SAND TRANSPORT IN THE SURF ZONE OF A DISSIPATIVE BEACH

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Abstract: Suspended sand transport measurements carried out on a meso-tidal beach at Egmond aan Zee, The Netherlands, during two Coast3D field campaigns in spring and fall of 1998 were used to examine the sand suspension mechanism and transport rates under waves. Two tests measured under similar wave conditions showed very different suspension patterns, due to different scales of suspension related to the bed form dimensions. Despite a wide range of bed form dimensions found in the field, the general trend of the data could reasonably well be predicted using a numerical model. Driven by the locally measured hydrodynamics and using a fixed bed roughness height the model predicted the current-related suspended transport rates near Egmond aan Zee shows reasonably good agreement with measured values (based on tuning of bed roughness).

INTRODUCTION

Sediment suspension and transport in the surf zone is a complex process due to the interaction between waves, currents and bed forms. In the last two decades important field experiments have been carried out in various regions of the world to study the hydrodynamic and sediment transport processes in the surf zone, also providing data against which models can be tested. Recently, field measurements were carried in the tidal surf zone of Egmond aan Zee, The Netherlands, in the framework of the European Commission's research program MAST-III RTD. The objectives of the Coast3D experiments were to collect field data for better understanding of the sand transport in the surf zone for evaluation of sand transport models. For that purpose two field sites were chosen, the first near Egmond aan Zee in the Netherlands and the second near

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Teignmouth in the United Kingdom. Herein attention is focused on the sand transport measurements near Egmond aan Zee.

Two measurement campaigns were conducted near the coast of Egmond aan Zee. The pilot campaign was held from 20 April till 4 May 1998 and the main experiments took place from 12 October till 20 November 1998. The activities during the measurement campaigns included bathymetric surveys of the beach and the nearshore, measurements of near-bed wave- and current driven processes, measurements of offshore wave conditions, tides and meteorological conditions and various other activities including sediment sampling, tracer experiments, bed form mapping, and video and radar imaging of the nearshore region. Soulsby (1998) gives more details on the objectives and experimental design of the Coast3D experiments.

In this paper we discuss the effects of the hydrodynamic conditions and bed form dimensions on the time-averaged suspended sediment concentrations and depth-integrated suspended sediment transport. We present data from two records of surface elevation, currents and suspended sand concentrations and show that the bed form dimensions are a major control in the sediment suspension mechanism. The bed form roughness is used as a key parameter in the modeling of the sand concentrations.

The outline of the paper is as follows. First, a description of the field site will be given and the measurement methods will be described briefly. Next, results will be shown of the concentrations measurements. Then, computed concentrations profiles and current-related transport rates using the TR2000 model will be compared with the measurements. Finally, the findings are summarized.

INSTRUMENTATION AND SITE

The data presented here were obtained from a field site near Egmond aan Zee, The Netherlands. The coastline near Egmond aan Zee is part of the central Netherlands coast, which contains 124 km of essentially continuous shoreline mainly consisting of sandy beaches and multiple barred nearshore zones. The orientation of the slightly curved coastline is essentially NNE-SSW. It is an inlet free, wave dominated coast. The wave climate is dominated by sea waves with a mean annual significant offshore wave height of about 1.1 m. The tidal range varies between 1.4 m (neap) and 2 m (spring). The tidal peak currents in the offshore zone are about 0.5 m/s; the flood current to north is slightly larger than the ebb current to south. The sediments are well sorted and composed of fine to medium sand with a median grain size between 200 and 300 μm. A more extensive description of the central Netherlands coast is given by Wijnberg (1995). During the experiments the nearshore zone of the study area was characterized by two subtidal nearshore bars. The outer nearshore bar was located at 550 m and the inner nearshore bar at 200 m offshore (Figure 1).

Measurements of wave height, velocity, and sediment concentration at four or five locations in a cross-shore array over the inner nearshore bar (Figure 1) were performed using the Coastal Research Instrumented Sledge (CRIS). Sand transport measurements were performed at eight elevations above the bed from 0.02 to 1.0 m. Instruments mounted on the CRIS included a pressure sensor, three electromagnetic fluid velocity meters (EMF), a five-fold acoustic sediment transport meter (ASTM), three optical backscatter sensors (OBS) and a sonar scanner. Dependent on the conditions, 8.5 or 17.1 minute long records were obtained. The instruments could be adjusted at a given elevation above the bed with an accuracy of ± 0.01 m using a vertically movable arm. The depth-integrated suspended transport rates ($q_{suspension}$) were determined using the measured time series of velocity and concentration.

Data from about 60 bursts have been analyzed. The water depth ranged between 1 and 5 m, and the significant wave height between 0.5 and 1.5 m. The relative wave height ranged between 0.06 and 0.5. The largest depth-averaged long- and cross-shore currents measured were 0.5 and 0.3 m/s, respectively.

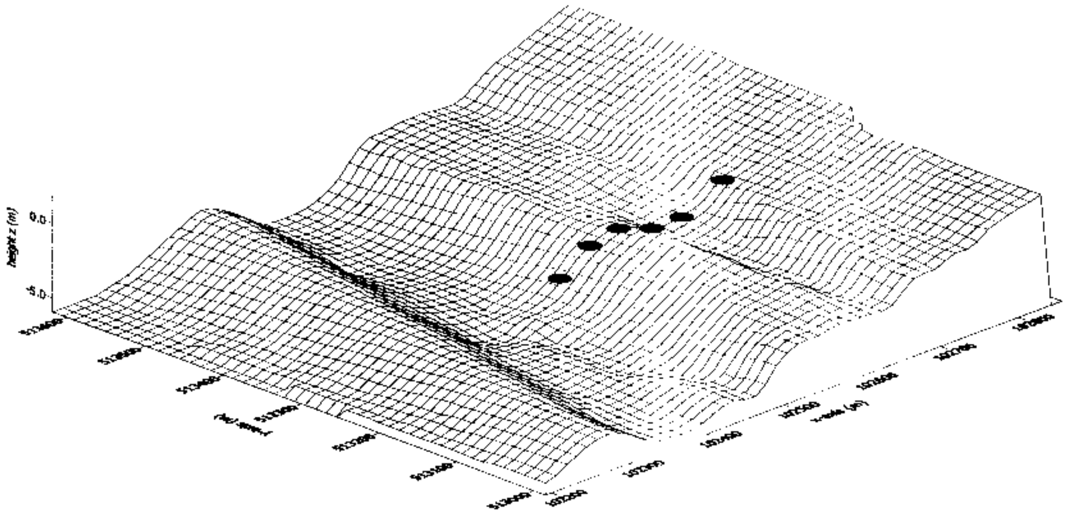

Figure 1 Example of nearshore morphology near Egmond aan Zee, The Netherlands, and CRIS positions across the inner nearshore bar on 9 April 1998.

FIELD DATA

The measurements were clustered according to their hydrodynamic conditions to get insight in the general trends. The time-averaged current velocities, sand concentrations and transport rates were grouped in 10 classes of increasing peak onshore orbital velocity ($U_{1/3,on}$ = 0.32, 0.50, 0.67, 0.89, 1.08 and 1.26 m/s).

The relation between suspended sand concentrations, the near bed orbital velocities and the bed forms is shown in Figure 2. The solid line in this figure indicates the concentrations at 0.02 m above the bed, the dashed line at 0.04 m and the dotted line at 0.10 m above the bed. Each data point in this graph is the average of 10 or more tests with the same onshore orbital velocity. The error bars show the standard error between those 10 tests. It can be seen from Figure 2 that the near bed concentrations remain more or less constant for orbital velocities between 0.32 and 0.89 m/s and increase for larger values. The bed forms generally change from a rippled bed for calm conditions to flat bed or mega ripples for mild storm conditions. This clearly illustrates the strong effect of the bed form dimensions on the suspension mechanism (see also Vincent et al. (1990) and Vincent and Green (1991)). In the presence of ripples the sediment is eroded from the bed at the onshore stroke of the wave and mobilized in vortices between the ripples. At flow reversal from on- to offshore, the vortex cloud is lifted and advected leading to relatively large concentrations just above the ripple crest. Similar processes are caused by separation vortices associated with the offshore phase of the wave cycle. In case of a flat bed these separation vortices do not occur or may occur but on a smaller scale. Vincent et al. (1990) and Vincent and Green (1991) found decreasing concentrations of sand close to the bed with increasing wave height and also attributed this to the different scales of suspension related to the bed form dimensions.

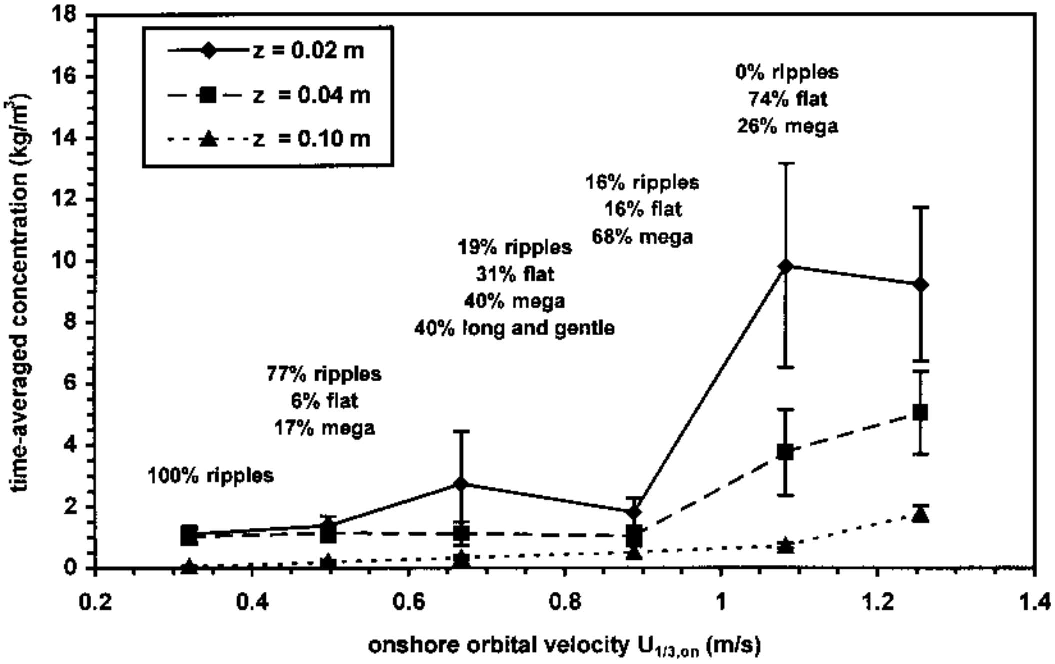

Figure 2 Class- and time-averaged near bed concentrations and bed form type as a function of peak onshore orbital velocity.

The difference in suspension pattern between a flat bed and a rippled bed is illustrated using two records, 11161 and 05031. The measurements were taken at approximately the same location and the hydrodynamic conditions were comparable with $H_{1/3}/h \approx 0.26$, $U_{m,long} \approx 0$ m/s, $U_{m,cross} \approx 0$ m/s and $T_p \approx 6.8$ s. Figure 3 shows time series (300 s) of near bed velocity and concentration at 0.02 m above the bed in case of a flat bed (11161). The suspension process is intermittent and the suspension events are related to groups of high amplitude waves in which the maximum concentration at 0.02 m above the bed is about 2 kg/m^3. The concentrations over a rippled bed are larger (Figure 4), showing peak values of nearly 5 kg/m^3 and the suspension events are more related to individual waves. However, not every wave results in suspension.

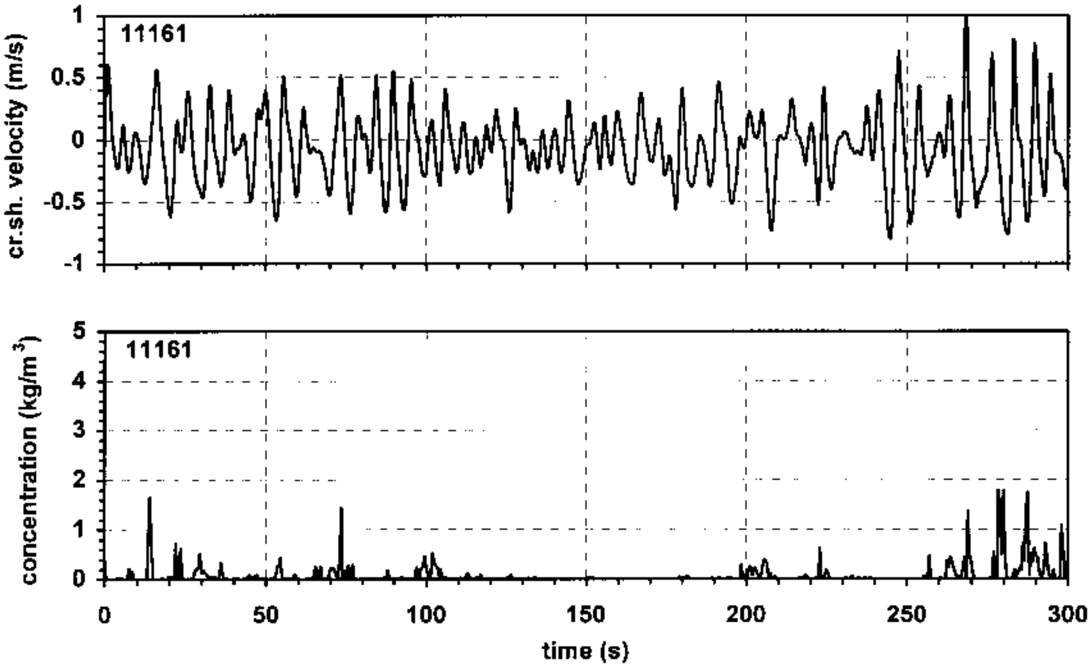

Figure 3 Time series of cross-shore near bed velocity (upper panel) and suspended sand concentration measured at 0.02 m above the bed (lower panel); test 11161, flat bed.

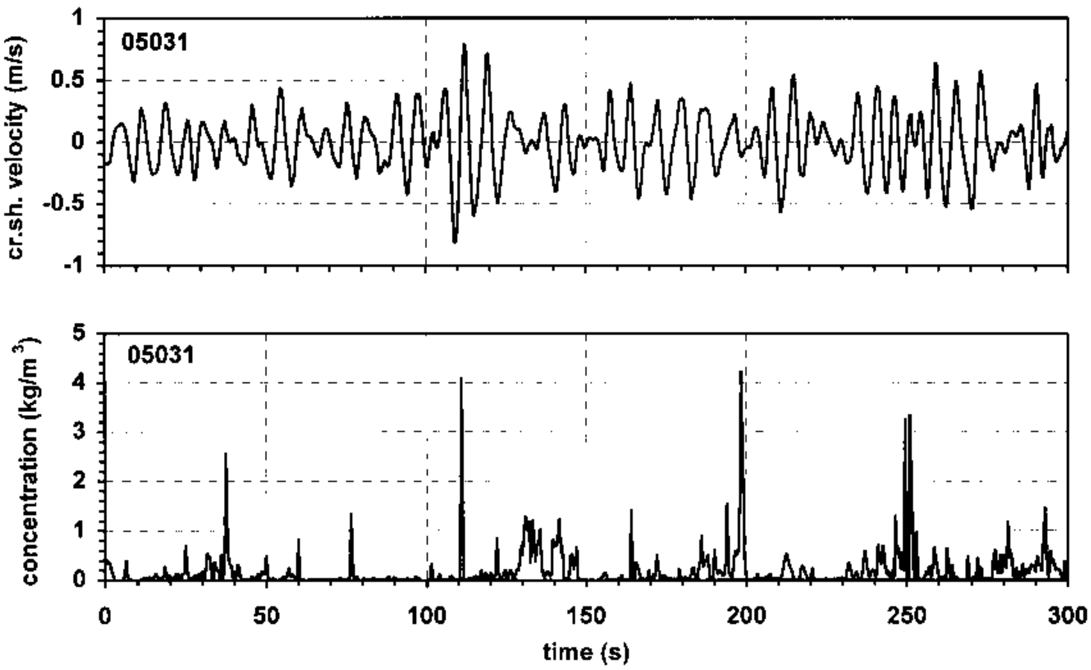

Figure 4 Time series of cross-shore near bed velocity (upper panel) and suspended sand concentration measured at 0.02 m above the bed (lower panel); test 05031, rippled bed.

A much clearer impression of the suspension mechanism and its relationship to the phase of the wave cycle can be obtained by ensemble-averaging the suspension due to a many waves. The ensemble-averaged wave was determined from the surface elevation time series and the concentrations were also ensemble-averaged in relation to its phase in the wave cycle.

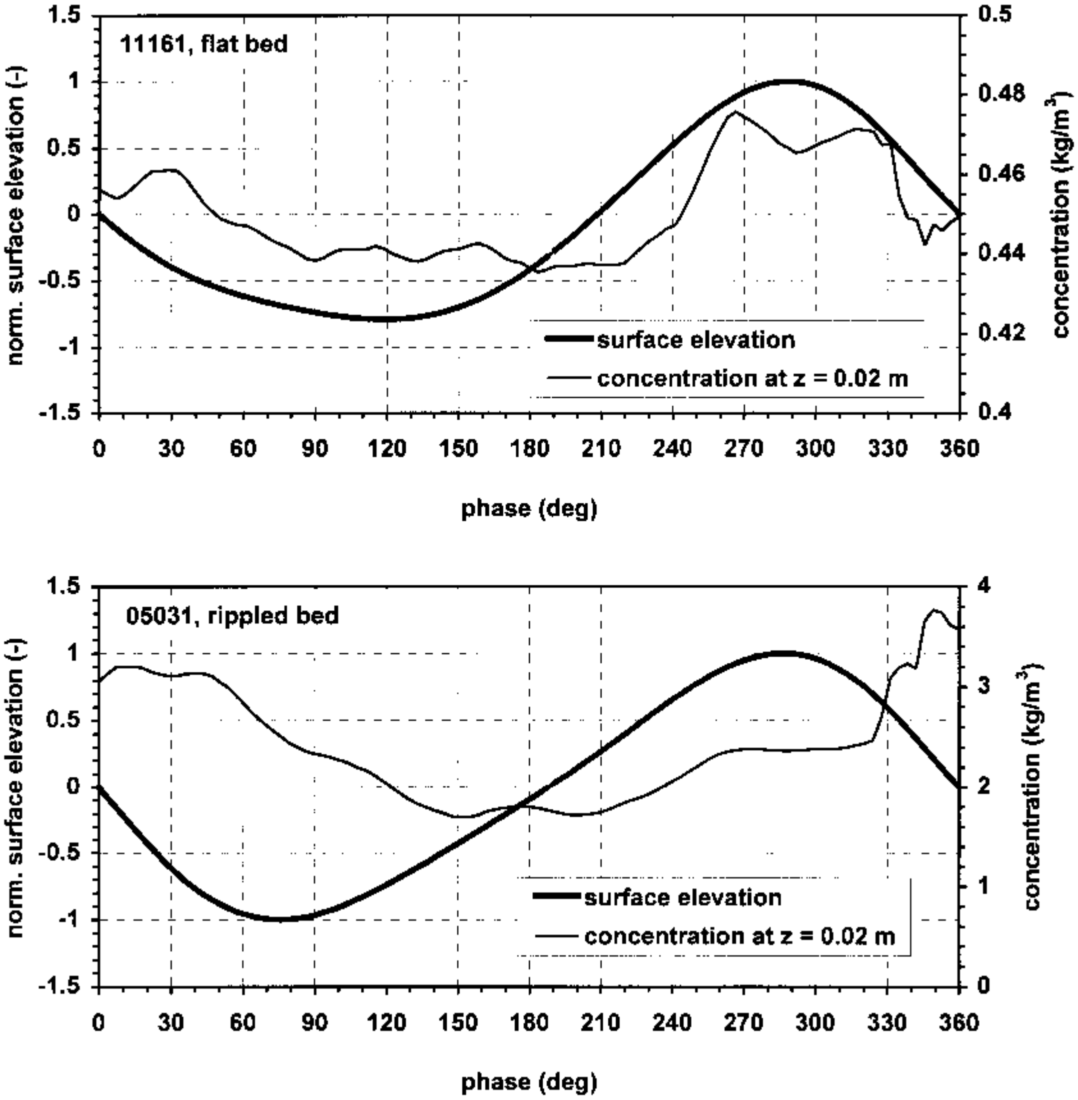

Figure 5 Ensemble-average surface elevation (normalized) and concentration in relation to the phase of the wave cycle for a test with a flat sand bed (upper; test 11161) and a rippled sand bed (lower; test 05031).

Two different suspension mechanisms are shown in Figure 5. The upper panel shows the normalized ensemble-averaged surface elevation, i.e. the significant wave profile normalized with its positive amplitude, and the concentration at $z = 0.02$ m over a flat bed for test 11161. Two concentration peaks can be discerned during a single wave cycle. The largest concentration peak of about 0.48 kg/m^3 occurs during the onshore stroke of the wave and a smaller peak of 0.46 kg/m^3 during the offshore stroke. The concentration signal is more or less in phase with the wave cycle.

The patterns of suspension during 05031 are very different (see lower panel Figure 5). The wave conditions are similar, although the waves were somewhat less asymmetric during test 05031. The concentrations are an order of magnitude larger than those during the flat bed test. The ensemble-averaged concentrations show a structure of suspension correlation to the timing of flow reversal. A concentration peak of almost 4 kg/m^3 occurs at flow reversal from onshore to offshore direction, which is due to the ejection of sand-laden vortices from close to the bed up into the water column.

A point that has to be considered when interpreting the analysis results of Figure 5 is that the horizontal position of the instruments relative to the ripple crest is not known. The bed forms interacting with the near-bed currents impose distinct constraints on both the timing and magnitude of suspension events relative to the phase of the wave motion. Bosman and Steetzel (1986) and later Osborne and Vincent (1996) analyzed sand concentration and velocity data at several positions along a rippled bed in laboratory conditions and found that the phase relationships between velocity and concentration are such that it could give completely opposite phase-relations between the velocity and the concentration values at different positions along the bed form.

Considering this, it was made sure that the present examples are illustrative of phenomena found at the Egmond site.

MODEL RESULTS

The sand transport rate of the model (TRANSPOR2000; shortly TR2000; Van Rijn, 2000) is determined based on the measured wave height, depth-averaged cross-shore and longshore velocities, orbital velocities, and sediment parameters. Herein, only the current-related suspended transport rate is discussed. The current-related suspended load transport ($q_{s,c}$) is defined as the transport of sediment particles by the time-averaged current velocities.

$$q_{s,c} = \int_a^h cu \, dz$$

The time-averaged concentration distribution is computed from the classical diffusion equation. The current-related mixing is derived from the standard expressions for turbulent flow. The wave-related mixing is described by an empirical expression based on data analysis. The sediment mixing near the bed depends on the bed roughness, and is related to the height of breaking waves. The near-bed reference concentration is computed from the excess bed shear stress and the relative wave height. The model can be used in single- and multi-fraction mode.

The computed concentrations and transport rates, based on the measured hydrodynamics, were also class-averaged to compare them with the measured values. Figure 6 shows a comparison between the measured concentrations and the computed profiles using bed roughness heights of 0.01, 0.02 and 0.03 m. It can be observed from this figure that the model underestimates the vertical mixing for calm conditions. The computed concentrations at elevations above 0.5 m are smaller than the measured values. Using the model in multi-fraction mode may give better results in this case. The finer fractions are stirred up higher in the water column in case of graded sediment. This vertical sorting effect is strongest under calm conditions. Figure 6 indicates that under calm conditions a bed roughness height of 0.02 m or 0.03 m gives best results. For mild storm conditions a roughness height of about 0.02 m suffices.

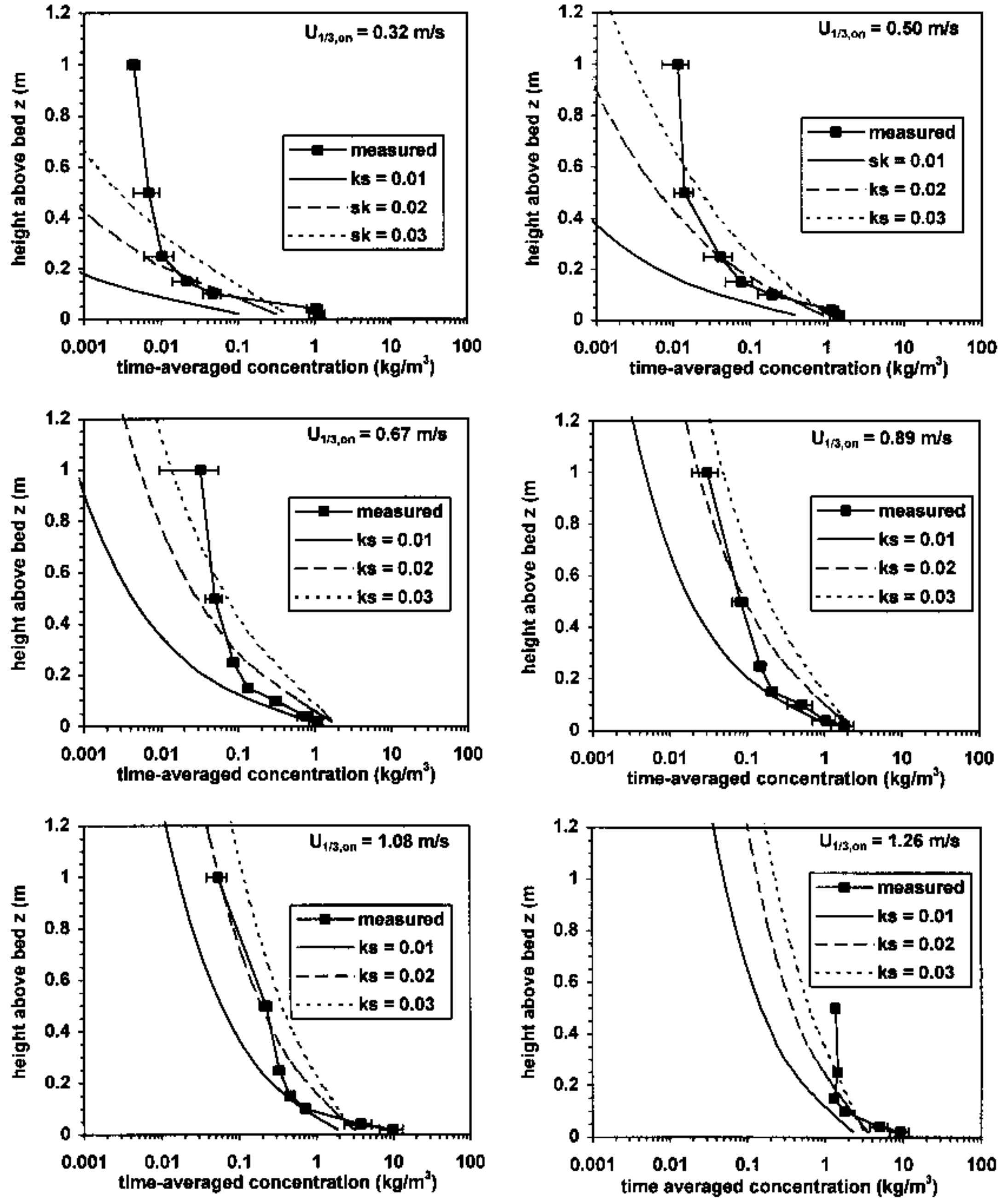

Figure 6 Measured and computed class-averaged concentration profiles

The model underestimates the near bed concentrations for mild storm conditions. As can be seen, the model is rather sensitive for the bed roughness at calm conditions. The measured current-related suspended transport rates were derived from the measured concentrations profiles (see Figure 6) and the measured current velocities. Figure 7 shows the measured current-related suspended transport rates as a function of the near bed onshore orbital velocity and the computed values using bed roughness heights of 0.01, 0.02 and 0.03 m. It can be observed from this figure that the model represents the general trend in the measured transport rates fairly well using a fixed bed roughness height of 0.02 m, which is a realistic value compared with the bed form height.

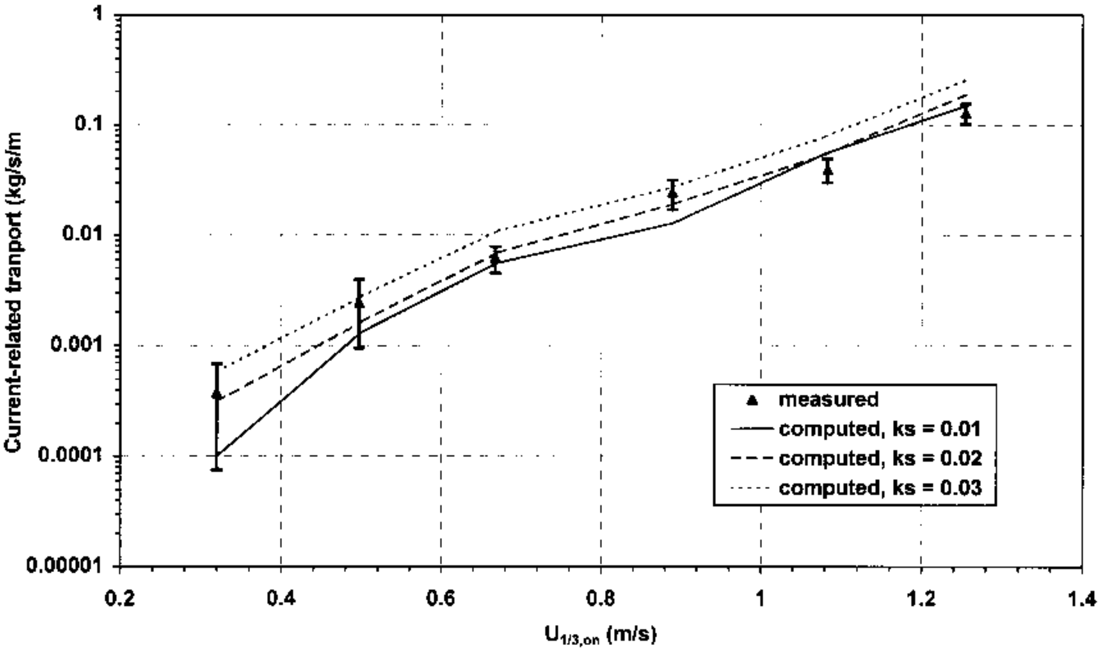

Figure 7 Measured and computed current-related suspended transport rates (class-averaged) near Egmond aan Zee, The Netherlands, as a function of the peak onshore orbital velocity.

CONCLUSIONS

Suspended sand concentrations near Egmond aan Zee measured under similar hydrodynamic conditions showed different suspension patterns due to different bed form dimensions. Despite the wide range of bed forms present in the field, the general trend in the concentration profiles could reasonably well be represented with the TR2000 model using a bed roughness height of 0.02 m for both calm and minor storm conditions. The vertical sorting of sediment is important under calm conditions and should be taken into account in the model computations (multi-fraction mode). Encouraging agreement was found between the measured and computed current-related transport rates (within a factor 2) after tuning of the bed roughness.

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