# The Impact of Episodic Events on Nearshore-offshore Transport in the Great Lakes: Physical Oceanography Observations

NOAA PI's: Saylor, Miller, McCormick

This proposal is written in response to the NSF/OCE and NOAA/COP Announcement of Opportunity for Coastal Studies in the Great Lakes. It is part of a multi-proposal, multidisciplinary program on the impact of episodic events on the coastal ecosystem in the Great Lakes. This group proposal focuses on observing and quantifying the offshore volume flux of water and suspended materials due to the coupling of a storm generated coastal turbidity plume and a two-gyre vorticity wave in southern Lake Michigan. This proposal was written in close cooperation with the **Hydrodynamic Modeling Program** of Schwab and Beletsky, therefore, much of the same material contained in the Introduction and Background sections appears in both proposals.

## Introduction

In the Great Lakes, as well as in the coastal ocean, the gradients of many biogeochemically important materials (BIMs) are considerably higher in the offshore direction than in the longshore direction (Brink et al., 1992, Scavia and Bennett, 1980). In the presence of these large gradients, cross-isobath circulation is a primary mechanism for the exchange of material between nearshore and offshore waters and is one scientific focus of the NSF/OCE NOAA/COP initiative. As with most coastal environments where tidal currents are negligible, the mean alongshore transport in coastal regions of the Great Lakes is typically much larger than the cross-isobath component (Csanady, 1982). However, both the alongshore and cross-isobath components of the current exhibit strong episodic behaviour due to wind forcing. Alongshore transport has been the major focus of previous large physical oceanography studies in the Great Lakes, including the International Field Year for the Great Lakes in 1972 (Saylor et al., 1981), the Lake Erie Binational Study (Boyce et al., 1987), and the Lake Ontario 1982-83 circulation study (Simons and Schertzer, 1989). As opposed to alongshore transport, the advective and diffusive mechanisms driving cross-shore transport and the time scales over which they operate have not been as extensively studied and are not well understood. A necessary step in understanding cross-shore transport of BIMs is to identify and quantify the physical processes that are responsible for the nearshore-offshore water mass and material exchange. The program we are proposing offers a unique opportunity to investigate cross-shore transport in the Great Lakes because of the unprecedented availability of satellite imagery, the combination of Eulerian, and Lagrangian current measuring systems, the development of high resolution meteorological, hydrodynamic, sediment transport, and food web models, and the accessibility to World Wide Web-based information and data management systems.

In the context of nearshore-offshore transport, the Great Lakes present somewhat different challenges than the continental shelf. Although many of the physical processes responsible for the movement of material from the coastline toward deeper waters are similar in both regimes, the fact that the lakes are fully enclosed by land has significant consequences. When material is transported offshore in the Great Lakes, it can only be removed from the system by permanent burial in the sediments or removal through an outflow. This is in contrast to the continental shelf where transport across the shelf break to the deep ocean can also be considered a removal mechanism. The physical mechanisms for cross-shelf transport are similar, and in some cases identical, to the processes that control nearshore-offshore transport in the lakes, but there is no analogue in the lakes for exchange with the deep ocean across the shelf break. The purpose of this proposal is examine the physical mechanisms primarily responsible for nearshore-offshore transport of BIMs in the lakes.

Recent satellite observations of suspended sedimentary material in Lake Michigan (Fig. 1, Eadie et al., 1996) appear to offer a unique opportunity to investigate a recurrent episode of cross-isobath transport. A 10 km wide plume of resuspended material extending over 100 km along the southern shore of the lake was first observed in satellite imagery by Mortimer (1988), and has since been observed every spring since 1992, when satellite imagery for the Great Lakes region first became available on a routine basis through the NOAA CoastWatch program (Schwab et al., 1992). The onset of the plume appears to be correlated with the disappearance of ice from the lake and a major storm with strong northerly winds, although there is evidence that this event can occur later in the year (Mortimer, 1988). The plume is apparent along the entire southern coastline of the lake. It occassionally veers offshore along the eastern shore of the lake, coincidentally near the areas of highest measured long-term sediment accumulation in the lake. The offshore structure of the turbidity plume often resembles the structure of cold water filaments seen in thermal imagery of the California Current by Strub et al. (1991) and others. We believe this type of event is ideal for studying the physical processes controlling cross-isobath transport of BIMs in the Great Lakes, and in Lake Michigan in particular.

## Background

*Climate and thermal cycle of the Great Lakes*

The physical dimensions of the Great Lakes (horizontal length scales of hundreds of kilometers, maximum depths of 200-400 meters except for Lake Erie) are similar to dimensions of continental margins, and many of the same physical processes occur in both areas. In contrast to the continental shelf, the Great Lakes exhibit a pronounced annual thermal cycle (Boyce et al., 1989). During the winter, the lakes are usually vertically well-mixed from top to bottom at temperatures near or below the temperature of maximum density for freshwater, about 4 degrees C. Further cooling in January and February can lead to inverse stratification, and ice cover. Springtime warming tends to heat and stratify shallower areas first leaving a pool of cold water (less than 4 degrees C and vertically well-mixed because of convection) in the deeper parts of the lake. In spring, stratified and homogeneous areas of the lake are separated by a sharp thermal front, commonly known as the thermal bar. Depending on meteorological conditions and depth of the lake, the thermal bar may last for a period of from 1 to 3 months. Stratification eventually covers the entire lake, and a well-developed thermocline generally persists throughout the summer. In the fall, sustained surface cooling and vertical mixing deepens the thermocline until the water column is again mixed from top to bottom. When the nearshore surface temperature falls below the temperature of maximum density, the fall thermal bar starts its propagation from the shoreline toward the deeper parts of the lake. Thermal gradients are much smaller during this period than during the springtime thermal bar.

Because of their mid-latitude position, the Great Lakes are subject to periodic extratropical storms, particularly during the spring and fall periods when the jet stream is crossing these latitudes. Typical intervals between storms are 5-7 days during winter and 7-10 days during summer. Storms can rapidly generate relatively strong currents which decay with time scales of several days. The spatial scales of extratropical cyclones are only a little larger than the dimensions of the lakes, often resulting in considerable nonuniformity in the wind fields across a lake. The spatial variablity of the wind field can have considerable influence on the resulting circulation pattern in the lake. Figure 2 from Schwab and Bennett (1987) shows wind stress and current energy in Lake Erie for 6 months in 1979. The episodic nature of atmospheric forcing and the lake's response is clear.

*Circulation in the Great Lakes: longshore and offshore transport*

Wind-driven transport is a dominant feature of circulation in the lakes. In addition to the spatial and temporal variability of the wind forcing, the earth's rotation, basin topography, and vertical density structure are all important influences in the dynamical response of the lake. As shown by Bennett (1974), Csanady (1982), and others, the response of an enclosed basin with a sloping bottom to a uniform wind stress consists of longshore, downwind currents in shallow water, and a net upwind return flow in deeper water. The streamlines of the flow field form two counter-rotating closed gyres (Fig. 3a Saylor et al., 1980 and Fig. 1, below), a cyclonic gyre to the right of the wind and an anticyclonic gyre to the left (in the northern hemisphere). In this classic two gyre pattern, there are two points along the shoreline where cross isobath transport occurs, one on the upwind shore where diverging longshore currents are accompanied by onshore flow, and one on the downwind shore where converging longshore currents are accompanied by offshore flow. As the wind relaxes, the two-cell streamline pattern rotates cyclonically within the basin with a characteristic period corresponding to the lowest mode vorticity wave of the basin (Saylor et al., 1980). For a Coriolis parameter and geometry representative of the Great Lakes, this period is on the order of 3-5 days, closely corresponding to the periodicity of storm forcing. Numerical models approximating actual lake geometry have proven to be remarkably effective in explaining observed circulation patterns in lakes (Sheng et al., 1978, Simons, 1980, Schwab 1983, Murthy et al., 1986, Schwab and Bennett, 1987 ). The results of these modeling exercises show that the actual bathymetry of each of the Great Lakes basins tends to act as a combination of bowl-shaped sub-basins, each of which tends to support its own two-gyre circulation pattern.

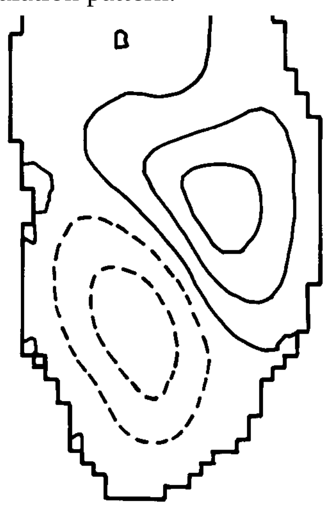


*Fig. 1. Numerically calculated counter-rotating gyres in southern Lake Michigan (Schwab, 1983). The dashed lines indicate cyclonic circulation and the stagnation point lies near the southeast coast.*

Besides bathymetry and geometry, two other important factors tend to complicate the simple lake circulation model described above, namely nonuniform wind forcing and stratification. The effect of horizontal variability in the wind field enters through the curl of the wind stress field (Rao and Murthy, 1970, Strub and Powell, 1986). Any vorticity in the forcing field is manifest as a tendency of the resulting circulation pattern toward a single gyre streamline pattern, with the sense of rotation corresponding to the sense of rotation of the wind stress curl. Coupled with stratification, wind stress curl can also contribute to the formation of frontal features and upwelling zones (DeSzoeke, 1980, DeRuijter, 1983). Because of the size of the lakes, and their considerable heat capacity, it is not uncommon to see lake-induced mesoscale circulation systems superimposed on the regional meteorological flow, a meso-high in the summer (Lyons, 1971) and a meso-low in the winter (Petterssen and Calabrese, 1959). As mentioned above, there can also be a considerable amount of vorticity imparted to the lake by the normal circulation pattern of an extratropical storm as it passes over the lake. In either case, the two-gyre lake circulation pattern set up by a uniform wind can be distorted or overwhelmed completely by the curl of the wind field.

Spring and summer stratification in the lakes adds a baroclinic component to the lake circulation. Thus, during the thermal bar period, longshore currents frequently form a single cyclonic gyre circulation pattern driven by onshore-offshore density gradients. It is also possible that cross-isobath transport may be induced by the vertical circulation cells accompanying the thermal bar as it moves slowly from shore toward the deeper part of the lake, but no direct measurements of this phenomenon have yet been obtained. The strong horizontal temperature gradient at the bar could also indicate that the bar is acting as a barrier to cross-isobath transport of heat and mass. Any cross-isobath transport would be the result of the combination of slow offshore advection and horizontal diffusion.The period of summer stratification is characterized by opposing currents in the upper and lower layers of the stratified lake which can also contribute to offshore transport.

Another ecologically important response during summer is upwelling. During the period of stratification, significant wind events will cause upwelling of the thermocline along the shore. Upwelling generally occurs on the upwind shore and the shore to the left of the wind direction, as discussed by Csanady (1982). These wind forcings, directly or through Ekman drift, move surface water away from the shore, so that it must be replaced by colder upwelled water. In Lake Michigan, because of its north-south orientation, the greatest upwelling is along the eastern shore resulting from northerly winds, and along the western shore resulting from southerly winds. The scale of the offshore distance over which this upwelling takes place depends on the wind stress and near-shore bathymetry, and is typically on the order of 5-10 km.

The balance of forces in the region of upwelling is between the wind stress, Coriolis force, and internal pressure gradient. When the wind subsides, a new balance of forces must be established. In addition to the topographic wave response discussed above, this results in two types of free internal waves: the Poincare wave and the Kelvin wave. As discussed by Schwab (1977), Poincare waves are a basin wide response with oscillations in the thermocline across the entire lake. The lowest order Poincare wave has maximum wave amplitudes on opposite sides of the lake, with a node at the center. Poincare waves are characterized by anticyclonic phase progression, and their period is slightly less than the inertial period, which is near 17.5 hours for central Lake Michigan. Maximum currents associated with Poincare waves occur in the center of the basin only if the lowest mode is excited. Observations show strong currents at other places suggesting that a complex spectrum of waves fill the basin. Whenever there is stratification in the Great lakes we expect a strong inertial signal. The internal Kelvin wave is the other free internal wave and is described as a coastally-trapped response of the thermocline that progresses cyclonically around the lake. The Rossby deformation radius is the e-folding scale for the amplitude of this wave as a function of distance from the shore. For mid-latitude lakes, the Rossby radius is roughly 3-5 km. The Kelvin wave period is generally much greater than the inertial period. Schwab (1977) calculated the internal free modes of oscillation in a two-layer model of Lake Ontario assuming uniform equivalent depth. The lowest frequency mode was an internal Kelvin wave with a period of 25 days.

All of the mechanisms discussed above can generate cross-isobath currents, however their relative importance to the short-term (episodic) and long-term (seasonal) transport of BIMs is not known. The Lake Michigan experiment and the physical oceanography observations program described here will allow us to determine the potential contribution and importance of a barotropic process for cross-isobath transport that is unique to enclosed basins.

**Objectives**

***It is our hypothesis that the forced, two-gyre vorticity wave response of the lake to episodic wind events, occasionally modified by stratification, is a major mechanism for nearshore-offshore transport in the Great Lakes.***

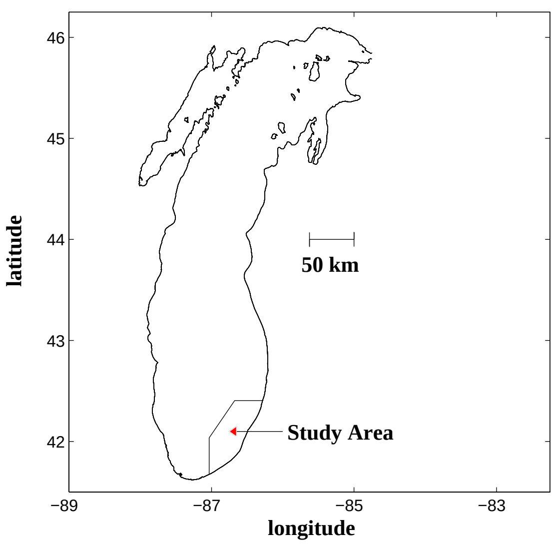
Our program is designed to test this hypothesis through the analysis of a carefully planned field program and the applicaton of numerical models by Schwab and Beletsky as outlined in their circulation modeling proposal.

Our specific objectives are:

(1) To identify and quantify the physical processes generating nearshore- offshore transport of biogeochemically important materials during winter/spring episodic events;
(2) To establish an observation strategy for generating maximum resolution of all the dominant time and space scales;
(3) To estimate the velocity field along and across the plume as it evolves;
(4) To determine the coastal energetics of the two-gyre vorticity wave under barotropic conditions and its response to increasing baroclinicity;
(5) To provide a Lagrangian platform for studying biogeochemical processes in collaboration with other group proposals;
(6) To estimate particle dispersion from Lagrangian statistics and compare with circulation model based estimates to assess model adequacy;
(7) To establish a database of all of our observations and make them easily available to other program participants.

## Approach

The recurrent winter/spring appearance of an extensive coastal turbidity plume in southern Lake Michigan (Eadie et al. 1996) provides us with the opportunity to examine the two-gyre vorticity wave hypothesis during a period when a large volume of suspended material can act as a natural tracer for lake circulation. We plan to exploit this opportunity by concentrating our observation program on the Lake Michigan plume along the southeast coast of the lake where it most frequently appears in AVHRR images to diverge offshore. Figure 2 depicts the study site and the planned mooring locations for both the pilot study (year 1) and the following two field years.



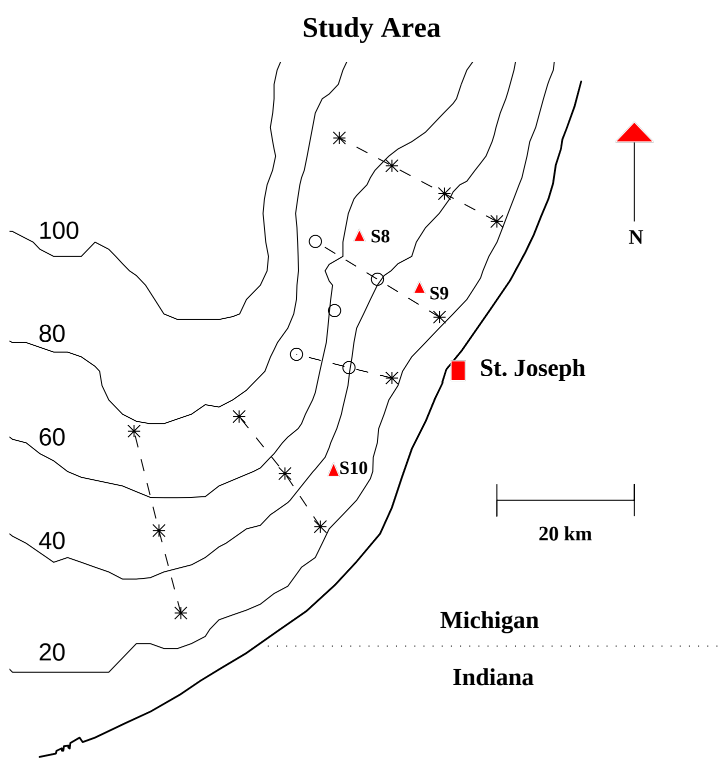




*Fig. 2. Lake Michigan and the proposed study area depicted above and enlarged at the right. Depth contours are in meters, *'s indicate planned VACM moorings, and O's indicate planned ADCP moorings*

Recent work in the study area (Eadie et al., 1996; McCormick, 1996) provide some site specific information on the lake's dynamics. Figure 3 is a plot of daily water intake temperatures from St. Joseph, Michigan (see Fig. 2) from 1960 through 1992. These data are representative of conditions approximately 400 m from the shoreline. During the period from late May through September large temperature variations are evident due to coastal upwelling. Although these upwelling events may be important mechanisms for the offshore/onshore transport of BIMs our proposal will focus primarily on the winter/spring period when the study area shows little or no significant thermal structure.

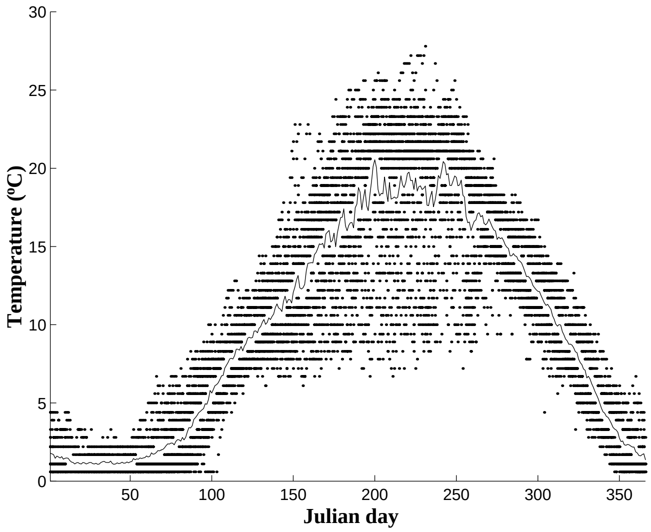
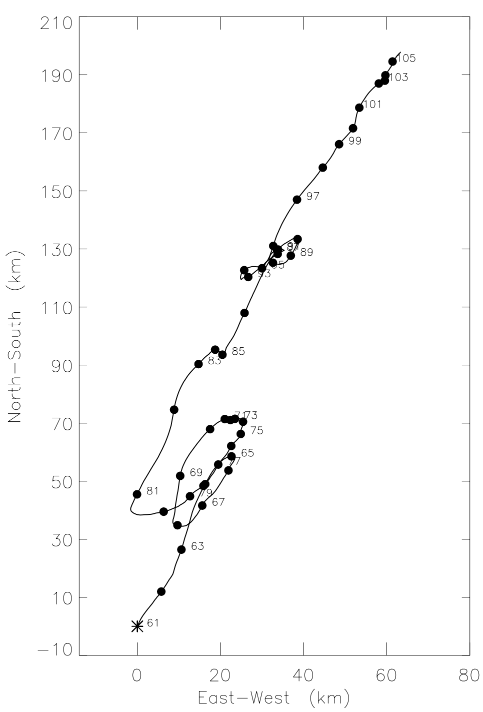



*Fig. 3. Daily water intake temperatures for St. Joseph, Michigan from 1960 through 1992. The solid line depicts the sample mean (McCormick, 1996).*

Figure 4 is a plot of a progressive vector diagram of data taken from a Vector Averaging Current Meter (VACM) that was deployed at S10 (see Fig. 2). The data shown are from 1 March through 14 April 1996. Conditions during this time period were barotropic and the current data in general closely follows the bathymetry. These data also clearly show flow reversals that are consistent with the passage of a vorticity wave and are associated with episodes of offshore - directed flow at this location. A major goal of this proposal is to rigorously examine the dynamics of episodes like this and quantify their contribution to cross-margin transport.




*Observation Strategy*

The observation strategy will consist of three components: (a) moored instruments, (b) Lagrangian measurements, and (c) shipboard surveys. Optimal data coverage also requires data from AVHRR imagery and multifrequency HF radar observations that are proposed by colleagues to complement this work. Three years of field activities are planned with the first year being a pilot study.

*Fig. 4. Progressive vector diagram of VACM data from S10 (see Fig. 2) from 1 March through 14 April 1996. Filled circles are depicted at the beginning of each day.*

*(a) Moored Instruments.* To observe the cross-shore and along-shore physical environment, current velocities and water temperatures will be measured on five coastal cross sections oriented normal to the shelf

bathymetry (see Fig. 2). A total of 17 moorings are planned to be deployed using all available equipment in the GLERL inventory. During the pilot study approximately half of the moorings will be deployed. Alongshore and cross-shore correlations will be studied to ensure that transect spacing during the two intensive field years is adequate to describe both the mean flow structure and the propagation of vorticity or coastally - trapped Kelvin waves.

During the last two field years we plan to measure the alongshore and cross-shore components of flow at five transect locations. The center transect will be located near the bathymetric hump close to St. Joseph, Michigan. The other transects will be placed north and south of this location (see Fig. 2). Of the 17 planned moorings, five will contain a bottom mounted Acoustic Doppler Current Meter (ADCP) and the remaining 12 moorings will contain Vector Averaging Current Meters (VACMs). During the pilot study year only four ADCPs will be used. The fifth ADCP will be upgraded by the manufacturer in order to reduce power consumtion and the need for lithium batteries and the problems associated with their use and the damage risk they pose to the instrument should the batteries leak. All five ADCPs will be used during the remaining two field years. A thermistor string will be deployed at each ADCP site. An additional 1200 KHz ADCP will be purchased and deployed near one of the shallow, 600 KHz ADCP moorings. The backscatter data from these two ADCPs will be used by Bedford and McDonald, in cooperation with other investigators, to calculate the vertical particle concentration profile. Specific details can be found in their proposal.

Moorings consisting of two VACMs are adequate to describe currents and water temperatures during periods when the water column is vertically well mixed, i.e., during the winter and early spring period when the coastal turbidity plume exists. A total of 24 VACMs will be deployed on 12 subsurface moorings. The subsurface moorings are necessary to avoid problems due to shipping and ice rafting. One VACM will be attached at the bottom of each mooring to measure close to the bottom (+1 m above the bottom) currents and temperatures to determine the frequency and magnitude of near-lake-floor cross shelf flow. An additional meter will be deployed approximately 12 m below the surface. Each VACM is also equipped with a thermistor and additional self-contained thermistor/data loggers will be added to the moorings with funds requested in this proposal.

Data will be sampled at 15 minute time intervals for the VACMs and ADCPs. The ADCPs we now have will measure current velocity profiles throughout 85% to 94% of the water column at 1 m vertical resolution. In order to be prepared for the pilot study in late winter 1997-98 the moorings will be deployed during October 1997 with GLERL's research vessel. For all three measurement years the moorings will be deployed in September or October and left in place until June of the following year. Full deployments are necessary to monitor the late winter plume because in some years the plume occurs prior to the navigation season. The instruments will be in place to monitor the development and offshore progression of spring thermal fronts and will also experience episodes of upwelling/downwelling in the fall.

*(b) Lagrangian Measurements.* This portion of the observational program is designed to make quasi-Lagrangian current measurements with satellite-tracked drifters. Together with the moored instruments and shipboard surveys information will be gathered on the velocity and temperature fields over broad time and spatial scales. This is necessary for both a comprehensive examination of the circulation and mixing and for evaluating hydrodynamic model simulations. The drifter trajectories will also be useful in identifying the offshore plumes during cloudy periods when the AVHRR images are not available (approximately 75% of the time according to Schwab et al., 1992).

Our objective is to provide a detailed description of the flow field (the currents, vorticity and convergence patterns and the net offshore transport of water) and understanding of its dynamics during the winter/spring transition in southern Lake Michigan. These observations will complement the other areas of this proposal and the biogeochemical proposals by: 1) providing estimates of the currents across and along the plume as it evolves; 2) being the only component of the proposed study which is capable of obtaining velocity fields over the entire domain of interest (i.e. we will be able to measure the plume and filaments no matter where they are located); 3) providing Lagrangian information which will allow us to evaluate the role of advection; 4) providing current observations to test model adequacy during the winter/spring transition period; and 5) providing a Lagrangian platform for studying biogeochemical processes.

Our primary instruments to measure the near-surface circulation will be the CODE-type drifters and the GLERL GPS/ARGOS drifters. Both of these drifters were designed to accurately follow the currents in the presence of winds and surface waves and the CODE-type drifters have been extensively tested in laboratory wind-wave tanks (Davis, 1985a). The GLERL GPS/ARGOS drifters are recent designs with a thermistor string (Muzzi and McCormick, 1994) based upon experience gained from mini-TOD drifters (McCormick et al., 1985) and sonobuoy type drifters (McCormick et al., 1991). In order to minimize slippage concerns the two drifter types will be configured with identical drogues and their buoyancy will be adjusted as necessary to insure similar aspect ratios (cross-sectional area of buoy and drogue below water/ cross-sectional area above water).

During the pilot study year we plan on purchasing ten CODE type drifters and deploying them from a research vessel during the plume event. Should the timing of the cruise not coincide with particular plume events we wish to study then the drifters will be deployed from a U.S. Coast Guard helicopter. To aid investigators studying plume materials and chemistry three of the GLERL drifters will be modified and tested in the pilot year. Modifications will be made to accommodate a sequential sediment trap on one drifter, a sequential water sampler on another, and a CTD, fluorometer, and transmissometer on the third one. These instrument packages will then be deployed in the plume during the following two field years and should be useful for better isolating biogeochemical processes from the physics.

An additional 20 CODE type drifters will be purchased for use in the two remaining field seasons. During years two and three all available drifters will be deployed from research vessels or USCG helicopters during the cruise periods to characterize the near surface circulation and determine the surface pathways of particles. GPS positions will be fixed every 10 minutes, recorded internally, and broadcast over ARGOS to aid tracking and recovery. During deployment we will rely on AVHRR, satellite images, and possibly circulation model simulations so that drifters adequately sample the circulation associated with the coastal current, the offshore filaments and their surroundings.

Particular attention will be paid to the convergence associated with the offshore flow, the mean currents associated with it and how flow is returned to the coast. Do drifters travel in large - scale gyres, smaller scale meanders and eddies, or does the shorter scale turbulence dominate the motion? Attention will also be paid to the circumstances under which drifters are able to cross the thermal bar should it develop during the study periods.

In addition to providing the approximate surface paths of particles, estimates of the strain field (divergence and vorticity) can be obtained when a minimum of three drifters are deployed and treated as a cluster (e.g. Molinari and Kirwan, 1975; Okubo and Ebbesmeyer, 1975 ; Paduan and Niiler, 1990). In practice, clusters of more than three drifters are typically used to determine horizontal gradients of the mean motion in order to test the adequacy of the method with smaller subsets of the cluster. In each of the field years one or more cluster experiments will be performed.

Several statistics are of interest including how often and by what means particles leave the coastal region, dispersion of particles about a mean path and single particle diffusivities. We will also calculate the Lagrangian decorrelation time scale of the velocity. A comparison of the

Lagrangian and Eulerian time scales will allow us to assess the importance of nonlinear advection of momentum compared to other ageostrophic terms (Davis, 1985b; Brink et al., 1991).

We will also compare the dispersion predicted by the primitive equation model by comparing these statistics with statistics based upon trajectories from the model. Since we expect the field data to not agree exactly with the model, it is of interest to determine if these differences are significant and whether we can statistically describe these differences. Such comparisons will allow us to consider the model adequacy and possibly to suggest improvements in the prediction of near surface currents and particle dispersion. In particular, small scale mixing fields might be different because of horizontal diffusivities required in the model and due to assumptions in the turbulence closure scheme employed.

*(c) Shipboard Surveys.* Shipboard surveys will be limited to CTD surveys and toyoing data on temperature and transparency made with a V-Fin and Optical Plankton Counter (OPC). The OPC instrument will be used extensively by colleagues proposing zooplankton work and their transparency and temperature data will be readily available to us. We are proposing to share the V-Fin platform in order to contain costs and consequently have included the associated V-Fin costs in our budget. These data in conjunction with all of the other observational data will enable us to define and track the evolution and decay of the offshore and coastal plumes with high precision. It should also be pointed out that no shipboard ADCP work is required to meet our objectives.

Vessel mounted ADCP surveys are most useful in regions where strong current shear exists, where circulation features of interest persist in time, and the magnitude of the velocity is sufficiently large that the signal/noise ratio is large enough to justify a vessel survey. In the work proposed here none of these conditions are compelling enough to justify the cost of obtaining this kind of data that can be more effectively obtained through other means already discussed. The current shear is primarily limited to the horizontal and not vertical because of the barotropic conditions that prevail. Analyses of Figure 4 data further suggest that in order to provide an adequate signal/noise ratio for valid ADCP data the vessel would be required to stop to allow suitable time averaging of the signals and would be restricted to slow speeds for resolving larger spatial scale features. These vessel sampling requirements would be too restrictive to justify the added expense.

Undoubtedly as new information on the sources of the water in the plume (determined from in situ biological and geochemical measurements as well as the current measurements) is revealed during the field program, new questions will arise, which may require modification of our sampling strategies.

**Work Plan**

Each PI will share equally in the responsiblity for all of the proposed work. In particular, Saylor and Miller will oversee efforts regarding the moored instruments and McCormick will oversee the Lagrangian measurements and shipboard surveys.

<u>Year 1  1998 (Pilot Year)</u>

- October 1997  Deploy 9 moorings in the vicinity of St. Joseph, MI.
- February - April 1998  Drifter experiments for physics and biology, and shipboard surveys,
- June - August 1998  Retrieve all instruments and assess sampling strategy.

<u>Year 2  1999</u>

- September 1998  Deploy 17 current meter moorings (24 VACMs, 5 ADCPs),
- February - April 1999  Drifter experiments with all drifters for physics and biology, and shipboard surveys,

- June 1999  Retrieve all instrumentation,
- January - December 1999  Process, archive and analyze data.

Year 3  2000

- September 1999  Deploy 17 current meter moorings (24 VACMs, 5 ADCPs),
- February - April 2000  Drifter experiments with all drifters for physics and biology, and shipboard surveys,
- July 2000  Retrieve all instrumentation,
- January - December 2000  Process, archive and analyze data.

Year 4  2001

- January - December  Complete all data archiving and data analyses.
- January - December  Synthesize all physical data and prepare journal articles

Year 5  2002

- January - December  Integrate all interdisciplinary data and participate in their interpretation and journal publication in joint cooperation with other program investigators.

## Relevant Experience Related To This Proposal

GLERL and the principle investigators of this proposal have a long record of physical measurements experience related to the submission of this proposal.  Dr. Saylor was the principal U.S. organizer of the water movements program in Lake Ontario performed as a major part of the International Field Year on the Great Lakes (IFYGL) in 1971 and 1972.  He was responsible for the design, testing, and operation of a large array of real time reporting moorings located throughout the U.S. waters of the lake that were configured to measure the over-water meteorology in addition to vertical profiles of currents and water temperature.  This effort was funded under the International Hydrologic Decade program and was the first really successful program of lake-scale physical limnological measurements performed jointly with U.S. and Canadian government participation.  Following IFYGL, Saylor and Miller directed GLERL's participation in a long series of lake-scale water temperature distribution and current and measurement programs performed jointly with colleagues at the Canada Centre for Inland Waters.  A study of the currents and circulation in Lake Huron was funded by the International Joint Commission as was a similar program in Lake Superior.  The hydrodynamics of Lake Erie were studied in a bi-national study performed in 1979 and 1980.  A large inventory of Vector Averaging Current Meters was acquired from these externally funded programs and are available for use in Lake Michigan.

Regional studies of currents and circulation have been supported by numerous EPA grants and federal government inter-agency agreements.  Investigations of hydrodynamic processes in the Straits of Mackinac, Saginaw Bay, Green Bay, and Lake Michigan have been performed.  The writers of this proposal are currently active in a congressionally mandated study of the physics of the Lake Champlain water masses.  In summation, the GLERL investigators have played important roles in nearly all Great Lakes hydrodynamics measurement programs of the past 25 years, except those performed regionally by the Canada Centre.  An extensive inventory of modern equipment and personnel experienced in Great Lakes studies can be committed to this research effort.

Dr. McCormick has broad experience with physical based field measurements and numerical modeling studies involving both physical and purely biological problems.  His experience with Lagrangian measurements began with conducting dye experiments in 1983 to quantify the water tracking ability of early GLERL drifter/drogue configurations. The early work with drifters led to participating in the design of a new GLERL GPS/ARGOS drifter and work with U.S. Navy scientists on prototype models. Because of the improvements in both drifter technology and numerical techniques for reconstructing flow characteristics from quasi-Lagrangian data from eddy on up to basin-wide scales, we will be able to maximize the potential benefit of these data to understanding cross-margin processes.

Outside funded research has focused on biological modeling activities related to the Gulf of Mexico for the NOAA/COP and on physical based modeling studies related to climate change issues in the Great Lakes. The Great Lakes work was part of a nation wide study that was mandated by congress and organized by the EPA's Office of Policy and Planning. Additional climate related research funded by NOAA's Office of Global Programs was conducted in the Great Lakes to determine if regional climatic trends were present in historical water intake temperature data sets.

The breadth of these experiences directly contributes towards skills for making this and related proposals fully successful.

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