Coastal Ocean Continuum

in surface Topography Observations Follow-On (COCTO-FO)

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1. Introduction and Objectives

This project proposes to contribute to the preparation of the SWOT mission and to the exploitation of the first data. It specifically addresses the science fields related to hydrodynamics of the estuary-shelf-deep ocean continuum and tides. In that sense, it strongly inherits from the COCTO project investigations and achievements (2016-2019 SWOT Science Team) while bringing innovative approaches and evolutions. For instance, the issues related to barotropic and baroclinic tides are broadened to encompass both the construction of de-tiding solutions from global to estuary scales and the issue related to the separation of internal tides and mesoscale circulation.

The scientific objectives are (1) to improve our knowledge and understanding on the physical processes and the observability in SWOT data of the estuary-shelf-deep ocean continuum and of the interaction between tides and ocean circulation, (2) to quantify the impact of SWOT pseudo-observations when assimilated in a coastal model and (3) provide the SWOT project with tools and products to analyze tides and correct the tidal signal in SWOT data at global scales and in the Gironde estuary.

This project will carry out methodological developments (tidal energetics, tides/circulation interactions and separation) that will be implemented in partner projects in different ocean regions and dynamical regimes. Our approach is mainly based on numerical modelling with state-of-the-art surges and tides 2D models and ocean circulation 3D models and on the use of the SWOT simulator. In collaboration with other groups, we will organize/participate in in situ campaigns to both assess the simulations and prepare some validation datasets for the SWOT observations.

Except for the science investigations aiming to support the future production of the global atlas FES2022, the focus is on two coastal areas: the Bay of Biscay (North East Atlantic) including the Gironde estuary, and the South China Sea, including the Gulf of Tonkin and the Red River delta. Bay of Biscay and Gulf of Tonkin have some geographical similarities (presence of an estuary or delta, wide shelf, macro-tidal dynamics) and disparities (mainly tropical vs. mid-latitude site), so similar modelling approaches can be developed on both sites while complementary scientific issues and applications can be addressed. Our collaboration with the University of Sciences and Technology of Hanoi (USTH), in particular through the Joint International Laboratory LOTUS (http://lotus.usth.edu.vn/), and with other Vietnamese institutions allows us to benefit from the expertise of Vietnamese partners and to have access to facilities for field measurements.

***Figure 1**: (left) Bay of Biscay GEBCO bathymetry basemap (Source: http://portal.emodnet-bathymetry.eu); (right) South China Sea bathymetry (Source: Wikimedia Commons)*

2. Approach

The project includes three work packages (WP):

- **WP 1: Estuaries and estuaries-shelf exchanges**
  Region of study: *Gironde estuary, Gulf of Tonkin*

Estuaries are very complex dynamical bodies, showing strong linear and non-linear interactions between several processes, among which tides and river discharge are preeminent. It is the place of mixing between ocean and continental waters, which conditions the characteristics of the river plume leaving the estuarine mouth. How much of the estuarine dynamics will be observable in the SWOT measurements is the central question of this WP. It will be addressed using numerical simulations as well as in situ observations (historical and operational data as well as dedicated in situ campaign).

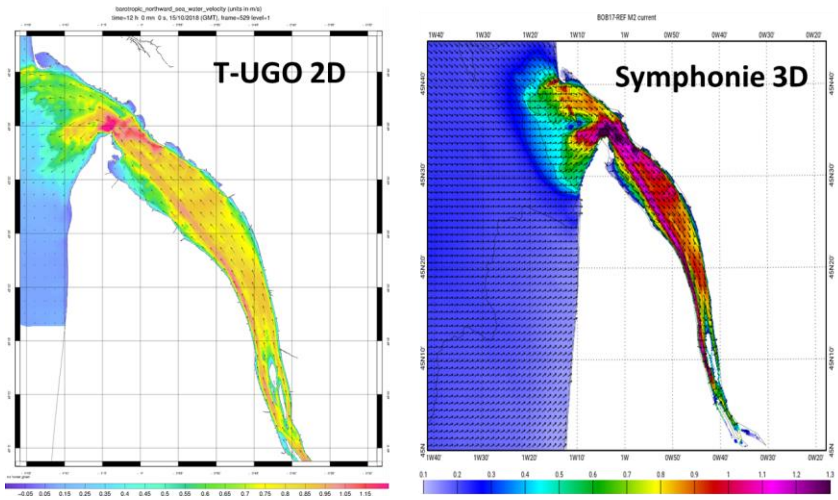

Figure 2: M2 current as simulated by the T-UGOm (left) and Symphonie (right) models inside the Gironde estuary.

Two modeling approaches are proposed: a shallow-water model (T-UGom) with an unstructured grid over the full estuary and a 3D ocean circulation model (Symphonie) with a structured grid in the downstream part. Due to its unstructured grid discretization, T-UGOm has already proven to simulate estuarine dynamics (tides, river discharge, storm surges) from the coastal buffer to the upper estuary (e.g. Chevalier et al., 2017). The 3D modelling effort will be based on the Symphonie model and existing configurations with variable mesh in both the Bay of Biscay and in the Gulf of Tonkin described respectively in Toublanc et al. (2018) and Piton (2019). Figure 2 compares for instance the tidal current (M2) as simulated by T-UGOm and Symphonie in the Gironde estuary.
In situ observations will be used to assess the numerical simulations (e.g. Piton et al, 2020, JMS) as well as to investigate data analysis approaches that allow to override the non-harmonic character of estuarine tides.

- **WP 2: Shelf dynamics and shelf-deep ocean exchanges**
  <u>*Region of study:*</u> *Bay of Biscay, South China Sea (incl. Gulf of Tonkin)*

First, in line with our previous project (COCTO) we will address the question: what is the nature of the physical signal that we can observe with wide swath altimetry in the coastal domain, in particular over the shelf and the shelf break? We will build on the work of Charria et al. (2017), Yelekci et al. (2018), Toublanc et al. (2018), Akpinar et al. (2020), Da et al. (2019), Piton et al. (2020 JMS, 2020 GMD), Ayouche et al. (2020) in the Bay of Biscay and South China Sea, to analyze several processes: mesoscale dynamics, circulation along the slope and shelf-slope exchanges, upwelling and river plume.
We will also investigate the interactions between surface gravity waves and currents in the Gironde river plume (within a collaboration with the French Navy- Shom). The study will rely on numerical simulations with Symphonie and WW3 (Michaud et al., 2012; Marsaleix et al., 2019) and therefore provide consistent scenes at high-resolution of SSH and surface gravity waves.

The second main topic in WP2 deals with data assimilation and stochastic modelling. Preliminary analyses of the observability in SSH based on pseudo-observations of SWOT (Ayoub et al., in prep, 2020) indicate a low signal to noise ratio over the shelf in the Bay of Biscay. To overcome such a difficulty, different strategies can be set up consisting for instance in filtering or averaging the data in order to smooth out part of the error. Data assimilation (DA) can be considered as another filtering option. Here, we propose to investigate the impact of the assimilation of SWOT observations on a coastal circulation model, using an Ensemble Kalman Filter method. We will start with pseudo-observations to address methodological issues arising from the complex error budget in SWOT data and from specific challenges inherent to coastal domains, such as errors arising from the open-boundary conditions (see for instance Ghantous et al., 2020).

From 2022, we plan to start using the SWOT observations, first comparing them with in situ data, conventional altimetry and numerical simulations in order to better understand the content of the SWOT signal, to guide our choices in some post-processing of SWOT data or identify possible biases or systematic anomalies. In the South China Sea, we will analyze the measurements along a pass during the fast sampling phase in an attempt to observe the large variability at daily time-scales of the circulation in this area. In the Bay of Biscay, we will use data from the nominal phase, in particular in the south-eastern area where a coastal mean dynamic topography is available (Caballero et al., 2020, submitted), in collaboration with AZTI (www.azti.es, Spain) and CLS.

- **WP 3: Barotropic and baroclinic tides**
  Region of study: *Global ocean, focus on Bay of Biscay*

In this work package, we address several questions related to the barotropic tide (contribution of the SWOT data of the fast-sampling phase, modelling and assimilation of the tide in global terms, constitution of the tidal atlas FES2022) and to the interactions between tides and circulation (generation and dissipation of the internal tide, separation between internal tidal signals and mesoscale eddies, observability of the internal tide in the SWOT data). This work package includes a wide range of developments and studies, all complementary to each other, and forming a coherent whole around the tidal theme and current scientific questions on the subject.
A large place will be given to methodological developments regarding, on the one hand, data assimilation and automated/optimal configuration setting for a tides/surges model at regional and global scales and, on the other hand, for diagnostics on internal tides and their interactions with ocean dynamics. These diagnostics are expected to be used in other SWOT projects at LEGOS.

A central question in the SWOT project is how much feasible will be the separation between meso- and submeso-scales ocean dynamics surface signals. Despite their periodic nature, internal tides regime shows a significant time variability because the variability in ocean stratification and interaction with surface currents. We investigate the time variability and observability of internal tides, and quantify how much of the internal tides surface signatures could be predicted for SWOT observations correction in the Bay of Biscay. Our approach is based both on 3D time-stepping modeling (SYMPHONIE model) to analyze realistic ocean conditions, and frequency-domain modeling (T-UGOm) which allows for more specific, parameter dedicated experiments (Barbot et al, 2020, in prep).

Regarding the estimation of barotropic tides at global scales we propose to work on the fast sampling phase measurements as well as on the scientific preparation for a new global atlas (FES2022), anticipating that the most recent one (FES2014, Lyard et al., 2020) will not be fully adequate to provide a tidal (and storm surge) de-aliasing correction over the full coastal ocean coverage and at high latitudes.

3. Anticipated results

The project will address methodological and technical issues in support to the SWOT project teams regarding data error budget and geophysical corrections as well as more general scientific issues on tides and on water level variability in coastal and estuarine environments.

A central topic is verification and validation of forthcoming SWOT observations in complex, challenging areas such as coastal/shelf seas and estuarine systems. We expect to identify sources of uncertainties on the observations (and simulations) and to help quantifying the error budget in the study areas, both by feeding the SWOT simulator with improved geophysical inputs and by comparing the actual instrument observations with realistic numerical simulations and in situ data (instrument networks, field campaigns). Ensemble-based uncertainty estimates on both observations and model simulations should allow us to (in)validate dynamical hypotheses in the interpretation of SWOT data in the coastal continuum.

In preparation to the future use of SWOT data in science applications, we will make available some data analysis and model configuration setup softwares as well as some numerical products for integrations in multi-disciplinary science investigations.

Regarding high-frequency dynamics, we aim at producing a new de-aliasing correction (barotropic and baroclinic tides, storm surges) dedicated to SWOT specific requirements. Our research work on theoretical aspects of tidal energy budgets and on a new approach to identify the interactions between tides and the ocean circulation will contribute to the understanding of internal tides dynamics and to the separation of the internal tides signal from the mesoscale circulation signature for the scientific use of SWOT data.

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