Internal Circulation in Tidal Channels and Straits

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LONG-TERM GOAL

The principal long-term goals of this project are to provide:

- A 3-D conceptual understanding of circulation and scalar transport in the numerous estuaries and straits worldwide with both strong tides and buoyancy forcing.
- Improved analysis methods based on continuous wavelet transforms for defining the non-stationary and non-linear processes that drive circulation in these environments.
- In concert with related projects, an improved understanding of vertical turbulent mixing and it consequences in stratified estuarine flows.
- Improved methods for determination of the suspended particulate matter (SPM) concentration and transport fields from acoustic and optical backscatter measurements.

OBJECTIVES

The past year's work focused on the final goal, finding improved methods for determination of the SPM concentration and transport fields from acoustic and optical backscatter measurements, given appropriate calibration data. As a part of this effort, we have used continuous wavelet transform methods to determine the importance of tidal and non-tidal mechanisms in horizontal SPM transport.

APPROACH

A variety of multiple-sensor inverse methods have previously been used for determination of SPM concentration. All methods to date have: a) assumed a scattering law to define the strength of ABS as a function of particle size, and b) used a W_s equation (Stokes/Gibbs laws) in the determination of size and concentration. Both of these are weak assumptions in typical coastal flows where a wide range of particle sizes from clay to sand and aggregates (with unknown density) are present. Our new, two-stage method determines scattering behavior as an output from the analysis, rather than using it as an input (Jay et al., 2000). Mass concentrations are determined based on gravimetric analyses, and the basis functions used in the inverse analysis are based on observed W_s spectra. Thus, there is no need to use Stokes/Gibbs law, except to provide equivalent spherical sizes for the W_s -classes used in the analysis. The acoustic frequencies used in the analysis should be chosen to match the range of SPM sizes in the system analyzed (the Fraser River and estuary). The data set is notable for providing data concerning a range of particle sizes from glacial flour to coarse sand. We have used 300 and 1200 kHz ADCPs, plus an optical backscatter (OBS) sensor. For flows with such a broad range of particles sizes, it is useful to have the OBS in addition to the acoustic frequencies.

Our multi-frequency inverses analysis, developed by Philip Orton and Douglas Wilson, consists of two stages. Stage 1 of this two-stage, multiple-sensor inverse analysis is to apply the single-sensor method developed in Fain (2000) separately to the backscatter profiles for each sensor. After the Stage 1 analysis is complete, Stage 2 defines scattering coefficients for each W_s and sensor. This is accomplished by requiring that the sensors agree (in a least-squares sense) on the total SPM concentration at selected common sampling locations. This multi-stage approach has been used with vessel data, so that salinity stratification effects on vertical mixing could be included in the basis functions used in the Stage 1 inverse analysis (the latter described in a companion report on our AASERT project). The two-stage approach is especially well adapted to situations where the presence of a broad range of particle sizes (possible including aggregates) causes the sensor responses to vary strongly over the observed size range.

WORK COMPLETED

The multi-frequency (two-stage) code has been developed and tested. It incorporates the single frequency (one-stage) code described in the report for the parent grant of this AASERT and in Fain (1999). It employs (like Stage 1) a non-negative least squares algorithm.

RESULTS

The two-stage method was tested using data collected in 1999 in the Fraser River estuary. Fraser River flow in 1999 was extreme (the strongest flood in 25 years); there was much sand in transport and little bacterial productivity or aggregation; zooplankton were almost absent. The two-stage inverse analysis was applied to data from a 4-day anchor station, to derive W_s-class specific ABS and OBS response coefficients. Four W_s-classes (C_1 to C_4) were employed with nominal $W_s = 0.01$, 3, 15 and 45 mms^{-1}, respectively. Data from two sensors (OBS plus single-beam 300 kHz ADCP backscatter). The response coefficients from the 4-day station were then applied to the results of a stage 1 analysis for an independent data set as a test of the method. Figure 1 demonstrates the theoretical response characteristics of sensors to the material present. Table 1 compares the empirically derived scattering coefficients to the corresponding values derived from scattering theory. The acoustic response to the finest settling velocity class is so weak that no coefficient can be determined. Otherwise, however, the derived values are within about a factor of two of those derived from theory.

The method requires further elaboration to: a) optimally include data from three or more sensors, and b) take into account the effects of horizontal SPM advection of vertical SPM profiles. A major advantage of the method is that it is not adversely affected by the presence of either aggregates or a broad range of particle sizes.

IMPACTS/APPLICATIONS

1. This technique shows promise for realization of an often sought goal – calculation of SPM transport (along with water transport) directly from ADCP velocity and backscatter data. Because multiple acoustic/optical sensors and calibration data (settling velocity spectra and gravimetric samples) are required to determine transport by settling velocity class, the two-stage analysis cannot be included

directly in ADCP firmware. However, a simplified, single-stage analysis using only one sensor could be built into ADCP firmware.

2. Another potential application would be to use this technique in the assessment of impacts of dredged material disposal. The dredging permit process requires that the bed material to be dredged be well characterized in terms of texture, organic content and other properties. These data would be sufficient, along with gravimetric samples, to calibrate field results. The basis functions used in Stage 1 would, however, have to take into account the distinctive boundary conditions of the dredged material disposal problem. Mass settling could not easily be accounted for.

TRANSITIONS

Two continuous wavelet transform tidal analysis programs with sample data sets illustrating their use have been placed on the PI's web page (see CWT software library sub-heading under http://www.ese.ogi.edu/~djay). Dr. R. Signell of the US Geological Survey has also set up a link to these programs on his Sea-Mat web site (http://crusty.er.usgs.gov/sea-mat). These programs and related codes have been used in the analysis of the SPM data derived from inverse analyses.

RELATED PROJECTS

Work for the Tidal Channels project has been coordinated with the National Science Foundation Columbia River Land-Margin Ecosystem Research (LMER) Program and with the Oceanographic and Environmental Characterization of Coastal Regions (OECCR) funded by ONR. SPM transport ideas developed here have led to the hypothesis that estuaries amplify climate signals through their sediment budget. This idea is being pursued through a funded NSF Small Grant for Exploratory Research.

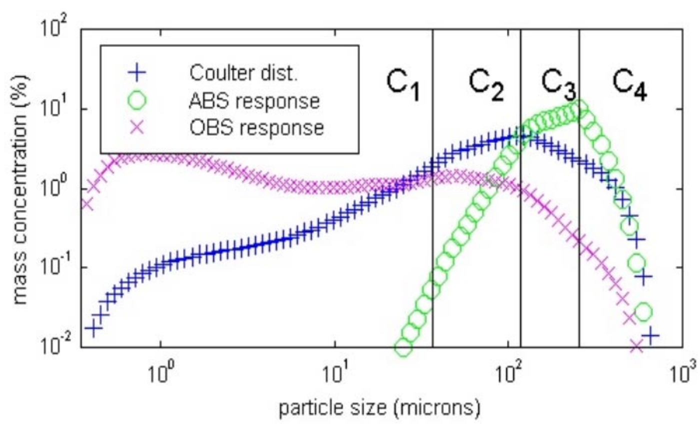

Fig. 3: Coulter counter size distribution (by size and W_s class) for a near-bed sample, with the optical (OBS) and acoustic (ABS) responses derived from scattering theory. The OBS response is considerably broader than the ABS response.

Table 1: Comparison of Response Coefficients from the Inverse Analysis and Theory[i]

W_s-Class	Inverse Analysis		Scattering Theory[ii]	
	OBS	ABS	OBS	ABS
C_1	0.26	--	0.27	2530
C_2	6.9	4.6	6.9	4.6
C_3	38	1.2	28.6	0.91
C_4	420[iii]	0.87	103	0.62

[i] OBS scattering is assumed geometric, while ABS scattering extends to the upper limit of the Rayleigh regime.
[ii] Values are arbitrarily scaled, so columns were scaled to set C_2 values equal to those from the inverse analysis.
[iii] The largest inverse coefficient may require a larger data set for accurate determination.

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PATENTS

None.