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# Simulated fate of catchment-derived sediment on the Great Barrier Reef shelf

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ABSTRACT

Numerical experiments using a 3D model of fine sediment transport in the Great Barrier Reef region indicate deposition of the bulk mass of catchment sediments from river plumes within a few tens of kilometres from river mouths. A very fine fraction of easily resuspended catchment sediment has a capacity to propagate over much greater distances reaching out into the mid-shelf and outer-shelf regions. The model suggests such particles, instrumental to the development of low density flocs in the marine environment, can play a critical role in altering optical properties of water masses over the shelf during wet years. The mid-term (4 year) impact of Great Barrier Reef catchments on the probability of suspended sediment concentration exceeding the ecologically significant trigger value of 2 mg/L is confined to inshore regions adjacent to river mouth locations.

## 1. Introduction

The Great Barrier Reef, off the north-east coast of Australia, is the world's largest coral reef system and a Marine World Heritage site. A general decline in ecosystem health of the Great Barrier Reef (GBR) in recent decades has been attributed to a number of factors including increased terrestrial loads of sediment and nutrients into the GBR lagoon over the last 150 years (Brodie and Furnas, 2001; Furnas, 2003; Kroon et al., 2012). These increases have been linked primarily to the altered land-use practices on catchments that translated into a reduced vegetation cover and elevated rates of the sediment erosion particularly during large flood events. A multi-year Water Quality Improvement Plan has been established and partly implemented in recent years by the Australian Government and the community to reduce run-off of pollutants through the improved management of catchments (Brodie et al., 2012, 2013). Demonstrating changes in marine systems that result from these management actions, however, is a challenge, because of the high natural variability of sediment processes on the shelf and limited understanding of the role of catchment sediment in maintaining suspended sediment levels over the GBR region. According to one school of thought, for example, changes in sediment loads from catchments will have a minor impact on chronic turbidity over coral reefs since the sediment store in the lagoon is already large (Larcombe and Woolfe, 1999). Another vision, based on recent measurements, suggests that newly imported materials from catchments can cause significant changes in water clarity inshore as well as mid-shelf (Wolanski et al., 2008; Fabricius et al., 2013, 2014, 2016).

This paper describes a numerical study aiming at better understanding of the distribution and fate of fine sediment delivered from catchments to the GBR shelf. Numerical experiments are conducted using a 3D fine resolution sediment transport model of the GBR region developed through the eReefs project (Schiller et al., 2014; Herzfeld, 2015; Baird et al., 2016). This model, tested through the extensive calibration and validation studies (Margvelashvili et al., 2016), represents the first 4 km resolution sediment transport model of the entire GBR shelf coupled to hydrodynamic and wave models.

The rest of this paper is organised as follows: the next section describes the numerical model and simulation scenarios. This is followed by the analysis and discussion of the numerical results and a conclusion summarising the key findings of this study.

## 2. Method

### 2.1. Numerical model

The sediment transport model solves the advection-diffusion

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equations of the mass conservation of suspended and bottom sediments and is particularly suitable for representing fine sediment dynamics, including resuspension and transport of biogeochemical particles (Margvelashvili et al., 2008). Suspended sediment particles settle on the seabed due to gravity and resuspend into the water column whenever the bottom shear stress, induced by waves and currents, exceeds the critical shear stress for erosion. Resuspension and deposition fluxes are parameterised with the Ariathurai and Krone (1976) formula. Estimates of the bottom shear stress, required by this formula, are derived through the Madsen boundary layer model (Madsen, 1994). Bottom roughness is considered a model parameter derived through the calibration study (Grant and Madsen, 1982).

Sediments in benthic layers undergo vertical mixing due to bioturbation, represented by local diffusion. The corresponding diffusion coefficient is scaled by sediment depth so that bioturbation ceases to operate beneath the biologically active layer. The resistance of sediments to resuspension increases with sediment depth, thus acknowledging the consolidated nature of fine particles in deep sediments. The initial thickness of sediments is 40 cm, and the top 20 cm of this layer is assumed to be biologically active.

The numerical grid for sediment variables in the water column coincides with the numerical grid for the hydrodynamic model (described by Herzfeld, 2015). For bottom sediments, the model uses a grid where the thickness of sediment layers varies with time to accommodate the deposition of sediment (Margvelashvili et al., 2008). There are 4 benthic layers in the GBR model grid. Horizontal resolution within sediments follows the 4 km resolution of the water column grid.

### 2.2. Initial conditions

The sediment transport model was initialised with the observed distribution of gravel, sand and mud in benthic sediments of the GBR shelf (Geoscience Australia MARine Sediment database, Fig. 1 right plot). The model simulates transport of fine sediments represented by mud and transport of sediments from catchments (to be discussed in the next paragraph). Heavier particles (gravel and sand, typically not resolved by the 3D model in the near bottom regions), were kept immobilised within the benthic layers.

The initial distribution of mud in the model domain reflects past accumulation of sediment in the region, but the model also simulates resuspension, deposition and transport of fine sediments that are discharged from catchments during the simulation period. The initial concentration of these catchment-derived sediments is established through the spin-up of the model running for several years and accommodating sediment loads from catchments. The sediment classes and key sediment processes as implemented in the model are summarised in Table 1.

### 2.3. Forcing

The sediment transport model was driven by hourly mean velocities and diffusion coefficients from the 4 km hydrodynamic model (Herzfeld, 2015) using a mass-conservative advection scheme (Gillibrand and Herzfeld, 2016). Sediment transport is simulated in off-line mode – the hydrodynamic model runs first to provide inputs to the stand-alone sediment transport model (specifically, velocity vectors in three dimensions, diffusion coefficients and surface elevation). The simulation time-step for the sediment model is 1 h (much larger than the time-step of the hydrodynamic model) and there is no feedback from the sediment processes to the hydrodynamics, i.e. the model assumes that sediments have no effect on the flow, density or turbulence. This decoupling of the sediment and hydrodynamic models substantially improved computational efficiency.

Wave data (RMS of the near bottom orbital velocity, wave direction and period) were obtained from the shelf-scale WaveWatch III (WWIII) model nested into the global-scale WWIII model (Tolman, 1991). Spatial resolution of the wave-model is about 4 km across the region and the data are generated with an hourly time-step.

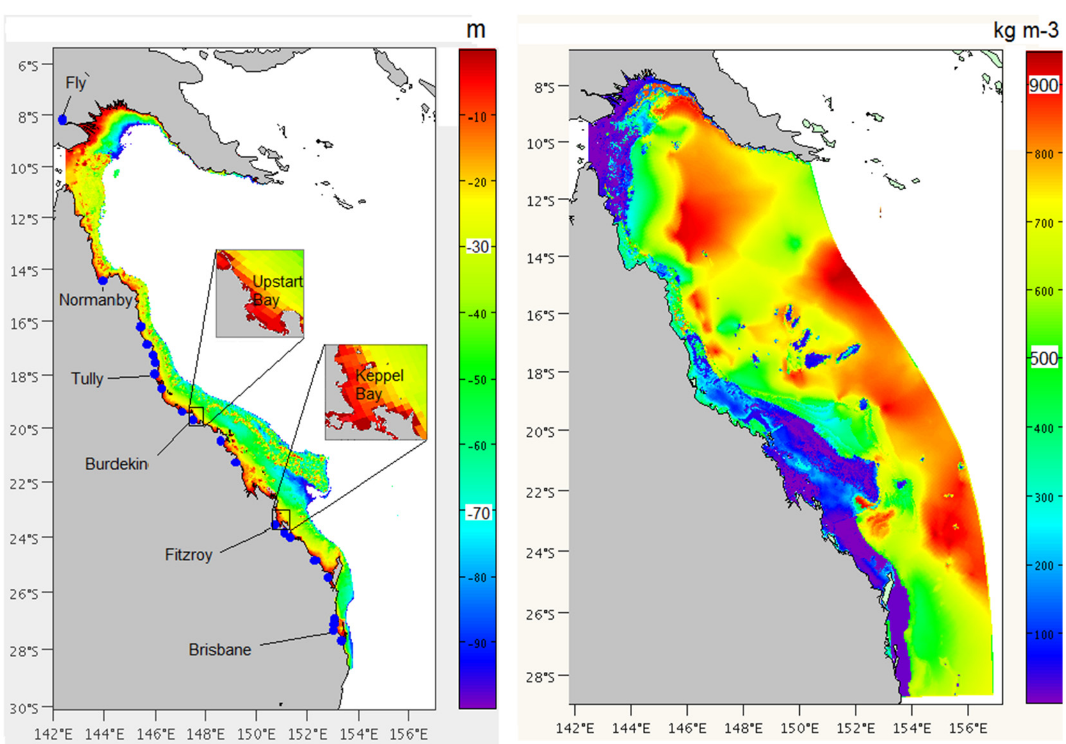


**Fig. 1.** Bathymetry map truncated to 100 m depth (left) and map of the distribution of mud (right) interpolated from GA MARS database. Blue dots on the left plot indicate river discharge points. Enlarged coastal regions represent coastal embayments receiving inputs from two major rivers in GBR – Burdekin and Fitzroy. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)