Coastal and Estuaries White Paper. Part 2 : Coastal seas and shelf processes

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1 Introduction

The SWOT Mission Science Document was published in 2012 and the general overview sections were written in 2011 (see http://swot.jpl.nasa.gov/). The Science Document contains a section on coastal seas and shelf processes that provides a good general overview. This white paper is aimed at providing an updated perspective on SWOT science and applications for coastal seas and shelves.

A separate white paper (“Coastal and Estuaries White Paper. Part 1 : Estuaries and nearshore processes) describes SWOT applications in estuaries and near-shore regions (where dynamics are strongly influenced by breaking waves). To avoid confusion, in this white paper we use the terms "shelf oceanography", "shelf circulation", and "shelf processes" to describe the ocean in the region within several tens to hundreds of kilometers from shore, often coinciding with the extent of a continental shelf. There are also regions, such as the European Shelf Sea, where the shelf extends over even larger regions between land masses.

The societal importance of the shelf regions derives from their many uses. By definition, these regions must be crossed by vessels carrying passengers and products to port cities. Safe navigation is a primary concern. The same regions are often the location of major fisheries, both industrial and artisanal, with mortality rates for fishermen much higher than for other occupations. Mineral extraction is another common activity over the continental shelves, with structures that must withstand severe conditions (or be moved in some cases). Recreational use is also concentrated over the shelf near land. These activities make shelf regions major focal points for operational oceanography, requiring not only observation, but prediction. The advent of SWOT sampling represents a major innovation and addition to the sources of information needed for nowcasts and forecasts of ocean conditions for this wide assortment of activities.

In these regions, bathymetric gradients as well as the shoreline directly influence the ocean circulation, hydrology and biogeochemistry. Exchanges between the deep ocean, the shelves, near-shore regions and estuaries also occur. In addition, shelf circulation studies often encompass an area of the open ocean, as exchanges of water, nutrients, or tracers between the shelf and the open-ocean are essential to understand both systems. Indeed, processes that originate on the shelf (jets and eddies) may leave the shelf and impact the deep ocean in a "coastal transition zone", as found in many of the Eastern Boundary Current Systems (EBCs) and elsewhere. The EBCs are briefly described in the SWOT Mission Science Document (Fu et al., 2012, Section 3.1.3.1). Conversely, eddies and strong currents generated in the deep ocean may also move onshore and interact with or drive processes over the shelf or at the shelf-break (such as shelf-break upwelling). Examples of deep-ocean currents affecting the shelf are more common on the wide shelves next to Western Boundary Currents.

SWOT sampling characteristics pose challenges for researchers investigating shelf circulation and shelf processes. As described on the JPL SWOT home page (swot.jpl.nasa.gov) in the SWOT Mission Science Document (Fu et al., 2012) and in the January 2015 SWOT Science Definition Team meeting, the sampling will provide high spatial resolution (≤ 0.5-1.0 km gridding) in nearly instantaneous swaths that are ~120 km wide, with a nadir "gap" of approximately 20 km. SWOT will also carry a conventional altimeter that will provide a line of data at the nadir location. SWOT's exact repeat period is ~21 days, and at mid latitudes, a given location will be observed 2-4 times during each 21-day period. At higher latitudes, more frequent observations will be available due to the convergence of tracks as the satellite approaches its inclination latitude (78°). While SWOT will mean a huge step forward toward observing coastal ocean processes compared to traditional nadir altimetry, the temporal resolution of the SWOT data may still be limited compared to relatively small (hours to days) temporal scales associated with physical variability over the shelf. Some approaches to address this mismatch of spatial and temporal sampling are described below (e.g. compositing and data assimilation), but this will remain a major challenge to those proposing to use SWOT data. To at least partially address this mismatch, during the first 60-90 days of the mission, the satellite will follow a different orbit, with a one-day repeat (albeit covering only a few swaths). Data collected during this one-day repeat will allow some evaluation of the time scales and phenomena that are missed or aliased by the standard 21-day repeat pattern that will be employed for the rest of the mission. Processes with time scales of one day and less will still be undersampled during this period.

2 Physical processes of interest

This white paper focuses on the physical processes that SWOT will help us to better understand. These physical processes underlie a broad range of science questions, including biochemical processes, making them fundamental to an understanding of interdisciplinary ecosystem dynamics. Interactions of shelf processes with the atmosphere, land and the open ocean result in a very active system, highly dependent on local conditions (shoreline, depth distribution, rivers and estuaries, local and remote atmospheric circulation, local and remote forcing from the open ocean, etc.). Some of the important physical processes are described in the Mission Science Document (Fu et al., 2012, Section 3.6), and more complete reviews of the global coastal ocean systems can be found in books such as several volumes of "*The Sea*" (Robinson and Brink, 1998a; 1998b; 2005; 2006) or in papers (e.g. Huthnance, 1995).

Thought of in physical terms, a region of coastal ocean is a volume of fluid, often stratified, in which the internal response is governed by forcing and conditions at the boundaries (fluxes of heat, momentum and fresh water) and internal forces (gravity and tidal potentials). This relatively simple conceptual picture results in a wide range of complex motions, which include:

- External tides;
- Surface gravity waves (including infragravity waves) and wave-induced circulation;
- Storm surge (mainly in the near-shore area)
- Internal tides and shear-generated internal waves, sometimes taking the form of wave trains and solitons;

- Fresh water plumes from large rivers or "line-sources" at the coast created by many small rivers;
- Upwelling and downwelling at the coast, driven by the alongshore wind stress or by wind-stress curl;
- Coastally trapped waves, propagating along the coast, influenced by the bathymetric cross-shelf slope;
- Offshore-propagating Rossby waves (along eastern boundaries of the basins);
- Creation of density fronts and frontal jets, usually close to geostrophic balance;
- Subsurface countercurrents, especially near the shelf break and upper slope;
- Currents generated by deep-ocean currents and pressure gradients that impinge the offshore edge of the shelf or extend onto the shelf;
- Non-linear interactions of surface waves, winds and currents, producing secondary circulation features with vertical velocities;
- Meanders, eddies and filaments generated by the barotropic and baroclinic instabilities, often creating horizontal or vertical shears that generate smaller-scale submesoscale features;

One could add others but this list is sufficient to make the point that the dynamics over the shelf can become complicated, and the interacting processes and features can create energetic and rapidly changing circulation structures, with strong vertical velocities. Vertical velocities are a primary mechanism for raising nutrients into the euphotic zone and feeding the typically high productivity of coastal oceans. Many of these processes have been studied for decades (e.g., upwelling), while others have only recently been recognized as being important (e.g. submesocale processes and SQG dynamics). Time scales for these processes range from hours to years; spatial scales likewise extend from tens of meters (fronts and plume edges, internal tides and waves) to tens of kilometers (fronts and submesoscale/mesoscale eddies) to hundreds of kilometers (mesoscale eddies). In general, spatial scales and time scales both decrease as one moves closer to the coast.

The observability in sea surface elevation of the processes listed above differs depending on the features. Some processes directly influence sea level, such as external and internal tides, surface waves, or storm surge. Other processes include the 'balanced' motions, defined to be in quasi-geostrophic or geostrophic equilibrium, such as slope currents, mesoscale eddies and some submesoscale features. Submesoscale patterns are usually depicted in satellite images (SST or chlorophyll), but to our knowledge there is not yet a clear understanding of the signature of these features in sea surface height. Downwelling/upwelling fronts and large river plumes that generate water density variability, and hence steric sea level changes, are also potentially observable. For example, in numerical simulations of the Columbia River, a SSH signal on the order of 10 cm is distinguishable (Giddings et al., 2014). Observability is a key issue to the use of SWOT data in coastal areas.

3 What have we learnt from past and present nadir altimetry ?

For the last two decades, spaceborne radar altimeters, measuring sea level variations, have provided major advances in ocean dynamics, including the ocean general circulation and its variability, response to wind forcing, eddies, waves, tides, mixing, etc. (*Fu and Chelton*, 2001; *Morrow and Le Traon*, 2012). Altimetry has also become one of the most important ocean observing components in operational systems and is routinely used to map the ocean surface topography. But "historical" satellite altimetry measurements encounter many problems in coastal environments, resulting in a rapid degradation of the data accuracy when nearing the coastlines. First, the radar echo itself interferes with the land topography, resulting in altimeter waveforms that deviate from Brown's theoretical model within a few km of coastlines. The corrections applied to the altimeter range (e.g. wet troposphere path delay, sea state bias, tide and high frequency barotropic response to atmospheric forcing) are not adapted to the intrinsic characteristics of shelf ocean dynamics. The coarse spatial and temporal sampling of sea surface topography, in comparison to the dominant scales of the coastal ocean variability, is also one of the most important factors that will need to be addressed in the future. In the last few years, however, considerable research has been carried out toward extending the capabilities of current and future altimeters to provide data as close as possible to the coast (see for example *Vignudelli et al.*, 2011). This has included new strategies in modeling and retracking radar altimetric waveforms, altimeter corrections (in particular tidal and water vapor path delay) adapted to the coastal ocean conditions, data processing and post-processing integrating regional/local information, as well as the use of the original, unfiltered along-track altimeter sampling at 1 Hz or higher frequencies. Reprocessed coastal altimetry data are now available from multiple sources and projects (e.g. PISTACH/CNES, COASTALT-eSurge/ESA, X-TRACK/CTOH). This large quantity of re-analyzed data is extremely important:

- To understand sea surface topography variations in terms of coastal dynamics,
- To define correctly the key factors that determine coastal altimetric data accuracy (in terms of instruments, data processing, auxiliary information) and to develop improved altimeter corrections as needed,
- To understand the issues for coastal altimetry in parallel with other ocean observing systems and numerical modelling,
- To optimize data products from the new generation of altimeters and to prepare for future altimeter missions.

At the same time, the CryoSat-2 altimetry mission has demonstrated the ability of synthetic aperture radar (SAR) altimetry to increase along-track spatial resolution, as well as the data accuracy, thus allowing measurement of smaller-scale changes in water elevations. The new Ka-band radar altimeter on board the SARAL mission, has also demonstrated an efficient alternative to conventional Ku-band altimeters in improving the signal-to-noise ratio and in resolving finer spatial scales. All these results are encouraging for the Ka-band SAR interferometry SWOT mission. But these new technologies also place the issues of coastal altimetry in a new context, allowing us to revisit a number of scientific and technical questions: understanding the radar measurement, improving the corrections, providing a precise geoid estimate or mean sea surface height, tidal aliasing, signatures of coastal ocean processes in sea level changes, geostrophic vs ageostrophic motions, CAL/VAL issues, and data assimilation techniques, amongst others.

One correction that deserves special attention in the coastal environment is the wet tropospheric path delay, which can have sharp gradients near the land/sea boundary. Uncorrected wet troposphere effects can thus produce spurious sea surface height signals in the coastal regime. SWOT is currently planned to have two radiometers, which will provide a measure of the large-scale gradient in the wet troposphere correction across the width of the swath. Careful use of atmospheric fields from reanalysis products should provide further information on the wet troposphere effects. Further enhancements to the radiometer on SWOT to increase the spatial resolution of the measurement and reduce the error when approaching the coast are recommended.

4 What can we expect from SWOT ?

What new capabilities will SWOT data give us? The primary attribute of SWOT data is the ability to produce high-resolution, nearly instantaneous "snapshots" of sea surface height (SSH), the primary variable, along with information about winds and waves with similar resolution. The basic spatial resolution over most of the shelf will be the same as in the open ocean: ~ 1 km gridded data points with uncertainties of several cm. Higher resolutions (500 m or 250 m) may be possible, with higher uncertainties, but for most applications presently envisioned, users will probably smooth the data even further, to create horizontal grid spacing of 3-5 km and even lower uncertainties in the SSH data.

The challenge lies in the combination of this high spatial resolution with lower temporal resolution. As described earlier, at mid-latitudes there will be several observations during each 21-day exact repeat period, producing observations every 5-10 days (more often at higher latitudes). Thus, it will not be possible to observe the temporal development of the small-scale features that will be seen in the instantaneous SSH fields. This situation is analogous to the current situation for infrared SST or visible bands of ocean color (chlorophyll-a concentration) in regions with high cloud cover. In these regions, extensive use is made of images that are available only at roughly weekly intervals (by compositing or by waiting for a clear day). Experience gained in using these types of images suggests several approaches to the SWOT fields.

Diagnostic Uses: Simply seeing data fields for the first time allows new types of features to be described. The ubiquitous filaments and eddies found throughout the ocean were revealed by the first high-resolution SST and ocean color images (with ~1 km resolution) in the early 1980's. They had not been expected before that. Statistical descriptions of the horizontal scales (wavenumber spectra, structure functions) provide metrics that test certain dynamical hypotheses about the fields. At scales on which the flow is geostrophic, the SSH fields allow estimates of the velocity and vorticity fields that can be diagnosed to infer vertical velocities. Combinations with other remotely sensed or in situ data, as well as with information provided by numerical models or the theory, will extend the interpretation and quantification of the SSH data in terms of underlying ocean dynamics. For example, many coastal regions are observed by HF coastal radars that estimate surface velocity (total velocity, not geostrophic). Combinations of SSH, radar velocity, satellite SST and winds will provide a fertile set of data products for oceanographic applications.

Efforts in recent years have included synthesis of altimetry and coastal SSH gauges, in particular, to estimate the intensity of alongshore currents on annual, seasonal and shorter time scales (Saraceno et al. 2008, Vinogradov and Ponte, 2010). SWOT altimetry will close the data gap in the 50-km zone next to the coast and allow a more direct comparison of the satellite and in-situ tide gauge data. This will lead to better understanding of processes responsible for sea surface height variability along the coast (due to winds, pressure changes, and waves).

Model Validation and Evaluation: Numerical modeling is essential for the study of shelf processes. Present observational networks are often limited in terms of space-time coverage with respect to the wide spectrum of scales characterizing the variability of shelf processes. Post-launch, SWOT data will be used to test coastal models. Even prior to launch, numerical simulations and the SWOT data simulator will help us to understand the dynamical nature of the SWOT observations.

A model's ability to represent targeted processes should be evaluated given the model's effective resolution and its physics. Model assessment in coastal areas requires specific approaches and metrics that differ from those used for to open-sea models, because of the specific scales and processes (as above mentioned). One challenging issue is the consistency verification of high-frequency dynamics (Maraldi et al., 2013).

Spatial resolution in numerical models is intrinsically linked to the model physics: for instance, taking into account wave-current interactions or the influence of river discharge on sea water turbidity over the shelf requires high resolution on both horizontal and vertical dimensions. Model resolution is constrained both by computing and storage costs and by physical hypotheses (e.g. hydrostatic/non-hydrostatic physics). Resolution choices are also linked to issues associated with downscaling from basin-scale circulation to the scales of shelf dynamics and hydrology. Several strategies have been adopted such as one-way or two-way nesting and/or grids with variable mesh size, with structured or unstructured models.

Data Assimilation: There are now coastal ocean models that improve their realism by assimilating multiple data sets, for instance to facilitate accurate forecasts of oceanic conditions to help navigation, environmental hazard response, fisheries, etc. The assimilated data include for example high-resolution SST surface radar (Yu et al., 2012), along track altimetry (Kurapov et al., 2011), temperature and salinity profiles from autonomous underwater vehicles and Argo floats (Moore et al., 2011; Todd et al, 2011). Adding the SWOT SSH observations to this mix will provide a new source of high-resolution information for the models. Assimilating models will "dynamically interpolate" SWOT observations to fill in the missing temporal coverage. A key question for SWOT is to determine how much information can be retained between passes at each timescale and length scale. This applies to a broad range of applications, including barotropic and baroclinic tides, as well as coherent and incoherent structures at, meso- and sub-mesoscale. Away from areas of existing dense in situ sampling such as coastal observatories, the impact of SWOT on the quality of assimilated products in coastal regions is expected to be critical (e.g. Le Hénaff et al., 2008, 2009). Eventually, the models will be the ongoing source of our time series to describe the changing environment in the ocean domain over the continental shelves, and it will be important that uncertainty estimates be available for these assimilated data products. SWOT will provide substantially more observations than are currently available from in situ data or nadir altimetry, meaning that they will provide significant constraints to assimilating models. Uncertainties in SWOT data may differ from uncertainties in other data products, so SWOT data will need to be released with uncertainty estimates in order to allow them to be weighted appropriately when they are assimilated.

Coastal ocean forecasts and impact on operational oceanography: We are just at the beginning of the period of "coastal operational oceanography" (e.g. De Mey et al., 2014), including coastal ocean forecasts that will become more realistic with better routine inputs (such as SWOT) and with more experience in data assimilation. To that end, plans are being initiated[1] to bring the coastal altimetry and coastal ocean forecasting communities closer to each other.

[1] Altimetry for Regional and Coastal Ocean Modelling (ARCOM) is one of the Focus Areas of the GODAE OceanView Coastal Oceans and Shelf Seas Task Team (COSS-TT, https://www.godae-

Polar oceans, ice and snow covers: SWOT will be of particular importance in high-latitude, sub-polar (e.g., Bering Sea) and polar marginal seas (e.g., Alaska North Slope). In these regions, the dominant scales of baroclinic jets and eddies (the Rossby radius of deformation) may be 20 km or less (Chelton et al., 1998). The along-track resolution of traditional nadir alongtrack altimetry is not sufficient to capture variability on these scales and is not as useful as at mid-latitudes. In addition, infrared and color imagery is plagued by persistent clouds in these areas. As mentioned above, SWOT will sample more frequently at any given point at high latitudes (compared to mid-latitudes) providing an unprecedented view of ocean surface variability in these data-scarce regions. In particular, SWOT surface topography maps will help us understand ocean variability along the dynamic ice edge, influenced by differences in surface heat, salt, and momentum fluxes over ice-free and ice-covered regions (e.g., Muench and Schumacher, 1985, Ohshima, 2000). Experts in ice dynamics and modeling should be encouraged to contribute to the work of the SWOT SDT to help assess the utility of SWOT measurements over ice. We do not yet know how useful SWOT will be (either in the 1 x 1 km ocean mode, or HR mode) for determining the ice free board height, ice concentration, ice thickness, ice deformation (Hutchings et al., 2011), snow cover, and statistics of ice leads on seasonal and inter-annual scales.

Bottom Bathymetry: A somewhat different use of the SWOT data will continue to be inference of bottom topography from surface height data, at unprecedentedly fine spatial scales. Those modeling tides and small-scale ocean currents have pointed to the lack of accurate bottom bathymetry data as one the prime limiters to the accuracy of their models. It remains to be seen whether the SWOT fields can help to monitor the temporal changes in bottom morphology caused by sediment transport over the shelves. This will certainly be a topic of research.

Some examples of processes over continental shelves that may be better understood through the use of SWOT data are given next, and the appendix reviews a sampling of regional applications.

5 Examples of processes

External tides.

Over the shelf, variations in tidal current amplitudes significantly influence bottom stress, which influences the coastal ecosystem. Regions of strong currents have high sediment transport capacity resulting in turbid waters, influencing phytoplankton production, and also high bottom stress, which controls benthic habitats. Therefore, a precise understanding of the tidal dynamics, which is currently lacking, is one of the basic requirements for defining the characteristics of the marine environment of shelves. In addition, the study of shelf dynamics other than tides, requires the removal of tidal signals from altimetric measurements. In both cases, whether one is interested in tides or in motions other than tides, a precise knowledge of tidal dynamics and accurate predictions of tidal signals in sea surface elevation over the shelves must be achieved.

As reviewed by Stammer et al. (2014), tide models that assimilate nadir altimetry data have reached a high level of accuracy in the open ocean (equatorward of 66°N/S). The

oceanview.org/science/task-teams/coastal-ocean-and-shelf-seas-tt/). The first ARCOM workshop is planned in September 2015 within the annual COSS-TT workshop. Preparing to use SWOT data in coastal models is one of the main objectives of ARCOM.

performance is also excellent over the shelves, but with significantly higher relative error (Arbic et al., 2015). Several factors can contribute to the tide models' loss of accuracy over the shelves, such as a more complex physics (e.g. resonance) and the large impact of uncertainties in bathymetry or in bottom friction coefficient. Future research in shelf tidal modelling is expected to follow several lines of research, such as improving hydrodynamical models, making bathymetry more accurate, and using inverse methods to estimate model parameters.

Internal tides : Internal tides have been depicted in nadir altimetric data in several regions of the global ocean (e.g. Ray and Mitchum, 1996; Egbert and Ray, 2001) but many questions remain regarding their stationarity, their dissipation and their spatial structure. SWOT altimetry observations should yield more information on internal wave propagation characteristics; however, the revisit time period of SWOT and the resulting aliasing will make internal tide detection a complex issue. In addition, the surface expression of the internal tides may prove too small to be detectable, given the measurement errors (see for instance the study of Maraldi et al., 2013, in the Bay of Biscay using nadir altimetry). Over the shelf, wavelengths are expected to be small. Finally, separating internal tides from mesoscale surface signals is non trivial, unless 3D in situ measurements are available to provide complementary information at high frequency and over time.

Slope currents : Slope currents are dominant features of the regional circulation as in EBCs (e.g. the Californian Current System, or the Iberian Poleward Current in the North East Atlantic) or in regional seas such as the Northwestern Mediterranean (see appendix). Instabilities may be generated at capes and canyons, resulting in the formation of eddies. The narrowness of the slope currents, as well as the small spatial scales of the variability in the along-shore flow direction, usually makes them difficult to observe. SWOT will provide 2D high-resolution data that are expected to fill gaps in our information about the current structure. Previous studies (e.g. Herbert et al. 2011, Dussurget et al. 2011) have illustrated the difficulties in dealing with coastal altimetry, since uncertainties in the geophysical corrections (e.g. the wet troposphere correction) are larger close to the coast. Future SWOT observations will also be subject to geophysical corrections and to instrumental corrections with complex geometry (e.g. roll errors).

River plumes: River plumes in the absence of significant external forcing, have a clear surface signature formed from an anticyclonic bulge located in front of the river mouth followed by a thin and elongated coastal current. However because freshwater flows at the ocean surface, river plumes are highly sensitive to the wind, giving them a strong high-frequency variability (Estournel et al., 2001) reinforced by potential tidal currents. River plumes can often be observed from space thanks to their suspended material load and to chlorophyll associated with high nutrient loading. However, during floods, which are associated with high transfers of continental material to the sea, the river signature is not always clear, as it is superimposed on re-suspension events which can impact a large part of the continental shelf. In this context, high-resolution altimetry coupled with ocean color images could help to discriminate recently discharged light waters from older shelf waters.

Recommendations

The regional ocean/shelf/continent should be considered as a continuum, and we suggest that numerical methods and data processing tools that exploit SWOT observations should be developed with this continuum in mind.

Although some of the shelf processes of interest have spatial scales of 1 kilometer or less, the height signals associated with these processes are usually only a few centimeters. Because the noise/uncertainty in the SWOT height measurements increases to more than a few centimeters when the size of the spatial average used to define each data point is reduced to less than 1 kilometer, the planned resolution of the deep ocean data set (0.25 km, 0.5 km or 1.0 km) will be adequate for most applications over the shelf. However it might be preferable if the SWOT onboard processor provided measurements at 0.25 km or 0.5 km resolution that could be averaged or filtered using algorithms designed to conform to the structure of the coastline, to the characteristic scales of variability of the shelf dynamics and to the error budget over the shelf.

In order to identify and solve the important factors for SWOT data accuracy in shelf areas (in particular in terms of altimetry corrections), efforts that have been undertaken in order analyze/re-analyze nadir coastal altimetry data should be extended. Users should be encouraged to incorporate altimetry data in shelf studies and applications, report their needs as well as the difficulties encountered. In addition, modeling and aircraft-based research should continue in order to characterize the magnitude and spatial structure of the wet troposphere path delay.

Accurate prediction and knowledge of external tides is essential for the use of SWOT data in coastal and shelf areas; we recommend that future efforts focus on this issue, based on both numerical developments as well as the deployment of moorings, not only in the nearshore region but also over the entire shelf.

Because the shelf and coastal circulation is complex and characterized by a broad spectrum of time and spatial scales, numerical modeling/assimilation will be a necessary 'companion' to the use of SWOT data. Modeling and assimilation are important to provide a better understanding of the observable physical processes and for dynamically mapping/interpolating SWOT data. Assimilation provides a natural framework for interpreting data from diverse sources within a dynamical context, and it provides a mechanism for evaluating consistency of theory and observations. Coastal and shelf seas over the world have distinct characteristics in terms of bathymetry, forcing, connection to the open ocean, etc., and different modeling strategies may be needed. Therefore a large diversity of numerical approaches should be encouraged.

The launch of SWOT will open a groundbreaking era for coastal ocean models, in terms of validation, data assimilation, forecasting and applications. In order to prepare for these uses, we recommend: (1) promotion of the knowledge of SWOT in the emerging coastal ocean forecasting community, (2) promotion of the development of new, efficient coastal data assimilation methods with built-in error dynamics, and (3) making plans to elaborate, validate and provide measurement error estimates of SWOT SSH that will be critically needed by the assimilation schemes.

Appendix. Example of regions of interest

The northwestern Mediterranean Sea (NWMED) appears to be an interesting test area to analyze how SWOT observations may impact our understanding of the shelf processes. First, because tides are weak in this region, tidal aliasing will not be a significant issue. This area is characterized by large differences in shelf width along the continental margin (up to ~70 km in the Gulf of Lion). The Rossby radius, of the order of 10 km (Grilli and Pinardi, 1998), is much smaller than over much of the world ocean. Ocean variability is affected by storm-induced fluctuations as well as by forcing mechanisms acting primarily at seasonal scales. Internal nonlinear dynamics give rise to an intense mesoscale eddy field. This region is relatively well observed from an oceanographic and geodetic point of view, and substantial effort has already been expended to understand the signature of regional and shelf processes in SSH data. Despite its narrow width (20-30 km), part of the seasonal variability of the slope current (Northern Current or NC) can be detected by satellite altimetry (Birol et al. 2010; Bouffard et al. 2011). The issue is to assess the smaller wavelengths of the surface circulation as well as to observe the NC instabilities and/or intrusions over the shelf, the submesoscale structures highlighted by in-situ observations over the Gulf of Lion (Hu et al., 2011), the Rhone river plumes, the coastal upwelling/downelling associated with strong local wind events.

The California Current System offers a second test area, where assimilation is routinely carried out (e.g. Li, et al. 2008, Moore et al 2011, Todd et al 2011, Mazloff et al 2014). It is well-positioned to work with AirSWOT observations, and like the Mediterranean, it has strong seasonal variability and an extensive observing system (including routine ship observations, glider observations, and HF radar). Small-scale eddies generated at the coast can coalesce into larger structures and propagate westward across the Pacific. This makes the California Current a natural environment for studying eddy generation mechanisms, as well as links between eddies, local topography, and winds. The California Current is also a highly productive Eastern Boundary Current system and thus a natural place to evaluate the extent to which vertical exchanges can be inferred from SWOT data in combination with ancillary data products from satellite and in situ observations.

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