Assessment of Approaches for Converting Acoustic Echo Intensity into Suspended Sediment Concentration

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Motivation

- Measurement of sediment transport is essential for:
  - coastal dynamic studies
  - maintenance of navigation channel
  - dredging monitoring
  - water quality assessments
  - set-up, calibration and validation of numerical model
  - etc.

Measuring sediment transport

- Techniques for sediment transport measurement
  - direct
  - indirect

- Direct measurement

  q in kg/m^{2}s

- Indirect measurement

  $q = u \times c$

  $= \text{m/s} \times \text{kg/m}^3$

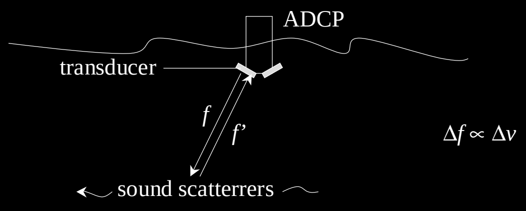
q = sediment transport rate, u = current velocity and
c = sediment concentration

Measuring sediment concentration

- Techniques for estimating sediment concentration:
  - direct sampling → low resolution, laborious
  - optical sampling → flow intrusive
  - acoustical profiling → complicated

ADCP

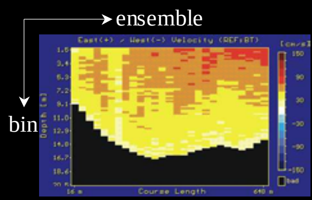
- Stands for Acoustic Doppler Current Profiler
- Employs Doppler effect:



Similar devices

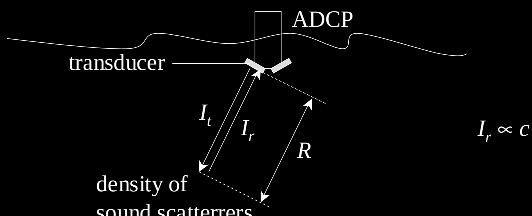
ADCP	Aquadopp	ADV	ADP
(RDI)	(Nortek AS)	(SonTek/YSI)	(SonTek)
4 transducers	3 transducers	3 transducer	3 transducers

ADCP data



ADCP backscatter

- ADCP backscatter (=reflected acoustic echo intensity) gives qualitative measure of sediment concentration in the water column



Backscatter (heuristic) theory

- Thorne et al. (1991), Holdaway et al. (1999)

$$c = K V_{rms}^{2} r_s^{2} e^{4(r_s \alpha_w + R\bar{\alpha})}$$

$$K = \frac{c(r_r)}{V_{rms}^{2} r_s^{2} e^{4 r_s \alpha_w}}$$

$$\bar{\alpha} = \frac{\zeta}{R} \int_{r_r}^{r_s} c(r_s)\, dr_s$$

c	= sediment concentration
K	= calibration constant
V_{rms}	= recorded voltage
r_s	= distance
r_r	= reference distance
α_w	= attenuation due to water
$\bar{\alpha}$	= average attenuation
R	= $r_s - r_r$
ζ	= f (sediment properties)

Empirical approaches

- Deines (1999), SonTek (2002)

  $EI - EI_r \propto 10\log(c / c_r)$

- Patino & Byrne (2001), Gartner (2002)

  $EI \propto 10\log(c)$

- Assumptions:
  - constant rate of attenuation
  - uniform sediment sizes

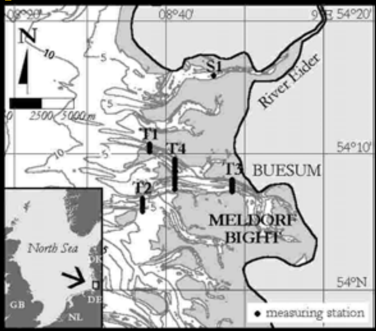
Devices

trap sampler (collection of water samples)

1200kHz BB ADCP (backscatter data)

optical beam transmissometer (optical transmission data)

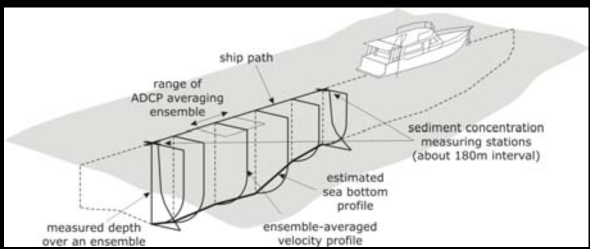
Measuring locations



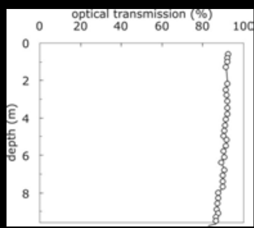
Physical characteristics

- Tide-dominated coast (semi-diurnal type, 3m range)
- Current velocity up to 1m/s
- Water depth up to 20m
- Bed sediment between 80 to 230µm
- Suspended sediment between 6 to 86µm
- Generally uniform concentration distribution

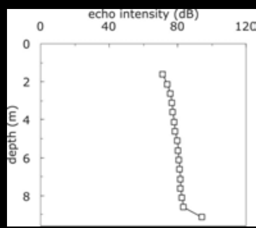
Measuring methods



Measurement data



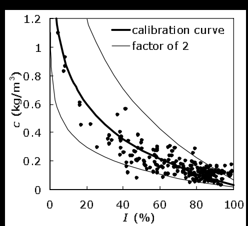
optical measurement



acoustical measurement

Optical calibration and validation

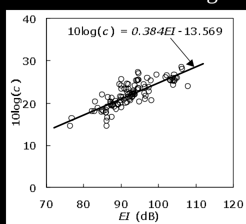
- Calibration (219 data)



- Validation (474 data)
  - data within a factor of 2 : 85%
  - average relative error : 30%
  - average absolute error : 0.06kg/m^3

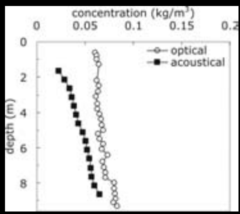
(Independent) backscatter calibration

- 105 data
  - average relative error : 32%
  - average absolute error : 0.06kg/m^3



Validation of backscatter calibration

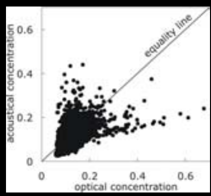
- 5007 data pairs



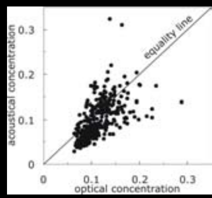
  - data within a factor of 2 : 93%
  - average relative error : 31%
  - average absolute error : 0.03kg/m^3

Bin and depth-averaged comparison

- Given in kg/m^3



bin comparison



depth-averaged comparison

Summaries

- Approaches for converting backscatter into sediment concentration have been discussed
- An empirical conversion approach was applied
- Field measurement data were used
- Evaluation of the performance of empirical conversion approach was presented

Conclusions

- Empirical conversion approach is applicable
- Acoustic measurement results show comparable performance with respect to those given by optical measurement
- The corresponding application is limited to physical characteristics of the study site

Further works

- Estimation of cyclic sediment balance
- Improvement of calibration curves
- Consideration of changing rate of attenuation
- Consideration of non-uniform sizes of sediment
- Application of such an approach in other domain