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Submitted: 24 July 1975
Accepted: 18 February 1976

Lake Ontario circulation in November

Abstract—A Lake Ontario current meter study during November 1972 showed counterclockwise circulation with higher speeds in the western portion of the lake. Results from wind-driven numerical models run for comparison agreed in the western section, but showed a clockwise gyre in the eastern portion of the lake.

A current meter study of Lake Ontario was conducted in 1972 as part of the International Field Year for the Great Lakes (IFYGL). Measurements were taken from U.S. and Canadian buoys and towers placed throughout the lake. One object of the study was to deduce mean circulation patterns for the whole lake for each month. Data for July 1972, a month when the lake was stratified, were analyzed first (Pickett and Richards 1975). They showed two counterclockwise gyres side-by-side in apparent geostrophic balance, with flow in the same direction at all recorded depths. One gyre occupied the western two-thirds of the lake and the other the eastern third.

This note adds the analysis of the November 1972 data, a month quite different from July because simultaneous temperature recordings showed the lake was isothermal. From this analysis, the mean flow in November also seems to be counterclockwise.

The buoys and towers in Lake Ontario were designed to record surface winds within 1 m s^{-1} and 5°, water temperatures within 0.2°C, and currents within 2 cm s^{-1} and 5°. Sensors were sampled every 6 min by the U.S. instruments, and every 10 min by the Canadian instruments. Details on equipment and sampling are given in IFYGL Project Office (1972). Data from instruments recording less than 20% of the full month's record were discarded. The remaining data were edited, and currents vector-averaged (by scalar averaging each component, then recombining) for each current meter at each depth for the entire month.

The current meter results in Fig. 1 show strong counterclockwise circulation at all recorded depths (–5 to –19 m) with higher speeds (up to 12 cm s^{-1}) toward the west. Data from the multilevel station off Rochester suggest that flow is in similar directions at all depths. The circulation appears to weaken toward the eastern portion of the lake, but the general flow pattern

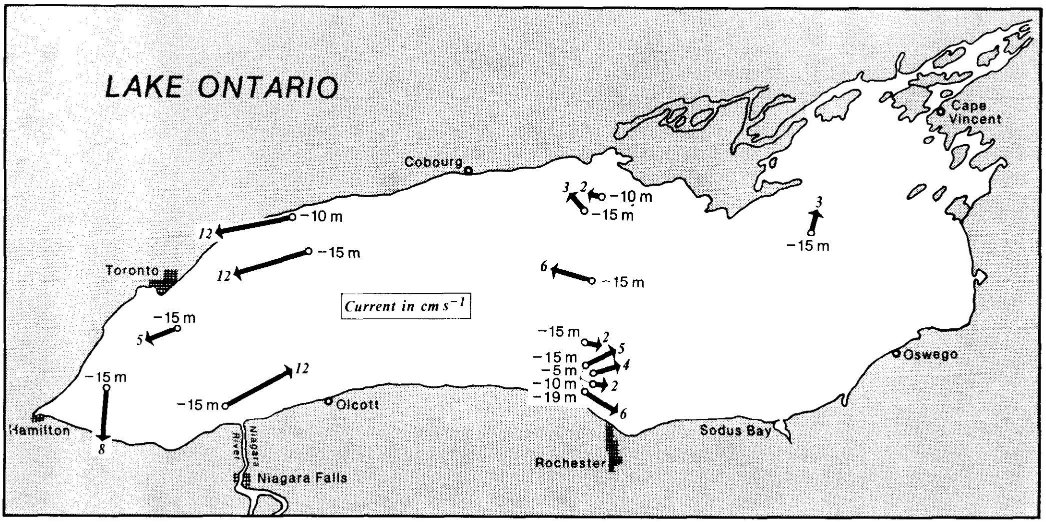

Fig. 1. November mean currents in Lake Ontario.

cannot be detected there because of the lack of data.

Since the wind and temperature data indicated a prevailing northeast wind over an isothermal lake, a steady state, numerical model (Rao and Murty 1970) was run to compare with the observed currents. This was a linear homogeneous model in which vertically integrated transports were calculated for a given wind stress. Bottom topography and the earth's rotation were also incorporated. Bottom friction was taken to be linear in transport:

$$\mathbf{F} = \frac{kV\mathbf{M}}{H},$$

where $\mathbf{F}$ = bottom friction vector ($cm^2\ s^{-2}$); k = constant = 0.0025; V = mean current speed $\simeq$ 10 cm s^{-1}; $\mathbf{M}$ = current transport vector ($cm^2\ s^{-1}$); H = depth (cm). The constant k was selected by successive model runs to produce current speeds comparable to those observed. The mean current speed V was derived from the observations.

Storms passing Lake Ontario on 1–4 November (with maximum wind of 13 m s^{-1} from 052°), 7–9 November (max 14 m s^{-1} from 124°), 14–15 November (max 19 m s^{-1} from 032°), and 19–22 November (max 12 m s^{-1} from 342°) resulted in winds predominantly from the northeast quadrant. By combining all buoy and tower wind data, I calculated the monthly scalar mean speed to be 5 m s^{-1} (7 m s^{-1} during storms, 4 m s^{-1} otherwise). By forcing the model with a 5 m s^{-1} wind from the northeast, I obtained the results in Fig. 2.

The model shows two gyres—counterclockwise in the western basin and clockwise in the eastern. The strongest flow, indicated by closely spaced transport streamlines, occurs in the western portion of the lake. The maximum is off Toronto and yields a vertically averaged flow speed of 20 cm s^{-1}. Toward the middle of the lake speeds decrease, and the flow shifts to a more southwest-to-northeast pattern. Near the east end of the lake the flow is around a clockwise gyre.

Even though northeasterly winds prevailed, the day-to-day wind variations might have significantly perturbed this steady state pattern. To find out if these perturbations could be important, I also ran a time-dependent, linear, homogeneous model (Schwab 1974). This model calculated vertically integrated transports for a given wind stress, and bottom topography and the earth's rotation were again included. The model was modified to have

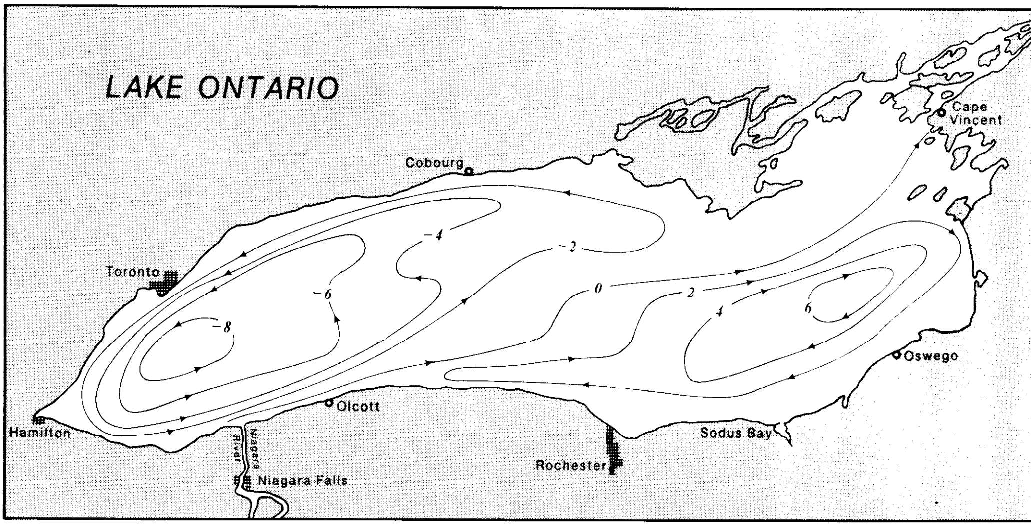

Fig. 2. Steady state model transport lines (10^{10} cm^3 s^{-1}) in Lake Ontario for 5 m s^{-1} northeast wind.

the same friction as the steady state model and to be driven with the observed day-to-day winds. Currents at each grid point were vector-averaged for the month just as the observed currents were. The resultant current pattern was the same as that from the steady state model. The speeds from the time-dependent model, however, were only about half of those from the steady state model. Apparently the constantly varying wind prevented a full buildup to the steady state values.

Do the observations in Fig. 1 and model results in Fig. 2 agree? From the observations one might deduce a single counterclockwise gyre covering the whole lake. From the models, on the other hand, one obtains a pair of counterrotating gyres. The core of the clockwise gyre in the east is unconfirmed, and there is directional disagreement at the midlake meter. Also model agreement off Rochester is questionable.

If one favors the single counterclockwise gyre interpretation, then some generating mechanism is needed. Most mechanisms proposed so far for single gyre counterclockwise lake circulation are for stratified lakes, and do not apply here. When single-gyre homogeneous model circulations have been produced, they were either too weak (e.g. Li et al. 1975, due only to river inflow and outflow) or rely on unusual wind fields (e.g. Paskausky 1971, due to a steady wind with constant horizontal shear).

If one favors the two-gyre model interpretation, then the generating mechanism is the prevailing wind. Theoretical and modeling studies (e.g. Csanady 1973; Rao and Murty 1970) have consistently shown that a uniform wind over a homogeneous lake with simple bowl-shaped bathymetry produces this pattern. Since both models gave this pattern, the storms must have been responsible for the prevailing wind which in turn was responsible for the mean circulation pattern. As for the clockwise gyre in November, the easternmost current meter hints at its existence, and gaps in the data network must have missed its core.

The key to the proper interpretation seems to be in fully observing the counterrotating gyres. According to the models, for example, Lakes Erie and Ontario should have two counterrotating gyres in winter, whose position would depend on the prevailing wind direction. If both gyres can be observed in their proper position in the mean circulation of such a lake, then the prevailing wind-driven mechanism would be confirmed. If, however, two gyres are not observed, then some other generating mechanism may be needed. Current data from other winter months in Lake Ontario are now being studied for the number and direction of mean current gyres.

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Submitted: 17 November 1975
Accepted: 26 January 1976

Influence of surface waves on subsurface current measurements in shallow water[1]

Abstract—Aanderaa current-meter readings were taken at 43 m at two sites 0.2 km apart in water 50 m deep near the central Oregon coast. The uppermost extensions of the subsurface moorings were about 3 and 18 m deep. During a 25-day period in July and August 1973, mean speeds differed by about 47%. For low frequencies (<0.7 cph) there was a 1 : 1 correspondence between the shapes of the kinetic-energy density spectra. For all frequencies, spectral density estimates of the data recorded beneath the deeper placed topmost float were lower than the estimates of the other data. The effect of surface wave motion on Aanderaa current measurements is discussed.

For 25 days beginning 1200 GMT 23 July 1973, current-meter readings were taken beneath subsurface moorings at two sites on the continental shelf off Oregon. The sites (nominal location 45°16.5′N, 124°01.5′W) were about 0.2 km apart in water 50 m deep about 5 km from the coast. On one of the moorings, ASTER, the uppermost float was about 18 m below the surface and on the other, *ASTER, it was about 3 m deep (Fig. 1). In this paper, Aanderaa current-meter observations made at 42 m and 44 m (nominal depth 43 m) are compared to determine the effects of the depth of the uppermost float in highly variable coastal waters.

Previous current measurements over the continental shelf off Oregon (Collins and Pattullo 1970; Pillsbury 1972; Smith 1974) showed that the mean current in the depth range of 20–60 m was southward during summer with velocities of about –15 cm s^{-1}. Throughout July and August 1973, current readings were taken from additional buoys installed 8 km west of the comparison site. During the 25-day comparison period the average velocity vector at about 3.5 m below the surface was about 41 cm s^{-1} toward the south (Halpern et al. Univ.

[1] This research was supported by the Environmental Research Laboratories of NOAA and by the IDOE office of the National Science Foundation under NSF agreement AG-299 (DH), and by NSF grants GS-28746 (RDP) and GS-33502 (RDP). This is a contribution to the Coastal Upwelling Ecosystems Analysis Program.