linear trend.
- In the current study, **only the first 2 parameters were used**.
- Since calibration parameters for S3A/B are small, currently these are not applied.
- S3A measures dryer than J3 by 2 mm.
- S3B and J3 are aligned.

Mean WPD differences between calibrated J3 and S3A (top) and S3B (bottom) (daily and 60-day means)



Offset = 0.16 cm
Scale factor = 1.00
Mean = 0.19 cm
RMS = 1.11 cm



Offset = 0.08 cm
Scale factor = 0.99
Mean = 0.02 cm
RMS = 1.10 cm

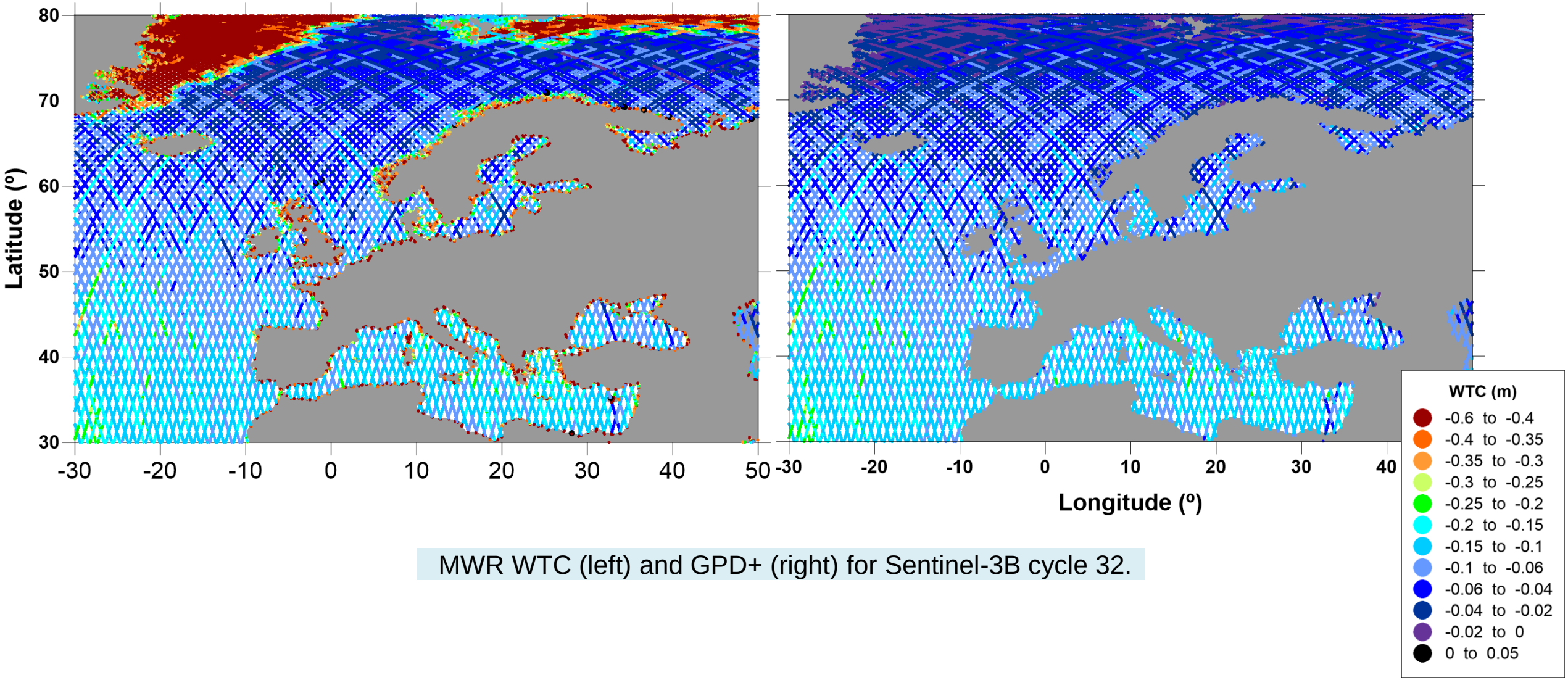
GPD+ product validation

Assessment and validation has been performed by means of:

- **Analysis of data completeness and data recovery**
- **Comparison with various WTC datasets**:
  - S3A/B Baseline MWR;
  - ECMWF model present in the S3A/B SRAL/MWR products and with ERA5;
  - WTC from GNSS.
- **Analysis of SLA variance and RMS differences at crossovers**

Product Validation Report: https://www.eumetsat.int/media/49075

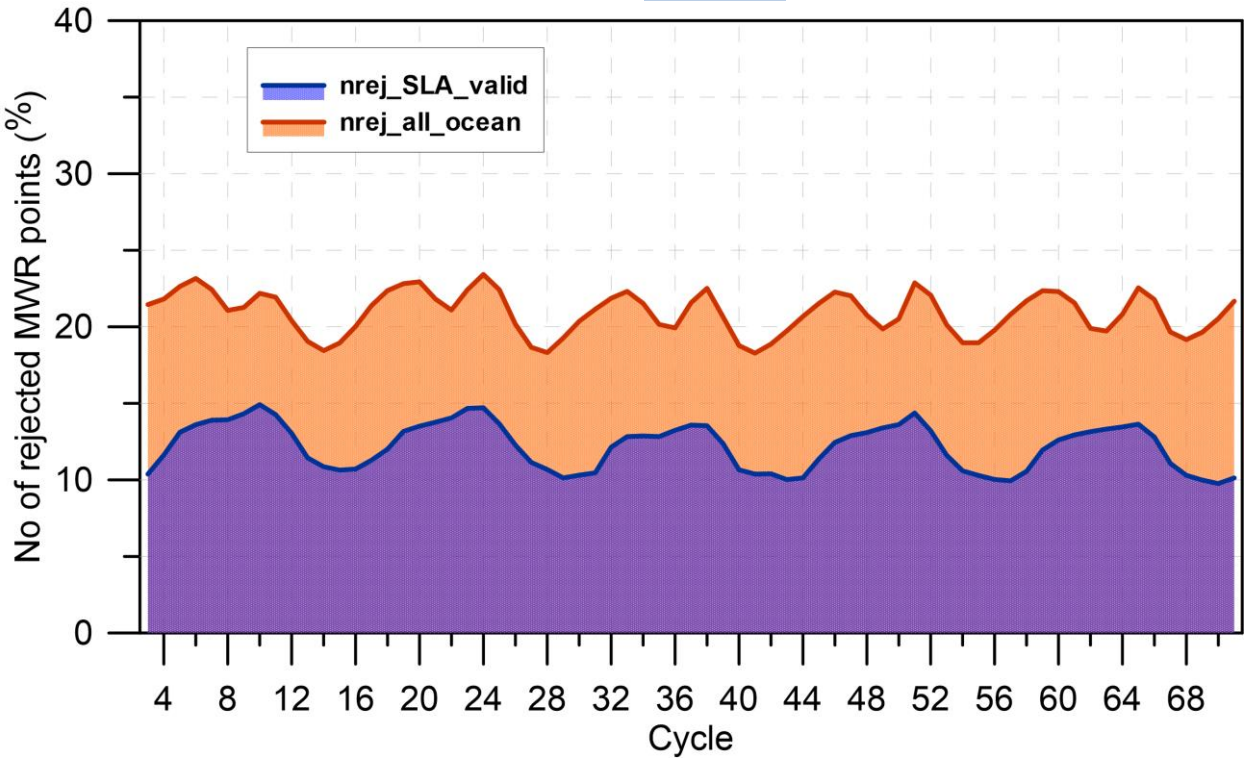
Data completeness



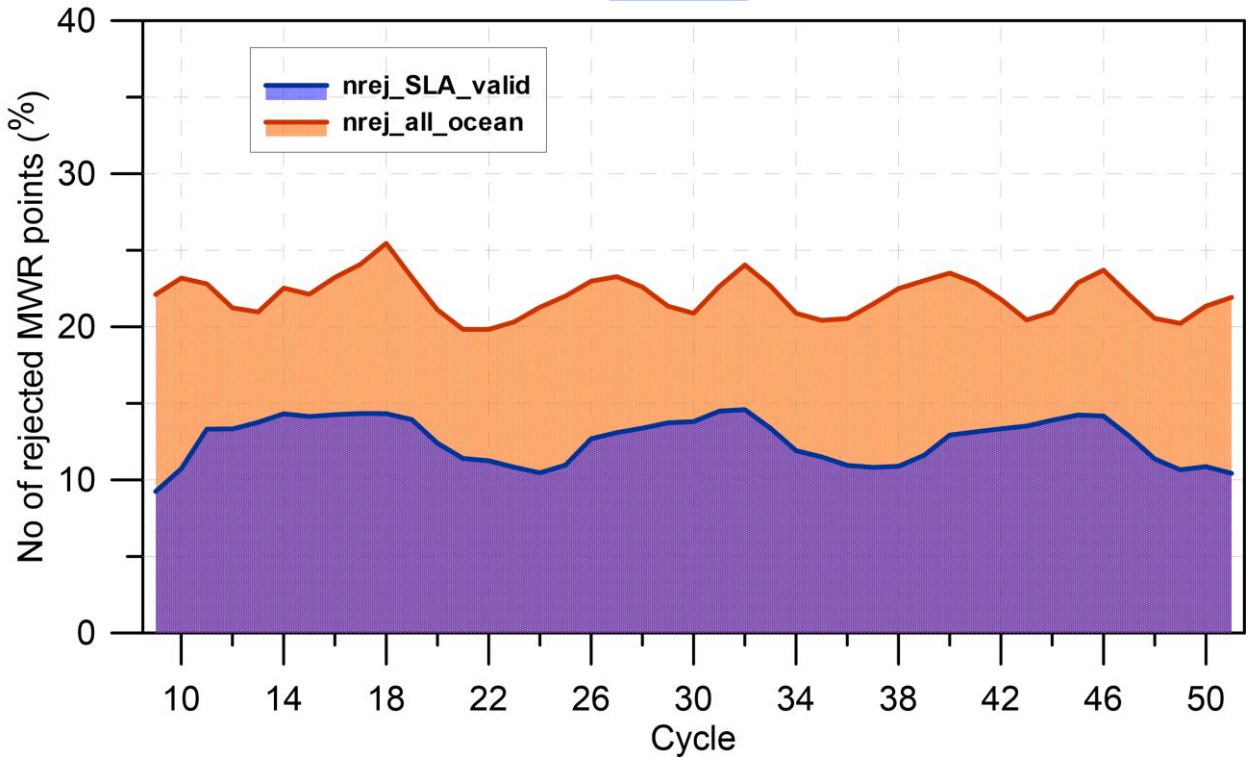
MWR WTC (left) and GPD+ (right) for Sentinel-3B cycle 32.

Data recovery

S3A

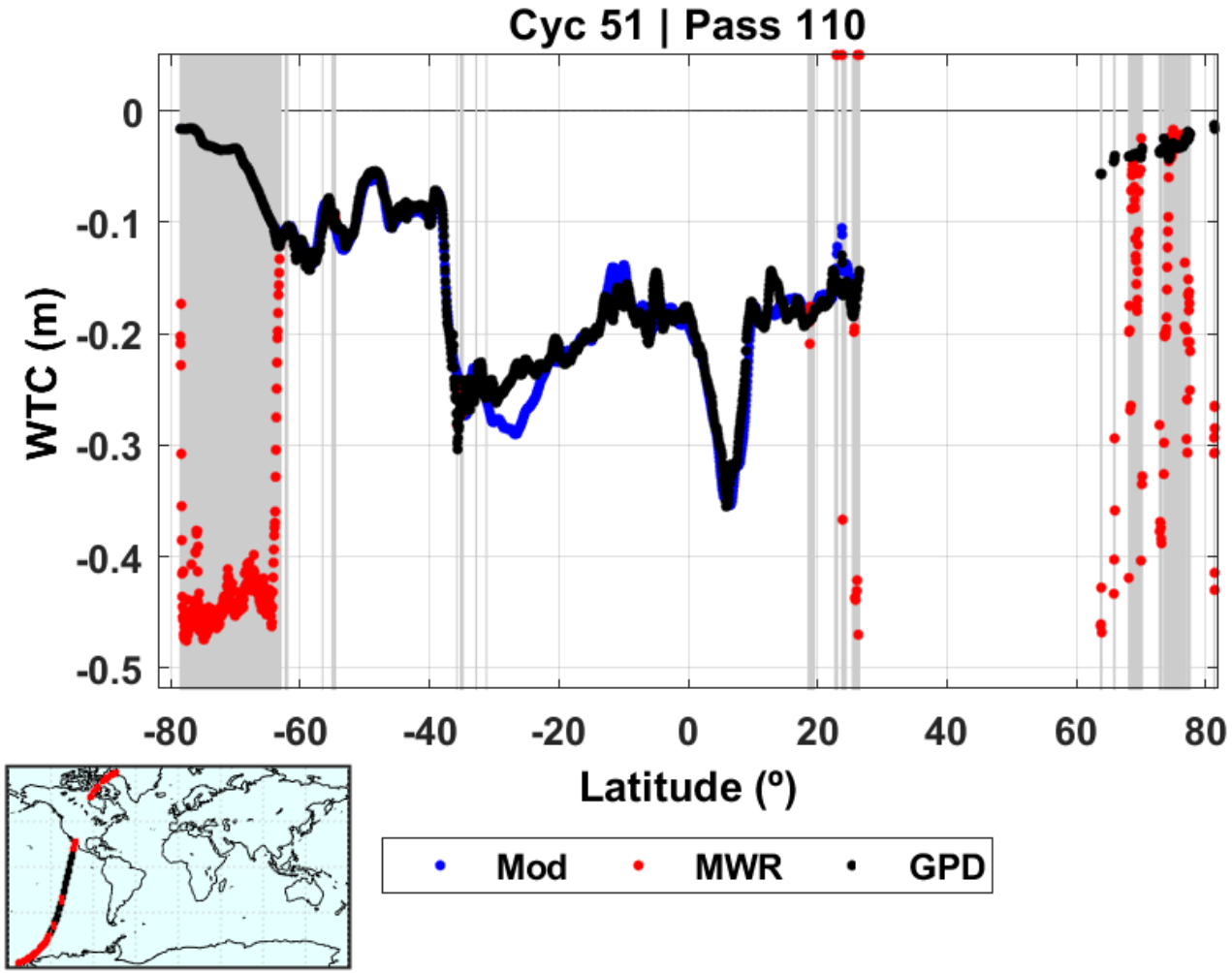


S3B



Percentage of points with MWR_Rej flag=1, i.e., with invalid on-board MWR WTC, recovered by GPD+, for the whole set of ocean measurements (orange) and for points with valid SLA (blue).

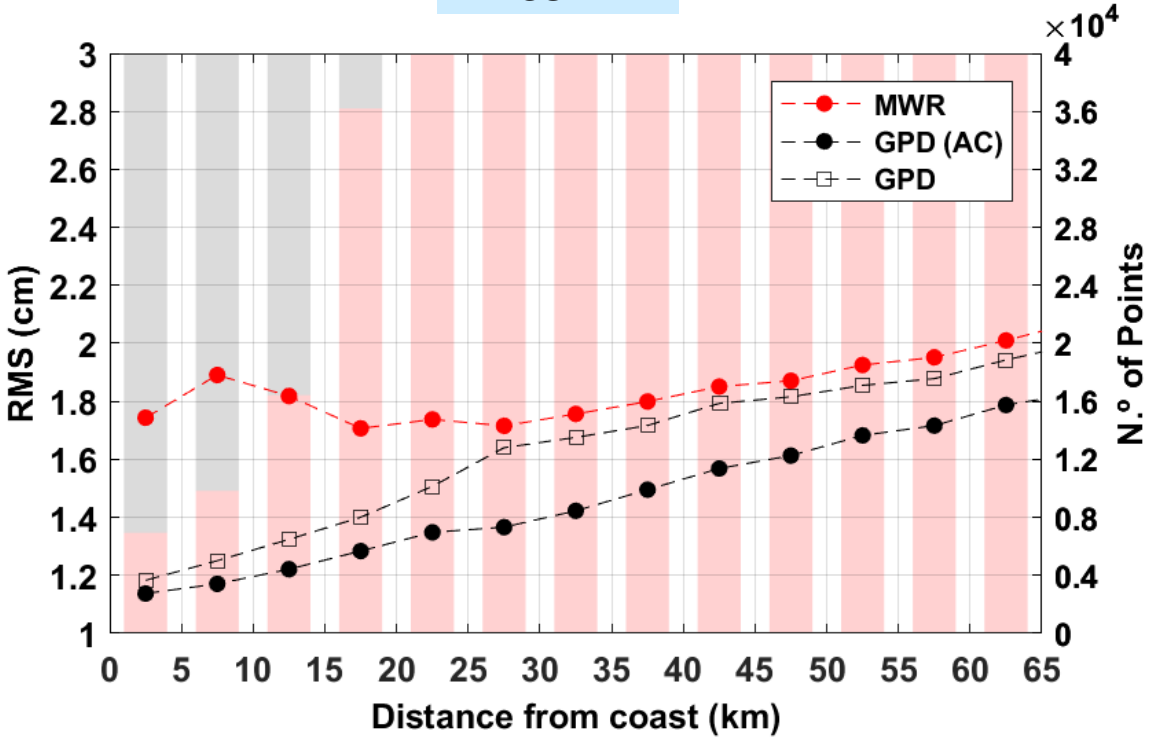
GPD product assessment – Comparison with MWR and ERA5: Pass examples



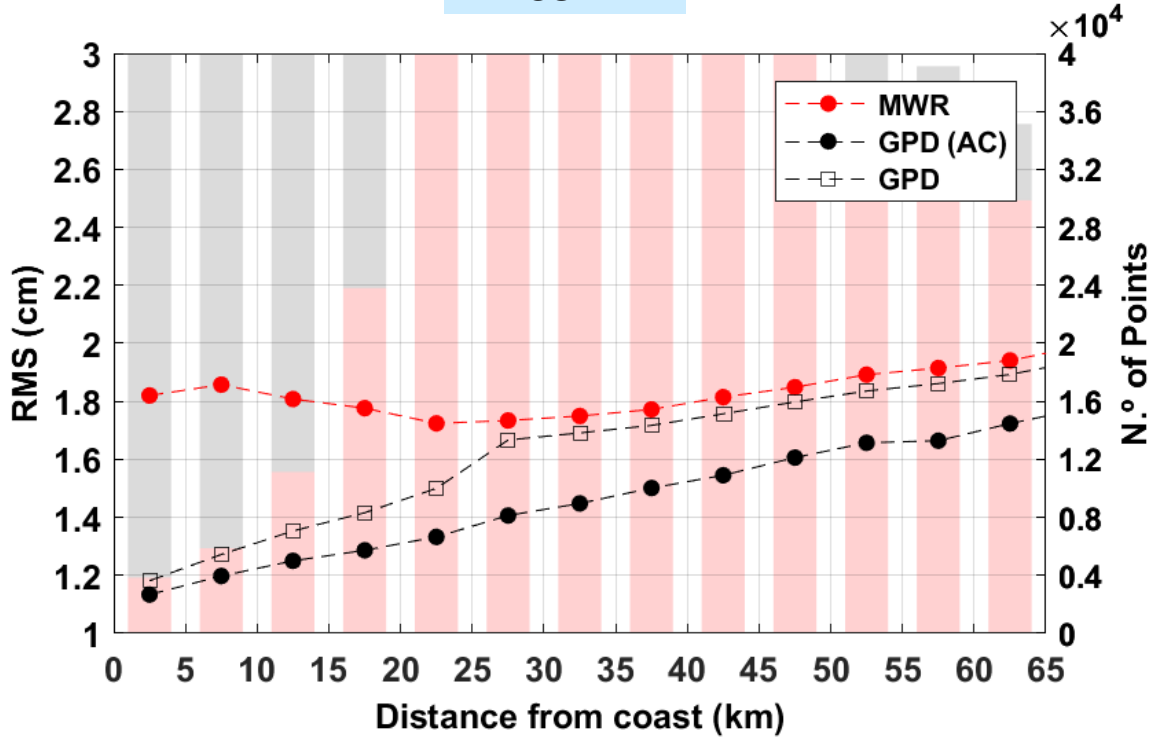
Example of passes showing various WTC. Grey bars represent points with invalid MWR (MWR_rej flag ≠ 0).

GPD product assessment – comparison with GNSS

S3A



S3B

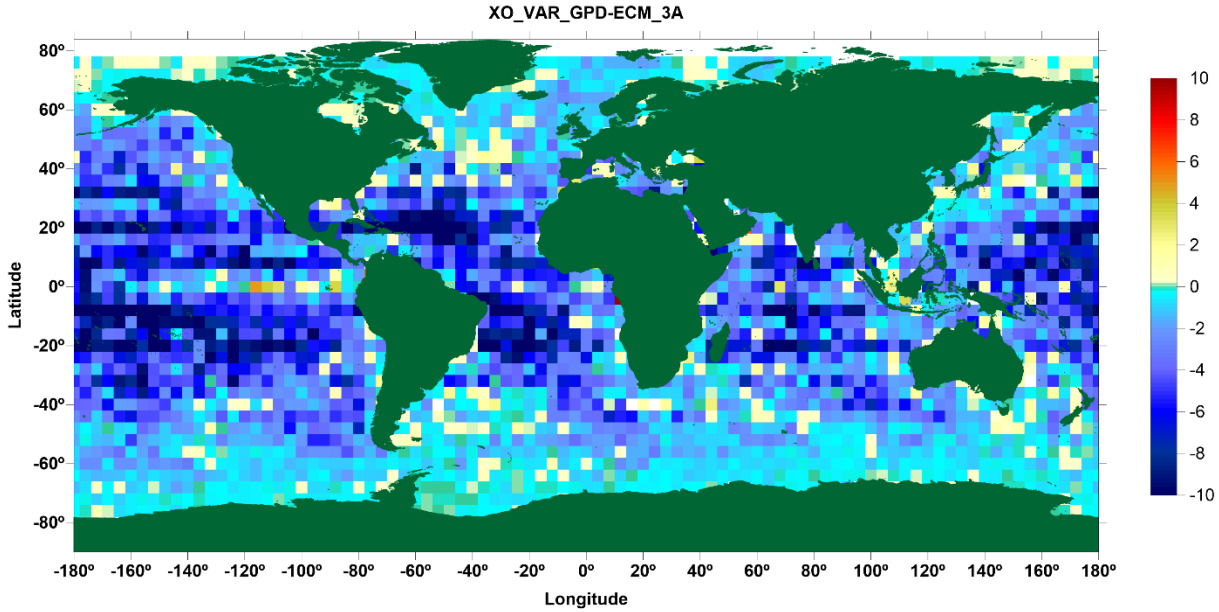


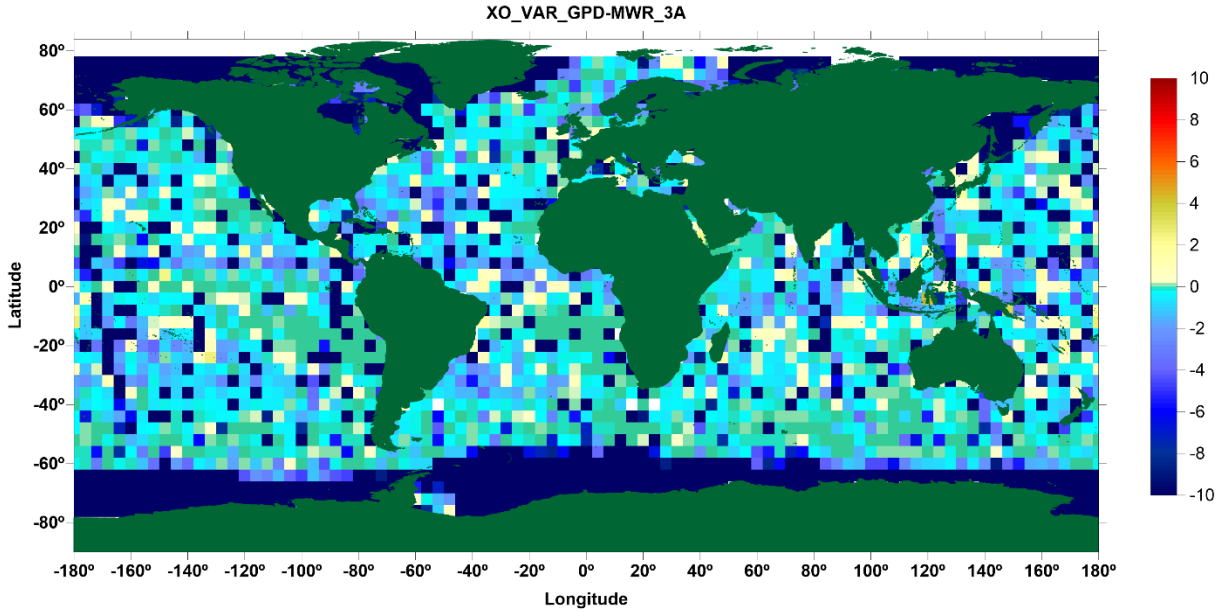
WPD differences between GNSS and on-board MWR (•), 'standard' GPD+ (□) and "a la CryoSat" GPD (•). In the first comparison, only points with valid MWR values, except for the criterion related with distance from coast, have been used. In all other comparisons, all points have been used.

GPD product assessment – SLA RMS diff. at crossovers (S3A)

GPD-ERA5

GPD-MWR



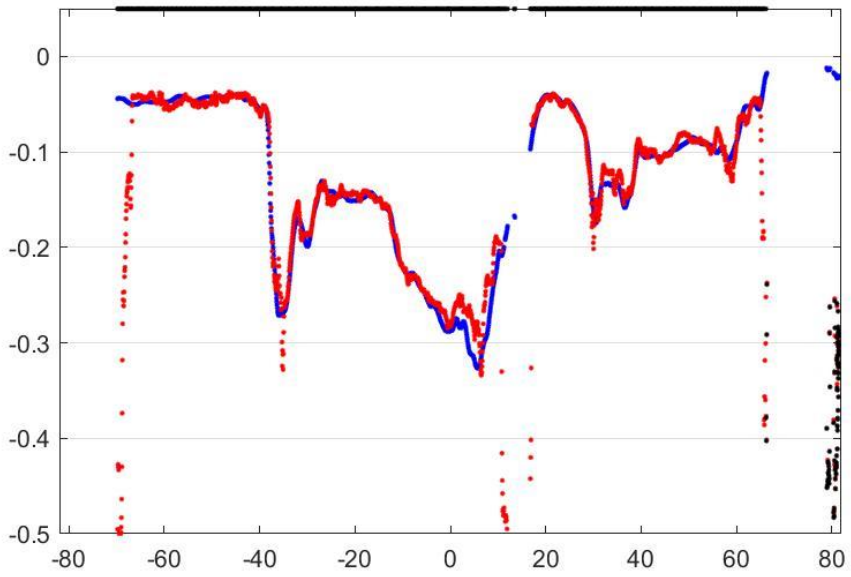


Spatial distribution of the weighted SLA RMS differences at crossovers (XO) (%) between GPD+ and ERA5 (left) and between GPD+ and on-board MWR (right) over the period corresponding to S3A cycles 03 to 71.

BC 004 versus **BC 005**

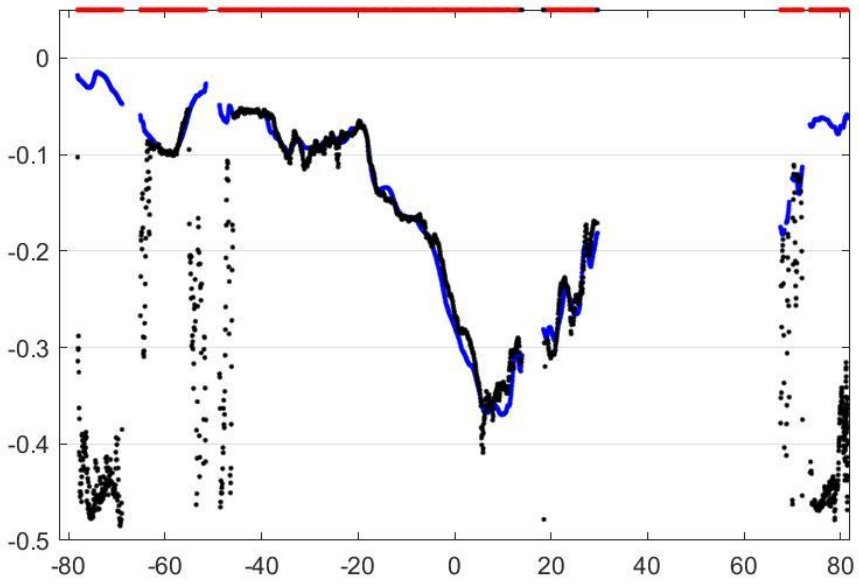
WTC for S3A cycle 39, pass 715

BC 005 is invalid



WTC for S3B cycle 11, pass 65

BC 004 is invalid



Various WTC for S3A cycle 39, pass 715 (left) and S3B cycle 11, pass 65 (right):

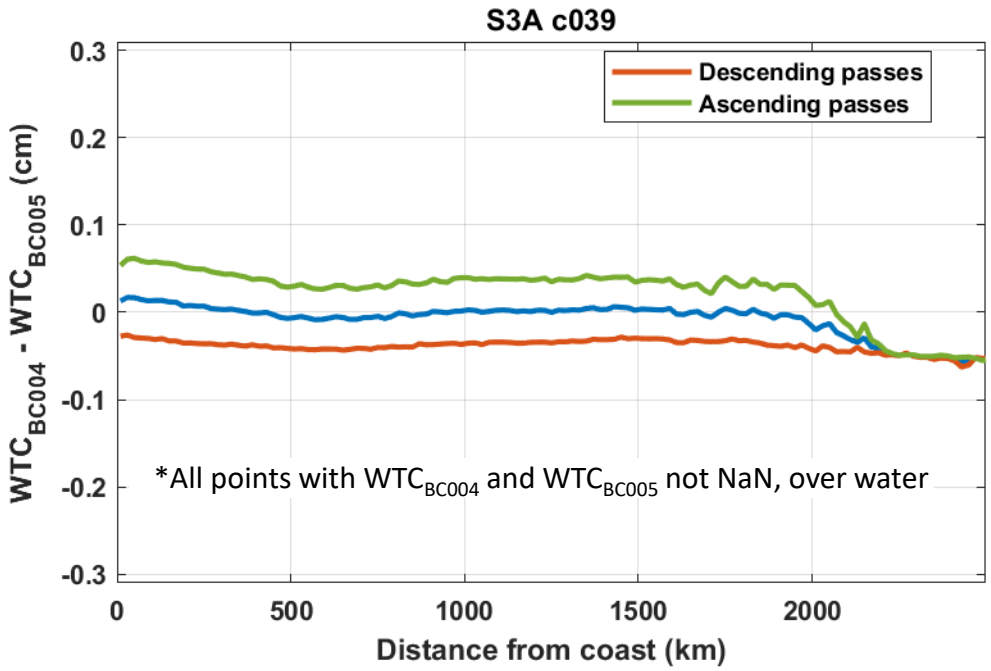
ERA5 – blue

MWR BC 004 – red

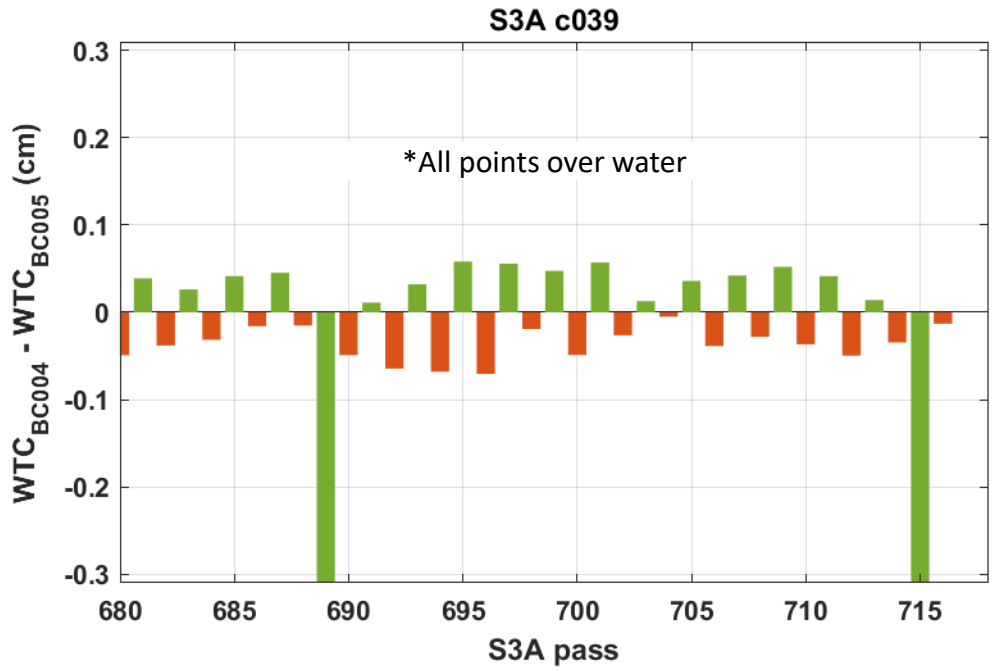
MWR BC 005- black

BC 004 versus BC 005: WTC for S3A cycle 039

WTC_{BC004}-WTC_{BC005} function of distance to coast



WTC_{BC004}-WTC_{BC005} function of S3A passes



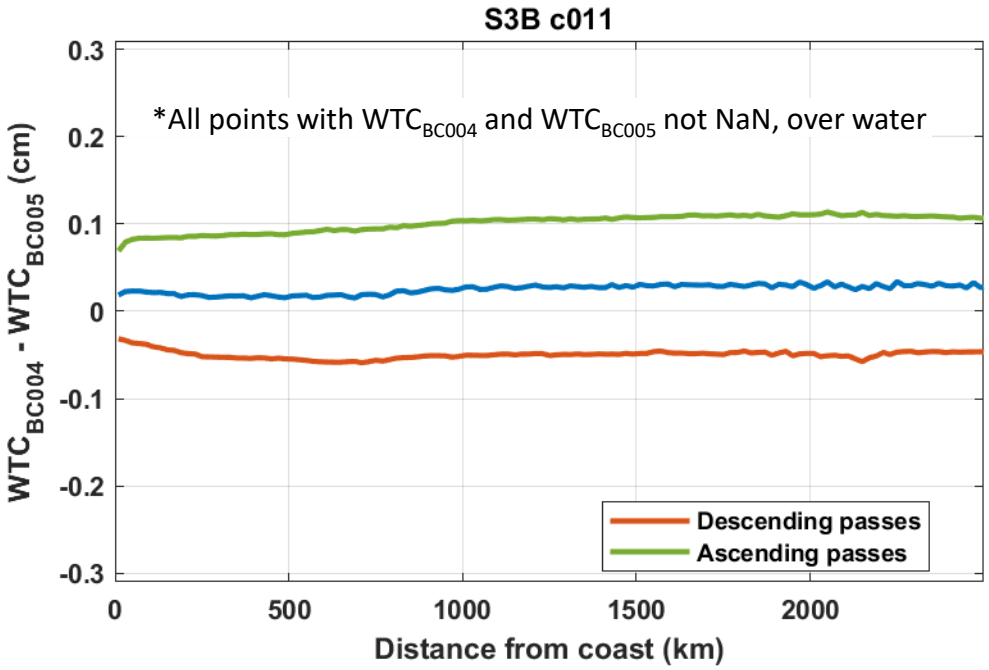
Descending tracks: WTC BC005 measures dryer than WTC BC004

Ascending tracks: WTC BC005 measures wetter than WTC BC004

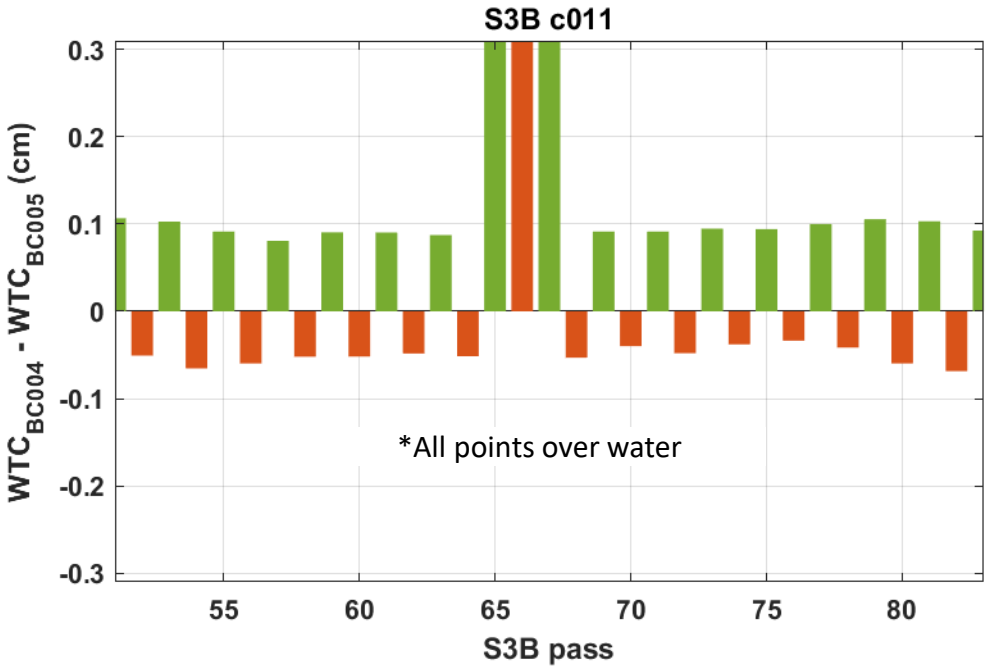
For S3A cycle 039, passes **689 and 715** WTC BC 005 is invalid (totally or a portion).

BC 004 versus BC 005: WTC for S3B cycle 011

WTC_{BC004}-WTC_{BC005} function of distance to coast



WTC_{BC004}-WTC_{BC005} function of S3B passes



Descending tracks: WTC BC005 measures dryer than WTC BC004

Ascending tracks: WTC BC005 measures wetter than WTC BC004

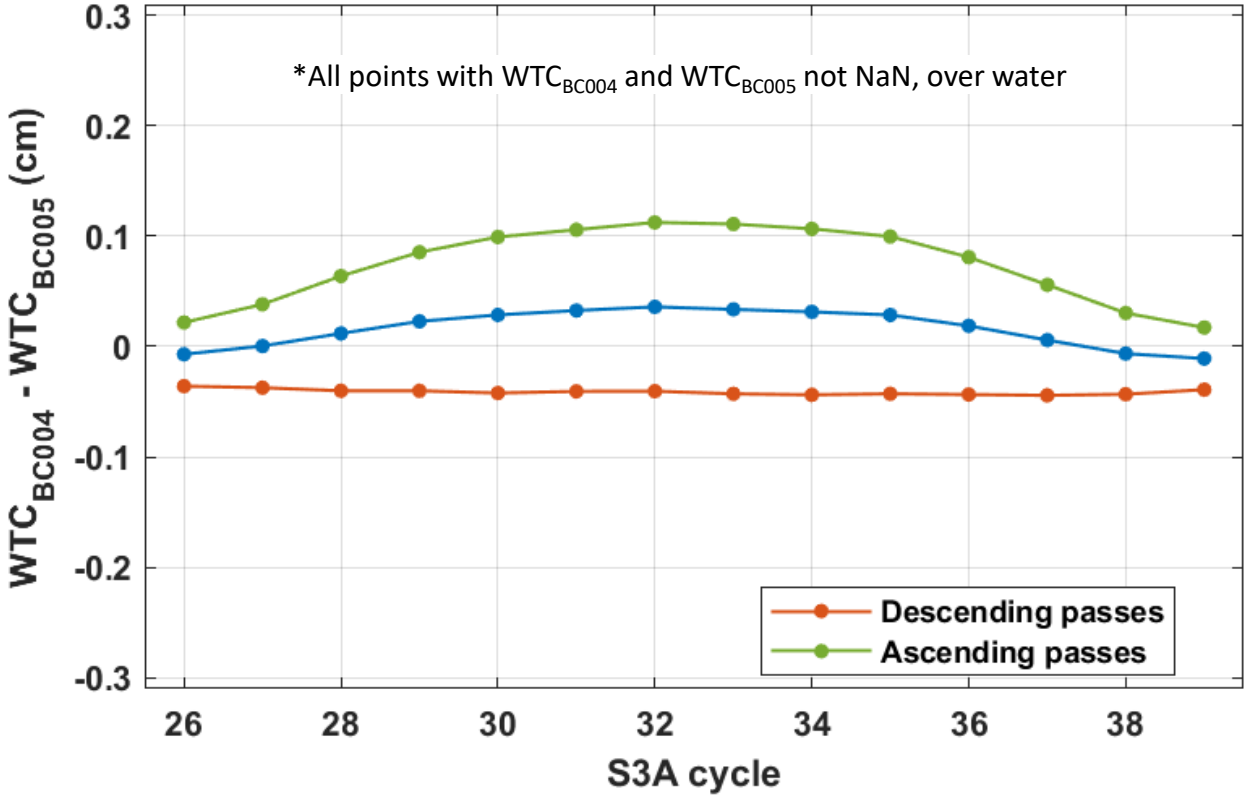
For S3B cycle 011, passes **65, 66 and 67** WTC BC 004 is invalid (totally or a portion).

BC 004 versus **BC 005: mean cycle differences**

WTC_{BC004}-WTC_{BC005}: mean cycle differences for S3A, year 2018

Descending tracks: WTC BC005 measures dryer than WTC BC004 – constant difference along the year.

Ascending tracks: WTC BC005 measures wetter than WTC BC004 – seasonal differences, larger in the NH summer.



Conclusions (1)

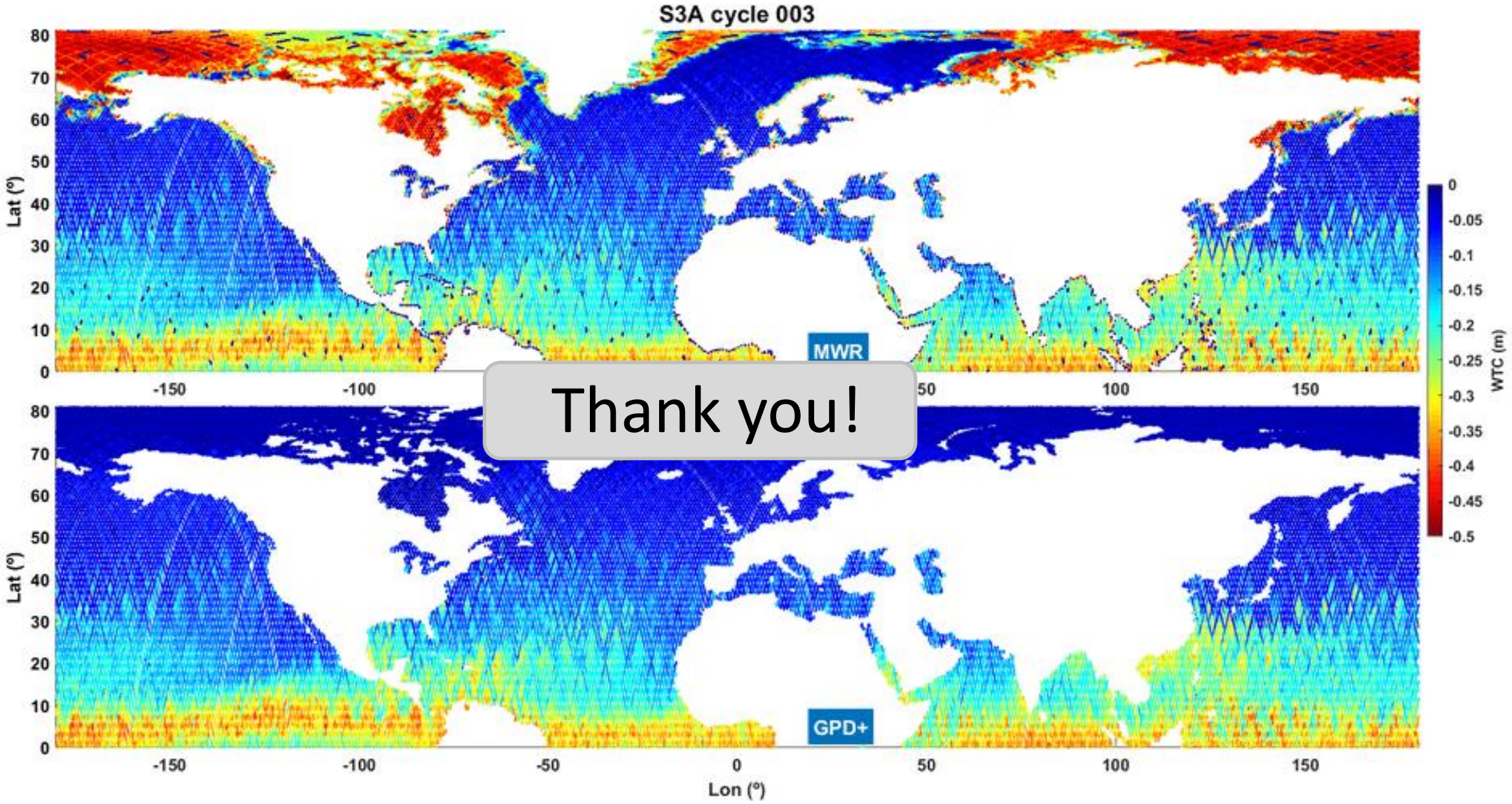
This study shows that the GPD+ WTC for S3A and S3B:

- **Preserve the properties of the best available WTC (on-board MWR), further extending this correction to regions and epochs where and when the former is not valid;**
- **Are continuous and consistent corrections, valid for all points in the S3A/B marine product;**
- **Are calibrated against the SSMI/S dataset, taken as reference;**
- **Improve data coverage, mostly in coastal and polar regions, filling gaps in the valid MWR observations;**
- **Are improved WTC both w.r.t. the MWR WTC for each satellite and to the ECMWF model-derived WTC;**
- **Since August 2022, the GPD+ WTC are being provided operationally to the S3 NTC products.**

Conclusions (2)

Comparison between WTC BC 004 and WTC BC 005:

- **The global differences between WTC BC 004 and BC 005 are small, at millimeter level. These are due to small differences in TB23 and sigma0.**
- **BC 005 tandem phase - same as for BC 004: WTC (S3A) – WTC (S3B) = 0.16 ± 0.19 cm.**
- **There are passes, or portion of passes, with invalid WTC BC 004 but valid WTC BC 005, while on others the opposite happens.**
- **There are systematic differences between ascending and descending tracks.**
  - **For descending tracks WTC BC 005 measures dryer than WTC BC 004 – constant difference throughout the year.**
  - **For ascending tracks WTC BC 005 measures wetter than WTC BC 004 – seasonal difference, maximum in the NH summer.**
- **For these reasons, to get a consistent data set, the GPD+ WTC should be made available for the whole BC 005 dataset, since missions start.**


S3A cycle 003
MWR
GPD+
Lat (°)
Lon (°)
WTC (m)
0
-0.05
-0.1
-0.15
-0.2
-0.25
-0.3
-0.35
-0.4
-0.45
-0.5

Thank you!