An integrated approach for investigating the impacts of climate change on the Weser Estuary

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Introduction

Climate change will influence estuaries in the German Bight through different mechanisms: The Expansion of the water volume and possibly melting of ice caps due to higher temperatures will lead to a rise of the mean sea level (IPCC, 2007). In the North Sea, this will lead to a change of astronomic tidal constituents and to changed tidal dynamics in the estuaries (Plüß, 2004). Changes in the wind regime in the North Sea may increase frequency and intensity of storm surge water levels and the wave conditions in the North Sea (Grabemann et al., 2008). Variations in precipitation will change water balances in the river catchments and consequently runoff patterns. Said factors form boundary conditions for the estuaries. Their future changes will influence estuarine dynamics. It is the role of climate impact research to investigate possible future changes on a regional basis and to find feasible adaptation measures.

Due to the extensive efforts in recent years to develop and run global and regional climate change models, the North Sea storm surge and wave conditions have been investigated closely with state-of-the-art models and ensemble-based statistical approaches. Nevertheless, estimations of the local impact on the estuaries have mostly been limited to the investigation of individual input variables or scenarios due to a lack of ensemble-based time series input data and partly limitations in model capacities.

The study presented here is part of a research cooperation for investigating climate impact on a regional basis in Germany[1] and focuses on the Weser Estuary. The aim is to assess the changes in estuarine dynamics under the influence of different climate change scenarios.

In this contribution, the first step towards this aim will be presented: In a sensitivity study, the aforementioned factors will be analyzed regarding their impact upon estuarine dynamics. It will be quantified which factors have a significant influence on the estuary dynamics. Also, the question has to be addressed whether the computed climate change signal can be distinguished from the uncertainty of the model chain on the regional or local scale. The study focuses on the estuarine hydrodynamics and salinity intrusion as main indicators of the system response.

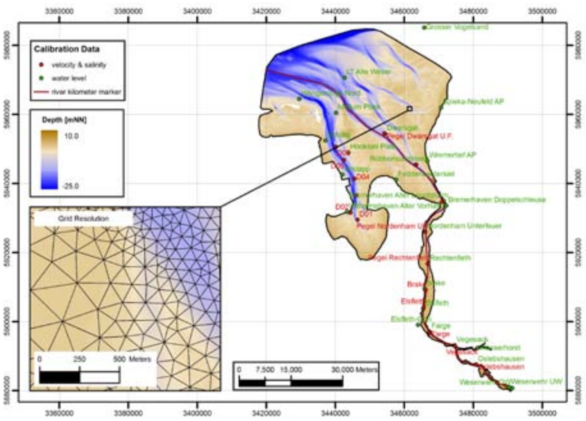

Fig. 1: Bathymetry of the Weser hydrodynamic model, indicating depth refined mesh and calibration data

To simulate climate change responses of the estuary, the baroclinic circulation modelling tool SELFE (Zhang & Baptista, 2008) is applied. It solves the shallow water equations and follows a semi-implicit Eulerian-Lagrangian finite-element approach. Based on unstructured grids and hybrid coordinates in the vertical, it is well-suited for cross-scale modelling. Calibration results show good agreement between observed and simulated values especially for typical estuarine processes such as salt intrusion which are in the focus of this study.

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Importance of eddy viscosity parameterisation in modelling lateral sediment accumulation in tidal channels

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Keywords: tidal estuaries, sediment trapping, eddy viscosity parameterisation

Abstract

Many recent investigations on sediment trapping in tidal channels are based on an idealised approach regarding the magnitude and the spatial distribution of eddy viscosity. An important aim of these studies is to identify areas of sediment accumulation and to explain their occurrence. Most of them share a two-step approach. In the first step, the time and space dependent flow pattern is determined for a prescribed time-invariant spatial distribution of eddy viscosity. Corresponding temporal and spatial variations in sediment concentration are determined in the second step, assuming that such variations have negligible effect on the flow. Combined with the assumption of a morpho-dynamic equilibrium, this yields a spatial pattern of tide-averaged sediment accumulation.

Our study adds to this development in the sense that we compare sediment accumulation computed for three essentially different assumptions regarding the spatial distribution of eddy viscosity: uniform (used by e.g. Huijts et al., 2006), parabolic over the vertical and a semi-parabolic distribution. The latter one is based on a study by Scully (2010), who found that vertical mixing may become relatively weak in the upper part of the water column around the central, deepest part of the channels cross section. This has a serious effect on lateral circulations which, in turn, affects locations where sediment can be trapped.

For our study we deploy a numerical model that consists of two modules. One of these modules simulates the flow in a cross-section of a (tidal) channel (Zitman and Schuttelaars, 2012). It solves the full three-dimensional shallow water equations and mass balance on a curvelinear grid that can be fitted to the cross-sectional bathymetry of most natural estuaries. The second module solves the full sediment balance using the same grid. In both modules we assume along-channel uniformity. Observations regarding a cross-section of Chesapeake Bay (USA) gathered and described by Fugate et al. (2007) serve as a reference for our study.

Preliminary computations indicate that with respect to locations of sediment trapping, the difference between assuming a uniform and a parabolic eddy viscosity distribution is larger than the difference between parabolic and semi-parabolic. With the latter two assumptions sediment is accumulated primarily around the deepest part of the channel, but the semi-parabolic distribution seems to yield larger concentrations than the parabolic one.

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Fugate, D.C., Friedrichs, C.T., Sanford, L.P. (2007) Lateral dynamics and associated transport of sediment in the upper reaches of a partially mixed estuary, Chesapeake Bay, USA. Continental Shelf Res., 27, 679-698

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Importance of eddy viscosity parameterisation in modelling lateral sediment accumulation in tidal channels

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Abstract

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Modeling the transport mechanisms in a low-dynamic stratified lake (Lake Grevelingen)

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Lake Grevelingen, a former estuary in The Netherlands, can be characterised as a low-dynamic, stratified salt water (28-30 psu) lake. The 110 km^2 area consists of a large shallow area (with a depth of around 1 m) intersected by gullies and a number of deep pits with a depth of 20 m to 45 m. Lake Grevelingen is connected with the North Sea through a sluice. This allows the lake water to be continually refreshed with salt water from the North Sea.

In the absence of tidal mixing since it was closed off at both the riverine (Grevelingen Dam, 1965) and the marine end (Brouwers Dam, 1975), both thermal and salinity stratification exist in Lake Grevelingen. Stratification is predominantly triggered by horizontal baroclinic pressure gradients due to inflow of more (or less) saline water through the Brouwers Sluice combined with runoff from adjacent land and rain, and is exacerbated by heat exchange through the surface. These two causes of stratification interact and amplify each other. In particular for water quality parameters such as dissolved oxygen concentration and primary production, stratification plays an important role. Stratification hampers the vertical transport of oxygen rich water towards the bottom layer, which after long periods of stratification can cause anoxia. Also, primary production of phytoplankton occurs in the top layer. Due to the absence of strong vertical mixing in a stratified water column, phytoplankton remains concentrated in the upper layer.

A possible remedy against the water quality problems associated with stratification is the proposed increase of the tidal exchange of water through the Brouwers Sluice. Various scenarios with increasing tidal exchange discharges have been assessed at their potential to get rid of anoxia. For this purpose a 3D hydrodynamic model was set-up with z-layers instead of the more common σ-layers to prevent numerical cross-wind diffusion upsetting the delicate mixing balance. The 3D Lake Grevelingen model was extensively validated against measurement data for two full years (2000 & 2008). Use has been made of extensive (bi-)monthly (summer and winter, respectively) salinity and temperature profile measurements from the regular Rijkswaterstaat monitoring campaign. From this source, data are available at 20 different stations along the former thalweg gully along Lake Grevelingen. The model was capable of reproducing both spatial and temporal distribution of temperature and salinity, as well as thermal and salinity stratification in terms of its duration and depth of the pycnocline.

Besides a quantitative assessment of the effectiveness of increasing the tidal range, the model was also used to perform a number of tracer scenarios aimed at gaining qualitative insight in the governing transport mechanisms. Among these is the so-called ‘conveyor belt’, which is the name of the residual velocities induced by the baroclinic pressure gradient. The horizontal density gradient drives an upstream bottom flow of saline North Sea water through the main gullies. This bottom transport of denser water is balanced by a downstream outward surface transport of lighter water. We compare the effect of this horizontal advectional exchange of water on the oxygen levels with the effect of vertical mixing.

The impact of stratification on bottom boundary layer thickness within shelf region

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The bottom boundary layer is an important factor in many continental shelf biogeochemical and physical processes such as nutrient transport, carbon cycling, and hypoxia. On the Texas-Louisiana shelf, predicting bottom boundary layer thickness is important because previous studies have shown that the bottom boundary layer is critical in the formation of seasonal shelf hypoxia; a well-developed, thin bottom boundary layer is correlated with low bottom oxygen. To identify the physical processes that impact the space and timescales of bottom boundary layer formation and destruction, a series of idealized and realistic models are used to determine how large-scale shelf stratification controls the thickness of the bottom boundary layer. The Texas-Louisiana shelf is unique in that there is a significant lateral stratification across the shelf due to the high discharge from the Mississippi and Atchafalaya Rivers. Different idealized model runs were performed, where the initial lateral stratification was modified systematically; all of the simulations were forced with an identical, realistic wind stress. As expected, results show that the bottom boundary layer is thicker when with weaker initial lateral stratification, while when the lateral stratification is strong; a relatively thinner bottom boundary layer is formed. The initial stratification and resulting thickness of bottom boundary layer are linearly correlated. Results from a realistic model of the Texas-Louisiana shelf are also used to illustrate how stratification controls the bottom boundary layer thickness. Regions of high vertical and lateral stratification are often co-located. There is also a relationship between vertical and lateral stratification, for example, strong lateral stratification may become strong vertical stratification under upwelling winds as the upwelling circulation tilts the isopycnals.

Effects of lateral spreading on the interfacial and frontal mixing in the laboratory scale river plume

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Geophysical gravity currents, such as river plumes, are responsible for transporting of nutrients, pollutants and sediment in the coastal ocean. The transition from a laterally confined estuary to an unconfined coastal ocean introduces a lateral spreading, which is hypothesized that it affects the plume structure and mixing dynamics. Earlier studies suggested that the mixing between these two water masses has a tendency to reduce spreading due to reduce the density difference, the inverse issue, how does spreading affect the mixing has not been addressed yet. As part of MeRMADE (The Merrimack River Mixing and Divergence Experiments), we are investigating how lateral spreading modifies the fundamental mixing processes in the core of the plume and along the front using the non-rotating laboratory experiments. All experiments were carried out in a 2.5m by 4m basin, over a range of inflow Froude numbers. For each external parameter we did two identical experiments in laterally confined and unconfined plumes. Although the lateral spreading significantly modifies the plume structure, the entrainment and turbulent buoyancy flux in the core of the plume stay the same order of magnitude in two cases. The enhancement of total mixing and entrainment in the unconfined plume are mostly due to the increasing of interacting area. A clear frontal bore is observed in both two cases, followed by an enhanced mixing region. The mixing in this frontal region is thought to contribute substantially to the overall plume mixing. A quantitative measurement of frontal mixing and the lateral spreading influence are also investigated in this research project.

INTERACTION OF TIDAL AND FLUVIAL PROCESSES IN THE TRANSITION ZONE OF THE SANTEE RIVER, SC, USA.

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Tides are subject to the frictional dissipation as they propagate inland through estuaries and river channels. We analyze time series of velocity profiles and bottom pressure that resolve along-channel momentum balance in the transition zone from tidal to fluvial regime of the Santee River, SC, USA. Three bottom tripods were deployed along the channel axis in the channel reach with water depth progressively decreasing upstream from over 4 m to less than 2 m. The along-channel extension of the array was approximately 1 km. The depth-averaged momentum balance includes local and advective inertia, pressure gradient, and bottom friction terms. Pressure gradient force and local inertia dominate the momentum balance during the flood and subsequent current reversal from flood to ebb. However, during the ebb the pressure gradient is nearly balanced by bottom friction. The dissipative term defined as a residual of inertia, advection and pressure gradient force is found to be comparable with the bottom friction term. Tides in the study area are flood-dominant, but most of the dissipation occurs during the ebb due to a superposition of river and tide currents subject to quadratic bottom friction. There is a convergence of momentum advection in the middle of the study site indicating stronger tidal dissipation over a shallower segment of the river channel. We hypothesize that strong tidal dissipation in the transition zone maintains highly variable topography with enhanced bathymetric gradients.

Connectivity within Great South Bay and its relation to tidal and wind-driven currents

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Abstract: Great South Bay is a coastal lagoon on the south shore of Long Island, NY, in which the circulation is controlled by semidiurnal tidal currents and synoptic period wind-driven currents. It communicates with the NY Bight through four tidal inlets. This lagoon is characterized by high rate of primary production and historically it has been an important hard clam fishery; it has been the focus of an intensive ecosystem based management study which includes an analysis of the connectivity between the different compartments of the lagoon. The 3D community model FVCOM (Finite Volume Coastal Ocean Model) is used to simulate circulation within the lagoon under the influence of tide and wind forcing. Results of Lagrangian trajectory experiments are analyzed in terms of a first order Markov Chain to obtain the transition probability matrices among compartments of the lagoon. This provides a quantitative and useful description of the connectivity pattern within the lagoon. The structure of model derived wind-driven circulation gyres within the lagoon, which is controlled by bathymetry, helps define the compartments of the lagoon used for the Markov Chain analyses.

Regime shifts in muddy estuaries: tidal response to river deepening and embanking

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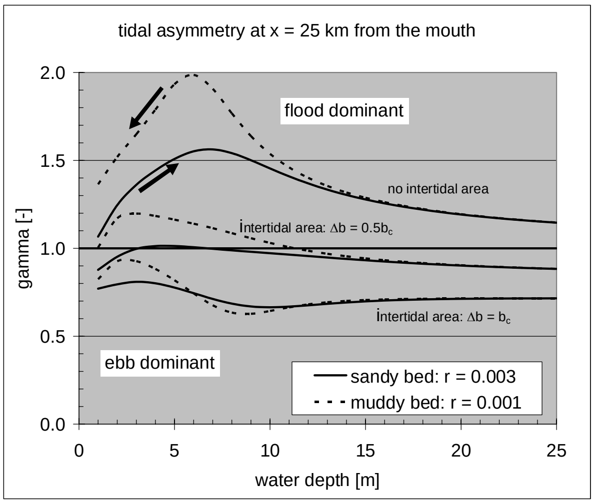
A number of tidal rivers in Europe, amongst which the Ems River in Germany-Netherlands, and the Loire River in France are characterized by hyper-concentrated conditions with pronounced layers of fluid mud and suspended sediment concentrations exceeding 30 g/l. From an ecological point of view the sedimentary conditions in these rivers are highly problematic, as oxygen levels and primary production are very low.

The present study aims at defining the conditions at which a regime shift in these rivers may occur, yielding a transition from a “normal estuary” with a classical estuarine turbidity maximum governed by estuarine circulation mainly, to hyper-concentrated conditions where sediment dynamics are mainly governed by tidal asymmetry. We hypothesize that these hyper-concentrated conditions are the result of large amplification of the tide and strong flood-dominant conditions, induced by ongoing deepening and embanking of the tidal river. Indeed, today many European rivers, amongst which the Loire and Ems, can be classified as synchronous, with an almost constant tidal amplitude along the main part of the river.

Here we present the evolution of tidal asymmetry in response to deepening and embanking based on an analytical solution of the one-dimensional, linearized water movement in a converging channel, with or without intertidal area. The solution of these equations is derived in the form of a dimensionless real and an imaginary wave number, which are both a function of the dimensionless width of the intertidal area, the dimensionless convergence length and a dimensionless roughness parameter. This dimensionless representation of the tide allows inter-comparison of a variety of rivers (e.g. Scheldt, Ems, Loire, Elbe, Weser and Humber/Ouse).

Here we present the analytical solution for the tidal asymmetry as a function of water depth, width of the intertidal area, and composition of the river bed. This graph suggests that for large intertidal area, the river is always ebb-dominant, and slowly changes towards flood dominancy upon canalization of the river. Such a response is well-known, of course. However, as a result of its flood-dominancy, the river starts to pump large amounts of fine sediments upstream, increasing the tidal asymmetry further. In the end, sediment concentrations become so high (up to several 10’s g/l) that synchronous, hyper-concentrated conditions develop, such as currently in the Ems, Loire and Ouse Rivers.



From a comparison with other rivers, based on said dimensionless numbers, we try to establish the environmental conditions, which may induce regime shifts evolving towards these synchronous, hyper-concentrated systems.

Tidal circulation on the Yucatan shelf

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The recent oil spill in the Gulf of Mexico highlights how vulnerable marine ecosystems are to oil production and exploration activities. The Deepwater Horizon incident was but the latest large spill in a sea where accidents take place on both sides of the border. Predicting oil spill trajectories requires knowledge of all different components of circulation. For short time predictions, tidal currents can be the most important. Here tidal elevations and currents are described and synthesized with a semi-analytical model for the Yucatan shelf, an area of great ecological value that is threatened by oil spills as well as coastal development.

The Gulf of Mexico is a kidney-shaped basin, about 1500 km east to west and 1000 km north to south. The maximum depth is 3000 m, and the average depth is about 1000 m. The barotropic wave speed is of order 100 m/s. The diurnal and semidiurnal wavelengths are therefore 8600 km and 4400 km. The length of the Gulf, from Habana, Cuba to Veracruz, Mx along the deepest countour is about 1700 km. This is somewhat less than a quarter of the diurnal wavelength and between a quarter and a half a semi-diurnal wavelength. This suggests that the diurnal tide should increase in amplitude from the entrance to the closed end, while a nodal line, along with an amphidrome are expected for the semidiurnal tide. These characteristics are confirmed by our observations.

Tidal currents have to provide the volume required to raise and lower sea level throughout the basin. While the tidal elevations in the Gulf of Mexico are moderate, the tidal currents are comparable to currents generated by other processes. Typical diurnal currents observed on the Yucatan shelf are about 0.1 m/s. Semi-diurnal currents are about half as large, even though semi-diurnal elevations are quite small. This is consistent with the hypothesis that semi-diurnal amphidromes are located over the yucatan shelf, with minimal elevation amplitudes and maximum curent amplitudes.

An analytic three-dimensional model of the barotropic diurnal and semi-diurnal tides is presented that is consistent with earlier numerical models and observations. Notably the semi-diurnal amphidrome is reproduced. This model is used to explore the relative importance of directly generated and co-oscillating tides in the basin.

Wind and ocean wave forcing on shallow intermittently open estuaries

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Bar-built estuaries in Mediterranean climates are frequently only intermittently connected to the ocean due to seasonal rainfall and near-shore sand transport. Traditional estuarine tidal straining analysis breaks down as tidal exchange is limited and wind and ocean waves become the dominant forcing mechanisms in these shallow, strongly stratified estuaries. In the closed state, tidal effects are limited to waves overtopping the blocked mouth during some high tides; even in the open state, a choked mouth may still limit tidal forcing. In one site in Northern California, a salt-stratified lagoon forms when the mouth is in-filled with sand, and wind is ineffective in destratifying the water column but does cause upwelling of the pycnocline at the downstream end of the estuary and subsequent internal seiches. Furthermore, entering infragravity waves near a resonant frequency of the basin also induce seiching of the stratified water. In the closed state, wind and ocean wave forcing, which drive internal hydraulic motion, are responsible for inducing the majority of vertical mixing. In the specific case of the Pescadero estuary, hypoxic conditions occur in the lower layer of water and vertical mixing has strong implications for water quality and fish habitat. Here, we present the two-layer dynamics of shallow, salt-stratified, intermittently open estuaries as forced by wind and ocean waves and quantify the conversion of energy inputs from wind and waves into seiching motion and turbulent mixing.

Sill Effects on Physical Dynamics in Long Island Sound

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The Long Island Sound (LIS) is a large and wide glacially modified estuary on the U.S. east coast. The Mattituck Sill crosses the eastern LIS approximately 45 km from the mouth. The Connecticut River, the estuary's major riverine freshwater source, enters the LIS between this sill and the mouth. This study is motivated by previous modeling research on this sill by Valle-Levinson and Wilson. New process model runs with and without the sill bathymetry and with realistic salinity and current fields are analyzed to isolate the effects of Mattituck Sill. Results indicate internal hydraulic control exists only near slack tides for mean tidal conditions. The spatial distribution of subcritical areas is little influenced by the sill. The sill modifies the subtidal flow field both locally near the sill and in other parts of the estuary. Anticyclonic subtidal circulation around the sill is consistent with a balance between tidal advection of barotropic vorticity and bottom stress curl. Tidal variations and subtidal values of salt fluxes are influenced by the sill. Results indicate that the sill reduces the amount of fresh water passing from the Connecticut River towards the head into the central and western LIS. The sill intensifies the flow pathway that carries Connecticut River water across-estuary (on the seaward side of the sill) and then along-estuary towards the mouth; this is among the shortest routes for fresh water exiting the estuary.

PECS 2012 ABSTRACT:

Simulation of cohesive sediment transport and fluid mud dynamics in the Ems Estuary

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ABSTRACT

Mud is an important factor in ecosystems as its relatively high content of organic substances and nutrients provides food for organisms. However, mud becomes an unwanted material when it accumulates, deposits and consolidates in fairways or harbors. In particular in many estuarine waters and harbors, the mud budget has been greatly affected by infrastructure projects over the past few decades. The increasing siltation of harbor basins, harbor access channels and parts of shipping channels leads to an increase in the level of maintenance requirements and, as a consequence, to higher costs.

Questions of hydrodynamics and cohesive sediment transport are usually investigated with three-dimensional numerical models to support the process understanding in estuaries. Classical hydrodynamic numerical approaches are based on the assumption of a Newtonian fluid. In case of fluid mud formations the rheological behavior can not be described by a constant viscosity anymore. The rheological behavior is dependent on the structural behavior of the mud suspension like break-up and recovery of aggregates under the influence of shear impact [3]. The classical numerical approaches for the simulation of cohesive suspensions are not capable to simulate this characteristic flow of high-concentrated suspensions. In [2] a numerical method was presented which enables the simulation of non-Newtonian flow behavior in a numerical model based on the Reynolds-averaged Navier-Stokes-Equations. This three-dimensional numerical model discretizes the vertical domain with isopycnal layers (layers of constant density).

Strong stratified flow with sharp density gradients results from fluid mud formations in estuarine systems. These strong and often stable stratified fluid mud bodies make an isopycnal numerical approach attractive for the simulation of fluid mud dynamics. Therefore, the isopycnal numerical model from [1] was extended for the simulation of high-concentrated flow.

The described fluid mud model was verified on schematically test cases [2]. The first real world application on the Ems Estuary is described in this paper. Further validation of the numerical model is obtained by comparison with observations of the development of the fluid mud body in the Ems Estuary. Cohesive sediment transport and formation of high-concentrated zones dominate the flow regime in the upstream part of the Ems Estuary which is located at the border of Germany and the Netherlands at the North Sea. A section in the landward part of the river Ems is investigated for improving the understanding of the formation, transport, re-suspension and settling of the cohesive sediments as well as the fluid mud. This is compared with an observation campaign which was carried out in 2011.

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Using bottom pressure measurements to quantify form drag on rough topography

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Dissipation of energy as ocean currents flow over undersea topography is a complex process that has been studied extensively but is still not completely understood. One tool that has yet to be commonly used in the ocean to quantify this process is form drag. In this study, sensitive bottom pressure recorders (Ppods) were used to measure form drag as tidal currents flowed back and forth around Three Tree Point, a headland with sloping side walls that is located in the Puget Sound. Since Ppods are new instruments, methods for data analysis and form drag calculations had to be developed. These bottom pressure measurements were then combined with detailed velocity, density and microstructure measurements and a numerical model simulation in an effort to not only measure the form drag but to describe the flow field and the physical processes that create the form drag. When the form drag was integrated over the entire topography, the energy losses due to form drag were found to be 30 times larger than the energy losses due to frictional drag. On average, Three Tree Point dissipates about 0.5 MW of power with peaks as high as 2 MW during strong flood tides. While the dissipation of energy at Three Tree Point is only a small fraction of the total energy dissipated in Puget Sound or the world's oceans, it is hoped that the results will help lead to a more complete understanding of form drag in the ocean and better parameterizations of topographic drag in models where the grid resolution is not sufficient to capture the dynamics that occur.

Impacts of past and future sea-level rise on shelf sea sediment dynamics

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Past changes in climate have resulted in major changes in sea level with implications for global and shelf sea tidal dynamics. Changing tidal dynamics on shelf seas can impact on the location of tidal mixing fronts, levels of tidally-driven mixing, changes in wave climates, shelf sea biogeochemistry and sediment transport. Global sea levels were around 130 m lower at the Last Glacial Maximum (LGM, ca. 21 thousand years ago) than they are today. Ocean-land loading and unloading by ice, referred to as glacial-isostatic adjustment (GIA), also influences the spatial variability of relative sea levels, particularly in formerly glaciated regions such as the British Isles. The numerical modelling of both tides and GIA has progressed significantly in the last few years with advances in observational and computational techniques. Although the accuracy of these models and techniques is improving, it is clear that there is still work to be done to produce good fit between model outputs and data across entire domains. This palaeo-study of the period since the LGM focuses on the impact of the evolving tides and the hydrodynamics of the northwest European shelf seas on large-scale sediment dynamics. The study uses some of the most recent GIA model outputs for the British Isles as palaeobathymetries within a tidal model to simulate tidal conditions at various time-slices since the LGM. The aim is to enhance data-model comparisons via new data from sediment sequences from the northwest European shelf seas to constrain palaeotidal model outputs. Increasing model output reliability through comparison with sedimentary sequences is not limited to this single variable and applies to other model outputs. Validated and constrained tidal models are powerful tools for predicting the evolution of the European coastline in response to future predicted sea-level change, with clear policy relevance.

Interaction between suspended sediment transport and tidal amplification in an estuary

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It is well known that tidal flow influences suspended sediment transport in estuaries. In this paper we show that although less known, the suspended sediment transport can also have influence on the tidal flow in an estuary. Due to this interaction an estuary can have two states: one with low turbidity and low tidal amplification and one with high turbidity and high tidal amplification.

Water level records at two stations in the Guadalquivir Estuary (Spain), one near the estuary mouth (Bonanza) and one about 70 km upstream (Seville), have been analysed to study the amplification of the tide in the estuary. The amplification factor, defined as the ratio between the amplitudes of the semi-diurnal tide at the two stations, show interesting temporal variations. Firstly, a spring-neap variation is present showing that the tide is less amplified during spring tide than during neap tide. This can be explained by the stronger damping during spring tide due to the bottom resistance which increases non-linearly with the tidal flow velocity, indicating that bottom resistance is an important factor influencing the tidal amplification in the estuary. Secondly, the variation shows some spikes of extreme lows, which appear to be related to river floods causing a large difference between the mean water levels at the two stations. Thirdly, it is interesting to see that the amplification factor has a larger value during a number of periods, also after smoothing out the spring-neap variation. Further analysis of the data together with the data of turbidity and river discharges in combination with the results from various sediment transport modelling studies for the estuary reveals that this phenomenon is caused by the non-linear interaction between the tidal flow and suspended sediment transport, initiated by high sediment input from the river during a river flood. The high sediment concentration, up to more than 10 g/l, causes a reduction of the bottom resistance to the flow resulting in stronger tidal amplification in the estuary. The larger tidal amplitude causes higher tidal flow velocity which in turn keeps the suspended sediment concentration high. Further it is observed that after such an event the tidal amplification in the estuary does not always drop back to the same level as before the event. This means that the river flood events have significant influence on the long-term development of the estuary.

We will further do a similar analysis to the Yangtze Estuary in China. The high turbidity in this estuary causes significant reduction to the bottom resistance to the flow as indicated by the fact 2DH tidal flow models for this estuary require a Chezy coefficient above 100 $m^{1/2}/s$ or a Manning coefficient of about 0.01. The tide propagates as far as more than 600 km upstream from the mouth of the estuary. However, last years the sediment load from the Yangtze River is decreasing substantially due to the developments in the river basin, especially the building of the dams. Decrease of the turbidity in the estuary is already observed, especially in the inner part. On the long-term this can significantly influence the tidal propagation in the estuary. A burning question is: has the decreased turbidity already influenced the tidal amplification in the estuary?

The influence of discharge, wind and tides on near field plume dynamics

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A series of moored acoustic Doppler current profilers (ADCPs) combined with temperature and salinity sensors were deployed to study the factors affecting plume dynamics during the spring freshets of 2007, 2010 and 2011. Wind is a major factor influencing surface velocity in the coastal area. Offshore wind drives an upwelling of cold salt water to the surface, where it interacts with the coastal current and plume water masses, which are pushed further offshore. Near the river mouth, a high frequency ADCP was used to get turbulence information. Significant variations in plume thickness and TKE production were observed from ebb to ebb. The total TKE within the plume on each ebb was calculated by a depth and time integral of the TKE production term. Both the plume energy and thickness are related to environmental variables, such as river flow, wind speed/direction, and tidal range in order to understand the mechanisms driving turbulence and mixing rates in the near-field plume.

Tidal Propagation in a Branching Tidal Estuary

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In branching tidal systems, tidal dissipation, propagation and reflection together define the spatial distribution of tidal energy. When specific locations or regions are altered, for example through the restoration of tidal marsh, there is uncertainty as to how the system will respond, including the spatial influence of the changes. When tidal marsh habitat is restored, it creates local tidal dissipation which may alter tidal energy in other parts of the estuary, potentially altering the function of tidal marshes elsewhere. It is important that this interaction be analyzed and understood before management decisions are made.

We present results of a simple analytic model of tidal propagation in a branching system. We develop wave equations for along-channel velocity and wave height which account for friction and changes in channel geometry. By linearizing the friction term in the depth-averaged along-channel momentum equation and including an amplification factor in the wave form, then combining it with the continuity equation, we solve for wave speed and amplification as a function of friction and channel geometry. We also solve for the tidal velocity and stage as a function of position and time. Using this solution within an idealized branching channel estuary and applying matching conditions at the branches, we analyze the effects of changes to one branch on tidal regimes throughout the estuary.

Hydrodynamics and salinity front position in the Amazon River's estuary

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Key Words: Amazon River's estuary, salinity front, hydrodynamics, tides.

Abstract

Measurements carried out at the Amazon River's mouth during different river discharges and tidal amplitudes allowed the observation of the position of the bottom salinity front. This paper explores the importance of both tidal energy and river discharge in determining the bottom salinity front position and stratification. The role of tides in the stratification pattern has been largely recognized and can be observed in several measurements in this area. The differences in the degree of stratification are noticeable along the whole tidal cycle, with stratification occurring inversely respect to tidal energy. Thus, there is an increase in the vertical water homogeneity during spring tides and the occurrence of very stratified water column during neap ones. Regarding the position of the front, it is observed that even during high river discharge conditions, neap tide favored the bottom salinity front advance, counteracting the river discharge effect. Results from a 3D hydrodynamic model reinforced these observations and allowed investigate other mechanisms that are playing a role in determining the salinity front position, as the local bathymetry and bottom roughness.

Sea breezes force near-inertial waves close to the critical latitude for resonance

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Inertial oscillations are anti-cyclonic motions at the local inertial frequency and are observed globally in regions with weak frictional damping. Near the latitudes 30 deg south and north the inertial frequency is approximately diurnal. Periodic forcing at these 'critical latitudes', by tides or diurnal variations in wind stress, can cause a resonant response in the currents. New observations from a location near the critical latitude for resonance off South Western Australia (Rottnest Shelf) reveal strong anti-cyclonic circular motions that often exceed the mean Leeuwin current by speeds > 0.3 m s^{-1}. The observations were made in a region of particularly low tidal energy, therefore the resonant response of the currents is purely driven by the diurnal sea breeze system. As a result the influence of the wind was observed to depths > 250 m (much larger than then the Ekman depth of ~ 70 m). The sea breeze system in South Western Australia is one of the strongest worldwide, frequently exceeding 15 m s^{-1}, and contributes to 35% of all wind patterns annually. Consequently, in the absence of significant tidal mixing, the sea breeze forcing of near-inertial waves in this region is an important candidate for vertical mixing across the pycnocline.

Water and sediment division at a stratified tidal junction

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An estuarine channel network consists of multiple estuarine channels that conjoin at tidal junctions. It usually has a complex pattern of bifurcating channels that connect the sea with a river. At the junctions water, salinity and sediment are exchanged between the connecting channels. These junctions therefore play a crucial role in the hydrodynamics and sediment dynamics of estuarine channel networks. However, our understanding of the transport mechanisms at tidal junctions is still very limited and literature is biased towards physical processes in single estuaries.

Here we present observations that were carried out in 2007 at a tidal junction in an Indonesian estuarine channel network. At the tidal junction, two sea-connected channels combine with a river-connected channel. Two 13-hour measurement campaigns were carried out, at spring and at neap tide. The three cross-channel transects were sailed about every half an hour and continuous ADCP measurement were taken. Each hour also CTD-casts and OBS measurements were taken. From the measured data the transport of water, salt and sediment were determined.

The results show that the transport processes at the junction are both influenced by local and by regional processes. On a regional scale, the differences in length and depth between the two seaward-connected branches resulted in strong phase differences in tidal flow at the junction. While high water is simultaneous in each channel, phase differences up to two hours between the three channels were recorded. This strongly influences the transport and exchange of sediment and salt and, for example, resulted in periods with reversed salinity gradients in which water in the downstream direction (=seaward) of a channel was fresher than in the upstream direction.

On a local scale, the presence of sharp bends resulted in periods with strong secondary flows. These secondary flows redistributed suspended sediment towards the inner bend, enhancing the suspended sediment flux into the channel closest to this inner bend. Further, water columns were strongly stratified at neap tides and periodically stratified at spring tide. During stratified periods flows in the upper and lower part of the water column were decoupled, resulting in large differences in exchange between the upper and lower layers of the three connecting channels.

The measured data provided valuable information to understand and predict the transport of water, salt and sediment within estuarine channel networks and highlight the complex exchange processes that can occur.

The effects of fetch-limited wind-waves and sea level rise on the evolution of tidal embayments

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Tidal embayments are complex environments at the boundary between land and sea and these systems can be found along many parts of the world's coastline. Human populations are increasingly concentrated near coasts and tidal embayments are of key importance to coastal communities. Moreover, these dynamic systems provide habitats for a range of benthic organisms and nursery grounds for fish. Our ability to successfully manage tidal embayments and maintain their value depends on our knowledge of the system and the ability to predict its evolution. The morphological behaviour of tidal embayments, however, is complex because of the variety of feedback mechanisms which leads to morphological change.

Previous studies have highlighted the importance of wave action in the morphological evolution of tidal flats and estuarine environments in general, but the long-term effects have not been studied in detail. Furthermore, sea level rise is expected to have a strong impact on tidal embayments, but the morphological response to a rise in mean water level is still unknown. Here we present a numerical model which accounts for the interactions between hydrodynamics (currents and fetch-limited wind-waves), sediment dynamics, and the evolving topography so that the long-term morphological evolution of tidal embayments can be simulated.

Numerical simulations were undertaken using an idealized initial bathymetry. This initial topography was composed of an offshore area, inlet, and basin and covered a total area of 17 x 17 km. Fluid flow was simulated with ELCOM which is a 3D-model based on the unsteady Reynolds-averaged Navier-Stokes equations for incompressible flow. The hydrodynamic model was forced with a semidiurnal sinusoidal tide. Wind-waves were evaluated using analytical equations linking wave energy and wave period to fetch, water depth, and wind speed. Instantaneous sediment transport rates were calculated by adopting the Engelund and Hansen formula which was modified to account for wave stirring. The computed bed level changes then feeded back into the hydrodynamic model.

The morphodynamic model was first used to simulate the formation of a well-developed tidal channel network in the absence of wind-waves and under a stable mean water level. The introduction of waves resulted then in erosion of the intertidal flats and infilling of the channels, causing changes in the characteristics of the channel network and altering the overall hypsometry of the tidal basin. The channel network became highly asymmetrical when the wind was from one dominant direction. Simulations of morphological change under a rising water level indicated that the currents redistributed the sediment during sea level rise such that intertidal geometry adjusted to the new hydrodynamic conditions. The channel network expanded landward because of headward erosion of the channels. Increasing water depths caused the existing channels to become larger and more widely-spaced. Sea level rise thus drove a landward shift of the channel network. Furthermore, rising water levels induced a change in the asymmetry between the flood and ebb tidal currents and could even lead to a transition from exporting to importing sediment.

Large-scale sand transport processes in the Westerschelde estuary

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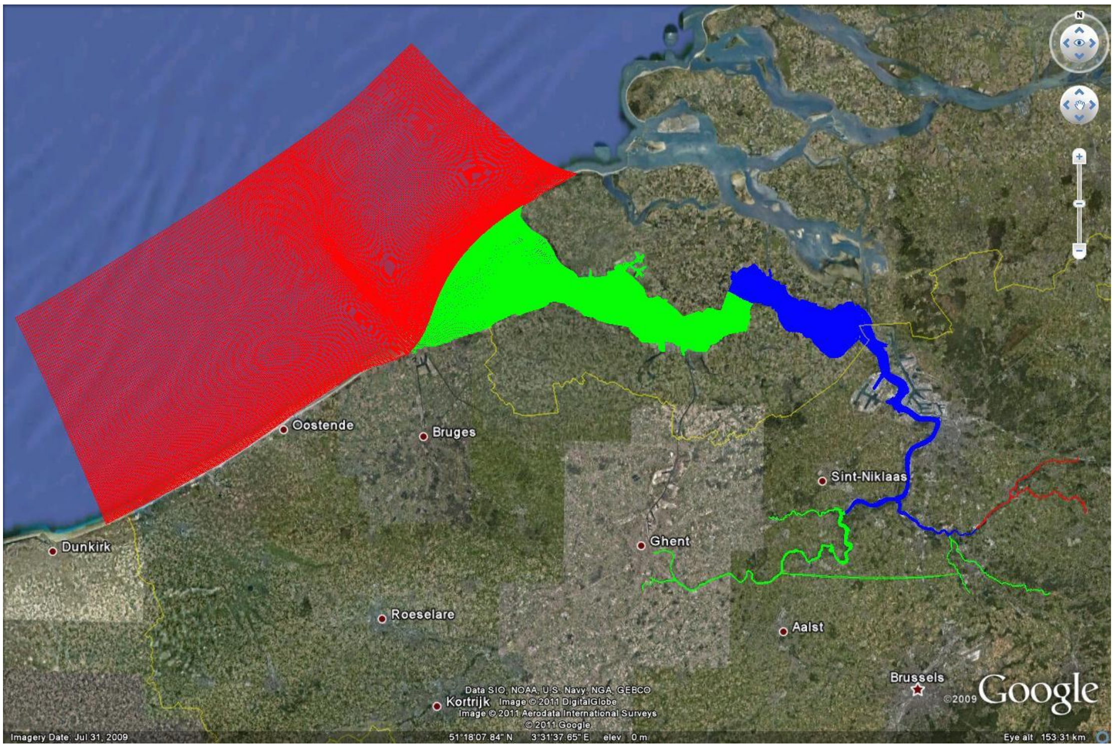
The Westerschelde is the marine part of the tide-dominated Schelde estuary in the southwest part of The Netherlands (see figure below). The morphology of the Westerschelde consists of mutually evasive ebb and flood channels. These main channels are separated by sub- and intertidal shoals and linked by connecting channels. The estuary is of large economic importance as it provides access to the ports of Antwerpen, Gent, Terneuzen and Vlissingen. Land reclamation, dredging, sand extraction and other types of human interferences have influenced the natural evolution of the estuary during the last centuries. Recently, three capital dredging programs were carried out in the periods 1971-1974, 1997-1998 and 2010.



Echo sounding data seem to indicate that the Westerschelde was importing sediment from the North Sea until around 1989. This compensated to a large degree for the extracted sand. From 1989 this importing trend seems to decrease, and there are indications that the estuary started exporting sediment. It is anticipated that the sediment exchange between the North Sea and the Westerschelde is strongly related to the bathymetry. At the same time, we found that the hydrodynamics have changed significantly during the last decades. The speed of tidal propagation has increased and the deformation of the vertical tide (flood and ebb dominance) has changed at a number of locations.

To investigate this, we have set-up a 2D Delft3D model of the whole Schelde estuary (see figure above). Flow and sand transport processes with both tidal and wind forcing are being modelled. We will carry out a number of simulations with different model bathymetries, representative for different years. The first step will be to study whether the model is capable of reproducing the typical, above-described hydrodynamic changes. Next, we will investigate the large-scale sand transport processes. Do we find significant changes in the sand exchange between the North Sea and Westerschelde, and if so: what processes are responsible for this?

Morphodynamic modeling of decadal channel evolution in San Pablo Bay, California: why does the channel narrow?

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Measured bathymetries at a 30-year interval over the past 150 years show that San Pablo Bay had periods of considerable deposition followed by periods of erosion. The deposition was the result of upstream hydraulic mining between 1852 and 1884. When mining stopped and reservoir dam construction increased in the middle of the 20th century, sediment yields towards the bay dropped considerably and net erosion occurred. However, bathymetric measurements show that the major channel in San Pablo Bay, California, has continuously narrowed during the past 150 years. This raises general questions on the processes governing the evolution of tidal channel geometry and the interaction between shoals and channels. The current work addresses these processes by means of a process-based, morphodynamic model (Delft3D) that includes 3D flow, salinity gradients, multiple sediment fractions, wind and wind waves.

Our model reproduces measured decadal deposition and erosion patterns in San Pablo Bay with significant skill, so that morphodynamic forecasts were made with confidence. Model results indicate that flooding of the shoals is an important (but not the only) hydrodynamic process that causes accretion of the channel slopes. High sediment concentration (SSC) in the channel is a prerequisite for channel slope deposition. We found different causes of high SSC in different parts of the channel. In the eastern part of San Pablo Bay channel, high SSC results from sediment supplied from upstream during high river flow conditions, whereas highest SSC in the western part of San Pablo Bay channel occur after high wind events generate waves that stir up sediment on the shoals. Sensitivity analysis shows that density currents, 3D circulation flows or sediment characteristics definition only have a secondary, very limited effect on the morphodynamic process. This suggests that the bay planform and bathymetry have a major influence on morphodynamic developments.

General theories on channel (network) evolution suggest that morphodynamic development leads towards decreasing energy dissipation levels. In contrast, model results reveal that the channels' efficiency has lowered over the past 150 years, which is reflected by higher energy dissipation levels for lower flows. Higher energy dissipation levels are primarily caused by continuous channel narrowing. The decrease in water storage volume is due to the large amount of deposition in the shallows of San Pablo Bay and areas located more landward such as Suisun Bay and the Delta. The narrowing of the main channel also has implications to the long-term sediment budget of San Pablo Bay. The flow confinement in the narrower channel has lead to a larger seaward sediment throughput through the San Pablo Bay main channel. In the future, with expected lower sediment concentrations in the watershed and less impact of wind waves due to deepening of the bay, it is possible that ultimately tidal flows will widen the channel again and increase its hydrodynamic efficiency.

A closer look into the transport of suspended matter in the Rhine ROFI plume

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Large amounts of suspended matter are transported through the Dutch coastal zone in the southern North Sea. No significant sources or sinks are present, but it is estimated that 20 Mton is transported yearly northward along the coast (Fettweis and Van den Eynde, 2003). Field measurements done in the Dutch coastal zone in the 70's, 80's and 90's indicated the strong influence of freshwater from the river Rhine on surface concentrations of suspended matter (Visser et al., 1991) and on the residual current (Visser et al., 1994).

In situ measurements done in 2003, and recently in 2010 and 2011 - as part of the Building with Nature program - focussed on detailed observations on total suspended matter (TSM) and currents in a small area in the most northerly extent of the Rhine region of freshwater influence (ROFI). These more detailed measurements show the presence of peak concentrations fairly close to the coast near the bottom, at about 1.5 km from the coastline and in a water depth of about 12 m. Concentrations 1 meter above the bottom reach up to 200 mg/l, which can be 10 times higher than near surface concentrations. Further offshore significantly lower concentrations are found. These peak concentrations have not been measured before and suggest that a large part of the northward suspended matter transport occurs very close to the coast.

Several processes may contribute to the location of this peak concentration. First of all, the horizontal density gradient, occasionally accompanied by a vertical stratification, drives an estuarine type of circulation. Surface water moves offshore, while bottom water moves inshore, bringing near-bottom TSM in a coastward direction. A second process is the wave driven transport in the wave boundary layer, which is onshore directed outside of the surf zone due to wave asymmetry, but offshore directed inside the surf zone. The offshore directed wave driven transport in the surf zone is enhanced by a gravitational component. And finally, on that location the highest density of the bivalve species *Ensis Directus* is found, which may contribute to the (temporal) burial of TSM and floc strength.

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Residual circulation in fjords: is it 2-layered or 3-layered?

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On the basis of theoretical results, the tidal residual circulation in a semienclosed basin can be one-layered, two-layered or three-layered. One-layered tidal residual flows are seaward throughout the water column. Two-layered flows consist of inflow at the surface and outflow at depth. Three-layered tidal residual flows consist of near-surface and near-bottom outflows with an inflow layer in between. Development of different vertical structures in tidal residuals is determined by the dynamical depth of the system, which is the ratio between the water column depth and a frictional depth. When the frictional depth occupies the entire water column, the net tidal residual flow is one-layered as in shallow basins. But when the frictional depth is only a small portion of the water column (>6 times smaller), the tidal residual is three-layered. In fjords, where frictional depths typically occupy a small portion of the water column, the tidal residual flow is expected to be three-layered. The surface outflow and inflow underneath are expected to be reinforced by gravitational circulation. A series of underway and fixed velocity profiles measured in several Chilean fjords are used to propose the conditions under which a three-layered residual circulation is expected. Observations in deep fjord portions, greater than ~150 m deep, essentially confirm theory by displaying a thin (<10 m deep) surface outflow layer and a near-bottom outflow layer delimiting an intermediate inflow layer. Time series at fixed locations indicate that this vertical structure persists >30% of the time and is likely perturbed by atmospheric forcing.

Influence of Lateral and Intratidal Variability in Currents, Hydrography, and Vertical Mixing on the Generation of Residual Currents in a Wide Estuary

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Residual currents in estuaries can arise through a variety of non-linear mechanisms involving the covariance on tidal time scales between currents, stratification, and mixing. These processes are hypothesized to occur in the eastern portion of Long Island Sound (LIS), a wide (width ~3-4 internal radii), relatively deep (depth ~3-4 Ekman layer thicknesses) estuary where tidal currents are strong (~1-1.5 m/s). Measurements of currents from a hull-mounted ADCP along with CTD and conductivity microstructure from a towed undulating profiler over a repeated cross-estuary section show significant variability in current shear, stratification, and vertical mixing, both laterally and over the tidal cycle. Vertical stratification is strongest under ebb currents and weakest during late flood. The lateral density gradient, on the other hand, is strongest during flood. A significant lateral circulation cell is observed at the end of the flood, possibly in response to the gravitational adjustment of the horizontal density structure. Vertical turbulent diffusivity, estimated from the microstructure measurements and analysis of vertical overturns, is highest in the lower portion of the water column, a region of low gradient Richardson number. Over the relatively shallow flanks of the estuary, the region of high diffusivity often spans the water column. These observations will be presented in the context of assessing the tidal-period covariances among the variables and how these covariances vary with lateral position. Results from a numerical simulation of the study area will be analyzed in the same fashion and compared to the observational results. An assessment of the relative importance of several different residual current generation mechanisms will be made for this region of eastern LIS.

ESTUARY-SHELF INTERACTION AND ITS INFLUENCE ON THE HYDRODYNAMICS OF A HIGHLY STRATIFIED ESTUARY: ITAJAÍ-AÇU RIVER ESTUARY, BRAZIL.

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The Itajaí-açu estuary presents a salt wedge circulation patterns driven firstly by the river discharge. However, alongshore winds produced by storms play a key role in the hydrodynamics and nontidal level can be observed as far as 55 km up estuary without lost of energy. The low frequency estuary-shelf interaction and hydrodynamics were assessed based on 52-days time series of currents and water level in two stations at the lower estuary and in the adjacent shelf. The time series were filtered in order to remove tidal frequencies and were analyzed using wavelet transformation. The estuary-shelf interaction was also assessed by calculating the estuarine exchange flow (EEF) in order to examine the residual circulation. The estuarine level was weakly related with river discharge, although strongly related and in phase in the periods of 3 to 8 days with the coastal water level (coefficient ~ 1), presenting good relationship with the alongshore wind stress (~ 0.6). The estuarine water level were also related with the mid-water cross-shelf currents (~ 0.8) and out of phase with it. The estuarine currents were well correlated with the river discharge, although with some lag. However, high correlation was observed between the mid-water and bottom estuarine currents and the mid-water and bottom cross-shelf currents for periods from 2 to 8 days, with coefficient > 0.7 and in phase, suggesting a rapid adjustment to the shelf forcing. The EEF was well correlated to alongshore wind stress and to cross-shelf currents (0.6 and 0.8), presenting in phase relationship with wind and out of phase with currents, which reveals a pattern of gravitational circulation intensification. An interpretation of these relationships may be delineated as the effect of barotropic pressure gradient (BPG) on the platform: the increasing in sea level due to southerly winds promoting the water level rise in the estuary, which due to BPG intensifies cross-shelf currents, and also influenced the estuarine vertical currents structure. The river discharge, on the other hand, produces BPG seawards, which can be attenuated by the sea level rise. Thus, we hypothesize that the BPG towards the coast mitigates the effect of river BPG, resulting in the intensification of the mid-water and bottom estuarine currents. Since this is a sub-tidal response, this effect will magnify the gravitational circulation, what results in net influx of mass during these events.

Ebb/flood dominance inversion over a neap/spring tidal cycle in the Charente estuary (France)

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Understanding the hydrodynamics and the sediment dynamics of estuaries is a sensitive issue, for both economic and environmental reasons. Many studies investigating these dynamics have been conducted on major estuaries (Hudson, USA; Severn, UK; Yangtze, China; Seine, France, …), whereas smaller systems such as the Charente estuary (France) remain poorly understood. This shallow estuary, with large intertidal zones, is characterized by a macrotidal range, and high cohesive sediment load.

This study focuses on the tidal asymmetry, a phenomenon commonly observed in estuaries (Aubrey *et al.*, 1985, Friedrichs *et al.*, 1988). Numerous studies proved that long-term significant changes in estuary characteristics (geometry, bathymetry, presence of tidal flats) can be responsible for a change in the ebb/flood dominance (Boon *et al.*, 1981, Fortunado *et al*., 2005, Bolle *et al*., 2010). More surprisingly, short term dominance changes in the tidal asymmetry have been observed in the Charente estuary. Indeed, a previous study (Stanisière *et al.*, 2006), and ADCP measurements carried out in 2011, revealed that the ebb/flood dominance was changing during the tidal cycle. For the lowest tidal ranges, the flood can be 3 times longer than the ebb. During spring tide, the ebb lasts, on average, 1.5 times longer than the flood. Both measurements were made at the mouth of the Charente River, which flows into the Marennes-Oléron bay. Preliminary results suggest that the tidal harmonic constituents S2 and MS4 are responsible for the inversion observed.

Further investigation, conducted using a 3D numerical model (MARS3D), gives us different hydrodynamic and sedimentary parameters. Numerical results will allow us to determine which mechanisms can explain the situation encountered in the Charente estuary, and to quantify their impact. Both in-situ measurements and numerical modeling will provide information about the consequences of short term dominance inversions on the sediment dynamics in the estuary.

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Analysis & Modelling of Turbulence-controlled Flocculation in a Macro-tidal Estuary

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Suspended particular matter (SPM) is a highly variable and important aspect of estuarine systems. It determines turbidity; impacting water quality and primary production, as well as generating benthic fluff on the seabed, modifying biogeochemical exchanges, and constraining primary productivity. Further, SPM carries important biogeochemical components (e.g. carbon, nitrogen, contaminants and pollutants), deciding the fates of anthropogenic inputs to the system.

Outside of the non-cohesive fraction (sand), little is known of the properties of estuarine SPM (i.e. particle sizes, densities, settling velocities) and how these impact upon fine particle entrainment and sedimentation. This is due to most SPM being in the form of flocs (aggregates of dead and living organic matter, cohesive inorganic matter, and water) that are dramatically modified by conventional sampling methods (easily ruptured and/or may aggregate during sampling). As such we lack reliable and comprehensive information on key floc parameters such as settling velocities, particularly since the properties of flocs change on a range of time scales: tidal (suspension/advection), lunar (spring-neap cycle), and seasonal (storm resuspension and biological production).

Turbulence is an important mediator of floc characteristics, with low turbulence promoting collisions between particles and flocculation, while high levels result in shear-induced rupture, literally tearing flocs apart. Because of this, floc characteristics can be related to the Kolmogorov Microscale, and turbulence parameterisation is key to understanding the relationship between turbulence and particle size for accurate modelling.

The results of an extensive field campaign and SPM flocculation modelling of the Dee estuary (N.W. United Kingdom) are presented, giving insight into the fates of SPM from the river, and that advected from offshore. Using data from a combination of acoustics, optics, moored deployments and CTD stations, a 1-D (GOTM) model shows variation across tidal, spring-neap, and seasonal time-scales. This is extended through the use of Son & Hsu's 2011 flocculation formula to predict D_{50} particle sizes.

Turbulence comparisons between data and a ROMS simulation in the Puget Sound estuary for tidal hydrokinetic turbine siting

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Comparisons between high resolution turbulence data from Admiralty Inlet in Puget Sound, WA, and ROMS simulation results show that the model's RANS turbulence closure scheme has skill. Turbulent dissipation rates and Reynolds stresses compare well, generally within a factor of 2. The higher-frequency, roughly isotropic turbulent kinetic energy from the data also agrees with the model output turbulent kinetic energy in this range. The lower frequency turbulence, however, which is principally quasi-horizontal, is not captured by the turbulence closure scheme; the scheme was developed to capture 'classical turbulence' including the inertial sub-range, and not the larger-scale, quasi-horizontal dynamics observed in the data. Based on spectra from the data, an extrapolation is used to extend the ROMS predictions to wavenumbers much lower than the inertial sub-range. The extrapolation is based upon the dissipation rate and the local advective mean speed, both of which compare favorably between ROMS and the field data. This extrapolation improves the turbulent kinetic energy comparisons somewhat. Another approach accounts for implicit diffusion and mixing in the simulation using the truncation error of the momentum advection terms in the numerical scheme. The resulting truncation error in energy dissipation rate is found to be small relative to the dissipation rate and shear production at one site, but nearly comparable at another site.

The results are discussed in the context of siting tidal hydrokinetic turbines, which respond to turbulence over a broad range of scales.

Dense Shelf Water Cascade (DSWC) on the Rottnest Continental Shelf in south-western Australia

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Temperature and salinity (and associated density) data collected by autonomous shallow water ocean gliders along the Rottnest Continental Shelf, revealed the formation and propagation of dense water masses which is defined as dense shelf water cascading (DSWC). Observations over a period of two years have confirmed that DSWC can be an occurrence even under sup tropical climatic conditions. Increase in salinity due to evaporation in summer and autumn and cooling in winter allows for relative increase in density in the inshore regions (depths less than 50m) of the shelf. This cross-shelf density difference (cross-shelf density gradient) is entirely responsible for driving the DSWC. Also it has been shown that DSWC continues throughout the year with varying degrees of intensity and transport dense water as a near sea bed plume, which may be 20m in thickness where the water depths are 40m. Offshore transport during autumn and winter are estimated to be 0.1 Sv / 100 km (of shelf width), which is nearly 60% of the mean along shore transport on Rottnest Continental Shelf. However occurrence of DSWC is minimal during summer, due to dilution of cross-shelf density gradients by strong wind mixing and upwelling at the edge of inner continental shelf. Hence DSWC on Rottnest Continental Shelf plays an important role in cross-shelf exchange of water and material thus contributing to control the water quality along the nearshore regions.

Using historical, 19th century tide data to understand secular variation in estuarine tidal properties

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Recent scholarship suggests that secular changes to tidal constituents in world oceans are being caused by changing tidal amphidromes and altered patterns of energy dissipation in the ocean and continental shelf. An additional explanation is that globally distributed, anthropogenically produced changes to estuarine bathymetry (e.g., channel deepening) have altered the resonance characteristics and/or reduced the frictional effects of tidal propagation. We investigate this hypothesis by comparing recently discovered 19th century tide data from the Columbia River Estuary with contemporary data. Spatially distributed data from 1877 are obtained from old hydrographic surveys, and multi-year data from 1853-76 are obtained either from paper records or by digitizing 'marigrams' (the original tide rolls with a pencil trace of the tide). These records are part of many hundred years of 'forgotten' 19th century tide data that are stored in the US National Archives. In both modern (1925-present) and historical Columbia river data we examine constituent ratios (M2/S2), phase changes, and shallow water constituents (M4), which are primarily produced by local frictional effects. Results show an increase in the spring neap cycle and a decrease in the M4 constituent, both suggesting a decreased effect of friction. These results are confirmed through an idealized Delft3D numerical model. To generalize these results, we harmonically analyze nearly 100 long-term gauge records worldwide and show that the largest secular trends occur in anthropogenically modified estuaries.

Circulation of a Hypersaline Estuary in Response to a Rise in Mean Sea Level

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Stromatolites in Hamelin Pool of Shark Bay in Western Australia are some of the most ancient records of life on Earth. They are present due to hypersaline (up to 70 ppt) conditions in the Bay which is a result of high evaporation (~2m per annum) and the presence of Faure sill at the entrance of the Bay. With anthropogenic climate change, a higher mean sea level is likely to increase tidal flow into Hamelin Pool across the entrance sill, which in turn may reduce the salinity and hence threaten the World Heritage values in this region. Previous hydrodynamic observations and numerical models of Shark Bay have tended to focus on the present state of the outer bay. In this study we: (i) analyse field observations to improve understanding of tidal inflow and distribution of water properties (salinity, temperature) through the complex channels of the Faure Sill at the entrance to Hamelin Pool in the inner Bay; (ii) configure and validate a high resolution hydrodynamic model of the region and use this to assess possible future changes to the salinity characteristics within Hamelin Pool with different projections of mean sea-level rise. The model was constructed using the General Estuarine Transport Model (GETM). Bathymetry data for the complex channels into Hamelin Pool were collected at 3m resolution using hyperspectral imagery. This high resolution dataset was used with bathymetric data on a larger scale to configure a high resolution model grid (~100m cell size) of the inner Bay. The open boundary was forced with tidal components from a coarser model setup for the whole of Shark Bay. The model was validated against current, temperature and salinity observations collected over a two-month period. Simulations are run for likely projections of mean sea-level rise. Realistic projections of climate change and predicting 3D circulation pattern of the hypersaline water (inner bay) and less saline water (outer bay) are key components of this study. In particular, the role of gravitational circulation within the bay through changing longitudinal density gradients resulting from lower salinity water input to the Bay will be investigated. The results will provide a basis for risk assessment and will enable monitoring needs and the development of management strategies, helping to achieve a real and measurable difference to Shark Bay's environment, biodiversity and sustainability.

Response of the German Bight hydro- and sediment dynamics to wave, tidal and atmospheric forcing

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This work deals with analysis of hydrographic observations and results of numerical simulations. We study here the impact of waves and the atmospheric forcing on the suspended particulate matter (SPM) transports. The data base includes HF-radar, ADCP observations, continuous measurements on data stations and satellite data originating from the Medium Resolution Imaging Spectrometer (MERIS) onboard the ESA satellite ENVISAT with a spatial resolution of 300 m. Numerical simulations use nested-grid circulation models based on the General Estuarine Transport Model (GETM) coupled with wave and suspended matter transport models. Modern satellite observations have now a comparable horizontal resolution with high-resolution numerical model of the entire area of the German Bight coastal area allowing to describe and validate new and so far unknown patterns of sediment distribution. The two data sets are consistent and reveal an oscillatory behaviour of sediment pools to the north of the back-barrier basins and clear propagation patterns of tidally driven suspended particulate matter outflow into the North Sea. The erosion of sediments due to waves and wind forcing is studied in the tidal flat areas. A number of sensitivity experiments are performed to analyse the effects of wind, waves, meteorological and tidal forcing on the suspended particulate matter fluxes. The good agreement between observations and the coupled model simulations is convincing evidence that the model simulates the basic dynamics and sediment transport processes, which motivates its further use in hindcasting, as well as in the initial steps towards forecasting circulation and sediment dynamics in the coastal zone.

Prediction of Ocean State by assimilation of temperature and salinity data. A case study for the German Bight

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Integrated ocean observing systems closely link in-situ and remote measurements with numerical models enabling the reconstruction and forecast of key state variables with full spatial coverage. Such a nowcast/forecast model system has been developed for the North Sea-Baltic Sea as an integral component of the COSYNA (Coastal Observation System for Northern and Arctic seas) project. It is used to produce nowcasts and short-term forecasts of the circulation and physical properties in the North Sea/Baltic Sea One of the expectations is that the model can provide consistent temperature and salinity three-dimensional fields to fill in the gaps in observation and satellite observations and eventually produce reliable physical components to be used in further bio-geochemical/management/fishery applications.

The three-dimensional primitive equation model GETM ("General Estuarine Transport Model") is used to simulate the circulation and salinity and temperature fields for the North Sea-Baltic Sea system. The horizontal resolution is ca. 5km and it has 21 sigma layers. The atmospheric data from the German Weather Service (DWD) are used for the metereological forcing. This work presents a framework of the nowcast/forecast system, which includes an algorithm to assimilate temperature and salinity derived from measurements (such as FerryBox, MARNET stations, etc.) as well as satellite derived sea surface temperature (SST) in the German Bight

The numerical performance of the German Bight model with the data assimilation method based on Kalman filter appears to be efficient enough to be used in an operational ocean forecast system. For the assessment of forecast skill of the regional ocean model we compare the free run and assimilation run with independent data from observations. Model-data comparison shows that the reanalysis produced by the data assimilation fairly well represents the physical properties in the German Bight. The overall root-mean-square errors between temperature and salinity fields of reanalysis and observation are significantly reduced after the assimilation. for the inter-comparison period. Furthermore, seasonal variation in temperature is well reproduced and the predicted synoptic variation is significantly correlated with its counterpart from the mooring measured temperature Of particular interest is the question how long the information from the measurements used in the model predicted system has an influence on the forecast.

MODELLING SEDIMENT TRANSPORT IN A MACROTIDAL, FUNNEL-SHAPED, BI-CHANNEL ESTUARY.

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In general good predictive capability of suspended sediment is crucial in determining sediment budgets and sediment pathways in estuaries and coastal environments. We present a study of suspended sediment transport in the Dee Estuary, for which we use a three-dimensional baroclinic process-based model.

The Dee Estuary is a macrotidal, funnel-shaped estuary located in the eastern Irish Sea. It is about 30 km long and 8.5 km wide at its mouth. The mean spring tidal range is approximately 10 m. The main channel bifurcates and results in two deep channels with depths ranging from about 20 m to about 30 m.

The Proudman Oceanographic Laboratory Coastal Ocean Model System, POLCOMS, includes a hydrodynamic model internally coupled to a sediment transport model and externally coupled to the General Ocean Turbulence Model. The hydrodynamic model coupled to the turbulence model has been validated against field data and used to investigate processes important for the estuarine circulation in the Dee.

The sediment transport model can calculate suspended load, bed load, and bed morphodynamics for an unlimited number of sediment classes. This model has been validated and used for simple scenarios, and is implemented here for the Dee estuary.

The model is set up for a numerical domain covering Liverpool Bay at a resolution of about 180 m. The hydrodynamic simulations take into account freshwater river input, atmospheric forcing, and wetting and drying.

Only suspended sediment transport is considered here and it may take into account a riverine sediment input. The model is set up using spatially and temporally constant physical parameters determining erosion and settling. The initial bed composition is also taken to be uniform.

The numerical results are compared to field data that were obtained in a period of moderate waves, 14th to 29th February 2008. The data were taken from two locations, one in each channel. Predicted suspended sediment concentrations are validated against values measured by LISST at both locations.

The Dee presents a very interesting challenge for modelling purposes in that the two channels exhibit different estuarine behaviours. In addition to presenting model-data comparisons in order to evaluate the predictive ability of the model and discussing the sources of discrepancies, we aim to investigate the importance of various physical sediment transport processes on numerical simulations.

In particular, we will discuss the relative importance of (i) multiclass representation of sediment transport, (ii) including riverine sediment input, (iii) advection processes. We will also discuss the limitations of the specific simplistic setup used here for the sediment transport simulations.

3D modelling of the turbidity maximum in the macrotidal Gironde estuary: validation and sensitivity to seasonal forcings

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The Gironde estuary (Bay of Biscay, SW France) is a macrotidal estuary characterised by high suspended sediment concentration levels, due to a well developed turbidity maximum. For years, extensive research focused on identifying mechanisms governing the trapping of suspended sediment, such as tidal pumping and residual gravitational circulation. Most of the sediment transport models applied in the estuary have attempted to reproduce qualitatively the turbidity maximum in the short term, i.e. after some tidal cycles. A key issue was also to grade the basic mechanisms inducing sediment trapping. This was achieved by a 3D numerical model which simulated the stability of the suspended mass budget due to density stratifications in the lower estuary. In this work we apply this 3D model to explore seasonal and long term changes in turbidity and suspended sediment transport in the estuary.

The model used is the SiAM-3D numerical model, developed by Ifremer. The hydrodynamic module solves the Navier-Stokes equations (shallow water) assuming hydrostatic hypothesis and Boussinesq approximation. The model computes separately external (depth averaged) and internal (3-D computation) modes for CPU time optimization. SiAM-3D is based on a mixing length turbulence closure scheme, which accounts for turbulence damping due to stratification through a local gradient Richardson number. The transport model is based on an advection/diffusion model and transports cohesive sediment and salinity. Deposition and erosion fluxes are calculated from the Krone and Partheniades formulations respectively. Erosion is controlled by the bed shear stress while deposition is always allowed.

In this work we use recent time series of velocity and salinity to validate the hydrodynamical model over seasonal time scales (several months). Because of the lack of knowledge on physical properties of flocs in the Gironde, the parameterization of the settling velocity is based on comparisons with time series of surface suspended sediment concentration (SSC). A settling velocity ranging from 0,1 to 2 $mm.s^{-1}$ is found to be the best adjustment to reproduce satisfactory the dynamics of measured turbidity, as well as to ensure the persistence of the turbidity maximum over time. The comparison with satellite imagery shows that the model reproduces well the geometry of the turbidity maximum at different seasons. In the lower estuary, the lateral suspended sediment flux from the main navigation channel to the eastern bank promotes the transfer of sediment towards the downstream part of the estuary and the escape of sediment through the mouth. One-year simulations allow the study of the mass budget in the estuary over seasonal cycles. These confirm the main role of tidal asymmetry on the turbidity maximum formation, and the secondary role of density gradients to maintain a stabe mass of suspended sediment within the estuary. Moreover, the role of changes of riverine bathymetry and river flow over decades on long-term trends of the turbidity maximum is discussed.

“The Ekman Drain”: a conduit to the deep ocean for shelf material

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Exchange between shelf and open ocean plays a crucial role in the sequestration of shelf organic material in deep sediments and in the supply of nutrients for primary production in shelf seas. Cross-slope transport occurs through a variety of processes which evade the constraint of bathymetric steering of the flow over the steep topography of the continental slope. While the principal candidate mechanisms of exchange have been identified, the relative magnitude of their contributions is difficult to quantify and largely unknown in most shelf edge regimes.. In this contribution, we will examine the evidence for for the contribution of the Ekman drain, a mechanism which seems to operate persistently under along-slope currents which extend down to the seabed. This is the case for the European Slope Current (ESC) which extends continuously from the Iberian peninsula to the Norwegian Sea. Along the Hebridean slope, this current has a core speed of up to 0.3 ms^{-1} and a transport of 1-2Sv.

The down slope transport involved occurs in the bottom boundary layer where the slowing of the Slope Current by bed friction breaks the geostrophic constraint, leaving an unbalanced component of the pressure gradient which should cause the current to veer downslope in a bottom Ekman layer of thickness $\delta \sim 0.02V/f$ with a net transport down-slope given by $ED = \frac{\tau}{\rho f} = C_d V^2/f$ where V is the slope current speed and C_d is the bottom drag coefficient. The extent of Ekman veering and the magnitude of the cross-slope transport under the ESC will be examined on the basis of ADCP and RCM records of the flow over the slope at the Hebridean Shelf Edge in summer adn winter regimes. The results will be considered in relation to the transport of organic carbon down the slope into deep water.

Biogenic material originating on the shelf, or in surface production over the slope, has been observed in deep water (>1000m). The presence of viable chlorophyll in this material indicates rapid transit from the surface layers in the Ekman drain rather than settlement in particle aggregations as “marine snow”. Measurements of the oxyygen consumption rates in the slope sediments indicate that remineralisation of organic carbon here is an order of magnitude greater than the vertical supply as measured by sediment traps in the water column which suggests a substantial horizontal advective supply. At the same time, burial rates of both organic and inorganic sediment components are small and much less than the vertical flux

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Changing estuarine processes through the gradual opening of a new inlet

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Through the application of a calibrated and validated numerical model (MIKE21 FM) we assess the effects of a gradual opening of a new inlet in a tide dominated estuary, the Caravelas estuary (Bahia, northeast of Brazil). The estuary reaches the ocean in front of the Abrolhos coral reef, the largest tropical reef habitat in the South Atlantic, making the understanding of its material exchanges of prime importance. Aerial photographs, satellite images and nautical charts show the natural morphological changes on the Caravelas estuary inlet, with coastal erosion causing the opening of a new inlet channel that gradually widens and becomes the main estuarine channel. The retroceding coastline reaches an internal drainage channel in the late 1950's, creating the new "Boca do Tomba inlet". With tidal flows controlling the hydrodynamics of this secondary channel, the initially narrow channel (aprox. 110 m wide in 1975) starts widening at a rate of approximately 9 m/year, reaching approximately 500 m in 2011. By widening and deepening, the newly formed channel gradually becomes the main channel of the estuarine system. Nautical charts show that during this process the old inlet channel (Barra Velha) becomes shallower, while the upstream part of the estuary becomes deeper, indicating changes in its dynamics. Our modelling experiments aim to understand the changing estuarine dynamics by simulating different inlet morphological conditions. The numerical model has been validated against measured data from two field campaigns conducted in 2007 and 2008. Based on this model, the estuarine hydrodynamics under different morphological conditions have been simulated. Results comparing the extreme situations (closed and wide open channel) show an overall increase in the tidal influence in the system. The lower estuary presents an increase in tidal flows, with mean currents increasing about 30 %. Moving upstream, at around 10 km from the original inlet, changes show to be not only related to the magnitude of the processes, but also in terms of changes in the asymmetry of tidal currents. A more symmetric flow condition is observed with the open inlet, with flood flows being approximately 10 % larger than ebb flows, while the pre-opening conditions show flood currents of about 40 % larger than the correspondent ebb flows. In general, the opening and gradual increase of the new inlet, that created a connecting channel at around 3 km upstream in relation to the original inlet, results in augmented flows and changes in the estuarine processes are mainly related to an increase of the tidal influence in the estuary dynamics. More materials are exchanged and an upstream shift of the influence of marine processes is observed.

Three Dimensional Numerical Modeling of sediment Transport in Open Channels using Lagrangian Approach

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Abstract: A Lagrangian particle tracking algorithm has been deployed for the purpose of numerical modeling of suspended and bed load transport in the open channels. Developed model incorporate an Eulerian three-dimensional fluid flow model for the prediction of flow pattern. Effect of various type of parameters (e.g. different forces acting on a particle, particle-wall interactions, turbulence etc.) have been studied. Particles are assumed to cover the bottom boundary of the study area, then different forces are inserted for each particle and the particle trajectory based on the sediment transport theories is predicted. By statistical analysis of results of computational particles trajectories and generalization of results for total study area, quantity and paths of transported sediments were predicted. Results obtained from developed model then compared with sediment transport cases cited in the literature.

Keywords: sediment transport; lagrangian model; particle tracking; numerical modeling

Shelf and slope circulation inshore of the Charleston Bump

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A cross-shelf moored array of current profiler observations, shipboard current profiler observations and glider-derived depth-averaged currents were collected over the first few months of 2012 as part of a study of wintertime phytoplankton blooms off the coast of northern South Carolina. The combined dataset is examined to document the circulation in the region inshore of the offshore deflection of the Gulf Stream, often called the Charleston Bump. The upper slope region is characterized by rapidly varying conditions associated with the dynamics of the Gulf Stream. The Gulf Stream rapidly transitioned from a strongly deflected state to a weakly deflected state during the field effort and permits a contrast of circulation under these varying conditions. Of note were repeated pulses of strong equatorward flow along the upper slope accompanied the leading edge of filaments during the strongly deflected state.

Parameterization of turbulence in estuarine models:
How well do we really understand mixing?

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Numerical circulation models are being used with increasing regularity to study biogeochemical processes in the estuarine and coastal environment. Accurately simulating these processes requires parameterization of turbulent mixing.
In most commonly used numerical models, this parameterization is done using two-equation turbulence closure models. And while there has been considerable debate in the literature as to which model is better, model results from a variety of estuaries demonstrate remarkably little sensitivity to the choice of turbulence closure. One feature of most implementations of this class of two-equation turbulence models is the so-called Galperin correction, which prevents the turbulent length scale from exceeding the Ozmidov scale. This limitation effectively sets the maximum value of dissipation for a given level of stratification. To examine the importance of this length-scale limitation, a simplified one-equation turbulence model is proposed. The full transport equation for turbulent kinetic energy is retained, but the transport equation for the second turbulent quantity is replaced with a simple analytic length scale limitation. Under this limitation, the turbulent length scale is set to either the Ozmidov scale or boundary layer scale, depending on which is smaller. This model is then applied in three estuaries with contrasting physical scales: 1) Chesapeake Bay; 2) the Hudson River; and 3) the Merrimack River. The predicted salinity distributions in all three systems show little difference between commonly used two-equation models and the simplified one-equation implementation. In all three systems, the salinity distributions are more sensitive to the choice of background diffusivity than to the choice of turbulence model—even when the simplified one-equation model is used. In Chesapeake Bay, simulations of dissolved oxygen are similarly insensitive to the choice of turbulence closure. However, model predictions of hypoxic volume of Chesapeake Bay change by roughly a factor of three simply based on the choice of advection scheme. This sensitivity to numerical diffusion and background diffusivity raises the question of how well we really understanding the key processes that ultimately result in mixing in estuaries.

Import of sediment resulting from internal mixing asymmetry

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Abstract

In many estuaries, there are distinct region where high concentrations of suspended sediment are observed. An example of such an estuary is the Ems estuary. The sediment dynamics in this estuary has changed dramatically over the years: in the eighties, sediment was trapped near the landward limit of salt intrusion, recent observations show that the sediment is trapped in the freshwater region. In Chernetsky *et al.* (2010) the mechanisms resulting in the change of the position of the ETM was investigated, using an eddy viscosity that was constant in time.

By assuming a time–independent vertical mixing, sediment transport due to internal tidal asymmetry was not taken into account, an important mechanism according to Burchard & Baumert (1998); Winterwerp (2011) . The main aim of this presentation is to investigate the relative importance importance of this mechanism, compared to other terms, and the resulting changes in the trapping location. To this end, an analytical 2DV model is developed that includes time–dependent vertical mixing. The water motion and the concentration equation are solved semi–analytically.

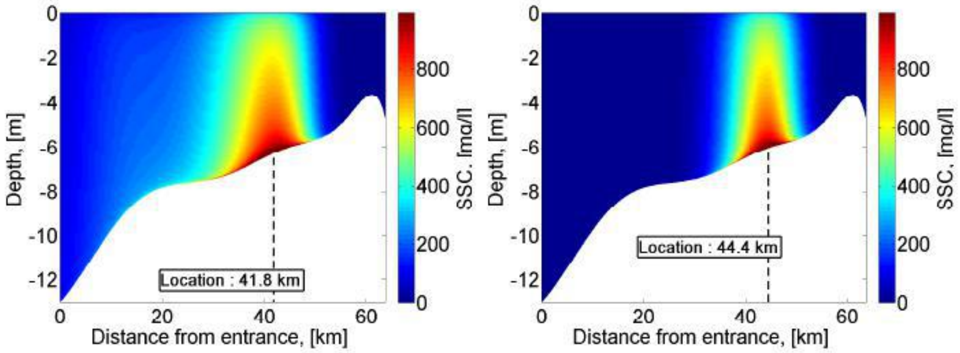

Figure 1: The tidally averaged suspended sediment concentration in morphodynamic equilibrium. In the figure on the left, transport due to internal mixing asymmetry is not taken into account, in the right–hand figure this contribution is included

In figure 1, the modelled tidally averaged suspended sediment concentrations in morphodynamic equilibrium are shown. In the left–hand figure the effect of internal tidal asymmetry is not taken into account, including the transport mechanism related to mixing asymmetry (see figure on the right–hand side) the sediment is trapped slightly more into the estuary, and the sediment is spatially more concentrated. In this presentation these observations will be explained in detail and the sensitivity of these findings to different parameter values will be discussed.

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OBSERVATIONS OF FLOC SIZE AND SETTLING VELOCITY ALONG A LONGITUDINAL ESTUARINE TRANSECT

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ABSTRACT

We conducted a 147 km longitudinal transect of flocculated cohesive sediment properties in San Francisco Bay on June 17, 2008. Our objective was to determine the factors that control floc settling velocity (w_s) along the longitudinal axis of the estuary. The INNSEV-LF video system was used to measure floc diameters and settling velocities at 12 stations. Floc sizes ranged from 26.5 μm to 584 μm and settling velocities ranged between 0.08 mm/s to 11.6 mm/s during the longitudinal transect. Mass-weighted settling velocity ranged from 0.5 mm/s to 6.2 mm/s. The transect took all day to complete and was not synoptic. During slack tide, larger and faster settling flocs deposited, accounting for most of the longitudinal variability. The best single predictor of settling velocity was water velocity 66 minutes prior to sampling, not suspended-sediment concentration or salinity. Resuspension and settling lags are likely responsible for the lagged response of settling velocity to water velocity. The distribution of individual floc diameters and settling velocities indicates that floc density for a given floc diameter varies greatly. A small portion (a few percent) of suspended sediment mass in San Francisco Bay is sand-sized and inclusion of sand in flocs appears likely. Fractal theory for cohesive sediment assumes that there is a single primary particle size that flocculates, which is not the case for these mixed sediment flocs. The wide variability in the physical, biological and chemical processes which contribute to flocculation within San Francisco Bay mean that spatial floc data is required in order to accurately represent the diverse floc dynamics present in the Bay system. This complexity in floc properties is perfectly demonstrated by the comparison of INSSEV-LF measured mass settling flux (MSF) and the large errors in fluxes calculated using a simple constant w_s assumption. For example, a slow constant fall velocity of 0.5 mm/s only reproduced 13% of the mean measured mass flux. At the other extreme, the 8 mm/s constant w_s inferred that the mean MSF was double what was actually present. Thus, no single settling velocity can adequately mimic all measured MSF. The importance in determining accurate estimates of floc effective density has been highlighted by the San Francisco Bay data, as these provide the basis for realistic distributions of floc dry mass and the mass settling flux across a floc population. The video-based INSSEV-LF instrument meets this data acquisition criterion, but commercial particle sizers do not meet this criterion. Floc size and settling data are needed to understand and simulate the depositional qualities of suspended cohesive sediment. For San Francisco Bay, suspended sediment should be simulated with multiple size classes or settling velocities or with a mass-weighted settling velocity that depends on lagged water velocity.

Effects of evolving estuarine floc population on acoustic and optically-derived estimates of SPM concentration over a tidal cycle.

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Cohesive particles in marine and coastal waters remain a significant challenge to sediment transport predictions. Given the relevance to water quality, pollution, benthic ecology and coastal engineering our ability to develop process-response models of cohesive sediments is poor. Suspended cohesive particles rarely exist in their primary state but form flocs which are aggregated, heterogeneous assemblages of mineral grains, biogenic debris, bacteria and organic material. Floc formation is thus a function of numerous variables whose inter-related processes are yet to be fully elucidated.

This complexity is exacerbated by a lack of suitable data, notably in characterizing floc populations. A floc may constitute over 1 million individual particles and size can range over 4 orders of magnitude within one population; effective densities and settling velocities can therefore span several orders of magnitude. Particle size ranges and concentrations are not adequately measurable by physical sampling which break up fragile flocs. However, recent innovations of *in situ* visualization of floc size and settling velocity using INSSEV & LabSFLOC mean we are now in a position to make simultaneous measurements of cohesive SPM populations using *in situ*, remote and physical sampling to aid development of methods that account for the flaws in remote measurements. The challenge is to develop data acquisition techniques that will allow accurate quantification of floc characteristics for the determination of SPM concentration and settling velocities for mass settling flux calculations via commonly available remote methods.

Remote methods offer the potential to greatly enhance our understanding of floc particle dynamics. However, the responses of light and sound to floc particles remain uncertain. Differences in derived mass concentrations of flocculated and non-cohesive suspensions occur because OBS measures projected area concentration not mass concentration. Laser interferometry (e.g. LISST) is only applicable in relatively low concentrations, can disturb fragile flocs and requires a smooth size distribution and near-spherical particles. Acoustic backscatter methods are limited by a lack of data from floc-dominated environments which has restricted the development of suitable acoustic inversion algorithms.

We present selected data collected in the meso-tidal Tamar Estuary, Devon, UK over several tidal cycles. INSSEV and LabSFLOC data were acquired at multiple heights and complimented by physically sampled SPM later analysed for mass and organic content. A suite of ABS and OBS sensors were used to provide multi-frequency vertical response profiles, and a LISST-XT was positioned at INSSEV height. These measurements were augmented by vertical ADV and ADCP profiles of velocity and regular CTD profiles.

Examples are shown that reveal different responses of acoustic and optical methods across the tidal cycle. These differences are compared to changes in floc characteristics, SPM concentration, organic content, hydrodynamics and water density over the tidal cycle in an attempt to determine the key parameters affecting the way in which sound and light interact with flocs. Ultimately, this information will be used to develop inversion algorithms that will allow the recovery of cohesive sediment mass concentrations using combinations of acoustical and optical instruments without the need for extensive field calibrations.

CIRCULATION AND HYDROGRAPHY OF SEMI-ARID BRAZILIAN LOW-INFLOW ESTUARIES.

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Many small estuaries exist along the Northeast Brazilian coast. Excluding the major rivers, such as the São Francisco and Parnaíba, most estuaries are strongly influenced by the regional semi-arid climate, in the sense that during the prolonged dry period they have no fresh water inflow. These types of estuaries are known as low inflow estuaries. We present here the results of a field experiment to assess the hydrodynamics of three low-inflow estuaries in the Ceará State, Northeast Brazil. A field experiment was carried out to acquire data in the estuaries of the Cocó, Pacoti and Pirangi rivers at the end of the dry period. Sampling was done during a complete tidal cycle at each estuary during consecutive days on November 6, 7 and 8, 2010 influenced by spring tides. The same procedure and equipment were applied in all three estuaries. The observations showed a richness of estuarine processes in nearby systems. Despite of capturing only a snapshot on their physical characteristics, the results are straightforward as they represent the dry season, which lasts over more than six months per year. The Cocó estuary shows typical gravitational circulation, as a result of water inflow from Fortaleza water supply; The Pacoti estuary shows nearly neutral buoyancy as the temperature compensates for the small salinity variations; The Pirangi estuary shows inverse estuarine circulation, as result of severe river damming.

DYNAMICS OF SAND DUNES IN THE NORTHERN YUCATÁN PENINSULA COAST.

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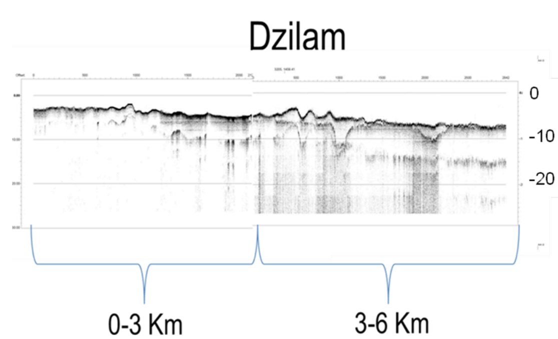
Large submerged bed forms are relatively common features in the inner continental shelf around the world. They range from megaripples, to sand dunes, sandbars, sand banks and sand ridges. Their origin, persistence and dynamics are diverse, and in most cases they actively participate in the nearshore and beach morphodynamics in different space and time scales. In particular, sand dunes can play an important role in conveying longshore transport in shallow shelves and non-linear shorelines, especially in low energy coasts with persistent unidirectional currents.

Recent studies have focused on the classification of these features (Dyer and Huntley, 1999), on their occurrence and persistence (e.g., Traykovski and Goff, 2003, Gutierrez et al., 2005), and on modelling the formation and evolution of submerged bed forms (e.g., Coco et al., 2006a and 2006b), suggesting some sort of self-organization but also a close functionality with the wave climate and its variability, water depth and sediment sorting, as well as association with longshore sediment transport (Murray and Thieler, 2003).

This work presents the preliminary results of field experiments in a shallow, sediment-starved and low energy inner continental shelf, where numerous stable and unstable 2D and 3D sand dune fields are present, as part of an ongoing three-year project designed to increase our understanding of sand dune genesis and behaviour in such low energy environments through observations and numerical modelling.

The study site is in the Northern coast of the Yucatán Peninsula, a low-energy coastal environment (Hs = 0.6 m and tidal amplitude ranging from 0.5 to 0.8 m), with a large and shallow continental shelf (80-120 km wide, average 1:1000 slope), which dissipates the outer-shelf incident waves, which in turn become highly non-linear near the coast. In the bottom floor, unconsolidated sand layer thickness is small, except in some localized areas and in particular where sand dune fields are present.



This study allows for a better understanding of the role of the sand dunes in the coastal sediment budget of the critically eroded beaches in the Northern Yucatán Peninsula.

Numerical analysis of sediment transport in the Juist marina

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Introduction

In recent years the East Frisian island of Juist located at the North Sea Coast of Germany in the Wadden Sea has complemented its municipal port with a marina. The marina is separated from the municipal port by a bulkhead with a small entrance opening, see figure 1. In its first years of operation it became obvious that the marina is facing high siltation. Mainly fine sands are transported into the basin and deposited behind the marina entrance. Silt is transported further into the basin and aggregates there leading to rapid siltation. Numerical studies aimed at capturing the flow patterns and sediment transport mechanisms inside the harbor are presented and validated by long-term field measurements.

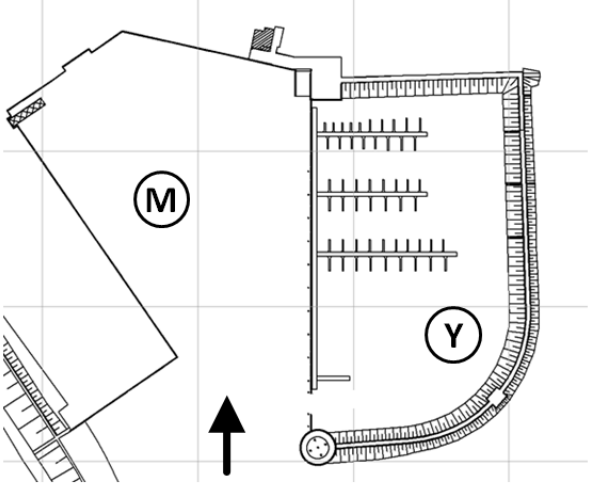

Fig. 1: Plan view of the municipal port (M) and marina (Y) on the island of Juist. The mutual entrance to the port facing the Wadden Sea can be seen at the bottom of the figure. The arrow denotes the inflow direction.

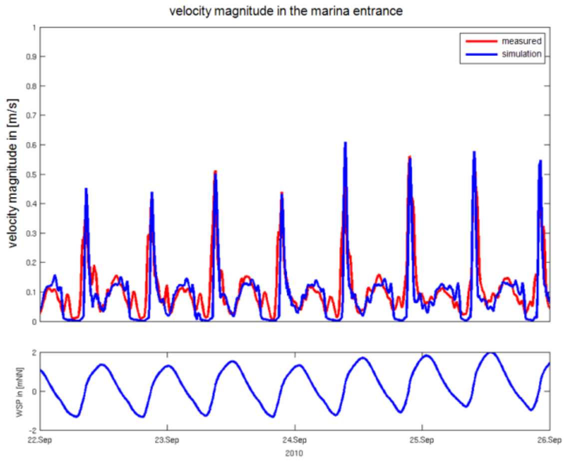

Fig. 2: Velocities (velocity magnitude) obtained by long term measuring station (red) and numerical simulation (blue) in the marina entrance for four days around spring tide in 2010. Water elevation in the bottom part.

Methods

Using the open source code SELFE (semi-implicit Eulerian–Lagrangian finite-element model), described by Zhang and Baptista (2008), numerical investigations on flow patterns and sediment transport mechanisms inside the Juist marina were carried out. Conservation equations in SELFE are based on the 3-dimensional Navier-Stokes equations in Reynolds-averaged form with Boussinesq approximation and shallow water assumption. Furthermore a sediment model for calculating sediment transport of non-cohesive sediments comprised of bed-load transport based on van Rijn (2007) and suspended load based on van Rijn (1984) is used which also calculates bed morphology according to erosional and depositional fluxes. Coupling of the sediment model to SELFE is achieved through the advection-diffusion equation.

A long-term measuring station was operated recording water-level, flow velocities and suspended solids concentration over a month in 2010. Tide asymmetry leading to comparably higher inflow velocities and thus a net influx of sediment into the marina was identified and analyzed. Hydronumerical simulations were able to capture the predominant phenomena using values obtained by the long-term measuring station as input data. With the help of those data a successful validation of the numerical model could be achieved, see figure 2. The validated numerical model was used to evaluate the effectiveness of possible actions to reduce sediment influx into the marina.

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Lagrangian observations with analysis of seasonal variation over a region influenced by the Mobile Bay outflow plume in the Gulf of Mexico

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In July, August and October of 2011 a total of twenty-nine drifters were deployed along a 25-km transect within the outflow region of the Mobile Bay, Alabama plume. The plume is located at approximately 30 degrees of latitude and is characterized by 24 h inertial periods, comparable to dominant diurnal tidal periods. The deployment of the drifters ranged from two to over 120 days with the purpose of determining the dynamical features of the flow. Each drifter contained a global positioning system which transmitted coordinates every ~30 minutes. The drifter trajectories followed three distinctive flow regimes. The first was within an inner shelf band ~15 km from the shore, where the drifters oscillated in inertial circles with net onshore displacement near 0.05 m/s. The diameters of these inertial circles were between 5 and 10 km with speeds that remained below 0.5 m/s in the offshore portion of the translation, but exceeded 0.6 m/s within the onshore portion. The flow within the inner shelf band is assumed to be geostrophic with weak frictional influence. Offshore of the inner shelf band, drifter meander also depicted inertial circles that were distorted by a strong eastward drift during the July and August deployments. The drift was in the opposite direction to that expected from Coriolis accelerations. The third flow regime was found during the October deployment of eighteen drifters, all of which showed westward displacement; this is opposite of the eleven drifters deployed in the summer months of July and August. This analysis aims to determine if the displacement is linked to wind forcing through Ekman dynamics or to a gulf-wide circulation driven at the Florida Strait.

Assessing the performance of standard bottom drag parameterizations on coral reefs

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In studies of ocean circulation, bottom drag is usually modeled with a quadratic drag law. In three-dimensional ocean circulation models, the drag coefficient (C_D) is typically adjusted for reference velocity height by assuming a logarithmic near-bed velocity profile. Here, we examine the implications of using quadratic drag parameterizations and roughness length scales to model drag on coral reefs, where the assumptions underlying these parameterizations are often not satisfied. On coral reefs, bottom topography varies continuously across a large range of spatial scales, roughness length scales can be similar to boundary layer heights, and flow occurs through layers containing solid obstacles as well as above them. Using observed velocity profiles on reefs, we assess errors in drag force estimates that arise from the assumption that near-bed velocity profiles are logarithmic and their shape is invariant in time. We examine the way these errors affect estimates of depth-averaged circulation, three dimensional velocity fields, and scalar transport rates. We also examine the reasons for the large range of drag coefficients and roughness length scales in the coral reef literature and illustrate that the range of previously reported C_D values could be reduced by an order of magnitude if a common definition was used.

Influence of time- and depth-dependent eddy viscosity on the formation of tidal sand waves

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Tidal sand waves are dynamic bed forms observed in tide-dominated shallow seas, characterized by wavelengths of hundreds of meters, heights of several meters and migration rates up to tens of meters per year. Understanding sand wave dynamics is important as they may pose a hazard to navigation and pipelines.

Tidal sand waves have been explained as an inherent instability of the flat seabed by HULSCHER (1996), who used a linear stability analysis with an idealized model focusing on symmetric tides, bed load transport and adopting a constant vertical eddy viscosity with partial slip at the bed. The fastest growing mode obtained with these models agrees with observations of sand waves in e.g. the North Sea. However, these models show unrealistic behavior for small topographic wave numbers (k=0), i.e. they fail to suppress very long bed forms. Adopting depth-dependent viscosity with a no-slip boundary condition at the bed does not resolve this problem (e.g,, BLONDEAUX & VITTORI 2005). Results by KOMAROVA & HULSCHER (2000) and BORSJE ET AL. (subm.) on the other hand suggest that the time dependency in the vertical eddy viscosity is crucial in suppressing these modes. The precise mechanisms have not yet been identified.

The present contribution studies the influence of time- and depth-dependent eddy viscosity on sand wave formation. Our idealized modeling approach uses the time-dependent parabolic eddy viscosity profiles obtained in numerical study of sand wave formation (BORSJE ET AL., subm.). The water motion is calculated using a spectral method, which is quick and transparent, thus enabling a systematic study of the parameter space. The correlation between water motion and time-dependent eddy viscosity results in residual circulation, analogous to the SIPS mechanism observed in estuaries (SIMPSON ET AL. 1990), which – in turn – affects the mechanism of sand wave formation. Particular attention is paid to the behavior near k=0.

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Modeling vs. satellite remote-sensing of near-surface non-algal suspended particulate matter in the English Channel.

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Concentration of near-surface suspended particulate matter (SPM) is a key parameter for the characterization of sediment dynamics and the quantification of light in the water column for hydrological and biological modeling in coastal seas. The influences of tides and wind-generated surface-gravity waves on non-algal near-surface SPM in the English Channel have recently been identified by Rivier *et al.* (2012) on the basis of statistical models applied to a large satellite dataset. The present study extends this analysis by comparing satellite images and numerical model predictions of non-algal near-surface SPM. Satellite images are MODIS and MERIS remote-sensing reflectance processed by the IFREMER semi-analytical algorithm (Gohin *et al.*, 2011). These data have been provided through the MyOcean/GMES project. The numerical modeling approach is based on the three-dimensional (3D) hydro-sedimentary model ROMS ("Regional Ocean Model System") (*e.g.*, Warner *et al.*, 2008). It considers realistic heterogeneous bottom sediments (Guillou and Chapalain, 2010), tidal forcing along open boundaries, wind stress at the sea-surface and wave-current interactions in the bottom boundary layer. Numerical results are compared with a series of "clear" satellite images gathered in 2008 under various tide and waves conditions. Modeling provides further insights of the spatio-temporal variability of non-algal surface SPM in the English Channel by resolving small-scale vertical transport processes and much shorter time-scales than daily satellite observation does. The granulometric distribution of non-algal near-surface SPM is examined. Finally, the focus is placed on two particular features: (i) the formation of a turbidity maximum zone around the Isle of Wight (English coastline) and (ii) the near-surface SPM variability in the Norman-Breton Gulf (French coastline).

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Effect of ocean-backbarrier basin exchange on the characteristics of ebb-tidal deltas

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*: Institute for Marine and Atmospheric Research, Utrecht University

The objective of this study is to assess the extent with which exchange processes between coastal seas and backbarrier basins affect sand volume and spatial patterns of ebb-tidal deltas. For this, results are presented of experiments conducted with a numerical morphodynamic model that simulates tides, sand transport and sand balance in a schematized tidal inlet system. The domain consists of a coastal sea bounded by a straight coast that is interrupted by one or more inlets, which connect the sea to the backbarrier basin. Different geometrical conditions of the backbarrier (area, depth) are considered and their effect on the characteristics of the ebb-tidal delta will be quantified. Additionally, it is investigated how the results depend on the applied sediment transport formulation and parameterisation of bottom roughness. Results show that the detailed channel-shoal pattern is sensitive to the selected formulation of sediment transport and bottom roughness. However, overall characteristics (ebb tidal delta sand volume and its centre of mass) turn out to be only weakly sensitive. Also, results of experiments will be discussed in which the back-barrier area consists of several subbasins that are mutually coupled.

SHORELINE BEHAVIOR IN A COASTLINE STRETCH INFLUENCED BY TEMPORARY BUILD MATERIAL LOADING JETTY OF COLOMBO HARBOUR EXPANSION PROJECT – A CASE STUDY.

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Coastal environmental impacts have been expected with the development of the temporary rock material-loading jetty of Colombo harbor expansion project in Sri Lanka.

For the expansion project of the harbor it is required a huge quantity of rock armor materials which has to be transported from countryside to port premises. The transportation of this much of quantity of material by land through bussy capital city of Colombo was challenge and alternative was to use sea transport using barges loading from a less bussy location of the island. The selected location was 25 km southern point to the port construction and a temporary jetty has to be constructed with two rock armed break waters to provide shelter from wave climate while loading material to barges.
The straight coast of Wadduwa is divided by this temporary loading out point breakwater into two coastal cells with a remarkable changes to coastal process such as along shore sediment drift predominantly towards north, causing a considerable accumulation in southern side of the jetty and a severe erosion in the northern side.

Predicting suspended particulate matter in shelf seas with an application to the Irish Sea

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Abstract

The fate of suspended particulate matter (SPM) in coastal and shelf seas is important for primary productivity, pollution and coastal erosion. A good understanding of the processes involved is necessary for proactive shelf sea management. The present study seeks to increase the predictive ability of SPM behaviour with a focus on the Irish Sea. We use a state of the art hydrodynamic model (POLCOMS, Proudman Oceanographic Laboratory Coastal Ocean Modelling System) that is coupled with a turbulence model (GOTM, General Ocean Turbulence Model) and a sediment module to obtain three dimensional distributions of SPM in the Irish Sea during a spring-neap tidal cycle. POLCOMS uses an Arakawa B-grid and sigma coordinates for the horizontal and vertical discretizations respectively. It employs a time splitting technique to obtain barotropic and baroclinic components. The depth averaged and free surface equations are solved following a forward-time centred-space differencing technique while advective terms use a piecewise parabolic method. In GOTM, a $k-\varepsilon$ closure model is used with stability functions C_μ and C_μ^s derived from second order models to obtain turbulent stresses and turbulent scalar fluxes. The dynamics of SPM are governed in the model by an advection-diffusion equation similar to those used for temperature and salinity but with an additional settling term. SPM can be divided in any number of sediment classes, each of which is described by its settling velocity, density and erosion characteristics. Exchange between the pelagic zone and the sea bed is based on erosion depending linearly on bed shear stress and deposition being due to gravitational settling. The overall modelling system is forced at the free surface by meteorological data obtained from a mesoscale model of the National Weather Service of the United Kingdom. Values for temperature, salinity, elevations and barotropic tidal currents are specified hourly at lateral open boundaries. The hydrodynamic and turbulence models are spinned up for 30 days before SPM computations are performed. Results show the main features of the sediment variability observed in the Irish Sea. Horizontal distributions show large concentrations in Wicklow Head, Anglesey and the Isle of Man. Model-data comparisons are employed to investigate the main factors that control the SPM dynamics. The Irish Sea is an interesting study area because the sea bed sediment distribution has coarse particles even at the sites of permanent large turbidity values. Although bed shear stress has large values in these zones, the source of fine sediments is not well understood. In such case, sediment supply from rivers could be a source of fine material which is transported horizontally by tidal currents. The effect of waves on the sea bed and coastal erosion could be another source of sediments to the system. This study is an approach to the prediction of SPM in shelf seas taking into account hydrodynamic conditions, turbulence and sediment characteristics.

Simpson number transitions in the Hudson River estuary

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The Simpson number (*Si*) measures the balance between the along-estuary density gradient and tidal mixing in an estuary. The Simpson number provides a scaling for the strength of the estuarine circulation, whether driven by the tidally averaged baroclinic pressure gradient or due to tidal asymmetries in stratification and velocity shear. Similarly, estuarine stratification also varies with *Si*, with greater stratification at greater *Si*. Various values for *Si* have been proposed as thresholds for regime shifts in circulation and stratification, ranging from 0.2 to 3.0. Quantitative evaluation of the link between *Si* and estuarine properties has been hampered by uncertainties in the appropriate definitions for the variables that go into the dimensionless number. For example, what are the appropriate spatial and temporal scales of averaging for the salinity gradient and bed stress, and where in the estuary should *Si* be measured to provide a representative value for the entire system? Here we use numerical model results to characterize the spatial and temporal distribution of *Si* over a range of forcing in the Hudson River estuary. We propose a standard set of definitions for the terms contributing to *Si* that can be applied in other estuaries, and suggest that comparisons among estuaries and evaluations of transitions in parameter space depend on consistent definitions of *Si* and other metrics. We relate the *Si* from the Hudson model results to estuarine properties such as stratification and the exchange flow, and compare the results with other dimensionless numbers that have been used including the freshwater Froude number (comparing the river velocity and the horizontal density gradient), the tidal Froude number (tidal advection and the horizontal density gradient), and the unsteadiness parameter (stratification and tidal mixing). The spatial and temporal variability in *Si* and the relationship to stratification and exchange flow are also assessed for numerical model results from estuaries in other parts of parameter space: the Merrimack River estuary (tidal salt wedge), Chesapeake Bay (partially mixed coastal plain estuary), and Puget Sound (fjord). We compare the results from the Hudson with these other systems.

A ONE-DIMENSIONAL MODEL FOR SEDIMENT DYNAMICS IN SHORT TIDAL BASINS

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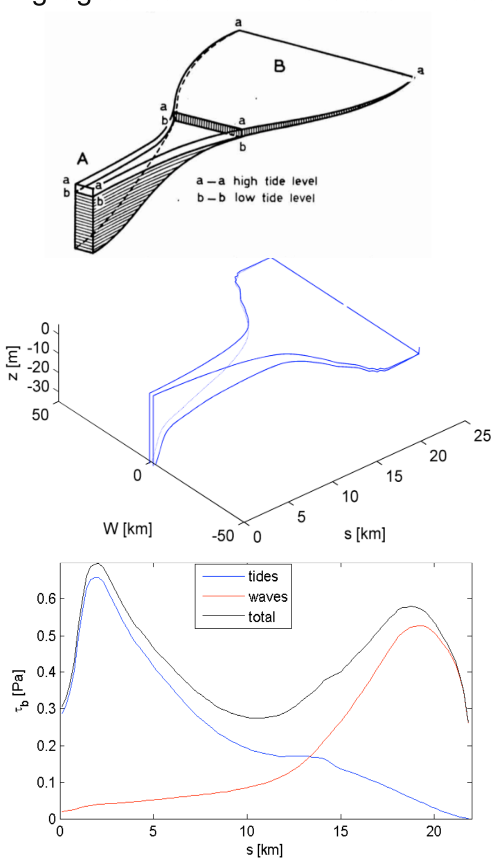
In order to unravel the sediment dynamics in short tidal basins, like the Wadden Sea, a one-dimensional cross-sectional averaged model is build that simulates tidal flow, depth-limited wave growth, sediment transport and bed evolution. The key for the one-dimensional model lies in the definition of the geometry (width and depth as function of the streamwise coordinate). We computed the geometry by the combination of the hypsometric curve, the continuity equation and several velocity and water-level maps from a two-dimensional flow simulation. Such a schematization is only possible for short-tidal basins with a dendretic structure, as it implies a direct relation between bed level and distance to the mouth along a streamline. By definition, the hypsometry of the one-dimensional geometry is exactly equal to the real hypsometry; a prerequisite for the proper modeling of the tidal volumes. The obtained geometry shows a striking agreement with the sketch made by Van Straaten&Kuehnen (*Geologie&Mijnbouw 1957, vol. 19, p325-354*), see figures. By means of a finite volume method, the tidal flow is simulated; imposing a water level boundary at the mouth side. A comparison is made with the results of a two-dimensional flow model. The amplitudes and phases of the M2 and M4 constituents of both the water level and velocity were accurately simulated. Waves are computed with a depth-limited growth equation for wave energy and wave number resulting in a reasonable agreement with field measurements. The lower figure shows the bed shear stress as function of the streamwise coordinate. Tidal flow dominates in the deeper part near the mouth and waves dominate on the tidal flats. Suspended sediment transport is simulated with the one-dimensional advection-diffusion equation with erosion and deposition terms. The measured changes in hypsometry over the past 70 years show an increase of the bed level on the intertidal flats, whereas the subtidal area decreases. These trends are also found in preliminary simulations over 70 years, where the wind forcing of a full year was used. More detailed verification is however needed. Furthermore, we will determine the contribution of different net sediment transport processes. Attention will be paid to the influence of tidal asymmetry, as the different components are well simulated, and to the effects of waves. Especially the balance between the effects of regular waves and storm events will be considered.



(top) Geometry as sketched by Van Straaten&Kuehnen (1958). (middle) Geometry as proposed in this contribution. (bottom) Yearly mean bed shear stress, based on waves, tides and the sum of tides and waves.

Roles of wind driven and tidal straining induced upwelling in the Rhine Region of Freshwater Influence

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Regions of Freshwater Influence (ROFIs), also known as river plumes, form when fresher waters discharge from estuaries into an adjacent coastal sea. Wind driven up and downwelling is known to play an important role in most shelf seas and controls the on and offshore displacement of most river plumes. Here we consider the role of wind forcing on the evolution and destruction of stratification in a shallow frictional coastal system. We use idealized simulations of the Rhine ROFI, together with a potential energy anomaly (φ) analysis to show that even in a shallow, frictional system the wind displaces the ROFI almost instantaneously in accordance with Ekman dynamics. However, the displaced downstream coastal current is still dominated by cross-shore tidal straining, while the bulge region is influenced by alongshore tidal straining and depth-mean tidal advection. We investigate the role of wind straining and show that averaged over the tide, wind straining also plays an important role in controlling the stratification of the Rhine ROFI. It can increase stratification under upwelling conditions and decrease stratification under downwelling conditions. We find that upwelling favorable winds of 7 m s^{-1} can suppress the downwelling stage of the tide due to tidal straining and enhance the upwelling stage. At wind speeds up to 10 m s^{-1} wind straining has an important role to play. However, at higher wind speeds (14 m s^{-1}) wind mixing dominates over wind straining. Interestingly the dominant wind-tide interaction happens at a certain phase of the tide. We show that the interaction between tidal straining and wind straining is of key importance to our understanding of wind mixing of ROFIs.

Boer, G.J. de, J.D. Pietrzak and H. Winterwerp, (2008) Using the potential energy anomaly equation to investigate tidal straining and advection of stratification in a region of fresh water influence, **Ocean Modelling**, 22(1-2),1-11

Interactions between dense shelf water cascades and wind driven upwelling in south-west Australia

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Australia, the driest continent, experiences high evaporation rates resulting in higher salinity (density) water in the majority of shallow coastal waters around Australia. This dense water is transported across the continental shelf near the seabed (dense shelf water cascade) due to the density difference between the nearshore and offshore water and is a mechanism for export of water containing suspended material and carbon away from the coastal zone to the deep ocean. Ocean glider measurements undertaken since January 2009 have indicated that the dense shelf water cascade is a regular occurrence along the Rottnest shelf particularly during autumn and winter months. In autumn the dense water formation is mainly through changes in salinity resulting from evaporation whilst in winter, temperature is dominant through surface cooling. In summer, although there is a cross-shelf density (due to salinity) gradient, DSWC is not present due to wind induced vertical mixing. The region experiences strong shore-parallel southerly sea breezes are which are upwelling favourable. During periods of strong southerly winds, upwelling of water onto the shelf is observed and a subsequent decrease in the wind speeds allow for the formation of the DSWC and offshore retreat of the upwelled (colder) water offshore.

Tide and Wave-Induced Variations in Turbulent Kinetic Energy at a Buoyant Jet Discharge

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Current velocity and hydrography measurements were used to determine the influence of tides and waves on turbulent kinetic energy (TKE) variations at a submarine groundwater jet discharge in a fringing reef lagoon located in the Yucatan Peninsula, Mexico. Measurements were obtained through a three-day period early in the wet season. Velocity and pressure values were recorded at a rate of 8 Hz, while salinity and temperature values were acquired at 6 measurements per minute at the spring nozzle. Records showed that tidal variations within the lagoon modulated the discharge from the buoyant jet, with maximum outflow values of 0.3 m/s when smoothed with a 20-minute low-pass filter. Values of TKE at the buoyant jet also showed a clear tidal modulation with up to 0.36 m^2/s^2 observed during low tides. Moreover, lagoon water temperatures were modulated by a diurnal cycle while the spring water temperature was modulated by the semidiurnal tides. Similarly, the salinity at the spring was affected by semidiurnal tides and TKE variations. Highest salinities (>34 psu) appeared during high tides while lowest salinities (<29 psu) developed between high and low tides. Interestingly, the highest salinity of the measurement period was observed during the first two tidal cycles, which also corresponded with high wave activity causing a wave-setup within the lagoon. The highest salinity was likely caused by a higher water level within the lagoon caused by the wave-setup which decreased the energy from the spring, thus allowing higher salinity water to intrude into the aquifer. Therefore, wave-setup should enhance salt intrusion into the spring, and its aquifer source, during high tides. At low tides, vigorous mixing between spring and lagoon waters was detected. Buoyancy production at the jet was calculated from salinity and temperature measurements, showing dominance in TKE production during high tides. Furthermore, dissipation values were only calculated during periods of low TKE production, using Kolmogorov's 5/3 Law, with values ranging between 10^{-3} and 10^{-6} m^2/s^3. Dissipation was not calculated during periods of high TKE production because the velocity's power spectra did not attain a -5/3 slope, most likely caused by an inadequate measurement frequency. Further measurements at higher frequencies are recommended. The combination of high tides and wave-setup is expected to threaten delicate aquifer conditions and vital water resources for local communities.

Detailed Modeling of Recent Severe Storm Tides in the NY/NJ Harbor Estuary

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Abstract

Detailed simulations, comparisons with observations, and model sensitivity experiments are presented for the August 2011 tropical cyclone Irene and a March 2010 nor'easter that affected the New York City (NYC) metropolitan area. These storms brought strong winds, heavy rainfall, and the fourth and seventh highest gauged storm tides (total water elevations) at Battery Park. To "dissect" the storm tides and examine the role of various physical processes in controlling total water elevation, a series of model experiments was performed where one process was omitted for each experiment, and results were studied for eight different tide stations. Neglecting remote meteorological forcing (beyond ~250 km) led to reductions of up to 34% in peak storm tide, neglecting water density variations led to reductions of up to 12%, neglecting a parameterization of enhanced wind drag due to wave steepness led to reductions of up to 11%, and neglecting atmospheric pressure loading led to reductions of up to 10%. Neglecting freshwater inputs to the model domain led to reductions of up to 47% at Albany on the tidal Hudson River, though only 1-2% near the ocean. Very few storm surge modeling studies or operational forecasting systems incorporate freshwater flows or water density variations, yet combined omission of these two processes leads to a low-bias in storm tide for New York City sites like La Guardia Airport (8%) and The Battery (6%), as well as nearby vulnerable sites like the Indian Point nuclear plant (21%). The negative bias of neglecting these contributions could be costly for a low-lying city like NYC with high financial and human vulnerability.

Hydrodynamics of the Papaloapan basin lagoons from measurements and numerical modeling

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The current state of the lagoons and rivers of the Papaloapan basin in Veracruz, Mexico, is studied in order to have a base line that may be used to compare with different sea-level rise scenarios. Particular interest is considered in the average salt content, its changes in different zones, and the salt intrusion length into the rivers. For this purpose, CTD data, water level, bathymetry, and current measurements were carried out. Also, a numerical model is calibrated and validated with these measurements. It is found that the major tidal components within the lagoons are O1 and K1, followed by the components M2, N2 and S2. During the surveys, Camaronera lagoon had larger salinity than Buen Pais, Alvarado and Tlalixcoyan lagoons.

An engineering approach to influence the net transport behavior in the Ems Estuary

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River Ems estuary in the north west of Germany exhibits strong accumulation of cohesive fine sand as a result high sedimentation rates due to several deepening's and straightening's that were conducted in the past. The driving phenomena are intensified baroclinic circulation and increased tidal asymmetry. The latter results in short, but strong periods of flood flow in combination with weaker ebb flow over longer durations. The investigation has shown here deals with modified use of the Ems river barrage in order to influence the tidal wave propagation towards a more symmetric shape, while maintaining the tidal volume. The proposed result is reduced maintenance costs (dredging efforts) as well as improved water quality with respect to reduced turbidity and in turn increased dissolved oxygen concentration. The investigation is conducted by means of a combination of physical prototype tests and three-dimensional hydro-morphological numerical modeling. The specific time dependent mode of the barrier's gates operation (cross sectional area is controlled by means of vertical gates with underflow) is implemented into the numerical flow model. The operational mode is subject to system optimization.

The Spatial Structure of Extreme Sea Level Statistics in Long Island Sound

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Abstract

The magnitude of the change of coastal sea level during storms is a crucial parameter in planning cost-effective coastal construction projects and wise environmental management strategies. We summarize the frequency of occurrence of meteorologically forced high water level anomalies in Long Island Sound using archived sea level records. We then explain the spatial variation of the return interval for anomalies resulting from extra-tropical (nor'easters) and tropical (hurricanes) cyclones. Extra-tropical cyclones generate much larger sea level anomalies in the western Sound because the locally generated setup augments the shelf response. As a result, 2m anomalies due to nor'easters have a return period of approximately a decade in the western Sound and a century in the eastern Sound. Hurricanes are infrequent and effect New England in the late summer. The direction of the winds they induce, and their rapid translation speeds does not lead to the same superposition of effects and statistics of sea level extremes in the summer are, therefore, similar throughout the Sound. Since larger anomalies occur much more frequently in the western Sound than the east, it is likely that the coastal communities in the east are more vulnerable to Hurricane induced surges. Further, sea level rise will have a greater impact on the return periods of anomalies in the eastern Sound.

Tidal control of biogeochemical cycling in a mesotidal estuary

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We tested the hypothesis that tidal currents can affect biogeochemical transformations in estuarine sediments through a manipulative field experiment. Denitrification (the microbial conversion of nitrate to nitrogen gas) is one of the most important transformations affecting the fate and removal of anthropogenically-derived dissolved inorganic nitrogen entering the coastal ocean. Because nitrate removal is an anaerobic process that occurs almost exclusively within suboxic sediments in estuarine environments, sediment resuspension by tidal currents could affect nitrate removal either directly through physical disruption of the sediment matrix (thereby moving nitrogen-cycling microbes out of their preferred environment) or indirectly by changing sediment porewater redox conditions (effectively moving the optimal environment away from the microbes). We hypothesized that fortnightly and semiannual modulations in tidal range can significantly affect sediment redox state and, in turn, affect the capacity of the estuary to act as a sink of terrestrial nitrate.

We manipulated the residence time of a tidal creek in a mesotidal estuary in central California, Elkhorn Slough, by installing a weir to impound water at low tide. We measured scalar fluxes of nitrate, oxygen, salt, and heat into and out of the tidal creek network both prior to and during this manipulation. Defining the tidal marsh as a control volume, the ebb/flood flux difference of a scalar constituent (e.g. nitrate) through the tidal creek cross-section provided a volume-averaged rate of change within the control volume. These observed rate changes were compared against fortnightly and seasonal variations in mixing and residence time traditionally invoked to explain changing scalar concentrations in estuaries.

The observations show that sediment mobilized during a large spring ebb affected the net flux of nitrate and oxygen within the tidal creek system. Additionally, the retention of water in the tidal creek at low spring tides following installation of the sill mimicked the retention of water during neap tides when the intertidal creek did not drain completely. In the undisturbed condition, severe nighttime hypoxia was limited to a few days during neap tide, whereas installation of the weir resulted in nightly hypoxia for a three week period. The implications of these disruptions to biogeochemical processing within the estuary were considered through numerical simulations with a hydrodynamic model and a coupled pelagic-benthic geochemical model. This research has important implications for restoration activities in shallow estuaries, as hydrologic manipulations may have strong feedback to water quality.

Long-term ferry-based observations of the Total Suspended Matter flux through the Texel inlet

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The Marsdiep tidal estuary or Texel inlet is one of the major connections between the North Sea and the Wadden Sea, of which the latter is part of a UNESCO world heritage site. Model studies have shown that the extension of the port of Rotterdam in 2008 increased the width of the Rhine Region of Fresh water Influence (ROFI). Since the total amount of suspended matter in the Dutch coastal zone remains unaffected, its concentration decreased as it was spread over a much wider area. Moreover, these model simulations also showed a small change in Total Suspended Matter (TSM) concentration in the western Dutch Wadden Sea. TSM is important for primary production, e.g. the growth of algae, which are at the bottom of the food web. On the one hand, light penetration is hindered by these particles in suspension and on the other hand TSM may be a source of nutrients. Thus it is essential to monitor any changes in the TSM concentration in the Wadden Sea.

Therefore, a unique set of long-term observations with an Acoustic Doppler Current Profiler (ADCP) mounted beneath the ferry crossing the Texel inlet was used to determine the residual TSM flux through the Texel inlet between 2003 and 2005. Besides vertical velocity profiles, ADCPs also register profiles of the acoustic backscatter intensity. The latter, corrected for geometric spreading and attenuation, is related to the amount of particles in suspension and thus the TSM concentration. This relation, however, is not straightforward. It depends on many physical factors, such as the grain size distribution and the threshold value of the ADCP, but also on the state of the system and in particular the dissipation rate of turbulent kinetic energy. For low rates, the relation between the corrected acoustic backscatter is linear. However, if the dissipation rate of turbulent kinetic energy becomes that high that the Kolmogorov wave length has a similar size as the wave length of the sound used by the ADCP, the relation becomes quadratic in the vertical derivate of the TSM concentration. Dedicated calibration cruises in the Texel inlet were performed to determine the exact relation.

TSM concentrations and current velocity locally at the ferry transect were used to determine the instantaneous water transport and TSM flux between 2003 and 2005. A least squares harmonic analysis revealed that the residual water transport changes sign mid 2004, while the TSM flux remained constant at about 9 Mton/year and was directed towards the Wadden Sea. Decomposition of the residual TSM flux showed that the tidal velocity concentration transport was significantly larger than the residual advective transport. This suggests that the settling and scour lag mechanisms are most important in determining the residual transport. The effectiveness of these processes could be demonstrated by fitting the relatively simple Groen model, decribing the TSM concentration evolution as a function of erosion and deposition, to the data.

Title	**Nonlinear response of shoreface-connected sandridges to offshore sand extraction for a realistic inner shelf slope**

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Abstract

On storm-dominated inner shelves of many coastal seas, patches of shoreface-connected sand ridges are observed that are obliquely oriented with respect to the coastline and have a rhythmic structure in the long-shore direction. Typical spacings between successive ridges range between 4 and 10 km, they have heights of several meters, they evolve on a timescale of centuries and they migrate with velocities of several meters per year along the coast. Examples of these ridges are observed on the inner shelf of Long Islands, and on the inner shelf of the North Sea. Shoreface-connected sand ridges absorb part of the energy of the incoming waves and thereby contribute to the stability of the coast. Because of the large amount of sand available on these ridges, they are potential candidates for sand extraction. However, there could be significant morphological consequences for extracting sand from them. From a previous study, it turned out that these ridges restore themselves after such an intervention, and the sand required for this process originates for a large part from the beach, leading eventually to beach erosion.

The first new aspect of the present work is to assess the consequence of sand extraction on the nonlinear dynamics of shoreface-connected ridges for a realistic bottom slope of the inner shelf. The second is the investigation of the role the wave-topography feedbacks and radiation stresses play in the nonlinear response of these ridges after sand extraction. We address both the impacts of extracting different quantities of sand, as well as of how often these quantities are extracted from these ridges. Also, the sand exchanges between the inner shelf and the nearshore zone, as well as between inner and outer shelf, are considered. The model we use is a modified version of an available numerical model, which is based on finite differences. This model already proved to be successful in simulating the development of finite-amplitude sand bars in the nearshore zone.

North Carolina Gulf Stream frontal interaction with surface currents on the continental shelf north of Cape Hatteras

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The complex dynamics of surface current interactions between the North Carolina shelf currents and the near - shore wall of the Gulf Stream north of Cape Hatteras are studied to provide a better understanding of the role of Gulf Stream on shelf exchanges.

A unique spatially and temporally rich surface current data set beginning in 2003 from coastal ocean radars is optimized by implementing previously utilized techniques, and developing new ones specific to the North Carolina current regime. Uncertainties in the data are quantified by comparing radar current data with that from moored current meters, shipboard acoustic doppler current data, and drifter tracks within the radar footprint.

Surface Current information is used to estimate Gulf Stream frontal positions and variability, and some hypotheses about the influence of the variability on shelf exchange are tested. Surface shelf transport is likely influenced by several surface current features including zones of convergence, divergence, and areas of high relative vorticity at shelf slope jets. These current features have previously been shown to be correlated in turn with variability in the position of the Gulf Stream front . The surface current data further defines and quantifies these interactions.

Gravity-driven transport on a relatively flat active margin with complicated bathymetry: the Waipaoa River Continental Shelf, New Zealand

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Flood deposits on continental shelves reflect terrestrial signatures, but are typically modified by the marine environment. Partitioning between various transport mechanisms (dilute suspension vs. gravity-driven) may influence the location and characteristics of these deposits. On the Waipaoa shelf, the coastal embayment Poverty Bay receives high sediment loads during floods. The timing of sediment delivery to shelf depocenters, however, seems correlated to the occurrence of energetic wave events rather than river discharge. This implies that initial deposits formed during floods are reworked by energetic waves and currents that redistribute sediment so that short-term (days to weeks) deposition differs from accumulation patterns that develop over longer timescales.

The MARGINS Waipaoa shelf initiative investigated these issues by conducting a thirteen month field campaign, and ongoing numerical modeling study of the Waipaoa River shelf, NZ. Sediment fluxes and fate during an eight-year recurrence interval flood and subsequent high wave event were analyzed by implementing a model based on the Regional Ocean Modeling System- Community Sediment Transport Modeling System (ROMS - CSTMS) model for the Waipaoa shelf. For wave forcing, the model is linked to a regional implementation of the NOAA's Wave Watch 3 model provided by National Institute of Water and Atmosphere (NIWA), New Zealand, while at its open boundaries, the model is nested within a regional barotropic ROMS model implemented by M. Hadfield (NIWA). The three-dimensional numerical hydrodynamic-wave-sediment transport model can account for gravity-driven transport by incorporating sediment concentrations into the model's equation of state.

Preliminary results indicate that high suspended sediment concentrations increase both stratification of the water column and sediment trapping within Poverty Bay during floods. During times of energetic waves, however, high suspended sediment concentrations enhance down-slope sediment fluxes from Poverty Bay toward deeper depths, including shelf depocenters and offshore. During smaller wave events and quiescent periods, buoyant transport dominates, and sediment fluxes are determined by local currents. The numerical model can be used to compare the relative contributions of dilute suspension and gravity-driven transport to cumulative sediment fluxes for different events (floods vs. energetic waves) and over various timescales (days to months).

Remote observation of suspended sediments and chlorophyll-a in the Río de la Plata estuary

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The Río de la Plata estuary is one of the most turbid systems of the world. Daily high resolution MODIS observations were processed for suspended matter and chlorophyll-a, using IFREMER OC5 algorithm (Gohin et al. 2002, Gohin et al., 2005). This article analyses those data for the 2002-2011 decade in order to investigate seasonal spacial patterns and the possible connections between both variables.

Results suggest that suspended matter and chlorophyll-a are highly correlated and strongly associated to the hydrodynamics. The surface suspended inorganic sediment concentration is maximum along the southern (Argentinean) coast of the upper and intermediate estuary and at the tip of Samborombón Bay. This might be linked to the higher solid discharge of the Paraná River (flowing in the southern part of the estuary) compared to the Uruguay River, and with the stronger tidal currents in the region, which may increase sediment suspension and, consequently, surface concentration. Suspended sediment concentrations exhibit overall a maximum in winter and a minimum in summer, which might be related to an increase of the mean wind speed in the region, inducing more wave-induced resuspension (and possibly liquefaction) in this very shallow part of the estuary. The concentration of inorganic sediments rapidly dampens downstream the Barra del Indio shoal, i.e. beyond the salinity front, partly as a consequence of flocculation. In association, a marked increase of the chlorophyll-a concentration is observed in this area, what seems to be linked with the availability of light. The concentration of both chlorophyll-a and inorganic matters increases along the northern (Uruguayan) coast of the exterior estuary in winter, whereas the opposite is observed in summer. This seems to be a consequence of the motion of the fresh water plume along those seasons, which moves towards the southwest in summer and towards the northeast in winter in response to wind variability. Finally, the chlorophyll-a concentration in the Río de la Plata maximizes in summer, whereas it does in spring on the continental shelf. A possible explanation is that in this highly turbid system, algal blooms are more limited by light and temperature than by nutrients.

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Salt-wedge dynamics and effects on contaminated sediment transport in the Duwamish River estuary, Seattle, WA

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Continuously modified for over a century, the Duwamish River estuary near Seattle, WA has lost 98% of its intertidal area and accumulated enough legacy contaminants to justify four EPA-designated Superfund sites. Yet the estuary has retain a surprising amount of biological activity, supporting salmon runs, aquatic birds, otters, sea lions, and benthic organisms. The primarily hydrophobic contaminants sorb onto fine sediments and are concentrated in bed, thus predicting contaminant fate requires an understanding of the hydrodynamic mechanisms suspending, transporting, and depositing the sediment. Strong, but seasonally varying, stratification within the salt-wedge regulates these mechanisms.

We use monthly observations beginning in May 2011 to characterize seasonal changes in tidal-scale hydrodynamic and sediment transport processes over a twenty-fold change in river discharge. We establish an empirical relationship between river discharge and salinity intrusion, and link that basic estuarine property to suspended sediment flux in order to quantify tidal trapping/export of suspended sediment. We also compare Reynolds stress profiles up- and down-stream of the salt-wedge toe to estimate vertical mixing during a high discharge event when the tidal excursion of the salt-wedge toe includes known hot spots of contaminated bed sediment.

M6 Overtides in a Frictional Estuary

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Nonlinear mechanisms give rise to overtide frequencies that are integer multiples of the principle tidal frequency. The M6 is an overtide with a frequency three times that of the primary M2 semidiurnal tide. Overtides are of interest because they modulate or distort the shape and timing of the fundamental tide. Because their generation and propagation is sensitive to a combination of physical factors, they can also serve as a means by which to evaluate hydrodynamic model performance.

Observations in Long Island Sound (LIS) indicate that the M6 overtide shows a notable increase in amplitude in the Western Sound compared to the East. M6 generation, however, should be greatest in the East, where the primary M2 current is strongest. We examine the generation and propagation of the M6 overtide in simple channels using numeric and analytic methods and show that, despite its higher frequency, attenuation at the M6 frequency is less than that at the M2. The observed spatial distribution of M6 amplitudes can therefore be explained as a consequence of non-local generation and propagation.

Our results also imply that those portions of an estuary which are strongly dissipative at the M2 frequency may nevertheless be only weakly dissipative at the M6 frequency. This effect would be particularly pronounced in shallow and shoaling areas of an estuary and the distribution of M6 amplitudes is a sensitive indicator for the tuning of hydrodynamic models in shallow regions. We conclude by comparing the observed distribution of M6 amplitudes in LIS with those from hydrodynamic models of the region.

Sediment Transport Processes and Regimes in the Lower Passaic River

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The Lower Passaic River (LPR), a tributary to Newark Bay and part of the New York/New Jersey harbor estuary, is the subject of an ongoing environmental cleanup and restoration process. As part of this process, a numerical hydrodynamic, sediment transport, and contaminant fate and transport model is being developed. An important consideration in the development of the model is the degree of complexity required and the physical processes to be reproduced by the model, and these in turn depend upon an understanding of the transport processes within the study area. An extensive data collection effort was implemented to collect information on the physical processes influencing suspended sediment transport in the LPR and Newark Bay. The monitoring program consisted of a series of *in situ* moorings with ADCP, OBS, and CTD sensors deployed at a number of stations during a period of several months in 2009 and 2010 throughout the 17-mile stretch of the LPR, within Newark Bay, and at the tidal boundaries of Newark Bay. These instruments provide a continuous time-series of water level fluctuations, currents, salinity, and suspended sediments (estimated from surrogate measurements of the acoustic and optical backscatter) over a wide range of flow and tidal conditions. Analysis of these data allows for an empirical understanding of sediment transport processes in the LPR. The data inform upon the relationship between sediment transport and the various forcings such as freshwater discharge from the head-of-tide, the medium-term (spring/neap), and the short-term (ebb/flood) tidal fluctuations. The data also inform on processes such as the location of the turbidity maximum and the exchange between the LPR and Newark Bay under various flow and tidal conditions. The data also show sediment import and export processes as a function of hydrologic forcings and estuarine circulation. The data analyses provide information to support the development of a conceptual model of sediment transport in the LPR and describe processes to be reproduced by the sediment transport model.

Astronomic, atmospheric and oceanographic controls of sea level and coastal currents on a wide and shallow continental shelf.

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The present study uses time series gathered in the field using bottom mounted (5 m) instruments, and meteorological station data, to analyze the seasonal, subtidal, and supratidal variability of temperature, sea level, and coastal currents on a shallow and wide continental shelf in the Gulf of México (Yucatán shelf). As expected, tidal oscillations are predominantly diurnal, with amplitudes during spring tides that reach 1 m. Cross spectra between horizontal velocity and surface elevation demonstrate a phase lag of ~ 90º at diurnal frequencies, suggesting quasi standing wave behaviour, results that are coincident with previous modeling exercises in the Gulf of México. The semidiurnal peak on the surface elevation data is rather small, at times smaller than the tridiurnal component, but the horizontal velocity has a clear semidiurnal peak. This behaviour is evidence of the vicinity to the semidiurnal amphidromic point which theoretically lies inland on the Yucatan península. Tidal currents occur simultaneously to wind effects due to a very periodic sea breeze pattern, therefore their relative contribution might be difficult to identify. Cross-wavelet analysis is performed on the data sets in order to identify and isolate the effects of diurnal sea breezes, from that of diurnal tidal currents. Subtidal sea level variability is additionally linked to lower frequency wind effects, and under certain circumstances evidence of a geostrophic balance between low frequency sea level and circulation exists (consistent with Coriolis effects). This phenomenon is especially interesting since such forcing is not expected in a shallow and broad continental shelf subject to large friction. Seasonal scale variations show sea level decreases of ~20 cm during spring and summer months, and in autum-winter sea level rises 25 to 30 cm. This is about 20-30% of tidal variability. The sea level oscillations have an effect on seasonal scale currents as well, with sea level decreases favoring westward current intensification, which correlates with intensification and occurrence of upwelling water from the Caribean Sea, evident in the temperature signals. Further analysis is presented on the effects of larger scale currents (Yucatan current) on the behaviour of the coastal Yucatan Sea.

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Observations of Floc Size and Settling Velocity Along a Longitudinal Estuarine Transect

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ABSTRACT

We conducted a 147 km longitudinal transect of flocculated cohesive sediment properties in San Francisco Bay on June 17, 2008. Our objective was to determine the factors that control floc settling velocity (w_s) along the longitudinal axis of the estuary. The INSSEV-LF video system was used to measure floc diameters and settling velocities at 12 stations. Floc sizes ranged from 26.5 μm to 584 μm and settling velocities ranged between 0.08 mm/s to 11.6 mm/s during the longitudinal transect. Mass-weighted settling velocity ranged from 0.5 mm/s to 6.2 mm/s. The transect took all day to complete and was not synoptic. During slack tide, larger and faster settling flocs deposited, accounting for most of the longitudinal variability. The best single predictor of settling velocity was water velocity 66 minutes prior to sampling, not suspended-sediment concentration or salinity. Resuspension and settling lags are likely responsible for the lagged response of settling velocity to water velocity. The distribution of individual floc diameters and settling velocities indicates that floc density for a given floc diameter varies greatly. A small portion (a few percent) of suspended sediment mass in San Francisco Bay is sand-sized and inclusion of sand in flocs appears likely. Fractal theory for cohesive sediment assumes that there is a single primary particle size that flocculates, which is not the case for these mixed sediment flocs. The wide variability in the physical, biological and chemical processes which contribute to flocculation within San Francisco Bay mean that spatial floc data is required in order to accurately represent the diverse floc dynamics present in the Bay system. This complexity in floc properties is perfectly demonstrated by the comparison of INSSEV-LF measured mass settling flux (MSF) and the large errors in fluxes calculated using a simple constant w_s assumption. For example, a slow constant fall velocity of 0.5 mm/s only reproduced 13% of the mean measured mass flux. At the other extreme, the 8 mm/s constant w_s inferred that the mean MSF was double what was actually present. Thus, no single settling velocity can adequately mimic all measured MSF. The importance in determining accurate estimates of floc effective density has been highlighted by the San Francisco Bay data, as these provide the basis for realistic distributions of floc dry mass and the mass settling flux across a floc population. The video-based INSSEV-LF instrument meets this data acquisition criterion, but commercial particle sizers do not meet this criterion. Floc size and settling data are needed to understand and simulate the depositional qualities of suspended cohesive sediment. For San Francisco Bay, suspended sediment should be simulated with multiple size classes or settling velocities, or with a mass-weighted settling velocity that depends on lagged water velocity.

Morphological Changes in Tidal Basins using Stochastic Bed Load Sediment Transport Predictor

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A three-dimensional layer integrated numerical model is refined to predict morphological changes in tidal basins. Governing differential equations consist of continuity and Reynolds Averaged Navier Stokes equations for incompressible, unsteady, free surface turbulent tidal flow, the transport equation for the suspended sediment fluxes and the sediment mass conservation equation for the bed level changes. An Alternating Direction Implicit (ADI) Finite Difference Method (FDM) is used to solve theses equations. As the random nature of the fluid forces caused by the turbulence, particularly for conditions close to the initiation of sediment motion, a stochastic approach for bed load sediment transport prediction is applied in the developed model which assuming a Gaussian distribution for probability density function for the grain shear stress. Moreover, the model includes different criteria for the initiation of motion namely Shields (1936) as a conventional method and Kolahdoozan (1999) which considered unsteadiness of tidal flow parameters. To validate the numerical model results, measurements of a short term bed level changes in a laboratory model harbor are used. Comparisons of numerical model using different initiation of motion criteria with stochastic bed load predictor, show acceptable agreement with the experimental data. The model is then applied to a real case study of the Humber Estuary, located in the UK, with comparisons being undertaken stochastic approach for the long term bed level predictions.

Keywords: Sediment transport; Numerical model; Stochastic bed load predictor; Tidal basin

Sediment dynamics in the shallowest regions of an estuary

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Observations of mean, turbulent, and wave-driven suspended sediment fluxes were used to discern the mechanisms that control sediment transport in the shallow subtidal and intertidal regions of an estuary. Field data were collected in the spring of 2011 along a cross-shore transect of San Pablo Bay (northern embayment of San Francisco Bay) that spans the transition from an intertidal to a subtidal mudflat. A general framework for understanding each site is provided by a decomposition of measured sediment fluxes, which yields the relative importance of the residual flow field, tidal dispersion, and Stokes drift. Within this framework, the details of each flux mechanism are explored by examining the influence of barotropic and baroclinic flows, turbulent fluxes, and wind waves on the magnitude and direction of sediment transport. Constraining all of these forcing mechanisms is the tidal stage: when water depths are low, transport is limited, and when they are high, the transmittal of wave energy to the bed is inhibited. Measurements indicate that in the absence of wind waves, sediment fluxes in the intertidal and subtidal regions were directed onshore. In the presence of wind waves, the magnitudes were greatly increased, and there was a divergence in sediment flux direction: it remained onshore in the intertidal, but turned offshore in the subtidal zone. The data show that the presence of wind waves reversed the tidal asymmetries in mean velocity, bed shear stress, and sediment resuspension at the subtidal stations, producing offshore sediment fluxes. The longer-term implication of this 6-week dataset is that tidal processes drive sediment into the shallows from the deeper regions of the bay, while meteorological events and wind waves produce offshore sediment transport in large but infrequent pulses.

A Lagrangian analysis of the estuarine exchange flow

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Many forms of averaging have been used to simplify the complex processes of the estuarine exchange flow. These include tidal averages, division into vertically- and horizontally-varying fluxes, division into salinity classes, and different decompositions of the momentum terms involved in the residual flow. The goal is to arrive at compact terms which have physical meaning and which may be predicted from external parameters such as bathymetry, tides, river flow, and wind. The work to be presented here takes a giant step backward, exploring the exchange flow from the point of view of individual fluid parcels. Parcel paths are calculated for a realistic estuarine simulation, and then the parcels are divided into "winners" and "losers," those that did, or did not, travel in a net direction consistent with the exchange flow. The history of forces acting on individual parcels is then examined to see if they resemble any of the leading theories for the exchange flow, for example the balance of mean pressure gradient and mean turbulent momentum flux divergence hypothesized in the classic Hansen and Rattray solution.

Modeling study of the mechanisms of wind-induced lateral circulation in a straight, stratified channel

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Lateral circulation is fundamental in estuarine dynamics because it redistributes momentum, alters stratification, transports sediments and provides an exchange pathway for biologically important materials. Recent understanding of lateral circulation has been focused on tidal time scales, despite observational evidence of strong wind-induced lateral motion. At subtidal time scale, a number of studies indicate that the along-channel wind stress could generate lateral flow, whose magnitude is compatible to the size of the along-channel exchange flow.

However, the dynamics of wind-driven lateral circulations in stratified estuaries of varying width are not fully understood. In a recent study by *Li and Li*, the dynamics of wind-induced lateral circulation was analyzed using a new approach based on streamwise vorticiy (ω_x), and the equation reveals a balance among three terms: titling of the planetary vorticity by vertical shear in the along-channel current ($f\partial u/\partial z$), baroclinic forcing due to sloping isopycnals at cross-channel sections ($-g\beta\partial s/\partial y$), and turbulent diffusion ($\partial^2 K_v \omega_x/\partial z^2$). A simple scaling from the results suggests that the baroclinic forcing is expected to play a larger role in narrow estuaries where lateral gradients are bigger. However, wider estuaries are expected to have a stronger lateral response to the along-channel wind forcing because of earth's rotation. In a more general sense, while Ekman dynamics are expected to drive lateral circulation in rotating estuaries, in the presence of salt, lateral salinity gradient can be regulated by differential advection, diffusive bottom boundary layer, or the lateral circulation itself. The consequent baroclinic forcing may work in concert or opposite with Ekman forcing based on the direction the wind blows, resulting in asymmetric response of lateral flow under similar down- and up-estuary wind conditions.

Further, the role of lateral circulation on along-channel exchange flow is ambiguous. at subtidal time scales. On one hand, *Lerczak and Geyer* (2004) and *Scully et al.* (2009) demonstrated that the nonlinear advection could augment the along-channel flows. On the other hand, the wind forcing period is usually longer than the rotation time scale, such that Coriolis acceleration could deflect momentum from estuarine exchange flow to fuel the lateral circulation and thus weaken the along-channel shear.

In order to investigate the governing mechanism of wind-induced lateral circulation and its role on estuarine exchange flow, a 3D hydrodynamic model is implemented in a stratified estuary. The channel is straight with a triangular cross-section, but the width, the Coriolis parameter, and the wind stresses are allowed to vary. Key parameters are identified to clarify the wind control over a wide range of estuarine conditions.

Vorticity Dynamics of Secondary Circulations in Idealized and Realistic Estuaries

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Abstract:

Differential advection and Ekman tidal rectification have been suggested as two key mechanisms to drive lateral circulations in tidally driven estuaries. We have conducted process-oriented modeling studies of an idealized estuarine channel and hindcast simulations of the James River estuary to assess the relative importance of these two mechanisms in driving the lateral flows in the estuaries. Previous studies of lateral circulation dynamics have focused on the analysis of subtidal momentum balance in the along- and cross-channel directions. We have developed a novel method to examine the dynamics of lateral circulations by diagnosing the equation for the streamwise vorticity. In the vorticity equation, the baroclinic forcing due to differential advection is represented $-g\beta\frac{\partial S}{\partial y}$ while the Ekman tidal rectification is represented by $f\frac{\partial u}{\partial z}$. The flood-ebb and spring-neap variability of lateral circulations can be interpreted as the balance between these generation terms and turbulent diffusion which is modulated by stratification. We also analyze the subtidal momentum balance in the along-channel direction and examined the role of the lateral flows in driving the estuarine exchange flows. The modeling analysis is closely aligned with the related analysis of the observational data collected at the James River estuary.

Effects of Cold Fronts in the Flushing of Barataria Bay, Louisiana: Case Studies for 2011

Chunyan Li

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The meandering of the Jet Stream in late fall to early spring sends cold and dry air from the arctic southward, bringing in dynamic weather systems with cold fronts. Cold fronts are particularly important to Louisiana bays, because of its repeated action on setting up oscillations of the bays every few days. The warm and wet air from the Gulf of Mexico provides heat and moisture to feed the storms associated with cold fronts. The southerly winds prior to the passage of a cold front push the bays against the coast, causing high water (storm surge) and even inundation. After the passage of cold front, wind switches rapidly to from the northerly quadrants, pushing water out of the bays. In examining the effect of such cold front induced bay oscillations, we analyzed some long-term velocity data from the Barataria Pass during 2011 cold front season. In this presentation, we provide a few cases quantifying the volume flux, rate of flux, and duration of the flux, associated with the cold front passages. We also compared with tidal flushing processes. Nearby currents measured from the GCOOS-WAVCIS stations are also used for comparison.

Cross-shore Surface Transport by Shoaling Nonlinear Internal Waves

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We use surface drifter measurements and moored time series of currents, temperature and salinity, collected in Massachusetts Bay during the summers of 2008 and 2009, to quantify cross-shore surface transport due to shoaling internal waves and its dependence on wave nonlinearity – here defined as the ratio of current amplitude of the wave (U_w) to wave speed (C_w). Massachusetts Bay is a location where large amplitude internal wave packets, generated by interactions between barotropic tidal currents and an offshore submarine bank, propagate toward the coast each semidiurnal period. The energy of these internal waves is correlated with the spring/neap cycle in barotropic tidal amplitude. Internal wave speeds were calculated between moorings based on arrival times of wave packets at different moorings and at specific moorings based on lags in wave arrival at individual transducer beams of the moored ADCPs. By both methods, C_w was about 24% greater than the linear wave speed, calculated from density profiles. Cross-shore transport was quantified based on trajectories of drifters, deployed just ahead of an arriving wave packet, and by Lagrangian integration of surface currents from moored ADCPs accounting for wave propagation passed the mooring. Wave nonlinearity ranged from 0.25 to one, with $U_w \approx C_w$ for several internal wave packets each spring tide. Cross-shore surface transport over a semidiurnal period was positively correlated with wave nonlinearity. When wave nonlinearity approached one, cross-shore transport exceeded 10 km, a significant fraction of the cross-shore extent of Massachusetts Bay.

sSalt-Trap Estuaries: Morphology, Hydrodynamics and Water Properties.

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Many "salt-trap estuaries" are found in California and along comparable high-energy coasts with seasonal runoff (e.g., South Africa). Wave-driven and tide-driven sediment transport at the mouth or winter-flow-driven sediment transport in the upper estuary result in shoals that allow landward intrusion of a salt wedge but that trap the dense saline waters in the estuary as the tide ebbs. Such salt traps may represent only a delay in ebb-tide salt export, or they may result in residence of weeks or months in the lower layer. With reference to a few case studies, specifically the Russian River estuary, this type of estuary will be described. The focus will be on hydrodynamics observed in salt-trap estuaries, but attention will also be given to the characteristics of the morphology conducive to salt traps and the ecological and environmental effects of salt traps. Salt-trap estuaries exhibit high levels of stratification, unexpected for such small energetic systems, and this has a first-order effect on water properties and ecology.

Effect of dynamical light fields on a biogeochemical model

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Abstract

The Liverpool Bay Coastal Observatory has been active since 2002. Starting in April 2010, a WET Labs ac-s instrument has been deployed at the Mersey Bar, recording time series of spectra of absorption ('*a*') and attenuation ('*c*', i.e., absorption plus scattering) coefficients near to the sea surface. These inherent optical properties are related to the amount of suspended particulate matter (SPM), chromophoric dissolved organic matter (CDOM) and chlorophyll in the water. Samples collected during cruises were processed and analysed in the laboratory to determine the concentrations of each component – the absorption spectra will be examined to find how they relate to their respective concentrations.

In the biogeochemical model, the present light extinction algorithm uses coefficients based on photosynthetically active radiation (PAR, flux of photons in the visible range); it includes the effects of the phytoplankton and particulate organic matter, but omits those of inorganic SPM, chlorophyll and CDOM. A Radiative Transfer model will be used to convert the absorption and scattering spectra into extinction coefficients for varying combinations of particulate matter, chlorophyll and CDOM concentrations. The resulting information will allow the model to account for all the in-water components, and to answer the question of whether the Liverpool Bay ecosystem is light-limited.

Submit by 15th March 2012 to: pecs2012@marine.rutgers.edu

Wave-height evolution in the shallows of San Francisco Bay

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Shoal-channel estuaries such as San Francisco Bay are characterized by broad shallow regions of nearly uniform depth. In the shallows, wind waves play a dominant role in mobilizing bed sediment. Wind-wave driven resuspension is a critical component of the sediment budget in shoal-channel estuaries, and correct parameterization of wind waves and bed shear stress produced by wind waves is essential to the accurate prediction of both sediment concentrations and sediment transport. As shallow-water waves propagate across regions of gentle slope, increasing fetch and shoaling act to increase wave height, while bottom friction exerts a damping influence. The relative importance of bottom friction is inversely related to bottom slope, so in regions of low slope, the combined effect of these factors can produce wave attenuation, or spatially invariant wave heights. In this talk, we will examine the spatial evolution of wave height across kilometers of shallow subtidal flats with data from three regions of San Francisco Bay: South Bay, San Pablo Bay, and Corte Madera Bay. Bed sediments at all three sites are fine-grained cohesive muds. Maximum observed incident wave heights were greater than 0.5 m at all sites, and wave periods were typically 2-3 s. At all sites, wave height decreased in the direction of wave propagation, but bottom orbital velocities (and thus bed shear stress) varied very little cross-shore distance, suggesting morphologic equilibrium. The influence of water depth and incident wave height and direction on wave attenuation will be investigated, and the evolution of wave spectra will be characterized. By comparing results from the three sites, the influence of bed slope on wave attenuation will be evaluated. For each region, the wave friction factor will be determined from the relationship between nondimensional wave height and distance from shore (following Le Hir at al. 2000), with the goal of establishing a single wave friction factor for the shallows of San Francisco Bay.

Quantification of tide-driven variations of suspended sediment properties and transport patterns over large bedforms in a tidal inlet channel

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Sediment transport and the evolution of bed morphology in tidal inlets are influenced by asymmetric tidal currents resulting in a continuous inter-action of bed load and suspended load transport patterns. Typically bed forms develop particularly in deeper channels through redistribution of non-cohesive sediments. Bedform dynamics in a tidal inlet channel in the Danish Wadden Sea were quantified by Ernstsen et al. (2006) through analysis of successive bathymetric surveys. Their findings suggest that bedform migration on a tidal scale is governed by bed load transport, while suspended sediment transport results in temporal local erosion or accretion of the bed. In the presence of dunes, erosion and vertical mixing of suspended sediment is influenced by the bedform induced flow field, characterised by large scale intermittent turbulent structures. In order to quantify the relative contribution of suspended transport to morphological changes in the dune field, this study aims at the investigation of suspended sediment transport patterns and a quantification of the spatio-temporal variability in concentration and grain size distribution of suspended sediment across bedforms and during a tidal cycle.

In this pursuit, ship-based high-resolution in-situ measurements of suspended sediment concentration (SSC) and the turbulent flow field were conducted over very large dunes in a tidal inlet channel in the Danish Wadden Sea. Repetitive shipborne transects were carried out for one tidal cycle, combining high-resolution multibeam echosounding (MBES) and acoustic Doppler current profiling (300 kHz ADCP). The transects covered three large dunes (6.5 m high and 200 m long). A multi-sensor probe equipped with laser in-situ scattering transmissometry (LISST) and a conductivity, temperature, depth sensor (CTD) was lowered into the water column and coupled online with the ADCP in the ViSea Plume Detection Toolbox (©Aquavison). Combining the acoustic and optical backscattering signals of these instruments enabled real-time detection of suspended sediment structures. Water samples were taken from within the structures by means of a water pump located on the multi-sensor probe.

The tidal range on the site was 1.8 m and the average water depth was 15 m. Tidal currents were asymmetric in strength (max. ebb flow: 1.5 ms^{-1} and max. flood flow: 1.1 ms^{-1}) and followed a plateau-shaped signature with a strong increase of flow velocity after slack water and relatively constant velocities during mid-tide. Current velocity profiles showed the typical evolution of flow over large bedforms with increased upward-directed flow over the stoss side, and flow reversal associated downwelling in the trough region. Acoustic backscatter profiles, SSC from water samples and the turbidity sensor indicated a general increase of SSC from 0.04-0.12 gl^{-1} during accelerating flow. Near-bed SSC values were observed to continue to increase during decelerating flow before slackwater, indicating a phase lag between the decrease in velocity and settling of suspended sediments.

On the macro-turbulent length scale, large structures of increased acoustic backscatter were observed behind the crest and over the lower stoss side during most of the tidal cycle. Interestingly, strong fluctuations of turbidity were detected in streamwise and vertical direction only during accelerating currents shortly after slack water. Simultaneously, a slight increase was found in the peak grain size of the generally uni-modal distribution (medium to coarse silt and episodically very fine sand) when lowering the sensor from the upper water column to approximately 2.5 m above the seabed. Around mid-tide, the dominant mode of grain sizes shows a greater variation with peak grain sizes ranging from silt to very fine sand throughout the water column. SSC values varied by up to 0.03 gl^{-1} between the individual plumes of the three dunes of each transect.

These preliminary results indicate that large turbulent structures develop early during acceleration of the flow at particular locations in the dune field. These cause scattered suspension and result in high lateral and vertical SSC patterns in the water column. As the acceleration of the flow continues these fluctuations decrease as more material is entrained and mixed into the water column. Acoustic backscatter profiles however indicate that these structures remain to exist even after the flow has decelerated. The suspended sediment transported in these structures is believed to have been eroded predominately from the trough and lower stoss side regions of the dunes and leads to accretion at the dune when the material is settling.

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Influence of viscosity formulation on tidal flow in estuaries

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Keywords: tidal dynamics, viscosity parameterisation, geometry, Ems estuary, Pearl River estuary

Abstract

Processes involving tidal motion in estuaries and lagoons can result in important contributions to the net circulation within an estuary. Furthermore it strongly influences the exchange with the adjacent sea. To get a better fundamental understanding of the tidal velocities in estuaries, analytical models have been developed that specifically focus on the longitudinal (Ianniello, 1977; Chernetsky *et al.*, 2010) and transversal (Wong, 1994; Huijts *et al.*, 2009) flow structures, allowing for a realistic representation of the bathymetry and spatially varying viscosity. It has been recognized that the transverse distribution of velocity plays a significant role in momentum balance and mixing in many estuaries (Geyer *et al.*, 1998; Scully *et al.*, 2009), suggesting that the interaction between lateral and transverse processes is essential to capture the tidal dynamics. Therefore, more recently an analytical model has been developed to study the three–dimensional tidal motion in an elongated basin (Winant, 2007). However, in this model, a spatially invariant viscosity, no–slip boundary condition at the bottom, and an idealised geometry are assumed.

In the work presented here, we extend the three–dimensional tidal model of Winant (2007) to describe the tidal motion in an estuary of arbitrary geometry. Furthermore, we investigate the influence of spatially varying viscosity on the tidal motion, using appropriate bottom boundary conditions. The results will be compared with those obtained from two estuaries, the Ems estuary on the border between the Netherlands and Germany and the Pearl River estuary in China.

Preferred type of presentation: Poster

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Large-scale morphodynamic modeling of the German Bight – Assessing meteorological effects

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Modeling of large-scale and long-term sediment dynamics in the past was mostly restricted to 1d- and 2d-models. With increased computational resources the project “AufMod” takes a process oriented modeling approach to further investigate the large-scale, long-term morphodynamic evolution of the German Bight (North Sea). The project’s aim is to identify sediment transport pathways and quantities by modeling and measurements.
Based on the method UnTRIM2007 a 3D hydrodynamic model of the North Sea has been built. It is coupled to SediMorph (sediment transport) and UnK (waves) to obtain a system for calculating long-term, large-scale sediment transport. Initially the model is run as a hindcast for the year 2006. The tidal wave is calculated reasonably accurate within the German Bight (RMSE < 0.4 m), thus reproducing observed water levels well. Sediment transport due to tidal currents, waves and wind driven circulation are taken into account. Starting from an average sediment distribution for the nine sediment fractions considered here, the model evolves towards observed values, reproducing finer sediments at the mudflats and coarser sediments in the tidal channels.
In order to disentangle the complex natural forcing of sediment transport, wind driven processes were studied in a set of process studies. Comparing different meteorological situations a strong influence of wind speed could be identified, but variations of tidal amplitude during the spring-neap cycle are of the same order. Individual pathways for different wind directions could be identified and are mainly in accordance to the residual wind driven circulation. However, the amount of transported sediment is subject to large uncertainty. In order to better quantify this uncertainty a multi-model approach was taken to corroborate modeling results by using a different method (Delft3D).

Lutocline Formation and Breakdown in a Muddy Estuary

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The FLUMES project (FLUid Mud in Energetic Systems) examines the formation of high-concentration bottom suspensions of fine sediments (fluid muds) in a macrotidal environment. The field area is the Petitcodiac River, Moncton, New Brunswick, Canada which experiences tidal flows in excess of 2.0 m/s and suspended-sediment concentrations that range from 0.5 to > 300 g/l. Thus the Peticodiac serves as an ideal natural flume for examining the behavior of muddy suspensions under both accelerating and decelerating flows. Field experiments in June and August 2006, June 2009 and November 2010 captured conditions of both fresh and saline water, with concurrent measurements of fluid properties (salinity, temperature, density), suspended-sediment concentration (SSC), current velocity and shear throughout the water column. Instrumentation included profiling packages, one with paired electromagnetic current meters, a CTD, and an Optical Backscatterance Sensor (OBS) with a pump system for in situ calibrations; and additional sensors in 2009 and 2010 including an ADV, Aquadopp acoustic profiler, and OBS5 (calibrated to measure SSC to 50 g/l) on a separate profiling package. A dual frequency echosounder (50 and 200 kHz) ran continuously with a downward looking 1200 kHz ADCP. The presence (or absence) of fluid mud and evolution with changing flow conditions is documented by the combination of instruments; for example the difference in depth of return from the two frequencies of the echo sounder, maximum depth of ADCP returns compared to actual depth reached by the profiling package, and direct measurements of concentrations from pumped water samples in connection with calibrated optical sensors show excellent agreement. Results support a carrying-capacity threshold, based on a critical gradient Richardson number, for high-concentration bottom-suspension formation. With the onset of ebbing currents, the dual frequency echo sounder recorded instabilities on the lutocline indicating resuspension with strong shear observed across the interface. In addition, rapid flocculation at high sediment concentration is essential for rapid deposition and the formation of fluid mud. The disaggregated inorganic grains size (DIGS) of the suspended-sediment samples showed that as current speed decreased all particles in suspension were removed at an equal rate leading to rapid clearing of the upper water column and the creation of the high-concentration bottom suspension. During freshwater conditions, high concentration bottom suspensions did not form, even though suspended sediment concentrations in the water column were similar to mixed salinity conditions.

A comparison of statistical and dynamical analyses on the local wind-driven circulation off southern San Diego

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The local wind-driven circulation off southern San Diego is addressed with complementary statistical and dynamical frameworks by using of observations of the surface and subsurface currents from high-frequency radars and a nearshore mooring and the local wind in conjunction with a numerical model (MITgcm) simulation with realistic coastline and bottom topography. Statistically estimated anisotropic local wind transfer functions characterize the observed oceanic spectral response to the wind stress in the *x* (east-west) and *y* (north-south) individual directions. At low frequency, the amplitudes of the transfer functions are enhanced near the coast, attributed to geostrophic balance between wind-driven pressure gradients and Coriolis force on currents. The response diminishes away from the coast, returning to the balance between friction and Coriolis, as in the classic Ekman model. On the other hand, transfer functions for near-inertial frequencies show reduced amplitudes near the coast due primarily to friction in contrast to the enhanced seaward response as a result of the inertial resonance.

Data assimilation for morphodynamic modeling of tidal channel migration

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This study investigates the use of data assimilation in morphodynamic modeling of channel migration. We use a tidal channel (Medem) at the Elbe estuary, German Bight, Southern North Sea as a study site. A lot of efforts have been done in model simulation of river channel migrations, however, rare in coastal tidal channels. Observed bathymetric data analysis shows a distinct pattern of migration of the Medem channel (Medemrinne) between 1990 and 2007. The Medem channel moved northward approximately 1700 m over 17 years with an average migration rate of 100 m per year. The southern bank is flatting while the northern bank is steeping. This pattern calls for a morphodynamic modelling simulation. This preliminary study focused on the period from 1990 to 1993. A 2D depth-averaged numerical model was set-up based on the modeling system DELFT3D. The model was calibrated and validated against measured water level data throughout the model domain. The morphodynamic model results show that the model was not able to reproduce the channel migration due to the complex physical processes and limitations of numerical models. A 3D-variational data assimilation scheme was then applied on the morphodynamic model to test the channel migration patterns. The 3D-variational method carries out the analysis by looking for a state which minimizes a cost function measuring the misfit between the model state and the observation term. The analysis is a combination of model prediction and the observation with weights inversely related to their relative errors. If the background errors are larger compared to the observation errors, higher weights will be distributed to the observation term, and vice versa. In this study, the observed bathymetry of 1993 was assimilated to the model predicted bathymetry. Specification of the model prediction error covariance matrix is one of the most crucial procedures of the assimilation scheme which was done by specifying the error correlations. The error correlations govern the spreading and smoothing of observational information during the assimilation process. A user defined correlation length scale for controlling the error correlation was selected as a parameter for testing the generated morphological patterns. The spatial selection of the correlation lengths was carried out in both circle and ellipse areas. General results show that the generated patterns of Medem channel are not sensitive to the error correlation lengths due to the larger model errors compared to observation errors. However, results demonstrate that smaller error correlation lengths generated discontinued bathymetry in the deep channel while larger error correlation lengths produced over-smoothed bathymetry and the information of deep channels and bars are missing. Brier skill scores evaluation show that the error correlation length similar to the grid cell size gives the highest score. By extending the searching length in the east-west direction in ellipse area, more realistic channel depth is produced. This study brings new insights to the application of data assimilation scheme to coastal morphodynmaic modelling of the channel migration.

Mixing and structure of a buoyant plume subjected to offshore winds

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Idealized model simulations are carried out examining the effect of cross shore winds on the mixing of a buoyant river plume system and later compared to realistic simulations of the Hudson River plume. After several inertial periods of wind forcing the plume is transported offshore and several plume properties (offshore distance, width, depth, density) reach a steady state dependent on estuarine outflow conditions. The plume has a strong downstream jet on the offshore side and a weak upstream flow on the inshore side. This flow pattern is driven by the cross-shore balance of the pressure gradient, wind stress, and coriolis acceleration. The strong vertical velocity shears on the offshore side of the plume drive relatively high vertical salt fluxes into the plume, even while the plume structure remains steady. We used a traditional salt equation and a salinity coordinate analysis to examine this constant plume structure. It is found that the wind stress drives a vigorous cross plume circulation that acts as a straining mechanism, stratifying the offshore side of the plume. This circulation is the strongest on the offshore side of the plume. The cross-shore advective term in the salt equation is generally balanced by the vertical mixing driven by the downstream geostrophic and Ekman velocities and is constrained to the offshore side of the plume. The residual is dominated by the downstream advection of freshwater. While the plume is steady in time from the Eulerian point of view, mixing is still occurring. This points out that while the alongshore advective term is smaller than the dominant terms, it plays an important role in resetting the system. Parcels of the plume are tracked in a Lagrangian reference frame to examine how the parcels evolve in time as they mix and are advected downstream in the plume. It is found that in a Lagrangian reference frame the plume mixes according to the prevailing theories of surface mixed layer deepening.

These results and theories developed using the idealized model simulations are compared to realistic model hindcast simulations of the Hudson River plume during the 2005/2006 winter season. During this period the prevailing winds were from the northwest (i.e. they had a strong offshore component), which is typical of the New York Bight during the winter. However, the response of the Hudson River plume during the winter has been typically described as a downwelling dominant regime. Here we show the scaling provided by the idealize model results apply to the Hudson River plume during the winter and that the strong offshore component to the wind significantly impacts the plume structure and freshwater transport pathways on the shelf. This response is large departure from the assumed downwelling response and has implications for salinity induced stratification over inner shelf during the winter season.

SAND FLUX AND BUDGET MEASUREMENT IN A MACROTIDAL ESTUARY: CAN DECADAL SCALE BUDGET ESTIMATES BE MADE FROM FLUX MEASUREMENTS OVER TIDAL CYCLES?

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Coastal managers concerned with the impacts of climate change need information on estuarine sedimentation rates on decadal time scales. However, oceanographers typically measure processes on much shorter time scales. There is doubt whether short term measurements can be extrapolated to decadal time scales. The problem is that the net sediment flux (a small number) must be derived from the difference between flood and ebb sediment fluxes (both big numbers with large error bars). This paper describes a field experiment to test the hypothesis that the errors in sediment flux determinations are too large to make meaningful estimates of sedimentation rates on decadal time scales.

The experiment was situated in the macrotidal Taf estuary in SW Wales, UK which has a tidal range up to 10 m and tidal currents exceeding 2 ms^{-1} on spring tides. Freshwater input is small (mean discharge 7 $m^3 s^{-1}$) in comparison with saltwater input (mean tidal prism 10^7 m^3). The estuary is emptied of salt water at low tide when large areas of intertidal sand flats emerge. The sediments are fine sands (mean grain size 130 µm). We have a unique and robust measure of the sedimentation rate since we have surveyed 10 transects across the estuary over a 45 year period since 1968; this shows that there has been net sedimentation of sand at an average annual rate of 0.017 m. Mineralogical evidence proves that this sand is derived from offshore.

The tide within the estuary is asymmetric, flood current velocities exceeding ebb velocities. Bed shear velocity exceeds 0.14 ms^{-1} on spring tides; the threshold u* for suspension of the fine sands is 0.02 ms^{-1} which is exceeded throughout most tidal cycles, so sand transport is mostly via suspension. Suspended sand transport through 2 cross sections of the estuary was measured over 10 tidal cycles using transmissometers and current meters at 7 stations spaced across the estuary. Suspended sediment concentration reached 1000 mg l^{-1} at peak flow, reduceing to 10 mg l^{-1} at slack high water. Much of the sediment flux occurred at the start of the flood tide (as the rising tide poured into the estuary) and towards the end of the ebb (as flow became confined to the main channel). Gross sediment flux per tide was $0.79\text{x}10^5$ kg and $22.40\text{x}10^5$ kg for neaps and springs, respectively. Net sediment flux, always up-estuary, was $0.19\text{x}10^5$ kg and $1.88\text{x}10^5$ kg per tide for neaps and springs, respectively. There were statistically significant exponential relationships between sand flux per unit width and tidal range. These relationships were used to compute daily flood, ebb, and net fluxes for 1 year using predicted tidal ranges. The calculated, cumulative annual net flux was used to derive the annual sedimentation rate (using a measured bed porosity of 40%) up-estuary of the measurement transects. This yielded a mean annual sedimentation rate of 0.015 m.

The sedimentation rate from short term flux measurements was therefore very close to the rate from decadal surveys. So our hypothesis is disproved. The success of our flux measurements is probably consequent on the ratio of net to gross flux (c. 10%). In many estuaries, this ratio is closer to 1% so the error bars on measurements become more significant.

Mudflat Evolution at Decadal and Seasonal Time Scales

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Mudflats evolve in response to changes in both hydrodynamic forces and sediment supply. To determine the relative importance of hydrodynamics and sediment supply, time series of bathymetry of the mudflat-channel system in South San Francisco Bay measured at decadal and seasonal time scales are analyzed in the context of regional change and local forcings.

A series of bathymetric surveys collected by the US Coast and Geodetic Survey/NOAA approximately every 30 years from 1858 to 2005 reveal long-term changes in mudflat area in both space and time that can be used to better understand the system. For example, the western mudflat in our study area just south of Dumbarton Bridge in South San Francisco Bay narrowed approximately 200 meters from 1858 to 1931. Since then this mudflat has accumulated sediment and is now wider than it was in 1858. Mudflat change is correlated with overall sediment losses and gains in the South Bay, which can be interpreted as a response to sediment input to the system. The main channel of San Francisco Bay abuts the mudflats at the study site and widened when the mudflats narrowed and vice versa.

Seasonal changes in the mudflat-channel system are explored in conjunction with wind, tide, and wave data to gain insight into the processes driving short-term geomorphic change. Interferometric sidescan sonar swath bathymetry data collected during 8 surveys from December 2008 to January 2011 document seasonal changes in the mudflats and channel. Changes on the mudflats were subtle, yet they tended to accrete during the winter and early spring when sediment supply from tributaries to the Bay is high and erode during the late spring, summer, and fall when stronger winds generate larger waves on mudflats. The channel behavior at the seasonal scale is more complicated than the behavior at the decadal scale. The channel and channel slope exhibited both the same (both eroded or accreted) and opposite geomorphic change. Likewise, at times the mudflat and channel slope/channel exhibited similar and opposite geomorphic behavior. Knowledge gained from correlations between observed seasonal mudflat-channel slope-channel system change and winds, tides, and waves during the study will be used to better understand the long-term evolution of the mudflat-channel system. Together, the seasonal and decadal changes give insight into the relative importance of hydrodynamics and sediment supply in mudflat evolution.

INTERACTIONS BETWEEN TURBULENCE AND SUZPENDED PARTICULATE MATTER CHARACTERISTICS IN THE RIVER ESTUARY TRANSITION ZONE OF A MARCOTIDAL ESTUARY.

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The majority of terrestrially derived suspended particulate matter (SPM) is transported to the open ocean by rivers; therefore the river estuary transition zone (RETZ) represents a globally significant boundary separating the riverine and coastal regimes. The RETZ plays a significant role in the formation and evolution of flocs whose properties vary on short temporal and spatial scales. Quantifying floc properties (composition, size and settling velocity) and floc dynamics in relation to the physical forcings are key in determining the transfer flux of SPM and associated biogeochemical components from the catchment to the coastal ocean. In addition the transfer flux of SPM in estuaries has important social implications due to the role of flocs in hydrophobic contaminant transport. The aim of this study is to interrogate the relationship between floc properties and the turbulence regime in the RETZ of the Aberdyfi macrotidal estuary (mid Wales) over a seasonal time frame.

Observations of floc development require high resolution; therefore *in situ* optical instruments (LISST, transmissometer and OBS) are deployed in the RETZ and the tidally influenced river (TIR) to obtain volume and mass concentrations of SPM, thus providing floc effective density. The turbulence parameters are determined via acoustic methods: 3 ADCPs and 4 ADVs are deployed in the RETZ to give vertical and horizontal turbulence gradients. Data is collected over one spring to neap cycle for 4 periods during the year, thereby supplying a large range of tidal and river discharge conditions in addition to seasonally variable biological conditions. The seasonal dimension is important because we hypothesise that the composition, properties, and behaviour of flocs will vary due to the seasonally variable nature of source material from the catchment.

Results suggest that hydrodynamic characteristics such as turbulent kinetic energy production (TKE) are directly correlated to median particle size (D_{50}) and suspended sediment concentration (SSC), displaying modulations on tidal and lunar time scales. Resuspension signals are observed in the TIR during periods of higher TKE production and velocities. Within the RETZ a similar signal is observed however the maxima of the resuspension signal is reached before the peak velocities, we hypothesises this is due to a finite amount sediment (benthic fluff layer) available for resuspension. Ebb dominance in SSC and flood dominance in velocity are observed due to the advection of aggregated particles formed in the upper RETZ during a period of reduced TKE production.

Preliminary results indicate there is a phase lag between variations in TKE production and the reaction of $D_{50,}$ which varies spatially within the estuary. Data also suggests a seasonal modulation of the relationship between TKE production and SPM characteristics, with increased biological activity enhancing the yield strength of flocculated particles, thus complicating the relationship between D_{50} and TKE production.

The RETZ is a complex environment to study however it is essential to gain understanding and quantify the relative importance of hydrodynamic and biological implications controlling SPM characteristics and thus the fate of the transfer of terrestrially derived organic matter to the coastal ocean.

Morphological Changes in Tidal Basins using Stochastic Bed Load Sediment Transport Predictor

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A three-dimensional layer integrated numerical model is refined to predict morphological changes in tidal basins. Governing differential equations consist of continuity and Reynolds Averaged Navier Stokes equations for incompressible, unsteady, free surface turbulent tidal flow, the transport equation for the suspended sediment fluxes and the sediment mass conservation equation for the bed level changes. An Alternating Direction Implicit (ADI) Finite Difference Method (FDM) is used to solve theses equations. As the random nature of the fluid forces caused by the turbulence, particularly for conditions close to the initiation of sediment motion, a stochastic approach for bed load sediment transport prediction is applied in the developed model which assuming a Gaussian distribution for probability density function for the grain shear stress. Moreover, the model includes different criteria for the initiation of motion namely Shields (1936) as a conventional method and Kolahdoozan (1999) which considered unsteadiness of tidal flow parameters. To validate the numerical model results, measurements of a short term bed level changes in a laboratory model harbor are used. Comparisons of numerical model using different initiation of motion criteria with stochastic bed load predictor, show acceptable agreement with the experimental data. The model is then applied to a real case study of the Humber Estuary, located in the UK, with comparisons being undertaken stochastic approach for the long term bed level predictions.

Keywords: Sediment transport; Numerical model; Stochastic bed load predictor; Tidal basin

Sediment dynamics in mangrove forests;
field data obtained in Trang, Thailand

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Mangroves are known to be a sediment trapping environment. Past studies have shown sediment deposition rates in mangroves. However, flow paths of water and sediments through mangroves have not been thoroughly studied yet. This paper elucidates the linkage between sediment transport and deposition in mangroves and between the input and output of sediment through creeks and over the mangrove fringe by analysis of field data obtained in a mangrove creek catchment in Trang, Thailand.

An extensive field campaign was executed within the study area. During five months data have been collected throughout this area on topography, vegetation cover, flow velocities, water levels, suspended sediment concentrations and sediment deposition. Analysis of these field data underlines the sediment trapping characteristic of mangroves. High tides transport suspended sediments into the mangroves, while sediment concentrations within the mangroves are negligible at outgoing tide since flocculated sediments cannot get re-entrained (Figure 1B). The creeks play a major role in this trapping as current directions indicate that flooding of the study area is initiated from the creek system. This supplying function causes the maximum current velocities in the creeks to be about 10 times higher than the within forest flow velocities (Figure 1A).

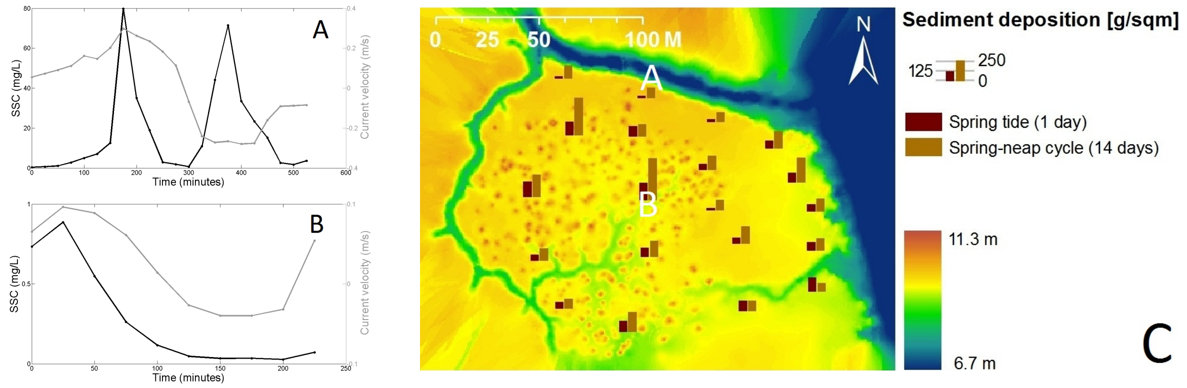

Figure 1: Time series of current velocities and suspended sediment concentrations over a tidal cycle for (a) the main creek and (b) the center of the creek catchment (note: timescales are different due to different inundation patterns). Sediment deposition rates (daily/fortnightly) are shown in the elevation map of the study area in (c), together with the locations of data collection for (a) and (b).

Combined with measured sediment deposition rates (Figure 1C), information was provided to link the flow routing through mangroves to a sedimentation pattern. At the riverside of the study area, most of the sediment transported into the mangroves is deposited directly in the densely vegetated forest fringe just in front of the bank. The area behind these banks is mainly fed by the creeks penetrating deep into the area. High flow velocities within these creeks funnel sediment rich water into the area at flood tide. At slack tides, these sediments settle on the forest floor, without being re-entrained again during ebb. These data will be analyzed more thoroughly during the next months to further increase our understanding of mangrove sediment dynamics.

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The Baltic Sea Tracer Releaser Experiment: Mixing processes and mixing rates

During the Baltic Sea Tracer Release Experiment (BaTRE) deep-water mixing rates and mixing processes in the central Baltic Sea were investigated by an injection of the inert tracer gas SF_5CF_3 in September 2007 at approximately 200 m depth into the anoxic/sulfidic deep layers. The subsequent spreading of the tracer was observed during 6 surveys until February 2009 and was used to infer diapycnal and lateral mixing rates. One main result is the dramatic increase of the vertical mixing rates after the tracer had reached the lateral boundaries of the basin. This suggests boundary-mixing as the key process for basin-scale vertical mixing. Basin-scale vertical diffusivities were of the order of 10^{-5} $m^2\ s^{-1}$ (about one order of magnitude larger than interior diffusivities) with evidence for a seasonal and vertical variability. By applying a one-dimensional diffusion model it was found that the basin geometry (hypsography) has a crucial impact on the vertical tracer spreading and leads to highly skewed concentration profiles. The time scale for horizontal tracer homogenization was of the order of 6 months.

Analysis of long-term moored instrumentation and ship-based turbulence microstructure measurements showed that basin-scale topographic waves, a deep-rim current, and near-inertial waves are the most important energy sources for turbulence. The importance of boundary mixing processes for overall vertical mixing seen from the tracer spreading correlates with increased dissipation rates in the bottom boundary layer, which were inferred from shear-microstructure observations. Varying bottom boundary layer (BBL) heights indicate the generation and the subsequent intrusion of the BBLs into the center of the basin. An Ekman transport induced by the deep-rim current has been identified as the source for the measured slightly unstable water-columns reaching up to 40 m height from the bottom.

The role of the identified physical processes responsible for mixing are further investigated using a high resolution numerical model calibrated with the BaTRE dataset. Having a horizonzal grid size of 600 m, the model can reproduce processes as the near-inertial internal wave spectrum, which is the dominant contributor of the internal wave kinetic energy, and the BBL generation at the slopes. The process chain of boundary mixing, generation of intrusions and isopycnal mixing of tracers is investigated by remodelling the BaTRE tracer release and additional tracer releases within the model. The generation of the topographic and internal waves as well as the deep-rim current and their individual contribution of the mixing processes is quantified using the model results.

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TRANSIENT DISPERSIVE PROCESSES IN CHANNEL-SHOAL ESTUARIES

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Dispersive processes in estuaries are often modeled as Fickian diffusion, with assumptions of complete lateral mixing and linear growth of the second central moment. We investigate scalar plumes in a channel-shoal estuary, focusing on transient dispersive processes during the period before lateral homogeneity can be assumed. For wide estuaries, with scalar sources and sinks away from the head or mouth, this is an important period and in many cases a plume never mixes completely shore to shore. Residual circulation, tidal stirring and turbulent mixing vie for dominance in determining the relationship between lateral mixing time and residence time. We show idealized simulations of a range of dispersive regimes, and as applied to South San Francisco Bay we find that the norm is not Fickian diffusion but closer instead to semi-bounded shear dispersion with quadratic variance growth.

Observations of turbulence in geophysical surface flows using ADCPs

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Acoustic Doppler current profilers offer various possibilities to support studies on turbulence in rivers, streams, lakes, estuaries and in the coastal ocean. Here we present and apply a technique to obtain estimates of the Reynolds stress tensor from coupled ADCPs oriented vertically, and investigate cross-channel exchange of streamwise momentum based on a horizontal ADCP deployment. Focussing first on vertical ADCP deployments, the variance method is commonly used to derive the two vertical shear components of the Reynolds stress tensor from ADCP data. The variance method cannot yield a robust estimate of turbulence kinetic energy, and depends strongly on perfect vertical alignment of the central ADCP axis. We extended the variance method to rigid deployments with two coupled ADCPs [Vermeulen et al., 2011]. Measurements from a bend in the Mahakam River show that ratios between normal stresses can differ strongly from ratios measured in laboratory experiments [or in small streams. This raises doubts about common assumptions about turbulence anisotropy in rivers. The new technique improves flexibility during data collection, relaxing the requirement of perfect vertical alignment. With eight beams and six unknown terms, the Reynolds stress tensor can be estimated completely, without making other assumptions than homogeneity of the turbulence field between the beams.

ADCPs are increasingly being deployed horizontally, most often with the aim to obtain continuous estimates of river discharge [e.g. Sassi et al., 2011], but also to monitor surface waves. A three-beam 600 kHz horizontal (h)ADCP, operating at a sampling frequency of 1.25 Hz, can be used to obtain estimates of the three horizontal components of the Reynolds stress tensor, along a profile aligned with the central ADCP axis. We deployed an hADCP at a bank in the outer bend section of the Berau tidal river, and investigate the cross-river exchange of streamwise momentum. Variance-preserved spectra of the hADCP velocity time-series show a gap around 1 cycle per hour, which separates the tidal and subtidal frequency bands from the turbulence frequency band. The averaging period for Reynolds stress calculations is therefore set at 1 hour. In general, the cross-river transport of streamwise momentum by turbulence is found to be two orders of magnitude smaller than the transport by transverse circulation. Close to the river bank, the secondary circulation weakens and even switches sign, but still dominates the transverse exchange of streamwise momentum. The hADCP observations are qualitatively in agreement with results by Van Balen et al. (2011), who argue, based on a modelling study, that complex interaction between the spatial distribution of turbulence stresses and centrifugal effects can result in counter-rotating secondary flow cells near the outer bank of a river bend.

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Varying exchange flow for two entrance channels in a subtropical inverse estuary

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In Shark Bay, Western Australia longitudinal density gradients drive gravitational circulation that is important for bay-ocean exchange and transport of biological matter. In this inverse estuary high salinity water is exported through the two main entrance channels at depth and is replaced by fresher ocean water at the surface. Hetzel et. al. (in review) recorded intermittent dense water outflows (~10 cm s^{-1}) from the western entrance channel on a weekly-to-fortnightly frequency during the winter that were modulated by the effects of vertical mixing by wind and tide. The present work explores the variability in the strength and persistence of dense water outflows using hydrographic and current velocity data collected in the other main (north) entrance channel in 2011. Results indicated that density-driven bottom currents in the north entrance were up to three times stronger (~ 30 cm s^{-1}) and more persistent than in the western entrance. Stratification in the deeper northern channel persisted even during periods of increased tidal mixing, and advection and mixing by intense wind events were important factors controlling exchange. Turbulent kinetic energy production was calculated from the acoustic Doppler current profiler (ADCP) data for both entrances using the variance method in order to examine the variability and vertical structure of turbulence in the water column with the aim of comparing and contrasting the effects of mixing on stratification in the two entrance channels. In addition to the field measurements, three-dimensional hydrodynamic simulations with the General Estuarine Transport Model were used to investigate the spatial variability of the dense bottom water outflows and the inhibiting effects of turbulence created by winds and tidal currents. The results support the hypothesis that the main pathway for the export of hypersaline bay water and biological material such as larvae is out of the northern entrance to Shark Bay, and that persistent density-driven bottom currents likely play a major role in maintaining the health of the ecosystem.

The Mississippi/Atchafalaya River Plume System

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A series of numerical models are used to examine circulation on the Texas-Louisiana continental shelf. Comparisons between model results and shipboard and moored observations suggests that the models are capable of reproducing primary circulation patterns and tracer distributions over the shelf. A model covering the Louisiana shelf was nested within a variety of data-assimilative parent models. Comparison of nested model results with hydrographic observations indicates that nesting improves model skill. However, using different parent models results in similar improvements, so it appears that it does not matter much which parent model is used to generate boundary conditions for the nested model. Perturbation experiments using modified forcing, by increasing and decreasing the amplitude of the fresh water and wind forcing, result in an ensemble spread that is greater than the deviation in the ensemble mean. In other words, small perturbations in forcing conditions causes large differences between simulations. Creating ensemble members through modified open boundary conditions, using different parent models to generate boundary information, results in similar spatial patterns of ensemble spread. The region of largest differences in ensemble members is along the Mississippi/Atchafalaya plume front. We believe this ensemble spread is caused primarily by small-scale, non-linear instabilities in the flow along the plume front, and results in a substantial noise floor that limits model predictive ability. Because these eddy-like features have space and time scales smaller than those typically resolved by hydrographic surveys, data assimilation is unlikely to reduce this model noise. A separate set of numerical experiments tagged Mississippi and Atchafalaya river outflows with a numerical dye, so that water from these two rivers can be followed separately. A shelf-wide budget for riverine fresh water from each river suggests residence time on the shelf ranging from about 3 to 12 months, with the Atchafalaya water having a longer residence time than Mississippi water. While there is obviously a strong seasonal patterns to inputs of fresh water, which is highest in spring during the freshet, the offshore fresh water flux at the shelf edge does not show a strong seasonal pattern. Although the net offshore flux of fresh water does not follow a seasonal pattern, there are temporal patterns in the location of offshore fresh water flux. These patterns are related to a combination of the curvature of the Texas coastline and seasonal shifts in the mean wind stress. These seasonal wind patterns are also linked with locations of convergent flow along the coastline, which are of interest for oil spill trajectory prediction and harmful algal bloom initiation. Cross-shore density gradients are correlated with along-shore currents in a thermal-wind balance with the level of no motion at the sea floor. Interestingly, there are many times when the flow is geostrophic, and upcoast. These upcoast currents are associated with a retrograde density gradient, fresher offshore, due to a strong intrusion of dense water in the bottom boundary layer during upwelling.

Morphological response of shoreface-connected ridges to high-energy hydrodynamic conditions

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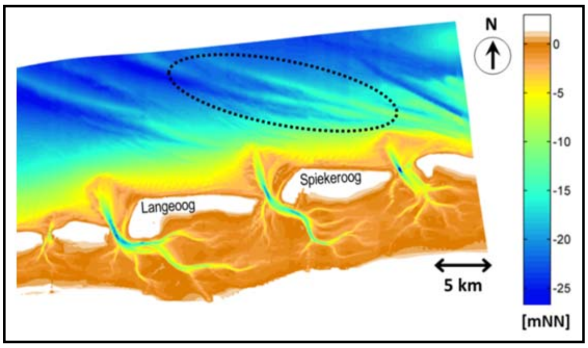
Shoreface-connected ridges (SCR) are large-scale morphological features typically located in the transition zone between lower and upper shoreface. In the southern North Sea, off the East Frisian barrier islands in Germany, SCR are found in water depths of 10-20 meters. The crests of these sandbodies are oriented from WNW to ESE. Their heights are up to 6 meters, lengths are typically more than 10km with maximal widths of 2km. Their location at deeper waters and their alignment with the direction of major storms suggests that the morphology of these structures is affected by high-energy events. Previous studies have shown that these bedforms are stable in place in time frames of several decades. Surface sediments at the crest and the upper seaward slope are characterized by fine to medium sands, while coarser grain sizes are found in the troughs - in contrast to the contrary sedimentology of near-shore tidal sand bars. Recently, it was shown that SCR can grow in the order of several centimeters as a morphological response to storm conditions. However, there is neither a consensus in literature on the geological genesis of these ridges nor about the interrelation of hydrodynamic forcing and ridge morphodynamics.



In this study, a major storm surge event in the North Sea (Nov. 9^{th} 2007) has been simulated by a process-based numerical model (Delft3D) to gain insight in sediment dynamics and the associated morphological changes under the imposed hydrodynamic forcing. A three-dimensional, multi-grain size morphodynamic model (figure) with a high-resolution numerical grid (30-60m) was set-up and forced by non-stationary tidal-, wave- and wind- boundary conditions. The interaction of wave forces, tidal currents and the changing bed level is realized by a fully bidirectional-coupled wave-current simulation. It allows the identification of sediment transport pattern and the differentiation between instantaneous and residual suspended load and bed load directions and quantities.

Simulated morphological changes and post-storm patterns of mean grain size agree with earlier field observations. Dominant sediment transport directions in the model are consistent with in-situ observations of small-scale bedforms super-imposed on the ridges. During the storm surge, in combination with significant wave heights of at least 4m, the model shows an accretion of the ridges' crests by approximately 10cm whereas the troughs are eroded. Fine-grained sand fractions are transported from the troughs over both lateral slopes to the crests. At flood-tide, the depth-averaged flow direction of the combined wave-, tide- and surge-induced currents is generally eastward directed; however near the SCR, bottom currents are governed by bathymetrical gradients. Near-bed currents with ridge-oblique vectors at the lateral slopes converge upon the crest where they turn crest-aligned towards ESE.

Preliminary process analysis suggests that two central mechanisms are involved in the deviation of bottom currents and associated sediment transport: (1) Wave refraction converges wave rays towards the crests and focuses the wave energy and momentum on the ridges slopes where sediment stirring occurs. (2) Near bed wave-induced currents are stronger over ridge crests than in the troughs due to the depth-dependency of wave orbital velocities. Residual gradients of flow velocities are considered to cause near-bed and upslope-directed compensation flows. These transport fine sediments up-crest, leading to the formation and maintenance of the typical sedimentology of shoreface-connected ridges.

Observations of small-scale spatial variability in currents and turbulence on coral reefs

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Significant gaps remain in understanding interactions between physical and biological processes on coral reefs, due in part to lack of understanding flow over complex, spatially variable topography. Here we describe measurements of spatial flow patterns on a coral reef at scales from a single colony to several adjacent colonies that were made using an array of acoustic Doppler velocimeters on a diver-operated traverse. Measurements indicate that currents and turbulent mixing can vary significantly at scales of 0.1-m to 10-m on reefs. Behind colonies, currents are reduced from free stream values and recirculation zones exist. Increased Reynolds stresses in shear layers around wake peripheries cause elevated turbulence production and enhanced mixing. Wake properties vary with incident flow speeds; faster flows result in longer wakes and stronger recirculation zones. Over complex reef patches, recirculation zones, reduced flow speeds, and elevated turbulence levels were observed behind flow obstructions and flow acceleration zones occurred above and between them. The data suggest that for many shallow reefs the bottom boundary layer is rarely fully developed, and is instead dominated by zones of overlapping wakes.

ESTUARY CLASSIFICATION REVISITED

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Estuaries are complex dynamical systems resulting from the competition between river and oceanic flows. While the former adds fresh water, the later adds denser salt water which moves landward due to tidal effects as well as gravitational circulation (or exchange flow). The complicated balances between river, exchange and tidal processes determine the estuarine salinity structure and therefore its type. Based on its vertical salinity profile, estuaries can be classified into three categories: (i) well mixed, (ii) partially mixed, and (iii) salt wedge or highly stratified. While tidal forces are dominant in well mixed estuaries, river input is significant in highly stratified ones. On the other hand, partially mixed estuaries are primarily exchange dominated.

Probably the best known diagnostic type estuary classification scheme is the “stratication-circulation diagram" of Hansen and Rattray (1966). It is derived from extensive field observations. They also determined analytical expressions for velocity and salinity profiles of a tidally averaged, rectangular estuary. However, these profiles depend on mixing parameters like eddy viscosity and diffusivities which are still poorly understood. In recent years, remarkable progress has been made in empirically parameterizing these mixing coefficients. Using them, we have built a nondimensional framework to completely express the estuarine governing equations in terms of relevant dimensionless numbers. They are (i) Estuarine Froude number (Fr), (ii) Tidal Froude number (Fr_T) and (iii) Estuarine Aspect Ratio (B/H, where B=width and H=depth at the estuary mouth). Moreover, based on these parameters, a prognostic type estuary classification scheme has also been proposed and compared with real estuarine data from Hansen and Rattray (1966). We have found that the comparison is remarkable.

Modelling impact of dredging and dumping in the ebb-flood channel systems of the Scheldt estuary

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The Westerschelde is the marine part of the tide-dominated Schelde estuary in the southwest part of The Netherlands. The morphology of the Westerschelde consists of mutually evasive ebb and flood channels. These main channels are separated by sub- and intertidal shoals and linked by connecting channels. The estuary is of large economic importance as it provides access to the ports of Antwerpen, Gent, Terneuzen and Vlissingen. Land reclamation, dredging, sand extraction and other types of human interferences have influenced the natural evolution of the estuary during the last centuries. Recently, three capital dredging programs were carried out in the periods 1971-1974, 1997-1998 and 2010.

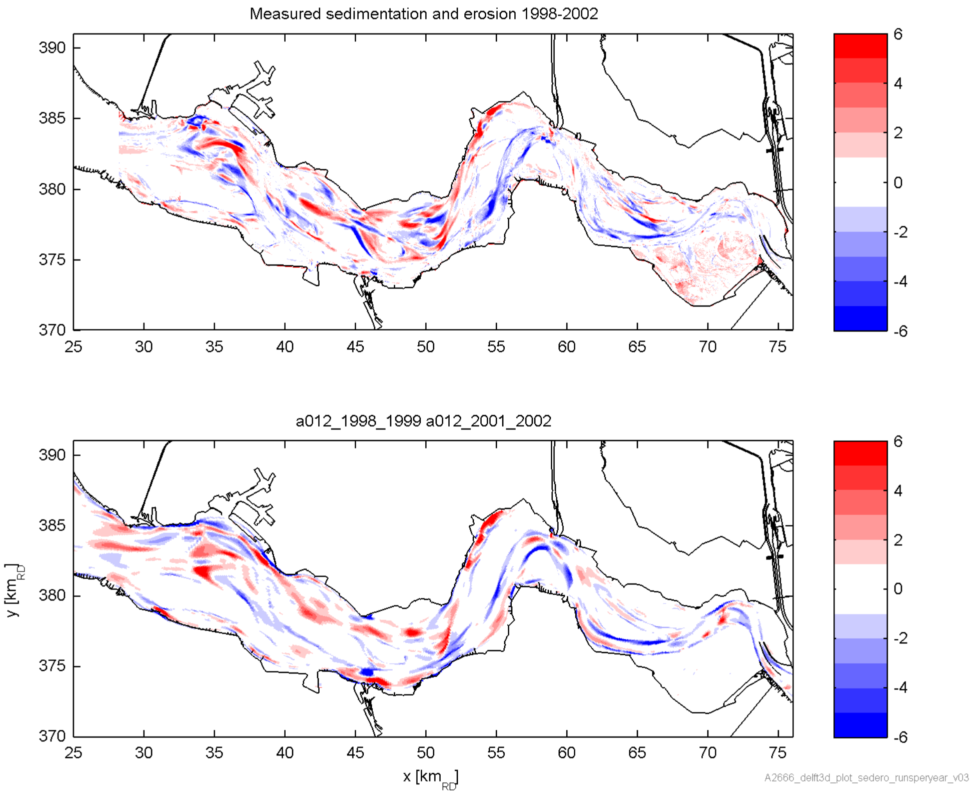

Figure 1. Measured and computed morphological changes between 1998 and 2002

A dredging strategy was chosen so that material dredged from the main channels was dumped into the side channels. Besides the safety of the hinterland, the leading factor in the further development of the Scheldt estuary seems to be the transport function of the estuary towards the port of Antwerp.

To investigate different dredging strategies, we have set-up a 2D Delft3D model of the whole Schelde estuary. Flow and sand transport processes with both tidal and wind forcing are being modelled. The first step will be to study whether the model is capable of reproducing the autonomous morphological changes for the period between 1998 and 2002. Next, we will investigate the effect of the different dredging strategies on the morphological changes. We will discuss the different sediment transport processes responsible for these changes. Figure 1 shows the measured morphological changes between 1998 and 2002 in the upper panel and a result of one of the simulations in the lower panel.

Enhancement of reverse estuarine circulation events and coastal connectivity due to plume intrusions from an alongshore estuary

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Connectivity between the coastal ocean and estuaries as well as between adjacent estuaries along a coastline can impact both the physics as well as the biology of these systems. Realistic hindcast ROMS simulations of the Pacific Northwest including the Salish Sea and Columbia River estuaries and the coastal ocean off of the Washington and Oregon coasts show these connections. The Columbia River plume during downwelling favorable winds can intrude into the Salish Sea via the Strait of Juan de Fuca. These frequent events reverse estuarine circulation in the Strait and create an important transport pathway both between the nearshore coastal ocean and the Salish Sea and between the Columbia River and the Salish Sea. While observations of these interactions have been made previously, particle tracking, model dye releases, numerical experiments, and a detailed examination of the total exchange flow at multiple cross-sections in the Salish Sea allow us to quantify the extent of the interaction between these two estuaries. In particular we find that downwelling wind alone can create these reversals, however the presence of the Columbia River plume strengthens the reverse estuarine circulation by up to two times within the Strait. The strength of this effect diminishes up-estuary but still strongly influences the exchange flow 100 km into the system, at the entrances to Puget Sound and the Strait of Georgia.

Validation of a wetting and drying algorithm in a shallow tidal creek and marsh system

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The Stevens Estuarine and Coastal Ocean Model (sECOM), a grandchild of POM and a child of ECOM, is a three-dimensional curvilinear hydrodynamic model that includes a robust wetting and drying algorithm. The model's wetting and drying performance and predictions were tested against observations in an application of sECOM to an interconnected, very shallow tidal creek and marsh system. Physical processes included downstream tidal and baroclinic forcing, upstream runoff, overland and overwater precipitation and evaporation, wind stress, and internally calculated two dimensional surface convective and advective fluxes. These dynamics were solved on a sub-meter scale numerical grid with average elevation above NAVD88, requiring an order-millisecond time step. The sECOM model was successfully validated against water level, temperature, and salinity datasets from multiple gages within the creek and headland marsh. Validation results will be presented, and comparisons with physically-truncated 2D barotropic model runs will be discussed.

How the effects of small and flexible seagrass (*Zostera noltii*) on flow modify erosion and deposition processes?

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By damping hydrodynamic energy from tidal currents and waves, seagrass canopies can strongly affect sediment transport and related erosion-deposition processes, with possible consequences on tidal flats morphological evolutions. Numerous studies focused on the modifications of hydrodynamics by long-leaf seagrass beds. Much less attention has been given to intertidal short-leaf species, such as *Zostera noltii*, and their cascading effects on flow modification and sediment erosion/deposition processes. The aims of this study were (1) to quantify the combined effects of leaf flexibility and growth stage of *Z. noltii* canopies (i.e., leaf density and canopy height) on hydrodynamics (i.e., current attenuation and turbulence), and (2) to deepen our understanding of the influence of vegetation-modified flows on bed erosion and deposition processes.

Flume experiments were conducted with natural seagrass beds of *Zostera noltii* and their substrate. Seagrasses were sampled at five different stages of their growth. One bare sediment was also sampled to be used as reference. The experimental protocol was designed in order to quantify the effects of seagrass development on (i) hydrodynamics, (ii) erosion fluxes of initial sediments, (iii) deposition fluxes of natural seeded sediments, and (iv) erosion fluxes of freshly deposited sediments.

Our results show an exponential decrease of canopy height when the free-stream velocity increased, resulting from the high flexibility of seagrass leaves. The flow attenuation pattern highlighted a density threshold resulting from the flow-induced reconfiguration of the canopy. Velocity attenuation was more efficient for denser canopies at higher velocities than for less-dense canopies. This was explained by the more-deflected flows for denser canopies at high velocities. The velocity attenuation was associated to a 2 to 3-fold increase in bottom shear stress compared with the reference, as measurements were recorded close to the upstream meadows boundary within the current velocity deflection zone. Few meters inside the meadow, bed shear stress strongly decreased compared to the reference case, due to velocity attenuation. An increase in sediment protection from erosion was observed for fully developed meadow, while sediment properties were found to be the main factor controlling erosion fluxes in a less developed meadow. A significant increase in deposition fluxes compared with the reference (from 10 to 50%) was found for all vegetated tests. This increase in deposition fluxes was related to the leaf density for low velocities. For higher current velocities, a canopy height threshold occurred, with enhanced deposition fluxes for higher canopies. The net deposition (after erosion of freshly deposited sediments) was found higher for all vegetated tests than for the reference. A development threshold was highlighted with a less net deposition for highest seagrass development. This less-efficient sediment trapping at high leaf area index was attributed to the sediment deposition on leaves, resulting in easier subsequent sediment resuspension. This novel flume experiment provided unique observations of plant/flow/sediment interactions for *Zostera noltii* seagrass species and quantification of erosion/deposition fluxes. These observations are used to calibrate an hydrodynamic and sediment transport model.

Modelling the water flow in presence of small and flexible seagrass *Zostera noltii*

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Seagrasses develop extensive submarine meadows in coastal areas around the world. By damping hydrodynamic energy from tidal currents and waves, seagrass canopies can strongly affect sediment transport and related erosion and deposition processes. Modelling the interactions between water flow and seagrasses is necessary (i) to better quantify the modifications of flow and turbulence in such environments, and (ii) to predict the implications of the presence of seagrass beds on sedimentation and morphological evolutions of coastal areas. Few studies focused on water flow modelling in presence of very flexible and short seagrass species such as *Zostera noltii*. The aim of this study was to provide a robust three-dimensional plant-flow interactions model to simulate the impact of *Z. noltii* beds on hydrodynamics from small-scale processes to regional-scale dynamics.

The three-dimensional hydrodynamic model MARS-3D (developed by Ifremer) was implemented and upgraded in order to simulate the effects of small and flexible seagrass species on hydrodynamics. These effects were taken into account through the impact of cylindrical structures on drag, turbulence production and dissipation. This was achieved by introducing additional source terms within the momentum equation and equations of the k-ε turbulence closure scheme. We introduced the plant-flexibility throughout variables describing vegetation features: (1) the modification of canopy height, (2) the modification the diameter of the cylindrical plant structure, realised by changing the angle between the plant structure and the bottom, and (3) the modification of the vertical distribution of plant elements related to modified canopy height. A 2DV flume-like model configuration was designed to reproduce hydrodynamic conditions observed during the flume experiments conducted in 2010 from real meadows patches and used for model calibration.

A good agreement between simulated and measured velocity profiles was obtained for different development stages of vegetation, both for the intensity and the shape of velocity profiles, and for the bed shear stress. A sensitivity analysis was performed over both the calibration parameters and the domain discretization. This showed that the model was mainly sensitive to the parameters describing the vegetation shape and density, and also to the vertical discretization. After a calibration against velocity profiles measured in the flume, the model demonstrated the correct simulation of flow establishment within a finite patch of vegetation. Further investigations were performed to evaluate the influence of seagrass beds with different spatial distributions on the sediment dynamics and morphological evolutions on the basis of a schematic cross-shore tidal flat.

A tale of two marshes: sediment flux mechanisms near Blackwater National Wildlife Refuge

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The Blackwater National Wildlife Refuge contains 53 km^2 of tidal marshes, on the periphery of Chesapeake Bay. Two adjacent regions of marsh, which drain into the Blackwater and Transquaking Rivers respectively, have demonstrated significant morphologic differences over the past century. Despite positive surface sediment accretion at both sites, landward tidal marshes drained by the Blackwater River have largely subsided and deteriorated into large expanses of submerged marsh plain while seaward marshes adjacent to the Transquaking River have successfully maintained their structure. Surface accretion does not guarantee stability, however, as net sediment fluxes constrain the sediment budget of the marsh-channel complex allowing inference into their relative stability. We measured sediment fluxes in tidal channels at both sites over a 10-wk period in Fall 2011. Dominant fluxes were identified as advective (mean flow), tidal dispersive (velocity and concentration correlation), and Stokes drift (velocity and area correlation) components, and normalized by the drainage area.

At the Blackwater River site (landward-most), mean advective flux (-0.64 kg m^{-2} y^{-1}, seaward) dominates and is correlated with northwesterly wind events that resuspend sediment over the submerged marsh plain; these same atmospheric events are responsible for forcing water out of Chesapeake Bay and out of the tidal channels on the subtidal timescale. Mean tidal dispersive flux (-0.21 kg m^{-2} y^{-1}, seaward) is of secondary importance due to the relatively low tidal energy at this site, and is caused by 25% higher concentration on ebb tide. Mean Stokes drift flux is an order of magnitude smaller (+0.08 kg m^{-2} y^{-1}, landward) as the tide range (and therefore fluctuation in channel cross-sectional area) is small.

Conversely, at the Transquaking River site (seaward-most), mean Stokes drift flux and tidal dispersive flux are of roughly the same magnitude (+0.83 kg m^{-2} y^{-1} each, landward) and are countered by the mean advective flux (-1.09 kg m^{-2} y^{-1}, seaward). In this case the progressive tidal wave leads to large correlations between flood-tide velocity and channel cross-sectional area; landward dispersive flux was generated by 15% higher concentration on flood tide and the presence of an estuarine turbidity maximum in the Transquaking River channel. SSC measurements from a site at the terminal landward end of the channel indicate that sediment advected in during flood tide is trapped within the channel/marsh complex.

In terms of net sediment availability, the stable marsh complex is importing sediment at approximately the same rate as the regional relative sea-level rise (~0.57 kg m^{-2} y^{-1}, or 3.1 mm y^{-1} at a bulk density of 182 kg m^{-3}), while the degraded marsh is exporting sediment due to a combination of resuspension and shoreline erosion. These results suggest that landward marshes, possibly formed during rapid land-clearing colonization, may be a source of sediment to seaward marshes that are favored by tidal processes over the short-term.

Relationships between erodibility and fine-grained seabed properties on tidal to seasonal time-scales, York River estuary, Virginia, USA

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Appropriate parameterization of time-dependent erodibility of muddy seabeds is a significant barrier to improved understanding and accurate modeling of sediment dynamics in estuaries and coastal seas. An ongoing sedimentological study at the MUDBED observatory in the middle reaches of the York River estuary investigates controls on cohesive bed erodibility by assessing changes in hydrodynamic and seabed properties over varying timescales. During April and May of 2010, multiple GOMEX box cores were collected over a five-week period chosen to correspond with the annual post-freshet dissipation of the York's secondary turbidity maximum (STM) while also resolving the relatively strong spring-neap cycle. Once a week for five weeks, box cores were subsampled for near-surface profiles of sediment water content, ^{7}Be activity, disaggregated grain size, and, based on gentle sieving, resilient pellet concentration and size distribution. In addition, images of internal layering were collected via digital x-radiography, and erodibility of the surface of the cores was determined via a Gust microcosm.

Over the observational period, bed erodibility (depth-limited eroded mass divided by bed stress) varied from about 0.5 to 1.2 $kg/m^2/Pa$. In terms of external forcings, erodibility was seen to generally decrease in time from April through May, following the annual post-freshet dispersal of the STM. In addition, bed erodibility fluctuated with the spring-neap cycle, with a maximum positive correlation found between erodibility and the averaged tidal range from the previous five days. Time since the end of the freshet combined with tidal range accounted for 80% of the observed temporal variation in bed erodibility. In terms of internal bio-geo-physical properties, bed erodibility was not significantly correlated with organic content (which varied from 6 to 12% dry weight), sand content (from 0 to 30% dry weight), or water content (from 60 to 80% by volume). Bed erodibility was, however, negatively correlated to pellet abundance (from 3 to 15% of total mud), positively correlated to ^{7}Be activity (from 0.8 to 3 dpm/g), and positively correlated to the degree of physical layering apparent in x-radiographs. Resilient pellet abundance alone accounted for 90% of the observed temporal variation in bed erodibility.

Together, these observations are consistent with the following conceptual model for the control of erodibility for biologically active, physically energetic muddy beds: Bioturbation and/or physical disturbance prevents dewatering of the uppermost (~ 1 to 2 cm) of the seabed to such a degree that bulk water content no longer plays its classically dominant role in determining erodibility. Rather, it is the fabric and aggregation state of the muddy bed that provides a better proxy for erodibility. Active trapping of flocculated mud particles results in a poorly aggregated and very easily eroded uppermost seabed. In terms of bio-geo-physical properties recovered by box cores, this state is more clearly identified by layered fabric in x-radiographs, high ^{7}Be activity, and an absence of pellets, rather than by percent water, sand, mud or organics. Conversely, under conditions of floc dispersal, resilient pellets are left behind and cohesion increases with time, which, in turn, lead to progressively reduced bed erodibility. Although active bioturbation and cyclical resuspension prevents a notable decrease in bulk water content within the upper few cm, the resultant churning of the bed and concentration of resilient pellets are clearly seen in box cores. Spring-neap cycles are superimposed on the above seasonal trend, with more intense physical disturbance at spring tide tending to break apart resilient pellets and cohesive bonds, increasing erodibility. Neap tide, in contrast, favors the net production pellets and increased cohesion, reducing erodibility.

PECS 2012, Manhattan, NY

Interaction of Near- and Super-Inertial Waves with East Flower Garden Bank

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Rough topography can promote mixing within the water column, and the intensity of the mixing varies with background flow. To quantify this mixing, an intense study was conducted at East Flower Garden Bank, part of the National Marine Sanctuary system. In addition to long-term instrumentation including acoustic Doppler current profilers (ADCPs) and temperature and salinity (TS) strings, short-term moorings were deployed for approximately ten days during the summer of 2011. These included 5 upward-looking ADCPs and one downward-looking ADCP each with a one-minute sampling frequency over and around the bank, and two TS string moorings that sampled every minute both over the bank and to the east of it. The string moorings had vertical spacing of approximately 10 meters. Additionally, either high-frequency pressure instrumentation or a wave-tide gauge was collocated with each ADCP. This suite of high-frequency measurements has allowed characterization of high-frequency internal waves over and around the bank, including spatial variability and changes relating to background flow conditions. Over the full year record for 2011, a series of near-inertial wave packets of varying intensity and duration were detected at the bank. These near-inertial waves, which overwhelmed local tidal flow, coincided with elevated super-inertial energy to the northeast and southwest of the bank. The rough topography of the bank is a likely generating mechanism for the high frequency waves when velocities are elevated by the near-inertial events.

Effect of reef roughness on wave set-up and surf zone currents

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The breaking of waves in the surf zone results in the generation of currents (cross and alongshore) which are important for the transport of sediment, larvae, nutrient uptake, and other processes. Several studies have shown that wind waves are the main drivers of circulation in reef lagoons (Coronado *et al*., 2007), and important efforts have been made to understand the effects of reef roughness on hydrodynamics (Hearn, 2011). Nevertheless, far less detailed knowledge exists on the wave driven processes that occur in the surf zone of reef crests and the effects reef roughness has on these flows. An integrated study, based on field observations and two-dimensional (2DV) numerical model simulations, is carried out in order to improve the understanding of wave-driven flows in the surf zone of a fringing reef. The model used in this study is Cornell Breaking Wave and Structures (COBRAS), which solves Reynolds-Averaged Navier-Stokes (RANS) equations. Due to their relatively high roughness, coral reefs alter the way in which waves break and dissipate their energy, and therefore affect the behaviour of radiation stress and wave-induced set-up. However, wave transformation may differ in these environments with respect to beaches. As an initial step, the effect of different roughness coefficients (Nikuradse) on wave height, wave set-up and radiation stress is studied for a mild-slope beach profile, which might represent the limiting scenario in a fringing reef at low tide. The Nikuradse roughness coefficient employed in the numerical model is expressed as a percentage of the grain size in metres. Model results revealed that wave set-up increases significantly with increasing bed roughness, consistent with prior studies on sandy beaches, while radiation stress remained relatively unchanged This has important implications, since the balance between radiation stress and set-up is the dominant forcing mechanism driving seaward flows such as undertows. Furthermore, an exploratory numerical experiment which includes small scale variations (order of metres) in an actual reef bathymetric profile explores the effects of roughness on hydrodynamics at different water levels. This approach evaluates reef structural complexity and avoids the use of arbitrary friction coefficients. Results of complexity effects on wave-set up and currents will be compared with detailed field measurements obtained from an instrumental array installed within the surf zone of the fringing reef lagoon of Puerto Morelos, Mexico

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Controls on particle settling velocity and bed erodibility in the presence of muddy flocs and pellets as inferred by ADVs, York River estuary, Virginia, USA

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Particle settling velocity and bed erodibility are key factors influencing fine sediment dynamics in coastal and estuarine environments. In order to better constrain inherently complex, temporally-varying relationships among hydrodynamics, bed properties and particle types, near-bed acoustic Doppler Velocimeters (ADVs) have been maintained at the MUDBED observatory in middle reaches of the York River Estuary since 2006. The ADVs provide measurements of burst-averaged bottom stress (τ_b, via Reynolds averaging of turbulent velocity), suspended sediment concentration (C, via acoustic backscatter calibrated by pump samples), and sediment settling velocity (W_s, via a balance between upward Reynolds flux and gravitational settling). Phase averaging of τ_b, C, and W_s reveal a hysteresis in suspension and settling which allows further separation of bulk W_s into components associated with wash load, low density flocs and high density pellets. Vertical integration of the settling component of C then provides an estimate of total eroded mass as a function of bottom stress. Finally, the proportionality between eroded mass and bottom stress provides a measure of the depth-limited bed erodibility (ε).

Analysis of data collected at the MUDBED site during the summer of 2007 highlights two distinct regimes with contrasting sediment characteristics. Regime 1 represents periods dominated by easily suspended, flocculated muds, while Regime 2 represents periods strongly influenced by less easily suspended, biologically formed pellets mixed together with flocs. Dominance by flocs during Regime 1 at the MUDBED site is associated with extensive trapping of flocs at a seasonally present density front; while the strong influence of pellets during Regime 2 reappears with the seasonal departure of the density front and dispersal of the recently trapped flocs. Bottom drag coefficients derived from ADV measurements were observed to be significantly lower during Regime 1 than Regime 2, consistent with the presence of a salinity-induced density front during Regime 1, possibly enhanced by sediment-induced stratification.

During the floc-dominated Regime 1, erodibility (ε) averaged about 3 kg/m^2/Pa and τ_b for initiation of erosion (τ_{cINT}) was only 0.02 Pa. During the pellet influenced Regime 2, ε dropped ~ 1 kg/m^2/Pa, and τ_{cINT} increased to 0.05 Pa. During the floc-dominated Regime 1, a remarkably stable value of W_s = 0.85 mm/s for the settling component of C was observed, consistent with floc size limitation by settling-induced turbulence rather than turbulence associated with τ_b. In contrast, during the pellet-influenced Regime 2, W_s for the settling component increased with greater τ_b, consistent with suspension of heavier pellets at higher τ_b and a limited supply of flocs due to bed armoring by pellets. Based on an estimate of 20% washload, 50% flocs and 30% pellets at peak τ_b during Regime 2, the mean W_s for the pellets was calculated to be about 2 mm/s.

Once τ_b had peaked and then started to decrease during a given tidal cycle, the pellet component of C was seen to decrease relatively quickly. But floc C did not rapidly decrease during either regime until τ_b dropped below about 0.08 Pa. This suggests that over individual tidal cycles, cohesion of settling flocs to the surface of the seabed is inhibited for τ_b larger than ~ 0.08 Pa. Averaged over 25 hours, floc erodibility on a given day was positively correlated to the magnitude of τ_b observed over the previous 5 days, providing an in situ estimate of a consolidation-relaxation time-scale for homogeneous estuarine mud. In contrast, erodibility during periods strongly influenced by pellets was inversely correlated to τ_b with a zero time lag, which is more consistent with bed armoring.

Mechanisms driving the circulation in a fringing reef lagoon: a numerical study.

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The circulation in fringing reef lagoons is often dominated by wave induced setup and radiation stresses. Puerto Morelos is a shallow tropical reef lagoon in the Mexican Caribbean, subject to intense solar radiation, seasonal high precipitation rates, and extreme meteorological events such as cold fronts and, tropical cyclones. Previous studies in Puerto Morelos confirmed the dominance of waves in driving the circulation inside the lagoon (Coronado, et.al. 2007). However, additional forcing such as wind, storm surges, tides and thermohaline gradients might influence the circulation too.

This study aims to investigate the relative importance of various forces that drive the circulation both inside the fringing reef lagoon and around the reef. Relative contributions were determined through sensitivity tests using the coupled wave-hydrodynamic model DELFT3D. Numerical results revealed that wind and thermohaline gradients affect the circulation, especially during moderate wave conditions, which are common in the region (significant wave height $\leq$ 0.8m). Dominant winds from NE to E enhance the setup inside the lagoon, which drives along-reef currents toward the south. Southeasterly winds, however, drive currents to the north and a well-developed onshore flow in the southern end of the lagoon. On the other hand, a thermohaline contribution results in different current pattern. Submarine groundwater discharges, found mainly in the northern part of the lagoon, produce anticyclonic circulation in the northern half and southward currents in the southern half. The tidal contribution is markedly weaker but generates residual currents directed to the southwest (parallel to the shore) in the lagoon plus it controls wave breaking (i.e., radiation stress gradient) on the reef barrier. Findings do not only confirm that waves are the dominant forcing mechanism driving the currents in Puerto Morelos lagoon, but also portray the flow structure generated by wave setup (affecting the lagoon circulation and water exchange) and by the momentum exerted from radiation stresses when waves break in the reef region (affecting the transport of nutrients, larvae, etc. within the reef).

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Sea breeze/land breeze (SBLB) forced currents in the Big Bend Region of the Gulf of Mexico

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Near the critical latitude of 30 deg N/S, the local inertial frequency is diurnal, and a near-resonant response to diurnal forcing can be observed in the atmosphere and ocean. Analysis of observed wind and currents in the Big Bend Region (BBR) in the northern Gulf of Mexico reveals that sea breeze/land breeze (SBLB) winds can be a source of shelf-wide wind forcing near the resonant frequency. Diurnal/inertial currents increase with distance offshore, and account for up to 70% of the total current variance. Maximum atmospheric forcing and associated response occur in spring, which has significant implications for larval transport of gag grouper and important fisheries.

SBLB-forced currents usually have a two-layer vertical structure, but previous work in the Georgia Bight revealed an unusual three-layered vertical structure of SBLB-forced currents, in which flow in the pycnocline is 180 degrees out of phase with surface currents, with no inertial/diurnal motions in the bottom boundary layer (generated by moderately strong tidal currents, 35-45 cm/s). While tides are generally weak in the Gulf of Mexico, the broad shelf of the BBR amplifies the barotropic tide on the shelf. Closer examination of co-located wind, ADCP, and T-chain data in the BBR and comparison to previous observations in the Georgia Bight suggest that the tides and their associated bottom boundary layer structure play a significant role in setting the vertical structure of SBLB-forced currents.

Numerical modeling of density-induced SPM transport into the Western Wadden Sea across tidal watersheds

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It has been known since long that fine suspended particle matter (SPM) is transported into the Wadden Sea from the adjacent North Sea (Postma, 1961). The Wadden Sea is located along the coast of The Netherlands, Germany and Denmark and separated from the North Sea by a chain of islands. The supply of SPM comes largely from The Channel; it is transported northward along the Dutch coast and is estimated to be in the order of 20 Mtons/year (De Kok, 1994). The SPM flux through the Marsdiep, the first inlet of the Wadden Sea, is estimated from NIOZ ferry measurements to be in the order of 5-10 Mton/year (Nauw, 2009). It is unknown if it is partly exported through other inlets back into the North Sea. To date, no observational information is available for the other major inlets of the Western Wadden Sea.

In this paper, the net SPM fluxes into the Western Wadden Sea are studied by means of the Delft3D and GETM/GOTM numerical models. Our first aim is to provide an indication of the direction and order of magnitude of the net transport for the second major tidal inlet, the Vlie. This work is part of the international project PACE where eight institutes from The Netherlands, Germany and Denmark are making a concerted effort to describe and quantify the sediment transport in the entire Wadden Sea.

Until recently, the trapping of SPM at the Wadden Sea was fully attributed to tidal asymmetries in sedimentation and resuspension of SPM (settling and scour lags). However, these processes are important only on the intertidal flats and not at the inlets. Therefore, an additional explanation is needed to understand how SPM ends up near the intertidal flats. Recently it was suggested that density-driven circulation across the tidal inlets is the dominant process importing SPM into the Wadden Sea (Burchard et al., 2008). This implies that accurately simulating the three-dimensional density structure is a prerequisite for meaningful SPM modeling. In the PACE project, we test the hypothesis that density-driven circulation is in fact the main process responsible for importing SPM into the Wadden Sea.

The density structure in the Western Wadden Sea is dominated by two fresh water sluices, which release an average of 400 m^3/s into the Marsdiep basin on a daily basis. Part of this freshwater leaves the Wadden Sea through the Texel inlet; the remainder crosses one or more tidal watersheds and leaves the Wadden Sea through subsequent tidal inlets. Hence a crucial modeling aspect is the location and handling of the open model boundaries near watersheds. Although the tidal velocities are by definition diminished near watersheds, it is shown that a closed boundary does not yield correct results, mainly because of the inhibition of residual exchange of (fresh) water across the watershed. It is found that at least the five tidal inlets from the island of Texel to Schiermonnikoog must be included to properly assess the transport at the Vlie inlet.

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Role of thermal fronts on the circulation over the bay of Biscay Shelf.

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Abstract

From the north to the south of the bay of Biscay, many strong thermal fronts have been pointed out over the last three years:

- the very well known Ushant thermal front have been proven to get a more complex structure than thought up to 2009 : Le Boyer et al (CSR, 2009) evidenced the existence of a bottom front which seems to be decoupled from the surface one already clearly seen thanks to remote sensing,
- Lazure et al (JMS, 2008), highlighted an intense autumnal circulation over the bay of Biscay shelf, to the south of Brittany. Their analysis based on many drifters tracks shows it approximately follows the 100m isobath and its mean velocity magnitude reaches 10 cm/s. SST satellite data show a large warm tongue expending from the south to the north that is strongly correlated with this autumnal current (fig 1).
- Batifoullier et al (JGR, 2012) describe a mechanism that drives a narrow coastal current which involves the formation of a thermal bottom front in the southern corner of the bay of Biscay.

We thus get a collection of processes in a very short extended area that all involves thermal bottom fronts in a way or another. The time and spatial scales of these fronts are very different and thus are the mechanisms that create and sustain them. They are finally deeply different from place to place because of the coastal geometry, width of the shelf, bottom slope, because of the tidal characteristics, the thermal stratification and last the wind regimes…

The main equilibriums that underlie the intense circulations tightly associated with these fronts are investigated thanks to numerical modelling and show the primary role played by pumping would it be induced by surface or bottom friction. Finally, as the circulations thus generated are very intense (from 20 cm/s to more than 70 cm/s) and close to each other (less than 600 km from the south to the north of the bay of Biscay) we investigate the way they are connected between each other and the impact they have on the renewal of the water masses of the bay of Biscay shelf.

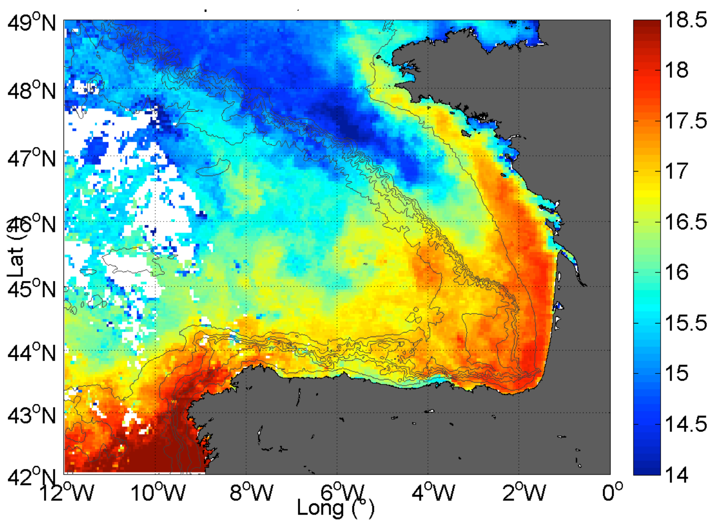

Figure 1 SST scene from MODIS on November 2006, 1st

Intercomparison of Sediment Transport Formulas in long term morphodynamics

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Morphodynamic models are increasingly adopted to investigate bed evolution of the coastal areas in different spatial and temporal scales (Dissanayake et al., 2009). Predictability of these models explicitly depends on the applied transport formula. Present study compares the bed evolution of the Ley Bay area under three sediment transport formulas, 1) Van Rijn (1993)-*VR93*, 2) Van Rijn et al (2004)-*VR04* and 3) Soulsby-Van Rijn (Soulsby, 1997)-*SVR*, which are dedicated for wave-current environments. The Ley Bay is located in the Osterems basin in the East Frisian Wadden Sea and has shown strong morphological changes due to construction of the *Leyhörn* peninsula in 1984. Simulations span over a 15 year period from 1975 to 1990.

Approach used the 2DH process-based model, Delft3D, with on-line morphology technique (Roelvink, 2006). Spatial discretization of the horizontal advection of momentum and transport was implemented in terms of Cylic method (Stelling and Leendertse, 1991). Model bed consisted of spatial varying bed roughness and multiple sediment fractions (Dissanayake et al., 2010). Tidal force was based on the astronomical tide and few statistically representative wave conditions were imposed for the wave boundary. Both tidal and wave boundaries used a nested approach to transform offshore conditions to nearshore. Three models were simulated applying each transport formula of which their sediment transport related coefficients are based on the previous long term morphodynamic studies in the Wadden Sea area.

Results indicate a sediment exporting system in the Ley Bay during the 15 year period. Prior to implementing the peninsula, application of *SVR* showed strong export (0.05 Mm^3) compared to that in *VR04* (0.04 Mm^3) and *VR93* (0.03 Mm^3). These amounts became one order of magnitude lower after applying the peninsula whereas they consisted with the similar trends as were prior to the peninsula. In all applications, the basin channel pattern showed strong sedimentation (Fig.1). Predicted basin channels of the *VR04* formula indicated an agreement with the 1990 measured bed (*BSS*>0) compared to the other two cases. This was further evident by comparing the evolution of the channel cross-sections and the overall geometry of the basin in terms of the area-depth hypsometry. Inherent strong sedimentation areas around the *Leyhörn* of the measured bed are expected due to the manmade activities. Ongoing work focuses on more detailed bed configuration around the *Leyhörn* peninsula in the simulation after its implementation.

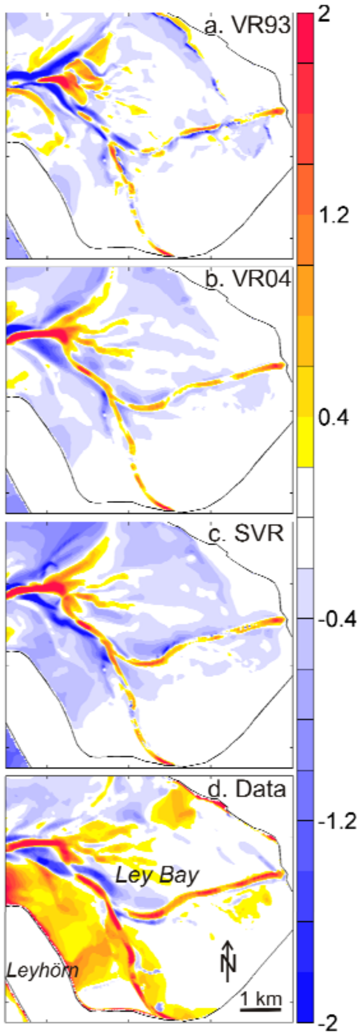

Fig.1 Erosion/sedimentation from 1975 to 1990

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Spatial and temporal variability of currents and total suspended matter in a periodically stratified estuarine tidal basin

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Abstract

Currents are important in estuaries driving sediment and nutrient transport. In the Marsdiep basin, the Netherlands, the most southern inlet of the UNESCO world heritage site the Wadden Sea, the spatial and temporal variability of current characteristics and their relation to Total Suspended Matter (TSM) transport is investigated.

The Marsdiep is a highly dynamic tidal inlet system consisting of two main channels with a variation in water depth between 5-35 m surrounded by tidal flats. Large density gradients have been observed with a high temporal and spatial variability mainly caused by fresh water inflow and differential advection. The variability of the secondary currents is described by Buijsman and Ridderinkhof (2008) along a transect in the Marsdiep inlet. Furthermore, the tidal channels are curved, inducing secondary currents which may enhance or oppose the density-driven secondary currents. Also, the Coriolis force may be of importance. Another example of the temporal variability of each contributors of secondary currents to the transverse momentum equation was done by Lacy and Monismith (2001) in the Northern San Fransisco Bay. In the Marsdiep, periodic stratification occurs frequently and fronts form every tidal cycle. The exact mechanisms determining the interaction between the occurrence of stratification, the behavior of the fronts and the currents has not yet been investigated.
The importance of asymmetry in mixing and stratification on the estuarine circulation as described by Geyer et al. (2000) has not been investigated in the Marsdiep but might be an important factor for sediment and nutrient transport. Flöser et al. (2011) concluded that an estuarine circulation is present in the German Wadden Sea based on an analysis of the vertical velocity profile. However, conditions are different in the Marsdiep and a brief analysis of Buijsman and Ridderinkhof (2007) found a different vertical velocity profile during ebb and flood. More research is required.

In the highly dynamic Marsdiep basin, a large variety of estuarine and tidal processes occur which makes it worthwhile to investigate the variability in tidal current characteristics and related total suspended matter transport in the Marsdiep basin.
At PECS 2012, a large variety of measurements (flow velocity, TSM, salinity, temperature and turbulence) in the Marsdiep are presented focusing on the analysis of the spatial and temporal variability of the vertical velocity profile, their tidal and residual component, the secondary currents and the relation of the tidal currents to TSM concentrations.

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Salinity and flow distribution in estuarine networks

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Many estuaries worldwide (e.g. Queen Charlotte Sound, Canada, Yangtze) are characterized by a network of bifurcating channels, in which water motion is primarily forced by fresh water discharge and tides. The interaction between density gradients and mixing processes result in a complex flow and density field. Observations indicate that distribution of flow and density fluxes at vertex points strongly depend on forcing parameters and on the geometrical characteristics of the network. Moreover, tidally averaged flow and density show significant variations over the spring-neap cycle and over seasonal timescales. Insight into the dynamics of estuarine networks is crucial to develop effective tools for maintaining or improving their ecologic and economic value.
The considerations given above motivate the aim of this presentation, i.e., to gain fundamental knowledge about feedbacks between tides, mean flow and salinity in an estuarine network configuration. A simple model will be discussed that involves the width-averaged shallow water equations, is prognostic in salinity and assumes partially to well mixed estuaries. Solutions are obtained by means of semi-analytical methods. Compared to earlier work, the new aspects here are the consideration of a network and the incorporation of a more realistic formulation for vertical and horizontal mixing processes. Results of flow and and salinity distribution (both tidal and mean components) will be shown and discussed for a triple channel network. Specific focus will be on how the distribution of mean flow and salt transport at the vertex point depend on values of the forcing and geometric parameters. Results will also be compared with field data that were collected in the Berau estuary (Indonesia).

Relating multiple years of SST and SPM surface signatures in the Southern North Sea to known water masses

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Keywords: Remote sensing; NOAA AVHRR Sea Surface Temperature; SeaWiFS Suspended Particulate Matter; Shelf sea stratification; Wind and tidal mixing; Turbidity

In a recent paper Pietrzak et al. (2011) investigated the joint behaviour of SPM and SST in the Southern North sea. For one year (1998), they had 167 SST (KNMI NOAA POES) and 163 SPM (NASA SeaWiFS) images at their disposal, and performed a harmonic analysis to extract spatial maps of the annual mean plus the seasonal and fortnightly cycles. These SST and SPM maps show similar behaviour in East Anglia plume and the Rhine ROFI (plume). In the Central North Sea a clear seasonal thermal stratification signal is observed in the SST, with an associated modification in the SPM signal. In the Rhine ROFI a clear fortnightly signal is observed in the SST signal, yet caused by haline stratification, with an associated modification of the SPM signal as well. The authors hypothesized that when an area is stratified, it typically exhibits low surface SPM values. The causal mechanism theoretically found by Geyer (1993) and confirmed by in situ data of de Nijs et al. (2011) is hindered mixing at the pycnocline. Pietrzak et al. (2011) found that this trapped fine sediment in the bottom layers, resulting in low surface SPM values as long as the stratification persists. When the waters become well-mixed, the bottom SPM values reappear in the surface signatures as observed by satellites.

Here we extend the analysis of meso-scale features in the Southern North Sea using infrared and ocean color remote sensing imagery. Using additional data, 15 years of SST data (1990-2005) and 4 years of SPM data (1998-2001), we now study the inter-annual variability of SPM and SST features. The increased length of the new datasets also allows us to assess the persistence or variability of the features identified by Pietrzak et al. (2011). In analogy with genetics, we treat the surface signatures of these features as remote sensing 'phenotypes' of the Southern North Sea, and investigate their relation to the 'genotypes' of the Southern North sea. The 'genotypes' are the well-known water masses or water types historically based on salinity and tracer information (e.g., Lee, 1980). We show that one water mass can have multiple 'phenotyical' appearances in SST and SPM imagery, but also that one 'phenotype' can be found in multiple water masses.

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The morphodynamic interaction between delta and estuary under conditions of sea level rise

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In the discussion about management of estuaries it is important to know the reaction of these systems to sea level rise. This research shows that the morphodynamic reaction of an estuary to sea level rise is closely related to the interaction with the (ebb tidal) delta seaward of the inlet gorge of an estuary. Highly schematized 1D and 2D modeling exercises show that the estuary is initially exporting more sand to the delta under sea level rise conditions. When the delta is regarded as an integral part of the estuary sea level rise causes less sediment loss under exporting conditions or more sand import under importing conditions, in accordance to general theory.
The base case of this research is a very simple estuary of 80 km long and 5km wide as investigated before by Hibma (2003) and Van der Wegen & Roelvink (2008). The initial depth is set at 8m and a 1.75 m amplitude M2 tide enforces the seaward boundary with no river runoff at the landward end. The case is carried out with an Engelund-Hansen sediment transport formula with a grain size of 240 µm. The research is carried out using a 1D depth averaged model with only 1 gridcel over the width of the estuary. Sea level rise was applied for a mild scenario of 10cm per century. In total 8000 year is simulated. Two models were constructed: the first case was without a delta and the second case was with the delta. The delta is expanding in width from the inlet to the seaward boundary and has a length of 20km. In the first case (without delta) it was found that under all circumstances the estuary is gaining sand due to sea level rise. In the second case with a delta in front of the estuary it was found that the estuary was initially exporting more sand to the delta under sea level rise conditions, which is different than the first case. The volume change of the estuary and the delta together still shows a gain of sand. Only after a few thousand years, when the sea level rise causes the bed level in the estuary to grow further and further the sea level rise case show less export than the case without sea level rise. Further extension of the research by allowing 2D pattern formation (similar to Hibma (2003) and Van der Wegen & Roelvink (2008)) shows similar results.
Furthermore a more realistic case was set up based on the outline of the Western Scheldt estuary. This estuary is also approximately 80km long and 5km width. A 2Dh model with a real bathymetry was set up, calibrated and verified against observed morphological developments. This model was then used to investigate the impact of sea level rise. The mouth of the Western Scheldt shows relative erosion under sea level rise conditions, while the delta and the landward side shows relative sedimentation, similar to the simplified 1D and 2D cases.
The M2 and M4 tides will be examined to give a physical explanation for this phenomenon. Other length scales of the estuary and depths will be included in future research, as well the influence of waves in the delta.

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Tidally-induced boundary mixing in a large scale estuary

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The Lower St. Lawrence Estuary (LSLE) is a large (~50km) and deep (> 300m) estuary located in eastern Canada and considered part of the Gulf of St. Lawrence. In a previous study, we showed that mixing at boundaries can play a significant but not dominant role in the mixing budget of the LSLE. With the aim of identifying mixing mechanisms occurring both at the boundaries and in the interior, i.e., far from boundaries, we examine the role of tides in the modulation of turbulence, using about 2000 casts taken between 2009 and 2011 with a vertical microstructure profiler and two high resolution moorings deployed in fall 2011.

Preliminary results show that while the semi-diurnal (M2) and fortnightly tide cycles have little incidence on interior mixing, they do influence mixing at the boundaries. Episodic shear intensification periods appear in the bottom boundary layer during low tide and higher dissipation rates of turbulent kinetic energy are observed ~2h before high tide. Observations from the microstructure profiler also show that the dissipation in spring tide is twice as high as during neap tide.

Circulation of the Terminos Lagoon, Mexico: observations and modeling

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ABSTRACT

The circulation patterns inside the Terminos Lagoon are investigated using a baroclinic 3D hydrodynamic model (MARS3D). The modeled sea surface elevation, currents, salinity and temperature are validated by comparison with data derived from measurements carried out in 2010 – 2011using ADCP's currents, a gauging network conformed by six self-recording pressure-temperature sensors, bi-monthly CTD campaigns over 35 points, bottom tracking, drifters and 3 meteorological stations.

Tidal patterns in the study area vary from mixed-diurnal outside and in the inlets of the lagoon to diurnal inside it. The numerical modeling was carried out considering 8 harmonic components, surface forcings from a high resolution meteorological simulation using the WRF, with boundary conditions from the NARR. The regional circulation in the Gulf of Mexico was considered using boundary conditions from the US NAVY operational HYCOM, and the river discharges were obtained from the Mexican hydrographic network. The hydrodynamic model is used to study the circulation patterns of the water masses inside the lagoon, considering different weather conditions that represent the most frequent over the study region, in order to evaluate the importance of the different forcings.

Horizontal motions in estuaries:
The range of scales and the implications for horizontal mixing

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Abstract:
Fluid motions in estuaries are characterized by a wide range of length and timescales, from turbulent motions at the smallest scales to basin-scale residual circulation at the largest. Intermediate to these endpoints lie tidal timescale motions, including tidal currents and secondary circulation. An important point of emphasis in the study of estuarine fluid dynamics has been how these shorter and smaller scale motions (on tidal and turbulent timescales, typically) affect the large-scale estuarine circulation. Analysis during the last two decades has concluded that tidal timescale processes are critical to establishing the estuarine circulation, and that turbulence dynamics are fundamental to the shear field on the tidal timescales. The dynamical connection across these widely disparate scales is one of the challenges in understanding estuarine dynamics.

Most study of small-scale motions in estuaries has focused on turbulence in the water column, where the production of turbulence is dominated by vertical shears in tidal currents. These turbulent motions then interact with tidal timescale features, including both the primary tidal currents and secondary flows, to define long-term transport. By going from water column turbulence to tidal circulation to estuarine circulation, however, an important class of motions is missed in the analysis. These motions, which are largely in the horizontal plane, are characterized by time variability shorter than the tidal period, but longer than turbulent timescales. Observational evidence of variability at these temporal and spatial scales has only recently become available, through the use of remote sensing, in-situ moorings and boat-mounted transects. In this talk, we present data from and analysis of a shoal-channel transition at which intra-tidal motions (variations on timescales from 10s of minutes to a couple of hours) play an important role in lateral mixing. The role of this mixing in establishing larger-scale estuarine transport is also explored. We concluded that scale-separation into “turbulent”, “tidal” and “residual” flows may not be appropriate in many estuarine flows, but instead a description based on a continuous distribution of motions may be required.

Turbulence Dynamics and Vertical Mixing at the Shoal-Channel Interface in a Partially Stratified Estuary

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In partially stratified shoal-channel estuaries, variations of vertical turbulent mixing develop across the shoal-channel interface: as a result of bathymetry variations the water column over the shoals is generally well mixed or less stratified than that over the channel. This study focuses on density stratification and turbulence dynamics on the slope, which are essential to quantifying momentum and scalar fluxes across the shoal-channel interface but remain poorly characterized. Vertical profiles of velocity, salinity and Reynolds stress collected every 30 minutes throughout a tidal cycle in South San Francisco Bay in March 2009 are used to estimate and compare the tidal evolution of turbulent kinetic energy (TKE), TKE shear production, TKE buoyancy production and TKE dissipation rate between the channel and on the slope. Consistent with previous studies, we find that TKE shear production is maximal at both locations when tidal currents are strongest (peak ebb and flood). However, we observe a late ebb increase in TKE shear production midway up the water column on the slope even though the tidal current velocity (principal component) has significantly decelerated. Simultaneous with this late ebb increase of TKE shear production, a transverse circulation develops over the slope, advecting water from the shoal in the lower half of the water column and from the channel in the upper-half of the water column. Using these observations and a one-dimension numerical model, we discuss the processes controlling turbulence dynamics on the slope and the implications for vertical mixing.

River plume source-front connectivity

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The transition region between the near-field and far-field plumes is the mid-field. This is where flow is redirected form offshore to downcoast. In a tidally pulsed regime, the transition from the near to far-field happens in conjunction with the transition from tidal plume to recirculating or far-field plumes. A division between the old and new plume waters is the tidal plume front; its propagation, relaxation and dissolution plays a significant role in mid-field dynamics. Recent studies tie frontal propagation to the timing and magnitude of estuarine discharge. The goal of these numerical experiments is to examine pathways of source water through the core of the plume, quantify the amount of source water versus entrained water that reaches the tidal plume front and determine when the connection between the source and the front is arrested during an ebb cycle. These objectives are pursued using numerical drifters and dye releases at the estuary mouth in idealized and realistic ROMS simulations of the Merrimack River plume. Numerical simulations indicate that drifters released at early ebb spread radially and reach the plume front everywhere while drifters released later in ebb only reach the portion of the front down the plume axis. A jet forms behind the front halting the communication between the mouth and the upcoast portion of the tidal plume front. The last dye patch to reach the front during ebb is released ~3 hours after the start of ebb. These experiments exhibit evidence of ebb-to-ebb interaction, as remnants of older plumes on the shelf are entrained into the new tidal plume. Dye releases at the estuary mouth by salinity class indicate that deep, high salinity source water is mixed to the surface in the near-field and overtakes the front during ebb. Furthermore, wind, discharge and ambient stratification modify the concentration of source water that reaches the front.

Data assimilation for morphodynamic modeling of tidal channel migration

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This study investigates the use of data assimilation in morphodynamic modeling of channel migration. We use a tidal channel (Medem) at the Elbe estuary, German Bight, Southern North Sea as a study site. A lot of efforts have been done in model simulation of river channel migrations, however, rare in coastal tidal channels. Observed bathymetric data analysis shows a distinct pattern of migration of the Medem channel (Medemrinne) between 1990 and 2007. The Medem channel moved northward approximately 1700 m over 17 years with an average migration rate of 100 m per year. The southern bank is flatting while the northern bank is steeping. This pattern calls for a morphodynamic modelling simulation. This preliminary study focused on the period from 1990 to 1993. A 2D depth-averaged numerical model was set-up based on the modeling system DELFT3D. The model was calibrated and validated against measured water level data throughout the model domain. The morphodynamic model results show that the model was not able to reproduce the channel migration due to the complex physical processes and limitations of numerical models. A 3D-variational data assimilation scheme was then applied on the morphodynamic model to test the channel migration patterns. The 3D-variational method carries out the analysis by looking for a state which minimizes a cost function measuring the misfit between the model state and the observation term. The analysis is a combination of model prediction and the observation with weights inversely related to their relative errors. If the background errors are larger compared to the observation errors, higher weights will be distributed to the observation term, and vice versa. In this study, the observed bathymetry of 1993 was assimilated to the model predicted bathymetry. Specification of the model prediction error covariance matrix is one of the most crucial procedures of the assimilation scheme which was done by specifying the error correlations. The error correlations govern the spreading and smoothing of observational information during the assimilation process. A user defined correlation length scale for controlling the error correlation was selected as a parameter for testing the generated morphological patterns. The spatial selection of the correlation lengths was carried out in both circle and ellipse areas. General results show that the generated patterns of Medem channel are not sensitive to the error correlation lengths due to the larger model errors compared to observation errors. However, results demonstrate that smaller error correlation lengths generated discontinued bathymetry in the deep channel while larger error correlation lengths produced over-smoothed bathymetry and the information of deep channels and bars are missing. Brier skill scores evaluation show that the error correlation length similar to the grid cell size gives the highest score. By extending the searching length in the east-west direction in ellipse area, more realistic channel depth is produced. This study brings new insights to the application of data assimilation scheme to coastal morphodynmaic modelling of the channel migration.

The role of lateral advection in residual dynamics of tidal estuaries

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The classical theory of estuarine exchange flow is based on a linear momentum balance in along-estuary direction assuming that nonlinear advection terms are negligible. However, the lateral advection that is related to lateral circulation has been recognized to be as important as longitudinal density gradient in driving residual estuarine currents. In this study, we carried out a series of generic numerical experiments using ROMS to explore the role of lateral advection in residual estuarine dynamics. The estuary channel has a triangular transverse section, and is 500 km long. Tides were specified as the turbulent mixing agent in the estuaries while winds were excluded. The turbulence closure, k-ω was used to calculated vertical eddy viscosities.

Two groups of experiments were conducted. In the first one, we examined the effects of stratification. The width and the depth of the transverse section of the estuary channel were fixed whereas the freshwater discharge and amplitudes of S_2 tide at the open boundary were changed in order to obtain various stratification conditions in the estuary. As turbulent mixing increases, the relative importance of lateral advection term in the along-estuary momentum equation increases, reaches a maximum that shows the same magnitude as the longitudinal density gradient, then tends to decrease. The result indicates that increasing tidal mixing accelerates lateral circulation but strong tidal mixing would suppress lateral circulation. The residual flow induced by lateral advection can be calculated using a decomposition method. The magnitude of lateral-advection-induced flow is smaller than the gravitational circulation when mixing is weak, and is larger (could be 3 times in this study) when mixing is strong. The transverse distributions of lateral-advection-induced flow indicate that lateral advection generally tends to reinforce gravitational circulation under strong mixing and tends to compensate gravitational circulation under weak mixing.

In the second group of experiments, we examined the effects of the width of an estuary. The maximum depth of the transverse section of the estuary channel, freshwater discharge and tidal amplitude at the open boundary were fixed. Along with increasing width, the relative importance of lateral advection in along-estuary momentum equation decreases. The ratio of magnitude between lateral-advection-induced flow and gravitational circulation shows a different trend, which increases, reaches a maximum, then decreases. From the transverse distributions of the lateral-advection-induced flow show, the residual flow tends to be laterally sheared as the estuary becomes wider, clearly reflecting the effect of Coriolis forcing. The lateral-advection-induced flow generally tends to reinforce the gravitational circulation.

Modeling the competition between wind-driven and density-driven circulation in the Ems estuary

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Keywords: wind-driven circulation, density-driven circulation, 2DV hydrodynamic model, Ems estuary

Abstract

The Ems estuary is a semi-enclosed body of water on the border between the Netherlands and Germany. Many aspects of estuaries (turbidity patterns, morphology, water quality) are controlled by residual circulation, which in turn results from the complex interplay among tides, wind, density gradients, river discharge and topography (De Jonge 1992, Talke & de Swart 2006). In this study, we investigate the relative importance of the (non-tidally induced) residual circulation by developing a simple analytical hydrodynamic model.

As a first step, we focus on the width-averaged dynamics in a basin with an arbitrary depth profile. We adopt the steady shallow water equations, imposing a spatially varying wind stress field at the free surface (see e.g. Schmidt & Von Storch 1993). Turbulence is represented using a constant vertical eddy viscosity combined with a partial slip condition at the bed. We use a diagnostic density field, based on observations (Talke et al. 2009). Furthermore, a river discharge is imposed at the upstream boundary, whereas the water level is prescribed at the downstream boundary.

A next step is to drop the width-averaged assumption and to develop a fully 3D residual flow model including rotation. We thus extend Winant's (2004) work by refining the turbulence model (partial slip) and including density-driven circulation.

In both cases, the solution is a superposition of river discharge, a wind-driven and a density-driven part. We analyze the relative importance of these contributions for the specific case of the Ems estuary and Pearl River Estuaries (China) and compare with observations. A broader goal of the project is to investigate the influence of topography on the above processes, related to the impacts of large-scale sand extraction.

Preferred type of presentation: Poster

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Across-stream momentum budget of positively and negatively buoyant river outflows

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The rapid spreading and mixing in the near-field region of river plumes have profound influences on the far-field plume evolution. Yet, the dynamics as the plume transitions from a near-field inertial jet and far-field geostrophic currents remains poorly understood. In this study, we use a 3D hydrodynamic model (ROMS) to investigate the across-stream momentum budget along the plume streamlines on sloping shelves. Both positively (hypopycnal) and negatively buoyant (hyperpycnal) plumes are considered. The hyperpycnal cases are motivated by outflows of mountainous rivers which occasionally have enough sediment to be denser than the ambient seawater. It is found that the layer-averaged, across-stream momentum balance of positively buoyant plumes is cyclo-geostrophic: a balance between Coriolis, centrifugal, and pressure gradient forces. In the near field, the balance is principally between centrifugal and pressure gradient, whereas in the far field the flow approaches a geostrophic balance. The transition appears to coincide with an along-stream location beyond which the flow switches from critical to sub-critical. For negatively buoyant plumes, before the plumes dive as undercurrents, the across-stream momentum balance is between pressure gradient and centrifugal, just as in surface plumes. In the far-field where the plume hugs the sea-floor, bottom friction dominates the across-stream momentum budget (Ekman balance), and an ageostrophic secondary circulation is evident.

Mixed sediments dynamics in the Río de la Plata

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The Río de la Plata is one of the world largest estuaries acting as a border between Argentina and Uruguay (34° 00' – 36° 10' South and 55° 00' – 58° 10' West). It drains the second largest catchment area of South America (3 170 000 km^2) after the Amazon. The estuary is fed by the Paraná and Uruguay rivers which provide more than 97% of the continental water input with an averaged discharge of 22 000 $m^3.s^{-1}$. While the inner part of the Rio exhibits fluvial characteristics, the mixing zone behaves as a micro-tidal estuary, driven by the river discharge and the astronomical tide on one hand, and meteorological tides and local winds on the other hand, which contribute to the main part of water level variations.

While the Rio's hydrodynamic circulation has been investigated by numerical models and in situ data (e.g. Simionato et al., 2005, 2007), its sediment dynamics is little known. Continuous dredging activities for the access to Buenos Aires and Montevideo harbours, chemical and bacteriological contamination as well as morphodynamic evolutions of the inner Rio have motivated the development of a sediment dynamics numerical model accounting for sand and fine sediment mixtures. The interest of this modelling experience lies in the dimension of the system, the intensity of the solid discharge (continental sediment inputs amount to 160 Mtons/year, split between 25% sand and 75% fine sediments), the complex distribution of various sediment types over the whole domain, and the importance of the resuspension by waves over water depths mostly lower than 10 m from the river mouth to the salt wedge.

This article describes the analysis of an extensive dataset covering the whole estuary (long term high frequency turbidity time series, vertical turbidity profiles and bottom samples) acquired over 2010, and the validation of a mixed sediment numerical model (Le Hir et al., 2011) coupled to MARS3D hydrodynamic model (Lazure and Dumas, 2008) and SWAN for wave modelling.

The sediment model calibration classically relies on the parameterization of vertical mixing, erosion, settling velocity and deposition. The adjusted model shows the respective contributions of waves and tidal currents on sediment dynamics, with different patterns depending on the location in the estuary. In the inner-middle zone, astronomical and meteorological currents generate a semidiurnal erosion-transport-settling process while waves generate greater erosion during storms. In the outer zone, storms always dominate the erosion of fine sediments, while having a great influence on the salinity distribution (and hence flocculation processes).

The adjusted model was used to explore net erosion and deposition zones over different time periods and to understand the time and space variability in the bottom sediment composition: bottom samples show that the inner zone is mostly covered with silt and sand mixtures while the clay content increases in the outer zone. Model results are used to investigate which parameters drive this bottom sediment distribution and to explain its dynamics.

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Residual flow profile decomposition of estuarine circulation

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Abstract

The residual sediment transport field in tidal estuaries can be decomposed into contributions from (i) the covariance between current velocity and sediment concentration and (ii) the residual flow (residual velocity times tidal mean sediment concentration). For the latter, it is of interest to analyze the hydrodynamic processes governing the residual flow (i.e., the estuarine circulation). To achieve this goal, the residual flow profile decomposition method developed by Burchard and Hetland (2010) and Burchard et al. (2011) is applied to idealized tidal estuaries without and with lateral flow variation, using the General Estuarine Transport Model (GETM, www.getm.eu). The method analytically decomposes the residual current into contributions from relevant processes such as gravitational circulation, tidal straining circulation, and lateral advective circulation. The complex analytical formulations are calculated numerically. In contrast to previous one-dimensional vertical and two-dimensional lateral studies using the rig-lid approximation for the surface elevation, the challenge for those estuaries is the periodic change in water depth due to tides, leading to effects such as Stokes drift. The sensitivity of the decomposition of estuarine circulation on freshwater run-off, tidal range, and bathymetric variations will be investigated.

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River, wave and external control of the tidally-dominated long-term residuals in an estuary channel.

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Abstract

The Dee Estuary, NW English – Welsh border, is major asset, supporting: one of the largest wildlife habitats in Europe, industrial importance along the Welsh coastline, and residential and recreational usage along the English coast. To understand the dynamics within the estuary the 3D circulation requires improved understanding. Using mooring data obtained in February – March 2008, a 3D modelling system has been validated to investigate the barotropic-baroclinic-wave interaction within the estuary under full atmospheric, tidal and riverine forcing. The system consists of a coupled circulation-wave-turbulence model (POLCOMS-WAM-GOTM) and has been validated against in situ salinity, velocity, elevation and wave observations. Understanding the residual elevation is important to determine total water levels causing the wetting and drying of inter-tidal banks, especially during storm events. While, improved knowledge of residual 3D circulation is important in determining sediment and particle movement to manage water quality and morphological change. Using this modelling system the contribution of different processes and their interactions are assessed. Analysis methods are presented to 'de-tide' both model and measured results. By studying a tidally-dominant channel under wave influence (namely the Welsh channel), it is found that baroclinicity induced by the weak river flow has greater importance in generating a residual circulation than the waves, even at the estuary mouth. However, the residual estuarine elevation is primarily influenced by external forcing, with secondary influence from the local wind conditions. During storm events the 3D radiation stress becomes important for both elevation and circulation, but has little impact in the long-term.

Influence of basin characteristics on equilibrium and stability of double inlet systems

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Understanding the mechanisms causing (multiple) tidal inlet systems to be cross-sectionally stable is of importance to anticipate natural or man-made changes in these systems. Examples of change are sealevel rise, barrier island breaching and basin reduction. Following Escoffier (1940) an inlet is considered to be in equilibrium when the amplitude of the inlet velocity equals the equilibrium velocity. The equilibrium is stable when after a perturbation the cross-section of that inlet returns to the equilibrium value.

In calculating the amplitude of the inlet velocity it has been customary to use a semi-empirical cross-sectionally averaged equation for the flow in the inlet and to assume a pumping mode for the basin (lumped parameter model). In particular the use of the pumping mode needs justification. It is postulated that the validity of the use of the pumping mode largely depends on the basin characteristics including depth, surface area and geometry. This in turn can cause inlet velocities to vary and therefore change the stability of the inlet system.

In view of these observations, the goal of this study is twofold: 1) To investigate the influence of the basin characteristics on equilibrium and stability of *double* inlet systems using a 2DH hydrodynamical model (see Fig. 1 for a co-tidal chart generated with this model) and 2) to compare the results with those of the lumped parameter model with special attention to the pumping mode.

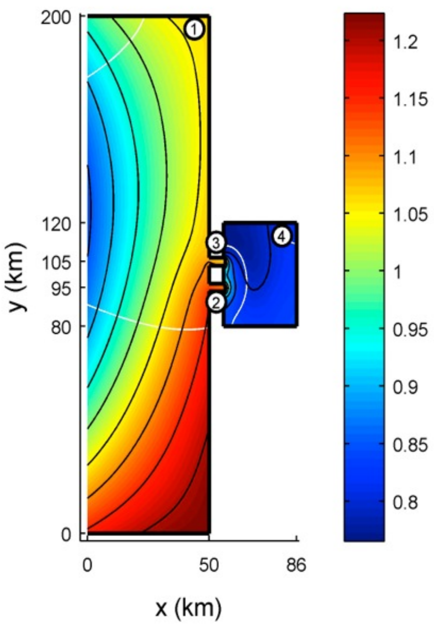

Figure 1: Co-tidal chart for an example of a double inlet system with 4 compartments. Elevation amplitudes are in meters, co-phase lines (*white*) have intervals of 30° and co-range lines (*black*) have intervals of 5 cm. The inlet widths and lengths are 3 km and 6 km respectively.

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The Po river plume modeling: state of art and new modeling tools for hydrodynamic studies in deltas

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Estuaries and delta areas are of major interest in the investigation of coastal hydrodynamics. These are transitional areas, where riverine characteristics interact with marine environments. Complex morphologies and processes interacting on different spatial scales are usually present.
From a modeling point of view, the river conjunction with the sea represents a challenge because neither open ocean models, applied in oceanography, nor hydrological models, generally used for engineering purposes, can fully reproduce the hydrodynamic processes occurring in these areas. The former are too coarse while the latter cannot be applied in open sea. Numerical models based on the finite element technique, due to the use of unstructured grids, can provide a proper degree in reproduction both offshore and in the near coastal zone, specifically close to deltas and estuaries. However, the high horizontal resolution is not enough to identify the most suitable tool for this kind of hydrodynamic investigations. The vertical resolution and discretization become important when passing from really shallow and meandering zones, like the inner river, to shelf and, finally, to the open sea.
In this work we present the implementation of a new version of SHYFEM (Shallow water Finite Element Model), based on the introduction of a hybrid zeta/sigma vertical discretization, for the reproduction of hydrodynamic processes at the Po river mouth, in the northern part of the Adriatic Sea. The dynamics of the Po estuary are mainly influenced by the baroclinic forcing (inshore-offshore temperature and salinity gradients) and the bathymetry. 10 years ago a preliminary study of the Po plume dynamics and its response to different forcing was presented at the PECS conference. That implementation tried to face the complexity of a system where a big river inflows into a basin like the Adriatic Sea, characterized by a large shelf in the North and deep areas in the South. To study the Po river hydrodynamics means to deal with its multi-scale influence both on the local dynamics and on the Adriatic Sea general circulation. At that time, the numerical tool was applied in 2D and a transport-diffusion module was used to reproduce temperature and salinity fields. Consequently a number of processes where neglected. SHYFEM model has been massively developed during these years including the baroclinic pressure terms in its 3D version and, as a last step, dealing with different vertical discretization techniques (zeta vs sigma layers). Just dealing with vertical zeta layers would lead to a rough, stair-shaped reproduction of the coastal areas, while, on the other hand, sigma layer would lead to unrealistic reproduction of areas with strong vertical bathymetrical gradients. Therefore hybrid vertical discretization is needed. The main aim of this work is to test and verify what is the improving of such a technique in the Po river hydrodynamic investigation, in order to reproduce also extreme events, such as big floods. Moreover, we have included a new module (FL-MUD) in order to account for the properties of high concentrated organic suspended matter (e.g. Fluid Mud). The approach includes a rheological model and the damping of the turbulence due to high concentration gradients as well as hindered settling. We show 1st results in a numerical wave tank, where we investigate the influence of the new additions. This module coupled with a hybrid model that uses sigma coordinates in shallow areas and zeta in the deeper ones is a perfect tool for further investigation of the complex hydro-sediments interaction at the bottom layer in the shelf.

The impact of morphology on tide-driven fluid mud dynamics in an estuarine turbidity zone

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Near-bed density stratification due to suspended, fine-grained cohesive sediments and the formation of fluid mud layers are frequently observed in tide-dominated estuaries. Significant progress was made during the past years in terms of the description and parameterization of fluid mud related sediment transport processes. However, only few studies present in-situ measurements of the spatiotemporal distribution of estuarine fluid mud deposits. In the Weser estuary (Southern North Sea, Germany), high resolution sediment echo sounder and acoustic Doppler current profiler measurements revealed ephemeral fluid mud layers, deposited during slack water. As validated by fluid mud samples from Rumohr-type gravity cores, sediments in the fluid mud layer consisted of large mud flocs. Sediment concentrations ranged from 25g/l below the lutocline to a maximum concentration of 70g/l at the river bed. The spatial distribution of fluid mud layers coincided with the location of the estuarine turbidity zone. Two types of fluid mud deposits were found. In the center of the tidally averaged location of the turbidity zone, fluid mud was deposited in form of contiguous layers on a predominantly flat river bed, characterized by fine-grained bed sediments. Due to the tidal excursion, the formation of fluid mud was also observed further upstream after the flood phase, and further downstream after the ebb phase. In these regions of the main tidal channel, covered by coarse-grained sediments, fluid mud accumulated in troughs of large dunes, while the dune height exceeded the fluid mud thickness. Along the extent of the turbidity zone, density stratification, induced by near-bed accumulation of suspended sediments, was initially observed 1.2h before flood slack water. In dune troughs, fluid mud remained for approximately 2h after slack water and was not entrained until current velocities exceeded 0.45m/s, measured 1m above the lutocline. Whereas fluid mud in dune troughs was entirely resuspended during the following tidal phase, a significant coverage of contiguous fluid mud layers was still observed during the next slack water. According to the local gradient Richardson number, calculated on the basis of average current velocities, fluid mud layers in dune troughs were stable with respect to shear instabilities during entrainment. Thus, entrainment of fluid mud in dune troughs is explained to be induced by the development of the dune specific turbulent flow field downstream of the dune crest and advection of strong turbulent stresses in direction of the lutocline. In regions without large dunes these additional turbulent stresses are absent, explaining the relative persistence of contiguous fluid mud layers on a flat river bed.

Evidence of tidal straining in well-mixed channel flow from micro-structure observations

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Shown are results of a study that presents, for the first time, micro-structure observations in tidally energetic, weakly stratified regimes obtained in the Wadden Sea, a tidal shallow coastal area in the South - Eastern North Sea characterized by barrier islands separated by tidal gulleys. The tidal currents are typically overlaid by a weak horizontal density gradient due to freshwater run - off from land or differential heating. Observations in the North-Frisian Wadden Sea clearly show the presence of tidal straining, believed to be one of the major drivers of estuarine circulation in well-mixed tidal flow and associated with that an important process for net sediment transport in such weakly stratified lagoon-like estuaries. Furthermore, we present micro-structure measurement data, of a campaign recently carried out in a similar lagoon in the East-Friesian Wadden Sea. Those data have a fine temporal resolution, with profiles each 1-2 minutes over several days, showing, besides a number of interesting small-scale effects, a clear indication of tidal straining under the conditions of an extremely weak horizontal density gradient mainly governed by temperature and slightly compensated by an even inverse salinity gradient. Even in such a small Simpson-number regime estuarine circulation is found to drive a residual circulation that is believed to act as a pumping mechanism for sediment from the open sea into the lagoon. In addition, continuous cross-channel micro-structure and ADCP transect data covering several tidal cycles deliver a unique view inside the variety of lateral processes interacting to generate and modulate estuarine circulation.

Freshwater influences on productivity in the northern California Current System, under present and future climate

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The U.S. Pacific Northwest coastal ecosystem is, like other highly productive eastern boundary systems, fueled primarily by the upwelling of deep oceanic nutrients, and it has traditionally been assumed that the strength and fate of biological production was regulated primarily by alongcoast wind stress. Results from three recent large programs (NOAA/NSF) have shown, however, that river plume dynamics and estuarine circulation complicate this picture in a number of ways. Most notably, the estuarine outflow from the inland Salish Sea (dominated by the Fraser River), in addition to supplying a modest load of terrestrial nutrients, drives an overturning circulation that brings a large and nearly steady flux of deep oceanic nutrients to the shelf, while at the same time suppressing wind-driven upwelling on the southern Vancouver Island shelf. The Columbia River plume drives a similar tradeoff—increased retention of oceanic nutrients and episodic suppression of coastal upwelling—but on a smaller spatial scale and shorter timescales.

These mechanisms suggest alternate lines of connection between global climate forcing and regional biochemistry, beyond the traditional focus on the coastal wind field. Competition between oceanic, atmospheric, and hydrological climate-change pathways is currently being explored through sensitivity experiments in a regional biophysical model coupled to future atmospheric and hydrological forcing scenarios downscaled from IPCC global models. Early results suggest that freshwater influences on the coastal ocean may perturb the seasonal timing of coastal productivity under future climate, but largely serve to buffer the system against long-term change in coastal winds and stratification.

Curvature Induced Secondary Circulation in the Taieri River

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Observations of salinity and velocity in a region of sharp curvature in the Taieri River, New Zealand captured the advance and subsequent collapse of a salt wedge. Conductivity Temperature Pressure and Acoustic Doppler Current Profiler measurements were obtained through the use of surface and bottom moorings, as well as vessel mounted operations. During the flood tide, the salt wedge structure advances from the river mouth until the surface manifestation of the tidal intrusion front is apparent within the region of curvature. As the structure passes around the bends it is subject to relatively strong, complex, curvature induced secondary circulation, which acts to locally adjust the lateral baroclinic pressure gradient. The decrease in tidal flow around slack water reduces the centrifugal forcing in the lateral momentum balance resulting in a local readjustment of the lateral baroclinic pressure gradient. The readjustment instigates a lateral seiche within the region of curvature, which appears to generate mixing across the halocline, lowering the depth of maximum stratification. The seiche continues until the collapse of the salt wedge structure during the early ebb tide. Upon the reduction in stratification, the curvature induced secondary circulation adopts a helical flow pattern. At the end of the ebb tide the remnants of the salt wedge are typically advected out to sea, allowing a new structure to develop with the next incoming tide.

Temporal Variability of Dissipation from Channel to Channel Wall in a Coastal Plain Estuary

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Measurements were collected at four locations in the James River estuary to estimate the temporal variability of turbulent kinetic energy (TKE) dissipation. Four 1200 kHz ADCPs sampling in mode 12 were mounted at the bottom, with two along-estuary locations of ADCPs at the channel and channel wall. Profiles of current velocities were collected for 40 days during April, May and June 2010. The purpose of this investigation was to determine if mechanisms could be attributed to the dominate modes of TKE dissipation. A Hilbert transform was performed on dissipation (calculated via the structure function) and a Complex Empirical Orthogonal Function (CEOF) was applied to decompose the signal into modes. The spatial and temporal evolution was explored for the three dominate modes at both along-estuary locations. Results for this analysis at the first longitudinal location showed that large (~$10^{-5-5.5}$ m^2/s^3) dissipation values were located near the surface and bottom at the channel and channel wall. Maximum values (~10^{-5} m^2/s^3) were observed during peak velocities. A pulse of the largest surface values (~10^{-4} m^2/s^3) was observed during a brief period (< 4 days) at both locations and corresponded with a wind event. The spatial variations of the three dominated modes were comparable at the channel and channel wall locations. Results showed that mode 1 (0.81) had the largest values near the bottom and surface, with a minimum observed at 3 m (1 m at the channel wall) above the ADCP. The corresponding phase profile, which represented the propagation of dissipation throughout the water column, showed that dissipation was initially generated near the bottom and propagated upward. Mode 2 (0.08) yielded a similar shape as mode 1, however featuring smaller maximums and a minimum at 2 m (1 m in the channel wall) above the ADCP. The phase of mode 2 simultaneously started at the bottom and surface and propagated toward the middle. Mode 3 (0.05) featured maximum values near the surface and bottom and exhibited a more uniform water column than modes 1 and 2. The phase of mode 3 showed that dissipation was initially generated at the surface first and propagated downward. A power spectra was performed on the time series of the three modes and featured the largest peak near 0.3 cycles/day (cpd) in all modes. This highlighted that metrological forcing was dominating the energy in all three signals. Modes 1 and 3 also featured a significant peak at 2 cpd, suggesting that modes 1 and 3 were tidally influenced. This analysis will be performed at the second along-estuary location and compared with previous results in addition to a power spectra of wind velocities collected at the nearby NOAA station.

Salt fluxes in Delaware Bay Estuary from an Eulerian and salinity classes perspective

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Numerical simulations of Delaware Bay suggest that the along channel, area integrated tidal oscillatory salt flux (Ft) plays a significant role in the landward advection of salt fluxes in this system (Fig. 1). The tidal oscillatory salt flux also presents a spring-neap variability that is contrary to previous parameterizations (MacCready 2007). In our results Ft is enhanced during neap tide and reduced during spring tide. This spring-neap variability is caused by the across channel flows that during ebb advect fresh water from the flanks to the main channel and induce vertical mixing (Fig. 2) bringing the along channel salinity and velocity out of quadrature. During neap tide, when stratification is large, the tidal component of salinity is enhanced and therefore Ft is enhanced as well. During spring tides, when stratification is small, the tidal component of salinity has significantly smaller values than during neap tide producing a reduction in Ft, even though the same across channel dynamics is present.

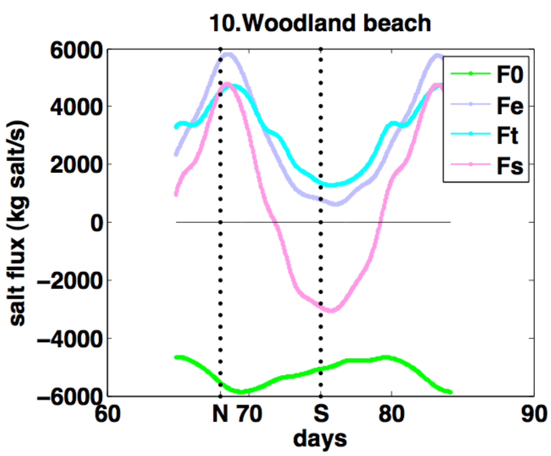

Fig. 1

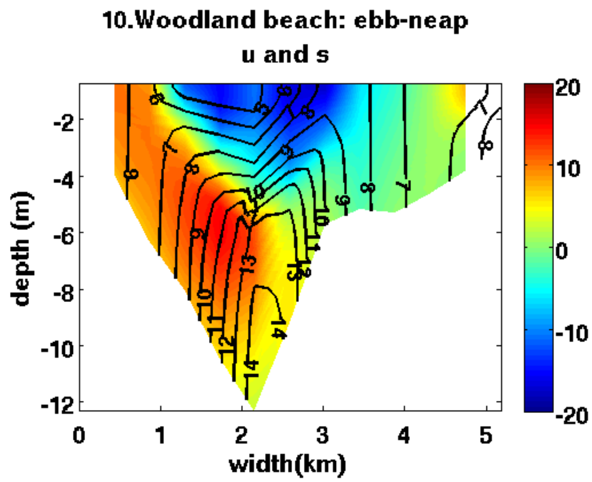

Fig. 2

Fig. 1: Along channel, area integrated salt fluxes at Woodland Beach, 69 km from the entrance of the bay. F0, Fe, Ft and Fs stand for river advection, steady shear dispersion, tidal oscillatory and total salt fluxes respectively.

Fig. 2: Salinity contours and across channel flows (color scale in cm/s) during ebb-neap tide at Woodland Beach. Warm colors are to the right of the cross section.

To further investigate the mechanics driving the tidal oscillatory salt flux we conducted field measurements in Delaware Bay in addition to the numerical simulations. The field program consisted of a cross channel array of 6 moorings, two moorings upstream and downstream from the main array, and a series of tidal cycle surveys at the location of the mooring array. Preliminary results have shown that the across channel flows are an important driver of stratification in this system. Our initial analysis will use an Eulerian decomposition (Lerczak 2006) for the along channel salt flux from the moored and ship board data and the model output in order to quantify the tidal oscillatory salt flux. In addition we will use the Total Exchange Flow (TEF) approach proposed by MacCready (2011) as an alternative way of calculating salt fluxes. Results from these two methods will be compared and interpreted with the objective of understanding the mechanism behind the tidal oscillatory salt flux.

Assessing Suspended Sediment Dynamics in the San Francisco Bay-Delta System: Coupling Landsat Satellite Imagery, *in situ* Data and a Numerical Model

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Rivers draining the Central Valley and Sierras of California, including the Sacramento and San Joaquin Rivers, meet in the Delta before discharging into the northeastern end of the San Francisco Estuary. The Bay-Delta system is an important region for a) economic activities (ports, agriculture, and industry), b) human settling (the San Francisco Bay area hosts 7.15 million inhabitants) and c) ecosystems (the Delta area hosts several endemic species and is an important regional breeding and feeding environment). Human activities, including hydraulic mining and agriculture development have affected the Bay-Delta system over the past 150 years. Other examples of anthropogenic influence on the system are damming of rivers, channels dredging, land reclamation and levee construction. Suspended sediment concentration (SSC) has varied considerably as a result of these activities. The change in SSC has a high impact on ecosystems by influencing light penetration that is closely related to primary production, contaminants distribution and marshland development. Better understanding of the spatial distribution and temporal variation of SSC opens the way to improved understanding ecosystem dynamics in the Bay-Delta system and to assess the impact of future developments such as water export, sea level rise and decreasing SSC levels.

This work aims to connect Landsat satellite imagery and in situ data for calibration of a numerical model. The model applied is D-Flow Flexible Mesh (D-Flow FM), a hydrodynamic, process-based, unstructured grid, finite volume model currently being developed by Deltares. The grid covers the entire Bay-Delta system and the simulation includes tides, river flow, pumping stations, wind driven currents and waves. The SSC dynamics are simulated with Del-WAQ, the water quality package of Delft3D (Deltares, 2004). The computational time is about 2 days for an entire year on an 8 node 2.4 GHz, 6 Gb RAM PC.

An extensive data set of measured parameters (SSC, temperature, salinity and water level) exists covering the Bay-Delta area for calibrating our model. However, the survey stations are spatially limited, sampling at discrete points. To overcome this limitation we apply a technique to retrieve SSC from remote sensing images (Lee et al., 1999; Zawada et al., 2007; Volpe et al., 2011). The technique is based in inversion method, deriving the properties of the water (SSC, in this case) from the total reflectance (remote sensing data), and drawing calibration curves. After computing the calibration curve it is possible to do the inverse process, from reflectance calculating SSC maps and retrieving information for the Bay-Delta area.

Developing a calibration method for remote sensing data is an important step for improving the Bay-Delta model, since it will result in data that will improve the model results for the SSC spatial and temporal distribution in the system. It will also provide information on the concentration and patterns in shallow waters, places where the in situ measurements are restricted. Another outcome of this work is the quantification of the maximum detected SSC from satellite imagery since precious work were focus in areas with a lower SSC. Ultimately, a calibrated inverse model for the Bay-Delta area will allow a quick assessment of SSC conditions from remote sensing data.