

# Episodic Events: Great Lakes Experiment

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## Overview

In August, 1997 the NOAA-Coastal Ocean Program and National Science Foundation-Coastal Ocean Processes program began a jointly funded study of the impact of episodic events on episodic sediment resuspension and constituent transport and subsequent ecological effects in Lake Michigan. This study was scheduled to include three field years and two years of subsequent interpretation and product development (1998 - 2003). Program components include a retrospective analysis of satellite imagery, water intakes, and other historical data, process and survey cruises, moored current meters, traps and data acquisition instruments and coupled hydrodynamic/sediment transport/ecological modeling.

**Program Goal:** to create an integrated observational and numerical modeling program for the winter-spring resuspension event(s) and to assess their impact on the transport and transformation of biogeochemically important materials and on lake ecology. Three fundamental hypotheses focus this program:

**Hypothesis 1:** The plume is a result of the first winter-spring storm after ice-out and represents the resuspension of particulate materials (and associated constituents) that have been stored in the lake as surface sediment "floc" for a distribution of times, during which they have undergone differential diagenesis.

**Hypothesis 2:** 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 of particulate matter and associated constituents in the Great Lakes.

**Hypothesis 3 :** Physical processes, (e.g. resuspension, turbulence) associated with the plume event are important in determining the nutrient and light climate, and in structuring the biological communities throughout the spring isothermal period, and in setting the conditions for the critical 'spring bloom' period.

**Issue:** A tight coupling between contaminated sediments and overlying water exists in lakes and coastal ecosystems through the process of sediment resuspension. Recent satellite observations of suspended sedimentary material in Lake Michigan illustrate a unique opportunity to investigate an annually recurrent major episode of nearshore-offshore transport, a 10 km wide plume of resuspended material extending over 300 km along the southern shores of the lake. The plume appears to be initiated by a major late winter storm after the melting of surface ice, and it eventually veers offshore along the eastern shore of the lake, coincident with the area of highest measured sediment accumulation in the lake. The inventory of particulate matter in the plume, on April 2, 1996, is approximately equal to the total annual load of fine sediments into the southern basin. Preliminary evidence indicates that this episodic event may be the major mechanism for cross-margin sediment transport in Lake Michigan. We believe this type of event is ideal for studying internal recycling of biogeochemically important materials

(BIMS), ecosystem responses, and one of the major processes controlling cross-isobath transport in the Great Lakes. While we are focusing on a particular episodic process in southern Lake Michigan, the program results will be applicable to similar events in many coastal areas.

**Significance:** The episodic resuspension and subsequent transport of surface sediments profoundly influences biogeochemical processes in coastal ecosystems. Resuspension and transport of the large inventories of nutrients and contaminants deposited over the past few decades (e.g. P, 137Cs, PCBs), presently results in much greater fluxes to the water column than from all external inputs. In addition, control of biological processes can occur as a result of effects on light and substrate availability and the introduction of meroplanktonic species. The magnitude and episodic nature of these processes in the Great Lakes has been poorly described from a few point measurements or as the residual term in mass balance models. This multi-disciplinary project will employ a comprehensive measurement and modeling approach to examine and compare effects of episodic physical forcing in relation to more persistent long-term (i.e., seasonal meteorological) forcing on nutrient inventories, fluxes and distributions, and on biological distributions and rate processes. The results of this proposed research will improve our understanding of critical processes and support the development of a resource management-oriented information and modeling system.

#### **2004 Accomplishments**

Chen, C., L. Wang, R. Ji, J.W. Budd, D.J. Schwab, D. Beletsky, G. Fahnenstiel, H. Vanderploeg, B. Eadie, and J. Cotner. (In Press) Lower Trophic Level Food Web Dynamics in Lake Michigan: A Comparison Between the 1998 and 1999 Plume Events. *J. Geophys. Res.*

Chen, C., L. Wang, J.W. Budd, D.J. Schwab, D. Beletsky, H. Vanderploeg, B. eadie, J. Cotner, and P.J. Lavrentyev. (In Press) Role of benthic flux in the ecosystem dynamics of Lake Michigan. *J. Geophys. Res.*

Hornbuckle, K.C., G.L. Smith, S.M. Miller, B.J. Eadie, and M.B. Lansing. ( In Press) Resuspension of PCBs and DDT in Southern Lake Michigan. *J. Geophys Res.*

Kerfoot, W.C., J.W. Budd, B.J. Eadie, H.A. Vanderploeg, and M. Agy. (In Press) Winter storms and community memory: Sequential sediment traps record *Daphnia* ephippial production, resuspension, and burial. *Limnol. Oceanogr.*

Rao, Y. R., M. J. McCormick, and C. R. Murthy. Circulation during winter and northerly storm events in southern Lake Michigan. *Journal of Geophysical Research* 109(C1):C01010 (2004).

#### **2003 Accomplishments**

Great Lakes Issue Identification Workshop, Univ. of Michigan, January 2003

Beletsky, D., D. J. Schwab, R. P. Roebber, M. J. McCormick, G. S. Miller and J. H. Saylor. Modeling wind-driven circulation during the March 1998 sediment resuspension event in Lake Michigan. *Journal of Geophysical Research* 108(C2):20-1

Gardner, W.S., P.J. Lavrentyev, J.F. Cavaletto, M. McCarthy, B.J. Eadie, T.H. Johengen, J.B. Cotner. 2003. The distribution and dynamics of nitrogen and microbial plankton in southern Lake Michigan during spring transition 1999-2000. *J. Geophys. Res* (8, 9, 12)

Murthy, R. C., R. Y. Rao and M. J. McCormick. Circulation in southern Lake Michigan during winter season and during northerly storm episodes. *Proceedings of the Fourth International Lake Ladoga Symposium 2003*, University of Joensuu, Joensuu, Finland, Publications of Karelian Institute, 138:84-89 (2003).

Schwab, D. J., and D. Beletsky. Relative effects of wind stress curl, topograph, and stratification on large scale circulation in Lake Michigan. *Journal of Geophysical Research* 108(C2):26-1 to 26-6 (2003).

## **2002 Accomplishments**

McCormick, M. J., G. S. Miller, C. R. Murthy, Y. R. Rao, and J. H. Saylor. Tracking coastal flow with surface drifters during the episodic events: Great Lakes experiment. *Verh. Internat. Verein. Limnology* 28:365-369 (2002).

Miller, G. S., M. J. McCormick, J. H. Saylor, R. C. Murthy, and Y. R. Rao. Temporal and spatial variability of the resuspension coastal plume in southern Lake Michigan inferred from ADCP backscatter. *Verh. Internat. Verein. Limnol.* 28:513-518 (2002).

Murthy, C. R., Y. R. Rao, M. J. McCormick, G. S. Miller, and J. H. Saylor. Coastal exchange characteristics during unstratified season in southern Lake Michigan. *Verh. Internat. Verein. Limnol.* 28:299-302 (2002).

Rao, Y. R., C. R. Murthy, M. J. McCormick, G. S. Miller, and J. H. Saylor. Observations of circulation and coastal exchange characteristics in southern Lake Michigan during 2000 winter season. *Geophysical Research Letters* 29(13):9-1 to 9-4 (2002).

Bogdan, J. J., J. W. Budd, B. J. Eadie, and K. C. Hornbuckle. The effect of a large resuspension event in southern Lake Michigan on the short-term cycling of organic contaminants. *Journal of Great Lakes Research* 28(3):338-351 (2002).

Chen, C., R. Ji, D. J. Schwab, D. Beletsky, G. L. Fahnenstiel, M. Jiang, T. H. Johengen, H. A. Vanderploeg, B. J. Eadie, J. W. Budd, M. H. Bundy, W. Gardner, J. Cotner, and P. Lavrentyev. A model study of the coupled biological and physical dynamics in Lake Michigan. *Ecological Modeling* 152:145-168 (2002).

Eadie, B. J., D. J. Schwab, T. H. Johengen, P. J. Lavrentyev, G. S. Mo;er, R. E. Holland, G. A. Leshkevich, M. B. Lansing, N. R. Morehead, J. A. Robbins, N. Hawley, D. N. Edgington, and P. L. VAN HOOFF. Particle transport, nutrient cycling, and algal community structure associated with a major winter-spring sediment resuspension event in southern Lake Michigan. *Journal of Great Lakes Research* 28(3):324-337 (2002).

Millie, D. F., G. L. Fahnenstiel, H. J. Carrick, S. E. Lohrenz, and O. M. E. Schofield. Phytoplankton pigments in coastal Lake Michigan: Distributions during the spring isothermal period and relation with episodic sediment resuspension. *Journal of Phycology* 38:639-648 (2002).

Ji, R., C. Chen, J. W. Budd, D. J. Schwab, D. Beletsky, G. L. Fahnenstiel, T. H. Johengen, H. A. Vanderploeg, B. J. Eadie, J. Cotner, W. Gardner, and M. Bundy. Influences of suspended sediments on the ecosystem in Lake Michigan: A 3-D coupled bio- physical modeling experiment. *Ecological Modeling* 152:169-190 (2002).

Lesht, B. M., J. R. Stroud, M. J. McCormick, G. L. Fahnenstiel, M. L. Stein, L. J. Welty, and G. A. LESHKEVICH. An event-driven phytoplankton bloom in southern Lake Michigan observed by satellite. *Geophysical Research Letters* 29(8):18-1 to 18-4 (2002).

### **Special Sessions**

1. Ocean Sciences, Honolulu, HI, Feb 2002
2. IAGLR - 03 Chicago, June 2003

### **Two final field efforts were also completed:**

Eadie and others - retrieved profiles of traps deployed at the centers of the northern and southern basins. This completed EEGLE-related trapping and two years of detailed water column profiles of fluxes. We were unable to accomplish this during the main EEGLE field years because traps were deployed elsewhere.

Fahnenstiel and others - conducted a two-week bio-optical cruise that could not be completed as scheduled in 2000.

### **2001 Accomplishments**

Major effort this year was focused on interpretation of data and development of products, including data bases, models, papers, and reports. The figure and table below illustrate the sampling success during the period 1998-2000.

Special Sessions were held at:

- SIL, Melbourne, Australia, Feb, 2001
- Ocean Sciences, Honolulu, HI, Feb., 2002

EEGLE All-hands meetings (3 day workshops) were held at

- Argonne National Lab, Dec, 2000
- Houghton, MI, Sep 2001

Some of the preliminary conclusions reached at recent EEGLE workshops include:

1. the magnitude of resuspended sediments is in the range of 1-5MMT, larger than annual external input of fine-grained materials to the southern basin,
2. resuspended total phosphorus is several times the annual external input, but only a small fraction appears to be available for primary production,
3. the reduction of light in the plume counteracts the increased nutrients and results in somewhat reduced productivity,
4. the ecological impacts (e.g. greatly increased heterotrophy) may be localized to the region near the plume, and
5. the events generally include substantial offshore transport.
6. further information can be obtained at the EEGLE website.

### **2000 Accomplishments**

The field program for 2000 was similar to 1999 efforts, although an extra nearshore-offshore sampling transect south of the St. Joseph River was added. One additional ADCP current meter and four additional sequencing traps were added to the measuring grid in southeastern Lake Michigan. The ROV sediment-interface sampling program will pursue less spatial coverage than 1999, but with much higher temporal frequency. This was the third and final year of field work for the program. There were two major spring events and sampling was very successful. The following bar graph and table describe the periods of time and numbers of samples collected throughout the three year field program.

### **1999 Accomplishments**

The winter-spring sediment resuspension events were smaller in 1999 than the very large 1998 events. Preliminary results from 41 EEGLE cruises totaling over 160 ship days during FY 99 confirm the fact that ice is not needed to create conditions necessary for massive spring sediment resuspension. We also have evidence of strong events in the fall as well as the spring and that the magnitude of event surrogates (water intake and other monitoring data) have ranged over an order of magnitude over the past 40 years. The immediate impacts of the spring resuspension event seems to be a reduction in primary productivity, due to low ambient light and high attenuation by the elevated concentration of particulate materials. Heterotrophic production however is very high in the region of the plume, exceeding autotrophic production. This implies that the bacteria can use the carbon provided by the resuspended sediments.

Data from the 27 moored current meters captured evidence supporting the hypothesis that the longshore convergence, near St. Joseph, MI, is associated with the forced, two-gyre vorticity wave, giving rise to offshore transport of resuspended materials. Preliminary hydrodynamic model results indicate qualitative agreement with these observed currents and long-term sediment deposition patterns. Over 150 sediment trap samples of mass flux clearly show that the materials resuspended by the winter-spring events are transported out into the center of the southern basin. These data support the major thesis within the program, that sediment-water coupling during large storms prior to thermal stratification strongly influences the nutrient and contaminant conditions for the water column for the remainder of the year.

## **1998 Accomplishments**

During this first year, the program was fortunate to have the opportunity to examine the largest event in the 37 year record of intake turbidity from the St. Joseph, MI water treatment plant. Although not scheduled to be a full field year, efforts were made to exploit the opportunity of examining this rare event. A total of 38 cruises on four different vessels totaling approximately 120 days and a 1 day Coast Guard helicopter drifter deployment flight have been completed. In addition to extensive sampling of the plume and background environments, several new instruments underwent testing during this first year, some with immediate success, while others are still going through modifications. Fourteen single point current meters plus four acoustic doppler current meters (ADCP), which measure profiles of currents, and eleven sequencing traps (230 samples of settling particles) provided good coverage of the 1998 event in the southeastern region of the lake. A complementary study of the importance of these events to the cycling of PCBs and other trace organics has been funded through the EPA-Great Lakes National Program Office. They have also provided time aboard their 180 foot research vessel, the R/V LAKE GUARDIAN, making winter-spring work safer and more efficient. Preliminary results from field studies and calibration runs of the comprehensive modeling efforts were presented at an October, 1998 program workshop. Preliminary findings from our efforts include: (1) high particle, nutrient and organic matter fluxes are associated with the event and synchronized throughout the basin, (2) low primary production (due to light limitation) was measured in the plume region, elevated rates of bacterial productivity, and elevated PCB concentrations within the plume region. Further information can be obtained from the program's web page.



**Table 1: EEGLE Cruise, Web, & Data Statistics as of November, 2001**

	1997 – 2000
Cruises	127
Total Days	459
Water Samples	835
Plankton Survey Tows	124
Trap Samples	816
Current Meters	66
Drifter Days	690
Papers	46
Presentations-Public	50
Presentations-Professional	145
Data Objects Submitted	1482 (612 MB)
Visits to EEGLE Web Site	93,601