# I-CASCADE: wave-atmosphere-ocean Interactions and oceanic CASCADe of Energy

## Contents

# I Identifying Information

**Title: I-CASCADE**, wave-atmosphere-ocean Interactions and oceanic CASCADe of Energy

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# II Introduction and Objectives

## II.1 Summary

The Gulf Stream (GS) and the Agulhas Current (AC), as Western Boundary Currents (WBCs), are the strongest oceanic currents on Earth and major features of the global ocean circulation that largely controls the Earth's climate. Understanding their equilibrium, variability and trend is critical to oceanic and climate research, as for instance atmospheric storm tracks above them are tightly linked with the oceanic thermal fronts (Minobe et al. 2008; Nakamura et al. 2008). There are still major gaps in our knowledge of WBCs dynamics, despite numerous international programs of observation and modeling. However, two relevant findings emerged in the last two decades: **the key roles played by mesoscale air-sea interactions and oceanic (sub)mesoscale processes**. Here we propose to **use the SWOT satellite mission to reconsider the mechanisms at play in the WBCs dynamics putting a new emphasis on the smaller scales**. Both GS and AC correspond to **SWOT cross-over tracks**. These measurements will provide a unique opportunity to measure Sea Surface Height (SSH) and wind stress (observed through the surface roughness ($\sigma_0$)) at scales down to several tens of kms. This will help to better understand the biases in coupled climate simulations and **what portion of the signal will be effectively captured by SWOT**.

Mesoscale air-sea interactions are important players in WBCs dynamics as they modify the mechanical energy budget of the ocean. The mechanical interaction between the oceanic surface current and the atmosphere (current feedback, see *e.g.,* **Renault** et al. 2016b) damps the mesoscale activity and, thus, modulates the eddy-flow interaction over WBCs (**Renault** et al. 2019a). Through the inverse energy cascade (*e.g.,* Capet et al. 2008), this affects the general circulation as well. On the other hand, oceanic submesoscales play an essential role in the dynamics of the oceanic surface layers. The high vertical velocities within the fine-scale fronts and filaments are responsible of a large amount ($50\%$) of the total oceanic vertical heat fluxes towards the surface layers (Su et al. 2018) and control the spatial variability of the surface Sea Surface Temperature gradients (Callies et al. 2015). From the atmospheric point of view, oceanic mesoscales have a strong imprint on the atmospheric boundary layer, as well as the storm tracks, through role played by SST anomalies or by surface oceanic currents (Chelton et al. 2004; **Lambaerts** et al. 2013; **Renault** et al. 2017a). However, we still lack from direct observations at scales below 100 km of these different processes in order to quantify more precisely the effects of air-sea interactions at scales below 10-200 km on the oceanic and atmospheric dynamics. Using the synergy with the CFOSAT satellite and other satellite data (scatterometers and radiometers), we aim to evaluate **the cascade of energy between oceanic scales from the finer scales observed by SWOT to scales of WBCs and their links with atmospheric and oceanic processes**, and to **characterize the air-sea interactions**. We also propose to use numerical coupled models to evaluate what portion of the signal is monitored by the future satellite products and to determine what is the minimal physics required is an oceanic model to be properly compared to satellite data. In that process, we will also take into account the wave interface between the atmosphere and ocean, contrary to standard models that assume an equilibrated sea state which is transparent to momentum transfers between the two media (momentum transfer to the wave field is immediately passed on to the ocean, and vice versa). We will range these effects under the term wave feedback.

Specifically, this project has 2 main objectives:

1. To assess the Cascade of Energy between Oceanic scales and their links with the air-sea interactions at both mesoscale and submesoscale and including the wave feedback. We showed in **Renault** et al. 2019a that AVISO was not able to properly monitor the cascade of energy. What portion of the signal will be monitored by the future SWOT products? To which extend the air-sea interactions (at mesoscale, submesoscale, and including the wave feedbacks) can modulate the cascade of energy? What physics needs to be represented in a numerical oceanic model in order to be comparable to the future SWOT data?
2. To better characterize the air-sea interactions at the (sub)mesoscale. We propose to determine how SSH fine-scales give their imprint to the wind. Are we able to see some relationship between submesoscale or mesoscale SSH and surface winds? In **Lambaerts** et al. (2013) and **Foussard** et al. (2019a), we showed that, in an idealized setting, for low winds, the adjustment of the atmosphere to the ocean is rapid (less than a few hours). In **Renault** et al. (2018), using numerical model, we show that the current feedback can imprint the wind at the submesoscale, does this relationship can be seen in the observations? Does the relationships between SST, current and wind change with horizontal scales? Finally, we will determine at which scales this coupling does not affect our interpretation of the SSH signal in terms of balanced signals (*i.e.,* filaments and eddies).

## II.2 Experimental Objectives

Western Boundary Currents (WBCs) such as the Agulhas Current (AC) and the Gulf Stream (GS) play an important role in the redistribution of heat at the global scale, affecting the Earth's climate. The AC and GS have specific traits. The GS is characterized by a separation near Cape Hatteras and penetration into the North Atlantic basin, where it acts as the main conduit for the upper branch of the Meridional Overturning Circulation. As for the AC around the southern coasts of Africa, it retroflects back to the Indian Ocean with most of its load of subtropical warm and salty water masses, although part of these waters can penetrate westward into the South Atlantic. This salient feature, known as the Agulhas leakage, is another potential driver of variability for the Meridional Overturning Circulation in the Atlantic. The linear Sverdrup theory predicts that WBC volume transport varies with the intensity of basin-scale wind stress curl. Notwithstanding, observations and high-resolution simulations suggest a more complex picture where nonlinearity, topography and stratification exert a strong influence over a wide range of temporal and spatial scales (from 1 day to 10 kyr, and from 1 km to 300 km). Due to this complexity, there are still gaps in our knowledge of the ocean energy budget and dynamics of WBC systems, despite numerous international programs of observation and modeling: the representation of WBCs remains challenging for modelers.

Over the past decades, numerous studies showed that a mesoscale resolving ocean model is required to simulate the main observed features of WBCs (*e.g.,* Chassignet and Marshall 2008). However, these studies also revealed consistent remaining biases, including *e.g.,* a mean Agulhas Retroflection position eastward (upstream) of the observed pattern. To date, no definite answer exists on why these biases occur, with no systematic method to prevent them. Research studies have relied on dissipation processes to correct simulation biases, but with little theoretical justification. **However, two relevant findings emerged in the last two decades: the key role potentially played by oceanic submesoscale processes and that played by mesoscale air-sea interactions.** Since SWOT will provide information on Sea Surface Height (SSH) at meso and submesoscale (*i.e.,* down to 30km) and surface roughness ($\sigma_0$) at finer scales (down to 1km), it will provide **unique opportunity to diagnose air-sea interactions at submesoscales**. In particular, we will take advantage of the fast-sampling phase during which we will have access to measurements every day both in GS and AC as they correspond **SWOT cross-overs**. These regions are also characterized by "transition scale" (*i.e.,* the spatial scales at which balanced mesoscale dynamics dominate over the unbalanced signals from internal tides and internal gravity waves) of $\approx 20$ km. Therefore, the cascades of energy that we will estimate from SWOT should not be aliased by internal tides and/or internal gravity waves (see also proposal from R. Morrow, LEGOS).

### Main Scientific Questions

This proposal responds to two fields indicated in the document provided by the SWOT ST call: **Mesoscale ocean dynamics** and **Ocean fronts and air-sea interactions**. Thanks to the future SWOT data, we aim to answer the following questions:

- What information on the ocean boundary layer (OBL) and atmospheric boundary layer (ABL) can be inferred from the different SWOT measurements (SSH, roughness, etc.)? Can we use these combined measurements to complement SSH estimates and interpretation ?
- What are the timescale of adjustment of the atmosphere to the ocean and what are the mechanisms at play at submesoscales in the atmosphere? Recent numerical studies (*e.g.,* , Gaube et al. 2019; **Lambaerts** et al. 2013; **Renault** et al. 2018) have shown that not only the mesoscales but also the submesoscales (the fronts and filaments between eddies, scales of O(km) have a signature on the atmosphere. These latter studies also highlighted possible different types of responses, depending on the oceanic scale or the atmospheric conditions. Given that, how does the wind stress correlate with submesoscales? Can we find linear relationships between wind stress and SSH (and related geostrophic currents) and define coupling coefficients at the submesoscale as we can do at mesoscale?
- What is the oceanic response to submesoscale air-sea interactions? can we expect the CFB to be a submesoscale catalyst over WBCs ? what is the effect of the TFB on the WBCs dynamics ?
- Among other effects, changes in ocean surface roughness induced by the waves can modulate the wind power input to the ocean (*e.g.,* Liu et al. 2017) and wave generation and breaking can redistribute spatially and temporally atmospheric momentum flux to the ocean. To what extent the wave feedbacks can alter the other air-sea interactions at both mesoscale and submesoscale ? What is the effect of the waves on the cascades of energy ?
- To what extent the future data SWOT will be able to characterize the cascades of energy between

oceanic scales ? What is the minimal physics required in a model in order to be comparable to the future SWOT data ? do we need to represent submesoscale processes and the wave feedbacks ?

So far, scatterometers and other satellite sensors have exposed the ubiquity of the effect of air-sea interaction on surface winds at the oceanic mesoscale (*e.g.,* Chelton et al. 2001; **Renault** et al. 2017a). The synergetic use of the future SWOT data and CFOSAT data (wave and stress) along with other existing satellite data will allow us to better respond to the aforementioned questions and also to better evaluate the models parameterizations and the representation of the air-sea interactions. Intercomparisons with models, synthetic data (from the models) and real data will allow to evaluate what portion of the signal is monitored by the future satellite products. **The comparison between two key WBCs (previously studied by the PI and the team (Renault et al. 2017b, 2016a) will further emphasize what is generic or regionally specific about waves and/or submesoscale effects.** The GS will be considered as a testbed and will serve as a leverage to study the AC.

## II.3 Approach

To answer these questions, we propose to rely on numerical simulations before the launching of SWOT), on synthetic SWOT data (derived from the numerical simulations) and on the SWOT data (when they will be available) in synergy with other satellite products such as CFOSAT (wave and wind) and SST products. We will use different types of simulations that exist to better understand what kind of information (in terms of air-sea interactions and cascade of energy) we can retrieve from SWOT. The simulations used in this project will range in three groups:

1. Existing numerical simulations from the team and also from other groups (JPL, through a collaboration with Patrice Klein at CalTech, and IGE, through a collaboration with Julien LeSommer) that have shown to be realistic and reliable both in representing key physical processes. We have at hand atmospheric simulations of several years consisting on an idealized storm track of size 9000x9000 km forced by a mesoscale SST field with 18km of spatial resolution (**Foussard** et al. 2019a,b). The SST field was provided from a SQG simulation, so that we also have access to the SSH. Also, regional simulations of the California Current, the Gulf Stream or the Agulhas Current (**Renault** et al. 2019a,b, 2017b, 2016a). Two new coupled models are being run: one at JPL at the global scale that will resolve submesoscales (based on the LLC4320 run at $1/48°$ resolution), and another one in Grenoble (done with the Grand Challenge Jean Zay ENERGETICS over the North Atlantic region). Such simulations will ensure the feasibility of the project and mitigate the risk of using only with new configurations. The Ocean-Atmosphere simulations (without explicit wave effect) will be our control runs.
2. New Ocean-Atmosphere coupled simulations. This project will benefit of an unprecedented suite of high-resolution realistic Ocean (CROCO, **Debreu** et al. 2012), atmosphere (WRF, Skamarock et al. 2008), and waves (WW3, Tolman et al. 2009), interacting through the OASIS coupler (Valcke 2013). Two kinds of configurations will be considered: 1) Mesoscale resolving simulations (based on configurations from **Renault** et al. (2019a)): the simulations have a spatial resolution of 5 km for the ocean and 18 km for the wave and atmospheric models; 2) Submesoscales simulations nested into the mesoscale resolving simulations: the simulations have a spatial resolution of 1 km for the ocean and 4 km for the wave and atmospheric models. The simulations will also be evaluated against available observations such as Altimetric Merged Sea Level Anomaly maps (from CMEMS), Sea Surface Temperature (satellite and in situ), Significant Wave Height (from along-track altimetry and CFOSAT), surface current (in situ and altimetric geostrophic currents), surface stress and wind (from *e.g.,* , ASCAT, QuikSCAT, and CFOSAT).
3. Idealized coupled simulations: we plan to develop a new framework of a coupled atmosphere-ocean system for idealized studies using Ocean (CROCO or NEMO) and atmosphere (WRF) coupling. Our aim is to be able to study the key mechanisms explaining the relationship between the wind and the SST and currents. To this end, we will develop configurations (*e.g.,* , double periodic channel as was used in **Foussard** et al. 2019b and **Klein** et al. 2008). Such simulations allow to keep the key ingredients of the dynamics of an atmospheric storm-track above an eddying ocean. It also allows to perform sensitivity studies as well as long term integrations to do statistical analysis to extract the coupled ocean-atmosphere signal.

We also plan to develop a single-column idealized model for the air-sea interface. It will include a wind-wave model which will take into account the effect of surface oceanic currents, atmospheric stability and winds. We will then provide a *backscatter coefficient simulator* that will be applied to the numerical datasets described above. Results from the model will further be compared to SWOT measurements when available. This will be crucial to understand the physical processes coupling atmosphere, wind and waves.

Evidently, when the SWOT data will be available, we plan to use them in synergy with other sensors (*i.e.,* SST) to do detailed analysis in particular locations, such as the cross-overs in the Gulf Stream or the Agulhas Current. Such regions have been (and will be) well documented by numerical studies and observations for their properties in terms of air-sea interactions at mesoscale. Starting from this knowledge, it will become easier to focus on the submesoscale dynamics.

## II.4 Analysis and Anticipated Results

L. Renault will coordinate collaboration with the team, and we will seek additional funding to hire a postdoc (*e.g.*, through a submitted ANR PRC). The work is decomposed in 5 Work Packages (WPs) described hereafter. The two first WPs are modeling-oriented but are crucial in order to determine what physics is needed in numerical models to be properly compared to the future SWOT data. We indicate in bold the PI of each WPs as well as the persons who are involved.

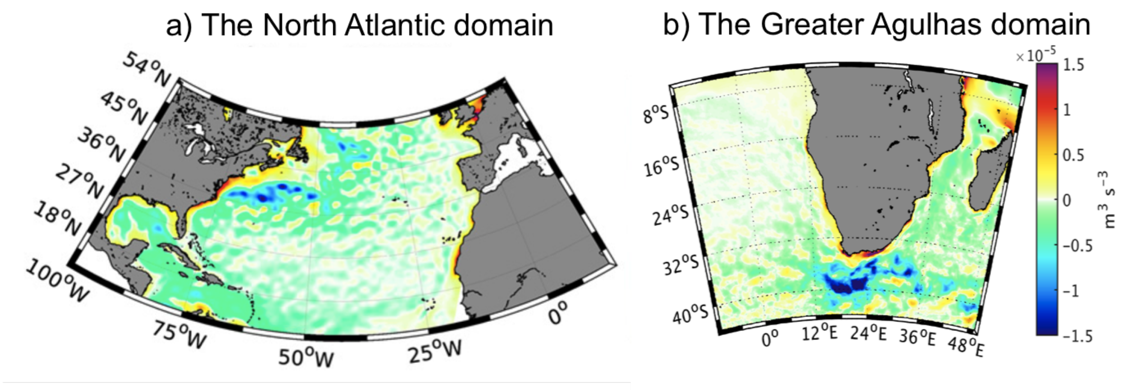


**Figure 1.** Domain configurations illustrated by the eddy wind work. The negative values represent a transfer of energy from the mesoscale currents to the atmosphere. They are caused by the current feedback to the atmosphere and induce a large dampening of the mesoscale activity. Figures adapted from **Renault** et al.; **Renault** et al. (2017b, 2016a)

### WP1: Role of the WAO in Determining the Cascade of Energy

*Persons involved:* ***L. Renault****, P. Marchesiello, R. Benshilla, J. Jouanno, M. Larranaga*

The wave feedback effect on the cascade of energy and on WBCs dynamics is unknown. In this first WP, fully coupled simulations over the North Atlantic and the Greater Agulhas Current will be carried out (see domain in Fig. 1) with 5-year integration in time. They will include all Wave-Atmosphere-Ocean interactions: sea-state effect on turbulent fluxes; redistribution of momentum flux by wave generation; Stokes-drift advection, vortex and Stokes-Coriolis forces; vertical mixing induced by wave breaking and Langmuir turbulence and will also consider both thermal and mechanical air-sea coupling. Complete budgets of momentum, energy, tracers (T,S) and potential vorticity, including horizontal and vertical turbulent fluxes of all quantities, will be computed online. This approach will highlight the role of the wave feedbacks on the WBCs energy budget. The simulations will also be systematically compared to the control runs from **Renault** et al. (2016a) and **Renault** et al. (2017b) in terms of: mean and eddy kinetic energy; energy budget; energy sink, coupling coefficients; dynamics of WBCs. Satellite and in situ data will be used to assess the improvement of the solutions. As in **Renault** et al. (2019a), we will estimate the cascade of energy over the Gulf Stream and the Agulhas Current and determine to which extent the wave feedbacks can modulate them. The main objective of this WP is to answer to the following questions: **To which extent the wave feedbacks can modulate the energy budget of WBCs and, in particular, the cascade of energy? Do we need to consider the wave feedbacks in order to properly assess the representation of the cascade of energy in SWOT and in numerical simulations?**

**Objectives**:

**O1-1** Running and validate the fully coupled simulations.

**O1-2** Assessing the atmospheric response (mainly wind and heat fluxes) to surface stress changes by undeveloped sea state and its effect on the ocean. Here, we will investigate the sensitivity of the atmospheric response from both atmospheric and oceanic viewpoints, with particular attention to the possible modulation of the mechanical interactions and of the transfer of energy between the ocean and the atmosphere.

**O1-3** Assessing how the redistribution of momentum and energy fluxes due to wave generation/dissipation impacts GS and AC dynamics and the associated cascade of energy. We will test the following hypothesis: the redistribution of momentum flux has a large-scale effect (reducing wind work input to the main currents) and a mesoscale (increasing the efficiency of the damping of the mesoscale activity by the mechanical air-sea interaction). A modification of SST is also expected, with potential feedback to the atmosphere.

**O1-4** Determine whether the wave feedback need to be considered in an oceanic simulation in order to be properly compared to the SWOT data.

**Tasks**:

**T1.1** Design and gather available diagnostics (*e.g.,* mean wind work, eddy wind work, baroclinic/barotropic conversion, spectral energy fluxes, AC retroflection and leakage ...) and observations (satellite and in situ data) that will be used to assess the effect of Wave-Atmosphere-Ocean interactions on the energy budget and other WBCs features.

**T1-2** Prepare and run the fully coupled simulation.

**T1-3**: Validate the simulations with existing observations (satellite and in situ).

**T1-4**: Analyze the new simulations. Assessing the impact on WBCs dynamics and changes in wind work, surface stress, vertical mixing, surface currents, and associated wind response.

### WP2: Role of Submesoscale Processes in determining the Cascade of Energy

*Persons involved:* ***P. Marchesiello****, L. Renault, J. Jouanno, R. Benshilla, G. Lapeyre*

Based on the simulations from WP1, we will develop new simulations with a spatial resolution of $dx \approx 1$ km for the Ocean and $dx \approx 4$ km for the Atmosphere and Wave over both the Gulf Stream and the Agulhas Current for a time-period of 5-years. Again, complete budgets of momentum, energy, tracers (T,S) and potential vorticity, including horizontal and vertical turbulent fluxes of all quantities, will be computed online. This approach will disentangle the submesoscale processes influence on WBCs energy budget from that due to mesoscale processes. To complete our approach, we will also use idealized coupled simulations based on **Foussard** et al. (2019b). Submesoscale processes can affect momentum, buoyancy and gas exchange between the ocean and atmosphere (Su et al. 2018). They can also impact the interior route to dissipation (**Gula** et al. 2016), possibly modulating the energy budget of WBCs, and, thus, the cascade of energy. Submesoscale currents and fronts can also strongly interact with waves (McWilliams 2016), potentially impacting the wave feedback to the atmosphere and the other air-sea interactions. This WP aims to answer to the three following questions: **Do we need a submesoscale resolving model to assess the cascade of energy? What is the effect of submesoscale processes (including air-sea interactions at submesoscale) on the WBCs energy budget? To which extent can we compare SWOT to non submesoscale permitting model?**

**Objectives**:

**O2-1** Run and validate the submesoscale coupled simulations.

**O2-2** Assess the influence of submesoscale processes on the energy budget of WBCs

**O2-3** Characterize to what extent submesoscale processes affect the cascade of energy (both inverse and forward)

**O2-4** Determine whether the representation of submesoscale processes in numerical models in needed to be compared to SWOT data.

**Tasks**:

**T2.1** Prepare and run the fully coupled simulations.

**T2.2** Determine the energy budget and compare it to the mesoscale resolving simulations.

**T2-3** Assess the control of submesoscale processes on WBCs and on the cascade of energy.

### WP3: Representation of the Cascade of Energy in SWOT over WBCs

*Persons involved:* ***L. Renault****, P. Marchesiello, J. Jouanno, G. Lapeyre, M. Larranaga*

This third WP aims to compare synthetic and real SWOT data to the fully coupled simulation. It will use as a leverage the simulations and results from the two first WPs. Both mesoscale and submesoscale simulations will be used. First, the synthetic SWOT SSH will be generated from the simulation using the SWOT simulator. A synthetic $\sigma_0$ signal will also be generated through its development in WP 4. Such data will be compared to the original signal. This methodology will allow us to determine what portion of the air-sea interactions signal the SWOT measurements will be able to retrieve. The cascade of energy will then be estimated from the original signal (done in the other WPs) and from the SWOT synthetic signal. Since the model will have spatial and temporal offsets from the observed fields, a classic statistical approach will be used (*e.g.,* seasonal mean).

**Objectives**:

**O3-1** Generate the synthetic SWOT data.

**O3-2** Compare the SWOT synthetic data to the original data.

**O3-3** Assess the representation of the cascade of energy in the SWOT synthetic data and in the real data.

**Tasks**:
**T3-1** Run the SWOT simulator of the coupled simulations.
**T3-2** Determine the cascade of energy using the synthetic data.
**T3-3** Determine the cascade of energy using the real SWOT data.

### WP4: Air-Sea interactions at mesoscale and submesoscale

*Persons involved: **G. Lapeyre**, B. Chapron, A. Ayet, L. Renault, P. Marchesiello, M. Larranaga*
*External Collaborators: P. Klein (CalTECH), E. Rodriguez (JPL), N. Rascle (CICESE)*

This WP will be declined in two parts: the first one related to better understand the relation between SSH, surface winds, stress and heat fluxes at submesoscales; the second one will be related to the additional product measured by SWOT (*i.e.,* $\sigma_0$), which relates to the sea surface roughness.

The WP will use as a starting point existing atmospheric simulations of **Foussard** et al. (2019a) and **Foussard** et al. (2019b), and then new coupled simulations obtained in the other WPs. We will also rely on the newly coupled global simulation that is being performed at JPL with a resolution of $1/48°$ in the ocean. This will be possible through a collaboration with Patrice Klein (at CalTech);

These simulations that will include submesoscale will allow us to document the response of the atmosphere to a submesoscale eddy field, in terms of surface heat fluxes and winds. For the moment, this response was not studied, or only in a regional context (Californian Current). In a region of a well defined storm-track, we expect that midlatitude storms will be the boost air-sea interactions when a cold front will pass over an eddying ocean. We aim to see how fast the atmospheric boundary layer (ABL) will adjust to the oceanic submesoscales and what are the relations between SSH (in particular SSH Laplacian) and winds in the ABL.

We will use the SWOT simulator to obtain the typical SSH SWOT product and we will study the relation of this signal with the surface wind stress. We will also use in a synergetic way data obtained using the CFOSAT simulator and mimicking scatterometers data such as ASCAT or QuikSCAT. In particular, we would like to see if the fast sampling phase with data every day can help us to better describe the SSH-wind coupling. We will extend the results from **Renault** et al. (2017a) and **Renault** et al. (2018) by assessing the coupling coefficient $s_\tau$ at both mesoscale and submesoscale using coupled simulations, synthetic data (from the SWOT and the CFOSAT simulator), and idealized coupled configurations. We will respond to the following questions: **Can we determine a linear relationship between currents and wind at submesoscale? are they similar to the mesoscale coupling coefficients? What are the main driving mechanisms ?**

Another question concerns the adjustment between the oceanic mixed layer (OML) and the ABL. In forced oceanic (atmospheric) simulations, the atmosphere (ocean) is viewed as an infinite source of energy. In the coupled case (i.e. in reality), both OML and ABL adjust to decrease the difference between SST and atmospheric temperature at the surface. Understanding this process is a key challenge for better representing air-sea interaction in climate models as we rely on bulk parameterization to represent them. We will concentrate not only wind stress but on heat fluxes, in particular latent heat fluxes (which have a strong impact on the large-scale atmospheric circulation, e.g. **Foussard** et al. (2019b)).

Part of the SSH signal of SWOT will give information on surface oceanic currents. Using a proxy of the surface stress (at zero order related to $\sigma_0$) from SWOT in addition to existing SST datasets and large-scale atmospheric variables (from ECMWF), it is tempting to develop some statistical model to diagnose fluxes at meso and submesoscales. Starting from the coupled numerical simulations, we will try to see the pertinence of this approach.

We intend to use the synergy between SWOT measurements: the nadir and near-nadir backscatter (*i.e.,* $\sigma_0$) and SSH, the nadir SWH (significant wave height) and near-nadir sea-state induced volumetric decorrelation.

First, we will first develop a single-column idealized model for representing the air-sea interface, initially proposed by **Kudryavtsev** et al. (2005). The model will be extended to fully include the wind-wave model derived in **Kudryavtsev** et al. (2014), in which we will also further include the effect of surface currents and related variations, following **Kudryavtsev** et al. (2005) and **Kudryavtsev** et al. (2012). This will lead to the *backscatter coefficient simulator*. In collaboration with E. Rodriguez (JPL) and N. Rascle (LOPS), we will further extend the model to include horizontal variations of the wind, currents and SST field, extending ideas from proposed analytical boundary layer models by **Kudryavtsev** et al. (2005) and **Ayet** et al. (2019), together with large-eddy simulations.

The idealized model will first be used to investigate the variability of the backscatter coefficient at the scale of SWOT SSH measurements (*i.e.,* $10 - 50$km), in order to quantify to what extend a measurement of this coefficient can be related to a reference height wind in the atmosphere. Extending the methodology proposed by Quilfen and **Chapron** (2019) to SWOT 2D measurements, we will more specifically study the link between the backscatter coefficient at scales of $500$m and fine scale currents, for a given large scale wind and stability. Information on the spectrum of surface currents $< 50$km are largely expected to sign in the variability of the backscatter coefficient and sea state estimates, to provide means to compare with 20-50 km SSH spectral estimates.

**Objectives**:
**O4-1** Develop the idealized coupled simulations.
**O4-2** Assess mesoscale and submesoscale relationships between SST, SSH, surface currents and wind.
**O4-3** Assess the mechanisms that drive the oceanic response to submesoscale air-sea coupling.
**O4-4** Assess the capability of the SWOT measurements to provide information on near-surface winds, and wind stress, at scales of $20 - 50$ km.
**O4-5** Understand the links between SWOT measurements, surface currents and stability conditions at scales down to O(1 km)

**Tasks**:
**T4-1** Run the idealized coupled simulations.
**T4-2** Assess the wind and heat fluxes response to submesoscale coupling from the simulations, synthetic data, and real data.
**T4-3** Determine what processes drive the oceanic and atmospheric response to submesoscale coupling.
**T4-4** develop a *backscatter coefficient simulator*. Develop a hierarchy of coupled models to be compared with real and synthetic data.

### WP5: Extending the results to other SWOT keys or crossover regions

*Persons involved:* ***L. Renault****, G. Lapeyre, J. Jouanno, P. Marchesiello, M. Larranaga, I. Dadou*
*External Collaborators: R. Morrow (LEGOS), O. Vergara (LEGOS)*

This last WP depends on the 2 first WP and aims to extend our results to other regions of the world and in particular over cross-over points of the fast sampling phase. It will use only existing simulations and will apply the developed diagnostics on them, therefore this will not require new development or run. We have several coupled simulations at different scales over various regions of the Word Ocean such as the California Upwelling (**Renault** et al. 2018, 2016b), the Gulf of Mexico and Caribbean Sea (PhD student co-funded by the CNES, M. Larranaga), the Pacific Ocean (L. Maillard, PhD student), the Western Mediterranean Sea (**Renault** and Arsouze 2019 and in collaboration with the CTOH (R. Morrow and O. Vergara, see their proposal)), the Gulf of Guinea (in collaboration with I. Dadou (LEGOS), see her proposal and S. Djoukoure (JEAI IRD)), and a realistic tropical channel that, among other, includes New Caledonia (see **Renault** et al. 2019b). If the wave feedback is not needed, both cascade of energy and air-sea interactions will be assessed over these regions, reproducing the main diagnostics from WP3 and WP4.

## II.5 Anticipated Results

Specifically, this 4-years project will respond to two objectives of the call: the study of **Mesoscale (and submesoscale) ocean dynamics** and **Ocean fronts and air-sea interactions**. We expect to:

- Better estimate the fluxes of energy between meso, submeso and basin scales.
- Provide guidance on what is the minimal physics required in an oceanic model to be compared to SWOT.
- Determine what portion of the SSH signal is monitored by SWOT and to what extend the cascade of energy can be measured.
- Characterize the air-sea interactions at both mesoscale and submesoscale by using SWOT data and other data from *e.g.,* CFOSAT, scatterometers, and radiometers.

This project will lay essential groundwork for assessing the quality of SWOT data and future missions, but also for further study of ocean dynamics and climate change impacts.

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