

Development of Recurrent Coastal Plume in Lake Michigan Observed for First Time

NOAA CoastWatch satellite imagery from early 1996 captured the initiation, development, and decay of a recurrent coastal plume in southern Lake Michigan (Figure 1). For the past 4 years intermittent satellite coverage has revealed a late winter-early spring plume in the lake, a feature also observed by Mortimer [1988]. In 1996, clear weather conditions allowed researchers to observe the plume's development for the first time and they also collected water samples from heliicopter and a small boat.

Preliminary results imply that the reflective substances in the plume comprise a substantial fraction of the total particle load to the lake and are similar to silty-clay materials eroding from bluffs along the shore of Lake Michigan or from exposed glacial clay deposits in shallow waters. Since these fine-grained materials are excellent substrates for sorption, this episodic event will play an important role in scavenging particles of contaminants such as PCBs from the lake waters to be absorbed by the sediments. The plume also plays a substantial role in phosphorus (P) cycling, thus it is important in the

development of the spring diatom bloom and subsequent production. Finally, the offshore eddies in the southeastern portion of the plume coincide with the area of maximum sediment accumulation in the lake, which implies that this event plays an important role in depositional patterns and subsequent sediment-water interactions.

The onset of the plume coincided with the disappearance of ice in the southern basin in late March, and with the occurrence of a major storm with strong northerly winds. Northerly winds can generate large waves in the southern part of the lake and currents that tend to run southward along the east and west coasts of the southern basin. These currents typically converge to produce offshore flow somewhere along the southeast shore; the exact location depends on the strength, direction, and duration of the wind. Within a few days, the plume was approximately 10 km wide and over 100 km long, implying that the source of the reflective materials is widely distributed alongshore. The feature persisted for over a month. Wind direction was predominantly from the north during this period. The few clear satellite images of the plume from previous years suggest that this year's plume may have persisted longer than usual.

Water temperature estimated from the thermal band in the satellite imagery was nearly uniform at about 1°C throughout the southern basin. Conductivity-temperature-depth (CTD) profiles to depths of up to 60 m in the

plume revealed constant temperature and transparency. Only at one station, located visually at the edge of the plume, did transparency decrease significantly with depth, implying that some of the sediment settled and was transported offshore. Total suspended matter (TSM) ranged from 4-10 mg/L at 4 plume stations, compared with an average of 1 mg/L measured at background stations. A correlation of surface TSM and channel I reflectance was used to estimate the TSM over the entire plume area as recorded in the April 1 satellite image. We conservatively calculate 3×10^5 tons of TSM, 25% of the estimated annual load of 'mud' to the southern basin [Colman and Foster, 1994].

P is the least abundant nutrient in the Great Lakes, which generally limits the primary productivity of biota. High concentrations of particulate and available P measured within the plume imply either an unidentified external source of considerable significance or undescribed internal nutrient dynamics. Chlorophyll ranged between 1.4 and 1.8 $\mu\text{g/L}$ for all samples, with levels within the plume 1214% below open lake concentrations. Biomass of diatoms that dominated the phytoplankton at this time was greatest in the plume. A small ($\sim 7\mu\text{m}$) centric diatom accounted for over 50% at all stations, however significantly higher numbers of *Stephanodiscus parvus*, usually associated with elevated nutrient conditions, were observed within the plume. The microbial community (picocyanobacteria, bacteria, and protozoa) was highest at the edge of the plume. These results

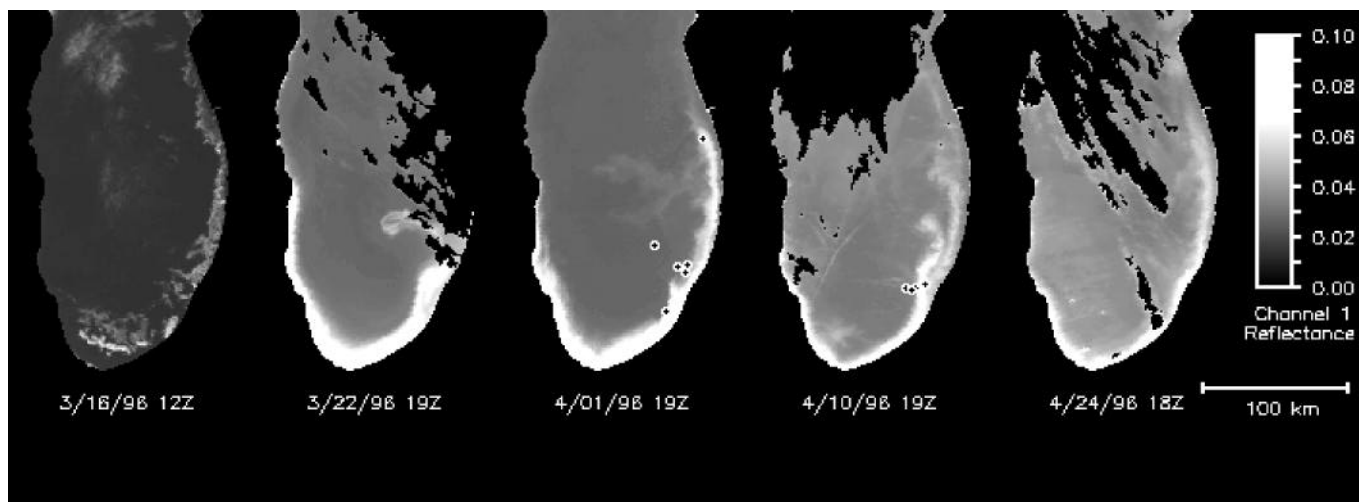


Fig. 1. Visible band satellite imagery of southern Lake Michigan. On March 16, the NOM 12 (morning) AVHRR Channel 1 satellite image shows shore-fast ice along the eastern shore of the southern basin and large ice floes at the south end of the lake. After several days of warming temperatures and strong northerly winds, the March 22 NOM 14 (afternoon) image shows the presence of a highly reflective plume that appears to originate along the southwestern shoreline and extend eastward along the southern shore. On April 1, a helicopter was used to collect five samples from the plume region and one sample and two conductivity-temperature-depth profiles were collected from Tom ship further north. A subsequent set of four samples and conductivity-temperature-depth profiles were collected by small boat on April 10. Sampling locations are marked by crosses. By April 24, the plume extended along the entire eastern shore, but the intensity was considerably diminished. The majority of the western shoreline is composed of silty-clay bluffs [Jibson et al., 1994], while the southern shore is highly industrialized with extensive man-made features. The eastern shore is primarily sandy beaches backed by dunes. The pattern of sediment accumulation is highly asymmetric; the western and southern regions do not accumulate recent sediments, while the highest sediment accumulation in the lake is on the southeastern slope (coincident with the eddy features in the figure) and not in the deep central region. Clouds are masked out on the March 22, April 10, and April 24 images.

suggest that the plume region is promoting biological activity.

Several potential tracers were analyzed to identify the source of the TSM in the plume. The low organic carbon and high C/N ratios compared to the open lake values were similar to a bluff sample from the western side of the lake. The $\delta^{15}\text{N}$ of the organic matter in the plume also resembled bluff material as well as samples measured deep in lake cores; more recent, anthropogenically impacted core materials are significantly different. TSM in the plume had a lower activity of ^{137}Cs than background TSM or recent fine-brained sediments that still contain the signature of this fallout radionuclide from the early 1960s.

These preliminary compositional results are consistent with silty-clay materials eroding from bluffs along the shore of Lake Michigan or from exposed glacio-lacustrine clays in shallow waters. The initiation of this event may signal the breakup of the nearshore ice complex as a result of the March 20 storm and resuspension of materials temporarily stored in

the coastal region. In addition to the plumes' impact on the cycling and transport of nutrients, it may also provide material to the benthic nepheloid layer that plays a major role in the coupling of the constituents in surface sediments with overlying lake water throughout the year.

The timing of the event relative to lake warming and increased solar irradiance will be important in the development of the spring diatom bloom and subsequent production. Biological recycling of nutrients within the upper layer of the water column is very efficient. The nutrients present in this layer when the lake thermally stratifies is the fuel that determines the magnitude of annual productivity.—*B. J. Eadie, D. J. Schwab, R. A. Assel, N. Hawley, M. B. Lansing, C. S. Miller, N. R. Morehead, J. A. Robbins, and P. L. Van Hoof, NOM Great Lakes Environmental Research Laboratory, Ann Arbor, Mich.; G. A. Leshkevich, NOM Great Lakes Environmental Research Laboratory, Ann Arbor, Mich., and Air Station Traverse City, US. Coast Guard*

Ninth District, Traverse City, Mich.; T. H. Johengen and P. Lavrentyev, Cooperative Institute for Limnology and Ecosystem Research, Ann Arbor, Mich.; and R. E. Holland, University of Michigan, Atmospheric, Oceanic and Space Sciences, Ann Arbor, Mich.

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