A new CryoSat-2 regional product for ocean applications: the Cryo-TEMPO Coastal Ocean Thematic Product

F. Nencioli[1], S. Dinardo[1], T Zilio[1], J.-A. Deguze[1], A Sanchez Roman[2], A. Pascual[2], S. Labroue[1] and J. Bouffard[3]

[1] Collecte Localisation Satellites, [2] IMEDEA, [3] ESA

2022 OSTST, 2022-11-02

fnencioli@groupcls.com

CryoSat-2 achievements in the Coastal Ocean

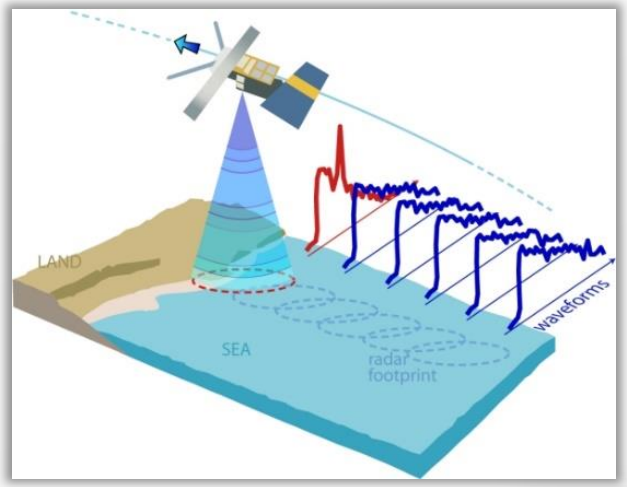
Although initially not a main objective of the mission
CryoSat-2 design offered **new capabilities for ocean observations**

- **Precursor of SAR mode processing over the ocean**
  Higher resolution and smaller footprint than traditional altimeters

- **Improvements over coastal areas**
  a. Better data coverage (reduced impact of land contamination)
  b. Higher precision (Lower SNR)
  c. Shorter spatial scale processes (<100 km)

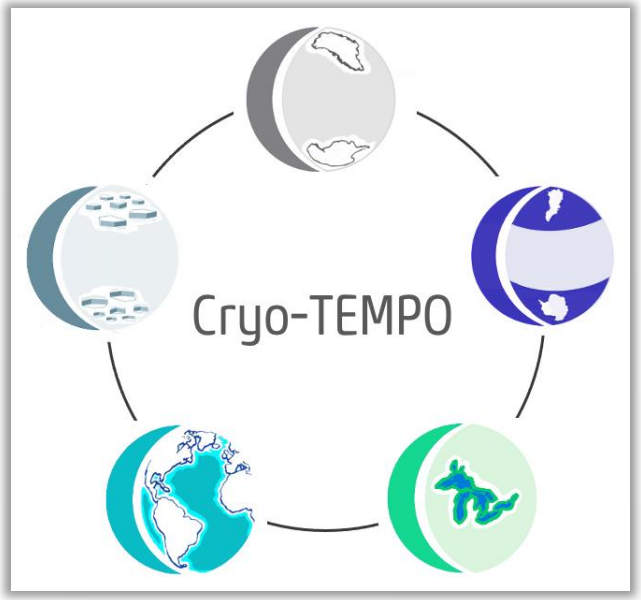
- **CryoSat-2 observations remain underutilized in oceanography**
  Definition of a regional coastal ocean product
  (**robust but simplified product** to expand the user community)

from https://earth.esa.int



from https://sentinel.esa.int

The Cryo-TEMPO project



Overarching goal

Develop **agile, robust, state-of-the-art** CryoSat-2 products dedicated to five Thematic Areas

1. Land Ice
2. Sea Ice
3. Polar Ocean
4. Coastal Ocean
5. Inland Waters

15 Institutions across Europe involved in the consortium

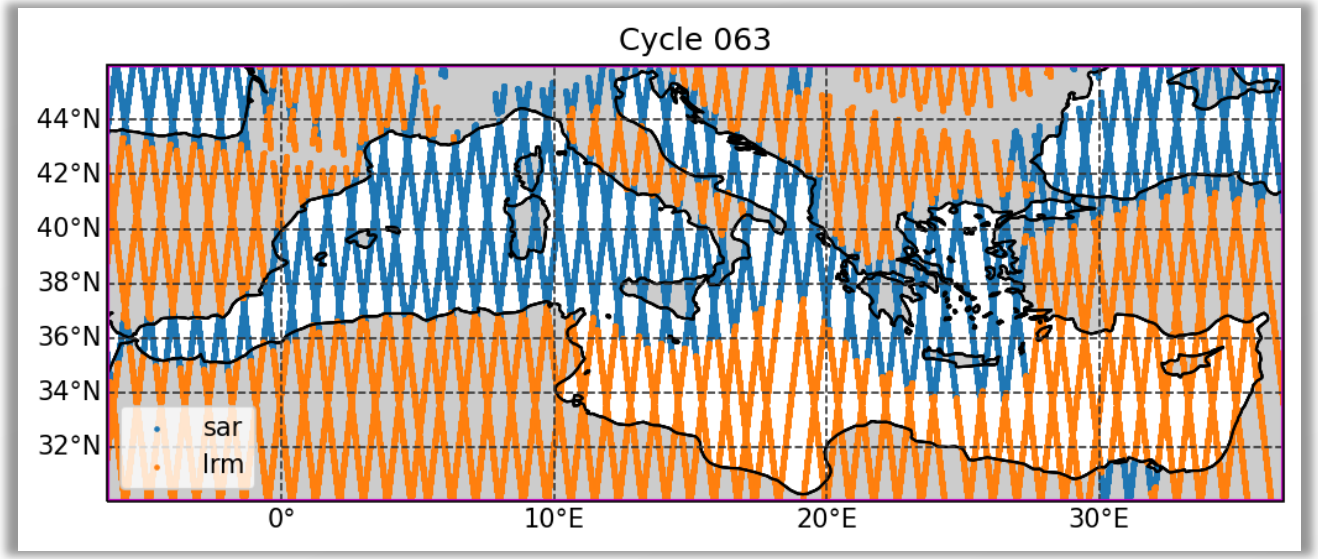
Lancaster University · cpom · AWI · LEGOS · DTU · irpi Istituto di Ricerca per la Protezione Idrogeologica · Shepherd SPACE ltd · NERSC · CLS · UCL Mullard Space Science Laboratory · ILMATIETEEN LAITOS METEOROLOGISKA INSTITUTET FINNISH METEOROLOGICAL INSTITUTE · NOVELTIS · UNIVERSITY OF LIVERPOOL · Instituto Mediterráneo de Estudios Avanzados · CSIC · Universitat

See also **poster SC42022-005**
Cryo-TEMPO: A new era of CryoSat-2 Thematic Products over Ice, Ocean and Inland Water
McMillan et al.

CLS

The Cryo-TEMPO Coastal Ocean TDP

Area of focus: Mediterranean Region



- ❑ Created from L1B and L2
- ❑ 20 Hz product
- ❑ GOP baseline-C product

Space

- ❑ -6.4 E to 36.5 E lon
- ❑ 30 N to 46 N lat

Mode

- ❑ SAR and LRM observations
- ❑ No SarIn (at the moment)

Time

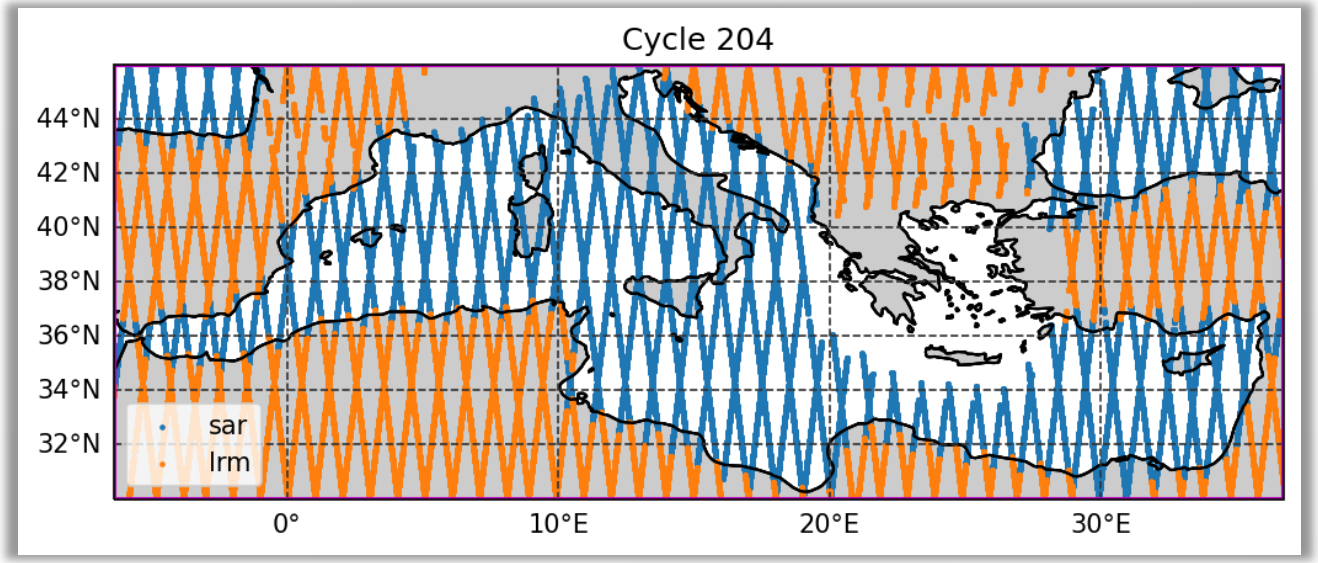
- ❑ 16 Jul 2010 to present (full CryoSat-2 mission)

Operational production

New observations updated on a monthly basis

The Cryo-TEMPO Coastal Ocean TDP

Area of focus: Mediterranean Region



Changes in CryoSat-2 mode mask after December 2015

- ❑ Created from L1B and L2
- ❑ 20 Hz product
- ❑ GOP baseline-C product

Space

- ❑ -6.4 E to 36.5 E lon
- ❑ 30 N to 46 N lat

Mode

- ❑ SAR and LRM observations
- ❑ No SarIn (at the moment)

Time

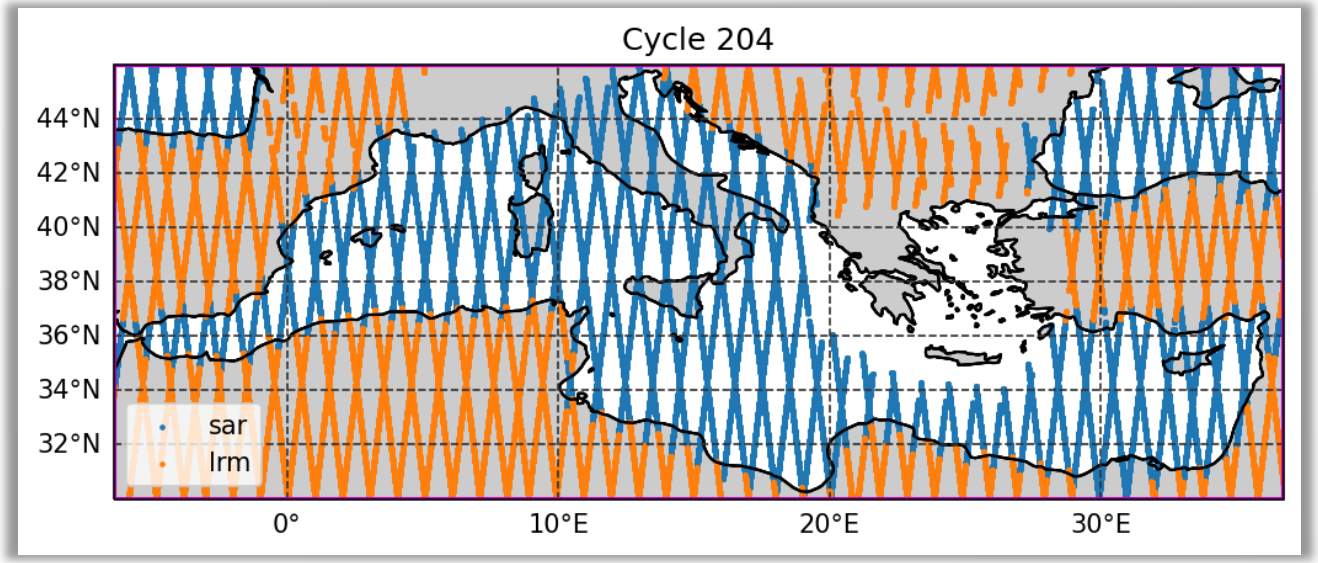
- ❑ 16 Jul 2010 to present (full CryoSat-2 mission)

Operational production

New observations updated on a monthly basis

The Cryo-TEMPO Coastal Ocean TDP

Area of focus: Mediterranean Region



- ❑ Created from L1B and L2
- ❑ 20 Hz product
- ❑ GOP baseline-C product

Space

- ❑ -6.4 E to 36.5 E lon
- ❑ 30 N to 46 N lat

Mode

- ❑ SAR and LRM observations
- ❑ No SarIn (at the moment)

Time

- ❑ 16 Jul 2010 to present (full CryoSat-2 mission)

Operational production

New observations updated on a monthly basis

Variables included

- Time
- Latitude
- Longitude
- Flags
- Variables
- Uncertainties

Flags

- ➢ Land/valid/invalid
- ➢ Instrument mode (LRM, SAR)

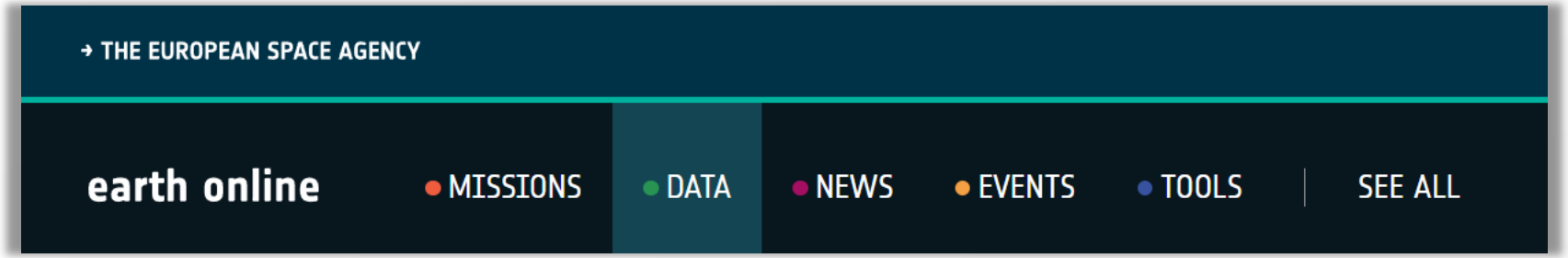
Variables (raw and filtered)

- ➢ SLA
- ➢ ADT

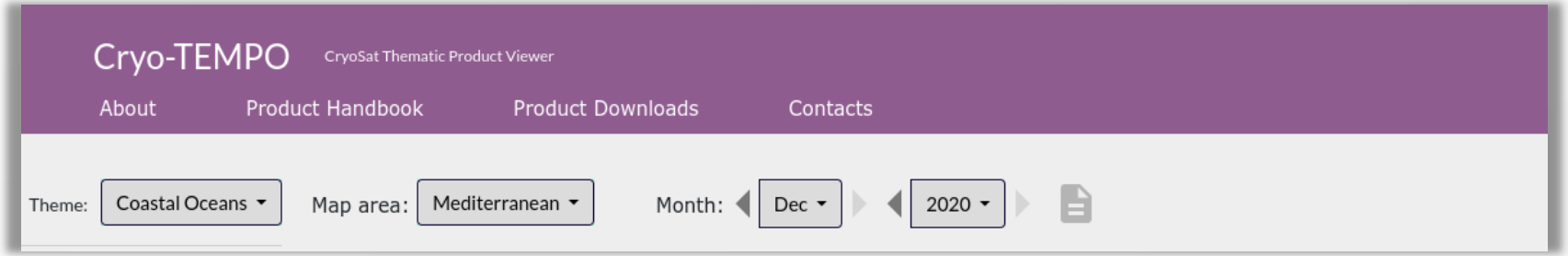
Accessing the Coastal Ocean TDP

Two main access points

1. The ESA CryoSat science server
https://earth.esa.int/eogateway/missions/cryostat/data

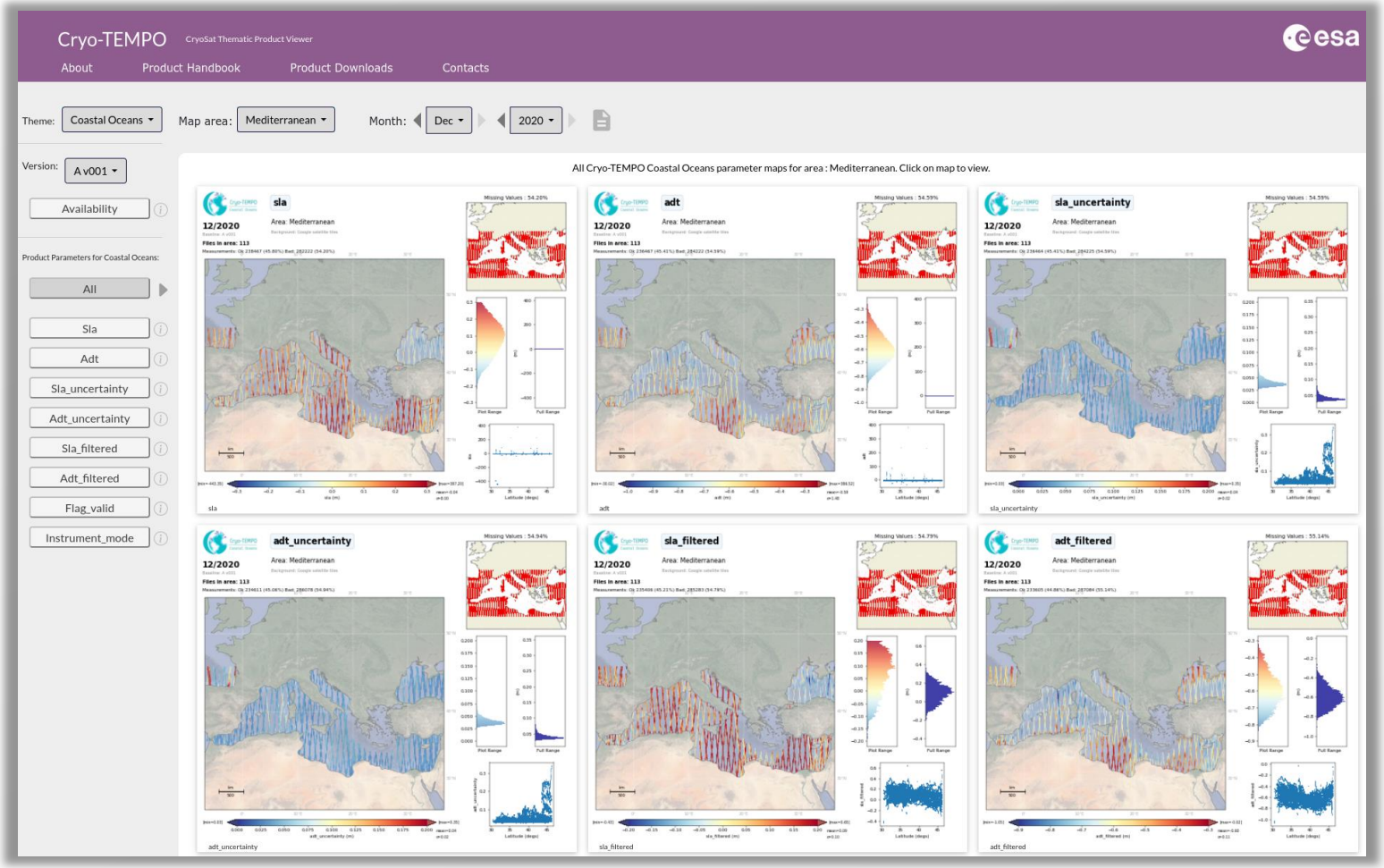


2. The Cryo-TEMPO web portal
http://www.cpom.ucl.ac.uk/cryotempo/index.php?theme=coastaloceans



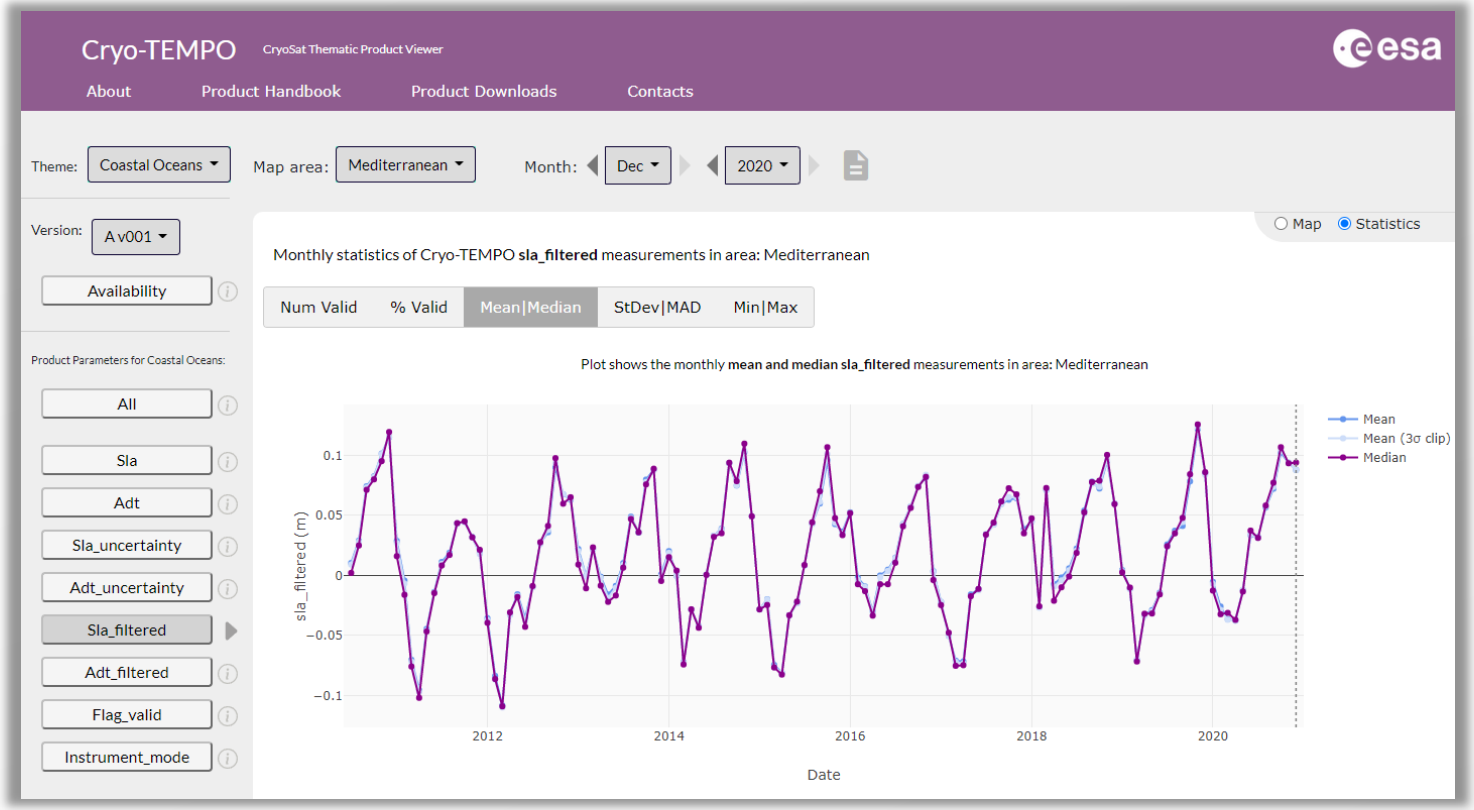
The Cryo-TEMPO web portal

- Easiest way to quickly access and visualize the data



The Cryo-TEMPO web portal

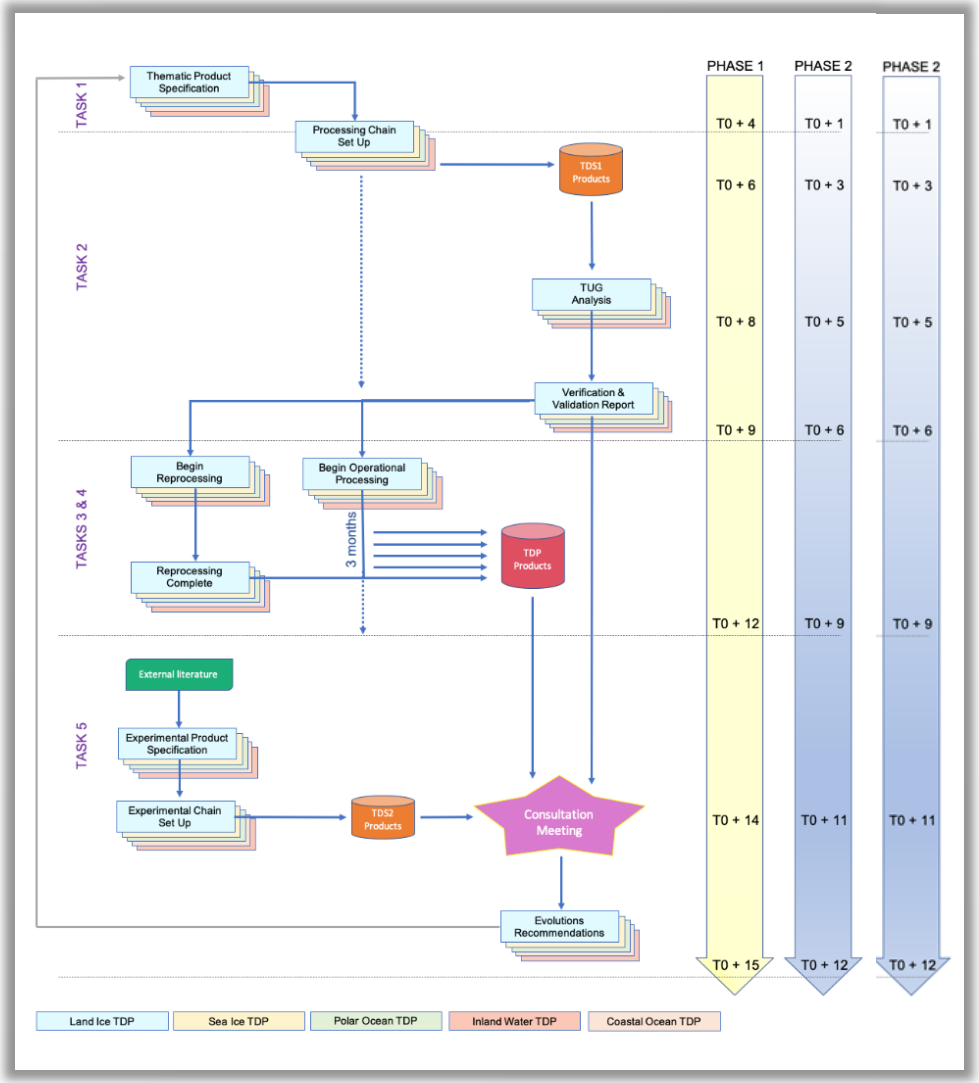
- Easiest way to quickly access and visualize the data



Time-series of average/median filtered SLA

http://www.cpom.ucl.ac.uk/cryotempo/index.php?baseline=A&version=001&parameter=sla_filtered&area=mediterranean&theme=coastaloceans&year=2020&month=12&map_or_stats_type=stats&availability_area=all&availability_type=files&stats_type=mean_median

The Cryo-TEMPO production cycle



- ❑ 3 year-long project
- ❑ 1 production cycle per year (3 total):

Task1: Thematic data product specification

Task2: Processing chain setup

Task3: Reprocessed product generation

Task4: Operational product generation

Task5: Definition of evolutions

Evolutions defined based on user comments/requirements: we need your feedbacks !!!

- Current status: Task3 of Phase2
- TDP1 completed and available
- TDP2 available by end of the month

The Cryo-TEMPO TDP1

Algorithm specifications

Wet troposphere	GPD+
Dry troposphere	ECMWF
Ionosphere	GIM
Altitude	WGS84
Retracker	**SAMOSA+ (SAR)** MLE4 (LRM)
Solid earth tide	Cartwright model
Ocean tide	FES 2014 B
Pole tide	**Desai 2015 with 2017 mean pole location**
DAC	MOG2D
SSB	**Tran 2018**
HFA	**Tran 2019 (only for LRM)**
MSS	**Composite (DTU, SCRIPPS,CNES-CLS15)**
MDT	**CMEMS_2020_MED**
Editing	**Iterative**
Filtering	**Lanczos low-pass**

Corrections from CryoSat-2 L2 products

- Provided at 1Hz
- Linearly Interpolated at 20Hz

CryoTEMPO specific corrections (in bold)

- **Pole Tide, MSS and MDT:**
  bilineraly interpolated from the reference fields
  (Pole Tide includes a LUT for pole position)
- Global MSS but MDT specific for the Mediterranean region
- **SSB, HFA, Editing and Filtering:**
  all based on 20Hz observations

More info in the Cryo-TEMPO Product Handbook:
http://www.cpom.ucl.ac.uk/cryotempo/pdf_viewer.php?theme=polaroceans

The Cryo-TEMPO TDP1

Algorithm specifications

Wet troposphere	GPD+
Dry troposphere	ECMWF
Ionosphere	GIM
Altitude	WGS84
Retracker	**SAMOSA+ (SAR)** MLE4 (LRM)
Solid earth tide	Cartwright model
Ocean tide	FES 2014 B
Pole tide	**Desai 2015 with 2017 mean pole location**
DAC	MOG2D
SSB	**Tran 2018**
HFA	**Tran 2019 (only for LRM)**
MSS	**Composite (DTU, SCRIPPS,CNES-CLS15)**
MDT	**CMEMS_2020_MED**
Editing	**Iterative**
Filtering	**Lanczos low-pass**

Corrections from CryoSat-2 L2 products

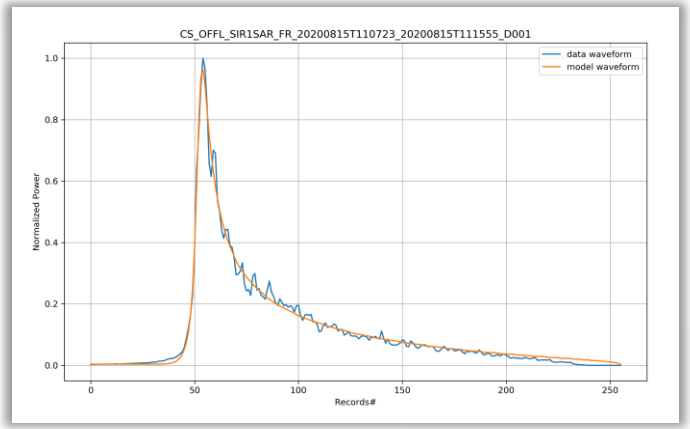
- Provided at 1Hz
- Linearly Interpolated at 20Hz

CryoTEMPO specific corrections (in bold)

- **Pole Tide, MSS and MDT:**
  bilineraly interpolated from the reference fields
  (Pole Tide includes a LUT for pole position)
- Global MSS but MDT specific for the Mediterranean region
- **SSB, HFA, Editing and Filtering:**
  all based on 20Hz observations

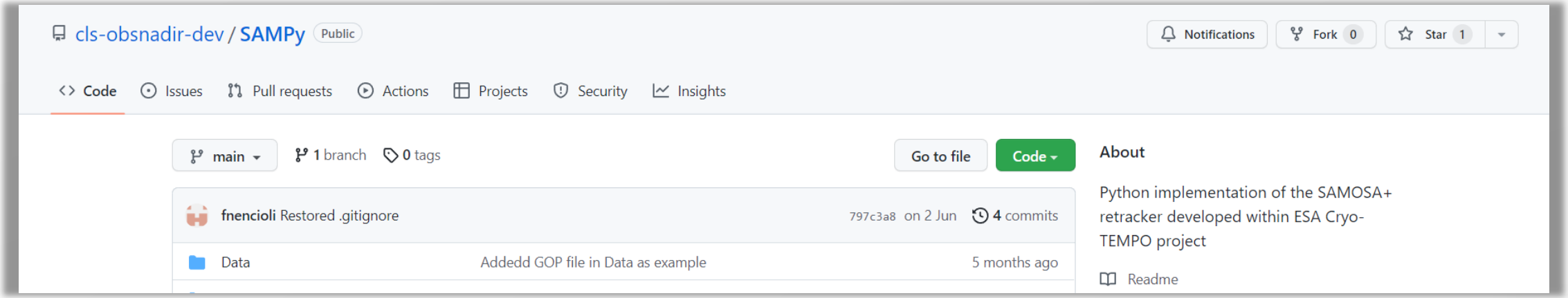
More info in the Cryo-TEMPO Product Handbook:
http://www.cpom.ucl.ac.uk/cryotempo/pdf_viewer.php?theme=polaroceans

The Cryo-TEMPO TDP1: SAMPy



- SAMOSA+: evolution of the SAMOSA retracker with enhanced performance in coastal regions (more info in Dinardo et al., 2018)
- Python implementation specifically developed for Cryo-TEMPO
- Validation performed vs analogous products from ESA GPOD

- Freely available GitHub repository of the Python implementation of the SAMOSA+ algorithm

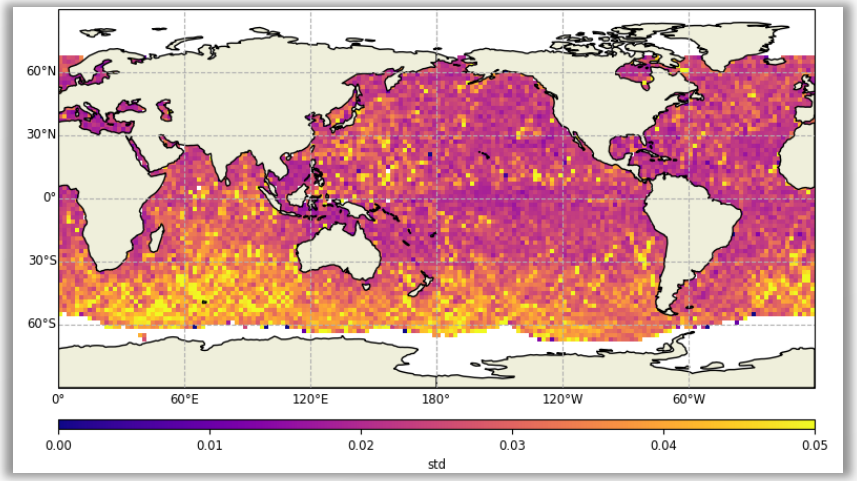


- https://github.com/cls-obsnadir-dev/SAMPy

The Cryo-TEMPO TDP1: HFA

- Correction for the correlation between significant wave height (SWH) and range errors
- Dependent on swell at the sea surface
- Computed based on **empirical models/relations** (in form of LUT)
- Correction **only for LRM @ 20Hz** (no SAR equivalent) (<u>however surface flag provided at 1 Hz</u>)

Example of SLA error: J3 20 Hz Cycle 20



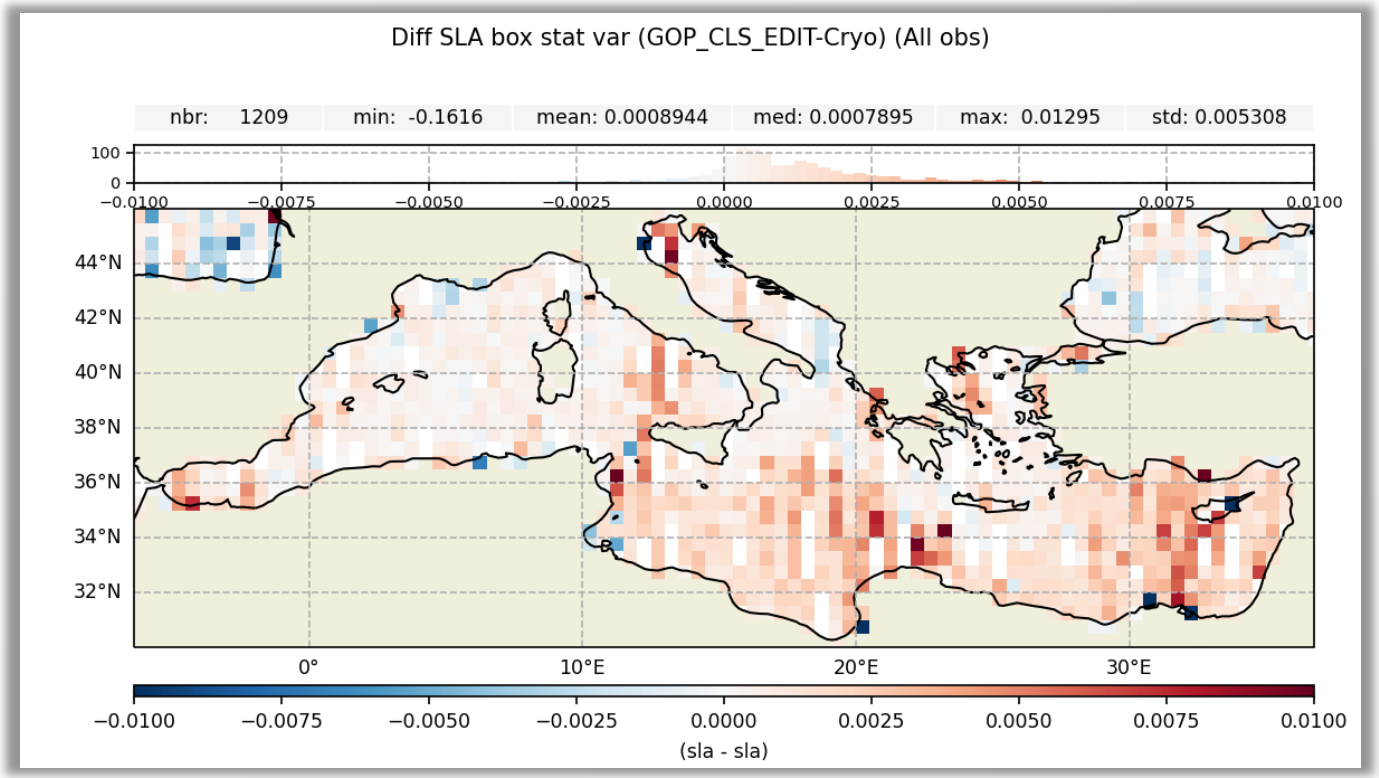
1. SWH @ 20 Hz filtered (Lanczos2 with 200 pts half widh window)
2. Portion of SWH residual converted into HFA correction (empirical relation dependent on local values of filtered SWH)

<u>Known issue</u> (to be verified for CryoTEMPO):

- Slight degradation of mesoscale (>50 km scale)

The Cryo-TEMPO TDP1: HFA

- Validation of the TDP1 performed against the GOP product
- Map of averaged SLA variance difference (1°x1° boxes) between GOP and Cryo-TEMPO



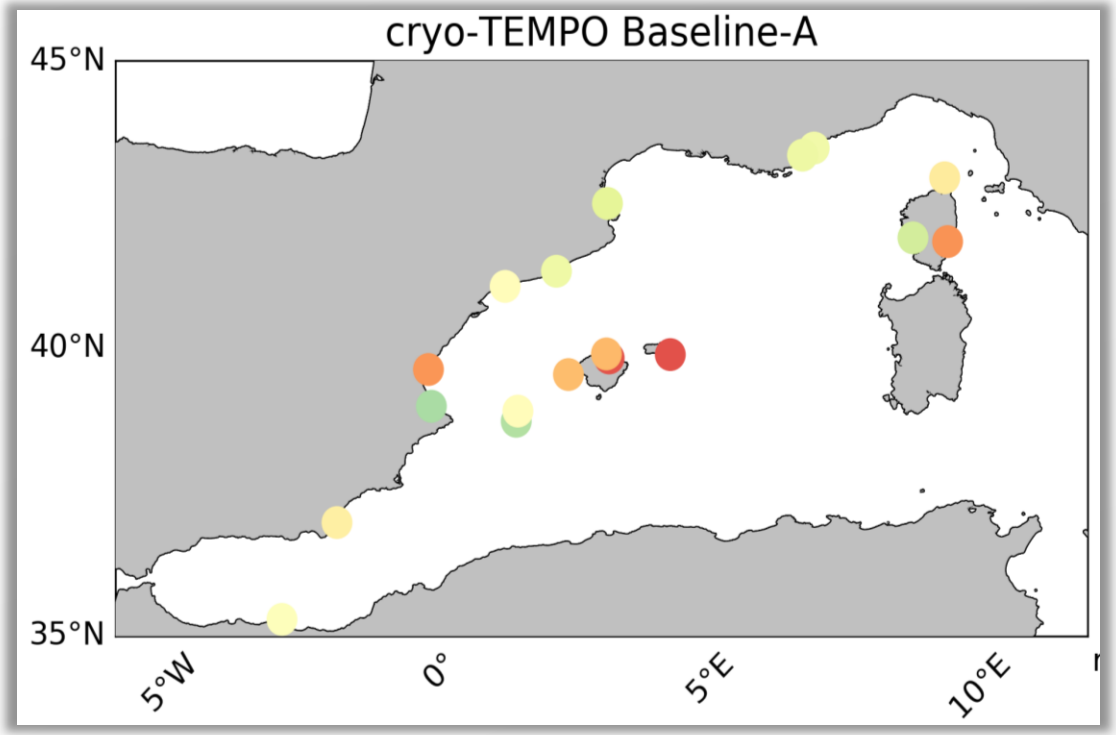
- Variance reduced mostly everywhere (reduced noise)
- Largest reduction in the LRM region
- Effect of the HFA correction

The Cryo-TEMPO TDP1: Comparison with in-situ

Sea Level assessment: comparison vs tide gauges in western Mediterranean sea

- Tide gauge records processed according to Sánchez-Román et al. (2020):
  - Removed tidal components
  - Dynamic Atmospheric correction from AVISO website
  - Corrected vertical movements from glacial isostatic adjustment (GIA)

❑ 18 tide gauge stations available for the inter-comparisons with CryoSat-2

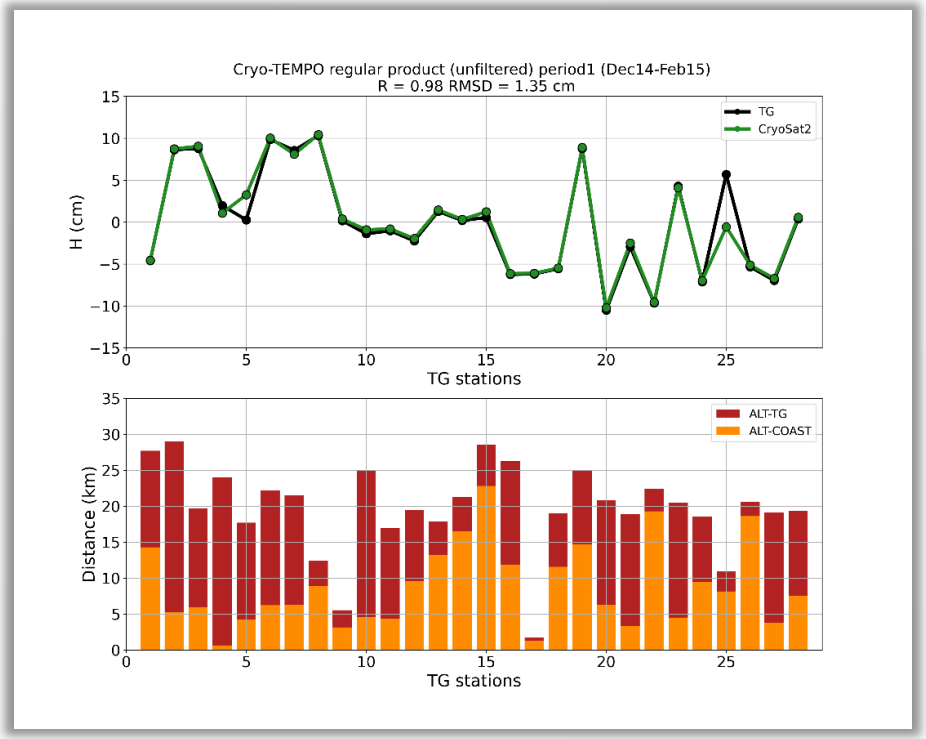


The Cryo-TEMPO TDP1: Comparison with in-situ

Sea Level assessment: comparison vs tide gauges in western Mediterranean sea

- Tide gauge records processed according to Sánchez-Román et al. (2020):
  - Removed tidal components
  - Dynamic Atmospheric correction from AVISO website
  - Corrected vertical movements from glacial isostatic adjustment (GIA)

Dec 14 - Feb 15



Raw SLA

- Very good correlation (0.98)…
- …probably too good !!!
- Limitations in the approach used for the comparison, due to short time span of TDS
- **Better results than official product** (not shown)

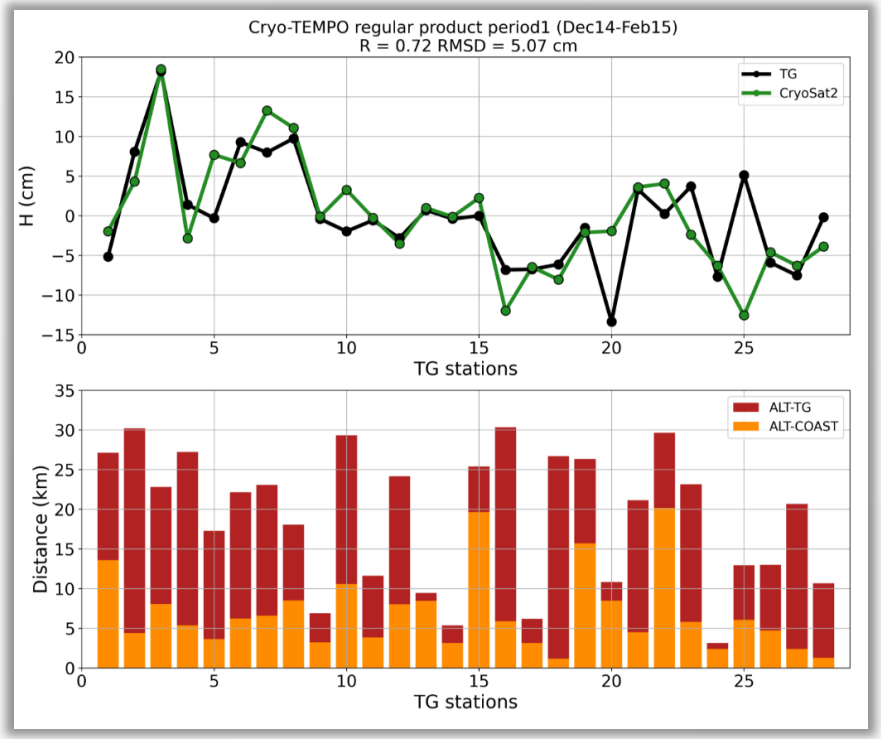
The Cryo-TEMPO TDP1: Comparison with in-situ

Sea Level assessment: comparison vs tide gauges in western Mediterranean sea

- Tide gauge records processed according to Sánchez-Román et al. (2020):
  - Removed tidal components
  - Dynamic Atmospheric correction from AVISO website
  - Corrected vertical movements from glacial isostatic adjustment (GIA)

Dec 14 - Feb 15

Western Mediterranean Sea	Regular product	
	Period 1	Period 2
R	0,72	0,84
RMSD (cm)	5,07	2,44
Variance TG (cm^2)	43	17
Variance ALT (cm^2)	49	20
Variance TG-ALT (cm^2)	26	6
Distance to tide gauge (km)	19	18
Distance to coast (km)	7	8
Stations	28	23



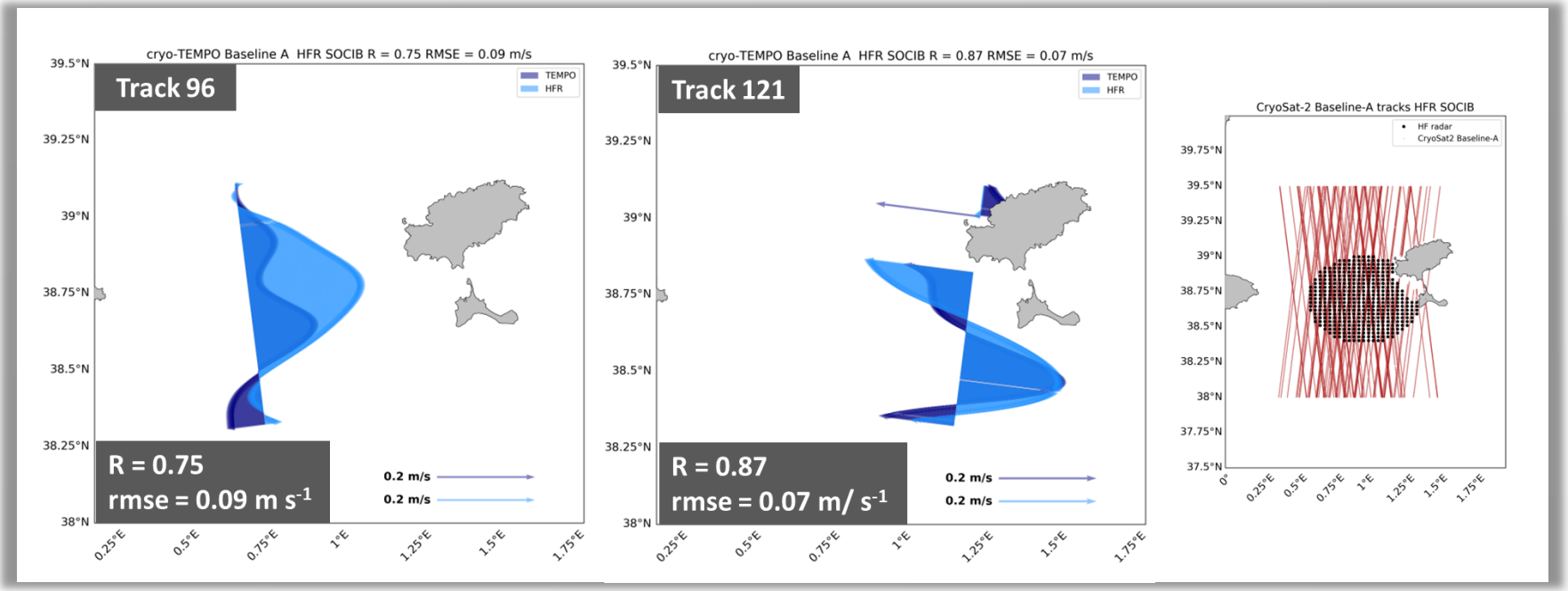
Filtered SLA

- Overall consistency between Cryo-TEMPO filtered SLA and TG records
- Correlations in line with those reported for Jason-3 and Sentinel-3A in the region (although larger RMSE)
- Further refinement of the analysis is currently performed

The Cryo-TEMPO TDP1: Comparison with in-situ

Surface current assessment: comparison vs HF radar velocities in the Balearic sea

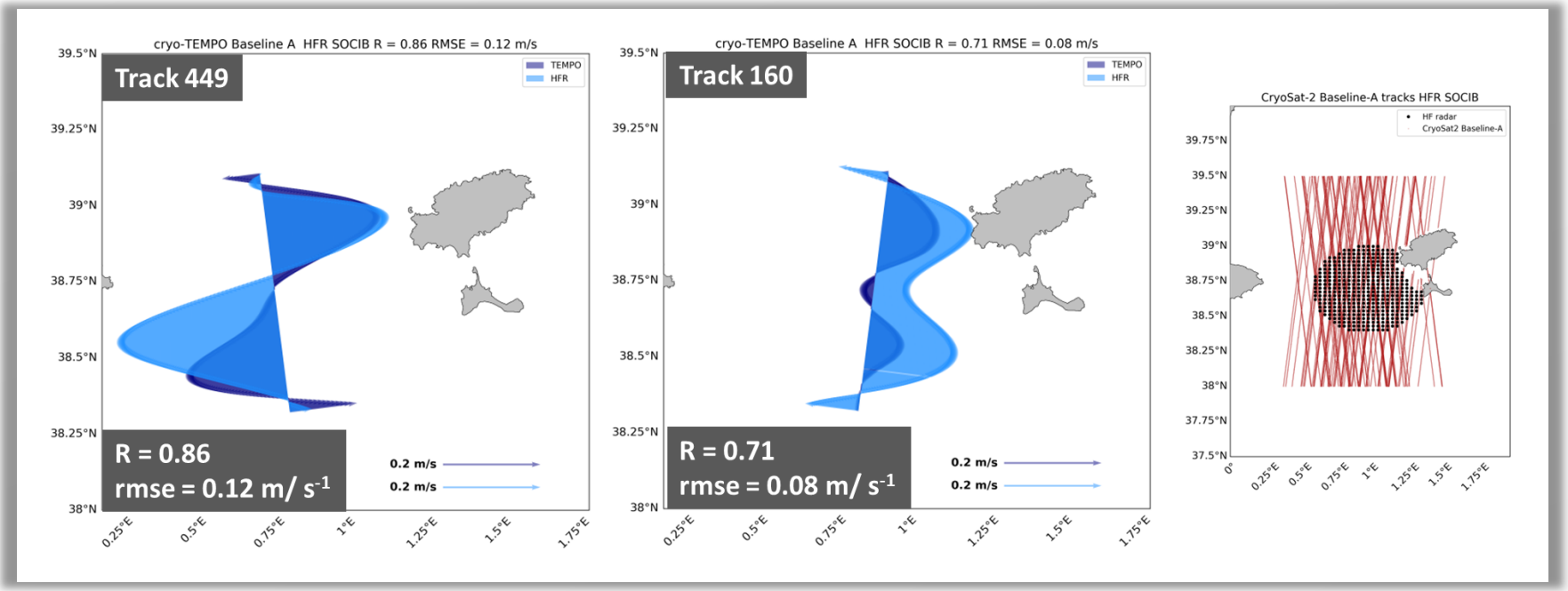
- HFR data processed according to the methodology proposed by Mulero-Martínez et al. (2021)
  - Butterworth low-pass filter (48-hours cut-off period) to remove the high frequency signal
  - HFR velocity bilinearly interpolated over the altimeter track measurement positions
  - Low-pass Loess filter (43 km cut-off wavelength) to remove the high frequencies not resolved by altimetry



The Cryo-TEMPO TDP1: Comparison with in-situ

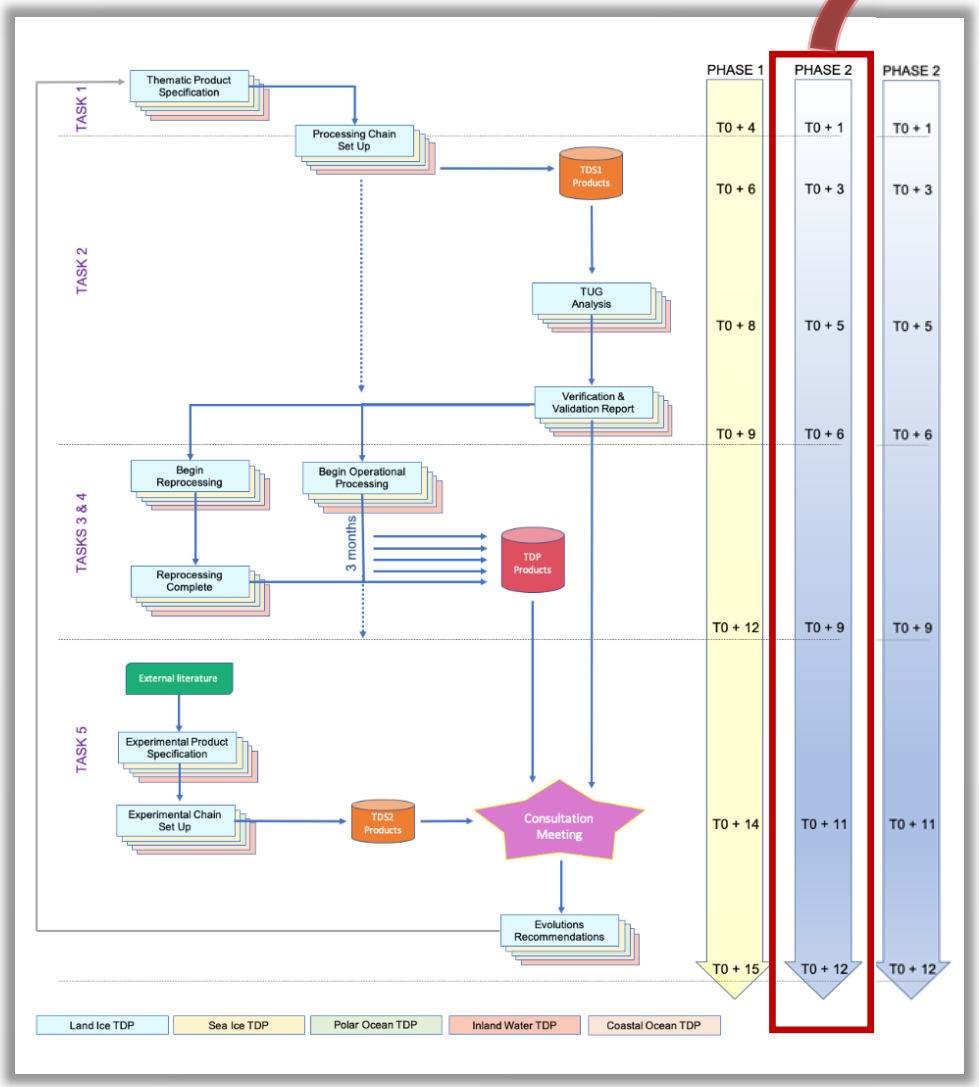
Surface current assessment: comparison vs HF radar velocities in the Balearic sea

- HFR data processed according to the methodology proposed by Mulero-Martínez et al. (2021)
  - Butterworth low-pass filter (48-hours cut-off period) to remove the high frequency signal
  - HFR velocity bilinearly interpolated over the altimeter track measurement positions
  - Low-pass Loess filter (43 km cut-off wavelength) to remove the high frequencies not resolved by altimetry



- Overall consistency between Cryo-TEMPO geostrophic velocities and HFR records
- Errors between the two smaller than previously reported from analogous comparison for Saral-AltiKa observations

Evolutions for TDP2



1. Improvements to uncertainty estimation
2. Implement dedicated processing near the coast (i.e. interpolation, filtering and stitching)
3. Add distance-to-coast variable to dataset
4. Update CryoSat-2 specific tuning of correction parameters
5. Remove land points from dataset
6. Add the **Black Sea** as new area
7. Include **Regional tide model** (collaboration with Noveltis)

The Cryo-TEMPO TDP2: Uncertainty estimates

Uncertainty Estimation: Small-wavelength errors (SWE)

- Errors associated with individual measurement
- Mostly due to **SWH** and **Distance from the Coast**

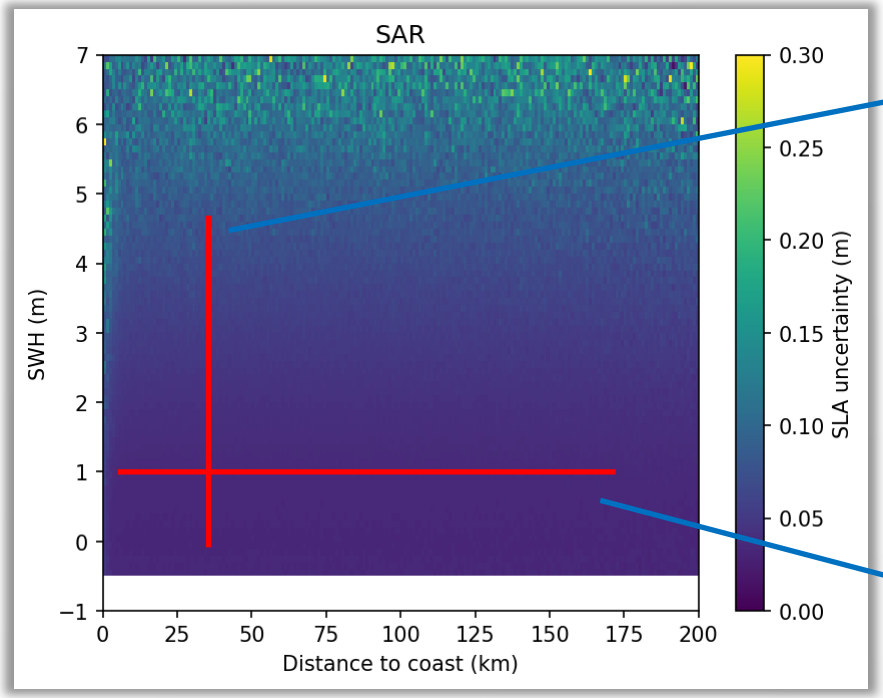
Hypothesis: consecutive measurements @20 Hz observe roughly the same conditions

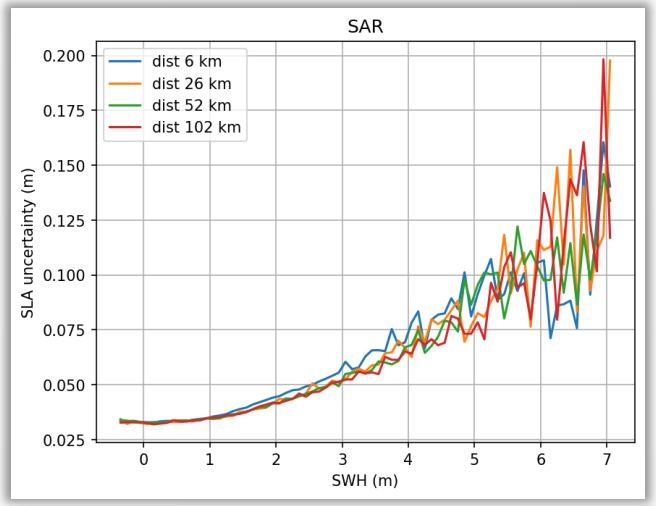
SLA difference of consecutive observations binned wrt to

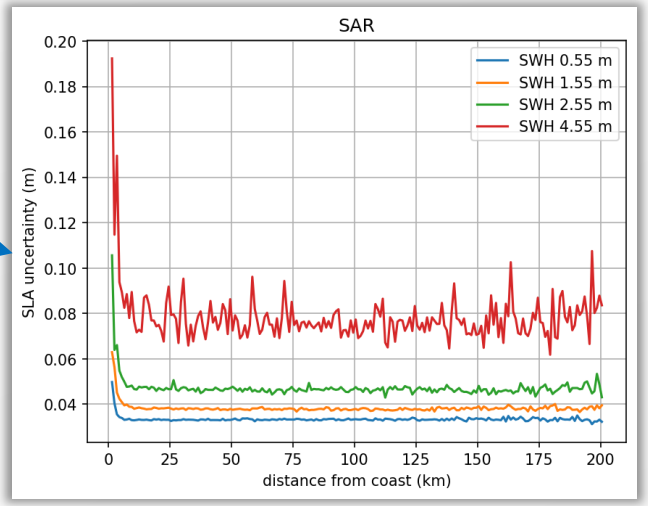
- ❑ SWH (every 10 cm)
- ❑ Distance from the coast (every 1 km)

Error = Standard deviation of the difference within each bin / sqrt(2)

The Cryo-TEMPO TDP2: Uncertainty estimates







- Error increases with increasing SWH
- For a given SWH, error does not vary up to < 5 km from the coast

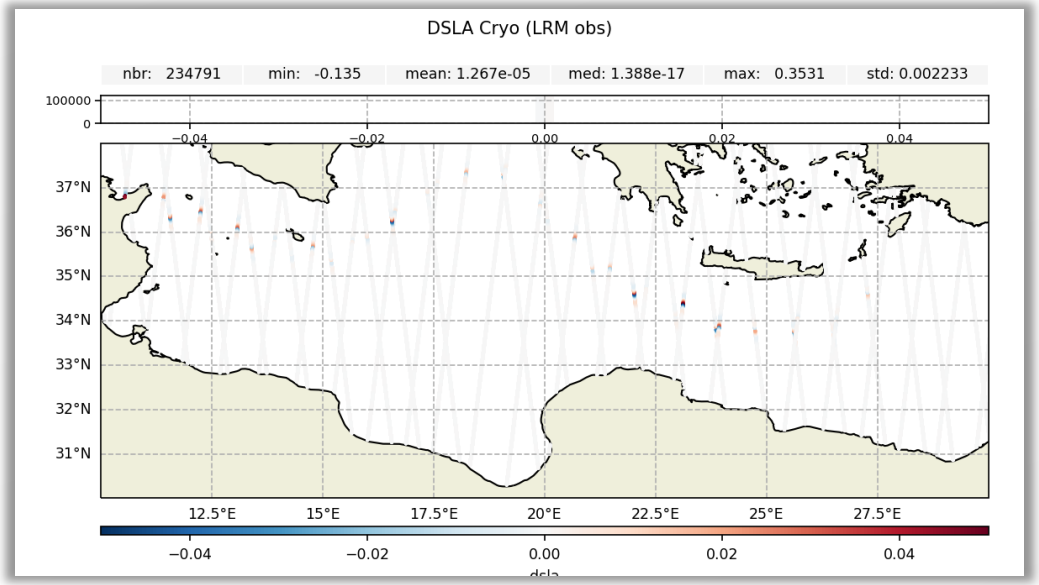
(CryoSat-2 uses modelled WTC)

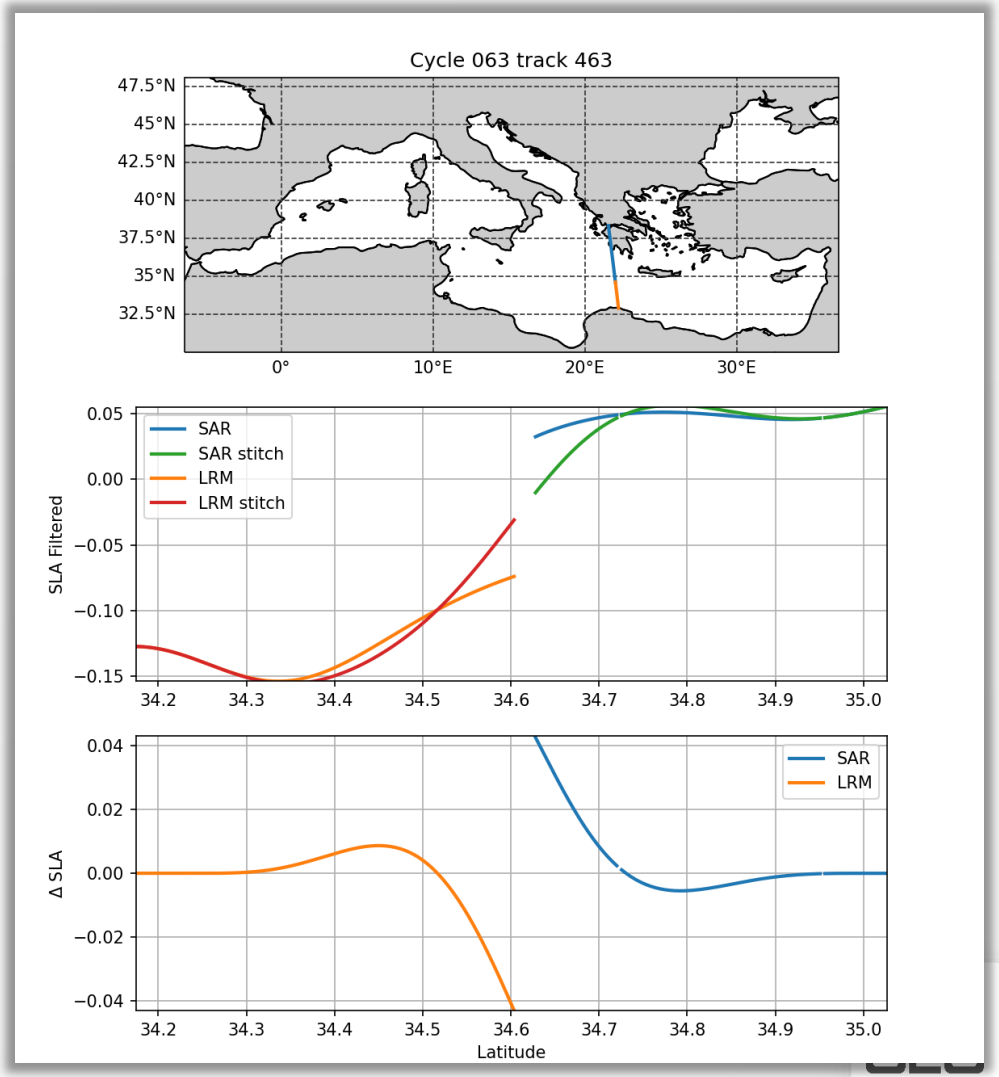
- Error increases within 5 km from the coast

CryoTEMPO TDP2: Filtering/stitching SAR and LRM granules

- Filter SLA after stitching the individual granules

Analysis of SAR/LRM bias: TDS1 vs TDS2 (Cycle063)

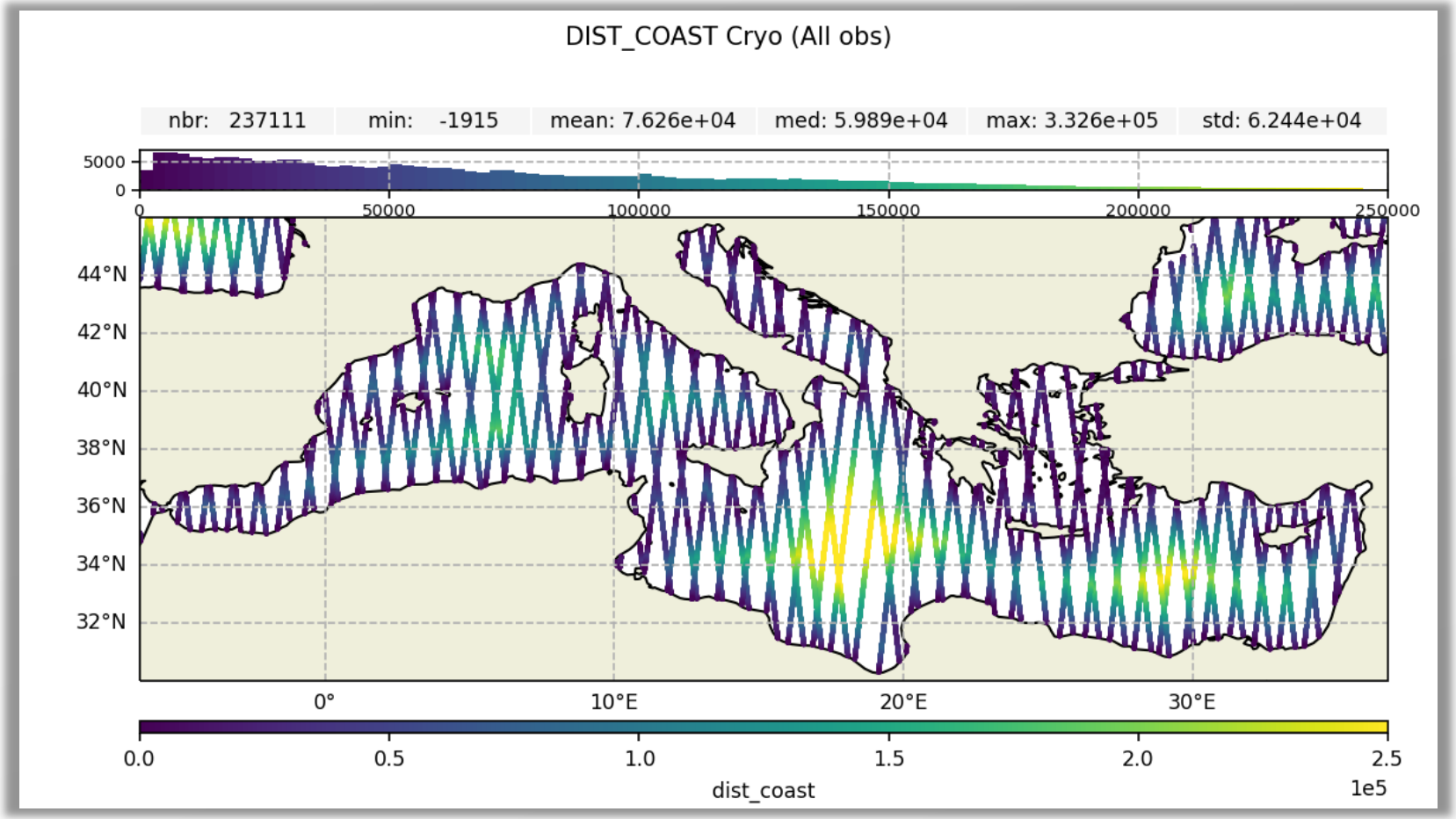




- Filtering after stitching can reduce differences in filtered SLA at the interface
- More consistent transition between SAR and LRM filtered SLA

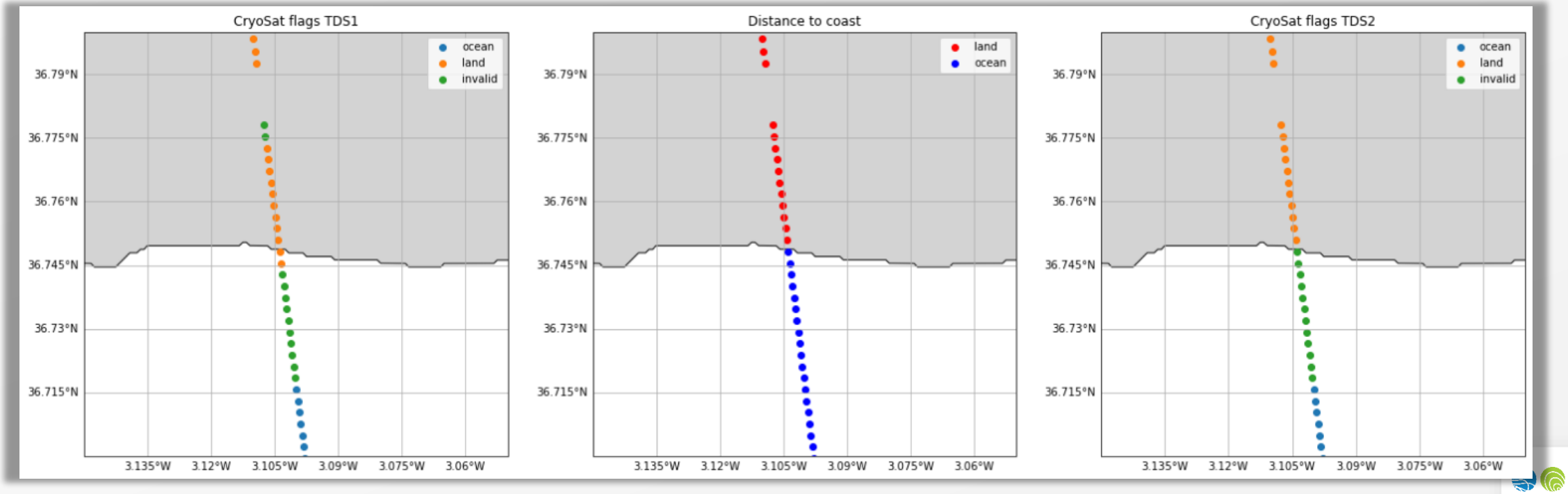
CryoTEMPO TDP2: Added Distance to the Coast

- Computed based on GSHHG database https://www.soest.hawaii.edu/pwessel/gshhg/



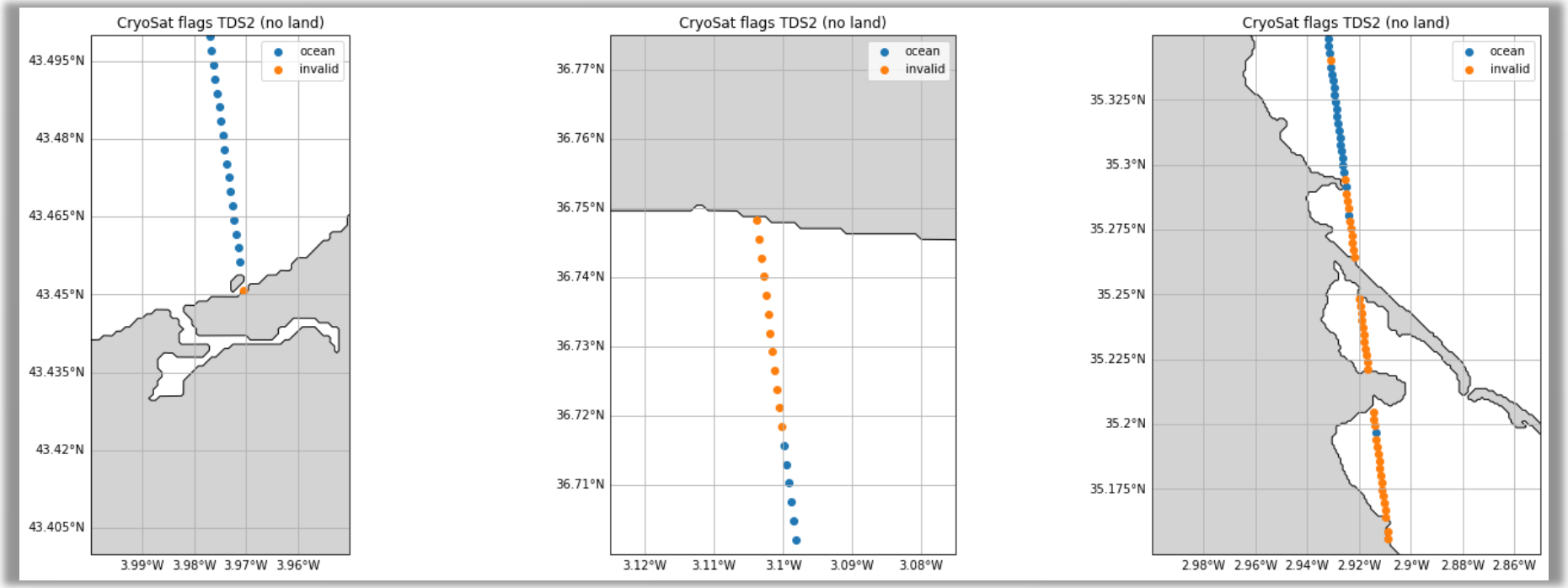
The Cryo-TEMPO TDP2: Coastal masking

- **In future TDP2**: improved land flagging (compared to GOP product) based on on GSHHG database https://www.soest.hawaii.edu/pwessel/gshhg/



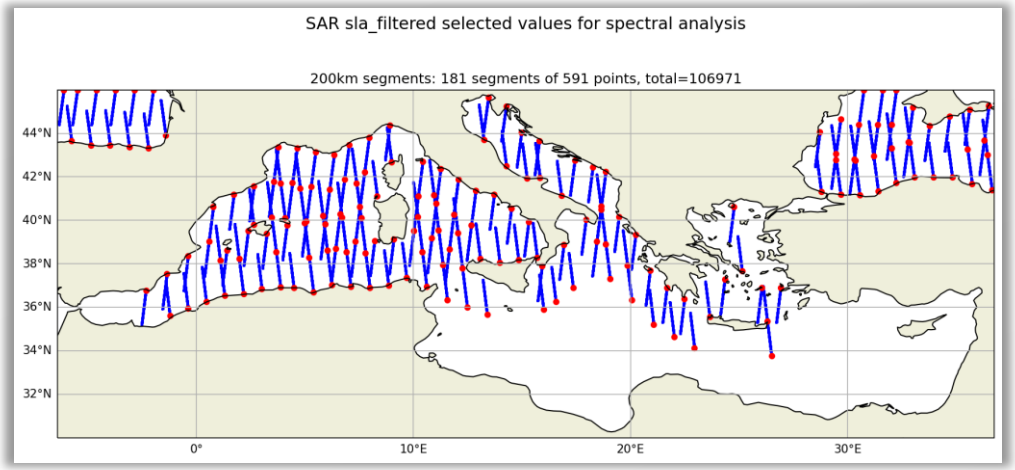
The Cryo-TEMPO TDP2: Coastal masking

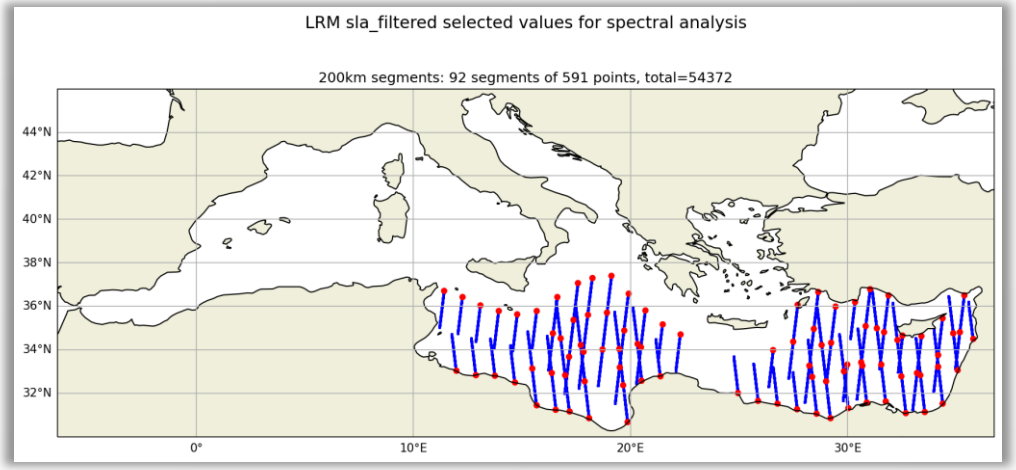
- **In future TDP2**: improved land flagging (compared to GOP product) based on on GSHHG database https://www.soest.hawaii.edu/pwessel/gshhg/
- Large number of invalid points (especially around complex morphologies)
- Improved interpolation/extrapolation methods for geophysical corrections to be explored

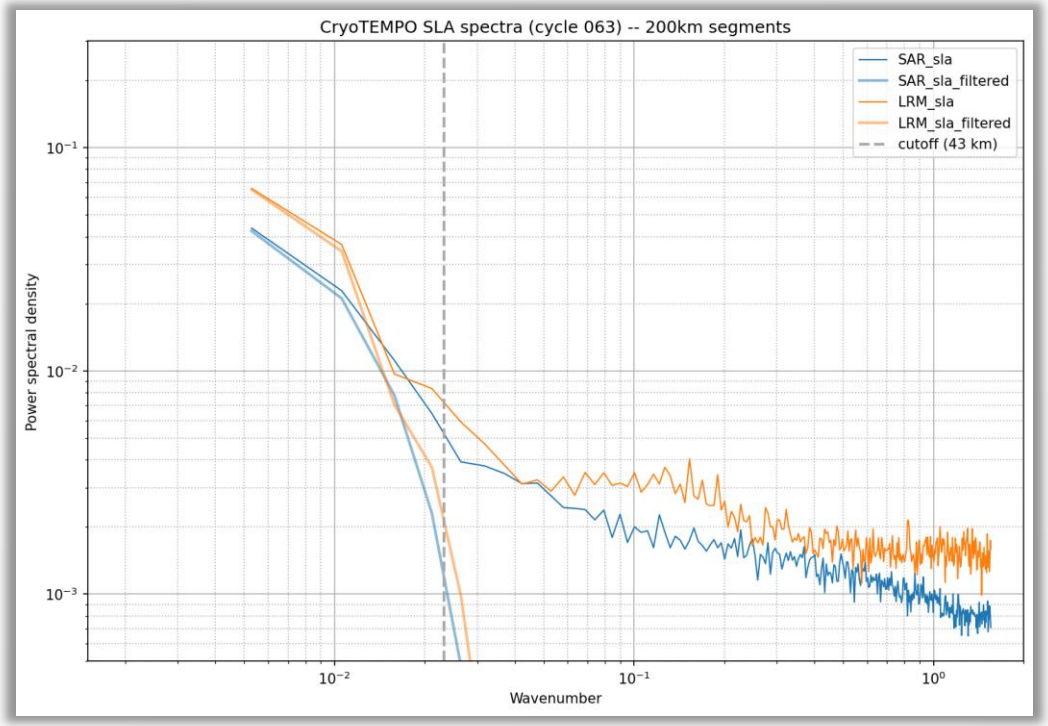


CryoTEMPO TDP2: Tuning of Correction Parameters

- Spectral analysis: **raw vs filtered SLA**







- Maybe cutoff too large?
- Could be closer to the LRM plateau
- Smaller cutoff (25 km) to be further tested with the TUGs

Conclusions

- CryoSat-2 observations remain underutilized in oceanography despite the advantages of SAR technology
- Dedicated CryoTEMPO regional coastal product in the Mediterranean sea
- Initial comparison with in-situ observations shows analogous or better performance than existing satellites
- Still room for improvements in the near-shore region (<5 km from the coast)
- Iterative cycle to improve Cryo-TEMPO products each year
- User feedbacks will be an integral part of the process to further improve the product performance near the coast

fnencioli@groupcls.com