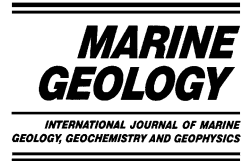




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Technical note

A simple method for calibrating optical backscatter sensors in high concentrations of non-cohesive sediments

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Abstract

A new method is introduced for calibrating optical backscatter sensors for suspended quartz sand concentrations of up to 200 kg m^{-3} . Due to the high settling velocity of quartz sand in water, considerable difficulties have arisen in the past to maintain a spatially and temporally homogeneous suspension suitable for calibration. Traditional methods are clumsy and prone to errors. Here, the sediment is calibrated in glycerol, a clear fluid with a higher viscosity than water. The settling velocity is reduced by three orders of magnitude. An empirical relationship is obtained which is used to correct for any optical differences in response of the sensors in the two fluids. Any extra errors introduced by calibrating with a different fluid from that found in the field are outweighed by the simplicity and reliability of this method.

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1. Introduction

Several methods have been used to measure suspended sediment concentration (SSC) in coastal environments in the last few decades. The use of optical instrumentation has emerged as a technique able to resolve rapid temporal fluctuations in SSC, which other methods such as in situ sampling cannot do. To provide a relationship between the output of the sensor and the concen-

tration of sediment being measured, the optical instruments must be calibrated using sediment from the field site, up to the concentrations expected in the field.

It is well documented that concentrations of suspended sediment in the surf and swash-zones of natural beaches are likely to reach very high values. Brenninkmeyer (1974, 1976) used a type of transmissometer to measure SSC in the inner surf-zone, and found near-bed concentrations as high as 380 kg m^{-3} . Recent interest in the swash-zone has highlighted the need for instruments capable of measuring concentrations up to 200 kg m^{-3} , typically found in this area (Beach and Sternberg, 1991; Butt and Russell, 1999; Osborne and Rooker, 1999; Puleo et al., 2000). The instruments used in these studies were optical backscat-

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ter sensors; for example the OBS3 (Downing et al., 1981) and the miniaturised fibre-optic backscatter sensor, or FOBS (Beach et al., 1992).

Calibration of optical backscatter sensors in quartz sand is notoriously difficult. The sediment settles out too rapidly for high concentrations to reliably be kept in suspension. Moreover, the sediment tends to be suspended in ‘bursts’, making it difficult to obtain a spatially and temporally homogeneous suspension.

The instruction manual for the Downing and Associates OBS1 and OBS3 optical backscatter sensors recommends that the sensors should be calibrated in a 25 cm diameter plastic bucket containing distilled water. The sediment is kept in suspension using a paint stirrer attached to an electric drill. Experience has shown that this method is only satisfactory with concentrations of 30 kg m⁻³ or less.

An improvement on the above method is the re-circulation tank (Downing and Beach, 1989; Green and Boon, 1993). Here a temporally and spatially homogeneous concentration of up to 100 kg m⁻³ can be obtained by continuously passing the suspension through the tank. The sensors under calibration are placed in the tank, and sediment is incrementally introduced. Once a stable reading is obtained from the sensors after each introduction of sediment, a sample is taken with a peristaltic pump to determine the ‘true’ concentration. Although this apparatus overcomes the problems of calibration to a certain extent, it is bulky and expensive, and difficulties still arise at concentrations above 100 kg m⁻³.

A simple, reliable method of calibrating optical backscatter sensors in high concentrations of quartz sand, such as those found in the swash-zone, has so far not been documented. The present paper suggests a simple method of obtaining stable homogeneous suspensions of up to 200 kg m⁻³, allowing quick and repeatable calibrations of optical backscatter sensors, without the use of large and expensive equipment.

2. Settling velocities

It is well known that, in water, flocculated co-

hesive sediment is easier to keep in suspension than quartz sand. This is due to the much slower settling velocity of the relatively low density flocs. Less stirring of the sediment is required to maintain the suspension and it can be kept in homogeneous suspension for longer periods of time without the need for re-circulation. Calibration of optical backscatter sensors in estuarine muds is a simple and straightforward procedure (e.g. Christie, 1997).

For the purposes of the present study it can be assumed that the settling velocity (w_s) of sediment in a fluid can be described by an equation such as Stokes’ law, i.e.:

$$w_s = \frac{(s-1)gd^2}{18\nu} \quad (1)$$

where d is the particle diameter, s is the specific gravity of the sediment (the ratio between the sediment and fluid densities), g is the acceleration due to gravity, and ν is the kinematic viscosity of the fluid. It can be seen that the settling velocity decreases with increasing fluid viscosity.

Based on the above, it seems reasonable that using a fluid of higher viscosity than water might allow sandy sediment to stay in suspension for longer periods of time. Less stirring would be required, and the sensor could be calibrated in much higher concentrations.

The relatively high kinematic viscosity of glycerol has been used in flume experiments to visualise vortical flow patterns under waves by several workers (e.g. Kaneko and Honji, 1979; Matsunaga and Honji, 1980, 1983). Glycerol is transparent and is soluble in water. The kinematic viscosity of glycerol is approximately three orders of magnitude greater than that of water. For a temperature of 20°C, $\nu = 1.2 \times 10^{-3} \text{ m}^2 \text{ s}^{-1}$ for glycerol and $9.8 \times 10^{-7} \text{ m}^2 \text{ s}^{-1}$ for water (Kaye and Laby, 1995). There are inevitable optical differences between glycerol and water, but these can be determined empirically by comparing the response of a sensor in water to that in glycerol. The advantages of calibrating the instrument to the concentrations expected in the field should outweigh any errors introduced through optical correction.

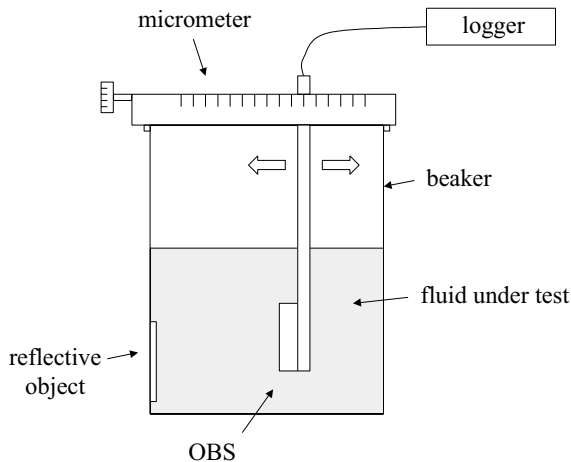


Fig. 1. Equipment for reflector test.

3. Optical differences between glycerol and water

To calibrate an optical backscatter sensor in glycerol, which will subsequently be deployed in seawater, requires some knowledge of the differences in optical behaviour of the two fluids. An optical adjustment must be applied before a suitable calibration relationship can be obtained.

The two fluids will behave in different ways according to factors such as refraction, and attenuation due to absorption and scattering within the fluid itself. The effect of these differences may also depend upon the physical layout of the sensor and the optical properties of the lens. Therefore, a relationship is required which encompasses all the relevant optical differences between water and glycerol in an environment as similar as possible to that during the calibration. For the purpose of introducing this method, an empirical approach was decided upon rather than constructing a theoretical model of the two fluids.

The response of an optical backscatter sensor in glycerol was compared with that in water by measuring the output of the sensor when a reflective object was placed at a series of incremental distances from the sensor in each of the two fluids. The difference between the resulting curves could then be used to infer the relevant optical differences between the two fluids. This difference could then be used to convert a calibration curve ob-

tained in glycerol to one which would have been obtained had the sensor been calibrated in water.

A single reflective object placed at different distances from the sensor is not the same as using different suspended sediment concentrations to infer the relevant optical differences between the two fluids during calibration, which would be ideal. However, if high enough concentrations could be obtained in water to perform this comparison then, paradoxically, this method would not be required in the first place.

The equipment used to obtain the conversion relationship between water and glycerol consisted of a single Downing and Associates OBS3 optical backscatter sensor, placed in a 1 l container with the sensor head facing horizontally (Fig. 1). A white reflective object was placed in the container opposite the sensor. A micrometer was used to carefully measure the distance between the sensor and the reflective object. The output of the sensor was recorded using a Seabird CTD logger.

The distance between the sensor and the target was increased in increments of 1 mm. The process was performed first in water and then repeated in glycerol. Approximately 70 readings were logged at each point, which were subsequently averaged. The mean standard error was 0.009 V for water and 0.016 V for glycerol. The resultant curves are shown in Fig. 2.

To obtain a relationship which may be used to convert a calibration curve obtained in glycerol to one which would have been obtained had the sensor been calibrated in water, the two regression equations from the curves in Fig. 2 are combined.

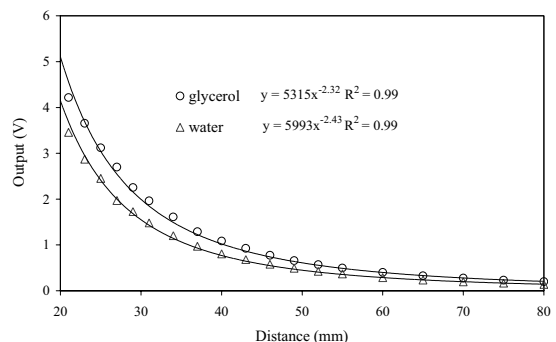


Fig. 2. Curves from reflector test for Downing and Associates OBS3.

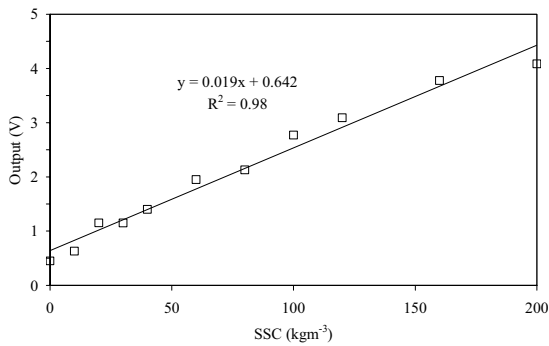


Fig. 3. Calibration curve obtained in glycerol, showing output voltage for sand concentrations suspended in glycerol.

The result gives the output voltage for the sensor in water, in terms of the output voltage in glycerol.

The regression equations are:

$$V_w = 5993d^{-2.43} \quad (2)$$

and

$$V_g = 5315d^{-2.32} \quad (3)$$

where V_w and V_g are the voltage outputs in water and glycerol, respectively, and d is the distance from the sensor to the reflector. By simple substitution an expression for V_w in terms of V_g may be found:

$$V_w = 5993 \left(\frac{V_g}{5315} \right)^{\frac{-2.43}{-2.32}} \quad (4)$$

i.e.:

$$V_w = 5993 \left(\frac{V_g}{5315} \right)^{1.05} \quad (5)$$

Eq. 5 may then be used to convert sensor outputs obtained from a calibration in glycerol (V_g) to outputs that would have been obtained had the sensor been calibrated in water (V_w).

4. Sample calibration

To test the validity of this method, a sample calibration was performed using the same D&A OBS3 sensor as above. Using glycerol instead of water, the calibration method may be simplified due to the greater temporal and spatial homogeneity obtainable at high concentrations.

The sensor was fixed facing horizontally in-

wards from the periphery of a beaker similar to the arrangement in Fig. 1. Incremental amounts of pre-weighed dried quartz sand were added to a known volume of glycerol. To keep the sediment in suspension, light stirring was applied by hand. The output of the sensor was recorded on the logging equipment with approximately 90 readings per increment. These were averaged to obtain the calibration curve shown in Fig. 3. This method provided stable and homogeneous concentrations up to 200 kg m⁻³. Eq. 5 was then applied to the curve, resulting in Fig. 4, which may finally be used to convert voltages recorded in the field to suspended sediment concentrations.

5. Discussion

Due to the high settling velocity of quartz sand in water, the possibilities of obtaining reliable suspensions for calibration in water are limited, especially at high concentrations. The purpose of this paper is to introduce an alternative method which itself is not foolproof, but whose practical advantages outweigh any further errors introduced. Traditional methods of calibration, even up to 100 kg m⁻³, are notoriously unreliable and methods used to keep the sand in suspension may themselves introduce errors that cancel out any advantages of using the same fluid.

Apart from the re-circulating tank of Downing and Beach (1989), we know of no other documented method of calibrating optical backscatter sensors to high concentrations. However, with the

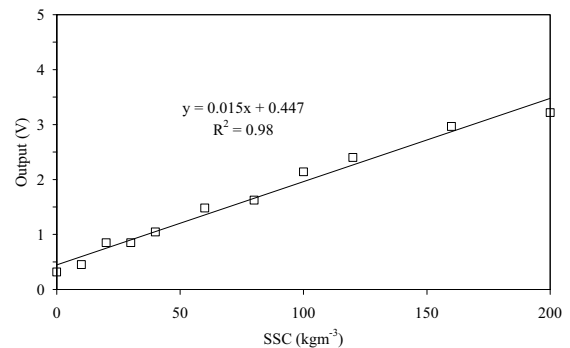


Fig. 4. Calibration curve after application of Eq. 5 to account for optical differences between water and glycerol.

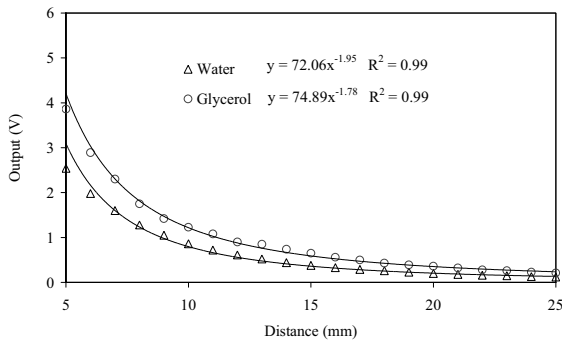


Fig. 5. Curves from reflector test for miniature optical backscatter sensor used by Butt and Russell, 1999.

recent increasing interest in swash-zone field studies, where suspended sediment concentrations are known to reach 200 kg m^{-3} , it is not known whether this type of equipment is capable of calibrating the sensors to the required concentrations.

The method suggested here solves the problem of keeping the sediment in suspension by reducing the settling velocity by about three orders of magnitude. The only uncertainty introduced is that due to the optical behaviour of the sensors in a fluid different from that found in the field. However, we are convinced that these optical differences are small enough and easily enough accounted for by a simple empirical relationship, that any errors will outweigh those introduced by poor methods of keeping the sediment suspended in water.

The results of the empirical test employed to infer the optical differences between the two fluids will depend on the type of sensor used. For example, the differences between the behaviour of the sensor in the two fluids due to refraction will not be consistent from one sensor to the other if each sensor has a different lens. Therefore it is recommended that a test be performed to obtain a relation such as Eq. 5, using the same type of sensor as that being deployed in the field.

Some additional sensors were tested as part of the present study. These were the much smaller miniature optical backscatter sensors, used in the swash-zone study of Butt and Russell (1999). Results (Fig. 5) show slightly different curves from those in Fig. 2. Note that the sensitivity of

these instruments resulted in shorter distances from the reflective object to the sensor.

6. Conclusions

With the recent interest in suspended sediment measurements in the swash-zone, where concentrations are known to reach over 200 kg m^{-3} , it was considered relevant to look for an alternative method of calibrating optical backscatter sensors to these high concentrations.

The sensors are calibrated in glycerol instead of water, which allows them to be easily calibrated up to and beyond 200 kg m^{-3} , without the use of complicated re-circulation equipment.

The disadvantage of this method is that the fluid used for calibration is not the same as that used in the field. Therefore an optical correction algorithm must be applied.

The optical correction was obtained by a simple test using the sensor and a reflective object. It is recommended that this test form part of any calibration procedure, as results may vary according to the type of sensor used.

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