

Water Volume Transport and Oscillatory Current Flow through the Straits of Mackinac¹

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ABSTRACT

Currents flowing through the Straits of Mackinac were recorded for a period of nearly 100 days during the summer and fall of 1973. Current meters were placed at four moorings on a north-south cross section at the Straits' narrowest constriction and arranged to measure vertical profiles of horizontal current velocity. The mean water volume transport from Lake Michigan to Lake Huron was measured at nearly $1900 \text{ m}^3 \text{ s}^{-1}$. Seasonal variations in the vertical structure of the mean current flows are related to density stratification of the water mass. Spectral analyses of the current records revealed many periodic features of the flow field which were superimposed on the mean discharge. The periodic components are identified and correlated with oscillations of water level in the Michigan and Huron lake basins.

1. Introduction

Lakes Michigan and Huron are connected through a narrow passage known as the Straits of Mackinac (Fig. 1). Inflow to the two lakes from tributary streams and precipitation is supplemented by the outflow from Lake Superior through the St. Marys River to Lake Huron just a short distance to the east of the Straits. Outflow from the Lake Michigan-Huron Basin is through the St. Clair River, Lake St. Clair, and the Detroit River system to Lake Erie. The Straits are wide and deep enough to permit the same average water level elevation in Lakes Michigan and Huron. Short-period perturbations to the water levels as long as several days in duration are known to occur, however, and are one of the subjects of this investigation.

The discharge from Lake Huron through the St. Clair River averages $5055 \text{ m}^3 \text{ s}^{-1}$, for years 1900-73 (Lake Survey Center, 1973), while the inflow to Lake Huron from Lake Superior averages $2120 \text{ m}^3 \text{ s}^{-1}$. The difference between these two figures represents the outflow through the St. Clair River contributed by the Lake Michigan-Huron Basin (excluding a diversion from Lake Michigan at Chicago of a few tens of cubic meters per second). Outflow from Lake Michigan to Lake Huron is through the Straits of Mackinac. Since the surface areas of the two lakes and their drainage basins are known with much precision and the hydrology of the region is reasonably well understood, estimates of the average outflow of Lake Michigan to Lake Huron can be made from a water mass budget

approach. Judson (1909) used this technique and reported a Lake Michigan outflow of about $1610 \text{ m}^3 \text{ s}^{-1}$. Powers and Ayers (1960) used water budgets and limited water current data from the Straits to determine an outflow of nearly $1560 \text{ m}^3 \text{ s}^{-1}$.

Physical characteristics of the water current flow through the Straits of Mackinac have not been well documented. A simple strait separating two large water bodies is often the site of a complex flow structure, and the Straits of Mackinac is no exception. Seiches occur in both Lakes Michigan and Huron and these oscillations in water surface elevation drive recognizable currents through the Straits. Longer-period oscillations are associated with meteorological events and possibly with seiches of the combined Lake Michigan-Huron Basin. The water column is density stratified during the summer months of July through September and a distinctly different flow structure was observed during stratification than during the non-stratified period. We attempt in this paper to sort out the periodic motions in current recordings taken in the Straits and to relate them with the driving components of lake level oscillations. Also, we shall present direct measurements of the net discharge from Lake Michigan to Lake Huron and discuss the short-term fluctuations of volume transport.

2. Method

A cross section of the Straits of Mackinac along the $84^{\circ}45' \text{W}$ meridian is shown in Fig. 2. The section is essentially at the Straits' narrowest constriction. The width is nearly 6.25 km and the maximum depth

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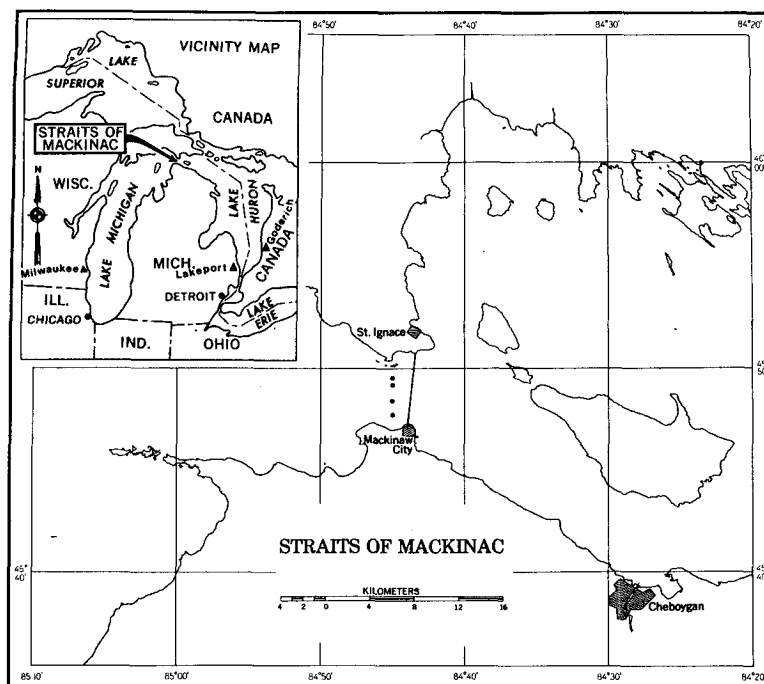


FIG. 1. Location map. Current meter moorings are shown on a Straits of Mackinac cross section. Milwaukee, Mackinaw City, Lakeport and Goderich are water level recording stations referred to in this report.

is 70 m. Four current meter moorings were spaced across the Straits as indicated in Fig. 2. The current meters at 5 and 10 m depths near the north and south ends of the cross section were suspended from rigid towers installed for this investigation, while current meters on the two moorings near the center of the cross section were suspended from subsurface buoys. The subsurface buoys were about 12 m below the water surface and below any significant influence of the moderate surface wind waves generated in this region of the Great Lakes.

All current meters were of Savonius rotor design. The direction and speed signals of the four meters on towers were transmitted to shore-based strip-chart recorders by underwater cables. The current meters

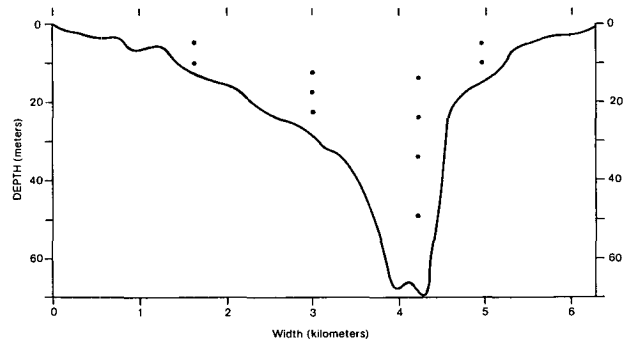


FIG. 2. Straits of Mackinac cross section along the $84^{\circ}45'W$ meridian showing current meter configuration.

supported from subsurface buoys were self-contained Geodyne A-100's, recording for a 50 s interval each 20 min on 16 mm film. The currents were measured during an interval of about 100 days, from 9 August 1973 to 15 November 1973. Concomitant with this investigation, temperature structure and the concentration of conservative lake water chemical parameters were measured at frequent intervals across the meridional section to determine the flux of dissolved materials from Lake Michigan to Lake Huron and vice versa. We shall refer to the temperature measurements and seasonal variation in density structure in this report, but will not attempt to interpret the chemical concentrations.

While the current meters were in place, two week-long surveys of current velocity distribution across the Straits were made by following the drift of a network of drogues released near the cross section. Typically, 10 drogues were set once or twice each day on the cross section at a spacing of about 500 m. Their drift was tracked by sequentially fixing the position of each drogue by sextant as the small tending vessel hovered near it. The drogues were of variable depth and were alternately configured to measure a vertical profile of horizontal current velocity and the horizontal current shear at one level.

3. Volume transport through the Straits

The dense array of current meters spaced across the meridional Straits of Mackinac cross section yields

TABLE 1. Straits of Mackinac cross-sectional area.

Depth interval (m)	Cross-sectional area (m ²)
0-10	43 800
10-20	29 900
20-30	18 400
30-40	12 400
40-50	8 600
50-60	6 600
60-70	4 000
Total	123 700

a direct measure of the water volume transport through this passage. Table 1 gives the cross-sectional area for depth intervals of 10 m in thickness across the Straits. The total area is slightly larger than reported by other investigators (e.g., FWPCA, 1967) because 1973 was a year of near record water levels in the Lake Michigan-Huron Basin. The stage averaged about 1.2 m above the low water datum depths shown on lake charts, and this stage has been added to the field sheet soundings used to compile the depth profile.

The original films on which the current data were recorded were developed, projected on the screen of a microfilm reader, and tabulated by hand. The data were then edited and corrected for slight timing inaccuracies in several of the current meter clocks. After correcting for magnetic variation, east and north components of the current flows were computed. As our cross section is oriented along the 85°45'W meridian, only the east component is needed to compute the volume transport. Fig. 3 shows a set of three easterly-directed current velocity profiles drawn from sets of data averaged over different time intervals. The profiles drawn are area-weighted means of all current recordings. No significant variation across the channel was found when comparing mean velocities at similar depths of observation. The profile shown by the solid line is the average easterly velocity observed at each current meter depth for the duration of the observations. Averaged over this nearly 100-day interval, the flow in the upper 20 m of the water column is directed eastward toward Lake Huron, while below this level the flow is directed toward Lake Michigan. The average easterly velocity in the upper 20 m layer is 4.50 cm s⁻¹. The average westerly velocity below 20 m is 2.81 cm s⁻¹. Multiplying these average flow rates by the cross-sectional areas above and below the 20 m level gives the following volume transports:

East flow (above 20 m)	3320 m ³ s ⁻¹
West flow (below 20 m)	1400 m ³ s ⁻¹
Net flow	1920 m ³ s ⁻¹ east

Powers and Ayers (1960) reported current measure-

ments of 14.9 cm s⁻¹ toward the east at 1 m depth and 11.4 cm s⁻¹ toward the west at 36 m. From these current measurements above and below the thermocline and the cross-sectional area of the Straits, their east-directed transport was computed to be 3200 m³ s⁻¹, while the west-directed transport was 1640 m³ s⁻¹. These reported values are lower than the transports we have calculated from current velocities of much smaller magnitude. The discrepancy must arise from their use of a markedly different cross-section area or of an assumed velocity profile different from that reported here.

The measured net flow from Lake Michigan to Lake Huron is about 25% greater than that reported by Powers and Ayers. We noted earlier that 1973 was a year of high lake levels and of correspondingly high flow rates in rivers connecting the Great Lakes. During August through November, 1973, the flow of the St. Clair River averaged 6650 m³ s⁻¹ while inflow to Lake Huron from Lake Superior through the St. Marys River averaged 2775 m³ s⁻¹. Both flow rates were nearly 30% above the 1900-73 average. The difference of 3875 m³ s⁻¹ is the contribution of the combined Lake Michigan-Huron Basin to the St. Clair River discharge. Our measured flow from Lake Michigan to Lake Huron through the Straits of Mackinac of 1920 m³ s⁻¹ leaves 1955 m³ s⁻¹ as the contribution from the Lake Huron watershed to the St. Clair River discharge, very nearly an equal contribution from each basin. Comparative results reported by Judson (1909) and Powers and Ayers (1960) are summarized in Table 2. The drainage basin of Lake Michigan contains about 48% of the surface area of the drainage of the combined Lake Michigan-Huron watershed.

Fig. 3 shows two additional easterly current velocity profiles which are averages of different time intervals.

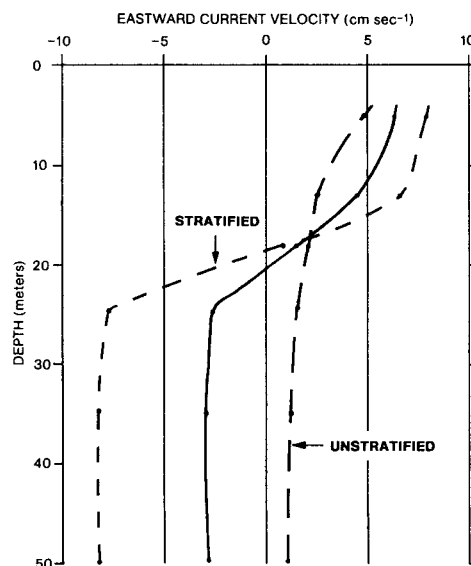


FIG. 3. Vertical profiles of eastward current velocity. Solid line is the average for the entire recording interval.

TABLE 2. Summary of reported flow rates from Lake Michigan through the Straits of Mackinac and from the Lake Huron watershed.

Investigator	Flow through Straits ($\text{m}^3 \text{ s}^{-1}$)	Flow from Lake Huron Basin ($\text{m}^3 \text{ s}^{-1}$)	Percent of flow from Lake Michigan
Judson (1909)	1610	1895	46
Powers and Ayers (1960)	1560	2010	44
Present study	1920	1955	50

The profile drawn with the dashed line gives the average velocities observed during the first 40 days of measurement, while the other profile gives the average velocities observed during the last 50 days of measurement. The remarkable velocity shear observed during the first 40 days is related to density stratification of the water column. Fig. 4 shows the temperature structure observed on the Straits of Mackinac cross section during the water chemistry sampling program of 1973. A thermocline started to develop in mid-June, intensified in stability and deepened through August, and terminated abruptly in mid-September. This density-stratified season is associated with mean flows in the surface layer directed toward Lake Huron and a deeper return flow toward Lake Michigan. The mean volume transport in the surface layer toward Lake Huron is $5700 \text{ m}^3 \text{ s}^{-1}$, nearly three times the net flow from Lake Michigan to Lake Huron. This flow distribution is of considerable importance in computations of the flux of materials between the two lakes and in computations of lake heat budgets. When the water is unstratified, the mean velocities are directed easterly at all depths, decreasing monotonically from the surface.

The complexity of current flow through the Straits of Mackinac is not revealed by considerations of the mean velocities. Fig. 5 shows the volume transports observed during the period of measurement. The flow oscillates between transport directed toward Lake Huron and transport directed toward Lake Michigan, with total volume transport at times being 30–40 times greater than the net flow between lakes. The volume transports shown in Fig. 5 are conservatively estimated to be reliable within 10%. The transports computed from mean velocities are likewise estimated

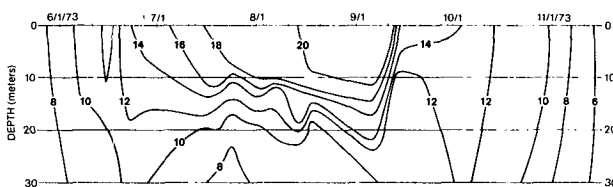


FIG. 4. Water temperature structure ($^{\circ}\text{C}$) in the upper 30 m observed on the Straits of Mackinac cross section during 1973.

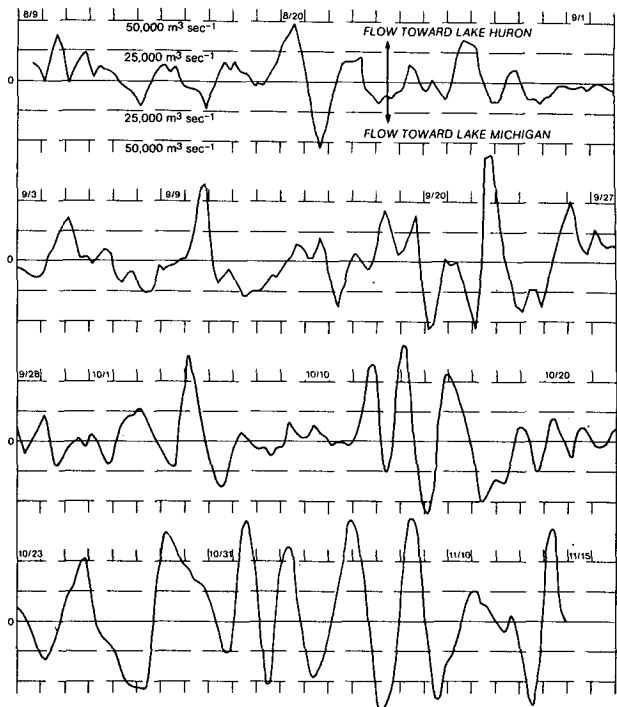


FIG. 5. Volume transport through the Straits of Mackinac from 9 August to 15 November, 1973. Transports shown are 6 h average values.

to be reliable within 5%, as the means are residuals of strong oscillatory current flows with speeds in ranges where the calibration characteristics of the Savonius rotors are quite uniform and linear. We shall next consider the determination of periodicities in the observed current flow.

4. Spectra of current flow

Spectra and cross-spectra were computed for varying intervals of the current recordings by use of the fast Fourier transform method. All spectra reported here have been derived from multiple, overlapping data subsets of 256 values of 2 h (in some cases 6 h) averaged data, regularly spaced through the analysis interval, which were first transformed and then ensemble-averaged. Fig. 6 shows a cross-spectrum between east-west velocity components measured by two current meters suspended from subsurface buoys. The spectra were computed from 2 h averages of the current velocity, and only the average power of the two spectra is shown because the spectra are essentially identical in energy density per frequency bandwidth. Coherence between the two records differentiates the significant periodicities in the records. Clearly revealed are the inertial period component (f), the lunar semidiurnal tide (SD), the first longitudinal oscillatory mode of Lake Michigan (M_1), and the first longitudinal oscillatory mode of Lake Huron (H_1). Also indicated are significant energy densities and

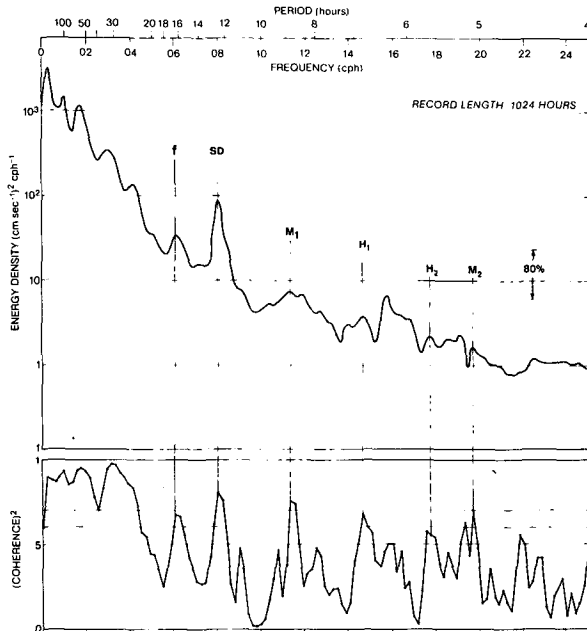


FIG. 6. Cross-spectrum of two current meter recordings revealing inertial (f), tidal (SD), Lake Michigan seiche (M_1 and M_2), and Lake Huron seiche (H_1 and H_2) components. Statistical confidence limits are computed for 2 h data in which no account is taken for averaging of data collected at 20 min intervals; the limits are therefore conservative estimates.

coherence in longer wave periods, which will be examined later in more detail.

Inertial period oscillations are known to occur in the deep lake basins with much regularity during the density-stratified season (cf. Malone, 1968). Their presence in Straits of Mackinac current recordings is therefore not surprising, as the spectra of Fig. 6 are taken from data collected during the first half of the recording interval when the water mass was stratified. The spectral signatures of the inertial and semidiurnal tidal components are clear and unambiguous, as the spectral energy density and coherence peaks are narrow and distinct. Energy density peaks for the M_1 and H_1 seiches are spread over a wider range of frequencies, with peak coherence occurring at 8.82 h for M_1 and 6.82 h for H_1 . Mortimer and Fee (1976) have examined the spectra of Lake Michigan and Lake Huron water level recordings in great detail and report M_1 as 8.96 h and H_1 as 6.67 h. Our seiche periods determined from spectra of Straits of Mackinac current recordings are in rather close agreement. Mortimer and Fee also give periods for the second normal modes of each lake as $H_2=5.26$ h and $M_2=5.04$ h. The Lake Michigan mode M_2 is shown in Fig. 6 at a period very close to 5 h, while the Lake Huron mode H_2 is centered about a period of 5.62 h.

Longitudinal seiches of Lakes Michigan and Huron are standing waves. The Straits of Mackinac are situated at the north end of each lake basin and therefore at antinodes of the longitudinal seiches in

each lake. The currents that the seiches drive through the Straits of Mackinac are hydraulic currents, similar to the tidal currents occurring in straits and canals which connect two bodies of water having independent tides. They are reversing currents due primarily to a temporary difference in head between the two lakes brought about by seiche activity, rather than by action of a progressive or stationary type wave passing through the Straits. This feature is useful in differentiating currents resulting from oscillations in each lake. Cross-spectra of Straits currents with Mackinaw City water level recordings reveal that the current flows resulting from Lake Michigan seiches are very nearly in phase with high water at Mackinaw City; i.e., peak eastward current flow through the Straits occurs at the time of high water at the north end of Lake Michigan when the head between the two lakes is largest. Conversely, high water at the north end of Lake Huron is associated with peak westward flow through the Straits of Mackinac so that the current flows resulting from Lake Huron seiches are very nearly out of phase with high water at Mackinaw City. These phase relationships have been used to

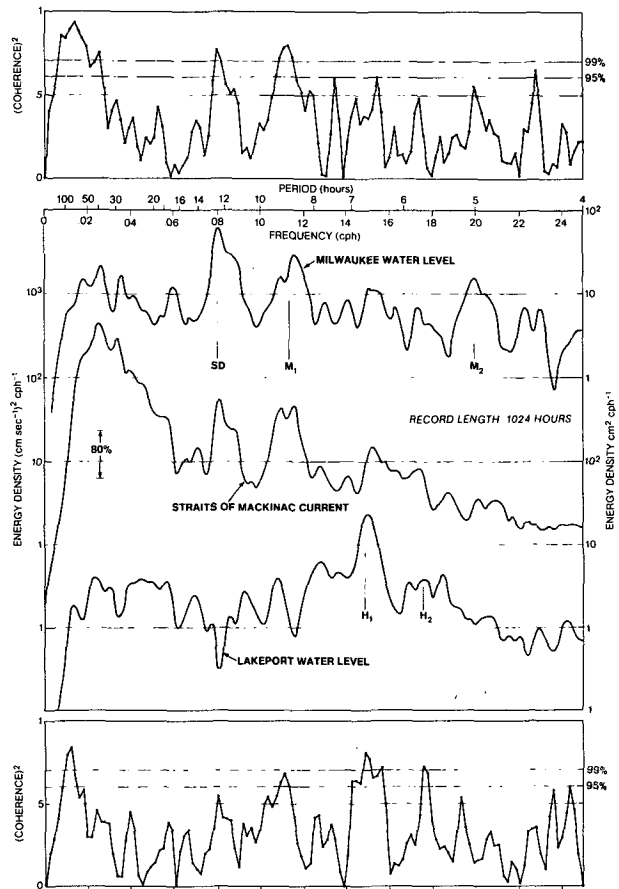


FIG. 7. Cross-spectra of Straits of Mackinac currents with Lake Michigan (upper) and Lake Huron (lower) water levels. Data were high-pass filtered to remove periods greater than 50 h.

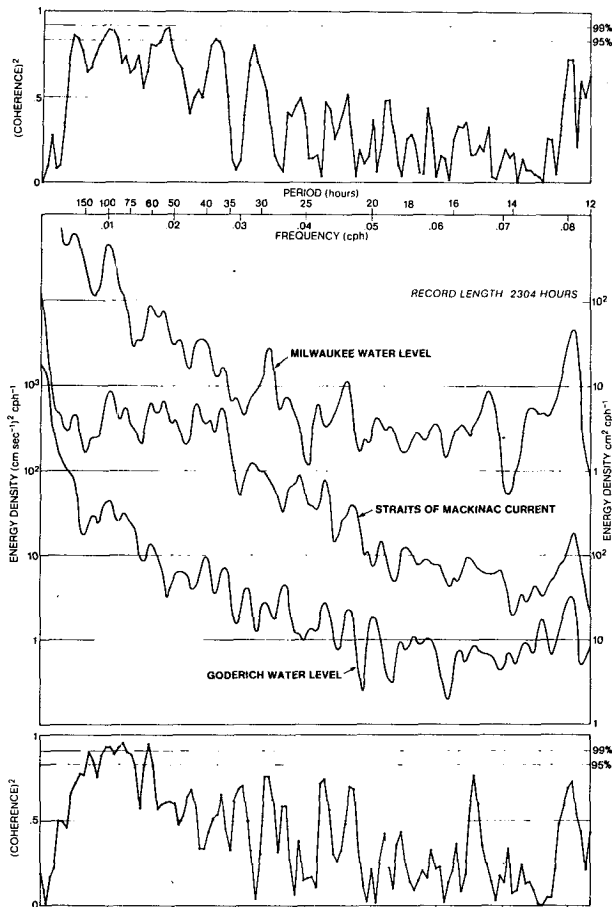


FIG. 8. Cross-spectra of Straits of Mackinac currents with Lake Michigan (upper) and Lake Huron (lower) water levels. Six-hourly averaged data are used to increase resolution in the low frequencies.

identify the Lake Michigan and Lake Huron seiche modes.

The relationships between Lake Huron and Lake Michigan water level oscillations and current through the Straits of Mackinac are better illustrated in Fig. 7, which shows cross-spectra of water levels recorded at Lakeport, near the south end of Lake Huron, and at Milwaukee on the west shore of Lake Michigan, with a Straits current record. All of the current recordings show similar spectral characteristics. Only meters very near the bottom show less intense energy peaks. Energy density and coherence peaks clearly define the Lake Michigan oscillations M_1 and M_2 and the Lake Huron oscillations H_1 and H_2 , with H_2 coherence peaking at 5.69 h. Fig. 7 also indicates coherence between Straits currents driven by Lake Michigan oscillations and Lake Huron water levels. This probably represents a forced response of Lake Huron to oscillations in Lake Michigan. The water level spectrum indicates that the amplitudes of the forced waves are very small. The reverse situation also occurs, as coherence is found between Straits currents and Lake

Michigan water levels for frequencies corresponding to Lake Huron modes. The current record used to compute the cross-spectra of Fig. 7 is from the second half of the recording interval, and the inertial period oscillation is not present as the water column was not stratified. Higher energy densities in the seiche peaks are associated with the more frequent passages of energetic weather systems during the fall months. Curiously, the semidiurnal lunar tide is not prominent in the Lakeport water level spectrum during this interval.

Due to small timing inaccuracies in the current meter clocks and to uncertainties in actual starting and ending times on the recorded films (a problem which has troubled all users of current meters of this type), we do not pretend to have verified the exact periodicities and phase relationships for the seiche modes, but our data indicate that the separation between the second mode of Lake Michigan and the second mode of Lake Huron may be a little larger than observed by Mortimer and Fee (1976). However, it should be kept in mind that the spectral energy density peaks are broad for all of the seiche periods, and in some of the spectral analyses peak coherences are shifted to frequencies that appear in Fig. 6 as sidebands. Some of our spectra have also shown a splitting of seiche modes into two peaks of energy density and coherence of almost equal significance. This is a topic worthy of further investigation.

To examine more closely the low-frequency components of Straits transport, spectra were computed for 6 h averages of currents and water levels. Cross-spectra of east-directed current velocity and water levels at Milwaukee and Goderich are shown in Fig. 8 (the Goderich gage was used in place of the gage at Lakeport because of a gap in the Lakeport data during October). Both cross-spectral computations show a broad peak of energy density and coherence in the meteorological scales of 4 to 9 days. Coherence is especially strong between Straits currents and the surface stage of Lake Huron.

Another strongly coherent peak is centered about the period of 53 h in the Milwaukee stage and Straits current cross-spectrum, and about the period of 61.5 h in the current versus Goderich stage cross-spectrum. The existence of a uninodal seiche of the Lake Michigan-Huron Basin in this period range has been suggested for some time. Computations of its period have assumed that the Straits of Mackinac are a nodal point of no vertical water displacement. Powers and Ayers (1960) reported a period of 51 h for this oscillation, while Rockwell (1966) computed the period at 48 h. The volume transport of this fundamental co-oscillation of the two lake basins is of course greatest at the nodal line through the Straits, and we should expect good evidence of its occurrence in the long-term current records. Mortimer and Fee (1976) re-

ported a broad spectral peak centered at the 60 h period in a record of Straits currents of about one month in duration. In the Milwaukee stage and the Straits current cross-spectrum, there is a frequency band of uniform high coherence which occurs in the 61.5–56.9 h period range and appears as a sideband to the coherence peak at 53 h. Similarly, in the Goderich stage and Straits current cross-spectrum, uniform coherence occurs in the 56.9–49.6 h period range, although the coherence is much lower than in the former case. It is not at all obvious why we find a shift in periodicity in the co-oscillation between the lake basins.

Evidence that co-oscillation of the two lakes does occur is afforded by the remarkable set of current oscillations through the Straits of Mackinac initiated 1 November 1973 (Fig. 5). The oscillations were triggered by the passage of an intense low-pressure system across Lake Superior to the east. Atmospheric pressure differences between Lakes Michigan and Huron during the morning hours of 1 November, when the low was centered just northeast of Georgian Bay, were sufficient to account for an approximate 10 cm difference in level between the two lakes. The next major frontal passage over the lakes occurred on 8 November. Fig. 9 shows water levels recorded at the south end of Lake Huron near Lakeport, at Milwaukee on Lake Michigan, at Mackinaw City, and also current flow through the Straits of Mackinac. The two lake basins oscillate out of phase with each other as we expect for the uninodal seiche, while the Mackinaw City stage does not exhibit the oscillations. Currents through the Straits exhibit the expected phase relationships. (The cross-spectral computations show that the Milwaukee water level peak leads the maximum eastward current by about 105° .) The period of the oscillation varies from 44 to 67 h in the current recordings, indicating that we should expect the spectral energy peak associated with the fundamental co-oscillation to be broad, as indeed it is. Fig. 9 also shows that very large volumes of water are exchanged between lakes during episodes of intense co-oscillation of the two lake basins. Volume transport toward Lake Huron of nearly $85\,000\text{ m}^3\text{ s}^{-1}$ is about 17 times the average discharge of the St. Clair River and corresponds to mean current flows across the Straits of Mackinac of 69 cm s^{-1} . Peak current speeds measured during the recording interval were about 110 cm s^{-1} .

Also shown in the Milwaukee water level and Straits current cross-spectrum are energy and coherence peaks at 38.4 and 31.3 h. These oscillations are not significant in cross-spectra of currents with Lake Huron stage. Their occurrence is evidenced by the series of nearly 30 h period oscillations recorded in the currents on 18–22 October (Fig. 5). Fig. 9 suggests that waves of this period may also occur in the Mackinaw City water levels as shown especially on

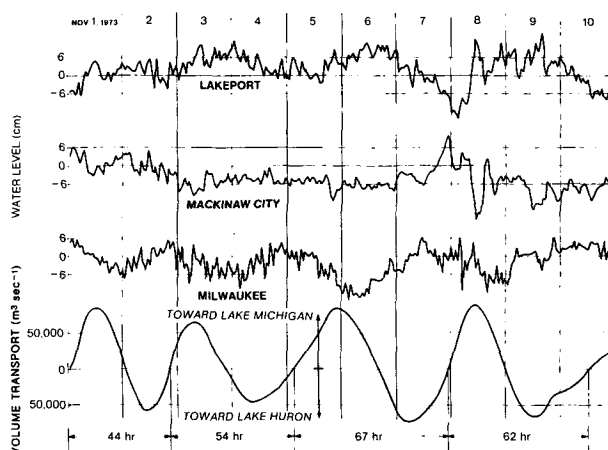


FIG. 9. Episode of Lakes Michigan and Huron co-oscillation, 1–10 November 1973. Six-hourly averaged transports have smoothed some of the shorter-period oscillations in the actual current recordings.

7–9 November, excited in this case by the passage of a frontal system across the lakes which did not trigger a strong co-oscillation of the lake basins. These oscillations may evidence a class of long-period waves in Lake Michigan which have not yet been investigated and reported. There are also frequency bands in the Lake Huron and Straits current cross-spectra showing coherence structure similar to the Lake Michigan situation, but not at significant levels. The semidiurnal tide is very prominent in both of the cross-spectra of Fig. 8.

We found previously that the first two modes of seiches in both Lakes Huron and Michigan were present in the Straits of Mackinac current spectra. This implies that aliasing might be significant in spectra computed from 6 h averages of currents and water levels. In the Goderich and current cross-spectrum of Fig. 8, aliasing of the first Huron mode would appear at a period centered about 96 h, and the second mode would appear centered about 15.5 h. In the Milwaukee and current cross-spectrum, aliasing of the first Lake Michigan mode would appear centered about the 45.2 h period, and the second mode about the 31.3 h period. Examination of the Fig. 8 cross-spectra indicates that aliasing is probably not too important, as the Huron first mode and the Michigan second mode do not significantly contribute to energy or coherence peaks at their respective aliased periods. The other aliased modes are submerged in energy and coherence peaks already discussed, and it is not possible to determine the total contribution aliasing adds to these spectral features. Spectra run from the 20 min current records do not show significant energy levels in higher order modes of either Lake Michigan or Lake Huron seiches.

For comparison with the cross-spectra presented between currents through the Straits of Mackinac

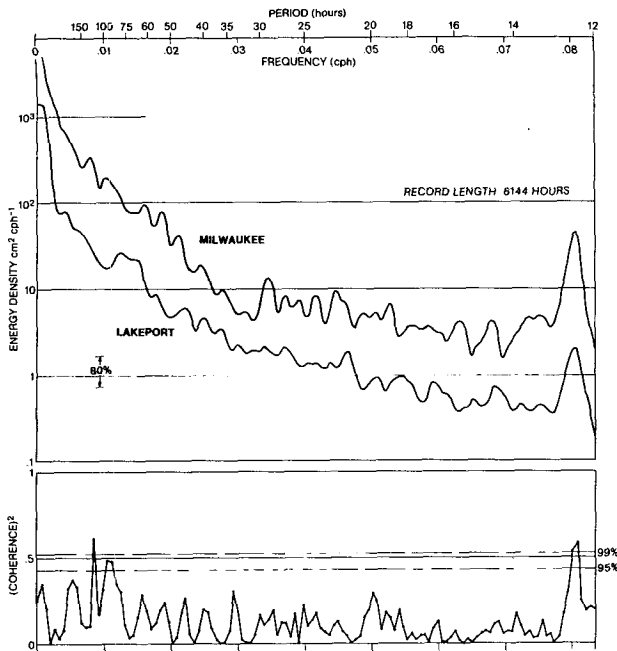


FIG. 10. Cross-spectrum of Lake Michigan and Lake Huron water level recordings from April through December, 1973. The spectral energy density scale for Lakeport is one-tenth of actual magnitude.

and water levels, Fig. 10 shows a cross-spectrum of Milwaukee and Lakeport water levels computed from 6 h averages of surface elevation from April through December, 1973. Significant coherence between the two recordings occurs only in the meteorological scale near 4 days in period and also at the lunar semi-diurnal tidal period. This apparent lack of correlation between the small-amplitude surface oscillations illustrates the difficulty in detecting the long surface co-oscillation of the two lake basins from water level recordings, as oscillations of this period are almost completely masked in the meteorological contributions. The small-amplitude oscillations produce intense current flows through the Straits, however, and this is why we have looked for evidence of their occurrence in current recordings.

5. Summary

Direct measurements of the water volume discharge from Lake Michigan to Lake Huron through the Straits of Mackinac show that nearly 50% of the total discharge from the Lake Michigan-Huron Basin is derived from Lake Michigan. This percentage is slightly larger than that reported by previous investigators. The characteristics of the outflow are markedly different during the summer interval of water density stratification, with the average discharge to Lake Huron above the 20 m level being nearly three times the long-term mean discharge from Lake Michigan.

Return flow below the eastward directed surface currents transports two-thirds of the volume of the surface discharge back toward Lake Michigan. This flow distribution is of considerable importance to lake heat budgets and to the flux of chemical and biological materials between lakes. During the unstratified season, a mean eastward flow was observed at all depths, monotonically decreasing from the surface toward the bottom.

The mean flow component of the current recordings is usually small in comparison with large, oscillatory water movements through the Straits. The intensity of the oscillatory components increases with the increasing frequency of storm passages across the Great Lakes in fall as compared with the summer months. Because of the strong oscillatory current flows, the season of density stratification is shorter in the Straits region than in the regions of northern Lake Michigan or Lake Huron which are distant from the Straits mixing influence.

The first two seiche modes of both Lake Huron and Lake Michigan drive recognizable currents through the Straits of Mackinac at periods near those reported by other investigators. Also prominent are lunar semi-diurnal tidal currents flowing between the two lakes. Inertial period currents are present in the current recordings when the water column is density-stratified. Longer-period current flows through the Straits correlate well with meteorological phenomena spread over periodicities of 4 to 9 days. Evidence is presented that a uninodal seiche of the two-lake system, with a nodal line at the Straits of Mackinac, does occur with spectral energy density spread over the period range of 50 to 62 h. This period is slightly longer than that computed by use of shallow water channel approximations in earlier studies. Peak coherence in spectral computations was observed at 53 h when currents were compared with Lake Michigan water surface oscillations and at 61.5 h when currents were compared with oscillations of the Lake Huron stage. Also prominent in the current with Lake Michigan stage comparisons are long waves which generate significant currents through the Straits at nearly 31 and 38 h periods. Waves in this period range have not been previously reported to our knowledge. Cross-spectrum coherence between Straits currents and Lake Michigan stage suggests that a Lake Michigan oscillation of period near 53 h may partially obscure the bi-lake seiche which appears prominently at 61.5 h in the current and Lake Huron stage comparisons.

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