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Littoral Transport Rates in the Santa Barbara Littoral Cell: A Process-Based Model Analysis

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ABSTRACT

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Identification of the sediment transport patterns and pathways is essential for sustainable coastal zone management of the heavily modified coastline of Santa Barbara and Ventura County (California, USA). A process-based model application, based on Delft3D Online Morphology, is used to investigate the littoral transport potential along the Santa Barbara Littoral Cell (between Point Conception and Mugu Canyon). An advanced optimalization procedure is applied to enable annual sediment transport computations by reducing the ocean wave climate in 10 wave height - direction classes. Modeled littoral transport rates compare well with observed dredging volumes, and erosion or sedimentation hotspots coincide with the modeled divergence and convergence of the transport gradients. Sediment transport rates are strongly dependant on the alongshore variation in wave height due to wave sheltering, diffraction and focusing by the Northern Channel Islands, and the local orientation of the geologically-controlled coastline. Local transport gradients exceed the net eastward littoral transport, and are considered a primary driver for hot-spot erosion.

ADITIONAL INDEX WORDS: *numerical modeling, sediment transport, coastal processes*

INTRODUCTION

The beaches of Santa Barbara and Ventura County (California, USA) have been subject to significant shoreline and bluff erosion over the last decades resulting in economic losses due to reduced recreational beach benefits, damages to residential developments and reduced coastal safety (REVELL, 2007, BARNARD et al.. in press). Beach erosion is commonly counterbalanced by shoreline armoring. Groins, seawalls and revetments can increase coastal safety, but often reduce natural habitat and recreation activities (causing economic losses). For sustainable coastal management it is essential that the underlying processes of coastal change are sufficiently understood. Coastal change in the Santa Barbara - Ventura region is complex. The coastline is irregular; there are numerous rocky headlands, river deltas and offshore reefs. Sediment supply is limited and has been reduced during the last century due to landscape urbanization, debris basins and damming of rivers. Longshore transport is disrupted due to numerous structures (harbors, groins, piers, jetties) and only limited information on littoral sediment sources exists.

This study aims to contribute to the general understanding of the sediment transport patterns and processes of the Santa Barbara Littoral Cell. Numerical model results, obtained from a process-based (Delft3D) model application, are used to identify and investigate the alongshore variability of sediment transport potential in relation to coastline position and orientation, and wave forcing. Determination and interpretation of the modeled transport gradients in combination with field data and expert judgment helps to identify areas that are susceptible to long-term erosion that therefore need to be given a higher priority for focused coastal management efforts.

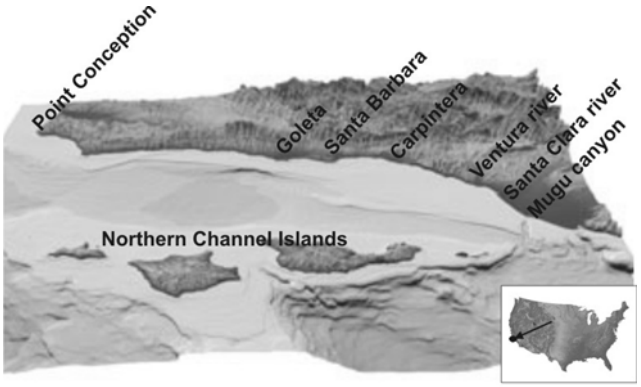

Figure 1. Location plot of the Santa Barbara Littoral Cell (SBLC)

STUDY AREA

The beaches of Santa Barbara and Ventura County form part of the Santa Barbara Littoral Cell (SBLC). The SBLC is located along the Pacific Southwest coast of the USA and extends over a distance of 150 kilometers between Point Conception in the Northwest and Mugu Canyon in the South (Figure 1). From Point

Conception, east 40 km, the coastline is oriented west-east, primarily consisting of bluffs. To the west, narrow beaches separated by bluffs are prevalent, curving to a more north-south orientation, south of the Ventura River. The Ventura River and the Santa Clara River have created a vast alluvial plane with wide sandy beaches stretching south to Mugu submarine canyon (see REVELL, 2007 for details). The Northern Channel Islands shelter a main part of the coast from south swell. Tides are diurnal with a strong semi-diurnal distortion. The diurnal range is 1.64m but tidal velocities along the coast are generally weak, below 5 cm/s (MÜNCHOW, 1997).

METHOD

Delft3D Online Morphology

The Delft3D (D3D) modeling system contains the necessary physical processes (e.g. waves, tides and wave-current interactions) to simulate sediment transport along the SBLC. The main D3D components are the coupled Wave and Flow module, and a steering module describing the sequence of alternating calls between waves and flow.

D3D-Flow forms the core of the model system simulating water motion, due to tidal and meteorological forcing, by solving the unsteady shallow-water equations that consist of the continuity equation, horizontal momentum equations, and the transport equation under the shallow water and Boussinesq assumptions. The discretized set of equations is solved using an alternating direction implicit method by specifying boundary conditions for bed (quadratic friction law), free surface (wind stress), and lateral boundaries (water level, currents, and/or discharges) on a staggered Arakawa B grid.

Wave effects, such as enhanced bed-shear stresses and wave forcing due to breaking, are integrated in the flow simulation by running the 3rd generation SWAN wave processor (version 40.41A). The SWAN-model is based on discrete spectral action balance equations, computing the evolution of random, short-crested waves. Physical processes included are: generation of waves by wind, dissipation due to white capping, bottom friction and depth induced breaking (0.73 breaker parameter), and non-linear quadruplet and triad wave-wave interactions. Wave propagation, growth and decay are solved periodically on subsets of the flow grid. The results of the wave simulation, such as wave height, peak spectral period, and mass fluxes are stored on the computational flow grid and included in the flow calculations through additional driving terms near the surface and bed; enhanced bed shear stress, mass flux and increased turbulence.

The D3D Online Morphology addition is used to resolve the sediment transport patterns dynamically at each computational time step using the default VanRijn1993 transport formulation (VAN RIJN AND WALSTRA, 2003). The Delft3D implementation of this formula follows the principle description of Van Rijn (1993) whereby a distinction is made between bed load and suspended load transports. Bed load transports represent the transport of sand particles in the wave boundary layer in close contact with the bed surface. Suspended sediment transport is computed by the advection-diffusion solver. To describe sediment characteristics additional formulations are included to account for: density effects of sediment in suspension settling velocity (VAN RIJN, 1993), vertical diffusion coefficient for sediment, suspended sediment correction vector and sediment exchange with the bed. The elevation of the bed can be dynamically updated at each computational time-step by calculating the change in mass of the bottom sediment resulting from the sediment gradients. In this study bed we focus on the maximum long-shore transport potential by turning off bed updating.

Complete overviews of the basics, testing and validation of the Delft3D Online Morphology with analytical solutions and laboratory data have been reported in LESSER (2000), and LESSER et al. (2004).

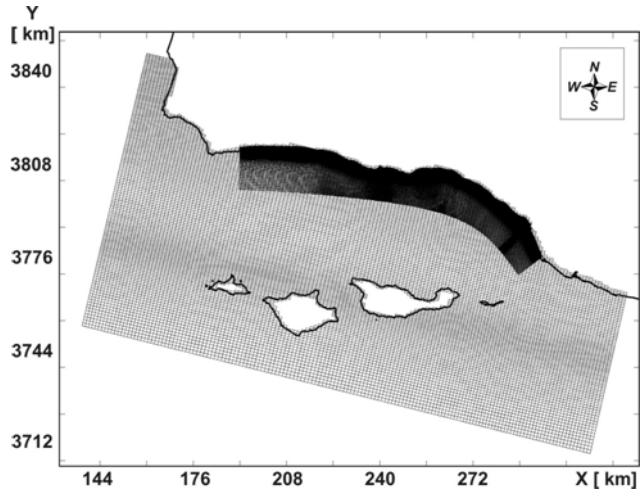

Figure 2. Model Grids for Flow (black) and Waves (gray).

Model schematization

To accurately capture the sediment transport a curvilinear model grid is constructed extending from Point Conception to Oxnard (5 miles south of the Ventura River) with an average 100 m longshore resolution. The seaward boundary is located well outside the morphologic active zone at approximately 12 km offshore, Cross-shore grid resolution increases from 250 m in the offshore sections to 10 m in the surfzone (115,758 grid cells in total). Groins and jetties are included as thin dams. Flow boundary conditions are prescribed by the tidal constituents of water levels on the southern seaward boundary and water level gradients on the west and eastward sea boundaries. Wave forcing is derived from nesting in a larger (lower resolution) wave grid, constructed to accurately capture the wave transformations from deep to shallow water due to refraction, diffraction and shoaling. The low resolution wave grid has a spatial scale of 90x180 km and includes Point Conception and the Northern Channel Islands. In total the grid consists of 22,800 grid points with grid sizes ranging between 550 and 1100 m.

The deep water ocean wave climate is specified uniformly on the open boundaries (significant wave height, peak wave period and direction) assuming a JONSWAP wave density spectrum. Comparison of model results with an inner-channel wave buoy showed a fair correspondence with less than 5 % error in wave heights, peak period and direction.

Model bathymetries were derived by grid cell averaging and triangular interpolation from several data sources. Cross-shore profile data with 20 m resolution collected by USGS (BARNARD et al., in press) was used for the main interest regions near Goleta, Carpinteria and Ventura, while the remaining bathymetry was based on SCCOOS (http://www.sccoos.ucsd.edu/data/bathy/?r=2) and National Ocean Service data (http://map.ngdc.noaa.gov/website/mgg/nos_hydro/viewer.htm). The bed is composed of a uniform (representative) sediment fraction d_{50}= 260 μm (MUSTAIN et al., 2007). Model details are described in BROCATUS (2008).

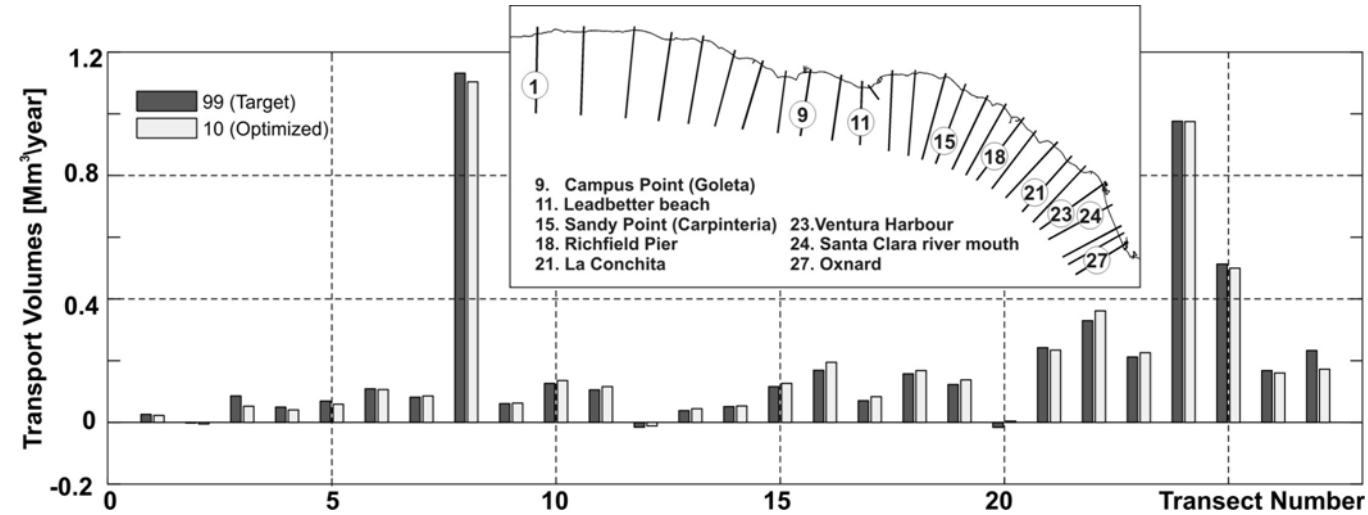

Figure 3. Comparison of target and schematized sediment transport through the transects. Insert shows transect locations.

Input schematization

Model simulations are run over a 1-year morphodynamic time frame. Input filtering of the hydrodynamic forcing conditions is used to bridge the gap between the hydrodynamic and morphodynamic time scales (STEIJN, 1992). Tides are reduced to a single representative HW-LW tide cycle. A simple method of running a morphologic simulation over a full spring-neap cycle and selecting the individual single tide that best reproduces the total sediment transports was applied (this tide equals approximately 1.1x the mean tide).

Table 1: Representative wave cases.

Condition	Hsig(m)	Tp(s)	Dir (º)	Weight
19	1.67	15.71	188	0.0080
24	1.74	12.24	279	0.4637
32	2.21	15.39	174	0.0391
35	2.24	15.47	237	0.0014
62	3.75	18.53	170	0.0002
63	3.95	18.50	187	0.0002
69	3.74	13.12	294	0.0911
88	5.71	15.53	278	0.0053
89	5.74	12.78	295	0.0080
99	7.08	14.13	307	0.0027

The OPTI method (WL|DELFT HYDRAULICS, 2007) was used to schematize the wave climate into a limited number of wave cases. NDBC wave data (http://www.ndbc.noaa.gov) for buoy's 46063 and 46069 were binned in 0.5 m wave-height classes and 15º directional bins. For each filled wave bin (99 in total) sediment transport was computed over a single tide cycle, multiplied by the probability of occurrence, and the sediment transport fluxes through 27 predefined cross-sections, perpendicular to the coast and evenly distributed over the SBLC, were stored (Figure 3, insert).

The OPTI routine starts with the target sediment transport (the cumulative result of the 99 wave cases) and through an iterative process, eliminates the wave condition (i.e. sediment transport calculation) that contributes least to the target by setting its weight to zero, and recalculating the probability of occurrence of the remaining conditions. The resulting morphological wave climate consists of ten classes that reproduces the target sediment transport (RMS error < 6%) and resembles the ratio between wave energy from the North and South (Table 1 and Figure 3).

RESULTS AND ANALYSIS

The spatial variation of the littoral transport potential is illustrated in Figure 4. Littoral transport acceleration at Goleta, Carpinteria, and Surfer's Point (just north of Ventura Harbor) correlate with long-term erosion trends in those areas, while deceleration of littoral transport rates near La Conchita, and the Santa Clara River mouth corresponds with the observed (decadal scale) accretion. The simulated longshore sediment transport rates are in good agreement with the annual dredging rates at the Santa Barbara and Ventura Harbor, while major transport divergences coincide with areas of observed hotspot erosion.

Dredging rates are underestimated by 10%. However, based on the frequency of littoral transport reversals in the vicinity of Ventura Harbor and slight reversal in the lee of the Santa Barbara Harbor, the modeled rates are likely more in line with true net littoral transport rates. Due to these reversals, using dredging rates as a proxy for net littoral transport at these harbors could result in a potentially significant overestimation at Ventura and Channel Islands Harbor, and a slight overestimation at Santa Barbara Harbor.

Changes in coastline orientation, alongshore water depth variations and spatial variance of the local wave climate result in significant longshore sediment transport gradients. With the exception of a local sediment reversal near the Santa Barbara harbor, sediment transports are unidirectional and increase in magnitude from west to east due to the prevalent wave conditions. A distinct difference exists in the magnitude of the net and gross (defined as average per wave condition) sediment transport rates between the coastline upcoast (transects 10-15) and downcoast (transects 16-28) of Sandyland. Large gross transports, equal in magnitude to the net transport but of opposite direction, dominate the net transports east of Sandyland. While to the west the maximum gross and net sediment transport rates are smaller

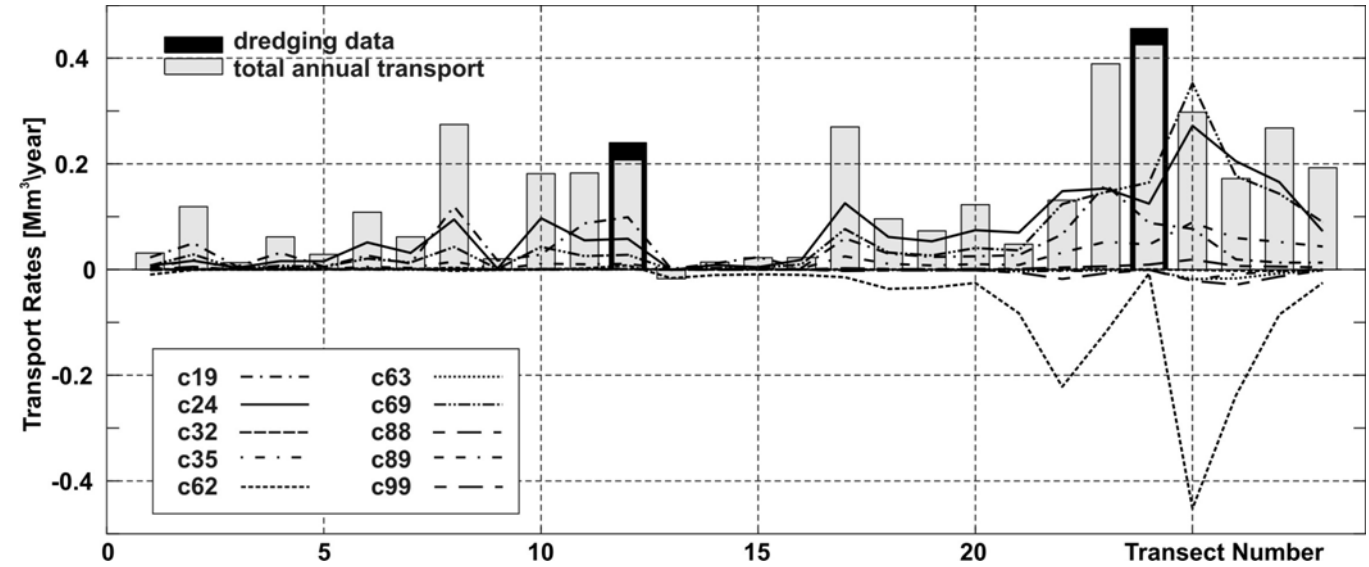

Figure 4. Modeled annual sediment transport rates through the predefined transects (bars) and the separate contributions of the individual wave cases (lines). Black bars provide the dredging rates for the Santa Barbara and Ventura Harbor (transects 12 and 24 respectively).

(factor 4 and 2 respectively) but unidirectional as contributions from southern wave cases are near negligible.

Shoreline orientation and the spatial variability in near-shore wave climate along the coastline (among others due to wave sheltering of south swell by the presence of the northern Channel Islands) are the main actors contributing to the strong alongshore gradients in sediment transports along the SBLC (Figure 4).

A representative wave-height distribution over the area for westerly waves is shown in the left panel of Figure 5 (left panel). The abrupt change in shoreline orientation introduces a significant difference in near-shore wave-height to the North and South of Point Conception. To the South, refraction and bed friction reduce the amount of wave energy at the shoreline drastically. Since longshore sediment transport is known to be a function of wave height and direction (according to the CERC formula sediment transport increases with increasing wave-height and wave angles approaching 45º), the slightly curving coastline south of Carpinteria (transect 16) increases sediment transports up to a local maximum at the Ventura Harbor region as wave energy decay reduces and wave angles are more efficient; see top plot of Figure 5 (left). Importantly, large local transport gradients are observed where there exists wave sheltering by capes/shoreline protrusions, e.g. Campus Point (Goleta) and Leadbetter beach, or local wave focusing further reduces or increases the wave energy.

Waves from a southerly direction induce a large spatial variability in wave heights and sediment transports along the SBLC due to wave sheltering by the Channel Islands (Figure 5, right panel). Sediment transport is large and directed to the north at the unsheltered coast south of Carpinteria. In the lee of the Channel Islands wave-heights and sediment transport are small, and transport direction reversals are commonly related to the variability of the coastline orientation, which is strongly influenced by the local geology.

DISCUSSION

Model results identified two primary drivers for the erosion problems in the SBLC: (1) a general trend of increasing sediment transport to the east/south that induces a long-term sediment loss from the region. In combination with the anthropogenic reduction of sediment supply to the SBLC (REVELL, 2007, BARNARD et al., in press) this might result in a long-term sediment deficit. (2) Locally large transport gradients exist due to the persistent variability in coastline orientation and wave energy. Many of the beaches that encounter erosion have a strong increase of the littoral transport rate at the upcoast side. By their adaptive capability, the beaches would normally rotate clockwise to decrease the angle of wave approach with the prevailing wave condition to create an equilibrium state. However, the orientation of many beaches in the SBLC is controlled by the underlying, hard-rock geology, limiting the ability of the shoreline to rotate in response to littoral transport gradients, resulting in erosional hot spots that are largely fixed through time. Shoreline response capabilities are further reduced by coastal protection structures. The sediment transport gradients combined with the structural controls on shoreline orientation are important sources of local erosion and accretion.

An important aspect for future coastal management is the distinct difference in the composition of the littoral sediment transport rates upcoast and downcoast of Sandy land. Upcoast of Sandyland the shoreline is relatively unprotected from southern swell resulting in small unidirectional transports. Downcoast of Sandyland gross sediment transport rates are significantly higher and bi-directional due to the southern swell contributions. Larger net and gross transport rates point to a larger seasonal shore-line variability.

CONCLUSIONS

- Dominant westerly waves and shoreline curvature induce a net increasing eastward sediment transport along the SBLC.
- Large spatial variations in sediment transport rates and direction occur due to sheltering and local wave focusing of southerly wave directions by the Northern Channel Islands.

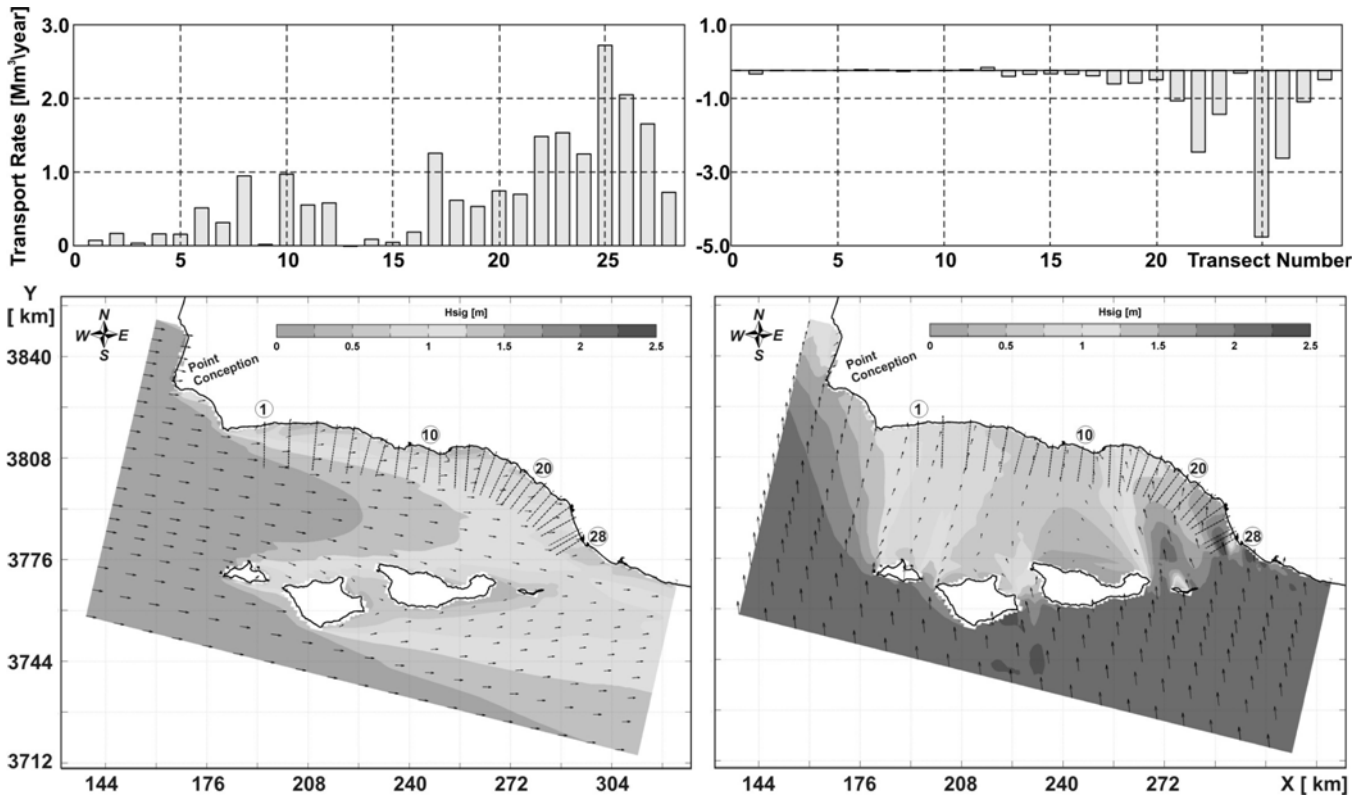

Figure 5. Modeled sediment transport rates (top panels), and wave height and direction (bottom panels) for forcing condition 24 and 32 (left and right). Dashed lines indicate the transect locations.

- Gross sediment transport rates upcoast of Sandyland are unidirectional to the east, downcoast of Sandyland bidirectional but dominant to the east.
- Local erosion and accretion in the SBLC is well explained by modeled littoral transport gradients.

LITERATURE CITED

BARNARD P.L., REVELL, D.L., HOOVER, and D., WARRICK, J., BROCATUS, J., DRAUT, A.E., DARTNELL, P., ELIAS, E.P.L., MUSTAIN, N., HART, P.E., RYAN, H.F. 2009. Coastal Processes Study of Santa Barbara and Ventura County, California. Santa Cruz, California: U.S. Department of the Interior, U.S. Geological Survey, Open-File Report 2009-xxxx, in press.

BROCATUS, J., 2007. Sediment Budget Analysis of the Santa Barbara Littoral Cell. A study to identify and quantify the pathways of sediment transport. Delft, The Netherlands: Deltares, 119p.

LESSER, G., 2000. Online Sediment Transport within Delft3D-FLOW. Delft, the Netherlands: WL|Delft Hydraulics, Report Z-2899.

LESSER, G. R., ROELVINK, J. A., VAN KESTER, J. A. T. M., and STELLING, G. S., 2004. Development and Validation of a Three-dimensional Morphological Model. *Coastal Engineering,* 51, pp. 883-915.

MÜNCHOW, A., 1997. Tidal Currents in a Topographically Complex Channel. *Continental Shelf Research*, 18, pp. 561-584.

MUSTAIN, N., GRIGGS, G. AND BARNARD, P.L., 2007. A rapid compatibility analysis of potential offshore sand sources for beaches of the Santa Barbara littoral cell. In: Kraus, N.C., Rosati, J.D. (eds.), Coastal Sediments '07, Proceedings of the 6th International Symposium on Coastal Engineering and Science of Coastal Sediment Processes, American Society of Civil Engineers, New Orleans, LA, Volume 3, p. 2501-2514

REVELL, D.L., 2007. Long Term and Storm Event Changes in the Santa Barbara Sandshed. Santa Cruz, California: University of California Santa Cruz, Earth Science Department, Ph.D. thesis, 162p.

STEIJN, R.C., 1992. Input Filtering Techniques for Complex Morphological Models. Delft, the Netherlands: WL|Delft Hydraulics, report H 824.65.

WL|DELFT HYDRAULICS, 2007. Schematisation of Boundary Conditions for Morphological Simulations. Delft, the Netherlands: WL|Delft Hydraulics, internal report.

VAN RIJN. C., 1993. Transport of fine sands by currents and waves. *Journal of Water-way, Port, Coastal and Ocean Engineering*, 119(2), pp. 123-143.

VAN RIJN, L.C. and WALSTRA, D.J.R., 2003. Modelling of Sand Transport in Delft3D-Online. Delft, the Netherlands: WL|Delft Hydraulics, report Z-3624.

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