Acoustic Vorticity Meter for Benthic Boundary Layer Flow Measurements

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Abstract - **An acoustic travel-time flow-meter that had been configured to measure vorticity on scales of 15 and 45 centimeters has now been configured to measure benthic boundary layer vorticity over a scale of 1.5 meters[1]. Closed square paths in each sensor define three orthogonal axes of vorticity. Originally constructed to measure shear in the presence of waves, the 15 cm and 45 cm sensors have an expected accuracy for shear of $10^{-2}s^{-1}$ and $3 \cdot 10^{-3}s^{-1}$ respectively. The 1.5 m sensor appears to have a noise floor of $2 \cdot 10^{-5}s^{-1}$. Strong boundary layer shear generates turbulence and turbulent vorticity. Measurements of vorticity are being made with these sensors at several scales in strong tidal flows from 1.2 m to 3.2 m above the bottom. Data are being stored internally and in a pop-up data logger for recovery at the end of the deployment and part way through the deployment. Absolute shear can be determined with the 45 cm sensor through careful zero flow calibration before the deployment. The 1.5 m sensor is part of the deployment tripod and too large to be calibrated in controlled conditions. Consequently, fluctuations in vorticity can be determined with the 1.5 m sensor.**

I. INTRODUCTION

Boundary layer flows are turbulent and turbulence exhibits vorticity [1]. Vorticity in flow can be measured by the fluid circulation around a closed path immersed in that flow. An acoustic vorticity meter was constructed by one of the authors (Thwaites) in 1992 based on acoustic flow measurements [2]. This 15 cm path length prototype was tested in tow tank and wave tank. The prototype was scaled up to a 45 cm path length sensor which was deployed at the sea surface under waves and suspended from the sea surface in internal waves in 1993. In each of these deployments, the relative velocity between the flow and the sensor was limited to wave orbital velocities. In 1994, two new vorticity meters were designed for measurement in the turbulent bottom boundary layer of a strong tidal flow. This application required the sensor to measure vorticity in high velocity mean flow.

Vorticity measured from a fixed platform should not be contaminated by an unsheared mean velocity or irrotational motions such as surface waves. It contains mean shear, internal waves, and turbulent vortices. The cancellation of irrotational flow along one portion of the acoustic path of the sensor by flow along another path of the sensor must be excellent to achieve this result. This requires the individual measurements of flow to be linear. The measurement paths must also surround a surface completely, i.e., there cannot be significant unmeasured segments of the circulation. Finally, noise in the form of electronic measurement variance, vibration of the structure, and induced vorticity in the measurement volume by the support platform, sets the resolution limit for detection of vorticity in the flow.

Three axes of vorticity can be measured with an acoustic array defining three orthogonal planes. Each plane is defined by the acoustic paths along its edge. Although a triangle of paths is a minimum configuration of acoustic axes to define a plane, we chose a square to increase the symmetry. Symmetry via parallel paths aids cancellation of mean flow or irrotational flow when the velocity determinations along the paths are slightly non-linear. Wakes tend to cancel with parallel paths as well. Intersection of the vorticity measuring planes in a compact region is possible with minimum structure by using square arrays, six supports for transducers being sufficient. The supports and the platform holding them may create vorticity so minimizing their number is desirable. (Only four supports would be required for a triangular array if the vorticity were measured on the faces of a tetrahedron but this geometry does not intersect in a compact region.) Two platforms have been built for supporting these geometries: a central strut version for a 45 cm path length array, and an outer cage version

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for a 1.5 m path length array.

II. VORT 2 ARRAY

The 45 cm path length vorticity meter has been constructed with a central tube supporting three inclined struts radiating from hubs at each end at 35° angles to the central tube and 120° in azimuth. A cluster of four acoustic transducers in a pod at the end of each strut defines the corners of two squares. Two vorticity sensors are stacked above one another with sensing volumes at 1.2 m and 3.2 m on the VORT 2 array. These sensors are supported within a tripod that sits on the bottom. Fig. 1 shows VORT 2 preparatory to launch. The 5 cm diameter tubes of the tripod are 0.8 m away from the lower sensor and 0.6 m away from the upper sensor. These provide the most significant wake disturbance in the sensing volume for horizontal flow. Asymmetric drag on the tripod could produce torque which implies vorticity would be generated in the flow. This is difficult to measure. Consequently, we have tried to keep the drag elements symmetric.

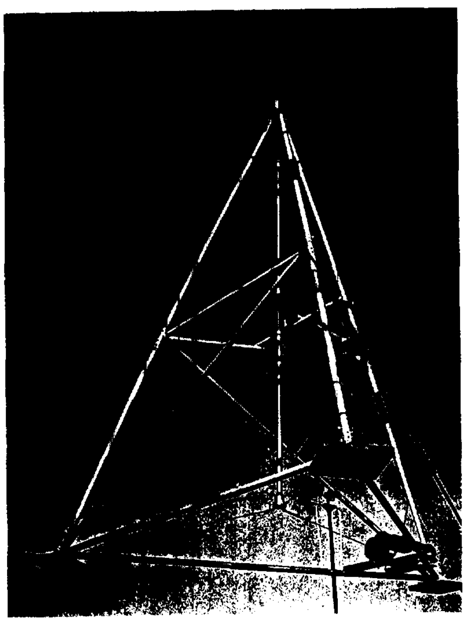

Fig. 1. VORT 2 tripod containing two three-axis vorticity sensors with 45 cm acoustic paths. The total height of the tripod is 4.6 m. The lower sensor is centered at 1.2 and the upper sensor at 3.2 meters above bottom.

Vibration, either cross flow by Strouhal oscillation or along flow by variable drag due to intermittent Strouhal oscillation, introduces noise in the velocity measurement. The diameter of the struts supporting the transducer is small to minimize wake and, as a consequence, excitation is possible in the flows expected. Stiffening of the struts by the choice of materials is not a solution although stiffening moves the onset of oscillation to a higher velocity. Damping is the solution and this was achieved by jacketing half the strut, near the hub, in a heavy pipe threaded into the hub, and filling the space between strut and pipe with urethane. The damping of ringing of the sensor structure in air is striking but diver observations in a 2 knot tidal flow (about 100 cm/sec over the struts) indicated there was no excitation of mechanical vibration. One diagonal brace of the tripod was excited to oscillate in a streamwise direction, but otherwise the tripod and sensor were quiet.

The geometry of the vorticity sensor gives vector velocities as well as vorticity. VORT 2 gives horizontal components of flow at four levels: 1.0 m, 1.4 m, 3.0 m and 3.4 m. This provides a measure of mean shear in horizontal velocity to compare to the vector vorticity projected onto the horizontal plane. Thermistors are embedded near the ends of the struts to permit gradients in temperature to be determined (and thus density in flows with known temperature - salinity relationships) over the same scale as the shear. But the new element in VORT 2 is the ability to measure vector vorticity at the 45 cm scale at two heights.

VORT 2 can sample as fast as 7 Hz. In a test deployment, 20 hours of 4 Hz velocity samples were recorded at 10 m depth in a 2 knot tidal flow. The spectrum of velocity shows surface waves, a -5/3 inertial subrange, and a noise floor at $2 \cdot 10^{-4} cm^2 s^{-2} Hz^{-1}$. This permits resolution to 0.7 Hz. In this test deployment, the VORT 2 tripod was overturned before the maximum tidal current was reached. Since then, additional weight has been added to the feet and redeployment in Vineyard Sound, Massachusetts (late June) and the Straits of Juan de Fuca, Washington (July, 1994) has been scheduled. Samples at 7Hz will be taken in June, and bursts of 7Hz samples at two hour intervals are expected in subsequent deployments. For these future measurements pressure will be sampled to determine surface wave conditions.

III. VORT 3 ARRAY

A second vorticity sensor has been constructed with a 1.5 m path length (Fig. 2). The geometry is the same as VORT 2 with six transducer pods defining 12 acoustic axes and 3 orthogonal planes upon which vorticity is measured. VORT 3 has no central strut, the transducers being supported by an outer cage. Only a single sensor fits in this cage, or exoskeleton. The noise floor for velocity is one-third that of VORT 2, $7 \cdot 10^{-5} cm^2 s^{-2} Hz^{-1}$, and the signal to noise ration for shear is expected to be nine times greater than VORT 2. The loss of spatial and wavenumber resolution is acceptable for increased sensitivity at the low wavenumber end of the vorticity spectrum.

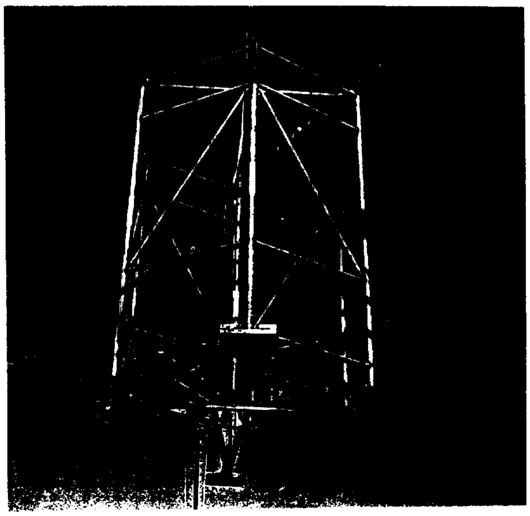

Fig. 2. VORT 3 tripod. The welded stainless steel hexagonal cage supports six spherical transducer pods on short stalks. These pods define the corners of the 1.5 m path length squares about which the acoustic travel time is measured. The plane of the lower transducer pods is 1.1 and the plane of the upper pods is 2.4 meters above bottom.

VORT 3 neither vibrated nor capsized in 2 knots of tidal current. Fig. 3 shows a section of the tidal velocity record from oppositely directed acoustic axes at 1.1 meters above the bottom and at 2.4 meters above bottom. The record is uniform in one direction and unsteady in the other direction. Fig. 4 is a short segment of 4 Hz measurements of the four acoustic paths making up one of the vorticity axes from day 1.29. At this time, four second surface waves were present and illustrate the character of the vorticity measurement. Fig. 5 is a frequency spectrum of the data illustrated in Fig. 4 showing the wave peak at 0.23 Hz. Figure 6, the vorticity spectrum for the same period shows no wave peak. The measurement of vorticity strongly cancels irrotational motion.

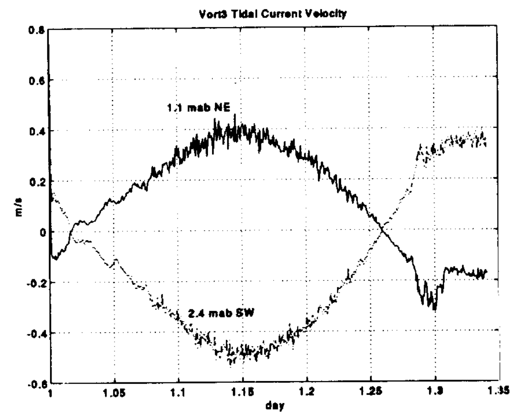

Fig. 3. VORT 3 velocity time series in Vineyard Sound. The two traces are 50 second averages of the 4 Hz measurements of velocity from two of the 12 axes of the vorticity sensor. The lower axis is anti-parallel to the upper axis and thus of opposite phase but lower amplitude. This pair of axes are horizontal and approximately aligned with the tidal channel.

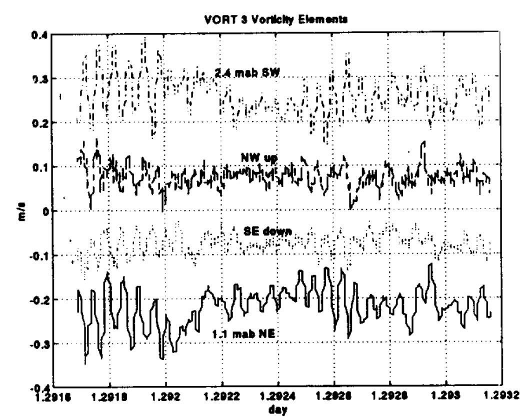

Fig. 4. 512 measurements of velocity components comprising a single vorticity axis of VORT 3. Summing around the path gives the circulation about the 1.5 m square.

IV DATA LOGGING

Each vorticity meter records velocity components, temperature, tilt, compass, and pressure internally on 340 MByte hard disks. Sixteen blocks of

512 records each are stored every other hour for one day in three in datafiles on disk for spectral processing. This gives a mission length of 140 days.

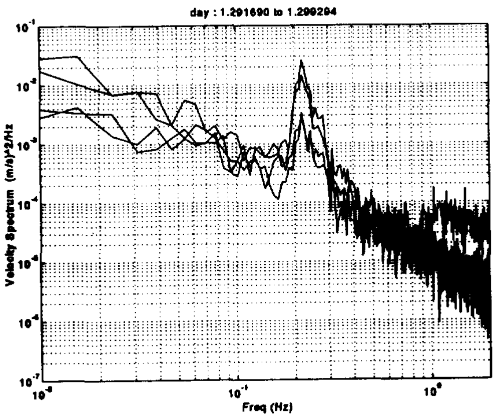

Fig. 5. Frequency spectra of the velocities of Fig. 4. The 0.23 Hz wave peak represents irrotational surface waves present in the 10 meter depth of the deployment. The 5/3 inertial subrange extends over almost two decades of frequency. The wave peak is 100 times as energetic as the turbulence at the same frequency.

Sampling is scheduled to avoid aliasing of tidal signals yet to extend the high frequency cutoff into the instrumental noise region. Presently this is assumed to be between 4 Hz and 7 Hz, the final decision to be made based on a week of 7 Hz measurements in Vineyard Sound, Massachusetts. A single burst of 512 records will be made every two minutes. Sixteen bursts will be made every two hours. This will adequately sample the maximum tidal flow. A full day of such measurements will be taken every third day. This will adequately sample the spring-neap cycle. Sixteen spectra can be averaged with modest assumptions about stationarity to give thirty-two degrees of freedom for the spectra of each burst.

Since 4.6 months is a long time to go before assurance that good measurements are being obtained, a pop-up logger will record duplicate measurements and be retrieved part way through the deployment. The pop-up logger is contained in a glass buoyancy sphere with its own power supply. The data generated in the vorticity meter electronics are transmitted in 74 byte records to the main data logger by 9600 baud UART. The main logger retransmits this signal to an inductive coil with 200 kHz CW modulation. A second coil inside the glass sphere close to the transmitting coil receives the CW signal for recording. The pop-up logger is held in a bracket by an acoustic command release. When released, the glass sphere floats to the surface, turns on an Argos beacon, and will be picked up by a small boat for interrogation.

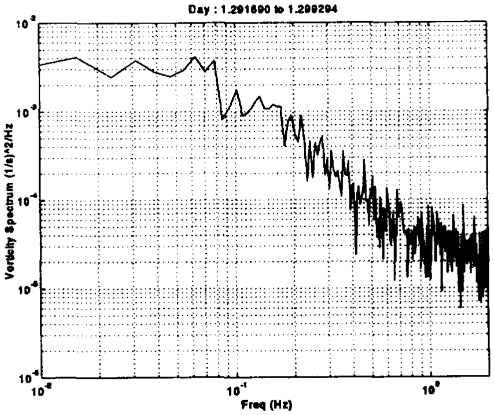

Fig. 6. The vorticity spectrum from the 512 points of Fig. 4 and Fig. 5. The strong wave signal is absent. The noise floor appears to be $7 \cdot 10^{-5} s^{-1}$

V. CONCLUSION

An acoustic vorticity meter has been built for benthic boundary layer studies. VORT 2 is a 45 cm path length vector vorticity meter with sensing volumes at 1.2 and 3.2 meters above bottom. VORT 3 is a 1.5 m path length version of this instrument, spanning a volume from 1.1 to 2.4 meters above bottom. Velocity, vorticity, temperature, and pressure measurements can be made as rapidly as 7 Hz to observe the inertial subrange of the turbulence spectrum of the boundary layer in up to 3 knots of current.

ACKNOWLEDGMENTS

Donald Peters and Allan Gordon designed and built the tripods and sensors, Gary Stanbrough wired the electronics and molded the transducers, Janet Fredericks and Naomi Fraenkel processed the data displayed here, and Judith White provided logistics. This is WHOI Contribution number 8748.

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Application of a Fluorescent Grain Detector/Counter

for Sand Transport Evaluation in the Littoral Zone

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Abstract **- A new instrumentation, which traces the displacement of fluorescent sand, has been developed at the University of Bordeaux. With this new technique, transport directions and transport rates can easily be determined over the sedimentary bodies within the surf zone.**

Résumé **- Un nouvel appareillage, développé à l'Université de Bordeaux, permet de détecter la dispersion d'un sable fluorescent injecté artificiellement dans la zone intertidale d'une plage. Les directions et taux de transport peuvent ainsi facilement être déterminés pour les différents corps sédimentaires des plages.**

INTRODUCTION

The use of tracer studies for the quantification of sediment transport is based on the detection of the movement of labeled particles. This concept has led to a number of attempts to create sediment tracing techniques which are suitable to measure sediment transport in the surf and nearshore zone [1, 2, 3, 4].

The successful use of fluorescent tracer sand to determine sediment transport rates relies on two basic assumptions:

1) that dyed sand behaves in the same manner as the natural sand and

2) that the dyed sand motion can be adequately monitored.

The first assumption is fulfilled when the tagging procedure, which consists of coating sediment particles with a fine film of tracer material, does not alter the mechanical and hydrodynamical properties of the sediment. It is tested by comparing the size distribution and the fall velocity of the tracer sand with the characteristics of the natural sand [5, 6]. With respect to the above conditions, this technique is suitable for coarse particles, such as sand, if the sediment to dye is collected at the release site [7].

Another key to accurate tracer measurement of sediment movement is to release the tracer in such a way that disturbance of the environment by the tracer is minimized.

Injection of the tracer in the environment should allow a rapid mixing and incorporation into the local sedimentary system [3, 7].

The second assumption can be checked by an evaluation of the sediment recovery during the tracer experiment. The newly developed Bordeaux technique yields extremely high recovery rates for a number of reasons [8]:

1) unlike all previous fluorescent techniques, the present setup can be employed during several consecutive low tides, during day and night-time.

2) the registration procedure (in situ fluorescence measurement) does not interfere with the natural development of the sedimentary system. There is no signal disturbance due to posterior sample uptake, transport and/or treatment.

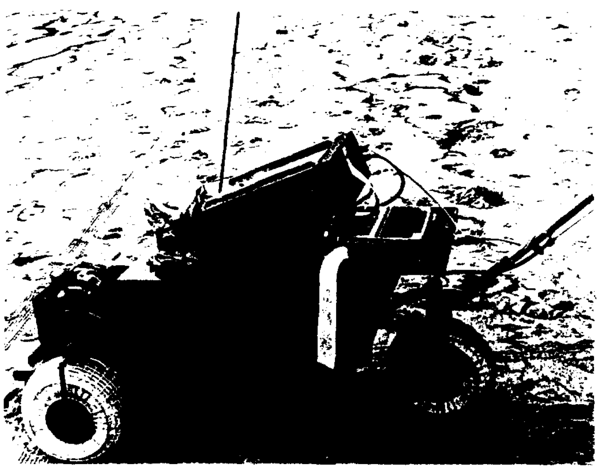

Fig. 1: The fluorescent grain detector/counter in operation.

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3) the automatic, computerized, data acquisition is extremely rapid, and allows detailed measurements over a far larger area than is possible with more conventional means.

In the remaining part of this paper, we will give a detailed description of the functioning of the Bordeaux technique, and will illustrate the method by some results from a tracer experiment performed in February 1994 in Middelkerke, Belgium.

THE BORDEAUX SETUP: FLUORESCENT GRAIN DETECTOR/COUNTER

The Bordeaux detector/counter automatically measures and records the spatial distribution of fluorescent grains within the upper sand layer of the studied beach. All measuring devices and data treatment and management tools are installed on a mobile trolley (Figure 1). During operation, the trolley is moved along a grid of lines, and automatically registers the precise distance from the starting point.

The basic setup is depicted in figure 2. Measurements take place in a vertically mobile dark box (size 20 * 20 * 30 cm), which is lowered to the sediment surface during data acquisition. The sediment is illuminated by two 360 nm Ultraviolet tubes.

Sand grain fluorescence is recorded by a CCD camera, provided with a filter which selects the light spectrum which coincides with the colour of the chosen dye. In order to avoid natural background fluorescence, a suitable detection level can be selected. This detection level decides at which luminosity pixels are submitted to the image analysis routine.

In the central unit, a binary image is generated, which is subsequently analysed line after line, resulting in a count of all illuminated pixels. All groups of bordering illuminated pixels are considered as belonging to one sediment particle only.

The data are simultaneously transmitted to a monitor (allowing rapid adaptions of the sample survey) and to a PSION-organizer II portable micro-computer.

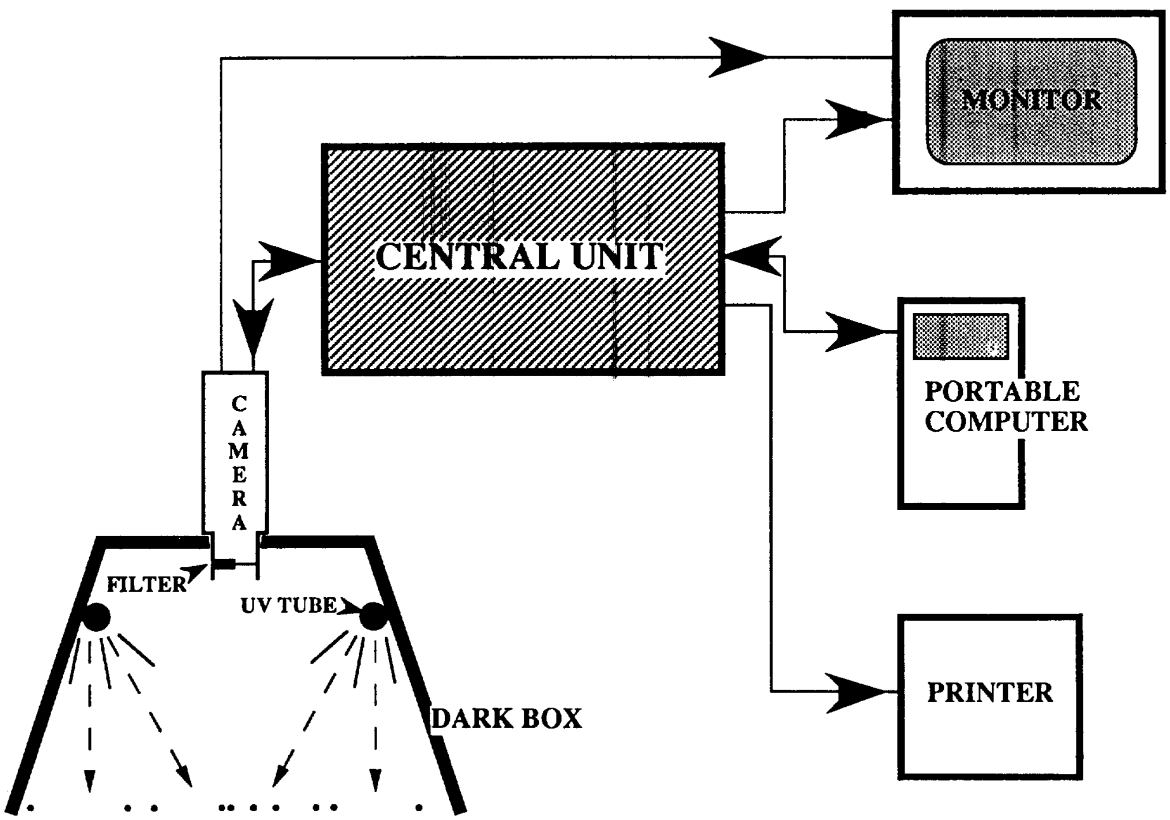

Fig. 2: Flow chart of the fluorescent grain detector/counter setup.

In the laboratory, field measurements are translated into mass concentration of the tracer by means of a calibration curve. This curve was established by visually counting the number of dyed grains per gram in reference samples with a known concentration. The data are used to calculate contour lines of equal fluorescent grain density, which form the basis for the interpretation of tracer sand movement.

Subsequently, the motion of the tracer centroid is examined, and interpreted as the main transport direction. The centroid velocity provides an estimate of the transport velocity which, when it is multiplied by the thickness of the moving sand, yields the transport rate.

CASE STUDY:
FEBRUARY 1994 -- MIDDELKERKE, BELGIUM

Experiments were carried out in the intertidal area of a sandy, megatidal, ridge and runnel type beach in Middelkerke.

The hydrodynamical conditions were those related to calm weather and spring tide.

The purpose of the research was to understand behaviour of a rectilinear, shoreline-parallel ridge, situated in the lowest part of the shoreface, just above the mean low tide level.

50 Kg of red dyed sand were deposited in a 100 x 100 x 5 cm pit, under 0.5 cm of natural sand, on the seaward slope of the ridge. The dispersion of the tracer was monitored during each of five consecutive low tides, following a grid with a 1 x 1 m mesh size. The surface detection made by the detector/counter was completed by taking short small diameter transparent cores all over the tracer cloud, in order to determine the thickness of the transported layer.

During the first two tidal cycles, the transport direction was exactly perpendicular to the ridge and runnel system (Figure 3). The tracer migrated on the seaward slope of the ridge in an onshore direction. The thickness of the sand layer in movement was about 3 cm and the displacement of the tracer centroid during these two cycles was about 4 m. On the basis of these data, we concluded that during calm weather conditions, the daily transport rate is about 1400 Kg per meter beach width.

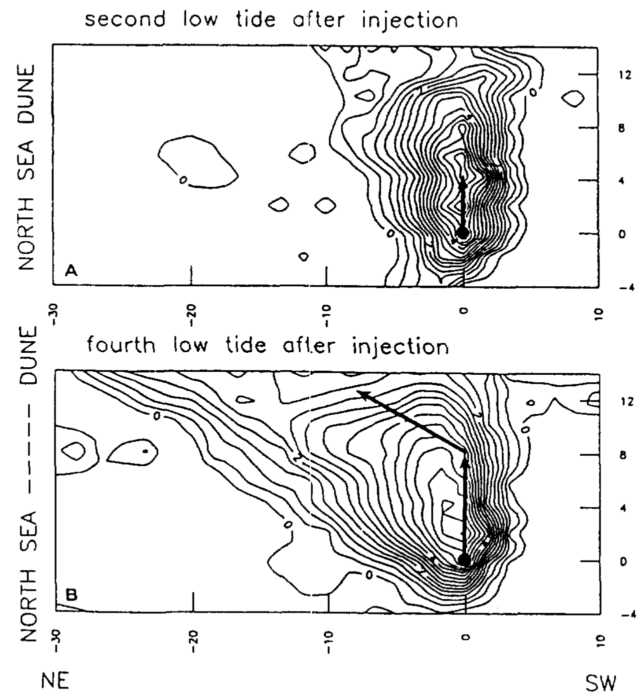

Fig. 3: Dispersion of tracer sand. The fat dot indicate the injection pit; contour lines are lines of equal tracer concentration expressed as number of dyed grains per cubic centimeter, on a logarithmic scale; distances are in meter. The arrows indicate the prevailing transport direction of the tracer centroid.
Figure 3A: Tracer distribution after two tidal cycles. Figure 3B: Tracer distribution after four tidal cycles.

During the fourth tide, when the tracer reached the runnel area, the dyed sand grains are taken up by a current flowing through the runnel. The sediment transport direction is then deflected towards the ENE and becomes parallel to the shoreline (Figure 3B). Unfortunately, the concentration of the tracer became to low to obtain a quantitative evaluation of the shoreline-parallel transport rate.

The results given by this technique fit well with other field measurements:

1) the movement of sand in onshore direction is consistent with the rapid landward migration of the ridge system, which was observed by a topographical survey (by means of a laser theodolite);

2) the sand volume involved in this migration corresponds well with the transport rate given by the tracer study;

3) the direction of transport within the runnel system is confirmed by the sedimentary structures which are present in the runnel.

CONCLUSION

We developed a new instrumentation in order to improve the fluorescent tracer technique in the littoral zone. On the basis of the assumption that hydraulic properties of native and tracer sands do not differ significantly, the cumulative effect of bedload and suspension transport can be recorded. With this improved method, the net result of active coastal processes in intertidal environments can much better be evaluated than before.

Our prototype detector/counter has been tested successfully along the Aquitaine Coast (SW of France), the littoral of Dunkerque (N of France) and the Belgian coast.

Because of the easiness of manipulation and its small weight, this new detector/counter allows to work very quickly in the intertidal zone. The advent of simultaneous detection and quantification permits to cover large areas without sampling. The very rapid data acquisition makes this method extremely suitable for routine operations.

ACKNOWLEDGEMENTS

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