ELSEVIER

Proceedings in Marine Science 8

Estuarine and Coastal Fine Sediments Dynamics

INTERCOH 2003

J.P.-Y. Maa, L.P. Sanford and D.H. Schoellhamer (Editors)

Proceedings in Marine Science 8

Estuarine and Coastal Fine Sediments Dynamics

INTERCOH 2003

Edited by

J.P.-Y. Maa
College of William and Mary
USA

L.P. Sanford
University of Maryland
USA

and

D.H. Schoellhamer
U.S. Geological Survey
USA

ELSEVIER

Amsterdam • Boston • Heidelberg • London • New York • Oxford
Paris • San Diego • San Francisco • Singapore • Sydney • Tokyo

Elsevier
Radarweg 29, PO Box 211, 1000 AE Amsterdam, The Netherlands
The Boulevard, Langford Lane, Kidlington, Oxford OX5 1GB, UK

First edition 2007

Library of Congress Cataloging-in-Publication Data
A catalog record for this book is available from the Library of Congress

British Library Cataloguing in Publication Data
A catalogue record for this book is available from the British Library

ISBN-13: 978-0-444-52163-7
ISBN-10: 0-444-52163-1

Printed and bound in The Netherlands

07 08 09 10 11 10 9 8 7 6 5 4 3 2 1

Estuarine and Coastal Fine Sediments Dynamics

INTERCOH 2003

Companion books to this title in the ***Proceedings in Marine Science*** series are:

Volume 1: **Solent Science** – *A Review*
M. Collins and K. Ansell (Eds.)

Volume 2: **Muddy Coast Dynamics and Resource Management**
B.W. Flemming, M.T. Delafontaine and G. Liebezeit (Eds.)

Volume 3: **Coastal and Estuarine Fine Sediment Processes**
W.H. McAnally and A.J. Mehta (Eds.)

Volume 4: **Muddy Coasts of the World: Processes, Deposits and Function**
T. Healy, Y. Wang and J-A Healy (Eds.)

Volume 5: **Fine Sediment Dynamics in the Marine Environment**
J.C. Winterwerp and C. Kranenburg (Eds.)

Volume 6: **Siberian river run-off in the Kara Sea**
Characterisation, quantification, variability and environmental significance
R. Stein, K. Fahl, D.K. Fütterer, E.M. Galimov and O.V. Stepanets (Eds.)

Volume 7: **The Ecology of Poole Harbour**
J. Humphreys and V. May (Eds.)

Preface

The twenty-seven papers in this monograph are selected from the manuscripts submitted to the International Conference on Cohesive Sediment Transport (INTERCOH 2003) held at the Virginia Institute of Marine Science (VIMS), College of William and Mary, Gloucester Point, Virginia, USA, during October 1-4, 2003. The papers presented in this monograph represent topics ranging from basic research (*e.g.*, flocculation, erosion, deposition, consolidation) to practical applications (*e.g.*, simulation of turbidity maxima in estuaries, transport of cohesive sediment during dredging). All of the manuscripts received at least two external peer reviews, and many were revised prior to final acceptance. Because the obvious titles had already been used by the six monographs from previous INTERCOH meetings, it became necessary to add the conference name and year to the title for this monograph. Therefore, the title "Estuarine and Coastal Fine Sediment Dynamics - INTERCOH 2003" was selected.

Only ten days before the conference, Hurricane Isabel swept through North Carolina and Virginia. Wind and storm surge caused significant damage in Virginia and resulted in a week-long power outage at VIMS. The last hurricane to pass through this region with such destructive force occurred nearly 70 years ago. Perhaps serving as an appropriate reminder for the conference, Isabel also deposited a lot of cohesive sediment on the VIMS campus. Despite these extraordinary circumstances, and thanks in large part to the tremendous effort of the VIMS staff, the conference proceeded as scheduled with about 100 participants from all over the world.

Financial support from HydroQual Inc., HoHai University, Korea Ocean Research and Development Institute, National Cheng-Kong University, the U.S. Geological Survey, and the Virginia Institute of Marine Science made this conference possible. The time and resources contributed by each participant were equally critical to make INTERCOH 2003 a great experience in exchanging new knowledge and exploring new approaches for understanding cohesive sediment dynamics. Finally, we would like to extend our thanks to J.-I. Kwon, H.-K. Ha, J.-Y. Kim, B. Marshall and C. Hornsby for helping with the logistics of the conference, and to Susan Stein for her editing assistance.

Additional information about INTERCOH conferences and proceedings volumes, past and future, may be viewed at www.intercoh.com.

Jerome P.-Y. Maa
Virginia Institute of Marine Science
College of William and Mary

Lawrence P. Sanford
Horn Point Laboratory
University of Maryland Center for Environmental Science

David H. Schoellhamer
U.S. Geological Survey

Contents

Estuarine and Coastal Fine Sediments Dynamics
J.P.-Y. Maa, L.P. Sanford and D.H. Schoellhamer (editors)

Preliminary findings of a study of the upper reaches of the Tamar Estuary, UK, throughout a complete tidal cycle: Part I: Linking hydrodynamic and sediment cycles

Bass, S.J.[a], A.J. Manning[a,b] and K.R. Dyer[a]

[a] School of Earth, Ocean and Environmental Sciences, University of Plymouth, Devon, PL4 8AA, UK.
[b] HR Wallingford, Howbery Park, Wallingford, OX10 8BA, UK.

KEY WORDS
Turbidity maximum, stratification, floc size, settling velocity, concentrated benthic suspension, Tamar Estuary

Preliminary results are presented from an experiment in the turbidity maximum region of the Tamar Estuary, UK, to acquire detailed particle information of the suspension in relation to the main physical and biochemical driving processes throughout several complete tidal cycles. Results presented here focus on the relationship between the evolving suspension characteristics and physical mechanisms through one tidal cycle. The experiment took place over 5 days during April 2003. *In-situ* floc properties (including floc settling velocity, size, shape and effective density) were measured using the video-based INSSEV system. Profiles of full water column velocity, salinity, temperature and suspension concentrations were supplemented with detailed near bed measurements of turbulence and sediment concentrations. Measurements were made during several days approaching spring tides and the results exhibit a strong contrast in flood and ebb hydrodynamics which is reflected in the observed vertical distribution of sediment and particle characteristics. The flood tides were short and well-mixed with high values of turbulent shear stress causing rapid erosion and resuspension at the onset of the turbidity maximum. Suspension concentrations were relatively evenly distributed vertically reaching concentrations of 1.1 kg/m^3 at the INSSEV height of 0.5 m. In contrast ebb tides exhibited tidal straining and development of a concentrated benthic suspension layer with a lutocline in the

region of the INSSEV height. Concentrations at this height reached 1.4 kg/m^3 while the INSSEV sampling height was just below the lutocline. Particles within the turbidity maximum on the ebb tide were typically much larger than the flood, with up to 30% greater than 400 μm just inside the lutocline. Turbulent shear stress measurements during the ebb exhibited a significant reduction in the region of the lutocline due to sediment stratification.

1. INTRODUCTION

Predicting the mass transport and deposition of cohesive sediments is highly desirable in estuarine and coastal environments where fine particles play an important role in issues relating to, for example, pollution, benthic ecology, water clarity and sedimentation. From the stand-point of estuarine environmental management, measuring and predicting when during a tidal cycle mud is suspended or deposited is crucial. For instance, the phase of suspension concentration is vital in determining residual flux magnitudes and directions, benthic ecology will depend on when fine particles are deposited, or knowing times of suspended load transport may be necessary before discharging waste. This paper addresses in particular the phase relationship between estuarine cohesive suspension characteristics and hydrodynamics over a tidal cycle.

The behaviour of fine sediments is complicated in particular by their cohesive nature and tendency to form aggregates or flocs which are both larger and less dense than the individual constituent particles. As a consequence there are delays or lags in the response of the sediment properties to velocity, shear stress and turbulence. In an oscillating tidal current, phase differences may occur as a result of slow and variable settling velocities, advection of non-local sediment, varying bed yield strengths and the time taken for resuspended sediment to be mixed upwards through the water column. In relation to the tidal cycle the phase differences of settling velocity, floc density and concentration become important in controlling net transport magnitudes and directions (Bass *et al.,* 2002; 2003). This paper presents preliminary results of quantitative floc size and settling velocity, and concentration measurements with an emphasis on the evolving behaviour through the full tidal cycle. In particular the cycle in hydrodynamics and suspension characteristics are related to the evolution of floc settling velocity, size and density.

Observations of fine sediment suspensions suggest that, except in highly energetic conditions, most of the sediment mass occurs in flocs (Kranck and Milligan, 1992). The flocculation of particles is a function of the mechanisms which bring the particles into contact (*e.g.* differential settling or turbulence) and the mechanisms that make them stick together (*e.g.* salinity or organic matter content) (van Leussen, 1988). Sediment concentration may also play a role in increasing flocculation. In addition to increasing particle collisions, turbulent shear may also act to break up aggregates (McCave, 1985) and various observations have demonstrated the role of shear stress in limiting the maximum floc size in both shelf (Berhane *et al.*, 1997; Hill *et al.*, 2001) and estuarine environments (Dyer *et al.*, 2002a, Manning, 2001).

The processes of aggregation and disaggregation are still not well enough understood to describe fully theoretically and at the moment predictions tend to rely on empirical generalisations. Until recently, lack of reliable floc measurements limited studies of the complex interactions between the factors affecting flocculation (shear, salinity, organic content and concentration) and floc characteristics. Laboratory experiments do not reliably represent field situations because of the difficulty of reproducing the chemical, physical and biological processes involved and *in-situ* measurements have historically been unreliable because of floc disruption when sampling (van Leussen, 1988). The recent advent of *in-situ* video techniques has allowed reliable, simultaneous measurements of floc size and settling velocity from which floc density may be estimated. Particle characteristics presented here were made using the low-intrusive INSSEV instrument (Fennessey *et al.*, 1994b) to measure *in-situ* floc settling velocity and size. These results are compared with near-bed measurements of vertical sediment concentration distribution, turbulence and currents throughout a complete tidal cycle. Detailed analysis of floc spectra is reported in the Part II companion to this paper (Manning *et al.*, in press). Such comprehensive data sets are still relatively sparse and will benefit cohesive sediment studies in general.

2. METHODS

Field data were acquired during a 5- day experiment from April 13th to 17th in the Tamar estuary in south-western England. The Tamar estuary is classified as a drowned-river valley, experiencing semi-diurnal tidal ranges of 4.7 m and 2.2 m at spring and neap tides respectively. Sediment in the estuary is predominantly composed of cohesive silts and clay admixtures supplied by river input. The experiment was in the turbidity maximum region near the Calstock boatyard (Fig. 1) which has been used for earlier experiments and its characteristics are well-documented (Uncles and Stephens, 1993). The channel width at the deployment site was 75 m. Throughout the experiment the tide ranged in height from about 0.5 m to 4.5 m with peak currents speeds of ~1 m/s. Data presented here represent results 3 days in advance of peak spring tides.

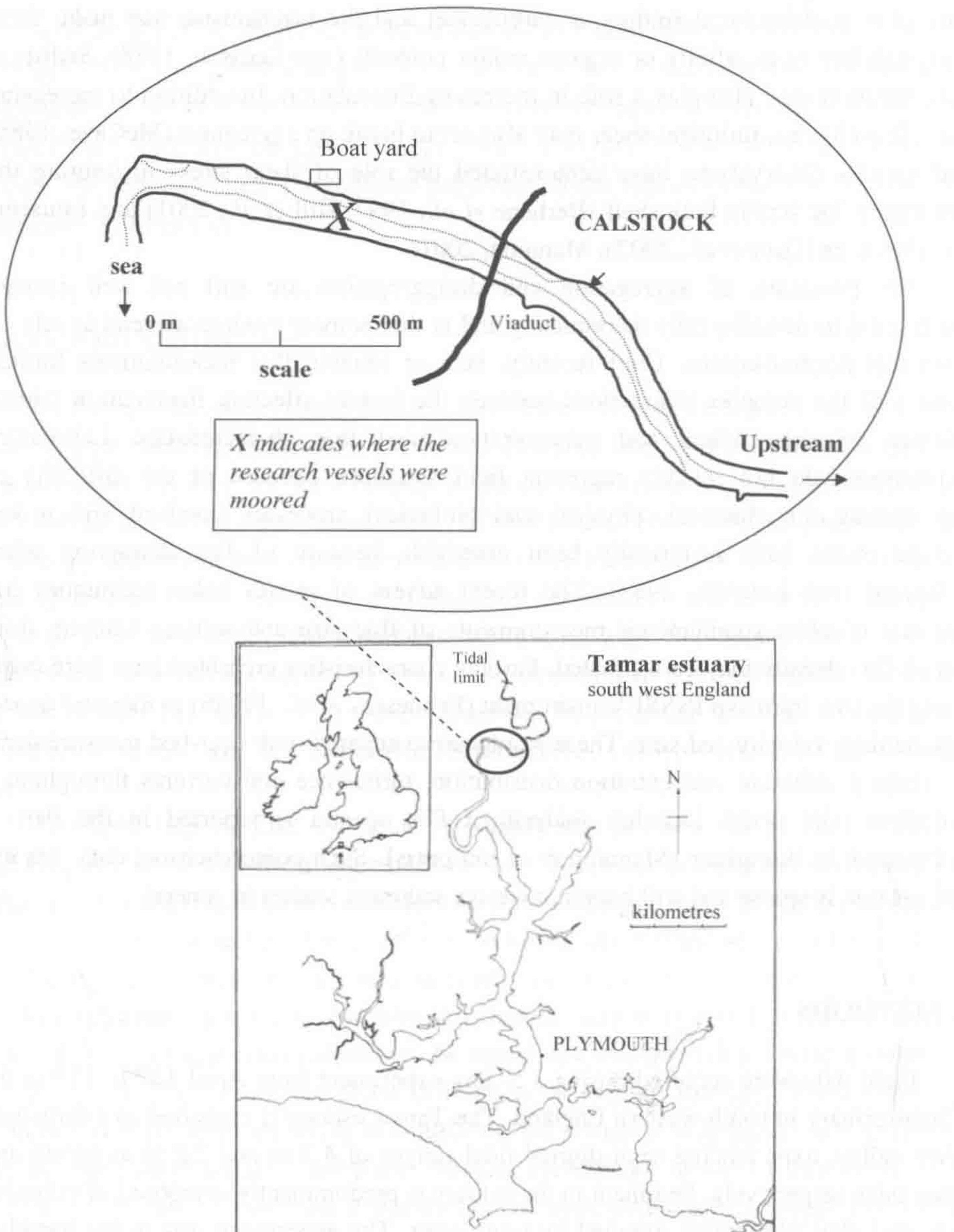

Fig. 1. Location diagram of the Tamar estuary showing the Calstock sampling station.

Instruments were mounted on a frame that was lowered to the bed from the moon pool of an anchored pontoon RP AMAP-1. The frame was positioned so that the instruments were facing the dominant alongstream flow. Results presented here were obtained from the instruments described below. High resolution near-bed mass concentrations were obtained using a vertical array of six Optical Backscatter Sensors (OBSs) from the POST system (Christie *et al.*, 1997) mounted on the frame from 0.05 to 0.98 m above bed. Calibration of the OBS took place on site using *in-situ* suspension samples. The POST system also included 4 2D electromagnetic current meters (EMCMs) arranged in pairs at 0.5 and 0.75 m to measure 3D components of flow. Two 3D Nortek acoustic doppler velocimeters (ADVs) mounted alongside OBSs at about 0.1 and 0.5 m provided detail of the turbulence and vertical distribution of current velocities in the lower boundary layer. Turbulent shear stress at the ADV heights were estimated using the turbulent kinetic energy approach (*e.g.*, Kim *et al.*, 2000).

Vertical profiles of salinity, temperature and suspension concentrations were obtained every 15 minutes using a Seabird Systems SBE 19-03 CTD together with a Downing OBS. Corresponding velocity profiles through the water column were obtained using a Valeport 108 mk III impeller current meter.

The INSSEV video system was used to measure floc settling velocity, size and floc populations. These quantities are measured manually after the deployments from the video monitor using initial image calibrations to convert to actual dimensions. Further details of floc data processing are given in Manning *et al.* (in press). During the experiment measurements were taken approximately every 15 minutes. Pumped water samples were obtained from 0.1 and 0.5 m above bed every half hour. Filtered samples were used to verify OBS and INSSEV estimates of suspended mass concentration and to estimate the percentage of organic matter content by loss-on-ignition tests.

3. RESULTS

3.1 Salinity and current velocity profiles

Depth profiles of current velocity and salinity over a tidal cycle on April 15th, 3 days before peak spring tides, are presented in Fig. 2, measurements starting half-way through the ebb tide. The shape of the tidal curve is asymmetric with a short flood (~5 hours) and long ebb (~7 hours) reflecting the decrease in depth as the wave moves up the estuary. Tidal height ranged from 0.5 to 4.5 m. The same measurements taken on adjacent days, April 14 and 16th, show a similar pattern in current and salinity measurements to those presented here.

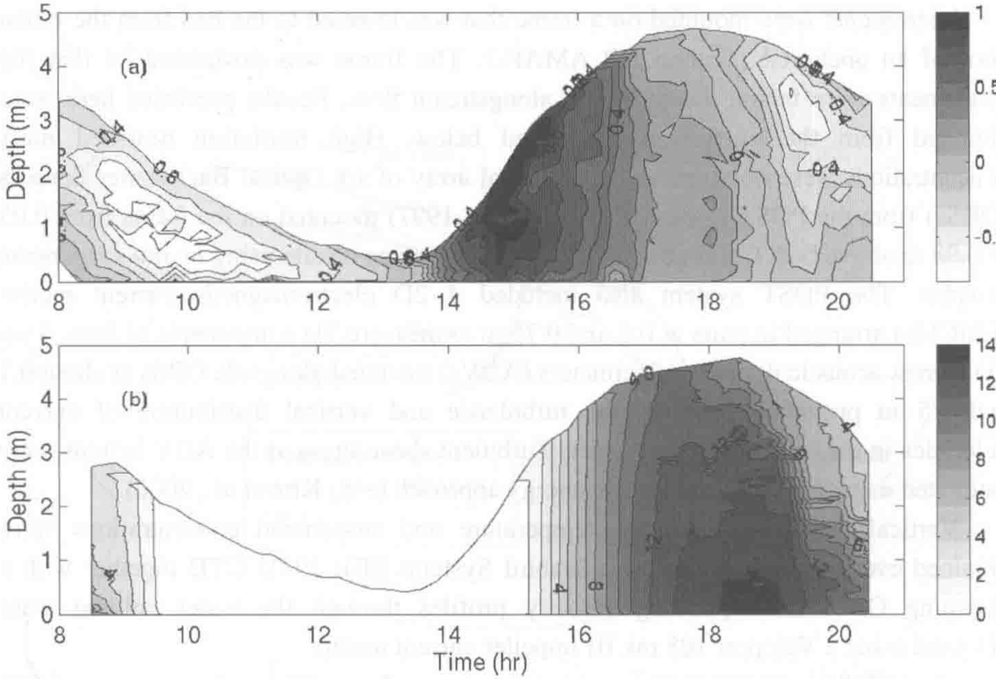

Fig. 2. Contour plot of (a) current velocities (m/s) and (b) salinity (psu) on April 15th.

The flood tide started at 13:30 h, coinciding with low water, and reaching current speeds of 1 m/s at the water surface. High water occurred at 18:00 h, 20 minutes after the start of the ebb tide at the water surface. The start of the ebb at the bed lagged the ebb at the surface by an hour. Depth profiles of salinity (Fig. 2b) show the water column as well mixed throughout the flood with salt water appearing at all depths at ~14:45 h. Peak salinities of about 14 psu were reached near the bed around high water.

Evidence of tidal straining on the ebb tide is apparent in the current and salinity profiles from 18:00 h on. The ebb started at the surface at 17:40 h, reaching the bed about an hour later and producing stratification in salinity. At 19:30 h, tidal-straining induced shear appears to have produced turbulent mixing towards the bed creating a minor peak in the ebb current speed near the bed with corresponding reduction in salinity at all depths below the halocline. The same pattern was repeated on adjacent days.

3.2 Turbidity maximum dynamics

Suspended sediment concentration profiles through the tidal cycle are presented in Fig. 3. Note that concentrations near the bed that appear inverted are an artefact of saturation of the optical sensor at concentrations above several kg/m^3 leading to an underestimate of concentration. While absolute magnitudes are suspect the results are useful for showing the general evolution of the vertical sediment distribution through a tidal cycle. Comparison with single height estimates of near-bed concentrations from both pumped samples and OBS mounted on the rig (Fig. 4a) show qualitatively similar results of relative concentration variations.

On the ebb tide the increase in suspended sediment concentrations at 9:00 h associated with the passage of the turbidity maximum occurred about half an hour before the disappearance of salt water. High concentrations of mud persisted for 3 hours so that the turbidity maximum occurred mostly within fresh water and just inside the tip of the salt intrusion.

On the flood tide sediment concentrations rose rapidly with current speed at 14:30 h leading the arrival of the salt intrusion at 14:45 h. The sediment started to settle as soon as current speeds slackened at about 15:15 h. With the appearance of salt water most of the sediment fell out of suspension fairly rapidly however elevated concentrations persisted for about 2 hours so that the turbidity maximum appeared mostly within the tip of the salt wedge. A minor peak in sediment concentration observed near the bed just after 16:00 h on the flood tide (seen in both Figs. 3 and 4a) was not apparently related to any increase in near-bed current shear suggesting advection of a concentrated near-bed muddy suspension layer.

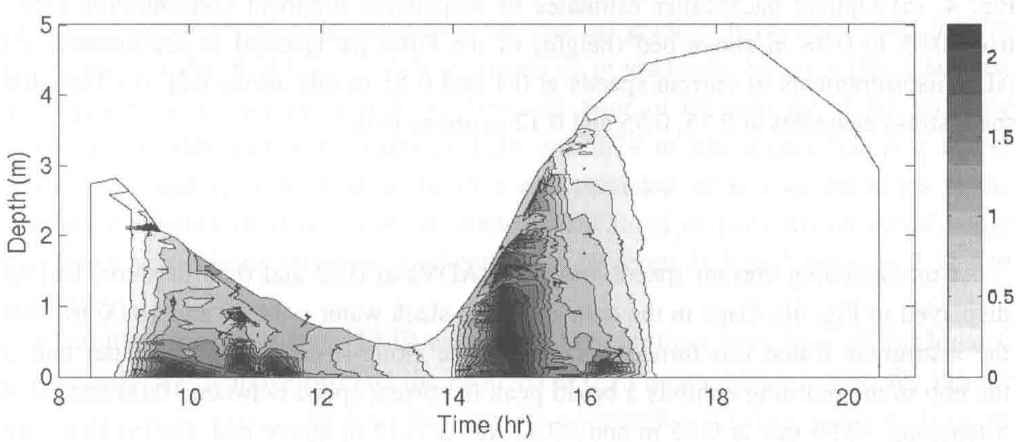

Fig. 3. Contour plot of suspended solids concentration (kg/m^3).