

Sediment Resuspension near the Keewenaw Peninsula, Lake Superior during the Fall and Winter of 1990-1991

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Introduction

The Keewenaw current is one of the most pronounced features of the circulation of Lake Superior. This coastal current flows along the north shore of the Keewenaw peninsula (Fig. 1) with a net transport to the east. There is a general belief that the presence of the current enhances the alongshore and inhibits the cross-shelf movement of terrestrial inputs. The effects of the current are also seen on the lake floor, where side-scan sonar studies have shown numerous furrows oriented parallel to the prevailing flow (Flood 1989). However no direct observations of sediment resuspension and transport have been reported. This poster describes some observations of sediment resuspension made in the fall and winter of 1990-1991.

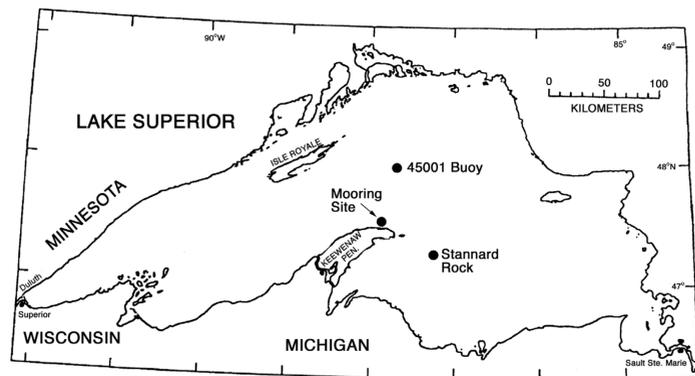


Figure 1. Location of the moorings, NOAA buoy 45001, and the meteorological station at Stannard Rock.

Methods

Two moorings were deployed on August 22, 1990 about 1 km offshore of Copper Harbor, Michigan in 91 m of water (Fig. 1). The deployment sites are located near the tip of the Keewenaw Peninsula and at the eastern end of the furrow field described by Flood (1989). Bathymetric contours in this area are essentially parallel to the shoreline (which runs east-west) to about 90 m. The lake deepens quickly to this depth (the 90 m contour is only about 1 km offshore), but farther offshore the slope lessens and the bathymetry becomes more irregular. On one mooring, vector averaging current meters (VACMs) measured current velocity and water temperature at 10 and 15 m above the bottom (mab). Beam attenuation (at 0.9, 5, 10, and 20 mab), temperature (at 0.9, 5, and 10 mab), and current velocity at 0.5 mab were measured at the other mooring (a bottom-resting tripod). Both the moorings were retrieved in June 1991, but since the tripod tipped over on January 10, 1991, only data collected prior to that date is reported.

Table 1. Storm Conditions

Storm #	Dates	Current Direction	Maximum Combined Stress (N/m ²)	Wave Stress (N/m ²)	Current Stress (N/m ²)	Resuspension
1	Sept 21-27	Varies	0.04	0.00	0.03	No
2	Oct 3-8	Varies	0.06	0.00	0.03	No
3	Oct 16-19	East	0.04	0.04	0.00	No
4	Nov 3-7	East	0.08	0.00	0.08	No
5	Nov 9-15	East	0.14*	0.00	0.09*	Yes
			0.20	0.00	0.12	
6	Nov 22-28	East	0.07*	0.01*	0.02*	Yes
			0.25	0.00	0.15	
7	Nov 29-Dec 4	East, Northwest	0.05	0.00	0.03	No
8	Dec 8-12	East	-	-	0.06	No
9	Dec 14-17	East	-	-	0.02	No
10	Dec 23-30	East	-	-	0.02*	Yes
					0.15	
11	Jan 1-8	East	-	-	0.05*	Maybe
					0.22	
					0.09*	

* indicates values at which resuspension began. Values of current and wave stresses are those at the time of the maximum combined stress. Stress values of less than 0.005 N/m² are reported as 0.00.

Results

Eleven storms (identified from the current velocity records) occurred during the deployment (Table 1, Figs. 2 and 3). Current speeds were low until the end of September when the first of the three storms responsible for the breakdown of the thermocline occurred. Eight other major storms occurred after the breakdown of the thermocline. Although the speeds at 25 mab during the last eight storms are similar to those during the first three storms, the bottom speeds are considerably greater. During the four largest storms (storms 5, 6, 10, and 11) bottom current speeds exceeded 0.2 m/s, with a maximum value of 0.31 m/s on Jan. 3. Current velocities during all of these storms were primarily alongshore to the east at all elevations, but the direction usually has an onshore component near the bottom and an offshore component at the upper elevations. Bottom currents were offshore at the end of storm 7, but otherwise the only times when the bottom current had an offshore component was between storms.

Fig. 3D also shows the bottom stress due to combined wave and current action, current action alone, and wave action alone. Only the current stress is shown after 2 Dec since no wave data are available. The combined stress was calculated using the model of Lou et al. (2000) and the wave stress from linear wave theory. The calculations show that the current stresses were considerably larger than the wave stresses throughout almost the entire deployment (storm 3 is an exception), but wave action did enhance the combined bottom stress during most of the storms.

The attenuation record from 0.9 mab shows that large attenuation increases occurred during storms 5, 6, and 10, and smaller increases during storm 11. Some indication of increased attenuation during storms 5 and 6 can also be seen in the 5, 10, and 20 mab attenuation records, but the variations are no larger than many other variations in these records.

Although the stress due to current action was the primary cause of sediment resuspension, surface wave action enhanced the bottom stress during most of the storms. Winds were from the west (where the fetch is greatest) during storms 10 and 11, so the waves during these storms were probably at least as large as those during storms 5 and 6, and may have been larger. Since there are no wave observations or wave model results for these storms, it seems best to assume that the waves were approximately the size of those observed during storm 6. This means that the combined bottom stresses during these storms would be similar to those observed during storms 5 and 6.

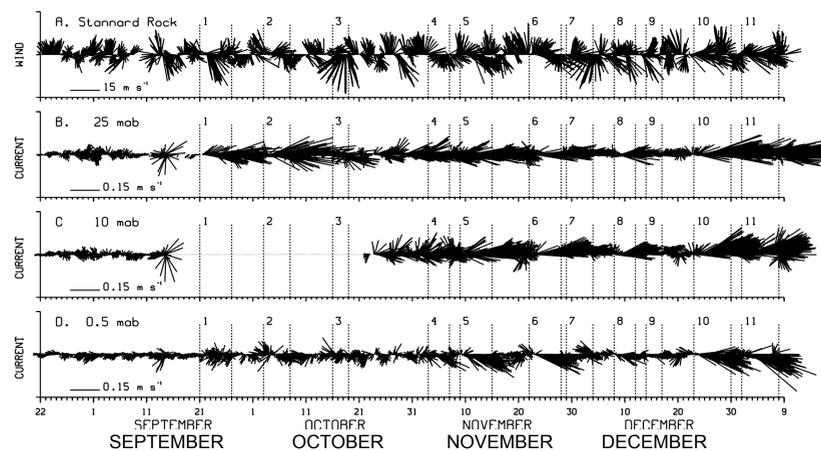


Figure 2. Stickplots of the wind and current velocities. The dashed vertical lines show the beginning and end of the eleven storms listed in Table 2. A. Wind velocity at Stannard Rock. The oceanographic convention is used, so the wind on October 18 is from north to south. B. Current velocity 25 mab. C. Current velocity 10 mab. The current meter did not work between September 15 and October 22. D. Current velocity at 0.5 mab.

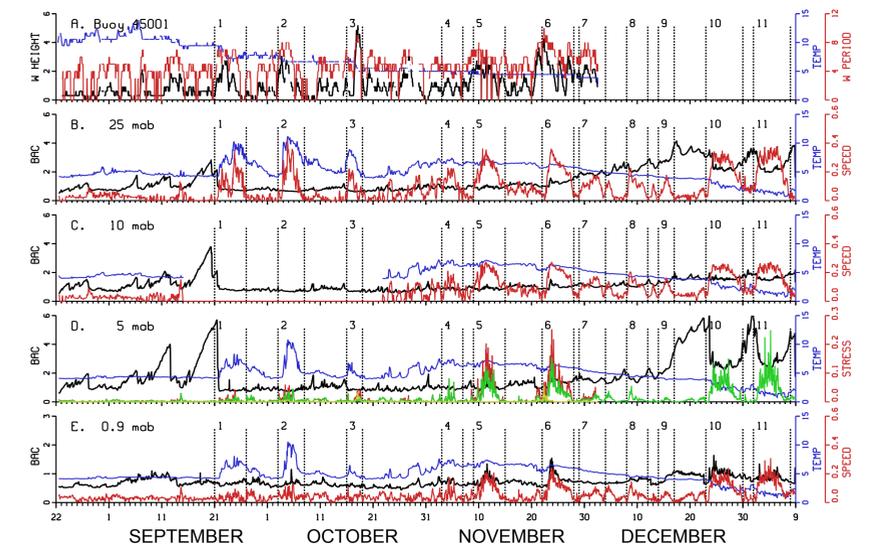
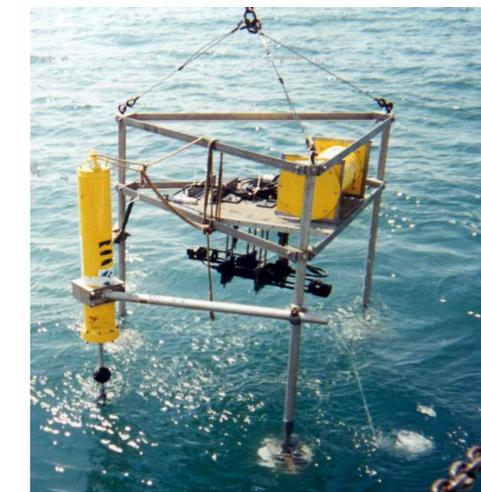


Figure 3. Time series observations. Line colors are the same as the appropriate vertical axis. Attenuation (BAC) has the units of 1/m, current speed is in m/s, and temperature in °C. Dashed vertical lines show the beginning and end of 11 storms listed in Table 2. (A) Observations at NOAA buoy 45001. Wave height is in meters and wave period in seconds. (B) Observations at 25 mab. Attenuation measurements were made at 20 mab. (C) Observations at 10 mab. (D) Observations at 5 mab. The bottom stress due to combined waves and currents is shown in red, the bottom stress due to current action alone in green, and the bottom stress due to wave action alone in yellow. (E) Observations at 0.9 mab (attenuation and temperature) and at 0.5 mab (current speed). Note that the attenuation scale is not the same as in the other panels.



Bottom resting tripod with Marsh-McBirney 585 current meter (vertical yellow cylinder), transmissometer (under the grate) and thermistor (not visible). Additional readings were made with instruments mounted on the mooring wire.

Discussion & Conclusion

Although the bottom current meter failed during early January, the measurements made at 10 and 25 mab continued until June 1991. These show that during storms 5, 6, 10, and 11, the current speeds exceeded 0.25 m/s at 10 mab. An examination of the current speeds for the entire deployment period shows that these values were exceeded four other times during the deployment – two more times in January and once each in February and April. Strong winds also occurred frequently during the remainder of the deployment, so it seems likely that waves as large as those observed during storm 6 also occurred. Although it is risky to extrapolate from data collected at a single site, if the conditions observed here are typical of those that occur along the entire Keewenaw Peninsula, then an estimate of the material transport during the winter can be made. The net alongshore transport at 0.5 mab during the periods of elevated attenuation in storms 5, 6, and 10 is 25, 33, and 36 km respectively, so a conservative estimate of the net transport during the winter is over 240 km (eight storms times 30 km/storm). Since the entire Keewenaw peninsula is only about 150 km long, this means that material resuspended at a depth of 90 m could have been transported the entire length of the peninsula during one winter.