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Complex Fluid-Sediment Interactions in Fluvial and Coastal Environments - Part 4

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Synopsis

This paper overviews some issues of complex fluid-sediment interactions that characterize the multi-scaled nature of sediment routing systems. It first demonstrates the capability of grid-based modelling for precipitation-derived processes of water flow and sediment transport in a hilly watershed (the Lesti River basin, Indonesia). The predicted and observed performances highlight the importance of vegetation cover in the sediment management that may relate closely to land-use practices. The paper then focuses on advanced numerical modelling for fluvial sediment dynamics, with particular reference to the reappraisal of groin systems in river restoration. There follows a concise discussion of the linkage between fluvial and littoral sediment delivery. Reviews are then directed on studies of coastal dynamical environments. The themes taken up include: the evolution of beach erosion such as occurring in Ogata coast; the coastal ocean dynamics pertaining to nutrient transport; and tsunami sedimentation - an attempt for exploring tsunami-induced submarine deposits.

Keywords: circulation; coastal erosion; cross-shore sediment transport; event deposit; groin; local scour; river restoration; run-off modelling; sediment routing system

1. Introduction

This paper is the fourth report from the Research Center for Disaster Environment that adds to the scientific contributions of the 21 Century DPRI-COE Program, Kyoto University. Specifically, the present report aims to highlight the Center's most recent research efforts for Research Project 3, the theme of which reads: "Atmosphere-Hydrosphere Modeling for Water/Mass Movement in River Basins and Community-based Hazard Mapping."

The organization of this paper is as follows. Section 2 below will concisely review recent developments in numerical modelling for hillslope and fluvial processes. Section 3 will be concerned with coastal dynamical environments, focusing on relevant research directions.

Before going into specific discussions, it may be instructive herein to imagine a sediment routing system,

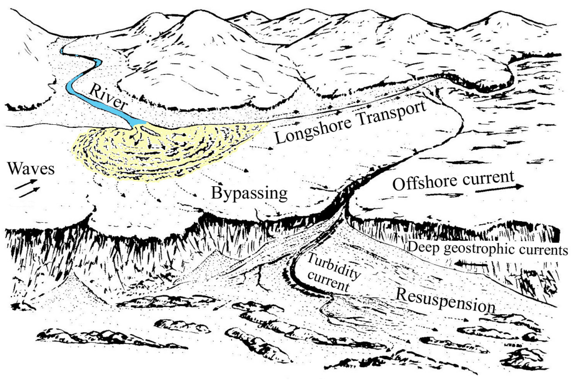

Fig. 1 Schematic of sediment routing system (adapted from Seibold and Berger, 1993)

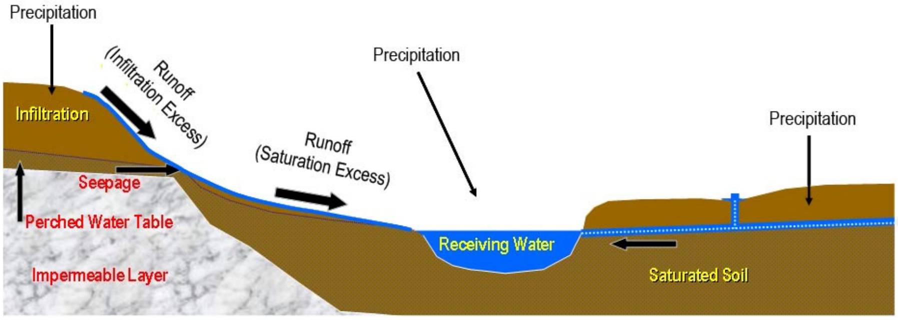

Fig. 2 Pathways of precipitation-derived water flow in hilly watershed

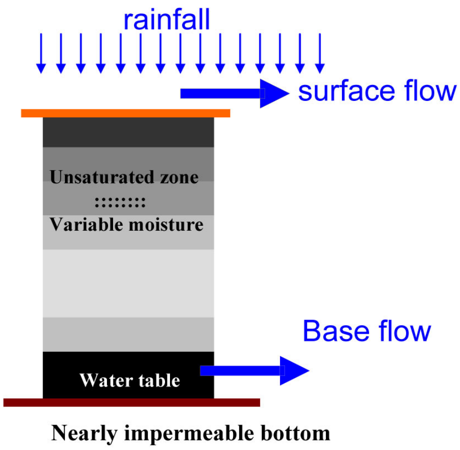

Fig. 3 Surface and base flows in grid-based model

such as visualized in Fig. 1 (Seibold and Berger, 1993). This sort of representation may be useful in remembering that the water motion and sediment transfer are integral part of the Earth's surface process and may best be addressed from a multi-scaled perspective.

2. Recent Advances in Modelling Hillslope and Fluvial Processes

2.1 Grid-based modelling for runoff and sediment transport in watersheds

The weathering and erosion commonly occur in mountainous areas and supply sediments downstream. The ways in which the sediments are released and transported in hilly watersheds, depend on a number of physical factors. Significant advances have recently been made in terms of grid-based modeling to address this important class of runoff/sediment transport issues. This section outlines the features and outcome of the research carried out by Nakagawa et al. (2007), with a hilly watershed being a targeted study area.

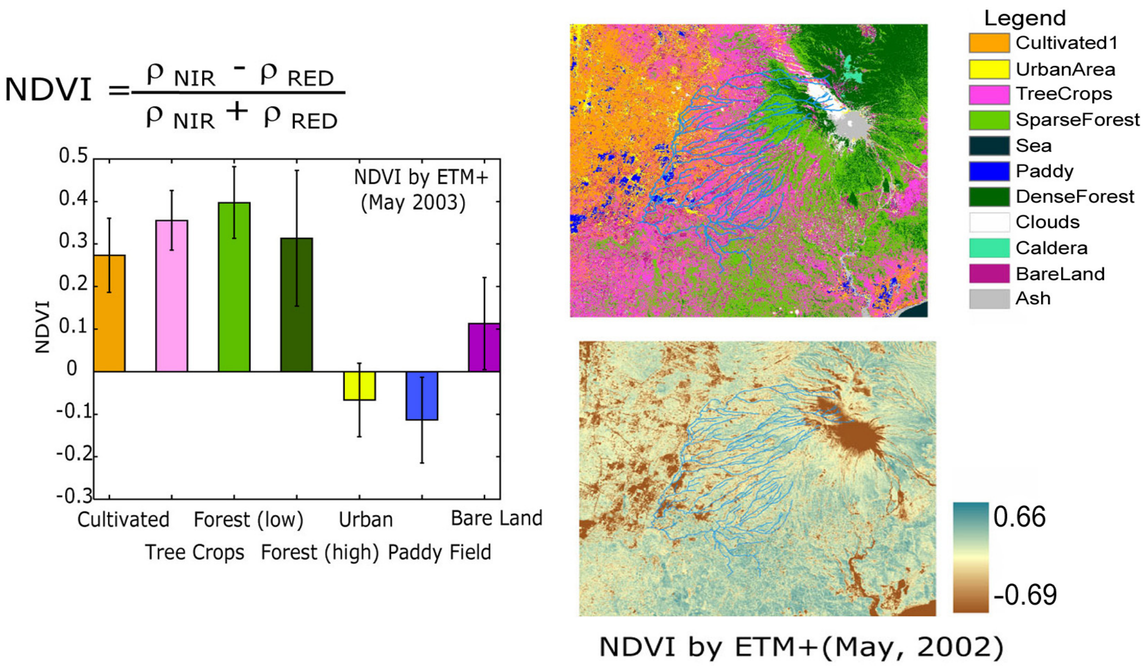

Fig. 4 Correlation of NDVI with land use patterns

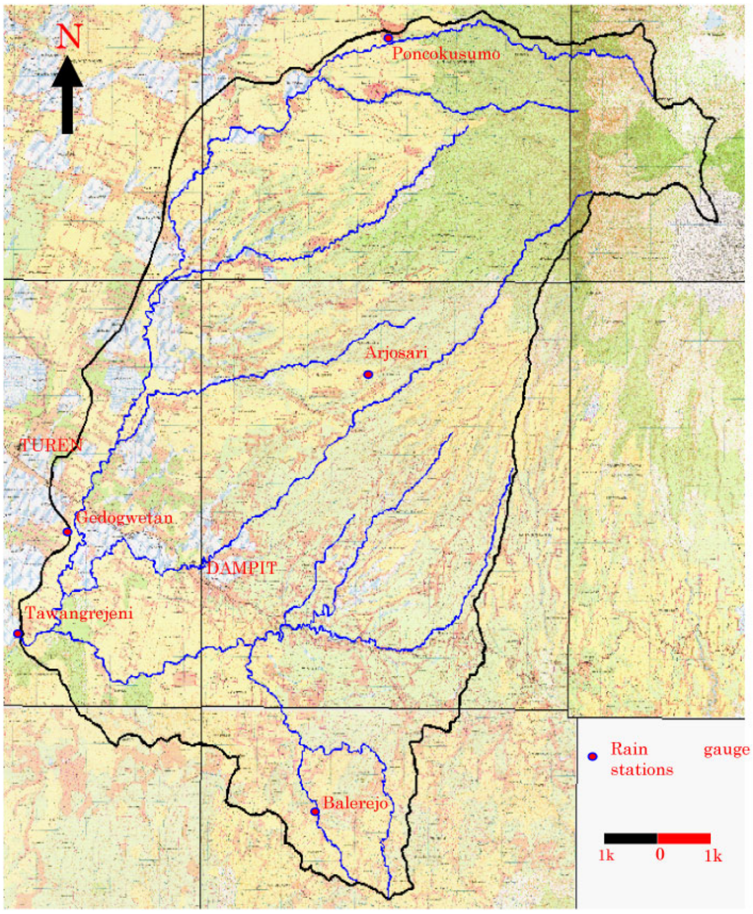

Fig. 5 Lesti Basin in east Java, Indonesia, which extends upstream of Tawangrejeni gauge station

Consider first pathways of precipitation-derived water flow in a hilly watershed (Figs. 2 and 3). Note in this regard that in tropical or sub-tropical areas, there annually occur distinct dry and wet seasons. The heavy precipitation following a prolonged dry season makes splash erosion an important mode of sediment transfer, in addition to erosion by overland flow. Nakagawa et al. (2007) developed a workable numerical model for splash erosion, which reads:

$$e_s = c_f F_w r^2 \quad (1)$$

Here e_s denotes the rate of splash erosion which is proportional to the square of the rainfall intensity, r. Coefficient F_w allows for the impact of raindrops in

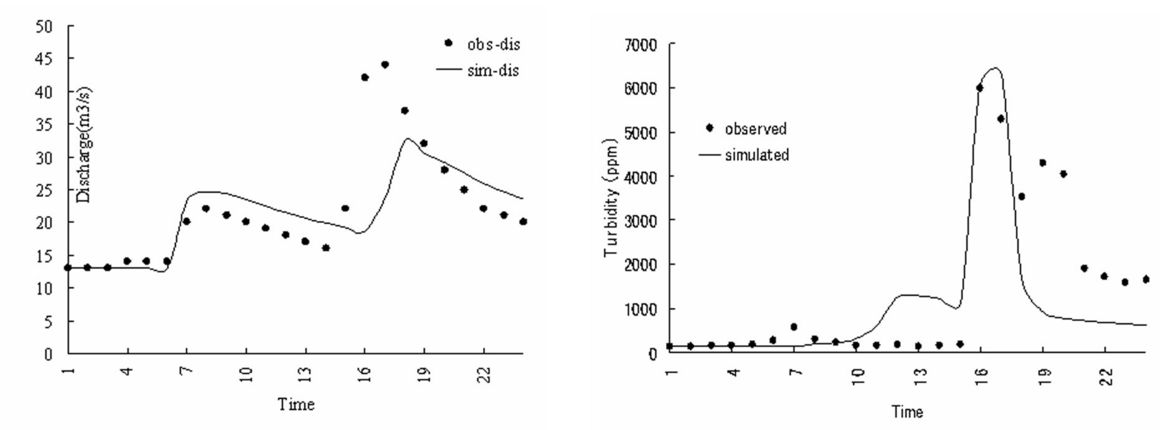

Fig. 6 Simulated and observed discharge and turbidity on 19 September 2005

◆ RANS equations (in tensor form)

$$\frac{\partial u_i}{\partial x_i} = 0$$

$$\frac{\partial u_i}{\partial t} + u_j \frac{\partial u_i}{\partial x_j} = f_i - \frac{1}{\rho}\frac{\partial p}{\partial x_i} + v\frac{\partial^2 u_i}{\partial x_j \partial x_j} + \frac{1}{\rho}\frac{\partial \tau_{ij}}{\partial x_j}$$

Reynolds stress tensor

$$\tau_{ij} = -\rho\overline{u_i' u_j'} = \rho\left(2v_t S_{ij} - \frac{2}{3}k\delta_{ij}\right)$$

◆ K- ε transport equations

$$\frac{\partial k}{\partial t} + u_j \frac{\partial k}{\partial x_j} = \frac{\partial}{\partial x_j}\left[\left(v + \frac{v_t}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right] + G - \varepsilon$$

$$\frac{\partial \varepsilon}{\partial t} + u_j \frac{\partial \varepsilon}{\partial x_j} = \frac{\partial}{\partial x_j}\left[\left(v + \frac{v_t}{\sigma_\varepsilon}\right)\frac{\partial \varepsilon}{\partial x_j}\right] + (C_{1\varepsilon}G - C_{2\varepsilon}\varepsilon)\frac{\varepsilon}{k}$$

u_i= time-averaged velocity;
x_i= Cartesian coordinate component;
ρ = density of the fluid;
f_i= body force;
p= time-averaged pressure;
v= molecular kinematic viscosity

Strain-rate tensor $S_{ij} = \frac{1}{2}\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right)$

Eddy viscosity $\nu_t = C_\mu \frac{k^2}{\varepsilon}$

Turbulence production $G = -\overline{u_i' u_j'}\frac{\partial u_i}{\partial x_j}$

$C_\mu = 0.09$	$\sigma_k = 1$	$\sigma_\varepsilon = 1.3$	$C_{1\varepsilon} = 1.44$	$C_{2\varepsilon} = 1.92$

Fig. 7 Governing equations for 3D model (Zhang et al. 2007a)

sediment release, in such a way that the value of it reduces with increasing depth of the surface water relative to the raindrop diameter. Coefficient c_f is a constant that relates to the soil type and surface properties.

The overall computational procedure developed by Nakagawa et al. (2007) is a comprehensive one and includes the following subsets:

- Hillslope sediment routing model that considers the sediment productions from splash erosion and hydraulic (overland-flow induced) erosion
- Infiltration and subsurface-flow models for the unsaturated soil domain, with Richard’s equation being incorporated
- Overland flow model covering an entire watershed in terms of fine grids (DEM-based modelling)
- Channel flow model that can deal with a wide range of sediment concentrations such as exhibited by stony debris flow, immature debris flow or turbulent flow with low sediment concentrations.

In the course of assessing the field performance of river discharge and turbidity in the Lesti river basin,

Fig. 8(a)

Discharge	Water depth	Mean velocity	Friction velocity	Sediment diameter	Reynolds number	Froude number
17.121 l/s	15 cm	25.0 cm/s	1.2 cm/s	0.385 mm	37, 544	0.21

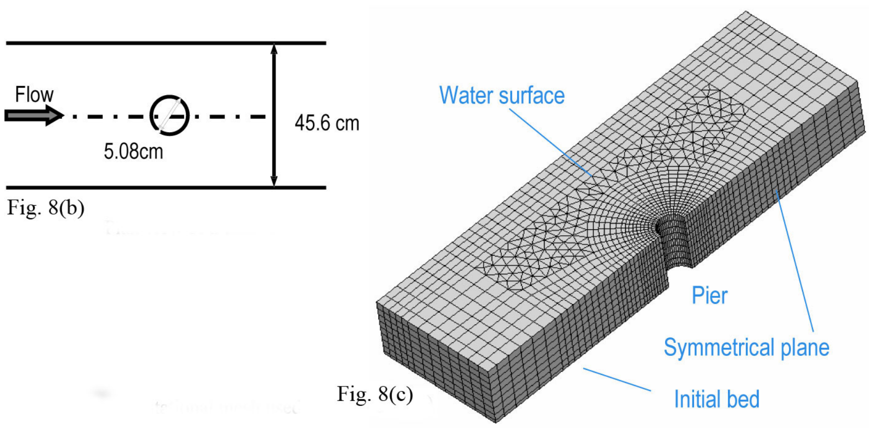

Fig. 8(b)

Fig. 8(c)

Fig. 8 (a) Experimental conditions for looking at local scour around a pier (after Melville & Raudkivi, 1977); (b) Plan view of a channel; (c) Computational mesh used by Zhang et al. (2007a)

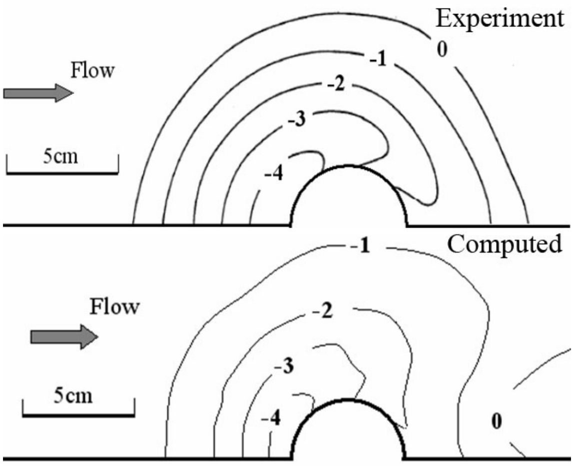

Fig. 9 Comparison between measured and predicted performances of local scour at T=0.5 hours. (Zhang et al. 2007a)

Indonesia, Nakagawa et al. (2007) found that the vegetation cover was an important factor strongly controlling the ways in which both splash erosion and hydraulic erosion occurred. In fact, Nakagawa et al. (2007) developed a practical procedure in which the value of Manning's roughness coefficient (n) could be determined by considering land-use practices. Specifically, they obtained the distribution of the Normalized Difference Vegetation Index (NDVI) over the watershed in terms of satellite images and correlated with NDVI values with the land-use patterns (Fig. 4). They further went on to determining the Manning roughness coefficient, n, as a function of NDVI. The predicted performance was with the Lesti basin in east Java, Indonesia that extended upstream of Tawangrejeni gauge station (Fig. 5). A typical set of predicted evolutions of river discharge and turbidity are presented in Fig. 6. It is seen that both of the evolutions of discharge and turbidity compare favourably with what has been observed.

2.2 Development of analysis tools for sediment management in river restoration

Sediment processes play a crucial role in the morphological and environmental changes of a river system. In order for a river-restoration project to be of sustainable nature, much attention should be paid to sediment management. A deeper insight into the channel morphodynamics is critically needed, while it involves a high degree of interactions among the stream flow, sediment, river bed and hydraulic structures.

With the above-mentioned in mind, Zhang et al. (2007) developed a range of advanced analysis tools for facilitating a better understanding of the channel morphodynamics. One of the most advanced models incorporates a fully three-dimensional formulation such as outlined in Fig. 7.

<u>Local scour around a bridge pier: validation for the 3D computational model</u>

Zhang et al. (2007) have validated their 3D computational model against the laboratory flume experiment that was carried out by Melville and Raudkivi (1977) on a movable sandy bed with a cylindrical pier being left to stand. The experimental conditions and the plan view of the channel used are presented in Figs. 8(a) and (b). The corresponding computational mesh adopted by Zhang et al. (2007) is presented in Fig. 8(c). The predicted and observed extents of the scour hole around the pier are shown in

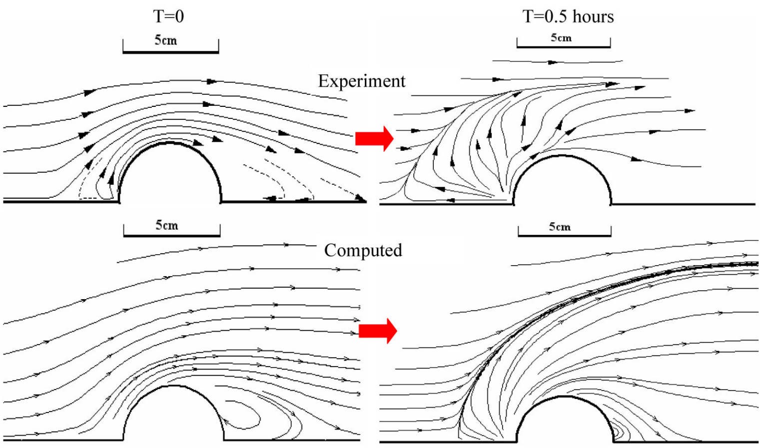

Fig. 10 Measured and predicted evolutions in streamlines at a level of 2mm above the bed (Zhang et al. 2007a)

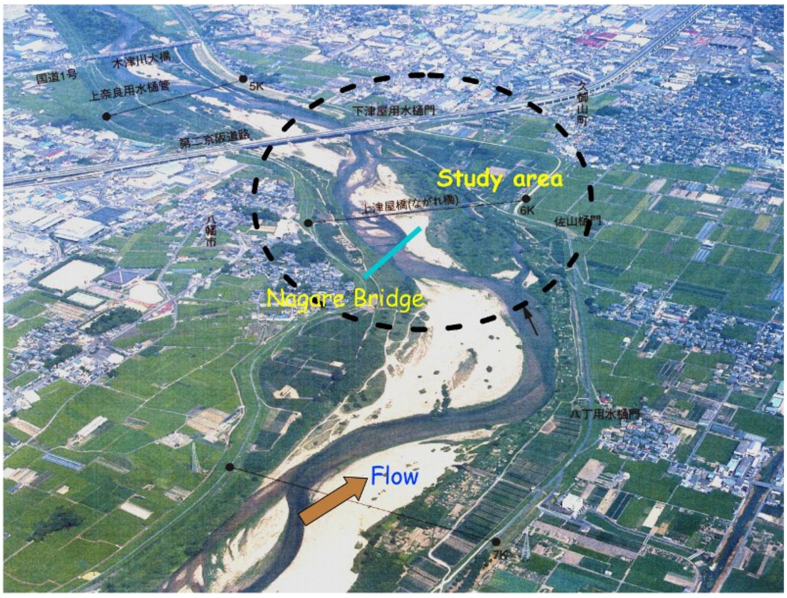

Fig. 11 Study area regarding river restoration with groins (aerial photograph adapted from a map of Yodogawa River Office)

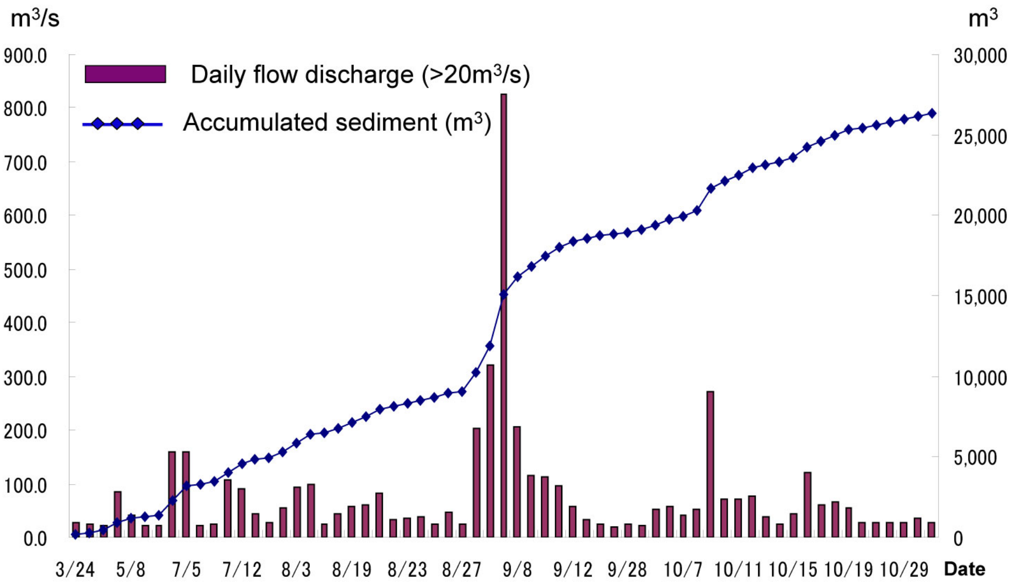

Fig. 12 Observed daily discharge and sediment conditions with Kizu River in 2005

Fig. 9. Also, the predicted and measured evolutions in streamlines around the pier are shown in Fig. 10 for the horizontal plane 2mm above the bed. It is seen from Figs. 9 and 10 that the calculated performance nicely reproduces the essential aspects of the experimentally observed performance of local scour around the pier.

The future will see the 3D computational model being used for wider classes of real-world problems. At the present stage, the use of workable 2D-computational models to practical situations seems to be equally worth attempting.

Sediment control in terms of groins in a river restoration project

The research project taken up here is concerned with the use of groins for sediment control in river restoration (Zhang et al., 2007b). Specifically, the river restoration work is symbolized by a famous wooden bridge called "NAGARE-BASHI" in Japanese that spans the Kizu River (Fig. 11). The main objectives of the project were to restore beach landscapes and improve riparian environments around the bridge. The restoration measures included cutting down a part of

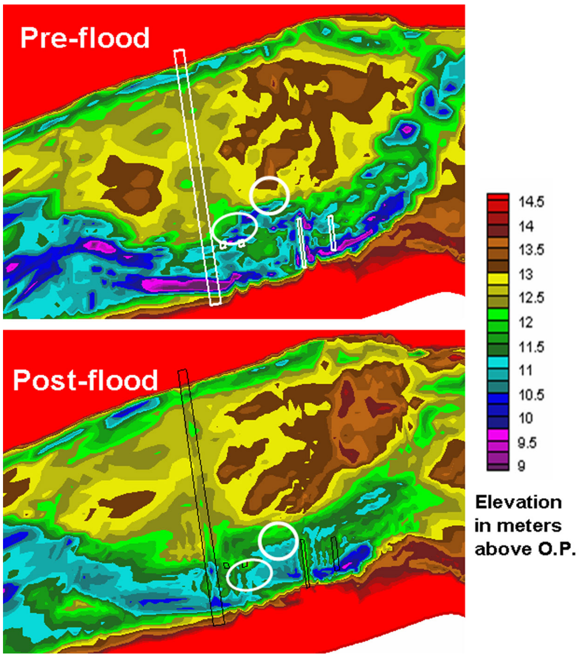

Fig. 13 Calculated evolution of bed topography (Zhang et al. 2007b)

the river terrace and constructing three groins. These works completed in 2004. In September 2005 there occurred typhoon-induced flood discharges (Fig. 12). The groins were significantly damaged by the flood, calling for a critical reassessment toward the optimal use of groin systems.

For this particular aim, two kinds of research undertakings were made (Zhang et al., 2007b). One was to perform a set of physical model tests at the Ujigawa Open Laboratory, with a reduced scaling as large as 1 in 65. The other interrelated undertaking was to perform a range of numerical analyses using the

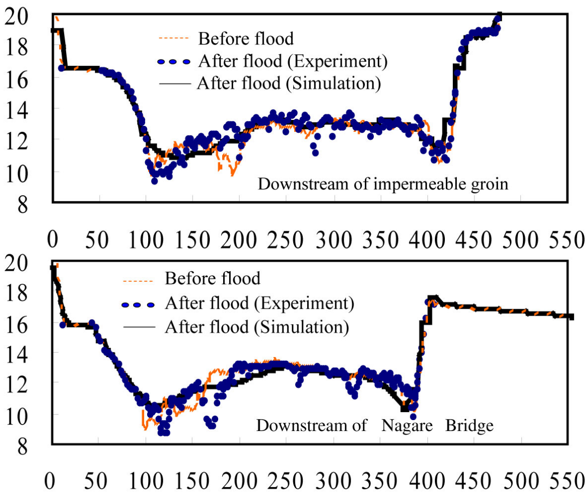

Fig. 14 Evolution of cross-channel profiles (Zhang et al, 2007b)

two-dimensional computational code (Zhang et al., 2007b). The numerical analyses gave insights into the ways in which the sediment bed responded to the flood flow and left particular morphological changes around the groins and bridge model (Fig. 13). The predicted and measured developments in cross-channel profiles are typified in Fig. 14. The computational model proved to reproduce the essential aspects of the observed profile development, warranting its further applications to assessing sediment control measures in river restoration.

3. Coastal Dynamical Environments of Multi-scaled Nature

3.1 Recent advances in studies of coastal morphological evolution

Quantification of coastal morphological evolutions for given localities has been and continues to be a challenging issue to the scientist, engineer and every stakeholders. The idea of littoral sediment budget, as illustrated in Fig. 15, may readily be perceptible. However, the quantification of sediment budget in a given coastal setting is by no means a simple task, rather requiring effort-intensive field observations. It is thus pleasing to see well-designed observational studies going on in Japan's coasts that are in diverse geomorphological settings. A few case studies will be referred to below, so as to gain insights into the physics of cross-shore sediment transport that has had less attention compared with longshore sediment transport.

An important consideration in this regard is the extent of continental shelves in coastal settings. There are coastal zones with very narrow shelves. The coastal zone with the Kurobe River draining into Toyama Bay is one such locality. Kanazawa et al. (2006) describe findings from long-term observations there (years 1966-2004). They include the morphological changes in the river mouth and connecting submarine canyon. Bathymetry surveys showed that underwater slope failures recurrently took place at the head of the canyon, causing considerable erosion to the river mouth area. For instance, the loss of sediment by the underwater slope failures in the period of 2002-2005 amounted to 200,000m^3. The sediment loss proved to be a very significant quantity, compared with the annual longshore sediment transport that was

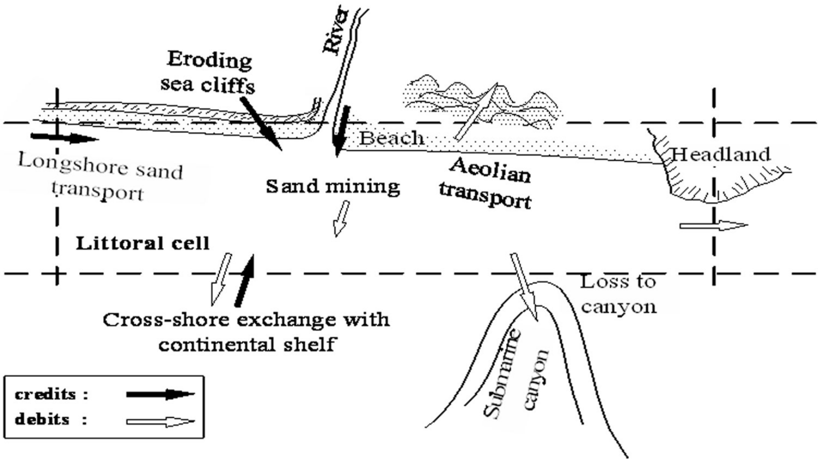

Fig. 15 Principal components involved in the development of a budget of littoral sediment (adapted from Komar, 1998)

estimated to be a few tens of thousand m^3. It is important also to note that in this coastal setting, an erosion-deposition cycle operates in the submarine canyon. In fact, floods bring much sediment into the valley underwater, making the deposited surface gradually steeper. When the slope reaches a critical value (approximately 1 in 2), a large-scale slope failure (flow slide) may take place leaving a much flatter sediment surface (approximately 1 in 5). The question may now arise as to what kind of forcing causes such a large-scale underwater slope failure, if storm waves were only a triggering factor. Gravity should be a major influential factor. Also, submarine groundwater conditions may be a factor to be examined carefully.

The littoral zone off the Miho Peninsula also is a setting where the presence of submarine canyons has exerted significant influences on the manner and extent of coastal erosion in the Shimizu coast. Yoshikawa and Nemoto (2007) describe results from their high-resolution morphological surveys using multi-beam echo-sounders (SEABAT9001s; SEABAT8125), together with sediment retrievals from the seabed using a grab-type sampler (Marine Seeker III-Zoom). Comparison of submarine topographies between July 2005 and November 2005 revealed that the clastic sediment transported toward the submarine canyons amounted to 28,000m^3, and that the sediment transport was effected in summer-autumn seasons under the influence of typhoons. The offshore-going sediment transport proved to be in far excess of the amount of the measured beach erosion that was equal to 5,000m^3. How can the sediment budget be closed then? It is important herein to remember that in the Shimizu coast the beach nourishment work has been done with an annual rate of approximately 35,000m^3. Notably, the work of Yoshikawa and Nemoto (2007) emphasizes the importance of looking at the sediment transport in a zone that encompasses the beach-to-shelf environments. Also, it is interesting to remark that the work of Yoshikawa and Nemote (2007) has demonstrated the practicality of high-resolution imaging of subaqueous bedforms, thereby inspiring the assessment of the fluid-dynamical conditions operational.

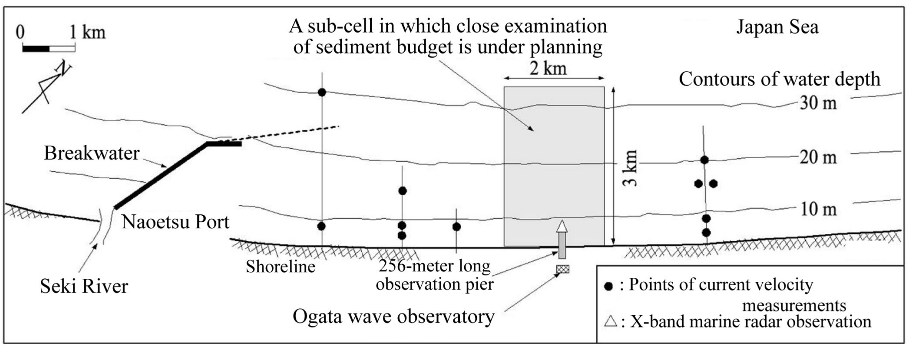

Fig. 16 A sketch showing the extent of Ogata coast with the location of 256-m long observation pier indicated

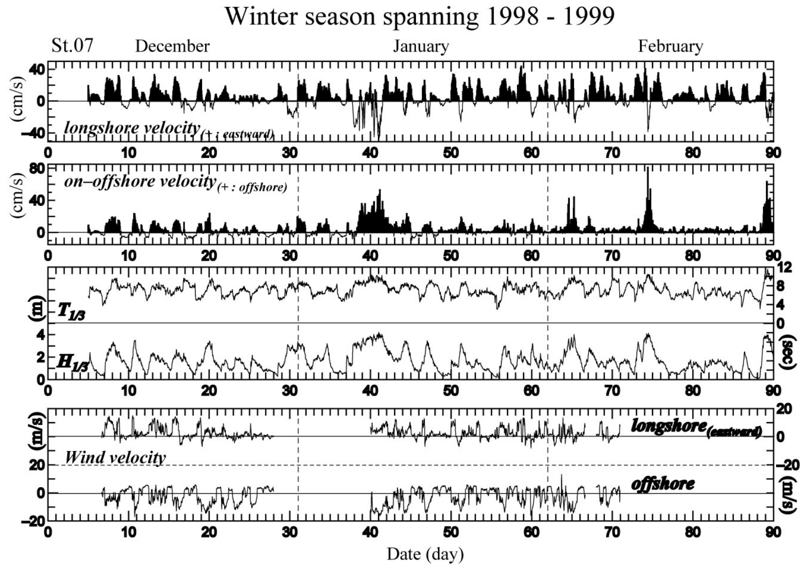

Fig. 17 Measured time histories of current velocities, wave climate and wind velocities that feature winter storminess in Ogata coast (Kato et al., 2002)

The third case is concerned with a wave-dominant coastal setting with a relatively wide shelf. Nakano et al. (2006) discussed morphological changes that occurred to the mouth of the Monobe River in Tosa Bay for a period of 1996 to 2005. They found that the littoral sediment transport onshore was dominant in the winter-spring seasons, leading frequently to complete closure of the river mouth (depositional pheneomena). In contrast, in the summer-autumn seasons the littoral sediment transport offshore was dominant and the river-mouth closure was far infrequent. According to Nakano et al. (2006), these seasonal effects on the river-mouth morphological evolution could be related to the wave climate, in particular to the difference in the wave period of incident significant waves. That is to say, the waves prevailing in the winter-spring seasons were primarily wind waves that had shorter wave periods. As such, they were effective in transporting littoral sediment onshore,

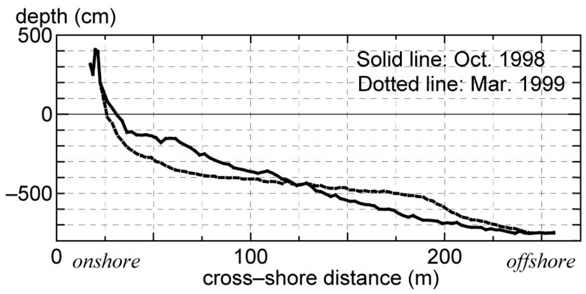

Fig. 18 Measured cross-shore profiles suggesting the occurrence of event-related sediment transport in a period between October 1998 and March 1999

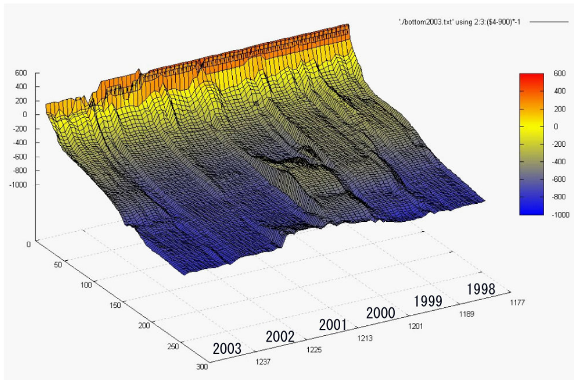

Fig. 19 A snapshot of the measured evolution of seabed profile along the observation pier

allowing the river-mouth bar to develop to a considerable or full extent. In contrast, the waves prevailing in the summer-autumn seasons were of swell type with longer wave periods, promoting the sediment transport going offshore. It is of particular interest to explore the underlying physics of the enhanced cross-shore sediment transport, with due consideration of the effect of occasional flood discharges.

3.2 Implications of field observations in the Ogata coast

The Ogata coast is featured by a long stretch of sandy beach that faces the Japan Sea. The dominant waves are due to winter monsoons. As such, they propagate principally from northwest, through a “window” that extends between the Noto Peninsula and

Fig. 20 A view of recently constructed erosion-protection work on Ogata coast, with the observation pier standing in the background

the Sado Island. The Ogata coast, in fact, is a part of the 28 km-long Joetsu coast that extends between the two natural headlands: Hijirigahana to the northeast and Gozu to the southwest. In 1986 a T-shaped observation pier was installed by DPRI on the Ogata coast (Fig. 16). The pier was designed essentially for looking at surf-zone dynamics. The tip of the pier extended to a distance of 256m offshore and reached a water depth of approximately 7m. Note that the water depth corresponded to the then estimated wave base.

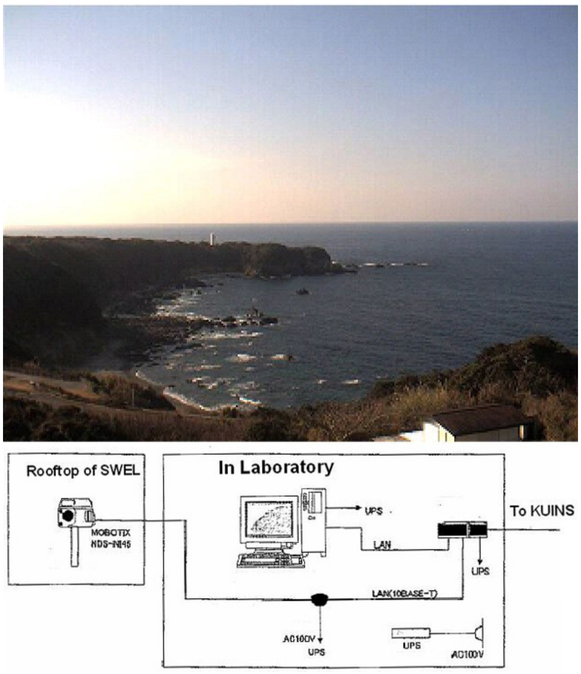

Fig. 21 A live-camera system recently installed at the Shionomisaki Wind Effect Laboratory

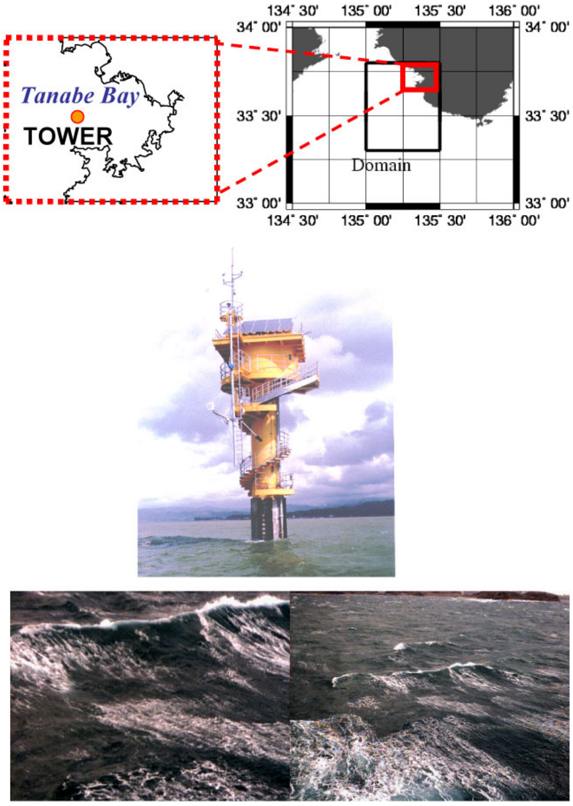

Fig. 22 Location of Tanabe Bay and snapshot of storm-surge observation tower

The field measurements made at the Ogata Wave Observatory have provided a range of useful datasets regarding coastal ocean dynamics. They include a dataset such as represented in Fig. 17, demonstrating severity of the wave climate in a winter season and the occurrence of offshore-going strong undertow (Kato et al., 2002). Also, long-term bathymetry surveys along the observation pier (conducted by Kiyoshi Uchiyama; compiled by Yasuyuki Baba) revealed the occurrence of event-accentuated cross-shore profile development (Figs. 18 and 19).

The 256-meter-long observation pier stood out on the sandy beach when there were no major adjacent coastal structures. However, it now appears to be far small in scale, compared with the adjacent large coastal structures such as the offshore breakwater in the Naoetsu port that extends to a water depth of 25m or so (refer to Fig. 16). Now that the observation pier has “witnessed” the evolution of the coastal erosion over twenty years (Fig. 20), it will be most essential to go back to the fundamentals. The mission will be to assist in developing high-resolution sediment budget for the Joetu coast in particular and to promote the physics of mesoscale sediment transport in general. In order for

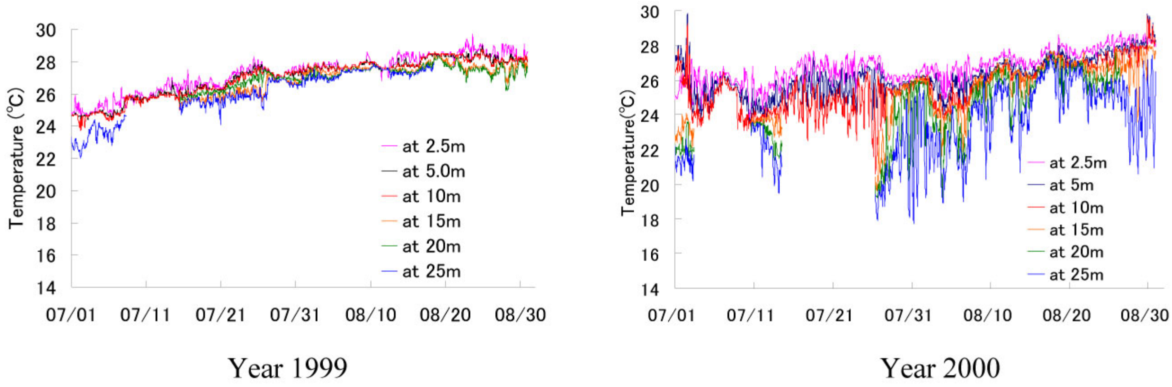

Fig. 23 Measured time histories of seawater temperatures at the observation tower in Tanabe Bay

these undertakings to proceed, reexamination of a number of physical processes will be indispensable. They include critical examination of the wave base and reevaluation of the evolutions of sediment supplies from the Seki River and Ogata sand dune, as well as other possible sources/sinks.

Strategically, an avenue of research in the envisaged direction will be opened up, through wider use of remote sensing technologies, such as X-band radar (Kobayashi et al., 2006; Takewaka et al., 2006), acoustic narrow multi-beam sounder (Yoshikawa and Nemoto, 2007) and combined geophysical/ sedimentological surveying for ground truth. Also, real-time coastal monitoring techniques are a promising area of high societal need. It is hoped that a live-camera system recently installed at the Shionomisaki Wind Effect Laboratory (Fig. 21; elaborated by Taiichi Hayashi with KAGI21) will see further developments in disaster reduction scheme.

3.3 Coastal ocean dynamics pertaining to nutrient transport

The coastal ocean is at the dynamic edge between ocean and land, involving the two fundamental sources of nutrients: the deep ocean and runoff from land (Atkinson et al., 2004). The impact of anthropogenic riverine inputs on the quality of coastal waters has received considerable attention over years. In contrast, the importance of oceanic inputs has received due

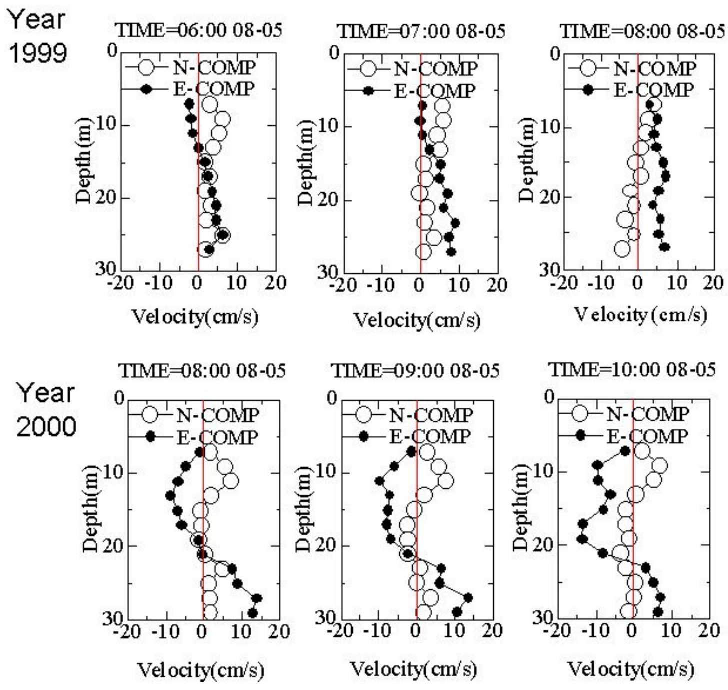

Fig. 24 Observed profiles of flow velocities of seawater

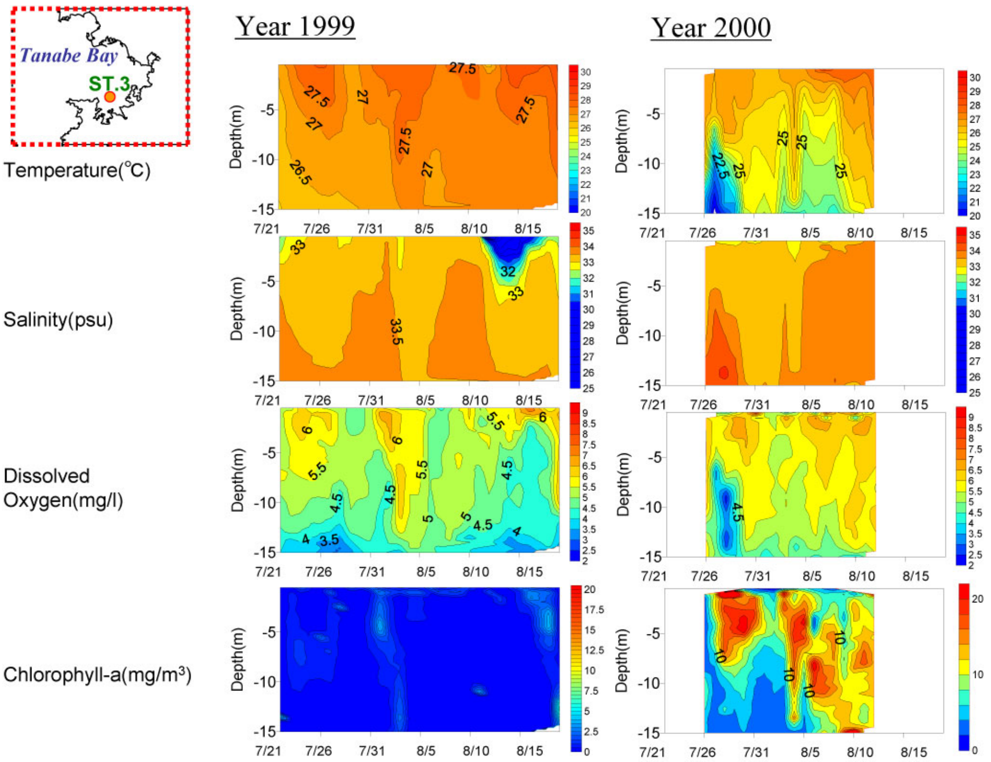

Fig. 25 Predicted performance of seawater temperature, salinity, dissolved oxygen and chlorophyll-a

attention only recently. In what follows, the work of Niki et al. (2005) with Tanabe Bay being a study area will be outlined with the aim of appreciating the diversity of processes of circulation and mixing in coastal oceans.

Tanabe Bay is situated on the west side of the Kii Peninsula and is open to the Kii Channel (Fig. 22). At the mouth of Tanabe Bay, there stands a storm-surge observation tower of DPRI. Its recently equipped live-camera system permits real-time observations of wave climate such as white cap coverage (refer to the lowermost panel of Fig. 22).

From an oceanographical standpoint, summer stratification is an intriguing feature in Tanabe Bay. Niki et al. (2005) examined datasets of relevant field measurements and concluded that the occurrence of summer stratification was in association with the meander of the Kuroshio, a well-known Western boundary current. When the Kuroshio current took a meander offshore such as occurring in the summer of 2000, stratification developed and cold nutrient-rich ocean water in the Kii Channel was brought into Tanabe Bay (Fig. 23). Niki et al. (2005) suggested that internal tides were operational in the summer of 2000 (Fig. 24) and played a role in the water circulation stated above. When coastal upwelling was effected concurrently by the Ekman transport or the like, the coastal water exchange was likely to have been enhanced. In contrast, when the Kuroshio took a meander onshore such as occurring in the summer of 1999, no distinct stratification was observed (Figs. 23 and 24).

Also, a set of field observations were made near the landward end of Tanabe Bay and some representative results are shown in Figs. 25 (Niki et al., 2005). It is evident that in the summer of 2000 with the Kuroshio meandering offshore, there occurred (a) sharp drop in seawater temperature, (b) slight increase in salinity, (c) reduction in dissolved oxygen and (d) marked increase in chlorophyll-a. All of these aspects were consistent with the afore-mentioned intrusion of the oceanic water that was colder, nutrient-rich and more saline.

The foregoing field observations led Niki et al. (2005) to performing a range of numerical analyses using Princeton Ocean Model (POM). A set of calculated seawater temperature distributions are presented in Figs. 26. It is seen that the calculated performance for the summer of 2000 reasonably reproduced coastal upwelling and the associated rapid drops in seawater temperature. It is interesting to make further elaborate computations to provide a clearer picture of the nutrient dynamics in Tanabe Bay, with

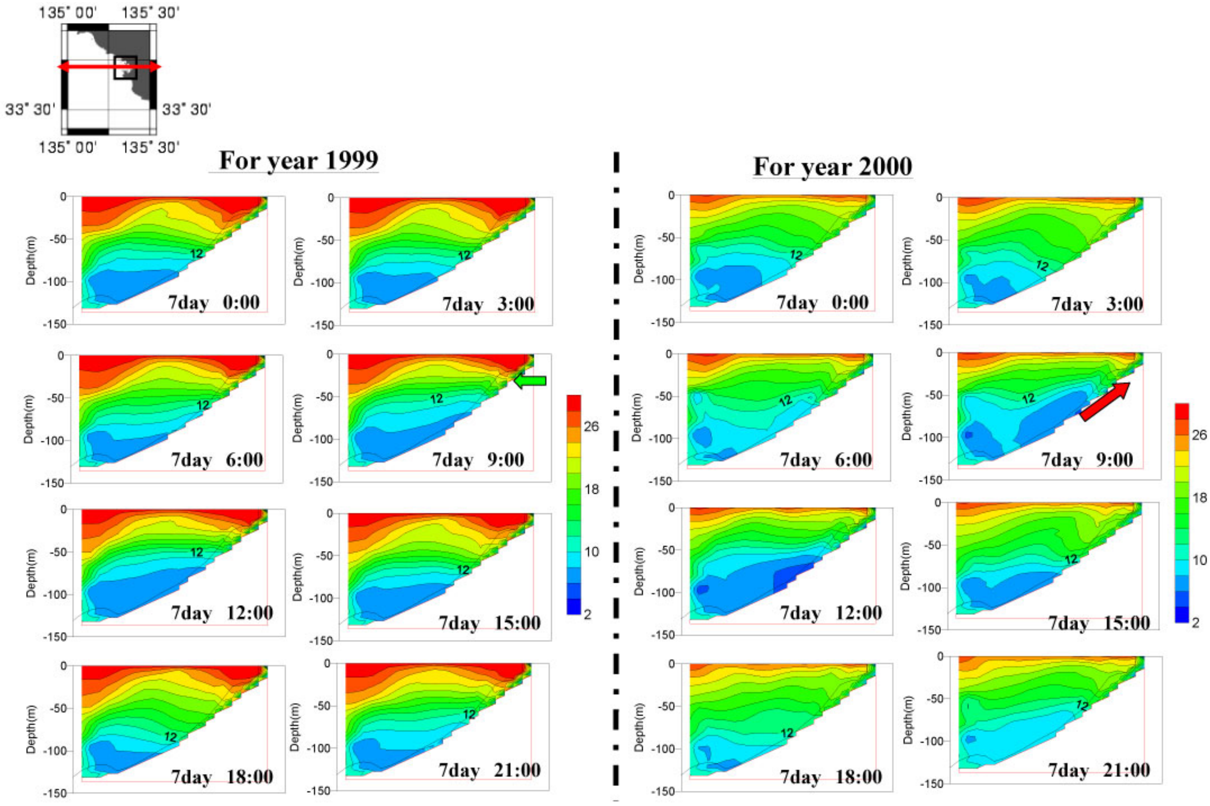

Fig. 26 Calculated profiles of seawater temperature across and beyond Tanabe Bay

due consideration of seabed processes.

3.4 Tsunami sedimentation

The 2004 Indian Ocean Tsunami was among the deadliest disasters in modern history, claiming more than 200,000 lives (http://www.drs.dpri.kyoto-u.ac.jp/sumatra/). This mega tsunami was a low-probability/ high-consequence event, acutely emphasizing the importance of promoting preparedness and mitigation efforts. In regions where tsunamis are infrequent, tsunami deposits may provide a sole clue for quantifying recurrence intervals and size estimates of past events (Bourgeois, 2006). In order for this approach to become more practical, it is crucial to address a number of issues, including the following (Bourgeois, 2006):

a. How can tsunami deposits be distinguished from hurricane and other storm deposits?
b. How can properties of tsunami waves be quantified from their deposits?
c. What are the geomorphic effects of tsunami erosion and deposition?

With the three issues in mind, Yui et al. (2007) made a preliminary field survey in Tanabe Bay for exploring tsunami-derived deposits. They first noted that the low-lying waterfront areas around Tanabe Bay had been repeatedly exposed to tsunamis (Fig. 27). The

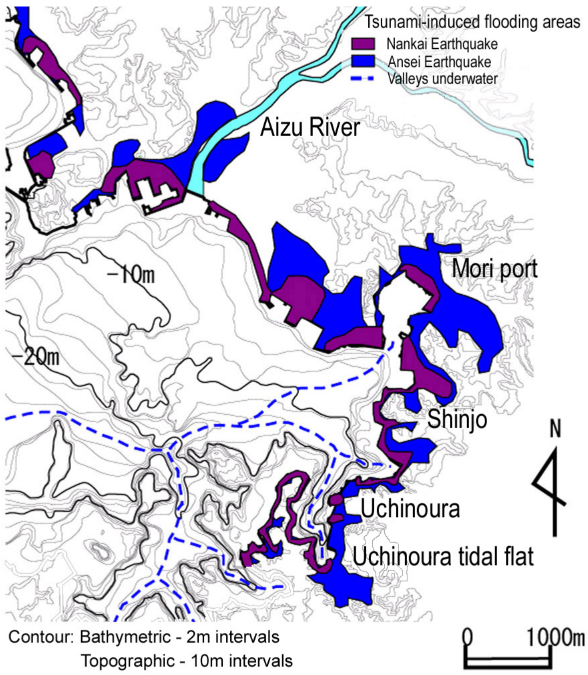

Fig. 27 Tsunami-induced inundation areas along Tanabe Bay

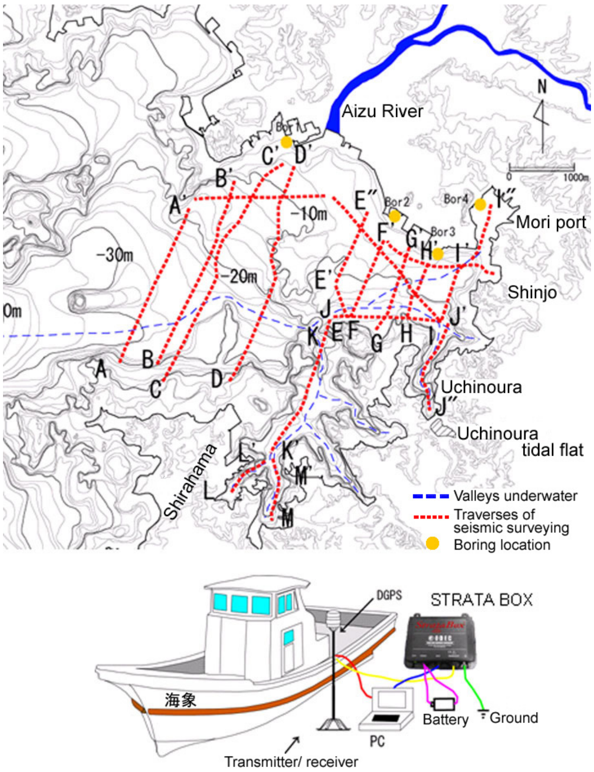

Fig. 28 Lines of seismic profiling performed with STRATA BOX mounted on KAISHO

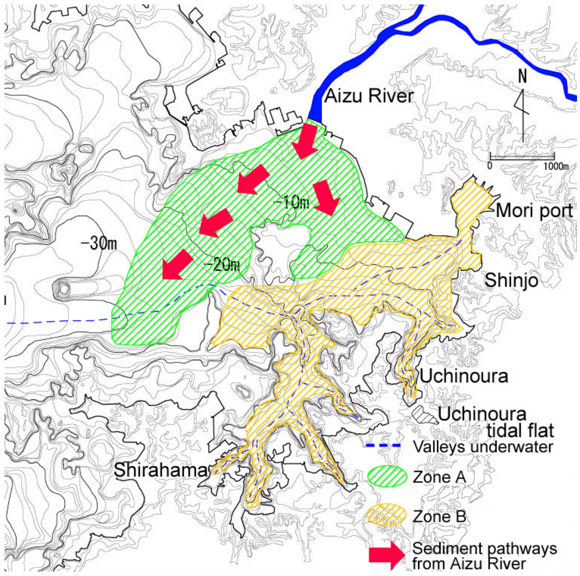

Fig. 29 Identification of distributions of coarse-grained sediment (zone A) and fine-grained sediment (zone B)

Uchinoura tidal-flat area, for instance, recorded tsunami run-up heights of 5.5m and 4.3m respectively in the 1854 Ansei and 1946 Nankai Earthquakes. However, no evident tsunami-related sediment traces were found in the surveys there (Yui et al., 2007).

The question now arises as to where the past tsunamis brought the affected sediments, if any. Considering that return flows could be the most likely conveyor, Yui et al. (2007) performed an extensive seismic-reflection surveys in Tanabe Bay using a research vessel named KAISHO of DPRI, along a total of 13 traverses over 30km (Fig. 28). A seismic sounder designated StrataBox was mounted on the vessel, together with a DGPS. The seismic sounder operated at a frequency of 10kHz. Its other principal specifications were as follows: the rated maximum sounding depth=40m; the resolution of sediment layer=6cm and the bathymetric resolution of 0.1m. During the cruise (19-20 September 2006), seabed sediments also were retrieved at several localities using an Ekman sampler.

The principal results from the field survey are typified in Figs. 29 and 30 (Yui et al., 2007). First, it proved useful to distinguish zones A and B in terms of the distribution of coarse- or fine-grained sediment in the seabed (Fig. 29). Zone A is featured by the presence

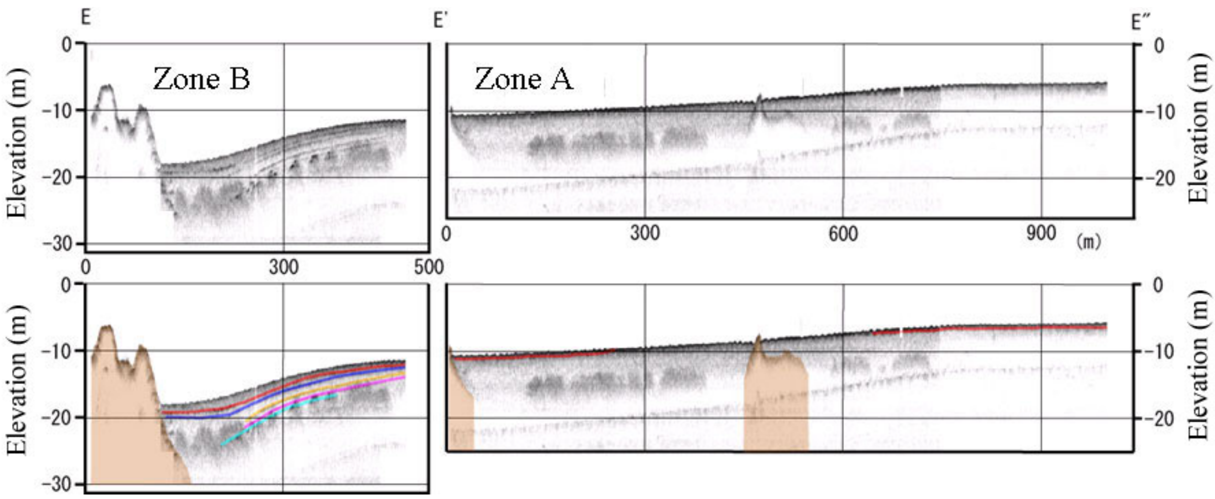

Fig. 30 Comparison of in-line seismic profiles with distinct reflectors captured

of coarse-grained sediment whose source may be attributed to the Aizu River. In contrast, zone B has no large rivers flowing into, and is featured by the presence of a series of drowned valleys (marked with dotted lines) that have been deposited with fine-grained sediment. Let us now examine seismic-reflection profiles along a representative traverse E-E'-E'' (Fig. 30). Along E'-E'' that traverses zone A, there is a distinct reflection immediately below the seabed. This is not surprising in view of the proximity of the Aizu River and of the associated abundance in riverine coarse-grained sediment. What is notable is the profile through E-E' that traverses zone B. Here one can clearly identify several distinct reflectors well below the seabed. This zone is a sheltered setting with calm waters (water depths of 10m or larger) where only fine-grained sediment could have been effectively deposited under commonly occurring physical conditions. Thus the distinct reflectors in the seismic profiles like E-E' are likely to correspond to tsunami-related event deposits.

Certainly, it is worth attempting to retrieve a continuous sediment core down to the firm base for close examination. Interestingly, promising observations have been made in the sediment core most recently retrieved (Tsuyoshi Haraguchi, 2007; personal communication).

4. Conclusions

The foregoing coverage has dealt with the performance of some important sub-systems of the Earth's surface process. The conclusions reached may be summarized as follows:

1) Grid modelling has advanced to a level such that the precipitation-derived runoff and sediment transport in watersheds may be predicted with a reasonable accuracy.
2) The combined numerical/field study with the Lesti basin, East Java, Indonesia points to the importance of the vegetation cover in the sediment management, and to the usefulness of NDVI so as to link the vegetation and hydrodynamic factors in an overall computational procedure.
3) Fluvial sediment management is integral part of sustainable river restoration, and requires a high-performance computational procedure to consider the complex interactions among the flowing stream, sediment, riverbed and structures such as groins. A range of computational models described by Zhang et al. (2007) have demonstrated their predictive capability, warranting further applications and developments.
4) Littoral sediment budget requires careful effort-intensive field observations. High-resolution geomorphological surveying is a key methodology for precise assessment of sediment budget in a given coastal setting.
5) Cross-shore sediment transport deserves far more attention, along with reexamination of the conventional wave base.
6) Tsunami sedimentation is an emerging field of interdisciplinary nature, with increasing societal needs. It may serve as a framework within which waterfront, coastal, shelf, slope and deep ocean environments may be integrated to give insights into tsunami disaster reduction.

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山地・河川・海岸系における物質動態に関する研究（第４報）

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武藤裕則・馬場康之・芹澤重厚・張　浩

要　旨

流砂漂砂系において重要な役割を果たしている流体と堆積物の複雑な相互作用について、最近の進歩および課題を概観している。流域規模における降雨流出と土砂流出については、分布型モデルの進歩により、実問題の要請に応えられる精度での予測が可能となってきている。その実例として、インドネシア国 Lesti 流域における土砂管理や土地利用計画に繋がる研究成果を紹介している。水制等を活用した河川環境再生には、高精度かつマルチスケールの流水/土砂挙動の予測が必要になる。木津川流れ橋エリアの河川環境再生プロジェクトに関連して、最新の多次元流水/土砂挙動解析コードの適用例を簡潔に紹介している。さらに、海岸域における研究課題として以下のようなテーマをとりあげ、今後の研究の方向性について言及している：　漂砂系の土砂収支におよぼす海底谷の影響、イベント過程を見据えた岸沖方向の堆積物輸送の再評価、海浜環境のリモートセンシング、内湾―海峡―外洋系をつなぐ海水循環ダイナミクス、津波災害環境の復原に繋がる海域音波探査/堆積学的調査法のポテンシャル。

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流出モデリング，流砂系