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INSSECT—an instrumented platform for investigating floc properties close to the seabed

Ole A. Mikkelsen[1,2], Timothy G. Milligan[2], Paul S. Hill[1], and Dan Moffatt[2]*
[1]Dalhousie University, Department of Oceanography, 1355 Oxford Street, Halifax Nova Scotia, Canada, B3H 4J1
[2]Department of Fisheries and Oceans, Bedford Institute of Oceanography, PO Box 1006, Dartmouth Nova Scotia, Canada, B2Y 4A2

Abstract

A new type of tripod, INSSECT (IN situ Size and SEttling Column Tripod), designed for floc measurements in the shallow parts of the continental shelf, is described. INSSECT orientates itself into the current so that instrumentation on it faces upstream, thereby minimizing flow disturbance. The instrumentation includes a digital floc camera, a video settling column, a unique sediment trap designed for capturing flocs intact, a laser sizer, an optical backscatterance sensor, a compass and tilt meter, and a current meter. It is designed for relatively short deployments of up to 2 weeks and can be recovered, turned around, and redeployed rapidly. It was designed for use in semi-synoptic surveys of the spatial variation in floc properties such as size and settling velocity and the factors that influence them. The paper describes the various components of the INSSECT and presents selected results from the first deployments, demonstrating its ability to turn in the current and capture single flocs intact. Contrary to recent findings on the influence on settling columns on floc size, intercomparison between the video settling column and the digital floc camera reveals that the sizes are similar.

Fine-grained suspended sediments in the aquatic environment aggregate into larger, porous aggregates commonly called flocs (Krone 1962; Kranck 1973; Mikkelsen and Pejrup 2000). The flocculation process increases the settling velocity of the fine-grained particles by several orders of magnitude when compared to the settling velocity of their constituent grains contained in them (Pejrup 1988; Hill et al. 2000). Hence, flocculation is of great importance in studies of fine-grained sediment transport and sediment fluxes in the aquatic environment. The two properties that are most often used to characterize flocs are their size and settling velocity, as these have implications for sedimentological as well as optical studies (Dyer 1989; Hill et al. 2001; Mikkelsen 2002). Also of interest is the structure and composition of the flocs as this can influence floc growth (Leppard et al. 1996; Milligan and Hill 1998). Due to the fragile nature of flocs, these properties have to be determined in situ. For this purpose, a variety of instruments have been developed (Dyer et al. 1996; Eisma et al. 1996; Wren et al. 2000). Most of these instruments have been able to measure only floc size and/or settling velocity and have lacked the ancillary data to evaluate the parameters that influence them. In this paper we introduce the INSSECT (IN situ Size and SEttling Column Tripod), which has the ability to simultaneously measure ambient floc size, settling floc size, and settling velocity, and Reynolds stress.

In situ settling velocities of fine-grained sediments are most commonly obtained using various settling column systems (Owen 1976; Dyer et al. 1996), some of which are equipped with video cameras (Van Leussen and Cornelisse 1993; Fennessy et al. 1994). Video-equipped settling columns usually provide floc size and settling velocity data, and several relationships between in situ floc size and settling velocity have been published (Hill et al. 1998; Sternberg et al. 1999; Mikkelsen and Pejrup 2001). Assuming Stokes Law, the densities of the flocs as a function of their size can subsequently be calculated and particle mass and/or settling fluxes can be derived for individual floc size classes (Syvitski et al. 1995; Fennessy et al. 1997; Hill et al. 1998; Sternberg et al. 1999; Manning and Dyer 2002).

Error in estimates of in situ floc density from observations of floc size and settling velocity may arise from several sources.

*Present address: Department of Fisheries and Oceans, Bedford Institute of Oceanography, PO Box 1006, Dartmouth Nova Scotia, Canada, B2Y 4A2. Email: mikkelseno@mar.dfo-mpo.gc.ca. Phone: 902-426-1865. Fax: 902-426-6695.

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Recent laboratory work by Curran et al. (2003) suggests that ongoing flocculation processes in settling columns may to some degree compromise their use for derivation of floc-settling velocities. Also, laboratory work has suggested that Stokes Law is not applicable to flocculated sediment because of different drag relationships for porous, permeable aggregates compared to spherical particles (Johnson et al. 1996). More specifically, Johnson et al. (1996) warned that Stokes Law underestimated floc-settling velocities. Hence, densities derived from the use of Stokes Law on observed size-settling velocity relationships would be overestimated, together with any estimate of mass fluxes. A solution to this latter problem would be to capture and weigh the settling particles observed by a video system, thereby obtaining an independent estimate of the total mass flux during the period of recording. This estimate could then be compared to the mass flux estimate obtained from the size-density relationship using Stokes Law.

Another confounding factor with respect to floc size and settling velocity is their mutual dependence on turbulence and total suspended mass (TSM) concentration. Numerous studies have been carried out in order to elucidate which of these factors—turbulence or TSM—is the more important to floc growth and settling. No general relationship between floc size and settling velocity and turbulence and TSM has been found, either in the laboratory (Krone 1962; Milligan and Hill 1998; Manning and Dyer 1999) or in the field (Berhane et al. 1997; Van der Lee 1998; Hill et al. 2000).

No single instrument package has yet been able to measure size, settling velocity, structure, composition, and flux of flocculated sediment simultaneously with measurements of turbulence and sediment concentration, which are widely believed to be major controls on flocculation rate and floc size. Nor has there been an instrument platform suitable for deploying the instrumentation required to make these measurements without altering the turbulence. Whereas numerous tripod systems have been conceived and deployed over the last three decades (Sternberg and Nowell 1999), the influence of the tripod on the flow measurements remains a concern. INSSECT has been developed to make simultaneous measurements of all parameters presently believed to control floc size and settling velocity without significantly altering the ambient flow. The INSSECT consists of a rotating frame attached to a tripod base. All instrumentation and a sediment trap carousel are attached to the rotating frame. The purposes of this paper are to describe the design of INSSECT and to present some results obtained during field deployments in Bedford Basin (Canada) and the Adriatic Sea (Italy).

Materials and procedures

INSSECT is a rotating sediment trap equipped with a digital silhouette floc camera (DFC) (Curran et al. 2003), a digital silhouette video camera (DVC) equipped with a settling column for obtaining size and settling velocity of the flocs, and a LISST-100 laser particle sizer (Agrawal and Pottsmith 2000). Particles that enter the settling column fall into small cups containing a transparent gel, allowing later laboratory analysis of the structure and size of settled particles. Cups without gel are used to measure sediment flux and for analysis of the primary grain-size spectra. A modular acoustic velocity sensor (MAVS) (Thwaites and Williams 1996) measures turbulence, while an optical backscatterance sensor (OBS) is used for estimating the turbidity. Thus, for the first time one compact package measures all parameters at present believed to influence the flocculation process and the flux of fine-grained sediment to the sea floor.

The frame—A rotating frame was required to obtain floc size and settling velocity and flow velocity data unaffected by flow disturbance caused by the DFC, DVC, and LISST-100 mounted on the tripod. These instruments all have preferred flow orientation. For example, the DFC and the LISST-100 have flow-through sensing zones, which must be kept more or less perpendicular to the flow to minimize the risk of floc breakup. Conventional fixed tripods are not ideally suited for deploying a DFC or LISST-100, as the current direction invariably will be unfavorable for parts of the deployment. Another issue is the size of the instruments. On a tripod equipped with current meters, the flow disturbance created by a DFC and/or a LISST-100 would be significant and could easily impact estimates of turbulence and currents. Thus, mounting the instruments on a tripod that orientates itself into the current minimizes the flow disturbance by the tripod and the instrumentation on it. It also ensures that the instruments do not block the flow of water and particles to other instruments.

The INSSECT (Fig. 1A-1D) essentially consists of two parts, the tripod base and the top frame, holding all instruments and a sediment trap. The tripod base has a urethane wheel with needle bearings on each of the legs, and top frame is in contact with the base only at the center and at the wheels. At the center of the tripod base, the top frame rests on an acetal bushing, and a nut and bolt holds the two together. This configuration allows the top frame to rotate freely. A set of fins is attached to the top frame to orient instruments with the current. The frame is balanced so that the in-water center of gravity is in line with the axis of rotation. Unlike conventional tripods, the rotating balanced frame ensures that the attached instrumentation is always facing the current, thus minimizing the flow disturbance from the structure itself.

Recovery of the INSSECT is carried out using an acoustic release and specially designed pair of floats. The recovery line is wound on an axle supported by two 11-inch Viny floats. This "spool of thread" configuration for the recovery line prevents tangling and provides a compact way of mounting both the release and recovery rope on the tripod.

Sediment trap system—The sediment trap (Fig. 1A-1D) contains 24 small rectangular cups (L × W × H = 95 × 50 × 25 mm) (Fig. 1C). The cups are held in place in a specially designed circular plate, hereafter referred to as "the cup plate," which has 25 cutouts for the cups (Figs. 1C, 2). Sediment enters the trap

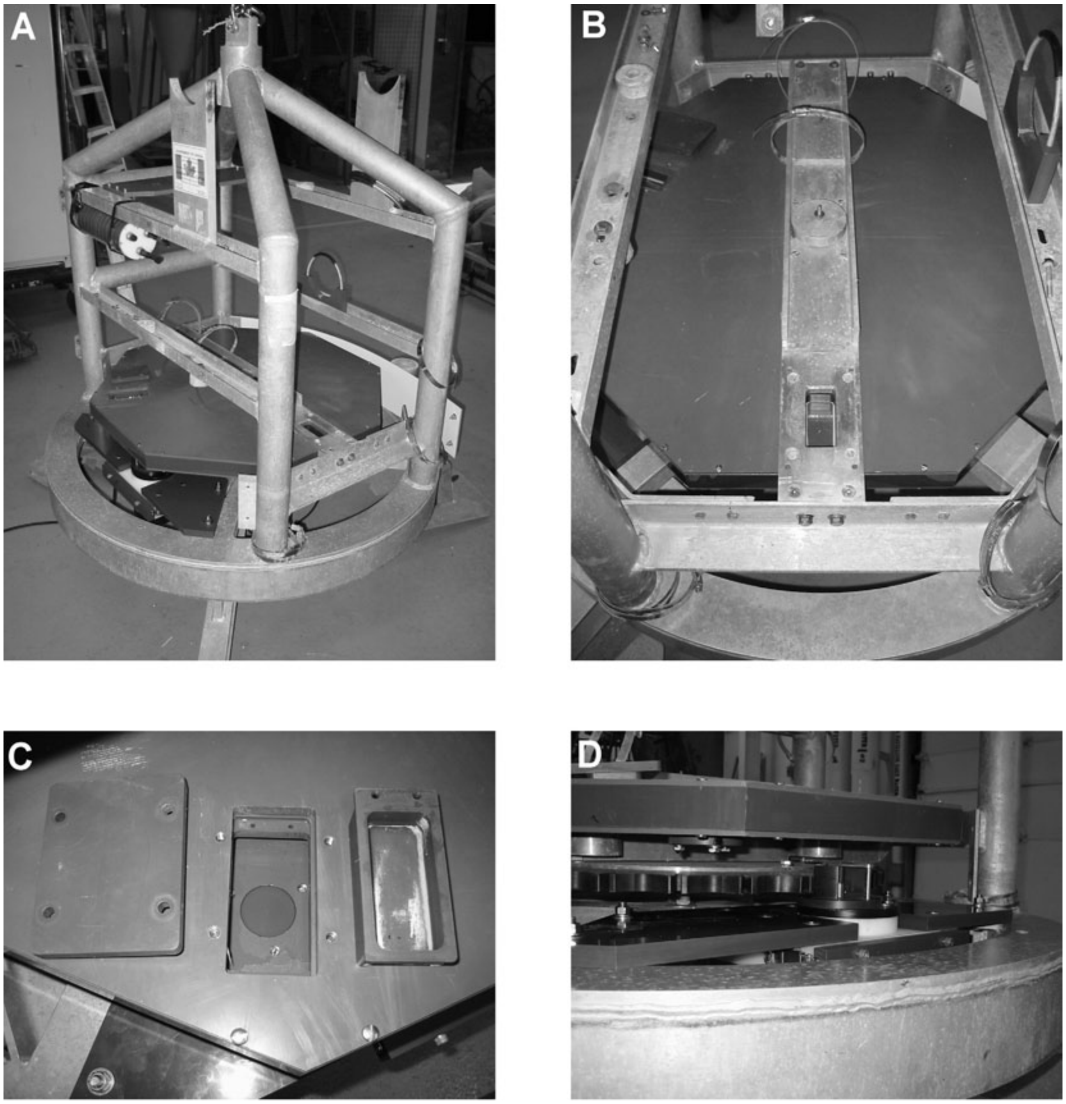

Fig. 1. (A) The INSSECT without mounted instrumentation and fins. The rotating frame is mounted on top of the tripod base. The sediment trap carousel and motor is mounted to the frame. (B) Detail of the sediment trap system. Shown is the hole for the settling column and the digital video camera. (C) Detail of the hole where the cups are loaded into the sediment trap. The lid is to the left and an empty cup is seen to the right. The finger hole is seen as well. (D) Detail of the motor mount. Note that the motor locks the cogwheel into place.

through the settling column, attached to the DVC. Two versions of the trap have been constructed, as the first design proved to let sediment enter the cups by pathways other than through the settling column. To assist others with design decisions for similar devices, both versions of the trap are described.

The cup plate originally was mounted on a cogwheel that was rotated by a McLane™ sediment trap motor (McLane Research Laboratories; Fig. 1D). A top plate (Fig. 3) was mounted flush with the top of the cup plate so that no particles would settle into the cups once they had been placed in the cup plate. The top plate had two cutouts, one for mounting the cups in the cup plate, and one for allowing the particles in the settling column to settle through the top plate and into the cups. When the cups had been loaded through the cutout in the top plate, a sealing lid was screwed onto the cutout. A skirt (Fig. 3) was mounted around the two plates, so that theoretically no particles would flow between the plates. A set of turnbuckles fixed the top plate to the frame. The second cutout was located directly under the settling column, allowing particles in the column to settle freely into the cups. The sediment trap motor rotated the cogwheel by means of a Geneva mechanism, providing for very precise sequential positioning of the cups under the top plate cutout and the settling column. The sampling times for the 25 cups were programmed in the motor controller prior to deployment. During deployment, the controller records the time of each rotation.

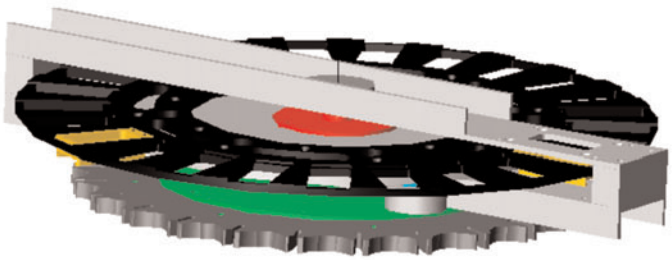

Fig. 2: Drawing of the sediment trap system (cf. Fig. 1), showing the plate that holds the cups, together with driveshaft and cogwheel.

Field trials were carried out in Bedford Basin while the first deployments were carried out in the western Adriatic Sea in the spring of 2003. The Adriatic Sea has a NW-SE orientation, an area of roughly 140,000 km^2 and is bordered to the north and the west by the coast of Italy and to the east by the coasts of Slovenia, Croatia, Bosnia-Herzegovina, Serbia-Montenegro, and Albania. During the winter months, strong winds from the NE (Bora winds) can occur, whereas during the summer and autumn, winds from the SE (Scirocco winds) prevail. Waves with a significant wave height (Hs), less than 2 m, generally come from an ESE-SSE direction, whereas waves with Hs greater than 2 m generally come from NE-ENE direction. Significant wave heights greater than 2 to 5 m are rare (Decouttere et al. 1998). The median value of Hs is 0.5 m—waves with Hs > 2 m occur approximately 4% of the time with a maximum value of Hs of approximately 5 m.

Bedford Basin is a small bay with an area of ~18 km^2 in Halifax Harbor. It has a NNW-SSE orientation, and it is connected to the Atlantic Ocean through Halifax Harbor and a small inlet, The Narrows, which is only 400 m wide. The maximum fetch in Bedford Basin is 7 km, as opposed to approximately 700 km in the Adriatic Sea. It is thus much more sheltered and less energetic than the Adriatic Sea. Therefore Hs is much smaller, with a maximum value of Hs of 1 m.

During the deployments in the relatively quiescent environment of Bedford Basin in the fall of 2002, sediment entered the cups only through the settling column. Cups that were not rotated under the column remained free of particles. During deployments in the Adriatic Sea in February and May/June 2003, however, it became evident that this design was not working in an energetic shelf environment, as sediment was observed to accumulate between the top plate and the cup plate. Thus, the observed fluxes and size distributions inferred from the cups were not necessarily representative of what had been observed in the settling column. The initial, shielded trap design apparently works in low energy environments, such as the Bedford Basin, but not in a higher energy environment such as a continental shelf. The results motivated a new trap design, with a fully enclosed cup plate.

In the new design, the cup plate is mounted inside a housing that completely surrounds it, preventing sediment from flowing into the cups from outside (Fig. 1A-1D). A shaft connects the cup plate to the cogwheel below the housing. The housing has three cutouts: one for loading the cups into the cup plate, one for allowing the particles in the settling column to settle through the top plate into the cups, and a finger hole at the bottom of the housing to facilitate removal of the cups upon recovery. The finger hole and the loading cutout are sealed with lids prior to deployment. The rotation procedure using the McLane™ sediment trap motor is the same as for the first version.

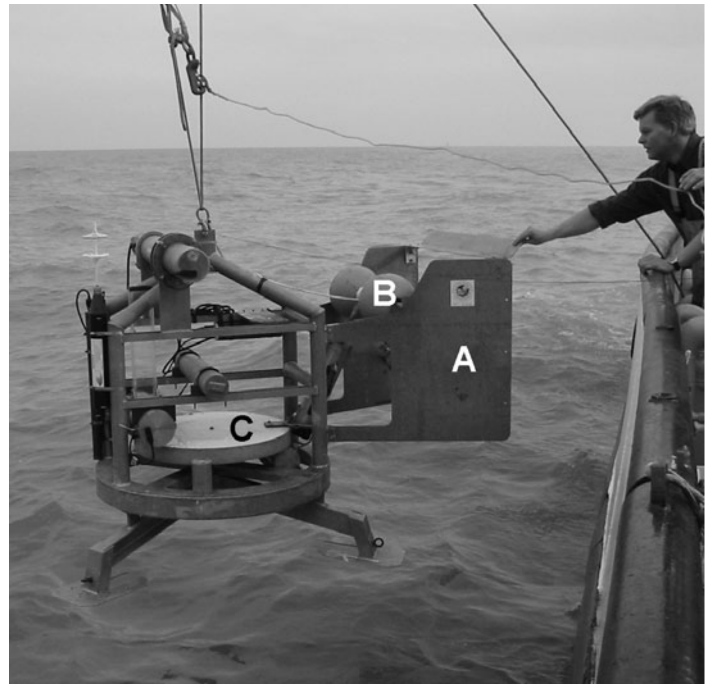

Fig. 3. INSSECT during deployment. (A) Fins; (B) release floats; (C) old sediment trap system, with top cover plate (white) and skirt.

Instrumentation—Fig. 4 shows the frame with instruments. On top of the frame, the DFC is mounted so that when the top frame rotates in the current, there is minimal disturbance from the DFC on the flocs. An OBS is mounted to the DFC. On the front right of the frame, a MAVS acoustic current meter is mounted, measuring current velocity and turbulence. The batteries and controller for the OBS and the DFC are mounted across the center of the frame. A LISST-100 in situ laser sizer (not shown) can also be mounted across the frame. A digital compass and tilt meter are attached to the side of the frame. The compass serves to check that the frame rotates and that it is level. If the roll becomes more than 2.5° from the vertical, particles will start to slide along the side of the settling column, instead of falling freely. The DVC is a SONY DCR-VX2000, mounted in a stainless steel watertight housing, located at the center front of the frame. A Plexiglas settling column is attached to the housing. On the front left of the frame, battery packs for the DVC are mounted. The DVC and settling column are mounted so that as the frame rotates in the current, the column faces the current, thereby minimizing

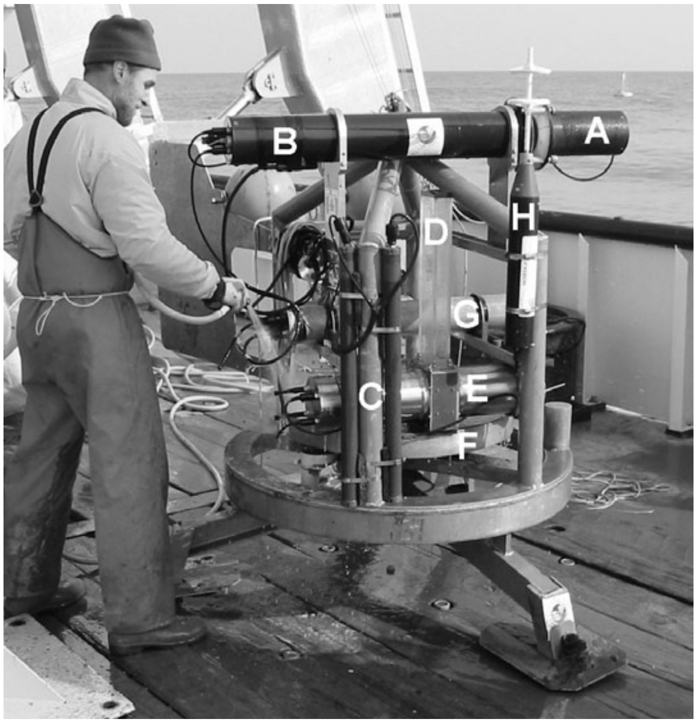

Fig. 4. INSSECT with instrumentation mounted. (A) Digital floc camera; (B) OBS mounted on rear end of DVC; (C) batteries for Digital video camera; (D) settling column; (E) digital video camera; (F) skirt (old version of sediment trap system); (G) controller for DFC and OBS; (H) MAVS current meter.

flow disturbance. The intake of the settling column (hence the DVC) in the present configuration is about the same height as the DFC and the MAVS, 1.7 m above the bottom. This enables direct comparison of the size distribution from the DFC with the size distribution from the DVC and turbulence estimates from the MAVS. The length of the settling column can of course be shortened, if settling velocities closer to the bottom are of greater interest.

Sampling procedure—The DVC is controlled by a Tattletale datalogger and is programmed to record clips of 1-min duration. The interval between clips can be varied. The pixel resolution is 66 µm with a depth-of-field (DOF) of 25 mm and a field-of-view (FOV) covering 640 × 480 pixels (4.1 × 3.2 cm). Thus, the resolution is somewhat lower than that obtained with video systems designed for use in highly turbid estuaries, such as the INSSEV (Fennessy et al. 1994) or the VIS (Van Leussen and Cornelisse 1993). However, because the INSSECT is designed mainly for use in shelf settings where the suspended sediment concentration is in general much lower than in estuaries, a large FOV is necessary to observe enough flocs for processing during the 1-min recording period. The DVC is focused on the middle part of the settling column. A small aperture setting in the video (F8) and a bright halogen lamp, lighting the particles from behind, produces a silhouette photograph that ensures the entire DOF is in focus when recording.

The DVC uses mini Digital Video (miniDV) tapes, capable of holding 60 to 80 min of high-quality, short-play video recordings. The tapes are transferred to an Iomega 120-gigabyte removable hard drive, using a Sony Vaio GRZ610 laptop. All Sony Vaio computers come with Sony's MovieShaker software, which allows for direct communication with and control of Sony cameras through a firewire connection. The MovieShaker software also automatically divides the 1-min video clips into separate files. Each minute of video takes up approximately 200 megabytes on the hard disk. The Iomega hard disk is connected to the Sony through a high-speed USB 2.0 port, allowing for fast access to the data on the disk. The files created by MovieShaker are stored as DV files, which can be played back in MovieShaker or QuickTime Player. From each 1-min video clip, the size and settling velocity of the particles appearing in the clip are obtained using the method described by Fox et al. (in press). The sediment trap rotation is programmed to match the sampling frequency of the DVC. Typically a cup is in position under the settling column for a duration of at least two video clips.

The DFC takes still pictures of the suspended particles in the ambient flow also by means of silhouette photography. The FOV is a 4 × 4 × 2.5 cm slab of water, and the DFC is focused on the middle part of the slab. As per the DVC, a small aperture and a bright light source ensures that all particles in the FOV are in focus. The images are stored on an internal hard disk, capable of storing up to 1,000 gray scale images with a size of 1,024 × 1,024 pixels. The resolution of the camera is 45 µm, which means that the smallest particle that can be resolved is approximately 135 µm. Upon retrieval of the DFC, the images are downloaded to a PC, and image analysis of each image is carried out using the MATLAB Image Processing Toolbox, according to the following routine. For each image, an area of interest (AOI) is selected and all particles in the AOI are counted and the area of each particle is computed. From this area distribution, the cumulated area distribution is computed, and the area corresponding to the second and third quartile of cumulated particle areas (A_{50} and A_{25}) is determined. A_{50} is thus the median area, and A_{25} is the lower boundary of the upper quartile of cumulated particle areas. The particle diameters associated with these two areas are called D_{50} and D_{25} and are computed as $\sqrt{(4/\pi)\times A_{50}}$ and $\sqrt{(4/\pi)\times A_{25}}$, respectively. D_{50} is thus the median equivalent circular particle diameter. Furthermore, based on the area of each particle, their volumes are computed (assuming the particles are spherical) and binned into size classes, thereby yielding a particle volume distribution as well. From the volume distribution, the particle size spectra can be plotted and the total volume of particles in the AOI computed.

The OBS attached to the DFC samples turbidity at a frequency of 1 Hz for 30 s every time the controller turns on the DFC to take a picture. Thus, the turbidity from the OBS can be directly compared to the particle volume concentration obtained from the DFC. The compass is programmed to sample every 5 min. It records the orientation, pitch, and roll of the frame. Finally, for measurements of current velocity and turbulence, the MAVS current meter is programmed to measure in burst mode with a sampling frequency of not less than 4 Hz (typically 4 to 10 Hz) and at the same time as the DFC and the OBS are sampling.

Preparation of gel—To preserve the structure of flocs in the cups, a polyacrylamide (PAA) gel is used (Lundsgaard 1995; Waite et al. 2000). The gel provides an optically clear medium, the viscosity of which prevents flocs from compressing in the cups. Materials needed for making a PAA solution are as follows: sodium chloride (NaCl); ammonium peroxydisulfate (AP, also known as ammonium persulfate, $[NH_4]_2S_2O_8$); *N*,*N*,*N*′,*N*′-tetramethylethylenediamine (TEMED, $C_6H_{16}N_2$); and acrylamide (AA, reagent grade, $CH_2CHCONH_2$). Acrylamide is a possible carcinogen and a neurotoxin, so care must be taken when preparing the solution. All work related to acrylamide should be carried out in a fumehood using goggles, gloves, and aprons.

One liter of gel in a 30‰ NaCl solution with a concentration of 7.3% PAA by weight is made up using the following procedure adapted from Lundsgaard (1995): (1) 27 g NaCl is dissolved in 900 mL of deionized water in a flask; (2) 3 g NaCl is dissolved in 100 mL of deionized water in another flask. (3) Both flasks are placed in a vacuum to remove dissolved oxygen in the water. The flasks remain in a vacuum until bubbling has ceased. Oxygen inhibits the polymerization process, so it is important that the NaCl solutions are free of oxygen. Steps 4 and 5 are carried out while continuously flushing the NaCl solutions with high purity oxygen free nitrogen gas: (4) 2.0 g AP is dissolved in the 100 mL NaCl solution, and then 2.0 mL TEMED is added. (5) 73.0 g AA is dissolved in the 900 mL NaCl solution under magnetic stirring, and the AP/TEMED solution subsequently added.

Polymerization starts within a few minutes, and after approximately 0.5 to 1 h, visible changes in viscosity appear and the N_2 flushing can be stopped. If no N_2 is available, it is possible to make up the gel simply by keeping the flask under constant vacuum after the AP/TEMED solution has been mixed with the AA solution. Under this procedure, the polymerization process takes longer to start, and visible changes in viscosity usually appear in 3 to 5 h. At this point the PAA gel is ready for storage. Bubbles appearing during the process dissipate within a day, but preparation should be done well in advance of deployment. According to Lundsgaard (1995), the solution can be stored indefinitely provided it is covered to prevent evaporation thus increasing the salinity and viscosity of the gel. The salinity of the gel should match the salinity of the ambient water to minimize osmotic differences and electrostatic forces between the flocs once they have settled into the gel (Lundsgaard 1995).

Prior to deployment of the INSSECT, some of the cups are filled with the PAA gel while others are left empty. The sediment settling into the empty cups can be filtered, dried, and weighed to obtain estimates of mass fluxes and other parameters, e.g., disaggregated inorganic grain size spectra and bulk chemical composition.

It was found that for the INSSECT work, a gel with a PAA concentration between 7.3% and 8.0% was suitable. Below 7.3% the gel was not viscous enough, and above 8.0% it became too viscous to be easily poured into the gel cups. However, gels with PAA content of less than 7.3% have been found to be useful in creating a two-layer structure in the gel cups: First, the cup is filled with a gel layer of ~15 mm thickness containing between 7.3% and 8% PAA. Second, a thin layer of gel containing 6% to 6.5% PAA is poured on top of the first layer of gel. This allows the flocs to settle relatively quickly into the gel and reduces the chance of overloading the cups. The viscosity of the gels can vary slightly from batch to batch, even when the same amount of AA was used. This problem seemed to worsen with increasing amounts of AA in the gel.

Particles embedded in the gel can be counted and sized using photographic techniques. Upon recovery the gels are taken to the laboratory for immediate photographic imaging. Of the several techniques tried, the best results have been obtained by mounting a Nikon Coolpix 950 digital camera on a tripod above the gels and using the macro mode of the Nikon to obtain images of the particles. The images obtained in this manner had a pixel size of approximately 25 µm. Subsequently the images were converted to grayscale and the particles in the images were analyzed using the same methods as DFC and DVC. Methods for determining the structure of the flocs in the gels are being developed.

Assessment

Deployments of INSSECT in the Bedford Basin and western Adriatic were conducted to evaluate its performance. As most of the instruments on the tripod have been previously tested, emphasis was placed on the performance of the rotating frame, comparison of the DFC and the DVC and the effect of the settling column on floc size, and the ability of the gels to preserve flocs.

Rotation of the frame in the current—To evaluate the frame's ability to orient the instruments mounted on it into the flow, data from the MAVS and compass and tilt sensors were used. The data were obtained during a short (8-h) deployment in the Adriatic Sea in May 2003 and provide a good example of tripod rotation (Fig. 5). From Fig. 5, three different orientations of the frame with respect to the current velocity and direction can be inferred (boxed areas). During the first period from 0555 to 0740, the current speed slowly decreased from ~0.04 m s^{-1} to 0.02 m s^{-1}. The current during this period did not change direction significantly from 294°, and the orientation of INSSECT remained constant at 286°. From 0745 to 0930, the current speed dropped to almost 0 m s^{-1} before changing direction by 180° to roughly 112° and increasing to 0.05 to 0.06 m s^{-1} by the end of the period. During this transition in current direction, INSSECT maintained

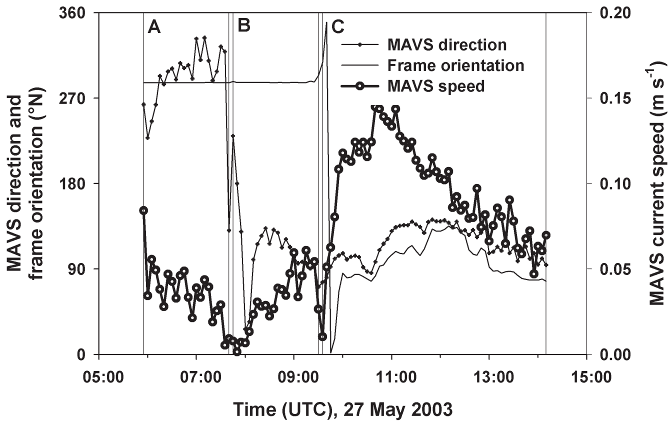

Fig. 5. Current speed, current direction, and compass direction during an 8-h deployment in the Adriatic Sea. Three "events" can be recognized: (A) During deployment (i.e., lowering), the INSSECT orientates itself into the current (~0.06 m s^{-1}) and keeps this orientation, regardless of small changes in current direction. (B) The current direction changes ~180° and the current speed almost drops to 0 m s^{-1}. The INSSECT does not move. (C) The current speed increases, and at a speed of 0.08–0.1 m s^{-1}, the INSSECT swings into the current and stays within 20° of the current direction for the duration of the deployment.

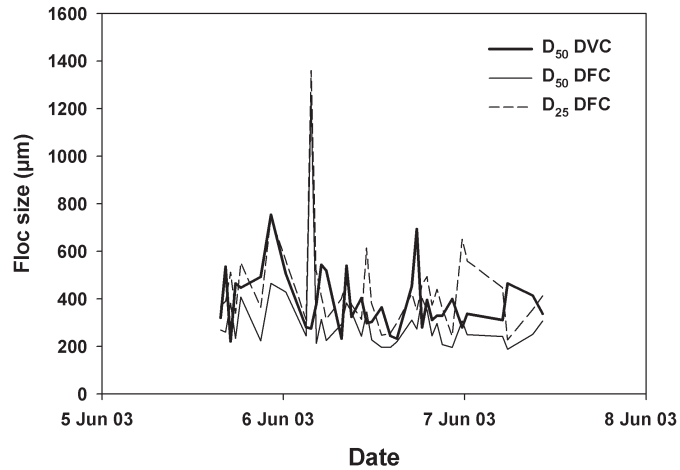

Fig. 6. Comparison of the variation in in situ floc diameter, as measured by the DFC and the DVC over a 2-d deployment. D_{50} and D_{25} from the DFC both compare well with D_{50} from the DVC.

its orientation of 286°. In the third period from 0935 to 1410, the INSSECT frame rotated as the current speed increased rapidly up to 0.12 m s^{-1}. Initiation of the movement occurred at approximately 0.08 m s^{-1}, and the frame orientation remained within 20° of the current direction for the rest of the deployment.

From the above results, it may be inferred that current speeds of ~0.08 to 0.1 m s^{-1} are required to keep the frame orientated in the current once the INSSECT is standing on the bottom. Furthermore, the fact that the INSSECT was more or less aligned with the current during the first period may suggest that the fins will align the INSSECT with the prevailing current during deployment, even if current speed is less than the current speed at which the INSSECT will rotate.

DVC and DFC data—One of the concerns with regard to settling columns is that floc formation and/or floc breakup in the column might change the size spectrum of the suspension in the column (Curran et al. 2003). Fig. 6 shows the temporal variation in D_{50} from the DVC as well as D_{50} and D_{25} from the DFC. The data are from a 2-d deployment off the Pescara River (Adriatic Sea) in early June 2003. D_{50} from the DVC corresponds fairly well to the D_{50} from the DFC. A *t* test (t = 3.169, df = 35) shows that neither D_{50} nor D_{25} from the DFC is significantly different from the D_{50} from the DVC ($P < 0.01$). These preliminary data indicate that floc sizes are not altered in the settling column, even in relatively energetic continental shelf settings.

Fig. 7 shows an example of processed images from the DVC used to calculate size and settling velocity (cf. Fox et al. in press). Fig. 7A is a composite image created from four frames from one 1-min video clip. The four frames are evenly spaced in time, in this case every 2 s. A MATLAB script is used to delete stagnant particles identified in each of the four frames. In this way, only pixels that make up moving particles are retained in each frame. The four frames are then overlaid, thereby creating a composite image showing the settling track of the moving particles (Fig. 7A). All particles retained in each of the four frames are then numbered and tagged with a color that shows the position of the particle in each of the four frames (red = frame 1, green = frame 2, blue = frame 3, yellow = frame 4). The tagged images are then overlaid to create another composite image, with tagged and colored particles (Fig. 7B). From the tagged particles, the settling track for each floc is then defined manually and entered into a .txt file. Thus, in Fig. 7B the sequences 1111, 2222, 5655, and 6766 make up the settling track for the four flocs in the top half of the image. The MATLAB script subsequently reads the .txt file and determines the distance each floc has moved between each frame. Knowing the time interval between each frame, the settling velocity is then computed. For the four flocs in Fig. 7A and 7B, defined by the four number sequences above, the settling velocities are 1.07, 0.86, 2.22, and 0.86 mm s^{-1} respectively. The floc at the bottom of Fig. 7A and 7B cannot be defined properly and is not considered. For analysis of floc images from the DFC, the interested reader is referred to Milligan (1996) or Kranck and Milligan (1988).

Gel photography—During the Bedford Basin deployment from 14 November–25 November 2002, each gel cup was exposed under the column for 18 h. Eleven gel cups containing settled sediment were recovered and photographed on 25 November 2002 (Fig. 8).

Variation in particle coverage as well as the size of the particles in the cups was observed. Some of the gels (1-3, 6-8) appeared to be "overloaded" in the sense that the particle flux

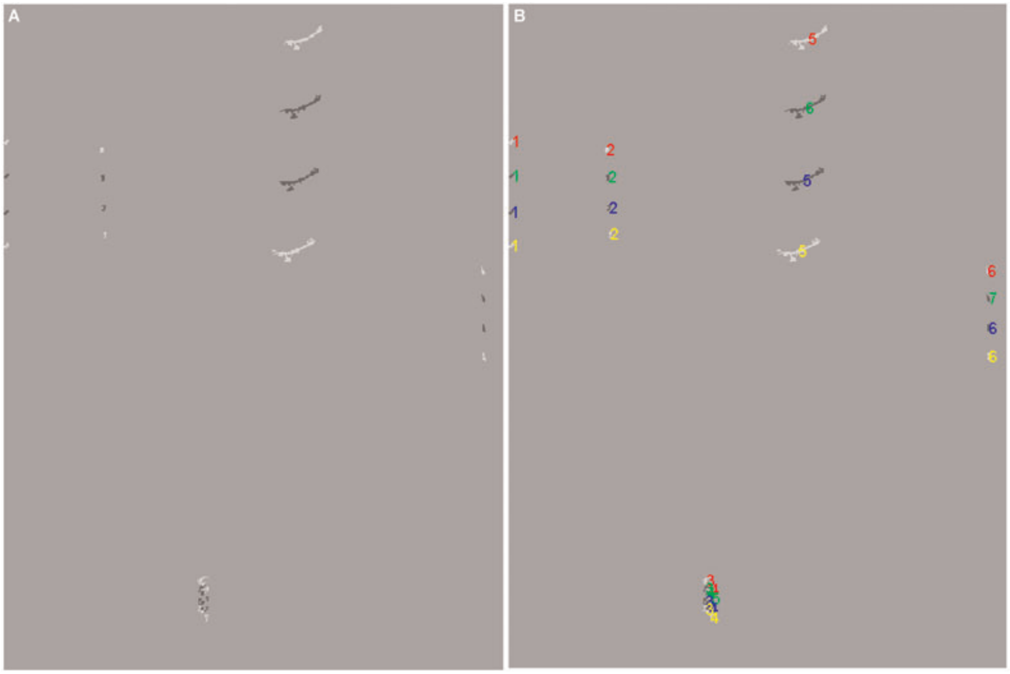

Fig. 7. (A) Example of a composite image from the DVC, showing how four flocs are displaced in time in four frames, each frame separated 2 s. (B) Composite image showing the same flocs as in (A), but now tagged and colored so that the settling tracks for each floc can be determined.

into the gel was so high that further flocculation took place on the gel surface, creating a network of coalesced particles. Based on the separation between flocs, some of the gels (9-11) did not show any significant signs of overloading. A comparison between the in situ floc size from the DFC and the floc size in the cups revealed that floc size was 3 to 6 times larger in the gel than in suspension for the overloaded cups (Table 1). Floc sizes in the cups that did not appear to be overloaded (9-11) were closer to those from the DFC but still appeared to have been exposed for too long for conditions in the Bedford Basin. To prevent overloading the cups the time each gel cup is under the column must be adjusted to suit the anticipated suspended sediment concentration and sediment flux during the deployment. Recent fieldwork in the Adriatic suggests that in typical coastal environments the cups should be under the settling column for no more than 30 min.

Fig. 8. Eleven gels with embedded flocs, obtained in the Bedford Basin during INSSECT deployment 14 November–25 November 2002.

Table 1. The maximum floc size observed in situ with the DFC (D_{DFC}) compared with the maximum floc size observed in the gel (D_{Gel}), together with their ratio (D_{Gel}/D_{DFC})*

Gel Nr	Max D_{DFC} (μm)	Max D_{Gel} (μm)	D_{Gel}/D_{DFC}
1	1170	6641	5.7
2	707	3656	5.2
3	690	4259	6.2
4	928	2685	2.9
5	741	2440	3.3
6	849	3740	4.4
7	956	3700	3.9
8	1248	4518	3.6
9	621	1832	2.9
10	1192	1818	1.5
11	403	1325	3.3

*The overloading of the gels is more severe in gels 1 to 8 than in gels 9 to 11.

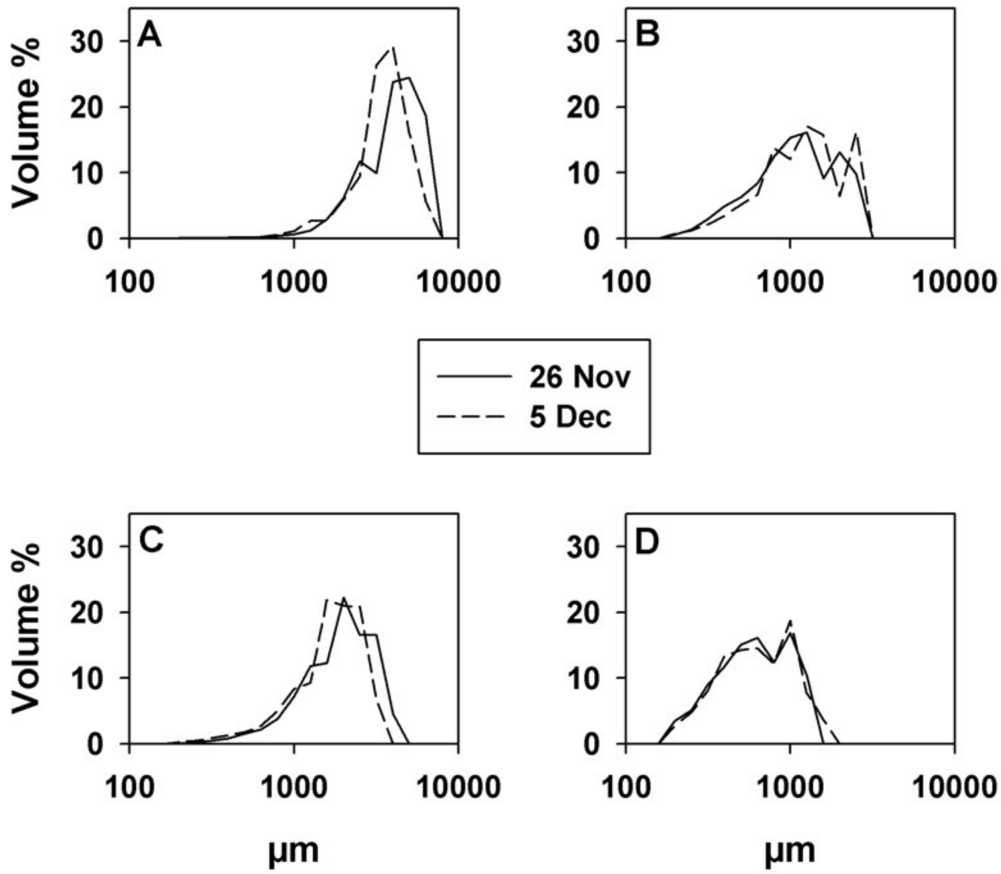

Fig. 9. Size spectra for four gels on 26 November 2002 and 5 December 2002. (A) Gel 1. (B) Gel 5. (C) Gel 7. (D) Gel 11. *See* Fig. 8 for gel photographs.

In addition to the overloading issue, another concern is the stability of flocs after they have become embedded in the gel. To investigate this further, pictures of the particles in each gel cup were taken every 1 to 2 d for 10 d after recovery. Particles in the pictures were counted and sized using the image analysis software IPP ver 3.0 from Media Cybernetics. Fig. 9A-9D compares the size spectra for four gels (1, 5, 7, and 11) for 26 November and 5 December 2002. Fig. 10 shows the mean particle diameter and the standard deviation (sorting) for each of the 11 gels on 26 November and 5 December 2002. Results from a t test ($t = 3.169$, df = 10) show that the variation in mean diameter, and sorting for the two dates is not significant ($P < 0.01$) indicating that flocs do not change their size after they are embedded in the gel. The lack of difference between the results from cup nr 1 and cup nr 11, which were opened 10 d apart, suggest that there was no evolution in floc size during the deployment once flocs were embedded in the gel. It appears that the flocs preserve their sizes in the gel for at least 3 weeks.

Roll—Roll is the deviation of the frame from the vertical along the axis of rotation. As mentioned above, the roll of the frame must not be above 2.5°, otherwise particles will start to slide along the side of the settling column. For the deployments in the Adriatic, data from the frame-mounted compass (not shown) indicated that roll was up to 1.2° from the vertical. Therefore, the possibility of particles sliding along the

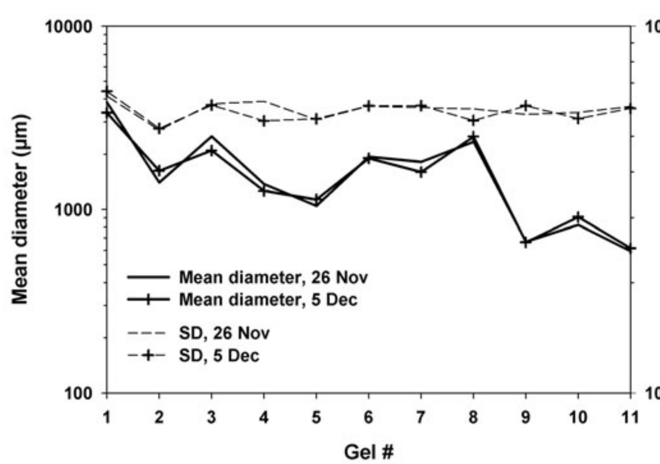

Fig. 10. Variation in mean floc diameter and sorting standard deviation (SD) for each of the 11 gels on 26 November 2002 and 5 December 2002.

inside of the settling column is minimized, and the INSSECT appears to be almost level when standing on the seabed.

Deployment and recovery—One of the most critical procedures is the recovery of the INSSECT. Delicate ship handling during recovery is necessary to prevent the loss of particles accumulated in the nongel cups. While the tight tolerances between the cups and the housing will reduce loss, examination of the housing will clearly reveal if any sediment has been spilled out of the cups.

Discussion

Prior to the initial deployment of the INSSECT, one of the major concerns was if it would rotate in the current. This has been shown to be the case for current velocities larger than 0.08 to 0.10 m s^{-1}. This is deemed satisfactory for deployments on the continental shelf, where current velocities of this magnitude are common (Ogston and Sternberg 1999; Traykovski et al. 2000). One possible option for decreasing the current speed to initiate rotation would be to increase the size of the fins.

Another concern was how well the sediment trap would function. The newly designed enclosed trap housing has proven to be sufficient to keep suspended sediment from entering the cups. This has been confirmed from recent deployments on the Scotian Shelf, where only the cups that had been rotated in position under the column contained sediment. All other cups and the housing itself were devoid of sediment.

As flocs have been found to preserve their size in the PAA gel for up to 3 weeks, the INSSECT data can be used to gather information about time variation in structure and composition of the flocs. Methods for further analysis of floc structure, based on the gels, are currently under consideration and will be dealt with in future publications.

In the future, INSSECT will be deployed in a variety of environments, to provide information on floc properties. Due to the size of the instrument, it can be deployed from small vessels, operate in shallow waters, and be recovered, turned around, and redeployed quickly. Combined with the fact that INSSECT is the first instrument package that can measure size, settling velocity, turbulence, structure, composition, and flux of flocculated sediment, it has a large potential to be used for semi-synoptic surveys of floc properties, as well as for longer time-series studies in the coastal zone.

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