The Holocene/Anthropocene Transition in the Mississippi River Delta

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This talk will examine how the Mississippi River Delta (MRD) transitioned from a system dominated by Holocene dynamics, to one dominated by Anthropocene dynamics. Whereas during the Holocene, rates of relative sea-level rise were relatively modest (often <1 cm yr^{-1}), and relatively constant over regional (1-50 km) spatial scales, during the Anthopocene, rates of relative sea-level rise were greater (>1 cm yr) and substantially more variable over the 1- 50 km spatial scale. Whereas during the Holocene, the course of the Mississippi River was driven largely by patterns of sediment infilling that drove avulsions, during the Anthropocene the course of the Mississippi River has largely been driven by needs for flood control and economic efficiency. Anthropocene and Holocene dynamics merge in subsurface flow, where levees influence the maximum stage of the Mississippi River, and the historic distribution of sandy channels influence pattern of groundwater flow. The early stages of Anthropocene development of the MRD were marked by nearly 4,900 km2 of land loss, about 20% of the deltas area. Looking forward, many plans to restore the Mississippi River involve Anthropogenic activities designed to partially mimic Holocene-era sedimentary dynamics. These involves the formation of artificial crevasses, designed to carry 100 to 2,000 m^3 s^{-1} of freshwater that distribution sediment across 10s to 1000s of km^2. The efficacy of these systems at providing ecosystem services can be further enhanced by the creation of artificial bars and barrier that enhance sediment trapping and retention. Ultimately, the sustainability of the MRD will require managing the interactions between hydrologic, sedimentary, economic and cultural factors.

Keywords: Mississippi , Groundwater , Restoration


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Late Holocene to Present shoreline change at the mouths of the Mekong River delta

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The Holocene Mekong River delta prograded rapidly in a relatively sheltered bight in the South China Sea under the influence of high fluvial sediment supply 5300 to 3500 years ago, developing from an estuary into a delta. This bight infill led to increasing exposure of the prograding shoreline of the delta to ocean waves, resulting in a greater wave influence on the patterns and types of shoreline. In the eastern half of the delta where the river’s sediment supply debouched into the South China Sea through several distributary mouths, deltaic progradation has been characterized by the construction of numerous sets of sandy beach ridges. The growth pattern of this sandy river-mouth sector over the last 2500 years has been determined from OSL dating of these beach-ridge deposits, while the most up-to-date shoreline trends (1950-2014) have been highlighted from the analysis of maps and satellite images. The OSL ages show that the total delta area remained nearly constant till about 500 yr BP, following which the mouths sector underwent significant accretion that may reflect changes in catchment land-use as well as in monsoon rainfall and attendant river water and sediment discharge. Since 1950, the trend has been dominantly one of accretion but punctuated by two periods of erosion. The first (1965-1973) occurred in the course of the second Indochina war, and the second more recently from 2003 to 2011, followed by mild recovery between 2011 and 2014. These temporal fluctuations most likely reflect changes in sediment supply caused by the vicissitudes of war and its effect on vegetation cover, as well as variations in monsoon rainfall and discharge, and, for the most recent period, massive sand mining in the river and deltaic channels. Continued accretion of the mouths sector has gone apace, over the recent multi-decadal period, with large-scale erosion of the muddy shores of the delta in the western South China Sea and the Gulf of Thailand, thus suggesting that the mouths sector may be increasingly sequestering sediment to the detriment of the rest of the delta shoreline. Fine-tuned analysis of the spatial pattern of change in the mouths sector shows marked variations that may reflect alongshore transport variations associated with gradients in wave energy caused by the multiple river mouths in a context of increasingly depleted sand supply. Accretion in the mouths sector is likely to be impacted in the coming years by large-scale channel bed sand mining, compounded by sediment trapping by recent dams in China. The overall current status of the entire Mekong delta shoreline, dominated by land loss, highlights increasing vulnerability to perturbations in sediment supply driven by human activities over the last few decades.

Keywords: River delta, Vulnerability, Sediment supply, Mekong

Risk trends in Vietnamese river deltas: Manifestations of environmental change or socio-economic transformation?

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Vietnam’s Mekong and Red River deltas are often numbered amongst the global hot spots of environmental risk. Climate change and regional hydropower development are typically listed as the main risk drivers. What is much less understood, however, is how the country’s socio-economic and political transformation process is changing the vulnerability of the population in the two deltas. The paper therefore analyses key risk trends in both deltas by examining, first, the role of changing hazard patterns and, second, the contribution of shifting vulnerability. It draws on empirical results collected in over six years of research in Vietnam, based on two long-term projects. The analysis brings to light an antagonistic pattern: While the political leadership is keen to frame deltaic environmental risks as being driven by external forces (notably climate change and upstream hydropower), the data suggests that locally driven environmental degradation as well as socio-economic marginalization and weak institutions play a much more immediate role in driving up natural hazards and social vulnerability, respectively. The paper discusses whether these local drivers of risk emerged “despite of” or “because of” Vietnam’s pronounced socio-economic and political transformation process in relation with doi moi-reforms. The article concludes with debating the relevance and transferability of the findings for other delta environments in Asia and beyond.

Keywords: Risk, Vulnerability, Vietnam, Deltas

Modelling floodplain inundation of the Mekong Delta using a regional hydrodynamic model with a view to future scenarios

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With a very flat, low-lying topography and immediate proximity to the coast, deltas are one of the most hazardous regions for flooding. Flooding does provide an important resource to distribute fertile sediment in these regions, but can also result in devastating loss of life and property, with perhaps the most potent recent example being the 2008 Irrawaddy Delta floods. Therefore, careful management of appropriate flooding is vital to ensure sustainable management of these delicate systems.
Deltas are becoming increasingly populous with an estimated 500 million people now living on them, with much of the growth in mega cities. Yet, these regions also provide an essential agricultural resource, resulting in a concentration of resources and people, and thus a high flood risk. This risk is growing disproportionately in developing countries, where most of the world’s most populous deltas are located. Future projections of sea level rise, subsidence and sediment delivery are predicted to significantly increase the risk in many of the world’s deltas. Flood inundation modelling of deltas at an appropriate scale can be applied to improve our understanding of the hazard. This work provides initial results of flood simulations on the Mekong Delta using a computationally efficient hydrodynamic model (LISFLOOD-FP) applied at the regional scale with freely available data.
The Mekong Delta, the world’s third largest delta, is densely populated and considered Southeast Asia's most important region for agricultural production. However, it is increasingly exposed to coastal erosion, subsidence and reduced sediment delivery, and thus there is a need to investigate the potential impact these pressures might have on future flood hazard. To enable this investigation it is first necessary to develop an efficient but sufficiently accurate hydrodynamic model of the delta.
Simulations were run across resolutions of 540m and 270m for a 6 year period between 2001 and 2007. Topographic data was taken from a custom bare earth version of SRTM developed at the University of Bristol, where a vegetation correction factor is obtained from ICEsat and MODIS data. River width data was supplied by the GWD-LR database. Further calibration data including gauge readings and bed elevation was supplied by the Mekong River Commission. Where bed elevation was unavailable a number of different methods were applied to estimate channel depth. These included a hydraulic geometry relationship approach and interpolating existing bed elevation along delta plain gradients. Tidal influences were considered by including several nearby gauges as downstream boundary conditions. Validation of results was achieved using satellite-derived flood inundation maps from the MODIS platform. Performance was also compared to other flood inundation models of the delta, including CaMa Flood. Results show that LISFLOOD-FP has considerable skill for the simulated period, with limitations largely occurring from terrain errors in the SRTM data.
This work demonstrates the potential of a regional scale hydrodynamic model to simulate flood hazard in deltas, providing an important resource towards assessing flood risk within these regions. It is envisaged that this work will enhance the representation of flood hazard in the risk portfolio of these complex systems. Further work is planned to run the model across a number of deltas under future scenarios that included sea level rise, subsidence, population growth, sediment delivery and runoff change.

Keywords: Mekong Delta, LISFLOOD-FP, Floodplain Inundation, Flood

Food and nutrition security trends, determinants and challenges in tropical mega deltas

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It is estimated that more than 20% of the global population remains food insecure (FAO, et al 2015, Wheeler and von Braun, 2013). Due to a rise in consumption and rapidly increasing population, food demand may increase by at least 70% by 2050 (Royal Society, 2009). The challenge of meeting this increased demand is exacerbated by demographic changes, political instabilities, and environmental change, including the impacts of climate change (Poppy, 2014). These challenges are particularly pertinent to the densely populated tropical mega deltas of the global south, dubbed the ‘rice bowls’ of the world.
In the last 20 years many developing countries have made considerable progress towards improving food security and nutrition. However, progress across countries and dimensions of food security have been uneven (FAO, 2014). For example, in countries home to major tropical deltas such as Bangladesh and Cambodia, about a third of children are still classified as undernourished (IFPRI, 2015). While challenges to food security in the context of environmental and climate changes have been studied widely, limited evidence exists for their implications for food and nutrition security in tropical deltaic regions. Delta areas are particularly vulnerable to food insecurity and malnutrition due the specific environmental, climatic and human development factors affecting agricultural production and fisheries. These include coastal flooding and storm surges, deforestation, changes to river flow patterns and water tables, increased soil salinity and water quality degradation. Due to the large number of people living in Deltaic regions and their importance in regional food production, there is a pressing need for a better understanding on how environmental factors affect food security and malnutrition.
This study explores the potential impacts and challenges posed by environmental and climate change on food and nutrition security in three tropical mega-deltas: the Amazon, the Ganges-Brahmaputra and the Mekong delta. Socio-economic, agricultural production, environmental, nutritional, health related and demographic datasets for each region for the period 2000-2015 will be used and analysed to assess the impacts of contextual environmental variables on food security and nutrition. This includes an assessment of how these relationships vary in strength of association between the 3 deltas.. In addition, existing socio-economic- and climate change scenarios and modelling results are used to assess potential changes in food and nutrition security under plausible future pathways of development and impact. Results are framed in the context of relevant targets of the proposed Sustainable Development Goals and describe the challenges for food security and policy implications for each mega-delta.

Keywords: Delta's, Food security, Environmental change, Nutrition, Climate Change

The GDVI –A blueprint for spatial vulnerability assessments in deltas facing multiple hazards

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Disasters continue to exact a heavy toll on humans, ecosystems and economies, thus undermining ongoing efforts to achieve sustainable development. River deltas host dense populations, feature rich biodiversity and are hot spots of both agricultural and industrial production. But due to their ecological and economic importance, they are increasingly recognized as central to research and policy-making in the context of regional sustainability. Being located at the interface between the land and the ocean, the long-term sustainability of deltas is increasingly under threat due to the impacts of a range of natural and man-made threats, including large-scale human interventions as well as a range of environmental hazards (e.g. sea level rise, floods, storms, droughts, salinity intrusion, etc.). Understanding risks associated with these hazards, including both drivers of exposure and vulnerability of deltaic social-ecological systems (SES), and identifying hotspots at the sub-delta scale is hence becoming increasingly important for the development of spatially-targeted adaptation options.

Drawing on a holistic SES-centered risk and vulnerability framework as well as a “library” of environmental, socioeconomic and governance-related indicators (Sebesvari et al., forthcoming), we developed the Global Delta Vulnerability Index (GDVI) as a blueprint for delta risk and vulnerability assessments worldwide. Relevant indicators to be included in the indicator library were identified by means of a systematic review of peer-reviewed (and grey) literature combined with expert consultations during a series of stakeholder workshops in three model deltas, the Amazon, the Ganges-Brahmaputra-Megna, and the Mekong delta. In the library, indicators are organized in a modular structure, i.e. according to their relevance for different environmental hazards, hence being responsive to the specific multi-hazard settings of a given delta SES while also considering the interactions between the hazards in a given location. Based on these preliminary steps we followed a largely sequential, multi-stage workflow to construct the GDVI for the above mentioned model deltas. Important modeling stages include data acquisition and pre-processing (identification and treatment of outliers, missing data and multi-collinearities), normalization, (weighted) aggregation, sensitivity analysis (e.g. impact of indicator choice, etc.) and visualization. Further, for one of the deltas a validation of the resulting risk against observed loss and damage information was carried out.

Results show that risk, exposure and vulnerability are very heterogeneous both between and within the three deltas, with varying contributions of the underlying indicators. The highest level of risk and exposure was observed in the Mekong delta, followed by the GMB and the Amazon, while vulnerability of the coupled SES was found to be particularly high in the Amazon. Both facts have crucial policy-making implications since (a) interventions aiming at reducing risk must be spatially targeted, and (b), due to its relatively high level of vulnerability, risk might increase dramatically in the Amazon delta if exposure to natural hazards increases in the future, hence calling for improved preparedness.

The presented work is part of a global project called ‘Catalyzing action towards sustainability of deltaic systems (DELTAS)’ funded by the Belmont Forum and the 2015 Sustainable Deltas Initiative, endorsed by ICSU.

Keywords: Deltas, Social-ecological systems, Spatial vulnerability assessment, Amazon, Ganges-Brahmaputra-Megna, Mekong

Connectivity in river deltas: Channel-wetland exchange, process couplings, and implications for water, sediment, and nutrient transport

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River deltas are highly dynamic landscapes composed of networks of channels and wetlands and subject to natural forcings such as waves, tides, and wind, and to multiple natural and anthropogenic stressors. Deltas are thus vulnerable to changes in sea level, subsidence, and extreme events such as storms, all of which pose significant risks to the large populations living in coastal areas. The delivery of water, sediment, and nutrients is fundamental to land growth and for maintaining a healthy and diverse ecosystem. Such delivery highly depends on the physical and process couplings in the delta system. Yet, portions of the delta (channels, wetlands, shoreline) are usually studied in isolation and process couplings are not quantified.
We present a framework for studying connectivity in river deltas based on field observations collected on Wax Lake Delta in Louisiana (USA) and numerical modeling. We show that wetlands are an important part of the delta hydrological network as up to 50% of the channel discharge is transferred from the channels to the wetlands. This value varies depending on the relative roughness of wetlands and channels, the discharge magnitude, and the tidal cycle, which we quantify by applying a numerical model under a range of conditions. Couplings among water depths, tides, wind, and discharge at different locations of the delta are quantified with an information theory approach, specifically by computing mutual information and transfer entropy from time series data. These metrics quantify the degree of information shared and transferred among variables and thus detect synchronization and forcing dominated couplings in the delta and associated scales.
The implications of connectivity on delta functioning are discussed in terms of land growth, potential for nutrient removal, and travel times through the system as a function of network structure.

Keywords: deltas, networks, connectivity

The hydrology and hydrochemistry of deltas and their significance to deltaic hydrochemical/diagenetic processes and deltaic ecology

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Once a delta has aggraded/prograded to become emergent above the level of high tide its hydrology and hydrochemistry generally are complex. This is particularly the case for large deltas because they are comprised of a diverse suite of landforms and stratigraphic units, a range of water sources of different hydrochemistry, and a range of hydrologic recharge/discharge mechanisms. Deltas set in the various possible tidal ranges and climate types provide further variation on the dynamics of hydrology and hydrochemistry. In the midst of standard salinity gradients and intra-annual variations resulting from seasonal river inflows, the size and complexity of the delta, and the size of an estuary where a delta may reside, there are important localized interactions between the different open water bodies around deltas, such as river to sea interactions, or sea to estuary to river interactions. Whether adjoined by seawater or open estuarine waters (into which the delta has been prograding) or dissected by distributary channels with waters that can vary seasonally from marine to brackish to freshwater, the core of a delta may contain a freshwater lens similar to that under an oceanic island that interacts hydrologically on its margins with the open ocean or with an enclosing estuarine water body or with the river channels. The freshwater lens has a saline/freshwater contact similar to the Ghyben-Herzberg saline and freshwater relation.

Local areas on the subaerial delta plain, comprising contrasting mud-floored lagoons/ponds or sandy cheniers, or abandoned channels, are affected by river inflow, or rain, or evaporation, and develop salinities and hydrochemically specific surface and near-surface water bodies and groundwater bodies, respectively, that perturbate the salinity/hydrochemistry of the main body of the delta groundwater. The delta is characterised by fluctuating watertables and hydrochemistry of groundwater and the marine and estuarine water between wet and dry seasons, the dynamics of discharge, intrusion and seepage that occur between the delta groundwater and marine or estuarine water, and the wetlands on the delta. The various water bodies and their hydrodynamic and hydrochemical characteristics and interactions are underlying determinants of the biota resident on the deltaic wetlands and determinants of diagenetic products that occur within a delta. Western Australian deltas and intra-estuarine deltas serve as case studies of the hydrology and hydrochemistry of deltaic systems.

Keywords: deltas, intra-estuarine-deltas, Western-Australia, hydrology, hydrochemistry

Delta channel network complexity for quantitative delta classification and vulnerability assessment

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Deltas are landforms that deliver sediment, water and nutrients from upstream basins to the shoreline through interconnected pathways of channels that self-organize to a variety of stunning and complex patterns. The question as to what information about the forming processes (river, tide, and wave energy, vegetation, sediment properties, flow characteristics, etc.) might these patterns encode is fundamental to developing a quantitative approach to delta classification and advancing the still-in-use qualitative approach of *Galloway* [1975] and *Orton and Reading* [1993]. In our recent work [*Tejedor et al.*, 2015a,b] we introduced a graph theoretic framework for analyzing delta channel network complexity from a topologic (channel connectivity) and dynamic (flux exchange) perspective and proposed a TopoDynamic complexity space where deltas can be uniquely positioned. Here we examine the potential of this framework, together with field, numerical and experimental deltas towards a systematic approach to delta classification and inference. Specifically, we show that sediment parameters (grain size and cohesiveness; acting also as surrogates for vegetation) leave a distinct signature on the channel structure in river-dominated deltas simulated by a morphodynamic model (Delft3D) -- deltas with coarser incoming sediment tend to be more complex topologically (increased number of looped pathways) but simpler dynamically (reduced flux exchange between subnetworks), giving hope for classification. This is encouraging and calls for further analysis of simulated and field deltas and possible expansion of the dimension of the TopoDynamic complexity space to introduce additional discriminatory metrics. Comparison of the “delta width function” (channels at a radial distance from the apex) with the time-evolving shoreline of simulated deltas provides insightful new information about delta formation. Finally, entropy-based metrics of delta complexity are analyzed for both field and simulated deltas to examine how complexity might relate to delta vulnerability (where vulnerability here is defined by the relative effect of upstream flux perturbations to the shoreline) and an inverse relationship is reported.

Keywords: Delta Classification , Graph Theory, Complexity , Vulnerability

Development of large scale fluvio-deltaic morphology: a long-term modeling study

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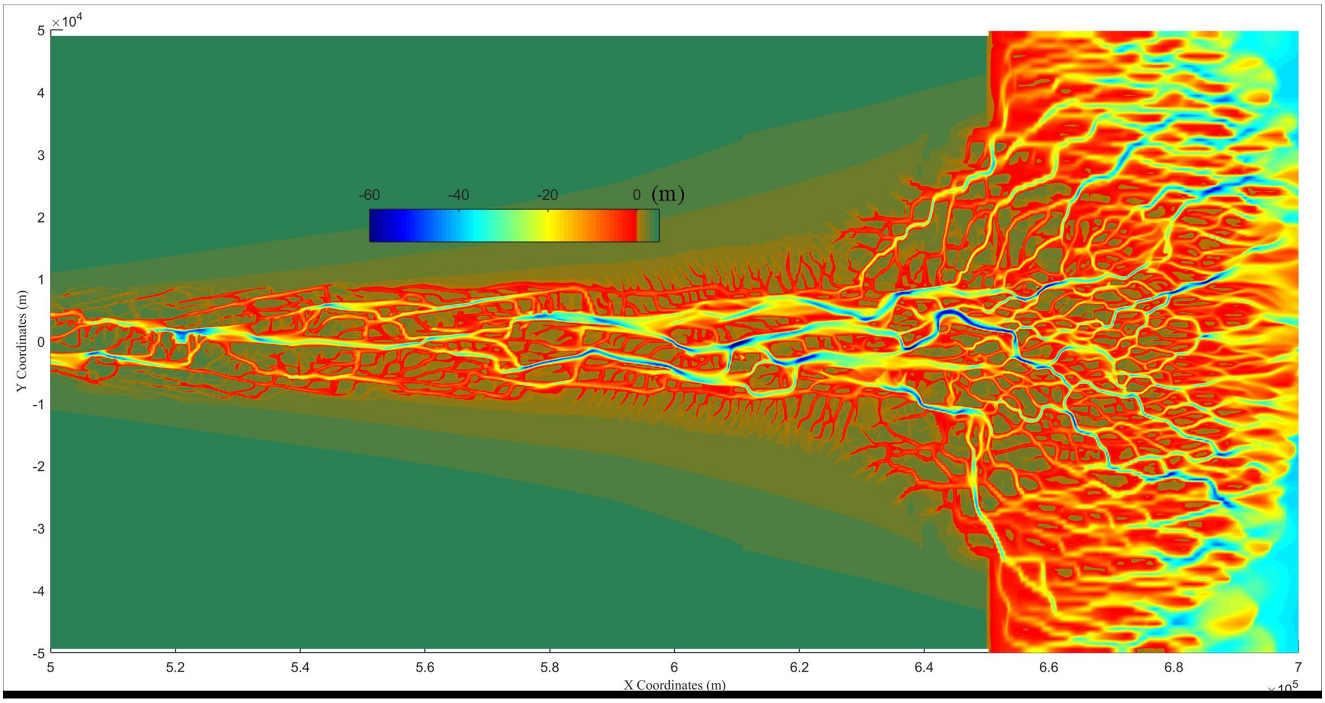
To investigate initial delta development and forcing controls, this study uses a process-based morphodynamic model (Delft3D) to simulate long-term (millennial time scale) morphodynamic development of a schematized large-scale fluvio-deltaic system (700 km long and 100 km wide) forced by high river discharge and strong tides. The model couples water motion, sediment movement, and bathymetric updating enhanced by a morphological acceleration technique which bridges the time scale gap between hydrodynamics and morphology (Roelvink, 2006). Model results (Figure 1) suggests that (1) river flow magnitude and sediment supply exerts strong controls on deltaic morphodynamic development and associated channel pattern; (2) estuarine bank erodibility plays a role by supplying sediment and providing space for channel migration and sand bar formation; and (3) initial basin geometry and shelf slope also have impacts on the deltaic morphodynamic development. The sensitivity simulations to varying governing factors thus help to unveil the basic controls on deltaic morphodynamics and provide guidelines to understand delta in nature.

Keywords: Estuary, Delta, Morphodynamic



Sediment Grain Size Trends throughout Delta Networks

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Commonly a network of channels forms once a feeding river channelbelt enters a low-gradient coastal plain, creating the classic delta planview morphology. This area is a zone of net deposition and consequently mass loss in the longitudinal direction. Tank experiments and subsurface data show that mass loss leads to down-channel sediment fining as deposition preferentially removes coarser particles (Paola and Martin, 2012). Understanding grainsize depositional trends is important for assessment of subsurface characteristics and importantly impact local subsidence rates and shallow groundwater flow.

We hypothesize that downstream fining trends are more pronounced 1) if rivers commonly experience overbanking and floodplain inundation, and 2) in deltas with a complex distributary networks.

We use a numerical model that describes fluvial transport with a simple geomorphic mass balance approach. It models a main channel belt as a 2D longitudinal profile that responds dynamically to changes in channel geometry, water discharge, sediment load, and grain-size distribution based on first-order, physics-based principles. Sediment flux is described with a modified Exner equation by separate erosion and sedimentation components. Erosion flux along the main flowpath depends on river discharge and channel slope, and is independent of grain-size. Depositional flux in both longitudinal direction and in lateral direction into the floodplain depends on stream velocity and on grain-dependent settling rates.

Model experiments show distinct thinning of deposits, and fining of grainsize downstream the fluvio-deltaic floodplain. An abrupt coarsening of the deposits and change in overall downstream fining trend occurs at the land-ocean boundary, associated with a decreased transport capacity and a rapid acceleration of sediment settling rates in the marine domain.

Preliminary scenarios with increased flood dynamics display a more rapid mass extraction and efficient sorting downstream, due to the upstream settling of sediment otherwise funneled downstream during bankful conditions.

A more complex delta distributary network dramatically affects mass extraction rates and associated overall fining trends. In addition, repeated occurrences of rapid grainsize coarsening are observed at distributary nodes.

Already these simple experiments provide new insights in grainsize distribution patterns in delta floodplains, but major advances can still be made by improving the simple modeling approach to a more sophisticated channel floodplain coupled model including tidal processes.

Keywords: numerical modeling, floodplain, grain size patterns, delta

Rock-barred deltas –an addition to the types of coastal deltas with examples from eastern Australia

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Modern delta classification has addressed that deltaic sedimentation and landform building is dependent on fluvial delivery of sediment to the coast and the building of deltaic coastal landforms by the interplay of oceanographic and fluvial processes resulting in a ternary classification that recognises wave-dominated deltas, tide-dominated deltas, and fluvial-dominated deltas. Granulometry and delta asymmetry also recently have been addressed in expanding the initial ternary delta classification. This paper explores a type of delta that currently is not captured by the classification of the present ternary system, nor by the partitioning of deltas according to their dominant granulometry. It is one where river flow has been prevented from forming one of the coastal landforms of deltas (digitate, lobate, or current-aligned shoals/islands) because they have been barred by barriers such as rock islands. These delta-lands *are still deltas*. This we term a "rock-barred delta". The Queensland coast as the sedimentary receptor for a range of rivers deriving from a 3500 km long highland (the Great Dividing Range) forms the framework for rock-barred deltas in that 1. the Great Dividing Range is continental-scale watershed; 2. numerous short rivers arise from this watershed; 3. the region has a high-rainfall climate; 4. the geological grain of the coast is comprised of N to NNE-trending rocky coastal strike-ridges and N to NNE-trending near-shore rocky coastal islands that form the obstructions to delta development; and 5. the Great Dividing Range as source material for riverine and coastal sediments yields sand and mud, and often mud > sand. The characteristics of rock-barred deltas are: 1. a triangular delta-plain that represents a valley tract almost to wholly filled with sediment; 2. a partial barrier of bedrock islands and peninsulae that bar the fluvial accumulations from the open ocean and perturbate oceanic waves; and 3. a tidal zone of low-tidal sand and/or mud flats, mangrove-vegetated mud flats, and high-tidal saline mud flats. In many aspects, the rock-barred deltas have features in common with traditional deltas, with the main difference being the seaward geometry because of the barriers, peninsulae, and nearshore islands. Bedrock island obstructions, however, do not stop tide-dominated delta landforms being developed in the interior of the delta-land, nor fluvial processes influencing development of fluvial landforms in the interior of the delta-land.

Keywords: delta, classification, rock-barred, eastern Australia