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13. ABSTRACT (Maximum 200 words)  As part of the Chemical Sensing in the Marine Environment (CSME) program, a series of field experiments were carried out to investigate the dispersion and mixing of chemical plumes in the near-shore environment in order to assist the design and application of biosensors for identifying and locating chemical sources like unexploded ordnance in the marine environment. Measurements of concentration field structure made in the littoral zone of the coastal ocean show that stratification effects and scale-dependent dispersion can be important. The data we obtained can be used to help make predictions of biosensor sensitivity requirements, as well as to help develop strategies for source location.				
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FINAL REPORT

GRANT #: N0014-96-1-0660

PRINCIPAL INVESTIGATORS: Prof. Stephen G. Monismith and J.R. Koseff

INSTITUTION: Stanford University

GRANT TITLE: Modeling and field studies of chemical plumes in benthic boundary layers

AWARD PERIOD: 4/1/96 to 12/31/97

OBJECTIVE: To investigate the dispersion and mixing of chemical plumes in the near-shore environment and use this information to assist the design and application of bio-sensors for identifying and locating chemical sources like unexploded ordinance in the marine environment.

APPROACH: Our activities were directed along two lines. Firstly, in collaboration with Prof. T.M. Powell's group at UC Berkeley, we participated in a series of field experiments that formed the core of the Chemical Sensing in the Marine Environment (CSME) Program. Participants in the CSME program included chemists from NRL, JPL, ORNL, and Rutgers. All experiments were carried out at NOTS pier, an NRAD (now SPAWAR) facility in the littoral waters of San Clemente Island (SCI) in the Santa Barbara Channel. The NOTS pier littoral zone was chosen because, among other things, it represents a reasonably typical coastal environment. Technical support, boats etc. for all of the experiments was provided by NRAD. For the first series of experiments, which were aimed more at field testing of detectability of selected analytes, like dissolved RDX, both a conservative tracer (Rhodamine WT) and the various analytes of interest were emitted from a near-bottom source. For our part, we made limited measurements of currents and dye concentration to characterize the physical conditions and dilution of the conservative plume. As the test series evolved, early measurements were used to design sampling protocols in later experiments and to help interpret simultaneous measurements of analyte concentrations.

The majority of our effort went into designing and carrying out a large field experiment at SCI in which made extensive measurements of currents using two acoustic Doppler current profilers (ADCPs) and a rake of three acoustic Doppler velocimeters (ADV), of density variations and turbulence microstructure using a fast CTD, and of the spatial and temporal structure of the plume. Temporal variability of the plume was documented using fixed sampling wands multiplexed onto a single pumped fluorometer. Spatial structure of the plume in the region between 50 and 700m downstream of the source was mapped using a 2 m high towed array of three in-situ fluorometers. The towed array also carried an altimeter to register height above bottom and a CTD to measure depth and temperature. Unfortunately, the CTD malfunctioned and did not return any data. The vertical position of the array was adjusted manually by winching it up and down in response to data returned in real-time and displayed on a laptop computer. During one 8 hour period, we obtained two coarse maps of the concentration field, first near to the source, and later at ranges of up to 700m.

This large data set was collated and later used by colleagues at UC Berkeley to assess the ability of various simple models to predict the observed dilution and structure of the plume. This analysis included testing of various scaling laws for concentration decay that postulate different types of mixing behavior including effects of density stratification and scale-dependent dispersion.

ACCOMPLISHMENTS: Firstly, we provided and analyzed hydrodynamics data that was used to formulate chemical sampling strategies, enabling CSME chemists to successfully determine the dilution of non-conservative explosive tracers like dissolved RDX and its breakdown products. This work will provide important information for the design of bio-sensors used for example in the MUDSS (MOBILE UNDERWATER DEBRIS SURVEY SYSTEM)

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program to develop tools for underwater surveying of various hazardous debris from military operations and facilities.

On the scientific front, the data set we collected at SCI is the first data set documenting on scales of tens to one hundreds of meters the dilution and structure of a continuous plume in the coastal ocean. We note that this spatial scale has received little attention by physical oceanographers until recently.

Used with concurrent measurements of velocity and density, our observations show that:

- (1) For much of the initial phase of the experiment, the plume traveled along the source isobath as it was advected away from the source. This probably resulted from the fact that tidal currents at the site, like many locations in the coastal ocean, are also primarily along-isobath.
- (2) The spatial decay of the centerline concentration of the plume indicates that both density stratification and scale-dependent dispersion play important roles in determining the structure of the concentration field. Our observations suggest an initial vertical spreading of the plume that is quickly arrested when the top of the plume reaches the base of the thermocline (from below). Horizontal spreading of the plume after this point increases at a rate that is faster than one would infer from constant turbulent mixing coefficients, a feature that shows that the rate of spreading of the plume increases as the plume is dispersed by larger and larger eddies. This takes place because when the plume is "small" the largest, energetic eddies bodily displace the plume, rather than shredding it. This meandering behavior is important to source location because it complicates location of the plume and relation of current plume location to source location and current direction.
- (3) Far-field behavior of the plume is complicated by the temporally changing structure of the velocity and density field. In particular, the onshore/offshore flow that developed due to intrusion at depth of colder water from offshore pushed parts of the plume at right angles to its otherwise along isobath path. This behavior is important in light of proposals to use gradient search algorithms to locate sources like that which our source modeled. Were one to attempt the standard gradient driven navigation upstream to the source in this case, one would be led to move in the direction perpendicular to the real source direction.

#### CONCLUSIONS:

Taken as a whole, our measurements show the importance of measuring the hydrographic conditions at the site where one is interested in locating chemical sources because mixing and advection of the plume were controlled by the local current and density fields. Moreover, in the coastal region these are strongly influenced by bathymetry, and so bathymetry data is at a premium. The importance of scale-dependent dispersion implies that they are yet to be defined limits to using random walk models of dispersion in these cases because random walk models do not include the stochastic structure of the velocity field that is responsible for meandering. Nonetheless, we conclude that for more complex time-varying flows, search algorithms will need to include accommodate flow history in some way to enable efficient location of near-bed chemical sources.

Finally, our work in the CSME program shows that it is feasible to proceed by separately considering physical dispersion and analyte chemistry and behavior.

#### SIGNIFICANCE:

Combined with other CSME measurements we can make predictions of bio-sensor sensitivity requirements. Aspects of plume dynamics in the near-coastal environment that will influence the use of these sensors can be specified. We have also identified future research needs for source location.

PATENT INFORMATION: none

AWARD INFORMATION: Monismith was made director of the Environmental Fluid Mechanics Laboratory at Stanford

PUBLICATIONS AND ABSTRACTS (for total period of grant):

Stacey, M.T., E.A. Cowen, T.M. Powell, S.G. Monismith, S.G., J.R. Koseff, & E. Dobbins, "Identification of Plume Source Location in Coastal Waters," in: Proceedings of the 12th Engineering Mechanics Conference, ASCE., pp. 1669-1672, 1998

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Cowen, E.A., M.T. Stacey, E. Dobbins, S.G. Monismith, T. M. Powell and J.R. Koseff. "Plume measurements in shallow coastal waters at scales of several hundred meters," (abstract only) EOS, Transactions, Amer. Geophys. Union, 79 (1),p. OS 83, 1998

Stacey, M.T., E.A. Cowen, T.M. Powell, S.G. Monismith, J.R. Koseff, and Dobbins. "Measurements and Modeling of an Unsteady Plume in a Stratified Near-Coastal Flow," (in prep - to be submitted to J. Geophys. Res. Oceans)