Excellent performances of the newly reprocessed ERS-1, ERS-2 and ENVISAT products for altimetry and radiometry : the FDR4ALT products

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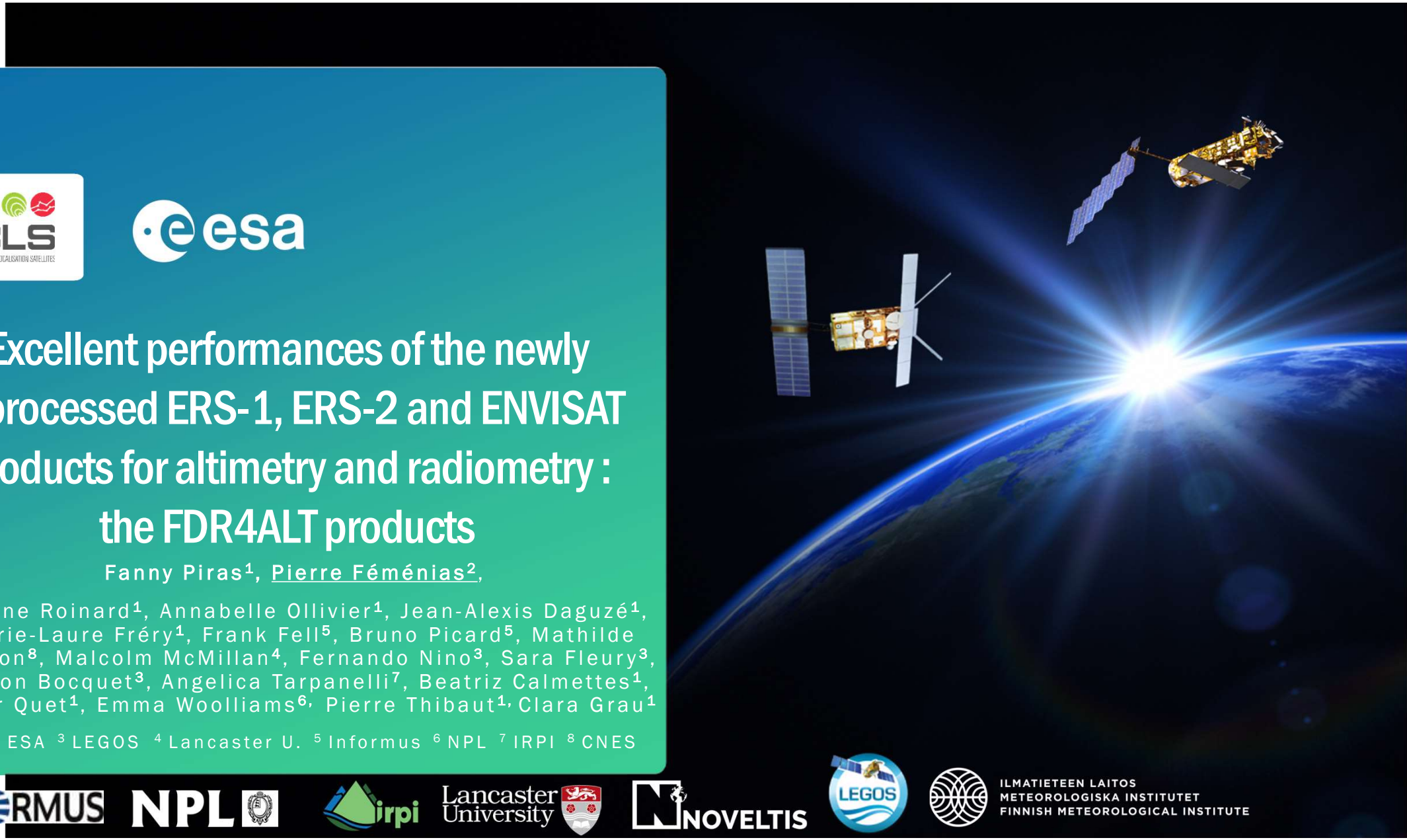

Introduction

FDR4ALT = Fundamental Data Record for Altimetry

ESA framework : Heritage Missions Programme

Reprocessing activity of ERS-1, ERS-2, ENVISAT Altimeter and Radiometer datasets : 23 years of data in total from 1991 to 2012

→ The objective of the project is to serve the different communities involved in long term data exploitation for different Earth surfaces

The project kicked-off in September 2019 and the final review was held in May 2023, with excellent results for all products

The products will be available to the public in Q4 2023. Therefore, this presentations aims at :

- ✓ Present the FDR4ALT products in terms of format and access
- ✓ For each of the **8 product types**, provide an overview of the content and performances

The consortium

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Project Manager
Fanny Piras (CLS)

Project Officer
Pierre Thibaut (CLS)

Fundamental Data Records

MWR FDR
Marie Laure FRERY (CLS) et **Ralf BENNARTZ** (Informus)

+ Bruno Picard (Informus)
+ Mathilde Simeon (CLS)
+ E.Woolliams (NPL)

ALT FDR
Jean Alexis Daguzé (CLS)

+ F.Piras (CLS)

Land Ice Thematic Data Products
M.MacMillan (Univ. of Leeds)

+ Andrew Sheperd (U. Leeds)
+ E.Woolliams (NPL)

Sea Ice & Polar Ocean TDP
Eero RINNE (FMI)
Sara Fleury (LEGOS)

+ H.Sallila (FMI)
+ F.Garnier (LEGOS)
+ M.Cancet (Noveltis)
+ S.Hendricks (AWI)
+ E.Woolliams (NPL)

Ocean & Coastal TDP
Florence BIROL (LEGOS)

+ F.Nino (LEGOS)
+ N.Tran (CLS)
+ H.Roinard(CLS)
+ M.Cancet (Noveltis)
+ E.Woolliams (NPL)

Inland Water TDP
Beatriz Calmettes (CLS)

+ A.Tarpanelli (IRPI)
+ J.F.Crétaux (LEGOS)
+ E.Woolliams (NPL)

Ocean Waves TDP
Annabelle Ollivier (CLS)

+ V.Quet (CLS)
+ N.Tran (CLS)
+ E.Woolliams (NPL)

Water Vapor TDP
Ralf BENNARTZ (Informus)

+ B.Picard (Fluctus)
+ F.Fell (Informus)
+ M.L.Frery (CLS)
+ M.Simeon (CLS)
+ E.Woolliams (NPL)

Thematic Data Products

Many partners on this project !

FDR4ALT Products : philosophy

Fundamental Data Records
L1B products containing all the ancilliary and instrumental data used to calibrate the instrument

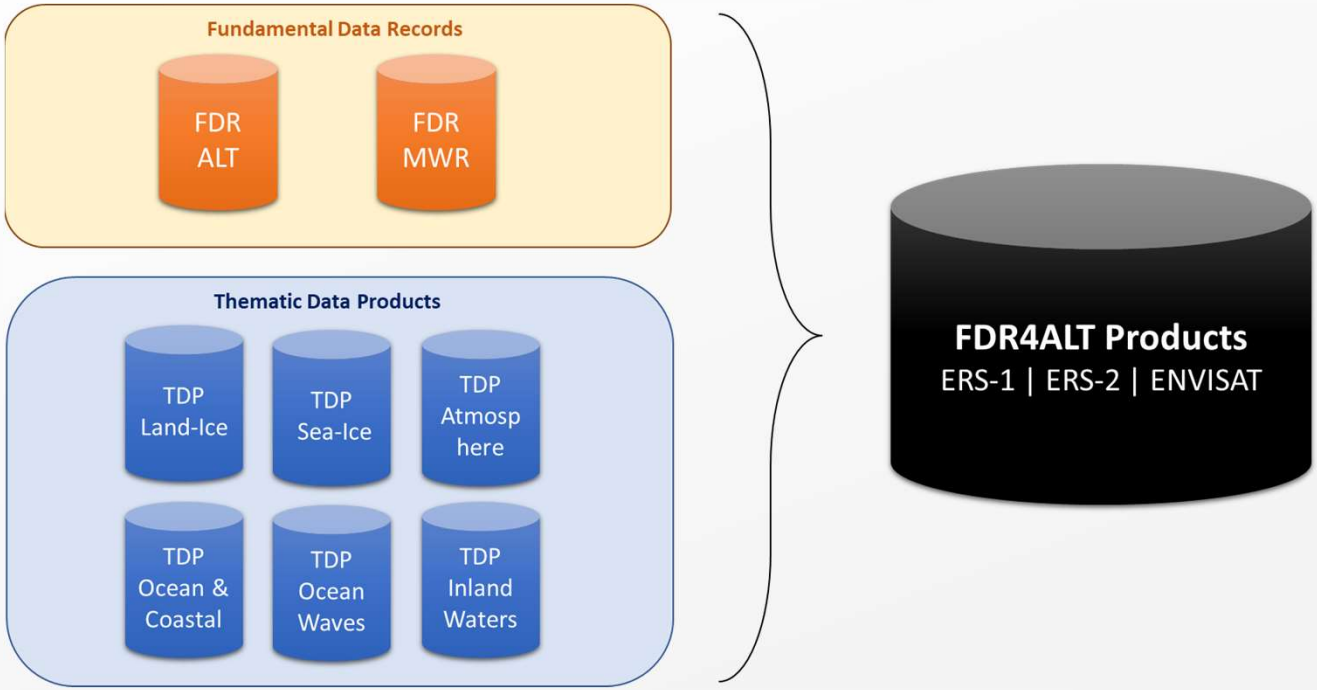
Thematic Data Products
Level-2P, easy to use, validated products with uncertainties included

NetCDF Format

Grouping to be user-friendly (Main, Expert)

One file per track (half-orbit)

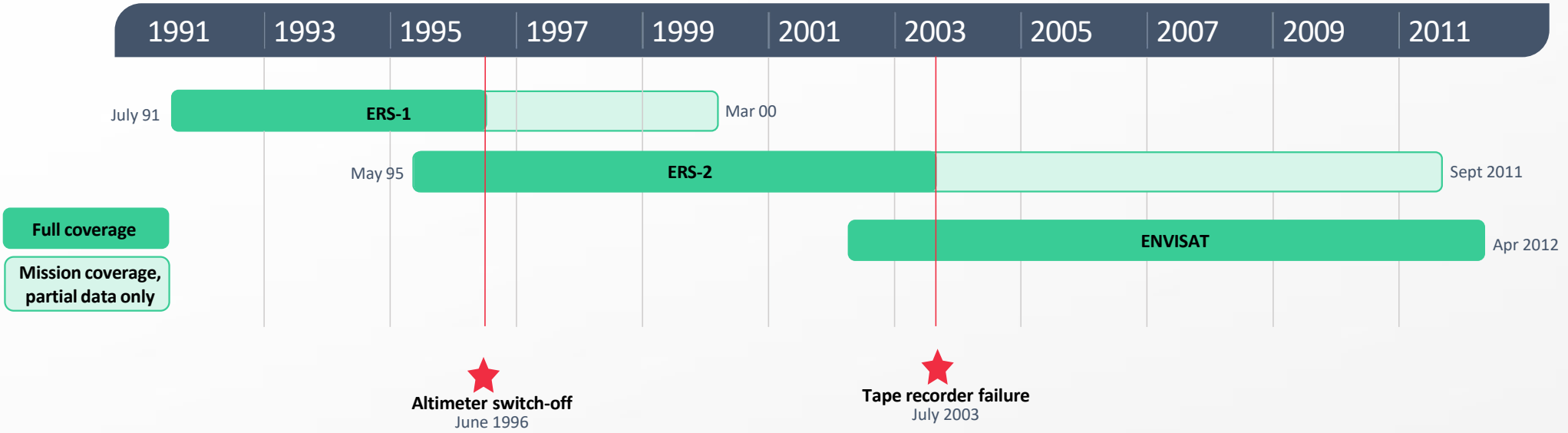
Uncertainty associated to each data point for all products



✓ Based on the best state-of-the-art algorithms and corrections

A detailed description of the products is available in the Product User Guide

FDR4ALT products : time coverage



- ✓ No ERS-1 altimeter data after June 1996 (altimeter switch-off) but radiometer data available
- ✓ No ERS-2 altimeter data after July 2003 (tape recorder failure) but radiometer data available

The FDR4ALT products cover data from July 1991 to April 2012 → 21 continuous years of homogeneous data

FDR4ALT products : data access & available documentation

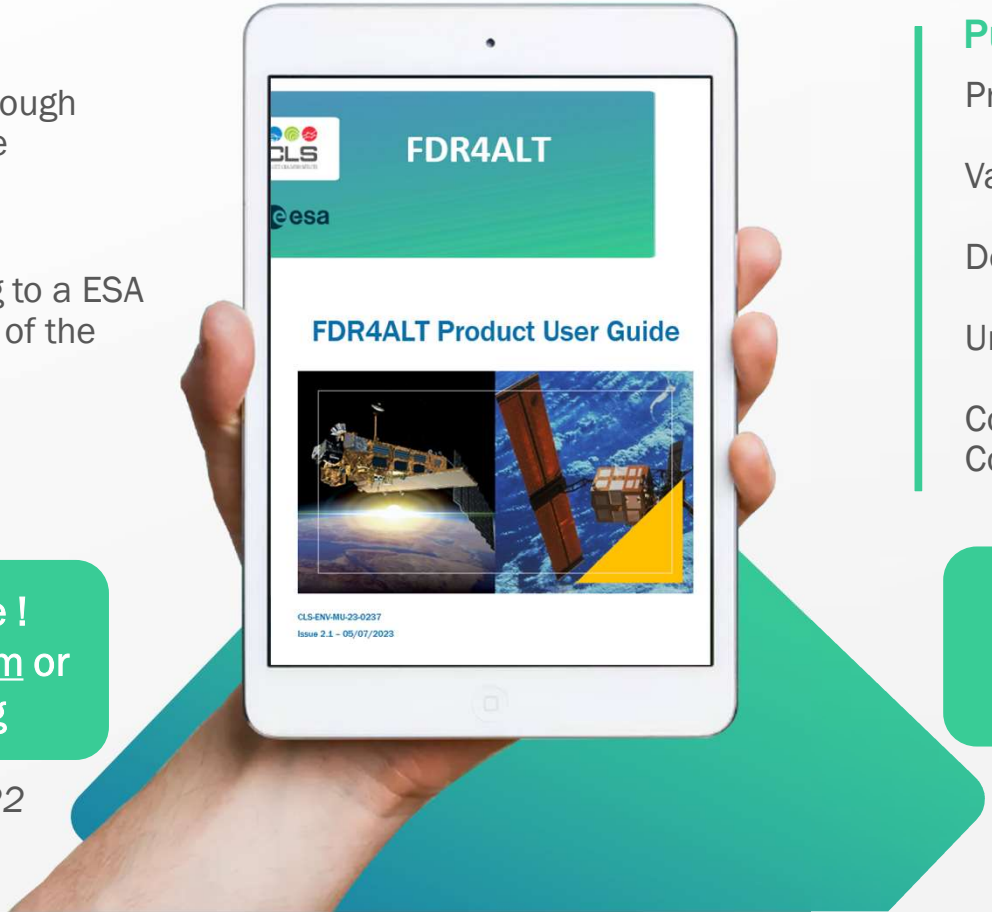
The FDR4ALT products

Products will be available through ESA's Earth Online Catalogue

Download via HTML and FTP

One DOI per product pointing to a ESA landing page with full details of the dataset

Release planned Q4/2023



Public documents

Product User Guide

Validation Report (for each product)

Detailed Processing Model

Uncertainty Characterization Report

Completeness Report ALT
Completeness Report MWR

A test dataset is available ! contact fpiras@groupcls.com or visit the www.fdr4alt.org

TDP updated w.r.t to OSTST 2022

Already available on the FDR4ALT website ww.fdr4alt.org

FDR4ALT products : content & performances

Orbit :

- ENVISAT orbit from CNES POD team's : POE-F solution. It was compared to the previous one and was selected
- ERS-1 & ERS-2 orbit from the DEOS solution showed the best performances [Otten, 2019]

Retrackers

Retracker	Ocean & Coastal	Ocean Waves	Sea-Ice	Land-Ice	Inland Waters	Atmosphere (*)
ENVISAT	Adaptive	Adaptive	TFMRA	ICE-1	ICE-1	Adaptive
ERS	MLE3	MLE3	TFMRA	ICE-1	ICE-1	MLE3

Geophysical corrections

Each correction has been adapted to the specific TDP needs & constraints → Table available in the Product User Guide

Uncertainties

For all products except the ALT FDR, an uncertainty is associated with each measurements along-track
Strong requirement of the project and challenging for the altimetry → Not detailed here, available in the FDR4ALT documents

Performances of each product presented in the next slides → Impossible to detail all the improvements of the products here so please refer to the associated documentation for more details

FDR4ALT products : FDR MWR

- ✓ Level-1 radiometer have been **entirely reprocessed from level-0,** with numerous improvements leading to **excellent performances** at level-1 and level-2
- ✓ The FDR MWR provides **intercalibrated brightness temperatures (BT) for ERS-1, ERS-2 and ENVISAT** missions, as well as bias corrected BT (1D-VAR), at the native MWR sampling rate **7Hz**

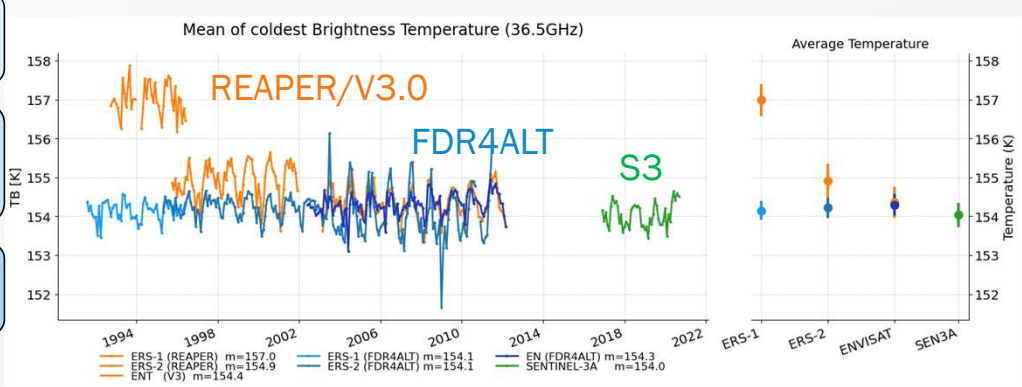
Review and homogenized L1

Uncertainties provided per measurement

Intercalibration by updated of variables of the radiometric model, analyzed by vicarious calibrations

Also provides all necessary information for reprocessing in expert groups

Vicarious calibration (coldest ocean) for ENVISAT, 36.5GHz



→ FDR4ALT now aligned with S3 calibration

The MWR products provide very good quality brightness temperatures over **25 years** for three missions.
A **dedicated paper** on radiometry is under preparation to detail the performances of the FDR MWR

FDR4ALT products : TDP Atmosphere

Two parallel retrieval approaches :
The neural network showed overall better performances.
1D-VAR is however provided in the products for experts users.

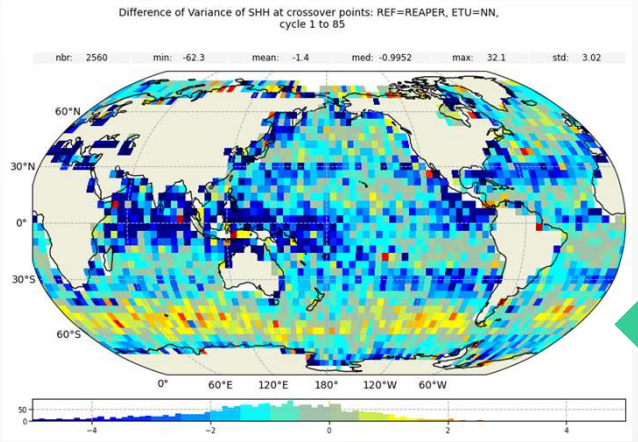
Neural network (CLS)

Expert variables

Main variables

- Wet tropospheric correction (WTC)
- Total Column Water Vapour (TCWV)
- Atmospheric attenuation at Ku band (ATT_Ku)
- Liquid Water Path (LWP)
- Uncertainty for WTC, TCWV, LWP
- Quality flag

1D VAR (Informus/Fluctus)



Difference of variance of SSH at Xover points for ERS-2

New & Improved L1 processing

Up-to-date L2 algorithms

→ **High quality results** for WTC, TCWW and ATT_Ku, for both retrievals

- ✓ The FDR4ALT Wet Tropospheric Correction (WTC) outperforms the former reference. **Difference of variance of SSH at Xover** : for ENVISAT -0.88cm², ERS-1: -0.91cm² & ERS-2 : -1.19cm²
- ✓ Uncertainty provided along-track (1DVAR only)

FDR4ALT products : FDR altimetry

- ✓ Most complex and heavy product with 99 variables for ENVISAT and 70 variables for ERS, including the waveforms
- ✓ Includes data from Ku-band and S-band (ENVISAT only)

Main group

All level 1b information from previous reprocessing activities
(ERS REAPER & ENVISAT V3.0)
+
★New Orbit
+
★ Correction of REAPER drawbacks : time jumps and negative waveforms
+
★new user-friendly flags
+
★ Neural-network waveform classification
+
★Distance to shoreline and surface flag GSHHG

Expert groups

ancillary_cal_ptr
ERS : PTR parameters
★ENVISAT : newly averaged PTR

ancillary_cal_lpf
ERS : LPF from REAPER
ENVISAT : LPF from V3.0

ancillary_2k
ENVISAT 2kHz data

★ **New, developed in the frame of FDR4ALT**

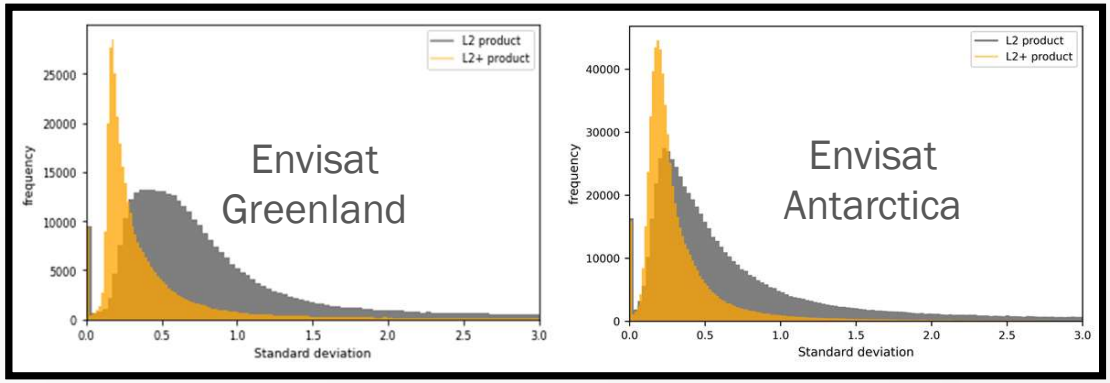
FDR4ALT products : TDP Land-Ice

Main variables

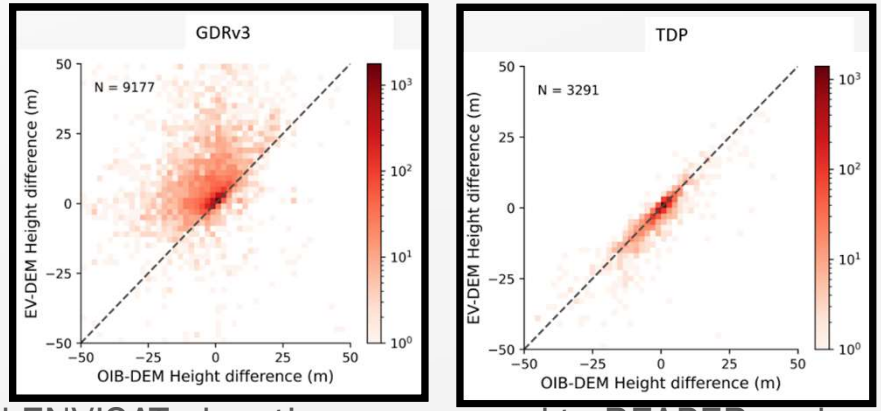
Surface elevation
Surface elevation uncertainty along-track
Flag surface type
Waveform class (from ALT FDR)
Sigma0
Reference elevation

- Enhanced L2 processing :
  - ✓ Dedicated ice sheet retracking
  - ✓ Enhanced slope correction (Roemer)
  - ✓ Waveform classification
  - ✓ Dedicated ice sheet quality flagging
- TDP processing :
  - ✓ Topographic correction for across-track drift
  - ✓ Homogeneous timeseries samples at regular along-track reference nodes

Elevation STD



Comparison to in-situ



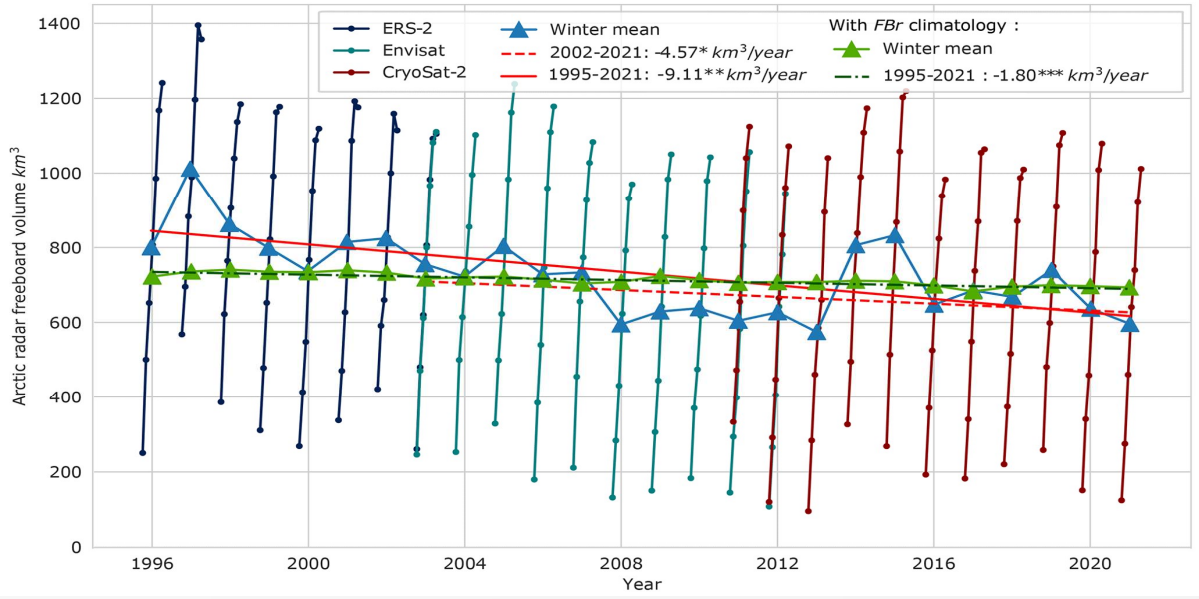
Major improvements in the accuracy & precision of ERS-1, ERS-2 and ENVISAT elevations compared to REAPER and V3.0 !

FDR4ALT products : TDP Sea-Ice

Main variables

Radar freeboard + uncertainty
Sea-Ice freeboard + uncertainty
Sea-Ice thickness + uncertainty
Sea level anomaly + uncertainty
Snow depth
Sea-ice type + surface type
Sea ice concentration

- ✓ Freeboard calibrated between missions (in the end all calibrated on Cryosat-2, the reference mission for sea-ice) using a **multi-parameter neural network** approach
- ✓ ERS pulse **blurring** error corrected using the deblurring procedure described in [Peacock,2004]



Innovative product extremely valuable for climate studies : the first ever time series of sea-ice estimates ever provided for ERS-1 and ERS-2 !!!

See [Bocquet et al, 2023], The Cryosphere

Radar freeboard volume time series for ERS-1, ERS-2, Envisat and Cryosat-2

FDR4ALT products : TDP Ocean Waves

Light product containing one group and **4 variables**

Strategy closely linked to the **CMEMS** roadmap 2022-2025

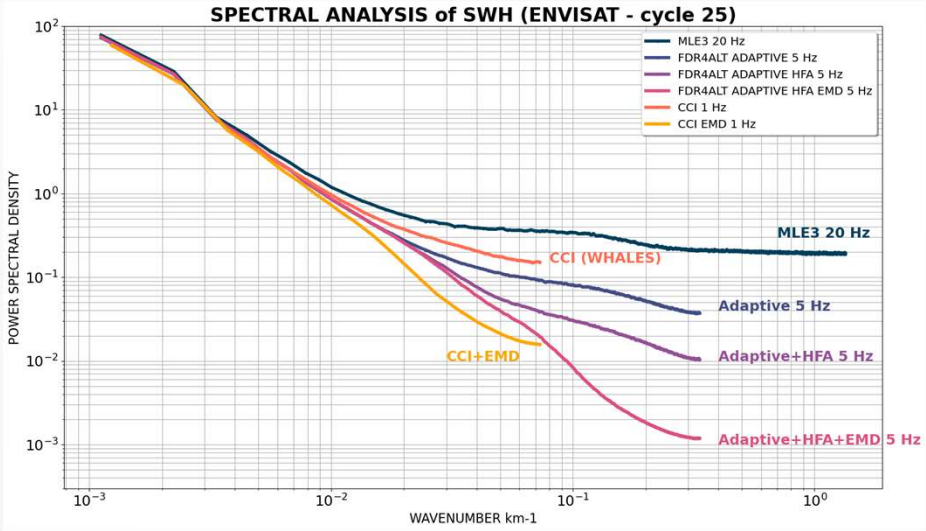
Great improvements has been demonstrated especially for ENVISAT thanks to the **Adaptive retracker** associated with **High-Frequency Adjustment (HFA)** (see Piras, *OSTST 2022*):

ENVISAT only

- ✓ More accurate
- ✓ Less biased (no Look-Up Table needed)
- ✓ Less noisy
- ✓ Better approach to the coast

ENVISAT, ERS 1/2

- ✓ Associated uncertainty
- ✓ ERS data calibrated with ENVISAT
- ✓ Better resolution (5Hz not 1Hz)



*Spectral analysis of SWH for different configurations. Large noise reduction observed with the **Adaptive**, even better with **HFA***

→ Coordination with CCI Sea-state Phase 2 (2023-2026) and ACELSU projects have been initiated

[See paper by DeCarlo et al., 2023]

FDR4ALT products : TDP Ocean & Coastal Topography

Main variables

Sea Level Anomaly
Inter-mission bias
Validation flag
Distance to coast
Uncertainty (short, meso & large scales)

Data available at 1Hz and 20Hz

Up-to-date orbit & geophysical corrections applied directly at 20Hz & 1Hz

Geophysical corrections available in an expert group

Uncertainty along-track provided for 3 different scales

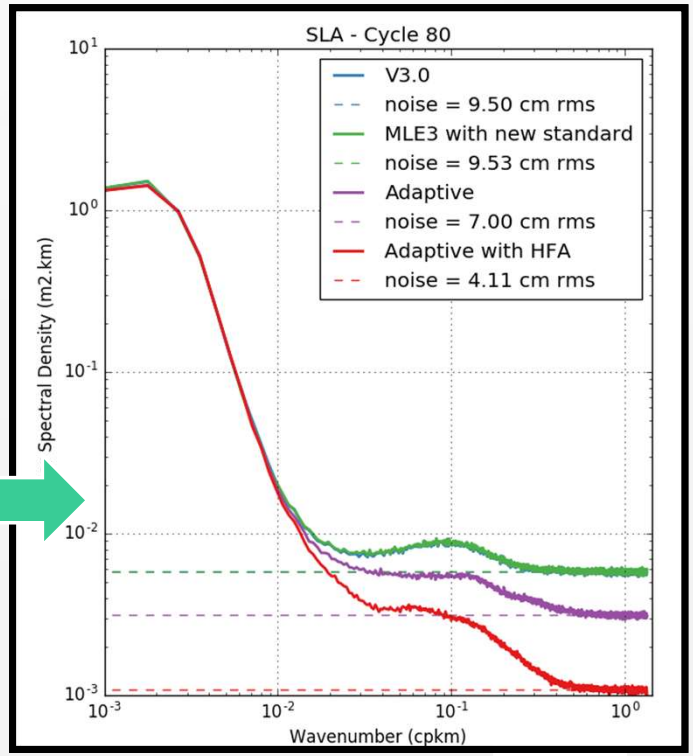
Dedicated processing for coastal areas (< 200km to the shoreline)

- ✓ ENVISAT & ERS-2 only
- ✓ Regional tides from Noveltis

See talk by F.Nino in Coastal Altimetry session

Great improvements on ocean & coastal has been demonstrated especially for ENVISAT thanks to the Adaptive retracker associated with High-Frequency Adjustment (HFA) (see Piras, *OSTST 2022*):

- ✓ Global noise reduction of ~56% at 20Hz
- ✓ Error deduced from SSH differences at 1Hz crossovers reduced by ~6%
- ✓ Better approach to the coast
- ✓ New GMSL trends now closer to Jason-1 : 1.39mm/year (V3.0) → -0.53mm (FDR4ALT)

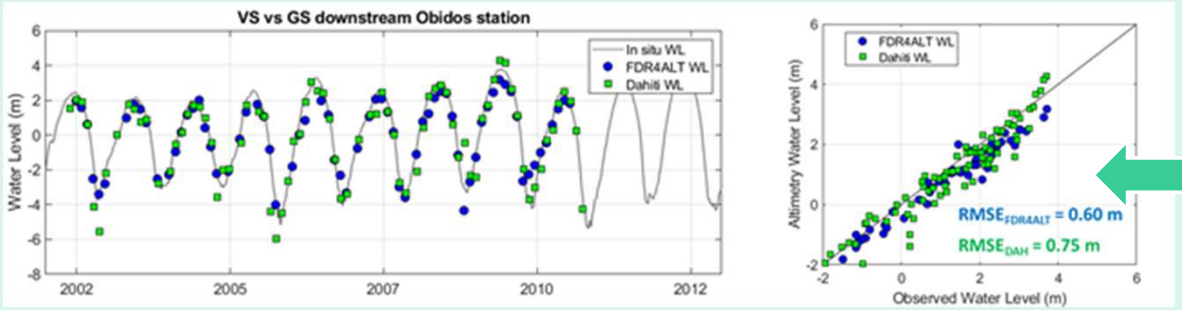


FDR4ALT products : TDP Inland Waters

Main variables

Water Surface Height (WSH)
Quality Flag
WSH uncertainty
Geoid
Occurrence of Water (PEKEL)
Surface Type from GLWD

- ✓ **Quality flag** based on the NN waveform classification indicated **good**, **medium** of **bad** quality
- ✓ **Uncertainty** computed as the quadratic sum of the uncertainty from each component of the WSH
- ✓ **Range** from Ice-1 Retracker
- ✓ Outputs from other retrackers available in expert group



Comparison between altimetry and observed water levels at Obidos station (Amazon)

Performances on rivers :

Products have been compared to ground stations for 3 rivers Po, Amazon and Godavari rivers

The FDR4ALT dataset often shows similar or better performances compared to the Dahiti* dataset

(*) Database for Hydrological Time Series of Inland Waters

Range resolution systematically ~1.8m for ERS on land w.r.t 0.48cm for ENVISAT
→ Limiting aspect to exploit ERS data on land

➢ First dataset oriented towards inland waters for these missions → Very valuable for the users !

Conclusions & Perspectives

→ The newly reprocessed products show clear improvements with respect to the former datasets REAPER and ENVISAT V3.0.

→ One paper has already been published regarding performances of the Sea-Ice TDP (https://doi.org/10.5194/tc-17-3013-2023), and two others are in preparation (Land-Ice Paper& General project paper)

→ Products will be soon available to the user with the associated documentation (Product User Guide available)

… What's next ? A follow-on of the project is already planned and will kick-off early 2024, to further improve the FDR4ALT products. Some improvements foreseen :

- ✓ Land-Ice : Application of the promising **CLS AMPLI** relocation solution on LRM (only exist in SAR for the moment)
- ✓ Ocean Waves : Investigation on wave groups and a possible **SSE correction**, complementary to the SSB solution
- ✓ New **WTC GDP+** correction to improve coastal performances
- ✓ Inland Waters : two distinct products for **rivers** and **lakes** and the state-of-the-art masking (SWOT)
- ✓ Improvement of the **uncertainty** characterization for Ocean Waves & Inland Waters
- ✓ Atmosphere : Improvement of the **1D-VAR** solution
- ✓ … and more ! Stay tuned ☺

Thank you

☺

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