Aplinkos tyrimai, inžinerija ir vadyba, 2007.Nr.1(39), P. 14-18 *ISSN 1392-1649*
Environmental Research, Engineering and Management, 2007.No.1(39), P. 14-18

Wind-Driven Response of the Hudson River Plume and its Effect on Dissolved Oxygen Concentrations

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(received in June, 2006; accepted in March, 2007)

The Lagrangian Transport and Transformation Experiment (LaTTE) study of the Hudson River Plume has now completed 2 of its 3 field seasons. The interdisciplinary study is being conducted in a sustained coastal research observatory that provides a spatial and temporal context for adaptive shipboard sampling. Observations from the second LaTTE field season are used here to describe the processes responsible for a previously unexplained recurrent hypoxia region along the New Jersey coast.

Key words: *dissolved oxygen, river plume, hypoxia*

1. Introduction

Hypoxia and anoxia in marine environments refer to the conditions occurring when the concentration of Dissolved Oxygen (DO) in seawater is reduced to the point that it negatively impacts marine organisms. In some cases, widespread fishkills are reported. In New Jersey, the most significant hypoxia/anoxia event occurred in 1976 when a combination of a prolonged hot summer with few mixing storms produced low DO conditions over much of the New Jersey continental shelf, resulting in 100s of thousands of 1976 dollars of damage to the shellfishing industry. Since the 1976 event, DO concentrations on the New Jersey shelf have been monitored on a regular basis by federal and state managers. NOAA measurements from the 1970s and 1980s (Warsh 1987) were used to identify four regions of recurrent hypoxia along the New Jersey shelf (Fig. 1). Early speculation was that the recurrent hypoxia zones were associated with riverine inputs of nutrients. However, as Fig. 1 indicates, some rivers with similar watersheds do not have hypoxic zones, and some hypoxic zones do not have rivers.

Through a series of individual science experiments in the early 1990's followed by integrated ocean modeling and observation Coastal Predictive Skill Experiments from 1998-2001, the processes responsible for the formation of the three recurrent hypoxia zones off southern New Jersey were identified (Schofield and Glenn 2004). The processes involve the interaction of coastal upwelling jets with bottom topography (Song 2001), resulting in the formation of a recirculating eddy on the downstream side of a series of topographic highs associated with ancient river deltas (Fig. 2). Sampling of actual upwelling eddies (Fig. 3) indicates that the eddies concentrate phytoplankton in these three regions, depleting the bottom DO concentrations as the phytoplankton die and are decayed by bacteria. (Glenn, Schofield et al. 2004). But what about the fourth region of recurrent hypoxia off of the northern New Jersey coast where bottom topography is quite different? Except for the speculation that this region is likely associated with the Hudson River, the processes responsible for this fourth northern hypoxic zone remained relatively unknown.

2. A Process Study in Research Observatory

The National Science Foundation (NSF) has sponsored Lagrangian Transport and Transformation Experiment (LaTTE) which is an interdisciplinary, multi-institutional study of the Hudson River Plume conducted within the footprint of a sustained coastal research observatory. The LaTTE Principle Investigators and their home Institutions are listed in Table 1. The experiment features two coordinated ships, one to conduct a dye release to tag and track a Hudson Plume water mass as it mixes with the shelf water as the transport component, and a second to observe the chemical and biological transformations that occur within that water mass.

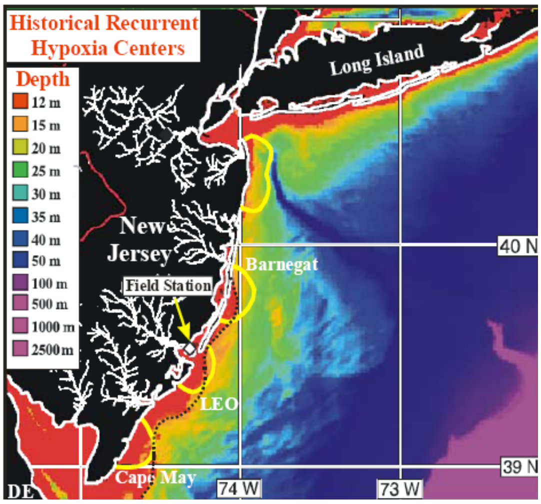

Fig. 1. Regions of recurrent hypoxia on the New Jersey Shelf (Warsh, 1987).

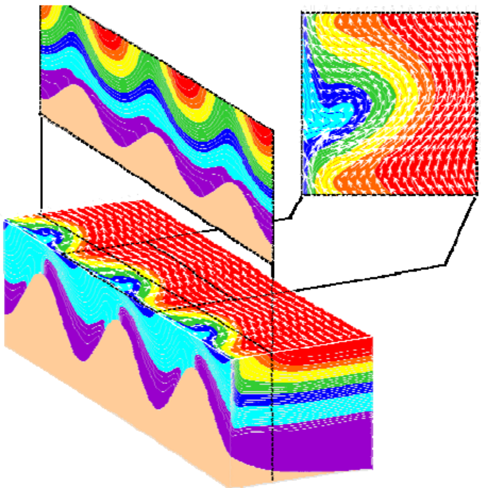

Fig. 2. Mechanisms for the development of upwelling centers along the southern New Jersey coast were identified in idealized models (Glenn 1996).

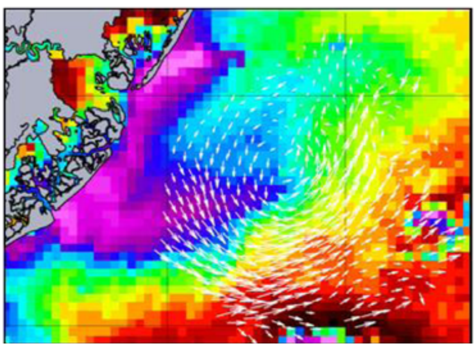

Fig. 3. Coastal Observatory identified upwelling centers in real-time for shipboard sampling (Glenn & Schofield, 2004).

Table 1. LaTTE Principal Investigators

Physics
Bob Chant (Rutgers U.)
Bernie Gardner (U.
Massachusetts)
Scott Glenn (Rutgers U.)
Bob Houghton (Lamont)
John Wilkin (Rutgers U.)
Chemistry
John Reinfelder (Rutgers U.)
Bob Chen (U. Mass)
Biology
Paul Bissett (FERI)
Tom Frazer (U. Florida)
Mark Moline (Cal-Poly)
Oscar Schofield (Rutgers U.)
Meng Zhou (U. Mass)
Plus Many Others

The sustained observatory is the New Jersey Shelf Observing System (NJSOS), operated by the Rutgers University (R.U.) Coastal Ocean Observation Lab's (COOL) Operations Center. The regional footprint of NJSOS provides a spatial and temporal context for shipboard-based process studies such as LaTTE. The R.U. COOL Operations Center includes two-way voice, video and data communications with the LaTTE research vessels so that all the information and guidance available from the observatory can be provided to the vessels sampling at sea.

3. LaTTE Results

LaTTE provides the first detailed look at the processes responsible for the northern New Jersey recurrent hypoxia center. .LaTTE data collected during the field season from April 2005 are used to illustrate these processes. The time period corresponds to high flow conditions during rainy spring. Satellite ocean color imagery (Fig. 4) of the Hudson plume during this time indicates that water from the Raritan River is distinct from the Hudson River. A strong front between the two river waters is often observed in the lower Harbor. Shipboard sampling across the front reveals that the Raritan has a significantly higher organic content than the Hudson, an observation consistent with the more organic sediments in the geologic record. The combined sediment laden flows are then observed to exit the Harbor and flow out onto the continental shelf.

The high-resolution inner nest of the NJSOS CODAR network provides more details on the outflow. The plume exits the estuary not as a steady flow, but as a series of ebb tide pulses (Fig. 5). With each ebb tide, a layer of fresh water squirts out onto the New Jersey shelf, forming a strong front that in the absence of wind would propagate down the New Jersey coast as a coastal plume. However, because each squirt is a layer of new fresh water, it is very buoyant and susceptible to wind forcing.

Springtime synoptic winds in the New York Bight Apex usually blow from either the northeast or southwest. During strong downwelling favorable winds from the northeast, the plume flows to the south along the New Jersey coast as a coastal current. During strong upwelling winds from the southeast, the plume responds by flowing to the east along the Long Island coast. During weaker winds, a seabreeze often develops in the New York Bight Apex. The offshore extent to the seabreeze is enhanced in the Bight Apex by the coastal geometry (Fig. 6). In this case, the synoptic flow from the north and northeast is blocked by a pair of sea breeze fronts over Long Island and Connecticut, resulting in a relatively stationary seabreeze front. The seabreeze over New Jersey, however, is able to propagate farther inland perpendicular to the synoptic flow. An enlarged area of low winds over the New York Bight Apex results, indicating that the offshore extent of the seabreeze circulation cell is enhanced by the Bight Apex geometry over that expected from a simple two-dimensional seabreeze model. The result is an enhanced seabreeze over the same area in which the buoyant Hudson plume is flowing onto the shelf

Fig. 4. Mixing of the Hudson River (tan) and the Raritan River (brown) in New York Harbor and the flow of the sediment laden plume onto the shelf is illustrated in this RGB ocean color image from India's Oceansat.

Seabreeze has been observed to have a profound effect on the plume. In the case of synoptic winds from the north, the morning ebb tidal pulse is observed to flow along New Jersey with the synoptic winds. As afternoon approaches, the seabreeze kicks in and reverses the wind direction in the Bight Apex. The afternoon ebb tidal pulse is observed to flow along Long Island forced by the afternoon seabreeze. As a result, the sediment and organic laden plume water can be spread over a wide area of the Apex.

The seabreeze also tends to reinforce the recirculation zone observed in the outflow bulge observed in the Bight Apex of Fig. 7. The bulge formation is predicted by some steady outflow models for coastal plumes. The Hudson River Plume was observed to form a persistent bulge with an embedded recirculating eddy during a series of seabreeze events in April of 2005. The recirculation zone remained intact for several days.

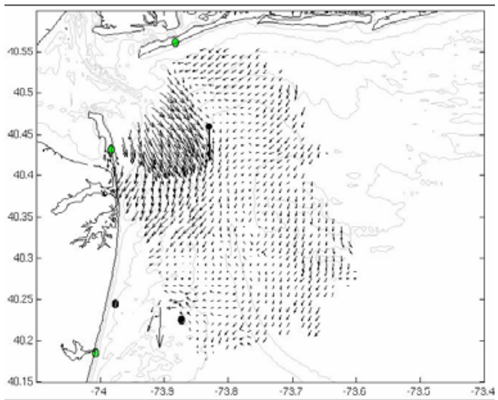

Fig. 5. Flow exiting the Hudson-Raritan Estuary as determined from the CODAR HF Radar network showing a tidal pulse exiting the harbor.

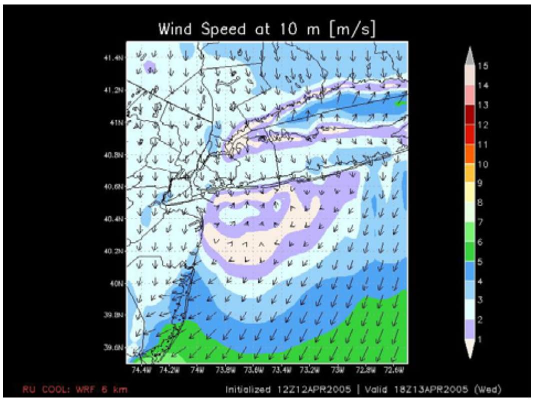

Fig. 6. Offshore extend of the sea breeze cell enhanced by the three-dimensional coastal geometry of the NY Bight Apex.

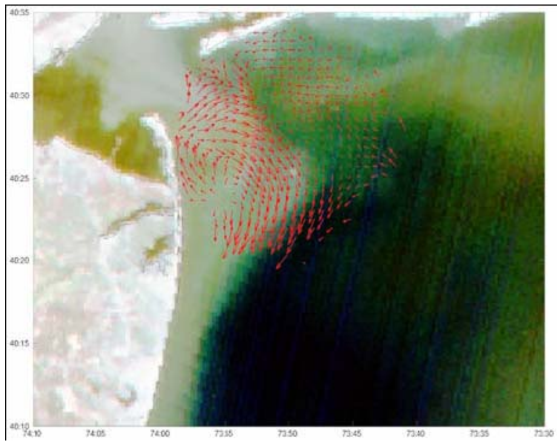

Fig. 7. RGB Ocean color image from Oceansat illustrating the plume bulge formation as the Hudson River Plume exits the estuary. The overlaid CODAR current vectors identify the recirculation zone within the bulge.

The persistent eddy that formed within the bulge acted as an incubator for large phytoplankton that were too big to be grazed by the prevalent zooplankton. The resulting rapid phytoplankton growth followed by the death and decay processes depleted oxygen within the bulge (Fig. 8). The saltiest water in the pcture is the bottom water under the plume with the lowest DO values. Dissolved oxygen values continued to drop well below their historical typical values for several days until a strong storm passed through the area, mixing the waters and returning oxygen values to their normal spring high.

But what happens to the plume water deposited in the Bight Apex? During LaTTE, several pathways out of the Bight Apex were identified. The most intriguing and previously unknown pathway is the cross-shelf transport route along the axis of the Hudson Shelf Valley. Virtual drifter studies in the CODAR surface current fields (Fig. 9) indicate that the transport pathways out for the Bight Apex are related to the wind forcing. Some exit to the south during strong downwelling winds, and some to the east during strong upwelling winds. Some of the virtual drifters flowing along the HSV are observed to flow all the way across the shelf to join the alongshore flows of the Shelf Slope Front. Others are found to only make it as far as midshelf, joining the alongshore flows of the Midshelf Front.

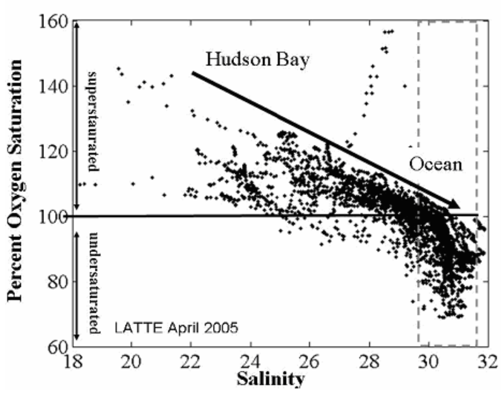

Fig. 8. *Dissolved oxygen concentrations plotted as a function of salinity the Hudson River and Plume during the April 2005 LaTTE.*

4. Summary and Conclusions

Long-term government monitoring has identified four regions of recurrent hypoxia along the New Jersey coast. A series of coast predictive skill experiments from 1998-2001 determined that the three southern low dissolved oxygen regions were caused by coastal upwelling jets interacting with three topographic highs in the alongshore direction, resulting in recirculating eddies that concentrated phytoplankton in these regions and depleting the oxygen as the dying phytoplankton decayed. The LaTTE experiment in a sustained coastal observatory has determined the fourth hypoxia center is also related to a recirculating eddy that collects phytoplankton, but that the eddy is caused by the recirculated bulge of the Hudson River plume that is enhanced by seabreeze. Knowledge of these processes and demonstration of new observing technologies have led to the collaborative design of more effective and cost efficient dissolved oxygen monitoring networks for federal and state managers.

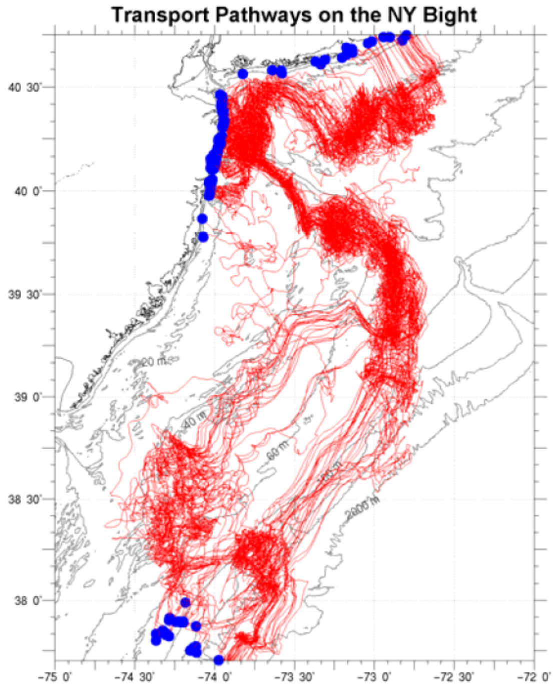

Fig. 9. *Virtual tracer release study during the 2005 LaTTE Hudson River Plume Experiment based on the CODAR HF Radar data. Drifters were deployed in the Hudson Plume in the Bight Apex every day during LaTTE and were tracked for an additional 40 days.*

5. Acknowledgements

The Lagrangian Transport and Transformation Experiment is supported by the NSF Coastal Oceans Program (CoOP) Buoyant River Plume Initiative. Rutgers Coastal Research Observatory is sustained through grant support from U.S. government agencies (ONR, NSF, NOAA, NOPP, DHS, DoD, & EPA), the power industry (PSE&G), the country of Norway, and the Great State of New Jersey.

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Vėjo įtaka Hudsono upės nuotėkio sklaidai ir ištirpusio deguonies koncentracijai jūroje

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(gauta 2006 m. birželio mėn.; atiduota spaudai 2007 m. kovo mėn.)

Šiuo metu yra baigtos nagrinėti dvi iš trijų Lagranzo transporto ir transformacijos procesų Hudsono upėje, tyrimo stadijos. Tarpdalykinė studija atliekama kranto mokslinių tyrimų observatorijoje, kuri teikia erdvės ir laiko situacijos duomenis, pritaikytus laivo bandinio ėminiams. Antrojo LaTTE tyrimų laikotarpio stebėjimai naudojami procesams, sąlygojantiems anksčiau nepaaiškintą hipoksijos zoną, besidriekiančią išilgai Niu Džersio kranto.