SWOT CONWEST-DYCO Project
CONtinuum of Water from ESTuaries to coastal DYnamics

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1. Introduction and Objectives

Coastal areas and estuaries are among the environments most affected by anthropogenic impact and climate change and are considered as multi-risk, due to coastline retreat, flooding by storms and river floods, and pollution. Estuaries connect ocean and land, salt and fresh water. The estuarine zone has a complex hydrodynamics, with a strong variability of the water level at various temporal and spatial scales caused by interactions of different water bodies (river, tributaries, groundwater and sea) and of different phenomena (tide, wave, surges, and sea level rise). Good knowledge of the hydrodynamics of these environments is mandatory to respond to the various challenges.

Satellite altimetry monitors water heights since 1992. Due to the land contamination of the reflected signal, conventional nadir radar altimetry data (CA) were discarded in the coastal zone, until the early 2000s. Moreover, at wavelengths larger than 100 kilometers CA contains information on the ocean surface height, while the measurement noise dominates the slope signal in the sub-mesoscale, the spatial resolution of the spatial maps is 200 kilometers. Thanks to the dedicated re-processing, called retracking, coastal and inland data are improved, and the same is done for the estuaries. Due to the tides, the estuaries are particularly challenging. The new altimeter generation which employs the Delay-Doppler (DDA) and the wide-watch techniques, gives: (a) higher resolution and higher accuracy of water level and discharge, (b) new additional parameters (e.g. river slope) and (c) sampling sufficient for flood events detection and long-term analysis.

The mission SWOT (Surface Water and Ocean Topography) will provide critical information on the spatial variability of water surface elevation. It will allow a better understanding of the interactions between hydrodynamic processes. River Water Discharge (RWD) is another parameter that can be derived from satellite altimetry. It reflects the drainage basin area dynamics and affects environmental conditions like currents and hydrography in coastal waters, it is a function of geology, relief, precipitation, vegetation and climate. For medium size basins (<10,000 km2) RWD is also indirectly estimated from satellite images in the visible and near infrared spectrum (e.g., MODerate-resolution Imaging Spectroradiometer – MODIS).
SWOT will observe at a previous unresolved scale. Its spatial along-track resolution in the ocean is estimated to be 15 km for 2 m significant wave height. However, both signal strength and and measurement error depend on seasonal conditions and the actual resolved wavelengths vary from 15 km in the tropics to 30-50 km at high latitudes.

The CONWEST-DYCO project (CONtinuum of Water from ESTuaries to coastal Dynamics) explores multi-satellite altimeter observations along coasts and estuaries of the German Bight and Baltic Sea, which are largely covered by SWOT in the 1-day repeat. The region of study has a deployed network of various instruments (tide gauges, GPS, ADCP, buoys) and operational/experimental models exist.

The project will investigate whether the combined SWOT-type and SAR/SARin observations have the potential to make progress at both spatial and temporal scales. The first scientific objective is to demonstrate the potential of SWOT to monitor the water exchange from land to ocean and to improve the understanding of the estuarine processes. The second scientific objective is to investigate mesoscale and sub-mesoscale ocean dynamics features, which are not yet resolved by satellite altimetry.

The specific objectives are:
(1) Understand the SWOT signal
(2) Compare the potentiality of SWOT and of nadir altimeter satellites
(3) Apply SWOT to coastal and estuarine environments to characterize the temporal and spatial variabilities of the hydrodynamics.
(4) Define issues for the application of SWOT for mesoscale and sub-mesoscale ocean dynamics.

For application of SWOT to coastal and estuarine environments, the technical objectives are:

(1) improve the understanding of observed signal, errors and processes in estuary and nearly coast
(2) predict the evolution and interaction of the sea/estuary/river environments.

The three estuaries of the German Bight, i.e. Elbe, Ems and Weser, and the German Bight coasts are considered (Fig. 1). The Elbe is the main study area and is partly located under the SWOT swath of the 1 day phase. A network of in-situ stations available in quasi-real time allows to combine in-situ with space observations and model simulations. The region is a mesotidal environment with varying geometry and difficult-to-couple interactions between the meteo-oceanographic and morphodynamic factors. A major similarity among the Elbe, Ems and Weser estuaries is the tidal and atmospheric forcing. Semidiurnal tides with a range of ~3–4m during spring periods are the primary drivers. Well-developed Estuarine Turbidity Maxima (ETM) are observed at the landward ends of mixing zones between saltwater and freshwater (Kappenberg and Grabemann, 2001), which are approximately at the landward ends of salinity fronts.

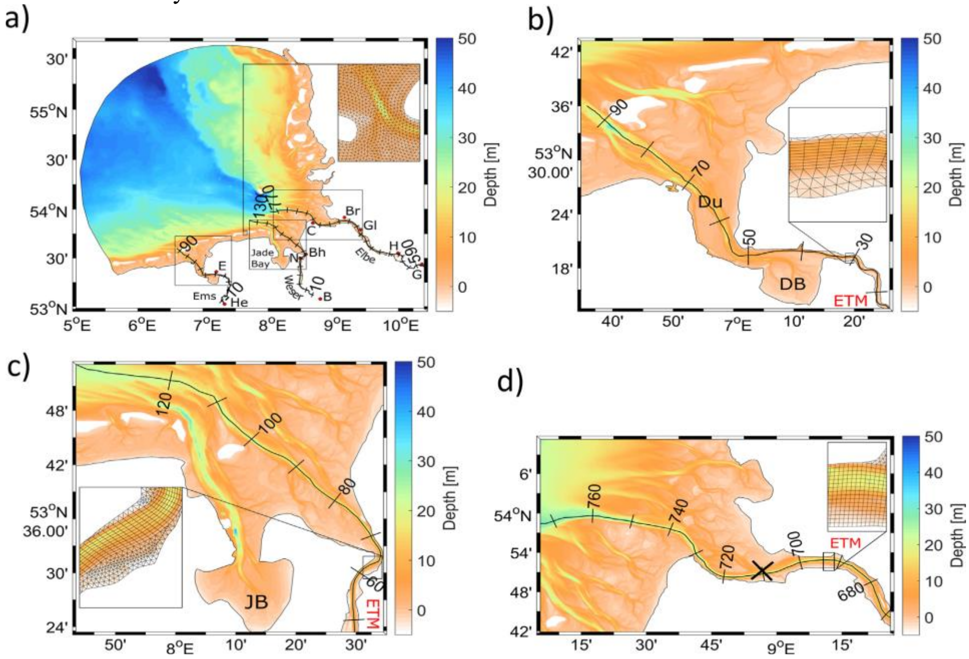

Figure 1: German Bight (a) and the three estuaries studied here (b, c, d). Boxes in (a) identify the positions of individual estuaries (b, c, d) (from Stanev et al., 2019).

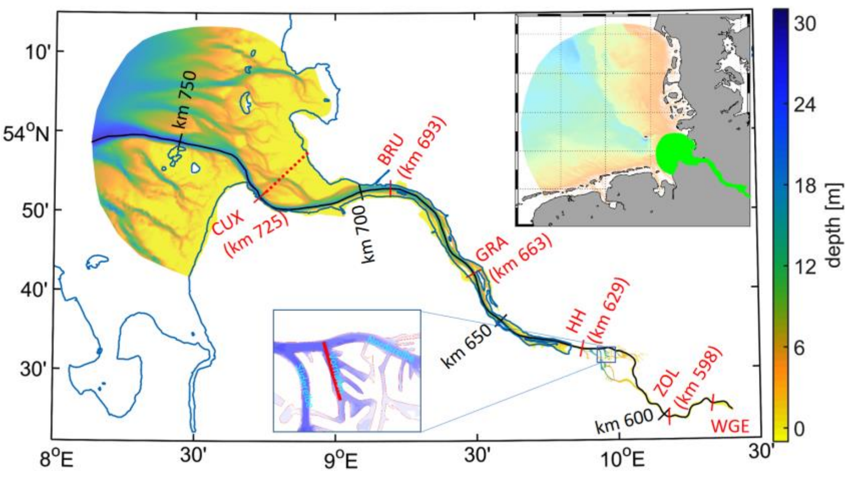

Fig. 2. Elbe SCHISM model domain with depth [m] in background. The black transect line indicates the Elbe navigational channel with labels identifying the official Elbe-km. Red labels and associated ticks mark the location of observation stations with respective official Elbe-km given as additional information. A zoomed-in view illustrates the central part of the Hamburg harbor area with red solid line marking transect used for dynamical analysis. The inset at the top right marks the location of the model area (green color) within the German Bight set-up used to force the Elbe-model hydrodynamically

For the application of SWOT to Mesoscale ocean dynamics, the technical objectives are:
(1) study the limit of SWOT observability of the small mesoscale/sub-mesoscale features at coasts
(2) disentangle the signal from the error
(3) improve the understanding of the physical processes

We consider sub-mesoscale suitable features in the southern Baltic Sea and the Danish Straits. Sub-mesoscale and mesoscale features are related to upwelling event and to exchange between the Baltic and the North Sea at

Skaggerack. This last controls the Baltic stratification and has a bottom flow critical for the deoxygenation. Parameters to be studied are temperature, salinity, oxygen, chlorophyll and fluorescence.

2. Approach

The project merges observations and model data to investigates the hydrodynamics of estuarine (tidal mixing, storm surges and salt water intrusions) and coastal processes (upwelling and water transport). The processes of interest are: (1) tides and discharge; (2) water exchange, (3) climate, (4) sub-mesoscale features. Seven **open research questions** have been identified. The first three are methodological and will improve space based data or surface representation, the last four are scientific questions:

(1) How can the SAR- and the SWOT-altimetry data be exploited in estuaries to compute discharge and tides, and how to deal at best with the HR data?

(2) How accurate are today the estuarine models and how can be enhanced by using the synergy with satellite data?

(3) Can the error estimation be improved to construct 2-dimensional maps?

(4) Which are the drivers of the multiyear and intra-annual hydrodynamic variability in the estuary?

(5) How are ***salinity fronts*** formed, and which is their evolution?

(6) What is the impact of climate change and ***extremes*** in estuary and floods on coastal biochemistry?

(7) Can processes in the sub-mesoscale structures be investigated with SWOT?

We expect that SWOT will reproduce the time variability of the ***hydrodynamics*** (discharge and currents are computed from water heights and slopes) and help to distinguish between estuary sub-regions dominated by tides and by streamflow.
To answer (1) for satellite altimetry, we apply the best state-of-the-art processing to along-track SAR altimetry (Dinardo et al., 2020). To answer (1) for SWOT data, we validate simulated and real SWOT data against external in-situ data and models to assess the improvement and estimate the SWOT error (question 3).
To answer (2) we use ocean models and OSSE experiments and assimilation procedures. The error in models is assessed today with in-situ and along-track altimetry. Assimilation of new data should improve the models, e.g. translating assimilation increments into model weakness and implementing improved process description.
To answer (3), a mapping of the surface water elevation (SWE) at HR in the 2-dimensional space and in time is derived from in-situ data, altimeter missions and model simulations. The goal is a smaller length scales of variability (< 30 m). The JPL SWOT ocean and LR CNES hydrology simulators generate nadir-like data and SWOT-like 2D outputs on a swath along the orbit ground track. Measurement error and noise can be added according to published technical characteristics. Processing tools for lower level data and point clouds have to be developed.
To answer (4), (5) and (6) observation and model results of the Elbe Estuary are studied. The physical setting of the Elbe estuarine eco-system is dominated by tidal motion and by the estuarine salinity gradient and their resolution is crucial for reproducing the interaction of physical and biogeochemical systems. Various methodologies will be used, including statistical techniques and frequency analysis, to study the content of information from observations and models. To answer (7) observation and model results of the South-eastern Baltic are studied.

To address the above questions, the project is based on the following approach:

(Obj1) Use a multi-sensor approach. Improve SAR (DDA) and SAR interferometry (SARin) data in the estuary region and use Satellite Imagery.

(Obj2) Characterize the ability of space-based observations (altimetry and simulated SWOT data) to register the hydro-metro events and their **temporal variability** (discharge, tides, etc.). We sample the time-series of water level and discharge according to the revisiting time of SWOT.

(Obj3) Perform hydrodynamic modelling and characterize the capacity of (simulated) SWOT to derive the **spatial variability** of the water height in different energetic conditions in the estuary.

(Obj4) Study possible assimilation of SWOT and DDA data in the actual estuarine model to improve the modelling of interactions between estuarine tide and discharge

(Obj5) Consider SWOT observations of the 1-day and 21-day phases

(Obj6) Investigate mesoscale features

Figure 3 shows the region considered. On the left, the three estuaries with in-situ stations, nadir track and left swath of SWOT 1-day repeat and the Sentinel-3A ground tracks are drawn. On the right, the number of observations during the 21-day is represented. The Weser estuary (TGBH station) and the Ems estuary (TGKN station) are less observed (1-2 observations) than the Elbe at the stations Nok and Glückstadt (3-4 observations). In the SWOT 1-day phase the tidal part of the Elbe is observed under the left swat for about 60 km between

Brunsbüttel and Blankenese (17 gauges) and under the right swat between Over Seevetal and Geerstacht (20 km, 4 gauges). The river Elbe is further under the right swat between Geerstacht and Bleckede (34 km, 5 gauges). The Seine, covered only in the 21-day repeat, is considered for comparison in the frame of the cooperation with B. Laignel (U. Rouen), coordinator of the SWOT 3MC project NASA/CNES SWOT 2020-2024.

The model system will be based on the Geesthacht Coupled Ocean Model System 3D GCOAST. The hydrodynamical model SCHISM has irregular grids (varying from 20 m to 1 km – with a mean resolution of 200 m, Stanev et al., 2019). Two additional models will be used for intercomparison studies: BSHcmod, with regular grid and resolution of 900 m (BSHcmod, Dick et al. 2006), and the operational 2D-hydrodynamic-numerical model of the Technical University Hamburg (TUHH, Institute of River and Coastal Engineering**,** Shaikh et al. 2016**),** with irregular triangulated meshes (Hervouet 2007, http://www.opentelemac.org/)).

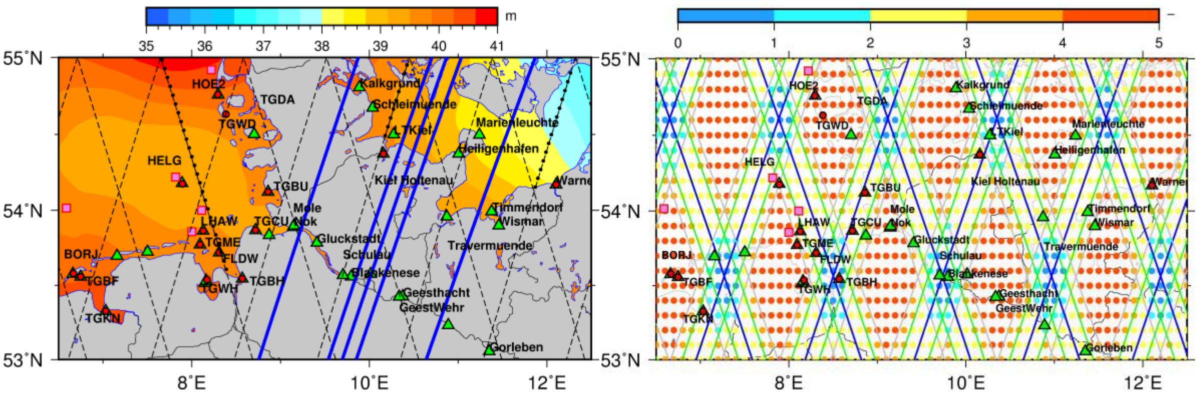

Figure 3. (left) Region of Interest (ROI) with Elbe, Ems and Weber estuaries and Sentinel-3A (black), SWOT (blue), tide gauge (green triangle), GPS (red circle), buoys (square). Coloured is the GCG2016 of BKG and IfE; (right) number of SWOT observations during the SWOT 21-day phase with SWOT nadir (blue), internal (green) and external (grey) ground tracks for the same ROI.

2.1 Analysis of existing multi-sensor data (IGG, HZG, TUHH, GEOMAR, BfG)

This first task combines modelling and in-situ data. It uses in-situ water level and discharge data from federal agencies BfG, BKG and BSH, campaigns measuring physical and water quality parameters of the CMEMS data databank. Re-tracking methodologies improve the conventional and SAR altimeter datasets. Water/flood masks from multi-sensor satellite data are derived from satellites.

Dedicated runs of the GCOAST model are performed for the Elbe, Ems, Weser and German Bight region. Simulations will cover the years 2017 and 2018 to include strong variabilities in river discharge, storing the relevant hydrodynamic output in hourly resolution to cover the tidal cycle (research question 1). Additionally, shorter scenario runs of coastal sea level rise will be conducted. To investigate research question 5, the dedicated Elbe model..

The major exchange gateways are located in the complex North Sea-Baltic Sea transition zone which is covered by the Pass 3 of the SWOT Cal/Val orbit. The two sites of Boknis Eck and Fehmarn Belt, located in the North Sea-Baltic Sea transition region, will be available for dedicated Cal/Val investigations. Particle velocities profiles along four slanted acoustic beams are recorded at both sites acoustic doppler current profiler with a sub-hourly temporal sampling. This data will be evaluated to derive accurate sea level variation, surface currents, and momentum flux (van Haren 2001, Zedel et al. 1996). By making use of up to 17 years of observations, a catalogue of surface characteristic with relevance for the SWOT mission will be created.

This approach allows also to study the SWOT ability to reproduce the temporal hydrological variability in different hydrodynamic conditions

2.2 Analysis of simulated SWOT data (IGG, TUHH, DLR)

To study the SWOT ability to reproduce the spatial hydrological variability in different hydrodynamic conditions, the second task combines modelling and simulators in the estuary and coast.

We use in the estuaries both the LR JPL SWOT ocean simulator and the LR CNES hydrology simulator. Input data to the simulators are the model simulations from the models in different hydrodynamic conditions (Neap tide/Spring tide, High/Low tide, with or without storm surges for coastline, and Neap tide/Spring tide, High/Low tide, high/Medium/Low discharge for estuary, high/Medium/Low discharge for the river).

2.3 Understanding SWOT Observations (IGG, HZG, TUHH, GEOMAR)

The third task compares SWOT real data with in-situ, satellites and model data to understand the observed 2D variability in the 1- and 21-day orbits. The geophysical altimeter parameters are usually calibrated against in-situ

data. The quantitative metric proposed to assess the data quality in the cal/val phase consists on STDD, bias (mean of differences), correlation computed for the three altimeter parameters sea level, sea state and wind (Fenoglio et al., 2015; Dinardo et al., 2018, Staneva et al., 2017, Wahle et al. 2017, Stanev et al., 2016). For the SWOT nadir altimeter measurements, the same procedure is applied. The wide swath low level (point clouds) and level 2 products are analysed instead by investigating the limits of SWOT for flood wave propagation detection, reconstruction of water heights from irregular sampling, ocean sub-mesoscale features.
HZG analyses and compares the SWOT observations to GCOAST-SCHISM model runs. A set of Observing System Simulation Experiments (OSSEs) is designed to investigate the contribution of SWOT data to the GCOAST ocean analysis and forecasting, for both repeats. A fundamental step of the experimental design is the characterization of the wide-swath measurements errors to improve the definition of the error covariance required to combine SWOT data and the ocean modelling system. This is the first attempt at HZG of applying OSSEs to GCOAST spatial domain with focus on sensitive areas (coastal ocean and estuary). The ocean processes to be resolved (sub-mesoscale, internal waves) and the sensitivity to wide-swath measurement errors will be characterized.
GEOMAR will analyze and compare the SWOT observations to in-situ data and simulated model runs in the South-West Baltic and the Danish straits. The two sites of Boknis Eck and Fehmarn Belt will be used for the dedicated Cal/Val investigation. An optimized sampling strategy of the in-situ data for the cal/val period could be considered.

2.4 Hydrodynamic interaction between the tide and the streamflow (HZG, IGG)

The time and space variability of the hydrodynamics is derived from observed and modelled water heights and discharge. The hydrodynamic changes can significantly influence coastal erosion, benthic environments, coral reefs, sea-grass communities, and coastal fisheries. Tides and river streamflows determine the size and shape of the river. The River Water Discharge (RWD) is one of the major processes that affect environmental conditions in coastal waters. It provides fresh waters that affect mixing and circulation processes in estuaries, thus modifying geomorphological and geochemical properties of the coast. Its control reduces the high flow amplitudes; this decreases the carrying capacity for SPM and modifies the seasonal estuarine circulation patterns and salinity distributions.
Salinity fronts and water mixing and turbidity are studied. River discharge influences fronts and the model performances, which is studied as a function of river discharge against in-situ observations.

2.5 Climate change and extremes in the estuary (HZG, IGG)

Changes in amplitude and frequency of extreme high estuarine water are expected, due to climate change and rise of the coastal sea level. IGG will analyse in WP5300 the characteristics and frequency of extremes in the estuary from in-situ and altimetry.

2.6 Sub-mesoscale in Baltic Sea corresponding to upwelling and change in water transport (GEOMAR)

The sub-mesoscale features in the North Sea-Baltic Sea transition zone corresponding to upwelling events and water transport will be investigated. Sea level variation, surface currents, and momentum flux will be derived.

3. Analysis and anticipated results

Preliminary work includes improved data processing and studies of the sea level change nearshore (Fenoglio-Marc et al., 2015, 2019; Dinardo et al. 2018, Schröder et al. 2019, Staneva et al., 2016). Coastal products which use the SAMOSA+ and STAR retrackers are less noisy and more accurate in the last 3 km from the coastline. In the in-situ validation the standard deviation SLA differences (STDD) is 2-4 cm in the Baltic and at Helgoland, is few decimetres in the Wattenmeer and reaches 40 cm at the Elbe estuary with the SAMOSA+ coastal retrackers. The application of tide correction reduces neither the standard deviation differences with the tide gauge nor the variability of the time-series (Fig. 4).

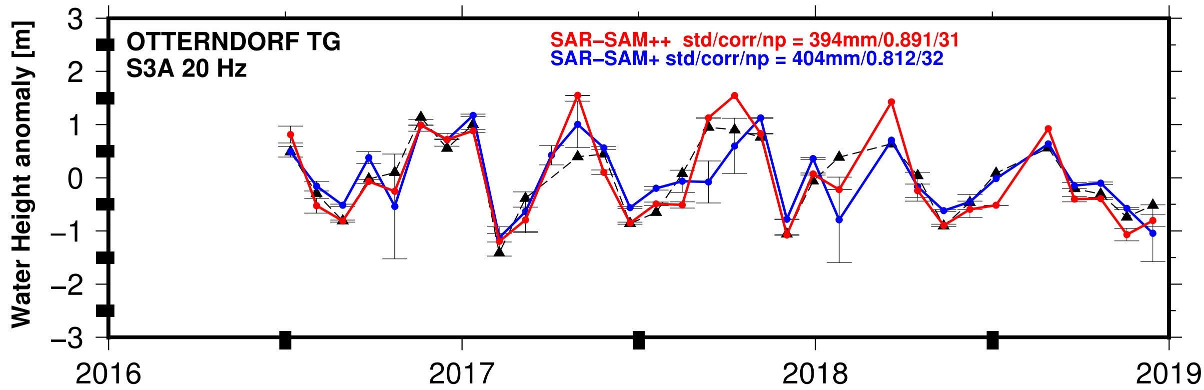

Figure 4. Time-series of water level from altimeter and in-situ corrected for the ocean tide.

Validation against tidal gauge data, fixed station data, and FerryBox data has demonstrated that the high resolution unstructured-grid model part of the GCOAST system adequately simulates tidal dynamics, salinity fronts and estuarine turbidity maxima). Comparisons with experiments with constant density confirmed the role of density control, which appeared to be strongest in the ocean-ward reaches of the limnic parts of the estuaries. Although the three estuaries Ems, Weser and Elbe, which are only ~100 km apart, were driven by similar tidal and atmospheric forcing, at they exhibited different extensions of tidal fronts as well as vertical stratification, mainly due to different river runoff conditions. Wind acted as the dominant factor driving the longer-term estuarine variability; the correlation between zonal wind magnitude and SSH appeared to be very strong. The river discharge influences the model performance in particularly the salinity fronts.
Wiese et al., (2018), Staneva et al., (2016), have shown the high synergy of the GCOAST coastal modelling system with in-situ (tide-gauge, GPS, CTD, ADCP, gliders, drifters) and remote sensing observations (Jason-2, Cryosat-2, Sentinel 3) in coastal and estuarine area. Synergy and the different error sources were also assessed through multiple collocations to obtain accurate estimates of measurements error (Schulz-Stellenfleth and Staneva, 2019). Preliminary investigations of the advantages of the wide swath altimetry compared to the existing nadir altimeters has been performed by Bonaduce et al. (2018). They show large improvements in the two-dimensional mapping and sampling of the ocean surface thanks to the unprecedented spatial resolution to wavelengths as shorts as 20km. The potential is great for ocean analysis, forecasting and mesoscale studies, while the capability of following the evolution of mesoscale eddies is under investigation (Ubelmann et al., 2015). The synergy of SWOT data with the existing observing systems OSS (e.g. conventional nadir altimeters) has been demonstrated. The contribution of the SWOT observations to the ocean analysis in the coastal areas, the impact of the repeating cycle of the future measurements (i.e. 1-day and 21-day repeat orbit) and the sensitivity to wide-swath measurement errors, can be assessed in the circulation model by means of OSSEs. OSSE performed in the Iberian–Biscay–Ireland region in Bonaduce et al., (2018) shows the improved representation of the ocean dynamics reached with wide-swath altimetry. In conclusion, the GCOAST integrated coastal modelling system and the OSSEs methodology will be used here to assess the contribution of the forthcoming observations to ocean analysis in coastal zone and estuaries. The impact of the SWOT 1-day and 21-day repeat cycle and of the sensitivity to wide-swath measurement errors has to be considered.

CONWEST –DYCO will improve the understanding of estuary and coastal processes. We anticipate a contribution in:

1) estuary hydrodynamic and in particular the interaction between tide and discharge/flux
2) water exchange in different hydrodynamic conditions
3) climate change and extremes
4) mesoscale and sub-mesoscale processes

The improvement by waveform retracking of the data near land and the availability of SWOT high-resolution data (~ 50 m) in the selected region, is expected to advance the understanding of the complex water flow and its effect on this vital environment. Methods and tools will be developed for the combination of observation with model data for the understanding of processes.

Finally, although CONWEST-DYCO is not directly involved in the planned SWOT cal/val activities, results may bear some significance to the cal/val objectives, since a calibration of the nadir altimeter pointwise at tide gauges collocated with GPS is planned and the intensive analysis foreseen in the 1-day phase is meant to contribute to the understanding of the SWOT measurements.

Bibliography

Bonaduce A., Benkiran M., Remy E. , Le Traon P.Y., and Gilles Garric G. (2018), Contribution of future wide-swath altimetry missions to ocean analysis and forecasting, Ocean Sci., 14, 1405–1421, https://doi.org/10.5194/os-14-1405-2018

Dick, S., & Kleine, E. (2006, May). The BSH's new operational circulation model using general vertical co-ordinates. In 2006 IEEE US/EU Baltic International Symposium (pp. 1-9). IEEE.

Dinardo S., Fenoglio-Marc L., Buchhaupt C., Becker M., Scharro R., Fernandez J. Benveniste J. (2018). CryoSat-2 performance along the German coasts, AdSR special Issue CryoSat-2, https://doi.org/10.1016/j.asr.2017.12.018

Dinardo S., Fenoglio L., M. Becker; R. Scharroo; M. J. Fernandes; J. Staneva; S. Grayek; J. Benveniste, A RIP-based SAR Retracker and its application in North East Atlantic with Sentinel-3, Advances in Space Research (2020), doi: https://doi.org/10.1016/j.asr.2020.06.004

Fenoglio-Marc, L., Dinardo, S., Scharroo, R., Roland, A., Dutour, M., Lucas, B., Becker, M., Benveniste, J., Weiss, R. (2015). The German Bight: a validation of CryoSat-2 altimeter data in SAR mode, Advances in Space Research, doi: http://dx.doi.org/10.1016/j.asr.2015.02.014

Fenoglio L., S. Dinardo, B. Uebbing, C. Buchhaupt, J. Kusche, M. Becker (2019). Calibrating CryoSat-2 ad Sentinel-3A sea surface heights along the German coast, In: International Association of Geodesy Symposia, https://doi.org/10.1007/1345_2019_73

Hervouet, Jean-Michel (2007): Hydrodynamics of free surface flows. Modelling with the finite element method. Chichester, Hoboken N.J.: Wiley.

Kappenberg, J. and Grabemann (2001) Variability of the mixing zones and estuarine turbidity maxima in the Elbe and Weser estuariesI. Estuaries 24: 699. https://doi.org/10.2307/1352878

Shaikh, S.,Gershovich, I., Manojlovic, N., Nehlsen, E., Gruhn, A., Froehle, P. (2016): An operational hydrodynamic-numerical model of the Elbe estuary with Telemac-2D based on predicted water levels, Proc. 12th International Conference on Hydroscience & Engineering Hydro-Science & Engineering for Environmental Resilience,

van Haren, H. (2001) Estimates of sea level, waves and winds from a bottom-mounted ADCP in a shelf sea, J. Sea Res. 45, 1-14

Schroeder S., A. Springer, J. Kusche, B. Uebbing, L. Fenoglio, B Diekkrueger, and T. Pomeon (2019). Niger discharge from radar altimetry: bridging gaps between gauge and altimetry time series Hydrol. Earth Syst. Sci., 23, 4113–4128, 2019 https://doi.org/10.5194/hess-23-4113-2019

Schulz-Stellenfleth J. and Staneva J. (2019). A multi-collocation method for coastal zone observations with applications to Sentinel-3A altimeter wave height data, Ocean Sci., 15, 249–268, 2019 https://doi.org/10.5194/os-15-249-2019

Stanev, E. V., Schulz-Stellenfleth, J., Staneva, J., Grayek, S., Grashorn, S., Behrens, A., Koch, W., and Pein, J. (2016): Ocean forecasting for the German Bight: from regional to coastal scales, Ocean Sci., 12, 1105-1136. doi.org/10.5194/os-12-1105-2016

Stanev, E.V., Jacob, B., & Pein, J. (2019): German Bight estuaries: An inter-comparison on the basis of numerical modeling. Continental Shelf Research, Volume 174, Pages 48-65, doi:10.1016/j.csr.2019.01.001

Staneva J., Wahle K., Koch W., Behrens A., Fenoglio-Marc L., Stanev E. (2016). Coastal flooding: impact of waves on storm surge during extremes. A case study for the German Bight. Natural Hazards and Earth System Sciences, DOI: 10.5194/nhess-2016-227

Staneva J.., Alari V., Breivik O, Bidlot J.-R. and Mogensen K. (2017): Effects of wave-induced forcing on a circulation model of the North Sea. Ocean Dynamics, Vol. 67, Issue 1, pp 81-191

Ubelmann, C., Klein, P., and Fu, L.-L. (2015). Dynamic Interpolation of Sea Surface Height and Potential Applications for Future HighResolution Altimetry Mapping, J. Atmos. Ocean. Tech., 32, 177–184, https://doi.org/10.1175/JTECH-D-14-00152.1

van Haren, H. (2001) Estimates of sea level, waves and winds from a bottom-mounted ADCP in a shelf sea, J. Sea Res. 45, 1-14

Wahle K., Staneva J., Koch W., Fenoglio-Marc L., Ha T. M. Ho-Hagemann Ha T. M., and Stanev E. (2017). An atmosphere–wave regional coupled model: improving predictions of wave heights and surface winds in the southern North Sea, Ocean Sci., 13, 1–13, 2017 www.ocean-sci.net/13/1/2017/ doi:10.5194/os-13-1-2017

Wiese A., J. Staneva, J. Schultz-Stellenfleth, A. Behrens, L. Fenoglio-Marc and J.-R. Bidlot (2018). Synergy of wind wave model simulations and satellite observations during extreme events, Ocean Science, https://doi.org/10.5194/os-2018-87

Zedel, L., Crawford, G.B., Gordon, L., (1996) On the determination of wind direction using an upward looking acoustic Doppler current profiler. J. Geophys. Res. 101, 12163-12176