Deliberate Tracer Injections of Sulfur Hexafluoride on the West Florida Shelf in Support of: An AUV-based Investigation of the role of Nutrient Variability in the Predictive Modeling of Physical Processes in the Littoral Ocean

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LONG-TERM GOAL

The overall goal of this project is to quantify advection and dispersion of waters on coastal shelves over several week's duration by following a deliberately tagged water mass. Monitoring the tagged water mass shows the unique dispersion mechanisms and pathways of transport in the coastal environment. Using the ratio of (biologically) reactive property to inert tracer concentration allows us to quantify biogeochemical transformation rates *in situ* in energetic environments such as the coastal seas. The work is performed with the inert gaseous tracer, sulfur hexafluoride and it includes development of sampling methods to characterize the tracer field with high spatial and temporal resolution in near real-time.

OBJECTIVES

The tracer sulfur hexafluoride, SF_6 is utilized to separate changes in nutrient levels caused by biological processes (production and respiration) and the changes caused by dispersion. SF_6 is a stable and inert man-made gaseous compound with no known hazardous environmental effects in water or air. The SF_6 studies offer three essential pieces of information:

- A marker for a true Lagrangian study of nutrient dynamics with focus on ammonia.
- A quantification of horizontal dispersion in the shelf region.
- A qualitative assessment of spatial variability.

The SF_6 tracer in essence "freezes" the processes under investigation in space in this dynamic shelf region.

APROACH

A cruise was performed on the West Fl Shelf on the research ship "Walton Smith" of the University of Miami from April 16-29, 2000. This complemented the previous two cruises to obtain seasonal information on the advection and dispersion rates and the impact on nutrient dynamics. The April cruise was the fifth in the Florida Shelf Lagrangian Experiments (FSLE) [*Wanninkhof et al.*, 1997]. The previous cruises funded by ONR were performed in July, 2000 (FLSE III) and in November, 2000

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14. ABSTRACT

The overall goal of this project is to quantify advection and dispersion of waters on coastal shelves over several week's duration by following a deliberately tagged water mass. Monitoring the tagged water mass shows the unique dispersion mechanisms and pathways of transport in the coastal environment. Using the ratio of (biologically) reactive property to inert tracer concentration allows us to quantify biogeochemical transformation rates in situ in energetic environments such as the coastal seas. The work is performed with the inert gaseous tracer, sulfur hexafluoride and it includes development of sampling methods to characterize the tracer field with high spatial and temporal resolution in near real-time.

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(FSLE IV) in the PORTAL ECOHAB region to study to impact of dispersion on nutrient dynamics. The SF_6 releases in the mixed layer served to show the influence of tidal currents and wind forcing, and resulting divergences, on the tracer and nutrient distribution.

The injection of SF_6 was performed by bubbling it through gas permeable hose at approximately 9-m depth in a 2-km streak. The temperature and depth of injection were monitored during injection. About 2 mol of SF_6 (0.3 kg) was bubbled in, which is sufficient to follow the tracer for the duration of the 10-day experiment. An analytical system, "the underway SF_6 system" was built to perform quantitative analyses of SF_6 in surface water at 2-minute intervals. It uses a Liqui-Cel flow membrane contactor (Hoechst Celanese Corp.) to assure rapid equilibration between gas and water phase while keeping the phases physically separated. The system is calibrated with standards obtained from Scott-Marin and cross-referenced to traceable standards from NOAA/CMDL and Dr. Ray Weiss of SIO. The system is used to track the location and spreading of deliberately injected SF_6 tracer patch in order to study the movement and horizontal dispersion of the tagged water. The Liqui-Cel membrane contactor has a single pass efficiency of 50 to 80 % which was determined from discrete samples taken from the same seawater line during the cruises. Because of transit time through the seawater line and analysis time, the lag time(distance) between location of sample and analyses is about 5 minutes (or about 500 m@ 3 Knot). The system is interfaced with a GPS receiver such that the output file can be produced in near real time that contains time, SF_6 concentration, and location information. This facilitates quick navigational adjustments during surveys of the patch.

For a vertically well-mixed mixed layer, as often is observed on the Florida shelf, the tracer is mostly homogeneous down to the bottom of the mixed layer. By accounting for the large-scale tidal motion, using a drogued GPS drifter, and performing surveys of the patch over time the second moment of growth of the patch in the mixed layer can be determined from which the apparent horizontal diffusivity is estimated [*Okubo*, 1971].

WORK COMPLETED

The third FSLE field study sponsored by ONR was successfully completed on the "Walton Smith". Based on the previous two field studies, the objectives were fine tuned to investigate the vertical dispersion of the tracer patch more fully. The study was optimized to use SF_6 to study the ammonia (NH_4^+) dynamics on the shelf (see report N00014-96-1-5024 of K. Fanning and J. Walsh). The study was executed on a cruise from Miami to St Petersburg with the study area located at 27° N, 83° W. About 2 mol of SF_6 (0.3 kg) tracer was injected in a 2-km streak during the third day at sea in a region with elevated NH_4^+ concentrations. This location was to the south of the previous injections and further removed from the NAVY 3 buoy which was the injection point for the previous studies. Intense surveys for the following 11-days showed the evolution of the tracer patch. Surface water SF_6 along with T and S measurements were made continuously along the cruise track. The SF_6 data has been reduced and initial interpretation has commenced along with comparisons with the previous studies.

RESULTS

Tracer surveys, interspersed with CTD casts, provided both a vertical and horizontal view of the evolution of the tracer patch. An example of the surface concentrations during the ninth day of the study is shown in Figure 1. The tracer field evolved into a long elliptical patch with its major axis roughly in an EW direction. This orientation is slightly different from the previous cruises where the

orientation is along shelf in a NW-SE direction. The translation of the patch is on day 9 is about 30 km to the SW. Based on modeling studies and current meter records both the orientation and the translations are in agreements with surface wind and tidal forcing [*He and 2001*, 2001; *Weisberg et al.*, 1996; *Weisberg et al.*, 2001]. The strong NW wind that blew during the first part of the study will cause the water movement in the direction observed.

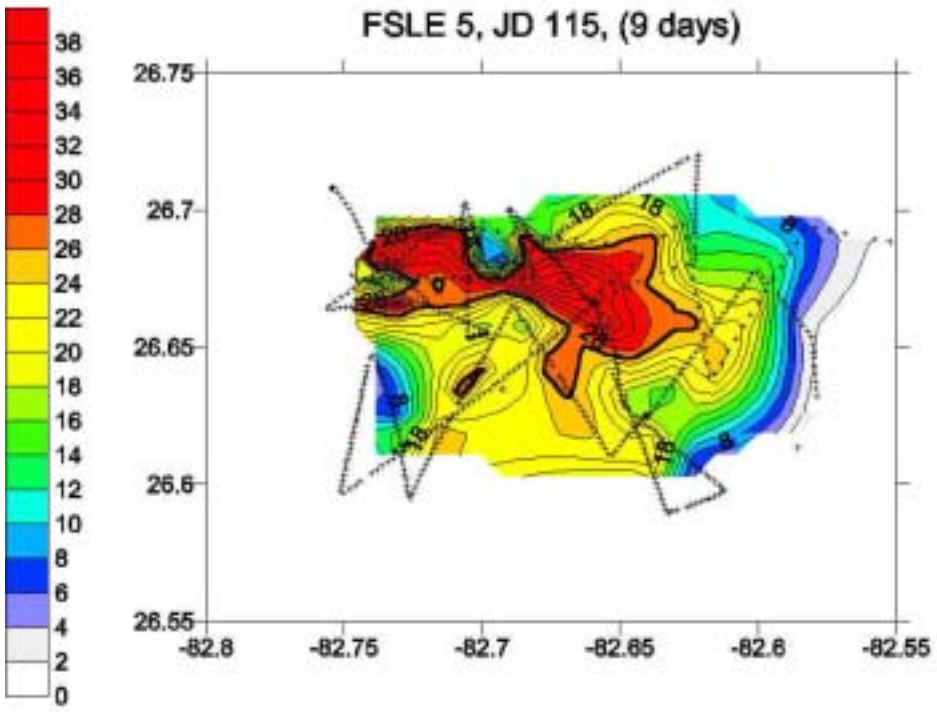

Fig 1. Contour plot of surface concentrations of SF_6 in part per trillion by volume (pptv) in the tracer patch 9-days after injection. The underway sampling locations along the cruise track are depicted by crosses. The injection took place about 30 km to the NW at 26.98 N, -82.82 W.

The vertical profiles obtained during the study shows an intricate pattern SF_6 in the water column with some evidence of enrichment in the benthic layer (Fig 2a). Several processes appear to be at work. Vertical eddy diffusion causes penetration downward. However, this cannot explain the higher concentrations near the bottom which must occur by (rapid) advective mixing. It is also apparent that vertical shear in the water column causes the surface, deep and benthic layers with their tracer to move relative too each other. Temperature profiles change significantly from day to day but the mixed layer has relatively homogeneous SF_6 profiles (Fig 2b). The fluorescence signal suggests higher chlorophyll below the mixed layer (Fig 2c).

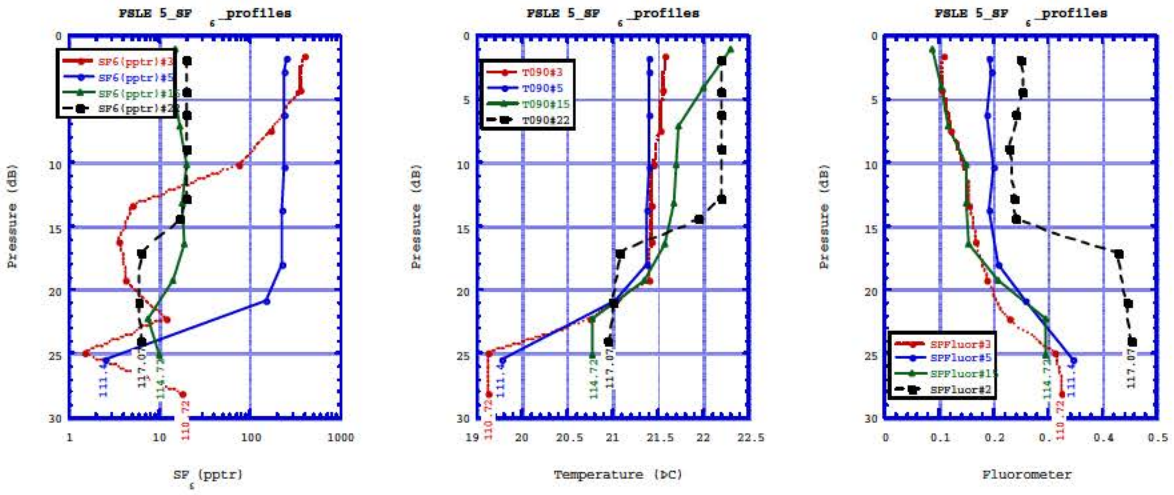

Fig 2. SF_6 temperature, and fluorescence profiles in the tracer patch 2, 3, 6, and 9 days after injection. The depth of injection was 9-m and the higher SF_6 concentrations near the bottom on JD110 and JD 114 (a) suggests that the penetration occurs at distinct downwelling zones. The temperature profiles (b) show significant day to day variations. In general, SF_6 is homogeneous within the mixed layer, except near the beginning of the study. The uncalibrated fluorometer signal (c) suggest higher chlorophyll concentrations below the mixed layer.

IMPACT/APPLICATION

The information from this field campaign will be compared with the Princeton Ocean Model (POM) set up by Prof. Weisberg of USF for the West Florida Shelf in order to elucidate shelf dynamics on a larger scale. In particular, the horizontal and vertical SF_6 concentrations and patch movement will be interpreted in the modeling framework. Encouraging correspondence has been found between the observed displacement of the patch and modeled water movement. The NH_4^+ concentrations remained high in and near the tracer patch suggesting either an active but unknown source of NH_4^+ or that NH_4^+ is more stable than previously believed. If so, it could be powerful natural tracer of coastal mixing.

TRANSITIONS

The work performed during the FSLE 3, 4 and 5 studies points towards the need to further study variability on 1-km to 10-km scale and to obtain a better quantitative information on the extent of communication of waters in the surface mixed, deep and benthic layer. The tracer studies have unequivocally shown that there is exchange between the layers but this exchange must be limited, and possibly episodic, for the layers to maintain their unique physical and chemical structures. Future studies will emphasize this aspect. This transition will require emphasis on improved near real-time sampling in the vertical either by towed undulating pumping systems or in situ analyzers.

RELATED PROJECTS

This study is part of a series of studies on the West Florida shelf to elucidate the physical forcing and chemical and biological transformations that occur on the shelf. The studies include the ONR AUV projects, the NOAA/EPA/ONR ECOHAB project, the mooring program and the ONR remote sensing and modeling efforts under HYCODE.

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