# Sea level variability in the Strait of Gibraltar from along-track high spatial resolution altimeter products

**Jesús Gómez-Enri (1), Stefano Vignudelli (2), Alfredo Izquierdo (1), Marcello Passaro (3), Carlos José González (1), Paolo Cipollini (4), Miguel Bruno (1), Óscar Álvarez (1), Rafael Mañanes (1)**

**(1)** UCA Universidad de Cádiz

**(2)** Consiglio Nazionale delle Ricerche

**(3)** TUM Technischen Universität München

**(4)** esa European Space Agency

**International Review Workshop on Satellite Altimetry CAL/VAL Activities and Applications (Chania – Crete – Greece, 23-26 April 2018)**

# OUTLINE

- OBJECTIVE
- STUDY AREA
- DATA SETS AND METHODS
- RESULTS
- CONCLUSIONS
- ACKNOWLEDGMENTS

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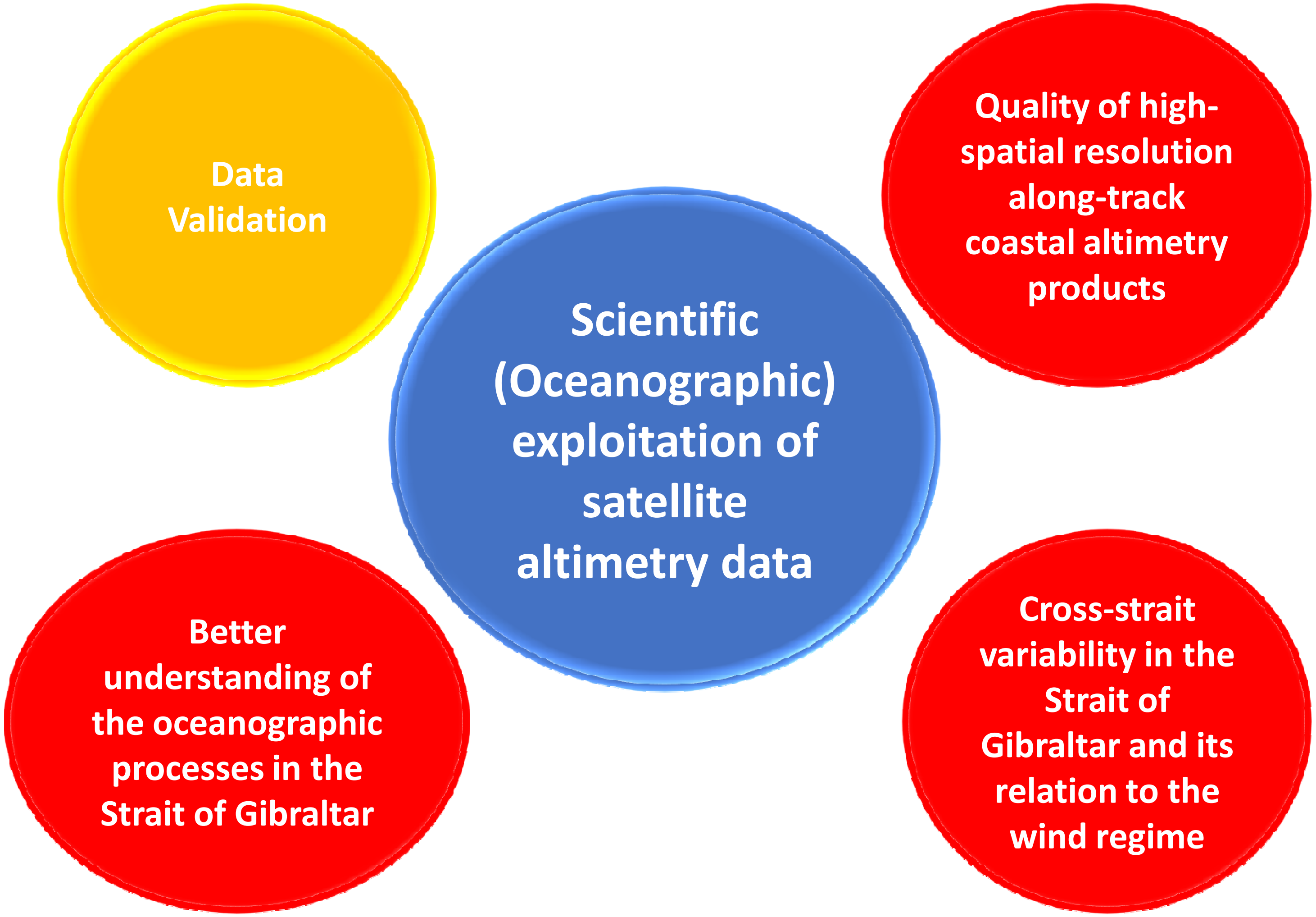

Sea level variability in the Strait of Gibraltar from along-track high spatial resolution altimeter products

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Data Validation

Better understanding of the oceanographic processes in the Strait of Gibraltar

wind regime

IEEE TRANSACTIONS ON GEOSCIENCE AND REMOTE SENSING, VOL. 54, NO. 9, SEPTEMBER 2016 5455

# Coastal Altimetry Products in the Strait of Gibraltar

Jesús Gómez-Enri, Paolo Cipollini, *Senior Member, IEEE*, Marcello Passaro, Stefano Vignudelli, Begoña Tejedor, and Josep Coca

**Abstract—This paper analyzes the availability and accuracy of coastal altimetry sea level products in the Strait of Gibraltar. All possible repeats of two sections of the Envisat and AltiKa groundtracks were used in the eastern and western portions of the strait. For Envisat, along-track sea level anomalies (SLAs) at 18-Hz posting rate were computed using ranges from two sources, namely, the official Sensor Geophysical Data Records (SGDRs) and the outputs of a coastal waveform retracker, the Adaptive Leading Edge Subwaveform (ALES) retracker; in addition, SLAs at 1 Hz were obtained from the Centre for Topographic studies of the Ocean and Hydrosphere (CTOH). For AltiKa, along-track SLA at 40 Hz was also computed both from SGDR and ALES ranges. The sea state bias correction was recomputed for the ALES-retracked Envisat SLA. The quality of these altimeter products was validated using two tide gauges located on the southern coast of Spain. For Envisat, the availability of data close to the coast depends crucially on the strategy followed for data screening. Most of the rejected data were due to the radar instrument operating in a low-precision nonocean mode. We observed an improvement of about 20% in the accuracy of the Envisat SLAs from ALES compared to the standard (SGDR) and the reprocessed CTOH data sets. AltiKa shows higher accuracy, with no significant differences between SGDR and ALES. The use of products from both missions allows longer times series, leading to a better understanding of the hydrodynamic processes in the study area.**

***Index Terms*—Coastal altimetry, data screening, retracking, Strait of Gibraltar (SoG), tide gauge, validation.**

## I. Introduction

COASTAL altimetry has become a mature discipline owing to the effort of many research groups and institutions [1].[1]

A global analysis of the sea level variability near the coasts using satellite altimeter data is now a realistic prospect by virtue of the availability of new reprocessed data with higher along-track spatial resolutions and better accuracy. However, putting this into effect requires a consistent validation effort.

Reprocessing efforts are targeting the two main factors that compromise the availability and quality of altimeter data near the coasts with respect to open ocean: 1) inaccuracies in the retrieval of geophysical information from the shape of the mean returned waveforms from the reflected surface (this retrieval is normally done by some waveform fitting procedures known as *retracking*) and 2) a poorer characterization of some of the geophysical corrections applied to the data. Present altimetry missions (Cryosat-2, AltiKa, and Jason-2) and near-future ones (Sentinel-3, Jason-3, and Sentinel-6/Jason-CS) minimize the impact of these factors on data quality by virtue of state-of-the-art radiometric performance (Cryosat-2, AltiKa, and Jason-2), use of the Ka-band that allows smaller footprints (AltiKa), and SAR-mode operation (Cryosat-2 and all future missions). For past missions (ERS-1/2, Topex/Poseidon, Envisat, GFO, and Jason-1), more efforts still need to be made in order to include their products in coastal applications and models [2].

A radar altimeter measures the two-way travel time of the emitted/reflected signal/echo and the returned power. The amount of energy received is recorded onboard in a time series called a "waveform." The pulse repetition frequency (PRF)

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# Sea level variability in the Strait of Gibraltar from along-track high spatial resolution altimeter products

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IEEE TRANSACTIONS ON GEOSCIENCE AND REMOTE SENSING, VOL. 54, NO. 9, SEPTEMBER 2016 5455

Strait of Gibraltar

EE, Marcello Passaro,
sep Coca

Overall, the results for the reprocessed ALES Envisat are improved compared to the standard (SGDR) and the reprocessed CTOH data sets. The mean along-track rmse in the Strait between ALES and the tide gauge is below 14/12 cm (D#0360/A#0831), which represents about a 20% improvement with respect to the SGDR.

were obtained from the Centre for Topographic studies of the Ocean and Hydrosphere (CTOH). For AltiKa, along-track SLA at 40 Hz was also computed both from SGDR and ALES ranges. The

The validation of the time series of SLA using ground-truth data has demonstrated that a more accurate *SSB* correction improves the comparison against *in situ* data.

shows higher accuracy, with no significant differences between SGDR and ALES. The use of products from both missions allows longer times series, leading to a better understanding of the hydrodynamic processes in the study area.

*Index Terms*—Coastal altimetry, data screening, retracking, Strait of Gibraltar (SoG), tide gauge, validation.

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# Sea level variability in the Strait of Gibraltar from along-track high spatial resolution altimeter products

OCTOBER 1989 MYRIAM BORMANS AND CHRIS GARRETT 1543

**The Effects of Nonrectangular Cross Section, Friction, and Barotropic Fluctuations on the Exchange through the Strait of Gibraltar**

MYRIAM BORMANS AND CHRIS GARRETT

*Department of Oceanography, Dalhou*

(Manuscript received 3 Augu

GEOPHYSICAL RESEARCH LETTERS, VOL. 27, NO. 18, PAGES 2949-2952, SEPTEMBER 15, 2000

**Western Mediterranean sea-level rise: changing exchange flow through the Strait of Gibraltar**

Tetjana Ross and Chris Garrett

Department of Physics and Astronomy, University of Victoria, B.C., Canada.

Pierre-Yves Le Traon

Oceanography Department, CLS Space C

GEOPHYSICAL RESEARCH LETTERS, VOL. 32, L04604, doi:10.1029/2004GL021760, 2005

**Wind driven upwelling along the African coast of the Strait of Gibraltar**

S. Stanichny,[1] V. Tigny,[2] R. Stanichnaya,[1] and S. Djenidi[2]

Received 14 October 2004; revised 17 January 2005; accepted 21 January 2005; published 18 February 2005.

Acknowledgments

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**Sea level variability in the Strait of Gibraltar from along-track high spatial resolution altimeter products**



**The Effects of Nonrectangular Cross Section, Friction, and Barotropic Fluctuations on the Exchange through the Strait of Gibraltar**

MYRIAM BORMANS AND CHRIS GARRETT

*Department*

(Ma

> *"Because of geostrophy, the sea-level on the south side of the strait is higher than on the north side."* (Ross et al., 2000)

.021760, 2005

**Wind driven upwelling along the African coast of the Strait of Gibraltar**

S. Stanichny,[1] V. Tigny,[2] R. Stanichnaya,[1] and S. Djenidi[2]

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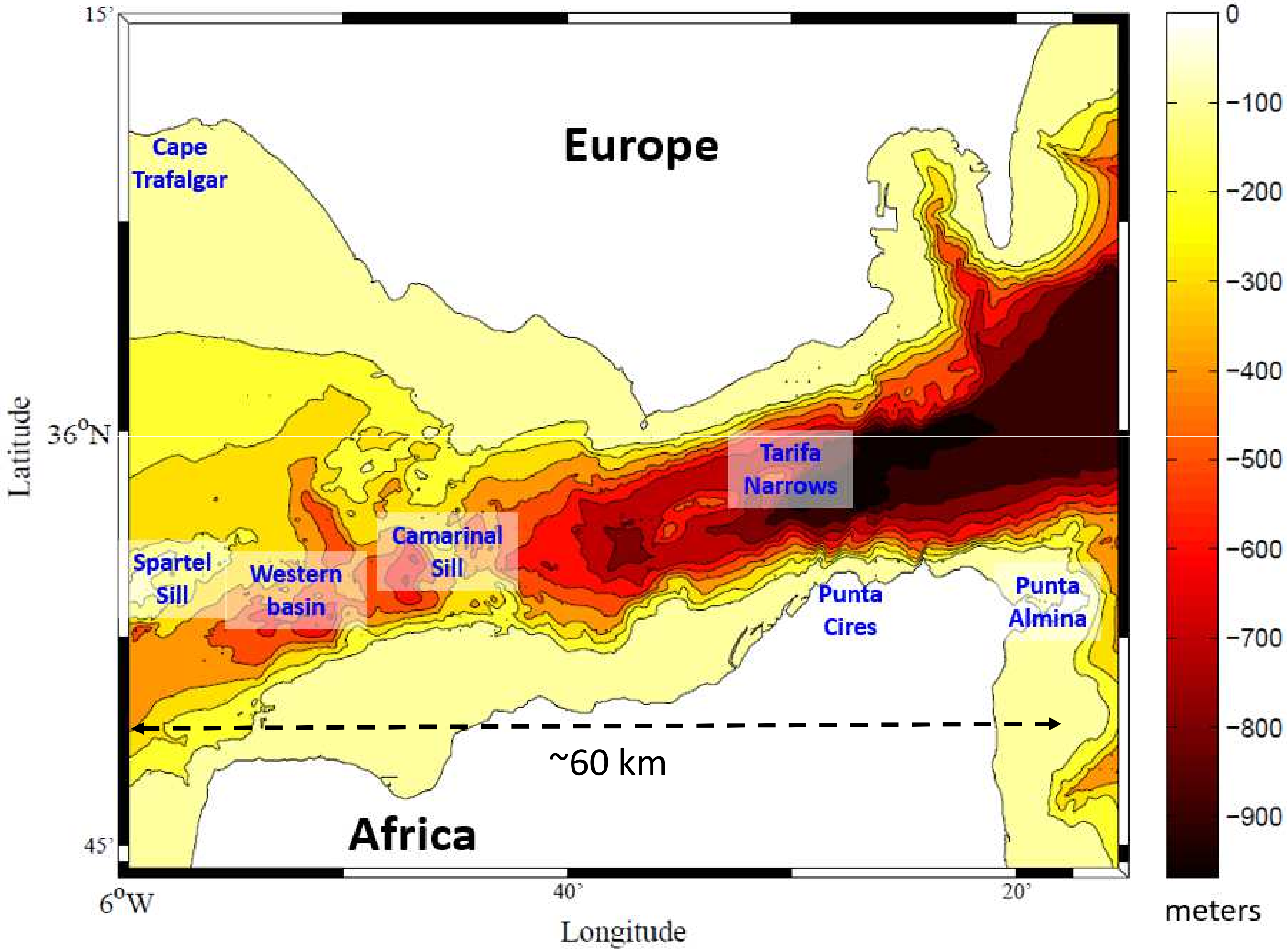
# Sea level variability in the Strait of Gibraltar from along-track high spatial resolution altimeter products

## The Strait of Gibraltar: where two worlds meet…



## Sea level variability in the Strait of Gibraltar from along-track high spatial resolution altimeter products

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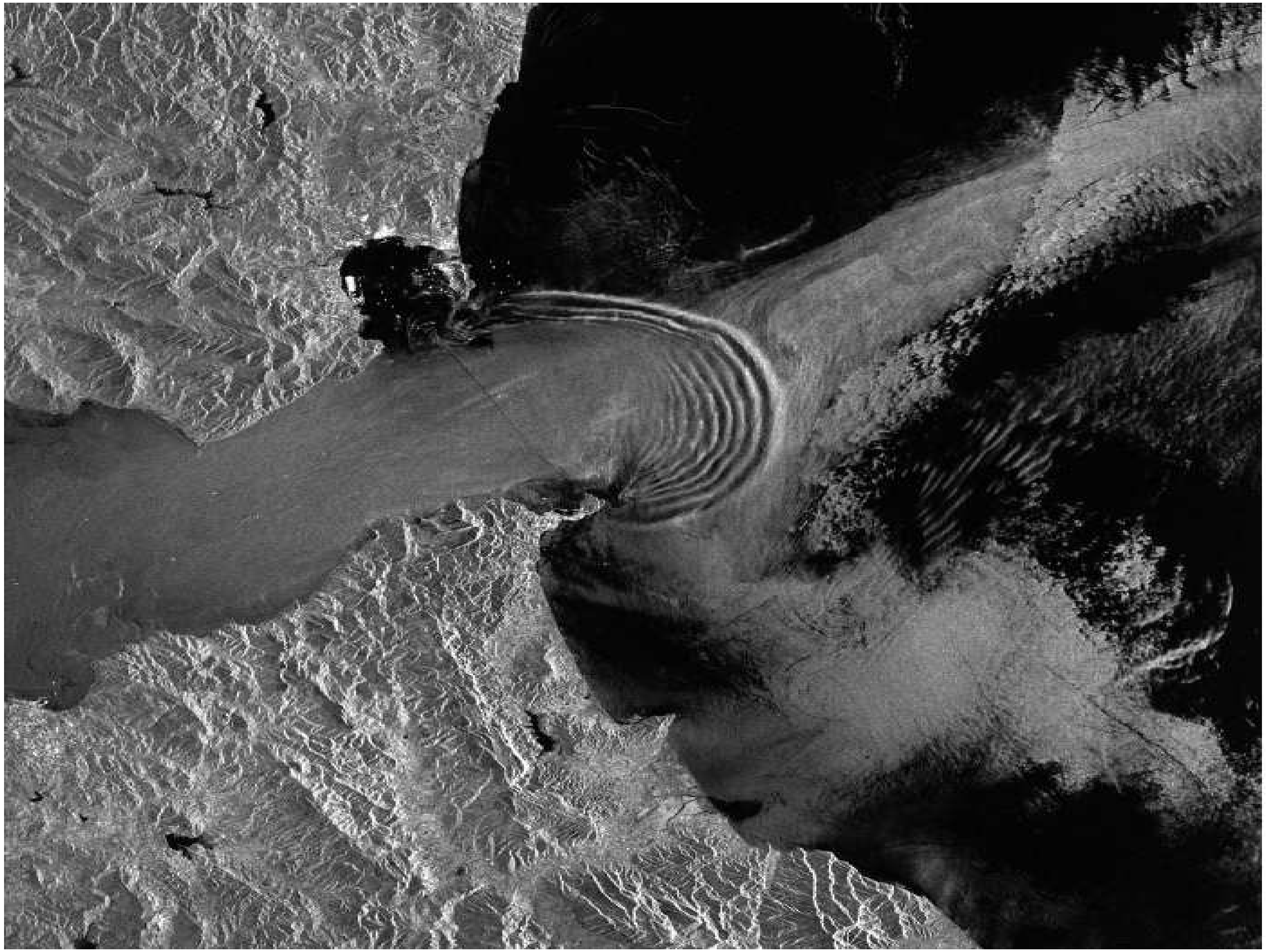


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# Sea level variability in the Strait of Gibraltar from along-track high spatial resolution altimeter products

**ESA Envisat RA-2 (SGDR: Phase E2)** descending track #0360: May 2002 (cycle 6) to September 2010 (cycle 93)

**Global Tidal Model** ***DTU10***

**Local Tidal Model** ***UCA2.5D***

**Global Mean Sea Surface** ***DTU15MSS***

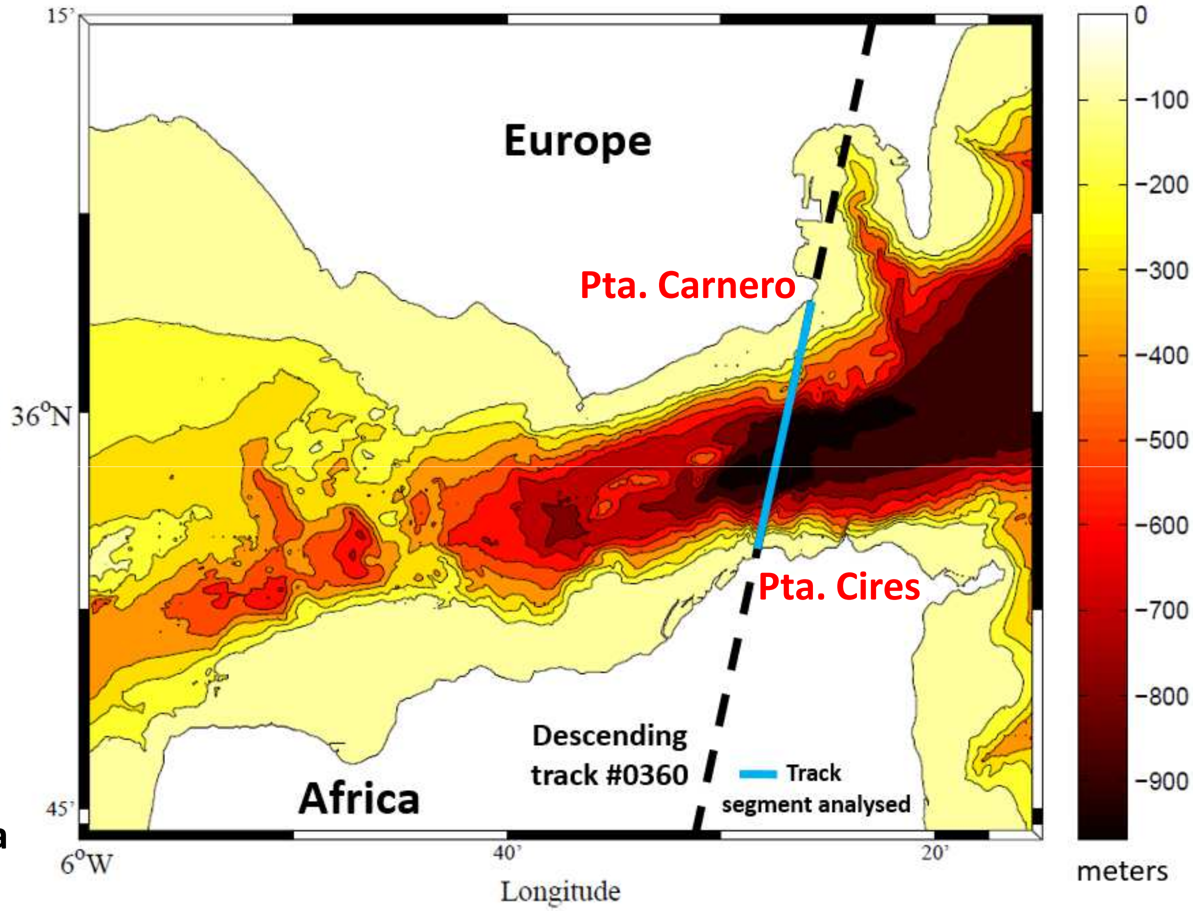
**Along-track Local Mean Sea Surface** ***AT_Local_MSS***

**Global MDT** ***DTU15MDT***

**Local MDT** ***UCA2.5D***

**Tide gauge and bottom pressure data**

**Bathymetry and Wind velocity**





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**ESA Envisat RA-2** descending track #0360 (SGDR 18 Hz along-track data)

$$AT\_SLA = Orbit - Range - Range\ Corrections - Geophysical\ Corrections - MSS$$

Sensor Geophysical Data Records (SGDR) official product: *waveforms, orbit*, *ionospheric, dry / wet tropospheric*, *solid earth tide and pole tide* corrections (ESA, 2007).

Adaptive Leading Edge Subwaveform (ALES) retracker: *Range*, *Sigma0* and *Significant Wave Height* (*SWH*) (Passaro et al., 2014) => recomputed *SSB* correction (Gómez-Enri et al., 2016)

Danmarks Tekniske Universitet (DTU): *mean sea surface* (*DTU15MSS*, Andersen et al., 2016) and *tidal model* (*DTU10*, Cheng and Andersen, 2011).

*Along track local mean sea surface.*

*Local Tidal model* (*UCA2.5D*) (Izquierdo et al., 2001).

**ESA Envisat RA-2** descending track #0360 (SGDR 18 Hz along-track data)

$$AT\_ADT = AT\_SLA + AT\_MDT$$

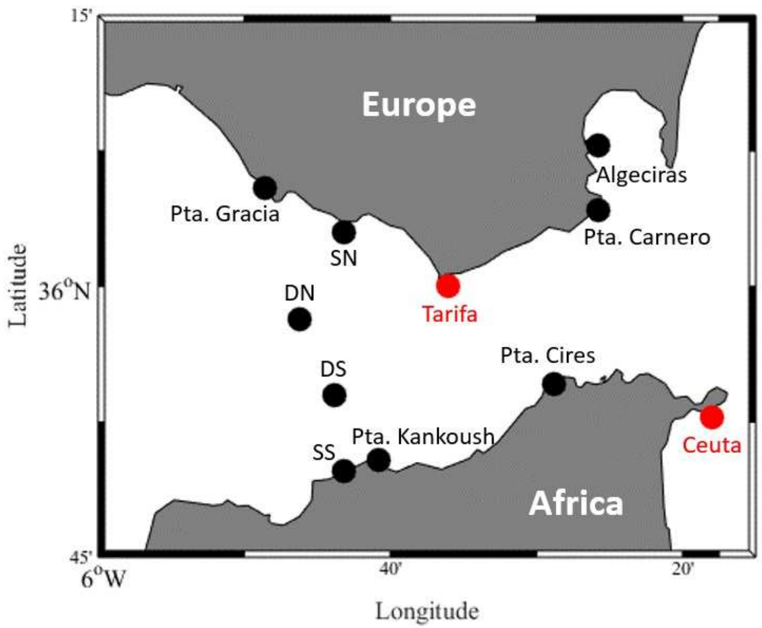
Danmarks Tekniske Universitet (DTU): *mean dynamic topography* (*DTU15MDT*, Knudsen et al., 2016).

*Local mean dynamic topography* (*UCA2.5D*) (Izquierdo et al., 2001).

# Assessment of models used for corrections

## *DTU10 vs. UCA2.5D tidal models*

***RMS*** **of the differences and the** ***RSS*** **of the main constituents: $M_2$ and $S_2$ (semidiurnals), $K_1$ and $O_1$ (diurnals) using information from a few tide gauges and bottom pressure instruments located within the Strait of Gibraltar**



# Assessment of models used for corrections

| | RMS differences (cm) | | | | RSS (cm) |
|---|---|---|---|---|---|
| | $M_2$ | $S_2$ | $K_1$ | $O_1$ | |
| | DTU10 / UCA2.5D | | | | DTU10 / UCA2.5D |
| **Tarifa** | 4.9 / 5.6 | 1.9 / 2.0 | 0.6 / 1.2 | 1.3 / 1.7 | 5.5 / 6.3 |
| **SN** | 4.9 / 5.6 | 2.1 / 1.9 | 0.4 / 1.0 | 0.6 / 1.1 | 5.4 / 6.1 |
| **DN** | 0.8 / 4.8 | 1.0 / 2.4 | 0.3 / 0.9 | 1.0 / 0.7 | 1.7 / 5.5 |
| **DS** | 4.0 / 2.4 | 0.2 / 0.9 | 0.9 / 1.0 | 0.9 / 1.2 | 4.2 / 3.0 |
| **SS** | 5.5 / 1.3 | 2.0 / 0.3 | 1.7 / 1.0 | 1.6 / 0.8 | 6.3 / 1.9 |
| **Pta. Gracia** | 3.6 / 6.3 | 2.2 / 2.2 | 1.1 / 1.5 | 0.7 / 1.5 | 4.4 / 7.0 |
| **Pta. Kankoush** | 7.0 / 3.4 | 1.5 / 1.3 | 0.8 / 1.7 | 1.2 / 1.8 | 7.3 / 4.5 |
| **Pta. Carnero** | 1.0 / 2.4 | 0.9 / 0.03 | 0.5 / 0.5 | 1.3 / 0.7 | 2.0 / 2.6 |
| **Pta. Cires** | 4.6 / 4.6 | 1.2 / 1.3 | 0.5 / 0.8 | 1.1 / 0.6 | 4.9 / 4.9 |
| **Algeciras** | 0.6 / 2.8 | 0.4 / 0.2 | 0.7 / 0.3 | 0.6 / 0.7 | 1.2 / 2.9 |
| **Ceuta** | 3.6 / 0.8 | 1.8 / 0.4 | 0.1 / 0.4 | 0.2 / 0.3 | 4.0 / 1.0 |
| | | | | | Total_RSS<br>4.3 / 4.2 |

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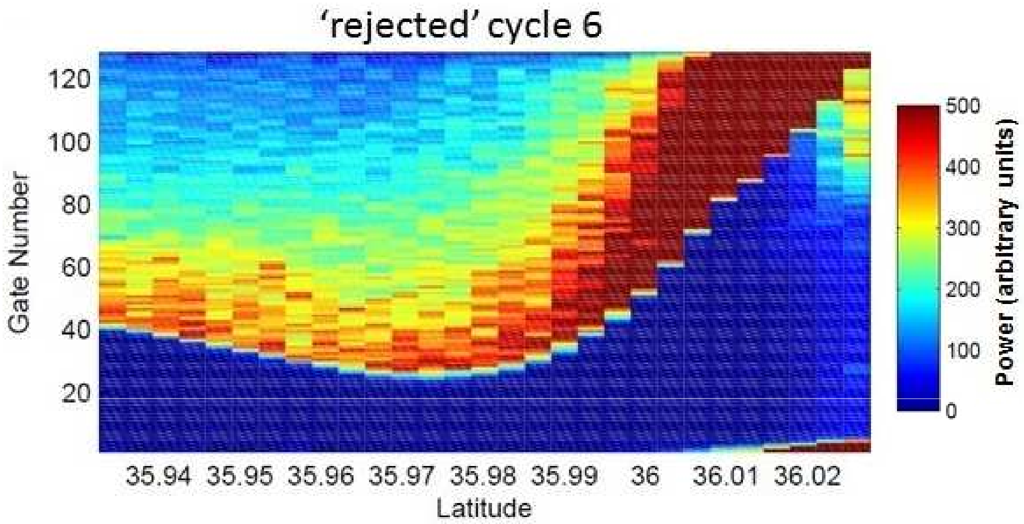
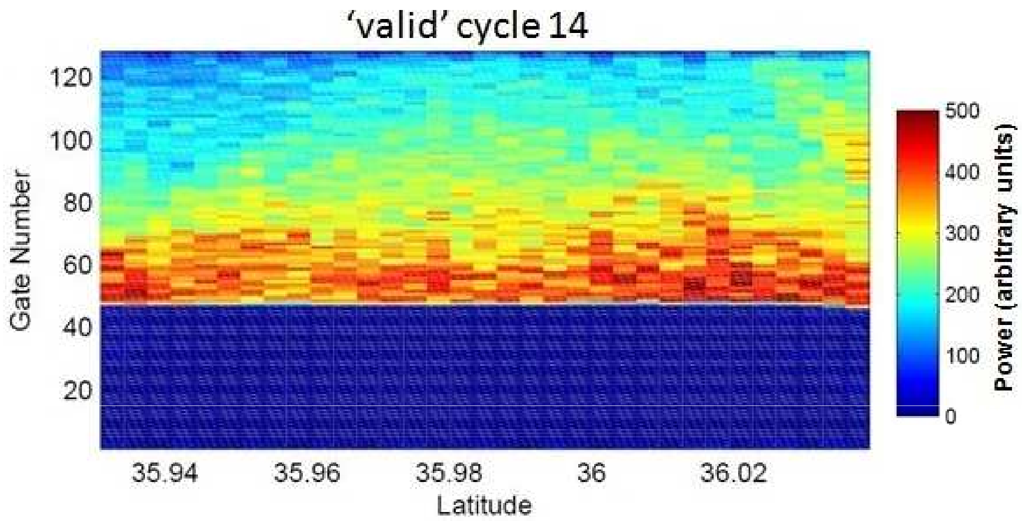
## Spatial variability of AT_SLA



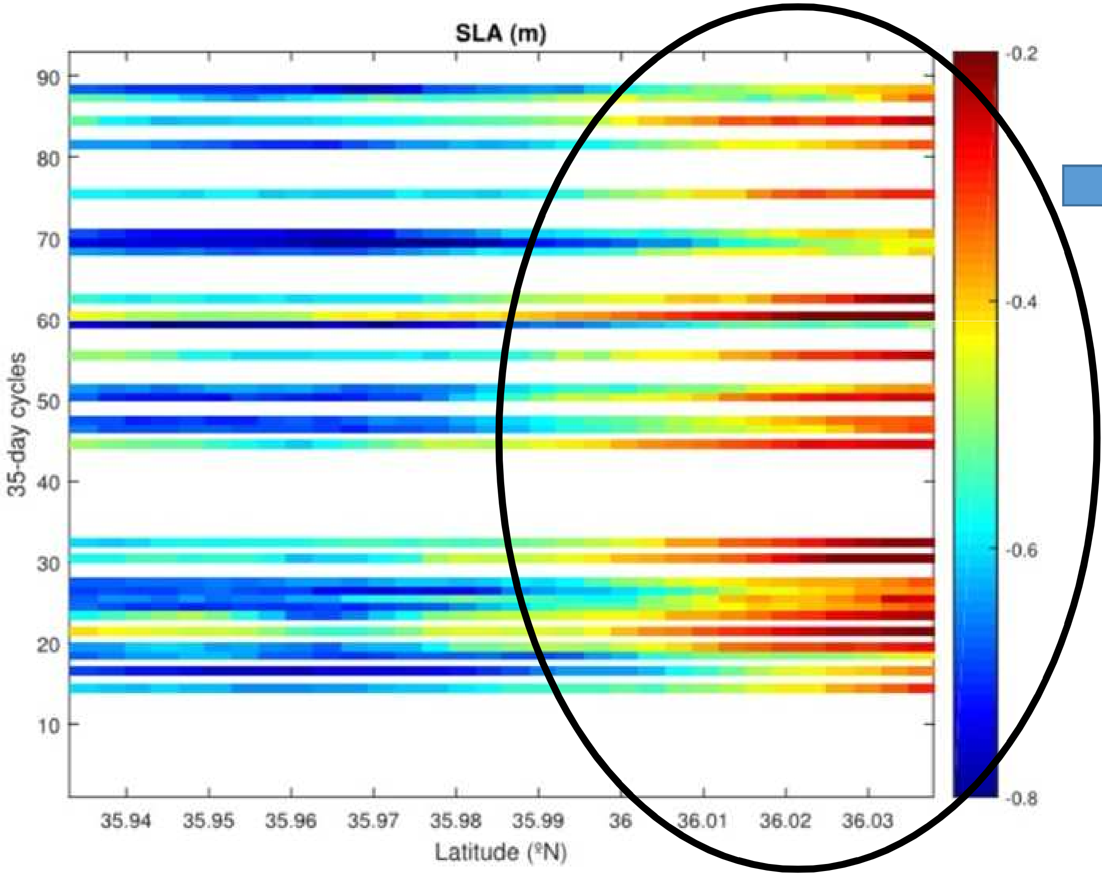




**Initial number of cycles: 78 (it should be 88!)**
**'Rejected' cycles: 48 (mainly due to 'non- stable' leading edge)**
**Final number of 'valid' cycles: 30 ('stable' leading edge)**

*AT_SLA = Orbit – Range – Range Corrections – Geophysical Corrections – **DTU15MSS***

# Spatial variability of AT_SLA

*AT_SLA = Orbit – Range – Range Corrections – Geophysical Corrections – **DTU15MSS***




**But, Houston we have a problem...**

Bormans and Garret (1989), Ross et al. (2000) and Stanichny et al. (2005) reported that in normal conditions there is a higher / lower sea level on the southern / northern side of the Strait, respectively.

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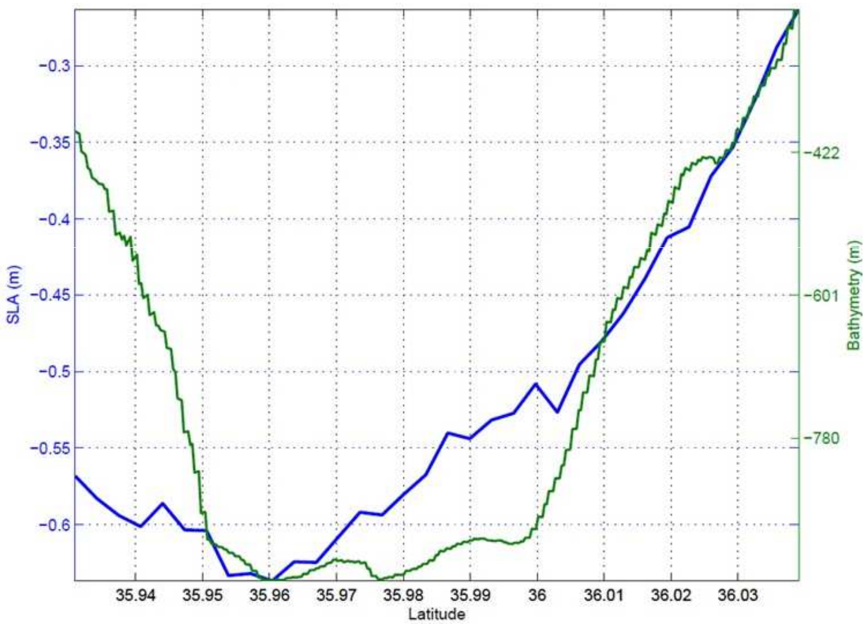
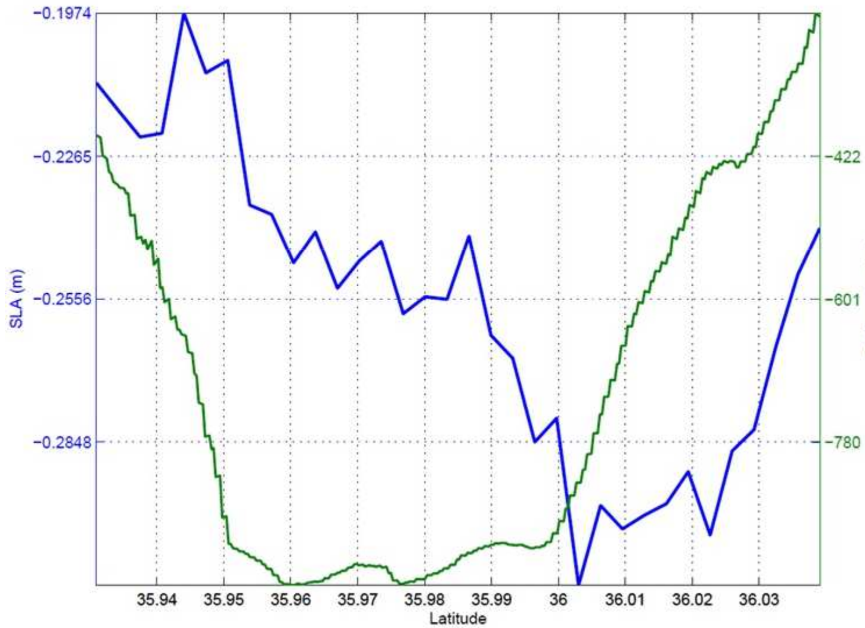
## Spatial variability of AT_SLA

*AT_SLA (**DTU15MSS**)* (cycle 14) *AT_SLA (**Local_MSS**)*




**Local_MSS:** ERS2 / Envisat derived mean sea surface based on ALES data.

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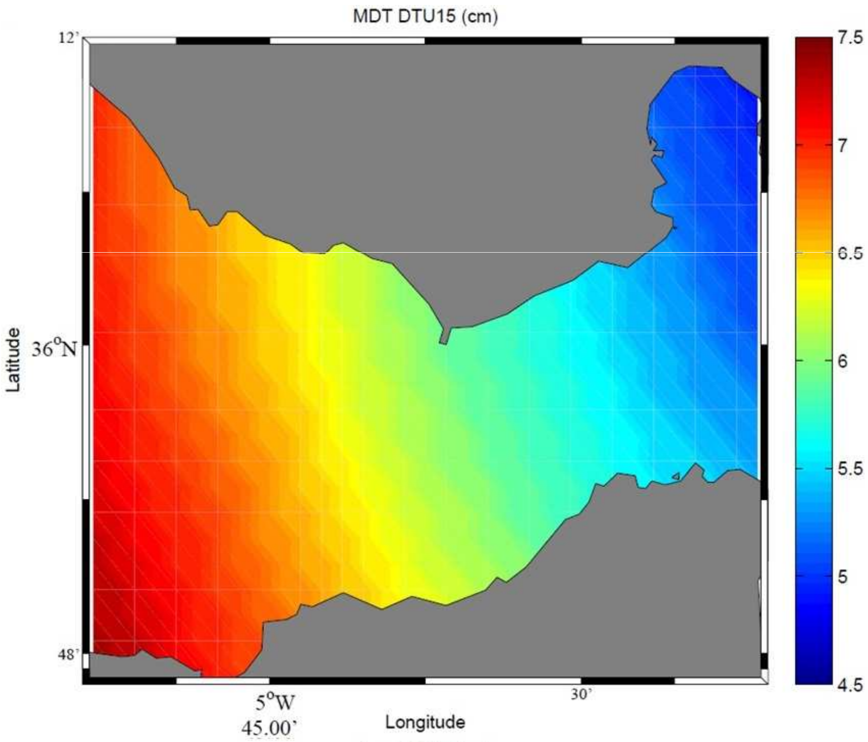
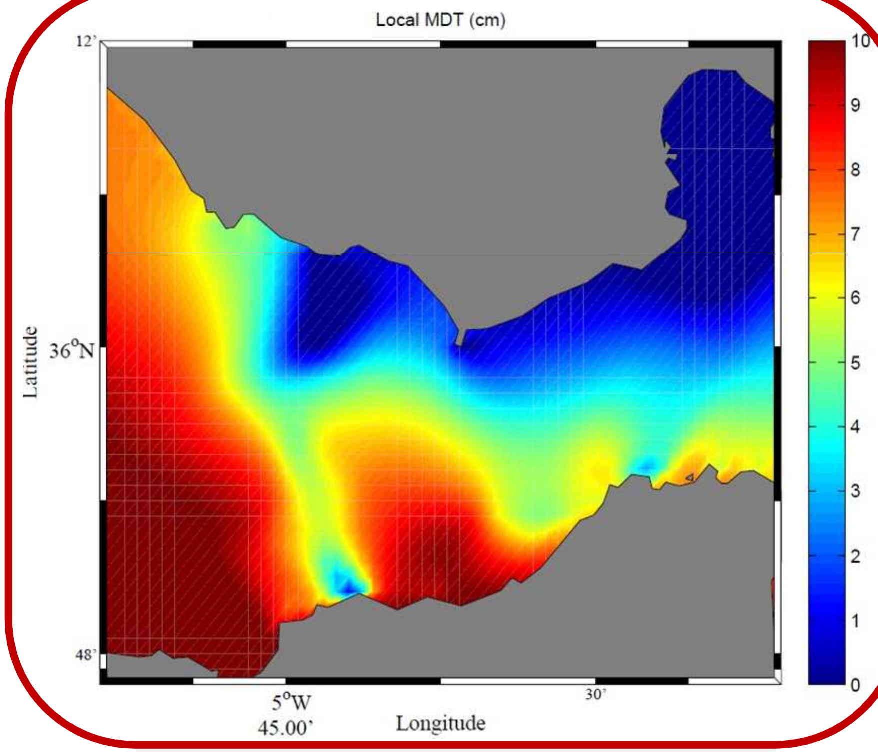
## Cross-strait variability

(along-track ADT)

$$AT\_ADT = AT\_SLA + AT\_MDT$$



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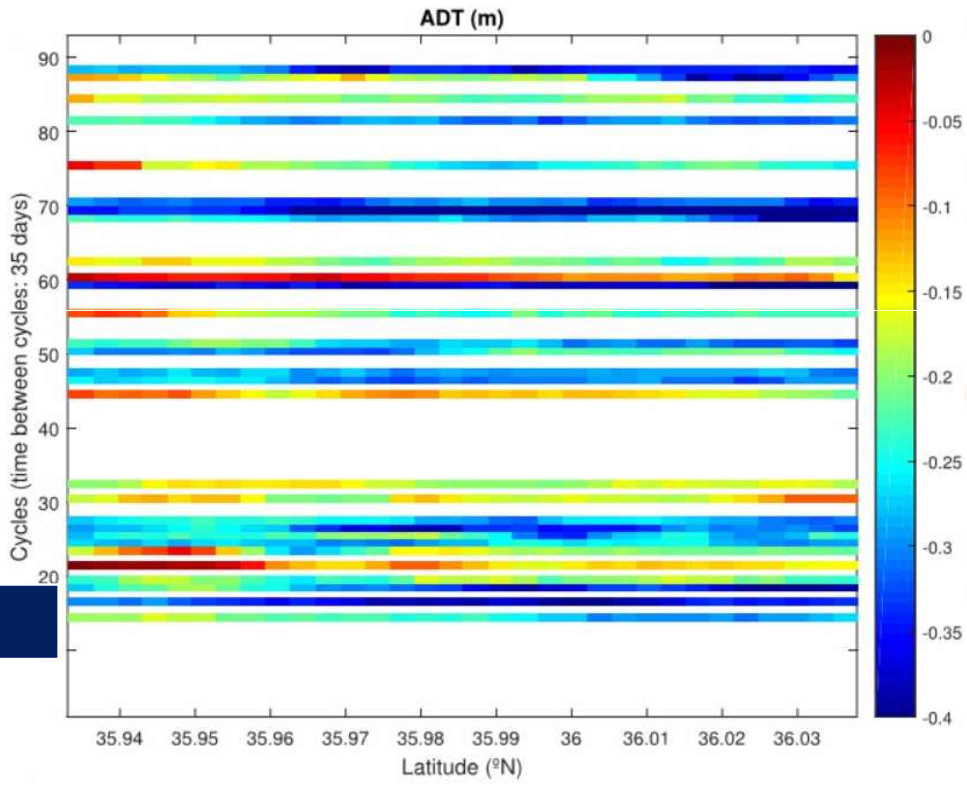
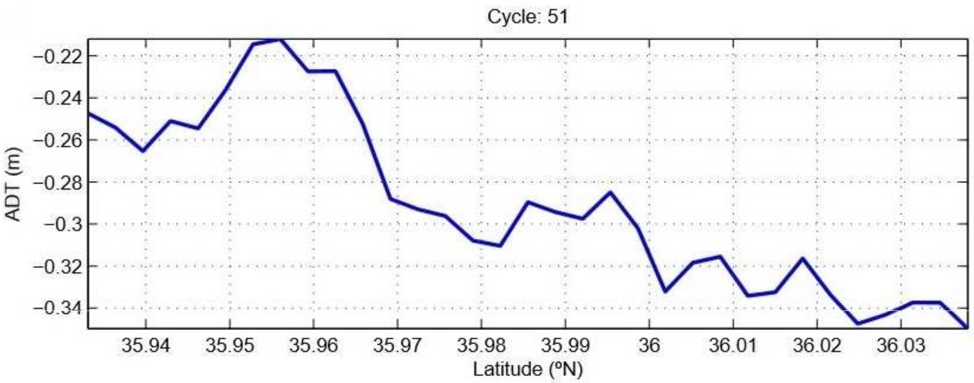
## Cross-strait variability
### (along-track ADT)

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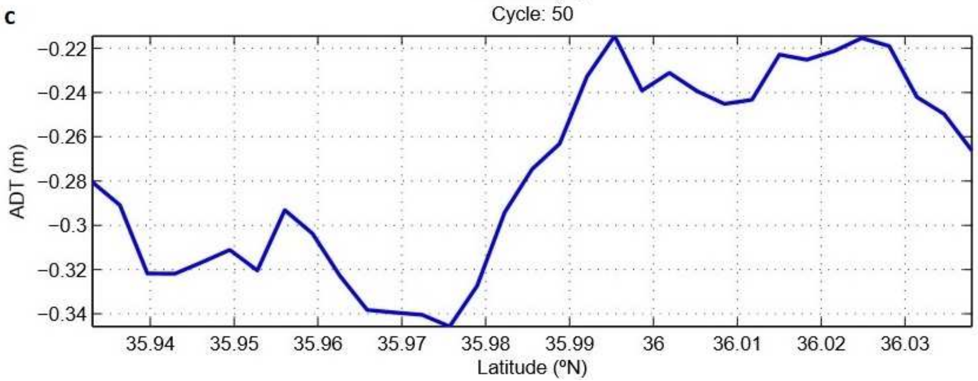


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# Sea level variability in the Strait of Gibraltar from along-track high spatial resolution altimeter products

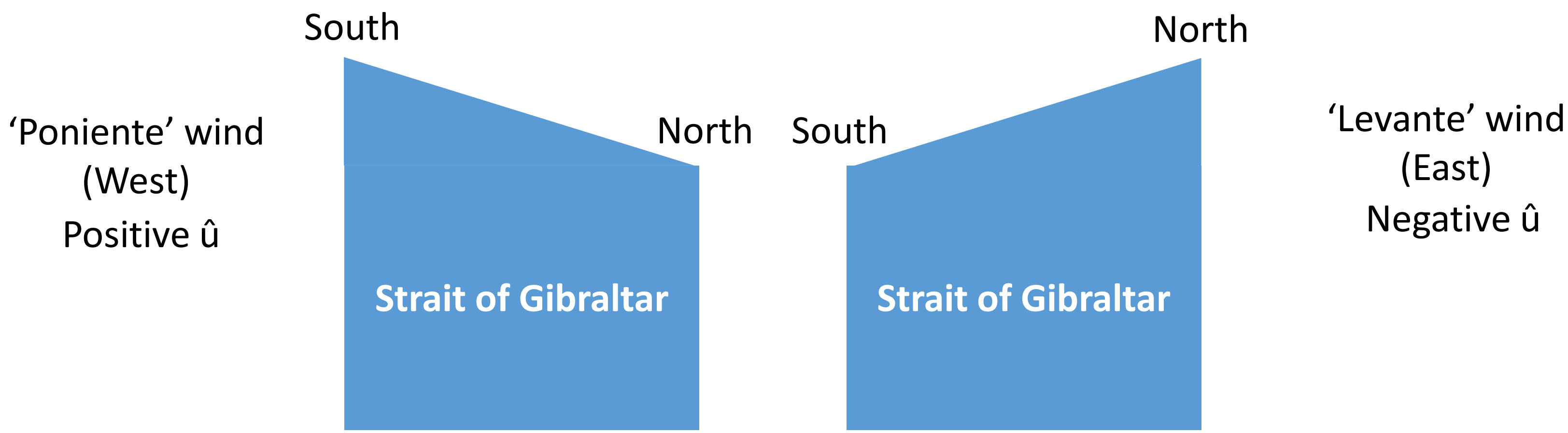
## Cross-strait variability

### (inversion of the cross-strait sea level drop due to wind regime)

Variability of the cross-strait sea level in the Strait of Gibraltar (eastern side) and its dependence with the wind regime.

Wind information: hourly mean zonal component (û) from a station located in Tarifa.

Comparison made with the sea level difference obtained from two tide gauges located in Ceuta (southern coast of the Strait) and Tarifa (northern coast).





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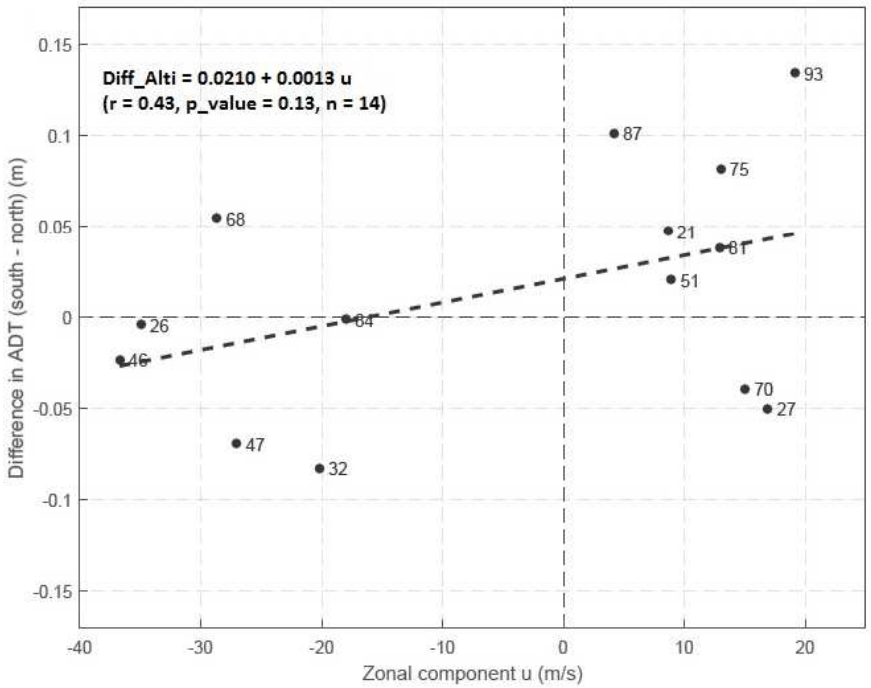
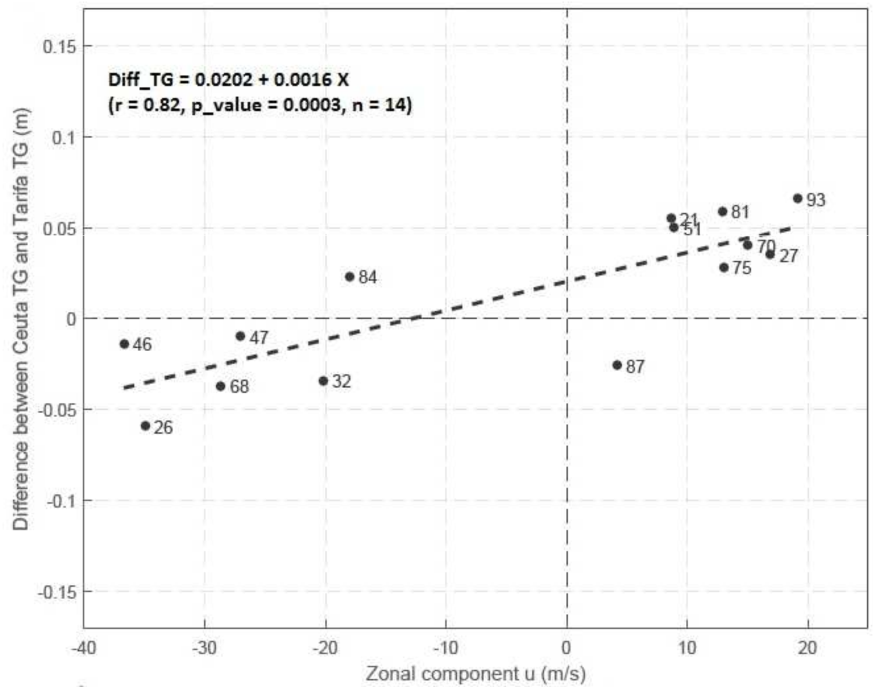
# Cross-strait variability

## (inversion of the cross-strait sea level drop due to wind regime)

Altimetry observations




In-situ observations

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**The global tidal model DTU10 shows a good performance in the Strait of Gibraltar to de-tide altimetric records.**

**The use of a global MSS in the Strait of Gibraltar to obtain the anomalies might hide some of the sea level variability, and hence complicate their oceanographic interpretation.**

**An ad-hoc local along-track MSS (based on ERS2/Envisat) gives a more realistic cross-strait variability in the Strait. This improves the analysis of the oceanographic processes in the area.**

**The analysis of the along-track ADT showed a positive correlation with the zonal component of the wind.**

# Acknowledgments

To the Spanish Instituto Hidrográfico de la Marina (IHM) for the bathymetric dataset

To the Spanish Agencia Estatal de Meteorología (AEMET) for the wind data

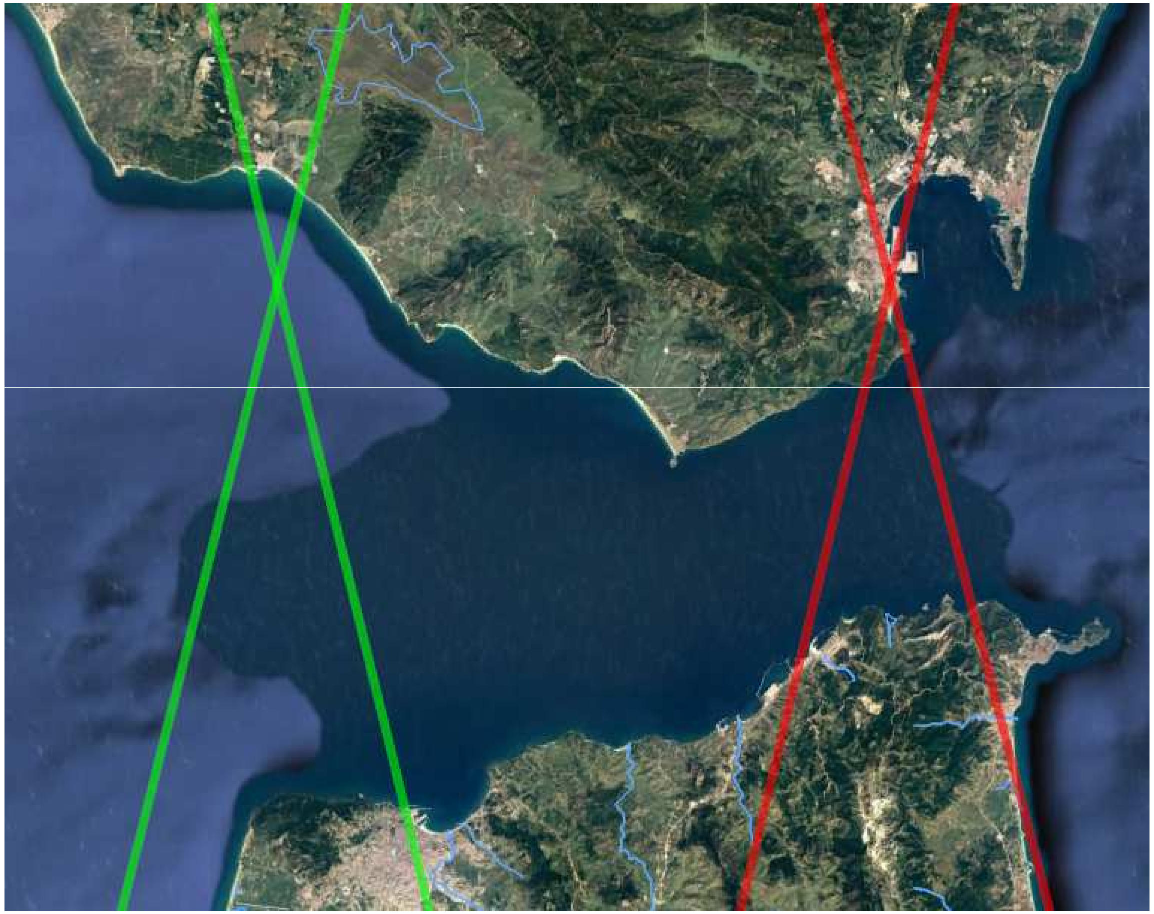
To the Spanish Puertos del Estado for the tide gauge data at Tarifa and Ceuta

To Ole B. Andersen (Denmark Technological University) for his comments on the global tidal model DTU10

***To EUMETSAT for its support to attend this meeting. THANK YOU!***

# FUTURE WORK…

SENTINEL-3B SENTINEL-3A




GRACIAS